Trofimuk Institute of Petroleum Geology and Geophysics
Siberian Branch of the Russian Academy of Sciences

International Commission on Stratigraphy
Subcommission on Neoproterozoic (Ediacaran and Cryogenian) Stratigraphy

IGCP 512: Neoproterozoic Ice Ages

IGCP 587: Of Identity, Facies and Time: The Ediacaran (Vendian) Puzzle

Neoproterozoic Sedimentary Basins
Stratigraphy, Geodynamics and Petroleum Potential

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Subcommission on Neoproterozoic (Ediacaran and Cryogenian) Stratigraphy, International Commission on Stratigraphy

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Welcome –

… to the International Conference focused on fundamental and applied aspects of geology of Neoproterozoic sedimentary basins of different geodynamic settings. The submitted 70 contributions reflect current problems in stratigraphy of Neoproterozoic sedimentary sequences, elucidate various paleontological, sedimentological, and geochemical patterns of the geological history, and discuss paleogeodynamic and paleogeographic reconstructions. Among the topics covered by the contributions are studies conducted under the auspices of IGCP projects 512 "Neoproterozoic Ice Ages" (leaders: Graham A. Shields & Emmanuelle Arnaud) and 587 "Of Identity, Facies and Time: The Ediacaran (Vendian) Puzzle" (leaders: Patricia Vickers-Rich, Mikhail A. Fedonkin, James G. Gehling & Guy M. Narbonne). The Conference Program includes a Neoproterozoic Subcommission (ICS) Workshop on Ediacaran acritarchs, with participation of paleontologists from U.S.A., Brazil, China, Australia, and Russia. The primary goal is to examine Kamo, Lakhanda, Miroedikha, Ura, Katanga, and Keltma fossil Proterozoic micriobiotas from Siberian and East European cratons; organized in the middle of the debate about whether or not the Ediacaran period can be subdivided into epochs, the timing of this Workshop could hardly be better. Collections of Ediacaran and Early Cambrian macrofossils, small skeletal fossils, and trace fossils from Siberia that are important for subdivision and correlation will also be demonstrated. In addition to the technical program, we would like to remind you of an opportunity to visit our core storage facilities and examine the core of boreholes with important Vendian sections from different parts of the Siberian Craton: Irkutsk Amphitheater, Nepa–Botuoba Anteclise, and Yenisei–Khatanga Pericratonic Basin. After the conference there will be IGCP 512 Excursion to the East Sayan Mountain Ranges to examine possibly the most accessible sections of the Siberian Vendian.

We look forward to welcoming you to the Institute of Petroleum Geology and Geophysics, and hope that we will all enjoy a stimulating meeting!

Organizing Committee

Chronostratigraphic space of the lithosphere, and the Vendian as a geohistorical subdivision of the Neoproterozoic

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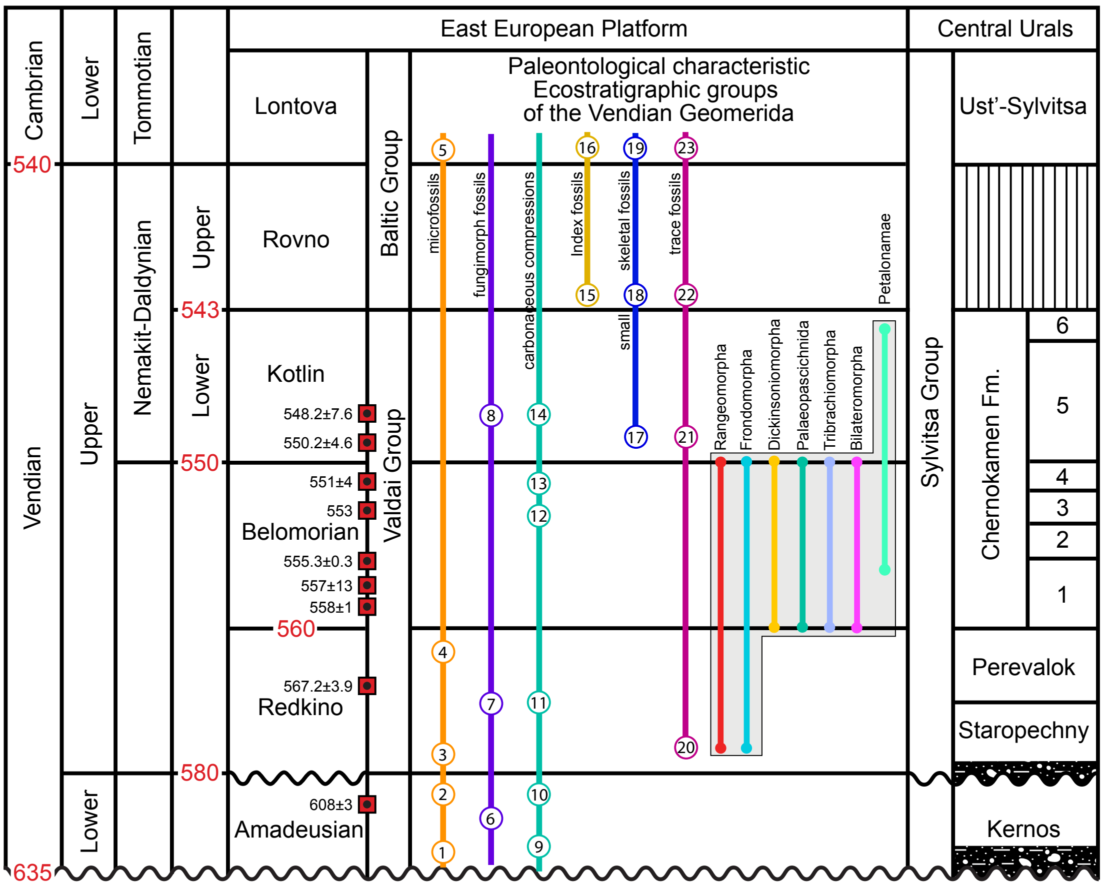
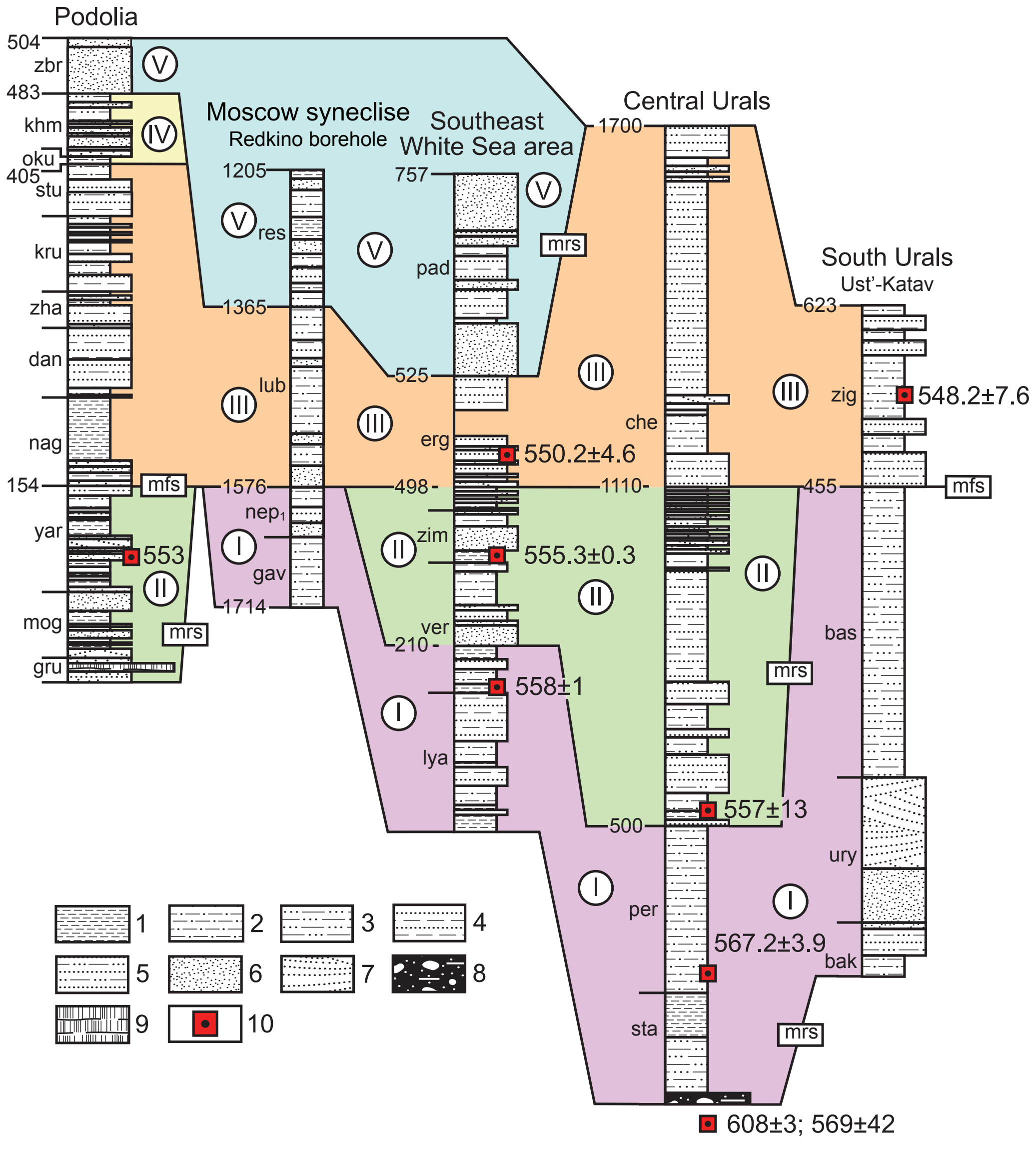
Stratigraphic subdivisions act as information-carrying media of the chronostratigraphic space, defined as the information on geological history and paleobiosphere. Elementary units in the Phanerozoic chronostratigraphic space are represented by chronozones, whereas in the Proterozoic their function is exercised by **sequenthems** of different rank. Systems and erathems can be regarded as global, high-ranked sequences. The Vendian is very unique because its boundaries are dual in nature. The upper boundary is a Phanerozoic-type boundary. Without a prejudice towards a final decision on placement of the Lower Cambrian boundary, it will be defined based on the Phanerozoic principle of biostratigraphic models. Similar Phanerozic-type boundaries can be established within the Vendian. However, biostratigraphic models fail to work for definition of the Lower Vendian boundary, even for the Lower Ediacaran boundary at the base of Nuccaleena cap dolomite. The latter is thought to be deposited in glaciomarine settings and related to the post-glacial eustatic rise of sea level following the last major (Laplandian=Varangerian=Nantuo=Marinoan) glaciation. Whether or not the glaciations are linked to riftogenesis, the lower boundary of the terminal Proterozoic system can only be defined on historical geo-biospheric principle, as is the case with older stratigraphic subdivisions, the **acrochrons**. The first three acrochrons (Archean, Karelian, and Riphean) correspond to the pre-Vendian evolution of unicellular prokaryotes and eukaryotes, which culminated in the emergence of their colonial forms in the Riphean era. The genuine histological



Microfossil assemblages: 1 – Ura Fm, 2 – Doushantuo Fm, 3 – Pertatataka Fm & Kel'tma Borehole, 4 – Kursovsky Fm, 5 – Lontova Regional Stage. Fungimorph fossils: 6 – *Primophlagella*, 7 – *Caudina*, 8 – *Sarmenta*. Carbonaceous compression assemblages: 9 – Lantian Fm, 10 – Jiulongwan, 11 – White Sea area & Us'va River, 12 – Khatyspyt Fm, 13 – Miaohe, 14 – *Vendotaenia*. Index fossils: 15 – *Sabellidites*, 16 – *Platysolenites*. Small skeletal fossil assemblages: 17 – *Anabarites trisulcatus*, 18 – *Purella antiqua*, 19 – *Aldanella attleborensis*. Trace fossils: 20 – *Nenoxites*, 21 – *Psammichnites*, 22 – *Treptichnus pedum*, 23 – *Rusophycus avalonensis*.

multicellularity of Metaphyta and Metazoa started to develop not earlier than late Neoproterozoic (Late Riphean Era). The explosion of macroscopic organisms in the Vendian was followed by the emergence of al types of multicellular organisms of the Phanerozoic level of development. Therefore, the last acrochron should be defined as Vendian–Phanerozoic. By virtue of the geological history itself and the early evolution of biosphere, the acrochrons cannot be defined on a Phanerozoic principle. The central meaning should be attributed to the sequences and sequence sets. There is no need in disseminating the Phanerozoic stratigraphic nomenclature to the Precambrian and establishing new systems. The new term **sequenthem** is best suited for designation of system-order stratigraphic subdivisions in the Proterozoic. The Vendian is regarded as a sequenthem of transient character because of the dual nature of its boundaries.



Editors' Note.–Correlation of reference sections of Upper Vendian of East European Craton and tracing of the marine flooding surface at the base of Kotlin Regional Stage.

Legend: 1 – fine laminated shale; 2 – alternating siltstone and shale; 3 – fine laminated siltstone; 4 – alternating shale and sandstone; 5 – alternating siltstone and sandstone; 6 – planar laminated sandstone; 7 – cross-bedded sandstone; 8 – diamictite; 9 – flood basalts; 10 – stratigraphic position of volcanic tuffs with U–Pb-zircon dates. Age, Ma.

Sequence boundaries: (mrs) marine regression surface; (mfs) maximum flooding surface.

Formations: (gru) Grushka, (mog) Mogilev, (yar) Yaryshev, (nag) Nagoryany, (dan) Danilov, (zha) Zharnovka, (kru) Krushanovka, (stu) Studenitsa, (oku) Okunets, (khm) Khmel'nitski, (zbr) Zbruch, (gav) Gavrilov-Yam, (nep) Nepeitsyno, (lub) Lubim, (res) Reshm, (lya) Lyamtsa, (ver) Verkhovka, (zim) Zimnegory, (erg) Erga; (pad) Padun; (sta) Staropechny, (per) Perevalok, (che) Chernokamen, (bak) Bakeevo, (ury) Uryuk, (bas) Basu, (zig) Zigan.

Regional Stages (numbers in circles): (I) Redkino, (II) Belomorian; (III) Kotlin, (IV) Rovno, (V) Lontova.

Using C–Sr-isotope values to understand the stratigraphy from the Proterozoic São Francisco Basin, Brazil

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An intriguing stratigraphic scenario is present in the base of the Bambuí Gr concerning ages of sedimentation of the different carbonate facies. The São Francisco Basin includes a basal dominantly siliciclastic-carbonate sedimentary succession of the Paranoá Gr (Meso–Neoproterozoic) and a higher pelitic -carbonate succession of the Bambuí Gr (Neoproterozoic) (Fig. 1: A). The distinction of these two groups is clear when the glacial Jequitaí Fm is present, separating these two stratigraphic successions. Nevertheless, when the Jequitaí Fm is absent the carbonate facies of Paranoá and Bambuí groups can be in contact, and due to their similarities it is difficult to determine their stratigraphic position (Fig. 1: B). Isotopic evidences indicate two carbonate succession: one for the Bambuí and other for the Paranoá Gr. These isotopic signatures distributed throughout the São Francisco Basin mark $\delta^{13}C$ excursions and $^{87}Sr/^{86}Sr$ ratios that can be tentatively linked to environmental events of the Meso–Neoproterozoic. In the carbonates of the Paranoá Gr the resulting $\delta^{13}C$ values are positive, ranging between +0.3‰ and +3.0‰ (Fig. 1: B). The $\delta^{13}C$ value along the Bambuí Gr begins at –5‰, cap carbonate, and rise upward reaching +12‰ (Fig. 1: B). This $\delta^{13}C$ stratigraphic curve of the Bambuí Gr can be correlated throughout the São Francisco Basin. The $^{87}Sr/^{86}Sr$ ratio for limestones of the Paranoá Gr is 0.7056–0.7068, while the ratio for Bambuí Gr, which is younger, is 0.7074–0.7075. These limestones have Sr > 500 ppm and Mn/Sr < 0.3, thus they reflect $^{87}Sr/^{86}Sr$ of coeval sea water. $^{87}Sr/^{86}Sr$ data for the Paranoá Gr, which is stratigraphically below the Bambuí Gr, are consistent with an age older than 750–800 Ma preceding the first Cryogenian glaciation. The isotopic results support and validate the carbonate stratigraphic reconstruction proposed for the São Francisco Basin and support the relative ages suggested for these two groups regarding the first Cryogenian glacial event.

Late Precambrian biostromes in the Iya–Biryusa Zone of Fore-Sayan Area

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Riphean strata in front of the Sayan Ranges constitute the Fore-Sayan Pericratonic Basin, and also occur in the Tagul–Biryusa Horst and the Uvat Uplift. In the Fore-Sayan Basin, the Riphean is represented by the Karagass Gr comprising the Shangulezh (300–1320 m), Tagul (300–800 m), Ipsit (300–600 m), and Marnya (265–315 m) formations and the Oselok Gr consisting of the Uda (290–340 m) and Aisa (1600 m) formations [1]. The Karagass Gr unconformably, with basal conglomerates, overlies heavily folded pre-Riphean rocks and is intruded by gabbro-dolerites of the Nersa Complex dated at 741 ± 2 Ma [2]. The Oselok Gr is devoid of biostromes and sits unconformably on various stratigraphic levels of the Karagass Gr. The Shangulezh Fm of the Karagass Gr starts with transgressive polymictic and arkose, poorly sorted sandstones interbedded with laterally discontinuous grits and conglomerates, with uranium mineralization along stratigraphic unconformities (Uvat, Tumanshet, Tagul–Biryusa mining departments), reaching 500 m in thickness. The sandstones are succeeded by a section (up to 820 m) of gray, variegated dolomites, alternating silicified dolomites, siltstones, shales, siliceous rocks, tuffaceous sandstones [3]. Biostromes occur as patches, their distribution, distance from each other, and area controlled by tectonic regime, geological structure, paleotopography, and hydrodynamics. In the Iya–Biryusa Zone, the Precambrian biostromes are confined to the central part of the Fore-Sayan Basin, localized in the most subsided part and less common on the flanks of the structure. Biostromes are common in the Shangulezh, Tagul, Ipsit, and Marnya formations of the Karagass Gr. Biostromes in the Shangulezh Fm are dolomitic

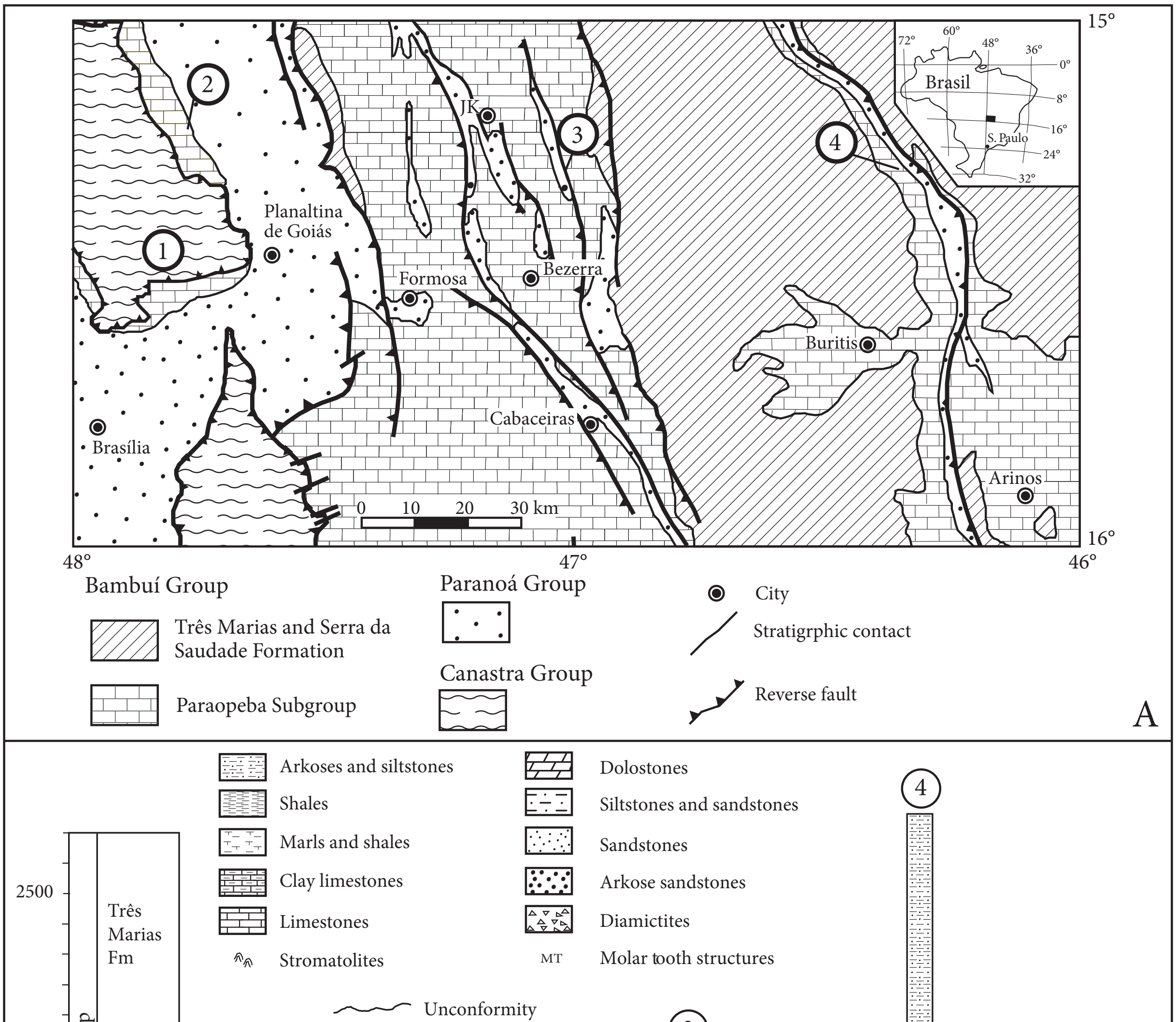

Figure 1. **A**: Simplified geologic map of the western part of São Francisco Basin, with location of 1, 2, 3 and 4 sections. **B**: Stratigraphic sections of Paranoá and Bambuí groups showing variations of $\delta^{13}C_{pdb}$ and $^{87}Sr/^{86}Sr$.

with minor microphytolitic sandy limestones, terrigenous rocks and shales. The biostrome part of the section is 140–150 m thick, some bioherms reach 12–15 m in height. Biostromes extend for up to 45 m, as seen in nine sections along the Bol'shaya and Malaya Biryusa, Mara, Uvat, and Iya rivers. They are made of columnar, nodular and stratiform stromatolites of *Compactollenia*, *Baicalia*, *Omachtenia*, *Sajania*, and *Tungussia* groups, concentric microphytolites *Osagia tenuilamellata* Reitl., *O. columnata* Reitl., *O. undos*a Reitl., *O. utchurica* Nar., and *O. libidinosa* Z. Zhur. and clotted microphytolites *Vesicularites compositus* Z. Zhur. and *V. rotundus* Z. Zhur. [4]. In the Tagul and Ipsit formations, the biostromes intercalate with microphytolithic complexes and are widely distributed in all parts of the Fore-Sayan Basin. The best exposure of these formations, with over 40 individual studied sections, can be seen along the Biryusa, Tagul, Uda, and Iya rivers, where the biostromes consist of nodular stromatolites of *Tinnia* Dolnik group represented by *Tinnia patomica* Dol., *T. punctata* Dol., *T. ipsitica* Dol., as well as nodular stromatolites *Colleniella gigantea* Dol. Columnar stromatolites *Inzeria gigantea* Dol., *I. tchentcha* Dol., *I.* aff. *tjomusi* Kryl., *Patomia ossica* Kryl. and *Linella avis* Kryl. form bioherms up to 1 m in diameter and 0.7 m in height, together with microphytolites: concentric *Osagia grandis* Z. Zhur. and *O. crispa* Z. Zhur.; radial fibrous *Asterosphaeroides multus* Voron., *A. usitatus* Voron., *A. legibilis* Z. Zhur., *A. defluxilis* Z. Zhur., *A. primus* Voron., *A. emendatus* Yak., *Radiosus aculeatus* Z. Zhur., *R. ravidus* Z. Zhur.; and clotted *Nubecularites uniformis* Z. Zhur., *Glebostes gentilis* Z. Zhur. [5]. Biostromes in the upper part of the Karagass Gr demonstrate thick biorhythms of alternating stromatolite buildups and microphytolitic and chemogenous carbonate rocks. Each biorhythm starts with chemogenous limestones and marls that prograde into organogenous stromatolitic and microphytolitic rocks, with evidence of hydrodynamic activity in a form of cross-bedding and erosional scour casts. The buildups extend for 1000 km along the Fore-Sayan Basin [6]. Poor exposure prevents the study of lateral variations of the biostromes across the basin. Their sudden disappearance near the Sharyzhalgai Massif and absence in the boreholes drilled on the Siberian Craton suggests that the biostromes were confined to a narrow zone favorable for stromatolite- and microphytolite-forming cyanobionts. The Tagul Fm hosts manganese ore deposits represented by iron-manganese and manganese varieties, usually characterized by increased amounts of phosphorus and cobalt. The ore bodies are stratiform, sheetlike and lenticular, confined to biostromes in the central part of the Fore-Sayan Basin. The Riphean biostromes of the Karagass Gr of the Iya–Biryusa Zone of Pre-Sayan area are referred to as the first Proterozoic-Riphean-Vendian planetary phase of biostrome formation, with several centers in the Urals, Eastern Siberia, Far East, Canada, North America, Kola Peninsula, etc.

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Geochemical constraints on the iron source of the Neoproterozoic Rapitan Iron Formation (Northwest Territories, Canada)

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The Neoproterozoic represents a time in Earth's history when significant environmental changes took place, including a pair of global glaciations that led to ocean stagnation and an apparent build-up of dissolved ferrous iron. As the ice receded and ocean circulation became re-established, the iron became oxidized and formed a suite of iron formations in the oxic zone of upwelling areas. However, the ultimate source of iron is still a matter of intense debate. Major Cryogenian (635–850 Ma) deposits include the ca. 715 Ma Rapitan Gr in northern Canada and the Urucum district in Brazil, the 750–650 Ma Chuos Fm in Namibia, and the 750–700 Ma Braemar Ironstone within the Adelaide Geosyncline of South Australia. Rare earth elements plus yttrium (REY) concentrations in IF have been successfully used as proxies to study secular trends in Precambrian ocean chemistry. Of particular interest are Ce and Eu due to their multiple redox states. While Ce is a useful proxy for paleoredox conditions, Eu is commonly used for assessing hydrothermal influence on the chemical precipitates. Despite a number of previous geochemical studies on Cryogenian iron formations, complete REY data sets are virtually absent. Here we examine bulk and mineral phase trace-element geochemistry (REY) of the Rapitan Iron Fm, ostensibly one of the most representative Neoproterozoic iron formations. Specifically, we attempt to establish the controlling factors in the source and distribution of various chemical elements, including iron, with the ultimate goal of understanding the conditions surrounding the deposition of this iron formation. Samples for geochemical analysis were selected on the basis of extremely low, if any, Th, Zr, Hf and Sc concentrations and lack of co-variations between Zr vs. Y/Ho, Y/Ho vs. Ce/Ce* and Th vs. La/La*. All the samples display similar REY patterns with depleted LREE relative to MREE (Pr/Sm_{PAAS} = 0.48–0.67), while MREE are depleted relative to the HREE (Sm/Yb_{PAAS} = 0.2–0.8). In addition, they show positive La (La/La^*_{PAAS} = 1.3–2.6), Eu (Eu/Eu^*_{PAAS} = 1.12–1.33), and Gd (Gd/Gd^*_{PAAS} = 1.08–1.2) anomalies as well as superchondritic Y/Ho ratios (28–33) and no or slightly positive Ce anomalies (Ce/Ce^*_{PAAS} = 1–1.23). The results of this study show: (i) REY profiles with distinctive seawater-like signatures (i.e., LREE-depletion relative to HREE, superchondritic Y/Ho ratios and positive anomalies of both La and Gd); (ii) precipitation under oxygen-deficient conditions (no to slightly positive Ce anomaly); and (iii) iron being sourced from hydrothermal vents (positive Eu anomaly). Of particular interest, along with Ce, is the identification of an Eu anomaly in all of the samples analyzed. The latter might be explained either by precipitation in an open stratified ocean involving ferruginous deep waters – through which hydrothermally sourced Eu (and iron) could travel long distances – or by deposition taking place in a somewhat restricted basin where the Eu signature is more easily retained. In the first scenario, our results might confirm, as previously proposed, that ferruginous conditions dominated during the Sturtian "snowball glaciation". Alternatively, a semi-isolated basin should be considered for the deposition of the Rapitan iron formation.

Structure and petroleum potential of the Fore-Sette-Daban Trough (southeastern Siberian Craton)

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Petroleum potential of the eastern part of Aldan Anteclise was regarded as high. Most of the publications are dated 1960s–1980s, followed by a time gap. The oil-and-gas survey of the Aldan–Maya Basin, within the borders of the Fore-Sette-Daban Trough, was renewed in 2005. During the period of 2005–2010 the joint-stock company "Yakutskgeofizika" conducted areal seismic survey. The results allowed higher estimate to be made for petroleum potential of Proterozoic complex. This contribution summarizes the new results, as well as the results of restudy of Mokui-1 and Khochom-1 parametric boreholes and the geological survey, thematic and other data obtained by the Siberian Research Institute of Geology, Geophysics and Mineral Resources.

Stratigraphy. A range of facies zones is established for the Riphean of the region, each characterized by unique structural features and section completeness. There is the Uchur Facies Zone in the southwest, the Maya Facies Zone in the east and northeast, and Yudoma–Maya Facies Zone in the east, the latter divided into the northern and southern subzones.

The Lower Riphean in the Uchur Facies Zone is divided into the Gonam, Omakhta, and Ennin formations of the Uchur Gr. The Gonam Fm sits on the crystalline basement and consists of poorly sorted, quartz and quartz-feldspar sandstones with siltstone streaks. The Omakhta Fm (50–400 m thick) consists of alternating purple and yellowish gray dolostones and variegated siltstones. The overlying Ennin Fm

(200–340 m) consists of solid sandstones, with a section of terrigenous-carbonate rocks in the middle. In the Yudoma–Maya Facies Zone, the stratigraphic equivalents of the Uchur Gr are identified in the Gornostakh Anticline where the group comprises the Trekhgorka and Dim formations. The former (1200 m) consists of siltstones and alternating sandstones and gray limestones in the lower part, and dolostones, sandstones and rare siltstones in the upper part. The Dim Fm (up to 2000 m) sits conformably of the Trekhgorka Fm and is represented by rhythmic alternation of terrigenous and carbonate rocks. In the Mokui-1 Borehole, possible stratigraphic analogues of the Gonam Fm (Uchur Gr) are identified in the interval from the bottomhole (3090 m) to 2280 m and consist of variegated poorly-sorted, solid sandstones and siltstones with dolostone streaks. Higher up in the section there is an interval (1836–2280 m) of alternating terrigenous rocks and dolostones, with rare sandy dolostones, which is correlated with the Omakhta, and Ennin formations of the Uchur Gr.

The Middle Riphean is subdivided into Aimchan and Kerpyl groups. The Aimchan Gr in the Yudoma–Maya Zone and in the south of Maya Zone comprises the Taloe and Svetlyi formations. The Taloe Fm (500–520 m) consisting of rhythmically alternating sandstones, siltstones and shales unconformably overlies different stratigraphic levels of the Uchur Gr; the Svetlyi Fm (310–320 m in the north of Yudoma–Maya Zone) is represented by gray stromatolitic dolostones, with gray shales and siltstones in the middle part. The overlying Kerpyl Gr comprises Totta, Malgin, and Tsipanda formations. The Totta Fm (400–700 m in the Maya Zone, 600–900 m in the Yudoma–Maya Zone) unconformably overlies the Uchur and Aimchan groups and is represented by alternating variegated sandstones, siltstones and shales. The Malgin Fm (90–100 m in the Maya Zone, up to 300–400 m in the Yudoma–Maya Zone) is conformable with the Totta Fm. It comprises variegated muddy limestones in the lower part and dark brown bituminous limestones, with streaks of dark bituminous shales, in the upper part. The Tsipanda Fm (150–200 m, thickening up to 400 m in the Yudoma–Maya Zone) is gradational with the Malgin Fm. It consists of light gray to yellowish flaggy dolosnotes in the lower part and gray thick cavernous dolostones in the upper part. In the Mokui Borehole, the Taloe and Svetloe formations are correlated with the interval of 1241–1836 m and unconformably overlaid by the Vendian deposits.

The Upper Riphean is divided into the Lakhanda and Ui groups which sit unconformably on the Tsipanda Fm; it is absent in the western part of the region including the Mokui-1 Borehole. The Lakhanda Gr comprises the Neryuen (340–360 m) and Ignikan (180–200 m) formations. The lower and upper parts of the Neryuen Fm consist of alternating variegated shales and siltstones, occasionally with sandstones; the middle part is represented by calcareous dolostones. The Ignikan Fm is conformable with the Neryuen Fm and consists of different colored limestones and dolostones. In the Yudoma–Maya Zone, the Lakhanda Gr is 1.5–2 times thicker. The Ui Fm occurs in the Yudoma–Maya Zone and in the east of the Maya Zone to the west of the Nelkan–Kyllakh Thrust. It comprises a thick section of terrigenous rocks which is subdivided into the Kandyk and Ust-Kirba formations. The Kandyk Fm (200–2000 m) consists of interbedded gray sandstones, siltstones and shales, with rare dolostones. The Ust-Kirba Fm (3500–3600 m) occurs only in the Yudoma–Maya Zone and is represented by interstratified sandstones, siltstones and shales.

The Vendian is represented by the Yudoma Gr, which is divided into lower and upper parts separated by a regional unconformity. To the north of the Yudoma River the group comprises the Yukanda and Sardana formations; to the south, it consists of the Aim and Ust–Yudoma groups, with the former being absent in the Bol'shoi Aim River Basin. The Yukanda Fm (up to 170 m) sits unconformably on various stratigraphic levels of the Upper Riphean. The lower part is represented mostly by dolostones and limestones, with a basal unit of sandstones with dispersed gravel material; the upper part comprises light gray and brown dolostones. In most parts of the region, the formation is partially or entirely eroded. The Sardana Fm (280–300 m) consists of dolostones, limestones and muddy limestones, with basal (20–100 m) quartz poorly sorted sandstones. The maximum thickness of the Yudoma Gr (up to 1000 m) is observed in the Belaya River Basin; the minimum thickness (200–280 m) is observed in the southwest, in the Aim Facies Zone. In the Mokui-1 Borehole, the Yudoma Gr is correlated with the interval 1030–1241 m.

Seismic geological characteristic of the section. Interpretation of seismic time sections is based on the proposed stratification of the Mokui-1 Borehole. At least four seismic horizons are traced in the section 846432A, which runs with nearly east-western trend in close proximity to the borehole, as well as in its eastward extension, the section 050401 (Fig. 2). The first seismic horizon (R6) is drawn between the

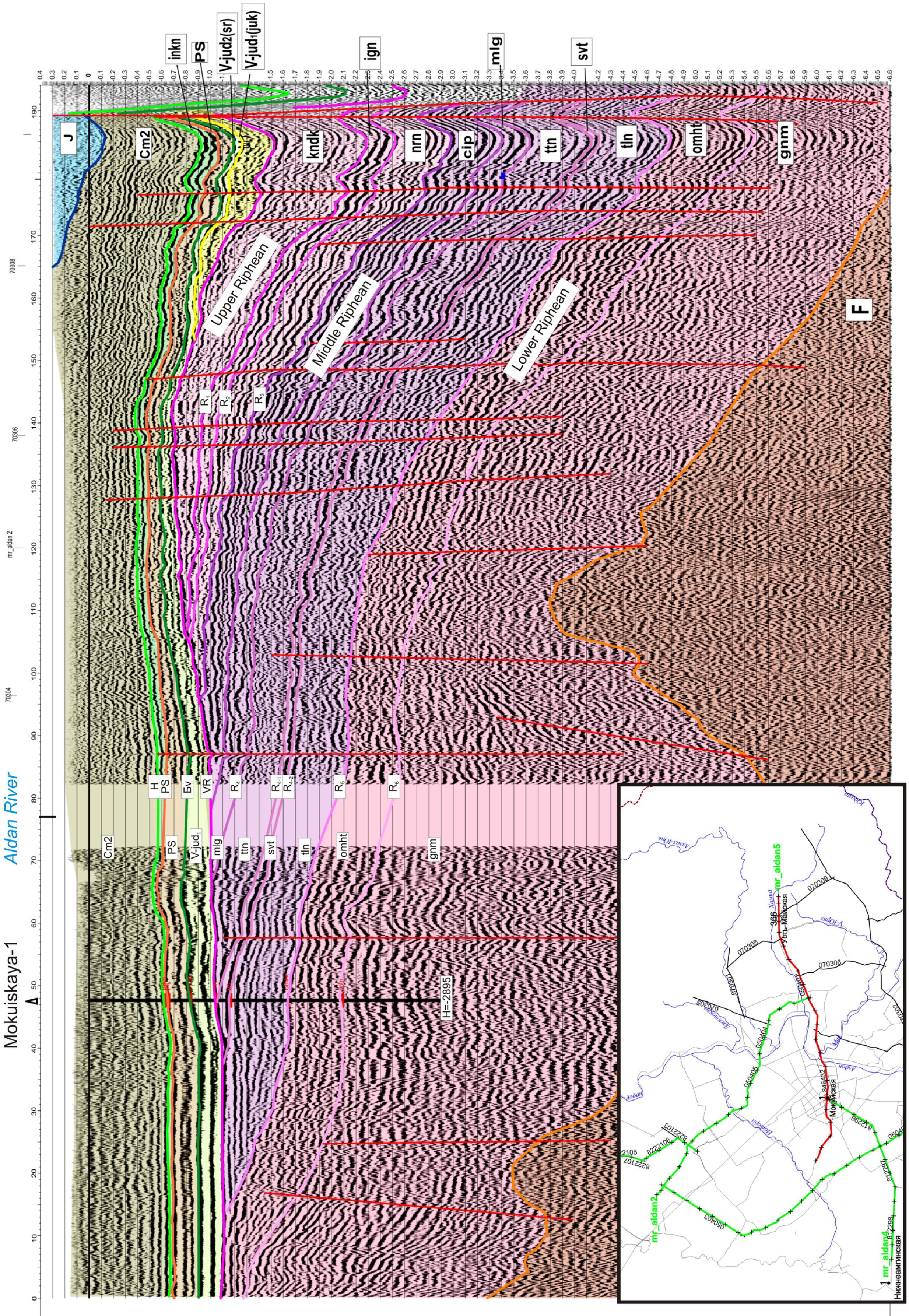

Figure 2. Deep geological geophysical profile along the line MR_ALDAN_5(ПР846432, ПР050401).

Gonam and Omakhta formations and traced to the Nelkan–Kyllakh Thrust. The second seismic (R5) coincides with the upper boundary of the Omakhta Fm and is recognized with confidence in the sections. The third (R4-2) horizon is traced in the top of the Taloe Fm descending in eastern direction in the adjacent section. The additional horizon R4-1 marks the base of the Totta Fm. The fourth seismic horizon (VR) coincides with the basal strata of the Yudoma Gr and is recognized by an angular contact with the underlying reflected horizons. Hence, instead of four reflecting horizons identified in the Mokui-1 Borehole, there are additional boundaries in the dipping zone to the east between the third (R4-2) and fourth (VR) horizons that are grouped into distinct seismic complexes identified by deposits of corresponding sequences. The sharp lithological contrast between carbonates of the Ignikan Fm and siliciclastics below (Neryuen Fm) and above (Kandyk Fm) determines the reflecting horizons R2 and R1 in the Upper Riphean succession. On the deep seismic profile 05041, the Kandyk Fm wedged between the top of the Ignikan Fm (seismic horizon R1) and the base of the Yudoma Gr (seismic horizon VR) reaches a thickness of 750 m in the most dipped eastern part and is truncated by the pre-Yudoma erosion in the western part. The reflecting horizon VR coinciding with the basal strata of the Yudoma Gr in the Mokui-1 Borehole can be traced on the 050401 seismic profile; it deepens in the eastern direction increasing the thickness of the Yudoma Fm, which in its lower part is differentiated as the Yukanda Fm. The increase in thicknesses to the east of the Mokui-1B Borehole suggests the presence of the Lower Vendian and additional formations in the Middle and Upper Riphean. This would explain the appearance of several seismic indices for the eastern part of the profile compared to the Mokui-1 Borehole (Fig. 2). Along with the above-mentioned boundaries, there are also reflecting horizons in the Paleozoic strata: ЮТ – Cambrian–Jurassic boundary, H – top of Inikan Fm (Middle Cambrian), PS – top of Pestrotsvet Fm (Lower Cambrian), БV – top of Vendian. The depths and thicknesses of the target horizons can be estimated from the deep geological and geophysical profile.

Tectonics. The studied region is located at the eastern margin of the Aldan Anteclise and in the western part of the Kyllakh–Nelkan Thrust of the Verkhoyanie Thrust and Fold Belt. The Aldan–Maya Basin is contiguous to the eastern slope of Aldan Anteclise in the southwest, and to the Yakutsk Dome, in the northwest; it shares a border with the Kyllakh Uplift to the east and is adjacent to the Omnya Uplift in the south. At least three structural stages can be recognized in the sedimentary cover based on the drilling of Mokui-1 Borehole and seismic geological survey: the Riphean, Vendian–Cambrian, and Mesozoic. The most complete section of the Riphean Structural Stage is established in the dipping zone on the eastern flank of the trough in front of the Kyllakh–Nelkan Thrust, where it reaches the thickness of 5200 m with the base resting at the depth 7000 m (Fig. 2). The Mokui-1 Borehole penetrated 1850 m of Riphean sediments (bottomhole at 1850 m). The Vendian–Cambrian Structural Stage rests unconformably on the underlying Riphean, is progressively truncated from east to west down to the basement, and reaches the largest thickness in the east of the Fore-Sette–Daban Trough. The Mesozoic Structural Srage reaches the thickness of a few hundred meters and consists of Jurassic deposits unconformable with the Vendian–Cambrian strata.

Petroleum potential. That the region has petroleum potential has been established in 1950s. Liquid oil inclusions were observed in the Malgin Fm in the Lakhanda Borehole (depth 513 m), whereas various heavy and solid bitumens were discovered in outcrops of the Middle–Upper Riphean carbonate and terrigenous rocks (Malga, Tsipanda, Neryuen, and Kandyk formations) in the course of geological survey and thematic studies. In terms of oil-source characteristics, the most interesting section is identified in the Upper Malga Fm. The sections reaches a thickness of 20 m and consists of dark bituminous limestones and oil shales. The C_{org} content in sapropelic marls of the Malgin Fm reaches 5.02–13.72%, the degree of catagenesis corresponds to the main zone of oil generation (MK2-3). In addition, there are several dark colored horizons with high organic matter content in the Lakhanda Gr. There are several potential reservoir horizons in the Middle Riphean and Vendian deposits. The first potential granular reservoir horizon in the Middle Totta Fm is characterized by a thickness of 100 m, porosity of 4.85%, and gas permeability 8.5–110 mD. It is sealed by a unit of shales and siltstones (up to 80 m) comprising the Upper Totta Fm. A horizon of cavernous dolostones (30–50 m) is identified in the Tsipanda Fm. It is characterized by a total porosity of 3.58%, effective porosity of 2.83%, gas permeability of 70–90 mD, and sealed by shales and siltstones of the Neryuen Fm. Another fractured and cavernous carbonate horizon (60 m) is recognized in the Middle Neryuen Fm. It is represented by stromatolitic limestones and dolostones, characterized by a total porosity of 7.35%, effective porosity of 6.12%, gas permeability 25–70 mD, and sealed by shales of the Upper Neryuen Fm. Higher in the Neryuen Fm there is a sandstone horizon (10–15 m) characterized by a total porosity of 8.12%, effective porosity of 6.81%, permeability of 80–90 mD, and sealed by shales and siltstones of the Upper Neryuen Fm. The upper reservoir horizon (30–40 m) is in the Lower Kandyk Fm (Ui Gr, Upper Riphean). It is characterized by a total porosity of 7.14%, effective porosity of 5.14%, permeability of 90–350 mD, contains kir in the lower part, and is sealed by shales of the Upper Kandyk Fm. Total geological resources D2 for the Middle Riphean, Upper Riphean, and Vendian are estimated to be ca. 1200 million of tons of hydrocarbon equivalent.

Seafloor barite in basal Ediacaran cap carbonates of Mongolia

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The Zavkhan (Dzabkhan) Basin of southwestern Mongolia hosts multiple Neoproterozoic glacial deposits within carbonate-dominated strata of the Tsagaan Oloom Fm. Glacial deposits had only been described in the basal Tsagaan Oloom Fm until mapping and geochemical analyses revealed an additional diamictite (Khongoryn Mb) >300 m higher in the succession (Fig. 3: A, B) [1]. The Khongoryn Mb is succeeded

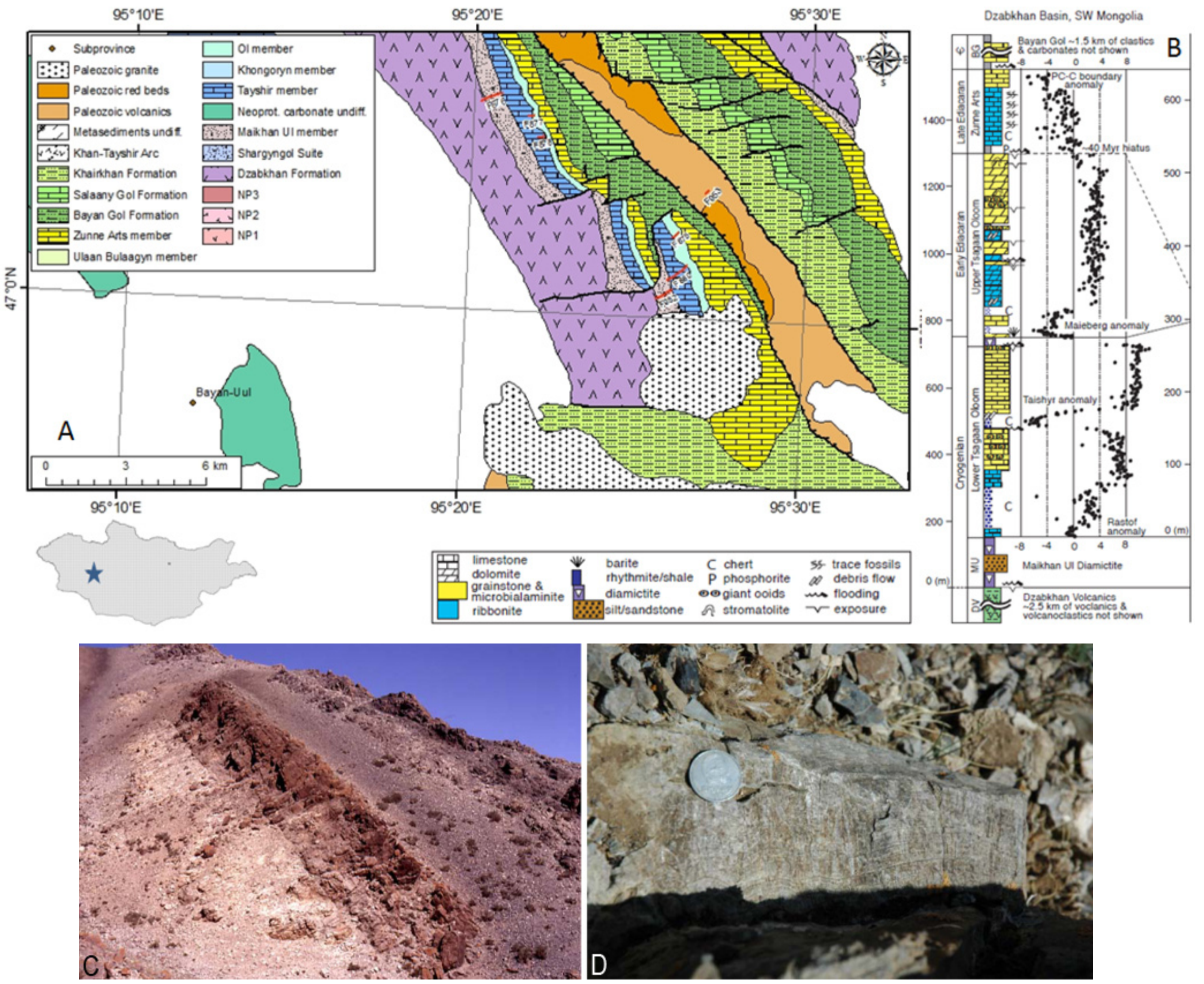

Figure 3. **A**: Geological map of Zavkhan Basin. Red lines show the sections measured. **B**: Stratigraphic column of Zavkhan Basin with $\delta^{13}C$ curve. **C**: Chocolate brown upper cap dolostone at Hoh Daava; brown coloring is due to disseminated iron and barite. **D**: Bedded barite at the top of the chocolate brown upper cap dolostone at Hoh Daava.

by the Ol cap carbonate, which contains giant wave ripples, tubestone stromatolites, and aragonite fans [1], all of which are characteristic of basal Ediacaran cap carbonates globally [2]. Here we report the discovery of sedimentary barite fans ($BaSO_4$) in the Ol cap carbonate in Mongolia along with carbon, oxygen and sulfur isotope analyses. Barite is also found in basal Ediacaran cap carbonates in South China [3], Central Australia [4], Northwestern Canada [2] and West Africa [5]. Samples were collected for carbon and oxygen isotope analyses in multiple sections across the Dzabkhan Basin spanning over 100 km. Large lateral gradients are present in carbon isotope profiles of the Ol cap carbonate. In the eastern portion of the basin, carbon isotope data display sigmoidal profiles with a nadir at −6‰, similar to that of cap carbonates around the world [2]. However, in the western most sections, carbon isotope values are extremely enriched with few negative values and a peak at ~+8‰. These values cannot be explained merely by diachronous deposition or alteration. The most isotopically enriched sections are also the sections in which sedimentary barite occurs. Barite fans were discovered at section F875 from the mountain pass, Hoh Davaa, Govi–Altay province (Fig. 3: C, D). Barites are bedded and form domal structures as well as breccia. Multiple sulfur analyses of $\delta^{34}S$ and $\Delta^{33}S$ show a positive trend, implying an enrichment in heavy sulfur isotopes. This trend is also present in barites from West Africa and NW Canada. The fans exhibit $\delta^{34}S$ values that cluster near 40‰, and a restricted range of $\Delta^{33}S$ values from 0.07 to 0.1‰. This range of compositions is typical of the post-Archean geologic sulfur isotope record, where they are taken to result from mass-dependent metabolic isotope selectivity during microbial sulfur cycling [6]. The paleoenvironmental significance of barite is that its solubility is highly redox-sensitive in sulfur bearing aqueous solutions. Large lateral gradients in carbon isotopes may be related to a spatial or temporal restriction of a strong redox gradient.

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Ediacaran soft-bodied organisms and macrophytes: two sides of one coin?

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There are two fundamentally different types of Proterozoic macrofossil preservation: casts (molds) usually attributed to soft-bodied organisms and carbonaceous compressions interpreted as macrophytes. That some of the casts (molds) of soft-bodied organisms have morphological analogues among carbonaceous compressions has long been appreciated [1], but the full scale of this phenomenon is revealed in a Konservat Fossil Lagerstätte discovered in the Arctic Siberia [2]. The Upper Vendian Khatyspyt Formation cropping out along the Khorbusuonka River of the Olenek Uplift (northeast of the Siberian Craton) is characterized by two types of macrofossil assemblages: (i) casts and molds of soft-bodied organisms (about 600 specimens) and (ii) carbonaceous compressions of macrophytes (about 250 specimens). The soft-bodied organisms are represented by rangeomorphs and frondomorphs, as well as microbial colonies, however the frondomorphs and microbial colonies can also be preserved as carbonaceous compressions, whereas the rangeomorphs are restricted to fossil assemblages with moldic preservation. Preservation of certain soft-bodied organisms in a style which is typical for macroscopic algae suggests that at least in frondomorphs their macrophyte nature cannot be entirely excluded. This has important implications for interpretation of the Avalon biota of Newfoundland, the oldest fossil assemblage of Ediacaran soft-bodied organisms, which is also represented by frondomorphs and rangeomorphs. The Avalon biota is interpreted as deep-sea communities that inhabited continental slope below the photic zone [3]; however, if frondomorphs are just seaweeds, then the Avalon biota inhabited the photic zone. In any case, a possibility should not be excluded that casts, molds and carbonaceous compressions could represent different modes of preservation of the same organism, not necessarily a metazoan (Fig. 4).

