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Neoproterozoic-Cambrian Biostratigraphy of the Ancient Phosphate Basins of Mongolia and the Influence of Bacterial Communities on Phosphorite Accumulation : A Review

D. DORJNAMJAA

Abstract – **This paper presents new information about Neoproterozoic-Cambrian biostratigraphy and biogenic bedded phosphorites in the Khubsugul and Zavkhan basins. We suggest that the ancient phosphorites are believed to be connected with specific biological events happened in the Cryogenian glaciation, which was followed by rapid deglaciation, Ediacaran bioradiation and the "great" postglacial transgression bearing phosphorites at its initial phase. The Mongolian phosphate basins give evidence of this phenomenon. Khubsugul basin is located in the northern Mongolia. The Ediacaran-Middle Cambrian phosphorite-bearing khubsugul group is subdivided into 4 formations as ongolik, kheseen, erkhelnuur, and ukhutologoy which are rich in organic fossils (stromatolites, microphitolites, archaeocyaths, trilobites, a group of cyanobacterial mats) in the ascending order. The Zavkhanbasin lies in the western Mongolia. The Cryogenian-lower Cambrian sediments are divided into five formations: maikhanuul (diamictites), tsagaanolom (phosphorite-bearing carbonate), bayangol (distinctive collophanitephosphorite-aluminous-bearing terrigenous), salaanygol, and khairkhan. All the formations contain the paleontological fossils (stromatolites, algae, sponges, cyanobacterial mats, ichnocoenosis, soft-bodied fauna, archaeocyathi, etc.0. The Ediacaran biota represent the largest known old multicellular organisms. It appeared immediately, after the post Cryogenian deglaciation (~ 635 Ma) and largely disappeared before biodiversity known as the Cambrian radiation (542 Ma). Bedded phosphorites being an object for comprehensive research of bacterial paleontology. It is shown by the example of the Mongolian Khubsugul and Zavkhan sea shelf phosphate basins. Today these Ediacaran - Lower Cambrian phosphate basins are the largest 80 basins of the world in the middle of the others. The expounded actual material clearly shows that the heterogeneous biologic activity, suitable geologic (transgressive systems tracts), and paleogeographic (glaciations, warm climate, etc.0 conditions played an important role in the formation, accumulation, and concentration of the bacterial or biogenic bedded phosphorites.**

Keywords – **Bacteria, Khubsugul, Phosphorite, Zavkhan.**

I. INTRODUCTION

Biostratigraphyis the branch of stratigraphy which focuses on correlating and assigning relative ages of rock strata by using the fossil assemblages contained within them. The fossils are useful because sediments of the same age can look completely different because of local variations in the sedimentary environment. For example, one section might have been made up of pelagic limestone and calcitic dolomite, while another has more glacial sandy clays, glauconitic sandstone, but if the fossil species recorded are similar, the two sediments are likely to have been laid down at the same time. Different fossils work well for sediments of different ages; archeocyaths and trilobites, for example, are particularly useful for sediments of Cambrian age, while another microfossils such as acritharchs, stromatolites, trace fossils, soft-bodied fauna are also frequently used for Neoproterozoic-Lower Cambrian sediments. The presence of the fossils Phycodes pedum and Spatangopsis mongolica were used to define the base of the Cambrian period. New discoveries of the cyanobacterial mat and different soft- bodied and tracefossils from the Khubsugul and Zavkhan biostratigraphic sections allow to decidethebiogenic genesis of bedded phosphorites. On the whole, bacteria are responsible for the formation of some mineralsand elements such as iron, uranium, pyrite, S, Mn, Ta, Nb, and canconcentrate economically important ores such as coal, oil, gold, also phosphorite. Bacteria are also responsible for the chemical composition of the atmosphere, which affects weathering rates of rocks. During the late Precambrian-early Cambrian period important increases took place in the oxygen concentration of the atmosphere and hydrosphere, the unicellular eucaryotes, procaryotes diversified, blue-green algae, stromatolites, microphytolites, and metazoa more appeared. The many new passive continental margins and oceans and consequent upwelling of nutrient-rich currents enabled global deposition of phosphorites and rapid development of biota with hard parts. The first major period of phosphate accumulation was in the Ediacaran - Lower Cambrian, contemporaneous with the fast development of shelly faunas [3, 5] Phosphorite genesis correlates with elevated sea-level resulting from transgression, allowing deposition on shellow shelves and with warm climate which may be related to an increased phosphorus flux to the oceans during times of increased chemical weathering on land, and to the development of widespread oxygen-depleted waters because rates of oceanic circulation and O_2 solubility are reduced [34] Broad oceanic areas are reconstructed between old continents. They embraced deep water basin, marginal seas, island volcanic arcs, etc. Carbonate sediments are revealed on continental margins. They are lithologically persistent, rather thick and envelop broad age interval, i. e. from Cryogenian to Middle Cambrian in Zavkhan basin and Upper Cambrian in Khubsugul basin. Carbonate sediments besides terrigenous rocks were most probably accumulated on littoral and mobile shelfes. These organogenous sediments are usually reservoir as host rock for phosphorite beds[8, 14]

II. Discovery of an Important Neoproterozoic Cambrian Non-skeleton and Skeleton Assemblages in Sectionsof the Khubsugul and Zavkhan Phosphate Basins

Thestart of the Neoproterozoic was anew placed at 1000. 0 Ma and the base of the Cambrian at 542±1. 0 Ma. According to D. Dorjnamjaa et al. [14] this era was a time of dramatic environmental and evolutionary change. The position of the Precambrian-Cambrian boundary is relevant to the Ediacaran fauna of soft-bodied organisms which developed in latest Precambrian time. At about 700-600 Ma the first Metazoa appeared in the form of the Ediacaran fauna. These are complex multicellular organisms that require oxygen for their growth. The Ediacaran fauna was soft-bodied, i. e. jellyfish, worms, and sponges and they probably contained collagen, the main structural protein in Metazoan tissues, which requires molecular oxygen for its synthesis, although collagen is particularly concerned with the formation of hard skeletons and shells, evidence for which appeared in the fossil record about 542. 0 Ma ago at the Precambrian-Cambrian boundary. The Cambrian biological explosion was the event when skeletal eukaryotes usurped the function of prokaryotes in removing greenhouse CO_2 through $CaCO_3$ precipitation [31] One of the key factors in the Cambrian explosion was compound specific carbon isotopic evidence for a change in the oxidation state of the Zavkhan basin at this time [8, 31] The late Precambrian metazoan assemblage contains at least 26 species in 18 genera and 4 or more phyla, and includes many species that are known today such as jellyfish, sea anemones, the seawasp (insecta: braconid and scelionid wasps), worms, sponges, sea pens, as well as several types of creatures unlike any known organisms[14] Many of the fossils are generally interpreted as coelenterates, and some as arthropods, annelids or other triploblasts [4] The Ediacaran fauna has a worldwide distribution with important localities in Russia (White Sea and N. Siberia), Australia, Canada (Mackenzie and Wernecke Mountains of NW Canada and SE Newfoundland respectively), Namibia, England (Charnwood, Leicestershire), Spain, China, and Mongolia. By M. E. Tucker [32] and D. Dorjnamjaa et al. [14], the radiation comprised five episodes or stages of development. 1. Prevendian (Preediacarn)-unicellular procaryotes and eucaryotes. 2. Mid-late Vendian (Tonian-Gryogenian) fauna, early trace fossils, and acritarchs. 3. Nemakit-Daldynian (late Vendian or Ediacaran- Early Tommotian)-phosphatic small shelly fossils, many shallow-water soft-bodied and trace fossils, and calcified cyanobacteria. 4. Tommotian (basal Cambrian)-calcareous small shelly fossils with the first archaeocyaths, molluscus, and medusoid. 5. Atdabanian-abundant archaeocyaths with trilobites, brachiopods, echinodermata, and deeper water trace fossils. All these episodes took place at a time when a supercontinent was breaking up, leading to the formation of the Iapetus ocean. A major factor in all the changes going on at the Precambrian- Cambrian boundary was the chemical change within the oceans, and this was related to two aspects, global climate, i. e. the change from Neoproterozoic (Sturtian) icehouse (glaciations) to Cambrian greenhouse, and global tectonics, i. e. the opening of few oceans and seaways. Nevertheless during these monumental changes some species did survive. Although the significant event during the "Cambrian biological explosion" was rapid development of organisms with exoskeletons and biomineralization, some soft-bodied Ediacaran (Neoproterozoic)-Tommotian faunas did survive, because they are preserved in the incredible Bivalved Burgess Shale-type faunas or arthropods and Martinssonia from the Upper Cambrian of Sweden (Plenocaris, Waptia, Perspicaris, Odaraia, Canadaspis) that are today known from nearly 40 Lower and Middle Cambrian localities in the world [4] Some of the famous Burgess Shale fossils found in Western Canada, about 530 million years old. They are some of the first evidence of the Cambrian explosion, the rapid radiation of animal life about 20 million years earlier. It should be mentioned that S. Q. Dornboss et al. [14] were described the trace fossils of Burgess Shale-type (multicellural algae fossils) from phosphorite-bearing layers in the Tsagaanolom formation. These new fossils from Zuun Arts section have been called as Zuun-Arts biota:Chinggiskhaania bifurcata. The Precambrian-Cambrian boundary records the time when organisms developed hard parts and skeletons, allowing their preservation as fossils [29], and when there was an explosive evolution in marine life [3, 5] Following nine phyla of marine invertebrates appeared for the first time in the early Cambrian: Protozoa, Coelenterata (jelly fish, anemones), Archaeocyaths, Sponges, Porifera, Bryozoa, Mollusca (gastropods, lamellibranchs, cephalopods), Brachiopoda, Arthropoda (trilobites), and Echinodermata (cystoids). Over 900 Lower Cambrian fossilspecies are known. According to Richel Wood etal. [26] at the beginning of the Cambrian, carbonate shelves were globally extensive and a considerable variety of metazoan-associated reefal buildups have been described from Europe, North Africa, Central Asia, North America, Antarctida, and Australia. In this way, the Precambrian-Cambrian boundary was the end of the beginning and the beginning of the end in the biogeological event. The uninterruped biostratigraphic sections with numerous non-skeleton and skeleton faunal assemblage (Khasagt group) confirmative the Neoproterozoic-Lower Cambrian boundary were detailed and fixed within the Zavkhan basin in the Bayan Gol, Tsagaan Gol alike Salany Gol area "Fig". 4).

