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Hydrothermal Mineral Formation Systems of Kamchatka and the Biomineralization

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Abstract - Kamchatka is known as area of geothermal fields. More then 80% of them are hydrothermal mineral formation systems. Intensive precipitation of carbonates, silicates, sulfates occurred from different types of the thermal waters with formation wide field of travertine, geyserites and silica sinters (consisted of carbonate, opal, oxides and hydroxide of Fe, Mn, sulfides of Fe, Cu, Zn, Hg, native and As-rich metals). Synthesis of variable minerals and biominerals occurs in natural conditions and this process can be accelerated by participation of microorganisms.

I. Introduction

Kamchatka is one of the most unique and inimitable regions not only of Russia, but also of the whole planet. In geographical respect Kamchatka is a large country with the area of 472.3 thousand km^2. It stretches from north to south from latitudes of Reykjavik – London to Kiev – Brussels for more than 1600 km with maximum width of the peninsular part equal to 470 km. This territory is the combination of the peninsula of spear-head shape (Kamchatka peninsula) and the continental part (Koryakia, Chukotka and Kolyma known as the Extreme North or North-East of Russia and Asia). It is washed by the Okhotsk and the Bering seas and the Pacific Ocean. Its territory, that is equal to the one of Japan and Iceland together, is inhabited by nearly 350.000 people. Here there are no railways and underground. All motor-roads are about 1300 km long; 300 km of roads is metalled. Population of four towns is more than 80% of the total population of the region. Thus, total density of population on major part of Kamchatka is less than 0.03 person per km^2. On the territory of Koryakia, the area of which is equal to the one of Italy, less than 26.000 people live. Kamchatka was and is the region of Russia that is the farthest one form Moscow. This region is poorly studied but known for its beautiful nature. Influence of anthropogenic factors upon the environment is minimum. In geological terms Kamchatka is one of the poorest studied regions of Russia. Unfortunately, there are no recognized and accepted by the majority of geologists schemes (charts) of tectonic, geological, metallogenic, hydrogeological and mining divisions into districts (there is still no common classification for all schemes and charts). Thus, in mining and metallogenic terms there are two metallogenic provinces and three mining regions here (these terms and notions are used by metallogenists and economical geologists). Kamchatka is the country of volcanoes. Here are more than 220 big and gigantic and 2100 small volcanoes of Quaternary time [1, 2, 3]. All of 31 active volcanoes of Russia are located here. Some years ago we thought that there were 29 of them here [4, 5, 6]. Then there happened the eruption in caldera of the volcano Academia Nauk. Detailed research in Sredinny ridge (Central Kamchatskii volcanic belt) of Kamchatka made it possible to register signs of work of one more volcano. So, 31 volcanoes belong to the group of active ones. Klyuchevskaya hill (4750m) is the highest and the most active volcano of Europe and Asia. Active volcanoes bring to the surface about 200 Mio tons of different erupted products per year, that is 14-15% of annual amount of substance erupted by all volcanoes of the Earth. Along the eastern coast of Kamchatka from Ust-Kamchatsk to Tokyo there is the most seismically active zone that stretches as a narrow stripe. It is known for the strongest earthquakes. A very strong disastrous earthquake might repeat here every 150 years [5]. 75% of all resources of thermal, mineral and fresh water of Russia are located in Kamchatka [3]. More than 14.100 rivers and brooks of different sizes, about 100.000 lakes and 414 glacial fields contain resources of clear drinking water. Here are main resources of the Russian earth's heat, namely more than 11 largest high-temperature systems, 24 rather large medium-temperature ($T < 100^{\circ}C$, usually 40-70°C) systems and a large number of small hot springs (about 150). They are located within 4 (we think 6) geothermal provinces. Four of them are on the peninsula and two of them are in the continental part. Hydrogeologists speak about four geothermal provinces (Northern-Kamchatskaya, Sredinno-Kamchatskaya, Eastern-Kamchatskaya and Southern-Kamchatskaya) and five geothermal areas (Pauzhetskaya, Mutnovskaya, Paratunskaya, Semyachinskaya, Kireunskaya) which include 23 hydrothermal systems of high and low temperatures [6, 7, 8]. Nowadays one can speak about as many as 24 modern hydrothermal systems in Kamchatka. During detailed prospecting and geological-prospecting works realized on the boundary of Mutnovskaya and Paratunskaya geothermal areas (Rodnikovoe or Vilyuchinskoe ore fields where Rodnikovoe and Vilyuchinskoe epithermal gold objects are

located) new data on geological structure and scale of Vilyuchinskie hydrotherms were obtained. These data point at existence in this area of a rather large hydrothermal system called Vilyuchinskaya [9, 10, 11].

