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Sedimentological and bacterial paleontological peculiarity of the vivianite phosphorites in the Zavkhan basin, Western Mongolia

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Discovery of the Ediacaran – Lower Cambrian Zavkhan phosphate basin in the western Mongolia was an impetus to investigating distribution of the bedded phosphorites in carbonate and detritus formations of the shelf framework. The Zavkhan phosphate basin has been discovered by us as a result of many years' standing scientific investigation. This basin locates in the west of Mongolia within the territory of Zavkhan and Gobi-Altai provinces inclusive 24000 km^2 of space. In this basin phosphate or stone of fertility was accumulated approximately 635-500 mya. The geologic history of the basin gives a possibility to correlate with 80 world phosphate basins. The phosphate-bearing sediments in the Ediacaran-Lower Cambrian Tsagaanolom and Bayangol formations have been described. The structure and lithological composition of the Zavkhan phosphate sedimentation are well-known to be essentially similar to the phosphate sediments of the main part of the Khubsugul and Karatau phosphate basins. In lithology and bio-geochemistry, the Tsagaanolom carbonate formation is distinctly subdivided into underlying phosphate, vivianite phosphate and overlying phosphate members. The Tsagaanolom and Bayangol formations are characterized by heterogeneous cyanobacterial mat, including zoo-benthos, zoo-plankton and phytogenic organisms. Bayangol Formation mainly consists of detritus sediments and aluminous and stony or collophanitic ($Ca_3P_2O_8 \cdot 2H_2O$) black meta-phosphate rock with pyritic gold, silver-bearing mineralization of sulfosalt type.

INTRODUCTION

The Zavkhan basin is located on the Central-Mongolian micro-continent, which was carbonate sub-platform in the Ediacaran-Cambrian Period. In the Ordovician it was accreted to the Siberian platform. By comparing its high-grade deposits with similar deposits of other basins in Australia, Asia, and Africa their resemblances were revealed and the general biotope model of the biogenic phosphate accumulation was improved (Dorjnamjaa et al., 1980, 1984, 1987, 2001, 2016; 2020; Dorjnamjaa, 2016). A biotope is an area of uniform environmental conditions providing a living place for a specific assemblage of bacteria, flora and fauna. The Ediacaran-Lower Cambrian Zavkhan phosphate-bearing shelf basin in inverse ratio is corresponded to biotope. The cyanobacterial mat community was preserved in phosphate rocks in the form of a stromatolite, microphytolite, blue-green algal remain, and micro-nodule side by side with trace, soft-bodied and small shelly fossils, also speculate sponges and various skeletal fossils. They are collectively referred to as biota. Hence, specific features of the vivianite biogenic phosphate deposits are also of essential interest for called biota. We have done study in detail for sections of phosphorites in the central (Argalant Uul, Alagiin Davaa, Tsakhir Uul, Bogdiin Gol, Zuun Arts) and southern (Khevtee Tsakhir, Bayangol, Urtuun Tsakhir) parts of the Zavkhan basin (Fig.1; Fig 2 Fig. 3).

Tsagaanolom Formation (1600-1900 m) is vivianite phosphate-bearing, which lies discordantly in the eroded form over Maikhanuul diamictite Formation (220 m).The latter formation which rests unconformable upon the Zavkhan volcanic sequence consists of glacioaqueous or glaciogenic and other detrital deposits and comprises two relatively thin units of diamictites or tillites separated

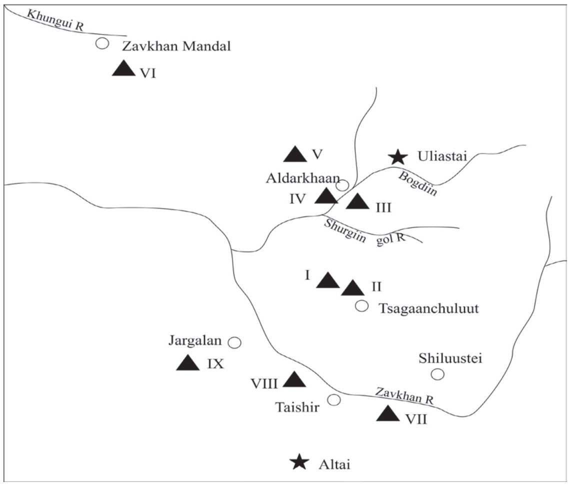

Figure 1. A-Diagram of location of main phosphorite deposits and occurrences in the Zavkhan phosphate basin. I. Baruun Arts, II.Zuun Arts, III. Buural Uul, IV. Bogdiin Gol, V.Alagiin Davaa-Tsakhir Uul deposit, VI.Argalant Uul, VII. Khevtee Tsakhir, VIII.Bayan Gol, IX.Urtuun Tsakhir (after Dorjnamjaa et al.,1987 with some terminological reproduced);

by a section of flysch sediments. The findings of problematical discoidal and circular remains in interdiamictite beds of the Maikhanuul formation show further evidence of microbial or bacterial life in ancient glacial settings. It is quite likely that bacterial aggregations were an essential element of Precambrian biota and were as well adapted to unstable conditions of glacial environments (Dorjnamjaa et al.,2018). The Tsagaanolom carbonate formation dated (according to phytolitha, sponge spicules, small shelly fossils) by the Ediacaran. According to U-PЬ and PЬ-PЬ dating the age of the lowermost part of the Tsagaanolom Formation is about 632 ± 14 Ma (Ovchinnikova et al., 2012). The superjacent Bayangol Formation (up to 940m) is detritus glauconitic sandstones, argillite-calcareous and lime-argillaceous shale), which has a gradual transition from the Tsagaanolom Formation through alternation of carbonate and detritus layers (Markova et al., 1972; Dorjnamjaa et al.,2001, 2019; Eganov et al., 1993). The Bayangol Formation is characterized by numerous faunal and floral fossils: trace fossils (*Phycodes pe-*