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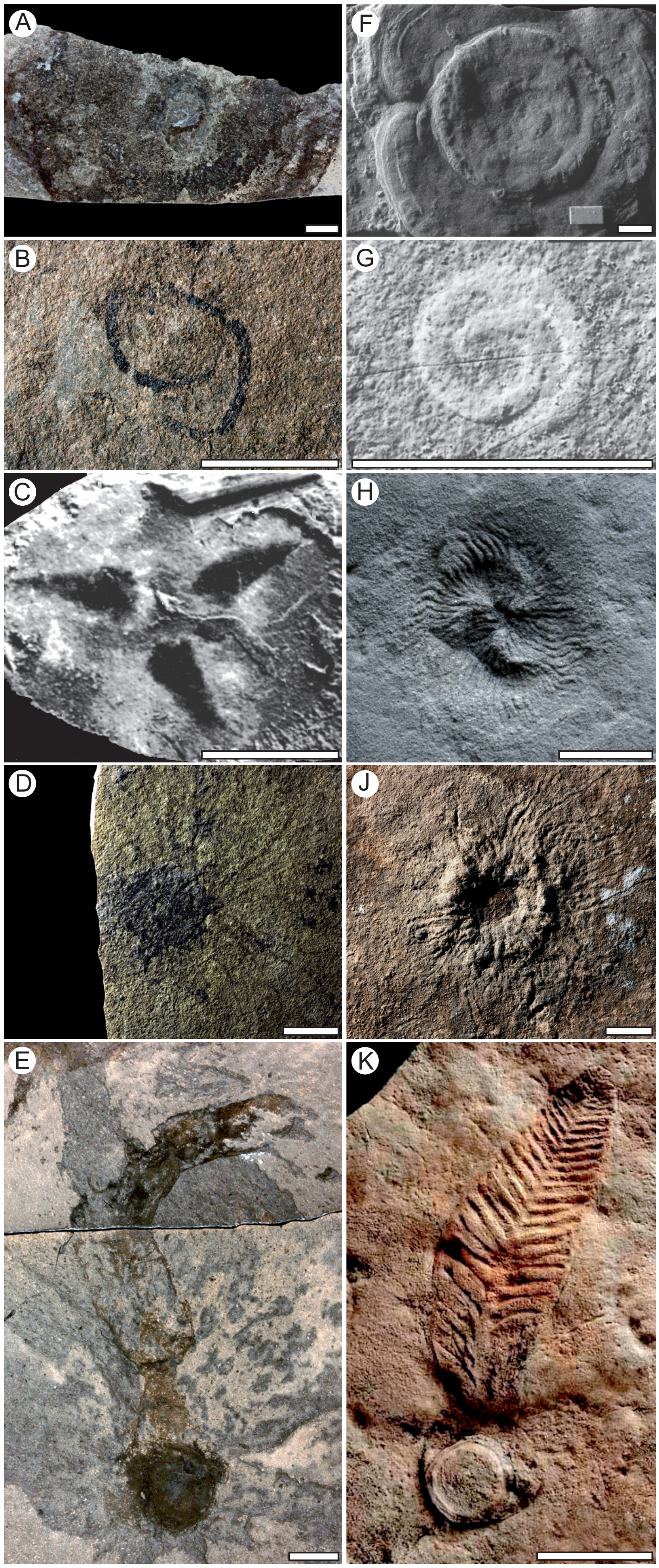

Figure 4. Ediacaran fossils preserved as carbonaceous compressions (A–E) and casts/moulds (F–K): **A**, **F**: *Ediacaria*; **B**, **G**: *Grypania*; **C**: *Triactindiscus;* **D**, **J**: *Mawsonites*; **E**, **K**: *Charniodiscus*; **H**: *Tribrachidium* (A, B, D, E, J: Khatyspyt Fm, Siberia, Russia; C: Doushantuo Fm, South China; F, H: Erga Fm, White Sea area, Russia; G: Rohtas Fm, India; K: Rawnsley Quartzite, Australia). Scale bar: A–J – 10 mm, K – 10 cm.

Vendian reference section of Central Siberia and the Neoproterozoic Ice Ages

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The Patom Complex of the Patom and North Baikal foldbelts and adjacent parts of the Siberian Craton comprises the Ballaganakh, Dal'nyaya Taiga and Zhuya groups that in the late 20th century were correlated with the Riphean. J.K. Sovetov and D.A. Komlev [1] proposed that the upper two groups were of Vendian age. Recent advance in chemostratigraphy, biostratigraphy and isotope geochronology [2–7] suggest that the Dal'nyaya Taiga and Zhuya groups together with the overlying Zherba and Tinnaya formations can be regarded as the most complete and dated reference Vendian section in Central Siberia. The uppermost part of this section below the paleontologically defined Tommotian strata is represented by the Tinnaya Fm and contains early and late Nemakit Daldynian fossils [8]. Carbonates of the Tinnaya Fm are characterized by strong variations of negative $\delta^{13}C$ values comprising −5…−3‰ on average [9], with two prominent negative peaks (−8…−7‰) in the middle part of the formation and two minor positive peaks (~ +0.5‰ near the top and ~ +2‰ near the base of the formation). The Zhuya Gr and the overlying Zherba Fm are both characterized by a single large negative $\delta^{13}C$ excursion [2], however it seems likely that the two stratigraphic units are separated by a disconformity corresponding to the Baikonur Glaciation. The Zhuya negative $\delta^{13}C$ excursion (−8…−12‰) can be correlated with the Shuram Excursion (600–550 Ma) of Oman and China younger that 600 Ma [10, 11]. Such correlation is supported by relatively high $^{87}Sr/^{86}Sr$ ratio of 0,7079 for carbonates of the Zhuya Fm which is typical for carbonate rocks 600–575 My old [12], as well as by the Pb–U LA age of 646.9 ± 3.4 Ma of the youngest detrital zircons from the basal sandstone of Zhuya Gr [7]. The Zhuya Gr therefore has middle–late Vendian age. Stratigraphically lower in the section, the Ura Fm of the Dal'nyaya Taiga Gr yielded an assemblage of Pertatataka-type acanthomorph acritarchs (ECAP palynoflora) of Early Vendian age [4, 5], and the Vendian taxon *Beltanelloides sorichevae* was found in the underlying strata of the Barakun Fm. The basal part of the Dal'nyaya Taiga Gr comprises the Central Siberian glacial horizon [13] correlated with the Lower Laplandian Horizon of the Vendian. With exception of cap dolomite, the Dal'nyaya Taiga Gr is characterized by large positive $\delta^{13}C$ values (4–8‰). All the available evidence suggests that the Tinnaya and Zherba formations, together with the Zhuya and Dal'nyaya Taiga groups, constitute a fairly complete Vendian section. This conclusion is corroborated by correlation of the Patom Complex with the Neoproterozoic of South China. The Central Siberian glacial horizon, therefore, could be coeval with the Nantuo Fm of China and the Yerelina Subgroup of Australia of the Marino glaciation.

There were several glaciations in the Earth history called glacial eras that lasted hundreds of million years [14]. Based to geochronological and biostratigraphic data, the Neoproterozoic African Glacial Era spanning the latest Riphean and Vendian can be divided into six discrete glacial episodes which are similar in extent and historical complexity to the Pliocene and Pleistocene glacial periods. The glacial periods of the African Era recurred every 25–50 My. The most pronounced (in ascending order) are the Kaigas, Rapitan, Sturtian Marino, Gaskiers, and Baikonur glacial periods. The duration of the periods can be only roughly constrained because of correlation error and low resolution of isotope dating techniques: 760–740 Ma for the Kaigas, 725–700 Ma for the Rapitan, 650–663 Ma for the Sturtian, 657–635 Ma for the Marino, 584–582 Ma for the Gaskiers, 549–542 Ma (possibly until 533 Ma) for the Baikonur. Each glacial period consisted of two or more glacial episodes that can be regarded as glacial epochs. This stratification is seen in the Yudnamutana and Yerelina subgroups [15], Rapitan Gr [16], Jbeliat [17] groups and in the Jetymtau [18] and Fiq [10, 19] formations. The Bol'shoi Patom Fm records two episodes of glacier advance. A complex nested hierarchy (epoch, period, era) describes Neoproterozoic glacial events of different scale and duration that triggered various perturbations and crises in the atmosphere, hydrosphere, continents and biota. Such biosphere crises could lead to extinctions, diversifications, acceleration of mutations and natural selection, and appearance of novel stable organismal forms.

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Uchur–Maya sedimentary basin of southeastern Siberian Craton: stratigraphy, geodynamics, and petroleum potential

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The Uchur–Maya sedimentary basin covering the area of over 200 000 km^2 is located in the southeastern part of the Siberian Craton. The petroleum potential of the basin was discovered in 1930s when a core of cavernous dolomites yielding a light-yellow liquid oil was recovered from the depth of 513 m in the Lakhanda 1 Borehole drilled in the right bank of the Maya River. The basin formed in Mesoproterozoic (1650 ± 50 My ago) on the peneplained granite-gneiss basement of the craton [1] and was filled with sedimentary rocks over a period of >1 Gy. It comprises a slightly deformed Meso- to Neoproterozoic complex and a horizontal Upper Neoproterozoic (Ediacaran) to Silurian and Mesozoic complex. The Meso- to Neoproterozoic complex is divided into six groups: the Mesoproterozoic Uyan (1650–1400 Ma), Uchur (1650–1400 Ma), Aimchan (1320–1200 Ma), and Kerpyl (1200–1000 Ma) groups, and the Neoproterozoic Lakhanda (1000–850 Ma) and Ui (730–665 Ma) groups, each separated by unconformities and corresponding to a major episode in depositional history.

The Uyan Gr of Calimmian age (up to 1650 m) comprises interstratified red sandstones and conglomerate, with vesicular basalts in the lower part of the section, deposited in delta channel, tidal and subtidal settings of a shallow epicratonic basin surrounded by peneplained land. The red color of terrigenous rocks is due to prevalence of ferric iron over ferrous iron state and suggests sedimentation under oxic conditions in a hot climate. The Uchur Gr of Calimmian age (1500–2000 m) sits unconformably on the Uyan Gr (locally on crystalline basement) and consists of red sandstones, siltstones and stromatolitic dolostones, with gray quartz sandstones, dolostones and siltstones in the upper part; siltstones and sandstones in the middle part have dolomitic cement. Cross-bedding, ripple marks, rain drop imprints are indicative of shallow-water setting. The Aimchan Gr of Ectasian age (130–1600 m) unconformably overlies the Calimmian strata. A tectonic slab of Archean metamorphic rocks 150–400 m thick (Batomga block) was recognized in the southern part of the basin between the Uchur and Aimchan groups [2]. The latter is represented by alternating sandstones and siltstones, with bituminous coarse-grained sandstones and conglomerates at the base, exhibiting a wide range of sedimentary structures of shallow-water origin (ripple marks, desiccation cracks) and hot humid climate (red color). The Kerpyl Gr of Stenian age comprises siliciclastic and carbonate rocks, occasionally carbonaceous, and demonstrates a gradual increase in the relative content of carbonates, fining of siliciclastic material, and increase in thickness from 340 to 780 m in eastern direction. It transgressively, with basal conglomerates, overlies the Ectasian strata. The Lakhanda Gr of Tonian age (300–1000 m) sits unconformably, with bauxite deposit at the base, on the Stenian strata and is represented by variegated, mainly stromatolitic, often bituminous limestones and dolostones interstratified with mudstones and siltstones formed in shallow marine and lagoonal, occasionally subaerially exposed settings. The Ui Gr of Cryogenian age (up to 3500 m) is confined to the eastern part of the basin, (the Yudoma–Maya aulacogen), transgressively overlies the Tonian strata and comprises siliciclastic rocks of shallow marine origin deposited in warm climate. The upper part of the succession is represented by variegated volcanogenic and siliciclastic rocks. The Yudoma Gr of Ediacaran age (less than 250 m) transgressively overlies the Cryogenian strata and constitutes the basal horizon of the platformal complex of the craton. It consists of bituminous dolostones, sandy limestones, mudstones, siliceous mudstones, and sandstones. The oil potential of the basin is demonstrated by high content of organic matter in some of the rocks (bituminous dolostones, sapropelic mudstone, and deltaic sandstone) and occurrence of productive reservoirs with traps impermeable to hydrocarbon fluid flows.

Analyses of paleomagnetic data and palinspatic reconstructions suggest that in Meso- and Neoproterozoic Siberia was located near the equator, and from late Paleoproterozoic [3] to early Neoproterozoic [4] it made a ~90° turn counterclockwise with respect to the meridian. In Early Neoproterozoic (950–900 Ma) Siberia was located in southern tropical latitudes (0–20°), with the Baikal margin facing to the west. Starting in Cryogenian (850–800 Ma), Siberia shifted 20° northward and made an almost 90° turn clockwise, with the Baikal margin facing north. In mid-Cryogenian (750–700 Ma) Siberia shifted 5–10° to the south, and by the end of Cryogenian (650–600 Ma) it further shifted 15–20° to the south retaining nearly the same orientation. In early Ediacaran (570–550 Ma) Siberia further shifted 20–25° to the south (Taimyr margin was near 40° S) and made a 10–15° turn counterclockwise [5].

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Neoproterozoic metaterrigenous–carbonate complex of the Derbina Block (Eastern Sayan): petrogeochemical composition, isotopic age constraints, and evolutionary settings

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Metaterrigenous–carbonate complex of the Derbina Block is one of the largest structural elements in the accretion–collision belt along the southwestern and southern margins of Siberian Craton. The study of

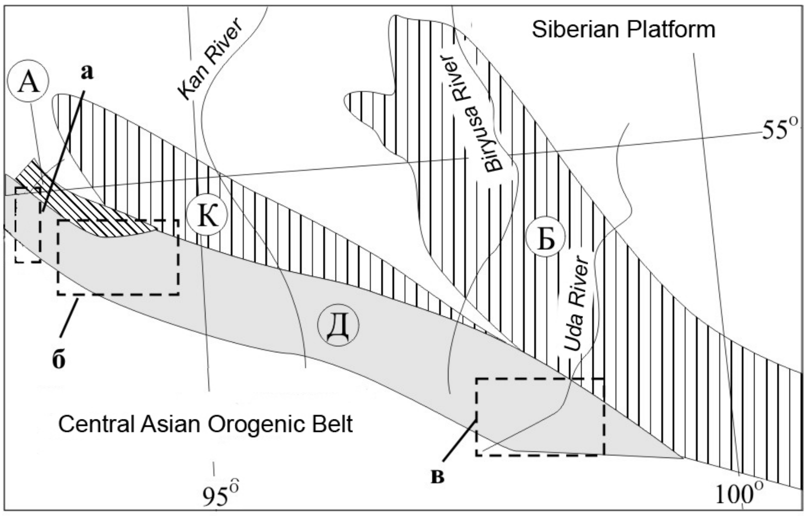

Figure 5. Position of the Derbina Block in the structure along the southwestern margin of the Siberian Craton. А: Arzybei Block, К: Kan Block, Б: Biryusa Block, Д: Derbina Block; а – Krol River basin, б – Mana Ranges, в – Uda River basin.

this block became crucial in discussing the earliest stages of crustal evolution of the Central Asian Orogenic Belt (CAOB). The Derbina Block is located in the central part of Eastern Sayan extending for 500 km from the mouth of Iya River in northwestern direction to the Yenisei River (Fig. 5). Metaterrigenous–carbonate rocks extend along the northwestern, or sublattitudinal direction and are grouped in linear folds that are verged to north or northeast at the angles of 50–80°. The block is delineated by the Main East Sayan Fault to the north and by the disjunctive thrust fault structures of southern or southeastern dip, to the south. The metasedimentary complex of Derbina Block is part of the Upper Precambrian Sayan Gr comprising Alykzher, Derbina and Zhaima formation. The metamorphic rocks are bedded and have sedimentary origin. In northwest of the Derbina Block, inside of Mana Ranges, the **Alykzher Fm** is represented by rhythmically interstratified schists (amphibolic, amphibole-pyroxenic, pyroxen-amphibole-calcitic, garnet-calcite-amphibolic), gneisses (biotite-amphibolic, biotite ± amphibole ± muscovite, amphibolic), as well as amphibolic marbles (calciphyre), micaceous and graphytic quarzites. In south-eastern part of the Derbina Block (Uda River basin) this formation consists of biotite-amphibolic, biotite-pyroxen-amphibolic plagiogneisses (65%), amphibole-biotitic, garnet-biotitic (± sillimanite) gneisses and schists (30%) interstratified with graphitic marbles and micaceous metaterrigenous quartzites. The **Derbina Fm** is everywhere represented by dominant white and bright gray graphitiferous medium- and coarse-cristalline calcitic marbles, graphitic and graphite-micaceous quartzites and subsidiary biotite-amphibolic and biotitic plagiogneisses and calciphyres, with plagioclase-amphibolic crystalline schists (metabasites) in the upper part of the section in Uda River basin. In the north (Mana Ranges) and in the south (Uda River basin) the marbles are conformably overlaid by the **Zhaima Fm** consisting of alternating graphitic gneisses, schists, quartzites, marbleized limestones and calciphyres. The rocks are metamorphosed to epidote-amphibolic and amphibolic facies, increasing in southwestern direction.

Within the Derbina microcontinent the granitoids are widespread, share structural, petrological and geochemical characteristics, and can be regarded as the single Derbina Complex. Granitoids form clusters of conformable, subconformable, and crosscutting small bodies (reaching several meters across) in the Sayan Gr of Mana Ranges and constitute sheets, veins and massifs in metamorphic rocks in the southeast (Agul, Gutara, Uda rivers basins) the granitoids form as well as areas of sheeted and veined bodies, that supply the section of metamorphic rocks. The granitoids consist of amphibole-biotitic quartz diorites and tonalites, biotitic plagiogranites, microcline granites and leicogranites, as well as their pegmatoid varieties [1].

The best studied metasedimentary rocks of **Alykzher Fm** are located in geographically separated south-eastern (Uda River Basin) and central (Mana Ranges) parts of the Derbina Block) (Fig. 5). The meta-terrigenous rocks were studied according to Neyelov Classification Diagram [2]. Significant variations of the parameter b = $Fe^{2+}+Fe^{3+}+Mn+Ca+Mg$ (atomic quantity) in crystalline schists are related to changes in melanocratic compound and carbonate quantity in original sediments. The amphibolic and pyroxen-amphibolic schists and gneisses with high calcium content (CaO = 7.0–17.7%) are positioned the calcareous siltstones and silty carbonates field of the diagram, whereas the biotite-amphibolic gneisses with low calcium content (CaO = 2.9–6.0%), in the graywacke and calcareous siltstones field. The calcium content in Alykzher Fm notably declines in southeastern direction. The rocks demonstrate a poor petrochemical differentiation by the parameter a = Al/Si (atomic quantity) and is positioned in the siltstones field, with exception of biotitic and garnet-biotitic gneisses with high alumina content (Al_2O_3 = 16.0–17.6%) positioned in the aleuropelites and pelites fields. These gneisses are characterized by high K_2O content (1.8–3.7%), compared other gneisses and schists (K_2O = 0.2–2.9%). All the rocks can be regarded as graywackes, as suggested by the high Sodium Module values (Na_2O/Al_2O_3 > 0.2) [3] reflecting sodium removal in the process of chemical weathering, as well as the position of representative points in the Pettijohn Classification Diagram [4].

Geochemical features point to low maturity of the metasedimentary rocks. The metaterrigenous rocks of Derbina Block have SiO_2/Al_2O_3 = 3.2–5.2 corresponding to igneous rocks [5] and suggesting inconspicuous fractionation of the material during transport and its low alteration during weathering. The maturity grade of the sediment with CaO content less then 5% can be quantitatively estimated using the Chemical Index of Alteration (CIA = $[Al_2O_3/(Al_2O_3+CaO+Na_2O+K_2O]\times100)$ [6]. The CIA values vary between 46 and 56, which is significantly lower than in clay schists (70–75) [7].

Because the terrigenous component of sedimentary protoliths in the studied metamorphic rocks has not suffered any differentiation and intensive chemical alternation, the sediment composition is determined based on the character and ratios of crystalline rocks in the feeding province. High $MgO+Fe_2O_3^*$ values (6–14%) and low (compared to PAAS [7]) K_2O/Na_2O values (0.1–1.8) indicate the presence of a significant portion of basic rocks in the source area. Metasediments correspond to graywackes of the continental island arcs as suggested by $MgO+Fe_2O_3^*$ and TiO_2 quantities and their rare element composition [8]. This conclusion is also corroborated by position of the metasedimentary rocks representative points in the Bhatia Discriminatory Diagrams [9].

Distribution of REE, Th, Hf, Co, Sc or their ratios are important for resolving rocks composition in source areas because concentrations of these elements significantly differ for acid and basic rocks. Comparison between the average Th/Co, Th/Sc/ La/Co, La/Sc and Eu/Eu* values in the studied gneisses, the PAAS and the sediments formed by weathering of granitoids and basic rocks [10] shows that the ratios of Th/Co and Th/Sc in the studied metasediments are similar to the sediments formed by weathering of basic rocks; at the same time, La/Co, La/Sc and Eu/Eu* values show the presence of terrigenous material derived from granitoids. The values of indicative ratios La/Sc, La/Co, Th/Sc and Th/Co significantly differ between the rocks from different areas, although show an increasing trend in southeastern direction suggesting the addition of terrigenous material formed by weathering of igneous and metamorphic acid rocks enriched by incoherent rare elements. The average values of REE and rare element content as well as Th/Co, Th/Sc, La/Co, La/Sc and Eu/Eu* ratios in gneisses and schists of the Sayan Group are not significantly different between formations and suggest that metasediments are derived from acid and basic rocks. Rare element composition of these rocks bares similarities with continental island arcs graywackes.

The studied quartzites of **Derbina** (Mana Ranges, Uda River basin) and **Zhaima** formations (Krol River basin) of the Sayan Group of Derbina Block correspond to two groups of sandstones in the Pettijohn Classification Diagram [4]: the quartz arenites (graphitic quartzites with SiO_2 > 86%) and lithic arenites, e.g. subarcose, arcose, graywacke (micaceous quartzites with SiO_2 < 86%). Based on the high content of Al_2O_3, TiO_2, Na_2O, K_2O and Zr relative to chemogenic quartzites, the studied rocks are most likely to be terrigenous. Low CIA values (45–63) indicate low degree of source rock alteration. The range of elements and their content in quartzites of the **Zhaima Fm** are similar to those of the **Derbina Fm** (Mana Ranges). Quartzites of the **Derbina Fm** from the Uda River basin are characterized by higher concentrations of K_2O relative to Na_2O, higher (La/Yb)n values and a prominent Eu anomaly. Similar rare element concentrations in quartzites of the **Zhaima** and **Derbina** formations (Mana Ranges) suggest similar composition (apparently andesite-basaltic) of feeding provinces. Quartzites of the Uda River basin probably formed with addition of the material derived from mature source rocks with high K_2O and LREE content.

Carbonates in these three formations are similar in distribution of Ti, Mn, Zr, Sr, Ba, the main typomorphic elements of carbonate rocks that define physical and chemical features of depositional environment, as well as of Cr, Ni, Co, V, Cu, Sc, Zn, Pb, Y etc., the accompanying elements that determine the petrogenic character of source rock. The content of main typomorphic elements Ti (180–300 g/t), Mn (100–240 g/t), Zr (7–27 g/t), Sr (660–2700 g/t) and Ba (77–936 g/t) in the carbonates are also similar suggesting that depositional facies were also alike. Similar content of the accompanying elements Cr, Ni, Co (above clarke) and Pb, Y (below clarke) indicate that feeding provinces didn't change much. The studied metaterrigenous–carbonate rocks of the Derbina complex, therefore, formed in similar depositional environments. The most likely feeding province was immature rocks of island arcs with high Sr, Sc, Co concentrations, with addition of material derived from geochemically differentiated source rock with high content of LREE and Th that is typical for granitoids and metamorphic complexes of Siberian Craton basement.

Nd isotopic composition data of metasediments provide a very important information about their source rock. The Derbina Block metagraywackes have T_{Nd}(DM) = 1.3–1.9 Ga and εNd = –3.5…+4.4 at T = 1000 Ma [11]. Based of isotopic Sm–Nd data and features of granitoids and terrigenous metasediments the rocks of crystalline basement of Derbina Block are similar to those of the Arzybei Block [1, 12]. The island-arc tonalites and trondjemites and post-tectonic granites of the Arzybei Block have T_{Nd}(DM) = 1090–1130 Ma [13]. Nd model ages for the Derbina Block granitoids range between 930 and 1060 Ma [1]. The isotope data show that crystalline basement rocks of the Derbina Block are similar to the Arzybei island-arc complex and both formed during the Meso- and Neoproterozoic crust-generating events. The isotopic composition of the Derbina Block suggests that the metasediments formed as mixture of a detrital material derived from island-arc igneous associations such as the Arzybei Block and an older cratonic material derived from granitoids and metamorphic complexes of the Biryusa Block having T_{Nd}(DM) = 1565–1535 Ma and εNd = –13.5...–14 at T = 1000 Ma [13].

The U–Pb-zircon date of 498 ± 5 Ma for a sinorogenic vein (1.8 m across) of quartz diorite (tonalite) in a metacarbonate–terrigenous section of the Alykzher Fm of Sayan Group [1] is compatible with the Ar–Ar-hornblende date of 501 ± 3 Ma for the host amphibolic crystalline schists. The high-temperature metamorphism, therefore, was coeval with the Late Cambrian sincollisional diorite-plagiogranite magmatism.

In conclusion, the isotopic-geochronological data indicate that terrigenous sedimentation in the Derbina and Arzybei terranes started not earlier than 1 Ga. The zircon-date of ~500 Ma from the sinorogenic quartz diorites constrains the upper age limit. All of the isotopic-geochronological data point to Neoproterozoic age of the Derbina terrane.

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A new approach to Neoproterozoic micropaleontology and sedimentology of Brazil

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The Paranoá and Bambuí groups are lithostratigraphic units of Mesoproterozoic–lowermost Neoproterozoic and Neoproterozoic age, respectively [1–3]. Both units are thought to be deposited in marine settings [4, 5]. Rock samples from these units were prepared and analyzed to develop a novel approach that would integrate micropaleontology with sedimentology and improve the efficiency of both methods. Recovering individual microfossils from the Paranoá and Bambuí groups has been a challenge for paleontologists, therefore most micropalentological studies were done as a part of microbiofacies analyses in thin sections. Several chemical, physical, and biological factors contributed to the low recovery of individual microfossils and prevented biostratigraphic and paleoecological studies. To overcome this problem, we combined the classical procedure of mineralized microfossil preparation, the palynological technique and the study of clay mineralogy with the analyses of diagenetic alteration and the search for possible microfossils in thin sections. In preparation for the search (and handpicking) of mineralized microfossils we studied every sediment fraction, even the finest one. Handpicking was conducted using a stereomicroscope with ×200 magnification, and three out of 40 samples yielded microfossils in 160 μm, 80 μm and >80 μm fractions. All 40 samples were prepared for palinological analyses, and one of the three samples that contained mineralized microfossils also yielded palinomorphs. Following this approach we recovered *Vetronostocale* aff. *V. amoenum* Schopf & Blacic, emend. Xu & Awramik 2001, *Trachyhystrichosphaera*? sp., *Myxococcoides*? sp. and *Melanocyrillium*? sp. (Fig. 6). Clay mineralogy from prepared and original samples are currently being studied in order to evaluate the effect of microfossil preparation technique using hydrogen peroxide on the results of sedimentological analysis.

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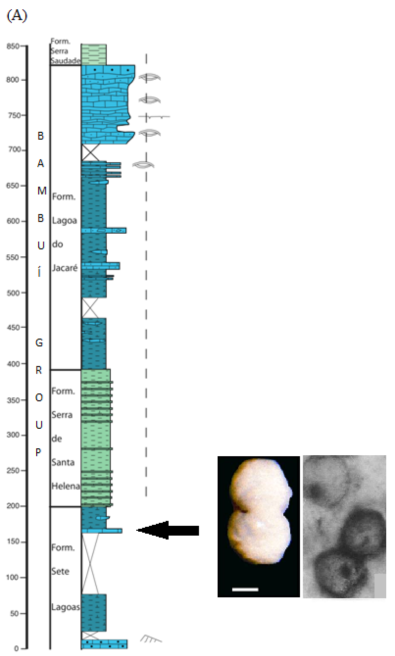

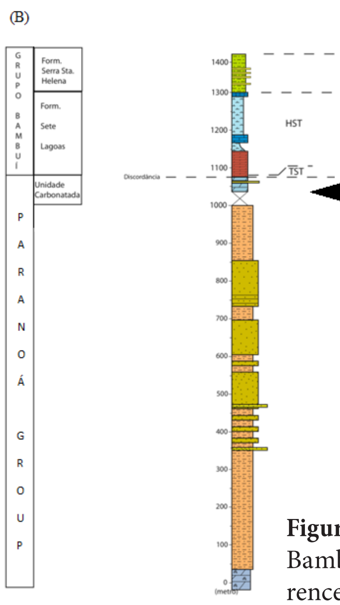

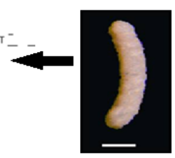

Figure 6. Studied logs of Paranoá and Bambuí groups and microfossil occurrences.

A: Bambuí Group; **B**: Paranoá Group.

Development of the South China Plate and the Paraguay Belt in west central Brazil during the Late Proterozoic to Early Cambrian interval (700–525 Ma)

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During the Late Proterozoic break-up of the Supercontinent Rodinia the South China Plate was situated within tropical latitudes probably either straddling the equator or lying just a few degrees to the north in an "upside-down" position (present day northern region facing south towards the equator). The post-Nantuo (Marinoan) deglaciation "cap carbonates" (with tepee structures) are ubiquitous in the region. There are also six pronounced disconformities (including one at the Precambrian–Cambrian boundary) separating major formations and traced in both shallow and deep water facies. These clearly established and correlated across the South China Plate disconformable (not unconformable!) contacts are probably linked to worldwide eustatic regressions. The same regressions are recognized in the west of Central Paraguay Belt of Brazil and at least in part associated with local tillite units (mountain glacier fans?) embedded in Ediacaran sediments above the Marinoan Puga Tillite at various locations in northwestern pericratonic sections ("Amazonia"). However, inter- and intraformational contacts are not yet sufficiently dated in Brazil because they lack fossils and also because of tectonic activities in the Brazilide–Panafrican Orogeny between ca. 550 and 525 Ma. The paleogeographic position of the most part of Late Proterozoic to Cambrian Paraguay Belt was apparently at high latitudes during the Ediacaran time interval.

Western part of the Baikal–Muya Foldbelt: new isotopic-geochronological data and aspects of reconstruction of the Baikal–Patom Passive Margin framework

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Reconstructions of Neoproterozoic basins for the Baikal–Patom area and the adjacent Baikal–Muya Belt have been discussed in a number of publications; however, there remain open questions regarding correlation between geological processes in the two adjacent (in a present-day structure) belts. For example, data obtained from volcanic and magmatic rocks proved the existence of arc-related complexes of the Baikal–Muya belt at 830 Ma [1, 2]; nevertheless, the presence of volcanics in the source area is uncertain for the coeval sedimentary sequences [3] leading to conflicting paleogeodynamic reconstructions [4–7]. Furthermore, the available tectonic schemes reflect different approaches to understanding the tectonic structure and evolution of southern Siberia. For example, L.M. Parfenov and coauthors [8] proposed the following structural elements: (1) **Baikal–Patom area** defined as the Neoproterozoic fault-bounded craton margin discordantly covered by the later Vendian and Cambrian sedimentary rocks; (2) **Baikal–Muya belt** included into the Circum-Siberia tectonic collage accreted in the Neoproterozoic and consisting of Neoproterozoic island arcs as well as small fragments of older terranes; (3) **Sayan–Baikal region** including the Central Mongolian microcontinent defined as part of the Yenisey–Transbaikal tectonic collage accreted in Vendian to Early Ordovician. Authors of another small scale tectonic scheme merged the above mentioned structural elements of the Baikal area and the Sayan–Mongolian region. New data obtained for the Kichera zone (southwest of the Baikal–Muya belt) can resolve the problem. Four formations are represented in the studied part of the Kichera zone: a granulite-enderbite-charnockite association, high-Ti gabbroids, pyroxenite-troctolite-gabbro complex of Tonkiy Mys massif, and a hypabissal diorite-plagiogranite complex intruding the first three formations. Geochronological data previously published for these complexes did not include later granitoids.

The hypabissal diorite-plagiogranite complex established in the course by our field and analytical studies marks the final stage in development of the structure. Granitoids of this complex yielded a U–Pb-zircon date of 591 ± 3 Ma. The isotope study was performed by laser ablation inductively coupled plasma mass spectrometry (LA ICP-MS) in the Laboratory for isotope geochemistry and geochronology (Vernadsky Institute of Geochemistry and Analytical Chemistry). We also confirmed the previously published age estimate of 617 ± 5 Ma for the enderbites [9] (LA ICP-MS in the same laboratory). Three samples of enderbites and gneisses representing several different complexes provided the U–Pb-zircon dates that fall between 603 and 620 Ma. The Slyudinskiy massif of high-Ti gabbronorites spatially related to the enderbite-granulite complex crystallized 618 ± 61 My ago [10]. The high-Ti gabbroids and granulite-enderbire associations in the studied area, therefore, are parts of a single evolutionary event. The available age constraints for the Tonkiy Mys massif (585 ± 22 Ma [10]) suggest that the troctolite-gabbro massifs crystallized in the upper lithosphere concurrent (or somewhat later) with the granulite-enderbite complex. They were juxtaposed with the gabbro-granulite-enderbite series from the lower levels of lithosphere as a result of differentiated tectonic movements and intruded by diorite-plagiogranite dykes 591 ± 3 My ago. The tectonic activity is also marked by conglomerates in the lower part of Kholodnenskaya Fm and the coeval formations.

The following events can be reconstructed for the Kichera zone of the Baikal–Muya belt. Formation of the heterogeneous accretional orogenic structure (tectonic collage), with ophiolites and remnants of earlier formed Neoproterozoic island arcs, was completed by the middle Vendian time. Cessation of the subduction process about 600–620 My ago resulted in oceanic slab break-off (or lithospheric delamination); it was probably the first stage in the process of collision between the Siberian Craton and the tectonic collage which resulted in termination of the subduction and later transformation of the tectonic collage into a relatively stable area (young microcontinent, compared to the Siberian Craton). The processes are manifested as granulitic metamorphism, enderbite and mafic intrusions of Vendian age in the margin of tectonic collage, as well as short-lived tectonic movements followed by tectonic stabilization of the area.

To summarize, the structure of Kichera zone of Baikal–Muya belt is the record of an early phase of collision between the shelf part of the Siberian Craton and the paleostructures of the mobile belt. This event occurred not later than 590 My ago. Consequently, the evolution of the shelf basin had been terminated at least in one of its segments by the late Vendian, and the shelf-type deposition gave way to accumulation of coarse-grained sediments in mountain valleys (Kholodnenskaya Fm and the coeval formations). At the same time basins of different depositional type existed in the area of tectonic collage. The collisional event between the southern part of craton (present-day reference frame) and the mobile belt structures took place not earlier than 490 My ago ([11], and references therein]). The strike-slip boundary between the Siberian Craton and the paleostructures, now forming the Central Asian belt, is reconstructed. The tectonic setting in the north of the present-day Australian shelf (Timor Island) can be used as a modern analogue to the reconstructed junction between the Neoproterozoic Siberian shelf and the adjacent mobile belt.

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Patterns of lateral distribution of microfossils in Vendian petroliferous deposits of the Nepa Dome of the Nepa–Botuoba Anteclise, eastern Siberia

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Microfossils in the Precambrian petroliferous sediments of the Nepa–Botuoba Basin of Siberia have been known since 1980s [1–5], but the biostratigraphic implications remained controversial on account of sporadic nature of the available paleontological data, taxonomic confusions related to the imperfect classification, and poor understanding of the facies control over microfossil distribution. As the new material accumulated in Russia and abroad [6–10], the perspective of establishing a microfossil-based biostratigraphy of the Upper Precambrian, and particularly, the Vendian, became more attractive. In particular, stratigraphically important assemblages of acanthomorphic acritarchs were established in central and southeastern regions of the Siberian Craton in the corse of recent micropaleontological investigations [11]. Nevertheless, correlation of certain characteristic taxonomic associations faced considerable difficulties because of unclear picture of their lateral distribution.

Patterns of lateral distribution of the microfossils were analyzed in over 30 sections of boreholes drilled through the Vendian strata in Verkhnechonskaya, Zapadnaya, Ozernaya, Khamakinskaya and Talakanskaya blocks of the Nepa Dome (Fig. 7). The most complete sedimentary sequences of the Upper Precambrian are in the eastern part of Nepa Dome. The studied Lower Vendian terrigenuous deposits of the Vilyuchan and Nepa regional stages are wedged between Upper Riphean sandstones of the Talakan Fm and Upper Vendian carbonate sediments of the Tira and Danilovo regional stages [12, 13]. More than 200 studied samples come from the Talakan, Talakh, Parshino and Byuk formations (Fig. 7).

The **Talakan Fm** (boreholes 806, 808, 826, 843) yielded low quantities of fragmented organic matter and no microfossils. The **Talakh Fm** (boreholes 804, 806, 808, 815, 817, 823, 824, 826, 843, 844, 845) contains abundant organic detritus and rare sphaeromorph acritarchs of the genus *Leiosphaeridia*. The **Parshino Fm** has variable paleontological characteristics. Boreholes 804, 810, 812, 815, 817, 827, 828 contained only organic detritus material, whereas other boreholes yielded taxonomically diverse microfossils. Four taxonomic associations can be distinguished named after most characteristic taxa. One of them (*Leiosphaeridia – Talakania* Association) is not very rich, but the other three (*Appendisphaera – Talakania*, *Appendisphaera – Hamakinia* and *Appendisphaera* – Gen. et sp. indet. 1 associations) are very diverse.

The ***Leiosphaeridia – Talakania* Association** established in the lower part of Parshino Fm in boreholes 806, 98, 780 and 811 is dominated by sphaeromorph acritarchs *Leiosphaeridia minutissima*, *L. crassa*, *L. tenuissima*, and *L. jacutica*, with minor filamental microfossils *Siphonophycus* sp. and *Talakania obscura*.

The ***Appendisphaera – Talakania* Association** established in boreholes 96, 780, 741, 742, 750, 761 contains abundant acanthomorphic acritarchs. Diagnostic microfossils include *Appendisphaera grandis*, *A. tenuis*, *"A". tabifica*, double-wall vesicles *Pterospermopsimorpha insolita*, oval forms *Cucumiforma vanavaria*, *Navifusa* sp., sphaeromorph acritarchs of the genus *Leiosphaeridia*, filaments *Talakania obscura* and *Siphonophycus* sp. The association also includes rare *Cavaspina acuminata*, *Ceratosphaeridium glaberosum*, *Cucumiforma vanavaria*, *Lophosphaeridium* sp. and other taxa. In addition, the Ozernaya-761 Borehole yielded *Tanarium conoideum* and *T. tuberosum*.

The ***Appendisphaera – Hamakinia* Association** established in boreholes 848, 806, 809, 823, 824, in addition to *Appendisphaera grandis*, *A. tenuis*, *"A". tabifica*, *Navifusa* sp., *Talakania obscura*, *Siphonophycus* sp., *Leiosphaeridia* spp. is also characterized by numerous forms referred to the genus *Hamakinia*. In addition, the Tsentral'no-Talakanskaya-806 Borehole yielded acritarchs *Cavaspina acuminata*, and the Tsentral'no-Talakanskaya-848 Borehole contained members of the genus *Tanarium*.

The ***Appendisphaera* – Gen. et sp. indet. 1 Association** established in boreholes 843, 844, 845, 849, 21301, 21302 is diagnosed by undescribed multicellular filamental algae Gen. et sp. indet. 1 and acritarchs

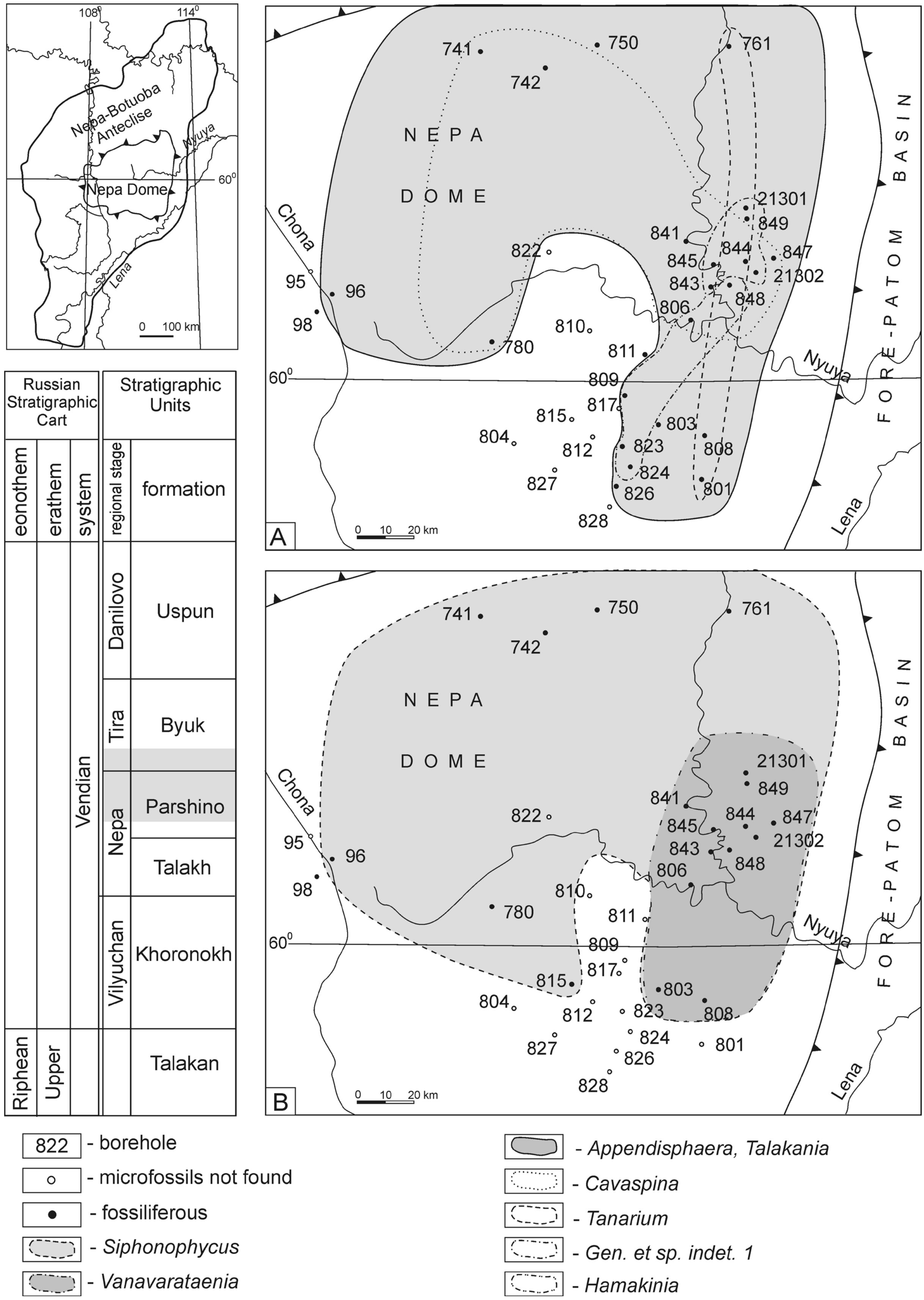

Figure 7. Patterns of lateral distribution of microfossils in the Vendian of Nepa Dome.
A: Parshino Fm; **B**: Parshino–Byuk boundary strata.

Appendisphaera grandis, *A. tenuis*; the association also includes *Cavaspina acuminata*, *Tanarium tuberosum*, *Leiosphaeridia* spp., *Talakania obscura*, *Siphonophycus* sp. and other taxa.

In the vertical section of the Parshino Fm there is a gradual decrease in taxonomic diversity of microfossils because of disappearance of certain sphaeromorph acrtitarchs, including the acanthomorphs. At least two associations are recognized, represented mostly by filamental algae, that characterize the **Parshino–Byuk boundary strata**. The first, ***Siphonophycus* Association** established in boreholes 96, 741, 742, 750, 761, 780, 815 is depauperate and contains filamental microfossils *Siphonophycus* sp., *Oscillatoriopsis* sp., *Glomovertella glomerata*, *Talakania obscura* and sphaeromorphs *Leiosphaeridia* spp. The second, ***Siphonophycus – Vanavarataenia* Association** established in boreholes 803, 808, 806, 841, 843, 844, 845, 847, 848, 849, 21301, 21302 contains *Siphonophycus*, *Oscillatoriopsis*, *Talakania*, *Leiosphaeridia*, but is notable for the presence of *Vanavarataenia insolita* and vendotaenids.

The overlying **Byuk Fm** was studied in boreholes 803, 806, 817, 741. It contains inconspicuous organic detritus and is devoid of microfossil.

The most diverse microfossil associations of the Parshino and lowermost Byuk formations of the Nepa and Tira regional stages are characterized by wide distribution. When ranges of the diagnostic taxa are plotted on the map of borehole position (Fig. 7), the maximum diversity of microfossils is localized in the eastern part of the Nepa Dome parallel to the contour of the Fore-Patom Basin. This pattern is interpreted as an expression of facies control over the microfossil distribution.

The results corroborate the available paleogeographic reconstructions for the late Riphean and Vendian of central parts of the Siberian Craton [14]. The Upper Riphean Talakan Fm and the lower Vendian Talakh Fm of the Nepa Dome were deposited in continental settings, with periodically flooded coastal plains in the east. The Parshino transgression from the east resulted in appearance and wide distribution (except for the southwestern part of the Nepa Dome) of diverse associations of microorganisms (Fig. 7: A). The transition from siliciclastic to carbonate settings in early Byuk time is manifested in disappearance of acanthomorph acritarchs and a wide short-lasted distribution of filamental algae *Siphonophycus*, *Oscillatoriopsis* and *Vanavarataenia* (Fig. 7: B).

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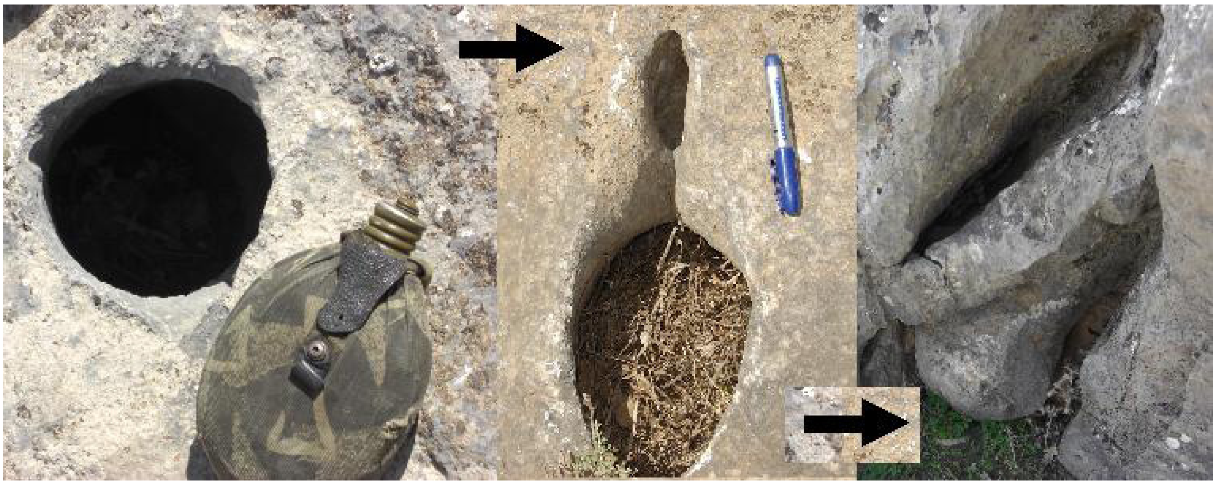

Figure 8. Taphonomic variation of the casts of megascopic mud-eaters as a result of lithogenetic transformation of carbonates of the Bogambir Fm (Northern Nuratau Ranges, Uzbekistan).

Stratigraphy and depositional environment of carbonates of the Bogambir Formation of Northern Nuratau Ranges (Uzbekistan)

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The age of carbonates of the Bogambir Fm of Uzbekistan is debatable. The strata are thought to have a very narrow distribution within the eponymous mountain range of Northern Nuratau Ranges and are correlated over a distance of more than 150 km with similar carbonates of the Suyaltash Fm of Mal'guzar Ranges. The Bogambir Fm, erected by P.N. Podkopaev in 1964, was originally thought to be of Wenlock–Ludlow age; however, the age was subject to repeated revisions (unpublished reports by Chukarov *et al.*, 1968; Posokhova *et al.*, 1968; Asatullaev, 1970; Bukharin, 1982; Usmanov *et al.*, 1984; Novikova, 1991; Vashchenko *et al.*, 1992) and varied between Lower–Middle Cambrian and Middle Devonian. A Precambrian age was not excluded from consideration when in 1972 I.A. Pyanovskaya and K.K. Pyatkov in western Bogambir and Z.M. Abduazimova and R.I. Mansurov in eastern Bogambir found fossils identified by M.S. Yakshin as Lower Riphean to Lower Cambrian microphytolites, although later in the same strata I.A. Pyanovskaya reported Wenlockian corals and stromatoporoids and Cambrian hexactinellid sponges. Stratigraphic age of the Bogambir Fm was discussed on a series of colloquiums and meetings (April 1989 and others); however, the Proterozoic age is still regarded as an alternative [1]. The formation was further subdivided into members, and the members with Silurian fossils were excluded from the formation [2]. Some authors [3] refer these strata to as Ludlovian, others (Z.M. Abduazimova, I.A. Pyanovskaya, M.A. Ahmedzhanov) hold to the idea of the Proterozoic age of the Bogambir Fm, but R.R. Usmanov thinks that both formations are Proterozoic. Neither the discovery of scolecodonts, acritarchs and fragments of skeletal fossils by T.N. Jankauskas (unpublished report, 1988) nor the special study by T.N. Novikova (unpublished report, 1991) helped to solve the problem. Despite having enough evidence in support of the Paleozoic age, V.P. Vashchenko and coauthors (unpublished report, 1992) could not defend their conclusion during production of the geological map (scale 1:50000). As of today, there are as many as 20 alternative points of view on the age of the Bogambir Fm. The Bogambir Fm (200–250 m) comprises fine laminated and massive limestones extending for 10 km), has fault contacts with the adjacent Ordovician aluminosiliciclastic sediments and Devonian to Middle Carboniferous effusive rocks, and locally is conformably overlaid by carbonates of the Yatak Fm (S_{1-2}). The lateral extent of the carbonates is complicated by two faults and metasomatism, however the fossil corals were found on the ridge least affected by tectonic dislocations. These fossils indicate a Lower Ordovician age [4], which agrees with the Lower Ordovician age of the aluminosiliciclastic sediments in the adjacent areas and does not support the idea of hypothetical thrust faults. Carbonates of the Bogambir Fm are interpreted as a reef barrier complex. The inter-reef facies are represented by fine laminated and, dark carbonates with soft sediment deformation and dewatering structures. Theses carbonates are notable for abundant open and spherical cavities of various diameter (from 3–5 cm to 15–30 cm) interpreted as casts of megascopic mud-eaters [5]. The cavities show a degree of taphonomic variation (Fig. 8). The eastern side of a ridge includes oolite-pisolite carbonates, with fragments of corals, deposited in wave-agitated environment. The age of reef carbonates of the Suyaltash Fm on the western termination of Mal'guzar Ranges is also debatable ranging from Upper Riphen to Devonian. Presence of similar open cavities in the limestones of Suyaltash Fm corroborates the correlation with Bogambir Fm.

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Lithological and isotope-geochemical indices of depositional environment of Neoproterozoic diamictites in South Urals

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Diversity of lithological types of Upper Neoproterozoic deposits of Bashkirian meganticlinorium (BMA) aggravates the recognition of global events and prevents the correlation of individual sections. Diamictites in the sections of western (Tolparovo) and eastern (Krivaya Luka, Arsha) parts of BMA are good correlation markers. Other sections (Bakeevo, Ust'-Katav) devoid of diamictites can be correlated with the Tolparovo, Krivaya Luka and Asha sections by stratigraphic position between the carbonates of Uk Fm (Riphean) and the sandstones of Uruk Fm (Vendian). This interval is poorly constrained; however, basaltoids from the Arsha graben (720 Ma), their possible analogues in the Volga–Urals region (borehole Kipchak-1; 730 Ma), and glauconite from the Bakeevo Fm (617 Ma) suggest that the interval lasted ca. 100 Ma. We established a correlation of events based on reconstructed variations of redox conditions of sedimentation, lithological and isotope-geochemical indices.

In the Tolparovo section, this interval is characterized by gray basal conglomerates, diamictites, sandstones and siltstones, with a unit of pink (due to presence of hematite grains) cap carbonates. Sandstones are mostly yellowish gray and contain small Fe-hydroxide nodules. The presence of rare non-oxidized sandstones and the fact that oxic alteration is found only around nodules of pyritic cement and pyritic micro-nodules with relict framboidal structure suggest euxinic sedimentation that was interrupted during the cap-carbonate deposition. Reduced conditions also characterized deposition of the lowermost gray conglomerates and sandstones of the Uruk Fm with preserved large crystals of feldspar. Red-colored hematitized sandstones in the upper part of Uruk Fm point to oxic conditions and severe climate aridization.

In the Krivaya Luka graben, diamictites of the Kurgashla Fm are red-colored suggesting the presence of hematite and oxic conditions of sedimentation. The overlying strata are greenish gray, including the conglomerates and sandstones stratigraphically analogous to the Uruk Fm. The underlying quartz sandstones and gray siltstones of the Krivaya Luka Fm contain Fe-hydroxide nodules formed over original pyritic nodules and, by analogy to the Tolparovo Fm, indicate euxinic conditions of sedimentation.

In the Bakeevo section, the relatively thin stratigraphic interval between the Uk and Uruk formations is represented by variegated, green- and red-colored rocks due to the presence of glauconite and hematite (minerals with different Fe-oxidation state). The overlying conglomerates and sandstones of the Uruk Fm are gray-colored in the lower part and become red-colored in the upper part. In the Ust'-Katav section, the pre-Uruk mudstones are grayish-green with preserved large clasts of feldspar.