III. Samples and Methods

Forthe Neoproterozoic-Cambrian biostratigraphy and particularly phosphorite-bearing sedimentary deposits were used by us more of all biogeologic, geobiofacial and paleontological methods. For our study wehavebeen able to use on some 400 micropaleontological analyses from the Paleontological Institute, RAS (Moscow) and Oxford University laboratory (London). The well exposed gorge and mountain sections of the Khubsugul area (Kheseen, Ongolik river gorges, Burenkhaan mountain) and Zavkhantrough (Alagiin Davaa, Tsakhir Uul, Zuun Arts, Baruun Arts, Khevtee Tsakhirmountains, BayanGol, TsagaanGol, and Salaany Golrivergorges) were sampled on some separate field thematicresearches and excursions during the Joint Soviet (now Russian)-Mongolian Paleontological expedition [7]; [16]; [35, 36] in the 1990's-2015's. Note that Joint IGCP Project 303 "Precambrian-Cambrian Event Stratigraphy" excursion in 1993 played an important role in the litho-biostratigraphic, microbio stratigraphic, and chemostratigraphic investigations of the glaciogenic marine and biogenic phosphate sediments in the Zavkhan basin[1]; [8, 17]; [19]; [23, 24, 25] Special purposeful petrographical study (petrification) of the vivianite phosphorites conducting in Novosibirsk laboratoty (Institute Geology and Geophysics) in 1990's in thin sections is allowed to reveal phosphatic algal cells, laminite texture, and biofragmentsof skeletal phosphate microfauna, as microcoquina, cone tubes (spicularor chiolite-like). E. A. Eganov, D. Dorjnamjaaet al. [8, 14] all the specimens (more 100 pieces) are sampled and examined from the upper phosphorite bed of the Alagiin Davaa, Tsakhir Uul, and Bogdiin Gol sections. These original results immediately followed by researches of bacterial paleontology in the Khubsugul and Zavkhan basins. It should be pointed out that collophane mudstone and glauconitic pelletal phosphorite were sampled from upper Bayangol formation at the Khundlun Uul occurrence. All sample scollected returned values on < 1. 0% P_2O_5. The diamictites of the Maikhanuul formation and phosphatic carbonate sediments of the Kheseen and Tsagaanolom formations were studied for biostratigraphic, ichnocoenosis, ichnofacial and palaeo environmental analysis. Over 300 specimens were studied in the field for biometric applications and a large number of samples were collected from the Tsagaan Gol and also Kheseen Gol sections for the laboratory study of their morphology and taphonomy. The cyanobacterial microstructure and elemental composition of some specimens were analyzed using SEM Leiss EVO50 microanalyzer with Oxford INCA (Energy 350). Collections are partially housed at the Paleontological Institute of RAS in Moscow (PIN) and Institute of Paleontology and Geology of MAS in Ulaanbaatar (IPG). According to M. D. Brasier et al. [1] and D. Dorjnamjaa et al. [8, 11, 12] the Mongolian evidence suggests that these two (later Nemakit-Daldynian and early Tommotian 0 "explosive phases" are actually biogeologic artifacts of slow sediment accumulation rate. We have analysed some trace elements in phosphate-bearing and their host rocks as well as their laminated clay fraction. Few samples permit only tentative conclusions. Fifteen trace elements were analysed. In sedimentary rocks, their overwhelming majority are contained in amounts less than the clarke (according to A. P. Vinogradov) or their contents vary about the clarke values. Nevertheless, individual elements acquire some order. The phosphorite-bearing interval lies between two formation parts different in contents of some trace elements. Thus, barium in the overphosphoritic rocks is more frequent in superclarke amounts with a greater range of variations than in the underphosphoritic rocks of the formation. The boron contents in the overphosphoritic beds are chiefly subclarke, while in the underphosphoritic beds they are more often superclarke. Manganese has the same pattern. The titanium contents in underphosphoritic and phosphoritic parts are subclarke, and above phosphorites, chiefly superclarke. It is surprising that in shales and cherts of the phosphatic part of the section the vanadium and uranium contents are exclusively subclarke and smaller [8, 14] Immediately in phosphorus (one test), the chrome content is abnormally about 100 times as high as the clarke. The distribution of many other elements (Be, Co, Mo, Cu, Ni, Ga, PЬ, Sr) is not illustrated. Thus, there is a set of trace elements, whose statistical distribution within the section of the Tsagaanolom formation permits the specification of over-and underphosphorite parts irrespective of their lithological propertites. These are B, Ba, Mn, Ti, and Cr. During this interval the Zavkhan basin was subject to a tectonically quite active regime, as the Khubsugul basin.