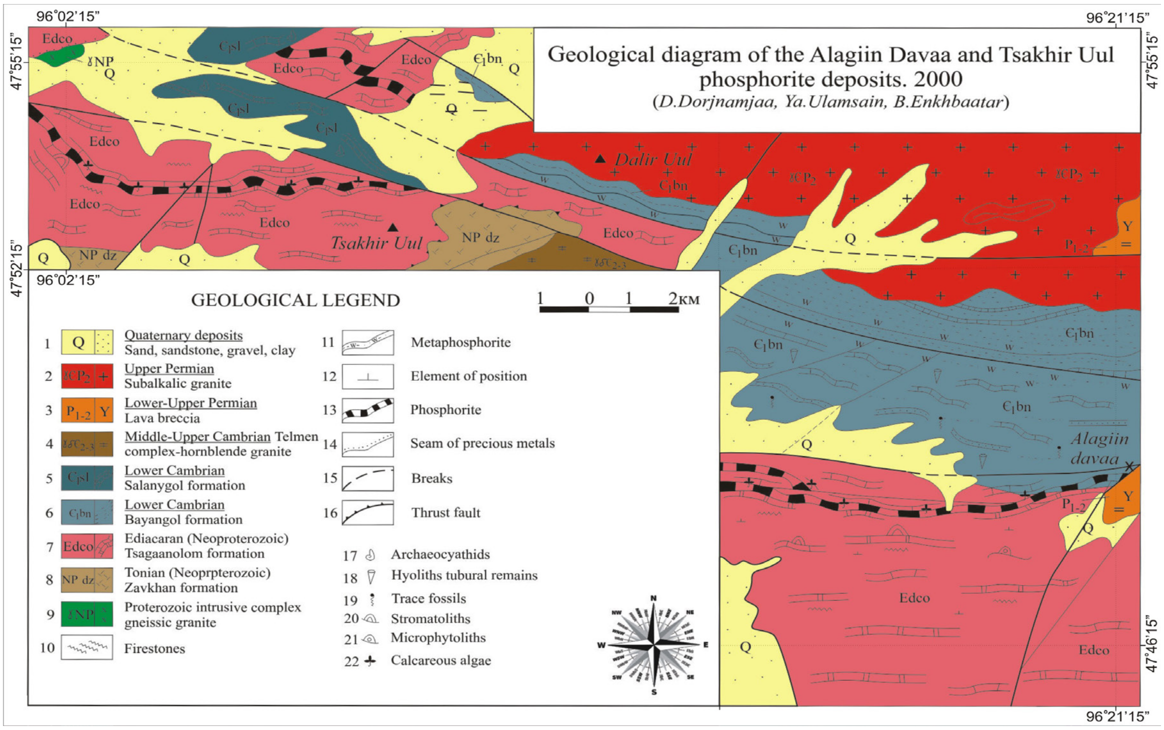

Figure 2. Daigram of geological structure and distribution of phosphate-bearing sediments within the Alagiin Davaa and Tsakhir Uul deposits. 1-Quaternary loose sedimentation (sand, sandstone, gravel, clay, gritstone, rock debris); 2- Upper Permian (sub-alkaline rosy granites and granosyenites);3-Lower-Upper Permian (variegated acidic volcanogenic rocks and their tuffs, lava breccia); 4.Middle-Upper Cambrian, Telmin complex (biotitic mica schist granites and granite-diorites); 5-Lower Cambrian, Salanygol formation (conglomerates, sandstones, limestones); 6- Lower Cambrian, Bayangol Formation (limestones, sandstones, siltstones, microquartzites, glauconites, metaphosphorites);7- Ediacaran, Tsagaanolom Formation (dolomites, dolomitized limestones, argillaceous slates, chert, bedded vivianite phosphorites);8. Neoproterozoic, Zavkhan Formation (volcanics, primarily of intermediate and acidic composition, their tuffs, tuffaceous sandstones, gritstones, conglomerates);9-Proterozoic gneiss-like granites and biotitic plagiogranites;10-Quartz, flint, secondary quartzite, 11- Alumina and metaphosphorites; 12-Element of bedding;13- Phosphorite horizons;14- Seam or organometallic zone of the sulfosalt type (Au, Ag).15-Lines of tectonic contacts;16-Reverse fault; 17-Archaeocyatha, SSFs, phosphate zoophyte or zooproblematicum(?); 18-Hyolitha;19-Trace fossils (Phycodes pedum Seilacher, Helmintoida isp., Rusophycus cf. avalonensis Grimes and Anderson), 20-Stromatolites (Boxonia grumulosa Kom., Conophyton garganicum Kor.);21-Microphytolites (Osagia, Volvatella, Ambigolamellatus); 22-Calcareous algae (Kordephyton sp., Renalcis sp.?)

dum Seilacher, Didymaulichnus miettensis Young, Rusophycus cf. so on), soft-bodied fossils (*Spatangopsis mongolica Dorjnamjaa, Paracharnia gen.nov., Oldhamia radiata Forbers, Medusoid,* so on), Hyolitha (*Latonchella ex. gr. Korobkovi, Cambrotubulus decurvatus Miss.,Heraullia sp. nov.* so on), Archaeocyatha (*Paranacyathus tuberculatus* (Vol.), *Archaeolynthus sibiricus* (Toll.), *Ajacicyathus sp.,* so on), mollusk (*Bagennoviella pectunata Aks.* (ms.), *Cambridium sp*. so on), phosphate zoophyte or zooproblematicum (*Sachitida, Siphogonuchitidae, Mongolodus rostriformis, Halkieria amorpha,* so on) and calcareous algae. The vivianite ($Fe_3(PO_4)\cdot 8H_2O$) phosphate-bearing member or a marker horizon lies just in the upper part in the Tsagaanolom Formation, 100-200 m below the bottom of the Bayangol Formation. Vivianite (Timofeev et al., 1988) is a secondary mineral found in a number of geologic environments: The oxidation zone of metal ore deposits, in granite pegmatite containing phosphate minerals, in clays and glauconitic sediments, and in recent alluvial deposits replacing organic material such as sapropelic peat, bituminous lignite, bog iron ores and forest soils. Bones and teeth buried in peat bituminous bogs are sometimes replaced by vivianite. Associated minerals include metavivianite, ludlamite (Fe,Mg,Mn)3(PO_4)·$4H_2O$, pyrite, siderite and

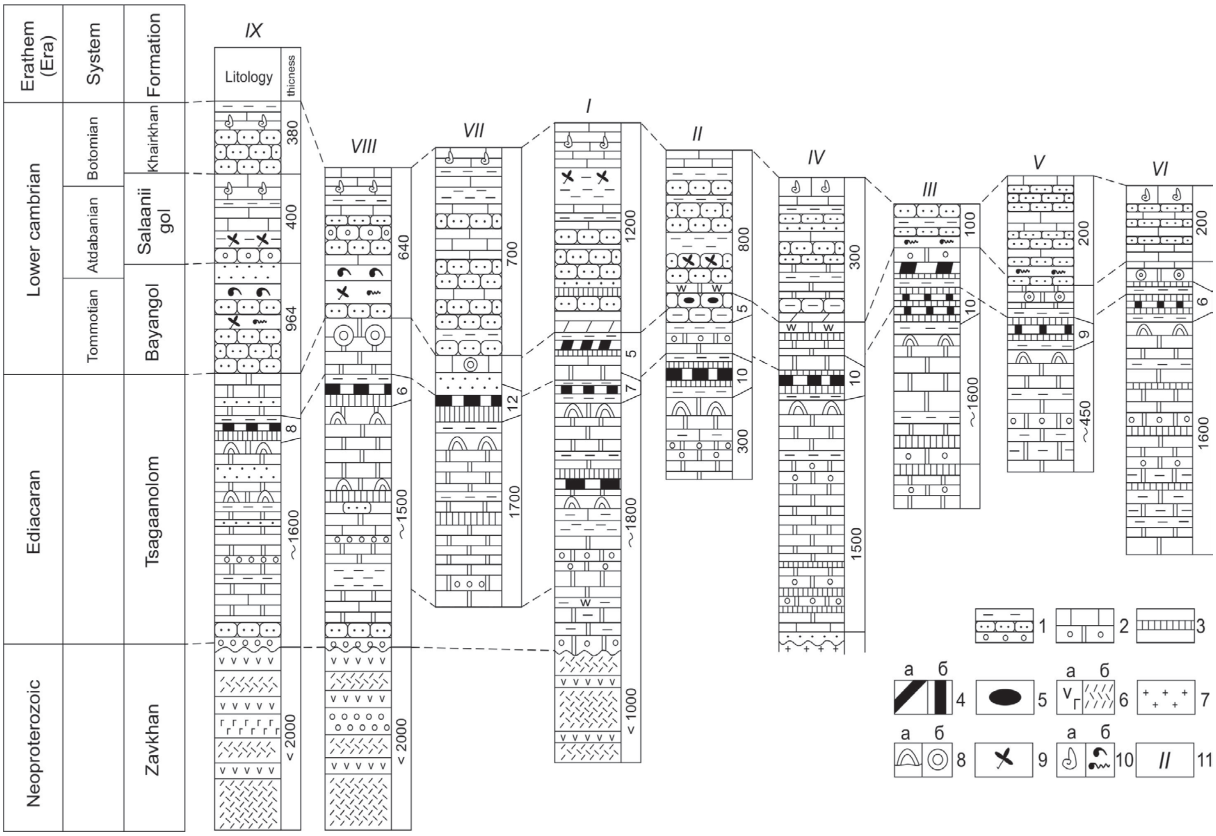

Figure 3. Diagram comparing cross sections of phosphate-bearing sediments in the Zavkhan basin.1.Conglomerates, gritstones, sandstones, quartzite sandsones, microquartzite, siltstones, argillaceous slates; 2.Dolomites, sandy dolomites, massive pale, sometimes breccia-like dolomites, detrital layered, bioherm limestones;3. Chert, phosphate-siliceous-argillaceous slates; 4.Vivianite phosphorites (a-siliciclastic, b-siliceous-carbonate);5. Sandstone phosphorites; 6.Volcanics of acidic and intermediate (b), less often basic composition and their tuffs, tuffstone (a); 7. Biotitic granites; 8-10. Organic remains: 8a- stromatolites, 8b- microphytolites, 9-calcareous algae, 10a- archaeocyatha, hyolitha, sponge spicules, 10b- unidentified tubular remains, detritophage or traces of worms' crawling; 11.Ordinal numbers of cross sections, the name and location of which are given in Fig. 3B (after Dorjnamjaa et al., 1987).