II. Geothermal systems of Kamchatka

Geothermal systems of Kamchatka are characterized by a great variety of chemical composition, temperature and activity. They are unique natural reactors where one can observe syntheses of different minerals and combinations [6, 7, 8, 12, 13]. Mineral composition of travertine, geyserites, silica sinters and products of reactions of thermal waters with host tocks and plant remains includes carbonates, modifications of SiO_2 and Mn, As-rich phases, sulfates, chlorides, oxides, sulfides, sulfosalts, native metals. Total number of identified minerals and combinations is more then 65. Different microorganisms and bacterial cells live and develop here despite extreme parameters of these systems such as high temperatures up to the boiling ones by pH from 3 up to 9-10, high mineralization and anomalous concentrations (often 10 and 100 times more than critical contents beyond which life is not possible) of such toxic elements such as As, Hg and others [14, 15, 16, 17]. They form complicated-organized organic-mineral systems where microorganisms are of great importance in mineral formation [16]. In Central Kamchatka in Apapelskie springs one can see cinnabar deposition. Globules of native mercury were discovered there. These mineral phases deposit by temperatures close to the boiling point in the zone of development of poly-stratum alga substrata. In these biomats we found high concentrations of antimony, arsenic and gold [3, 10]. In Dvukhyurtochnye and Kireunskye geothermal springs one can notice deposition of pyrite globules mercury, arsenic and antimony-rich. These globules are of concentric zonal composition and in some zones contents of these elements are 5-20%. Around needles of fir-trees and pine-trees falling down into boiling water there is formation of peculiar micro-tubes or cases 0.5-2.0 μm wide as around crystallization centers. Their structure is also zonal and they are formed by micro-layers of pyrite, apatite and opal. SEM study opened bacterial cells in them. Mutnovsko-Asachinskii volcanogenic-ore forming centre is one of the most interesting geological structures not only of Kamchatka but also of the whole Kurile-Kamchatsky island arc are located in Southern-Kamchantskaya geothermal province, Mutnovskii thermal region [3, 13, 8, 18, 19]. This is the long-living centre of endogenic magmatic (volcanic), hydrothermal and metallogenic activity, which has been going on since Miocene until present time. Main reserves of Au-Ag ores and geothermal heat of South-Kamchatka mountain-ore region are localized here. Asachinskoe, Mutnovskoe and Rodnikovoe epithermal deposits of Au and Ag with reserves of Au>100t, Ag>10 000t and significant qualities of different ore manifestations were formed during Pliocene-Pleistocene time. Presently we have no reliable data about true sizes for any of known ore objects. All of them require further geological study. It is possible that real sizes of ore gold and silver can be significantly larger. More than 20 groups of hydrothermal springs (natural hydrothermal solutions) have been discovered in this region. Most of them are connected with the three largest geothermal systems – Mutnovskaya, Zhirovskaya and Vilyuchinskaya [18, 20]. The largest in Russia geothermal electric power station with capacity up to 100 Mw is being built on the basis of the largest one/system. The first unit of the station with capacity up to 40 Mw began working in September, 2002. Recent activity of the centre is represented by two active volcanoes – Mutnovskii and Gorelyi and numerous fumarolic fields and crater lakes [3]. Rodnikovoe and Mutnovskoe epithermal Au-rich deposits are in the influence zone of Vilyuchinskaya and Mutnovskaya hydrothermal systems [18]. Thus, the main body of Mutnovskoe ore deposit known as vein zone Opredelyayuschaya is located 1200 m away of the industrial geothermal drill of Mutnovskoe geothermal deposit (temperature of vapour-steam mixture is more than 270°C). Where and how to mark the border between these two (ore and geothermal) deposits? Does it really exist? Prospecting adits at Rodnikovoe deposit showed thick zones of anomalous heating flow and intensive recent hydrothermal activity. On territory of both deposits, immediately next to ore bodies there is a great number of natural surface outcrops of hot springs – hydrothermal mineral forming solutions and three hydrogeological drills made to heat main geological settlements. Results of long term research show that Vilyuchinskaya hydrothermal-magmatic ore forming system has been in existence for at least more than one million years [3, 13, 20, 21]. Its activity is of pulsating (oscillation) character. Evolution of this system resulted in accumulation of significant concentrations of Au, Ag, Sb, As, Hg which are known as Rodnikovoe deposit. The formation process of this deposit is far from being over and it hasn't yet acquired its final shape. Maybe in some hundreds thousands or even millions years (for example K/Ar age of ores taken at Northern flank of Mutnovskoe deposit is 3.3-0.7 Mio, of Asachinskoe deposit is 4.5-4.1 Mio years) it will acquire its final shape. Activity of these solutions in adits of the deposit caused formation of new associations (28 new minerals not found before in main ore bodies – veins 42, 43, 44 – were discovered), which is taking place alongside with transformation of productive parageneses formed during the period 1.050 – 950 years ago. Is it regeneration, oscillation, another stage or a new step of ore formation? An intensive carbonation with formation of large travertine fields from chloride-carbonate-sodium waters with T=54-78°C is taking place on day surface. The following minerals – calcite, aragonite, opal, oxides and hydroxides of Fe, Mn, sulfides of Fe, Cu, Zn, Hg and native metals (single inclusions and impregnations of native gold with complicated micromorphology) – are a part of travertine mineral composition. At Vilyuchinskie therms around grass straws and small branches one can observe formation of calcite-argonite microcases 1-3 μm wide. Native gold was found in one polish section of such a microtube. Despite the fact that these thermal waters are characterized by high temperatures, mineralization and anomalous concentrations