IV. Interpretation and Discussion

Biostratigraphy, Khubsugul Phosphate basin, EZPF "Fig". 1

The Khubsugul phosphate basin is located on the Tuva-Mongolian microcontinent, which was carbonate platform in the Neoproterozoic-Cambrian period "Fig". 1. Eight phosphorite deposits and about a dozen smaller occurrences were found in the Khubsugul basin. The estimated total resources of the Khubsugul phosphate basin amount to 3 bil. t. phosphorites with P_2O_5 content more than 20%. The biostratigraphycal study of phosphorite has greatly expanded over the past forty odd, and more years. In the 1970's- 1990's there existed a need for the recognition of spatial and temporal relationships of the explosive appearance of hard skeleton of organisms on the beginning of the Cambrian as well as the contemporary formation of the largest deposits of phosphorite in China, Mongolia, and Kazakhstan. N. A. Donov and E. V. Edemsky discovered the first phosphorite deposit in Mongolia in 1963 on the western coast of the Khubsugul Lake [7] This discovery was followed in 1964-1967 by detailed investigations of the All-Union Air-Geological Trust and Nilzarubezhgeologia institute. A. L. Yanshin, N. S. Zaitsev and A. V. Ilyin

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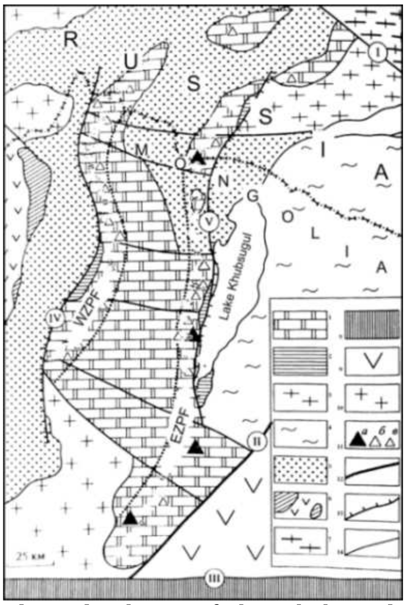

Fig. 1. Geological scheme of the Khubsugul phosphate basin and surrounding area. 1, 2-Neoproterozoic-Cambrian sediments: 1-khubsugul group: ongolik, kheseen (phosphorite-bearing), erkhelnuur, and ukhutologoi formations-sandstone, gravelstone, limestone, dolomite, phosphorite, 2-darkhat group (arasan formation)-arkose, sandstone, rhyolite, basalt, pelitomorphic dolomite, 3-6-ancient complex of basement: 3-granulite of Gargan balance block (Paleoproterozoic), 4- gneiss, crystalline schist, amphibolite, slaty quartzite, and marble of Khamardavaa and Urigol upstanding blocks (Paleoproterozoic-Mesoproterozoic), 5- green schist, limestone, graywacke, andesite-daciticvolcanite of Khug formation (Mesoproterozoic), 6- ophiolite of Shishkhid arc (Neoproterozoic), 7-9-framing of Tuva-Mongolian massif: 7-Siberian craton, 8-Central mongolian microcontinent (Pre-neoproterozoic), 9- Jid oceanic zone (Neoproterozoic-Cambrian), 10-Early paleozoicgranitoid, 11- phosphorite deposits and phosphate occurrences: a, b- large deposits; (a-explored, b- unexplored), в- phosphate occurrences, 12-suture (accretionary) zone: I-Big Sayan fault, II-Argyingol fault, III-Khangay-Khentey fault (the earthquake suture of 1905), 13-marginal thrust framing khubsugul basin: IV-Khugiingol, V- coastal; 14- ancient fault in basement determinative block structure of basin. WZPF- western zone of phosphatic facies or biofacies, EZPF- eastern zone of phosphatic facies or biofacies (based on the map compiled by D. Dorjnamjaa et al. [12, 13] revealedthat the Khubsugul basin is among the largest phosphate basins of the world. From 1968 to the present, the Khubsugul phosphate basin wasstudied by collaborators of the Geological and Paleontological institutes (Russian Academy of Sciences), as well as the Joint Russian -Mongolian Geological and Paleontological expeditions[7, 9, 10, 11, 12, 13];[16]; [35, 36] TheNeoproterozoic (Tonian-Cryogenian and Ediacaran)-Cambrian sediments are dividedin two groups: lower Darkhatand upperKhubsugul“Fig”. 2. Withinthe Arasan and Kheseen rivers

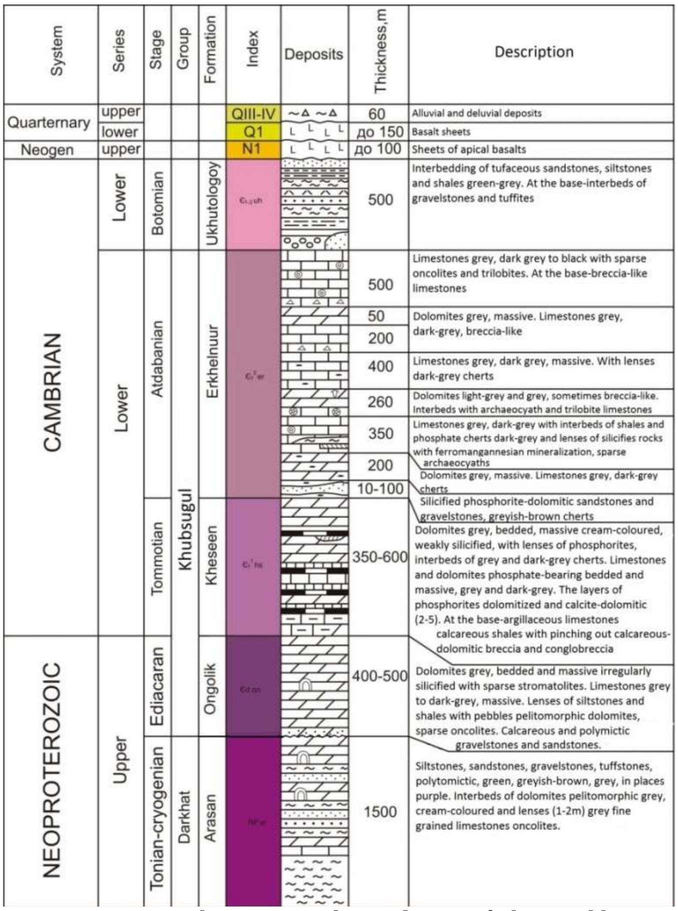

Fig. 2. Common biostratigraphic column of the Darkhat and Khubsugul groups in the Kheseen river valley, Khubsugul basin [12]

(Khubsugul phosphorite deposit) the Darkhat group is represented by its uppermost Arasan formation (1500 m) which consist predominantly of siliciclastics and volcanics-siliciclastics, namely green, gray, brown, or rare violet siltstone, sandstone, tuffaceous sandstone, and gravelstone withsome layers ofgrayish-creampelitomorphic dolomite and lenses (1-2 m) of gray thin-grained limestone with oncolites (microphytolites). The Khubsugul group lies unconformably on the Darkhat group and is subdivided into three formations in the ascending order, Ongolik, phosphorite-bearing Kheseen and Erkhelnuur formations. The Ongolik formation (400-500 m) overlies the Arasan formation with a wash out and basalquartz-feldspathic sandstone and gravelstone of about 2-15 m in thickness. They pass upward togray bedded and massive dolostone, silicified in places, with rare microphytolites and algamorphic texture. The uppermost part of the Ongolik formation consists of conglomerate-breccia slump features and erosional surface. From the dolostone we have been able to reveal microphytolites (Osagia minuta Z. Zhur., etc.0 and stromatolites (Colonella sp.0. Note that them edusoide fossils found in the correlated formation of the Ukha-Gol deposit in the northern part of Khubsugul basin and were correlated with Ediacaran complex by B. S. Sokolov [16] These fossils indicate the upper Vendian or Ediacaranage. The Kheseen formation overlying the Ongolik formation is subdivided into three members. The lower member consists of argillaceous limestones and calcareous shales with lenses of calcareous-dolomitic breccia and conglomerate-breccia. The middle member is the principal productive horizon of the formation and contains several phosphorite layers of the Khubsugul basin. Carbonate bedded phosphorites builds the main horizon, 10 m thick with average 22% P_2O_5. The upper portion of the unit contains rich small-grained phosphorites, with 28-34% P_2O_5. The phosphorite layers alternate with bedded and massive limestone and dolostone, in places with siliceous-aleuritic-argillaceous shale and black chert. The upper member begins with black amorphous chert of thickness from several meters to 50 m, overlian by dolostone and limestone with a significant admixture of argillaceous and arenaceous particles. The total thickness of the Kheseen formation varies from 350 to 600 m. Russian paleontologists [35] first time did discovery a group of cyanobacterial mats (Khubsugul biota) from the middle part of the phosphorite member "Fig". 5-7. The overlying Erkhelnuur formation (2060 m) contains Atdabanian trilobites. Along the Kheseen and Ongolik rivers M. N. Korobov [7] in the presence of D. Dorjnamjaa in 1974 found two levels with trilobites. The lower one is 400-550 m above the base of the formation and contains Archaeaspis sp., Malykania ongolica Korob., Elganellus delatatus Korob., E. pensus Suv., E. elegans Suv., E. probus Suv., E. elongatus E. Rom., Resserops kharganicus Korob., Pseudoresserops obesus Korob., Minusella priva Korob. The upper level is 250 m above the lower one, spans about 250 m and contains Bulaiaspis teseevica Rep., Fallotaspidella chesenica Korob., and Fallotaspis mongolicus Korob. The oldest (middle Atdabanian) trilobites include genera and even some species which are very typical of the 'western' facies basin of the Siberian platform [12] At the Burenkhaan deposit area, the upper Erkhelnuur formation contains numerous Botomian archaeocyathids. The revealed numerous Late Atdabanian and Botomian archaeocyaths are typical Altay Sayan, and more exactly Tuvinian, species. Archaeocyathan-algal reefs are also shallow water indicators. The tuffaceous-siliciclastic Ukhutologoy formation (500 m thick)overlies the Erkhelnuur formation with a break. At the southern border of the Khubsugul lake, on the right coast of Egyingol river the upper part of this formation contains archaeocyaths (Irinaecyathus ex. gr. ratus (Vol.0, and Pycnoidocyathus sp.0 and middle Cambrian trilobites (Oryctocephalops-Oryctocara-Tonkinella), which correspond to the Siberian Amgan stage, Taijiagian formation in China, Stage 5 of the Global chart, etc. [9, 14] The phosphorite - bearing Kheseen formation is considered to be as Tommotian (Lower Cambrian) age.

