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On the Great Lena River - Grand Creations of Nature and Vivid Testimony of Early Beginning of Skeletal Biodiversity

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Introduction

Those who have ever visited the mid-Lena river area in the Sakha Repulic (Yakutia), eastern Russia, are familiar with the grandiose Lena Pillars. Not far from them the Earth's most ancient Oymuran reef is located. Here and in some other prehistoric natural sites of the Lena Pillars Nature Park mass appearance of many groups of skeletal marine animals first occurred on Earth more than 530 million years ago (fig. 1).

Fig.1. Location of the Lena Pillars

Below is a brief description of natural sites nominated under a common name.

The Lena Pillars Nature Park

Three sites (I, II, III) are nominated for inclusion on the Unesco World Heritage List by geologic criteria (VII: superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance; VIII: outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of land forms, or significant geomorphic or physiographic features).

Criterion VII

Site I. **The Lena Pillars natural monument**

1. Significance

The Lena Pillars are a unique natural phenomenon: an impressive pillared landform (one of the wonders of nature) that was formed through frost weathering of carbonate rocks in the zone of permafrost and a sharply continental climate with large day and night temperature changes. Studying the Lena Pillars provides a better understanding of how the earth's landscapes formed and what processes shaped their present-day appearance. It is very important to preserve this unique landscape for future generations for they could further study the complex process of its formation.

542-518 Ma ago, in Early Cambrian time, when the world average temperature was higher than today (Frakes, 1979), the territory of present-day West Yakutia was occupied by an enormous, rather warm (+28-32°C, after I.V. Nikolaeva) shallow sea. A long-term (ca. 25-27 Ma) subsidence of the area beneath the sea was compensated for by the newly formed carbonate sediments. As a result, a sedimentary rock sequence hundreds of meters thick was deposited in the Early Cambrian. Within the Lena Pillars Nature Park area, near Sinsk village, the sequence is about 500 m thick as indicated by deep drilling data. At a later time, the sediments were buried beneath the younger (Ordovician and Silurian) strata. Then tectonic processes brought them to the surface where they formed the Prilensk plateau in East Siberia. In the Park, the rocks are widespread on the northern slope of the Aldan anteclise (uplift).

The Aldan anteclise is one of the largest structures of the Siberian platform. Its area is more than 180 thousand sq. km. In the structure of the Archean crystalline basement and a sedimentary cover made of Proterozoic and Lower Paleozoic rocks, the anteclise is represented by a large uplift framing the Aldan shield on the north and gently plunging beneath the Mesozoic strata of the Vilyui syneclise and the Preverkhoyansk foredeep (Tectonics of Yakutia, 1975). In the Vilyui syneclise, northeast of the Markha river mouth (left tributary of Vilyui) a borehole penetrated the sediments to a depth of about 4 thousand meters. From geophysical data, on the northern slope of the Aldan anteclise the basement of the Siberian platform is cut by a series of faults, among them the large Buotama fault of northeast strike. In the central part of the Aldan anteclise, where the basement uplift occurs, the 40-110 km wide Aldan-Lena megaswell is identified, extending for 250 km from north to south (Tectonics of Yakutia, 1975).

The formation of stone pillars extending along the right bank of the Lena river and its tributaries (Sinyaya and Buotama) is related to a deep downcutting of their valleys, which exposed massive sedimentary rocks – limestones. In the area of a sharp bend of the eastern limb of the Aldan anteclise, where the Lena, Sinsk and Buotama Pillars occur now, limestones of the Kutorgina Formation as thick as 120 m are found. The formation was established by O.V. Flerova in 1941. It is named after brachiopods of the genus *Kutorgina* Billings, 1861, order *Kutorginida*. The order was named after geologist S. Kutorga who lectured on geology and mineralogy at the Petersburg Pedagogical Institute. In 1849-1854, D.I. Mendeleev, a future outstanding scientist, attended the lectures. The Kutorgina formation is cut by numerous W-E-striking (over 100 measurements) subvertical (80-90°) extension fractures (photo 1-8). They were produced by pulse tectonic stresses of the Siberian platform superposed by those of its southern framing. The well-fractured rocks permit easy penetration of wind and circulating waters which cause their physical and chemical destruction. Under sharply continental climatic conditions, with the average annual temperature of about 10°C below zero, seasonal temperature extremes from - 60°C in winter to +40°C in summer, and average precipitation of 250 mm, the fractures grow wider due to the large temperature changes between day and night. In spring and autumn, the daytime temperature is above zero, dropping to –15-20°C at night. In these conditions, the destructive role of water is significant. Water that seeps through fractures in the daytime freezes at night, making the initially narrow fractures wider (it is well known that frozen water increases in volume by 9-11% producing a pressure of 900 kg per sq. cm).

Moreover, on seeping through fractures water dissolves the limestones. In the region, the temperature is below zero for 200 days a year, hence karstification is poorly manifested here. The karst "towers" typical of tropical areas are absent. Winds blow mostly from the north (the Lena river flows from west to east and the Lena Pillars are located on its right bank) causing physical disintegration of the rocks. Under conditions of continuous permafrost (-4-5°C) penetrating to a depth of 200-400 m and a sharply continental climate, an increase and decrease in the rock volume due to a rise and drop in air temperature also contribute to rock weathering. The permafrost does not allow karst to form in the Lena Pillars area, though faint karst features are locally found along the river bed. The permafrost serves as a monolithic basement under the Lena Pillars, promoting the formation of small fractures in the rocks, which causes their physical disintegration. Cold air rises along the faults and subvertical fractures (Tolstikhin, Spector, 2004) to cool the rocks heated in the day time. In addition, the contact of deep cold and surface warm air as well as differing temperature between the air and the rock promote condensation of water on the fracture walls. When it freezes, the water causes the destruction of the rock. Well-fractured rocks crumble easily to form waste that gradually moves down slope to the foot of the mountain. On the way down the waste material breaks down to smaller fragments, which are carried away by high water in spring time. As a result, the once continuous limestones take the form of pillars, towers, castles, etc. (Kolosov, 1997, 2008). If it were not for the accumulating role of the permafrost, it is most likely that with the average annual precipitation of 250 mm, a steppe ecosystem would exist in the Lena Pillars Park area rather than a forest one as occurs nowadays. Many of the stone pillars in the Park are very high due to a deep downcutting of the Lena river valley (the pillars record a long, approximately 400-500 ka, history of this mighty Siberian river, one of the largest in the world). A tendency toward a higher relief is evident here (the relative heights of the rocks grow at a rate of half a millimeter a year). The Lena Pillars have resulted from unique on-going coastal geological processes. It is a site of exceptional natural beauty and aesthetic importance.

Among the Lena Pillars are those which are rather thin (photo 9-10). A question then arises: "Why haven't they fallen down being so high and thin?" The answer is that limestones are rather monolithic rocks, they were formed with the involvement of photosynthetic cyanobacteria and algae and, hence, the rock layers have rough surfaces preventing them from sliding.

Thus, the Lena Pillars are unique in that their formation was favored by a combination of factors including the specific environmental conditions of the Lenan limestones, geological and geomorphological processes, as well as the peculiar climatic conditions such as the pronouncedly continental climate with large temperature changes and frost weathering of the rocks.

2. Comparative analysis.

It is known that rock weathering proceeds quickly in areas with a continental climate with seasonal temperature extremes. For example, the great deserts of the world such as the Gobi, Sahara, etc. were formed under the conditions of a hot continental climate. Unlike these, the Lena Pillars originated in the permafrost zone, under conditions of a cold continental climate characterized by large seasonal and day and night temperature changes and frost weathering of the rocks. This makes them a site of outstanding universal value from a scientific point of view.

Danxia relief in China is any topographic form made from red gritstones (granular rock) as well as low mountains and hills of red sandstone that form for many years through the weathering activity of wind and water ("China", July, 2009, No.7(45)). These terrigenous rocks with an admixture of iron were deposited 70-90 Ma ago, in Late Cretaceous time. Danxia relief is particularly beautiful at dawn and sunset. In the Tainin Park (Fujian province), which is often visited by tourists, red rock peaks and islands with luxuriant vegetation all around them look very beautiful reflecting in the waters of Lake Jinhua. Bridges across small rivers and numerous pavilions with images of God in them add to the atmosphere.

The Lena Pillars, along with their exceptional natural beauty and aesthetic importance, are of outstanding universal value from the point of view of science as they are formed by complex geological, geomorphological and physico-chemical processes in the zone of continuous permafrost. In this they are superior to Danxia relief in China, Nahanni landscapes in Canada, Krasnoyarsk Pillars on the Enisey river, Russia, and many other landforms.

Grand Canyon (Arizona, North America) with its long rock walls, steps, shelves, towers, temples and pyramids is located in the middle reaches of the Colorado river that contributed to its formation. The river bed is made of Precambrian (2.0 Ma) crystalline schists overlain by later granites. Still higher occur Precambrian limestones with trace fossils of cyanobacteria (blue-green algae).

One can see in the river bluffs dramatic exposures of Permian (299-251 Ma) limestones and sandstones interlayered with red shales and grey sandstones alternating across section. The uppermost limestones are of Late Triassic age (ca. 230 Ma). Along with the weathering activity of the Colorado river, winds aided in the formation of this world-largest valley, which continued for 10 million years. So we see that the walls, shelves, towers, pyramids etc. of the Grand Canyon have a strong basement made of Precambrian crystalline schists and cyanobacterial limestones. The Lena Pillars are also shaped as walls, pyramids, towers, etc., but the basement for them is 400 m-thick permafrost. In the Grand Canyon, plant roots penetrate into small fractures in the rocks thus widening them. In the Lena Pillars, the same is done by frozen water drops. Like in the Grand Canyon, the limestones of the Lena Pillars preserve fossils of cyanobacteria but here these rock-forming organisms define not only the density of the fractures but the size of the Pillars too.

In the Cappadocia Mts., Turkey, sharp-pointed poles and cones, towers and pyramids made of Paleogene-Neogene (65.5-2.6 Ma) volcanic tuffs up to 500 m thick are present. The climate is warm here. For millions of years, raindrops pecked at the volcanic tuff, which is softer than limestone, to tear off small particles and wash them away. Winds also aided in rock weathering. The remnants of former mountains mainly arise in places where side gorges enter the main valley. On the slopes one can see towers covered from above by less strongly weathered rock, which look like people with caps on their heads. But unlike the Lena Pillars this relief form is made of soft volcanogenic rocks and its formation occurred under warm climatic conditions. Examples of mountain remnants are plentiful in tropical regions. Well-known are Ayers Rock in central Australia and Sugar Head Mountain in Rio-de-Janeiro, Brazil. Similar structures are found in North America, e.g. Georgia, and Asia. It is only in hot and mild climates that the surface of granular rocks gets broken to form large scales and a meter-thick crust washed away by heavy showers in the rainy season. That's why the slopes of Ayers Rock arise so steeply over the plain (Bower, 1978).

Thus we see that the Lena, Sinsk and Buotama Pillars are unique in size, diversity of shapes, and mechanisms of formation under permafrost conditions. Also, they record the history of the Lena river, one of the largest in the world. Formation of the Lena Pillars was favored by joint tectonic processes, large day and night temperature changes, and frost weathering of the rocks. The good state of preservation of the thin (5-10 m in diameter) but high (30-40 m) pillars may be

explained by the nature of their composing limestones that were formed with the involvement of the Early Cambrian calcareous cyanobacteria and algae.

3. Authenticity and/or integrity

The Lena Pillars natural monument is located in the Nature Park of the same name, which is managed in accordance with the federal and republican laws, including the Law on natural sites of the Sakha Republic (Yakutia) worthy of special protection. Juridical mechanisms for the Lena Pillars protection are specified in the regulations of the Park, approved by the government of the republic.

4. Criteria by which the Lena Pillars site is nominated for inclusion on the World Heritage List

The Lena Pillars are a site of outstanding universal value from a scientific point of view as they formed about 400 Ma ago (Pleistocene) and continue forming through coastal geological processes under conditions of permafrost, sharply continental climate, and frost weathering of the rocks. A physical peculiarity of the Lena, Sinsk, and Buotama Pillars as a landscape is in the above-mentioned unique past and on-going geological processes. The Lena Pillars are an outstanding example of the formation of fantastic landforms under severe climatic conditions with minimal karstification. They resemble landforms (karst tower) that develop in tropical areas where thick limestone units with vertical jointing are intensely dissolved in hot and humid conditions.

The Lena, Sinsk, and Buotama Pillars are of exceptional natural beauty and aesthetic importance. They are one of the natural wonders of the world. One is striken by their magnificent view. Moreover, they record past and active processes involved in the formation of relief on the Earth.

This unique landscape in the permafrost zone adds to the variety of natural sites produced by various natural phenomena that occur on Earth. That's why the Pillars are nominated for inclusion in the World Heritage List in accordance with the World Heritage Convention, article 2: natural sites or precisely delineated natural areas of outstanding universal value from the point of view of science, conservation or natural beauty. They meet criterion VII (superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance) and one of four elements of criterion VIII (significant geomorphic or physiographic features) established by the World Heritage Convention.

5. Description

The Lena Pillars are the most famous natural monument of Yakutia. There is no doubt that the forefathers of the Yakuts admired them as early as the 2000-1000 B.C., when, in the mid-Lena area, newcomers from the southwest and aboriginal Tungus tribes mixed to form a new national group. Early in the 17th century, the Lena Pillars could be observed by Russian explorers heading for northeast Russia and further for North America.

"I have never seen anything so beautiful in all my life" – wrote V.G. Korolenko, a famous Russian writer, an Honored Member of the Petersburg and Russian Academies of Sciences who was in exile in Yakutia in 1881-1884. Nowadays the Lena Pillars arouse great interest in people as a natural site of exceptional natural beauty. For example, when Jan Dierks, a student from Germany, heard about them he immediately skied there from Yakutsk along the right bank of the Lena river and spent 5 nights in a tent, though it happened in March when the night temperature was about 30° below zero, and the ground was covered with snow.

The name Pillars follows the dominant pillared shape of the weathered Early Cambrian limestones. The Lena Pillars are located on the right bank of the Lena river, 200 km upstream from the city of Yakutsk. Not far from them, in the lower Sinyaya river, the Sinsk Pillars occur which, like the Lena ones, make part of the Lena Pillars Nature Park founded in 1995.

The Lena Pillars relief is represented by mountains of exceptional natural beauty produced by unique on-going coastal processes.

The criteria for the aesthetic value of the Lena as a landscape are: their unique shape, spectacular view, accompanying effects, combination with other landscape features, artistic representation, and emotional perception.

Unique shape. Fantastic stone sculptures about 200 m high (separate pillars are 30-40 m in height) extend for 35-40 km along the Lena river (photo 1-5, 14, 15). They are shaped as towers (photo 11), medieval castles, Gothic churches, Moslem

minarets, Egypt pyramids, Indian totem poles and orthodox temples. Beautiful hanging bridges and crossings created by nature are also present. Some stones look like living beings (photo 12), for example a man standing motionless and absorbed in thought, known among the natives as a "Kuhu-taas" (a stone man) (photo 13). With regard to their scientific value, great size and beautiful view, the Lena Pillars surpass the Krasnoyarsk Pillars located in the Enisey river valley. They are as unique as spectacular limestone rocks and isles rising up from the water of HaLong Bay into the sky, which are included in the Unesco World Heritage List.

Spectacular view. The Lena Pillars are comparable to the World's Wonders. They arouse our admiration when we look at them from the majestic Lena river side and when we climb up the slopes between the huge stone pillars, walls and arches. They are marvelously beautiful at dawn and sunset, before a thunderstorm and after a heavy rain, in golden autumn and in snowy winter. And what a magnificent view opens up from the top of the rocks!

The world-renowned Lena Pillars are the realm of Lenan stone, a natural wonder in the zone of permafrost (photo 5, 13-15, 22).

Photo 36. With foreign guests of Ysyakh

Photo 37. The painting "April. Lena Pillars". 70x130 cm. (artist Yu.V. Spiridonov)

Accompanying effects. The Early Cambrian epoch spans a time when marine skeletal invertebrates such as archaeocyaths, brachiopds, hyoliths, trilobites, etc. first appeared and rapidly diversified. The rock beds making up the Lena Pillars yield well preserved fossils of brachiopods: *Kutorgina lenaica Lerm., Acrotretidae gen. et sp. indet.* and trilobites: *Bergeroniellus asiaticus* Lerm., *Neopagetma sp., Binodaspis sp., Binodaspis secunda* Suv., *Bergeroniellus expansus* (Lerm.), *Bergeroniellus kutorginorum* Lerm., *Bergeroniellus spinosus* Lerm., *Bathyunscellus sp., Neopagetina primaeva* Lerm., *Bergeroniellus lermontovae* Suv., *Bergeroniaspis divergens* Lerm., *Delgadella lenaica* (Toll)., *Binodaspis paula* Suv., *Neopageiina aff. primaeva* Lerm., *Bergeroniaspis sp., Pagetia sp., Bergeroniaspis ornata* Lerm., *Olekmaspis bobrovi* Suv., *Aldonaia ornata* Lerm., *Bergeronielus fterovae* Lerm., *Binodaspis spinosa* Lerm., *Bergeroniaspis subornata* Lerm., *Micmaccopsis redlichoides* Lerm., *Bergeroniellus solilarius* Lerm., *Proiolentdae gen. et sp. Indet., Binodaspis lecta* Jeg. Calcareous algae of the genus *Proaulopora* Vologdin and cyanobacteria of the genera *Globuloella* Korde and *Palaeomicrocystis* Korde are also present.

The fossils can often be seen on the exposed surfaces of the limestone beds. In the Labyya river valley, a deep fault striking across the Lena river valley can be traced (Tolstikhin, Spector, 2004). Here one can feel the "breathing" of the permafrost (there are sites at the foot of the slope where the temperature is 8-10°C below zero on a hot summer day). Prof. O.N. Tolstikhin, an outstanding Russian ecologist called the top of the mount near the Labyya river mouth a "geovitagene zone" – a zone of life ("Mud", 2008, Nos. 1-2, p. 58). He himself felt the recreative inspirational effect of this place. This effect was repeatedly mentioned by many tourists who visited the place, among them cardiologists.

The Lena Pillars are located on the Lena river bank, so while being there you hear the sound of breakers, you feel the freshness of air and admire the sunrays reflected in water. You can take a refreshing swim on a hot summer day. When climbing a slope between the huge stone pillars created by nature you enjoy a pleasant coolness. And what is over there, on top of the slope? It is wonderful there: a thick forest with its melodious sounds, fragrant air, fresh breeze, pathways of the musk deer, berries, and a magnificent view of swifts flying over the rocks (photo 29, 30, 33, 34).

Combination with other landscape features. The Lena Pillars look marvellous in combination with the wide Lena river, its thickly flowered islands, fields on its left bank, small villages, haystacks in autumn time, and forests extending as far as the skyline. Northern man derives inspiration from wide space around him and beautiful distant views. That's why the Yakuts settled down in places best suited both for their spiritual needs and for fishing, hunting and cattle-breeding, which were the main sources of their livelihood.

Artistic representation. A need for beauty is human. According to D. Diderot, a French encyclopaedist, nature is the main model in art. Many artists and photographers have been inspired by the Lena Pillars. They are represented in many canvasses and color photographs published in books and albums. For example, Charles de Lespinass, a famous French artist of the mid-17th century, depicted the Lena Pillars in his engraving "Vue d une partie de la ville d Yakutsk".

Many famous Yakutian artists such as F.T Pavlov, L.A. Kim, A.N. Osipov, M.V. Lukin, N.M. Zasimov, V.G. Petrov, M.E. Fillipov, O.M. Kovalevsky, M.G. Sirotkin, I.E. Kapitonov, V.D. Artamonov and others painted the Lena Pillars. A.N. Osipov, an Acting Member of the Russian Academy of Arts exhibited his works at the UNESCO headquarters in Paris in 2006, among them were pictures depicting the Lena Pillars.