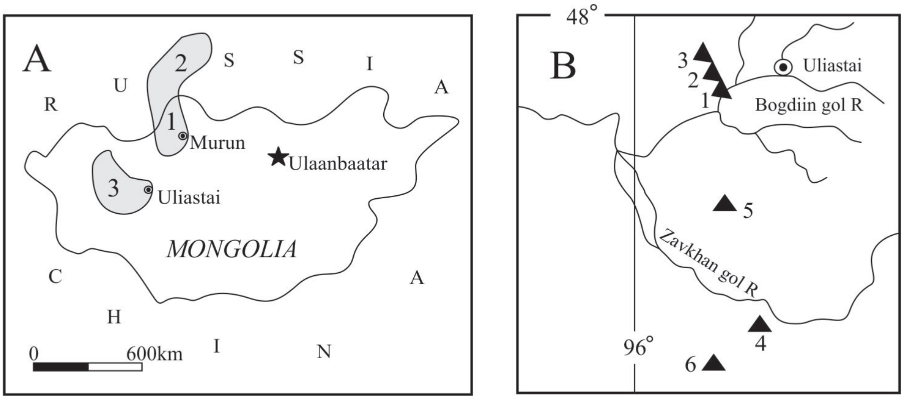

Figure 4. A. Index map of localization of visible parts of the Khubsugul, Zavkhan basins and Oka sub-basin: 1-Central and eastern parts of Khubsugul basin in the northern Mongolia, 2-Oka sub-basin in Russia, 3-Zavkhan basin in the western Mongolia. B-Map of localization of the sites with the section under study:1-Bogdiin Gol, 2-Alagiin Davaa, 3-Tsakhir Uul, 4- Khevtee Tsakhir , 5-Zuun Arts, 6-Bayan Gol (after Eganov et al.,1993).

pyrrhotine (Fe 1-x S). Phosphate interlayers, where phosphate is coquina and stromatolite (thrombolites), algal laminites, trace fossils, small shelly fossils, phosphate zoophyte are also described from the Bayangol Formation bottom, the Tommotian age (Il'in, 2008; Markova et al., 1972; Ross et al., 1983; Voronin et al.,1983). But they are beyond comparison with richer and thicker phosphorites from the Tsagaanolom Formation. Taking into account the uncertainly of the Ediacaran-Cambrian boundary, we do not rule out the same age of the Tsagaanolom, Boskhat or Ukhaagol formations (Tsagaannuur deposit in Darkhat intermountain trough) and Khesen phosphorites, though some authors (Il'in, 2008; Ross et al., 2018; Volkov R.I, 1974; Voronin et al., 1983) admit that only the Bayangol phosphate layers are contemporaneous to those of Khubsugul and Karatau. But even if the Khesen and Tsagaanolom phosphorites are of Ediacaran age (Ross et al., 2018), and the Karatau ones of Lower Cambrian, the interest to comparative study of their positions is quite significant.

RESULTS

Relatively detailed data on the phosphate-bearing marker horizon in the Tsagaanolom formation are given somewhere. However, this and another paper (Khomentovskii et al., 1996) on the Tsagaanolom and Bayangol formations are still far from the necessary detailed relative to phosphorite position. In this connection some new sections of three localities in the central part of the basin, on the right riverside of the Bogdiin Gol (Fig.3B) were described in detail in the book (Dorjnamjaa et al., 2001). These data were completed by D. Dorjnamjaa's description of the vivianite phosphate-bearing part of two more sections-in the central and southern parts of the basin. The present paper generalizes these materials. To reach our goal, it is important to subdivide the ore-enclosing formation into underlying phosphate, vivianite phosphate-bearing and overlying productive parts. The vivianite phosphate-bearing part is several ten meters above the section from its basal detrital layers as in the Khesen Formation in the Khubsugul basin. There are two remarkable intervals in the underlying phosphate part of the section. 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 oncolitic cross-layered carbonates, underwater slide breccia, silicic-detrital horizons. This lower interval (500-700 m) reflects the initial stage of pulsation transgression. Shallow depositions are well predominant in the upper underphosphorite interval. These are detritus, biomicrite, oncolite (*Nubecularites abustus Z.Zhur., Vesicularites cocretus Z.Zhur., V.rectus Z.Zhur., V. bothrydioformis (Krasnop.), V.lobatus Z.Zhur., Radiosus vitreus Z.Zhur., Ambigolamellatus horridus Z.Zhur., Volvatella vadosa Z.Zhur., V.zonalis Nar., Osagia minuta Z.Zhur.*) and stromatolite (*Boxonia grumulosa Kom.*) carbonates, calcareous algae (*Botominella lineata Reitl., Epyphyton Bornem., Renalcis Vol.*), crackle breccia, occasionally quartz-sandstone admixtures are abundant. This part is several ten meters thick. It reflects a significant shallowness of the water basin completing the initial stage of transgression. A new transgression interval begins with massive dolomite breccia, somewhere with sandy admixture and plane-wave stromatolite building between detritus, with coarse cross-bedding. The breccia was evidently preceded by underwater erosion: they are drastically contrasted to underlying thin-layered micrite. The interval is 25-30 m thick, the breccia making up third to half of this thickness. Above the breccia the unit is thin-layered, contains black wave-thin-layered dolomites, but the interval is a whole is characterized by persistent detritus nature, cross bedding, abundance of carbonate intra-detrital, and even a layer of variegated quartz sandstone with re-depositing phosphate grains is noted in the Alagiin Davaa section. The stromatolitic layers (2-4 m thick) number up to three and associate usually with oncolitic dolorudite-oncolitic layers (up to 2-3 m thick). The vivianite phosphate-bearing layer is often a single layer whose thickness, e.g. in the Tsakhir Uul, Khevtee Tsakhir nuruu, and Bayangol gorge (Fig. 5), reaches 40 m /based on field observation (Fig. 6). Usually it reaches only few meters or less.

Figure 5. Field view of the columnar stromatolite (Boxonia grumulosa Kom.). A-vertical view, Б- transverse section of columnar stromatolite. Khasagt Khairkhan Range, Bayangol gorge, vivianite phosphate-bearing member, Tsagaanolom Formation. GPS:N 46º 42’ 42’’; E 96º 18’ 44’’ (1857 м)

The horizon marks is beginning of a vivianite phosphorite member, these is an erosion surface in its bottom. To judge by the coarse – detrital composition of the overlapping carbonates, the roof possibly is also erosion surface. Above the basal breccia of the second phase of transgression, 2-4 erosion surfaces can be traced. These are no detritus admixtures in the stromatolite horizon. The grains in this rock are either microphytolites, biomicrites or intradetritus.

Figure 6. A. Tsakhir Uul deposit, location of prospecting trench № 8, length 45m, depth 3 m, ore thickness 12-40 m. B. Alagiin Davaa deposit, location of test pit № 3, depth 44 m.

