

Areas of Bacterial Communities of Aquatic Mud Volcanic Depositions in Lake Baikal Region

A.V. Tatarinov¹, L.I. Yalovik¹, E.V. Danilova²

¹Geological Institute SB RAS, Ulan-Ude, Russia

²Institute of General and Experimental Biology SB RAS, Ulan-Ude, Russia

670047 Ulan-Ude, Sakhyanovoy str., 6a, Geological Institute SB RAS

tatarinov@gin.bscnet.ru

Abstract-In the Lake Baikal region, freshwater Baikal mega area and six spatially isolated areas of bacterial communities, localized in water reservoirs of mineralized waters of mud volcanic origin, have been identified. The fluid-dynamic factors of areal formation have been considered, and analysis has been conducted regarding the characteristics of prevailing and specific functional groups and the genera of microorganisms, representing bacterial communities.

Keywords- Areas; Bacteria; Seismicity; Heat Flow; Geo-fluid-dynamic Mode; Thermal Spring

I. INTRODUCTION

Within the unified regional geological-ecological system, we have analyzed and described many known published references (chart 1), including unpublished original microbiological materials. The preferences in the work are given to microorganisms, of which distribution is limited by lake-reservoir depositions (fresh, soda, salty) and by mineral, principally thermal springs (ground and underwater). These depositions have been previously established as mud volcanic depositions [10, 11, 13, 21, 22]. The ecological-geological zoning of the bacterial communities of Lake Baikal region has been conducted for the first time.

II. GENERAL CHARACTERISTICS OF THE ECOLOGICAL-GEOLOGICAL SYSTEM OF LAKE BAIKAL REGION

The Lake Baikal region is a potential oil-gas-bearing province, according to fluid-dynamic characteristics comparable to the cryptogenic or under-foundation types of oil-gas-bearing basins [24].

The microorganisms of the Lake Baikal region, represented by water depositions, which are the subjects of our research in addition to bacterial communities, are determined by the fluid-dynamic mode of mud volcano function. This mode is directly dependent on the seismic (tectonic) activity of the subsoil [2], which has an impulsive nature and unequal intensity in various sectors of the earth's crust. The combination of unstable and often extreme parameters of the geo-fluid-dynamic mode of such sectors determines the formation of spatially (geographically) isolated areas of bacterial communities in the Lake Baikal region, characterized by the presence of functional groups composed of various genera and types of bacteria

The mud volcanism in the Lake Baikal region evokes plume fluid-dynamic processes, which accompany the formation of rifts and folded tectogenesis in the Mesozoic and the Cenozoic [23].

III. FLUIDS OF THE ECOLOGICAL-GEOLOGICAL SYSTEM OF THE LAKE BAIKAL REGION

The composition of fluids, which form the litocomplexes of mud volcanoes and areas of bacterial communities at various stages, is characterized by a large amount of variability. This includes gases of various origins, with basic components represented by CH₄, N₂, CO₂. The most common impure gases consist of H₂, H₂S, CO, NH₃, HF, heavy hydrocarbons, He, Ar, and Rn.

The liquid phase of fluids is represented in varying degrees by mineralized (from fresh to salty) waters with an admixture of oil.

The formation and activation of destruction zones is determined by catastrophic earthquakes, hypocenters of which are within their boundaries. Tectogenic clasts are formed within these zones, possibly with the participation of deep fluid [21].

These clasts are created by the flow of tectogenic and mantle gases (CH₄, N₂, H₂, CO, He) into water-bearing horizons, where a gas-water-mud pulp is formed. Then, according to seismic dislocation, another disruption erupts onto the surface, forming hill-like and caldera-like mud volcanic constructions.

Simultaneously, oxidation of reconstructed gas fluids, the heating of ground waters forms hydrothermal which appear on the surface as hot springs, which are transformed into salty and soda lakes [4, 22].

IV. AREAS OF BACTERIAL COMMUNITIES

The geo-fluid-dynamic mode of aquatic ecosystems creates very unstable and often extreme conditions for bacterial life and activity, leading to the formation of spatially isolated areas of bacterial communities (Fig. 1, Table 1), characterized by the presence of various functional groups in their composition.