I. Standling, a journalist from Sweden, who visited Yakutia in the late 17th century, noted the exceptional natural beauty of the Lena Pillars: "Colossal rocks of red sandstone alternating with forested hills are reflected in the waters of the giant river. Here rise Cyclopean sandstone walls brought one against another by some supernatural forces. Over there hangs a giant rock that would surely fall down if not supported by equally sized neighboring columns".

In March 2007, the "National Geographic" published an article devoted to the Lena Pillars entitled "Tourists from across the globe come to Yakutia to see stone giants on the Lena river banks".

A colorful album "The Lena Pillars Nature Park" was issued in 2007 (Penta Publishing House, Moscow). A number of films and TV programs were shot, which were shown on Russian TV in 2007-2008, Dutch TV in 2001, and American TV in 1998. In 2007, the "Sakha" National Radio and TV Broadcasting Company released a documentary film "The Lena Pillars Nature Park".

Emotional perception. "From afar, the Lena Pillars look like a grand monolithic wall steeply dipping into the water. However, on nearer approach, the wall turns into fantastic sculptures that catch your eyes for hours. They resemble

either oriental columns or rows of warriors ready to fight the enemy or many other things, it all depends on the fantasy of a spectator. They charm everyone with their fascinating beauty. Having seen the Lena Pillars once you will never forget them» (Kolesov, Mostakhov, 1985, p. 96). The Lena and Sinsk Pillars are sites that tourists like to visit very much. Here is a comment of Bruno Alenda from the Nancy Zoological Museum (France): "Imagine the Siberian nature. The rocks looking very much like sculptures rise up into the sky. Words fail you to describe the width of the Lena river, the rough and endless taiga. The nature is particularly beautiful at sunrise and sunset. We see all the beauty of the rocks in the sunlight. My admiration is endless, and I am standing still before this beauty. The Lena river banks, the unbounded Lena Pillars….and silence. The beauty of rough nature. I feel quite small standing before the Lena Pillars. I dare not to touch this nature for fear to disturb it. I look at all this in wonderment. I am fine here. I breathe in air which is so clean! I've absorbed this nature so deep in myself that it will always be kept in my soul".

And here are the words of Dr. Allison R. Palmer, an eminent American paleontologist dealing with Cambrian trilobites: "My personal memories of the dramatic dolomite pillars rising from the forested shores of the Lena river left me with thought that these pillars became part of the mythological lore of the early migrating peoples whose descendants crossed the Bering land bridge to inhabit the western coast of Canada and northwestern United States". Dr Palmer suggests that many migrants who rafted along the Lena river must have looked with admiration at the grandiose Lena Pillars.

Visitors from many countries say they had never expected to see such beautiful natural formations on the Lena banks (photo 1-5, 14, 15).

Many of those who happened to see this natural wonder with their own eyes wrote about the impression they made on them.

Decembrist Alexander Bestuzhev-Marlinsky wrote the following words: "On a dark night, when water is as smooth as a mirror, and the sky is as clean as water, a sacred silence falls down on this virgin creature, and your soul and the wild but sublime beauty merge all together".

Vyacheslav Shishkov, the author of the book "Ugryum river" called the Lena Pillars "a natural wonder", and the famous journalist Leonid Shinkarev – "a realm of stone". Well-known Russian poets Rimma Kazakova and Evgeny Evtushenko praised the beauty of the Lena Pillars in their verse.

Evenks, the native peoples of the North, glorified the natural beauty and aesthetic value of the Lena Pillars in their legends. Their beauty is celebrated in Olonkho, an ancient heroic epos of Yakuts, which is included in the Unesco Cultural Heritage List.

The Lena Pillars are described in the works of Yakut writers and poets such as I. Gogolev-Kyndyl, M. Efimov, Kh. Gorokhov-Elgestey, I. Fedoseev, N. Kharlampieva, I. Ertyukov, L. Popov and many others.

Thus, the Lena Pillars represent a natural monument of exceptional beauty. They are unique in shape, well observable on the bank of the great Lena river, combine well with other landscape features, and are a favorite object for artists, photographers, poets and tourists. The Lena, Sinsk and Buotama Pillars exert a positive recreative effect on man through emotional, cognitive and spiritual levels of his consciousness (Kolosov, 2008) (photo 1-15, 22, 25-37)."When being in the Lena Pillars, in private with virgin nature, you have a feeling that these stable rocks calm you down, make you sure of yourself so that you can face the future with confidence. And if you lie, in silence, for 10-15 minutes on the sharp-edged debris, thinking of anything good or not thinking at all, then your cheerful mood and pleasant reminiscences of that day will remain long after you come back home (Tolstikhin, Spector, 2004, p. 106).

The Lena Pillars Nature Park is also of outstanding cultural-historical value. In 1735-1756, the Tamginsk iron-producing plant, the oldest in eastern Russia, was operating in the region, which supplied with iron the 2d Kamchatka Expedition headed by Vitus Bering, which in 1741 discovered Alaska together with the Expedition of Aleksey Chirikov.

An important role of the Lena Pillars in the national arts and culture is well seen from an extensive bibliography to the book "The Lena Pillars Nature Park "which includes 569 references covering a period of 1844-2005.

Many Russian travellers and scientists as well as those from other countries wrote about the Lena Pillars in their works, e.g. F.B. Shmidt; A.L. Chekanovsky; E.V. Toll, M.D. Brasier, G. Vidal; J.W. Cowie; S. Bengston; G. Brown; K. Hrabovsky; A. Bryan; K. Holm; H. Boksted; B. Bower; B. Dietrich; L. Foster.

The traditional to the culture of the peoples of Yakutia model of the universe forms an understanding of the importance of environmental protection as a basis for welfare. The Yakuts glorify the nature around them in songs and original art works, in their clothes decorated with images of northern lights, birds, mammoths and other animals, in carvings made of wood and bone. From the very beginning when northern national groups began forming about 30 thousand years ago, they idolized nature, and this formed their respectful and careful treatment of it, which is expressed in their customs and traditions. According to A.E. Mordinov, a famous philosopher of Yakutia, the relationships between the spirit and nature are well represented in the heroic epos of Olonkho acknowledged by Unesco as a masterpiece of nonmaterial culture.

Criterion VIII: **the record of life (evolution of life on Earth)**

Site II. **Oymuran reef**

1. Significance

The Oymuran reef is an early reef on Earth. This is an outstanding example of the earliest "island of vital activities" (F.J. Pettijohn, 1975) of photosynthetic cyanobacteria and algae either alone or in symbiosis with skeletal marine animals. It also exemplifies the appearance on Earth of a fundamentally new reef ecosystem wherein various groups of organisms evolved over a long period of time, advanced adaptive morphological structures formed, a "transition occurred from reef-lovers to reef-builders, and in this highly favorable biotope, within an extremely narrow space, various biocenotic and more intimate symbiotic and parasitic relationships developed (photo 16-21). And all this repeated over and over again during the long history of the organic world beginning in the Cambrian" (Gekker, 1968, p. 24). This ecosystem continues to develop nowadays. "In biology you cannot understand anything but in the light of evolution" (Dobzhansky,). "Evolution is based on symbiogenesis, co-existence, harmonious unity of two or more organisms… Species as such cannot evolve by themselves. It is the whole ecosystem that evolves (Sokolov, 2006, p. 301).

2. Comparative analysis

No later than 2.0 Ga ago (Precambrian), a new ecosystem originated on the floor of epicontinental sea basins in many regions of the world. It was produced by cyanobacteria, bacteria and, to a lesser extent, algae. This is evidenced by Precambrian stromatolitic buildups and bioherms described as reefs by some researchers. In fact, these organogenic structures do not contain skeletal organisms serving as a framework and, thus, cannot be referred to as reefs (Heckel, 1974; Hallam, 1983; Kuznetsov, 2003). However, in the Precambrian new relationships began forming between living organisms in these buildups, and new mutualistic functions developed, which supported the ecosystem as a single whole. A fundamentally new, more complex reef ecosystem originated early in the Cambrian, following the appearance of skeletal animals and bushy algae. The earliest reef-forming skeletal animals are archaeocyaths (The Fossil Book, 1989). They appeared

in the eastern Siberian platform (territory of present-day West Yakutia) at 535 Ma (from Bowring et al., 1993), which is earlier than in other regions of the world (Rozanov, 1986; Debrenne et al., 1990) where the oldest of them are dated at ca. 530 Ma (Rozanov, 1986; Rozanov, Zhuravlev, 1992). Thus, all of the archaeocyathan-algal reefs and bioherms found in many countries (they are particularly abundant in Australia) are younger than Oymuran.

Coral reefs are widespread in the world. These organogenic structures first appeared in the Silurian (440-400 Ma). The general public is well informed of modern coral reefs such as the Great Barrier Reef off the coast of Australia. This is the largest (2300 km long and 2-150 km wide) structure on Earth built by living organisms. It was formed during the Holocene transgression. This is a ridge of 2100 coral reef buildups surrounded by 540 barrier islands in the Coral Sea, extending along the northeastern coast of Australia (Fashchuk, 2009). The waters of the Great Barrier Reef are inhabited by some 14 thousand species of living organisms. The hard framework of the reef is constructed by calcareous corals. A very important aspect of mutualistic symbiosis between animals and algae is that "through very complex, as yet poorly known, biochemical processes, algae force corals to more intensely secrete carbonate for skeleton formation. There is, on average, 1.5 million algae cells per each square centimeter of a coral colony" (Fashchuk, 2009, p.94). And it all began with the West Yakut barrier of which Oymuran is a fragment. Here we can see the world's first mutualistic symbiotic relations between skeletal animals and calcareous algae (it is only these organisms that can produce the firm framework of a reef). The following geological periods saw further development of the reef ecosystem inhabited not only by cyanobacteria and algae but skeletal animals too, as opposed to Precambrian ecosystems. The reef ecosystem turned out to be suitable for animals to live and evolve.

Like the Great Barrier Reef, the West Yakut reef is locally explored by drilling.

There are many fossil reefs in the world that are built by skeletal animals in association with algae. In different geological periods, the following animals were involved in the construction of the reef framework: archaeocyaths (Early Cambrian), sponges (Cambrian and later), corals (Ordovician to Recent), bryozoans (Ordovician-Silurian, stromatoporoids (Ordovician-Silurian, but mostly Devonian), fuzulinids and hydractinoids (Permian), crinoids (Jurassic), and sessile foraminifers (nubecularia) (Neogene, Miocene). Among the reef-loving organisms are trilobites, brachiopods, cephalopods, and others. The Late Cambrian thin-layered impure limestones of the Wilburns Formation in central Texas, North America, include numerous bun-shaped buildups of fine-grained limestone of lighter color. The largest of them is 30 m long and 15 m thick. This is thought to be an old reef of algal origin, rising a few feet above the surrounding seafloor (Dunbar, Rodgers, 1962). Here, trilobites were the reef-lovers. Platform-type reefs are reported from Ordovician strata in Virginia and Tennessee, Silurian rocks in Indiana and Illinois, Devonian deposits in Michigan and Alberta and elsewhere. They were formed in vast shallow epicontinental seas. Another old reef worthy to note is the Permian Captain Reef, Guadeloupe Series, on the northern side of the Delaware basin in western Texas and adjacent part of New Mexico. The transverse section of the reef shows successively changing facies – from normal marine to lagoonal (Dunbar, Rodgers, 1962).

Abundant and diverse animals and water plants inhabiting waters of modern reefs also indicate that a reef ecosystem is suitable for organisms to live and evolve. The Great Barrier Reef and other past and present-day reefs are all continuations of the early Cambrian Oymuran reef. Since the Oymuran reef ecosystem was the first to appear on Earth in the Early Cambrian, it naturally couldn't be inhabited by a diversity of organisms. But it is quality rather than quantity that matters – a fundamentally new quality in the evolution of ecosystems and, hence, the whole of the biosphere. However, as seen from the following list of species of archaeocyaths, hyoliths, brachiopods, algae and other representatives of organic world, the Oymuran reef was inhabited by a variety of taxa.

3. Authenticity and/or integrity.

The Oymuran reef is a natural feature located in the Lena Pillars Nature Park, which is managed in accordance with the federal and republican laws including the Law on natural sites of the Sakha Republic (Yakutia) worthy of special protection. Juridical mechanisms for the protection of this natural site are specified in the regulations of the Park approved by the government of the republic.

4. Criterion VIII, category "record of life" by which the Oymuran reef is nominated for inclusion on the World Heritage List (and justification for nomination).

The Oymuran reef is a natural site of outstanding universal value from the scientific point of view (Operational Guidelines for the Implementation of the World Heritage Convention. WHC. 99/2. February 2, 2005; II. The World Heritage List. IIA. Definition of the World Heritage. Article 2 of the World Heritage Convention defines natural heritage as "natural sites of outstanding universal value from the aesthetic or scientific point of view"). The Oymuran reef is an outstanding example representing a major stage of earth's history (B. Criteria for the inscription of natural values on the World Heritage List. Article 44: "...Nominated natural values should be: a). 1. An outstanding example representing a major stage of earth's history").

From the IUCN Thematic Study (Wells, 1996), a diagram was developed illustrating the nature of life on the planet through time. Unfortunately, the emergence of a reef ecosystem, "an island of vital activities of organisms", which is extant nowadays (the Great Barrier Reef and others) is not reflected in the diagram. However, the origin of this ecosystem in the Early Cambrian is as important as the appearance in the Silurian of land ecosystems inhabited by first terrestrial plants and animals, which is reflected in the diagram (Wells, 1996, Fig. 1). Many genera and species of marine invertebrates such as archaeocyaths, sponges, gastropods, brachiopods, hyoliths, trilobites and calcareous algae first appeared in the Early Cambrian in the area of present-day West Yakutia in the Oymuran reef ecosystem wherefrom they spread all over the world (Rozanov, 1986). Thus, the Early Cambrian reef ecosystem is an outstanding example of a natural environment wherein diversification of skeletal animals occurred representing a major stage in Earth's history. The West Yakut barrier reef (about 2000 km long), represented in the Lena Pillars Nature Park by the Oymuran reef, was in the Cambrian as important in the formation of a specific environment and the origin and evolution of life in it as is the well-known Great Barrier Reef nowadays.

The dominant role of algae in the Cambrian as noted by Wells (Wells, 1966, Fig. 1) is well seen in the Oymuran reef where abundant calcareous algae and skeletal animals (archaeocyaths) produced a reef ecosystem on the seafloor. From the IUCN Thematic Study, it is recommended (see Recommendation 1) to choose natural sites with a high diversity of species, which, in context, clearly demonstrate the evolutionary history of the living nature and environment.

A reef ecosystem with a wide variety of species characterizes an environment in which various representatives of living nature existed for over 500 Ma, sequentially changing one another, and still exist nowadays. The earliest example of such an environment is the Oymuran reef easily accessible to the public for examination. Here we observe an early example of mutualistic symbiosis between skeletal animals and calcareous algae (only these organisms can build the firm framework of a reef). Later geological periods saw further development of the reef ecosystem, which was inhabited not only by cyanobacteria and algae but by animals too as opposed to Precambrian ecosystems. It was highly favorable for living organisms to evolve. This is evidenced by abundant and diverse microbiota living in the waters of modern reefs. The Great Barrier Reef is a continuation of the Early Cambrian Oymuran reef. Being a fundamentally new natural system, the Oymuran reef ecosystem couldn't contain abundant and diverse organisms such as seen in modern reef systems but it is quality rather than quantity that matters, a fundamentally new quality in the evolution of ecosystems. The origin of the reef ecosystem in the Early Cambrian may well be compared with the appearance in the Silurian of land ecosystems inhabited by the first terrestrial plants and animals.

5. Description

Academician A.A. Borisyak was the first (1919) to note the presence in the Cambrian rocks of reef-building organisms. In the Eastern Siberian platform (area of present-day West Yakutia), in the mid-Lena river where the Lena Pillars Nature Park is located now, the existence of an archaeocyathan-algal reef in the variegated carbonate rocks was first mentioned by O.V. Flerova in 1939 and later by A.K. Bobrov (1944). The latter wrote: "As early as 1944, in an attempt to explain different environmental conditions in the eastern and western halves of the Aldan shield, we supposed the presence between the Aldan and Anabar shields of a crystalline uplift, which promoted favorable conditions for the intense growth of reef-building algae and archaeocyaths; the reef buildups made communication between the eastern seaward basin and the western interior basin difficult or even impossible (Bobrov, 1964, p. 171). Separate fragments of the elongate archaeocyathan-algal bioherm zone in the eastern Siberian platform have been studied by I.T. Zhuravleva, K.K. Zelenov, K.B. Korde, V.M. Sundukov, I.V.

Nikolaeva and others from the Lower and Middle Cambrian exposures along the Lena, Amga, and Buotama rivers. The bioherms were formed "in a shallow water zone which made the water exchange difficult" (Strakhov, 1962, p. 356). In 1970-1980, workers from the Reef System Sector of SNIIGIMS, headed by V.E. Savitsky and V.A. Astashkin, carried out studies which revealed the presence of the Early-Middle Cambrian West Yakut barrier reef extending between the Aldan and Anabar anteclises (fig. 3, 4). According to geochemical-geophysical and drilling data, the reef occurs beneath thick Paleozoic and Mesozoic strata. The reef ecosystem of the Cambrian is discussed in detail in journals published in English (Zhuravleva, 1999, 2001).

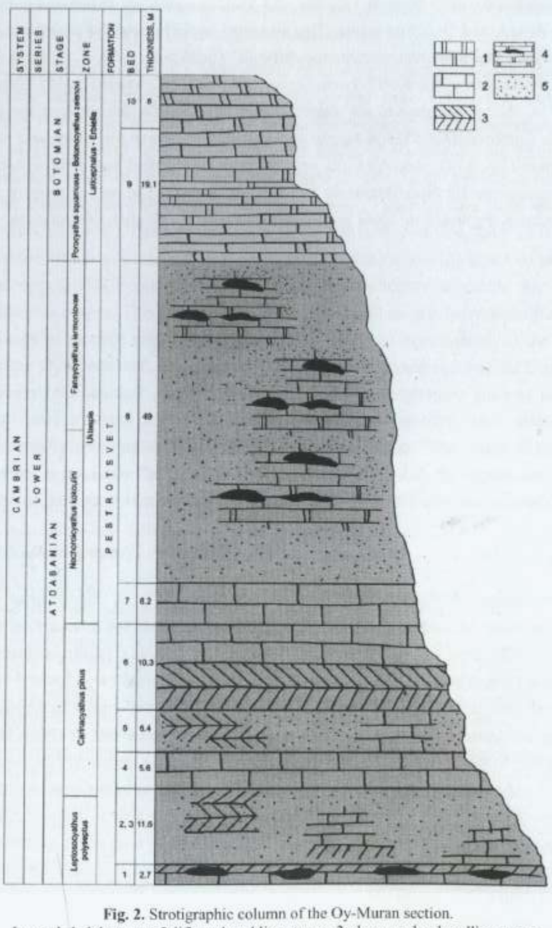


Fig. 2. Strotigraphic column of the Oy-Muran section.
Legend: 1-dolostones; 2-lifht-colored limestones; 3-claueu red-coloredlimestones; 4-archeocyathan bioherms; 5-unexposed intervals

A fragment of the above mentioned large (over 2000 km long and a few to several tens of kilometers wide) West Yakut barrier reef is well exposed over a distance of 3 km, 25-27 km upstream from Sinsk village, on the left bank of the Lena river. Geologists and paleontologists from many countries of the world know it as the Oymuran reef. Its coordinates are: 61° 04´ 18´´ N, 126° 10´ 44´´ E. The reef is made of red and grey massive, recrystallized and mostly secondary limestones and dolomites (fig. 2, 5). The rocks are formed from fossils of skeletal archaeocyaths and red algae of the genus *Epiphyton* Bornemann.