Biostratigraphy, Zavkhan Phosphate Basin "Fig". 3

As everybody knows, thisphosphate basin extends towards the western part of Mongolia in Govi-Altay and Zavkhan area and forms a broad structural-tectonic zone of Neoproterozoic and Early Paleozoic sediments "Fig". 3. By D. Dorjnamjaa was discovered Zavkhan phosphate basin in western Mongolia [7, 8, 14] The Alagiin davaa and Tsakhir uul deposits about 20 deposits and occurrences were discovered within the Zavkhan phosphate basin (undiscovered potential resources more than 1 bil. t.0. Orginally the Neoproterozoic to Cambrian stratigraphy of the Zavkhanbasin was described by V. V. Bezzubtsev [7] in the Bayangol Gorge area. It was further studied byRussian and Mongolian geologists and paleontologists between 1974-2015 [7, 8. 10, 11, 12, 13, 14, 17, 18, 21, 22, 23, 24, 25, 31, 32] and researchers participating in the IGCP Project 303, "Precambrian-Cambrian Event Stratigraphy", in 1993 [1, 2]; [15]; [19, 20]; [26] According to these investigations the Neoproterozoic and Lower Cambrian strata of the Zavkhan basin are divided into six formations: the Zavkhan (3000 m), Maikhanuul (220 m), Tsagaanolom (1900 m), Bayangol (720-1000 m0, Salaanygol (600 m), and Khairkhan (380 m) formations "Fig". 4. The Zavkhan formation (773 ±3, 6 Ma by Dorjnamjaa et al. [9]; 803±8 Maby Levashova et al. [18] is represented by andesitic-basalts and andesites in the lower and by felsic volcanics in the upper part of the section, with numerous explosive units, such as pyroclastic tuffs and ignimbrites and towards the top, arkosic and quartzose sandstones appear. The Maikhanuul formation (220 m) which rests unconformably upon the Zavkhan volcanic sequence consists of glaciogenic and other clastic deposits and comprises two relatively thin units of diamictites separated by a section of flysch sediments. The Maikhanuul tillites are overlain by massive carbonate units of the Ediacaran (Nemakit-Daldynian) Tsagaanolom formation . The rocksofthe lower and upper units of the Maikhanuul formation contain highly angular boulders, bed penetrating dropstones, striated clasts that show evidence of glacial activity. The key sections of the phosphorite-bearing Tsagaanolom formation were studied by us within the Alagiin Davaa and Tsakhir Uul deposits, also in the Zuun Arts, Baruun Arts, Bayangol, Salaanygol and Khevtee Tsakhir area. Especially the Bogdiin Gol and Alagiin Davaa phosphorites are evidently subdivided into a thin lower and a thicker upper horizons. There are sections with three phosphate layers, the intermediate one separating the inter-ore members. In the sections of the Bogdiin Gol, Tsakhir Uul and Alagiin Davaa phosphorites are concentrated in the upper part of the member, where their thickness being always more (5-8 m, rare up to 15-20 m) than the thickness of the lower phosphorite level (1-2 m, sometimes 2-4 m). Below the lower phosphorite lies a sand-carbonate-chert seam, the same interval separates both phosphorite horizons. The upper phosphorite bed is covered by ferruginous dolomites (1-2 m and less) which are persistent in they pay member roof. Occasionally these dolomites contain small lenses and land pebble, noticeable algal or stromatolite buildings. It is an intensive ferruginous, synsedimentally crushed micro stromatolitic or microphytolitic dolomite - a specific crust of weathering, a horizon of discontinuity. The very distinctive vivianite phosphorite ($Fe_3(PO_4)_2 \cdot 8H_2O$) is good seen in the Alagiin Davaa, Tsakhir Uul and Bogdiin Gol alike Zuun Arts, Baruun Arts, Khevtee Tsakhir, Bayangol and other sections in the form of rare black and blue lute crusts in dolomite of the "hard ground" type. Yellowish beds of argillaceous dolomites occur occasionally in the lower part of this unit. Thus, the phosphorite interval lies between two extreme surface-surfaces of discontinuity. The lower surface is marked by breccias and sandstones above which follow depositions, predominantly, shallower than before the breccias. The upper surface corresponds to the level of ferruginous dolomites with “hard ground” crusts, in places with sings of the crust of weathering or its resedimented products - quartz aleurolites. These levels limit an intraformational (for the whole Tsagaanolom formation considered as a carbonate formation) cycle with the maximum (for the whole carbonate unit) range of depth variations. A bed (from 3-5 to 10-12 m thick) of black shales with chert seams was deposited immediately before the appearance of phosphorites. Sometimes, small(up to microscopic) bioherms of phosphate composition are found in the cherts with seams of quartz sandstone. We call this bed inter-ore. For example in the sections of Tsakhir Uul, Bogdiin Gol, Alagiin Davaa, ZuunArts, Baruun Arts, and Khevtee Tsakhir the cherts (with and without phosphate) occur mainly in the upper member. The cherts are always secondary. These are either regenerated quartz sandstone, or stratiform stromatolite, i. e., silicified algal mat. The upper phosphorite is covered by ferruginous dolomite, conglomerate with carbonate cement and land pebble. These roof rocks associate with products of weathering (iron oxides with an increased Mn content, quartz aleurite). Shallower depositions are well predominant. On the whole, in lithology and geochemistry, the Tsagaanolom formation is distinctly subdivided into underphosphoritic (dolomitic), phosphoritic and overphosphoritic members. Under the surface, the phosphoritic member itself is subdivided in the same way. Within the underphosphorite part of the section there are two remarkable intervals. The lower interval (with the exception for basal layers) shows monotonous alternation of dark and light indistinct finely grained pelagic dolomites with separate rare members and layers with signs of shallower conditions - stromatolitic and microphitolitic cross-layered carbonates, slide breccias, silicified horizons. This lower interval (500-700 m) reflects the initial stage of pulsation transgression. The phosphoritic member (70-80 m) above the “lower” dolomite is essentially siliceous and terrigenous. It consists of 2 or 3 phosphate horizons with P_2O_5 from 0. 2-0. 7 to 20-26, not in frequently may get through to 30-35%. The phosphoritic horizon is often a single layer whose thickness, e. g., in the Tsakhir Uul(deposit) and Khevtee Tsakhir (occurrence), reaches up to 40 m. Usually it is less, only a few meterson the erosionalsurfaces. Just this horizon marksthe beginning of a phosphorite member, there is an erosion surface in its bottom. Precisely this marker horizon is very characteristic for the whole Zavkhan phosphate basin. The overphosphoritic member (~ 1000-1100 m) begins with black shales (1-3 m), which contain no more sand-aleurolite impurity. Above follows the alternation of wave-bedded and thin-layer