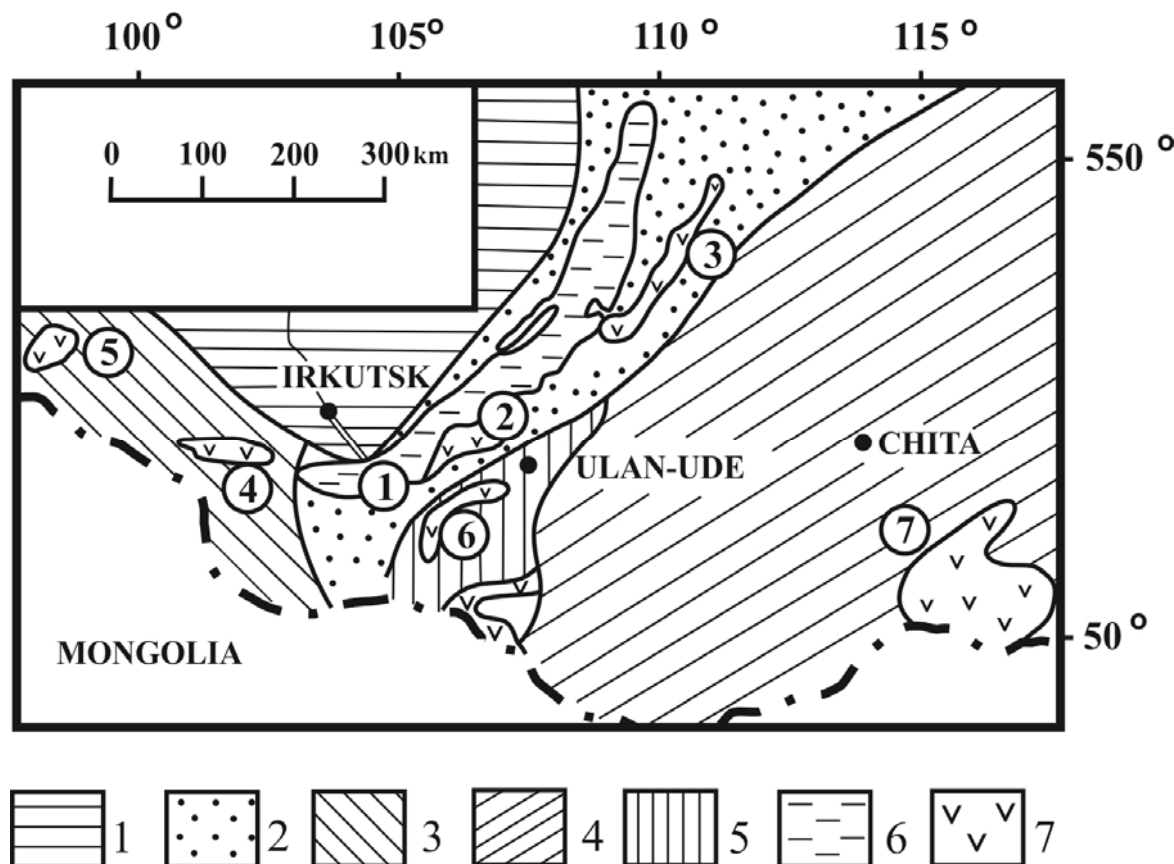


Fig. 1 Location scheme of studied areas of bacterial communities in aquatic sediments of mud volcanic origin of Lake Baikal region

1-5 – distribution areas and regions of thermal and cold mineral groundwaters of various types (Tkachuk et al., 1961): 1 – Angaro-Lenskaya area of chloride sodium and calcium nitrogen and methane-nitrogen and methane sodium waters; 2 – Baikalo-Charskaya area of thermal nitrogen and methane sodium waters; 3 – East-Sayanskaya area of thermal nitrogen, methane and carbonic waters having various chemical compositions; 4 – Dauruskaya area of cold carbonic and radon-carbonic waters having various chemical compositions; 5 – Selenginsky region of prevailing distribution of not-gassing radon waters; 6 – lake Baikal – freshwater habitat of microorganisms; 7 – ecosystems of mineral waters.