Certain parameters of sedimentation can be reconstructed using S isotope composition in pyrite from the Tolparovo section and C and O isotope composition in the cap carbonates [1]. Dolomites in the cap carbonates have $\delta^{13}C$ and $\delta^{18}O$ values similar to those from other Neoproterozoic sections [2]. There are several occurrences of pyrite in the Tolparovo section. First, the diamictites contain pyritic pebbles ($\delta^{34}S$= –16.2‰) that were not affected by oxidation and fragmentation in debris flow due to anaerobic conditions of sedimentation. Second, pyrite is also found in the sandstones below and above the diamictites in the form of pyritic micronodules that became fully oxidized to Fe-hydroxides, whereas $\delta^{34}S$ = +9.7‰ suggests transformation of marine sulfate to sulfide amid limited sulfate reservoir. Occasionally, pyrite in diamictite has positive $\delta^{34}S$ values: according to the "snowball Earth" hypothesis, ice-covered ocean facilitated almost complete sulfate reduction in anaerobic conditions [2]. Isotope data from the South Urals do not contradict this assumption.

Neoproterozoic sections of the BMA reveal a pattern related to the variation of redox regime of sedimentation. Stagnant reduced conditions within the incised valleys several hundreds of meters deep (Krivaya Luka, Tolparovo) led to precipitation of pyrite in sandstone cement, whereas relatively oxic conditions in shallow areas (Bakeevo, Ust'-Katav) are represented by thin sections with hematite, glauconite and chlorite. Depositional environment of conglomerates and sandstones of the Uruk Fm started as medium-reduced, and then switched to oxic. This sequence of events of anaerobic conditions giving way to oxic agrees with the hypothesis of fast ice cap melting, with formation of cap carbonates and climate aridization. Sections in the South Urals reveal that this process was not single-stepped, but happened twice; specifically, the gray colored lowermost Uruk Fm could represent a transition to ultimate aridization. Eastern sections of BMA demonstrate a similar sequence of events, although the red diamictites of Kurgashla Fm correspond to the first episode of melting and aridization, and the second episode was likely to be erased by pre-Paleozoic erosion. The lithological and isotope-geochemical indices in the South Urals sections, therefore, record two global climatic events that can be used for inter-regional correlation.

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Evolution of infaunal scavengers and closure of the Vendian taphonomic window

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Fossil record of Ediacaran soft-bodied organisms discontinues at the lower Tommotian boundary. Were these organisms members of extinct groups or was it the termination of unique taphonomic circumstances (closure of the Vendian taphonomic window) that led to disappearance of the fossils? Was it vanishing of sediment-sealing microbial mats, an increase in degree of bioturbation, or an advent of scavenging that led to the ultimate closure of the taphonomic window? The answer is probably found in Arctic Siberia in a package (26 m) of wavy-, hummocky-, and convolute-bedded sandstones interstratified with shales, siltstones, and calcitic mudstones constituting the Syhargalakh Formation of the Kessyusa Group. The package contains trace fossils (*Treptichnus pedum*), small skeletal fossils (*Purella antiqua* Zone) and macrofossils (*Sabellidites cambriensis*) of pre-Tommotian (Fortunian) age (Fig. 9). Upward the section is succeeded by a unit (80 m) of alternating shale and siltstone, with laterally discontinuous sandstone and ooid grainstone beds, marked by the first appearance of arthropod trace fossils

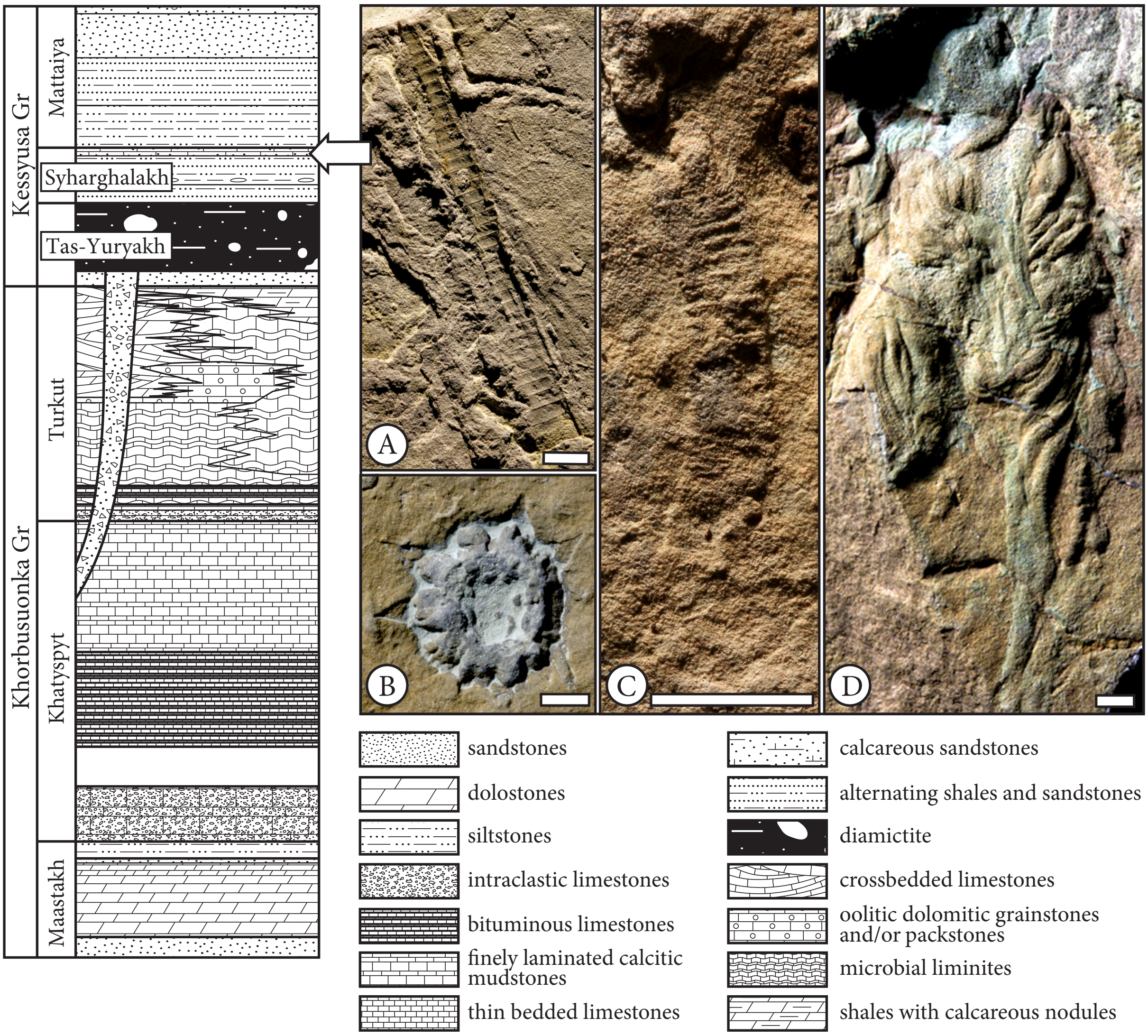

Figure 9. Composite section of Upper Vendian and Vendian–Cambrian boundary strata of the Olenek Uplift, with stratigraphic position of the fossil assemblage of Syharghalakh Fm. The Khatyspyt and Turkut formations are intruded by diatremes consisting of tuff breccia that yielded a U-Pb zircon age of 543.9 ± 0.3 Ma.

A: cast of a corrugated tubular sheath; **B**: composite mold of a bulbous holdfast with root-like extensions of the frondomorph organism *Mawsonites* sp.; **C**: mold of a copressed sheath of the Nemakit-Daldynian index-fossil *Sabellidites cambriensis*; **D**: composite mold of a frond structure of a frondomorph organism. Scale bar: 5 mm.

Rusophycus avalonensis, macrofossils *Platysolenites antiquissimus*, and small skeletal fossils of the Tommotian *Nochoroicyathus sunnaginicus* Zone. Sandstones of the Syhargalakh Formation are bioturbated, except for the lowermost part containing a fossil assemblage of soft-bodied organisms of frondomorphs (fronds and holdfasts) and corrugated tubular sheaths. The fossils are preserved in exquisite detail, with considerable relief, which is typically found in the Vendian taphonimic window; however, lithified microbial substrates and associated fossil soft-bodied organisms of the extinct kingdom Vendobionta are not present in the assemblage. The pre-Tommotian increase in bioturbation could have been responsible for disappearance of sediment-sealing microbial mats, but it did not alter sediment properties to a degree that would facilitate disintegration of soft tissues prior to the onset of diagenesis. The absence of vendobionts, therefore, most likely reflects the destruction of microbial substrates, their principal biotope in the wave- and current-agitated zone, by sediment-mixing animals. The soft-bodied frondomorphs are preserved as Ediacaran death masks in bioturbated, biomat-free sediment. This occurrence suggests that neither bioturbation nor destruction of microbial substrates, but scavenging of smothered dead organisms by infaunal macrophages, was responsible for the ultimate closure of the taphonomic window.

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Ediacaran fauna from the Neoproterozoic – early Cambrian strata of the southwestern East Siberia

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Ediacaran faunas are not well known from the southwestern part of East Siberia. There is only one discovery of *Cyclomedusa* ex gr. *davidi* made in 1976 by Chechel' in this area. The Riphean – early Cambrian sedimentary succession was studied in southwestern East Siberia along the Nizhnyaya Terya and Irkineeva rivers on the Irkineeva Uplift. We present a new discovery of Ediacaran fossils from these sections. Among them are *Arkarua*, described previously from the Flinders Ranges of South Australia [1] and the problematic fossil *Arumberia* known from many places all over the world [2]. Examples of other, so far unidentified, enigmatic fossils, trace fossils and microbial mat structures described from the Irkineeva Uplift sections will be presented as well. These finds are an important tool in age determination, regional correlation and paleobiogeographic reconstructions.

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The India and South China cratons at the margin of Rodinia – synchronous Neoproterozoic magmatism revealed by LA-ICP-MS zircon analyses

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The palaeogeographic position of South China in relation to India in the Neoproterozoic is controversial. Resolution of this controversy constrains the reconstruction of Rodinia during its breakup and contributes to our understanding of Snowball Earth. This work compares the Neoproterozoic histories of the Lesser Himalaya in northern India and the Yangtze block in southern China. We present U–Pb LAICPMS ages of detrital zircon grains from six Indian and three Chinese siliciclastic sedimentary rocks, such as sandstones or diamictites/tillites. In total, 1148 grains were analyzed from which 833 measurements gave ages with a degree of concordance between 90 and 110%. The correlation of the Indian and the Chinese sections is possible using the tillites of both areas purportedly deposited during the Snowball Earth time interval: the Blaini tillite from India and the Nantuo tillite from China. In addition to the tillites, representative detrital zircon ages from over- and underlying clastic rocks were determined. The Chinese samples are dominated by zircons with Neoproterozoic ages with a main peak between ca. 750 Ma and ca. 950 Ma and are characterized by the absence of Archaean ages. The Indian samples contain abundant Neoproterozoic zircon grains, but also contain Mesoproterozoic to Archaean zircons. For all samples, a local source area that provided the Neoproterozoic zircons is likely. A synchronous Neoproterozoic magmatic event in both cratons probably reflects the breakup of the supercontinent Rodinia and therefore the same tectono-magmatic event. Our results indicate a similar history for India and South China which both underwent at least one synchronous episode of crustal growth during the Neoproterozoic. In addition, our data set shows that both passive margin clastic sequences had the same source area for all zircons older than Neoproterozoic. Therefore we infer that India and South China were close to each other and along the same passive margin during the breakup of Rodinia in the Late Neoproterozoic.

Geochemistry of Precambrian oils of Eurasia

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Geochemical analyses of Upper Proterozoic oils of the Siberian, East European and Arabian platforms leads to identification of distinctive features of Precambrian oils that distinguish them from their Phanerozoic counterparts. The examined Precambrian oils are enriched in the light carbon isotope ^{12}C and have essentially aliphatic composition dominated by normal alkanes. Based on the composition of aliphatic and cycloaliphatic biomarker hydrocarbons, all the oils were divided into two groups. Oils from some basins of the Siberian, East European and Arabian platforms were assigned to the first group characterized by the absence of 12- and 13-monomethylalkanes. Among the steranes, St_{27}–St_{29} hydrocarbons are almost in equal concentrations, with some predominance of either cholestane (St_{27}) or ethylcholestane (St_{29}). These oils have low contents of tricyclanes in terpanes. The concentrations of Hh_{31}–Hh_{35} hopanes monotonously decrease with the growth of molecular mass. In terms of major characteristics, oils of this group are similar to Phanerozoic marine oils derived from lipids of prokaryotes and protozoan eukaryotes. The second group includes the most widely distributed oils from East Siberia (Baikit, Katanga, and Nepa–Botuoba petroleum fields) as well as those from the Arabian Platform (Oman). These are characterized by the presence of 12- and 13-monomethylalkanes, marked predominance of ethylcholestanes in sterane distribution, high contents of tricyclanes in terpanes, and, often, predominance of Hh_{35} over Hh_{34} homohopanes. Specific features of marine oils of this group are demonstrated by anomalously high concentrations of 12-, and 13-monomethylalkanes, ethylcholestanes in steranes, and tricyclanes in terpanes. There are no analogs to these oils among the Phanerozoic marine oils. In the Upper Paleozoic and younger complexes, high concentrations of ethylcholestanes in steranes are characteristic of nonmarine oils which were derived from lipids of higher land plants; however, they are lacking 12- and 13-monomethylalkanes and contain much lesser concentrations of tricyclanes and higher concentrations of carbon isotope ^{13}C. The differences between these two groups of oils are related to specific character of biochemistry of lipids of the oldest prokaryotes and protozoan eukaryotes in individual ecological niches of the Precambrian seas. Investigation of the geochemical features of oils is extremely important for identifying the “kitchens” of oil and gas generation and natural petroleum systems and assessing the petroleum potential of the Precambrian complexes of ancient platforms.

Carbon, oxygen, and strontium isotope stratigraphy of the Oselok Group, Sayan Mountains, Siberia

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A newly-recognized Neoproterozoic glacial diamictite and cap carbonate of the basal Oselok Gr in the Sayan Mountians on the southern Siberian Craton have been assigned a terminal Cryogenian (Marinoan, ca. 635 Ma) age based on the presence of metazoan fossil remains in overlying siliciclastic strata. The marginal marine and terrestrial succession, however, lacks radiometric constraints, and further preserves physical evidence of stratigraphic discontinuities that make the affinity of the glacial and immediately postglacial deposits to the fossiliferous strata uncertain. To test the age assignment and evaluate the preservation and global correlation of carbonates in the succession, we constructed time series carbon, oxygen, and strontium isotope trends from well-preserved carbonate associated with the Ulyakha Mb diamictite. The stromatolitic Karabchatui Mb carbonates below were collected between interbedded glacio-fluvial outwash deposits, while those above were taken from immediately post-glacial bituminous shale (Tygnei Mb) and a >45 m thick cap dolomite (Ozerki Mb), as well as a 17+ m thick microbialaminte limestone in the overlying Uda Formation (Peshchernyi Mb). Carbon isotope trends define a shallow negative excursion in the Karabchatui stromatolites and homogeneous negative $\delta^{13}C$ in the post-glacial Ozerki cap carbonate. Oxygen isotopes in the cap dolomite become enriched in ^{18}O coincident with sedimentologic changes indicative of shallowing into evaporitic environments. In contrast ^{13}C abundances in the Peshchernyi Mb of the overlying Uda Gr are enriched with generally homogeneous $\delta^{13}C$ values around +6 to +7‰. The lowest $^{87}Sr/^{86}Sr$ measured in Peschernyi limestones is ~0.7077, which is consistent with early Ediacaran limestone in the well-studied Doushantuo Fm in South China. A dolomitic limestone in the Ozerki Mb cap carbonate has a significantly radiogenic Sr isotope composition, but a limestone breccia within the post-glacial Tygnei Mb shale has an $^{87}Sr/^{86}Sr$ value as low as ~0.7072, which has no match in Ediacaran strata of South China above Marinoan glacial deposits, but is notably equivalent to high Sr ex-aragonite precipitates in both the Sête Lagoas and Maieberg formation cap carbonates in Brazil and Namibia, respectively. Insofar as the former is directly dated at ca. 740 Ma (and the ~635 Ma age constraint for the latter is a matter of stratigraphic correlation and debate), it is possible that the Ulyakha Mb diamictite is a phase of earlier Marinoan or Sturtian glaciation. If this chemostratigraphic age assignment is correct, there exists a major hiatus between the Ozerki Mb cap carbonate, which preserves simple and enigmatic trace fossils, and the overlying fossiliferous beds in the Ediacaran portion of the Marnya Fm.

Evolution of the Neoproterozoic Patom Basin: the results of sedimentology and isotope geochemistry

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The Upper Neoproterozoic Dalnyaya Taiga and Zhuya groups of the Patom Highlands of eastern Siberia were deposited in a stratified basin bounded to the northwest and northeast by terrigenous-carbonate shelf. Sedimentation from gravity flows alternated with precipitation of hemipelagic deposits and distal turbidites. Central part of the basin, where the section reaches the thickness of ca. 800 m, is characterized by increased concentrations of organic material (from 1.5–2.5% to 5.0%). Carbon-bearing sediments accumulated in deep depressions in oxygen-depleted zone with a reduced input of terrigenous and carbonate material from the adjacent shelf. In the late Valyukhta time, the oxygen-depleted depth extended onto shallow edge of the shelf, indicating a trend towards stagnation of the basin possibly due to existence of island-arc barriers to the south that limited water exchange with paleocean. Partial hiatus in the basin occurred in the Zhuya time.

The specifics of the Neoproterozoic Patom Basin is reflected in $\delta^{13}C$ variations. Carbonate rocks have high $\delta^{13}C$ values up to 7.6‰ in the Dalnyaya Taiga Gr, are characterized by a sharp negative excursion (up to −10‰) in the Zhuya Gr, followed by a trend of increasing $\delta^{13}C$ values to −5.0‰, (most values fall between −5.5‰ and −6.5‰) in the upper Chencha Fm. The trend continues in the overlying Zherba Fm where $\delta^{13}C$ values are close to zero. Higher in the sequence, after a thick (60–80 m) package of coarse-grained sandstones, $\delta^{13}C$ values reach 2.5‰ in altered muddy limestones of the Zherba Fm. High concentrations of Sr in the limestones are probably due to presence of primary aragonite in the lime, as indicated by fine fibrous structure in some columnar stromatolites of the upper Chencha Fm.

The C-isotope composition of the dolomitic phase in the Nikol'skoe and Chencha formations is heavier than in the calcitic phase. The difference in $\delta^{13}C$ values in the Nikol'skoe Fm ranges between 2.4‰ and 6.7‰ indicating significant postdepositional alteration of calcium carbonate component. Furthermore, the material for muddy limestones of the Nikol'skoe Fm was deposited by bottom currents, turbidity flows and hemipelagic precipitation. The carbonate material was produced with direct or indirect participation of microbial communities and transported from shallow shelf. Dolomite component is a result of partial syndepositional dolomitization of calcareous shelf sediments and their subsequent redeposition. Since the dolomite phase is more resistant to recrystallization and can better preserve the initial C-isotope ratios than the calcite, the $\delta^{13}C$ values –4.7…–8.7‰ in the dolomitic component should be close to the primary. Situation in the Chencha Fm is different. $\delta^{13}C$ values in the calcitic and dolomitic phases are similar and usually differ by less than 1‰. Light C-isotope composition in the dolomitic phase in limestones of the Mariinka, Dzhemkukan and Barakun formations suggests hydrothermal influence on the origin of the dolomite. This is confirmed by very low (up to –22.3‰) $\delta^{18}O$ values in the dolomitic phase.

Isotopic composition of dissolved carbon dioxide in deep and surface waters of the modern ocean varies between 1.2‰ and 2.6‰, but in the stratified basins this difference is significantly larger. Thus, the isotopic composition of dissolved CO_2 in bottom waters of the Black Sea is –6.3‰ compared to –0.8‰ on the surface [1]. It is likely that the observed C-isotope differentiation in the Neoproterozoic Patom Basin records stratification of the water column. Partial disturbance of the water stratification in the Zhuya time (recorded as an abrupt change from dark-colored shelf and slope sediments of the Valyukhta Fm to green-colored and variegated rocks of the Zhuya Gr) could be the cause of the sharp negative excursion of $\delta^{13}C$ values due to upwelling of isotopically lighter deep waters to the slope and shelf. The $\delta^{13}C$ values for the Zhuya Gr will remain negative even after post-depositional and syn-depositional alteration is taken into account. This is corroborated by high $\delta^{13}C$ values (up to 5.5‰ in calcite phase and 6.7‰ in the dolomite phase) in the dolomitic limestone of underlying Valyukhta Fm of Dalnyaya Taiga Gr. Therefore, to explain the Zhuya negative background $\delta^{13}C$ values requires correlation with one of the C-isotope events recorded in the Neoproterozoic. These events were controlled by global changes in the balance of organic carbon and carbonate in seawater and changes in rates of organic matter burial in sediments with high content of light carbon isotope ^{12}C and/or episodes of introduction of gas hydrates in the basins. The available sedimentological and isotope geochemical data show that the late Neoproterozoic Patom Basin had limited connection with the ocean and was stratified.

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Passive and active margins of southwestern Siberian Craton in Neoproterozoic and Early Paleozoic

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It is now possible to approximately restore the succession of magmatic and metamorphic events and the phases of active fold tectonics in the time spans between 2.6–1.8 Ga and 1000–450 Ma using our new data and published information. Geological events played an important role during the evolution of the Neoproterozoic sedimentary basins. We established four principal milestones, at about 1 Ga, 800 Ma, 600 Ma, 570 Ma and 490–450 Ma, that mark major phases of activity related to these events at the margins of Siberian continent and Paleo-Asian ocean.

The most prominent phases during the structural evolution of the Siberian Craton were the Vendian (600 Ma) and earlier Ordovician (490 Ma). Our reconstructions and published data for the Neoproterozoic suggest that a large intra-continental Paleo-Asian oceanic basin was located between Baltica, Siberia, Kazakhstan and North China continental blocks, which were all separated at this time. The existence of this ocean is supported by the development of the Circum-Siberian ophiolite belt, in which ophiolites and subduction-related magmatic arc complexes become progressively younger away from Siberia to the south and west [1], and by the passive margins of Siberian Craton. The following data confirm this conclusion. The oldest ophiolite complexes so far dated in the Cental-Asian belt occur in the East Sayan Ranges [2]. Supra-subduction complexes developed along the active margin of the craton 800–600 My ago and are preserved in the present-day structure as ultramafic-mafic intrusions [3, 4], volcanics and granitoides [5]. The granulite-enderbite-charnockite association from the north Baikal area (northeastern segment of the belt) yielded zircon crystallization dates of 600–615 Ma that according to our data reflect the time of regional metamorphism. The metamorphic complex is intruded by relatively fresh granites crystallized 590 My ago. The hereby formed integrated heterogeneous structure of the Baykal–Muya belt (tectonic collage) was later reorganized into a passive margin (northeastern segment of the Siberian Craton margin) and formed a new stable area with the basement much younger that the Siberian Craton.

During the time interval of 570–530 Ma an active structural rearrangement took place to the south of craton (present-day reference frame), the convergence of earlier formed volcanic arc systems with continents and microcontinents. These events are confirmed by ophiolite, supra-subduction and spreading volcanics and gabbroides of late Vendian – early Cambrian age. It was also the time of an extensive transgression that led to passive margin sedimentation on continents and microcontinents.

The late Cambrian – early Ordovician (490–460 Ma) was the time of another phase of accretion and obduction onto the margins of adjacent continents and microcontinents. Formation of asthenospheric windows beneath microcontinental margins was followed by ophiolite obduction, high-temperature metamorphism, emergence of granite-gneiss domes and intrusion of mantle-derived mafic-ultramafic rocks [3, 6, 7]. Granulites from the western Mongolia, Eastern Sayan, Khamardaban and Priolkhonye crystallized 490–470 My ago [8, 9]. Metamorphic complexes of this age occur at the western, southwestern and south margins of the Siberian continent and microcontinents. The inherited zircons from granite-gniesses of these complexes yielded the Archean and Paleoproterozoic ages.

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Integrated stratigraphical framework for the Vendian complex of southern Siberian Craton

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Vendian deposits are widely distributed in the south of Siberian Craton. They represent disparate sedimentary environments, have different composition and variable stratigraphic completeness. A reliable stratigraphic framework for Vendian of this area is important for correlation with the International Stratigraphic Chart, petroleum geology and paleogeodynamic reconstructions. The framework is based on tracing the major sequence boundaries, analyses of fossil distribution, interpretation of geochemical and geochronological data.

The stratigraphic extent of the Vendian is constrained from above by the lower boundary of the Tommotian Stage. There are several opinions on placement of the lower boundary of the Vendian relative to the Varanger glaciation: at the bottom of the tillite, above it, or below it [1–3]. The base of the Tommotian in the south of Siberian Craton is defined in the Patom Upland sections by small skeletal fossils as the

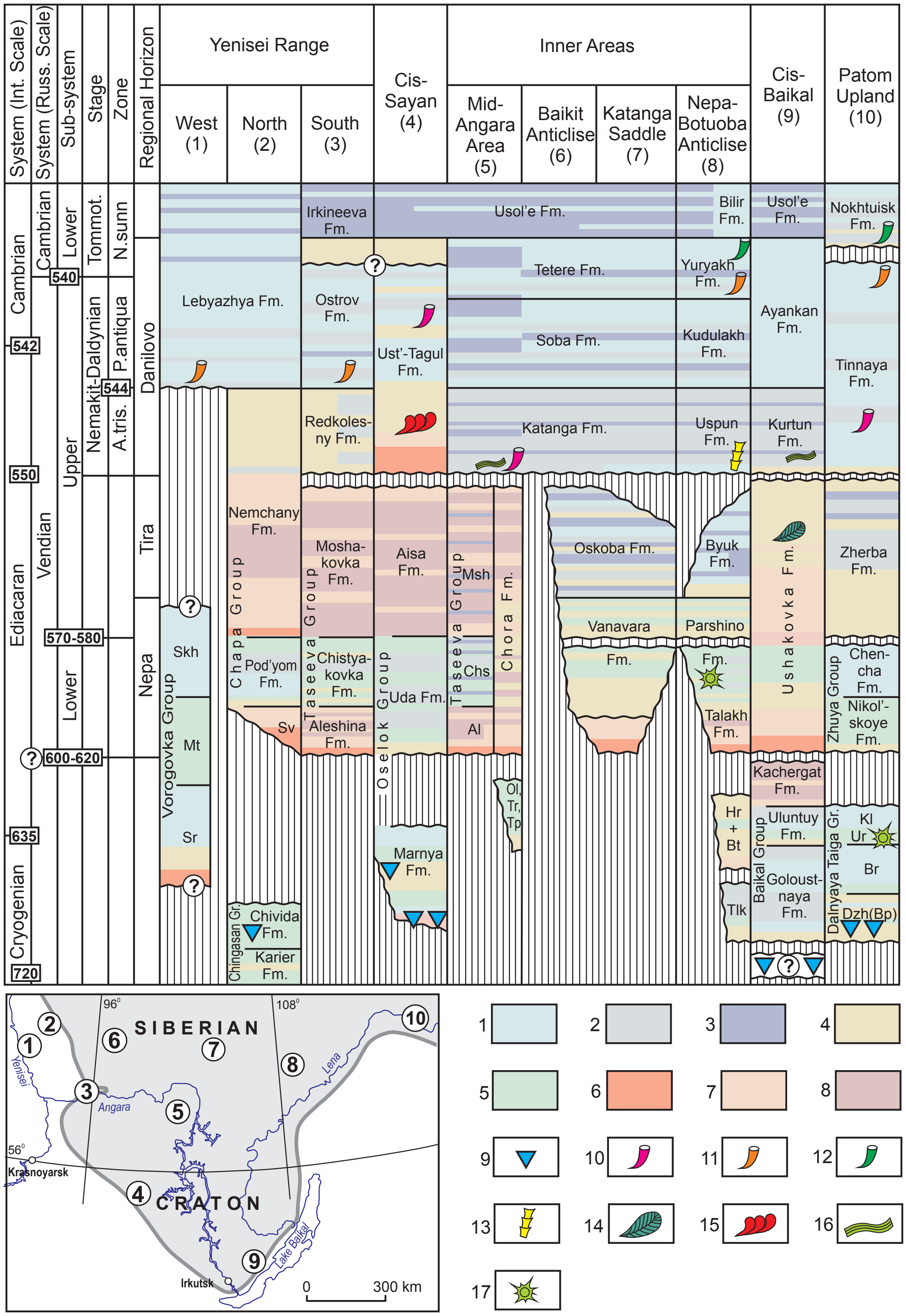

Figure 10. Correlation chart of the Vendian complex in southern Siberian Craton.

Legend: 1–5 – marine deposits: 1 – carbonates (shelf), 2 – siltstones and carbonates (shelf and slope), 3 – evaporites, 4 –proximal siliciclastics, 5 –distal siliciclastics; 6–8 – non-marine and coastal deposits: 6 – conglomerates (fluvial), 7 – sandstones (fluvial), 8 – siltstones (alluvial and deltaic); 9 – diamictites; 10–12 – small skeletal fossils: 10 – *Anabarites trisulcatus* Zone, 11 – *Purella antiqua* Zone, 12 – *Nochoroicyathus sunnaginicus* Zone; 13 – *Namacalathus*; 14 – Ediacaran-type fossils; 15 – *Treptichnus* trace fossils; 16 – *Vendotaenia*; 17 – Pertatataka-type microfossil assemblage.

Formations: Sr – Severnaya Rechka, Mt – Mutnina, Sr – Sukhaya Rechka, Sv – Suvorovskiy, Msh – Moshakovka, Chs – Chistyakovka, Al – Aleshina, Ol – Olkha, Tr – Tyret', Tp – Typta, Hr – Khoronokh, Bt – Betinche, Tlk – Talakan, Kl – Kalancha, Ur – Ura, Br – Barakun, Dzh(Bp) – Dzhemkukan (Bolshoy Patom).

boundary between the *Purella antiqua* and *Nochoroicyathus sunnaginicus* zones [4, 5]. This boundary is marked by local hiatuses and a sea-level fall manifested as sudden change from shallow-water carbonates to red-colored siliciclastic-carbonate sediments. This boundary also characterized by negative $\delta^{13}C$ excursion in the south of Yenisei Ranges and Patom Upland [4, 6]. In the interior parts of Siberian Craton this boundary is conventionally placed in the uppermost Danilovo Regional Stage [7].

Another sequence boundary that can be traced in the south of Siberian Craton is at the base of *Purella antiqua* Zone of Nemakit-Daldyn Stage. In the western Yenisei Ranges this boundary is placed at the lower boundary of the Lebyazh'ya Fm represented by shallow-water carbonates resting unconformably on early Proterozoic and Riphean deposits. The small skeletal fossils of *Purella antiqua* Zone were found at the base of the formation in two localities [5]. To the west and east of this area, in West-Siberian Basin and in eastern and southern part of Yenisei Ranges, the *Purella antiqua* Zone is underlaid by Upper Proterozoic deposits [7, 8], thus confirming the existence of sedimentary barrier between these two basins in Neoproterozoic. The base of the zone can also be traced in the southern Yenisei Ranges, where small skeletal fossils were found in the lower part of the dolostone-siliciclastic Ostrov Fm [5]. Consequently, the basement of this zone marks the transition to carbonate-dominated epicontinental sedimentation over the entire territory of the southern Siberian Craton.

The lower boundary of the Nemakit-Daldyn Stage is marked by the first appearance of metazoan skeletal fossils and particular trace fossils. Thus, the lowermost small skeletal fossils, together with vendotaenian fossil algae, occur in basal layers of the Danilovo Regional Stage in the southern Angara–Lena Step 300 m below the supposed base of Tommotian [5]. The correlative strata in Chaikinskaya-279 Borehole drilled on the southeastern slope of Nepa–Botuoba Anticlise yielded the *Namacalathus–Cloudina* fossil assemblage (see contribution by A.A. Terleev and coauthors to this volume). The predominantly siliciclastic Ust'-Tagul Formation in the southwest of Siberian Craton, correlated with the lower part of Nemakit-Daldyn Stage, is characterized by trace fossils *Treptichnus* [5]. The base of Danilovo Regional Stage is transgressive and marked by a hiatus in most of the studied sections, but it is best expressed on paleouplifts where the transgressive sequence gradually truncates the underlying strata [7].

The underlying Tira Regional Stage represents a regressive system tract characterized by a wide range of depositional environments. Mixed siliciclastic-carbonate-sulfate shallow water, often evaporitic deposits are found in interior parts of the southern Siberian Craton. Along the southwestern margin of the craton, the relatively thin marine sequences of the interior parts are replaced by prodeltaic, deltaic and alluvial deposits with thickness of several kilometers, some of them interpreted as foreland basins [9]. The lower boundary of the Tira Regional Stage is usually gradational, except for the interior parts of the craton where the boundary is erosional. The Tira Regional Stage contains Ediacaran-type fossils; however, the fossils are known only in the south [10], suggesting that there is possibly a hiatus in other parts of the craton.

Further down the sequence, the Nepa Regional Stage is recognized in the interior parts of the craton where it comprises a transgressive and a highstand systems tracks. The transgressive systems track consists of non marine siliciclastic deposits at the base grading upward to marine coastal and shelf deposits and is bounded from above by a maximum flooding surface. The highstand systems tract represents a supply-dominated regime [11]. This sequence is also traced in some of the pericratonic basins as thick, mainly siliciclastic successions. The mudstones of the lower part of Nepa Regional Stage contain microfossil assemblages of early Ediacaran (Pertatataka-type) affinities [12], but the distribution of microfossil associations in the Nepa Regional Stage is controlled by facies [13].

There are no reliable radiometric age constraints for the Vendian in the south of Siberian Craton. Correlation with the best studied reference section of the Olenek Uplift in the northeast of the craton is possible mainly for the upper part of the section. The occurrence of Tommotian small skeletal fossils in the upper part of Kessyusa Fm of Olenek Uplift, however, is accompanied by a pronounced sea-level fall, although trace fossils of Tommotian age are found near the base of the formation together with small skeletal fossils of the *Purella antiqua* Zone [14]. The U–Pb-zircon date 543 Ma refers to the boundary between Kessyusa and Turkut formations, which is characterized by a volcanic activity, change in sedimentation style and a hiatus; however, this boundary is not expressed in the facies of interior parts the craton and can be traced only by rare fossil occurrences in outcrops along the periphery. The oldest occurrence of small skeletal fossils at the base of Turkut Fm and Danilovo Regional Stage is possibly as old as 550 Ma [15]. All confirmed Ediacaran fossils in the Siberian Craton (northern Cis-Baikal area and Olenek Uplift) fall within the time interval 550–575 Ma. Distribution of Ediacaran fossils in general is controlled by facies, and the interior parts of Siberian Craton are devoid of facies that favored their preservation; correlation of the Tira Regional Stage with Upper Ediacaran [4], therefore, is tentative.

Another spectrum of problems is related to recognition of Neoproterozoic glaciations on the Siberian Craton. The only reliably dated diamictites of pre-Vendian Stirtian age (formed between 703 and 753 Ma [16]) are found in the north of Yenisei Ranges. Glacial sediments at the base of the laterally discontinuous Marnya Fm in Eastern Sayan, thought to be of Marinoan or Varanger age [17], are likely to be older (early Marinoan or Sturtian – see contribution by A.J. Kaufman and coauthors to this volume). The problem of dating the Dzhemkukan (Bolshoy Patom) tillites in the base of Dal'nyaya Taiga Gr of Patom Upland is not easy to resolve. Although Sr-isotope data and the associated acantomorph microfossils of the Dal'nyaya Taiga Gr suggest a Marinoan age of the diamitites [18], the detailed correlation shows that a similar microfossil association from the Nepa Regional Stage in the adjacent interior part of the craton is much younger [19]. It seems entirely possible that Pertatataka-type microfossil associations have wider stratigraphical range and that the Dzhemkukan tillites could be older than the base of Ediacaran or Vendian.

Summarizing the available data (Fig. 10), only the uppermost Nemakit-Daldyn stage can be identified with confidence in the south of Siberian Craton and also in other carbonate-dominated basins of the World. The occurrences of Ediacaran fossils are all confined to the Tira Regional Stage, although fossiliferous facies have a limited spatial distribution. Diamictites of Gaskiers age are not recognized in Siberia, whereas the age of older diamictites is poorly constrained, suggesting a possible regional hiatus at the base of Vendian.

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From offshore to onshore: a new rangeomorph species from Central Urals

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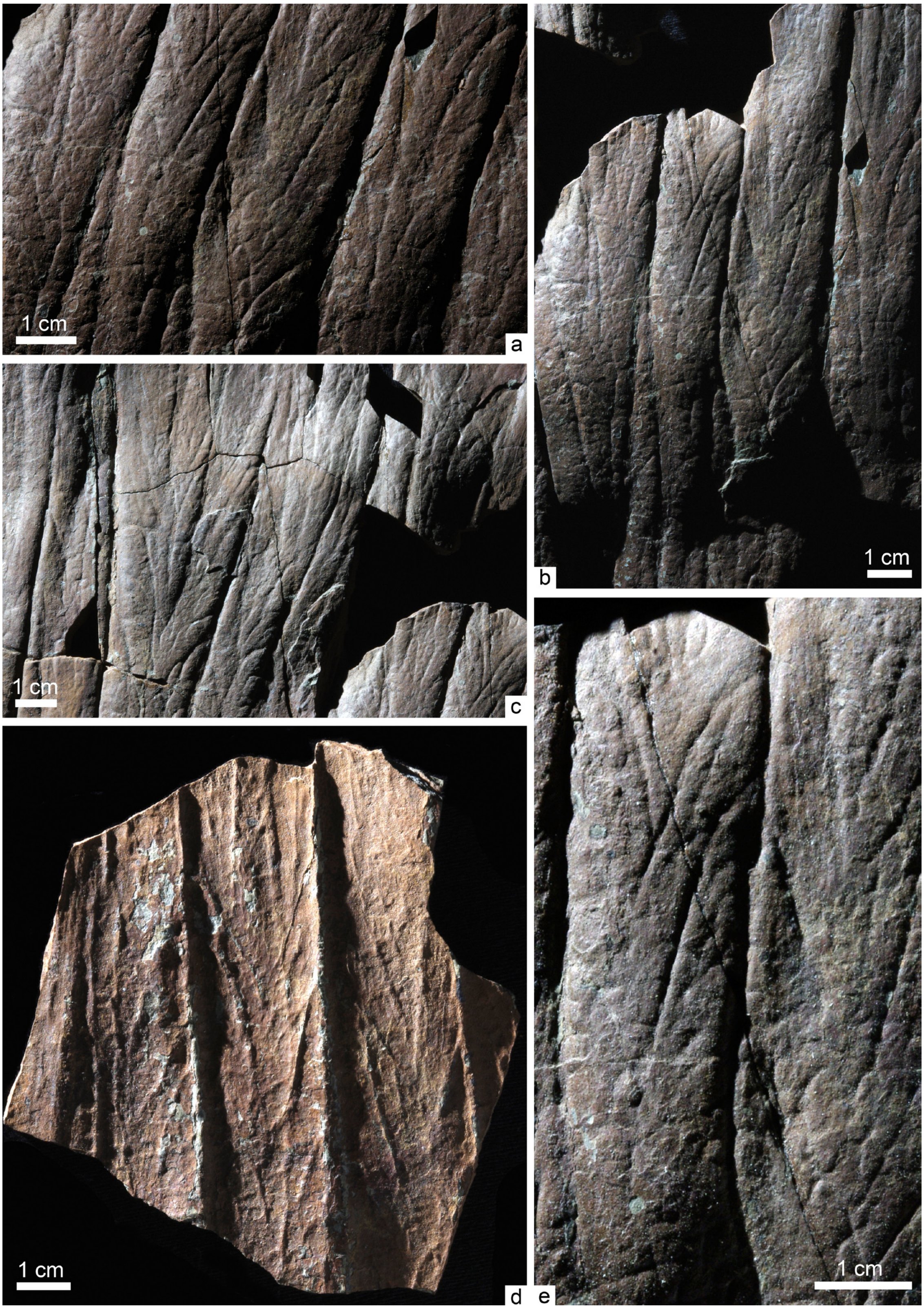

Figure 11. A new rangeomorph species from Late Ediacaran of Central Urals.

An onshore to offshore evolutionary pattern is evident in benthic marine invertebrate clades of the Paleozoic and post-Paleozoic age. Ordinal rank taxa are observed to originate onshore, diversify offshore, and eventually relinquish nearshore habitat [1]. An important exception to this pattern is found in rangeomorphs, a group of Late Proterozoic foliate organisms that have a body divided by numerous commissures into chambers resembling ramified tubules. It is the oldest group of Vendian macroorganisms, as suggested by the fossils found in the Drook Fm of the Conception Gr of Newfoundland with U–Pb-zircon age 578.8 ± 0.5 Ma [2]. Theoretical growth modeling of rangeomorph structural elements has demonstrated that the growth strategies used by these organisms allowed them to maintain high surface area to volume ratios despite their macroscopic size, which is consistent with morphological expectations for osmotrophs [3]. Rangeomorphs originated offshore in distal low-energy shelf where they dominated sessile macrocommunities until their sudden mysterious disappearance 560 My ago (with a notable exception of *Charnia masoni*). There is growing evidence, however, that 560 My ago rangeomorphs migrated from distal low-energy shelf to higher energy proximal habitats. For example, the rangeomorphs *Rangea schneiderhoehni* and *Bomakellia kelleri* from the time interval of 560–545 Ma are confined to distributary channels of prodelta. In 2003 fossils of a new rangeomorph species (Fig. 11) was found in the Krutikha Mb of the Chernokamen Fm cropping out along the banks of the Usva River in the Central Urals. Preliminary study allows the following conclusions to be drawn: (1) The new rangeomorph species is characterized by unusually large chambers and relatively simple arrangement of commissures; hence, it would be incapable of attaining the surface area to volume ratios necessary for strict osmotrophy. (2) The Krutikha Mb is correlated on the basis of sequence stratigraphy with the Zigan Fm of the South Urals; volcanic tuffs within Zigan Fm in a section near Ust-Katav gave a U–Pb-zircon age of 548.2 ± 7.6 Ma which makes the new species one of the youngest members of the group. (3) The Krutikha Mb is characterized by chanellized sandstones with multistory cross-bedding, casts of desiccation cracks, salt crystal pseudomorphs, and weathered surface paleohorizons; the new species, therefore, was adapted to extremely shallow water habitats with variable salinity and periodic exposure. Discovery of the new rangeomorph species in the Central Urals is the first demonstration of invasion of terrestrial environments or at most extremely shallow-water environments by a major group of benthic marine macroorganisms previously restricted to offshore, relatively deep-water environments. This work was supported by the Russian Academy of Sciences Program “Biosphere Origin and Evolution” and the Russian Foundation for Basic Research (projects no. 09-05-00279 and no. 10-05-00953).

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Carbonate hydrocarbon reservoirs and the role of algae in oil generation in Neoproterozoic strata of the Fore-Patom basin

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Within the Fore-Patom petroleum basin, the Neoproterozoic carbonate rock complex formed mainly by cyanobacteria and red algae remains poorly studied in terms of paleobiology and paleoecology. The basin was penetrated by only a few deep boreholes, and there is not much core obtained from the Neoproterozoic strata. Material collected by the author over the course of several years from outcrops in southern framing of the interior petroleum regions of south Yakutia in an attempt to find indications of potential hydrocarbon reservoirs. The **Kalancha Fm** in the Lena River section (400 m) in its upper part includes a 12-m-thick package of recrystallized, fractured, coarse bedded, porous, dark-gray, partly dolomitic, oncolitic limestones with a large amount of bitumen inclusions. This carbonate reservoir is capped by 21-m-thick highly packed microcrystalline dolomites, with a single 4-m-thick unit of light-green clayey siltstone, followed by siltstones and mudstones of the Kullekin Fm (70–100 m). The **Chencha Fm** (500 m) is localized at the periphery of Patom highlands, between the Chara, Zhuya and Chaya rivers, at the boundary between the shallow-water and relatively deep-water zones of the basin and contains numerous algal biostromes and bioherms. The author predicts that it extends into the outer zone of the Fore-Patom basin, in the territories east of the Peledui Uplift and south and southeast of the Nepa–Botuoba Anteclise. In this zone, dolomite-terrigenous sediments are expected to play an important role along with organogenic depositst. On the Peleduy uplift, the formation is replaced by terrigenous rocks of the Karam Fm (also known as lower member of the Talakan Fm). The Chencha (Torgo) Fm is likely to be present within the Khotogo–Murbay area. In the Vitim River mouth area, crystalline basement occurs at the deapth of 4 km [1]. North of the Vitim River mouth, in the Nyuya River basin, south of the Chayanda gas deposit, the basement is identified at the depth of 1.3 km from seismic data (Nyuya uplift) [2]. The data imply that Torgo Fm extends onto the slopes of the Nyuya uplift where oil and gas accumulations are expected to occur not associated with anticlines. In the areas of the Fore-Patom Basin adjacent to the craton, the commercial hydrocarbon deposits are recommended to be sought at the level of the upper part of Kalancha Fm and, most strongly, in the Torgo Fm (known as the Chencha Fm within the Fore-Patom Basin). The latter contains hydrocarbon reservoirs in its upper part. Thickness of the reservoir in the uppermost Chencha Fm of the Ura anticlinorium (Lena River section) is 30 m. It is mainly made of algal limestones (10 m) and, locally, algal, partly weakly arenaceous and oolitic dolomites (20 m). They are sealed by alternating dolomites, clayey dolomites, and clayey fine-grained sandstones with chlorite (22 m) followed by an 11-m-thick unit of highly packed, cryptocrystalline dolomites with pyrite inclusions. The carbonate rocks of the Kalancha and Chencha (Torgo) formations contain abundant oncolites and spherulites suggesting high hydrodynamic activity of depositional setting. In the course of late diagenesis, seawater more actively penetrates into this type of rock, thus increasing the intensity of recrystallization and dolomitization processes and improving reservoir properties. Study of outcrops in the south of Beryozovsk Basin showed that Neoproterozoic cyanobacterial-algal dolomites in the areas adjacent to the craton are strongly recrystallized, fractured and rather porous, which enhances their reservoir properties. Their thickness is 20–30 m. They make up the upper part of the Neoproterozoic Torgo Fm. The oil pools in the Ediacaran (Upper Vendian) Botuoba sandstones and the Lower Cambrian Osinsk limestones within the Nepa–Botuoba Anteclise formed in the Neoproterozoic [3, 4]. The author believes that the organic matter that generated oil in the Fore-Patom Basin was secreted by Neoproterozoic cyanobacteria, red and green algae. First, the Neoproterozoic rocks of the basin contain, along with cyanobacteria, nearly macroscopic red algae (rhodophytes) *Dzhelindia* Kolosov 1970, *Chaptchaica* Kolosov 1975, etc. [5]. The activities of these algae and cyanobacteria led to the formation of thick organogenic rocks over the vast territory of the basin. Second, petroleum from the Nepa–Botuoba Anteclise contains both hopanes and steranes [6]. It is known that hopanes are characteristic of prokaryotes (e.g., cyanobacteria). Steranes are a geological form of molecules such as sterols. It is generally believed that these molecules are synthesized exclusively by eukaryotes [7]. Red algae are eukaryotes.

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Upper Proterozoic – Paleozoic Fore-Yenisei Sedimentary Basin in southeastern Siberia: geology and hydrocarbon saturation

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Large-scale geological and geophysical survey in the left bank area of the Yenisei River confirmed the existence below the Mesozoic–Cenozoic cover of West-Siberian Geosyncline (WSG) of an Upper Proterozoic – Paleozoic epicratonic-type petroleum potential sedimentary complex, the Fore-Yenisei Basin (Fig. 12). The new information, particularly from drilling of the boreholes Lemok-1 (had direct indicators of petroleum), Tyiskaya-1, Averinskaya-150, and Vostok-4 in the Krasnoyarsk Region, Vostok-1 and Vostok-3 in the Tomsk Region, as well as seismic survey (common midpoint reflection procedure) anticipated wide extent of thick (up to 10–12 km) weakly deformed Upper Proterozoic and Paleozoic strata analogous to the Siberian Craton [1–7].

Boreholes in the left bank area of the Yenisei River penetrated a thick section of salt-bearing and carbonate Lower Cambrian and silicictastic-carbonate Middle–Upper Cambrian, with identified trilobite fossils, in the depth range from 700 to 5100 m. Correlative strata on the Siberian Craton are represented by the Usol'e, Belaya, Bulai, Angara, Zeledeevo, and Upper Lena (Evenki) formations. Sedimentological study suggests that the Lower Cambrian was deposited in an evaporite basin representing a large embayment of a vast Cambrian megabasin of the Siberian Craton. Farther to the west, the Lower Cambrian is reduced in thickness (from 2–3 km to a few hundred meters) and consists of highly carbonaceous sili-

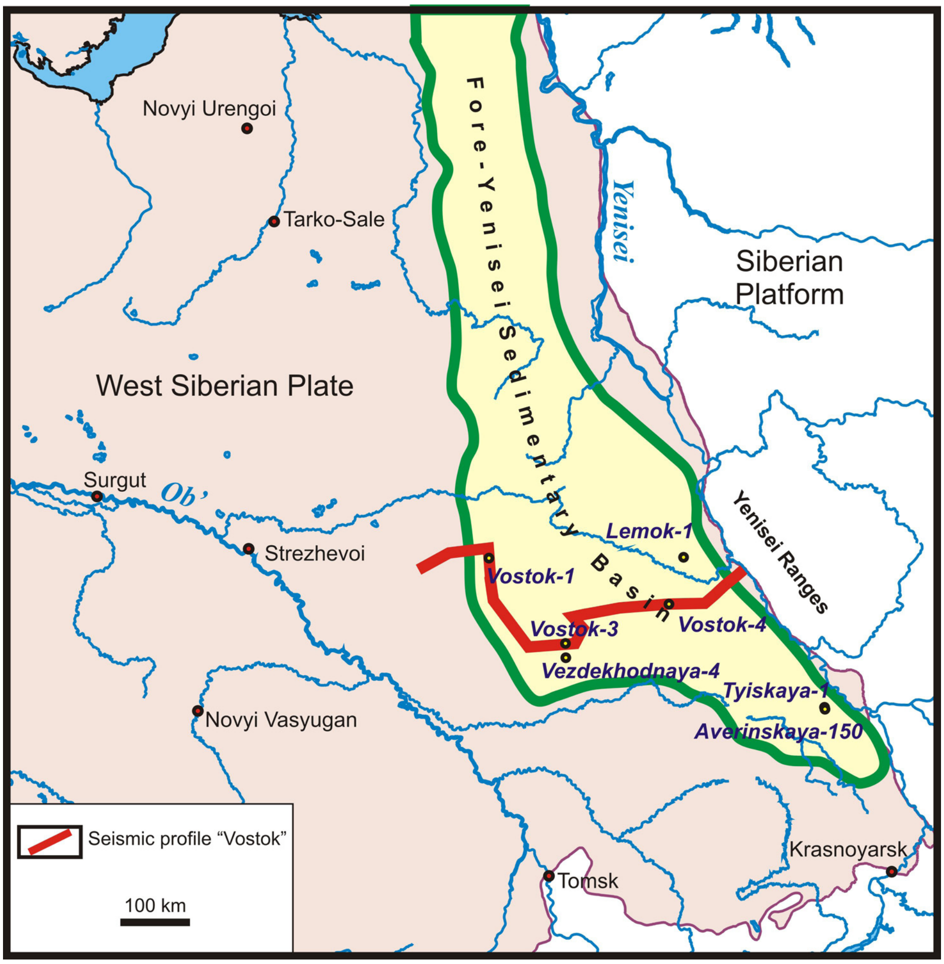

Figure 12. Boundaries of the Upper Proterozoic – Paleozoic Fore-Yenisei Sedimentary Basin.