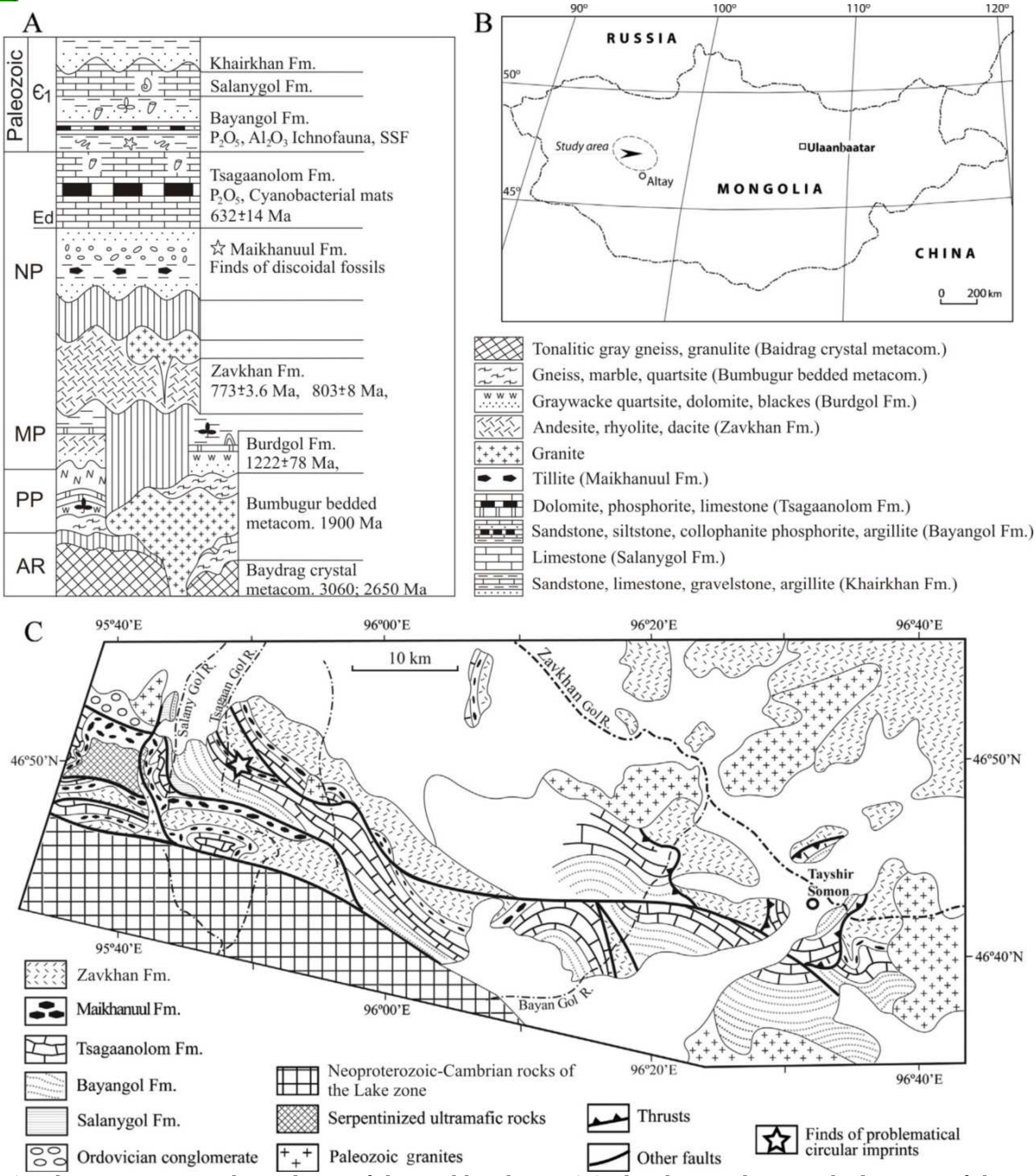

Fig. 3. (A) Schematic stratigraphic column of the Zavkhan basin. (B) Sketch map showing the location of the study area (Zavkhan basin) in Western Mongolia. (C) Schematic geological map of the Salany Gol R., Tsagaan Gol R., Bayan Gol R., and Tayshir Somon (Khevtee Tsakhirnuruu) areas within the Khasagt Bogd mountain [30]

black and yellowish (argillaceous) limestones, calcareous dolomites, sometimes with cross-bedding and intraclasts (small plane carbonate pebble) or calcarenites (20-30 m). The lower layers contain plane-wave stromatolitic textures [8, 15], trace fossils, lenses of derived phosphate. Above lie, chiefly, black limestones with plane-rounded, spheroidal and semispherical algal bioherms, calcarenites. Thispostphosphate stage (3rd part) proceeded as a new phase of transgression but already on the background of an essentially planed relief of the bottom of the regressed basin. It began with deposition of clay material in lagoons, later giving

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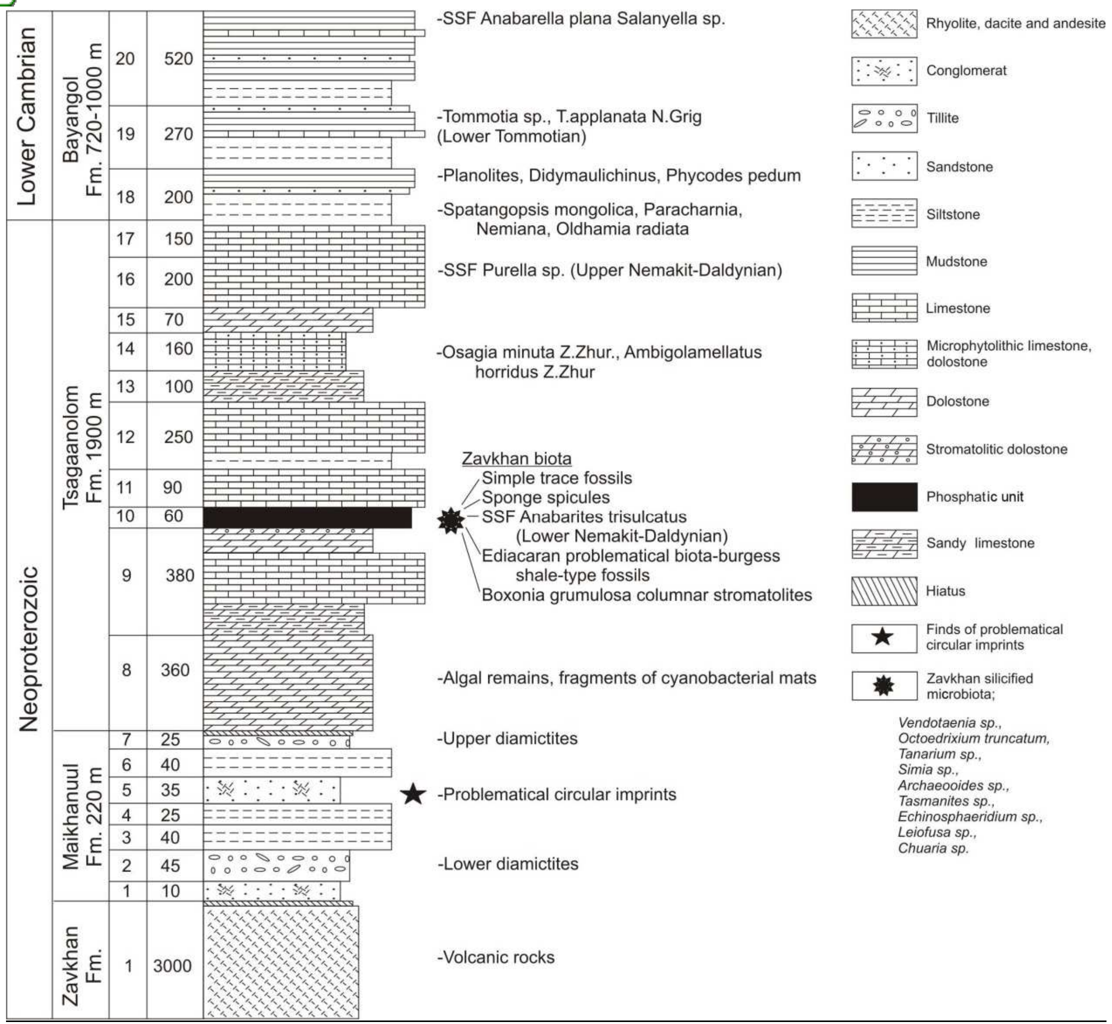