Numbers in circles – areas of bacterial communities: 1 – the Baikal group (Baikalsky megaareal), 2 – Ustj-selenginsky, 3 – Barguzinsky, 4 – Tunkinsky, 5 – Tissa-Okinsky, 6 – Gusino-Ubukunsky, 7 – Onon-Borzinsky

TABLE 1 GEO-FLUID-DYNAMIC CHARACTERISTICS OF THE HABITATION AND FUNCTIONAL FEATURES OF AERIALS OF BACTERIAL COMMUNITIES OF LAKE BAIKAL REGION DATA USED [1, 3-8, 12-15, 17-20, 25-28]

Areas	Seismic activity, intensity	Heat flow, mW/m ²	Fluid system	Typical functional groups, genera of bacteria
Baikalsky mega area	5-9	80-100, locally 115-155 up to 7900	Fresh waters of l. Baikal with local demersal anomalies of dilute deep sulfate-chloride waters. Gas hydrates CH ₄ and N ₂ . Oil manifestations with degassing CH ₄ , N ₂ , H ₂ S, CO ₂	HC-oxidizing Rhodococcus, Pseudomonas, Bacillus, Proteobacteria, methanotrophs; Methanogens, nitrogen fixers saprophytes
Ustj-Selenginsky	4-9 (up to 10)	50-100	Hydrocarbonate-calcium, hydrocarbonate-sodium, chloride-sodium thermal waters with variables containing CH ₄ , N ₂ , H ₂ , CO ₂ , NH ₄ . Oil manifestations.	UV-oxidizing bacteria; saprophytes, cellulose-decomposing bacteria
Barguzinsky	3-8	60-80	HC-gases with oil drops. Concentrations of diluted HC 0.01-3.46 mg/l. Methane-nitrogen, methane and nitrogen composition of gases	Alkaliphilic and halophilic cyanobacteria and organotrophs; HC-oxidizing oil and bitumen – amylolytic, Clostridium, Bacillus, Bacterioidetes, sulfate-reducers; methanotrophs; ammonium-oxidizing, nitrifying and denitrifying bacteria
Tunkinsky	7-8	40-100	Cold carbonic and nitrogen-carbonic sulfate-	HC-oxidizing Bacillus, proteobacteria;

			carbonaceous, sodium-calcium-magnesium waters; thermal nitrogen and methane-nitrogen hydrocarbonate-sulfate-sodium, nitrogen-methane and methane hydrocarbonate-chloride-sodium waters	saccharolytic, proteolytic iron bacteria
Tissa-Okinsky	5-6	70-80	Hydrocarbonate-calcium-sodium thermal waters with CO ₂ , N ₂ , H ₂ S in various quantitative proportions	HC-oxidizing β -Proteobacteria, sulfate-reducers; sulfur bacteria, iron bacteria
Gusino-Ubukunsky	7-8	40-50	Sulfate-hydrocarbonateous, sulfate-chloride-hydrocarbonaceous saltish, salty and fresh waters of the lakes with CH ₄ , N ₂ , H ₂ S. Oxidized oil manifestations	HC-oxidizing sulfate-reducers, amycolytic bacteria; proteolitics, cellulose-decomposing bacteria
Onon-Borzinsky	2,7-3,3	60-80	Methane alkaline sulfate-chloride-sodium and chloride-sulfate-calcium lake waters; presence of H ₂ S, N ₂ and CO ₂ . Local oil manifestations	HC-oxidizing amycolitics, alkaliphilic sulfate-reducers and methanotrophs. Halophilic microbes

A. Baikal Mega Area

According to geo-fluid-dynamic indicators the ecosystem of bottom sediments of Lake Baikal is the most extreme for bacterial communities (Table 1). Foremost, we note high level of seismicity, maximum density of epicenters and frequency of earthquakes. Presence of hydrated layer, development of underwater mud volcanism processes often with CH₄ and N₂, liquid oil, wide range of heat flow values are the main factors, determining particularity of functional groups of Baikal mega area of bottom bacterial communities. In shallow areas of Lake Baikal the supply of significant amount of riverine fragmentary stone material and organic matters of vegetable origin has a great influence on the habitat and composition of functional groups of microorganisms.