The horizon is quite specific and is a homologue of the “lower” dolomite, which begins the section of the Chulaktau phosphate-bearing suite (Formation) in the Karatau basin. Like Karatau, it is dated (according to stromatolites) by Ediacaran (Eganov et al., 1993). The phosphoritic member above the “lower” dolomite is essentially siliceous and sandy. It consists of 2 or 3 phosphate beds

0.2-0.5 m thick, with 6-7 to 20-29% and up to 36% P_2O_5 (Dorjnamjaa et al., 2001). The vivianite phosphorites are either quartz sandstones with grains and detritus of phosphorites, or cherts with phosphate lens-layers detritus. There are thin pure phosphate layers as well. The phosphate layers are underlain and separated by layers of black mica-siliceous shale with interlayers quartz sandstones, reddish dolomite and black chert. The shale shows all intermediate phases in their transition to siltstones. Quartz sandstones dominate in places. In the sections of Khevtee Tsakhir Nuruu and Bayangol occurrences the chert (with and without phosphate) occur mainly in the upper horizon. The Bogdiin Gol and Tsakhir Uul phosphorites are evidently subdivided into a thin lower and the thicker upper horizons. There are sections with three phosphate layers, the intermediate one separating the inter-ore members. In the sections Bogdiin Gol, Tsakhir Uul and Alagiin Davaa phosphorites

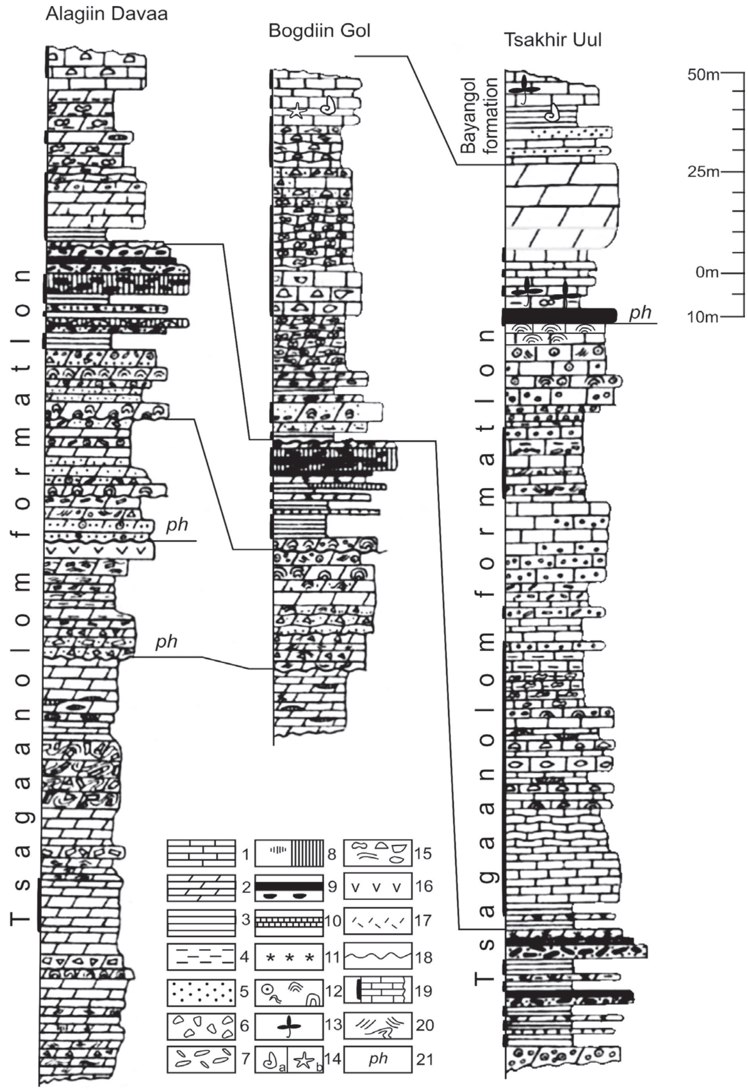

Figure 7. Lithological-stratigraphic columns of the detailed sections of the phosphate- bearing member and enclosing deposits of the Tsagaanolom formation.1-Limestones;2-Dolomites;3- Clay shale, black chert; 4-Clay admixtures; 5-Sand-aleurolite admixtures, sandstones; 6-Conglomerates, breccia, pebble, debris; 7-Plane intra-detritus; 8-Chert, 9-Phosphorites;10-Allites, bauxites, iron rocks;11-Intense ferruginization;12-Oncolites, stromatolites;13-Floral fossils;14-Faunal fossils; 15-Other various algal textures;16-Extrusives;17-Tuff material;18-Erosion surfaces;19-Black carbonaceous intervals of the section from the side; 20-Cross-bedding; 21-Increased phosphate content (modified after Eganov et al.,1993).

are concentrated in the upper part of the mem ber, where that, although small (up to 2-6 m), thickness being always more than thickness of the lower phosphorite level (1-2 m). Below the lower vivianite phosphorite lies a sand-carbonate-chert bed, the same interval separates both vivianite phosphorite horizons. It means that as in many phosphorite deposits, the shale members precede high-grade layers. The upper vivianite phosphorite bed is covered by ferruginous dolomites (1-2 m and less) which are persistent in the pay member roof. Occasionally these dolomites contain small lenses and land pebble phosphorite, small stromatolite buildings. There is a thin (0.2-0.3 m) but very important formation in the Alagiin Davaa section at this level. It is an intensively ferruginous, synsedimentary crushed microstromatolite dolomite -a specific crust of weathering, a horizon of discontinuity. The high-grade member ends with alternation of black shale with light ferruginous or black limestone. Somewhere, it is a thin (2-3 m) black shale bed with or without seams of ferruginous carbonate. Phosphorite is seen here in the Bogdiin Gol and Bayan Gol sections in the form of rare black lusterless in dolomite of the "hard ground" type. Still higher follow dark limestone with algal textures in the Tsakhir Uul section. Yellowish members of argillaceous dolomites occur occasionally in the lower part of this unit. These are already depositions of the third phase reaching depth of the "basin". It should be mentioned that some stratigraphers and sedimentologists often use hard grounds as marker horizons and as indicators of sedimentary hiatuses and flooding events. Hard grounds and their faunas can also represent very specific depositional environments such as tidal channels and shallow marine carbonate ramps. The above-said is illustrated by section columns (Fig. 7). Thus, the phosphorite or phosphate rock interval lies between two extreme surfaces-surfaces of discontinuity. There are no other better expressed signs of a gap in sedimentation in the rest of the section of the Tsagaanolom carbonate formation. The lower surface is marked by breccia and sandstones above which follow depositions, predominantly, ferruginous dolomites with "hard ground" shallower than before the breccia. The upper surface corresponds to the level of crusts, in places with signs of the crust of weathering or its re-sedimentation products-quartz siltstones. These levels limit an intra-formational (with the whole Tsagaanolom Formation considered as a carbonate formation) cycle with the maximum (for the whole carbonate unit) range of depth variations. There are no dry land signs in the form of erosions and no distinct change of rock types below and above them. An intermediate layer (from 3-5 to 10-12 m thick) of black shale with chert seams was deposited immediately before the appearance of phosphorites. The clay material contains occasionally abundant grains of perfect round shape made up of clay as well. Seams of quartz sandstone and ferruginous dolomite are frequent and sometimes predominant in the upper shale member. All this is evidence of shallow depth at which the initial shale member was formed in spite of the chiefly argillaceous composition of the material groundmass.

The lower phosphorite bed lying above the lower shale member consists of quartz sandstone or chert with quartz and lutite, where detritus of the phosphate rock are dispersed. Above lying seams similar shale-sandstone member commensurate with the lower one in thickness (some meters). Its upper part is also richer in sandstones. Sometimes, small (up to microscopic) bioherms of phosphate composition are found in the cherts with flat seams of quartz sandstone. We call this member inter-ore. The upper phosphorite layer is often continuous but sometimes it is separated by argillaceous, argillaceous-siltstone shale with seams enriched with detrital phosphorite.The layer can contain chiefly cherts (with phosphate seams and detritus) or coarse-grained quartz sandstone with land pebble. The cherts are always secondary. There are an either a re-generation quartz sandstone, or stromatolitic stratiform, 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, metavivianite, pyrite, quartz mudstone). The overlying phosphate member begins with organic black shale (1-3 m), which contains no more sand-siltstone impurity. Above follows the alternation of wave-bedded and thin-layer black and yellowish (argillaceous) limestone, calcareous dolomites, sometimes with cross-bedding and intra-detritus (small plane carbonate pebble) or calcarenites (20-30 m). The lower layers contain plane-wave stromatolitic textures, trace fossils, lenses of derived phosphorite. Above lie, chiefly, black limestone with macrocyanobacterial fossils as plane-rounded, spheroidal and semispherical algal bioherms, calcarenites (Fig.8).