Archaeocyaths were among the first skeletal animals to appear on Earth. On the territory of the Lena Pillars Nature Park, they were found by geologist N.G. Meglitsky in 1850. 11 years later they were reported from North America, and still later from France, Scotland, Morocco, Australia, Spain, China, Mongolia and other countries. Archaeocyaths acquired a calcareous skeleton in the early Cambrian, in a reef ecosystem in the eastern Siberian platform due to symbiosis with calcareous red algae of the genus *Epiphyton* Bornemann. In the beds where archaeocyaths are present epiphytons are commonly found too. These algae appeared on Earth earlier than archaeocyaths.

Archaeocyaths together with calcareous algae and cyanobacteria were the main reef-building organisms in the Early Cambrian. This island of intense vital activities of animals (archaeocyaths), red algae of the genus *Epiphyton* Bornemann and bacteria originated in the eastern Siberian platform in the early Early Cambrian (535 Ma, from Bowring et al., 1993). This was the earliest ecosystem on Earth in which various groups of organisms such as corals, stromatoporoidea, branching bryozoans, calcareous sponges and algae, etc. subsequently evolved.

In Early Cambrian time, mass appearance of calcareous algae and cyanobacteria occurred in the eastern Siberian platform. These include green (genera *Proaulopora* Vologdin, *Subtifloria* Maslov, *Aldanophyton* Kryshtofovich) and red (genera *Epiphyton* Bornemann, *Razumovskia* Vologdin, *Lenaella* Korde) algae and cyanobacteria (genera *Girvanella* Nicholson et Etheridge, *Renalcis* Vologdin, *Globuloella* Korde, *Palaeomicrocystis* Korde, *Uranovia* Korde, *Chabakovia* Volgdin). Numerous species of calcareous algae performed a rock-forming function (Korde, 1961, 1973; Kolosov, 1979, 2000). Most extensively growing were bushy calcareous red algae – epiphytons (*Epiphyton*), forming visible nice patterns, spots and bushes in the claret and red-claret limestones. The Oymuran reef (about 100 m thick) consists of abundant archaeocyaths and algae. Here are some of the archaeocyath species found there: *Archaeolynthus polaris* (Vol.), *A. nalivkini* (Vol.), *Fransuasaecyathus subtumulatus primus* Zhur., *Dokidocyathella incognita* Zhur., *Dokidocyathus lenaicus* Roz., *Kaltatocyathus sp.*, *Nochoroicyathus anabarensis* (Vol.), *N. tkatschenkoi* (Vol.), *N. mirabilis* Zhur., *N. grandis* Zhur., *N. dissepimentalis* Zhur., *N.arteintervallum* (Vol.), *N. sublenaicus* Korsh. et Roz., *Robertocyathus meshkovae* Zhur., *Rotundocyathus novus* (Zhur.), *Robustocyathus robustus* (Vol.), *R. biohermicus Zhur.*, *R. syssoevi* Korsh., *Orbicyathus mongolicus* Vol., *Sibirecyathus suvorovae* (Zhur.), *Lenocyathus lenaicus* Zhur., *Loculicyathus membranivestites* Vol., *Erismacoscinus rojkovi* (Vol.), *Carinacyathus pinus* (Zhur.), *C. kigitasensis* Zhur., *Coscinocyathus «dianthus»* Born., *C. isointervallumus* Zhur., *C. vsevolodi* Korsh., *C. ex. gr. macrocanoides* Zhur., *Leptosocyathus polyseptus* (Latin), *Baikalocyathus rossicus* (Zhur.), *Heckericyathus heckeri* (Zhur.), *Arturocyathus varlamovi* A. Zhur., *Jakutocarinus jakutensis* Zhur., *Carinacyathus kigitasensis* Zhur., *Compositocyathus muchattensis* (Zhur.), *Geocyathus botomaensis* (Zhur.), *G. latini* (Zhur.), *Batchatocyathus tunicatus* (Zhur.), *Dictyocyathus translucidus* Zhur., *Squamosocyathus taumatus* Zhur., *Sphinctocyathus oimuranicus* Zhur., *«Protopharetra polymorpha»* Born., *Paranacyathus tschuranicus* (Zhur.), *Ataxiocyathus subartus* (Zhur.), *Tumulocyathus kotuyikensis* (Zhur.), *T. sp.*, *Tumulocyathellus platiseptatus* Zhur., *T. sp.*, *Tumuliolynthus tubexternus* (Vol.), *Tumulocoscinus sp.*, *Fallocyathus dubius* Roz., *F.* sp., *Fransuasaecyathus subtumulatus secundus* Zhur., *Propriolynthus vologdini* (Jak.), *Ringifungia vavilovi* Korsh., *Taylorcyathus subtaylori* Zhur., *Gordonicyathus sp.*, *Thalamocyathus apprimus* Korsh., *Fansycyathus lermontovae* Korsh. et Roz., *Mennericyathus gratus* (Korsh.), *Isiticyathus ultrus* (Korsh.).

Also present are hyoliths (*Doliutus* sp., *Novitatus* sp., *Tetratheca clinisepta* (Sys.), *Doliutus inflatus* (Sys.), *Tchuranitheca* sp., *Obliquatheca acostae* (Sys.), brachiopods (*Cryptotreta neguertchenensis* Pelm., *Oboella chromatica* Bill., trilobites (*Uktaspis (Prouktas) insolens* (Sys.), hyolithelminths (*Hyolithellus tenuuuunuuis* Miss., *Hyolithellus sp.*, *Torelella sp.,T. lentiformis* (sys.), stenothecoids (*Cambridium nikiforovae* Horny), tommotiids (*Lugoviella ojmuranica* Grip.), and skeletal problematica (*Rhomobicorniculum cancellatum* (Cobb.), *Lenargyrion knappologicum* Bengt. (Cambrian System of the Siberian platform, 2008). There are plenty of algal species of the genus *Epiphyton* Bornemann: *E. plumosum* Korde, *E. botomense* Korde, *E. inobservabilie* Korde, *E. novum* Korde, *E. cristatum* Korde, *E. fasciculum* Korde, *E. induratum* Korde, *E.*

confractum Korde, E. bifidum Korde, *E. racemosum* Korde, *E. durum* Korde, *E. scapulum* Korde, *E. nubilum* Korde, *E. crassum* Korde, *E. tuberculosum* Korde, *E. vulgare* Korde, *E. carptum* Korde (Кордэ, 1961). Along with epiphytons, species of the genera *Renalcis, Girvanella, Proaulopora, Subtifloria*: *Proaulopora glabra* Krasnop., *Renalcis jacuticus* Korde, *R .gelatinosus* Korde, *R. pectunculus* Korde, *Epiphyton scapulum* Korde., *E. durum* Korde, *Girvanella problematica* Nich. et Ether, *Subtifloria delicate* Masl. are present.

A deep bore hole penetrated the red and grey massive dolomites and limestones of the Oymiran reef to a depth of 100 m not reaching its base. An old age of the Oymuran reef is supported by the presence of archaeocyaths characteristic of the early Early Cambrian strata. They were recognized in the borehole core by I.T. Zhuravleva, an outstanding investigator of archaeocyaths. The lowermost part of the reef recovered by the borehole yielded the following archaeocyaths: *Archaeolynthus polaris* (Vol.), *Nochoroicyathus tkatschenkoi* (Vol.), *Dokidocyathus sp.*, *Okulitchicyathus disciformis* (Zhur.) (The Cambrian System of the Siberian platform, 2008).

The Oymuran reef is a natural site of outstanding scientific, cognitive and educational value. It is a very interesting museum of prehistoric nature in the open air. One can see here the biodiversity that existed on Earth in its early periods: abundant fossils of cup-shaped benthic animals (archaeocyaths) and lower plants (calcareous bushy algae of the genus *Epiphyton)*. Richly fossiliferous limestone specimens collected from the Oymuran reef show clearly how rich biodiversity was in this ecosystem (fig. 6-9). You can see here the Earth's first diverse calcareous fauna and flora that appeared in the near tropical environment. Nowadays this is a region of permafrost and a sharply continental climate.

Fig. 3. Schematic position of the "transition" zone (II) separating "lagoonal" (I) and open sea (III) basins of the Siberian platform (Rozanov, 1986). The extensive West Yakut barrier reef is located in the transition zone

Fig. 4. Schematic position of basins separated by the West Yakut barrier reef (boundaries are shown by dashed lines) on the northern slope of the Aldan anteclise (Kolosov, 1997)

Fig. 5. Schematic representation of the visible (surface) part of the Early Cambrian Oymuran reef. Scale: horizontal – 1 cm equals 1 km, vertical – 1 cm equals 10 m

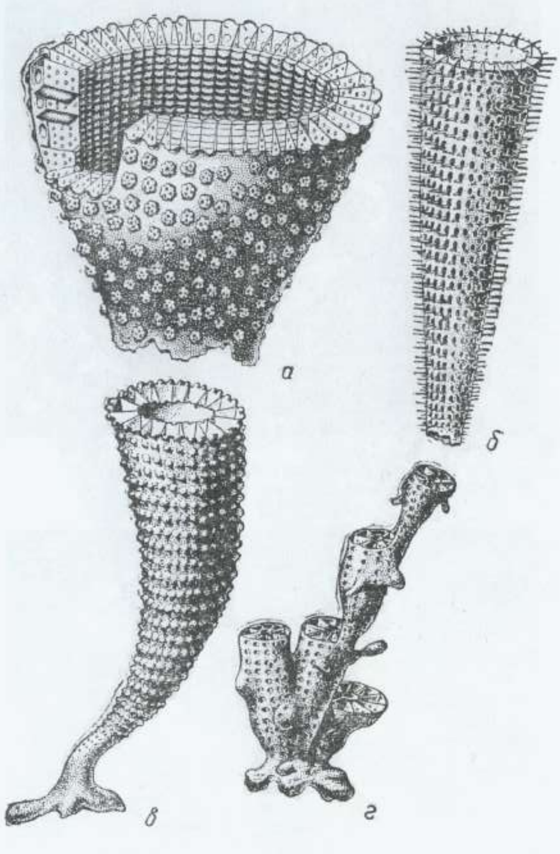


Fig. 6. Reconstruction of Lower Cambrian archaeocyaths: *a* - Lenocyathus; *b* - Robutocyathus; *c* - Kotuyicyathus; *d* – Paranacyathus (after I.T. Zhuravleva) (from; Paleontology of invertebrates, 1962, p.112, Fig.67)

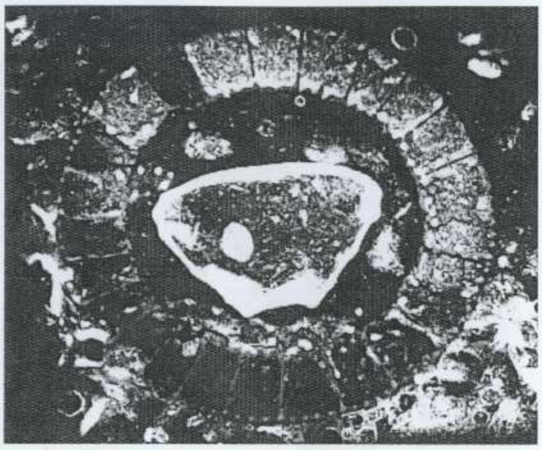


Fig. 7. Cross-section of a two-walled archaeocyath

Fig. 8. A fragment of the reef ecosystem

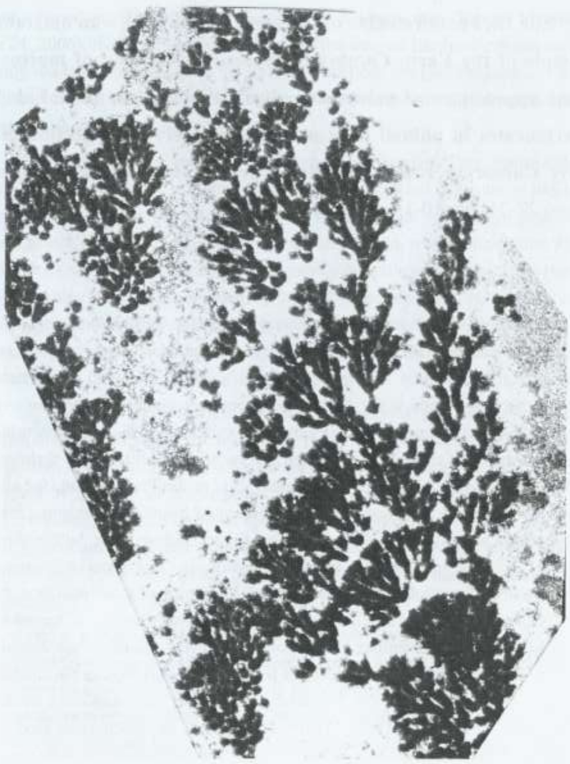


Fig. 9. Red algae *Epiphyton* Bornemann in thin sections

Site III. **Fossil remains of the Lena Pillars Park - an outstanding example of the Early Cambrian Explosive Evolution of marine life (mass appearance of calcareous algae in plant life and of skeletal invertebrates in animal life); a nearly uninterrupted section of the Early Cambrian rocks reflecting a major stage in earth's history** (photo 22-24, fig. 10-15, paleont. plates 1-5).

1. Significance

On a global scale, fossils present in the Lena Pillars Nature Park provide an outstanding example of the Early Cambrian Explosion: mass appearance of calcareous algae in plant life and of skeletal animals in animal life. The well-exposed carbonate strata in the Park, which continuously accumulated for over 20 Ma (535-514 Ma), record a drastic event in the evolution of the organic world - the mass appearance of calcareous algae and marine animals with a hard skeleton or a shell. Paleontologists know well that before this, in the Precambrian, for about 3 billion years, life on Earth was mainly represented by microorganisms (bacteria, cyanobacteria and noncalcified algae). Then, in the Ediacaran, i.e. before the onset of the Cambrian, soft-bodied animals (medusoids, dickinsoniids, supposedly flatworms and other problematica) dominated. Formation of a skeleton or a shell in animals allowed them, for the first time in the evolutionary history, to spread across the globe. Competent scientists of the world have every reason to pay attention to the Early Cambrian period. They describe it as: "a sudden change in the character of life as yet puzzling to us" (V.I. Vernadsky, 1965); the first occurrence of skeletal animals (Dr. Zhuravleva, 1968); rapid development of skeletons in animals (R. Fairbridge, Prof., Columbia University, 1968); the appearance of 475 genera of skeletal organisms (Brazier, 1979); the culmination of a long evolutionary history (Lowenstam, 1984); an epochal evolutionary event (G. Rasmussen, Prof., Yale University, USA, 1989); a unique explosive diversification of animals (Prof. D. Levinton); the appearance during two ages of the Early Cambrian of almost all phyla of animals (A. Yu. Rozanov, Prof., Moscow University, member of the Russian Academy of Sciences, 1986 and other publications); an outburst of biodiversity immediately after animals formed a skeleton of different type and composition (Basic Science of new Russia, 2006, p. 884: opening address of Yu. S.

Osipov, President of the Russian Academy of Sciences at a General Meeting on May 24, 2006); the mass appearance, for the first time on Earth, of calcareous algae (mainly red bushy), which when living on the seafloor increased the amount of free oxygen in the sea basins, as well as offered other possibilities for animals to form a calcareous skeleton (Kolosov, 2008).

We, human beings, are skeletal organisms as are many other representatives of the organic world. We couldn't exist without a skeleton. Calcium is present in large quantities in our skeleton. And it all began on the territory of present-day West Yakutia, in the Early Cambrian, more than 500 Ma, when animals first formed a calcareous skeleton. This was a fundamentally new stage in animal evolution, the very beginning of the development of important new features, new opportunities that were realized in subsequent geological periods. An outstanding example of this stage are paleontologic and paleoalgologic (algal) fossils from the Lena Pillars Nature Park.

In general, paleontologic records objectively reflect dynamics of biodiversification on a geologic time scale, if not taking into account time intervals shorter than a century. As to the Cambrian diversity of marine invertebrates, it is supported by a group of researchers (36 people) who analyzed stratigraphic and geographic ranges of 3.5 million specimens from 44445 collections containing 18703 genera and used data from over 5 thousand publications (Alroy, Aberhan, Bottjer et al., Phanerozoic trends in the global diversity of marine invertebrates // Science. 2008. V. 321. No. 5885. P. 97-100).

"The importance of the Park from the Cambrian perspective lies in the fact that it provides a richly documented transect across a lower Cambrian reef complex, from seaward (present East) edge well back into the interior basin...The park includes the best representation of low latitude Cambrian faunas, across a range of environments, that we know of, and the simple geological structure means that lateral changes in marine habitats can be accurately, and almost uninterruptedly, traced across the entire transect. No other Cambrian area in the World has such a nearly continuous, well preserved, transect. For this reason, it will continue to be of interest to Cambrian scholars and to yield new insights into the early evolution of shell-bearing organisms as well as enriched understanding of details of Early Cambrian ecological relationships. The archaeocyathids (elaborate sponge-related organisms) that make up the reef complex, are among the best-preserved in the world. The potential of the Sinsk formation to contribute new information about soft-bodied faunas has barely been scratched… It is the best place in the world to study, in context, one of the earliest reef complexes, and the preservation of fossils in this complex is significantly better than that in more or less contemporary complexes in North Africa with different species compositions" (from a letter of Dr. A.R. Palmer, retired President of the Institute for Cambrian Studies to Ms. Julia Marton-Lefevre, Director General, IUCN, May 31, 2009).

2. *Comparative analysis*

Among the sites already on the World Heritage List are but a few that record the Cambrian period. These include, for example, the Canadian Rocky Mountain Parks where the Burgess Shale with abundant Cambrian fossils occurs, and the world-renowned Grand Canyon in the southwestern USA with exposed rocks of different geological epochs including the Cambrian.

The Burgess Shale (British Columbia province) yields well-preserved soft-bodied invertebrates of Cambrian age: a small lens of dark-gray shale, about 3 m thick, contains several tens of thousands of animal fossils belonging, as determined by Conway S. Morris (1989) to 120 monotypic genera (sponges, arthropods, bristle worms, mollusks, hyoliths, echinoderms, cnidarians, , brachiopods, etc.). This is indicative of a specific habitat of biocenosis confined to a silty seafloor at the foot of a reef scarp made of calcareous algae (Stone Book. Prehistoric record, 1997) as well as of a peculiar type of preservation and high diversity of the Middle Cambrian biotas. Contrastingly, the exposed carbonate rocks of the Lena Pillars yield abundant fossils of different well-preserved calcareous algae and skeletal invertebrates of the Early Cambrian. These algae and animals appeared there more than 20 Ma earlier than in Burgess. Also, the Lenan fossils exemplify mass appearance, for the first time on Earth, of skeletal or shelled animals, with calcium carbonate being the mineral of choice for most of them. Later animals also had a skeleton formed mostly from calcium carbonate. Burgess is but "a half-open window" into the Middle Cambrian biodiversity as it spans a short period of geologic time. By contrast, the Lenan fossils encompass the whole of the Early Cambrian and, partly, the Middle Cambrian (a period of time longer than 20 Ma). In Chengjiang (Yunnan province, China) there are plenty of Early Cambrian faunas in a good state of preservation, but they are soft-bodied like in Burgess. They belong only to one stratigraphic zone (*Eoredlichia)* thus characterizing a geologically short

period (Jun-Yuan Chen, Lindstrom Maurits, 1991). Since 1995, researchers of the Paleontological Institute, Russian Academy of Sciences (Moscow) have been studying the Sinsk Formation of Lower Cambrian age in the Lena Pillars Park. As a result, several localities of fossil algae, sponges, cnidarians, cephalorhynchs, trilobitomorph arthropods, bivalved arthropods and other organisms have been found and studied. They are comparable in the type and state of preservation to fossils from Burgess and Chengjiang (Unique Sinsk Localities, 2005).