B. Ust-Selenginsky Area

The boundaries of the area are determined by the Ust-Selenginskaya basin, located at the delta of the Selenga River. As a result of an area gas survey [9, 11] it was revealed that the composition of free gases in various parts of the depression vary from methane (CH₄=85,27 tot.%, N₂=12,38 tot.%) and nitrogen-methane (CH₄=62,64 tot.%, N₂=33,05 tot.%) to methane-nitrogen (CH₄=37,45 tot.%, N₂=61,02 tot.%) and nitrogen (CH₄=12,47 tot.%, N₂=76,63 tot.%). In this territory, there are three thermal springs, two of which aerate methane, and one of which aerates nitrogen. According to geo-fluid-dynamic characteristics, these indicate very high seismic and thermal activity. In addition of the above-mentioned endogenous geo-fluid-dynamic formation conditions of the studied areal of the bottom bacterial communities, exogenous factors play a large role in the composition and quantitative proportion of functional groups and microbe genera.

Primarily important is the mixing of mud volcanic deep water with riverine and atmospheric elements, and an abundance of allochthonous and autochthonous matter in the sediments. A combination of endogenous and exogenous factors determines the manifestation of peculiar features in the Ust-Selenginsky area of bacterial communities:

- high total number of microorganisms (0.4-1.4·10⁹ cl/ml);
- prevalence of saprophytes (8.2·10³ – 1.25·10⁷ cl/ml) and HC-oxidizing bacteria (up to 10⁵ cl/ml);
- low number of methanogens and sulfate-reducers (100-1000 cl/ml);
- very high destruction of organic matter: anaerobic – 380-560 mgS/(m²·24 hours), aerobic – 440-501 mgS/(m²·24 hours)

C. Barguzinsky Area within Barguzinskaya Basin

According to seismic activity and heat flow values it is below Ust-Selenginskaya depression and basins of Lake Baikal. The typical geo-fluid-dynamic features of the aquatic ecosystem in the Barguzinskaya basin are:

- wide development of thermal springs aerating nitrogen According to their water composition (mineralization 0.1-0.5 g/l, pH=7.1-9.8), they are divided into sulfate-hydrocarbonate-sodium, hydrocarbonate-sodium, sulfate-sodium, sulfate-carbonate-sodium and hydrocarbonate-calcium springs [3];
- wide distribution of soda, salty and saltine lakes, making craters in the mud volcanoes, as well as in water output zones from gryphons of thermal springs (Kulinye swamps);
- the prevailing geochemical types of free gases [10] are nitric (N₂=60-90 tot.%) and methane-nitric (N₂ up to 50 tot.%);
- presence of oil bitumens in travertine depositions of thermal springs and bottom sediments of lakes;
- predominantly autochthonous origin of organic matter in the bottom sediments of lakes

Along with endogenous exogenous factors, additional features also influence the formation of the aquatic ecosystem in the Barguzinskaya basin: atmospheric condensation and seasonal climatic changes. The bacterial communities of the Barguzinsky area have several distinct features, which differ from the areas of Baikal and Ustj-Selenginsky.

These differences include the wide distribution of cyanobacteria mats, alkaliphilic and halophilic genera of cyanobacteria (Phormidium, Oscillatoria, Anabaen), and organotrophs (Bacillus, Halomonas, Cytophaga). In the sedimentations of thermal springs microorganisms of nitric cycle (Table 1) serve an active function.

D. Tunkinsky Area

The area's area occupies the territory of the basin of the same name and zone of the Tunkinsky fault (Fig. 1). At the high level of seismicity in the Tunkinskaya basin and its surroundings, the values of heat flow vary according to a wide range.

Unlike the Barguzinskaya area, the Tunkinskaya basin has no lake reservoirs of mineral water. There are instead dry lakes in the craters of large mud volcanoes, formed by gryphon sands [8]. Thus, the habitations of microorganisms in the Tunkinsky area are represented by outputs of mineral and fresh water from gryphons of active hot and cold springs.

One of the characteristic features of the aquatic habitation of the Tunkinsky bacterial community is the presence of significant concentrations of oil HC-components (2-110 mg/l) in dissolute organic matter [29].

