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Yagodninskaya-Bannaya Hydrothermal-Magmatic System: A Geological-Geochemical Model and Importance for Socio-Economic Development of Russia's Kamchatka Krai

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ABSTRACT

Yagodninskaya-Bannaya hydrothermal-magmatic system is a part of Banno-Karymshinkii long-existing (from Eocene to Holocene) centre of magmatic, geothermal and ore-forming activity. This centre is located within one of the most geodynamically-complicated region of Kamchatka: South-Kamchatka depression of the infolded-block zone of East-Kamchatka volcanic belt, the system is a large geothermal (ore) region. The region is characterized by propagation of contrast rocks, wide occurrence of ignimbrites and rhyolite tuffs, formation of large calderas and dome-circumferential structures. The Yagodninskaya-Bannaya hydrothermal-magmatic system is localized within the dome-circumferential volcanic-tectonic structure with a diameter of about 30 km. The central part of the structure is identified by accumulation of large multi-phase intrusive-subvolcanic and extrusive-subvolcanic complexes whose composition ranges from syenite-diorites to trachyliparites and basalts. The Yagodninskoye deposit of zeolite materials, perlites and active mineral additives is confined to the extrusive-subvolcanic complex of elevation 1081: a more than 100 m thick stratum of vitro-lithoclastic tuffs contains clinoptilolite, mordenite and other high-silica zeolites up to 80-90% of rock volume. The rocks of the region are differentiated by super-alkalinity, hydrothermally-altered rocks are distinguished by high contents of potassium. Fields of propylites, secondary quartzite and argillaceous rock areas with disseminated sulphide ore mineralization and quartz (quartz-carbonate) veins propagate on the periphery of the hydrothermal-magmatic system. An epithermal ore deposit and Bolshebannoye geothermal deposit are confined to one of such large intrusive-subvolcanic complexes of syenite-diorites-dacites. Probably, another discharge of thermal waters named Maliye Banniye Springs is connected with this complex. Hydrocarbonate infiltration waters of the Bolshebannoye geothermal deposit are formed with participation of a deep-seated source; they contain elevated concentrations of numerous chemical elements (boron, fluorine, a number of metals) and possess balneology properties. The region is a great tourist destination ─ there have been recently built two spa-tourist compounds at the geothermal deposit; however, the place can be reached only by off-road vehicles.

On the whole, the described geothermal (ore) region and the Yagodninskaya-Bannaya hydrothermal-magmatic system have great mineral and energy resources and are of a significant importance for future socio-economical development of Kamchatka Krai. A concept for such development can only be built upon compilation of results and new comprehensive scientific studies. Based on lithological, petrographic, mineragraphic, hydrogeochemical and other activities, the authors of the report discuss a working model for evolution of post-magmatic, hydrothermal-metasomatic and geothermal processes in the structure of the Yagodninskaya-Bannaya system.

1. INTRODUCTION

South Kamchatka as a whole and, particularly, Banno-Karymshinskii region has captured attention of researchers for many years due to the local evolution of long-lived volcanogenic-ore centres and formation of contrast magmatic rocks, a large area of propagation of ignimbrites and rhyolite tuffs, formation of large calderas and thick strata of hydrothermally-altered rocks including epithermal ore mineralization. The region features well-known modern thermal-mineral Banniye Springs (Bolshiye (‘Large’) and Maliye (‘Small’)), Karimchinskiye Springs and Karymshinskiye Springs (Serezhnikov, Zimin, 1976); Bolshebannoye geothermal deposit was drilled there (Krayevoy et al., 1976). The region is one of the well-studied ones in Kamchatka: state-run geological surveys with various scopes were conducted there from 1958 to 2001. Based on results of well drilling and mine workings, the Yagodninskoye deposit of zeolites, perlites, and active mineral additives which possessed raw materials of high quality was studied (Nasedkin, 1983). The Bolshe-Bannoye epthermal ore deposit was identified. In recent years, the territory of Karymshinskii volcanic center which is adjacent to our study area has been in focus of topical geological-structural activities carried out under leadership of V.L. Leonov, a giant Karimshinskaya caldera has been identified (Leonov, Rogozin, 2007). On the whole, this is of a great importance for developing notions about the history of magmatism, volcanic and hydrothermal activity on the area of the Banno-Karymshinskii region. However, the studies have not formed a comprehensive notion about the evolution of hydrothermal-magmatic and metasomatic processes responsible for formation of a wide number of deposits on a modest area. The objectives of this report are to specify a geological structure of the Yagodninskaya-Bannaya hydrothermal-magmatic system that we identified, to characterize composition and formation conditions of epithermal ore and zeolite mineralization, to build a general concept for the evolution of magmatic, geothermal and mineral- and ore-forming processes within the same long-evolving geological structure.