Fig. 4. Generalized biostratigraphic section of the Neoproterozoic-Lower Cambrian sediments in the Zavkhan basin; distribution of organic remains and trace fossils in the TsagaanGol and Bayan Gol sections (Zavkhan microbiota). Modified after Serezhnikova et al. [29]and Dorjnamjaa et al. [11]

way to carbonates. The carbonate and carbonate-terrigenous sediments of the Tsagaanolom, Bayangol, Salaanygol, and Khairkhan formations, which are compiled the Zavkhan shelf basin have abundant shallow faunal and floristic fossils. We must emphasize that for last 15 years we have conducted new research on bacterial paleontology combined with old bedded phosphorites in the both Zavkhan and Khubsugul basins. As a result of this investigation were discovered by us the unexpected new finds (Zavkhan microbiota) of the cyanobacterial mats (Octoedrixium truncatum, Tanarium sp., Simia sp., Archaeooides sp., Tasmanites sp., etc.) in bedded phosphorites of the Kheseen and Tsagaanolom formations [25]; [36] In turns, the early Cambrian clastic sediments of the Bayangol and other abovedeposited formations rest conformably upon the limestones of the Tsagaanolom formation. It should be emphasized that we have discovered a stony or black metaphosphorite occcurrence with high content of Al_2O_3 (up to 15-33%) in the Bayangol formation close to the Alagiin Davaa deposit (Khundlun Uul area) of the Zavkhan phosphate basin. This distinctive metaphosphorite of Khundlunuul type also has been revealed by us within the Alag Uul mountain in the south-west of Alagiin Davaa deposit. The common reserve of this deposit was estimated as 80 million tonne of the phosphorite ore in the presence of average content P_2O_5 18% [8] We can conduct and improve the comparative description at the database of the phosphate original biosubstance and biomicrite (bioherm) of the Zavkhan basin, as follows. 1. Phosphatic laminated, lamino-undulatory, and circular algal and bioconstructed limestone, also laminarite occurs usually in the uppermost phosphorite bed. There are only clasts, pebble or centimeter-size layers of this phosphorite at the base of the section. It contains fragments of skeletal phosphate microfauna. Initially it was phosphatized calcareous reef-building blue-green (colonial) algae or algal mat with phosphatic microfauna admixture and nonphosphatic reef detritus. 2. A variety of phosphatic algal laminite is phosphate laminite rims of various grains (phosphatic and nonphosphatic). Sometimes the structure of these formations in the sections is identical to structures of carbonate microbioherms from under phosphatic stromatolite and especially microphytolite dolomite. 3. Phosphatic skeletal biofragments are widespread. Typically, they are grains, cone tubes (corneosiliceous and phosphatic hexactinellid, polyactinal and triactinal sponge, Anabarites trisulcatus, A. tripartitus, Cambrotubulus decurvatus, Palaeosulcatus biformis, etc.0, wedges, and wings in shape, initially phosphatic, they are replaced by quartz to a different extent. 4. Microphosphoritic - structureless phosphatic - forms of thin (micro- or millimeter size) layers. Their disintegration gives rise to a shape diversity of rounded structureless pellets of psammite size clustered into layers of typically "micrograined" phosphorite. In places, these are evidently fragments of phosphatized algal mat of fibrous texture- "interwoven felt" of phosphate "threads", "interlaminated noodles". Some microphosphorite pellets show concentrically- layered (oolite or oncolite) structure together with radiolith one. In other cases, due to quartzing, microphosphorite is decomposed into a "roe-like" aggregate of grains (20-40 µm), similar in texture with sections of algal bladdery cells.

V. Bacterial (Biogenic) Factor for Accumulation of the Bedded Phosphorites in the Khubsugul and Zavkhan Basins of Mongolia

According to A. Yu. Rozanov et al. [28] and D. Dorjnamjaa et al. [8, 11, 12] we must speak about a phosphorite is the real object for comprehensive research of bacterialpaleontology. Bacteria are neither plants nor animals. They belong to a group all by themselves. Bacteria, singular bacterium, any of a group of microscopic single-celled organisms that live in enormous numbers in almost every environment on Earth, from deep-sea vents to deep below Earth's surface to the digestive tracts of humans. Hence, bacteria are beginning of life and found everywhere as in the air, water, top-soil, high-temperature springs, permafrost (frozen soils and rocks), different type of an ice, and shifting sands of desert. Scientists have discovered bacteria growing in the hot springs of Yellowstone National Park, America, where the water reaches near boiling temperatures. Bacteria have been found deep inside ice above Lake Vostok in the Antarctic. Planet Earth is estimated to hold at least 5 nonillion (or 5x 10^{30})bacteria. Scientists say that much of Earth's biomass is made up of bacteria. Modern bacteria's ancestors-single-celled microorganisms-appeared on earth about 4 billion years ago and were the very first form of life to exist on Earth. For the following 3 billion years all life forms on Earth were microscopic in size, and included two dominant ones: 1. Bacteria, and 2. Archaea (classified as bacteria, but genetically and metabolically different from all other known bacteria). Bacteria come in three main shapes:1. spherical or coccoid (like a ball), 2. rod shaped or vibrio, 3. spiral or spirochetes. On the whole, bacterium applies to the ordinary microscopic organism consist of an alone cellular without noticeable nucleus, but possessed of colossal biochemical energy. Also bacteria were accepted an active participation in process of descopmosition and oxidation of the organic matter. Here it should be emphasized that by the process of mineralization primary matter of skeleton and cyanobacterial mats is substituted with other mineral matter or pseudomorphism. The most prevailing bacteriogenic mineral matters are calcium, mineral carbon, mineral oil, magnesium carbonate, phosphate, sulphide (pyrite), oxides and hydroxyls (silica in different modification), and indigenous limonite. Phosphorite sediments and phosphorites in the Khubsugul and Zavkhan bassins are realizable fact for an explanation of this phenomenon. It is clear shows at example of the bedded phosphorites [8, 11, 12, 13] Here this problem will be examined separately for two phosphate basins, as follows. We have to characterize the paleontological data associated with definition biofacies and ichnofacies both underlying and overlying phosphorite-bearing rocks of the alike bedded phosphorites. The point is diverse organic fossils in the shallow shelf basins closely connected with united biogeologic accumulative formation. By the end of 1970 S. R. Riggs [27] already has shown that bacteria-like rods (0, 5-1 microns in size) are ubiquitous components of the Miocene Florida phosphategrains. Undoubtedly, both the inferior plants or thallophyta (bacteriophyta, algae, eumycete fungi, myxomycetes, lichenes) and the simple (protozoa) unicellular, also lowest multi-cellular (porifera, trace fossils, spongia, archaeocyathi) biota were symbiotic planktonic and benthic organism in the ancientbassins. AccordingtoRichel Wood et. al. [26] bacteria were in all probability the main primary producers, from both planktonic and benthic cyanobacterial communities.