Another characteristic feature of the Tunkinskaya aquatic ecosystem is the presence of springs of cold sulfate-hydrocarbonate and sodium-calcium-magnesium waters (Khangarulsкая group). Their sediments do not display a functional diversity of microorganisms. Thus, the bacterial communities of the Zheludochny spring are basically represented by iron bacteria (Geobacter, Leptothrix) and cyanobacteria (Leptolyngbya), and the bacteria of the Lwgochny spring consist of proteobacteria (up to 1000 cl/cm³).

E. Tissa-Okinsky Area

The area is situated in the East Sayan area of carbonated waters. Aquatic habitation of its microorganisms is formed by a large number of thermal mineral springs. Seismic activity and values of heat flow indicate that the crust in the area is much less in comparison to the mentioned-above areas [16]. Places of water output onto the surface are usually represented by half-closed depressions. An earlier example of the Khoito-Gol spring showed that the physical-chemical and hydrochemical water characteristics change farther from gryphon flows [25]. This results in large changes in the structure and composition of bacterial communities. It follows from our previous publication that exogenous factors (vegetative leftovers in the water, filtering of water by pre-existing bacterial mats and films) are of huge, significance to the formation of bacterial cenosis in the Tissa-Okinsky area.

This is proved by quantitative domination of organic matter destructors: saprophytes (105-109 cl/ml) in composition of bacterial communities. Another characteristic feature of the area is the wide development of cyanobacterial mats (prevailing genera Oscillatoria and Phormidium) and the presence of sulfur bacteria (Thiothrix, Beggiatoa).

F. Gusino-Ubukunsky Area

This area is situated within the basin of the same name. High seismic activity and low heat flow (Table 1) are typical for this area. The water habitation of microorganisms is represented by the Gusino-Ubukunskaya group of lakes [27], including fresh and salty reservoirs and mineral springs.

Organic matter in the bottom sediments of the lakes consists of carbon and oil bitumens, phytoplankton, microbial mats and in-shore vegetation. As a consequence of an abundance of organic matter in the reservoirs, bacterial communities of the bottom sediments consist of cellulose-decomposing microorganisms (up to 106 cl/ml) and proteolythics (up to 1.1·106 cl/ml) prevail in it composition. The dominating microorganisms in the microbial mats of Sulfatnoye lake (Selenginskoye) are cyanobacteria of Anabaena and Phormidium genera.

G. Onon-Borzinsky Area

This area occupies a part of the Central-Asian system of oil-gas-bearing mesozoic-cenozoic lake basins of mud volcanic origin, belonging to the Transbaikalia-East-Mongolia Rift system [22]. It occupies large basins such as Ononskaya, Toreiskaya and Borzinskaya. Characteristic features of this area territory include: very low seismic activity at relatively high values of heat flow (Chart 1). It is supposed that alkaline (pH=8-11.2) waters of the numerous highly-mineralized saltine, soda-salty and salty lakes, which are the habitat of the area's bacterial communities (the microorganisms of cold carbonic springs were not considered), emerged as a result of the mixing of cold carbonic and thermal methane-nitrogen sulfate-chloride ground waters [3]. Not only the presence of solid bitumens is noted, but also liquid oil, enclosed in gypsum and trona of the bottom lake sediments. Some peculiarities of the Onon-Borzinsky area of bacterial communities are:

- wide development of alkaliphilic and halophilic types of microorganisms typical for the lake system of the Barguzinsky area;

- Contrast to freshwater Baikal megaarea, another group of HC-oxidizing oil components (amycolitic, up to 2·10⁵ and sulfate-reducers);

- High quantity of phototrophic microorganisms in the bottom sediments of salty lakes, especially cyanobacteria [18].