2. GEOLOGICAL STRUCTURE OF THE STUDY AREA

The study area is located within the limits of the southern segment of the East-Kamchatka volcanic belt and occupies a complicated structural (geodynamic) position: the South-Kamchatka infolded-block zone is superimposed on the Okhotsk platform, its north-eastern end is intersected by the Malko-Petropavloskaya zone of crosswise (north-western) tectonic dislocations **(Figure 1).**

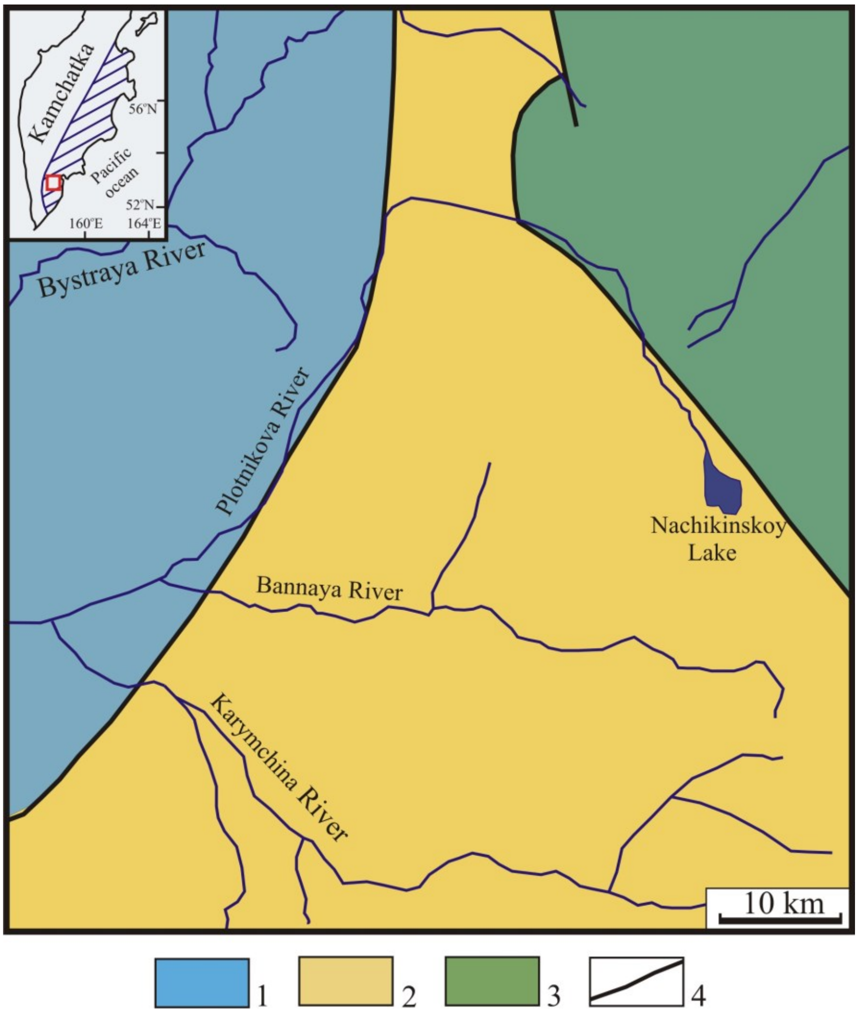

Figure 1: The geological structure of area. (1) the Okhotsk platform; (2) the South-Kamchatka infolded-block zone; (3) the Malko-Petropavlovskaya zone of crosswise tectonic dislocations; (4) the main faults. Used the dates of state-run geological surveys (edited by Borovtsev, A.K., 2002)

The area is the Banno-Karymshinskii long-lived (from Eocene to Holocene) centre of magmatic, geothermal and ore activity and is characterized by evolution of terrigenous and volcanogenic formations, contrast magmatic rocks, wide occurrence of ignimbrites and rhyolite tuffs, formation of thick intrusive-subvolcanic complexes, formation of large calderas and dome-circumferential structures **(Figure 2).**

