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Bio-inert Dome and Columnar Structures of Mud Microvolcanism in Baikal Rift Zone

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ABSTRACT: The structure, mineral composition, genesis features of bio-inert dome and columnar small – and mini-structures detected by the authors in depressions of the Baikal rift zone are considered. It is specified that they were formed with active participation of bacterial community at the actual discharge sites of mud micro volcanoes gas-water fluids. These structures order and growth mechanism are considered. Main role for such type structures formation in BRZ (Baikal Rift Zone) belongs to fluid-dynamic processes of plume nature.

KEYWORDS: bio-inert morphostructures, mud volcanism, depressions, griffon, bacteria.

I.INTRODUCTION

Mesozoic-Cenozoic system of inter mountain rift basins of Baikal region and Transbaikalia is considered as a specific oil and gas province [1], possessing many similarity traits with oil gas regions of movable belts [2]. For it as for latter one, a paleo- and actual mud volcanism wide development is typical [3]. Relief forms sizes, formed by mud volcanic lithocomplexes, typically positive (massives and griffon sand mounds, hills, travertine constructions) and negative (moulds, craters) widely vary (from 400km² to 100-50m²). Their construction, material composition and genetic characteristics are more or less studied. Along with them, in mud volcanic depressions of Baikal region there is a group of less investigated, debatable by origin, positive small- and mini structures (fig.1), by size, by morphology and partly by content – similar to dome-shaped travertine-like and columnar stromatolite constructions of Precambrian and Cambrian. Some researchers [4] consider them hydrolaccolites (permafrost heaves), others [5] refer them to carbonate kutans (sinters), appeared as a result of soil solutions freezing. The third associate these structures formation in Baikal lake region, Eastern Transbaikalia and Eastern Mongolia with mud microvolcanism [6-9].
The submitted article discusses the construction features, mineral composition and Genesis of dome and columnar structures, accepted by most geologists for the permafrost heaves or bog hummocks of phytogenic origin.

II.PROCEDURE AND RESEARCH OBJECTS

The geologic-microbiologic research covered lake-swamp parts of Baunt, Ust-Selenga (Proval gulf zone) and Tunka basins, presented by mud volcanic caldera, transformed by thermal sources spouts into small stagnant lakes, marshy lowlands. Bagdarin depression upland knolls fragments (the Aunik river valley) and griffon sand massives (“kuituns”) of Barguzin depression were specially surveyed. We studied the dome-like and the columnar small- and mini-structures construction, mineral contents making their layers, zones, bacterial mats and biofilms, using artificial concentrates. Diagnostics, minerals chemical composition definitions were carried out with an electron, scanning microscope LEO 1430 having an energy-dispersed attachment “Jnca-Energy”. For a bacteria isolation and a cultivation, we used traditional procedures of practical microbiology.

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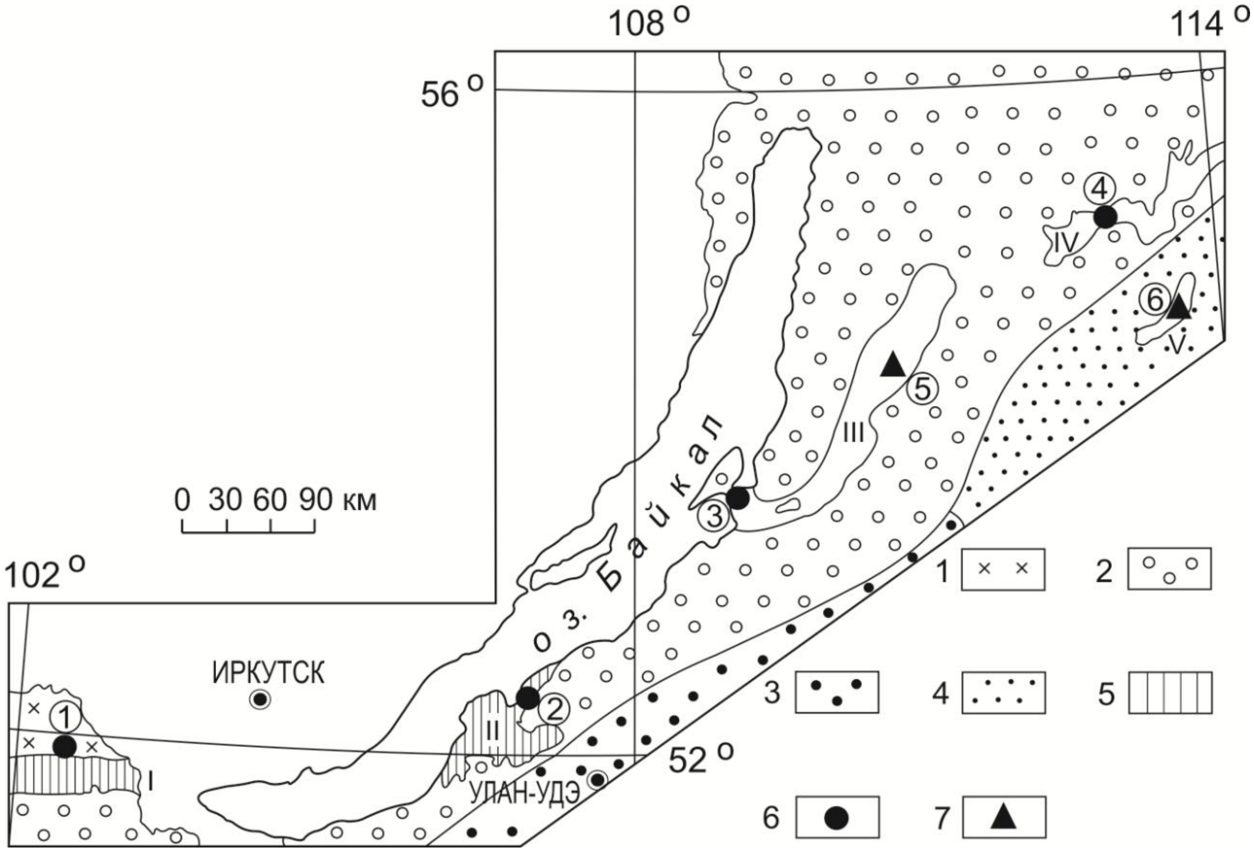