"…present-day Siberia was essentially a distinct Cambrian continent that had its own unique shallow-marine organisms, most of which, at low taxonomic levels (genera and species), are typical only for Cambrian Siberia. Thus, it is not appropriate to compare it to localities in Laurentia (most of present North America), Gondwana (most of southern Eurasia and the continents to the south), or Baltica (present-day northern Europe)" (from a letter of Dr. Allison R. Palmer, retired President of the Institute for Cambrian Studies to Ms. Julia Marton-Lefevre, Director General, IUCN, May 31, 2009).

Thus, in view of the high representativeness of the fossils of the Earth's first skeletal and shelled animals and the long geological period they encompass (the whole of the Early Cambrian epoch) the rock sequences that yield them have a global significance. In this they are comparable to some natural sites from the World Heritage List such as Miguasha (Devonian) in Canada, Dorset and East Devon Coast (Mesozoic) in Great Britain, Ischigualasto and Talampaya (Triassic) in Argentina and Messel (Eocene) in Germany.

3. *Criterion VIII, component: major stages of earth's history including the record of life*

Paleobiological fossils from the Lena Pillars Nature Park provide an outstanding example representing the explosive evolution of sea life in the Early Cambrian (mass appearance and domination of calcareous algae in plant life and of skeletal invertebrates in animal life); a complete section of the Early Cambrian rocks representing a major stage in earth's history. The natural sites of the Park meet criterion VIII, component (element) – "represent major stages of earth's history including the record of life". The diagram developed from the IUCN Thematic Study (Wells, 1996) reflects the domination of algae in the Cambrian, and this stage in plant evolution as having outstanding universal value may be nominated in accordance with the World Heritage Convention.

4. Description

Abundant well preserved fossil remains of the early richly diversified marine skeletal fauna from different stratigraphic levels of the Cambrian in the Lena Pillars Nature Park (Pokrovskaya N.V., Zhuravleva I.T., 1960; Chernysheva N.E., 1961; Khomentovsky, Repina, 1965; Zhuravleva I.T., 1968; Repina L.N., 1968; Korshunov V.I., 1972; Sysoev V.A., 1972; Val'kov A.K., 1975, 1987; Pel'man Yu.L., 1977; Rozanov et al., 1981; Missarzhevsky V.V., 1989; Debrenne F., Rozanov A., Zhuravlev A., 1990; The Ecology of the Cambrian Radiation, 2001; Kolosov, 2007; Rozanov et al., 2008; etc.) provide an outstanding example of the onset of biodiversity on Earth (Kolosov, 2008). Many faunal groups (e.g. archaeocyaths, from Debrenne et al., 1990; trilobites, brachiopods of the genus *Aldanotreta*, from A.Yu. Rozanov, 1986) as well as calcareous algae appeared in West Yakutia earlier than elsewhere.

Participants of the 13th International Field Conference of the working group on stage subdivision of the Cambrian (July 20-August 1, 2008; West Yakutia) noted unique Lower Cambrian transects in the Lena Pillars Nature Park (Episodes, 2008, v. 31. no. 4, p. 440-441).

Below is a brief description of the Lower-Middle Cambrian Pestrotsvet, Perekhod, Sinsk, Kutorgina, Keteme, Tit-Ary, Elanka, Kychik and Ust-Botoma Formations and the Mukhatta sequence recognized within the Park area.

Pestrotsvet Fm was established by I.P. Atlasov in 1935. Its type section is located on the right bank of the Lena river, opposite Sinsk village. It overlies unconformably the Ust-Yudoma Fm. Their contact was established opposite Isit village in 1915. It is composed of red, clayey limestons with interbeds of grey, locally algal, limestone. The formation encloses plenty of archaeocyaths, hyoliths and algae. Thickness ranges from 80-90 m opposite Isit village to 160 m (apparent) on Zhurinsky Mys to 240-250 m (from drilling data) opposite Sayylyk village.

Mukhatta sequence was recognized by V.E. Savitsky in 1971, in the exposures near the Oymuran reef massif. West of the massif, the sequence grades into the Pestrotsvet Fm. It is made of grey and yellow, massive, recrystallized, often

clastic dolomites with interbeds of dolomite sandstone, gritstone and intrasedimentary conglomerates. Within the reef massif, the cross-section includes archaeocyathan-algal organogenic and organogenic-clastic limestones and dolomites. Apparent thickness is about 100-120 m.

Perekhod Fm was distinguished F.G. Gurari in 1994. The type section is in the lower Sinyaya river. As seen from the lower Cambrian transect, the formation conformably overlies the Pestrotsvet Fm. It is made of yellow-grey and grey limestones with archaeocyaths, trilobites and algae. Thickness increases from 25 to 75 m from the Sinyaya river mouth westward.

Sinsk Fm was recognized by I.P. Atlasov in 1935. The stratotype is in the lower Sinyaya river. It overlies conformably the Perekhod Fm. Present are dark grey bituminous, nonuniformly platy, locally flaggy limestones with abundant trilobites and brachiopods. Thickness increases from 40 to 80 m eastwestward.

Kutorgina Fm was established in the Lena Pillars area by O.V. Flerova in 1941. Light-brown limestones interbedded with dolomites yield plenty of trilobites and brachiopods. Thickness is 120 m.

Keteme Fm was distinguished by O.V. Flerova in 1941. The type section is located on the left bank of the Lena r., in an area between Tit-Ary and Blanka villages. The formation overlies conformably the Kutorgina Fm. Grey and light-grey, locally organogenic-clastic limestones alternating with yellow and brownish-yellow dolomites. Trilobites and brachiopods are present. Thickness is 55 m.

Tit-Ary Fm was established by F.G. Gurari in 1944. The type section is on the left bank of the Lena r., 2.5 km upstream from Blanka village. Yellow and yellowish-brown massive dolomites with trilobites. Thickness is 55 m.

Elanka Fm was distinguished by O.V. Flerova in 1941. The type section is on the left bank of the Lena r., 2.5-05 km upstream from Elanka village. In the section it overlies conformably the Tit-Ary Fm. At the bottom there are dolomitic conglobreccia overlain by light-grey clastic, organogenic, nonuniformly platy limestones, in the upper part with dolomite interbeds. Thickness is 50-65 m. The lower 27-28 m of the formation belong to the Lower Cambrian, while the upper beds are Middle Cambrian in age.

Kychik Fm was recognized by Yu.Yu. Shabanov and V.E. Savitsky in 1976. The type section extends for 0.5-0.6 km along both sides of Kychik Creek flowing across the village of Blanka. Grey and dark-grey, locally clayey, nonuniformly platy limestones interbedded with clastic limestones and clayey dolomites. Trilobites and algae are present. Thickness is 85-95 m.

Ust-Botoma Fm was established by I.P. Atlasov in 1935. The type section is represented by rock exposures on the left bank of the Lena r., between the villages of Elanka and Mokhsogollokh. The formation conformably overlies the Kychik Fm, and is overlain, with erosional traces, by Late Jurassic deposits. Grey and greenish-grey, locally clayey, nonuniformly platy limestones with rare interbeds of conglobreccia. It contains trilobites. Apparent thickness is 300-340 m.

Finally, we present fossil remains found in some Lower Cambrian transects (exposed and recovered by drilling) in the Lena Pillars Nature Park.

Fossil remains in borehole 1-bis (Lena r. 4.5 km lower stream Isit exposure): *Archaeocyatha* gen. et sp. indet., *Brachiopoda* gen. et sp. indet., *Chancelloria sp.*, *Cambfotubulus sp.*, *Protospongidae* gen. et sp. indet., *Torellella sp.*, *Hyolithellus* cf. tenuis Miss., *Kijacus kijantcus* (Miss.), *Hyolithellus ct. vladimirovae* Miss., *Palaeosulcachites sp.*,. *Hyolithelius sp.*, *Halktieria sacciformis* (Mesh.), *Hyolithellus vladimirovae* Miss., *Sulugurella sp.*, *Hyolithellus tenuis* Miss., *Turcutheca cf. annae* (Sys.), *Egdetheca aldanica* Miss., *Laratheca cf. nana* Miss., *Jahutiolithus sp.*, *Torellella cf. curva* Miss., *Siphogonuchrtidae* gen. et sp. indet., *Stellaria sp.*, *Alfonia tropodophora* Dore et Reid, *Allathecidae* gen. et sp. indet., *Turcutheca crassecocfilia* (Sys.), *Helcionelloidae* gen.et sp.indet., *Aldanella attieborensis* (Sh.et F) (from: The Cambrian System of the Siberian platform. Book 1: Aldan-Lena region, 2008, p.48, Fig. 18).

Zooproblematica and mollusks in the Isit section: *Archaeopetasus sp.*, *Hyolithellus insolitus* Grig., *Hyolithellus vladimirovae* Miss., *Coleoloides trigeminatus* Miss., *Halkieria sacciformis* (Mesh.), *Hyolithellus tennis* Miss., *Chancelloria symmetrica* Vas., *Archiasterella tetraspina* (Vas. et Sayut.), *Conotheca mammilata* Miss., *Cambroiubulus decurvatus* Miss., *Torellella sp.*, *Tiksitheca licis* Miss., *Tommotia admiranda* (Miss.), *Coleolella billingsi* Miss., *Tommotia kozlowskii* (Miss.), *Tiksitheca korobovi* (Miss.), *Anabarites sp.*, *Sunnaginia imbricata* Miss., *Torellella lentiformis* (Sys.), *Hyolitheilus grandis* Miss., *Lapworthella tortuosa* Miss., *Tommotia plana* (Miss.), *Camenelia garhowskae* Miss., *Torelleloides giganteum* Mesh., *Lapworthella bella* Miss., *Anabarites isiticus* Miss., *Hyolithellus isiticus* Miss., *Torellella biconvexa* Miss., *Chancelloria ex. gr. lenaica* Zhur. et Korde, *Rushtonia sp.*, *Rushtonites insolutum* (Miss.), *Archiasterella sp.*, *Latouchella korobkovi* (Vost.), *Aldanella attleborensis* (Sh.et F.), *Mellopegma indecora* (Miss.), *Igorellina monstrosa* (Miss.), *Watsoneila crosbyi* Grabau, *Bemella jacutica* (Miss.), *Ilsanella sp.*, *Aldanolina magna* Pelman, *Aldanella operosa* Miss. (from: The Cambrian System of the Siberian platform. Book 1: Aldan-Lena region, 2008, p. 61, Fig. 23).

Archaeocyaths in the Isit section: *Nochoroicyathus virgatus* (Zhur.), *Nochoroicyathus sunnaginicus* (Zhur.), *Nochoroicyathus similis* (Vor.), *Nochoroicyathus nolabilis* (Vor.), *Nochroicyathus vulgaris* Zhur., *Batchatocyathus tunicatus* Zhur., *Cryptorocyathus junicanensis* Zhur., *Nochroicyathus aldanicus* Zhur., *Nochoroicyathus artabarensis* (Vol.), *Nochoroicyathus tkatshenkoi* (Vol.), *Retecoscinus sakhaensis* A.Zhur., *Nochoroicyathus supervacuus* Roz., *Nochoroicyathus belvederi* (Roz.), *Retecoscinus retetabulae* (Vol.), *Archaeolynthus polaris* (Vol.), *Robustocyathus robustus* (Vol.), *Dictyocyathus translucidus* Zhur., *Dokidocyathus regularis* Zhur., *Ramuscyathus proximus* Fonin., *Erismacoscinus rojkovi* (Vol.), *Nochoroicyathus mirabilis* Zhur., *Tumulocyathus kotuyikensis australis* (Roz.), *Okulitchicyathus discirofmis* (Zhur.), *Sakhacyathus subartus* (Zhur.), *Korshunovicyathus melnikov* (Korsh. et Foz.), *Ataxiocyalhus subartus* (Zhur.), *«Protopharetra poiymorpha»* Born., *Kotuyicyaihus kotuyikensis australis* Roz., *Paranacyathus tschuranicus* (Zhur.), *Rotundocyathus isiticus* (Roz.), *Sphinctocyalhus oimuranicus* Zhur., *Nochoroicyathus pseudoccultatus* Roz., *Tumuliolynthus primigenius* Zhur., *Nochoroicyathus turbidus* Roz., *Nochoroicyathus fabrefactus* (Vor.), *Nochoroicyathus ridiculus* Roz., *Dokidocyathus ex gr.lenaicus* Roz., *Nochoroicyathus grandis* Zhur., *Nochoroicyathus mutabtlis* (Vor.), *Tumulocyathus sp.*, *Nochoroicyathus sublenaicus* Korsh.et Roz., *Rotundocyathus ignotus* (Korsh. et Roz.), *Nochoroicyathus arteintervallum* (Vol.), *Retecoscinus zegebarti* Korsh., *Loculicyathus membranivestites* Vol., *Coscinocyathus "dianthus"* Born., *Bicyathus ertaschkensis* Vol., *Archaeolynthus sp.*, *Cryptoporocyathus sp.*, *Dokidocyathus sp.* (from: The Cambrian System of the Siberian platform. Book 1: Aldan-Lena region, 2008, p.62, Fig. 24.).

Hyoliths in the Isit section: *Circothecidae* gen et sp.indet., *Conotheca sp.*, *Spinulitheca billingsi* (Sys.), *Laratheca nana* Miss., *Turcutheca crasseocochlia* (Sys.), *Exilitheca multa* Sys., *Ladatheca annae* (Sys.), *Allatheca corrugata* Miss., *Korilithes sp.*, *Exilitheca ancestralis* Sys., *Loculitheca rugala* (Sys.), *Tuoidachites costulatus* (Miss.), *Egdetheca aldanica* (Miss.), *Laratheca tchurani* (Sys.), *Antiquatheca pauca* Miss., *Jacutolituus fusiformis* Miss., *Oblisicornus* *tetraconcavus* Syss., *Tchuranitheca simplicis* (Sys.), *Crestjahitus compressus* Sys., *Burithes distortus* (Sys.), *Notabilitus simplex* Sys., *Locuirtheca sysoievi* (Mesh.), *Oblistcornus compositus* Sys., *Oblisicornus dupleconcavus* Sys., *Dorsojugatus sedecostatus* (Sys.), *Jacuticornus ienuistrigatus* (Sys.), *Isititheca lenae* Sys., *Obliquatheca bicostata* (Miss.), *Majatheca umefacta* Miss., *Conotheca mammilata* Miss., *Eonovitatus grandis* (Mesh.), *Notabilitus orientalis* Sys., *Eonovitatus superbus* Sys., *Microcornus simus* Miss., *Ovalitheca rasa* Sys., *Uniformitheca jasmin* (Sys.), *Doliutus sp.*, *Burithes erum* Miss., *Burithes cuneatus* Miss., *Dorsojugatus sp.*, *Oxytus sagittalis* Sys., *Eonovitatus obruptus* (Mesh.), *Lenatheca dolosa* (Sys.), *Obliquatheca aldanica* (Sys.), *Dorsojugatus multicostatus* Sys., *Lenatheca groenlandica* (Poulsen), *Obliquatheca acostae* (Sys.) (from: The Cambrian System of the Siberian platform. Book 1: Aldan-Lena region, 2008, p. 64, Fig. 25.

Trilobites in the Ulakhan-Kyyry-Taas section: *Judomia sp.*, *Pagetiellus lenaicus* (Toll), *Olenellidae* gen. et sp. indet., *Bonnia aff. arguta* Rep., *Triangulaspis sp.*, *Pagetiellus sp.*, *Botomella sp.*, *Triangulaspis lermontovae* Laz., *Dolichometopidae* gen. et sp. indet., *Bonnia sp.*, *Micamacca sp.*, *Neocobboldia sp.*, *Erbiella sp.*, *Micmacca enormis* Rep., *Bonnia venefica* Rep., *Sinskia obtabilis* Suv., *Triangulaspis annio* (Cobb.), *Granularia sp.*, *Kootenia nebulosa* Rep., *Atdabanella plana* Rep, *Kootenia sp.*, *Neocobboldia dentata* Rep., *Binodaspis sp.*, *Neocobboldia paradentata* Rep., *Protolenidae* gen. et sp. indet., *Judomiella heba* Laz., *Hebediscus attleborensis* (Sh. et F.), *Redlichina tchermschevae* Rep., *Bergeroniaspis jucunda* Rep., *Validaspis uzitata* (Rep.), *Inouyina sp.*, *Poulsenia sp.*, *Erbiella musta* Rep., *Granularia muchattaensis* Rep., *Micmaccopsis lata* Rep., *Erbiella pjankovskia* Fed., *Judomiella sp.*, *Aldonaia pokrovskayae* Kor., *Jakutus sp.*, *Chondrinoyina olekmica* Rep., *Inouyina sp.*, *Tarynaspis brevis* Rep., *Bergeroniaspis dualis* Jegor., *Bergeroniellus micmacciformis* Suv., *Lenadiscus unicus* Rep., *Tungusella manica* Rep., *Labradoria asiatica* Rep., *Bonnana sp.*, *Granularia protolenorum* Lerm., *Kolbineila sp.*, *Sinijanella rara* Rep., *Bergeronieilus spinosus* Lerm., *Bathyunscellus aff. robustus* Lerm., *Altitudella tenera* Rep., *Neopagetina primaeva* (Lerm.), *Bergeroniaspis lenaica* Laz., *Bergerontellus gurarii* Suv., *Pagetiellus tolli* Lerm., *Neopagetina sp.*, *Bathyuriscellus sp.*, *Sergeroniaspis sp.* (from: The Cambrian System of the Siberian platform. Book 1: Aldan-Lena region, 2008, p. 143, Fig. 61.).

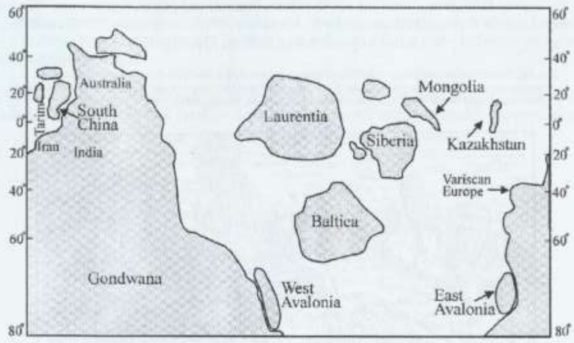


Fig. 10. Palaeographical map for the Early Cambrian (after Steiner et al., 2007)

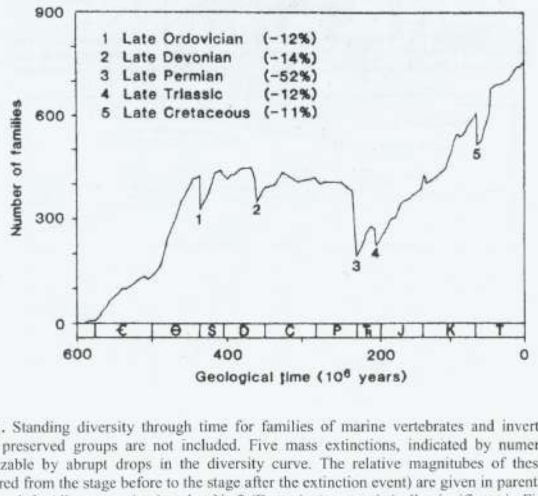
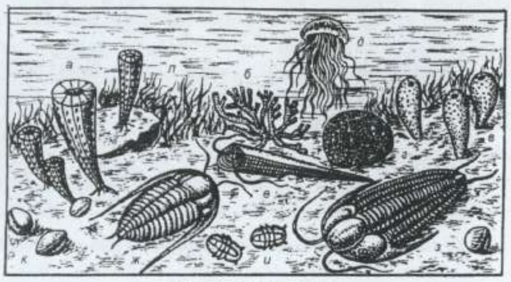


Fig. 11. Standing diversity through time for families of marine vertebrates and invertebrates. Rarely preserved groups are not included. Five mass extinctions, indicated by numerals, are recognizable by abrupt drops in the diversity curve. The relative magnitubes of these drops (measured from the stage before to the stage after the extinction event) are given in parentheses in the upper left. All mass extinctions but No.2 (Devonian) are statistically significant in Fig. 1 and three (Nos. 1, 3, and 5) are highly significant (P<01). (David M.Raup, J.John Sepkovski, 1982, p.1502).