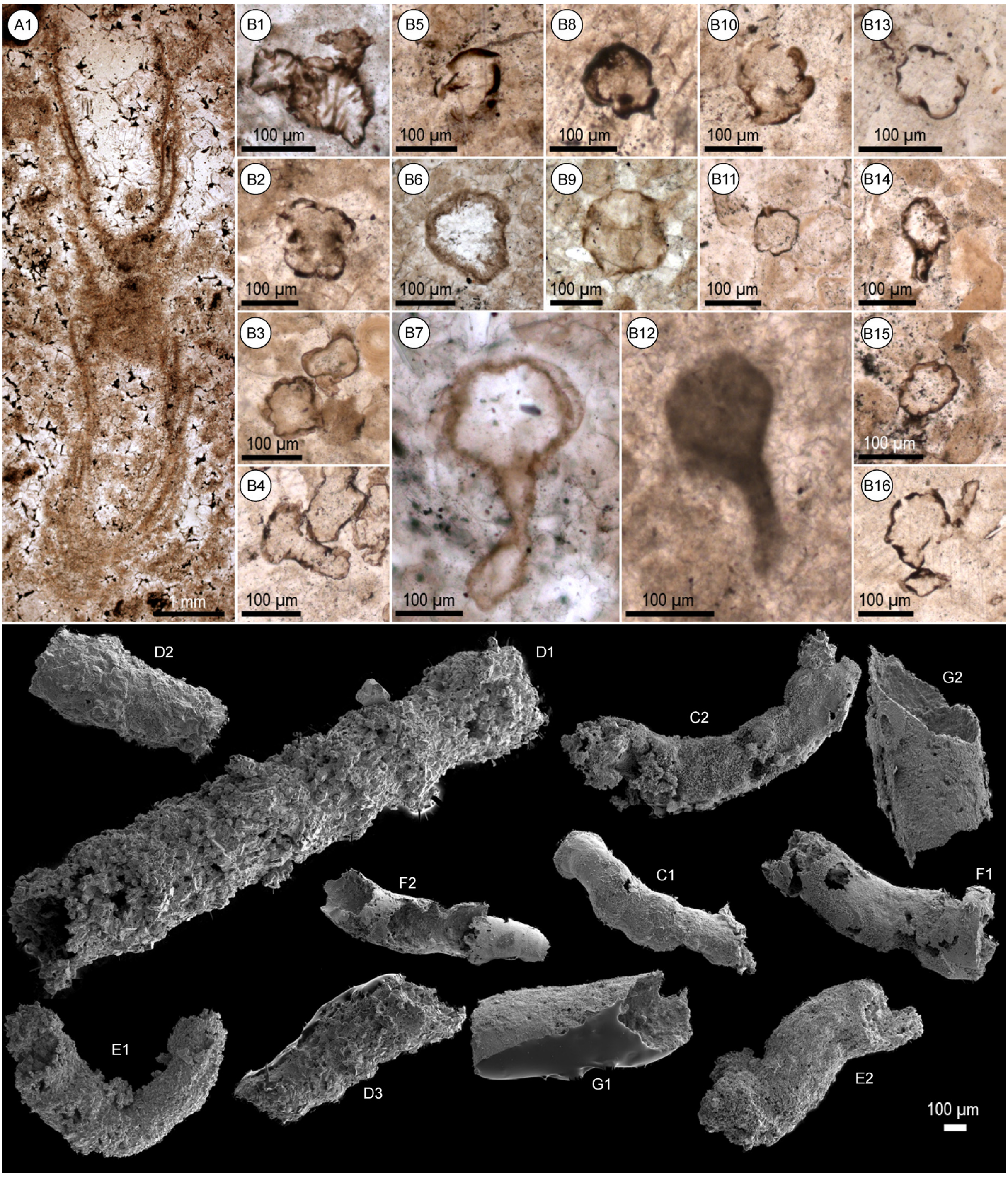

Figure 13. Upper Proterozoic fossil assemblage from the Vostok-3 Borehole section.

A: *Cloudina hartmanae*; Raiga Fm, depth 4161–4149 m. **B1–B16**: *Namacalathus* sp.; Kotodzha (B12; depth 4412–4405 m) and Raiga (B1–B11, B13–B16; depths 4161–4149 m and 4061–4054 m) formations **C–G**: A heterogenous assemblage of mineralized and agglutinated tubes from the Kotodzha (E) and Raiga (C–G) formations. **C1–C2**: Phosphatic, chambered, C-curved, slightly conical tests (up to 1.5 mm in length, 0.25–0.30 mm in diameter); chambers spherical (0.2 mm long); wall thickness is 0.004 mm; surface smooth, homogenous. **D1–D3**: Agglutinated, straight, slightly conical tubular tests with transverse ridges (0.95–2.50 mm long, 0.27–0.50 mm in diameter); tests consist of dolomitic grains; wall thickness is 0.027–0.075 mm; ridges raise 0.045–0.06 mm above the surface of the test, evenly spaces (from 0.12 to 0.4 mm in different specimens). **E1–E2**: Agglutinated, curved, slightly conical or tubular tests (1.24–1.43 mm long, 0.33–0.38 mm in diameter) with ridges; wall thickness is 0.017–0.036 mm; grain composition is not studied, but is assumed to be dolomitic; could be the same as (D). **F1–F2**: Thin-walled, smooth, conical or tubular C-curved tests (up to 0.86 mm in length, up to 0.35 mm in diameter); wall thickness is 0.005–0.014 mm); grain composition is not studied. **G1–G2**: Phosphatic, thin-walled, straight or slightly C-curved tubular tests (0.75–0.85 mm in length, up to 0.35 mm in diameter); consist of a coarse-grained (upper) and a relatively smooth (lower) layers; wall thickness is 0.009–0.019 mm.

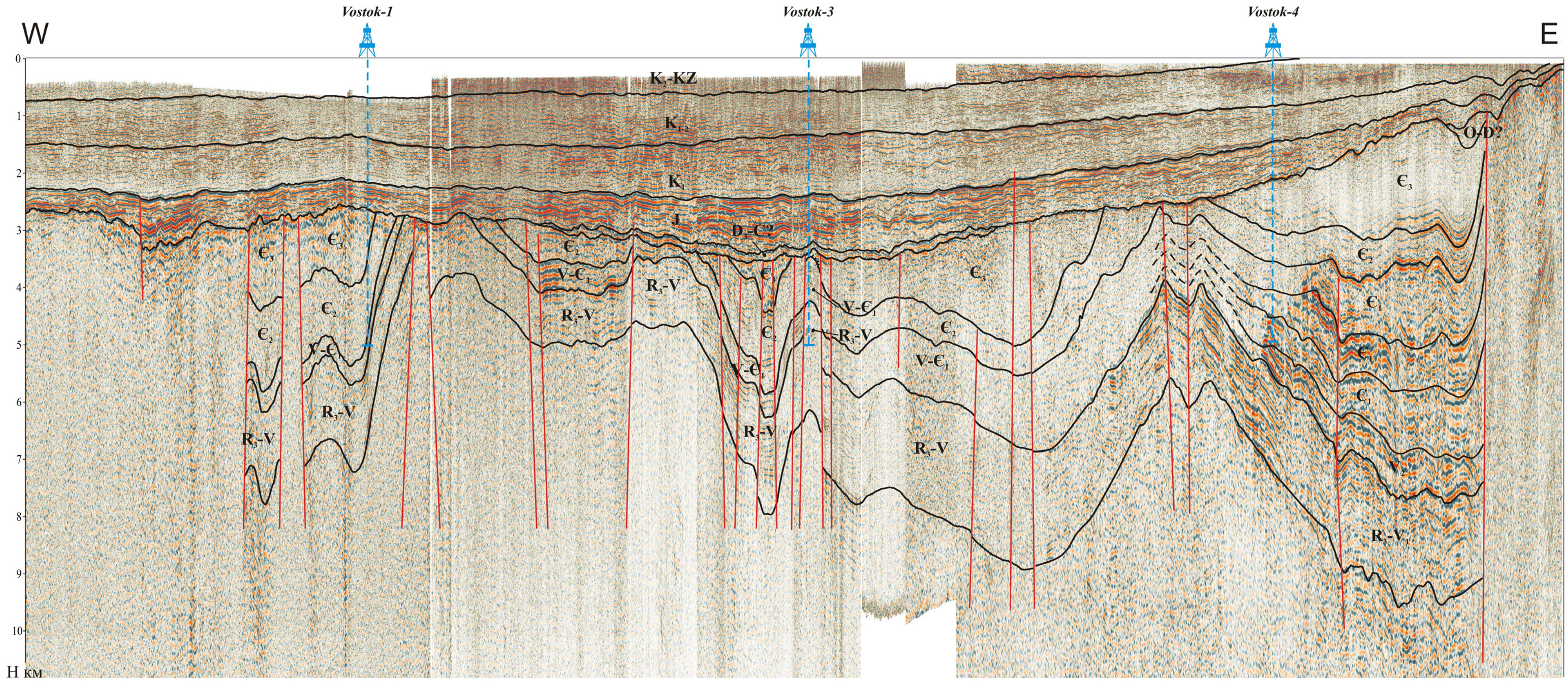

Figure 14. Deep seismic geological composite profile Vostok (see Fig. 12 for location).

ceous mudstones and carbonates of open marine ramp setting developed in front of a reef system; these could be analogous to Shumnaya and Kuonamka formations in the north of Siberian Craton.

Below the Cambrian deposits, the boreholes Vostok-3 (depths 5002–3660 m) and Averinskaya-150 (depths 4430–4770 m) penetrated siliciclastic and carbonate (with sulphates in the latter borehole) Vendian strata [3, 6]. The Vostok-3 section starts with microbialites and biostromes (Poiga Fm) of a stromatolitic barrier reef system formed within a stable shelf isolated from fine aluminosiliciclastic input. The overlying carbonates of the Kotodzha Fm contain aluminosiliciclastic material and cherts and are interpreted as carbonate ramp setting. Higher in the section, in the Raiga Fm, gravity flow deposits become abundant. The Vendian sedimentary sequence in general is the record of a gradual deepening and lateral extent of a marine basin, with the Poiga Fm corresponding to westernmost progradation of biostrome facies. This biostrome system supplied the depositional system of Kotodzha, Raiga, Churbiga, and Paidugina formations with fine clastic carbonate material. The volcanoclastic (acid and basic tephra) material is likely to be derived from an island ark to the south of Vostok-3, and the aluminosiliciclastic material, from an offshore land mass located in place of a modern day Yenisei Ranges.

The Vendian section of the Vostok-3 Borehole yielded an important paleontological information (Fig. 13). The lower part of the Poiga Fm is characterized by calcareous algae *Korilophyton* of Nemakit-Daldynian age. The Kotodzha and Raiga formations host a typical late Ediacaran association represented by tubular skeletal remains of calcitic *Cloudina hartmanae*, showing eccentric nesting of funnels flaring out at the apertural end in transverse sections, skeletal remains of slightly calcified goblet-shaped fossils, which can be referred to as *Namacalathus*, carbonaceous compressions *Vendotaenia*, and a heterogenous assemblage of mineralized and agglutinated tubes. *Cloudina*, a globally distributed tubular calcified fossil found in the Vostok-3 section, is widely known from rocks of Namibia, Uruguay, Argentine, Brazil, Mexico, southwestern U.S.A., Canada, China, Spain, Antarctic, Oman, and Sayan–Yenisei folded area. U–Pb-zircon dates from Namibia and Oman constrain the age of the *Cloudina* zone in the range between 549 ± 1 and 542 ± 1 Ma, which corresponds to the Late Vendian (Nemakit-Daldyn). The Vostok-3 Borehole is the first Siberian occurrence of *Namacalathus* and the world's fourth occurrence of the *Cloudina–Namacalathus* assemblage.

Several seismic facies have been identified based on wave pattern analyses, and each region is characterized by a unique seismic facies. Seismic data reveal a wide extent (as far as 300 km west of Yenisei River) of the Upper Proterozoic and Lower Paleozoic strata, expressed as laterally continuous, prominent, low-amplitude reflecting horizon, in the Fore-Yenisei Basin. Wave patterns in the left bank of the Yenisei River and western parts of the Siberian Craton are identical.

Interpretation of wave pattern in the seismic profile (Fig. 14) and integration with borehole sections suggests a large thickness (up to 3 km) of Upper Proterozoic terrigenous-carbonate strata giving a contrast image with prominent reflecting surfaces. In the Yenisei Ranges, these strata are coeval with the lower Lebyazh'ya Fm and the Chapa Gr (Pod'yom and Nemchany formations) of the Vendian, as well as the Chingasan Gr of Upper Riphean. The coeval strata on the Siberian Craton include Vanavara, Oskoba, Katanga, Soba and Tetere formations. The Fore-Yenisei zone, therefore, represents a terrane that accreted to the Siberian Craton in late Riphean; starting from late Vendian, it formed a single epicratonic-type, terrigenous-carbonate and carbonate-evaporite complex. Geochemical studies of the naphtides, conducted in the Institute of Petroleum Geology and Geophysics and supervised by Academician A.E. Kontorovich, confirmed hydrocarbon (primarily, oil) migration and accumulation in pre-Jurassic strata of the left bank area of the Yenisei River. The direct indicators of petroleum in the Lenok-1 Borehole are related to marine highly carbonaceous sections; their chemical composition points to late Proterozoic age for the source of petroleum. The total bulk of the sedimentary basin infill is estimated to be over 2.2×10^6 km^3; the bulk confined between the base of Jurassic and the depth of 7 km is ca. 10^6 km^3. Total geological resources D2 exceeds 10 billion of tons of hydrocarbon equivalent. Large petroleum field are expected to be discovered in the Fore-Yenisei basin in the 21st century.

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Stratigraphic range of late Precambrian rocks in the central part of the Altai–Sayan Foldbelt

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Carbonate and carbonate-terrigenous-volcanogenic sections earlier interpreted as Riphean are widely distributed in the Kuznetsk Alatau and Gornaya Shoriya in the central part of the Altai–Sayan Foldbelt and referred to as the Kabyrza, West Siberian and Belka formations of Gornaya Shoriya, as well as the Charyshtag (Ulugzas), Bidzha (Khomgol), Martyukha (Khabzas) and Sorna formations of the Yenisey Gr of the Azyrtal Ranges in the upper reaches of Tom' River. The Yenisei Gr is correlated with carbonate-terrigenous-volcanogenic deposits of the Batenev Ranges and Belyi Iyus River basin consisting of the Synnig, Tuyrim, Kul'byurstyug, Amar, Tarzhul' formations. These are the most complete and accessible and hence the most representative Upper Proterozic sections of the Altai–Sayan Foldbelt. Recently, correlation between the Bidzha and Kabyrza formations, as well as between Martyukha and West Siberian formations has been revised based on new data on the occurrence in Gornaya Shoriya of stratigraphic analogues of the uppermost Charyshtag Fm (Ust-Kezes Fm according to V.A. Sivov) of the Azyrtal section [1]. This corroborates the fact that the Mras–Azyrtal Block consisting of Mras and Asyrtal parts in the modern structure represents a single massif. The carbonate type section of the Mras–Azyrtal Block to the north (Belyi Iyus River basin) is replaced by carbonate-terrigenous-volcanogenic sections; further north (Kiya River section), it is replaced a new carbonate type section consisting of the Kabyrza, West Siberian and Belka formations of Gornaya Shoriya [2].

According to Resolutions of the Interdepartmental Stratigraphic Session (Novosibirsk, 1979), the Kabyra Fm and the coeval Synnig and Tyurim formations comprise the Kabyrza Regional Stage of Middle Riphean; the West Siberian Fm and the coeval Martyukha, Kul'byurstyug and Amar formations comprise the West Siberian Regional Stage of Upper Riphean; and the Sorna Fm and the coeval Belka Fm comprise the Belka Regional Stage of Vendian. Recent paleontological studies suggest a younger age of the strata [3–6]. According to a new stratigraphic scheme of the Altai–Sayan Foldbelt, proposed by the authors on a Workshop on Upper Precambrian and Cambrian stratigraphy of Central Siberia (Novosibirsk, 2005), the Kabyrza Regional Stage (Kabyrza, Bidzha, Synnig and Tyurim formations) is Lower Vendian and the West Siberian Regional Stage (West Siberian, Martyukha, Kul'byurstyug and Amar formations) is Upper Vendian. This conclusion was based on calcareous algae *Korilophyton*, *Razumovskia*, *Proaulopora*, *Renalcis*, *Botomaella* etc., small skeletal fossils *Cambrotubulus decurvatus*, *Anabarites trisulcatus*, *Cloudina*, *Sinotabulites* and Ediacaran fossils in the West Siberian Regional Stage. The Vendian–Cambrian boundary was drawn between members 1 and 2 of the Sorna Fm of the Azyrtal Ranges (Figure 15) by the first appearance of Cambrian small skeletal fossils and calcareous algae [6, 7]. The dolomitic Tarzhul'

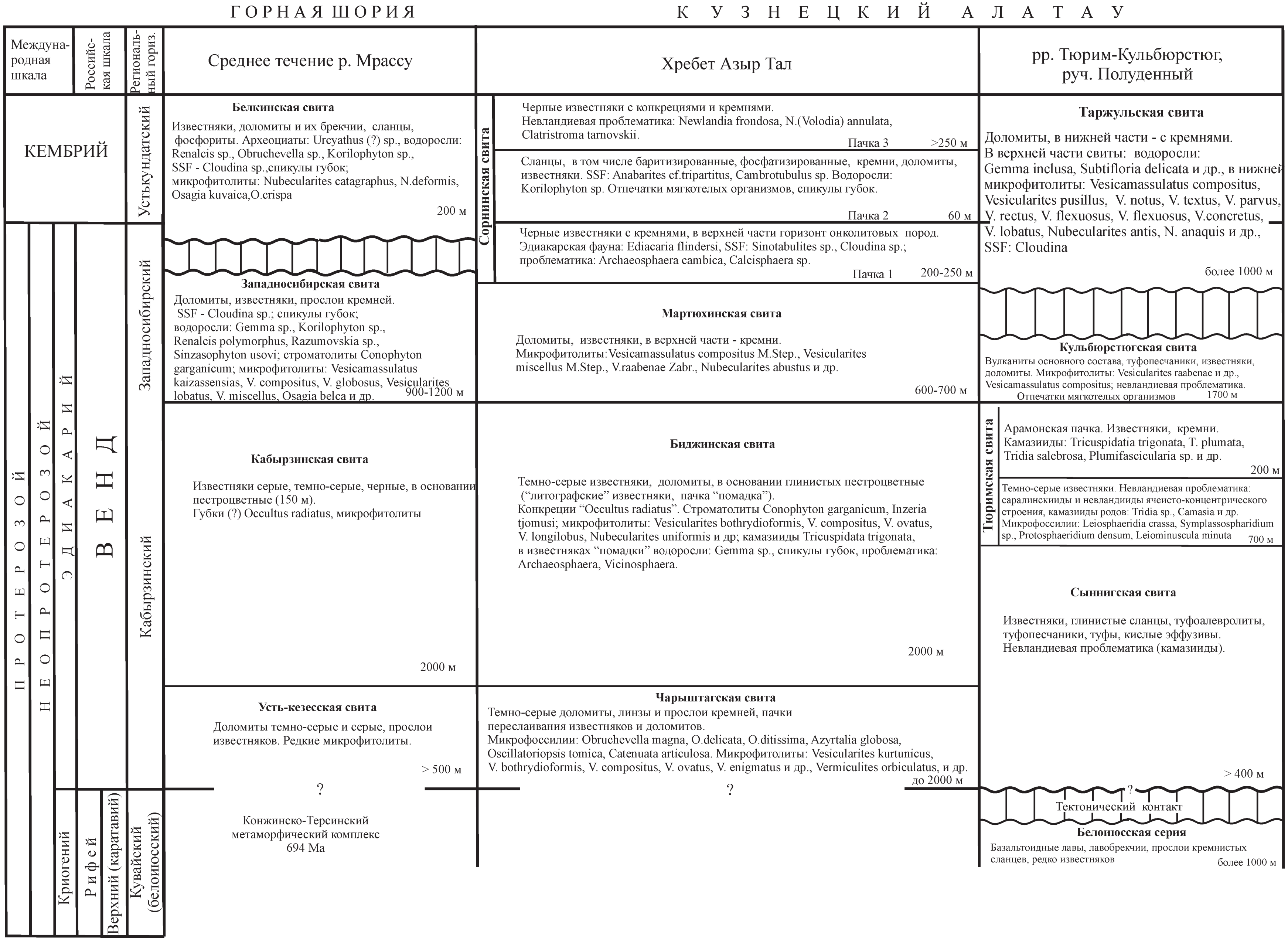

Figure 15. Fragment of the stratigraphic chart for Upper Precambrian of the Altai–Sayan Foldbelt.

Fm (that includes the lower boundary of the Cambrian) is correlated with the Sorna Fm. It yielded small skeletal fossils *Cloudina* and microphytolites *Vesicamassulatus compositus* in the lower part, and calcareous algae *Gemma inclusa* and *Subtifloria delicate*, in the upper. The early Cambrian age of the upper part of Tarzhul' Fm is supported by a conformable contact with overlying carbonates of the Tunguzhul Fm, which contains trilobites 30 m from the base and late Atdabanian trilobites of the Kameshki Regional Stage 200 m from the base. The Vendian age of the Kabyrza Fm and the coeval strata is based on calcareous algae (*Gemma*), sponge spicules (*Hexactinellida* and *Monoxonellida*), and conformable contact with the West Siberian Fm. Of special interest is the Charyshtag Fm underlying the Bidzha Fm in the Azyrtal Range section. Although there is a local hiatus at the base of the Bidzha Fm, it sits conformably on the Charyshtag dolostones. Carbonate samples from the Charyshtag Fm as well as from the base of Bidzha Fm have $^{87}Sr/^{86}Sr$ values typical for Lower Vendian [8]. The Konzhinskiy–Ters metamorphic complex of the Tom' Inlier that have an isotopic age 694 Ma [9], as well as the metabasites of Belyi Iyus Gr of Kuznetsk Alatau below the Synnig Fm are both pre-Vendian (Riphean) (Fig. 15).

In East Sayan Tanges, the volcanogenic strata of the Kuvai Gr (930–1000 Ma), the metamorphic rocks of the northwestern Arzybei terrane (775 Ma) and the Sarkhoi Gr of the southeastern part of the terrane (718 Ma) have Neoproterozoic age [7]. All the strata underlying the Kabyrza Regional Stage can be referred to as the Kuvai (or Belyi Iyus) Regional Stage. According to modern geodynamic models for development of the southern part of Siberian Craton, there is a significant tectonic restructuring at the Riphean–Vendian boundary [10], and the central part of the Altai–Sayan Foldbelt is no exception to this. It is this restructuring that was responsible for the observed major differences between the Riphean and Vendian, and for the presence of hiatuses and unconformities between them.

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Paleontological phenomenon of the Onega Structure (Karelia) as the base for stratigraphic correlation in Mesoproterozoic

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Breccia zones are widely distributed in Paleoproterozoic carbonaceous sedimentary rocks of the Zaonezhskaya Fm of the Onega Structure (Karelia) (Fig. 16). These brecciated rocks called **maksovites** include veins of anthraxolite (shungite-1, in old terminology), the pitch-black shiny rock consisting of an aggregate of quartz–carbon (shungite)–pyrite–magnetite–iron, etc., as well as apatite and monatzite exhibiting microfolding of quartz–carbon laminae less than 5 μm thick. Microprobe analyses of quartz matrix show that overgrowth is represented by SiO_3 (C – 35–32%; O – 50–53%; Si – 15%), and kernel,

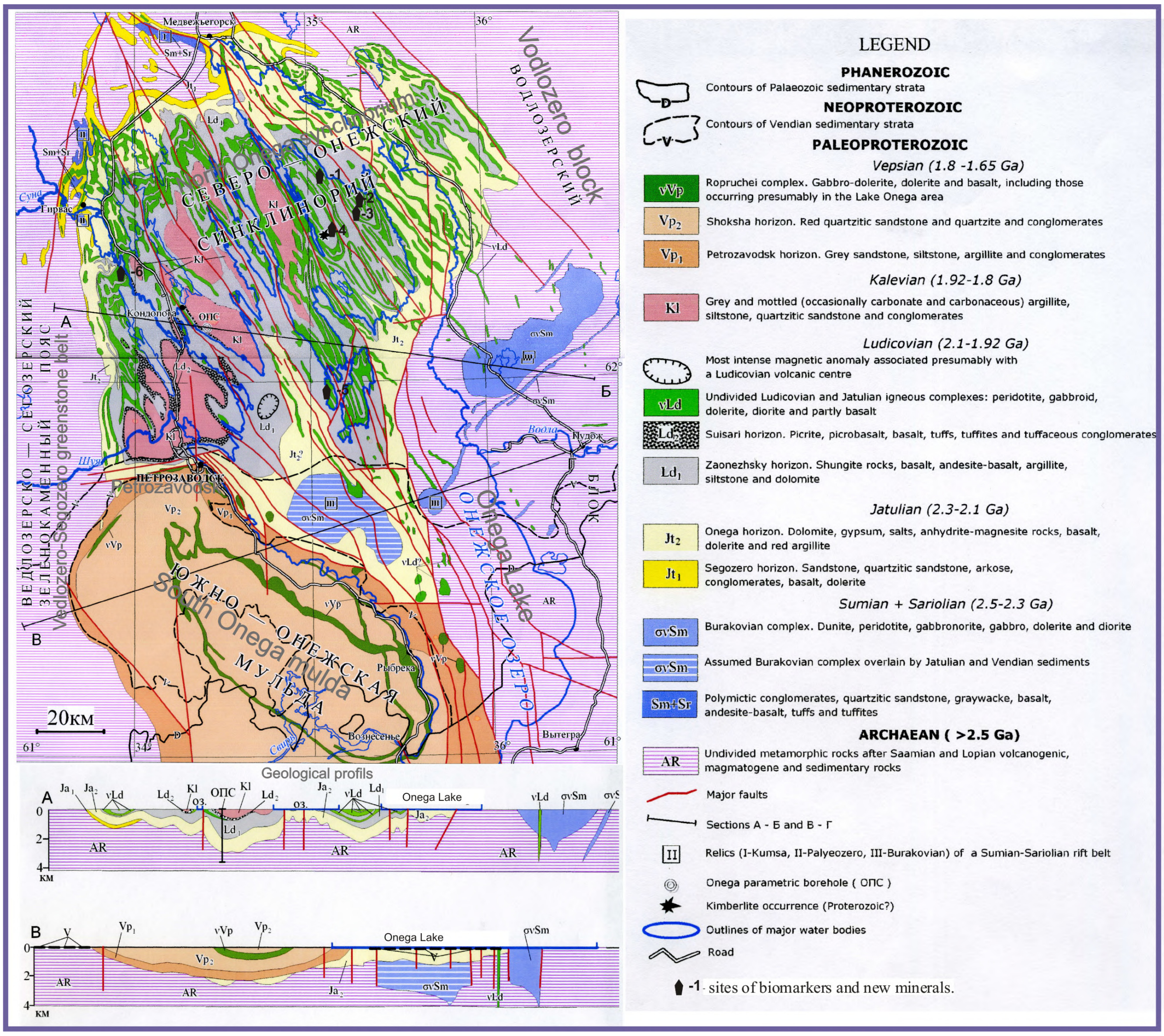

Figure 16. Geological map of the Onega Structure (compiled by V.S. Kulikov, M.G. Leonov, N.V. Sharov, A.A. Makariev, A.K. Polin et al. 2011; based on data from "Sevzapgeologiya", Polar IMGRE, Institute of Geology of Karelian Science Center of the Russian Academy of Science, with modifications).

by SiO_2 (C – 27%; O – 51%; Si – 21%). Although anthraxolite is a high metamorphic rock unsuitable for preservation of microfossils, the maksovites and the host shungites in the locality Shun'ga (Fig. 16: site 1) contain problematic magnetite–iron films interpreted as fossilized microbial mats. Their carcass is made of individual Fe needles (≤1 μм), rosettes, individual "cocci" (≤3 μm) and laminated "mats" (up to 5 nanolayers). These forms were possibly generated by iron bacteria similar to obligate-anaerobic Mn-precipitating bacteria *Metallogenium*. The characteristic spider-shaped metal crystals form only in strongly oxic (?) conditions. In the locality Maksovo (Fig. 16: sites 2–3), acritarchs (10–100 μm in diameter) consisting of K-, P- and S-enriched framboidal pyrite in the core and covered in siliceous substance SiO_3 were found in troughs between supposed ripple marks (C – 59.57%; O – 37.09%; Si – 0.46%; P – 1.21%; S – 0.17%; Fe – 1.50%; or Si – 14.88%; P – 40.58%; S – 6.68%; Fe – 37.89%). An "oncolite" relict was observed in the quartz matrix (SiO_3–SiO_2) in immediate proximity to the acritarchs. Carbonaceous concretions reminiscent of *Palaeolyngbya* were also noted. In the south of the studied ares, on the Berezovets Island (Fig. 16: site 5), the acritarchs (20–50 μm) have numerous (up to 5) chambers filled with framboidal pyrite and are covered by pyrite (≤1 μm in thickness). Microscopic carbonaceous compressions found on the territory of the Kivach National Reserve (Fig. 16: site 6) have "medusoid" shapes, with a fringe consisting of sulfur, potassium, chlorine, and titanium in the form of rutile (?). Acritarchs consist of framboidal pyrite which is different from cubic forms of pyrite from the Berezovets Island and instead is represented by flat, irregular frond- and rosette-shaped structures. The acritarchs are confined to a structure that can be interpreted as Onego Astrobleme [2–4] that was filled with water of high salinity. A section of halite penetrated by one of the parametric boreholes (depths 2751–2944 m) [7] sitting on the Archean basement could represent a paleobasin that was displaced by deep faults. This hypothesis is corroborated by the known geological data [1, 2] and Kimozero diamonds (Fig. 16: site 4) [6] as well as discoveries of kamacite–taenite with Widmannstatten pattern, native Fe and Ni, yarlongite, awaruite and Ir in metamict zircons by the authors [5] in the epicenter structure (Shun'ga–Maksovo). Samples were studied using energy-dispersive microbe analyzer OXFORD INCA Energy 350 and scanning electron microscope TESCAN VEGA II LSH (accelerating voltage 20 kV; beam current 340 pA). This work was partially supported by the Russian Foundation for Basic Research (project no. 09-05-00376).

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Vendian volcanogenic complex in the western East European Craton

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Vendian of the western East European Craton consists of three lithologic complexes: diamictites of glacial origin (Vilchan Gr of Belarus and coeval strata in Russia and Ukraine), volcanogenic rocks (Volyn Gr) and sandstones, siltstones and shales of marine origin (Valdai Gr) [1, 2]. The lower Cambrian boundary is conventionally placed at the base of Rovno Regional Stage, although some authors [3] draw it at the base of Lontova Regional Stage (Baltic Gr). The lower Vendian boundary is marked by first appearance of glacial deposits. Recent isotope dating of the Volyn–Brest magmatic province (VBP), specifically a U–Pb-zircon date (SHRIMP) of 551 ± 4 Ma for the tholeiite basalt tuffs of Poland [4], a Rb–Sr-isochrone date of 552 ± 59 Ma for the bulk sample of tholeiite basalts of Ukraine [5], a U–Pb-zircon date (NORDSIM) of 549 ± 29 Ma for the tholeiite basalts of Ukraine [6], and a U–Pb-zircon date (SHRIMP) of 557 ± 9 Ma for the rhyodacites of Belarus [7] constrain the age of intensive volcanic activity at ca. 550 Ma. Correlation of the VBP flood basalts, however, shows that there are two volcanic units separated by a hiatus and that all dates from the basalts refer to the upper volcanic unit, whereas the rhyodacites correspond to the final stage in formation of the lower volcanic unit (Fig. 17). Composition of the lower volcanic unit of VBP is similar to the coeval (554–550 Ma) subalkaline mafic rocks of Canada [8, 9], although older (615–564 Ma) normal basic rocks from Canada don't have analogues among the rocks of VBP. The Canadian rocks have been subject to regional low-temperature metamorphism, which is not the case in VBP. Flood basalts in Canada and VBP both formed in continental settings and had similar mixed mantle sources (subcontinental lithospheric mantle and mantle plum components). The VBP basalts crystallized in low-temperature conditions and low oxygen volatility close to the quartz-fayalite-magnetite buffer [10]. Both provinces formed in a single tectonic cycle during the second phase of Rodinia break-up and have preceded opening of the Iapetus ocean. The lower boundary of Upper Vendian is currently placed at the base of Redkino Regional Stage (Valdai Gr) and defined by paleoclimatic changes and appearance of metazoans [11]. Glacial and volcanic complexes of the East European Craton formed during global climate cooling. The new reliable isotope dates for the Volyn flood basalts suggest that the age of lower boundary of the Upper Vendian is younger than 550 Ma. This work was supported by the BRFBR (project no. X09K-048).

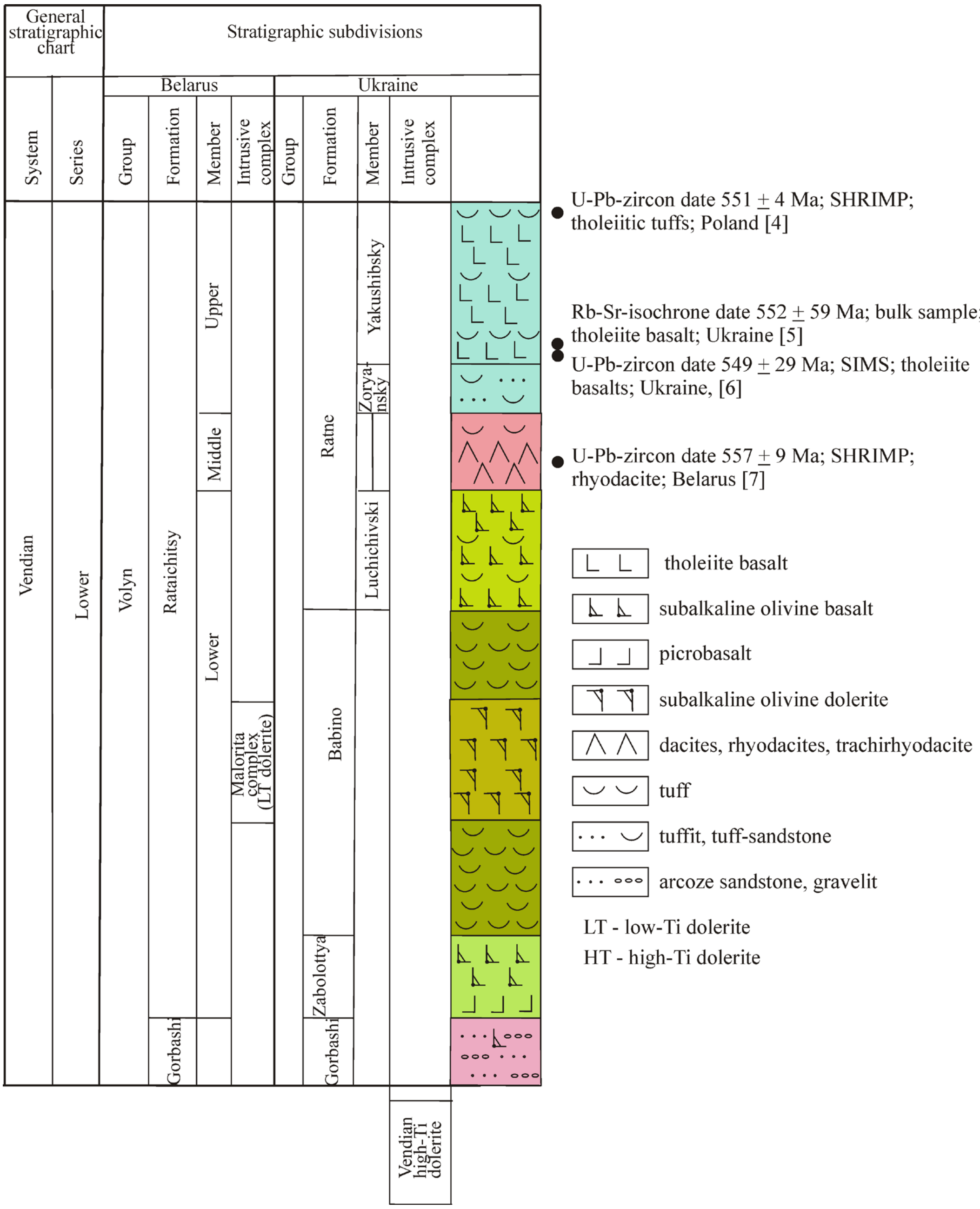

Figure 17. Correlation of the Vendian flood basalt formations of southwestern Belarus and northwestern Ukraine.

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Vendian–Cambrian interval of carbonate sedimentation in the eastern segment of Paleoasian Ocean: Sr-isotope chemostratigraphy

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The Vendian and Cambrian of Paleoasian Ocean is represented by thick sedimentary successions. The Baikal Gr in particular characterizes passive continental margin settings of the Siberian Craton associated with opening of the Paleoasian Ocean [1]. The coeval carbonate sequences on the shelf of microcontinents have very poor stratigraphic constraints on account of insufficient paleontological (despite rare occurrences of Ediacaran fossils, archaeocyathids and trilobites) and geochronological information. Sr isotopic chemostratigraphy appears to be the only approach to establish the relative age of sedimentation of these carbonate sequences. We studied Sr isotope composition of Vendian and Cambrian carbonates in the south of Siberian Craton (Baikal Gr), as well as Tuva–Mongolia (Boxon and Hubsugul groups and Muren Fm of eastern Sayan and northern Mongolia), Dzabkhan (Tsaganolom and Bayangol formations of Western Mongolia) and Batenev (Eniseyan formation, Alatau Kuznetsk) terranes (Fig. 18). Based on petrographic and geochemical analyses we identified the least altered rock samples; these samples are thought to have primary Sr isotope composition reflecting that of the paleocean. We used samples with the lowest amount of terrigenous component and meeting the following criteria: Mg/Ca<0.024, Fe/Sr<5.0, Mn/Sr<0.2 for limestones and Mg/Ca<0.6, Fe/Sr<3.0, Mn/Sr<1.2 for dolomites with the lowest degree of postsedimentary alteration [2]. Samples from the Baikal Gr have $^{87}Sr/^{86}Sr$ values of 0.7084–0.7087 [1];

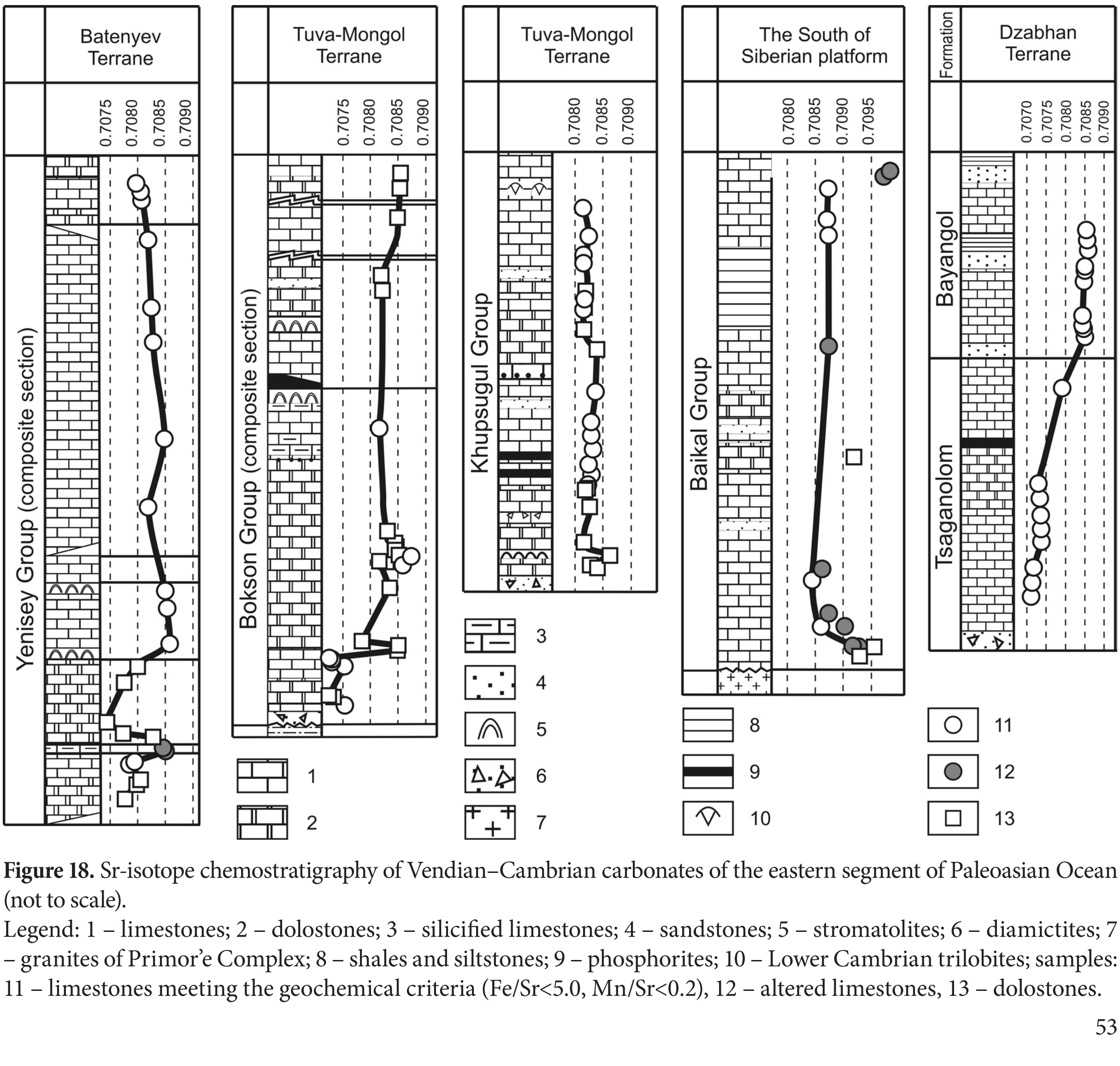

Figure 18. Sr-isotope chemostratigraphy of Vendian–Cambrian carbonates of the eastern segment of Paleoasian Ocean (not to scale).
Legend: 1 – limestones; 2 – dolostones; 3 – silicified limestones; 4 – sandstones; 5 – stromatolites; 6 – diamictites; 7 – granites of Primor'e Complex; 8 – shales and siltstones; 9 – phosphorites; 10 – Lower Cambrian trilobites; samples: 11 – limestones meeting the geochemical criteria (Fe/Sr<5.0, Mn/Sr<0.2), 12 – altered limestones, 13 – dolostones.

from the Tsaganolom Fm, 0.7072–0.7079; and from the Bayangol Fm, 0.7084–0.7086. The least altered carbonates of the Tuva–Mongolia terrane have Sr isotope values of 0.7073–0.7086. The lowest $^{87}Sr/^{86}Sr$ ratios are obtained for carbonates of the Zabitsk (Uha-Gol River) and Muren formations [3]. The Yenisei Gr is characterized by $^{87}Sr/^{86}Sr$ rations of 0.7075–0.7085 [4–6]. The following age constrains are established by methods of isotope chemostratigraphy. Maximum age of the Baikal Gr in the south of Siberian Craton is late Vendian (550–520 Ma). Carbonates of the Tsaganolom Fm formed during the Vendian (590–560 Ma), and the Bayangol Fm, mostly in the early Cambrian (550–520 Ma). Carbonate sedimentation in various parts of the Tuva–Mongolia terrane was diachronous and started between 600–580 My ago and continued into middle Cambrian. The Yenisei Gr was deposited during Vendian and early Cambrian (580–517 Ma). The commence of carbonate sedimentation in the Vendian was not synchronous in different parts of the Paleoasian Ocean and cannot be used for lithological correlation of the carbonate successions. The work was supported by the Russian Foundation of Basic Research (projects nos. 09-05-01030 and 10-05-00971) and the Presidium of the Siberian Branch of Russian Academy of Sciences (project no. 19).

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Neoproterozoic Timan–Varanger–Urals passive margin of Baltica: constraints from detrital zircon ages from Neoproterozoic aluminosiliciclastic rocks

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Collision between the Arctida and Baltica (separated by Pechora ocean) (Fig. 19: A) during the time of transition from Neoproterozoic to Cambrian is the key episode in the initial phase of Wegener's Pangea north part assembly (continent–continent collision) [1–3]. Collision between the Varanger–Timan sector of the Varanger–Timan–Urals passive margin of Baltica and the Bolshaya Zemlya active margin of Arctida resulted in the Pre-Uralides–Timanides collisional orogen and formation of the Arct-Europe composite continent (Fig. 19: B). Relicts of the Pre-Uralides–Timanides constitute the basement of the region extending from the Pechora basin and the northern parts of western Urals to Svalbard archipelago, and from the northern edge of Kola Peninsula and western Timan Ranges to the central part of Novaya Zemlya Archipelago. The accumulating isotopic dates for crystalline (magmatic/metamorphic) rocks of the relics of Pre-Uralides–Timanides fall within the range ~750–500 Ma [2–4]. U–Pb dating of detrital zircons (dZr) from Neoproterozoic formations from four localities (Fig. 19: A) along the Varanger–Timan sector of the Varanger–Timan–Urals edge of Baltica produced following results:

1. Northwestern part of the Central Urals.–U–Pb dZr dates are available for sandy matrix of tilloids of the Tany Fm (Lower Serebryanaya Gr) and sandstones of the Kernos Fm (Upper Serebryanaya Gr) of Upper Neoproterozoic [5]. The Tany Fm yielded only Paleoproterozoic (49%, the youngest grain is ca. 1.9 Ga), Neoarchean (~48%) and Mesoarchean (rare grains) dZr dates, whereas the Kernos Fm yielded Mesoproterozoic (~25%, the youngest grain is ~1.03 Ga), Paleoproterozoic (~60%), Neo- and Mesoarchean (together 15%) dZr dates.

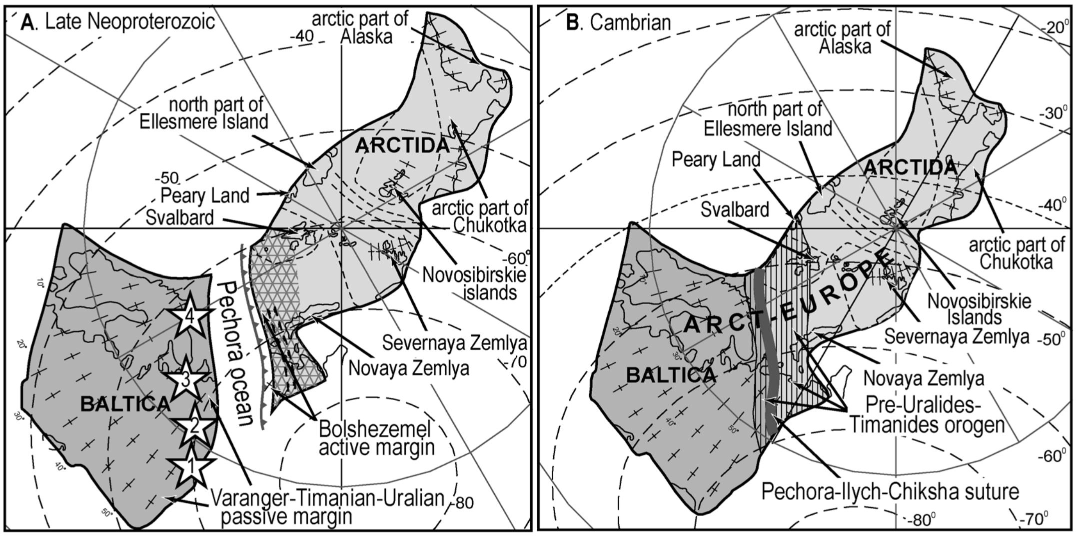

Figure 19. Illustration of the "Arctica–Baltica collision"–concept. Plate tectonic reconstructions for Late Neoproterozoic (A) and Cambrian (B) [1–3]. Stars with numbers (correspond to numbers in text) mark localities with detrital zircons.

2. Dzhezhim–Parma range (southern Timan ranges).–Ca. 70 dZr grains were dated from red cross-bedded sandstones and red siltstones of the Lower Neoproterozoic Dzhezhim Fm. The youngest dZr age is ~1.2Ga [3].

3. Winter coast of the White Sea.–The Upper Ediacaran Zimnegory Fm consists of interstratified sandstones, siltstones and shales, with Ediacaran fossils. The formation also includes a few thin beds of volcanic tuff with zircons that yielded a U–Pb date of 555.3 ± 0.3 Ma [6] and 550.2 ± 4.6 Ma [7]. I believe that the volcanic tuffs and the coeval basaltic-rhyolitic associations of Volyn large igneous province (western Baltica) [8] are pasts of the same event. Four dZr from the Zimnegory Fm yielded dates ranging from 1.33 (youngest) to 1.93 Ga [7].

4. Varanger peninsula.–Most dZr have Paleoproterozoic and Neoarchean ages; the youngest age is ~900 Ma [9].

Not a single dZr grain in the studied Neoproterozoic rocks from the Varanger–Timan sector of the Varanger–Timan–Urals margin of Baltica yielded dates that can be correlated with crystalline complexes of the Pre-Uralides–Timanides (750–500 Ma). Instead, all dated dZr can be correlated to probable magmatic or/and metamorphic sources within Baltica (Fig. 20). The Archean and Paleoproterozoic grains probably originated from crystalline complexes of Volga–Uralia, Sarmatia and Fennoscandia, but younger, Mesoproterozoic and early Neoproterozoic grains could be derived from the Sveconorwegian part of Baltica. The passive margin regime of the Varanger–Timan–Urals edge of Baltica lasted at least until the end of Ediacaran (possibly, until early Cambrian).

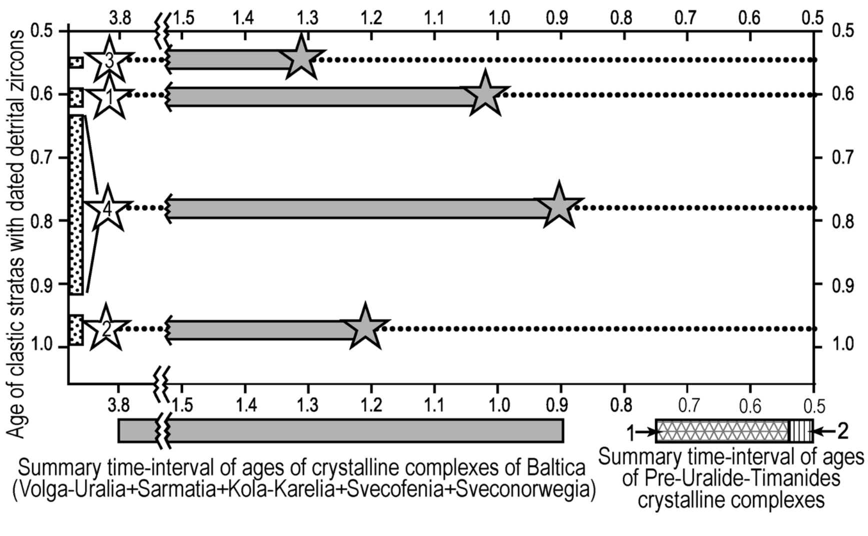

Figure 20. Diagram of age distribution of aluminosiliciclastic units (dotted bars and stars with numbers, see Fig. 1A) of the Varanger–Timan sector of the Varanger–Timan–Urals passive margin of Baltica versus age intervals (gray bars, stars mark the age of the youngest grains). 1, 2 – Pre-Uralides-Timanides: magmatic and metamorphic complexes of the Bolshaya Zemlya active margin of Arctida (1) and the Arctida–Baltica collisional zone (2).

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Hydrocarbon accumulation in allochthon of the Nyuya–Dzherba Basin (Siberian Craton)

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The Nyuya–Dzherba Basin is located in the north of Fore-Patom regional depression of Siberian Craton. The sedimentary infill is complicated by fold and thrust deformations in front of the Baikal–Patom Foldbelt. The basin was set in Riphean, when thick sedimentary successions formed on the passive margin of Siberian Craton. These strata were also a major source of hydrocarbon [1]. Overthrust faulting and folding in Silurian and Devonian facilitated the hydrocarbon migration from the Baikal–Patom Paleobasin towards the Siberian Craton across the Nyuya–Dzherba Basin, whereas compressional deformation led to formation of various hydrocarbon traps in the allochthon. In plan view, the fold and thrust belt is arcuate in the direction of movement. The hydrocarbon deposits are confined to the thrust faults. Each prominent thrust fault is attended by a folded zone consisting of numerous small antiform structures. The folded zones reach 10 km in width and extend over dozens of kilometers. Furthermore, the autochthon surface is complicated by kinks in front of the thrust faults that prevent smooth allochthon movement and cause crenulation of the folded zone. Such areas experience both overthrusting and strike-slip tension, as first noted by A.V. Migurskiy. Tectonic activation leads to formation of variously oriented cracks. Overthrust faulting and folding under conditions of compressional deformation, with a sub-vertical orientation of the maximum stretch axis, facilitates opening of sub-horizontally aligned cracks. The tension cracks have horizontal orientation in overthrust faulting and vertical orientation, in strike-slip movements (Fig. 21) [2].

Under conditions of prevailing horizontal compression, an abnormally high pore pressure builds up, decreasing in the direction of maximum compression. The abnormally high pressure, together with the prevailing crack orientation, promote massive lateral fluid migration. This migration enables hydrocarbon accumulation in the autochthon. Under favorable conditions, the hydrocarbons can migrate from the autochthon into the allochthon. Such conditions include formation of thrust faults branching from the main fault or crenulations caused by irregularities of the main fault [3] that lead to generation of vertical cracks for hydrocarbon migration.

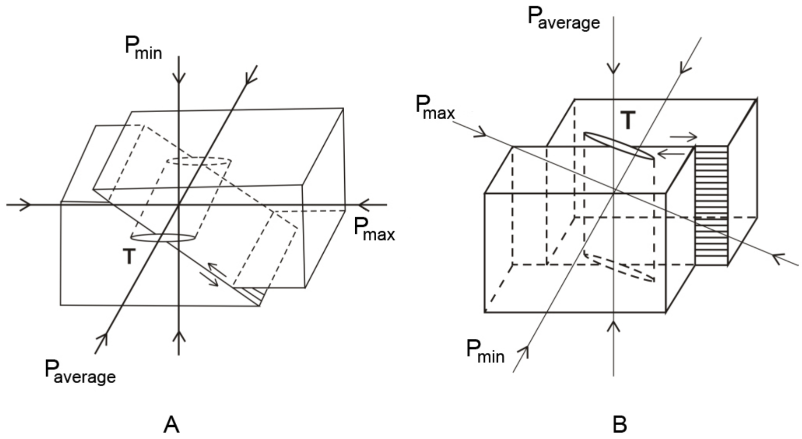

Figure 21. Orientation of tension cracks (T) and compressing strain (P) in overthrust faulting (A) and strike-slip movements (B).