Fig.1. Layout of detected mud volcanic travertine- and stromatolite-shaped structures areas in Baikal rift zone. (Underground mineral waters map is used [10].

1 - East-Sayan region cold and hot mineral waters of carbon dioxide and mixed (CO_2, N_2, CH_4) gas composition; 2 – Baikal-Chara region hot mineral waters, gas-emanating N2 and CH4 ; 3- Selenga region of mainly fresh radon (not gas-emanating) waters; 4- Dauria region of cold carbon dioxide and radon waters; 5 – intermountain depressions with nitrogen and methane (I – Tunka), mainly methane (II – Ust-Selenga), methane-nitrogen and nitrogen (III –Barguzin, IV – Baunt) thermal waters; V – Bagdarin depression (thermal waters are not studied); 6-7 – bio-inert morphostructures (6 –travertine-like dome-tussocky, 7 –stromatolite-like columnar).

III.RESEARCH RESULTS

The Baikal rift zone (BRZ) is considered now as a continuously progressing oil gas basin, where large-scale gas formation processes are taking place [11-13]. A high fluid-generation potential is manifested in a gas and a mud volcanism, in a thermal sources functioning, in a large progress of seismodislocations. This determines the lithogenesis specify, the biocenoses developing, the landscapes forming. The BRZ distinctive feature is a large propagation of microorganisms populations in water ecosystems of mud volcanic origin [14], their active participation in lithocomplexes forming processes and mineral formation [3], [14], [15].

All Cenozoic depressions, where considered morphostructures are detected, have mainly a mud volcanic origin [3]. A high seismicity (4-9 points), heat flow anomalous values (50-100mWt·m²), presence of low ohm fluid saturated layers in upper parts of earth crust sections, fixed with magnetotelluric sounding results. Mud volcanic fluids contain large total portion of recovered gases (CH_4, N_2, H_2, NH_4, H_2S, heavy hydrocarbons).

Mud volcanoes activity is intermittently pulsatile phasic in nature, in the ideal case manifesting itself by a change in time of gas explosive stage, griffon-salsas (gas-water-mud) and griffon (water). For lithocomplexes identification, formed in different stages of mud volcanoes functioning there are developed and used mineralogical indicators [3].

Main big mud volcanic morphostructures of all five depressions (fig.1) are: moulds, lake-crater one, not seldom swampy caldera constructions, more often with ring mounds, round one, cone, oval-like and mound-shaped massive (“kuituns”) of griffon sands. Small mud volcanic constructions are presented by: water sources griffons – in Tunka and

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Barguzin valleys - surrounded by cape-shaped, dome-like travertine formations; salsas: dike-shaped, vein-shaped and tubular bodies of clay-sand bodies.