Fig. 12. Typical Ediacaran (Vendian) and Cambrian animals and plants. Not to scale. (Biological encyclopaedic dictionary, drawings by N. Kondakov, 1989; Stone book, 1997, modified; Mikhailova, Bondarenko, 2006, p. 533, Fig. 333)

Рис.16. Характерные животные и растения эдиакария (венда) и кембрия. Соотношения размеров различных организмов не соблюдены (Биологический энциклопедический словарь, худ. Н.Кондаков, 1989; Каменная книга, 1997, с изменениями; Михайлова, Бондаренко, 2006, с.533, рис.333)



Кембрийский период

а, б — археоциаты: *а* — одиночные, *б* — колониальные; *в, г* — губковые: *в* — одиночные, *г* — колониальные; *д* — медуза; *е* — хиолит; *ж–и* — трилобиты: *ж, з* — многочленистые *Lusatiops* (*ж*), *Paradoxides* (*з*), *и* — малочленистые агностиды; *к* — беззамковые брахиоподы; *л* — водоросли

Вендский период

а — *Tribrachidium*; *б* — *Parvancornia*; *в* — колониальные губки; *г* — *Dickinsonia*; *д* — *Tomopteris*; *е* — *Pennatula*; *ж* — зарывающаяся червеобразная форма; *з* — *Ediacara*. Преобладают сегментированные и медузоподобные формы

Cambrian

а, б – archaeocyaths: *а* – singe, *б* - colonial; *в, г* – sponges: *в* - single, *г* - colonial; *д* - medusae; *ж-и* -trilobites: *ж,з* – multiarticulate *Lusatiops (ж), Paradoxides (з), и* – uniarticulate agnostids; *к* - brachiopods; *л* - algae.

Vendian

а - Tribrachidium; б - Parvancornia; в – colonial sponges; *г - Dickinsonia; д - Tomopteris; е - Pennatula; ж* – burying worm form; *з -Ediacara;* Segmented and medusoid forms predominate.

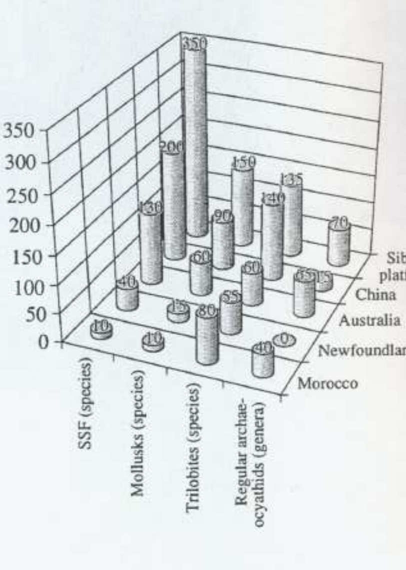


Fig.13. Amount of species and qenera of Early Cambrian fossils in key regions of the world (Rozanov, Khomentovsky, Shabanov et all., 2008)

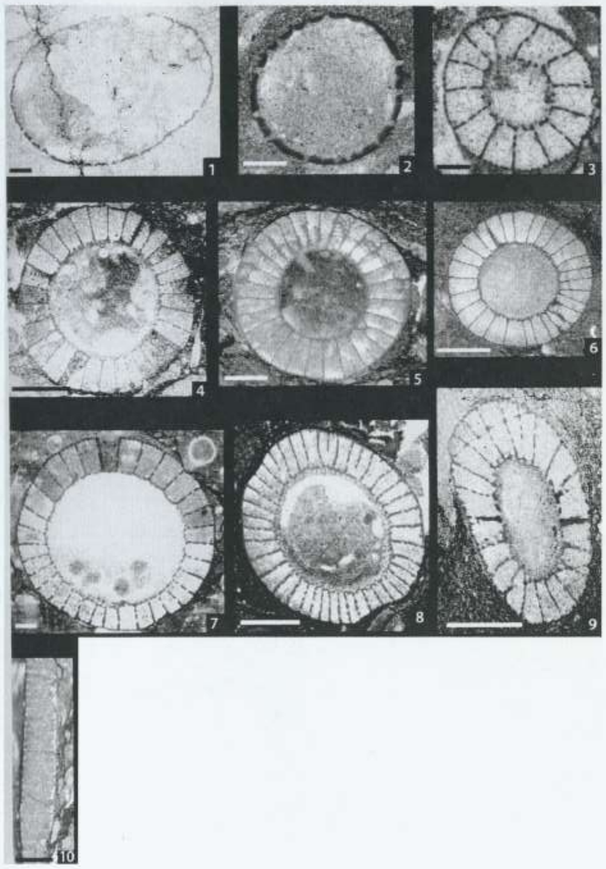
Fig. 14, 15. Trilobites (Unique Sinsk Localities of Early Cambrian Organisms (Siberian Platform). – Moscow: Nauka, 2005. – 143 p.)

Fig. 14. Superbly preserved trilobite *Aldonia ornate* Lermontova, 1940 from the Lower Cambrian Sinsk Formation, Lena R., Lena Pillars Nature Park, Sinsk village area. Latex cast, ammonium chloride coating (x2.4) (Unique Sinsk Localities, 2005, Pl. XXVI, Fig. 6)

Fig. 15. Trilobite-likea rthropod *Phytophilaspis pergmena* Ivantzov, 1999 with big eyes from the Lower Cambrian Sinsk Formation. Scale bar 2 cm (Ivantzov, 1999, fig. 2B)

Paleontological plates showing some Early Cambrian marine skeletal animals found in the Lena Pillars Nature Park area

Plate 1



Explanation of Plate 1

(The Cambrian system of the Siberian platform. Part 1: The Aldan-Lena region, 2008, p.202, plate 3) Archaeocyaths of the *Dokidocyathus regularis* Zone (scale bar 1 mm)

Figs. 1, 2. *Archaeolynthus polaris* (Vologdin, 1937)Ж 1 -slice PIN, no. A-06/is-10-1.75-XIX, specimen no. 16, oblique transversal section; 2 - slice PIN, no. A-06/is-10-1.75-XVIII, specimen no. 2, transversal section; Lena River, Isit Section.

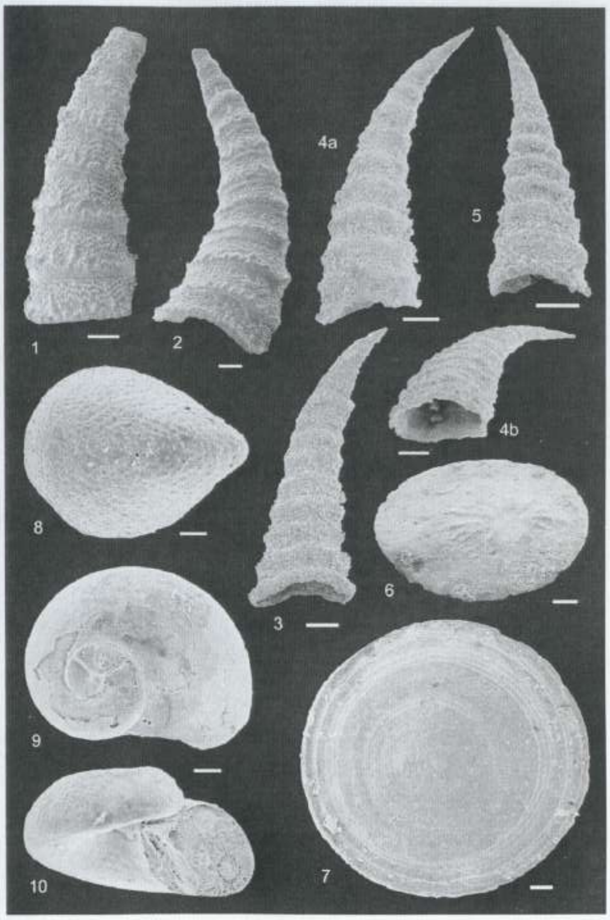
Fig. 3. *Nochoroicyathus tkatschenkoi* (Vologdin, 1937); slice PIN, no. A-06/is-10-X, specimen no. 1, transversal section; Lena River, Isit Section.

Figs. 4-6. *Retecoscinus retetabulae* (Vologdin, 1931); transversal sections, Lena River,Isit Section: 4 - slice PIN, № A-06/is-10-1.95-VI, specimen no. 7; 5 - slice PIN, no. A-06/is-10-2.70-XXI, specimen no. 1; 6 - slice PIN, no. A-06/is-10-1.75-XVIII, specimen no. 1.

Figs. 7, 9. *Nochoroicyathus anabarensis* (Vologdin, 1937); transversal sections, Lena River, Isit Section: 7 - slice PIN, no. A-06/is-10-1.75-XVII, specimen no. 2; 9 - slice PIN, no. A-06/ is-10-1.75-XIX, specimen no. 1.

Fig. 8. *Nochoroicyathus mutabilis* (Voronin, 1979); slice PIN, no. A-06/is-10-1.75-XVIII, specimen no. 8, oblique transversal section; Lena River, Isit Section.

Fig. 10. *Okulitchicyathus disciformis* (Zhuravleva, 1955); slice PIN, no. A-06/is-10-1.75-XIX, specimen no. 10, longitudinal section; Lena River, Isit Section.



Explanation of Plate 2

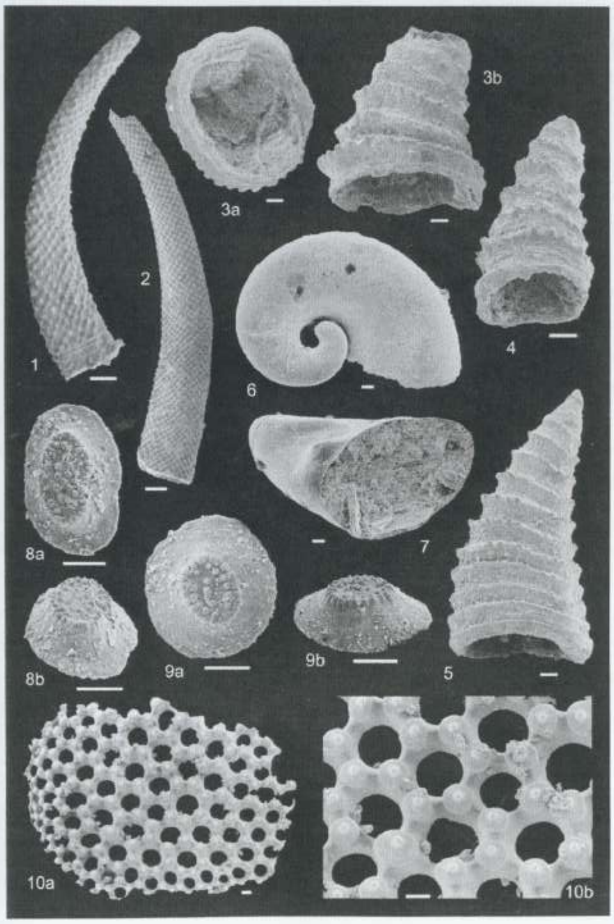
(The Cambrian system of the Siberian platform. Part 1: The Aldan-Lena region, 2008, p.230, plate 17) Zooproblematics and mollusks of the *Dokidocyathus regularis* Zone (1-5, 8-10) and *Dokidocyathus lenaicus* Zone (6, 7) (scale bar 100 μm)

Figs. 1, 2. *Lapworthella tortuosa* Missarzhevsky in Rozanov et Missarzhevsky, 1966, sclerites, lateral views: 1 - PIN, no. 3848/1040, 2 - PIN, no. 3848/1041; Lena River, Isit Section. Figs. 3-5. *Lapworthella bella* Missarzhevsky in Rozanov et Missarzhevsky, 1966; sclerites: 3 - PIN, no. 3848/1073, lateral view, 4 - PIN, no. 3848/1068: 4a - lateral view, 4b - oblique basal view, 5 - PIN, no. 3848/1071, lateral view; Lena River, Zhurinskiy Mys Section.

Figs. 6, 7. *Mobergella radiolata* Bengtson, 1968, sclerites: 6 - PIN, no. 5279/5052, oblique ventral view, 7 - PIN, no. 5279/5059, dorsal view; Lena River, Zhurinskiy Mys Section.

Fig. 8. *Auricullina papulosa* Vassiljeva, 1998, PIN, no. 5083/0038, steinkern, dorsal view; Lena River, Tiktirikteekh Creek.

Figs. 9, 10. *Aldanella operosa* Missarzhevsky in Rozanov et Missarzhevsky, 1966: 9 - PIN, no. 5083/0264, shell, apical view, 10 - PIN, no. 5083/0262, shell, apertural view; Lena River, Achchagyi-Kyyry-Taas Section.



Explanation of Plate 3

(The Cambrian system of the Siberian platform. Part 1: The Aldan-Lena region, 2008, p.232, plate 18) Zooproblematics of the *Carinacyathus pinus* Zone (1, 2) and *Fansycyathus lermontovae* Zone (3-5, 8-10) and mollusks of the *Nochoroicyathus kokoulini* Zone (6, 7) (scale bar 50)

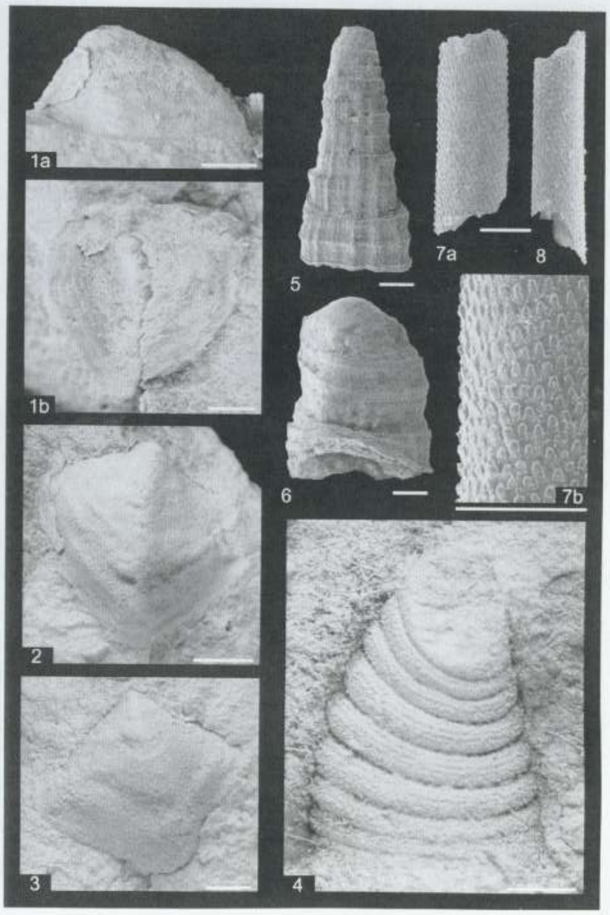
Figs. 1, 2. *Rhombicorniculum cancellatum* (Cobbold, 1921), saber-like sclerites, lateral views: - PIN, no. 3848/1088; 2 - PIN, no. 3848/1029; Lena River, Oy-Muran Section.

Figs. 3-5. *Lapworthella dentata* Missarzhevsky in Rozanov et al., 1969; sclerites: 3 - PIN,
no. 5083/5012: 3a - basal view, 3b - lateral view, 4 - PIN, no. 5083/5010, oblique lateral
view, 5 - PIN, no. 5083/5008, lateral view; Lena River basin, Sinyaya River.

Figs. 6, 7. *Pelagiella adunca* Missarzhevsky in Missarzhevsky et Rozanov, 1966: 6 - PIN, no. 5083/0300, steinkern, apical view, 7 - PIN, no. 5083/0298, steinkern, apertural view; Lena River, Chekurovka Village.

Figs. 8, 9. *Hadimopanella knappologica* (Bengtson, 1977), sclerites: 8 - PIN, no. 5083/5006: 8a - dorsal view, 8b - lateral view; 9 - PIN, no. 5083/5003: 9a - dorsal view, 9b - lateral view; Lena River basin, Sinyaya River.

Fig. 10. *Microdictyon effusum* Bengtson, Matthews et Missarzhevsky, 1981; PIN, no. 4349/3850, sclerite, dorsal view: 10a - general view, 10b - fragment; Lena River, Ulakhan-Tuoydakh Creek.



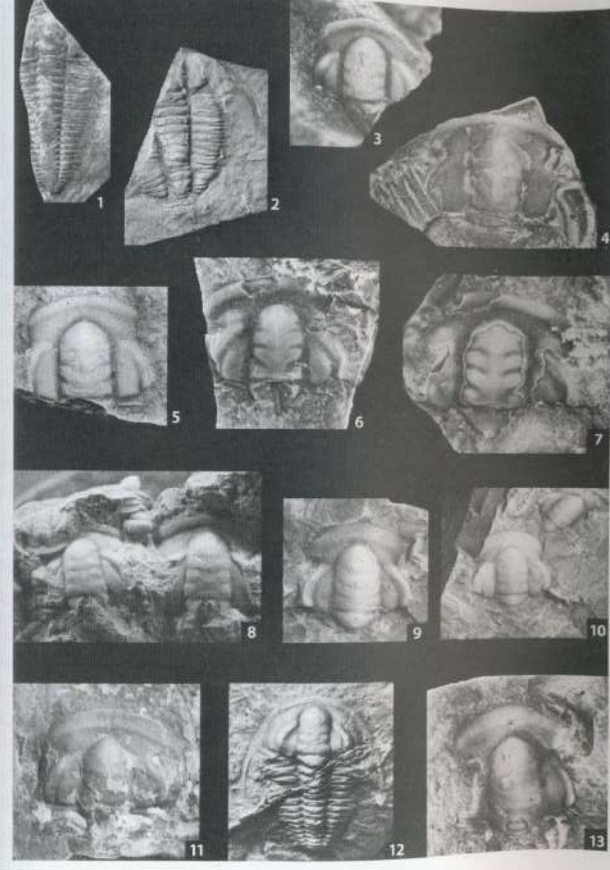
Explanation of Plate 4

(The Cambrian system of the Siberian platform. Part 1: The Aldan-Lena region, 2008, p.234, plate 19) Mollusks of the *Carinacyathus pinus* (1-3) and *Fansycyathus lermontovae* (4) zones, zooproblematics of the *Porocyathus squamosus - Botomocyathus zelenovi* (5-8) Zone (scale bar: figs. 1-4 - 2000 μm, figs. 5-8 – 200)

Figs. 1-3. *Cambridium* sp.: 1 - PIN, no. 5278/0006, shell: la - lateral view, lb - dorsal view; 2 - PIN, no. 5278/0007, shell, dorsal view; 3 - PIN, no. 5278/0008, shell, dorsal view; Lena River, Bachyk Section.

Fig. 4. *Ilsanella atdabanica* (Missarzhevsky in Rozanov et Missarzhevsky, 1966), PIN, no. 5278/0001, shell, oblique posterior view; Lena River, Achchagyi-Kyyry-Taas Section. Figs. 5, 6. *Lugoviella ojmuranica* Grigorjeva, 1983, sclerites, lateral views: 5 - PIN, no. 3848/1047, 6 - PIN, no. 3848/1046; Lena River, Oy-Muran Section.