of heavy metals (Fe, Mn, As, etc.) formation and active development of complex algae and microorganisms communities-biomats, that are also known for great bacterial diversity, take place in them [3]. Existence and active functioning of bacterial communities of this kind are typical of hydrothermal systems [16, 22, 23]. Biomats of Vilyuchinskaya system are known for their variety and presented by green and diatomic algae, cyanobacteria, stick-like and cocci-like bacterial cells. Microorganisms making up the major part of biomass of this system are present both as separate cells 0.5-2 μm large and large colonies or aggregates with mineral particles. There are some processes of mineral formation controlled by microorganisms. This is formation of Fe-Mn concretions and crystalline oxides and Fe sulfides, by Fe- and Mn-oxidizing bacteria, algae, cyanobacteria and bacteria participation in formation of stromatolites and carbonates [16, 23]. There are several known ways how microorganisms accumulate metal ions which lead to mineral particles formation both on the surface and inside cells. We obtained data that prove active participation of microorganisms in processes of metal formation of Vilyuchinskaya hydrothermal-magmatic ore-forming system. These processes exist due to mechanisms of active sorption and accumulation on the surface/membrane of the cell side that points to presence of bacterial cells with thick multi-layered capsule and cells with a cover formed by fine mineral particles up to 200 nm large. Presence of cells with internal mineral inclusions makes it possible to suggest that there is a mechanism of active transportation or passive diffusion of metal ions inside a bacterial cell. Here one can see the way of calcium, silica, iron and arsenic precipitation and accumulation [18, 23, 24].

III. Summary and Conclusions

Thus, recent hydrothermal systems of Kamchatka are unique mineral forming environments or natural chemical reactors which result in synthesis of various chemical substances. Microorganisms take active part in synthesis of the kind. They are undoubtedly unique natural scientific laboratories deserving the closest observation of not only academic but also environmental organizations. Geothermal systems of Kamchatka are unique objects, natural laboratories of study of processes of hydrothermal mineral formation and biomineralization.

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