Dome-like and columnar microstructures are georeferenced with two different types of actual mud volcanic landscape and geomorphological settings. The first are localized in the lake-swamp crater-caldera setting of Barguzin, Baunt, Ust-Selenga, Tunka depressions made by spouting of water sources, being a favorable habitat of bacterial communities. With thermal mineral sources of Barguzin (Garga) and Tunka (Arshan, Zhemchug) depressions they associate the travertine formation, to deposits of which the dome-like morphostructures are characteristic but of the large size [16], [17]. As for columnar microstructures of Barguzin and Tunka valleys, they are found in the upland knolls landscape and geomorphologic setting, characterizing parts of big mud volcanic constructions without griffon water spouts and as a result of this a lack of small ponds and water logging areas.

A.Dome-like structures

This structures size in diameter is 1-2 m, in height - 20-30 cm, rarely more. Their content and formation peculiarities are studied on a dome-like construction as an example, located in the shallow semi-stagnant lake (70x40 m), appeared in the caldera of mud volcano at the resort Baunt outskirts (fig.2). The lake supply takes place due to the inflow of deep griffon nitrogen-sulphate-sodium waters (T=28-47˚C), (fig. 3A). In the lake there are widespread 3-layer cyanobacterial mats causing the domes growth. Their upwards layered cut looks like: purple (0.2-0.5 cm), green (0.5 cm), ochre (0.5-0.7 cm). 16 species of cyanobacteria are identified [15].

The first two growth stages of dome-like structures (fig. 3) are formed by layered bacterial- mineral domes, similar by configuration, composition and genesis to the actual caldera Uzon stromatolites (mineralized “vulcanite”) [18].

At T=47-40˚C the shape-forming cyanobacteria are mainly represented by the genera *Phormidium* and *Lyngbya*. At lower temperature (about 30˚C) of water medium the bacteria genera *Phormidium* and *Oscillatoria* dominate (fig. 4).

In composition of an organic mineral complex, the carbonates (the calcite, the manganocalcite, the dolomite,the thermonatrite) predominate. In subordinate quantity there are found the sulphates (the barite, the gypsum, the jarosite, the glauberyt, the mirabilite), the silicates (the tridymite, the chlorite, the hydrous Ca, the hydromica). It was also determined the presence of the ore minerals association (pyrite, marcasite, ilmenite, hematite, magnetite, Fe hydroxides).

In the final stage the bacterial mineral dome constructions are overbuild by soil-plant “hat”, transforming thus into soil-plant hammocks (fig. 3B, 5) the formation of which is due to the soil microorganisms community active life, taken over the “baton” of structuring from early cyanobacterial mats.

B.Columnar structures

In the upland knolls landscape setting there is formed a specific *columnar type of pyramidal and cone-like morphostructures*, especially wide spread at the surface of the Barguzin and the Bagdarin depression griffon sand massives, where grown together they form small fields (fig. 6, 7).

The columnar structures are studied in details at the area of the proven valley gold placer along the river Aunik. Here, on the interval of 200x50 m, sporadically, by land pieces of size from 1x0.5 to 5x5 m, there are observed clusters of newly formed sandy-clayed soil cone-like (stalagmite-like) individuals, raised on crushed-stone or crushed-stone-gravel substrate. Their height reaches 3-6 cm at horizontal sections (in the middle part) of 1-3 cm [fig. 8]. They are partially covered with a crust of sulfate-carbonate composition. In the sand-clay material composition of columnar formations, thin layered bacterial dark green colored mats fragments of up to 3-4mm size were determined.

Socket-like and fan-shaped gypsum aggregates penetrate into the upper soil-plant layer topping the section of the columnar individuals. Thus, there is a pseudomorphic replacement of moss with mineral aggregate (fig.9). Minerals of psammite-pelitic sediments composing the columnar structures are represented by feldspars, quartz, zircon, tourmaline, sericite, biotite, chlorite, vermiculite, actinolite, siderite, calcite, ilmenite, rutile, magnetite.