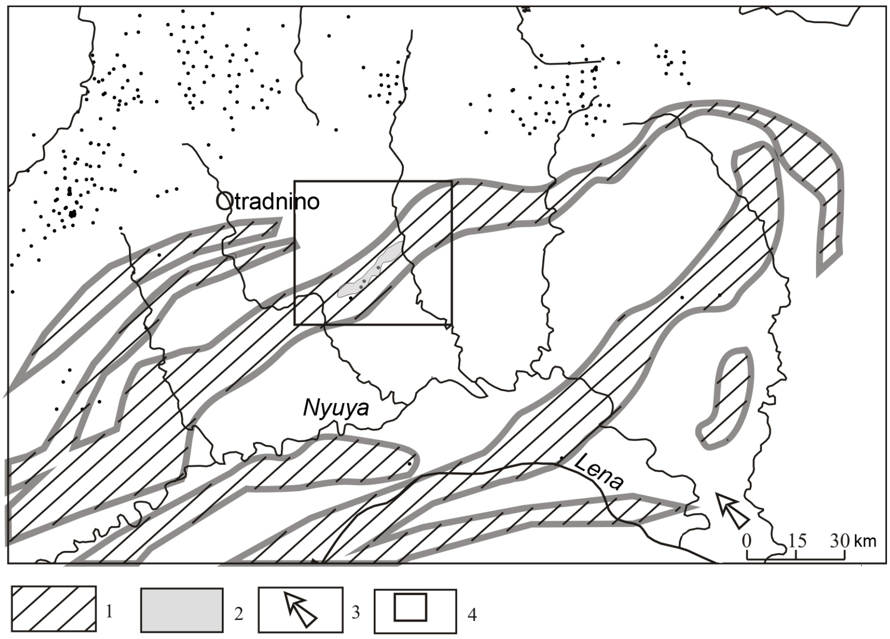

Figure 22. Northern part of the Nyuya-Dzherba Foldbelt.

Legend: 1 – zones of overthrust faulting; 2 – hydrocarbon deposit; 3 – general direction of the compressing strain; 4 – the area of compressional and strike-slip deformation

Such conditions that favored hydrocarbon migration from autochthon to allochthon existed in the Pilyuda and Otradnoe oil fields. In the Pilyuda oil filed, hydrocarbon inflow was obtained from the Ust'-Kut (V–$Є_1$jur) and Osino ($Є_1$us) horizons of the allochthon; however, these fields are likely to be secondary, and the source fields are probably located in Vendian terrigenous strata of the autochthon. The hydrocarbon seepage occurred along a thrust fault branching from the main fault associated with the Vendian evaporites of the Tira Fm. In the Otradnoe oil field, hydrocarbons are associated with the Telgepsit productive horizon of the Byuk Fm of Vendian terrigenous sequence of the autochthon. Hydrocarbon migration into the traps of the allochthon led to formation of the Yuryakh (V–$Є_1$jur) productive horizon. The seepage occurred along the thrust fault branching from the main fault as well as along a system of sub-vertical of cracks, as suggested by a characteristic curvature of the fold and thrust zone (Fig. 22) and presence of vertical cracks in borehole core material.

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Neoproterozoic petroleum systems of Central-West Africa and Brazil

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Neoproterozoic petroleum systems, which occur in basins across China, Oman, Russia, and Brazil, are a frontier area for both academic research and petroleum exploration. Globally, oil and gas accumulations are known to occur in Tonian (1000–850 Ma), Cryogenian (850–635 Ma) and Ediacaran (635–540 Ma) strata. In many basins where there is a proven, or potential, hydrocarbon presence, deposits of the "Sturtian" and the "Marinoan" Cryogenian "snowball Earth"-style glaciations occur. These viable discoveries have given a momentum for new studies in Central-West Africa where exploration is underway. To understand the Neoproterozoic petroleum system of Central-West Africa an industry funded collaboration program is established between the Royal Holloway, University of London and the Royal Museum for Central Africa (MRAC, Belgium, Democratic Republic of Congo), the Federal University of Ouro Preto (Brazil), the University of Namibia and the University of Zambia. The area of study is articulated between the São Francisco Craton (Brazil), the West Congo Belt, the Katanga Region (DRC), the Copper Belt and the North Western Provinces (Zambia), the Otavi Mountains and the Nama Basin (Namibia). Recent studies show evidence of petroleum system in the São Francisco Basin, which can be used as an analogue for the African counterpart of the Congo – São Francisco Craton. Wider aims of our group are (i) to define the mega regional tectonostratigraphy, (ii) the sequence stratigraphy and (iii) to define the best source rocks, reservoirs and seals in these Neoproterozoic successions. In this project, seismic reflection data interpretation in the Owambo Basin (northern Namibia) is being used to complement our outcrop-based understanding of stratigraphic architectures in these regions. Initial results suggest that the location of mound-like build-ups, potentially representing microbialite growths, may be mapped. The extensive collections of rock samples and archives of the MRAC will complete and help the fieldwork data acquisitions. Among potential source rocks, we plan to sample and study black shales described in several of our areas, but also to sample seeps to characterize fluid origins. At this time, massive Neoproterozoic carbonates are the best potential reservoir and some of them can also act as source rocks. Detailed surveys of carbonate sedimentology, extent, architecture and fractures networks as determined by LiDAR data interpretation will be used to build a geocellular model and subsequently for reservoir simulation.

Diversification of calcareous algae in reef systems in transition to Phanerozoic

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Transition from cyanobacterial (stromatolitic) to algal ecosystems in Vendian–Cambrian time changed the course of biological history of Earth. The Vendian–Cambrian calcareous algae are represented by genera *Epiphyton*, *Renalcis*, *Proaulopora*, *Girvanella*, *Subtifloria* and others, sometimes referred to as microbialites, calcimicrobes, dendrolites, or calcibionta. Phylogenetic affinities of these genera are debatable. They are often compared to cyanobacteria and red algae, although small number morphological characters of their thalli gives rise to various fantasies. Of special interest are recent calcareous microbialites with microstructures similar to *Epiphyton* and *Girvanella* discovered in the freshwater Pavilion Lake, British Columbia (Canada); however, metabolic activity of the heterotrophic bacteria could not elucidate the nature of the algae and the comparison with *Epiphyton* was made only on the basis of visual observation [1].

History of the study of *Epiphyton* goes back to J. Borneman, who described the genus in 1886 from the Lower Cambrian of Sardinia Island. Over the last 150 years, *Epiphyton* was regarded as an artificial group of unknown systematic position [2], cyanobacteria [3, 4], sometimes divided into several genera, some of which are considered as cyanobacteria and others are compared to red algae [5–9]. The bushy thallus, its size, degree of calcification of the branches resembled the red algae; however, the presence of cellular structure implied by some researchers was not supported by a convincing evidence. The calcification of *Epiphyton* occurred in the same manner as in *Renalcis* and *Girvanella* unanimously attributed to cyanobacteria. The original structure of the branches in the thallus of *Epiphyton* is hidden behind the dark calcareous sheath, and only in rare cases there is light calcite visible in inner parts of the branches. B. Pratt [10] suggested that coccoid cyanobacteria settled on the surface of the algae after the death and formed calcareous cover (sheath) on the thallus, and regarded *Epiphyton* as well as *Renalcis* as diagenetic taxa. The idea ofa unified nature of stromatolites and *Epiphyton* was earlier brought by V.P. Maslov [11]. The nature of *Epiphyton* is resolved thanks to the discovery of new morphological elements in the material discovered by A.A. Terleev in the Eastern Sayan (Mana Depression) in the Upper Anastas'ino Fm of Tommotian age (Early Cambrian), and then in the Kuznetsk Alatau on the Kiya River in the Ust-Kunda Fm (Tommotian–Atdabanian). Thin sections of the calcareous algae show contrasting black, not gray sheath allowing the discovery of plasmodesmata, cells and nemathecia and bushy thallus structure that put an end to a long-term dispute about the systematic position of *Epiphyton* and confidently place it within Rhodophyta [12, 13]. Comparison *Epiphyton* with modern calcareous red alga *Corallina* explains the discontinuity between the branches of *Epiphyton* due to loose connections between the calcified and noncalcified parts of the thallus [14, 15] and the lack of attachment structures in the fossil record.

The nature of the genus *Renalcis* is no less mysterious, although most researchers assign it to cyanobacteria. It often occurs together with *Epiphyton* and other calcareous algae. The genera *Chabakovia*, *Shuguria*, *Izhella* and even *Epiphyton* are regarded as synonymous with *Renalcis*, but the evidence for such conclusion is very weak. The problem was resolved thanks to the discovery of a unique preservation of microbialites Gemma with "monospors" giving rise to *Korilophyton*, the initial stage *Epiphyton*. Without the "monospors" the same thin section would be described as *Renalcis*, so similar were the colonies of both genera. Based on this observation, we have concluded that the life cycle of *Epiphyton* consisted of two heteromorphic stages of the interim phase of growth of palmelloid and dendroid forms [16].

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Problematic structures in the Upper Neoproterozoic of eastern Kuznetsk Alatau Ranges

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Problematic structures were found in two samples (nos. 1243 and 1244) from the Martyukhina Fm of the West Siberian Regional Stage cropping out on the eastern slope of the Kuznetsk Alatau (upper reaches of the Kiskach River). The structures were studied using microscope Axioskop 40 with photocamera Axio-Cam MRc 5. They represent amorphous carbonate inclusions of irregular shape, dark gray color due to presence of finest (1–3 μm) particles organic matter, and are distinct from the host granoblastic calcite grains (Fig. 23: A, C). At low magnification (×10), a reticulate pattern of distribution of these structures is observed, the largest cells being 0.5 × 0.5 mm. Each inclusion represents a single monocrystal, as in echinoderms (Fig. 23). When studied in polarized light, internal structures are occasionally observed (≤300 μm in width; ≤1 mm in length) resembling astrorhizal canals of hydroid polyps (Fig. 23: E–G). Sometimes little transverse septa can be seen in the "canals" (Fig. 23: H). The phylogenetic affinities of these problematic structures remain unknown.

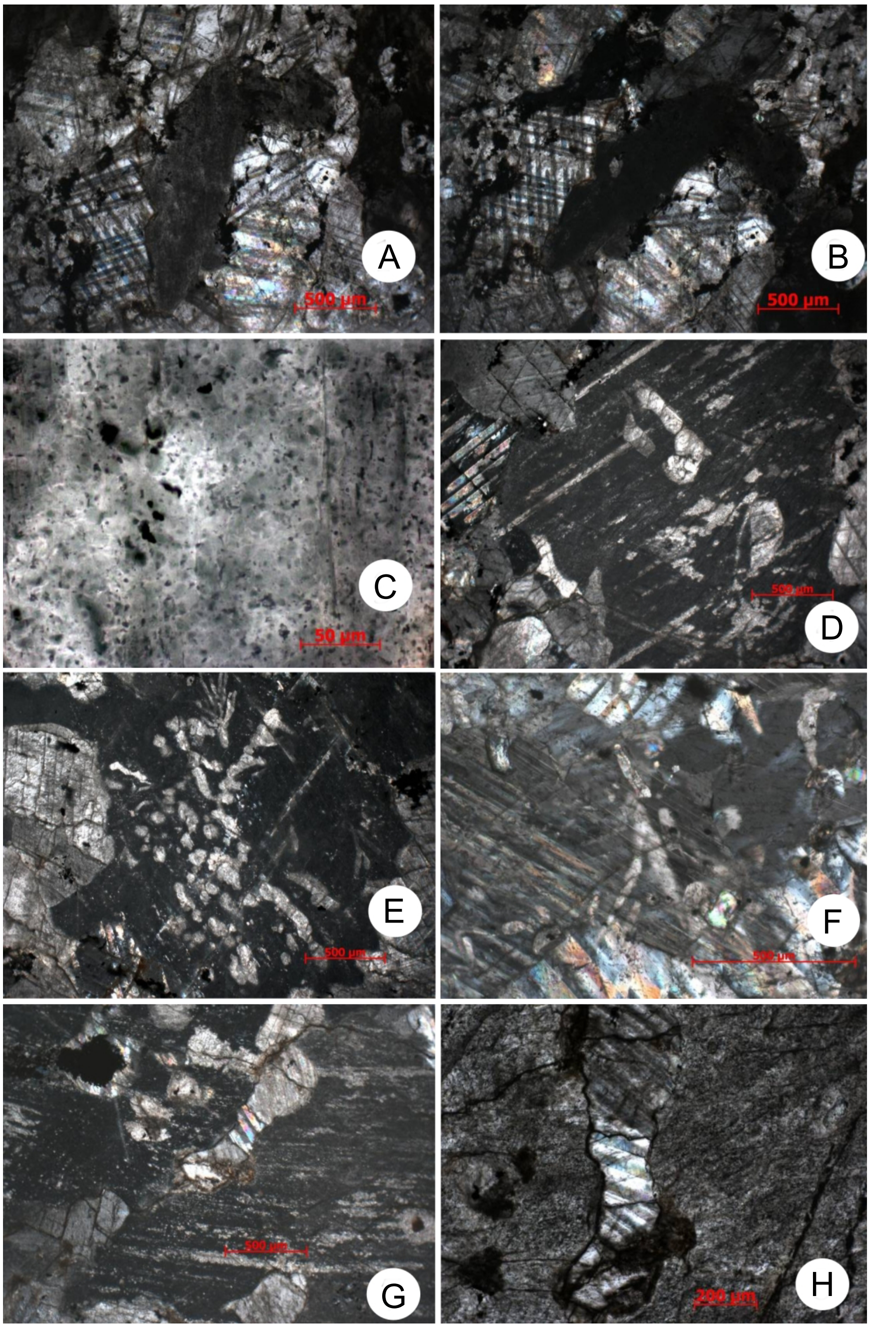

Figure 23. A: Problematic gray carbonate structures (center and right); unpolarized light; slide 1243a. **B**: The same object in polarized light; slide 1243b. **C**: Sponge-like microfabric of the problematic structure; unpolarized light; slide 1243b. **D**: Astrorhiza-like canals within a monocrystal of the problematic structure; polarized light; slide 1243c. **E**: An astrorhiza-like system of small canals; polarized light; slide 1243d. **F**: Astrorhiza-like inclusions; polarized light; slide 1244a. **G**: Astrorhiza-like inclusions; polarized light; slide 1243e. **H**: A single astrorhiza-like canal; unpolarized light; transverse septa are visible; slide 1243e.

Evolution of organism–sediment interaction in transition to Phanerozoic biosphere

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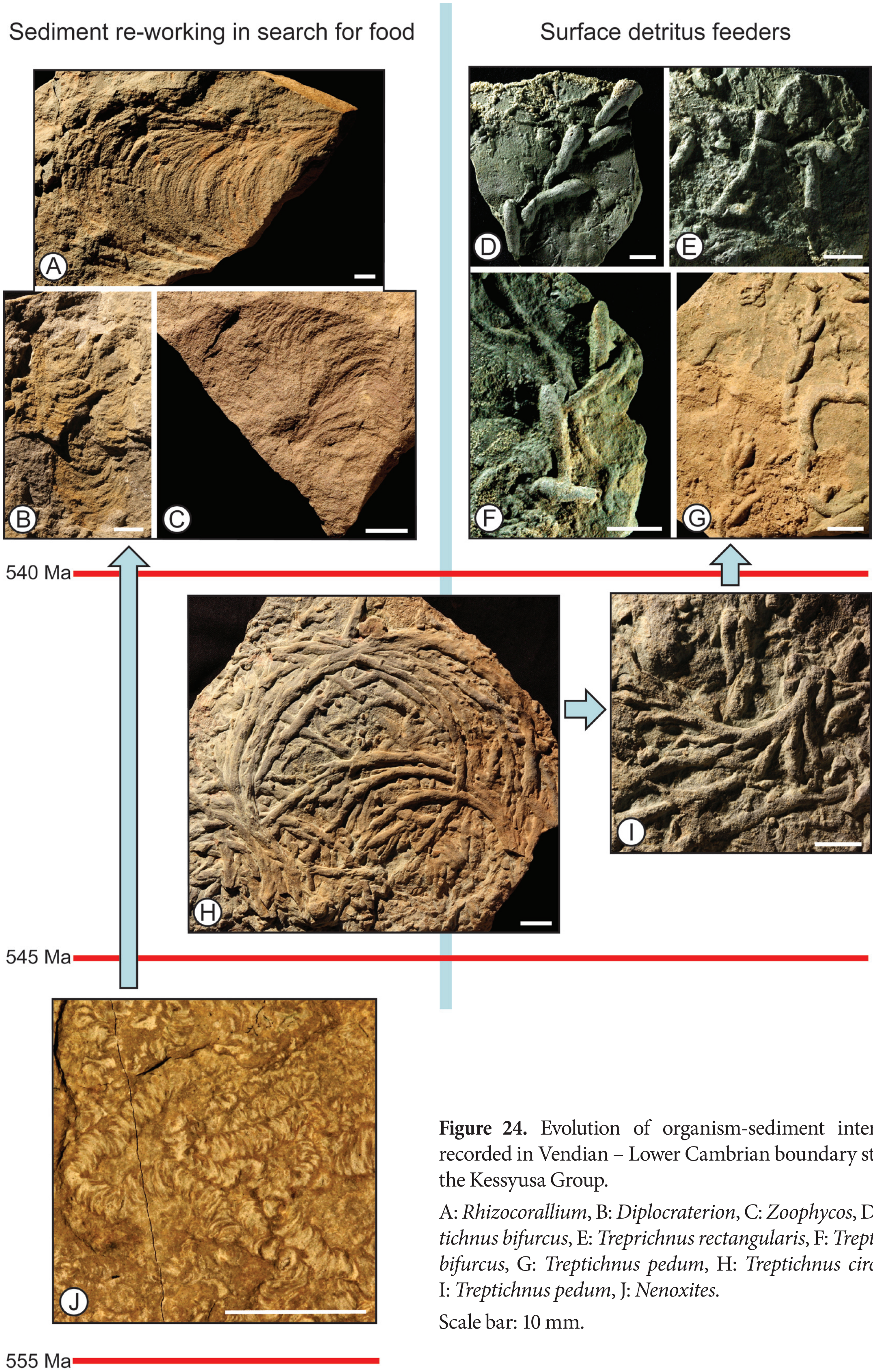

Figure 24. Evolution of organism-sediment interaction recorded in Vendian – Lower Cambrian boundary strata of the Kessyusa Group.

A: *Rhizocorallium*, B: *Diplocraterion*, C: *Zoophycos*, D: *Treptichnus bifurcus*, E: *Treprichnus rectangularis*, F: *Treptichnus bifurcus*, G: *Treptichnus pedum*, H: *Treptichnus circularis*, I: *Treptichnus pedum*, J: *Nenoxites*.

Scale bar: 10 mm.

That infaunal habit evolved concurrent with origin of Bilateria has long been appreciated, but the triggering mechanism remained unclear. J. Dzik [1] argues that trace fossils from the Vendian–Cambrian transition represent shelters of infaunal animals feeding from the sediment surface, and that infaunal habit evolved as a protective measure against predators. We studied trace fossil record through Vendian–Cambrian transition in the Khorbusuonka and Kessyusa groups in the Olenek Uplift of Arctic Siberia and came to the following conclusions. 1. The world's oldest bioturbation is in the Khatyspyt Fm of Khorbusuonka Gr and represented by meniscate backfilled burrows *Nenoxites*. Several features of the *Nenoxites* ichnofabric (absence of fecal material, avoidance of earlier self-made trails) suggest that the organism actively burrowed by peristalsis without processing sediment through the gut. The most likely purpose of borrowing was search for food. 2. Lower Cambrian is characterized by a diversity of meniscate burrow systems that represent sediment processing behavior in search for food. These are U-shaped burrows with spreite-structures formed as a result of intensive horizontal or vertical sediment reworking (trace fossils *Rhizocorallium* and *Diplocraterion*), meniscate backfilled burrows radiating from a central vertical mine (*Zoophycos*), J-shaped burrows with protrusive or retrusive spreite-structures (*Syringomorpha*). 3. Trace fossil *Treptichnus* is generally regarded as permanently open burrows used as shelters by a surface detritus feeders [2]. Importantly, ichnofabric in the uppermost Vendian *Syharghalakh* Fm of the Kessyusa Gr consists of compact descending spirals typical for sediment-processing behavior. These trace fossils were discovered and described by M.A. Fedonkin [3], albeit as two separate ichnospecies *Planispiralichnus grandis* and *Protospiralichnus circularis*; however, the spirals consist of series of sediment-probing elements that are diagnostic of treptichnid trace fossils and are therefore reinterpreted as ichnospecies *Treptichnus circularis*. Trace fossil record of the Khorbusuonka and Kessyusa groups reveals the true meaning of the Vendian–Cambrian Agronomic Revolution: organism-sediment interaction started as exploration of new food resources, and not as sheltering from evolved predators (Fig. 24). This study was supported by Russian Foundation for Basic Research (projects no. 09-05-00520 and no. 10-05-00953, Russian Academy of Sciences Program "Biosphere Origin and Evolution" and National Geographic Society.

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Precambrian basins and depositional environments

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Precambrian basins demonstrate intimate relationships between sediment supply, subsidence, and eustatic sea level fluctuations, same as in Phanerozoic basins [1]. Paleoclimate, too, played an important role; e.g., deposition of the Huronian Supergroup (2.4–2.3 Ga) was influenced by glacial environments. Study of Precambrian basins, however, is complicated by the lack of clear model for early crust evolution and early plate tectonics, the evidence for a much more (2–3 times) intensive heat flow in the Archean, different atmospheric and biospheric conditions [2], different rates of erosion and sedimentation, etc. It is further complicated by the incompleteness of the geological record, often poor temporal constrains, and superimposed metamorphism. The available reconstructions of the interplay between sedimentary infill, magmatism, tectonic movements, eustatic fluctuations and paleoclimate for the Witwatersrand (3.0–2.8 Ga) and Hurwitz (~2.45–1.9 Ga) basins, as well as the earliest of carbonate platforms and banded iron formations all suggest high sea level standing and aggressive weathering in Neoarchean and Early Paleoproterozoic. It is possible that up to 90% of the modern ocean volume existed 4 billion years ago. Deposition of carbonates in Archean was confined to relatively small stable crust blocks. Accretion of greenstone terranes in Late Archean lead to appearance of protocratons, first large epicratonic and rift sedimentary basins. In Proterozoic these basins became more stable, widespread, and included braided river, wave-, storm-, tide-dominated coastal settings. The important differences between Early Precambrian and younger sedimentary environments is almost full absence of eolian forms and scarcity of barrier island and lake depositional systems in deposits older than 1.8 Ga. The wide distribution of sheet sandstones and the absence of tidal channel deposits in Early Precambrian sections possibly suggests larger deltaic systems with low amplitude and low intensity of tides. The ubiquitous Precambrian fluvial quartz arenites could be the evidence of different weathering processes or simply a result of multiple recycling. Later Precambrian depositional environments were similar to their Phanerozoic counterparts [3]. The wide range of sedimentological, paleogeographical, climatic and other factors determined the diversity of facies and played a crucial role in formation of low-order lithostratigraphic subdivisions. Late Precambrian intra- and pericratonic depositional systems are represented by several large-scale facies associations: terrigenous alluvial, alluvial-deltic, "supra-shallow", shallow-marine, mid-shallow and also some specific facies as shallow-marine and mid-deep marine volcanic-terrigenous. Carbonate facies associations are characterized by "supra-shallow", shallow-marine, and carbonate ramps below storm wave base. These facies associations determine a modern outlook of many Late Precambrian intra- and pericratonic sedimentary associations of North Eurasia, North America, China, India, Africa, Australia and other regions, but the relative abundance of these facies can be different. Analyses of vertical and horizontal stacking of facies associations as well as thicknesses allow correlation and typification of sedimentary sequences and reconstruction of sedimentary basins. Following this approach we studied Riphean sedimentary basins of the East European Craton and South Urals and demonstrated that each basin is characterized by a specific facies associations reflecting unique depositional processes. This conclusion has important implications for the search of mineral (including petroleum) resources [4–7].

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Macrofossils and microfossils in the Kessyusa Formation from boreholes drilled in the Molodo River area (Arctic region, Siberian Craton)

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Macrofossils and microfossils were discovered in greenish gray fine aluminosiliciclastic rocks of the Kessyusa Fm of Nemakit-Daldynian and Tommotian age in the Serkino-1 Borehole (depths 106.8 and 182–183 m) drilled in the area of Molodo River, 170 km to the south of the Olenek Uplift. Macrofossils are represented by compressed conical thalli showing alternating wrinkled and smooth transverse zones; the wrinkles are aligned along the body axis, increase in number, and become thinner toward the broad end (Fig. 25: R–S). Microfossils are represented by 9 varieties: (1) small acanthomorphic acritarchs (Fig. 25: O–Q); (2) filaments with funnel-like extensions (Fig 25: N); (3) conical sclerites of different size with two rows of spines *Ceratophyton spinuconum* Zang (Fig. 25: A, B, E, F); (4) smooth conical sclerites *Ceratophyton vernicosum* Kirjanov (Fig. 25: C, I), sometimes with small dark particles (Fig. 25: G, H); (5) nested conical sclerites (Fig. 25: D); (6) conical sclerite with zonal structure (Fig. 25: J), possible Protoconodonts; (7) cluster of conical sclerites (Fig. 25: K); (8) fragment of a cuticle with fine-granulose surface sculpture (Fig. 25: L); (9) fragment of a cuticle with relatively small conical sclerites (Fig. 25: M). The diversity of different types of sclerites and cuticle fragments as well as the presence of compressed macrofossils proves the Tommotian origin of Burgess Shale-type fossil preservation. This confirms the concept of N.J. Butterfield

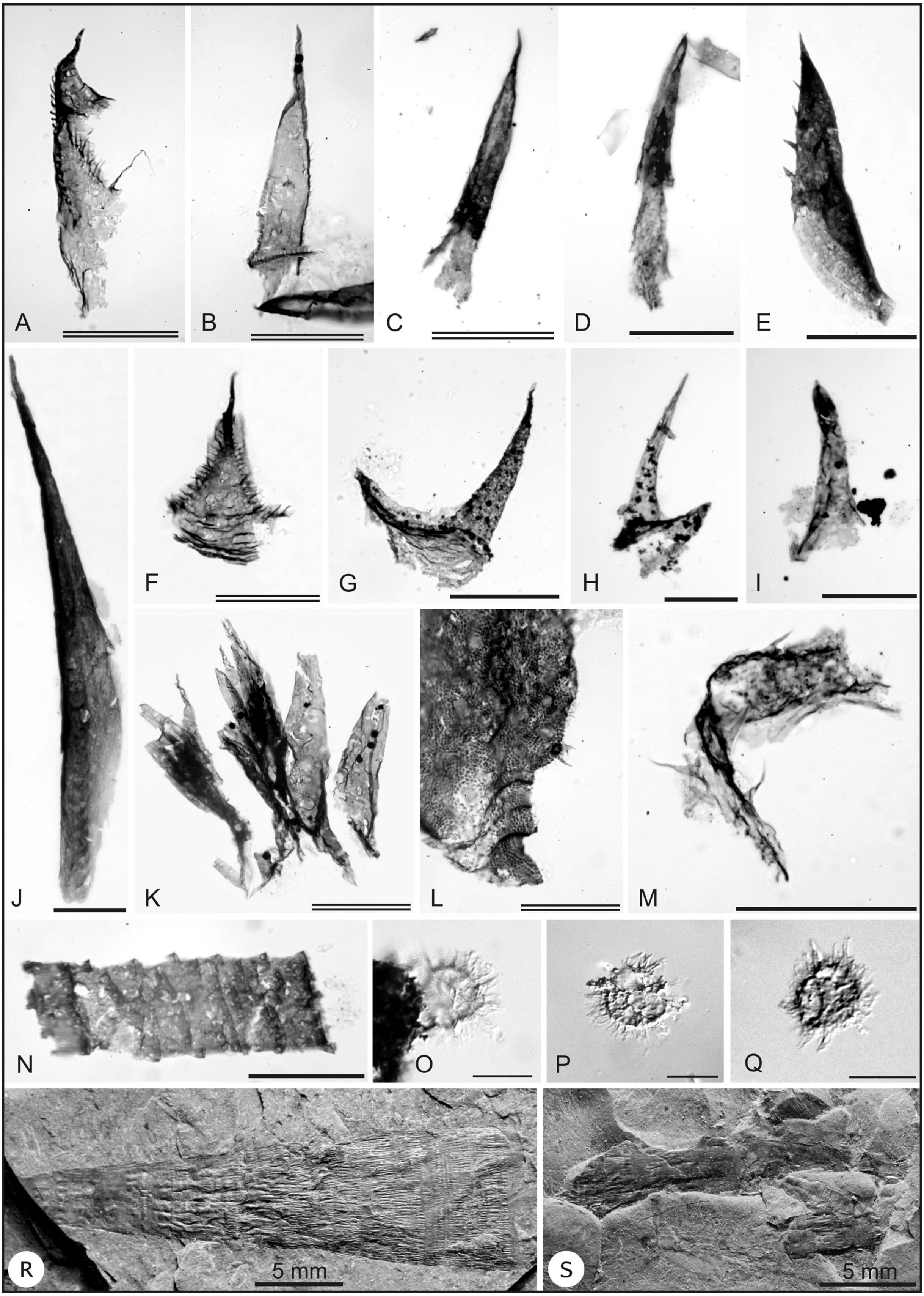

Figure 25. Macrofossils and microfossils in the Kessyusa Fm from boreholes drilled in the Molodo River area (Arctic Siberia). See text for explanation. Scale bars: single thin – 10 μm, double – 50 μm, single thick – 100 μm.

about the wide spread of micro-Burgess Shales type preservation. In addition, this microfossil association is the oldest association of numerous and different metazoan fragments. This study was supported by the Russian Foundation for Basic Research (projects no. 09-05-00520 and no. 10-05-00953, Russian Academy of Sciences Program "Biosphere Origin and Evolution" and National Geographic Society.

Late Miroedikha diversification of acanthomorph acritarchs: revision of stratigraphic age of the Upper Riphean on the Turukhansk Uplift

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The Riphean section of the Turukhansk Uplift (Siberia) is the best studied Riphean section of Siberian Craton in terms of sequence stratigraphy, sedimentology, and paleontology (research conducted by the Geological Institute, Moscow). Miroedikha Fm is situated in the upper part of the Riphean section and is conformable with the underlying Shorikha Fm and overlying Turukhan Fm. We studied a section of Miroedikha Fm in the right bank of the Yenisei River downstream from the mouth of Kamennyi Creek (14 km upstream from the mouth of Nizhnyaya Tunguska) and discovered microfossils in the upper siliciclastic member, previously thought to be unfossiliferous [1]. Of special interest are small acanthomorph acritarchs represented by four morphological varieties. 1. Vesicles (22–40 μm in diameter) with distinct dense straight processes (>0.2 μm in thickness, 2–5 μm in length) (Fig. 26: A–E). 2. Vesicles (ca. 40 μm

Figure 26. Microfossils from the Miroedikha Fm of Turukhansk Uplift (Siberia). See text for explanation.

in diameter) with short (3–4 µm) straight distinct (>0.2 µm in thickness) less dense (1–2 µm apart) processes (Fig. 26: F). 3. Vesicles (36–40 µm in diameter) with short (2–3 µm) and very thin (<0.2 µm) densely arranged and entangled processes (Fig. 26: G, H). 4. Vesicles (17–22 µm in diameter) with relatively long (5–6 µm) distinct (>0.2 µm in thickness) straight and irregularly curved processes (Fig. 26: I, J). All these varieties van be referred to as members of the Late Neoproterozoic and Early Paleozoic genus *Comasphaeridium*. Specifically, the second morph is similar to *Comasphaeridium tonium* Zang from the Alinia Fm (750–800 Ma) of South Australia [2]. The third morph by the shape of processes can be compared to *Comasphaeridium pollostum* Zang et Walter from the Bitter Springs Fm (750–800 Ma) of Central Australia [3], although the Siberian specimens are twice larger. The assemblage also includes of other Siberian Late Riphean microfossils: *Glomovertella eniseica* Hermann (Figure 26: M) and spherical vesicles surrounded by threads (Fig. 26: K) also known from the Lakhanda microbiota [4, 5]; *Obruchevella uralense* (Jankauskas) (Fig. 26: O) and *Palaeogomontiella* sp. (Fig. 26: N) also known in the Seryi Klyuch Fm of the Yenisei Ranges [6]. There are also peculiar ellipsoidal vesicles with equatorial zig-zag ridge and meridional thickenings (Fig. 26: L) dividing the vesicle into polygonal plates that resemble dinocyst plates. The discovered assemblage of acanthomorph acritarchs is unknown from the rocks older than 800 Ma. The stratigraphic age of the upper part of the Miroedikha Fm can be revised accordingly. This study was supported by the Russian Foundation for Basic Research (project no. 10-05-00953) and Russian Academy of Sciences Program "Biosphere Origin and Evolution".

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The paleoenvironmental significance of the banded iron formations of the Ediacaran Arroyo del Soldado Group, Uruguay

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The Neoproterozoic (1000–542 Ma) is characterized by seemingly unprecedented environmental fluctuations and various hypotheses have been proposed as to whether these fluctuations played a role in biological evolution. In this context, previous studies have suggested that the rise in oxygen during the late-Neoproterozoic created an environment that facilitated the radiation of metazoan life. These studies indicate that the Earth's oceans became increasingly oxygenated during the late Neoproterozoic, most notably after the end of the Marinoan glaciation approximately ~635 My ago. However, recent geochemical analyses from various Ediacaran sediments suggest that some deep ocean basins were instead anoxic and ferruginous [Fe(II)-enriched] throughout the Ediacaran and possibly into the Cambrian, suggesting a more complex global redox structure than previously thought. Unfortunately, universal acceptance of this idea has been hindered by an apparent absence of Ediacaran iron formations (IF); chemical sediments that were common under such Fe-rich conditions in earlier Archaean – Paleoproterozoic oceans. Here, we report detailed sedimentological, stratigraphic, petrographic and geochemical data from an Ediacaran IF and associated rocks, including "iron-rich" black shales, siltstones and chert deposits of the Arroyo del Soldado Gr in Uruguay. The Arroyo del Soldado Gr is a mixed siliciclastic-carbonate succession interrupted by two major episodes of basin flooding and sediment starvation characterized by the deposition of IF and cherts.

On the basis of stacking patterns, two stratigraphic sequences are identified within the group. Sequence A consists of continental shelf siliciclastic facies (Yerbal Fm) grading upward into a carbonate ramp system (Polanco Limestone Fm). Separated by a major erosional unconformity, sequence B is composed of coarse-grained alluvial conglomerates and sandstones (Barriga Negra Fm) capped by finer marine siliciclastics (Cerro Espeulitas Fm). The Yerbal and the Cerro Espuelitas formations, which constitute the main subject of this study, are characterized by retrogradational stacking patterns with fining-upward units deposited during transgressive system tracts. Significantly, the top of both units are characterized by distinct fine-grained siliciclastics and chemical sediments, consisting of banded siltstones, cherts and IF for the Yerbal Fm, and "iron-rich" shales interbedded with black shales that pass upwards into thick chert deposits for the Cerro Espuelitas Fm. Significantly, the Yerbal Fm is a pre-Gaskiers glaciation deposit (ca. 600–590 Ma), whilst the Cerro Espuelitas Fm is post-Gaskiers (ca. 570–560 Ma) in age, providing insight into the paleoceanographic conditions immediately before and after the last major Precambrian glacial event. The IF and cherts have coherent rare earth element and yttrium (REY) patterns and display the essential shale-normalized characteristics of marine precipitates. Rare earth element and yttrium signatures and mixing calculations show that they differ from Archaean and Paleoproteorzoic IF in that high-temperature hydrothermal input did not influence their chemistry. Instead, we suggest that low-temperature hydrothermal input may account for the geochemical signatures displayed. By analyzing the REY signature of chemical precipitates (cherts and IF) and evaluating the redox chemistry of the marine water column within a sedimentological and sequence stratigraphic framework, our results confirm that ferruginous conditions dominated the pre-Gaskiers but also the post-glaciation deep-water chemistry, and that global ocean oxygenation may not have occurred well into the upper Ediacaran or even during the Cambrian.

Integrated chemostratigraphy and basin architecture of the Edaicaran Doushantuo Formation and implications for global correlation and ocean redox models

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The Ediacaran Doushantuo Fm in the Yangtze Gorges of South China plays an important role in our understanding of biological evolution as well as the calibration of global correlations, due to available radiometric dates, and the development of ocean redox models, based on high-resolution chemostratigraphic studies. However, most of the high-resolution data is focused on the Jiulongwan succession, which was largely deposited below wave base in a restricted shelf lagoon. Studies of shallower water successions are lacking, which presents a challenge to tests of Ediacaran stratigraphic correlation and models of ocean redox stratification. To reconstruct the basin architecture, we conducted a high-resolution integrated study of the Doushantuo Fm at the northern Xiaofenghe (NXF) section approximately 35 km to the northeast and paleogeographically updip of the Jiulongwan section. With the exception of the basal 20 m, NXF sediments were likely deposited above wave base, and a flooding surface in the Doushantuo succession there may be correlated with the mid-Doushantuo sequence boundary present elsewhere in South China. Integrated biostratigraphic and chemostratigraphic data indicate that the 140 m thick NXF section correlates with the lower Doushantuo Fm (Member I and II, ca. 70 m thick) at Jiulongwan. The carbon and sulfur isotope data from NXF is consistent with redox stratification wherein the shallow Doushantuo ocean consisted of an oxic surface layer underlain by a thin ferruginous layer at the chemocline, and euxinic lagoonal bottom water between the proximal inner shelf and distal shelf margin. Further integrated studies are necessary to test whether euxinic conditions extended to open marine shelves in South China and elsewhere during the Ediacaran Period.

The Vendian Patom Basin: correlation of biotic and abiotic events

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We have analyzed mineralogy and geochemistry of shales across the Mariinka Fm, Dalnyaya Taiga (Dzhemkukan, Barakun and Valyukhta formations) and Zhuya groups in sections along Zhuya, Malyi Patom and Ura rivers. Mineralogical signal, together with paleoweathering indices (CIA, CIW, etc.), demonstrate that upper Mariinka, Dzhemkukan, Barakun and lower Valyukhta formations consist of chemically immature and relatively unweathered material (CIA = 60–74, K_2O/Al_2O_3 = 0.18–0.38). Decomposition and chemical analyses of clays (linear programming method) shows that relatively mature (CIA = 68–82), smectite and/or kaolinite-bearing products of weathering are abundant in the Upper Valyukhta and Zhuya formations (Nikol'skoe and Chencha formations). Shales in the predominantly carbonate Upper Vendian Zherba and Tinnaya formations show a primary chlorite-illite/mica association, with minor smectite and kaolinite (few samples) components and are moderately mature (CIA = 72–83), suggesting the predominance of recycled micaceous clays input near the Precambrian–Cambrian boundary.

In the Ura Uplift, the gray and greenish-gray shales of the Ura Fm represent a transition from delta fan to shelf sedimentation of a passive continental margin and contain a diverse lower Vendian (Ediacaran) microfossil association [1, 2]. The Ura shales show chemically low to moderately mature (CIA = 71–80) sediments, with variation of redox indices V/Cr (0.9–1.9) and Ni/Co (0.95–3.1) suggesting that disoxic and transitionary from disoxic to oxic conditions existed during the deposition and early diagenesis of the clay fractions. A similar conclusion can be drawn based on the low values (0.21–0.30) for the ratios of highly reactive Fe to total Fe (FeHR/FeT) in the fine-grained sediments. The fossiliferous shales of Ura Fm have high apatite-combined P concentrations (P_2O_5 = 0.23–0.84%) with specific MREE enrichment in the REE spectra that corresponds to an initial, oxic stage of oceanic anoxic event. The influx of nutrients could increase primary productivity and result in biotic radiation and subsequent oxidation of dissolved organic carbon (DOC). The input of chemically immature smectite-chlorite-illite clay products into the Ura Basin reflects relatively low level of weathering in source areas. The chemical composition, REE distribution, and the ratios of La_n/Yb_n (7.5–10.8) and Gd_n/Yb_n (1.3–1.8) in the Ura, Kalancha and Valyukhta shales indicate erosion of pre-Riphean igneous and metamorphic complexes of the Siberian Craton rather than synchronous arc sediments.

The distal, shelf to slope, Dalnyaya Taiga succession (the Barakun and Valyukhta formations cropping out along Zhuya and Malyi Patom rivers) contains dark gray and black pyritized shales with high (0.36–0.82) FeHR/FeT ratios and pronounced variations of redox indices V/Cr (1.4–2.7) and Ni/Co (1.9–7.1) suggesting disoxic to anoxic and euxinic conditions during clay fraction deposition. The chemical composition of the shales and REE distribution indicate that interior parts of the Patom Basin were fed from cratonic and volcanic arc sources during the Barakun and Valyukhta time. Active sulfate reduction due to higher sulfate influx from the continents caused remineralization of the large DOC pool in the open Patom Basin, produced a negative $\delta^{13}C$ anomaly, and led to a sharp decrease in microfossils diversity.

Microfossil associations in the Ura and Parshino formations include acantomorphic acritarchs of Early Ediacaran affinities [2, 3]. The fossiliferous Ura Fm is part of the Vendian Dalnyaya Taiga Gr. The observed variations of $\delta^{13}C_{carb}$ (+8…–13‰, VPDB) in the Patom succession, with a characteristic two-stage negative shift up to –8‰ in the Dzhemkukan carbonates [4, 5] and –10…–12‰ in the Nikol'skoe and Chencha formations [6], correlate with $\delta^{13}C_{carb}$ curves obtained for most representative Ediacaran successions around the world [7, 8]. Variations of $^{87}Sr/^{86}Sr$ ratio in limestones of the Barakun and Chencha formations indicate the 660–580 Ma time interval of their deposition and the Marinoan age (≥635 Ma) of the Zherba diamictites [9], although the trend and the magnitude of the values are reminiscent of the 600–550 Ma Shuram–Wonoka isotope event of estimated minimum duration of 10 Ma [6]. Despite the uncertainty with stratigraphic position of the Dalnyaya Taiga and Zhuya groups (Marinoan vs. Shuram–Wonoka glaciations), our data are consistent with the conclusion that the intervals with low $\delta^{13}C_{carb}$ values are associated with the destruction and oxidation of large masses of accumulated organic matter in the sediments [10]. This phenomenon is not associated with the superposition of Cadomian Orogeny, but is more likely to be due to a feedback during a quasi-stationary state of atmosphere-ocean system recovery event that has an order of no more than a few million years.

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Petroleum potential of ancient shelf of the Paleoasian Ocean

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Opening of the Paleoasian Ocean (1000–900 Ma) was the most important event in the Riphean–Cambrian geodynamic history of western and southern margins of Siberian Craton, when intracontinental rifts were transformed into passive margins (e.g., Kassk–Kansk, Baikal–Vilyui). The coeval thick carbonate platform in the west of Siberian Craton suggests that starting in late Riphean and until 850 My ago the craton was in the phase of tectonic stabilization. The Paleoasian Basin was divided by the Angara–Anabar land into two parts; southeastern and eastern margins of the craton were also characterized by carbonate sedimentation. Geomorphology of the sedimentary basin floor was represented by rift depressions separated by raised blocks. In the end of Riphean the territory was uplifted as a result of volcanic arc and terrane collision with the Siberian Craton along its entire perimeter. Concurrent reactivation of early Riphean rift systems manifested as downthrow of central rift blocks and uplift of inter-rift blocks along a system of rift bordering faults that intensified erosion of Riphean deposits and peneplanation of the land. The uplift and tectonic activation in early Baikalian were accompanied by widespread glaciation. By early Vendian (630–620 Ma) the Siberian Craton was surrounded by passive margins that consisted of accretionary collisional orogenic complexes including pre-Vendian structures of different geodynamic nature: terranes, volcanic arcs, forearc and backarc basins. These orogenic complexes separated the platform marine basin in the west and southeast from the Paleoasian Ocean and were the source of clastic material for foreland basins. The widespread transgression from south and southeast covered the entire Siberian Craton. Starting in late Vendian (580 Ma), the Siberian Craton reached the platform phase marked by stable tectonic regime and development of shallow marine basins with carbonate sedimentation. According to paleomagnetic data, the Siberian Craton in Vendian and early Cambrian (630–550 My ago) was located in sub-equatorial area, as suggested by the available sedimentological evidence for interior and marginal basins. In Cambrian time, the basin was isolated by orogenic complexes to the west, south and east and by a riff barrier to the north and northeast, which led to thick salt accumulation in an arid climatic setting. During all this interval of geological history, the southern margin of the late Riphean–Cambrian sedimentary basin represented a shelf of the Paleoasian Ocean. These deposits formed major petroleum complexes of the Lena–Tunguska province. The oldest natural reservoirs are confined to Upper Riphean carbonates of the Baikit Anteclise (Yurubchen–Tokhomo, Kuyumba oil fields). The producing strata were deposited in the most shallow part of the basin. Riphean riff complexes in the west of Siberian Craton are thought to have high petroleum potential. Commercially productive hydrocarbons (Abakan, Agaleev, Imba oil fields) were also discovered in Late Riphean alluvial fan deposits confined to the slopes of paleorift depressions that complicated shelf margins of the Paleoasian Ocean in the period of 850–640 Ma. The main hydrocarbon resources occur in alluvial-deltaic complexes of the Vendian shelf of Paleoasian Oceans (Kovykta, Verkhnyaya Chona, Yarakta oil fields). Significant hydrocarbon accumulations are also related to the Cambrian barrier riff structures that divided the shallow shelf from the oceanic basin (e.g., Markovo oil field). The shelf margins of Paleoasian Ocean, therefore, host giant oil and gas reserves. Their exploration is one of the strategic tasks for the Russian fuel and energy complex.

Neoproterozoic sedimentary basin of the South Urals and its place in the development of Baltica–Timanides paleogeodynamic system

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In South Urals, the Neoproterozoic corresponds to the upper part of a thick (>15 km), continuous section of weakly metamorphosed sedimentary and volcanic rocks developed in the Bashkirian Meganticlinorium (BMA). It is a standard for the Riphean and Vendian. The Lower and Middle Riphean correlates approximately to the Mesoproterozoic, while the Upper Riphean and Vendian are well correlated with the Neoproterozoic of the International Scale [1, 2].

The type of the Upper Riphean is the Karatau Gr represented by variegated sandstones and siltstones of unstable feldspar-quartz composition, dolomites, limestones, shales, rare conglomerates. The group is divided into Zilmerdak, Katav, Inzer, Minyar, Uk, and Krivoluk formations, with gradational boundaries, of total thickness of 2800–5300 m [3]. It is well characterized by fossils. Microfossils are present practically at all levels of the section, but the most important for the inter-regional correlation are Muldakaevo and Shishenyak microbiotas (organic-walled microfossils) and Minyar microbiota (silicified microfossils). In carbonate rocks, columnar stromatolites are described, as well as microphytolites of the III and VI (Upper Riphean) complexes. The lower age limit is decreed as 1030 ± 30 Ma [1, 3]. The Uppermost (Terminal) Riphean (Arshinian) corresponds to the Arsha Gr represented mostly by sericite-chlorite-quartz, often calcareous schists, quartz and feldspar-quartz sandstones, quartzites, metabasalts, their tuffs, tuff breccias. Tillite-like conglomerates are present in the section below and above the volcanic level. The series is subdivided into Bainass, Makhmutovo, Igonino (volcanic-bearing) and Shum formations, with gradational contacts; the total thickness varies between 1100 and 1900 m. The Arshinian transgressively overlies the Karatavian and is in turn overlain by the Vendian Asha Gr, also with an erosional contact [3]. The U–Pb-zircon (SHRIMP) date for volcanics in the middle of the section is 709.9 ± 7.3 Ma. Together with the SHRIMP age of the Barangulovo gabbro-granite massif, cutting the group, the lower limit of the Arshinian is accepted as 720 ± 7 Ma [1, 4]. The analogue of the Vendian in the South Urals is the Asha Gr widely developed at the western limb of BMA. The group is almost completely terrigenous, composed mostly of polymictic, feldspar-quartz and quartz sandstones and siltstones, with conspicuous polymictic conglomerates, and is subdivided into Bakeevo, Uryuk, Basu, Kukkarauk, and Zigan formations, with gradational boundaries, of total thickness 1400–1800 m. The deposits correspond to the time interval from 600 ± 10 to 530 ± 5 Ma [1]. The described deposits belong to the upper part of the Meso-Neoproterozoic structural stage traced through the whole territory of the Timan–Urals region [5].

Early parts of the Riphean–Vendian history of the Timanide Foldbelt and the adjacent territories of Baltica are poorly studied. After the Volga-Urals, Sarmatia and Fennoscandia subcontinents amalgamated into the Baltica Craton, the latter probably became a part of the Nuns (Columbia) Supercontinent in close connection with Laurentia and Amasonia.

In the beginning of the Mesoproterozoic, Baltica was affected by rifting with a formation of a series of transcontinental aulacogens, opening towards future Timanides. The Lower and Middle Riphean is well represented only in the South Ural segment of the Timanides. With much less confidence these strata are established in Cis-Polar and Polar Urals where they may constitute lower parts of microcontinent cover in the metamorphic surroundings of dome-shaped uplifts. Only the Upper Riphean and Vendian are recognized in the Central Urals. The Upper Riphean is certainly present in the Timan Range, whereas the Arshinian and Vendian are absent, and the presence of Middle Riphean is under some doubt.

The beginning of the break-up of the Nuna Supercontinent at ~1400 Ma coincides with a Mashak riftogenic epoch in the South Urals, accompanied by magmatism (began in 1385, ended ~1350 ± 15 My ago). There, the rift structure had an "uralian" strike, which was inherited in Vendian by the Timanian Orogen. This rift is not discernible along the margin of Baltica because of the poor evidence in northern areas. The only indication of the Mashak event in the Timanides to the northeast of Timan Range is a Rb–Sr isochron date of basalts from the 21-Pal'yu Borehole. The volcanic rocks of the same age are present in Greenland, so that a contour of a rift and a subsequent passive continental margin can be outlined between the South Urals and Greenland. The margin opened into a hypothetical Pechora Ocean separated from the Mirovoj Ocean by terranes [5].

A more clear picture can be drawn for the Neoproterozoic of Timanides, where the structure can be divided into externides and internides. The former corresponds to a pre-collisional stage and is represented by a continental margin, with a transition from shallow to deep-water sedimentation; the former contains Late Riphean ophiolites and subductional complexes and is interpreted as an oceanic crust.

The break-up of Rodinia started 800–750 My ago and, with time, spread to the territory of future Amazonia, Laurentia and Baltica. It is expressed as a wide development of basic volcanics and subalkaline intrusions the South and Central Urals, Timan and circum-Ladoga areas in the interval of 720–600 Ma. The date of 615 Ma is now thought to be one of the latest episodes of Rodinia break-up, with formation of Laurentia, Amasonia and Baltica sensu stricto. These events were accompanied by several widespread glaciations that left their signature in South and Cental Urals.

Orogenic movements activated along the margin of Baltica in the interval of 600–550 Ma and lead to a formation of the Timanide Orogen. These processes were accompanied by thrust and fold movements, deposition of Late Vendian molasse in foreland and intermontane basins, metamorphism and granite intrusions. The linear structures of Timanides changed their strike from the sublongitudinal in the south to northwestern in the north, forming a wide virgation.

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Carbon isotope geochemistry and geochronological constraints of the Neoproterozoic Sirohi Group from northwest India

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The early Neoproterozoic carbonates of the Sirohi Gr, northwestern India, were studied for carbon and oxygen isotopes across three different sections to correlate with the contemporaneous global events. Two sections out of three showed similar variations in $\delta^{18}O$ (±2‰) that range narrowly while the third section had a slightly wider range of values (±5‰). The difference observed in oxygen isotope values in the three sections is attributed to diagenetic and metamorphic differences. However, the generally narrow range in variation of $\delta^{18}O$ values is consistent with preservation of primary compositions. The $\delta^{13}C_{carb}$ values of these carbonates vary between −4.1 to +4.7‰ and correlation of the three sections is proposed on the basis of cross-plots. The carbonates of the Sirohi Gr show isotopic compositions similar to the Bitter Spring Fm in Australia, Akademikerbreen Gr in Svalbard, and the Shaler, Little Dal, Lower Tindir, and Fifteenmile groups in Yukon, Canada. We studied $^{207}Pb/^{206}Pb$ single zircon ages from the Sirohi Gr in order to constrain its age span within the Neoproterozoic. ca 920 Ma single zircon date of granodioritic basement provides the maximum age of the Sirohi Gr. On the other hand, the single zircon age of synkinematically emplaced Erinpura granite is ca 822 Ma. The isotope ages therefore help to constrain the maximum and minimum ages of the Sirohi Gr between 920 Ma and 822 Ma. However, taking into account the possible time of peneplanation of the basement before basin opening and deposition of Sirohi carbonates, and the time of actual basin closing we interpret a smaller time span for the Sirohi Gr. Range of $\delta^{13}C$ values along with the new geochronological constraints of the Sirohi Gr carbonates correlate well with the records of biogeochemical changes reported from different parts of world during the early Neoproterozoic. The time of deposition of the Sirohi carbonates may be little older than the ca. 811 Ma age reported for the deposition of the Bitter Spring Fm, Australia.