I. Paleontological data of the Khubsugul shelf basin

As was aforementioned, within the WZPF and EZPF we have revealed the cyanophyceae (stromatolites (Colonella sp.0 and microphytolites) from the gray grain-supported limestone of the Arasan and Ongolik (boskhat) formationsalike Ediacaran medusoide fossils "Fig". 1. Among the microphytolites Osagia nimia Z. Zhur., Ambigolamellatus horridus Z. Zhur., Volvatella vadosa Z. Zhur., Vesicularites sp. are dominated. It is claimed that the microphytolite assemblages were revealed in all three members of the Kheseen formation, including Nubecularites catagraphus Reitl., N. parvus Z. Zhur., N. densus Z. Zhur., N. angulatus Z. Zhur., Radiosus marginatus Z. Zhur., Osagia senta Z. Zhur. [7. 9, 10] In places, these fossils are formed microbioglyph, rare biohermite or bioherm. Group of Russian paleontologists was discovered "Khubsugul biota" in bedded phosphorites of the Kheseen formation for the first time [36] From the middle part of the phosphorite member were distinguished Archaeooides sp., A. granulatus Qian, Tasmanites tennellus Volkova, Obruchevella sp., Spirellus sp., and filamentous cyanobacteria of Microcoleus group, belonging to genera, known from older rocks, namely, Siphonophycus robustum (Schopf), S. typicum (Hermann), S. septatum (Schopf), Oscillatoriopsis obtusa Schopf, 1968. It is recognized that especially filamentous types, and sheath-like microfossils range in size from sub-micrometric (coccoides <30 µm) to the limits of resolution by the eye are all known from 2. 5 to 1. 6 Ga, and coccoid types > 30 µm from 1. 9 to 1. 65 Ga. The Khubsugul biota was mostly cyanobacterial mats "Fig". 5-7. The cyanobacterial mats community were preserved in the phosphorites, as microstromatolites, microphytolites, and micronodules. The micronodule sizes usually vary from tens to several hundreds of microns. The cyanobacterial filaments surrounded by numerous bacterial cells were observed as typical of all recent cyanobacterial mats. The concrete occurrence of abundant matbuilding filamentous cyanobacteria in the phosphorite layers of the Kheseen formation suggests their formation within the photic zone (the first dozen meters of depth). The wide development of cyanobacterial mats also indicates low hydrodynamics. There are remains of acritarchs (phytoplankton), Tasmanites, Leiosphaeridia together with diverse Archaeooides species in several of the phosphorite layers. The latter ones are known from South China and South Australia and indicate episodic southern connections of the Khubsugul basin, as it was emphasized by E. A. Zhegallo et al. [35] Thus, thick carbonate sediments of the Khubsugul group are characterized by abundant finds of the microstromatolites, microphytolites, micronodules, archeocyaths, trilobites, also bacterial fossils. The principal phosphorite is concentrated in the Lower Cambrian Kheseen formation, containing the cyanobacterial mats and purple bacteria. The preservation of the planktonic species (Archaeooides, Tasmanites) is really astonishing and each of them consists of calcium phosphate, that meansthey are secondary phosphatized similar to cyanobacterial mats [36] Lower Cambrian archaeocyaths from Erkhelnuur formation arePalaeoconularia baileyi (Vol.0, Sibirecyathus naletovi Vol., Formosocyathus vermiculatus (Vol.0, Tubericyathus clathratus Vol., Clathricoscinus vassilievi (Vol.0, C. dentatus (Vol.0, Claruscoscinus billingsi (Vol.0, Archaeocyathus operosus (Zhur.0. As it aforesaid the trilobites were discovered rich in Erkhelnuur formation. The trilobites are connected with shallow facies exclusively.

Fig. 5. Phosphatized bodies of cyanobacteria ***Fig. 6.*** Type of preservation of and bacteria from Khubsugul phosphorite. cyanobacterial mat. The hollow tubes are Khubsugul basin [36] from cyanobacteria. Kheseen formation, Khubsugul basin [36]

SEM photomicrographs of the phosphatized microorganisms from the Lower Cambrian Khubsugul phosphorites that exhibit similar form and size to the recent cyanobacterial mat microorganisms.

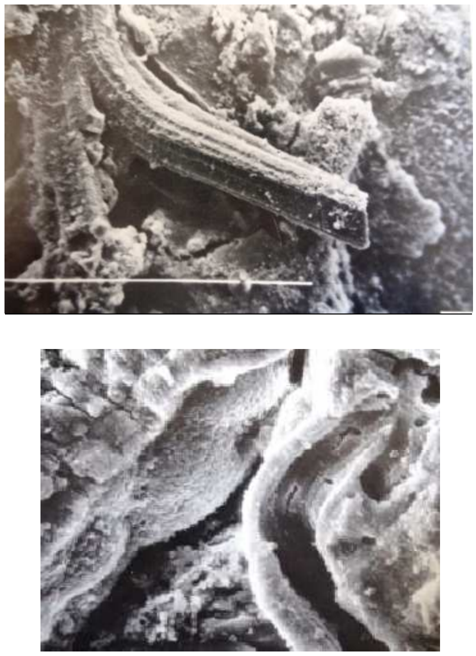

Fig. 7. Type of preservation of cyanobacterialfilaments and purple bacteria. Kheseen formation, Khubsugul basin [36]

II. Paleontological data of the Zavkhan shelf basin

All these paleontological data from the enumerated formations have been documented in detail by D. Dorjnamjaa et al. [7, 8, 9, 10], E. A. Zhegallo et al. [34], E. A. Eganov et al. [8, 9], M. D. Brasier et al. [1, 2], R. Goldring et al. [15], V. V. Khomentovsky and A. S. Gibsher [17], J. F. Lindsay et al. [19], A. L. Ragozina et al. [23, 24, 25], W. Richel et al. [26], and E. A. Serezhnikova et al. [30] Microfossils and some problematical Ediacara-type fossils were recovered in Bayan Gol and Taishir sections in 2006-2014. Thethin layers of bituminous siltstones in phosphatic unit of the Tsagaanolom formation in the Bayangol section contain some problematical carbonaceous remains which can be described as Chuaria sp. The phytolites reperesented by stromatolites: Boxonia grumulosa Komar (Bayan Gol, Khevtee Tsakhir, Tsakhir Uul, Alagiin Davaa, and other sections), Conophyton garganicum Kor. (Zuun Arts section) and microphytolites. Note that stromatolites are layered stratiform, conical or columnar, biogenic sedimentary structures that are built by trappings and binding and /or precipitation of sediment. Studies on modern stromatolites show that they grow in platform and shallow coastal zones where theyare associated with cross-bedded sediments deposited in extensive tidal flats and characteristically they occur in limestones. Precambrian-Cambrian stromatolites thrived in open shelfenvironments and occur in dolomites and limestones. Microphytolites (Osagia minuta Z. Zhur., Volvatella vadosa Z. Zhur., V. zonalis Nar., Vesicularites bothrydioformis (Krasnop.0., V. rectus Z. Zhur., V. lobatus Z. Zhur., and Radiosus vitreus Z. Zhur.0 were revealed in numerous sections of the Tsagaanolom formation. It should be pointed out that M. D. Brasier et al. [2] was discovered spongeous fossils in the phosphate layers from the Bayan