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Fig.2. Lake-swamp landscape of the Baunt thermal source crater mud volcanic structure.
1 - the output of thermal waters of the active source; 2 – the bodding area with mikrogryphons

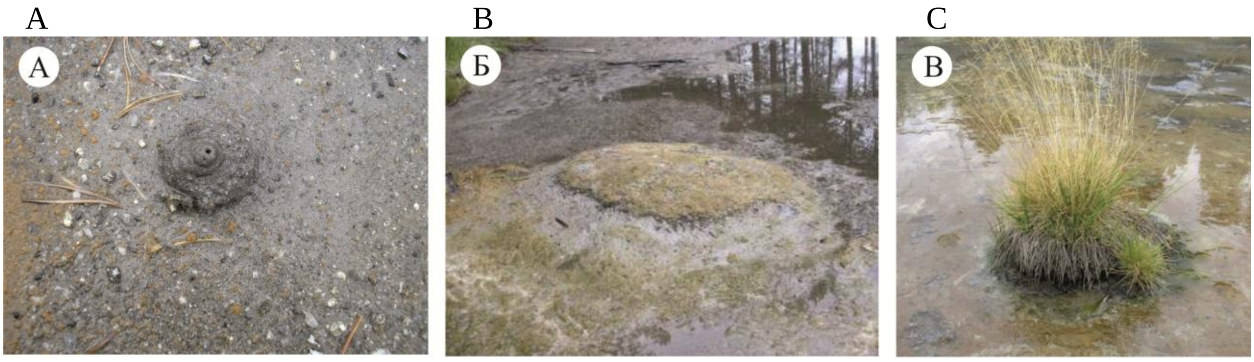

Fig.3. Successive stages of dome morphostructures formation at the Baunt depression (as illustration).
Stages: A – the formation of griffon dome-like mud volcanic construction from fluid-clastogenic pelite-psammite material on shallow ponds. It is covered by black silt, saturated with microorganisms; B – transformation of pelite-psammite griffon structure in dome-like one (upwards and outwards growth) as a result of active cyanobacterial mat formation, intensive formation of bacterial organic mineral aggregates in above water part of the structure, under conditions of griffon water outpouring attenuation; griffon channel blockage; c – domelike structure transformation in normal marsh soil plant hummock, associated with soil microorganisms functioning.

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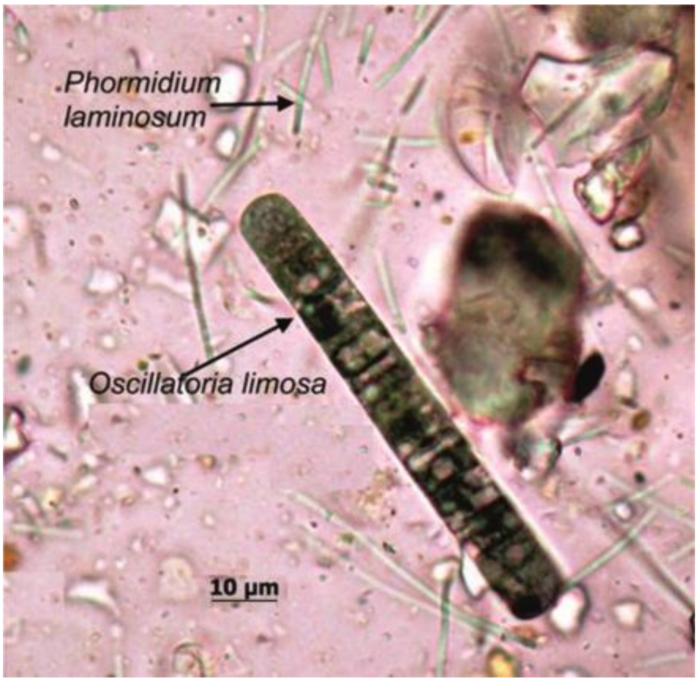

Fig. 4. Shape-forming microorganisms kinds of cyanobacterial layers in dome structure (see fig. 3B), growing at the aqueous medium temperature (≤30˚C).

Fig. 5. Domelike structures in dried part of the crater lake Kulinye swamps (Barguzin depression). In central part of photo - clay-sandy dome with shrinkage cracks. In upper part of photo, there are two fragments of these domes with soil-plant cover.

To reveal the formation genetic peculiarities of the considered structures type, the study results of the bacterial organomineral aggregates composition and mineralized biofilms (fig. 10, 11, the table) are used. Their analysis and geological data permitted to make the following conclusions.

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Columnar structures appear at the exit points of gas-water-lithoclastic small quantity pulp from the mouths of the actual mud volcanoes to the ground surface, characterizing the manifestation periods of their fluido-dynamic mode functioning various stages. Using the lithocomplexes distinctive mineralogical attributes of mud-volcanic origin [3], in the minerals set listed in the table, the associations genetic groups peculiar to the lithocomplexes of the early gas-explosive (fluido-natural and fumarole groups – columns 3, 4 of the tables) and the later gas-water-mud and water (gas-hydrothermal injection and hydrothermal groups – columns 1, 2 of the table) phases of mud microvolcanoes activity are selected. Many minerals from this list are met in the composition of technogenic and household scales of factory boilers, water heating appliances, and also they are formed at breakpoints of steam lines [19]. From the table data analysis we can assume the chloride-sulfate-hydrocarbon composition of mud volcanic fluids water component.