The oldest evidence of bioturbation on Earth

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We documented intensely bioturbated ichnofabric and associated discrete, identifiable trace fossils in the Khatyspyt Fm cropping out on the Olenek Uplift in the north-eastern part of the central Siberia. Stratigraphic sections of the Khatyspyt Fm were logged for ichnofabric indices (percentage of original sedimentary fabric disrupted by biogenic reworking). The upper part of the Khatyspyt Fm appears to be moderately to intensely bioturbated (Fig. 27). There are two styles of ichnofabric preservation in the Khatyspyt Fm: three-dimensional and compressed. Three-dimensional preservation is attributed to early diagenetic silicification of discrete sedimentary layers and provides insights into the structure of both individual burrows and the entire ichnocoenosis. Each burrow demonstrates a terminal backfill structure which is a result of active displacement of a tunnel within the substrate and emplacement of the material by an animal posteriorly as it progressed through sediment. There is no trace of wall lining in the tunnels. Branching burrows have never been observed. Backfill menisci are composed of little-altered substrate sediment. Intervening menisci consist of early diagenetic microcrystalline silica (with dispersed grains of dolomitic mudstone) that could be selectively replacing areas with elevated levels of organic matter. In compressed preservation the intervening menisci consist of silicified mudstone with dispersed pyrite globules; the color contrast in these menisci can be greatly enhanced by diagenetic processes during fossilization. The appearance of ichnofabric can be severely disturbed by diagenetic overprint. For example, the menisci can be connected with each other by a string of silicified material or pyrite globules. In other

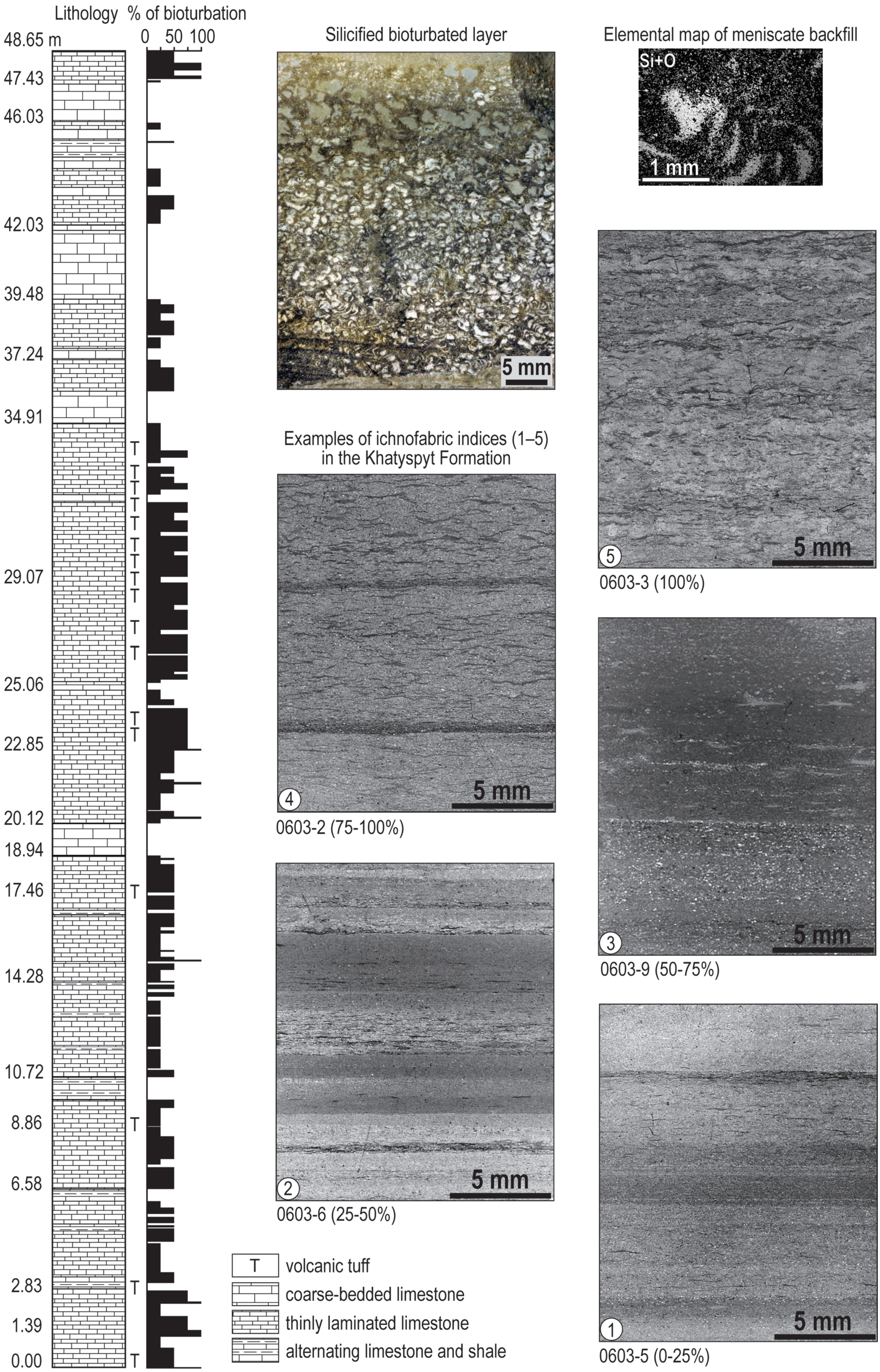

Figure 27. Bioturbation index in a logged section of the Khatyspyt Formation (T – volcanic tuff beds), representative examples of the ichnofabric, and three-dimensional preservation of the ichnofabric in silicified calcitic mudstones.

specimens the original saucer-like shape of the menisci has been exaggerated and transformed beyond recognition, or the entire burrow is surrounded by a halo of microcrystalline quartz. Most burrows have width 0.5–3.0 mm, with the maximum reaching 6.5 mm. Depth of bioturbation measured from silicified sedimentary layers that were subject to minimum sediment compaction reached 5 cm. Meniscate backfill represents a locomotion structure (repichnion). The lowest stratigraphic occurrence of the ichnofabric is at the base of the Khatyspyt Fm 185 m below the lowest appearance of *Cambrotubulus decurvatus* and 335 m below the lowest appearance of *Treptichnus pedum*. By all means, the Khatyspyt ichnofabric is of late Ediacaran age which makes it the oldest reliable paleontological evidence of bioturbation. This study was supported by the Russian Foundation for Basic Research (projects no. 09-05-00520 and no. 10-05-00953), Russian Academy of Sciences Program "Biosphere Origin and Evolution" and National Geographic Society.

Discoidal macrofossils in Precambrian interglacial rocks of Western Mongolia

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Neoproterozoic glaciations are correlated using microfossil, radiometric and chemostratigraphic data that accumulated in recent years [1]. Although tillites and tilloids are widely distributed in Precambrian sequences, only few of them are associated with occurrences of authentic macroscopic fossils [2]. We found problematic discoidal macroscopic fossils in Late Precambrian tillites of Dzabkhan region of Western Mongolia in the course of field study conducted by Precambrian team of the Russian-Mongolian paleontological expedition in 2006–2007. The glacial marine deposits (Maikhanul Fm), discovered in Dzabkhan region in 1990s [3], discordantly overlie the persilicic intrusive bodies of Dzabkhan Fm (732–777 Ma) [4] and are conformably overlayed by the limestones of Tsagaan Oloom Fm. The Maikhanul Fm comprises two relatively thin units of diamictites separated by a section of flysch deposits; total thickness of the formation reaches 220 m. The presence of two diamictite units, cap dolomites, radiometric dates of underlaying volcanics, rock composition, shape and size of intraclasts all suggest correlation of the Maikhanul tillites with Central Australian Neoproterozoic glacial marine deposits. The flysch formed between the two glacial events, and the cap dolomite records the maximum postglacial transgression [5]. There are still uncertainties about the exact age of Mongolian tillites because of the lack of Ediacaran fossils in the overlying strata. They could be of Stirtian age; however, $\delta^{13}C$ values from limestones of the overlaying Tsagaan Oloom Fm (+2.8‰) do not exclude of possibility of Varanger age [5]. The Tsagaan Oloom Fm of Dzabkhan structural zone can be correlated with the Doushantuo Fm of South China (600–550 Ma) by the complex of microfossils [6]. Doushantuo Fm overlies diamictites of the Nantuo Fm. Radiometric dates from volcanic tuff beds in cap carbonates of the Doushantuo Fm (635.23 ± 0.57 Ma) are similar to the dates from tuffs in the postglacial Ghaub Fm of Congo [7]. The correlation model of Mongolian and Nantuo tillites was first presented by V.V. Khomentovsky and A.S. Gibsher [3]. Consequently, the age of Maikhanul Fm tillites is not older than Sturtian and not younger than Marinoan.

Problematic cm-sized discoidal molds were found on bedding surfaces in sandstones and siltstones in the uppermost part of the flysch unit. Over 300 specimens were studied on a single bedding plane. The molds never overlap and are never current aligned; instead, they form irregular clusters. Structures that would suggest sediment biostabilization were never observed. The fossil assemblage is interpreted as an in situ preserved population of benthic organisms based on the normal distribution of the mean diameter of the discoidal structures and the presence of clusters consisting of small individuals. The discoidal molds range from a few millimeters to a few centimeters in diameter and demonstrate sharp radial structure. Most specimens have very low relief and can only be distinguished from the surrounding bedding plane by difference in color. The fossils resemble cross-sections of nodules with radial structure and sometimes are surrounded by a narrow rim of faint color. Results of the study under SEM show that the fossils are enriched with biophilic elements Ca and C, compared to the host rock. The morphological, taphonomic, biometric and geochemical evidence suggest that the discoidal structures are biogenic.

Problematic fossils from the Maikhanul Fm can be interpreted as hypothetical microbial colonies. M.F. Glaessner [8] was the first who considered a possibility that microbial colonies can be preserved in the fossil record: merged discoidal molds from Late Precambrian Bass Fm (Arizona, USA) were interpreted as algal colonies and compared to modern examples. Many discoidal fossils from Precambrian strata have been compared to microbial colonies [9–11]. The main argument is morphological similarity between the discoidal molds and living microbial aggregations; however, molds preserve only one aspect of an organism. It should also be noted that some specimens are preserved in high relief and show complex structure, sometimes in a form of stem- and frond-like extension. Perhaps, this explains why the "microbial" nature of many discoidal fossils is not universally excepted. For example, fossils from the Stirling Range Fm of southwestern Australia (2.0–1.8 Ga) were not recognized as microbial colonies because of their high relief, preservation in hydrodynamically active environment and absence of microbial textures on surface of enclosing beds [12]; also there is an opinion of their abiotic nature [13]. Circular structures from intertillite beds of the Twitya Fm of northwestern Canada (U–Pb date for granite intraclasts is 755 ± 18 Ma [14]) were provisionally identified as Ediacaran taxa *Nimbia occlusa*, *Vendella* (?) and *Irridinitus* (?); a microbial origin for the Twitya fossils was suggested, but there was only one obstacle – morphology of these remains was more sophisticated than of microbial aggregates [1]. Circular fossils recently found in Malyi Karatau Range, Kazakhstan (U–Pb age 776 ± 7 Ma; i.e., older than the Aktas tillites of Stirtian age) were interpreted as metazoan taxa *Nimbia* and *Aspidella* (?), although alternative interpretations were discussed as well [15].

Discoidal fossils have a wide stratigraphic range; it is quite likely that microbial aggregations were an essential element of Precambrian biota [9, 11]. The morphology of modern microbial colonies is variable and depends of environmental conditions [16], therefore biostratigraphic potential of the fossil microbial colonies is very low. Nevertheless, these fossils are very interesting as an evidence of prokaryote ecology; it was prokaryotes that catalyzed the system of biochemical cycles and were the base for further evolution [17].

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Paleobiology and biostratigraphy of the Neoproterozoic Chichkan biota of Kazakhstan: new data from new technIques

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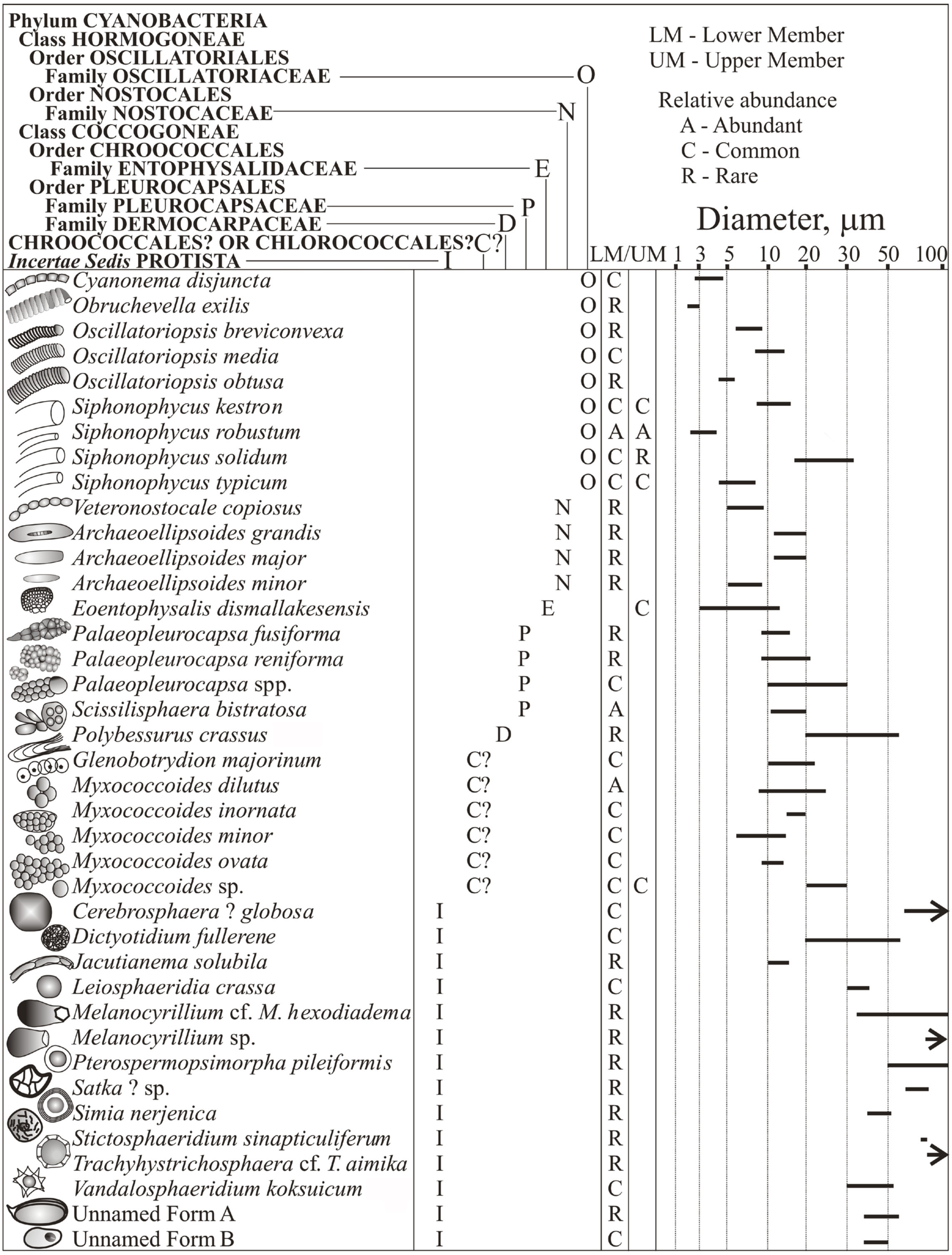

Figure 28. Composition of the Chichkan microbiota from the open-marine and shallow-water environments [1].

Carbonaceous bedded cherts of the late Neoproterozoic (800–750 Ma) Chichkan Fm of south Kazakhstan contain an abundant assemblage of exquisitely preserved microorganisms. Like many Proterozoic microbiotas, the Chichkan assemblage is dominated by prokaryotic cyanobacteria, both filamentous (oscillatorialeans and nostocaleans, represented primarily by cellular trichomes and empty sheaths) and coccoidal (chroococcaleans and pleurocapsaleans, including solitary, colonial, and stalk-forming specimens). However, unlike Proterozoic microbiotas known from peritidal settings, the Chichkan fossils, permineralized in cherts deposited in the open shelf facies of the formation, include diverse microscopic eukaryotes: vase-shaped testate amoebae; spiny (acanthomorphic) phytoplanktonic unicells; large (up to ~1-mm-diameter) megasphaeromorphic acritarchs; and sausage-shaped vaucheriacean green alga-like filaments. The Chichkan assemblage is composed of 39 taxa, comprising 23 genera, of microscopic prokaryotes and eukaryotes [1] (Fig. 28). Given the composition of this biota and the presence in it and similarly aged assemblages of taxa typical of late Neoproterozoic deposits (e.g., *Cerebrosphaera*, *Jacutianema*, *Melanocyrillium*, *Stictosphaeridium*, *Trachyhystrichosphaera*, and *Vandalosphaeridium*), the Chichkan Lagerstätte appears representative of the Cryogenian biota as now known, thereby documenting the status of the marine biosphere closely preceding the radiation of the Metazoa. As such, we interpret this and other coeval mixed assemblages of prokaryotic and eukaryotic microfossils as representing an evolutionary stage transitional between the predominantly prokaryote-dominated Precambrian and the eukaryote-dominated Phanerozoic biospheres. Because of its high diversity and excellent preservation, the Chichkan biota has been suggested as one of the type assemblages for the Cryogenian (Yuzhnouralian) biostratigraphic unit [2].

In addition to studies by standard optical microscopy, we have analyzed numerous taxa of the Chichkan biota using two other techniques recently introduced to paleontology: confocal laser scanning microscopy (CLSM) and two- and three-dimensional Raman imagery [3]. Used together, these techniques have documented, in situ and at micron-scale resolution, the cellular and organismal morphology of the thin section-embedded organic-walled fossils. Moreover, the spectra provided by Raman imagery characterize the molecular-structural composition of the carbonaceous Chichkan fossils and their embedding mineral matrix, identify the composition of intracellular inclusions, and provide a basis by which to assess quantitatively the geochemical maturity of the Chichkan organic matter. This first in-depth study of diverse taxa from a single Precambrian microbiota shows that the combined use of CLSM and Raman imagery can provide information in three dimensions at high spatial resolution about the organismal morphology, cellular anatomy, kerogenous composition, mode of preservation, and taphonomy and fidelity of preservation of chert-embedded organic-walled microfossils.

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Neoproterozoic microfossils from the northeast margin of the East European Craton and the model of the Cryogenian (Upper Riphean) – Lower Ediacaran (Vendian) transition

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The Kel'tminskaya-1 borehole, drilled in the Timan Trough on the northeastern margin of East European Craton reveals some 3600 m of Neoproterozoic sedimentary rocks, mostly confined to the subsurface. The upper 1000 m of the drilled section correlates with late Ediacaran Redkino and Kotlin successions on the East European Craton, whereas the lowermost 2000 m can be related to pre-Sturtian (Upper Riphean) deposits in the Ural Mountains. The Vychegda Fm lays in between, a 600 m siliciclastic succession that has no counterpart either in classic East European Craton stratigraphy or the Riphean type section of the southern Ural Mountains. The Vychegda Fm is poorly exposed but is well documented by a series of cores drilled in the Timan Trough region like Kel'tminskaya-1 borehole. Vychegda microfossils can be separat-

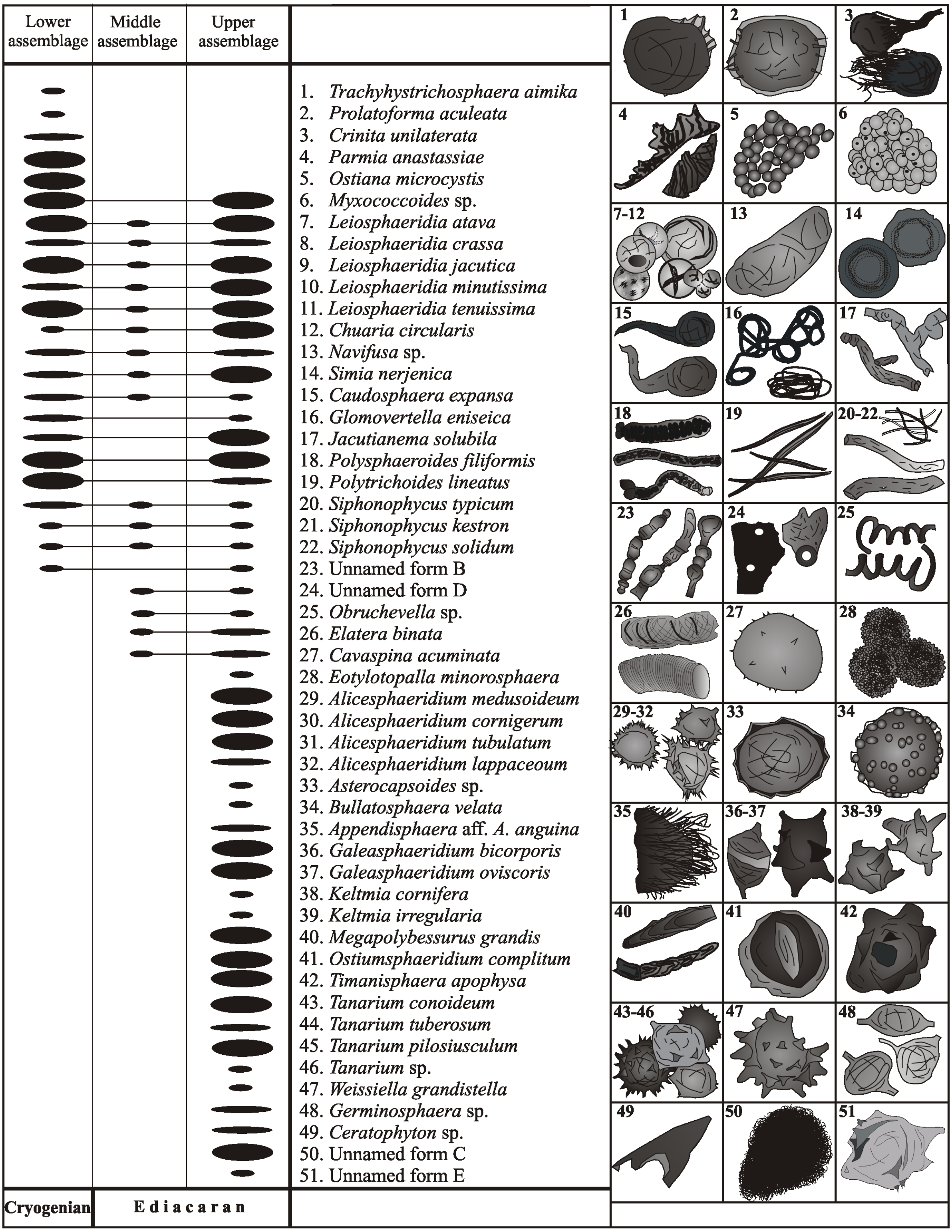

Figure 29. The updated stratigraphic chart showing taxa recovered from the Vychegda Formation and their distribution among the three stratigraphic assemblages [1].

ed into three assemblages (Fig. 29). The upper part of the formation contains large, profusely ornamented acritarchs broadly comparable to those of the Ediacaran Complex Acanthomorph Palynoflora (ECAP), including species of the genera *Alicesphaeridium*, *Asterocapsoides*, *Cavaspina* and *Tanarium* confined to Ediacaran-aged assemblages elsewhere [1, 2]. Diverse large acanthomorphs are known from Ediacaran strata in Australia, China, the Lesser Himalaya of India, Siberia, Svalbard, and Norway, but have not previously been recognized from the East European Craton, an absence attributed to a hiatus between the glacial Laplandian (>635 Ma) and Redkino (mostly <555 Ma) regional stages. The large acanthomorphic acritarchs called as large ornamented Ediacaran microfossils (LOEM) record eukaryotic organisms with resting stages in their life cycles and likely include egg or diapause cysts of early animals [3]. In contrast, the lower Vychegda assemblage, found in the basal 10 m of the succession, contains acanthomorphic acritarch taxa and fragments of problematic macrofossils known elsewhere only from pre-Sturtian deposits. The middle assemblage is dominated by simple filaments and spheroidal microfossils, but a first Ediacaran (?) acanthomorphic acritarch *Cavaspina acuminata* occurs here as well. The upper assemblage is comparable to the first (Ab/Am/Gp) assemblage zone for the ECAP of Australia [4]. This distinctive set of taxa is known elsewhere only from lower, but not lowermost, Ediacaran rocks. The most parsimonious interpretation of Vychegda biostratigraphy is that pre-Sturtian or pre-Marinoan rocks in the basal part of the formation are separated by a cryptic unconformity from early (middle assemblage) and middle Ediacaran (upper assemblage) deposits above. This interpretation is consistent with data from China and Australia, which indicate that the major paleontological transition to diverse ECAP assemblages took place within the Ediacaran Period and not in association with the preceding ice age. Therefore, currently the base of the Ediacaran System is to be correlated with the Vychegda Fm layers bearing the second microfossil assemblage with the rare *Cavaspina* acritarchs.

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Paleomagnetic evidence of the Neoproterozoic age of the Purpol Formation of the Baikal-Patom Region

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The Purpol Fm is distributed within the Baikal-Patom margin of Siberian Craton from middle reaches of the Chuya River to the Lake Nichatka. It represents the basal sedimentary unit of Siberia's sedimentary cover, resting on the crystalline basement (mostly Paleoproterozoic, ca. 1.8–1.9 Ga). The Purpol Fm consists of mature red-bedded sandstones that are interpreted to have formed in a shallow sea environment. Sedimentary strata overlying the Purpol Fm and representing Siberia's passive margin sequence are conventionally regarded as Riphean in age. Their age has been revised recently and is though to be younger. For example, tillites at the Lake Nichatka, which directly overly the Purpol Fm, were correlated with the Varanger Tillite. At present, there are no geochronological or paleontological data to constrain the age of deposition of the Purpol Fm. Thus, formally the age of the Purpol Fm can be anything between 1.8 and 0.7 (or 0.6) Ga.

Fine-grained red sandstones of the Purpol Fm were sampled for paleomagnetic studies in the outcrops at Lake Nichatka (57.80° N; 117.64° E) (Fig. 30: 1A) and Chuya River (58.73° N; 112.59° E) (Fig. 30: 1B). A total of 60 samples were collected. Studied samples are characterized by well-defined vector end-point diagrams (Fig. 30: 3A – sample from the Lake Nichatka section; 3B, 3C – sample from the Chuya River; 3B – high-temperature component; 3C – intermediate component). On the stereogram with Nichatka samples paleomagnetic directions, there is a cluster of NW declinations – low inclinations ($n = 25$, $Ds = 291.5$, $Is = -19.3$, $ks = 19.2$, $a95s = 6.8$, $Dg = 295.1$, $Ig = -4.8$, $kg = 27.1$, $a95g = 5.7$). Single paleomagnetic directions for the Chuya River section (Fig. 30: 2B, 2C; squares an circles correspond to intermediate and high-temperature components, respectively) are distributed quasi-chaotically, with some clustering around the contemporary re-magnetization direction (in situ coordinates).

Anisotropy of magnetic susceptibility is planar (not exceeding 4%) for Nichatka collection (Fig. 30: 4A). Such values of anisotropy are common for sedimentary rocks. The Chuya River samples (Fig. 30: 4B) are

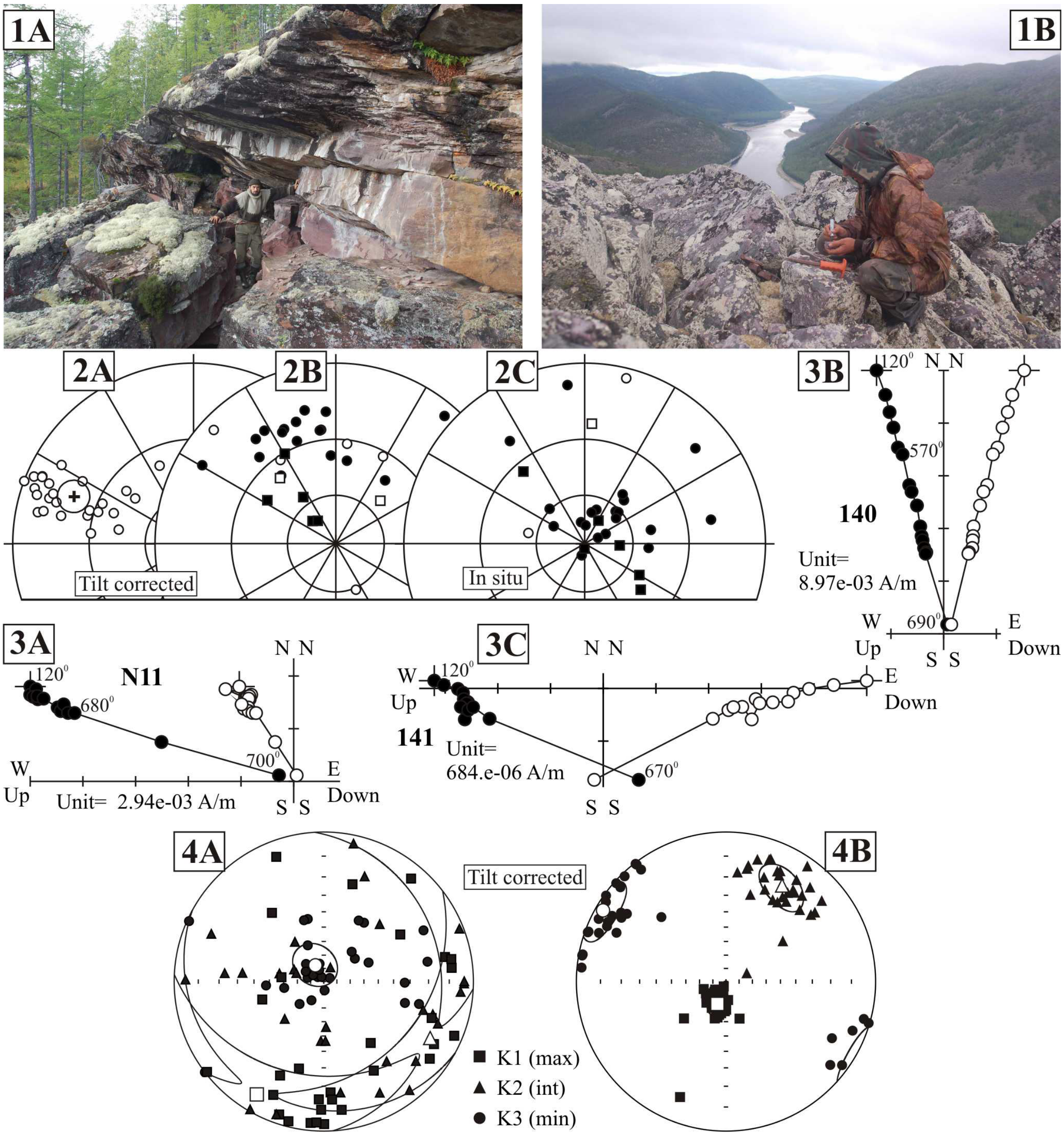

Figure 30. See text for explanation.

characterized by a well-defined ellipsoid with minimum axes that are parallel to bedding, and perpendicular to strike direction, and the maximum axis, which is perpendicular to bedding. Anisotropy values of the Chuya River samples are anomalously high (up to 40%). Such values are likely caused by tectonic deformations of sediments. Samples with anisotropy values above 5% are not suitable for paleomagnetism; therefore, we do not use paleomagnetic data from the Chuya River section.

Paleomagnetic pole acquired from the Purpol Fm in the Lake Nichatka section, independently of coordinate system, falls inside the Equatorial Africa (PLong = 4.2, Plat = 2.7, A95 = 5.1, bedding corrected). Derived paleomagnetic pole nearly coincides with the poles of Kandyk and Ust-Kirba formations from the Uchur–Maya Region, which are regarded as key poles for the base of Siberian Neoproterozoic (1000–950 Ma) [1, 2]. Therefore, the age of the Purpol Fm can be estimated with paleomagnetic methods as Early Neoproterozoic.

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High-resolution correlation of Vendian oil-and-gas bearing deposits in central regions of the Siberian Craton

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Vendian petroliferous strata, the main oil exploration target in central parts of the Siberian Craton, are widespread and represented by terrigenous, carbonate, terrigenous-carbonate and terrigenous-sulfate-carbonate rocks. Local stratigraphic units of different composition in the Vendian rocks can be traced laterally; they constitute larger cyclic stratigraphic units (regocyclites), the Vilyuchan, Lower Nepa, Upper Nepa, Tir, Lower Danilovo, Middle Danilovo, Upper Danilovo that are referred to as regional stages (horizons) and regional substages. The most prominent are first-order zone-cyclites used in high-precision correlation. The studied Vendian sections are unfossiliferous and represented by boreholes with low core recovery; the cyclites, therefore, were identified based on structural approach [1]. Cyclites in the Vendian terrigenous rocks of Vilyuchan and Nepa regional stages were defined using patterns of granulometric variations. In the sulfate-carbonate and clay-carbonate sections of the Danilovo and Tir regional stages, the main criteria for cyclite recognition were gradations from low-soluble carbonates to high-soluble anhydrites and from pure carbonates to marls. Cyclites in the terrigenous-sulfate-carbonate sections of Tir Regional Stage are represented by alternating terrigenous, sulfate-carbonate and clay-carbonate rocks. Thickness of the cyclites varies between 5–10 and 50 m; cyclite boundaries are sharp. The cyclic structure is revealed on geophysical data diagrams. The subdivision and correlation are carried out using the Geophysical Well Logging (GWL); i.e., Gamma-Ray Logging (GRL), Neutron Gamma-Ray Logging (NGRL), Electric-Resistivity Logging (ERL), Lateral Logging (LL), Acoustic Logging (AL), visual layer-by-layer borehole core description and also microscopic-, sieve- and chemical-analyzing. Correlation of the fine laminated Lower Cambrian and Vendian carbonates is corroborated by the geophysical-data diagrams. The Vendian mudstones with thin marker beds of carbonates and black bituminous shales can be directly correlated. Correlation of the Vendian terrigenous-sulfate-carbonate rocks is less certain, although the sections include thin continuous shale units. Correlation of the sandstones is very tentative. The Vilyuchan, Nepa, Tir and Danilovo regional stages were respectively divided into 4, 23, 13 and 9 cyclites and correlated along 32 profiles covering all structural and facies zones of the interior parts of Siberian Craton. Some of these profiles are represented in Figures 31–33. The revealed structure of the Vendian deposits only partially complies with the recently established facies demarcation scheme of Siberian Craton [2]. Demarcation scheme for the Nepa-Botuoba Anteclise can be modified. In particular, the Gazhen zone should be expanded on account of the adjacent northwestern parts of the anteclise characterized by a reduced thickness and clayey composition of the Nepa Regional Stage and absence of the Tir Regional Stage. The Peledui zone can be reduced and restricted to the northeastern part of the Nepa Uplift, where the full thickness of the Nepa Regional Stage and a shortened section of the Tir Regional Stage are observed. The extent of hiatuses between the Vilyuchan and Lower Nepa, Lower and Upper Nepa, Upper Nepa and Lower Tir, Upper Tir and Lower Danilovo, and Lower and Middle Danilovo has been revised. These hiatuses are not fully represented in the established stratigraphic scheme [2]. In each pair of the coeval units of Tatar and Yuryakh, Sobina and Kudulakh, Katanga and Uspun formations, characterized by similar lithologies, thicknesses, and GWL data, only one stratigraphic name should be used in the studied regions. The correlation also showed a diachronous nature of the productive sandstone units on a scale of 2–3 cyclites.

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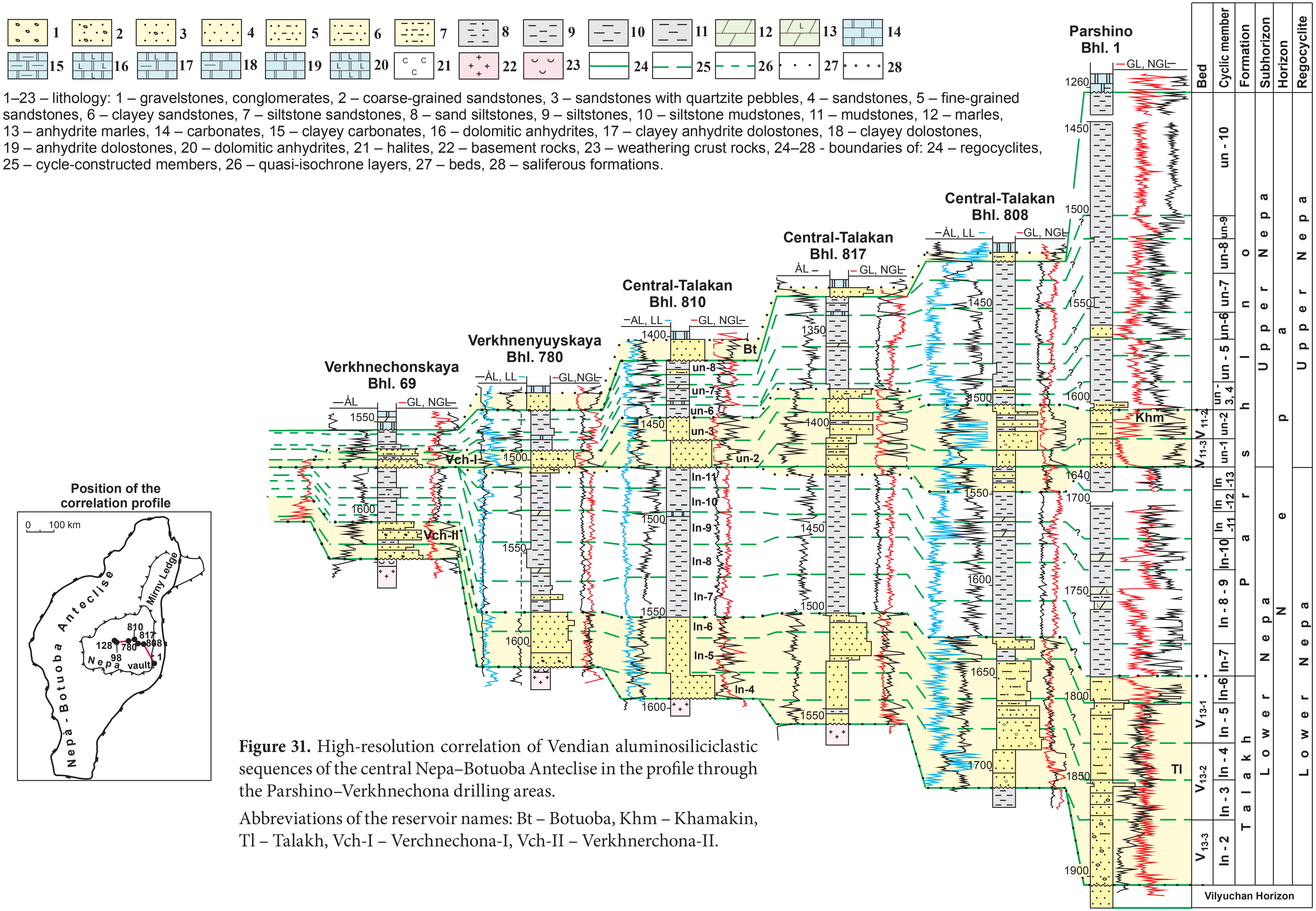


Figure 31. High-resolution correlation of Vendian aluminosiliciclastic sequences of the central Nepa–Botuoba Anteclise in the profile through the Parshino–Verkhnechona drilling areas.

Abbreviations of the reservoir names: Bt – Botuoba, Khm – Khamakin, Tl – Talakh, Vch-I – Verchnechona-I, Vch-II – Verkhnerchona-II.

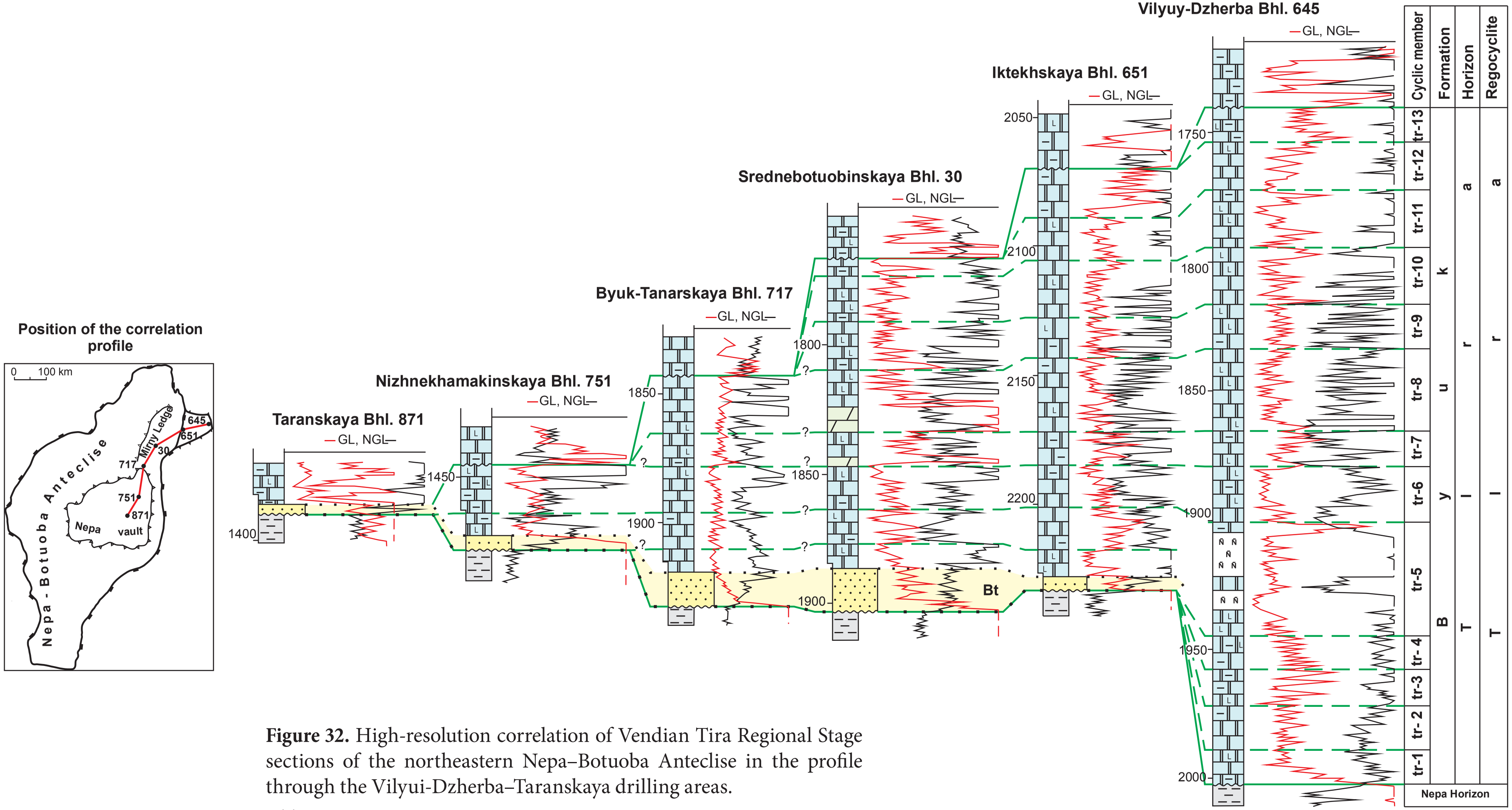
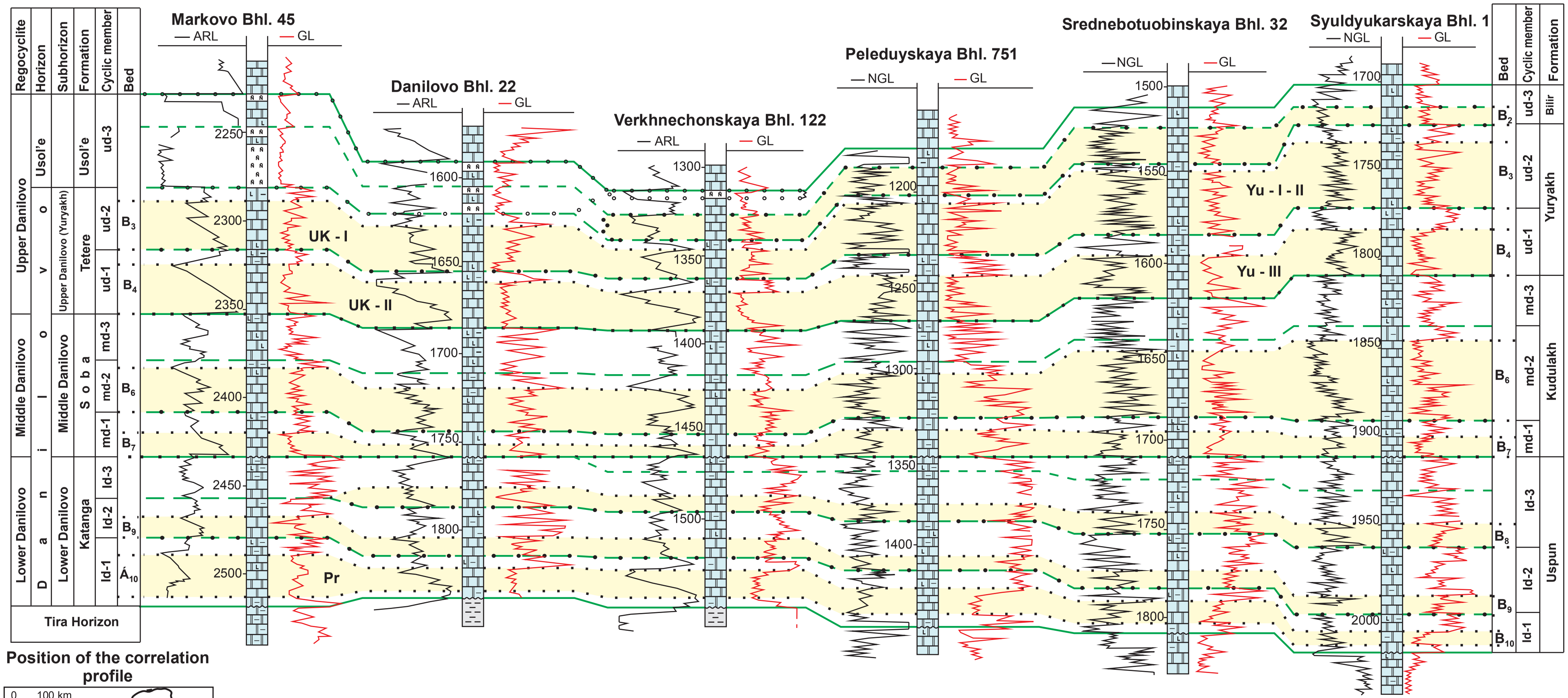


Figure 32. High-resolution correlation of Vendian Tira Regional Stage sections of the northeastern Nepa–Botuoba Anteclise in the profile through the Vilyui-Dzherba–Taranskaya drilling areas.

Abbreviations: see Fig. 31.



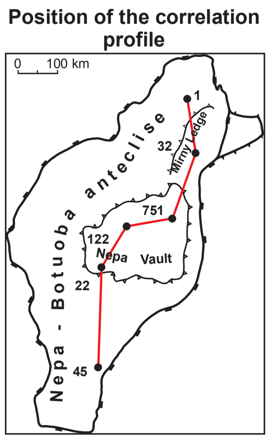


Figure 33. High-resolution correlation of sub-saliferous Vendian and Lower Cambrian carbonate sequences of Nepa–Botuoba Anteclise in the profile through the Markovo–Syuldyukarskaya drilling areas.

Abbreviations: UK-I – Ust'-Kut-I; UK-II – Ust'-Kut-II; Yu-I – Yuryakh-I; Yu-II – Yuryakh-II; Pr – Preobrazhenskoe; other abbreviations – see Fig. 31.

Quantitative biostratigraphy: global correlation for Early Cambrian strata

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Early Cambrian strata record a range of events that can be used to correlate global sections, constrain time, and calibrate chemical and biological records. These events include volcanic ashes, changes in ocean chemistry, and originations and extinctions of species. Optimization algorithms in the CONOP9 software [1] use a randomly inputted sequence of events to create a model sequence of the ranges of all events that best fits the locally-observed data. Global correlations for Nemakit-Daldynian through Tommotian strata have been previously suggested [2], but these correlations used only carbon isotope chemostratigraphy of carbonates ($\delta^{13}C_{carb}$) and U–Pb zircon geochronology of interbedded volcanic ashes (Fig. 34). Early Cambrian correlations using solely carbon isotope stratigraphy is problematic for a few reasons: 1) regions are correlated by matching positive and negative anomalies to those of other sections, but some of the excursions are not present in certain regions; 2) not all carbon isotope excursions are accurate indicators of primary seawater; 3) there are not enough absolute ages constraining time or rates of deposition to be confident in the chemostratigraphic correlations. One of the few ages, a Pb–U ID-TIMS zircon age of ca. 533 Ma from China [3], unfortunately is a region where there are much fewer carbon isotope excursions, making global chemostratigraphic correlations much less convincing. Carbon isotope curves during the Nemakit-Daldynian are not consistent enough from region to region for this to be the only method of correlation. This work incorporates carbon isotope chemostratigraphy, U–Pb zircon geochronology, and small shelly biostratigraphy using CONOP9. Small shelly fossils, fossils of the lowest Cambrian [4], are significant because they record the onset of widespread biomineralization of animals. First appearances and last appearances of small shelly fossil species are entered into CONOP for each section. Other events such as ashes and carbon isotope values are added to each section and weighted based on the confidence in the values. The composite section is a hypothetical section that contains all of the stratigraphic correlation events, in which local taxon ranges are extended to approximate the true range in time. This work is of interest because it has implications for the nature of the Cambrian explosion; was it actually an explosion or a more gradual increase in diversification of animals? A quantitative compilation of global sections using all available data will provide a new approach to calibrating the early Cambrian record and answering questions about the nature of the early Cambrian radiation.

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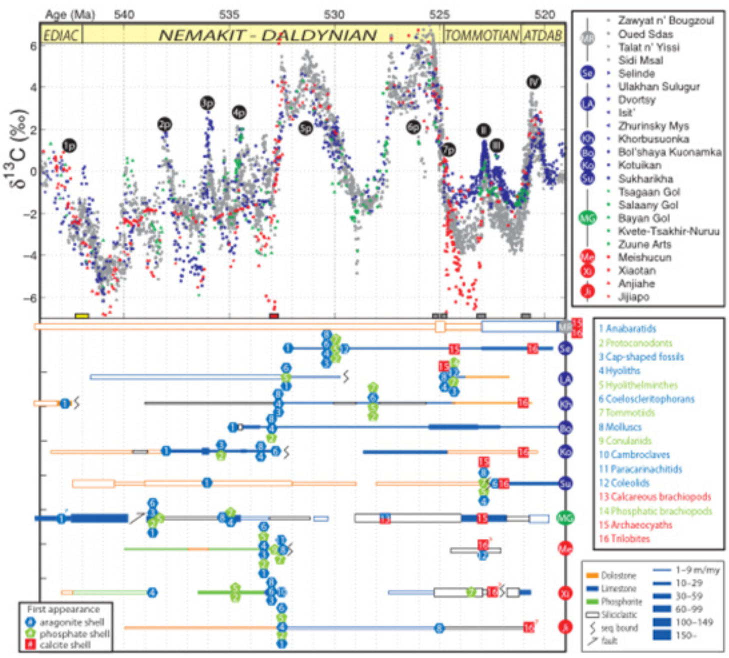

Figure 34. Global correlations for early Cambrian strata from four regions: Morocco, Siberia, Mongolia, and China [2]. Here the small shelly fossil record is calibrated with carbon isotope chemostratigraphy.

Geodynamics and petroleum content of Riphean complexes of western Arctic shelf, Russia

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The Kara Sea – Barents Sea petroliferous basin is relatively well studied by geological and geophysical methods; however, the mechanisms of spatiotemporal hydrocarbon distribution, as well as historical and genetic aspects of the regional evolution are still not clearly understood. In the Late Archaean the northern and northwestern (in northern limbs) margin of the East European Craton underwent a series of collisions with the North American lithospheric plate [1], as evident by comparison of the structure and composition of Svecofennian (Baltic Shield) and Cetilidian (South Greenland and Canada). At around 1350–1050 My ago, the Peri-Timan and Kandalaksha–Dvina Basin subsided, and the accommodation space was filled with continental terrigenous sediments and volcanic rocks. The coeval sediments in the northeastern part of East European Craton are represented by passive margin successions of shelf and continental slope deposits [2]. The available data indirectly indicate that at that time the Canadian–Greenland continent and the adjacent structural and compositional complexes of the Baltic Shield, once comprising a single continent, were separated by opening of the Paleo-Iapetus Ocean. This agrees well with the time of Stille's Megagaea break-up that started ca. 1.7 billion years ago and lasted until another supercontinent, the Mesogaea, assembled in Late Riphean (ca. 1000 My ago) [3]. The Dalsland Foldbelt formed herewith at the northwestern periphery of East European Craton was an extension of the Grenville Belt of Canada and Greenland and marks the suture of Paleo-Iapetus closure. The period of tectonic stability in the eastern and northeastern parts of East European Craton that lasted for ca. 780 My (1350–570 Ma) was accompanied by accumulation of thick passive margin sequences of Riphean age cropping out on the Varanger Peninsula of northern Norway, on the Sredniy and Rybachiy peninsulas and Kil'din Island in the north of the Kola Peninsula, and on the Kanin Peninsula and Timan Ranges in the Arkhangel'sk Region (Fig. 35). In the geological literature these are referred to as the Timan–Varanger Foldbelt [4, 5] consisting of slightly metamorphosed monoclinal Middle–Late Riphean and Vendian sedimentary complexes that were tectonically upthrusted and locally thrusted over the Archaean and Early Proterozoic rocks of the Baltic Shield and Russian Plate [6]. The geodynamic setting of accumulation agrees with a single sequence of shelf, continental slope, and continental rise sediments [2].