Figure 8. Calyptra-biostromal algal mound building organisms or saprophyte, laminarite. Bayangol gorge, Tsagaanolom Formation, 11th bed. A. Mainly spherical-circle shape (5-20-30 cm in diameter) chainlike colony (bushy, shrub) biostrome.

Having calcareous nature, the deep-black color, algal textures, trace fossils, wavy and cross-bedding, abundance of relatively large intra-detritus the overlying phosphate section differs from the pure dolomite underlying phosphate part, which is gray and more evenly bedded, with small intra-detritus (expect for horizons of block-mega-detrital slide breccia). Hence, the phosphate-bearing part of section is underlain by a prephosphatic sediment portion, which is more monotonous dolomitic, slightly enriched in organic, quietly bedded (with separate slide horizons), and is overlain by a phosphate rock part of the carbonate rock mass, which is more variegated in composition, more saturated in organic, with abundant trace fossils, essentially calcareous rather than dolomitic. The phosphate-bearing interval, which can be reasonably determined as a phosphate-bearing formation, is also subdivided into three parts: lower underlying phosphate rock, middle vivianite-phosphorite, upper overlying phosphate rock. They are contrast against the background of more monotonous under- and imbricated overlapping of the carbonate formation due to their saturation with detritus, abundance of well-expressed surface of erosion, inland discordant drainage, intermittent or maximum shallow water. The rather deep erosion accompanying with basal breccia and occasionally detritus variegated rocks took place at the beginning of the phosphate stage, which ended by essential shallowness and inland drainage producing a crust of weathering in places. The next, phosphate stage (second 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 way to carbonates. The clay supply, however, was sometimes repeated until the plain shore appeared to be flooded with transgressing waters quite far.

Comparison of position of the phosphate-bearing formation of the Zavkhan basin in the carbonate sediments in the context of phosphorites in adjacent regions of the Altai-Sayan and Khubsugul regions as well as in the Karatau basin reveals a lot of common besides that they belong to a carbonate-cherty interval of carbonate formation. Throughout the Altai-Sayan region, Khubsugul included, the phosphate-bearing interval is situated inside thick carbonate sediments. In all cases it is beginning conformity with detritus change in sedimentation conditions toward the contrast of setting, ubiquitous shallowness. In the Karatau basin, however, the phosphate-bearing formation lies above the basal part of the carbonate formation characterized by the abundance of various detritus components, cherts, stromatolites and microphytolites. Of detrital rocks there are only clays in the phosphate-bearing interval within the Khubsugul region. Glauconitic rock is absent completely, littoral is no exposed. Fig. 9 shows a sedimentological and lithological correlation of the phosphate-bearing formation of the Karatau, Zavkhan and Khusugul basins with a homotaxy of its main beds, which essentially coincide. The difference is that there is no detritus-stromatolite overlying phosphate rock part near Khubsugul, in the most productive part of the basin; it is replaced by carbonate-clay-shale deposits. The homolog of the overlying phosphate-bearing Fe-Mn bed is slightly expressed here, even local crust of weathering is absent at its level. Quartz-sand material is absent either at the level of phosphorite beds and inter-ore member. All this suggests a deeper-water and off-shore setting of phosphate formation near within the Urandush mountain area (Jinkhain deposit) in Khubsugul.

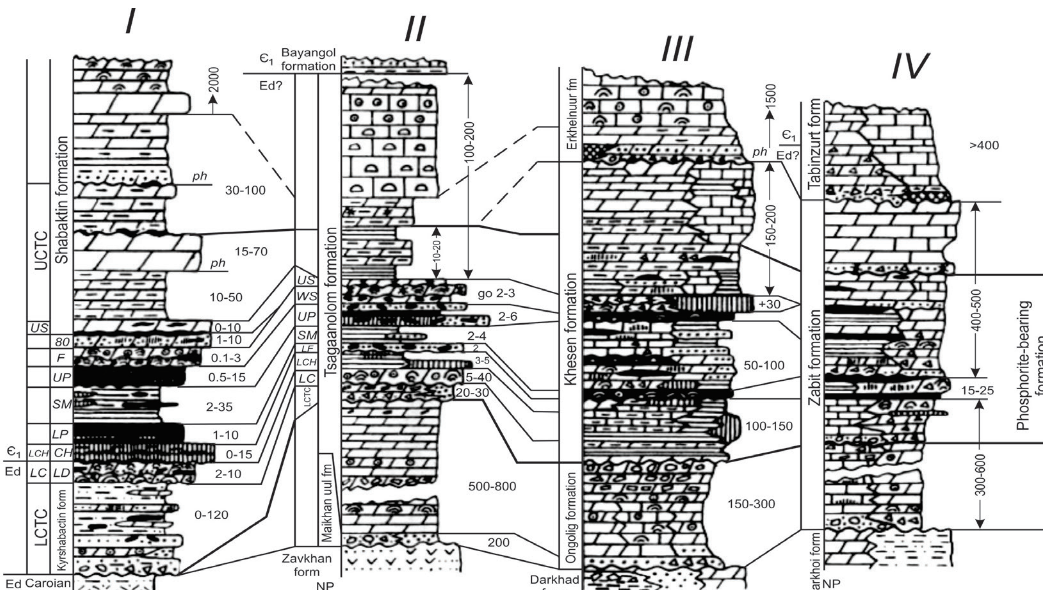

Figure 9. Correlation of lithological homologs of a phosphate-bearing Formation and its host carbonate Formation of the Khubsugul, Zavkhan and Karatau basins (out of scale).I- Karatau basin, II- Zavkhan basin in the western Mongolia, III- Khubsugul basin in the northern Mongolia, IV- Oka sub-basin in Russia. Thicknesses are given in meters. Section I contains the Chulaktau phosphate-bearing formation subdivisions: LD-"lower" dolomite, SH-siliceous horizon, LP-lower phosphorite, SM-shale member, UP-upper phosphorite, Fe-Mn horizon, BD-brown dolomite, Homologous components of phosphate-bearing sections: LCTC-lower carbonate-detritus complex; LC- lower carbonate; LCh-lower chert; LP-lower phosphorite; IM-inter-ore-member; UP-upper phosphorite; CW-crust of weathering, gap horizon; UCh- upper chert; UC- upper carbonate; UCT(D)C-upper carbonate-detritus complex. F- Horizons with derived phosphate material. Column symbols follow FIG. 5 (modified after Eganov et al., 1993).

DISCUSSION

We can improve the comparisons at the cost of data on phosphate substance of the Zavkhan vivianite phosphorites.

1. The phosphatic algal lamination occurs usually in the uppermost phosphate bed. There are only detritus, pebble or centimeter-size layers of this phosphorite in the rest

Figure 10. A-C. A slice photograph through sections of plane pebbles of phosphate rock of algal-mat lamination texture. Black and gray is phosphate, white is quartz. The phosphatized algal mat or saprophyte contains admixtures of sand particles and debris of phosphate micro-fauna replaced, partly or completely, by silica. A, B x 204, C x 340 polarizing nicol II. D and E. The slice photograph through a plane fragment of the phosphorite made up of fragments wedge-like in section of skeletal micro-fauna or packed biomicrite (phosphate zoophyte) of phosphate composition (phosphatized limestone). The fragments are partly or completely replaced by quartz with the phosphate rim, which is conserved (dark).Matrix is phosphate cement (dark). Phosphate pebble is included into coalescent quartz-phosphate sandstone, x 60; nicols II. All the specimens are sampled from the upper phosphate bed of the Bogdiin Gol occurrence (after Eganov et al., 1993; after Dorjnamjaa et al., 2001).

of the section. It contains cyanobacteria mats, saprophyte and fragments of skeletal phosphate micro-fauna or phosphate zoophyte, zooproblematicum (Fig.10, A-D; Fig.11; Fig. 12). Initially it was phosphatized algal mat with phosphate micro-fauna admixture and non-phosphate detritus. Its undestroyed form is quite rare, usually it occurs as fragments.