Fig.6. The colony of clustered columnar silty-sand formations on the large griffon sand massive ("kuituns") of the Barguzin depression. CK – sulphate-carbonate coatings of silty-sand individuals with bacterial biofilms [3].

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Fig. 7. Columnar structures on proven gold placer in the valley of Aunik river (Bagdarin depression).

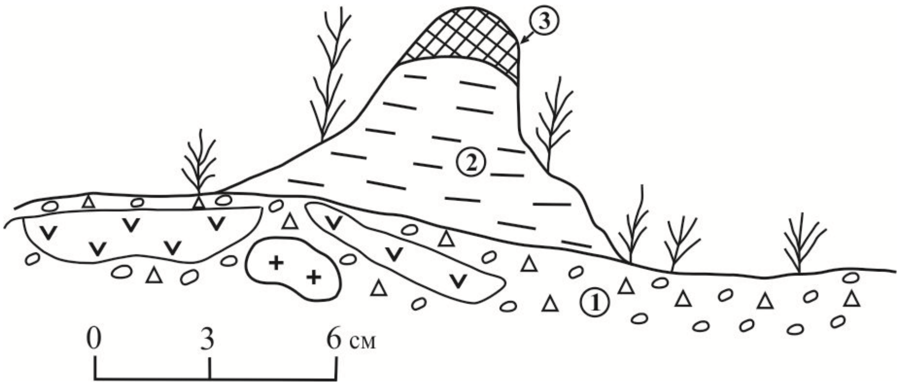

Fig.8 Columnar morphostructure construction, detected in the Aunik river valley (see fig.7)

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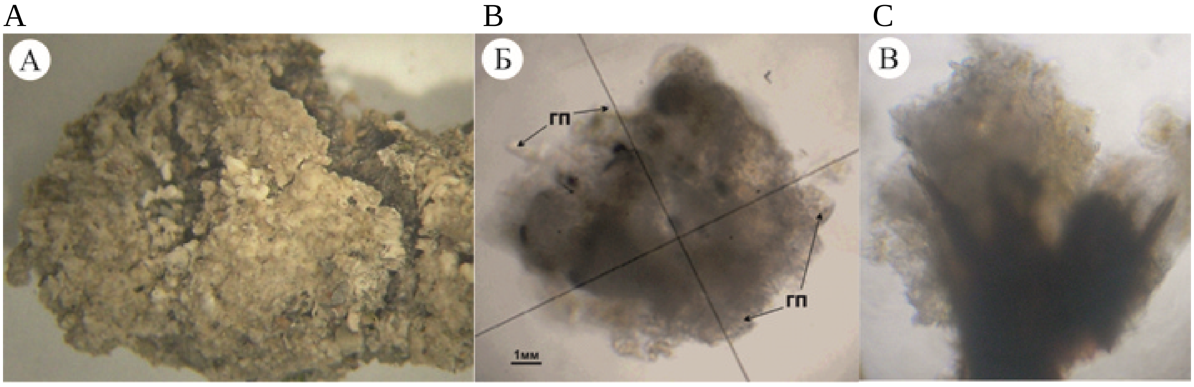

Fig. 9. The granular framboidal sulphate (A) aggregate from the bacterial-carbonate-sulfate coat of the columnar individual (see fig.8) with bacterial biofilms remains (B, zoom 21x10); C – pseudo-morphic replacement of moss (sphagnum) inflorescences by gypsum (zoom 8x10).