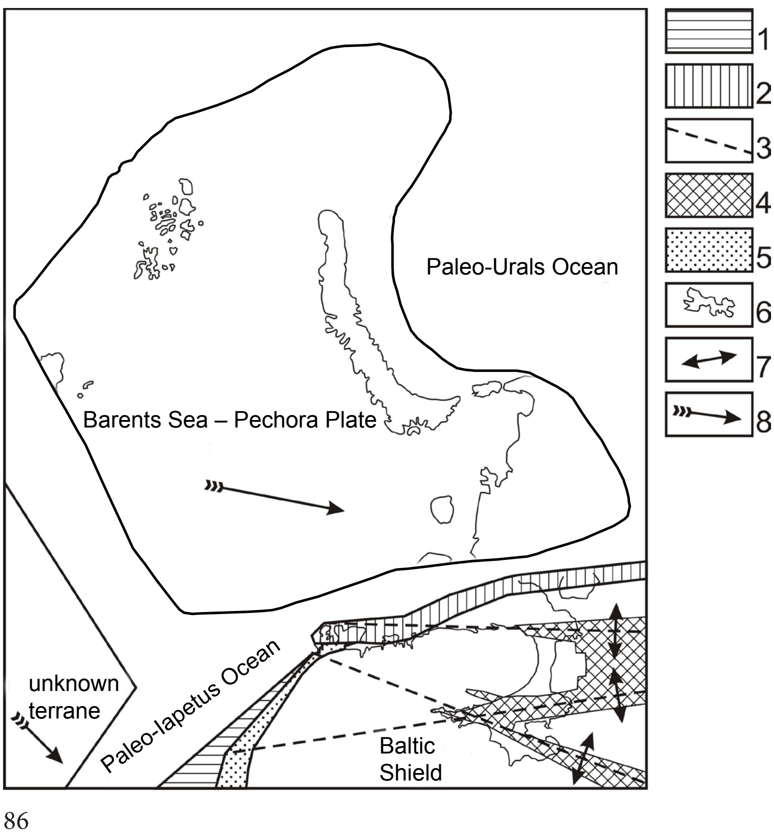

Figure 35. Palaeogeodynamic reconstruction of the northern part of East European Craton and the adjacent Arctic Basin for Middle Riphean – Vendian (1350–540 Ma).

Legend: 1 – Middle–Late Riphean Dalsland Foldbelt (1200–900 Ma), 2 – Middle–Late Riphean and Vendian sedimentary shelf and passive margin continental slope complexes of the northeastern Baltic Shield and Russian Plate (1350–620 Ma), 3 – main lineaments of the Baltic Shield, 4 – Late Riphean riftogenic complexes, 5 – Vendian continental terrigenous sediments (650–570 Ma), 6 – contour of the modern coast line, 7 – stress field vectors in the continental lithosphere, 8 – generalized direction of the lithosperic plate movement.

This part of East European Craton almost completely lacks any signs of superimposed igneous, metamorphic, and orogenic processes, or presence of active continental margin. The burial depth (over 20 km) of potentially petroliferous Riphean complexes in this region apparently minimizes their economic significance. However, the superimposed Caledonian and Hercynian processes that resulted in formation of the Norwegian–Mezen rift system and intensive folding of the Timan–Pechora region could also promote the accumulation, transformation and secondary migration of hydrocarbons into the upper structural levels, as suggested by gas shows on the Rybachiy Peninsula.

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Newlandian biota of Upper Proterozoic

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The Newlandian biota comprises attached marine colonial organisms preserved in carbonates as stratiform bioherms as three-dimensionally fossilized elements reaching large sizes and consisting of dark calcite. Several groups are distinguished based on morphological features.

Group Newlandiida Sosnovskaya et Shchipitsyn 1986. Hemispherical, spherical, discoid, cup-shaped and lamellar bodies consisting of parallel, often concentrically organized elements in the form of plates (lamina) or rings that can be connected by short columns, have discontinuities, or intersected by radially oriented long cylindrical columns. Sometimes these elements show "porous" structure. In some specimens, the columns are better developed than lamellar elements. Laterally merged columns have meandering cross-sections. Bioherms are 10–100 mm thick; lamellar elements and rings are 2–3 mm thick; columns are 2–3 mm in diameter. Includes genera *Newlandia* Walcott 1914, *Clathristroma* Pospelov 1978, *Volodia* Sosnovskaya 1980, and probably *Namapoikia* Wood *et al.* 2002. Fossils are considered as stromatolites [1, 2] or metazoans [3–5]. Their constructional body plan is reminiscent of sponges (sphaeractinia and stromatoporata).

Group Camasiida Sosnovskaya 1981. Stratiform bioherms consisting of bushy, radial or fanlike aggregations of long or short subconical or prismatic columns of circular or triangular cross-section. Columns branch longitudinally (fully or incompletely) and laterally and have simple or complex structure. The complex structure includes axial and peripheral zones, the latter consisting of dense microcolumns oriented in a direction of growth of the colony. Columns are 1–10 mm in diameter and up to 150 mm in length. Includes genera *Camasia* Walcott 1914, *Copperia* Walcott 1914, *Caryschia* Sosnovskaya 1981, *Tricuspidatia* Sosnovskaya 1981, *Tridia* Shchipitsyn 1984, *Plumifascicularia* Shchipitsyn et Sosnovskaya 1984 and *Yangtziramulus* Shen *et al.* 2009. The group is heterogenous; some of the specimens are interpreted as algae, cyanobacteria and metazoans [4, 6, 7].

Group Saralinskiida Sosnovskaya et Shchipitsyn 1997. Bioherms consisting of small isometric (gleba) and large elongated clodds (glebula) circular in cross-section corresponding, respectively, to early and late stages in colony growth. Laterally merged gleba form branching elements (filaments). In addition, bioherms comprise spherical or hemispherical bodies (globules) and bushy aggregates. Gleba are over 0.3 mm in diameter; glebula are 2–8 mm in diameter and up to 15–20 mm in height, globules are 10–50 mm in diameter. Includes genera *Saralinskia* Krasnopeeva 1933 and *Incertadia* Shchipitsyn et Sosnovskaya 2011. Represent fossil cyanobacteria or algae [8, 9].

The Newlandian biota ranges from Lower Riphean to Lower Cambrian (Lower Tommotian). It was first discovered in the U.S.A. (Newland Fm, Belt Supergroup; Montana) and described by C.D. Walcott in 1914. Most fossil localities occur in Russia and Uzbekistan: the Altai–Sayan Foldbelt [10], Siberian Craton [6, 11], Tien Shan and central Kyzylkumy [12], and Hingan [13], where the fossils are found in Upper Riphean, Vendian and Lower Cambrian rocks. A stratigraphic succession of Newlandian biota is established in the Neoproterzoic of Kuznetsk Alatau [10, 14]. Fossils of the Newlandian biota are also described in China (Shibantan Mb, Dengying Fm; Yangtze Gorges area) [7] and Namibia (Dabis and, possibly, Zaris formations) [5]. Other known occurrences include the Riphean of India [2, 15] and Lower Proterozoic of the Scandinavian peninsula [16].

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Vendian subsidence of the southwestern Siberian Craton: geodynamics and basin formation

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Vendian sedimentary basins in the Siberian Craton record a major evolution stage of deposition associated with stable subsidence after a long gap and denudation. The latter shows up as an unconformity at the base of the Vendian section being especially prominent in the craton interior though found throughout the craton periphery in the marginal zones of pre-Vendian subsidence. Specifically, the unconformity has been reliably recognized for the Yenisei Ranges where the Vendian Chapa Gr overlies and seals Late Riphean (Cryogenian) sediments in local Teya-Chapa and Vorogovo failed rifts and older Riphean sedimentary-metamorphic complexes in the basin sides [1]. In the Sayan Region, the pre-Vendian stratigraphic discordance is evident in deep erosion (reaching 1000 m) of structurally conformal Late Riphean Karagassy Gr that underlies the Oselok Gr, as well as in the position of the latter immediately upon the Paleoproterozoic metamorphic basement in the basin side.

The unconformity at the Vendian base corresponds to a genetically integrate basal complex of glacial and related deposits which, in the southwestern Siberian Craton marks the onset of deposition of the Chapa, Taseeva, Oselok, Baikal, and Dalnyaya Taiga groups. The climate cooling equated to the Marinoan glaciation [2–4] and the Early Vendian regional-scale subsidence of the Siberian Craton are correlated events.

Judging by the stacking patterns of glacial and interglacial deposits in the Sayan foredeep, the glaciation history consisted of three stages in which the ice sheet advanced first in the SW–NE direction (Karapchatui stage) and then from the north and northeast to the southwest (Ulyakh and Plity stages). The Ulyakh ablation moraine contains granite and gneiss stones brought from the Siberian Craton basement.

The Vendian sedimentary basins have been identified proceeding from sedimentology observed in exposures, as well as from cyclic sedimentary architecture and correlation of sequence boundaries. Evidence from sections drilled for petroleum exploration being insufficient for direct correlation, sedimentological analysis for this study was done with reference to logging data, with all their advantages and shortcomings [5, 6]. There are three features of lithological-facies zoning and evolution of Vendian sedimentary basins that cause controversy in stratigraphic correlation of formations and members: (1) distinct changes in thickness and lithology of sediments on transition from foredeeps to separating uplifts; (2) terrigenous-to-carbonate sediment change within a short distance; (3) different paleogeographic zones and geodynamics of Vendian sedimentary basins at two basically different stages of craton subsidence.

An earlier paleotectonic model which interpreted the Vendian southwestern Siberian Craton as a foreland basin explained the thinning of the Vendian complex on transition from the marginal basins to the plate interior in terms of tectonic zones associated with a collision between the craton and several accreting terranes [7]. According to new sedimentological data for the Oselok and Baikal groups of the Sayan and Baikal foredeeps, the tectonic settings during two stages of the Vendian craton evolution were dramatically different. The difference was revealed in the directions and lithology of clastic fluxes, in the geographic position of land and sea, and in features of specific sedimentary systems.

The Vendian sedimentary complex in the Yenisei Ranges and in the Sayan and Baikal regions includes two subcomplexes: (i) a mostly marine one below and (ii) a continental one above. Note that the genetic (marine vs. continental) attributes of the subcomplexes are, in a sense, conventional, and just reflect their main characteristics in the foredeeps. The boundary between the two subcomplexes is especially prominent in the sections where shallow-marine limestone borders channel and floodplain sandstone or where storm shelf facies contacts deltaic deposits. This boundary separates the Pod'yom and Nemchanka (Tayozhnaya) formations in the northeastern Yenisei Ranges, the Chistyakov and Greben' formations in its southeastern part, the Uda and Aisa formations in the Sayan Region, and the Uluntui and Kachergat formations in the Baikal Region [2, 8].

The marine subcomplex in the Sayan region was divided into cyclic sequences (Ulyakh, Ognit, and Uda) which are separated from one another by sharp erosive boundaries and gaps and are traceable from the northern Yenisei Ranges to the Patom upland [2, 9]. Chemostratigraphy on the basis of the $\delta^{13}C$ curve [4, 10, 11] confirmed the correlation among the sequences and the age consistency of the isotope system of carbonates between the Marnya and Uda formations (Oselok Gr, Sayan Region) on one side and the Barakun and Valyukhta formations (Balaganakh Gr, Patom Upland) on the other side. A $\delta^{13}C$ negative anomaly in limestone of the overlying Zhuya Gr [11] correlates with that in dolomite from the Oskoba Fm in the Siberian Craton interior and in limestone from the Kachergat Fm in the Baikal Region [4, 10]. The correlation is supported by the isotope ages of detrital zircons from the Zhuya Gr rocks [3].

The transition from the Sayan and Baikal foredeeps to the Irkut synsedimentary uplift is a key element of the regional correlation in Vendian sediments. The previous traditional interpretation of the dramatic thinning and lithology changes in Vendian sediments on the Irkut uplift, where the Oselok Gr pinches out before the Moty Gr deposition [12–14] has been revised as new data on the stratigraphy of marker sedimentary systems became available due to analysis of sedimentology and paleocurrents [9]. The updated correlation corroborates the age synchronicity of the Aisa Fm (1300–1500 m) in the Biryusa area with the lower Moty Gr in the Irkut Area of the Sayan Region, i.e., with the Khuzhir and Bolshoi Lug formations (250 m) [1] or the Khuzhir and Kosmic formations (225–300 m) [6, 13]. The correlation of sediments changing dramatically in thickness and lithology on the foredeep-to-uplift transition has been checked against stratigraphic correlation between (1) tillite at the base of the Marnya Fm and breccia at the base of the Olkha Fm, (2) marine complexes of the Early Oselok and Olkha formations, (3) red fluvial deposits in the lower subformations of the Ust'-Tagul and Nurtei (Shamanka) formations, (4) variegated terrigenous-carbonate shallow-marine deposits of the upper members of the same formations. The latter sedimentological boundary has been traced from the Tagul and Biryusa river catchments to those of the

Urik and Irkut rivers (from foredeep to uplift) and records a regional transgression marked by carbonates with abundant *Treptichnus pedum* trace fossils. This boundary shows up in all Vendian–Cambrian sections in the craton interior as the radiating M_2 log marker and as a regional hiatus at the base of the Katanga Fm [5, 6, 13].

The generally accepted correlation of gravel and sand at the Moty Gr base (Khuzhir Fm) with basal sand of the Chora Fm (Bokhan Mb) [13, 16] in the craton interior is implicit evidence that the boundary appeared with a new large source of clastic material. Judging by paleocurrent directions, that source belonged to an orogen wherefrom clastic transport was to the Yenisei, Sayan, and Baikal foredeeps and further, beyond the basins, to the plate. The Late Vendian mountain building first produced fluvial sands of the Kagat and Muksut members of the Aisa Fm [2] or members IX and X of the Ikei Fm [17]. As one may infer from the directions of clastic transport to the Siberian Craton recorded in the continental subcomplex in the Yenisei Ranges and in the Sayan and Baikal regions, the Bokhan Sandstone Mb in the lower Chora Fm (craton interior) is the most plausible stratigraphic equivalent of the Muksut member. In the Sayan Foredeep, the latter marks the onset of rapid mountain growth and correlates with the lower member of alluvial sandstone member in the Greben' and Nemchanka formations in the Yenisei Ranges and gravelly sandstone in the Kachergat Fm of the Baikal Gr in the Baikal Region [9]. The inference became possible after the proof had been obtained for the alluvial origin of the Aisa Fm deposited by river systems similar to those of the Greben' and Veselaya formations of the Taseeva Gr in the Yenisei Ranges [8]. This is supported by correlation of the overlying Ust'-Tagul Fm and its equivalents with the upper unit of the Chora Fm (Parfenovo Sandstone Mb) [4]. The correlation between the Muksut Mb of the Aisa Fm and the Bokhan Mb of the Chora Fm is evidence for the stratigraphic consistency between the Vendian lower marine subcomplex in the Sayan Foredeep and that of the Typta (Tyret') Fm in the plate.

The correlation of Vendian deposits in the craton interior became problematic because terrigenous sediments (Chora Fm) abruptly change north-northeastward to terrigenous-carbonate deposits (Tira Fm). Independent petrography [15] and logging [18] data have proven that it was wrong to identify the Parfenovo Mb in the Nepa-Botuobia Anteclise (uplift) as equivalent to a member of the same name in the stratotype (middle reaches of the Angara River) which was done during petroleum exploration drilling [6, 19]. In fact, the base of the "Parfenovo" Mb in the Nepa-Botuobia uplift stratigraphically corresponds to the base of the Bokhan Mb (Chora Fm in the Angara), according to the M_1 log marker [16, 18], and hence correlates with the base of the Muksut Mb and its equivalents in the foredeeps. They are rather the terrigenous-carbonate and sulphate deposits of the Tira, Oskoba, and Byuka formations in the forebulges that are the stratigraphic equivalents of the entire upper (continental) subcomplex in the foredeeps (Tayozhnaya, Greben', Veselaya, Aisa, and Kachergat formations), the uplifts and the foredeeps constituting a synsedimentary paleotectonic couple [7, 8]. All underlying Vendian terrigenous sediments of the Nepa, Kursovka, and Vanavara formations in the Nepa-Botuobia and Baikit uplifts become replaced in the southwestern periphery of the Siberian Craton by the lower (marine) Vendian subcomplex.

Two different types of paleogeographic zoning represent the lower and upper subcomplexes. The lower level, in the craton interior, corresponds to lowland with a radiating drainage network which carried clastic material to marginal seas. Specifically, deposition by the radiating river system, with the craton provenance of mature quartz and arkose material, produced the Nizhneudinsk Mb of the Uda Fm in the Sayan Region as well as the channel deposits of the Markovo Mb (Nepa Fm, Nepa-Botuobia uplift) which I interpret as its equivalent. The shelves of the marginal seas were located within the Yenisei Ranges and the Sayan and Baikal regions, while the deepwater zones above the continental slope and the continental rise were restricted to the Patom Upland. In the facies series from the craton to the marginal seas, continental sediments grade smoothly into shallow-marine deposits, which is evident from the appearance of microphytolite carbonate banks and stromatolite biohermal buildups in the shelf. Large stromatolite frameworks and banks occur in the Stolbovaya and Pod'yom (Yenisei Ranges), Uda (Sayan Region), and Goloustnaya and Uluntui (Baikal Region) formations.

The paleogeographic zones change dramatically in the upper stratigraphic level as a centripetal drainage system appears being associated with the formation of flanking orogens and alluvial plains that accreted to them. The accommodation shallow sea basin was located in the central, northern, and eastern parts of the Siberian Craton, while its deepest part was far in the east, beyond the craton, in the Yudoma-Maya Trough. The series of facies from the orogen to the intracontinental sea is remarkable by transition from red and variegated continental molasse to a peculiar terrigenous-carbonate unit with dolomite, magnesite, and anhydrite lenses which resulted from reactions in the zone of freshwater/seawater mixing.

The deposition of the two Vendian subcomplexes had a strong geodynamic control. At the early stage (lower marine subcomplex), the craton experienced extension pulses since the early Cryogenian. Before the Vendian deposition, after local rift basins had opened in the Yenisei Ranges area, the sea stepped back, the craton had high elevations, and the deepwater sediments became exposed and subjected to denudation. It was likely during the high hypsometric stand of the craton when Early Vendian glaciers appeared, as well as the rugged erosive surface topography and intracratonic source areas. The final phase of ice sheet melting produced large lakes (seas) and was responsible for the earliest regional pericontinental paleogeographic zoning. The regional transgression of the Ognit sequence transformed the continental glaciation zones into shelves which evolved discontinuously as long as the Late Vendian orogeny. The third-order cycles (sequences) are obviously related with eustatic sealevel change. Generally, the Early Vendian deposition occurred during the final stage of rifting which appears to have controlled all Cryogenian glaciations.

At the late stage (upper continental subcomplex), some unknown terranes collided with the southwestern Siberian Craton, and the resulting peripheral mountain system became a large source of clastic material transported by rivers toward the craton. The collision was accompanied by subsidence of foredeeps, which accumulated Late Vendian molasse (up to 1500 m), and formation of forebulges with a thin (under 100–150 m) terrigenous-carbonate sedimentary cover [4, 8]. That stage was coeval with the Cadomian Orogeny and corresponded to the amalgamation of Gondwana [7]. The third-order cyclic molasse sequences record orogenic pulses and deposition stages in a peripheral foreland basin.

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Geodynamic aspect in the Neoproterozoic stratigraphy of the southern Siberian Craton

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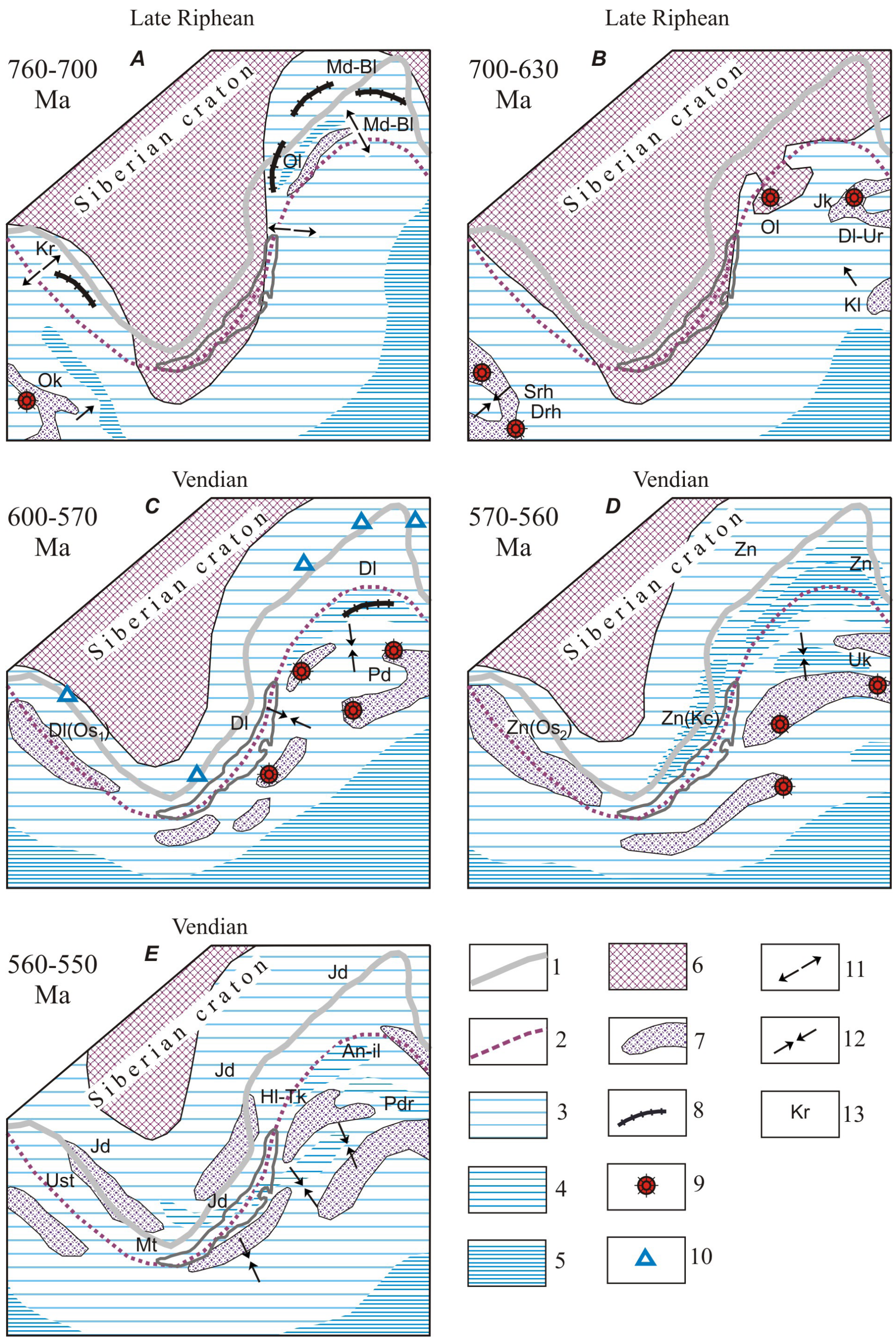

Figure 36. Tectonic paleogeographic reconstructions for the Neoproterozoic of southern Siberian Craton.

Legend: 1 – boundary between Siberian Craton and Sayan–Baikal Foldbelt; 2 – morden boundary of the Siberian Craton; 3–5 – marine body: 3 – shallow marine basins and shelf, 4 – isolated and semi-isolated basins, 5 – deep marine basins; 6 – land mass; 7 – islands; 8 – riftogenic zones with basic magmatism; 9 – subaerial bimodal volcanism; 10 – glaciated area; 11 – divergence; 12 – convergence; 13 – stratigraphic units (formations): An-il – Anangra-Iligir, Dl – Dalnyaya Taiga, Dl(Os1) – Dalnyaya Taiga (Oselok), Dl-Ur – Delun-Uran, Drh – Darkhat, Hl-Tk – Kholodnaya-Tukolami, Jd – Yudoma, Jk – Yakor, Kl – Kelayna, Kr – Karagas, Md-Bl – Medvezhevka-Ballaganakh, Mt – Moty, Ok – Oka, Ol – Olokit, Pd – Padra, Pdr – Padrokan, Srh – Sarkhoi, Uk – Ust'-Kelyana; Ust – Ust'-Tagul; Zn – Zhuya; Zn(Kc) – Zhuya (Kachergat); Zn(Os_2) – Zhuya (Oselok).

New isotope data [1, 2] call for a revision not only of the age of Late Proterozoic formations in the south of Siberian Craton, but also of the correlation charts [3]. The correlation of Neoproterozoic formations can be revised on the basis of correct isotope and radiochronological data and in view of interpretation of geodynamic situation. A new sequence of geological events for Neoproterozoic of the southern Siberian Craton is proposed to satisfy the existing information (Fig. 36).

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Tectonic setting of Riphean and Vendian basins on Siberian Craton

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The Riphean part of geological history of the Siberian Craton is connected with and is largely caused by the development of its crystalline basement structure, which composition in the results of geological surveys, drilling and geophysical works is represented by intensively metamorphosed schists and magmatic acid and basic rocks. These rocks constitute zones and blocks that consolidated in Archean and Early Proterozoic time. Although it may look like a heterogenous structure, the long break in sediment accumulation (until Late Proterozoic) diffused all the differences between the blocks, which did not influence the subsequent tectonic movements. Exceptions include isolated, sometimes extended, mainly deep-rooted faults delineating the blocks and zones of the basement, such as the Taimyr–Baikal transregional lineament being the northern extension of the Lesser Asia – Taimyr lineament established by B.B. Brok in 1957. This element of tectonics is the original submeridional axis for the Siberian Craton marked by a chain of positive anomalies of magnetic field. Since 1950s, it has been depicted in all schemes of the basement structure as the boundary between heterochronous blocks, emphasizing the old age of formation of this extended (more than 2500 km) tectonic element.

Sedimentary cover of Archean–Proterozoic Siberian Craton started to accumulate in Riphean and reached its maximum (or mature stage) in Vendian and Cambrian. Stratigraphic hiatus at the base of the Vendian, first of all, is a major angular unconformity of the Siberian Craton; therefore, the tectonic settings of basin formation in Riphean and Vendian time must have been essentially different. At early stages, deposition in the Siberian Craton was confined to narrow pericratonic basins along its western (Fore-Yenisey), southern (Fore-Patom) and southeastern (Fore-Sette-Daban) margins, as well as in the interior Angara–Kotui Rift Basin (Fig. 37) originated at the southwestern margin of the craton and traced in CDP seismic profiles in the northeastern and then northern direction along the Taimyr–Baikal transregional lineament and the junction zone between the later developed Anabar Anteclise and Tunguska Syneclise. The depth of these basins is measured in several kilometers; the width, in dozens of kilometers; and the length, in hundreds of kilometers. The sedimentary infill is aluminosiliciclastic, grading upward into aluminosiliciclastic-carbonate and carbonate, and is locally aluminosiliciclastic in the top.

The shape of the Riphean basins was predetermined by their connection to the elongated mobile belts controlled by regional faults, therefore deposition was confined to their stepped flanks (resembling one-sided grabens). The stepped structure of the Riphean basins is shown on transverse CDP seismic profiles (record time ca. 20 s) thus far received mostly for flanks of the Angara–Kotui Rift Basin. The Riphean Fore-Yenisei and Fore-Patom pericratonic basins were reactivated during Phanerozoic, which makes the reconstruction of Riphean paleotectonic motions difficult. The Fore-Sette-Daban Basin was reactivated in Carboniferous, as suggested by the results of geological survey in the Sette-Daban overthrust belt and the recent seismic survey of the adjacent territories to the west. The mapped microthrusts in Riphean (0.9 Ga) deposits in the Fore-Yenisei Basin have latitudinal strike subperpendicular to its axis suggesting a distinct tectonic episode. Most likely, the Riphean complex was overthrusted to the east along a system of large amplitude faults, with formation of submeridional crest-like folds, after the eruption of flood basalts in Early Triassic. The eastern flanks of the crest-like folds consist of steeply dipping Vendian and Lower Cambrian strata (Platonovskaya and Kostinskaya formations) overturned to the east; however, the presence of sublatitudinal pre-Phanerozoic dislocations in the Riphean deposits of the Fore-Yenisei Basin has been confirmed in outcrops on the Kamenka River (left tributary of Shorikha river), where the Riphean strata steeply (80–85°) dip to the north and are overlaid by gently dipping Platonovskaya Fm.

The discordant Riphean grabens in the junction zone between Fore-Patom Basin and Nepa-Botuoba Anteclise can be seen on CDP seismic profiles and are confirmed by boreholes. In particular, the Borehole 804 penetrated a section of poorly sorted aluminosiliciclastic rocks of pre-Vendian age (more than 600 m of thickness) that infill a narrow graben of northwestern orientation, whereas Vendian rocks sit directly on the crystalline basement in the territories adjacent to the graben. The described graben is just one of many such structures parallel to each other, some of which probably have branches. The poor sorting of the aluminosiliciclastic rocks suggests the synsedimentary formation of the Riphean grabens.

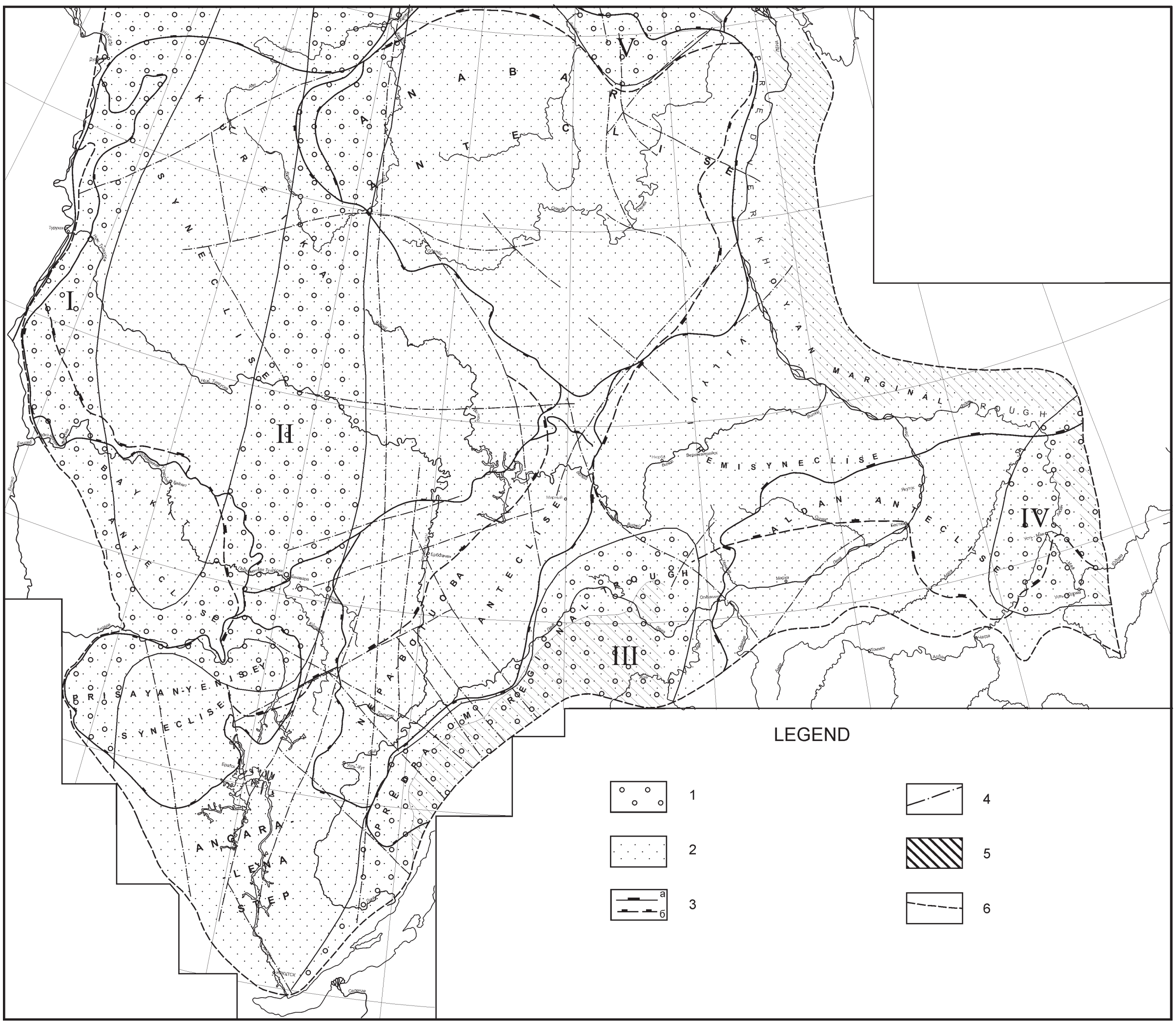

Figure 37. Riphean and Vendian–Cambrian sedimentary basins and petroleum potential territories of the Siberian Craton.

Legend: 1 – Riphean sedimentary basins (I – Fore-Yenisei, II – Angara–Kotui, III – Fore-Patom, IV – Fore-Sette-Daban, V – Udzha); 2 – Vendian–Cambrian sedimentary basins; 3 – structures at the lower boundary of the Vendian–Cambrian deposits (a) and superimposed Late Paleozoic and Mesozoic regional depressions (b); 4 – major faults; 5 – overthrust zones; 6 – petroleum potential territories.

Apart from the Riphean rift and pericratonic basins, the available geological and geophysical information also shows approximately the position of uplifted areas with thin and unevenly distributed Riphean sediments. The largest of uplifted areas is the Angara–Anabar Anteclise stretching across the entire Siberian Craton from the upper reaches of Angara and Lena rivers in the southwest across the upper reaches of Nizhnyaya Tunguska River to the lower reaches of Olenek and Muna rivers in the northeast. It is connected to the Angara–Kotui Rift Basin in the west, the Fore-Patom Pericratonic Basin and Lindenskaya Depression in the east, and the Olenek–Lena Depression in the north. The anteclise itself is characterized by a relatively thin cover of Riphean deposits (0.5–1.0 km) compared to 2.5–3.0 km or more in the adjacent basins. Other uplifted areas include the Baikit–Kotui Anteclise in the west of Siberian Craton, between the Fore-Yenisei and Angara–Kotui basins, and the Aldan Anteclise in the very southeast of the craton, between the Fore-Patom and Fore-Sette-Daban pericratonic basins. The paleorelief of the cristalline basement of the Siberian Craton, therefore, was relatively differentiated, exposed on the anteclises and dropping down to 3 km in major depressions.

In the Vendian and Cambrian time, the entire Siberian Craton and the adjacent tectonic regions were subject to subsidence and aluminosiliciclastic, carbonate and evaporitic-carbonate deposition (Fig. 37). Compared to the Riphean, this subsidence was very poorly differentiated: only the Lower Vendian strata increase in thickness on CDP seismic profiles above the Riphean basins. The tectonic movements were characterized by low amplitudes. In general, the Siberian Craton was divided into large areas of relatively slow and relatively rapid subsidence that produced anteclises and syneclises in the Vendian–Cambrian sedimentary cover (Fig. 37). Most of the western part of the Siberian Craton was involved into subsidence, with the amplitude exceeding 2.0–2.5 km by the end of Early Cambrian, with formation of a vast (over 1.5 million km^2) syneclise that completely buried the Riphean basins as well the entire Baikit–Kotui Anteclise and the southern part of the Angara–Anabar Anteclise. The Aldan Anteclise and the northern part of the Angara–Anabar Anteclise remained the only uplifted structures.

The Anabar Anteclise deserves special attention in terms of tectonic settings of Vendian and Lower Cambrian sedimentary basins, including the Lower–Middle Cambrian bituminous Kuonamka Fm. This area, where total thickness of the Lower Cambrian slightly exceeds 200 m, is bordered from the southwest and northeast by significantly thicker coeval reef formations. To the west of the reef barrier, thickness of the carbonate platform reaches 2 km; to the southwest this complex is gradually replaced by evaporites and carbonates of total thickness more than 3 km. The area of small total thickness of the Lower Cambrian is confined to the northern part of the Riphean Angara–Anabar Anteclise, whereas the region with an order of magnitude larger thicknesses, to the Riphean basins and the small Baikit–Kotui Anteclise. Arguably, the Vendian and Early Cambrian basins inherited major Riphean tectonic structures. Therefore, it seems unlikely that the Kuonamka Fm corresponds to an episode of increased subsidence. Quite the opposite, starting in Riphean, the anteclise was subject to slow gradual subsidence throughout the Paleozoic. The available paleosedimentary profiles running from the southwestern part of the Siberian Craton, where the Lower Cambrian evaporites and carbonates have thickness of more than 2.0–2.5 km, to the Anabar Anteclise in the northeast, with Lower Cambrian carbonates and bituminous sediments of total thickness 200 m, fundamentally distort the historical and tectonic setting of the studied region and require substantial correction. The amplitude of Early Cambrian subsidence of the southwestern part of the Siberian Craton was an order of magnitude (in extreme cases, several orders of magnitude) larger than that of the Anabar Anteclise. In any case, the depth of Early Cambrian basins with bituminous aluminosiliciclastic and carbonate sedimentation could not be several times larger than in the coeval basins with evaporite and carbonate sedimentation.

Cloudina–Namacalathus–Korilophyton association in the Vendian of Altai–Sayan Foldbelt (Siberia)

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The *Cloudina–Namacalathus* association was first described from the Upper Proterozoic Nama Gr of central and southern Namibia. In the following years, the geography of its occurrences was significantly widened. *Cloudina* now has a worldwide distribution in Late Vendian deposits (Namibia, Brasilia, Canada, China, Oman, Spain, Russia and others) [1–5] constrained by U–Pb-zircon dates of 548.8 ± 1 [4] and 542.0 ± 0.3 Ma [6] from Namibia and Oman. In Russia, the association was found in the Vostok-3 borehole section drilled in the Fore-Yenisei Petroleum sub-Province (Tomsk Region) [7]. We discovered new occurrences of *Cloudina* and *Namacalathus* in association with calcareous algae *Korilophyton* in several parts of the Altai–Sayan Foldbelt (Kuznetsk Alatau, northwestern part of Eastern Sayan, Gornaya Shoriya) that prove the Late Vendian age of the Tarzhul', Anastas'ino, West Siberian and Belka formations.

Kuznetsk Alatau. Eastern side of the Kuznetsk Alatau Ranges is characterized by a continuous section from Riphean to Lower Cambrian with abundant microphytolites, stromatolites, Newlandian problematic fossils, Ediacaran fossils, calcareous algae, sponge spicules, very good exposure and easy access [8, 9]. *Cloudina* was found in the right bank of the Karasug Log, at the base of Tarzhul' Fm. Specimens showing the eccentric nesting of funnels up to 6 mm in length and 2.5 mm in width flaring out at the apertural end can be referred to as *Cloudina hartmanae* (Fig. 38: D, E), whereas specimens more than 3 mm in length and 1.5 mm in width with longitudinal ribs and nor showing the eccentric structure are assigned to *Cloudina carinata* (Fig. 38: F). The middle part of Tarzhul' Fm in the Podtemnyi Log section yielded calcareous algae *Epiphyton*, *Proaulopora*, *Subtifloria*, *Renalcis* and *Girvanella* suggesting correlation with Lower Cambrian [8]. The upper part of Tarzhul' Fm is represented by dolomites, calcareous dolomites and gray quartzites with microphytolites *Vesicularites miscellus*, *V.* aff. *concretus*, *V. pusillus*, *V. filiformis*, *Conferta tuvaensis*, *Nubecularites antis* and small skeletal fossils *Cloudina*. The Tarzhul' Fm is over 800 m thick. The underlying essentially carbonate Tyurim Fm (800–900 m) contains the problematic fossils *Camasia fruticulata*, *C. crispa*, *Newlandia subtila*, *Tridia koptevi*, *T. salebrosa*, *Tricuspidatia trigonata*, several species of *Plumfascicularia* known from the Vendian of the Patom Highlands, interior parts of the Siberian Craton, Lesser Khingan, and Tian Shan [9, 10].

Northwestern part of Eastern Sayan (Mana Depression). The Anastas'ino Fm crops out along the Kolba and Kuvai rivers. In the stratotype near the village Anastas'ino, the formation can be divided into four members [8]. Member 1 (320–360 m) is represented by green-gray graywackes, coarse-grained sandstones and silty limestones. Member 2 (400 m) comprises alternating black limestones and siltstones with rare calcareous graywackes. Member 3 (over 400 m) consists of interstratified black limestones and packages of alternating limestones and siltstones. The upper part of the member 3 yielded *Namacalathus*, *Cloudina* and *Korillophyton* (Fig. 38: A–C, I). Member 4 (210 m) is represented by dark gray organogenic limestones (bioherms, biostromes etc.) with rare siltstones. Abundant calcareous algae *Epyphyton* in this member suggest correlation with Lower Cambrian [8].

Gornaya Shoriya.–Vendian deposits in this region are represented by the Kabyrza, West Siberian and Belka formations [8]. The Kabyrza Fm (>1000 m) is dominated by black, fine laminated and platy limestones. The West Siberian Fm (800 m) comprises alternating organogenic (stromatolithic, microphytolithic) dolomites and limestones. The upper part of this formation yielded *Cloudina* (Fig. 38: G, H). The overlying Belka Fm consists of four members. Member 1 is represented by dolomitic, coarse-clastic gray silicified breccia and dark gray to greenish gray quartzites. Member 2 comprises gray fine-clastic breccia interstratified with dark-gray knotty phosphatic dolomites that contain *Cloudina hartmanae*. Member 3 consists of alternating phosphatic gray and dark gray brecciated dolomites and limestone-dolomitic phosphorites. Member 4 is represented by pale gray limestones, dolomites, and gray massive phosphatic dolomites that contain *Cloudina hartmanae*. The formation is conformably overlaid by the Karchit Fm containing Lower Cambrian archaeocyathids.

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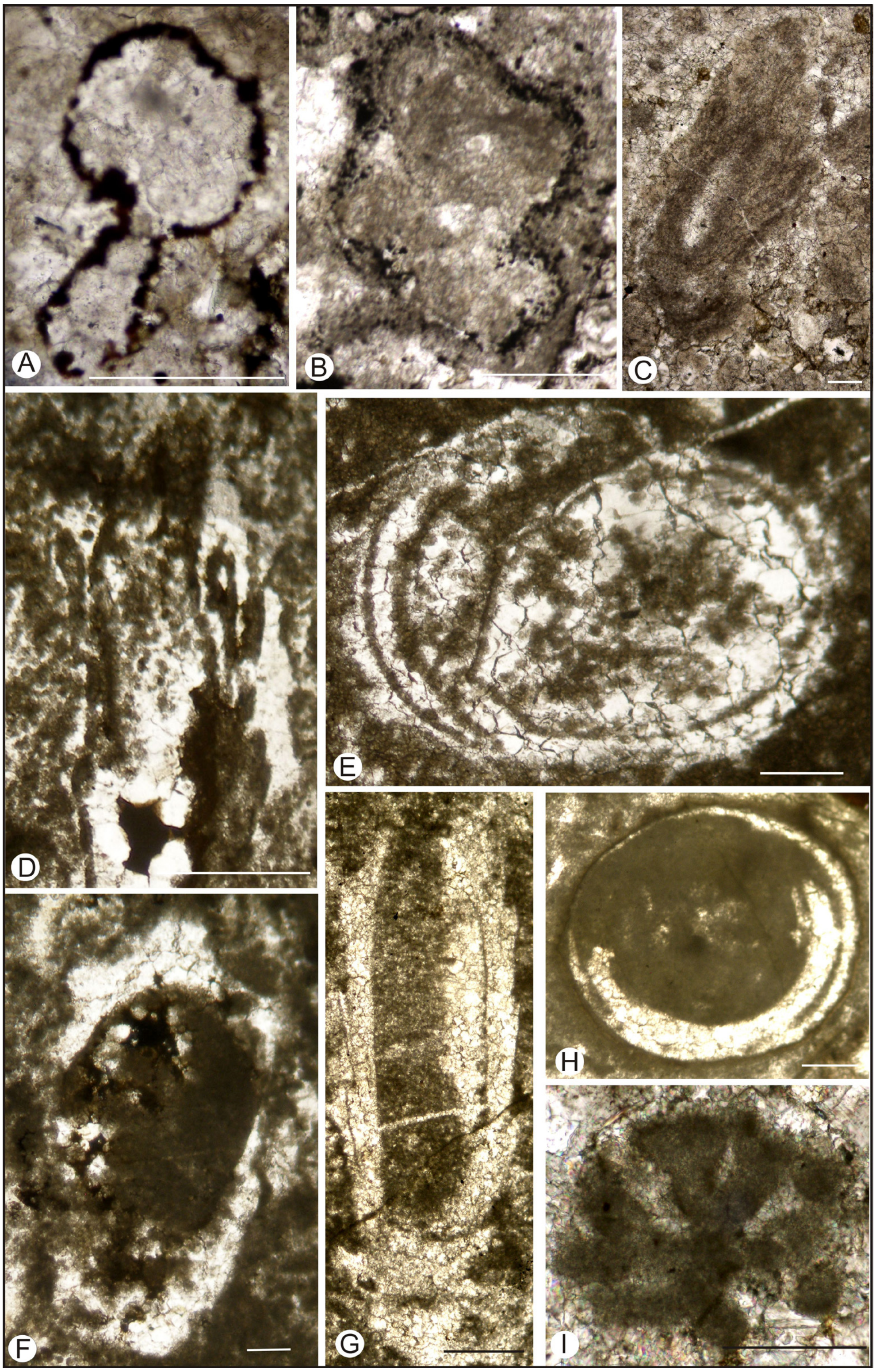

Figure 38. A, B: *Namacalathus* sp.; Anastas'ino Fm; Eastern Sayan. C: *Cloudina* sp.; Anastas'ino Fm; Eastern Sayan. D, E: *Cloudina hartmanae*; Tarzhul' Fm; Kuznetsk Alatau. F: *Cloudina carinata*; Tarzhul' Fm; Kuznetsk Alatau. G, H: *Cloudina hartmanae*; West Siberian and Belka formations; Gornaya Shoriya. I: *Korilophyton* sp.; Anastas'ino Fm; Eastern Sayan. Scale bar: 125 µm.

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Late Vendian (Ediacaran) index-fossil *Namacalathus* in the Nepa–Botuoba Anteclise of eastern Siberia (parametric borehole Chaikinskaya-279)

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Borehole Chaikinskaya-279 is located in Nyuya Zone of the Fore-Patom–Vilyui Area of Sibirean Craton. The Vendian aluminosiliciclastic and carbonate succession in this area comprise the Bilir, Yuryakh, Kudulakh, Uspun, Biuk, Parshin, Talakh, Khoronokh and Betichin formations that overlie the Riphean Talakan Fm and are overlaid by the Lower Cambrian Yuryagin Fm [1]. Nearly all of these stratigraphic units are represented in the section of borehole Chaikinskaya–279, except for the Khoronokh and Betichin formations.

Talakan Fm (2041–1910 m): alternating red fine laminated mudstones and lenticular greenish gray siltstones, with pale-, dark- or greenish gray planar- and wave-bedded sandstones and siltstones in the upper part, locally with small (up to 1 cm) pebbles. The formation sits of crystalline basement represented by plagiogranites, quartzites, amphibolites, metagabbro and granosyenits.

Talakh Fm (1910–1782 m): interstratified pale, yellowish and greenish gray medium- to coarse-grained planar- and wave-bedded sandstones, locally with well-rounded quartz gravels and small pebbles (up to 3 cm) and dark gray shale units, in the lower part of the section (1910–1820 m); alternating greenish gray shales and planar-, wavy-, lenticular-, and cross-bedded sandstones in the upper part of the section (1820–1782 m).

Parshin Fm (1782–1388 m): lower member (1782–1630 m) comprises gray, greenish gray, pale gray fine laminated, lenticular and cross-bedded siltstones with soft-sediment deformation structures, interstratified with packages (up to 1.2 m) of dark gray and black dolomites and siltstones and a unit (1683.8–1677.2 m) of gray dolomitic sandstones with mud clasts (tempestites?); upper member (1630–1480 m) consists of gray, dark gray, greenish gray, pyritized, planar-bedded muddy dolomites, dolomitic marls, dolomitic shales and siltstones, interstratified with greenish gray and reddish brown dolomites, siltstones, and muddy limestones with anhydrite inclusions in the upper part.

Biuk Fm (1480–1388 m): wavy-, lenticular-bedded dolomites with anhydrite intercalations (1480–1462 m; Telgespit Mb), coarse-crystalline halite (1462–1414 m; Torsal Mb) and dolomite and anhydrite breccia with anhydrite intercalations (1414–1388 m; Ayan Mb). Contains calcareous algae *Renalcis granosum* (1392.27–1387.8 m).

Uspun Fm (1388–1281 m): gray, dark gray, planar-, wavy-, and lenticular-bedded dolomites, muddy dolomites, dolomitic marls, dolarenites, with individual grains and intercalations of anhydrites and dolomite-anhydrite breccia. Fossil assemblage includes goblet-shaped *Namacalathus* sp. (1346.75–1344.75 m), conical tubes (1346.75–1344.75 m), calcareous algae *Renalcis* sp. (1387.8–1380.96 m), *Korilophyton* sp. (1346.75–1344.75 m), *Gemma* sp. (1346.75–1344.75 m), microphytolites *Radiosus* (1361.7–1357.7 m), *Ambigolamellathus horridus* (1354.9–1353.5 m), *Hierogliphites mirabilis* (1354.9–1353.5 m), *Volvatella vadosa* (1380.98–1374.69 m) (Fig. 39).

Kudulakh (1281–1198 m) and **Yuryakh (1198–1110 m)** formations are not represented in the core samples. According to borehole geophysical survey data and drilled cuttings description, these intervals consist of gray and pale brownish gray dolomites and muddy dolomites of different grain size, with intercalations and individual grains of anhydrite.

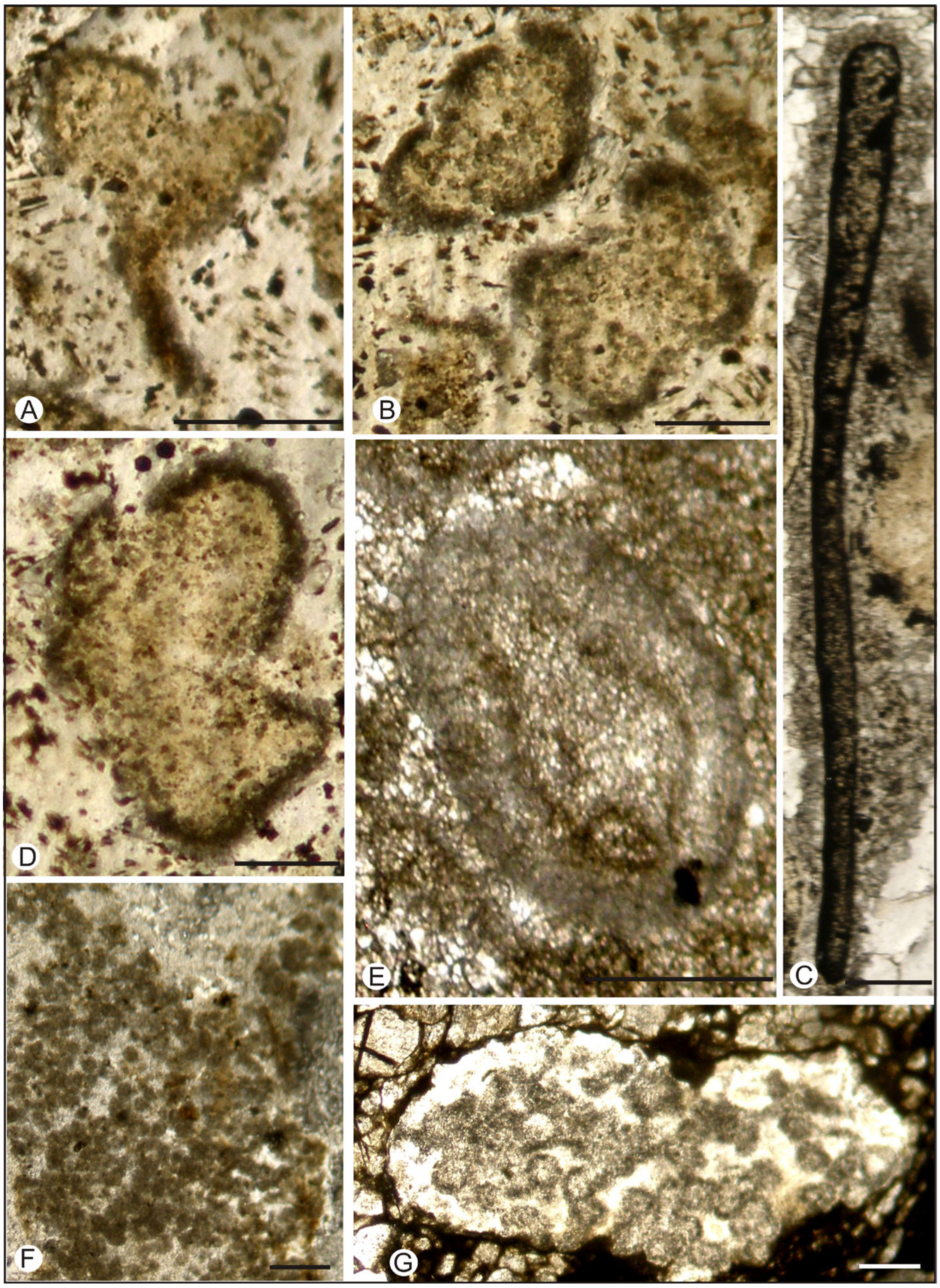

Figure 39. Fossil assemblage of the Uspun Fm (parametric borehole Chaikinskaya-279).
A, B, D: *Namacalathus* sp.; specimen Ч-279-30, depth 1344.75–1346.75 m (1.45 m from core top). C: unidentified elongated subconical skeletal fossil; specimen Ч-279-35, depth 1357.7–1361.7 m (1.4 m from core top). E: *Ambigolamellathus horridus*; specimen Ч-279-31, depth 1353.5–1354.9 m (core top). F: *Gemma* sp.; specimen Ч-279-30, depth 1344.75–1346.75 m (1.45 m from core top). G: *Renalcis* sp.; specimen Ч-279-37, depth 1380.96–1387.8 m (2.15 m from core top). Scale bar: 250 μm

Goblet-shaped fossils *Namacalathus* are widely distributed in Upper Ediacaran strara of Oman, Namibia, Canada and now have been found in the petroliferous Upper Vendian strata of Western Siberia (boreholes Vostok–3 and Chkalovskaya–501) [2–4]. In these areas the fossils co-occur with *Cloudina* [5, 6]. U–Pb-zircon dates 548.8±1 [7] and 542.0±0.3 [8] from the host rocks in Namibia and Oman constrain the interval of *Namacalathus* distribution, which corresponds to the Nemakit-Daldynian Regional Stage. In the section of borehole Chaikinskaya–279, *Namacalthus* is associated with microphytolites *Ambigolamellathus, Volvatella zonalis, Hierogliphites mirabilis* described from the Yudomian (Vendian) strata of Siberian Craton [9]. The Uspun Fm is correlated with the Katanga Fm of Irkutsk Amphitheatre (southern part of Siberian Craton) that yielded small skeletal fossils and vendotaenids of Nemakit-Daldynian age [10]. The lower boundary of the Danilovo Regional Stage of the interior parts of Siberian Craton [1], therefore, corresponds to the base of Nemakit-Daldynian Stage, which has important implications for interregional and global correlation.