Figs. 7, 8. *Mongolitubulus squamifer* Missarzhevsky, 1977, sclerites: 7 - PIN, no. 3848/1034: 7a - basal view, 7b - fragment; 8 - PIN, no. 3848/1033; Lena River, Oy-Muran Section.



Explanation of Plate 5

(The Cambrian system of the Siberian platform. Part 1: The Aldan-Lena region, 2008, p.244, plate 24) Trilobites of the *Bergeroniellus gurarii* Zone

Fig. 1. *Bathyuriscellus* sp.; TsSGM, no. 1008/23, incomplete carapace, x 1.4; section at the Sinyaya River.

Figs. 2, 4. *Bergeroniellusguriari* Suvorova, 1956:2 - TsSGM, no. 1011/12, incomplete carapace, x 1.6; section 5 km downstream the Ulakhan-Tuoidakh Creek mouth; 4 - TsSGM, no. 700/322, cranidium, x 2.

Figs. 3, 5. *Bergeroniellus spinosus* Lermontova, 1951: 3 - TsSGM, no. 263, cranidium, x 3; section at the Mukhatta River; 5 - TsSGM, no. 11/16, cranidium, x 3.8; section opposite the Oy-Muran Settlement.

Figs. 6, 7. *Bergeroniaspis lenaica* Lazarenko, 1974: 6 - TsSGM, no. 1020/4, cranidium, x 3.2; section downstream the Mukhatta River mouth; 7 - TsSGM, no. 1020/4a, cranidium, x 2.6; the same section.Trilobites of the *Bergeroniellus asiaticus* Zone

Fig. 8. *Bergeroniaspis divergens* Lermontova, 1940; TsSGM, no. 700/488, cranidia, x 2.5.

Figs. 9, 10. *Bergeroniellus asiaticus* Lermontova, 1940: 9 - TsSGM, no. 1023/17, cranidium, x 2.5; section 4 km from the Batamai Settlement; 10 - TsSGM, no. 1008/22, cranidium, x 1.8; section at the Sinyaya River. Fig. 11. *Bergeroniellus expansus* (Lermontova, 1951); TsSGM, no. 1023/8, cranidium, x 2.8; section 4 m from the Batamai Settlement. Fig. 12. *Bergeroniaspis kutorginorum* Lermontova, 1951; VSEGEI, no. 106/5156, carapace, x 1.3; section at the Sinyaya River.

Fig. 13. *Bergeroniellus lermontovae* Suvorova, 1956; TsSGM, no. 1029/1, cranidium, x 3; the Labaia section.

ANSWERS

to questions in the International Union for Conservation of Nature Fossil Site Evaluation Checklist

1. Does the site provide fossils which cover an extended period of geological time: i.e. how wide is the geological window?

The Lena Pillars Nature Park is marked by a high diversity of animal genera and species: archaeocyaths (40 genera, 111 species), trilobites (78 genera, 122 species), hyolithozoa (55 genera, 88 species), brachiopods (14 genera, 14 species), mollusks (10 genera, 14 species), sponges (1 genus, 1 species), hyolithelminths (3 genera, 9 species), tubular problematica (7 genera, 10 species), tommatiids (1 genus, 1 species) and other zooproblematica. All in all 215 genera and 382 species of Early Cambrian animals. Many of them were first established from the material collected in the Park. Also, a great number of genera and species of trilobites are known from the Middle Cambrian rocks of the Park (Stage subdivision of the Lower Cambrian in Siberia. Atlas of fossils, 1983; The Cambrian System of the Siberian platform. Book 1, 2008; Kolosov, 2007, 2008, the last monograph is published in three languages: Russian, English and German). The fossils cover an extended period of geological time (over 20 Ma).

2. Does the site provide specimens of a limited number of species or whole biotic assemblages: i.e. how rich is the species diversity?

Whole biotic assemblages are present in the Park including 8 phyla and over 400 species (382 for the Early Cambrian and over 30 for the early Middle Cambrian). They characterize a range of environments: from the seaward basin through barrier reef to the interior basin. This is rather a rich species diversity for such an early stage in the evolution of marine skeletal animals. As has been known since Charles Darwin's time, new life forms are limited in number and range.

3. How unique is the site in yielding fossil specimens for that particular period of geological time: i.e. would this be the "type locality" for study or are there similar areas that are alternatives?

The Lena Pillars Nature Park is unique with regard to skeletal faunas present there. According to many famous Early Cambrian paleontologists (E.V. Lermontova, I.T. Zhuravleva, A.Yu. Rozanov, etc.), the Park faunas are more extensively studied than those elsewhere in the world. Present-day Siberia, which includes West Yakutia and the Lena Pillars as part of it, was a distinct Cambrian continent that had its own unique shallow-marine skeletal organisms.

"No other Cambrian area in the world has such a nearly continuous, well preserved, transect. For this reason, it will continue to be of interest to Cambrian scholars and to yield new insights into the early evolution of a range of shell-bearing organisms as well as enrich the understanding of the details of Early Cambrian ecological relationships. The archaeocyathids (elaborate sponge-related organisms) that make up the reef complex, are among the best-preserved in the world…It is the best place in the world to study, in context, one of the earliest reef complexes, and the preservation of fossils in this complex is significantly better than that in more or less contemporary complexes in North Africa with different species compositions" (Dr. A. R. Palmer, retired President of the Institute for Cambrian Studies, USA, May 31. 2009).

4. Are there comparable sites elsewhere that contribute to the understanding of the total "story" of that point in time/space: i.e. is a single site nomination sufficient or should a serial nomination be considered?

There are many sites in the world with Early Cambrian fossils but, as noted by A.Yu. Rozanov, Director of the Paleontological Institute, Russian Academy of Sciences, acting member of the Russian Academy of Sciences, "it is only in the Lena Pillars Park that one can see complete and nearly undisturbed Late Precambrian-Middle Cambrian sections with rich records of the earliest skeletal organisms on Earth. This makes the territory unique. The Lena Pillars and the Burgess Shale differ both geologically and paleontologically. The former is marked by unique geological features, and the latter by unique biological characters. But these two major objects with rich fossil records may supplement each other in

studying the evolution of life on Earth" (May, 2009, Moscow). The same is true of Chengjiang (China) with a diversity of soft-bodied (as opposed to skeletal animals of the Lena Pillars Park) Early Cambrian faunas.

5. Is the site the only main location where major scientific advances were (or are) being made that have made a substantial contribution to the understanding of life on Earth?

The Lena Pillars are the main site where great scientific discoveries were made, which shed light on the earliest stages in the Cambrian evolution of life on Earth. Paleontological studies of the Lena Pillars Park were initiated more than 70 years ago, in 1934, by E.V. Lermontova who investigated trilobites and brachiopods from collections of A.L. Chekanovsky, I.P. Atlasov, O.V. Flerova and other geologists. Since then over 400 genera from 8 phyla of animals have been discovered covering a time interval of more than 20 Ma.

In-depth studies of that rich diversity of taxa contributed grandly to the understanding of the Early Cambrian stage in the evolution of life on Earth. One of the most important scientific discoveries is the well-established fact that the "Cambrian Explosion" in animal forms occurred immediately after they formed a skeleton (Basic Science, 2006). Mass skeletonization of animals occurred earlier in Siberia than elsewhere in the world. This was promoted by a unique temporal coincidence of factors both abiotic (tropical climate, specific tectonics, transgression, epicontinental basin, basic, mainly potassic, composition of volcanic rocks, cooling of weather and regression) and biotic (environment-controlling red algae and bacteria, symbiotic assemblages of algae and animals, highly evolved microscopic soft-bodied metazoans) (Kolosov, 2008).

As early as the first part of the 20th century, the outstanding scientist E. V. Lermontova, who spoke several foreign languages, in her monograph (prepared in 1941 but issued in 1951) made several important conclusions. For example, from the analysis of published literature on fossils and an in-depth study of the Early Cambrian trilobites and brachiopods of Siberia (mainly those collected on the territory of the Lena Pillars Park) she has concluded that first, "such a complete, nearly undisturbed and richly fossiliferous section of Cambrian rocks with a diversity of Cambrian faunas, as seen in Siberia, can be found nowhere else in the world (the same, p. 4); second, the Early Cambrian basins of Siberia, northern

America and northern Europe communicated with each other as judged by the presence of brachiopods of the species *Botsfordia caelata Hall, Kutorgina,* trilobites of the families *Pagetidae, Olenellidae, Solenopleuridae* and other organisms in them; third, some trilobites of the family *Protolenidae* had their origin in Siberia from where they spread throughout the world; and fourth, she reconstructed the main paleoconditions of the sedimentary environment on the territory of the Lena Pillars Park and beyond its limits in Pestrotsvet, Sinsk and Kutorgina.

6. What are the prospects for ongoing discoveries at the site?

During the course of the long evolution of life on Earth some organisms disappeared and new ones appeared. This was due to changing environmental conditions and, as supposed by D. Raup and S. Stanley (1974) to some other factors that controlled the main genetic and physiological features of animals.

It is only studies of fossil communities sequentially changing one another in time that can provide a better insight into the evolution of life on Earth. Such communities covering the epoch of mass appearance of skeletal animals and calcareous algae are present in the Lena Pillars Park (Lermontova, 1951; Suvorova, 1960; Khomentovsky, Repina, 1965; Stage subdivision, 1983, 1984; The Cambrian of Siberia, 1992; The Cambrian System of the Siberian platform: Book 1, 2008, etc.). The good state of preservation of the skeletal fauna and calcareous algae in the Park permits the acquisition of a radically new knowledge by studying in detail their early evolution in different sea basin environments. There are prospects for getting new information through the investigation of the microstructure of fossils that suffered little or no diagenesis.

The Oymuran reef is promising for getting new paleoecological data because, first, it yields archaeocyaths and epiphytons well preserved in their life position; second, like reefs of other ages it records communities of organisms that changed one another through time; and third, the West Yakut barrier reef (including Oymuran) controlled environmental conditions which resulted in the formation of two sea basins (seaward basin and interior basin).

The Sinsk Formation with exceptionally preserved Early Cambrian soft-bodied faunas has yet been poorly studied. Its potential to contribute new information has barely been unveiled. The first results of studies published in a separate book (Unique Sinsk localities, 2005) indicate they are as important as the data obtained from Burgess (Canada), Chengjiang (China) and Sirius Passet (Greenland). The Sinsk soft-bodied biota has been preserved under quite different environmental conditions, and is represented by animals and lower plants absent from the above-mentioned localities. This is the evidence for its high informative potential.

7. How international is the level of interest in the site?

The object is of great interest to paleontologists, paleoecologists, stratigraphers and geologists from around the world. This is evident from the following facts:

1. Paleontologists studying Early Cambrian faunas and stratigraphers correlating deposits from different continents use extensively numerous families, genera and species of archaeocyaths, trilobites, hyoliths, calcareous algae and other organisms first established from material collected in the Lena Pillars Park.

2. International excursions and field conferences were organized on the territory of the Park in 1973, 1981, 1990 and 2008. Over 200 scientists from 23 countries took part in them. Among the participants are eminent researchers such as John Rodgers and Allison R. Palmer (USA), John W. Cowie and Adrian M.A. Rushton (Great Britain), Peng Shanchi (China), Francoise M. Debrenn (France), Stephan Bengtson (Sweeden), Josef Kazmierczak (Poland), Vladimir V. Menner, Alexey Yu. Rozanov, Inessa T. Zhuravleva, Alexey I. Tugarinov, Nina E. Chernysheva, Lada N. Repina, Nina P. Suvorova (Russia) and many others. All of them were deeply impressed with what they had seen. Here are some comments: "I am impressed by perfect rock sections and fossil faunas" (Xuejian Zhu, China); "All the participants were deeply impressed "(Games Vintaned Jose Antonio, Spain); "The excursion was perfectly organized, and the geology and the Lena river beauty are very impressive (Xinan Mu, China).

3. Type sections of the Lower Cambrian subdivisions of the Siberian platform, which are located within the Park territory, and nomenclature of the stages (Tommotian, Atdabanian, Botomian and Toyonian) were included in 1989 into the International Stratigraphic Scale by the International Commission on Stratigraphy. For over 20 years geologists from across the world have been using them in compiling maps for different regions.

4. In 1995, the International Union of Geological Sciences included the Cambrian sections of the Lena Pillars Park into the Global Indicative List of Geological Sites. As currently known, only globally significant sites are included in the list.

5. The comments of Dr. John W. Cowie (England, U.K.), a consultant in geology with the World Heritage Commission: "I agree that the Lena Pillars be designed as a World Heritage Site (July 20, 1992) and of Dr. Allison R. Palmer, President of the Institute for Cambrian Studies: "This letter is in strong support for designation of the Lena Pillars as a World Heritage Site... This is the only area on the planet that can be reached easily in which such an extensive development of nearly undisturbed, richly fossiliferous marine rocks of Early Cambrian age is exposed " (April, 2, 2007) (Kolosov, 2008, pp. 54, 61).

8. Are there other features of natural value (e.g. scenery, landform, and vegetation) associated with the site: i.e. does there exist within the adjacent area modern geological or biological processes that relate to the fossil resource?

The "Lena Pillars Nature Park unites in itself the Lena, Sinsk and Buotama Pillars, the Oymuran reef and other natural features that do not relate to fossil resource. They are nominated, along with the unique Cambrian section with abundant skeketal fauna and calcareous algae, by criteria VII and VIII.

9. What is the state of preservation of specimens yielded from the site?

There are several tens of monographs describing the Cambrian faunas in detail. The photos from them show the good state of preservation of the fossils yielded from the site. Excellent preservation of the fossils was more than once noted by the participants of field excursions. Archaeocyaths from the Park are among the earliest and best preserved on Earth, as noted by Dr. Palmer in his letter of May 31 to Ms. Julia Marton-Lefevre, Director General, IUCN. Dr. I.T. Zhuravleva, who studied the Early Cambrian faunas from different regions of the world for over 60 years, in her letter of May 1, 2007 to Mr. S.V. Lavrov, the head of the Unesco National Commission, wrote that trilobites, archaeocyaths, brachiopods, small shelly forms, algae and other groups of organisms yielded from the Park are better studied than elsewhere on the planet.

CONCLUSIONS

In the Early Cambrian, the territory of present-day West Yakutia was occupied by a sea. Environmental conditions were highly favorable for the skeletonization of animals. This gave rise to more than a thousand species of animals and lower plants. That part of the sea where the Lena Pillars Nature Park is located now was inhabited by several hundreds of species belonging to 200 genera of invertebrates and calcareous algae. That amazing diversification of animals is known as the "Cambrian Explosion". It began from the Late Precambrian microscopic organisms and continued to post-Cambrian diversified skeletal faunas and algae. The Cambrian Explosion occurred all over the world where Early Cambrian living organisms existed.

The Early Cambrian fossils of animals and plants (algae) from the Park are diverse and well preserved. They are yielded from a 980-1370 m thick nearly continuous Early to Middle Cambrian rock section. On the territory of the Park, the exposed rocks are observed over a distance of 157 km. A tectonically simple platform setting produced conditions under which the rocks suffered neither metamorphic heating nor tectonic dislocation. It is important that the Early-Middle Cambrian sequence covers an extended period of geological time, ca. 20 Ma (535-515 Ma). Each member of the sequence contains rich fossil assemblages that record the evolution of life through time. They also characterize environmental conditions that existed at the time: from seaward basin to barrier reef to interior basin.

The Oymuran reef is formed by the earliest archaeocyaths and algae, indicating that a fundamentally new reef ecosystem with a diversity of plants and animals formed there much earlier than elsewhere in the world. And it still exists now. An example is the best-known Great Barrier Reef off the coast of Australia inhabited by some 14 thousand species of living organisms. But it traces back to the Oymuran reef that originated in the Lena Pillars Park area at about 500 Ma.

The Lena Pillars represent a landscape formed on the bank of the great Lena river by unique coastal geological processes related to permafrost. The processes still go on now as seen from the dynamics of this unique landform. In addition, the Lena Pillars are mountains of exceptional natural beauty and a high aesthetic importance.

The data presented for each of the three nominated natural sites combined within the Lena Pillars Nature Park, all formed at one time and in one place, prove that this is a unique natural site, which is of great value to present and future generations of all humanity.

It is in the best interests of the whole of mankind to preserve the Lena Pillars Nature Park – an outstanding example representing:

1. A major Early Cambrian stage in the history of Earth and of life (skeletal animals) as well as of a reef ecosystem;

2. A unique landform of exceptional natural beauty and aesthetic importance, produced by striking natural phenomena such as permafrost.

Role of cyanobacteria, bacteria, and algae in the emergence of skeletal animals on Earth

According to many biologists, the main wealth of the Earth is the diversity of its life forms. Understanding of the early stages in the evolution of life on Earth comes from the studies of fossil remains buried in sedimentary strata. It is supposed that life originated on Earth at about 3.5 Ga (Earth's Earliest Biosphere, 1983). The first to appear were bacteria.

As judged by *Oscillatoria*- and *Lyngbya*-like filaments known from the Tumbian Formation in West Australia (Cloud, 1984), cyanobacteria first appeared on Earth no later than the Neoarchaean, i.e. at about 2.8 Ga. Phycobilin, a pigment found in certain algae, absorbs sunlight energy and transfers it to chlorophyll for use in photosynthesis (Kolesnikov, Egorov, 1977). The carbonate-producing activity of cyanobacteria was enhanced about 2 billion years ago, probably due to the origin of phycobilin. As a result, photosynthesis became more intense, and carbonate production increased.

Formations dated at 2.0 Ga such as Gunflint, Kasegalic, and McLeary in Canada, Dac Krik, Ajron, and Fler in West Australia, and Yatuliy in Karelia contain abundant cyanobacterial buildups in the form of stromatolites. The overview is made by the author (Kolosov, 1985). V.I. Vernadsky (1965, p. 155) wrote: "In Cryptozoic Eon we deal, primarily, with calcareous algae". Among the Paleo- and Mesoproterozoic cyanobacteria were those that suppressed algae by their specific secretions as supposed by analogy with recent species that secrete toxins during life (Korde, 1973).

A wide variety of micro-organisms are known from the rocks dated at 1.0-0.65 Ga (Kolosov, 1970a; Schopf, 1981; Riding, 1982; Knoll, 1994, etc.). They were studied in many countries and regions of the world such as Canada, Australia, Svalbard, the Turukhansk region and the Siberian platform in Russia, and elsewhere. The micro-organisms include cyanobacteria and rhodophytes (red algae). Due to sexual reproduction, the latter began to develop rapidly, particularly in the Cryogenian. To cite an example, filamentous calcareous rock-forming benthic *Dzhelindia* Kolosov (fig. 16, 17).

Fig.16. Benthic red alga (Rhodophyta) *Dzhelindia* Kolosov, 1970 from the Chenchin Formation (Cryogenian, 850-650 Ma), South Yakutia

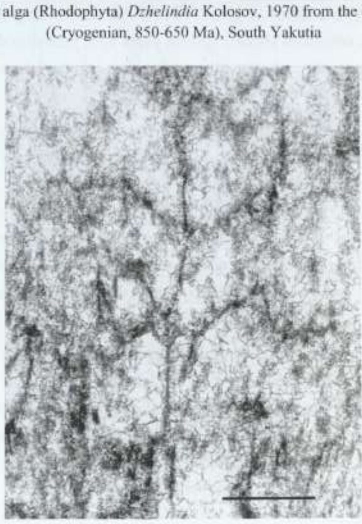


Fig.17. Benthic red alga *Chaptchaica viva* Kolosov, 1975; Neoproterozoic (Cryogenian), Nikol'sk Formation, upper part; Lena r., Tinnaya village area. Scale bar 0.5 mm.

are reported from the Cryogenian in the Baikal-Patom folded region and the Beryozovka basin (Kolosov, 1970); rhodophytes allied to recent *Bangiophyceae* are known from Proterozoic carbonate rocks (1250-750 Ma) on Somerset Island in arctic Canada (Butterfield, Knoll, Sweet, 1990; Taylor E., Taylor T., 1991). Fossil remains of rhodophytes are also reported from Proterozoic strata in China. In the Tonian and Cryogenian, the water environment was still unfavorable for animals to evolve, because the remains of cyanobacteria fell to the seafloor where the concentration of dissolved oxygen was low due to the decay of the organic matter. In these conditions the role of rhodophytes increased greatly. At that time, some representatives of *Metaphyta* and *Metazoa* first appeared.