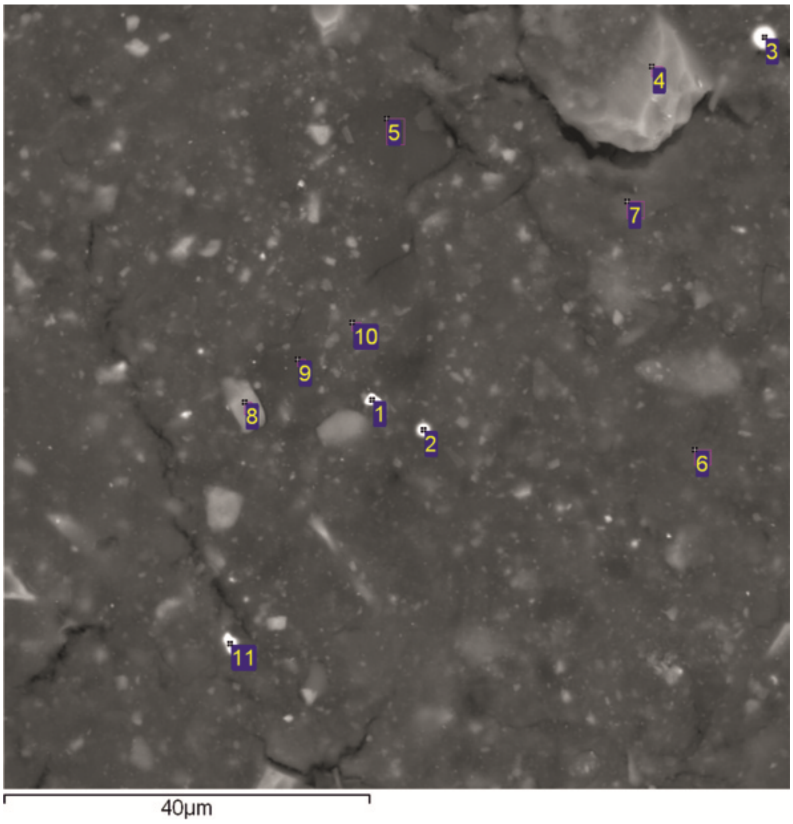

Fig. 10. Bacterial film fragment with trace mineral particles, appeared from mud volcanic fluids.
1-galenite (60%), partially replaced by cerussite (5%) and with normative nanominerals inclusions (Fe – Ca carbonate – 4%, quartz – 2%, kaolinite – 1%); 2 – iocit (53%) with nanoinclusions of normative nahcolite(7%), calkinskite and cerite (5%); 3 – iocit; 4 – native Si with quartz (11%); 5- carbon matrix with normative nanophases of anorthite (0,8%), tugarinovite (0,7%), calcite (0,5%) and quartz (0,3%); 6 – carbon matrix with normative nanophases of corundum (15%), anhydrite (6%), garnet with 21% of pyrope minal (5%), halite (2%), anorthite (1%), quartz (1%); 7 – carbon matrix with normative nanophases of quartz (8%), anhydrite (6%), kalishpat (6%), sideroplesite (2%), kaolinite (1%); 8 – moissanite (55%) with inclusions of normative nanophases of quartz (11%), calcite (1%) and siderite 1%. The content of the Corg=32%; 9 – carbon matrix with the normative nanophases of kaolinite (5%), goethite (3%), gypsum (1%); 10 - carbon matrix with the normative nanophase of carbonates (magnesite – 11%, calcite – 4%, calicinet – 1%, nahcolite – 1%), boehmite (6%), kaolinite (5%), gypsum (3%), halite (1%); 11 –native Pb (34%) with normative nanophase inclusions of calcite (2%), sylvine (1%) and goethite (1%). The Content of Corg= 62%.