This study was supported by the Russian Foundation for Basic Research (project no. 10-53-00953).

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New paleontological data from the Upper Vendian of the Chkalovskoe Territory of the Fore-Yenisei segment of the West Siberian Megabasin (boreholes 10, 17, 26, 501)

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The Trofimuk Institute of Petroleum Geology and Geophysics has been conducting revision of stratigraphic age of the oldest strata in the basement of West Siberian Geosyncline [1, 2]. Until recently, the oldest rocks (except for the Fore-Yenisei sub-Province) were thought to be located in the Poludennaya Territory in the Var'egan structural facies region [3] and correlated with uppermost Cambrian [4]. The Chkalovskoe petroleum-condensate deposit is related to an uplifted area in the western part of Ust'-Tym Depression. According to geophysical and geological survey, the basement of this erosional tectonic uplifted area has complex structure. This uplift can be divided onto several blocks demarcated by a system of low-amplitude faults; however, the sections of the boreholes are all unique and do not correlate with each other. Presumably, the Chkalovskoe Uplift consists of several terranes of Siberian–Chinese region. The borehole 501 recently drilled in the central part of Chkalovskoe Territory is characterized by a relatively detailed core recovery in the interval of 3000.0–2938.3 m and yielded new paleontological information about the age of pre-Mesozoic part of the section that allowed a revision of the core from boreholes 10, 17 and 26.

The paleontological association is represented by four types of fossils: (i) heavily recrystallized goblet-shaped structures (up to 450 μm high; 150–300 μm wide) with a circular opening and side holes that can be referred to as members of the genus *Namacalathus* (Fig. 40: A–E, L); (ii) small irregularly branching

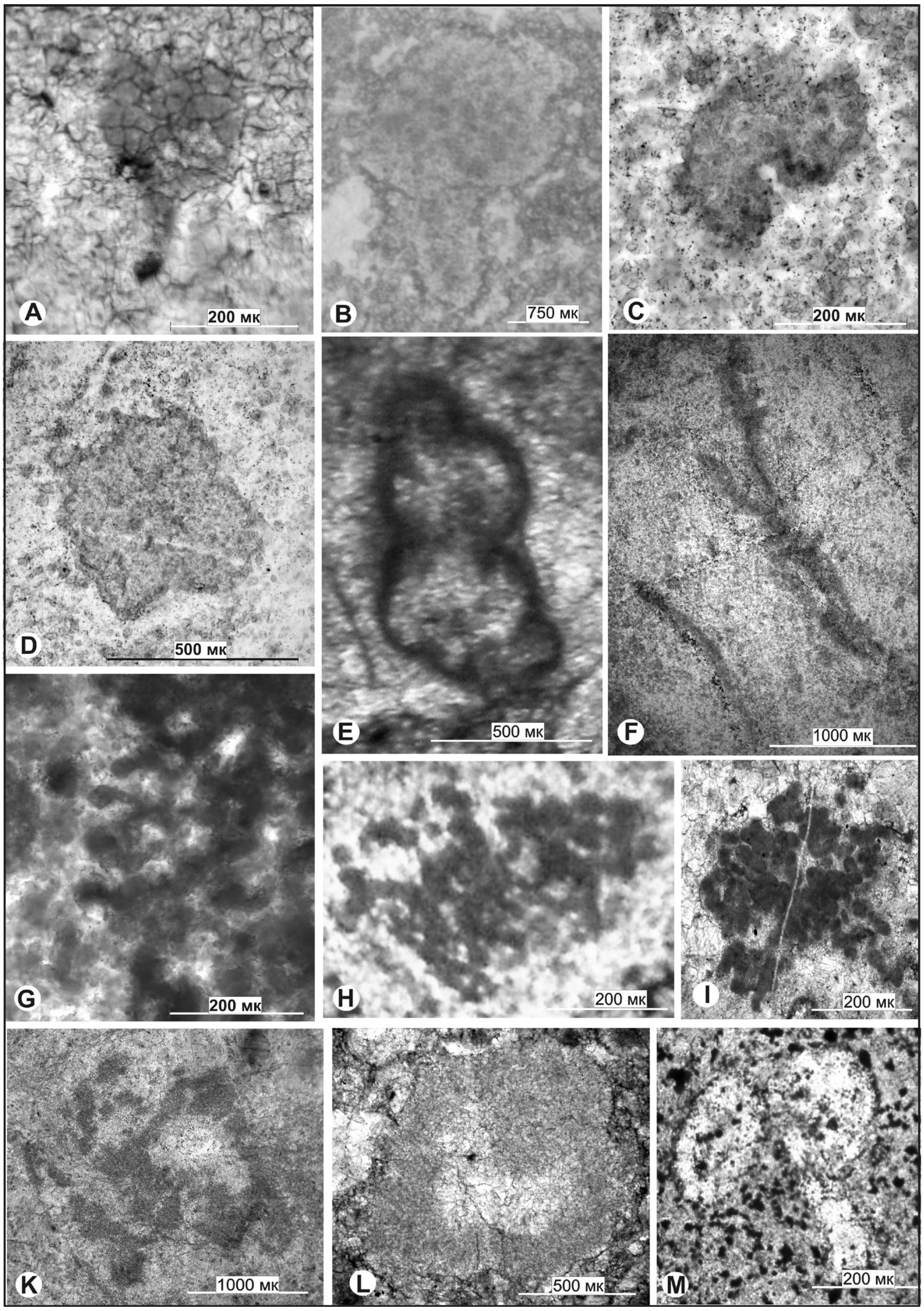

Figure 40. A–E, M: *Namacalathus* sp.: **A–D**: borehole Chkalovskaya-501, slide Чк 501-10, depth 2976.6–2997.2 m: **E**: transverse cross-sectional view; borehole Chkalovskaya-17, slide Чк 17-4, depth 3042.8–3047 m; **M**: longitudinal cross-section; borehole Chkalovskaya-17, slide Чк 17-9, depth 3040.8–3042.8 m. **F**: *Cloudina* sp.; borehole Chkalovskaya-501, slide Чк 501-9, depth 2976.6–2997.2 m. **G–I**: *Korilophyton* sp.; short irregular branches: **G**: borehole Chkalovskaya-501, slide Чк 501-9, depth 2976.6–2997.2 m; **H, I**: borehole Chkalovskaya-17, slide Чк 17-2, depth 3042.8–3047 m. **K**: *Renalcis* sp.; borehole Chkalovskaya-26, side Чк 26-4, depth 3090.8–3093.8 m. **L**: *Renalcis granosus*; borehole Chkalovskaya-26, slide Чк 26-14, depth 3064.8–3067.8 m.

structures (up to 70 μm) that can be referred to as calcareous algae *Korilophyton* (Fig. 40: G–I); (iii) tubular structures reminiscent of *Cloudina* (Fig. 40: F); and (iv) nodular structures with a pelitomorphic sheath and radial structure bearing similarities to calcareous algae *Renalcis* (Fig. 40: K). Small skeletal fossils *Cloudina* and *Namacalathus* are globally distributed in the rocks of Late Ediacaran age (Namibia, Brazil, Canada, Oman, Spain, China and others) [5]. Calcareous algae *Korilophyton* are characteristic of the Nemakit-Daldynian strata of Siberian Craton and Altai–Sayan Foldbelt [6]. Therefore, the fossiliferous rocks in the Chkalovskoe Territory penetrated by boreholes 10 (depths 2965.9–2962.9 m), 17 (depths 3047–3040.8 m), 26 (depths 3093.8–3090.8 m and 3067.8–3064.8 m) and 501 (depths 2997.2–2976.6 m) can be correlated with Upper Vendian. Similar fossils have recently been found in the Upper Vendian Kotodzha and Raigin formations in the borehole Vostok–3 section of the Fore-Yenisei sub-Province [1, 2].
This study was supported by the Russian Foundation for Basic Research (project no. 10-53-00953) and the Integration of Siberian and Ural branches of the Russian Academy of Sciences and Ministry of Education and Science (project no. 7 "Geological structure and petroleum content of the basement of West Siberian Mesozoic–Cenozoic sedimentary basin and the adjacent foldbelts").

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Hydrogeology of the Yurubchen–Tokhomo Zone of petroleum accumulation

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In the scheme of hydrogeological demarkation, the territory of Yurubchen–Tokhomo petroleum accumulation zone is located in the southwestern part of the Tunguska Artesian Basin of East Siberian Artesian Area [1]. Hydrogeology of this zone is complicated by fault tectonic, presence of flood basalts, and high level of rock salinization of the geological section (especially Lower and Middle Cambrian). The conditions of water exchange and the chemistry of groundwater in zone of hypergenesis are strongly influenced by topography and the presence of permafrost. Despite the intensification of exploration works on the Siberian Craton, study of the hydrogeological conditions is extremely uneven: the most studied are the southern areas, whereas the territory of Baikit Anteclise is very poorly studied in terms of hydrogeology, especially in the upper part of geological section. The latest scheme of hydrogeological stratification made in relation to the conditions of the studied area is described in works by M.B. Bukaty [2]. According to this scheme, the hydrogeological horizons and complexes are organized into three hydrogeological formations (from top to bottom): over-salt, saliferous, under-salt.

The **over-salt groundwater formation** discharges to the surface. Water of this formation being part of free water exchange zone is widely distributed. Total thickness of this zone is not more than 200–400 m and depends on roughness of the relief, rock lithology, thickness of permafrost. Recharge is supplied by infiltration of precipitation at the watershed areas, partly due to the seasonal thawing of permafrost and ground water inflow from the zone of hindered water exchange, whereas the discharge occurs in river valleys. The speed of groundwater filtration depends on filtration features of rocks, and the behavior depends on climatic conditions.

Water in the Quaternary sediments is widespread, fresh, odorless and colorless, with a substantial admixture of organic matter sometimes of iron, hydrocarbonate, magnesium, calcium, rare sodium; as an example, the formula of the salt composition of groundwater sources on the Yurubchen River (flow rate 10 L/s) is:

$$0.23\,\frac{(HCO_3)^{-}96.2\ \ Cl^{-}3.8}{Ca^{2+}50.5\ \ Mg^{2+}34.4\ \ Na^{+}12.4\ \ (NH_4)^{+}1.9\ \ Fe^{3+}0.8}.$$

Water in the underlying Ordovician aquifer system is fresh, hydrocarbonate sodium-magnesium-calcium (calcium-magnesium), alkaline. In the area of shallow groundwater occurrence many springs are coming from rocks to the surface such as in the valley of Dulisma River, where the spring 13-218 (O_1 pr) has been tested with a discharge rate of 4–8 L/s:

$$0.36\,\frac{(HCO_3)^{-}87.8\ \ Cl^{-}8.6\ \ (SO_4)^{2-}3.6\ \ (CO_3)^{2-}0.1}{Mg^{2+}42.6\ \ Ca^{2+}28.8\ \ Na^{+}28.4\ \ (NH_4)^{+}0.2}.$$

Areas of carbonate rocks have widely developed karst. Mineralized water is sometimes discharged from the the zones of the Ordovician rock destruction.

Groundwater in the Middle–Upper Cambrian ($Є_{2\text{-}3}$ ev) is fresh; it becomes salty with depth and changes into brine. The chemical composition varies (chloride, less hydrocarbon, hydrocarbon-sulphate calcium-sodium); for example, the water salinity was measured as 0.4 g/dm^3 in the spring 6028 (Upper Evenki Fm) on the Chavichine River show, and as 2.4 g/dm^3 in the spring 8005 (Middle Evenki Fm) on the river Nizhnyaya Madre:

$$0.4\,\frac{(HCO_3)^{-}66.5\ \ (SO_4)^{2-}31.8\ \ Cl^{-}1.6\ \ (CO_3)^{2-}0.1}{Na^{+}58.6\ \ Ca^{2+}36.5\ \ Mg^{2+}4.9},\qquad 2.4\,\frac{Cl^{-}81.2\ \ (HCO_3)^{-}16.1\ \ (SO_4)^{2-}2.7}{Na^{+}78.9\ \ Ca^{2+}14.8\ \ Mg^{2+}6.2\ \ (NH_4)^{+}0.1}.$$

Chemical composition of the groundwater in the lower part of over-salt sediments is represented mainly by sodium chloride with subsidiary amount of calcium and magnesium and low content of bromine. Water mineralization varies between 72–93 g/dm^3 and 259 g/dm^3, generally increasing with depth. For example, the chloride sodium brine with mineralization of 95.5 g/dm^3 was sampled from the well 12 in the Kuyumba Territory at the depth of 228 m:

$$95.5\,\frac{Cl^{-}93.8\ \ (SO_4)^{2-}6.1\ \ (HCO_3)^{-}0.1}{Na^{+}93.4\ \ Mg^{2+}5.8\ \ Ca^{2+}0.5\ \ K^{+}0.3}.$$

Some of the wells yielded highly metamorphosed, very strong brines with the salinity of up to 344 g/dm^3 of chloride sodium-calcium composition.

The **saliferous formation** is characterized by stagnant hydrodynamic conditions and, hence, high salinity and metamorphization of chemical composition of brines. It reaches the thickness of 1650–1800 m and is almost devoid of collectors, except for some sporadic watered, mostly poorly permeable Lower Litvintsevo, Bulai, Upper Belaya, Lower Belaya and Osa horizons in various muddy and sulphate-rich limestones and dolomites

Brines that fill the permeable horizons in the saliferous hydrogeological formation are mostly sedimentary in origin and distinct from the overlying brines in their high mineralization (typically from 250 to 450 g/dm^3) and high metamorphosed chloride calcium sodium and calcium compound. For example, brine sample collected from the well 2 in the Ust-Kamov Territory at a depth of 380 m ($Є_{1\text{-}2}$ lit) has the salinity of 147.1 g/dm^3, whereas the brine from the interval of 1965–1977 m in the well 156 in the Madra Territory ($Є_1$ us (os)) has the salinity of 404.3 g/dm^3:

$$147.1\,\frac{Cl^{-}99.1\ \ (SO_4)^{2-}0.7\ \ (HCO_3)^{-}0.1\ \ Br^{-}0.1}{Na^{+}74\ \ Ca^{2+}24.7\ \ Mg^{2+}1.2\ \ (NH_4)^{+}0.1},\qquad 404.3\,\frac{Cl^{-}98.6\ \ Br^{-}1.2\ \ (HCO_3)^{-}0.2}{Ca^{2+}62.9\ \ Na^{+}18.2\ \ Mg^{2+}12.9\ \ K^{+}5.2\ \ (NH_4)^{+}0.8}.$$

In the **under-salt hydrogeological formation**, salinity of the brines from Mezo- and Neoproterozoic (Riphean) productive horizons gradually decreases to 180–290 g/dm^3. Their cationic composition also changes to sodium-calcium, and then to calcium-sodium:

$$192.4\,\frac{Cl^{-}99.4\ \ (SO_4)^{2-}0.3\ \ Br^{-}0.2\ \ (HCO_3)^{-}0.1}{Na^{+}60.3\ \ Ca^{2+}29\ \ Mg^{2+}10.2\ \ (NH_4)^{+}0.5},$$

(sampled from well 19, depths 2347–2375 m, Yurubchen Fm, Riphean (R_2 jr), Yurubchen Territory).

These brines have a mixed, sedimentary and paleo-infiltration origin. Groundwater all over the area is characterized by stagnant hydrodynamic conditions. The high degree of hydrogeological isolation of the petroliferous section is provided by the thick evaporite deposit of Usol'e Fm.

The Yurubchen–Tokhomo petroleum accumulation zone is located on the southwestern margin of the Tunguska Artesian Basin potentially productive for industrial brines. Despite having low concentrations of mineral components, compared to northern areas, this zone possesses sufficient resources of K, Mg, Br, I, B, Sr, Li, Rb and other components in the brine [3].

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Lithology of vendian terrigenous reservoirs of the south of the Siberian Craton

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Vendian aluminosiliciclastic deposits of the southern Siberian Craton is the most prospective stratigraphic level for oil and gas exploration in Eastern Siberia. Lithological factor significantly contributed to the formation of these high-capacity reservoirs. Most of the hydrocarbons are confined to the Upper Vendian petroliferous complex, in particular to the Parfenovskiy productive horizon and its analogs. Deep drilling in central regions of the Angara–Lena Step (ALS) and in the northeastern Nepa–Botuoba Anteclise (NBA) elucidated the composition and structure of these collectors [1].

Parfenovskiy horizon (60 m) at the base of the Upper Chora Fm is widely distributed on the territory of ALS. In the central part of the ALS (Levoberezhnoe Feild), it has a mixed structure and consists of unevenly alternating sandstones, siltstones, and mudstones. In general, the horizon is divided into two parts. The lower part is characterized by interstratified mudstones and siltstones, with rare sandstones, deposited in storm agitated shallow shelf environment gradually passing into a bar system, which in turn is replaced by tidal flats and tide-influenced fluvial environment. Filtration and capacitive properties (FCP) of sandstones in the lower part of the horizon are low. The upper part of the horizon consists mainly of fine- to coarse-grained, poorly and medium sorted sandstones in the west and is dominated by medium- to fine-grained sandstones in the eastern sections, with intercalations of siltstones and mudstone. Sections are dominated by litito-feldspar-quartz sandstones (mostly quartz sandstones in the northeast), with porous-film clay and clay-ferruginous, regenerative quartz and poikilitic dolomite types of cements. The poorly sorted coarse-grained sandstones in western sections accumulated in a coastal alluvial plain, predominantly fluvial environment. They contain high clayey-ferruginous cement (up to 20%) with almost complete absence of other types of cement and high porosity (10–20%). The eastern sections of the upper part of the horizon correspond mainly to tide-influenced alluvial-deltaic environment. Episodic cessation of channel activity was accompanied by fine aluminosiliciclastic deposition in shallow bays and/or tidal flats. Siltstone and mudstone layers and packages (up to 5 m) in the eastern sections reduce the quality of reservoir rocks in this part of the field. The porosity of sandstone is also low, not more than 5%. Nevertheless, poorly sorted fluvial sandstones are ubiquitous, with mostly clay and clay-ferruginous cement (5–10%) characterized by good porosity (5–12%). The bar system in the northeast consists of quartz sandstones with minimal development of cement and low porosity (≤5%). By the end of Parfenovskiy time, the coastal-marine regime was restored, as suggested by borehole sections with a trend of increasing quartz clastic material, quartz regeneration and poikilitic dolomite cement up the section, accompanied by decreasing FCP.

Botuobinskiy horizon (30 m) is the major Vendian terrigenous collector of the NBA corresponding to the Lower Byuk Fm. It is associated with a major oil and gas field, the Srednebotuobinskoe. The horizon can be divided into three parts. The lower part consists of interstratified mudstones and sandstones. The middle part is composed of dark, oil-saturated, fine laminated sandstones characterized by alternating siltstone and coarse-grained sandstone fractions. Each lamina shows good sorting of the clastic material. The alternation consists of coarsening-upward meter-scale packages (0.5–1.5 m), which is typical for bar deposits. In general, this part is dominated by medium- and fine-grained fractions. The upper part of the horizon is represented by gray poorly and medium sorted sandstones (mostly coarse- and medium-grained fractions), with intercalations of thin (up to 2 mm) mudstone layers, and is characterized by gradual transition to the overlying dolomite. The section also includes coarsening-upward meter-scale packages. Depositional environment of the Botuobinskiy horizon is reconstructed as a large bar system periodically affected by tidal currents and waves. Sandstones of the Botuobinskiy horizon are quartz and feldspar-quartz in composition. Up in the sequence the amount of feldspar decreases from 20% to 2–5%. Sandstones are characterized by extremely low (first percents) content of cement, which is represented by poikilitic dolomite, porous film and film-chlorite-quartz hydromicaceous and regenerative types. The content is minimum in the rocks of the most productive middle part (1–5%). The dolomite poikilitic cement is most widely developed in the lower and upper parts of the horizon, where its content reaches 10%. The lower part has slightly higher content of clay cement (3–5%). In general, the entire horizon is characterized by good reservoir properties. The oil-saturated sandstones of the middle part have the highest porosity (16–20%) and permeability (≤2000 mD) values. The FCP of the sandstones in the lower and upper parts, in general, are slightly lower (8–13% and ≤500 mD), which is associated with the development of dolomite poikilitic cement.

To conclude, the best reservoir properties in the Parfenovskiy horizon are found in the alluvial-deltaic sediments, whereas the productive sandstones of the Botuobinskiy horizon represent a large bar system. Formation of the Parfenovskiy reservoirs was primarily due to the composition of the rocks and to a lesser extent, grain size and grading. FCP of sandstones of the Botuobinskiy horizon, on the contrary, were mainly controlled by type of cement, grain size and grading.

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Aldan–Maya Pericratonic Syneclise of the Siberian Craton: tectonic setting, structural- and petroleum-geological demarkation

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Riphean–Cambrian sedimentogenesis on the southeastern margin of Siberian Craton was confined to a single basin of area more than 200000 km^2, which underwent substantial restructurazation as a result of Phanerozoic tectonic and geodynamic activity, but preserved the original lithological and stratigraphic features. The author erects the Aldan–Maya Pericratonic Syneclise which includes the area of Neoproterozoic petroleum prospective aluminosiliciclastic-carbonate complexes of the southeastern margin of Siberian Craton and the adjacent southern segment of Verkhoyan Foldbelt (Fig. 41) [1]. The syneclise includes the Uchur Gr of rift graben structures (Uchur, Algoma, Toki, Maimakan, Amulikan, Verkhneugayan, Verkhnebatomga) [2] located within the disintegration zone of the eastern Aldan–Stanovoi Shield into Idyuma-Khainkan, Tyrkan, Omnin-Batogma terranes; platform structures of the Aldan–Maya Megatrough (Maya, Ust-Maya, Khandyga depressions); fold-thrusted structures of the Yudoma–Maya (Tompo–Maya) Aulacogen (Kyllakh and Sete-Daban structural zones), and South-Verkhoyan synclinorium of the Verkhoyan Foldbelt [1]. Structural-geologic demarkation of the syneclise is shown in Figure 42. All the structures except the Uchur rift zone are prospective for oil and gas, bitumen, and asphaltic rocks [3]. Structures of the Yudoma–Maya (Tompo–Maya) Aulacogen are of an increased interest in terms of gas hydrate exploration.

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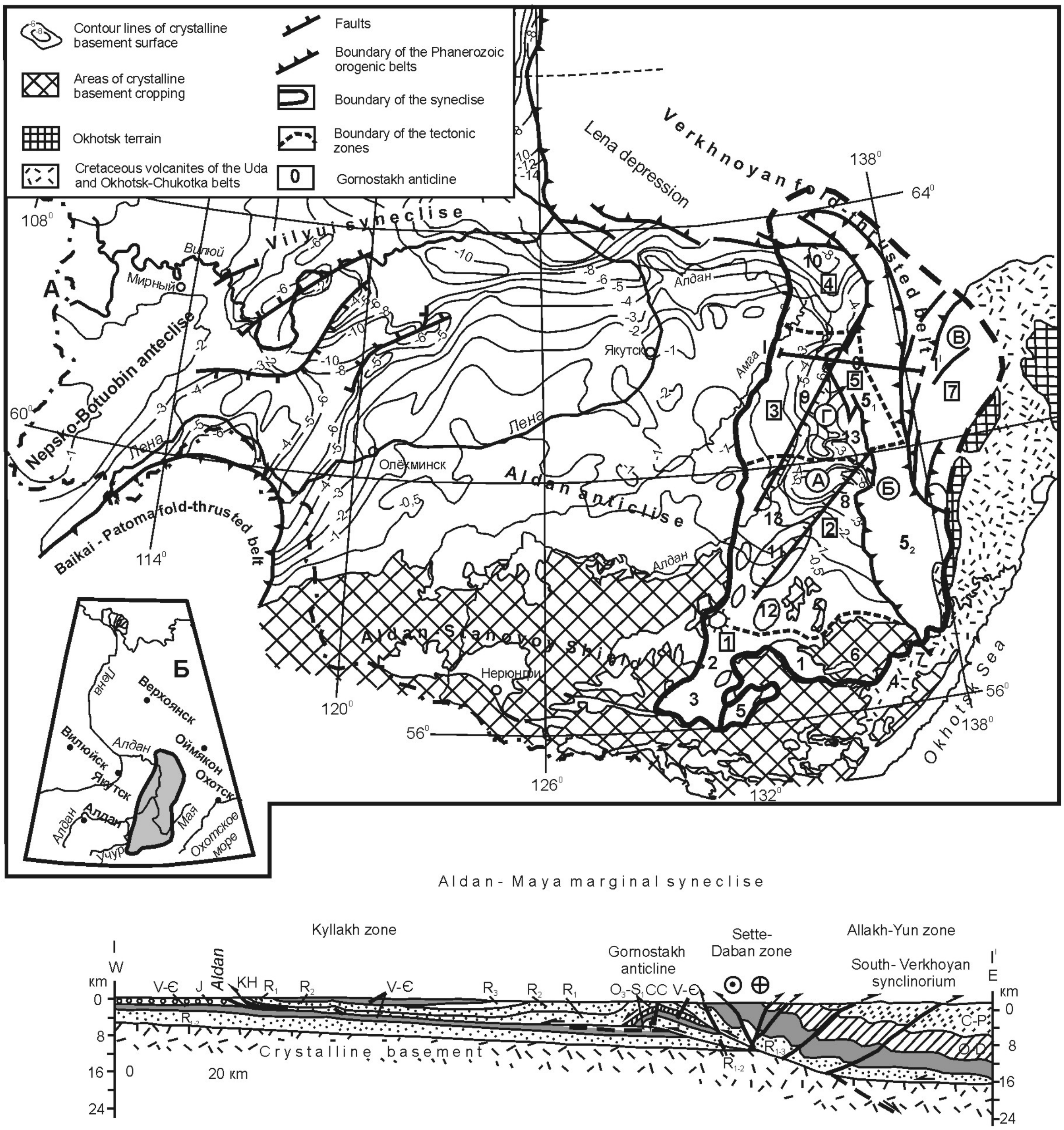

Figure 41. Location and structure of the Aldan–Maya Pericratonic Basin (marginal syneclise).

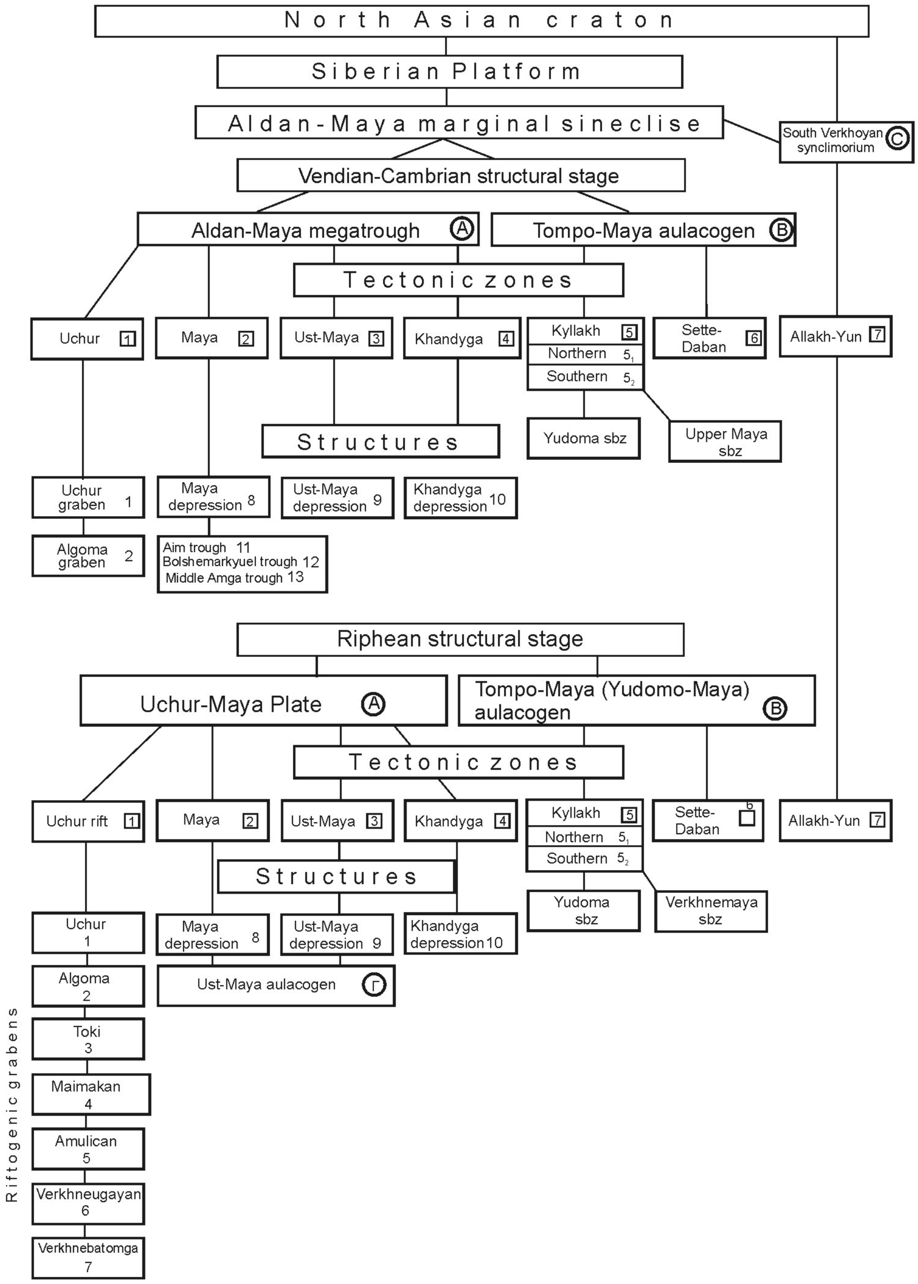

Figure 42. Structural-geological demarkation of the Aldan–Maya Perocratonic Basin (marginal synecllise).

New discoveries in Nambia, the end of the Vendians (Ediacarans)

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Since 2003 a multinational team involving many researchers under the umbrella of UNESCO Projects IGCP 493 and currently IGCP 587 have recovered a wealth of both paleoenvironmental and biota data from southern Namibia relating to the very end of the great radiation of early animals in the Late Neoproterozoic. In particular, large samples of *Pteridinium* and forms related to both *Ernietta* and *Rangea* have been found in quite specific microenvironments, some in situ while others transported. As a result there is now a better understanding of the environmental preferences of each of these taxa as well as their detailed morphology, and add to that understanding of the changes occurring in the dynamic oceans that hosted these quite unique forms, very near the end of their existence.

Vendian–Cambrian boundary in the eastern Podlyasie–Brest Basin (from lithological data)

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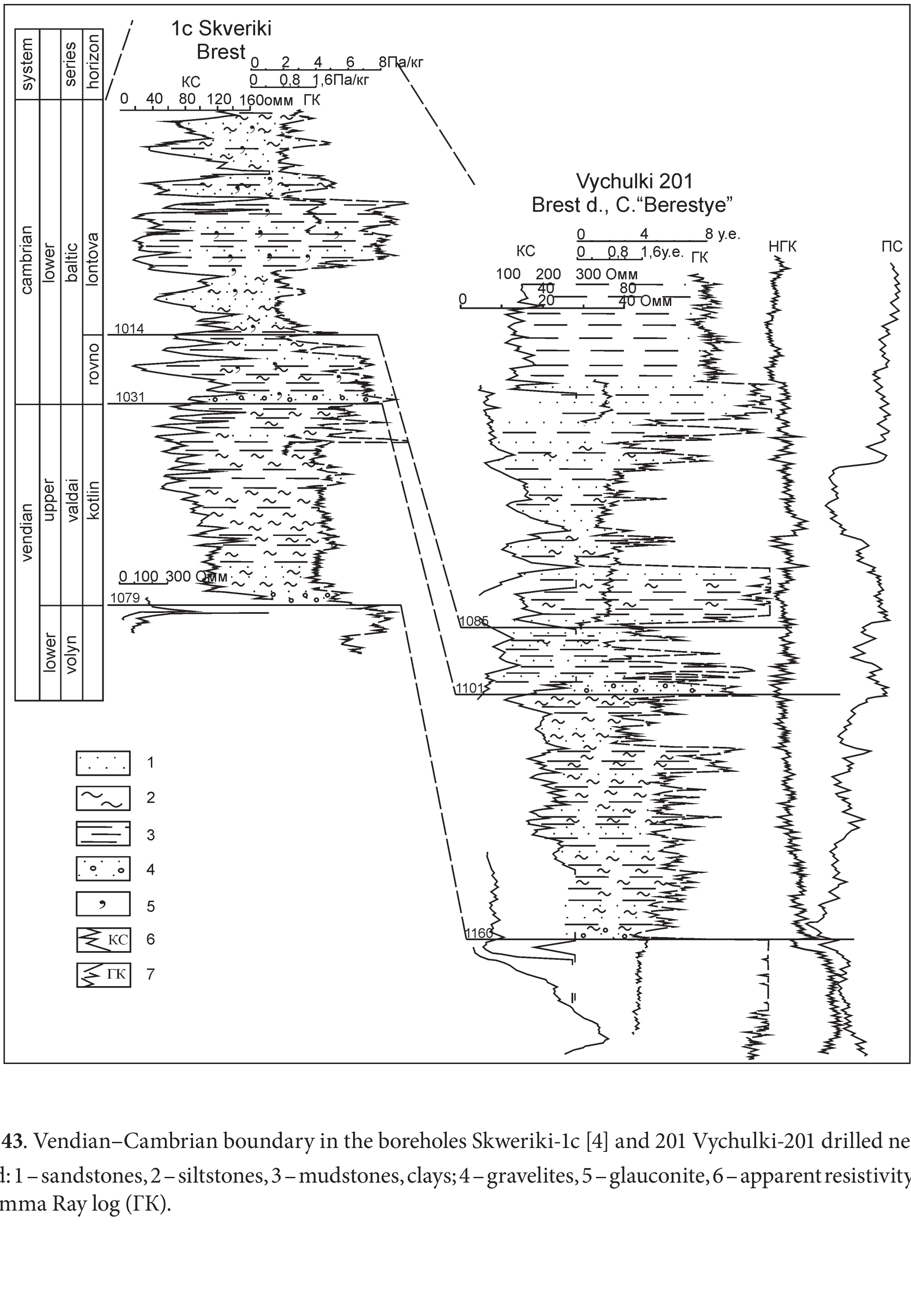

Figure 43. Vendian–Cambrian boundary in the boreholes Skweriki-1c [4] and 201 Vychulki-201 drilled near Brest. Legend: 1 – sandstones, 2 – siltstones, 3 – mudstones, clays; 4 – gravelites, 5 – glauconite, 6 – apparent resistivity log (КС), 7 – Gamma Ray log (ГК).

Upper Vendian strata of the eastern Podlyasie–Brest Depression (the territory of Belarus) constitute the Valdai Gr of the Redkino and Kotlin regional stages [1]. The Vendian is overlaid by sedimentary formations of different age ranging from Lower Cambrian (Baltic Gr of the Rovno and Lontova regional stages) to Jurassic and Cretaceous. Although the aluminosiliciclastic type of section is specific to the Upper Vendian and Cambrian formations of western East European Craton, the adjacent Iapetus ocean and Tornquist Sea sedimentary basins are characterized by carbonates. Cambrian stratigraphic subdivisions of Belarus are correlated with the biostratigraphic zones of West European scale [1, 2]. The Upper Vendian Valdai Gr and successive Lower Cambrian Baltic Gr are represented by aluminosiliciclastic rocks of marine origin. The Rovno Paleobasin inherited the Late Vendian paleobasin, and within the territory of Belarus it appeared as a northeasterly stretched shallow marine epicontinental Kobrin–Polotsk Trough which connected with the Moscow Syneclise [3]. Despite similar depositional settings, the Vendian and Cambrian basin each shows distinct lithological features. A section of Vendian–Cambrian boundary strata (core and GIS–log data) was penetrated by boreholes 1C (Skveriki) and 201 (Vychulki) near the town of Brest (Fig. 43). Greenish gray fine laminated and rhythmically bedded quartz-feldspar sandstones and micaceous siltstones of the Valdai Gr (Kotlin Reginal Stage) contain feldspar (30–40%), quartz (20–30%), hydromica (20–40%), and ubiquitous dark brown organic films. The cement is kaolinitic of porous and basal-porous type, carbonate in the lowermost part. The Vendian–Cambrian boundary is marked by kaolinite weathering crust. The Rovno Regional Stage is represented by rhythmically bedded feldspar-quartz sandstones and siltstones and kaolinite-hydromica clays containing feldspar (10–30%), quartz (60–80%), hydromica (up to 30% or more) and accessory amounts of pyrite, zircon, leucoxene and ilmenite. The glauconite (up to 20%) is present in some sand laminae and reflected as a sharp increase in gamma-ray activity of rocks. Cement is kaolinite of porous type, occasionally carbonate. The lowermost part (1–2 m in thickness) of the Rovno Regional Stage is represented by feldspar-quartz sandstone with cement of contact-porous kaolinite type and characteristic lenticular-lumpy nodules of pyrite. The Vendian–Cambrian boundary is marked by a sharp change in composition (decrease in feldspar and increase in quartz up to 90%) and maturity of clastic material. The apparent resistivity (GIS-log data) is 60–70 Ohm·m in the top of the Kotlin Regional Stage and up to 80–120 Ohm·m in the Rovno Regional Stage. The study was supported by BRFFR (projects no X09K-048 and X11-132)

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Ediacaran stratigraphic correlation between South China and northern Siberia

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Although the South China Block and Siberia Craton were paleogeographically separated during the Ediacaran Period, both were located in tropical oceans [1], and the late Ediacaran successions in these two cratons share remarkable biostratigraphic and chemostratigraphic similarities that allow stratigraphic correlation. Ediacaran successions in South China are bracketed between the Cryogenian Nantuo Formation and basal Cambrian cherts (see contribution by C. Zhou and coauthors to this volume), and are divided into the Doushantuo Fm (635–551 Ma) and Dengying Fm (551–542 Ma, further divided into the Hamajing, Shibantan, and Baimatuo members). In the Khorbusuonka region of the Olenek uplift in northern Siberia, Ediacaran successions sit unconformably on the Riphean Khaipakh Fm and conformably below the Kessyusa Fm, and they are divided into the Mastakh, Khatyspyt, and Turkut formations [2].

In the Yangtze Gorges area of South China, the Ediacaran succession is characterized by large carbonate carbon isotope excursions [3, 4]. Organic carbon isotopes, however, show remarkably stability in the lower Doushantuo Formation [5]. Further, the Doushantuo Formation is characterized by variable sulfur isotope data and show a significant rise in $^{87}Sr/^{86}Sr$ ratio from 0.708 to 0.709 [6]. Previously published carbonate carbon isotope data from the Khorbusuonka region [2] indicate that the Mastakh, Khatyspyt, and Turkut formations represent late Ediacaran deposits. New paleontological and lithostratigraphic data from the Khorbusuonka region support this correlation [7] and further suggest that the Mastakh, Khatyspyt, and Turkut formations may be equivalent to, respectively, the Hamajing, Shibantan, and Baimatuo members in the Yangtze Gorges area. If this correlation is confirmed by organic carbon isotope data, the Ediacaran successions in the Khorbusuonka region are between 551 Ma and 542 Ma in age. Similarly, the Yudoma Group in southeastern Siberia also represent late Ediacaran deposits equivalent to the Dengying Fm, as evidenced by recent paleontological discovery from the Aim Fm of the lower Yudoma [8]. Early to middle Ediacaran deposits equivalent to the Doushantuo Formation are probably represented by the Dal'nyaya Taiga and Zhuya groups in the Patom Complex of central Siberia, as supported by the recently available micropaleontological, carbonate carbon isotope, and geochronological data [9–11].

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Acanthomorph biostratigraphic succession of the Ediacaran Doushantuo Formation in the East Yangtze Gorges, South China

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Large acanthomorphic acritarchs have been found from the Ediacaran Doushantuo Fm in several localities in South China, including the East Yangtze Gorges of Hubei Province, Weng'an area of Guizhou Province and elsewhere. However, their potential for the biostratigraphic subdivision and correlation of Ediacaran successions is limited by facies control, taphonomic biases, and taxonomic problems. In the Yangtze Gorges, the Doushantuo Fm is generally subdivided into four lithologic member. However, in Weng'an area, the Doushantuo Fm is represented by lower and upper parts separated by a mid-Doushantuo erosional surface. The Doushantuo succession in the Zhangcunping section in the Yangtze Gorges is similar to that in Weng'an area. So far, the correlation between the Yangtze Gorges and Weng'an area and elsewhere has been an issue of debate. To solve the debate, we selected eight sections in the Yangtze Gorges area and systemically sampled chert nodules of the Doushantuo Fm, focusing particularly on the upper Doushantuo Fm. Our data confirm two different assemblages separately appearing in the second and third members separated by a $\delta^{13}C$ negative excursion (EN2). The lower assemblage is characterized by *Tianzhushania* and a diverse suite of large acanthomorphic acritarchs. The upper assemblage is dominated by *Tanarium* and *Appendisphaera*, and is distinguished from the lower assemblage by (i) absence of *Tianzhushania*; (ii) occurrence of abundant, 100–150 μm, smooth-walled spherical microfossils; (iii) occurrence of highly diverse acanthomorphic acritarchs including species extending from second member and new forms in this member; (iv) occurrence of unnamed new forms of protists; and (v) occurrence of the tubular microfossil *Sinocyclocylicus guizhouensis*. Our upper assemblage shares a number of species with Ediacaran acanthomorph assemblages in Australia and East European Craton. Since the *Tianzhushania*-dominated assemblage is not present in Australia, it seems that only the upper acanthomorph assemblage is present and thus the lower Doushantuo acanthomorph assemblage is missing in Australia; however, it may be present in northern India and Svalbard. The new work provides a new datum point toward consideration of a three-fold biostratigraphic subdivision of the Ediacaran System comprising a lower subdivision characterized by *Tianzhushania*, a middle subdivision characterized by various species of *Tanarium*, *Ceratosphaeridium*, *Appendisphaera* and *Alicesphaeridium*, and an upper subdivision characterized by macroscopic Ediacaran fossils.

Paleoecology of two smothered metazoan communities from the Arkhangelsk Region

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Late Vendian (Ediacaran) soft bodied organisms are preserved on bedding plane surfaces as small clusters from several meters to several dozens of meters across that are different from each other by taxonomic composition, dominant species, and size of the organisms. The differences are observed even between the clusters in adjacent beds despite similar taphonomic conditions of preservation. We studied two clusters of Ediacaran type fossils known as Solza SL1 (VII) and Zheltyi Verkhniy Z11(XXII) assemblages in two different localities (Verkhovka and Zimnie Gory formations, respectively) [1]. The fossils are preserved in life positions attached to the lithified microbial substrate (in most cases, it was a microbial mat). The two clusters have different microbial structures. The Solza SL1 (VII) assemblage is characterized by aggregations of large (up to 6 mm) bulges, whereas the Zheltyi Verkhniy Z11(XXII) assemblage shows relatively small (1–3 mm in diameter) evenly distributed bulges. The two assemblages have similar sets of genera, but the species composition and numeric diversity are different. Furthermore, the Zheltyi Verkhniy Z11(XXII) assemblage has low numerical diversity of vagile organisms of different size (the disparity between groups of different size specimens is large) and large numerical diversity of holdfasts. The Solza SL1 (VII) assemblage, on the contrary, is dominated by small- and medium-size specimens, includes a small number of large holdfasts, and has ubiquitous feeding traces of *Kimberella* [2]. Each fossil assemblage is a result of a sequence of events: event sedimentation, development of microbial mat, seasonal settlement of planktonic larvae of vagile and sessile benthos, and immigration of mature individuals from adjacent areas. The Solza SL1 (VII) assemblage consists of two generations: an early generation of sedentary benthos and a late generation of vagile benthos (Fig. 44: A). The absence of earlier generations of vagile benthos suggests only one episode of colonization prior smothering. Three-dimensionally preserved large holdfasts of *Palaeophragmodictya spinosa* projecting through several layers represent the earliest generation of sedentary (sessile) benthos in the assemblage that could survive several episodes of sedimentation[3]. Later generations of sedentary organisms are absent probably because the larvae could not settle down on the structured matured microbial substrate. The matured microbial substrate had low rate of regeneration and therefore preserved feeding traces of *Kimberella*. The Zheltyi Verkhniy Z11(XXII) assemblage consists of two early generations of vagile benthos and one late generation of sedentary benthos (Fig. 44: B). Presumably, the sessile organisms populated immature microbial substrate that was thin, easily regenerative, and could not preserve feeding traces of *Kimberella* and proarticulates. Large excavated surfaces revealed the presence of large vagile animals that migrated from adjacent territories and reproduced in this assemblage. The studied assemblages demonstrate several distinct pathways of development of

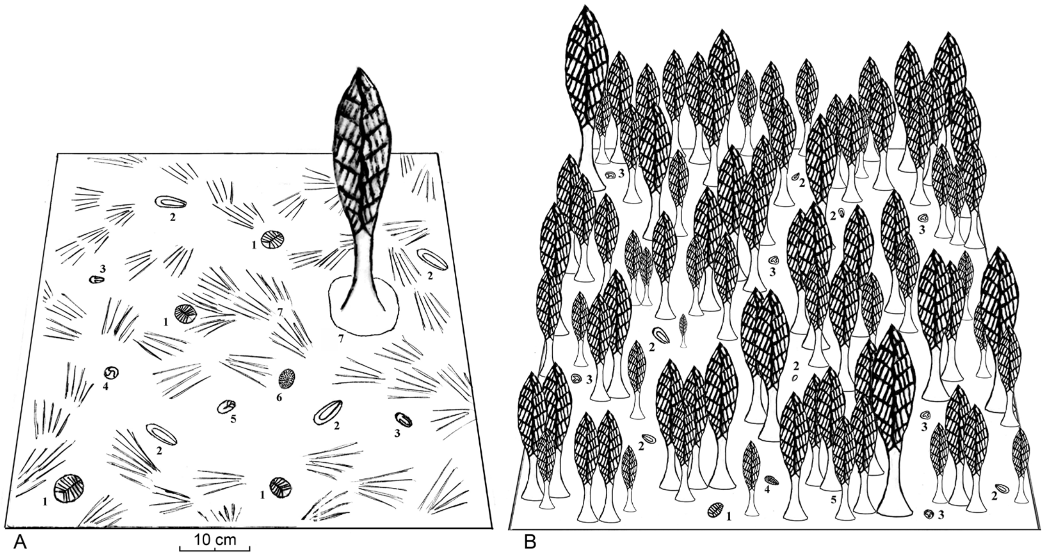

Figure 44. Reconstruction of fossil communities averaged for 0.5 m² plots; linear dimensions of the organisms are exaggerated (×2.5).

A: Solza SL1 (VII) assemblage: 1 – *Dickinsonia* cf. *tenuis*, 2 – *Kimberella quadrata*, 3 – *Parvancorina sagitta*, 4 – *Tribrachidium heraldicum*, 5 – *Vendia rachiata*, 6 – *Solza margarita*, 7 – *Paleophragmodictya spinosa* with a hypothetical frond, 7 – scratch marks produced by *Kimberella quadrata*; **B**: Zheltyi Verkhniy Z11(XXII) assemblage: 1 – *Dickinsonia costata*, 2 – *Kimberella quadrata*, 3 – *Parvancorina minchami*, 4 – *Cyanorus singularis*, 5 – *Protodipleurosoma* sp. with hypothetical fronds.

communities of Ediacaran soft boded organisms reflecting event (including seasonal) colonization of marine substrate and degree of microbial substrate maturity.

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Carbon isotope chemostratigraphy and biostratigraphy of the Ediacaran System in South China

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The Ediacaran System in South China was deposited in a southeast-facing (present orientation) passive margin on the Yangtze Block. It overlies ~635 Ma glacial deposits of the Nantuo Fm and underlies basal Cambrian cherts and phosphorites, and consists of the Doushantuo and Dengying formations. Doushantuo lithologies are dominated by organic-rich, fine-grained siliciclastics, especially in the basinal settings on the southeast Yangtze Block, whereas carbonates and phosphorites occur in inner shelf and shelf margin facies in the northwestern. The overlying Dengying Fm has more uniform lithologies on the shelf and is characterized by thick successions of carbonate with minor siliceous shales and mudstones, whereas it is dominated by black cherts in basinal environments. Numerous studies of Ediacaran $\delta^{13}C$ chemostratigraphy in South China have been carried out in the past two decades, and the $\delta^{13}C$ profiles in the shallow-water platform facies on the Yangtze Block show broad similarities, making it possible to construct a composite $\delta^{13}C$ curve. The composite $\delta^{13}C$ profile of the Ediacaran System in South China shows, in chronostratigraphic order, 1) a negative $\delta^{13}C$ excursion (EN1) in the Doushantuo cap carbonate that overlies Nantuo diamictite; 2) a broad and pronounced positive $\delta^{13}C$ excursion (EP1) in the lower Doushantuo Fm, with the shift from the nadir of EN1 (<–5‰) to the peak of EP1 (> 5‰) occurring at ~30 m above the cap carbonate in the Yangtze Gorges; 3) a short-lived, but strong negative $\delta^{13}C$ excursion (EN2) in the middle Doushantuo Fm; 4) a positive $\delta^{13}C$ excursion (EP2) in the upper Doushantuo Fm; 5) a sharp negative $\delta^{13}C$ excursion (EN3) to a nadir of <–8‰ in the uppermost Doushantuo Fm; 6) a positive $\delta^{13}C$ excursion (EP3) in the lower Dengying Fm; 7) a stable $\delta^{13}C$ plateau (ca. +2.5‰ PDB; EI) in the middle and upper Dengying Fm; and 8) a –10‰ negative $\delta^{13}C$ excursion (EN4) immediately below the Ediacaran–Cambrian boundary. This composite $\delta^{13}C$ curve provides a first-order chemostratigraphic framework for the subdivision and correlation of the Ediacaran System in South China. Detailed palaeontological investigations in the past 30 years have revealed fossil assemblages including abundant large acanthomorphic acritarchs (Doushantuo–Pertatataka acritarchs), micro-algae, tubular metazoans, animal embryos, putative bilaterians, and Burgess-shale type carbonaceous compressions (mainly macro-algae, but also including animal fossils such as Eoandromeda octobrachiata) in the Doushantuo Fm of South China. Biostiatigraphic studies indicate that Doushantuo–Pertatataka acritarchs make their first appearances during the interval with a broad and pronounced positive $\delta^{13}C$ excursion (EP1), shortly after the termination of Nantuo glaciation (~ 635 Ma), and disappear before the rise of large Ediacara organisms, and below the pronounced negative $\delta^{13}C$ excursion EN3 in the uppermost Doushantuo Fm. Biostratigraphic data from South China and elsewhere indicate that Doushantuo–Pertatataka acritarchs are characteristic of the lower-middle Ediacaran System and can be a useful biostratigraphic tool. The Dengying Fm (~551–542 Ma) in South China contains macroscopic Ediacara macrofossils, trace fossils, and tubular skeletal fossils such as *Cloudina* and *Sinotubulites*. Of these fossils, *Cloudina* has the widest biogeographic distribution and greatest biostratigraphic potential. Paleontological data from South China clearly demonstrate that distinct fossil assemblages occur in the LowerMiddle (characterized by Doushantuo–Pertatataka-type acritarchs, macro-algae, and micrometazoans) and Upper (characterized by macrometazoans and biomineralizing animals) Ediacaran. The broadly consistent bio- and chemostratigraphic patterns among Ediacaran successions in South China, Mackenzie Mountains, Namibia, Siberia, Oman, and Australia shed promising light on the patterns of isotopic and biological evolution of Ediacaran oceans, although recent data seem to suggest some degree of geochemical and ecological heterogeneity in different regions (particularly between shallow and deep oceans).

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