2. A variety of phosphate algal lamination is phosphate laminate rims of various grains (phosphate and non-phosphate). The structure of these formations in the sections is identical to structures of carbonate microbioherms from underlying phosphate stromatolitic dolomite.

3.The phosphate crustified cement is like lamination rims. It is visibly a chemofacies association, whose microscopic crusts are constant in thickness. This cement fills interstices covers detritus. Most frequently it occurs in phosphate micro-coquina, usually in the form of spicule bio-fragments wedge-like in section.

4. Phosphate skeletal bio-fragments are widespread. Typically, they are grains, cone tubes (spicule or hyolitha-like), wedges, and wings in shape. Initially phosphate rock, they are replaced by quartz to a different extent (Fig. 10, E).

5. Micro-phosphate structure-less matter forms thin (micro-or millimeter-size) layers. Their disintegration gives rise to a shape diversity of rounded structure-less pellets of psammofauna clustered into layers of typically "micro-grained" phosphate rock. The layers are no more than a decimeter thick, but when micro-grained phosphate rock prevails, they can reach two meters. Sometimes the organic textures can be seen in micro-phosphate rock under large magnification. In places, these are evidently fragments of phosphatized algal mat of fibrous texture-"interwoven felt" of phosphate "threads", "intertwined noodles". Some micro-phosphate rock pellets show concentrically - layered structure together with radial one. In other cases, due to quartzite, micro-phosphate rock is decomposed into a "roe-like" aggregate of grains (20-40 µm), similar in texture with sections of algal cells.

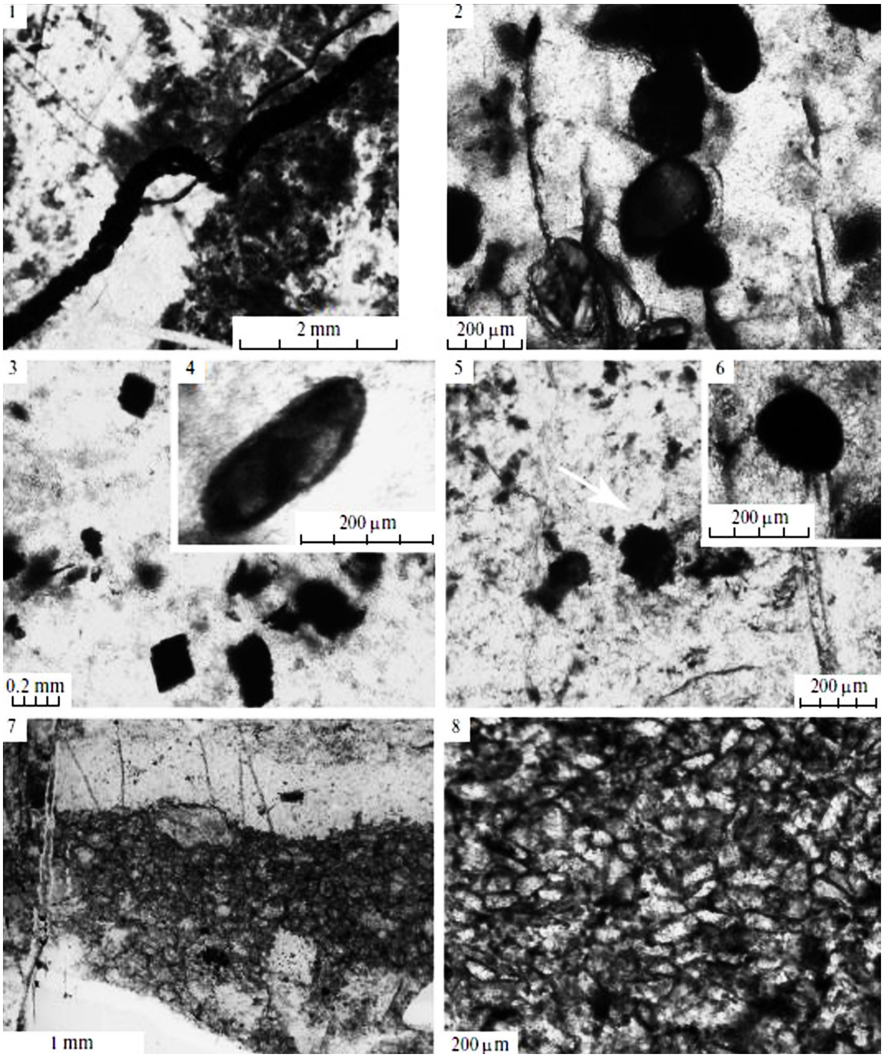

Figure 11. 1-6. "Zavkhan biota" from the Ediacaran Tsagaanolom Formation of the Zavkhan basin, Western Mongolia.1-Tyrasothaeniapodolica Gnilovskaya,1991, specimen PIN no. 5492/7; 2- Archaeooides sp. Tasmanites sp., specimen PIN 5492/8; 3- Octoedryxiumtruncatum Rud., 1989; specimen PIN 5492/3; 4-Problematicum Navifusa sp., specimen PIN 5492/9; 5-Tanarium sp., specimen PIN 5492/4; 6-Tanarium sp., specimen PIN 5492/10.

We can state that in the studied part of the Zavkhan basin nearly all phosphorites formed in situ, namely micro-coquina and saprophyte or algal-mat lamina, were disintegrated by wave activity and re-deposited just after their appearance. The abundant supply of quartz sand during phosphate deposition and stromatolites available suggest the littoral setting alternating with deep-laid lagoon when black and / or sulfide dolomites appeared. The phosphate formation stopped at these moments. The extreme shallow water permitted the origination but did not favor the accumulation of phosphatized algal organics. Small-skeletal organisms (probably, those of planktonic type included) flourished, but for concentrating their debris the situation appeared to be unfavorable. A micro-phosphate des-integration could not provide the accumulation either because of the lack of "raw material"-"initial phosphate concentration" (Dorjnamjaa et al., 2018; Ragozina et al., 2019), whose role phosphatized algal laminates had to play. The Zavkhan basin, however, was much shallower than the productive sites of Karatau and especially as compared with the Khubsugul water paleoequator or territory. But the mutual arrangement of homologs of the components of the phosphate-bearing formation in the Tsagaanolom sediments is the same as in high-productive regions. The main difference is an abundance of sandy and coarse - detrital material at the level of a productive interval. It is interesting to note the small tubular remains (Anabarites, Cambrotubulus) which come from transitional layers between the Tsagaanolom and Bayangol formations in the