Rocks aged at 650-542 Ma commonly preserve cyanobacteria and algae with a thick calcareous cover (Kolosov, 1970b, 1979). Along with these organisms, the rocks in Australia, East Europe, the northeastern Siberian platform, and some other regions yield rare, due to poor preservation, fossils of soft-bodied animals (Fedonkin, 1987).

The Paleozoic and Early Cambrian rocks show a rich biodiversity: many phyla and classes of skeletal marine invertebrates. These include mollusks, zooproblematica, archaeocyaths, hyoliths, brachiopods, etc., (Zhuravleva, 1968; Tommotian Stage, 1969; Rozanov, 1986; etc.). A wide range of calcareous cyanobacteria and algae are known from these rocks: *Renalcis* Vologdin, *Proaulopora* Vologdin, *Subtifloria* Maslov, *Botomaella* Korde, *Epiphyton* Bornemann, *Bija* Vologdin and others. Invertebrates first appeared in the eastern Siberian platform (Zhuravleva et al., 1964; Tommotian Stage, 1969; Rozanov, 1980, 1986; etc.). How can this be explained? And how did animals form exoskeletons at the Proterozoic-Paleozoic boundary?

Before answering these questions let us note that the main hypotheses for the reason of rapid diversification of skeletal animals at the Ediacaran-Cambrian boundary were analyzed in detail by A.A. Shevyrev (1967). He relates "a phenomenal thriving of organic world" in the Early Cambrian to "a synchronous spread of some plankton groups to seafloor habitats, adaptation to new biotopes, new ecological niches, isolation of populations, and natural selection (p.70). The overview of hypotheses explaining the explosive speciation at the Ediacaran-Cambrian boundary was made by M.A. Fedonkin (1983, 1987).

Mass appearance of invertebrates occurred at the Ediacaran-Cambrian boundary immediately after they formed an exoskeleton (Tommotian stage…, 1969).

As currently known, the main stages in the evolution of the organic world on Earth were related to changing compositions of hydrosphere and atmosphere due to photosynthetic activity. Marked changes in animal evolution at the Precambrian-Cambrian boundary were also caused by photosynthesis and intense growth of calcium-rich algae (Vernadsky, 1965; Fairbridge, 1968; Korde, 1973; Kolosov, 1977, 1979, 1982). This was favored by a combination of biotic and abiotic factors (Zhuravleva, 1968; Sokolov, 1977; Kolosov, 1982, 1984; Rozanov, 1986). A.H. Knoll (1991) has drawn attention of researchers to close relations between global tectonic, climatic and biogeochemical events, and to significant changes that occurred during Cryogenian-Early Ediacaran time.

Let's turn back to the reasons for the appearance of skeletal animals in the eastern Siberian platform earlier than elsewhere. "Why did all begin in Siberia?" (Rozanov, 1986, p. 68). First let's see what the environment was like in this vast region in the Late Precambrian before the Cambrian explosive evolution of animals which is described by researchers as: a sudden change "in the character of life as yet puzzling to us" (Vernadsky, 1965, p. 154); the first occurrence of skeletal forms of animals (Zhuravleva, 1968); a rapid development of skeletal forms (Fairbridge, 1968); appearance of 475 genera of skeletal organisms (Brazier, 1979); culmination of a "long evolutionary history" (Lowenstam, 1984); formation of almost all phyla of animals in the Tommotian and Atdabanian ages (Rozanov, 1986); an epochal evolutionary event (Rasmussen, 1989); a unique explosive diversification of fauna (Levinton, 1993); an outburst of "diversification immediately after animals formed a skeleton of different type and composition" (Basic Science of New Russia, 2006, p. 884).

Neoproterozoic cyanobacteria and algae in the epicontinental basin ecosystem in the eastern Siberian platform

According to the paleomagnetic data of the American scientist P. Hoffman and other researchers, a single protocontinent Rodinia existed on Earth in the second part of the Proterozoic. It included the entire northern Asia. Most of the territory of Rodinia was located in the near-equatorial zone. The climate was warm, close to tropical, and the basins were shallow there. Massive volcanic eruptions in the region (Shpount et al., 1982; Spount, 1987) produced a further increase in the air and seawater temperature. They also favored the ascent of large volumes of carbon dioxide from depth to the surface (Vinogradov et al., 1952) as well as of nitrogen, phosphorus, manganese, sodium, potassium, magnesium and other chemical elements indispensable to cyanobacteria, algae, and animals. "Most of seaweeds prefer alkali environments as they need high concentrations of K^+, Na^+, Ca^{2+}, and Mg^{2+} for their growth. In natural conditions, many of them grow in the pH interval of 8.8-10.8, in which a carbonate-bicarbonate buffer system is functioning, which controls the concentration and form of CO_2 in the environment" (Kondratieva et al., 1989, p. 257). It is established that the Precambrian biosphere was low in oxygen and high in carbon dioxide (Vinogradov et al., 1952). Noted an important role of prokaryotes in environmental control. Massive growth of cyanobacteria is seen in places where no oxygen accumulation occurs (Gusev, Nikitina, 1979).

Conditions were favorable in the Mesoproterozoic (1.6-1.0 Ga) and in the Tonian-Cryogenian (1.0-0.65 Ga) (Fig.1) for calcareous cyanobacteria and algae which flourished for almost a billion years in the eastern Siberian platform (Kolosov, 1970a, 1975, 2003). They seem to have controlled biogenic migration of nitrogen, phosphorus, carbon, calcium, and other chemical elements (Vernadsky, 1965) concentrating them in cells, colonies, and thalli. As a result of photosynthesis, they produced large volumes of primary organic matter, including carbon and carbohydrates as supposed by analogy with their modern counterparts (Wilson, 1984).

Recent cyanobacteria contain 44-48% C, 1.5-14% N, 6.4-6.8% H, 0.5-2.0% P, and 5.0-10.7 % ash in cells (Guseva, Nikitina, 1979). They accumulate iron, zinc, cobalt, and nickel. With the water temperature in a sea basin higher than 15°C they become dominant (Course of lower plants, 1981). In the presence of phosphates, stromatolite-building cyanobacteria are excluded by algae (McNamara, 1990). It is cyanobacteria themselves that precipitate phosphates, thus raising the pH of the environment.

In search of the reasons for biocalcification as the main type of skeleton biomineralization in invertebrates, we are mainly interested in the production of calcium carbonate, a function uncharacteristic of recent cyanobacteria but quite typical of their Precambrian counterparts. It is in the Precambrian that "biogenic origin of natural Ca, Si, C, H, O, N, Fe, Mg compounds is most evident. Their biogeochemical functions in the structure of biosphere had already existed" (Vernadsky, 1965, p. 155). The effect of microbial (organogenic) carbonates on metazoans has been established (Riding, Liang, 2005). Biogenic formation of carbonate minerals (calcite, aragonite, amorphous calcium carbonate) is discussed in the paper of G.V. Voitkevich and O.A. Bessonov (1986).

K.B. Korde (1961) noted the rock-forming role of blue-green algae from the studies of Cambrian material. She writes: "It is found that carbonate precipitation is a side effect of photosynthesis... Large volumes of calcium carbonate are transformed into an insoluble state" (the same, p.21). CO_2 consumption in the process of photosynthesis leads to increased pH and a higher content of CO_3^{2} ions which combine with Ca^{2+} to precipitate $CaCO_3$ (South, Whittick, 1990). R.V. Fairbridge, Professor at Columbia University, USA demonstrated that there is undoubted evidence that near-shore carbonate facies contained, in the past, more magnesium calcite than other facies due to calcareous algae that entered into their composition.

The Tonian and Cryogenian organogenic carbonate rocks from the eastern Siberian platform contain metastable formations of magnesian calcite-type. This is indicative of the generation of metastable carbonates by blue-green and red algae (Kazansky, 1977). In course of photosynthesis the algae produced significant amounts of calcium salts of organic and physiologic origin (Maslov, 1961), and transformed soluble calcium bicarbonate ($CaHCO_3$) into insoluble carbonate ($CaCO_3$).

Calcium salts of biochemical origin are found buried in thick (400-1100 m) sequences of carbonate rocks, often cyanobacterial, algal, and stromatolitic, which cover vast (hundreds of thousands sq. km) areas in the eastern Siberian platform and its framing. "Calcium carbonate forms in the sea in a solid state, essentially exclusively in a living matter or biochemically" (Vernadsky, 1927, p.219). In the

geological past, calcium salts were mainly produced by rock-forming calcareous algae, particularly by red ones (rhodophytes), which secreted them "from their cell juice" (Maslov, 1961, p.83). Carbonate-producing cyanobacteria also played an important role in the Precambrian (Kolosov, 1970a, 1975; Serebryakov, 1975; Riding, 2000). This was a vivid manifestation of the calcium-forming function of living matter, an early stage in the evolution of a calcium biosphere. As supposed by V.I. Vernadsky (1965), "calcium earlier existed in some other form" (p.249).

The end of the overlong period of cyanobacteria domination. Increasing role of bacteria and algae

The nearly global fall in temperature that occurred in the Early Ediacaran (Vendian) at about 650-700 Ma (Chumakov, 1984) led to mass mortality of living organisms, mainly cyanobacteria that inhabited warm intertidal zones. Another reason for the expulsion of stromatolite-building cyanobacteria by algae was that the latter switched over to living on the seafloor and thus enriched it with oxygen. It is known that cyanobacteria cannot grow well in oxygen-saturated environments. This is apparent from considerably reduced amount and thickness of organogenic rocks (stromatolites) in the eastern Siberian platform and its environs in the Ediacaran. By analogy with recent cyanobacteria (Guseva, 1965), one may assume a sharp increase in the number of bacteria (reducers, medium purifiers, foodstuff for animals) following the considerable reduction of cyanobacteria in the Ediacaran.

Remains of dead cyanobacteria and many other unicellular organisms living at the surface of water or at shallow depths fell to the seafloor. Their decay caused changes in the environmental parameters such as O_2 content, pH, temperature, and light conditions, and favored its enrichment in phosphorus and organic matter. As mentioned by A.V. Sochava (1992), a significant decrease in O_2 content in the atmosphere and hydrosphere was due to the death of cyanobacteria whose dead bodies fell to the seafloor where they required large O_2 amounts for decay. Following the death of calcareous algae, their $CaCO_3$ precipitates were dispersed in lime mud (Dunbar, Rodgers, 1962).

In the Late Ediacaran, a significant marine transgression (the seawater was cold due to a fall of temperature) over the pre-Ediacaran mainly organogenic (algal) limestones and dolomites occurred. Waters saturated with respect to free carbon dioxide (it was but little consumed due to the mass death of cyanobacteria) and organic substances got in contact with cyanobacterial and algal carbonate rocks and thus dissolved them. The latter, as noted above, had high concentrations of calcium salts of organic and physiological origin.

As noted by R. Fairbridge (1969), solubility of $CaCO_3$ increases with the growing CO_2 content of seawater. Solubility of calcite is 68 mg/l calcium carbonate, at 20°C and CO_2 partial pressure of 10^{-3} atm. (Shutskaya-Myuksar, 1973). It is known that organic masses change physico-chemical conditions of the aquatic environment, shifting a dynamic Mg-Ca equilibrium "towards carbonate matter

dissolution" (Lukashev et al., 1973, p. 520). The reason for excess calcium carbonate in the seawater in the early Cambrian was unclear before. It is quite improbable that calcium fell down, in mass volume, with comets at 600 Ma as supposed by A.A. Barenbaum (2004).

From the aforesaid it follows that the amount of biogenic calcium carbonate and calcium phosphate sharply increased in the waters of the Late Ediacaran sea basins in the eastern Siberian platform. "In the Cambrian system we have clear evidence for a sudden change in the history of calcium in the hydrosphere… Ca-rich microscopic life could have existed before this time, which has left no remains. American geologists assume that at that time chemical composition of seawater changed, it became richer in Ca than it is nowadays and than it was in all other geological periods known" - V.I. Vernadsky wrote (1965, p.249).

In the Late Ediacaran and Early Cambrian, due to reduced vegetation activity of cyanobacteria that consumed CO_2 and enriched seawater in organic matter, the sea basins in the studied region became richer in free carbon dioxide and dissolved oxygen (due to its sharply decreased biochemical consumption). Also, the amount of rhodophytes and bacteria increased.

Thus, the overlong period of cyanobacteria domination in sea basins ended at the Cryogenian-Ediacaran boundary. Due to the reduced photosynthetic activity of cyanobacteria, the Late-Ediacaran-Early Cambrian epicontinental sea basins became enriched in soluble CO_2. They were mainly inhabited by rhodophytes (benthic organisms survived the fall of temperature as they lived at a greater depth). Waters of the basins were rather clear, not oversaturated with organic matter and, hence, contained more oxygen. The sunlight penetrated deep into the water thus making photosynthesis possible. This gave rise to diverse life forms. Unlike cyanobacteria, which evolved in shallow parts of the sublittoral zone, Cryogenic rhodophytes such as benthic *Dzhelindia, Chaptchaica* and others preferred its deeper parts, i.e. a zone below the wave front nowadays inhabited by abundant and diverse marine fauna. The above-mentioned nearly global Ediacaran cooling of the climate also caused a progressive increase in the CO_2 content of seawater. Oxygen is known to dissolve better in cold water that goes downward thus delivering it to the deeper parts of the basin.

According to B.S. Sokolov (1977), a rapid appearance of the main phyla of invertebrates was due to adaptive radiation when they spread to the bottom of shelf seas inhabited by plant benthos. Indeed, the Late Precambrian algal overgrowths constituted a primary habitat (biotope) and a source of food for animals at that time (Shenborn, 1987; Burzin, 1996). A diversity of evolutionary cycles offers strong adaptive possibilities for rhodophytes. This is evidenced by a great number of recent genera and species of these algae which are mainly sessile organisms (Petrov, 1986).

Along with calcium, cyanobacteria and algae accumulated phosphorus, nitrogen, carbon, potassium and other chemical elements delivered from depth as a result of volcanic activity. By the late Neoproterozoic-early Early Cambrian, massive accumulation of phosphates has occurred (Cook, Shergold, 1984). This was partly due to the mass burial of P-bearing cyanobacteria as a result of a decreased temperature in the Ediacaran. Accumulation of calcium phosphate in sedimentary rocks, and its dissolution and subsequent entry into sea waters as a result of transgression, played an important role, in the Late Precambrian-Early Cambrian, in the exclusion of stromatolite-building cyanobacteria by algae and in the formation of a phosphate coat in algae and a phosphate skeleton in animals.

Accumulation in the eastern Siberian platform in Tommotian time of lime muds with high iron content (which imparted a red coloring to limestones there (Rozanov, 1986) also was the result of bacterial and cyanobacterial activities. They accumulated iron in amounts an order of magnitude higher than other lower plants (Kalinenko, 1952). Ferric iron precipitation was related to decomposition of cyanobacteria and iron bacteria. "In the epoch of stromatolites, iron was mostly extracted from the ocean" (Zavarzin, 2006, p.532).

Basic volcanic rocks that formed in the southern Siberian platform in the Late Ediacaran (Shpount et al., 1982) may be regarded as a source of iron salts for the Early Cambrian sea basins. Iron was also supplied in aqueous solution from distributive provinces in the south of the platform. Organisms consumed it as a colloidal oxide, Fe $(OH)_3$, and then dissolved it with the aid of acidic secretions of cells. After the death of the organisms, Fe was precipitated from their dead bodies. It is known that iron bacteria (e.g. *Thiobacillum ferrooxidans*, *Gallionella ferruginea*, *Leptothrix orchaceae*) live in habitats with a high content of reduced iron salts. Often, the slimy coat of some *Nemaliales* (red algae) is covered not only with carbonates but with iron salts too (Algae, 1989). An example is a specimen of an Early Cambrian stromatolite from a stratotype section in the mid-Lena area. As seen in the photo, stromatolitic microlayers are sharply demarcated by Fe-rich (red on the color photo and black on the black-and-white one) mineral matter. Like all the fossilized and recent stromatolites, the shown Early Cambrian structure was unquestionably formed with the activity of bacteria and cyanobacteria.

Skeletonization of animals in the light of environmental conditions in the Siberian platform

One of the most hotly debatable questions in the long evolutionary history of animals is that concerning the reasons for exoskeleton formation. It is established that the amount of benthic animals in the present-day low-oxygen bodies of water depends on their O_2 content. With regard to O_2 content, D. Rhoads and J. Morse (1971) have distinguished three zones: the first with 0.1 ml/l, where multicellular animals are absent; the second with 0.3-1.0 ml/l where soft-bodied animals buried in mud are found, and the third with 1.0 ml/l characterized by a diversity of animals with a calcareous skeleton. From these observations, the author (Kolosov, 1982) has concluded that the Lower Precambrian enrichment of the Siberian platform seas in oxygen played a significant role in the evolution of animals in Ediacaran and Cambrian time, and that the most important of the biotic factors was the algal one.

A high oxygen content in seawater is harmful for cyanobacteria (Gusev, Nikitina, 1979). With this in view, the author related the formation, in the Ediacaran, of a thick calcareous cover in cyanobacteria and algae as "a necessity to protect cells and filaments from harmful environmental conditions which became constant in character, and to increased atmospheric and hydrospheric oxygen levels (Kolosov, 1984, p. 34). L.M. Gerasimenko and G.A. Zavarzin (1993) also noted the protective function of a slimy coat in the cyanobacterium *Microcoleus* and its thickening in response to unfavorable conditions.

Later, A.V. Sochava further developed the idea of protection of the Late Ediacaran-Early Cambrian organisms from excess oxygen through the development of a calcified coat by cyanobacteria and an exoskeleton by animals. He related it to the most important physiological processes, such as respiration, of organisms (Sochava, 1992). The support for this model comes from the appearance of cyanobacteria and algae in the Proterozoic and of animals in the Neoprotrozoic and Ediacaran, when O_2 content was low in the hydrosphere. Of course, the organisms were well-adapted to that environment. In the late Ediacaran-early Cambrian, the amount of oxygen in the sea basins increased, as discussed earlier. The organisms had to adapt to these novel environmental conditions unusual to them. So it may with good reason be assumed that a coat in cyanobacteria and algae and an exoskeleton in animals fulfilled a protective function from excess oxygen (Sochava, 1992). As a result, less oxygen got into the bodies of the organisms. B.V.

Andrianov and N.L. Reznik (1999) assume oxygen poisoning of the environment with the origin of photosynthesis.

According to the paleomagnetic data of American scientist J.L. Kirschvink jointly published with the Russian paleontologist A.Yu. Rozanov in 1984 and well accepted by a large body of scientists from the USA, Canada, Great Britain, France and elsewhere, in the Cambrian the Siberian platform still was within the paleoequatorial area. The latter crossed the platform from northwest to southeast (Fig.2). Red algae of the genera *Epiphyton* Bornemann, *Subtifloria* Maslov, *Batinevia* Korde and others were abundant there. The cyanobacterial environment gave way to an algal one, more suitable for animals.