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Gol section for the first time. These calcareocorneous sponge is mainly fine-grained (~ 0. 1 mm) and present phosphatic hexactinelled, polyactinal and triactinal diversity. The cyanobacterial mats (Octoedrixium truncatum, Tanarium sp., Simia sp., Archaeooides sp., Tasmanites mongolicus Ragozina sp. now.0 occur in Tsagaanolom formation "Fig". 8 and problematical circular remains are preserved in glacial deposits of the Maikhanuul formation. These organisms include filaments with an irregular cellular structure and spore-like spheres only a few microns in size. Besides microphytolite and stromatolite-like macrostructures, there are abundant remnants of bacteria-like structures and irregular lumps of organic material. According to A. L. Ragozina et al. [25] and E. A. Serezhnikova et al. [30] the presence of bacterial communities is indicated by abundant argonic carbon inhost rocksand by laminated carbonaceous microstructures resembling coccoidal and filamentous bacteria "Fig". 8. The earliest small skeletal fossils are simple phosphatized tubes (hyolithoidea, as camerotheca) that occur a little above the base of the upper phosphorite member of the Tsagaanolom formation and also Bayangol formation: Anabarites trisulcatus Miss., and Cambrotubulus decurvatus Miss. Both are typical elements of the Anabarites trisulcatus Zone which defines the various part of the Nemakit-Daldynian Stage in Siberia. A similar suite of bioconstructional types is reported from the Zuun Arts succession, where cyanophyceae (microphytolites and stromatolites) are abundant. In general, these unicellular procaryotes and eucaryotes, many shallow-water trace fossils, phosphatic small shelly fossils (SSF), calcareous small shelly fossils with the first archaeocyaths and phosphatic sponge spicules are closely connected intercommunicate by one's genesis and accumulation in this shelf phosphate basin. The phosphate-glauconitic and aluminous-bearing Bayangol formation has abundant assemblages of trace fossils which are confirmed by R. Goldring and S. Jensen [15] In the lower part of the Bayangol formation were revealed many new locations of the soft-bodied and trace fossils (ichnofauna): Didymaulichnus miettensis, Helminthoida cf. miocenica, Planolites isp. and Phycodes pedum Seilacher together with the psammocorals Spatangopsis mongolica Dorjnamjaa and Nemiana. In the upper part contains a more diverse assemblage including Treptichnus pedum, T. bifurcus, T. cf. triplex, Helminthoida cf. miocenica, Palaeophycus tubularis, Rusophycus cf. avalonensis, Monomorphichnus isp., Cochlichnus isp., Hormosiroidea isp., Planolites isp., Didymaulichnus miettensis [12, 13] Moreover, in 1988 year from lower Cambrian section close to Taishir sum (province) we have revealed trace fossils (imprint) of genus Paracharnia Sun, 1986., which first was known in China at the base of the Dengying formation (Shibantom member) and Ichnogenus Oldhamia radiata (or medusoids) Forbes, 1848 [9] At the same time it is well known the calcimicrobial bioherms and biostromes of early Ediacaran-Nemakit-Daldynian and Tommotian age, which are widespread in the Zavkhan basin. Actually, these ichnospecies appear at very similar stratigraphic positions in numerous sections in the world [6] They are constructed by Renalcis, Korilophyton, Tarthinia and Botominella, among other forms. Nemakit-Daldynian bioherms were domal to stacked-columnar at least, while by Tommotian time domal, bulbous, prolate or columnar-oblate examples are known. Late Atdabanian-early Botomian calcimicrobial crusts, calcimicrobial bioherms and radiocyathan-archaeocyathan bioherms are recognized in the Salaanygol formation at Salaany Gol. Overall, the archaeocyathan assemblage of the Salaanygol formation shows a clear species-community with Siberian faunas. It is typified by simply organized archaeocyaths: Archaeolynthus, Dokidocyathus, Nochoroicyathus and Rotundocyathus, with simple outer and/or inner walls, are most abundant among the regular archaeocyaths. The deposition of the Salaanygol formation under reasonably high-energy conditions is supported by associated lithological features such as well-developed marine cements and more or less abundant grainstones and packstones. The late Atdabanian-early Botomian Zavkhan basin bioconsructions can be compared with those of the same age range in neighbouring Siberia and China.

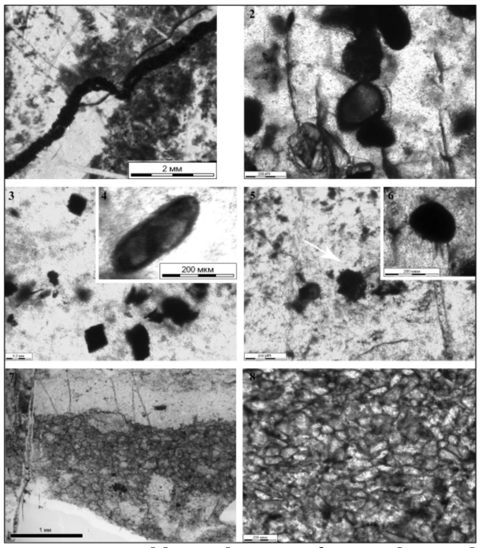

Fig. 8. 1-8. "Zavkhan biota" from the Ediacaran Tsagaanolom formation of the Zavkhan basin, Western Mongolia. 1- Tyrasothaeniapodolica Gnilovskaya, 1991, specimen PIN no. 5492/7; 2- gr. forma Archaeooides sp. Tasmanites sp., specimen PIN 5492/8; 3-Octoedryxiumtruncatum Rud., 1989, specimen PIN 5492/3; 4-ProblematicumNavifusa sp., specimen PIN 5492/9; 5-Tanarium sp., specimen PIN 5492/4; 6-Tanarium sp., specimen PIN 5492/10; 7-8- Tallophycoides sp., fragments of lamellae, specimen PIN 5492/11-12[25]

VI. Conclusion

1. The Khubsugul phosphate basin is a built by Neoproterozoic-Middle Cambrian strata. Two thick groups are recognized: the Cryogenian Darkhat group and Ediacaran-Middle Cambrian Khubsugul group. The Khubsugul group is subdivided into four formations in the ascending order, Ongolik, phosphorite-bearing Kheseen, Erkhelnuur, and ukhutologoy. The Neoproterozoic-Lower

Cambrian strata of the Zavkhan basin are divided into six formations from the bottom: Zavkhan, Maikhanuul, Tsagaanolom (phosphorite-bearing), Bayangol (metaphosphorite-aluminous-bearing), Salaanygol, and Khairkhan.

2. In fact biogenic phosphorites are the concrete evidence and object for an academic research of bacterial paleontology. Actuallybacteria were a beginning of an any life. The"Khubsugul" and "Zavkhan" biota was mostly cyanobacterial. According to A. Yu. Rozanov [36] a start of forming of the bacterial paleontology was kick off research of the mongolian phosphorites. The cyanobacterial mat community was preserved in phosphorites in the form of a stromatolite, microphytolite, blue-green algal remain, and micronodul side by side with trace and small shelly fossils (SSF), also spiculate sponges. The micronodules are clearly predominant in our observations. The micronodule sizes usually vary from tens to several hundreds of microns(Archaeooides, Tasmanites). Soft-bodied animals resemble organisms such as coelenterates and annelids and may be early forms of these groups. In all probability, all the fossils are closely connected intercommunicate by one's genesis and accumulation in the ancient phosphatic basins. This is a target for future investigation.

VII. Acknowledgment

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AUTHOR'S PROFILE

Dorj Dorjnamjaa born in Bayankhongor Aimag, Bayanbulag Sum, Mongolia on 12 March 1941. Hi was educated at Moscow State Univ. (1967), PhD, Geological Inst., Moscow, (1975) and DSc, Inst. of Geology and Geophysics, Novosibirsk (1989). He is a leading scientific researcher at the Institute of Paleontology and Geology, Mongolian Acad. of Sciences (MAS). He made scientific discoveries including the Zavkhan phosphate basin in 1997, a new diamond-bearing astropipe structure in Mongolia in 2005, and the Ulaanbulag massive sulphide deposit in Bayankhongor ophiolite zone in 2009. He established the found. For eco-geological science in Mongolia in 2000. His honours include: Order of Red Labour Banner of Mongolia, V. I. Vernadskii Silver Medal and V. I. Smirnov Gold Medal, Russian Acad. of Natural Sciences; seven certificates of the Mongolian Intellectual Property Organization for academic phosphorite (1997), diamond (2011) and gold-copper deposit(2013)'s research, including the monographs of the Mongolian Paleontology, Stratigraphy and Tectonics (2013). D. Dorjnamjaa has more than 300 scientific publications, including thematic books, maps and papers. D. Dorjnamjaa is member of the TWAS (2003) and academician of the Russian Academy of the Natural Sciences (2010). Major field of study are precambrian geology, bacterial paleontology, mineral deposits, phosphorite, diamond, astropipe, and ecogeology.