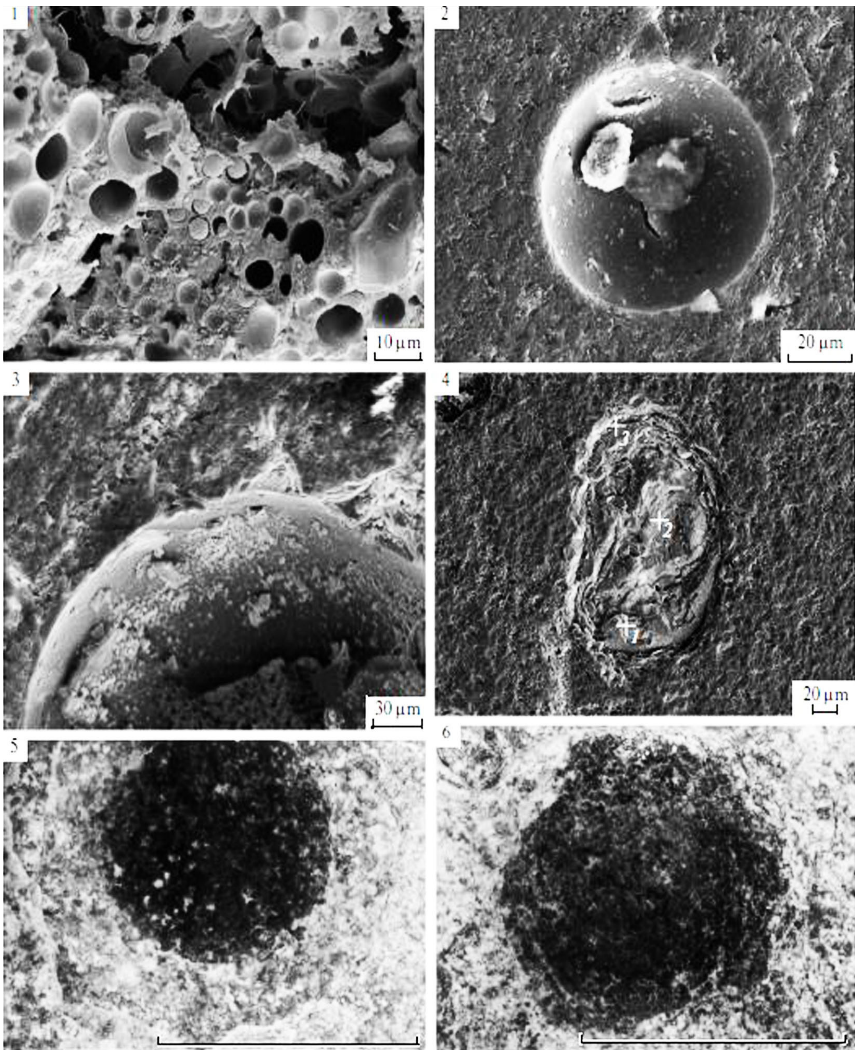

Figure 12. 1-6. Microfossils from Zavkhan association, Western Mongolia. Upper Vendian (Ediacaran), Tsagaanolom Formation.(1-4-electronic microscopy; 5-6, optical photographs):1-4-Spheromorphic microfossils Tasmanites sp., specimen PIN 5492/15,16; 5,6-Beltanelliformis brunsae Menner,1974, specimen PIN, № 5492/91,92 (Scale bar equals 1 cm)

Salanygol area within the Khasagt Khairkhan Range heavily phosphatized and, for their dense surface layers, show a content of phosphoric anhydride ($CaSO_4$) from 11 to 22% / pers. comm. with Zh.Yondonjamts/. Thus, a significant part (about 100-140 m) of the thickness of the cross-section of the limestone-siltstone bed classified as a transitional layer from the Ediacaran to the Lower Cambrian contains phosphate. At present, we have succeeded in establishing the upper, sandstone phosphate rock horizon in only two areas, Alagiin Davaa (Ikh Khanan and Alag Uul) and Zuun Arts. For the remindful occurrences, it is difficult, for now, to give more definite information on account of the lack of necessary factual data. The Ikh Khanan and Alag Uul occurrences are located about 50 km in west part of Uliastai city and Zuun Arts is 18 km northwest of the Tsagaan chuluut village (sum). Here, the phosphate horizon being distinguished is confined to a limestone-sandstone stratum at the base of the Bayangol formation of the Lower Cambrian. The Bayangol Formation (up to 1000 m thickness) is represented by glauconitic sandstones, argillaceous, and calcareous-argillaceous slates with a subordinate amount of bioherm limestones and calcareous clay rocks containing an archaeocyatha, algae, small shelly fossils, trace fossils, and soft-bodied fossils (Dorjnamjaa et al., 2018).
The phosphate horizon consists of aluminous and stony or collophanite black meta-phosphate rock with pyritic gold, silver-bearing organometallic mineralization of sulfosalt type. Sulfosalt minerals are those complex sulfide minerals with the general formula: Ac, Am, An,; where Ac represents a metal such as copper, lead, silver, iron, and rarely argental mercury, zinc, vanadium; Am usually represents semi-metal such as arsenic, antimony, bismuth, and rarely germanium, or metals like tin and rarely vanadium; and An is sulfur or rarely selenium or/and tellurium. About 200 sulfosalt minerals are known. We have some data about it. For example, by Amgalan and Gerbish (pers. comm. with) from Chemical Institute Mongolian Academy of Science (MAS) in 1997 mineralogical sample №160 gave evidence content of Au 6.33-6.71 g/t, of Ag 0.1-0.8 g/t, mineralogical sample 1520/2 showed content of Au 28.9 g/t, content of Ag 141 g/t from Ikh Khanan occurrence. The Alag Uul occurrence is located within the Alag Uul mountain (2485.0 m) associated with pyritic gold mineralization in the black, merging, glassy (lacquered) slate micro-quartzite (thickness ~ 250 m., extent of the ore horizon ~3.0 km) of the Bayangol formation (thickness at least 1000 m).

We can state that Zuun Arts is unique area for study of the Precambrian-Cambrian boundary equally Bayangol area (Voronin et al., 1983). The Zuun Arts section consists of Tsagaanolom phosphate-bearing carbonate formation and of Bayangol pyritic detritus formation. By electron microscopic study the black, merging, glassy (lacquered) on weathered surface micro-quartzite, quartzite sandstone, and indurated aluminous siltstone of the lower part of the Bayangol Formation (thickness 413m) contain pollen sulfide-gold (?) mineralization of sulfosalt type. The Neoproterozoic carbon-bearing gold-pyritic black shale is widely spread within the Western Prikhubsugul in Shishkhidgol area and occupy 75-100 km2 (Agafonov et al., 1989). The organometallic (Timofeev et al., 1988) black shale has such ore minerals as pyrite, pyrrhotine, chalcosiderite, chalcopyrite, titanomagnetite, marcasite and titanite or sphene. According to atomic absorption (Au, Ag, Cu, Ni, Cr, Co, Zn, Pb, V, Mo), spectral analysis (Ga, Ba, Be, Zr, Sr, Se, Y, Yb) and gamma-spectrometry (U, Th) the organometallic sulfide-bearing black fissile shale has content of Au-0.23-0.60 mg/t, of Ag-16-1100 mg/t, of U-0.2-31.2 g/t, of Th-0-19.0 g/t. The analytical data show that in the most part of organometallic black shale is characterized by uranium content exceeding thorium and content of silver much more than gold.

Based on sufficient closeness of positions of phosphate - bearing members in carbonate formations of the Karatau and Khubsugul regions with that in the Zavkhan basin, the latter can be supposed to have more favorable depth, system of water circulation, and shelf slope. It is possible that, an apart of the littoral zone with all known, until now, phosphate deposits and occurrences of the Zavkhan basin along the eastern periphery of the Tsagaanolom sediments outcrops (see Fig.1), we can expect outcropping more productive sections of the Tsagaanolom phosphate - bearing formations, most likely west of the Argalant Uul, Tsagaan Khairkhan, Tsakhir Uul, Alagiin Davaa, Baruun Arts direction (Dorjnamjaa, et al., 2001). The transgression trend for the Tsagaanolom time is to be established by detailed study and comparison of visible parts of the lithological and bio-stratigraphic sections, also their lithological genesis as a whole. We add some data obtained when investigating contents of trace elements in phosphate-bearing and their host rocks as well as their clay fraction. Few samples permit only preliminary conclusions. Fifteen trace elements were analyzed. In sedimentary rocks, their overwhelming majority is contained (in both rocks and clay fraction) in amounts less than the clarke (pers. comm. with A. P. Vinogradov) or their contents vary about the clarke values. Nevertheless, individual elements acquire some order. The vivianite phosphate-bearing interval lies between two sediment parts different in contents of some trace elements. Thus, barium in the overlying phosphate rocks is more frequent in superclarke amounts with a greater range of variations than in the underlying phosphate rocks of this strata.The bottom contents in the overlying phosphate beds are chiefly subclarke, while in the underlying phosphate beds they are more often superclarke. Manganese has the same pattern. The titanium contents in underlying phosphate and phosphorite parts are subclarke, and above phosphorites, chiefly superclarke. It is surprising that in shale sand cherts of the phosphate part of the section the vanadium contents are exclusively superclarke.