In 1981, H.A. Lowenstam distingushed two fundamentally different processes of mineral formation: a biologically induced process and an organic matrix-mediated process (Lowenstam, 1984). In the biologically induced mineralization process there is no biological control, and the deposited minerals have crystal habits similar to those produced by precipitation from inorganic solutions. In the second process, nucleation and subsequent growth of minerals occur in contact with the preformed organic matrix framework. The products of the organic matrix-mediated process are mostly located extracellularly, forming mineralized hard parts. Morphology of paracrystalline minerals is under genetic control.

The organic matrix-mediated mineralization began in the Precambrian when the organic matrix of cyanobacteria and algae was substituted for by silica, calcium carbonate, and calcium phosphate. The improvement of this type of mineral formation was mainly associated with the evolution of red algae. Lowenstam (1984) was right saying that by the time when fully mineralized animal skeletons first appeared in the fossil record, the organic matrix-mediated mineralization had already existed and, from the evolutional standpoint, it was quite an advanced process. So it was not necessarily initiated by animals. It is thus unlikely that this type of biomineralization was due to mass appearance of skeletal fauna early in the Cambrian as suggested by I.S. Barskov (1984).

A switchover from the biologically induced (e.g. formation of stromatolites) to organic matrix-mediated mineralization occurred in the Ediacaran with a wide development of algae of "Paleozoic habit" (Kolosov, 1970b) having a calcareous cover (*Proaulopora* Vologdin, *Subtifloria* Maslov, *Renalcis* Vologdin, *etc.*). Some of these algae are reported, though quite rarely, from Neoproterozoic (Upper

Riphean) rocks (Terleev, 1993). From the studies of Paleozoic algae, B.I. Chuvashov (Calcareous algae fossils, 1987) has concluded that "among red algae are many forms with a mineralized, mostly calcified, coat" (p.112).

With regard to destruction resistance, R. Ginzburg (1956) has recognized six types of exoskeleton: massive, branched, chambered, segmental, crustal, and spiculate. In the Late Ediacaran, many species of algae (mainly blue-green and red) from the eastern Siberian platform began forming calcareous exoskeletons of different types. We see that *Proaulopora* Vologdin, *Subtifloria* Maslov, and *Globuloella* Korde have a massive exoskeleton, *Renalcis* Vologdin and *Girvanella* Nich. et Etheridge a crustal exoskeleton, and *Korilophyton* (primitive *Epiphyton* Bornemann) a branched one.

Most of the plants and animals have resulted from a mutualistic symbiosis. Defining the "living matter" as a combination of organisms, V.I. Vernadsky (1965, p.265) noted that "a homogeneous living matter fully isolated from other organisms doesn't exist in nature". A.A. Lyubishchev (1982, p.195) wrote: "...here is a small flatworm, utterly green, capable to assimilate carbon with the aid of symbiotic algae. They are so intimately associated that algal rudiments are transferred to it via sexual cells just as chloroplast rudiments are transferred in green plants".

Surprisingly, some recent cyanobacteria, when living inside invertebrates, retain their photosynthetic ability (Lewin, 1984). Due to photosynthesis, carbon is utilized by organisms in the form of CO_2. Sulfate-reducing bacteria present in organisms change the pH of the environment thus making $CaCO_3$ deposition possible (Kuznetsov, 1970). There are some cyanobacteria that fix nitrogen.

Zinova (1967) reported about a branched, uniserial, filamentous thallus of algae of the family *Bangiacea* (S.F. Gray) living in the calcareous shells of mollusks.

Algae play a certain role in calcification; about 20% of photosynthetically fixed carbon subsequently appears in the shells of foraminifera (Smith, Wiebe, 1977; South, Whittick, 1990). The growth and calcification of corals in a reef ecosystem depend on the abundance of algae from which they get 85% of their organic carbon (Muscatine, Porter, 1977). Taking all this into account, the author (Kolosov) suggests that the same situation existed at the beginning of the mass appearance of skeletal invertebrates.

Cyanobacteria and rhodophytes were both exosymbionts and endosymbionts. When living on soft-bodied animals, they supplied them with oxygen and consumed carbon dioxide. When living inside animals with an organic cover they promoted, through complex biochemical transformations in cells and heterotrophic metabolism and with the aid of bacteria, biomineralization of the organic matter of soft-bodied animals and the origin of skeletal fauna. This gave rise to the diversity of the Early Cambrian animals with a calcareous skeleton (mollusks, brachiopods, sponges, archaeocyaths, etc.). The microstructure of some of these animals (e.g. archaeocyaths) is similar to that of most Cambrian calcareous algae, *Epiphyton* Bornemann and *Renalcis* Vologdin genera in particular (Rozanov, 1986). This is direct evidence for the important role of algae and cyanobacteria in skeletal formation in early animals. In rare cases, algae could settle on dead bodies of animals. There is evidence that symbiotic bacteria defined the microstructure of the calcareous skeleton of Archaeocyatha, Renalcis, Epiphyton, and sponges (Camoin et al., 1989). These algae seem to have precipitated $CaCO_3$ during life (Tikhomirova, 1990). Constructive symbiosis of the Late Ediacaran-Early Cambrian soft-bodied animals with cyanobacteria and rhodophytes played an important role in the "skeleton revolution" (Kolosov, 1984, 1997, Buddemeier, Fautin, 1996).

If algae, alone or together with bacteria, in symbiosis with animals promote calcification of the organic cover of the host animals, then a question arises: "Why did not this biomineralization process occur in the Late-Precambrian stage of the invertebrate evolution?" (Morris, 1994). It is well known that algae precipitating carbonate (Kuznetsov, 1970) or, in other words, forming $CaCO_3$ (Isachenko, 1948) existed at that time. In search for an answer to this question one may assume by analogy with recent algae that along with organic substances the Late Precambrian algae secreted phenols slowing down the cell growth of animals (Kondratieva et al., 1989). Moreover, phenols occurring on the cell surfaces hampered $CaCO_3$ crystallization (Reynolds, 1978). It is quite possible that phenol-secreting cyanobacteria and algae existed in the Late Precambrian. One should also keep in mind that if CO_2 concentration in water exceeds a certain critical value, then no $CaCO_3$ precipitation occurs but a soluble calcium bicarbonate – $Ca(HCO_3)_2$ is formed (Zimina, 2006). It is not improbable that this was the case in the Ediacaran. The fact that an opportunity arose for algae to form a calcareous coat, as was noted by B.I.Chuvashov (1987), suggests that situation had changed, and that the Late Ediacaran-Early Cambrian algae and invertebrates had good prospects to form a calcareous coat and a calcareous exoskeleton, respectively. It is known that if

cyanobacteria grow in water supersaturated with respect to calcite, then their coat may be rich in carbonate crystals and, therefore, quite noticeable as with the Cambrian forms.

As discussed above, the Late Ediacaran-Early Cambrian seas contained high concentrations of phosphorus compounds of biochemical origin. It has also been established that intense nitrogen and phosphorus cycling occurred in symbiotic associations of algae and foraminifera (South, Whittick, 1990). In the Late Ediacaran-Early Cambrian (Tommotian age), in the eastern Siberian platform, some invertebrate forms such as *Camenella, Lapworthella, Hyolithelmintes*, etc. formed a phosphate skeleton (Tommotian stage, 1969). According to M. Brazier (Brazier, 1979), 475 genera of skeletal organisms appeared on Earth in the Early Cambrian. 55 of them had a phosphate shell. There is good reason to assume that they utilized phosphorus that cyanobacteria and algae accumulated in the Neoproterozoic and that returned after their death to the hydrosphere. "A biogenic migration of some chemical elements (atoms) from the environment into living matter and vice versa occurs. An organism takes from the environment all the needed elements in the form of compounds and atoms in the form of isotopes" (V.I. Vernadsky, 1965, p. 265). The above-mentioned early fossil animals with a phosphate exoskeleton became quite rare in the strata deposited later than Tommotian time.

Abundant biochemical (cyanobacterial and algal) calcium compounds dissolved in seawater appear to have been energetically more suited to animals to form a skeleton from them. We mean here phylogenetically advanced small animals of Late Ediacaran-Early Cambran age (Fedonkin, 1987; Crimes, Fedonkin, 1996), which apparently "waited for a better time to develop a skeleton" (Kolosov, 1982, 1984). Cambrian adaptive radiation was accompanied by the formation of soft-bodied organisms quite different from Ediacaran ones. In the eastern Siberian platform, those animals that utilized calcium carbonate and calcium phosphate of cyanobacterial and algal origin and lived in symbiosis with bacteria, cyanobacteria, and rhodophytes (mollusks, brachiopods, sponges, archaeocyaths, etc.) formed an exoskeleton in the Late Ediacaran-Early Cambrian. In the Neoproterozoic, this was for protection from some of the cyanobacteria that consumed them, and in the Ediacaran and later times from predators.

The formation of an exoskeleton in animals and their following diversification in the Early Cambrian occurred in conditions of high oxygen, phosphorus, and calcium saturation of seawater. Moreover, bacterial activity favored purification of water from decaying organic (cyanobacterial and algal) remains. In many sea basins of the world, the Tommotian time was marked by marine regression. By contrast, in the eastern Siberian platform the sea was transgressing at that time, and environmental diversification occurred. Oxygen-saturated habitats of benthic red algae were quite livable biotopes for animals. The water temperature was +28-32°C as determined on glauconite.

In the Phanerozoic Eon, including the Paleozoic, Mesozoic, and Cenozoic Eras, abundant and diversified invertebrates lived in the sea. The life span of a genus was, on average, 10.6 Ma. The Early Cambrian was the time when most phyla and classes of recent marine invertebrates originated. The rates of evolution at that period of time have remained poorly known until recently. A more precise dating of the onset of the Tommotian (534.6 Ma) by American scientists (Bowring et al., 1993) in cooperation with the author (Kolosov) revealed that the evolution rates were much higher than it was thought before. For example, in the Ordovician, the life span of a genus of Trilobite averaged 6.3 Ma. In the Early Cambrian, the life span of a trilobite genus was less than a million years, and that of a species 750 thousand years. E.O. Wilson (1989) demonstrated that about 170 families of various life forms originated in the Cambrian that lasted for a hundred million years. In accordance with our dating of the onset of the Cambrian, now generally accepted, the aforementioned 170 families emerged over a much shorter (35-54 Ma) period.

One of the reasons for the explosive evolution of sea animals at the very beginning of the Cambrian (Bowring et al., 1993) is that during the Late Precambrian evolution, which apparently proceeded smoothly, the early soft-bodied animals attained in their development an extremely unstable state. Since favorable hydrospheric conditions (primarily additional oxygen liberated by benthic red algae and biogenic calcium compounds) were set up in the eastern Siberian platform in the Late Ediacaran-Early Cambrian, small soft-bodied animals began to form an exoskeleton. As a result, a rapid diversification of animals occurred in the sea basins of the region in the Early Cambrian. And by the late Atdabanian-early Botomian (Early Cambrian) their evolution had stabilized. "Experiments" aimed at choosing suitable material for building a skeleton and at developing new body shapes were over. This is evidenced by the appearance of nearly all main phyla of invertebrates by the time (Rozanov, 1986; Basic Science, 2006). It appears that this is the case when evolution "doesn't need hundreds of millions of years to proceed…

It sleeps long, but when forced to wake up it does its work quickly and resolutely" (Nazarov, 1992, p. 113).

Rocks of Early Cambrian age are found not only in the Siberian platform but in many other countries and regions including China, Mongolia, Kazakhstan, Australia, the East European platform, Poland, Norway, Great Britain, Germany, France, Spain, Morocco, Newfoundland, Labrador, the Mackenzie Mountains in western Canada, California, USA and elsewhere. But it is in the eastern Siberian platform that they are most fully represented. As discussed above, Tommotian time in the eastern Siberian platform was marked by marine transgression in contrast to the regression observed in many other regions of the world. Massive development of animals in those regions occurred as late as the Atdabanian (Zhuravleva et al., 1964; Rozanov, 1984). The remarkable diversity of Early Cambrian life forms observed in the eastern Siberian platform can be found nowhere else on Earth.

Acquisition of a skeleton by animals for the first time on Earth as a result of the combination of many factors and events

The appearance in the Early Cambrian of more than 500 genera of marine invertebrates, of which most phyla and classes exist today, is the earliest example of biodiversity on Earth. As currently known, the Cambrian explosion in animal forms occurred in the eastern Siberian platform earlier than elsewhere in the world, which was related to their acquisition of a skeleton. What were the reasons for the formation of a skeleton in invertebrates? Mass acquisition of a skeleton or a shell by animals and, hence, their explosive evolution in the Early Cambrian in the eastern Siberian platform resulted from a combination of successive geological and biological factors and events in the Neoproterozoic-Early Cambrian. These are as follows:

1. According to the paleomagnetic data of P. Hoffman and other authors, in the second part of the Proterozoic and in the Cambrian, the Siberian platform was a separate continent located in the near-equatorial zone. The climate was warm, close to tropical, and the temperature of the water in the epicontinental sea basins ranged from +28 to +32^{0}C. These were favorable conditions for the evolution of life.

2. The specific tectonics of the Siberian platform: the presence of the Aldan and Anabar anteclises with a NS-striking elongate uplifted zone between them. The warm shallow-water environment on the slopes of these and smaller positive structures was suitable for the growth of cyanobacteria and algae. In addition, the mentioned uplifted zone is cut by NS-trending deep faults through which primordial solutions penetrated into the seawater. Subsequently (in the Early Cambrian) the earliest reef ecosystem ("an island of intense vital activities" after F.J. Pettijohn) originated in this zone.

3. Manifestations in the Neoproterozoic-Early Cambrian of rift and volcanic processes, including volcanism of basic (potassium) composition (from B.R. Shpount). Supply into the aquatic environment, along with potassium, of large volumes of carbon dioxide, calcium, phosphorus, magnesium, iron, sodium, nitrogen and other biogenic elements from depth was a further factor. The iron present in the water accelerated the process of photosynthesis, which led to increased biomass of algal communities.

4. The above-mentioned environmental conditions were quite favorable for the thriving of rock-forming microorganisms for over a billion years on the Siberian platform. In the Mesoproterozoic (1.6-1.0 Ga) these were mainly cyanobacteria, and in the Tonian and Cryogenian (1.0-0.65 Ga) of the Neoproterozoic – chiefly benthic calcareous red algae (rhodophytes) of the genera *Dzhelindia* Kolosov, 1970, *Chaptchaica* Kolosov, 1970, etc. The mentioned Meso- and Neoproterozoic aquatic microorganisms produced large volumes of oxygen, organic matter, and photosynthetically fixed calcium carbonate and phosphate buried within thick (a few hundreds of meters) strata; they performed environment-controlling and rock-forming functions within the ecosystems of epicontinental basins. Along with carbon dioxide and water, involved in the photosynthetic process were biogenic elements such as nitrogen, phosphorus, potassium, magnesium, calcium and iron. Cyanobacteria and algae concentrated them in cells, colonies, and thalli.

5. Due to a rather long period of thriving of cyanobacteria and algae in the Precambrian, the amount of CO_2 in the atmosphere and hydrosphere decreased. This caused a fall in temperature at the Neoproterozoic-Ediacaran boundary, which was followed by marine regression and mass mortality of cyanobacteria inhabiting warm water bodies in the littoral zone. By analogy with their recent counterparts, after a considerable decrease in the number of cyanobacteria in the Late Ediacaran and Cambrian one may assume an increasing role of: 1) bacteria that purified the water environment, fixed nitrogen (animals can assimilate nitrogen only in a fixed state), and, as opposed to cyanobacteria that reigned earlier, served as food for originating animals; 2) highly productive benthic red algae of the genera *Floribundaphyton* Kolosov, 1975, *Epiphyton* Bornemann, 1886 etc. that enriched the seafloor with oxygen. After the dead bodies of cyanobacteria fell to the seafloor to decay there, biogenic elements were mostly preserved in shallow-water seas due to reducers (bacteria), and continued to participate in biochemical cycling. As a result of the reduced activity of cyanobacteria, the waters of the Late Ediacaran-Early Cambrian epicontinental basins became even more numerously inhabited by benthic red algae (which survived the drop in temperature because they lived at a greater depth on the shelf than cyanobacteria) and bacteria, including iron bacteria; they also became more transparent, not oversaturated with organic matter and, hence, more oxygen-rich. The sunlight penetrated deep into the water. The enrichment of the bottom of sea basins within the Siberian platform in oxygen was favored, along with benthic algae, by the above-mentioned falls in temperature, which caused cooling of the water and origination of currents (as evidenced by

oncolites present at many stratigraphic levels of the Upper Ediacaran and Early Cambrian). As a result of all the mentioned changes, a significant part of the bottom of sea basins became a photic zone. Opportunities for the origin of life in different forms were ample.

6. In the Late Ediacaran, a significant marine transgression (with cold seawater due to the fall in temperature) over the Precambrian, mainly organogenic (cyanobacterial and algal) limestones and dolomites began. The waters rich in free carbon dioxide (due to the mass extinction of cyanobacteria it was but little consumed) and organic matter got in contact with the mentioned cyanobacterial and algal carbonate rocks (e.g. thick algal limestones outlined as the Chenchin Formation), dissolved them, and saturated with photosynthetically fixed calcium carbonate and phosphate, which were good material for the formation of a cover in calcareous algae and of a skeleton in animals.

7. As a result of transgression, the slopes of paleo-uplifts were covered with water. At the same time, epicontinental conditions continued to exist (as evidenced by abundant stromatolite rocks), which led to the formation of various ecological niches, and potential biotopes.

8. The existence of soft-bodied metazoa in the cold-water zone of an open sea basin; the presence among them, in the late Ediacaran-early Cambrian in the northeastern Siberian platform, of microscopic and small (e.g. *Kursovia* Kolosov et Rudavskaya, 1984) evolutionary advanced, possibly genetically flexible, animals with an organic cover waiting for "a better time" to form a skeleton.

9. A symbiosis between algae and animals is well known from many ecosystems. Algae supply animals with oxygen and consume the carbon dioxide they exhale. In the Early Cambrian, the smallest unicellular rhodophytes could settle down on animals with an organic cover, and physiologically (through the process of photosynthesis) alkalinize the environment causing $CaCO_3$ precipitation. In 1996, Yu.T. Dyakov, Professor at Moscow University, demonstrated that recent symbiotic red algae, when settled on the surface of a host, inject their nuclei into the host's cells, thus displacing its own ones. Being both exosymbiotes and endosymbiotes of animals with an organic cover, they are likely to have promoted, through complex biochemical transformations in cells and optional heterotrophic metabolism, the biomineralization of the organic covers of metazoa. As a result, a great number of Early Cambrian skeletal animals came into being (mollusks, brachiopods, sponges, archaeocyaths etc.).

Let's note one more possible way of using calcium carbonate by animals to form a skeleton. In the Early Cambrian, in the eastern Siberian platform, in a shallow-water sea basin, under the geochemical effect of organic compounds, in the water and in bottom precipitates, a rather dynamic calcium-carbonate equilibrium could change in such a way that here migration of photosynthetically fixed calcium carbonate from water into a precipitate and vice versa occurred reaching neither complete precipitation nor complete dissolution. This calcium carbonate could be intensely used in the Early Cambrian by algae (e.g. genera *Epiphyton, Proaulopora, Subtifloria* etc.) as well as by archaeocyaths and other animals to form a cover and a skeleton, respectively. As a result of the rapid reproduction of these organisms, the Earth's earliest reef ecosystem originated in the aforementioned zone. Subsequently it played an important role both in the formation of basins with different environmental conditions and in the evolution of life.

With the formation of a calcareous cover in algae and a skeleton or a shell in animals they became protected from the effects of unfavorable factors (e.g. excess oxygen, being eaten by other organisms, destruction, cold, undesirable chemical elements). As a consequence, their rapid morphological evolution began, which in the Early Cambrian in the Siberian platform led to the earliest known explosion in biodiversity on Earth.

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