V. CONCLUSIONS

1. Aquatic habitation of the analyzed areas of bacterial communities is formed and constantly changes as a result of mud volcano activity, which has discontinuous-pulsating phasic characteristics.
2. Fluid systems of mud volcanoes arise in the process of seismic (deformation) activation of tectonic dislocations of deep zones of the earth's crust under the influence of plume, fixed by the foci of earthquakes (10-25 km). Ascending gases, oil, deep sulfate, and chloride waters migrate to the surface of the earth, mixing in various proportions with surface and atmospheric fresh waters, forming water reservoirs and habitats of microorganisms.
3. The areas of self-arranging bacterial communities have adapted to various fluid-dynamic conditions of the ecological-geological system of Lake Baikal region by according to parameters of the latest quantity and qualitative composition of functional groups and genera of microorganisms.
4. Endogenous and exogenous factors also influence the structure of areas.

REFERENCES

- [1] V.P. Garankina and O.P. Dagurova, "Destruction of organic matter in the coastal zone of Posolsky sor bay of Baikal". Irkutsk state university news. Series "The Earth sciences", 2 (2), pp. 65-71. 2009.
- [2] R.M. Gataulin, "Cylindrical collapse zones – "gas pipes" of the north of West Siberia", In Genesis of hydrocarbon fluids and deposits, pp. 222-238. 2006.
- [3] B.B. Namsarayev, D.D. Barkhutova, E.V. Danilova, A.V. Braynskay, C.P. Burykhaev, B.G. Garmaev, V.M. Gorlenko, O.P. Dagurova, V.B. Dambaev, S.V. Zaytseva. et. al. Geochemical activity of microorganisms of hydrothermae in the Baikal Rift Zone, Academic edition: GEO: Novosibirsk, 2011.
- [4] V.A. Golubev, Conductive and convective heat expulsion in the Baikal Rift Zone. Academic edition, GEO, Novosibirsk, 2007.
- [5] V.M. Gorlenko, B.B. Namsaraev, A.V. Kulyrova, D.G. Zavarzina, T.N. Zhilina, "Geochemical activity of sulfate-reducing bacteria in the bottom sediments of soda lakes in Transbaikalia", Microbiology, 68 (5), pp. 664-670. 1999.
- [6] N.G. Granin, L.Z. Granina, "Gas hydrates and gas outputs in Baikal", Geology and geophysics, 43 (7), pp. 629-637. 2002.
- [7] T.I. Zemskaya, T.Y. Sitnikova, O.M. Khlystov, "Exploration of deep zones of Baikal", Vestnik of the RAS, 84 (6), pp. 500-505. 2014.
- [8] V.P. Isayev, "About gas paleovolcanism in Baikal", Oil and gas geology 5, pp. 45-50. 2001.
- [9] V.P. Isayev, N.G. Konovalova, P.V. Mikheev, "Natural gases of Baikal", Geology and geophysics 43 (3), pp. 638-643. 2002.
- [10] V.P. Isayev, Natural gases of the Barguzin Basin, Irkutsk university issue: Irkutsk, 2006.
- [11] V.P. Isayev, "Mud" volcanic basins of the Baikal Rift System", In Geology and minerals of West Siberia. Irkutsk university issue: Irkutsk, pp. 133-137. 2007.
- [12] E.S. Kashkak, N.L. Belkova, E.V. Danilova, Identification of dominant genotypes in microbial communities of mineral springs of Zhoigon (the Eastern Sayan). Irkutsk state university news. Series "Biology Ecology", pp. 42-49. 2014.
- [13] F.P. Krendelev, V.I. Fleshler, V.P. Cherednichenko, B.Kh. Shamsutdinov, "Heavy hydrocarbons in the salses of the Torey Basin (East Transbaikalia)", The reports of the USSR academy of sciences. 300 (4), pp. 910-913. 1988.
- [14] L.I. Lokot, T.A. Strizhova, E.P. Gorlacheva, V.Kh. Shamsutdinov, A.P. Chechel, M.Ts. Topolov, O.K. Itigilova, Z.P. Klishko, E.V. Oglou, M.S. Balushkina et al. Soda lakes of Transbaikalia: Ecology and productivity, Science, SB RAS, Novosibirsk, 1991.
- [15] A.V. Lomakina, O.N. Pavlova, A.G. Gorshkova, A.V. Likhoshvai, T.I. Zemskaya. "Microbial communities of the regions of natural oil manifestations of Baikal: biodiversity, functional gens, the role in the process of oil degradation", In Geology of seas and oceans: the proceedings of the XIX International conference (School) on marine geology. II. Moscow, pp. 71-73. 2011.
- [16] S.V. Lysak "Heat flow in the zones of active faults in the south of East Siberia" Geology and geophysics 43 (8) pp.791-803. 2002.
- [17] B.B. Namsarayev, A.V. Kulyrova, V.M. Gorlenko, T.N. Zhilina, "Bacterial methane production in the alkaline lakes of Transbaikalia" Microbiology 6 (5) pp. 671-676. 1999.
- [18] B.B. Namsarayev, V.M. Gorlenko, Z.B. Namsarayev, E.Zh. Garmayev, E.Yu. Abiduyeva, V.B. Dambayev, D.D. Barkhutova, B.B. Hakhinov, L.V. Zamana, I.M. Borzenko et al, Saltish and salty lakes of Transbaikalia: hydrochemistry, biology, Publishing house of the Buryat state university: Ulan-Ude, 2009.
- [19] B.B. Namsarayev, T.I. Zemskaya, Microbiological processes of carbon cycle in the bottom sediments of Baikal, The publishing Siberian office of the Russian Academy of Sciences GeO: Novosibirsk, 2000.
- [20] Z.B. Namsarayev, V.M. Gorlenko, B.B. Namsarayev, D.D. Barkhutova, Microbial communities of alkaline hydrothermae, The publishing Siberian office of the Russian Academy of Sciences: Novosibirsk, 2006.
- [21] V.I. Sizykh, T.T. Taisayev, M.P. Lobanov, "New understandings of quaternary genesis of sandy strata of the Baikal Rift System", The reports of the academy of sciences, 400 (2), pp. 219-223. 2005.
- [22] A.V. Tatarinov, B.N. Abramov, "Formation features and prospects for oil and gas of Mesozoic-cenozoic riftogenic troughs of Transbaikalia" Geotectonics 4 pp. 55-67.2001.
- [23] A.V. Tatarinov, L.I. Yalovik, "The role of mud and gas volcanism in Mesozoic-cenozoic trough formation in Lake Baikal region", In Volcanism and geodynamics: the proceedings of the III All-Russian symposium on volcanology and paleovolcanology. Publishing house of the Buryat scientific center of the Siberian office of the Russian Academy of Sciences: Ulan-Ude, pp. 351-355. 2006.
- [24] A.V. Tatarinov, L.I. Yalovik, V.G. Izotova, L.M. Sitdikova, "Prospective oil and gas evaluation of Transbaikalia", Exploration and