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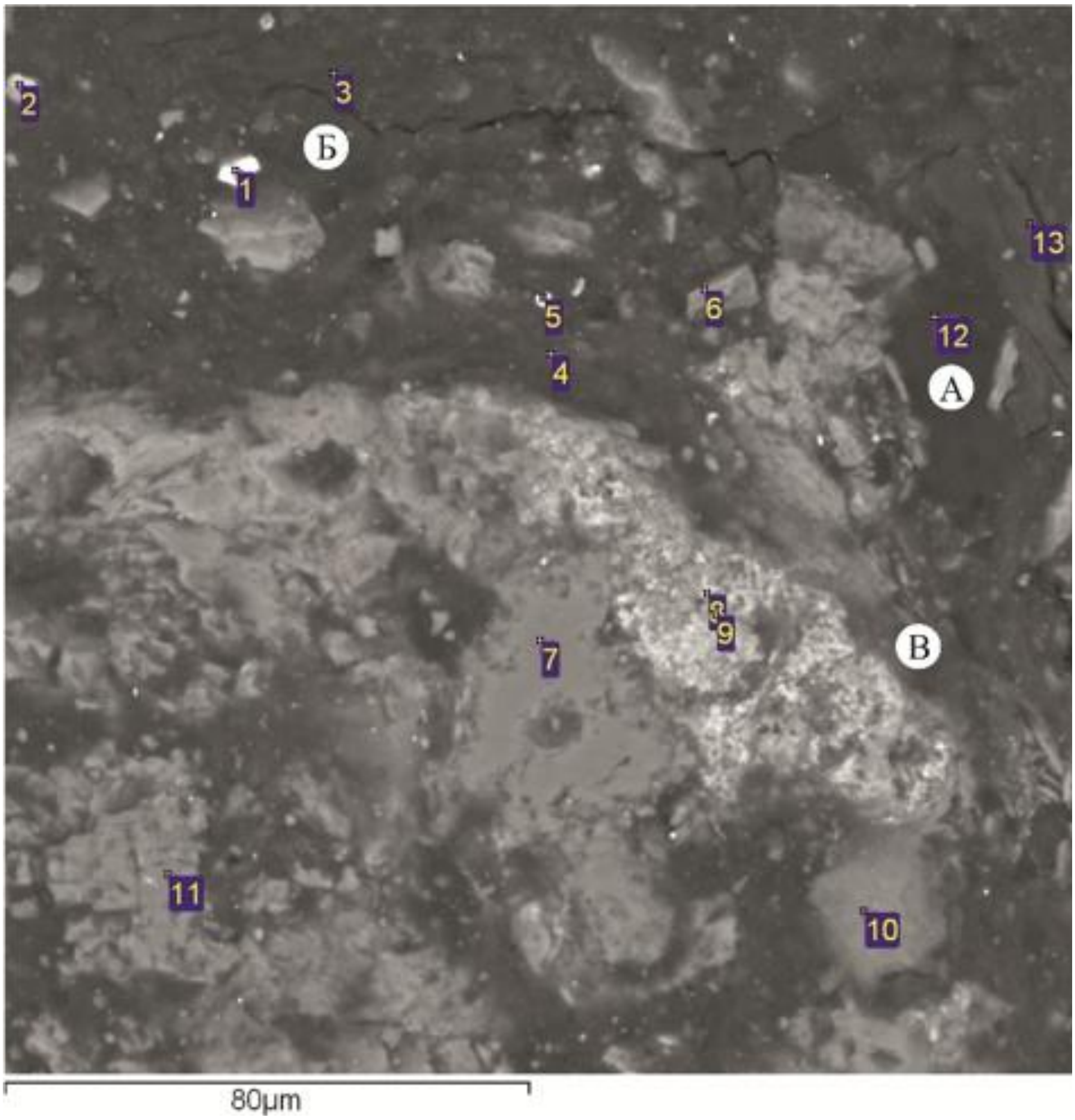

Fig.11. Fragment section of mineralized 3-layered bacterial mat from columnar morphostructure (see fig.8).
A – mat lower biofilm (Corg=81%) with association of carbonates nanophases (normative composition) carbonates (Mg-calcite – 6%, $BrCO_3$ – 2%, calcinite – 1%), sulfate (thenardite – 3%, mercallite – 1%), chlorapatite (3%), halite (1%), quartz (1%) and goethite (1%); B – mat middle biofilm (Corg) with the association of trace minerals (quartz, barite, rutile, hydrocassiterite) and a mixture of carbonates nanophases (siderite – 1-3%, calcite – 1-3%, calcinite – 1%), sulfates (kiserite – 2 %, somolnokite – 2%, alunite - 2%, gypsum -1%), chlorides (halite - 1%, sylvin -1%), silicates (kaolinite – 1-3%, paragonite – 5%), apatite, arizonite, native Al; C -the upper mat biofilm, covered mostly by silica-quartz and the rutile-goethite aggregates, and containing also inclusions of albite, muscovite and siderite.

Table. Mineral composition of bacterial organomineral aggregates from columnar structures in Aunik river valley of Bagdarin depression

1	2	3	4
Pyrite	Sphalerite	Fe, Au, Cu-Zn, Al, Pb	Fe, Al, Si, carbides(Fe-Si-Ti) hamrabaevite, cogenite, moissanite
Magnetite, hematite, goethite, hydro-cassiterite diaspore	Halite, sylvin, lawrencite, hydrophillite, chloromagnesium, molysit	Anorthite, oligoclase, kyanite, wollastonite, olivine, enstatite, ferrosilite, garnet of almandine-pyrope series, cordierite	Rutile, ilmenite, arizonite, magnetite, magnesioferrite, hematite,iocit, spinel, hercynite, chromite, tugarinovite beidellite, corundum, lime, periclase
	Goethite		
Calcite, oligonite, pistomezit, sideroplazit, mesizit	Calcite, siderite, dolomite, magnesite, witherite, calicinite, indigirite, nahcolite		
Kalishpat, albite, quartz, chlorite, chloritoid, muscovite, kaolinite	Albite, anorthite, kalishpat, barium kalishpat, sphene, tremolite, quartz, muscovite, kaolinite, pyrophyllite, makatite, norbergite,ferripyrophyllite, paragonite		
	Apatite, chlore-apatite, strengite, bobierite		Anorthite, andesine, barium orthoclase, quartz, ferrosilite, rhodonite, pyrope, tremolite
Apatite, fluoride-apatite, xenotime	Anhydrite, gypsum, barite, somolnokite, melanterite, jarosite, kiserite, mirabilite, thenardite, leonhardite, mercallite, alunite		
Gypsum, anhydrite, barite			