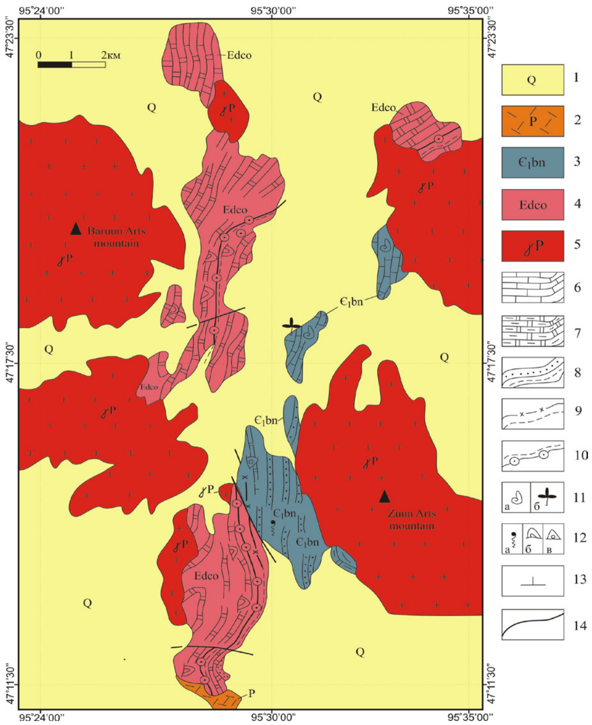

Figure 13. Geological diagram of Ediacaran-Lower Cambrian phosphate-bearing sediments in the region of the Baruun Arts and Zuun Arts mountains (Zavkhan basin).1.Quaternary sediments; 2.Permian acidic lavas and their tuffs; 3. Lower Cambrian, Bayangol formation- limestone bioherm, calcareous dolomites, sandstones, quartzite sandstones, siltstones, alumina phosphorites; 4.Ediacaran, Tsagaanolom formation-dolomites, calcareous dolomites, argillites, cherts, sulfide phosphorites; 5.Permian sub-alkaline rosy granite, granite-syenite, spilite; 6.Layered limestone; 7.Massive, pale, platy, sometimes marbleized, dolomites;8. Sandstones, quartzite sandstones, siltstones; 9.Phosphorite horizons: a) alumina collophanite stony phosphate rock, b) sandstone-carbonate vivianite phosphorites, 10.Siliceous sulfide phosphorites; 11. Sites of finds of fossil organic remains (a-Archaeocyatha fauna: Ajacicyathidae, Robustocyathellus abundaus, Aldanocyathidae, brachiopods, calcareocorneous sponge so on, phosphatic zoophyte?), b- calcareous algae: Saprophyte, Renalcis gelatinosus, Razumovskia sp., Zaganolomia sp., Epiphyton pusillum Korde.); 12a- traces of worms' crawling (Phycodes pedum Seilacher, planolites sp., Didymaulichnus cf. so on), 12b – remains of stromatolites (Boxonia grumolosa Kom., Conophyton garganicum Kor.), 12c-remains of microphytolites (Osagia minuta Z.Zhur., Ambigolamellatus horridus Z.Zhur., Nubecularites catagraphus Reitl.); 13. elements of position; 14. breaks (after Dorjnamjaa et al., 1987 with some terminological reproduced).

The chrome contents are steadily greater than clarke (both in the rocks and in their clay fraction). Immediately in phosphorus (single 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 illustrative. These are B, Ba, Mn , Ti, Cr, and Au. Preliminary data show that the detrital sediments of the Bayangol Formation within the Alagiin Davaa deposit, also Baruun Arts and Zuun Arts occurrences area by data of Chinese prospecting well in 2011 year contain high content of alumina and sulfide mineralization (Fig. 13). Predominant minerals are the aluminum and ferrophosphatic compound, argillite, and secondary- quartz, feldspar, hydromica (sodium illite), pyrite, and other admixture. Some preliminary chemical and spectral analyses of nodular phosphate rock gave the following results: P_2O_5-0,18-1,0; 4-9%, sometimes to 25-30%; Al_2O_3-15,2-33%; organic matter-1-5%; SiO_2-60-65%; Fe_2O_3-6,8%; TiO_2-0,84%; CaO-3,18%; MgO-3,86%; MnO-0,10%; K_2O-2,78%; Na_2O-2,38%; Ba-0,05%; V-0,005%; La-0,003%; Cr-0,003%; Sr-0,02%; also Au and Ag for Ikh Khanan occurrence in particular. It must be emphasized that investigation of mechanical activation of both siliceous and sandstone phosphorites was conducted at the applied-chemistry laboratory of the Chemical institute MAS under the supervision of Dr. J.Amgalan in 1986 year, for the purpose of determining their assimilability by plants. To do this, samples of phosphate ores were subjected to dry mechanical activation for 60 min. In this case, the assimilability of both types of phosphorites by plants was up to 50% of the ores' original content of phosphorus anhydride. This property of the phosphorites is extremely promising. In connection with this, it seems necessary to study in greater detail electro-thermal processing of yellow phosphorus, for the purpose of obtaining a new technological method of processing phosphorus raw material.

CONCLUSIONS

The data reported enable us to draw four main conclusions.

1. The discovery of the biogenic phosphorites in the Zavkhan shelly basin is of undoubted scientific and practical interest. Phosphate-bearing deposits of the Tsagaanolom and Bayangol formations occupy a fairly wide stratigraphic range from the upper part of the Ediacaran to the Lower Cambrian inclusive. Particularly the upper part of the Tsagaanolom Formation, which is analogous in all its characteristics to the Doodnuur, Kharmai, Boskhat and Khesen formations in the Khubsugul basin heavily permeated with vivianite phosphate material. The vivianite phosphorite is very characteristic for shallow shelf Zavkhan phosphate basin exclusively. Thus, the vivianite phosphate rocks are main base for mining and chemical industry with the object of receipt of the ecological mineral fertilizer.

2. For the first time we have discovered a collophanite stony or black meta-phosphate rock occurrence with high content of Al_2O_3 (up to 15-33%) in the Bayangol formation close to the Alagiin Davaa deposit (Ikh Khanan and Alag Uul occurrences) of the Zavkhan phosphate basin. Detailed study of substantial composition of the phosphorites is very important for explanation of regularity of genesis of the "Khundlun uul type" phosphorites within the sub-platform environment, and also practical significance on the whole. These data gave us possibility to put biometallogenic study, associated with pyritic gold, also silver-bearing mineralization of sulfosalt type, possible.

3. The cyanobacterial mat community in the Ediacaran-Lower Cambrian phosphorites was preserved in the form of a stromatolite, microphytolite, blue-green algal remain, and micro-nodule side by side with

trace and small shelly fossils (SSFs), also spiculate sponges. Phosphate zoophyte or zooproblematicum (*Anabarites, Mongolodus, Halkiera, Tianzhushania* so on) were discovered from Tsagaanolom and Bayangol formations. The micro-nodules are clearly predominant in our observations. The micro-nodule 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 phosphate basins. Thus, in direct ratio the Zavkhan phosphate basin is spontaneous biotope area for future investigation.

4. The Ediacaran biota represents the largest known old multicellular organisms. It appeared immediately, after the post Cryogenian de-glaciation and largely disappeared before biodiversity known as the Cambrian radiation (541 Ma). In any case the Ediacaran phosphorites were formed before the Cambrian bioradiation. Thus, the Ediacaran biota timely coincided with the phosphogenic epoch and glaciation can be regarded as a principal cause for the massive phosphogenesis in the Ediacaran period.

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