- conservation of mineral resources, 11, pp. 26-30.2008.
- [25] A.V. Tatarinov, E.V. Danilova, L.I. Yalovik, D.D. Barkhutova, Z.B. Namsarayev, A.V. Bryanskaya, A.M. Plyusnin. "Bacterial communities of thermal spring Khoito-Gol (the Eastern Sayan) and ecological-geological conditions of their formation" *Geochemistry* 2pp.164-175.2010.
- [26] V.G. Tkachuk, N.V. Yasnitskaya, L.M. Orlova, Mineral waters of the southern part of Eastern Siberia. Publishing house of Academy of Sciences of the USSR Moscow-Leningrad 1961.
- [27] V.V. Khakhinov, B.B. Namsarayev, I.D. Uljzutuyeva, D.D. Barkhutova, E.Y. Abiduyeva, T.G. Banzaraktsayeva, "Hydrochemical and microbiological characteristics of Gusino-Ubukunskiye reservoirs", *Water resources*, 32 (1), pp. 79-84. 2005.
- [28] D.D. Tsyrenova, A.V. Bryanskaya, Z.B. Namsarayev, V.N. Akimov, "Taxonomic and ecological characteristic of cyanobacteria of some saltine and salty lakes of South Transbaikalia", *Microbiology*, 80 (2), pp. 230-240. 2011.
- [29] G.M. Shpeizer, Y.K. Vasilyeva, G.M. Ganovicheva, L.M. Mineyeva, V.A. Rodionova, I.S. Lomonosov, Van Yansin, "Organic substances in mineral waters of mountain-folded areas of Central Asia", *Geochemistry*, 3, pp. 302-311. 1999.