Note: 1- biogenic macro- and trace-minerals, appeared with microorganisms active participation; 2 – the same – normative nanominerals of bacterial films calculated by stoichiometric ratios of mineral-forming chemical elements; 3 –trace-minerals appeared with mud volcanic fluids gas components active participation; 4 – the same – normative nano-minerals. In the list of minerals the xenogeneic sphene, feldspars, quartz, chlorite, tremolite, magnetite, ilmenite, muscovite were partially included.

IV.THE RESULTS DISCUSSION

The results of submitted research augment a range of the previously specified in BRZ bio-inert travertine bedded and dome structures [16], [17] of mud volcanic origin with the small- and mini structures of dome and columnar types group. From travertine morphostructures, the latter differs by a sudden predominance in their composition of a silty-sandy aluminosilicate material in comparison with a sulfate-carbonate, the proportion of which does not exceed 10-15%.

For structurally self-organizing bacterial organic mineral constructions of BRZ mud volcanoes, the plume nature fluidodynamic processes have a definite meaning [20]. BRZ formation is mainly associated with Central-Asian superplume, lifetime of which is estimated at 15 million years [21]. It is a cause of a pulse degassing manifestation in the form of the mud volcanism. This plume activity result is an ecologic-geological system creation of the Baikal region, good for the actual bio-inert structures formation. It (system) is characterized by ecologic-geological conditions contributing to the bacterial biocenoses development and which are mostly determined by the BRZ features inherent to oil-gas moving belts [3].

Similar to the considered by morphology, size, formation mechanisms, the bio-inert dome-like travertine and stromatolite-like microstructures have geyserites [22], and also phosphorites [23] carbonate constructions on the bottom of ocean basins at gas-ware fluids spouting sites (gas seeps, mud volcanoes) [24],[25].

More diverse by matter composition and geological formation conditions – the columnar microstructures: phosphor [23], barium [26], sandstone [24], [25], [27], sand [28], limestone-clay [29], iron-manganese [30] travertine [31].

However, only some of them are proven the bio-inert and mud volcanic, formed with the bacterial mats and films and that bacterial-algal complexes participation. They are primarily sandstone and sandy, ferromanganese.
Bio-inert domelike structures of mud volcanic genesis have a great morphological similarity with the cryogenic one, like permafrost heaves, but they can be lightly differed by the presence or the absence of the microorganisms and algae mat biofilms remains in composing lithocomplexes. However, there are complicated cases when mud volcanoes mouth are formed in permafrost heaves [32]. Such a combination of different genesis positive morphostructures, perhaps, is not uncommon in the seismically active land areas of the Earth Northern hemisphere.

V.CONCLUSIONS

It is determined that bacteria communities play a major role in forming processes of the dome-shaped and columnar microstructures spatially-correlated with two, of different types, actual mud volcanic landscape-geomorphologic settings of the lake-swamp caldera-crater and upland knoll. Structure forming activity of the bacterial communities in BRZ depressions are directly connected with mud micro-volcanism processes, which have provided good conditions for micro-organisms habitat, their population rapid growth.
The formation sequence of the considered bio-inert structure-morphological types of the mud volcanic origin bacterial-mineral micro-constructions in BRZ depressions is the same. Differences in morphology, size, material composition of composing them litho - and mineral complexes are mainly determined by fluid-dynamic characteristics of the mud volcanism manifestations and correlating with them the bacterial communities progress range, primarily cyanobacteria. Cyanobacteria biomass high speed growth with the mats and biofilms formation is determined by deep recovered gases supply to the earth's surface initiated by mud volcanoes functioning. It is known that cyanobacteria grow more intensive when H_2, H_2S, N_2, CH_4 are available or in the atmosphere, transforming with this the gas fluid composition to substantially carbon dioxide (CO_2 to 70-90%) [18].
The selected by the authors, bio-inert morphostructures, quickly covered by soil-plant formations, i.e. finally transformed into phytogenic hummocks, seal the griffon sandy massives. Thus, they inhibit the aeolian sandy material separation, the dunes formation and rolling, i.e. the desertification processes in the Baikal region.

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