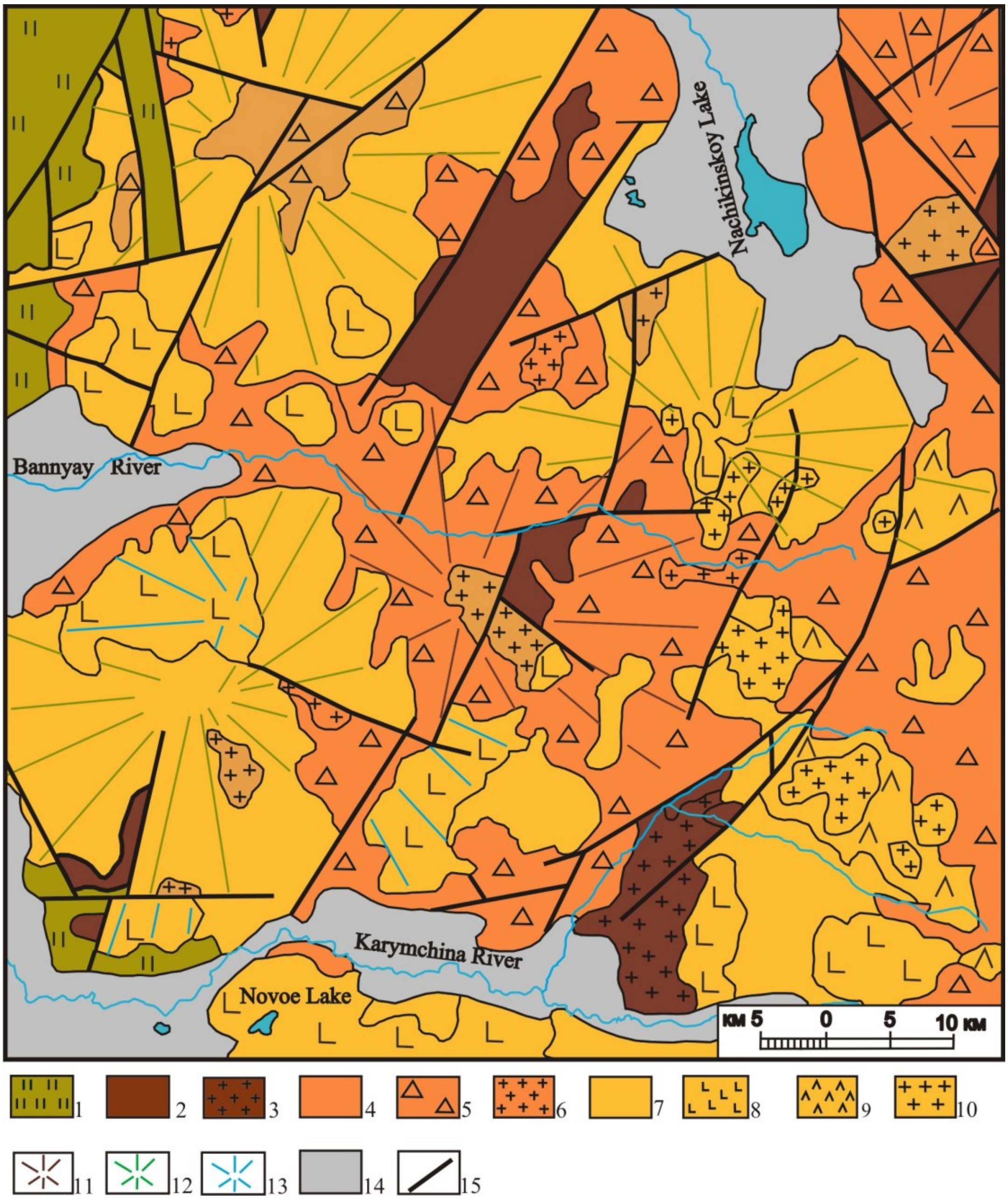

Figure 2: The Banno-Karymshinskii volcanogenic-ore centre. Used the dates of state-run geological surveys (edited by Borovtsev, A.K., 2002). (1-3) formations of Eocene-low-Miocene Lower stage: (1) volcanogenic, (2) terrigenous, (3) intrusive-subvolcanic diorite-monzonites; (4-6) formations of middle-upper-Miocene Middle stage: (4) molasse (sand tuffs), (5) volcanic (riodacites-andesites), (6) extrusive-subvolcanic complex of contrast rocks; (7-10) formations of Pliocene-Quaternary Upper stage: (7) basalts, (8) rhyolites, (9) basalt-andesites, (10) extrusive-subvolcanic complex of contrast rocks; (11-13) volcanic-tectonic structures of various ages: (11) Miocene, (12) Pliocene, (13) Pleistocene; (14) modern alluvial deposites; (15) main faults.

The following three structural stages have been identified: Lower stage is of Eocene-low-Miocene age, significantly terrigenous and volcanogenic-sedimentary, Middle stage is middle-upper-Miocene volcanogenic early-orogenic, Upper stage is Pliocene-Quaternary volcanic orogenic. Karimchinskii, Bannii and Nachikinskii troughs, apparently, of upper-Quaternary age, are developed on the periphery of Banno-Karymshinskii volcanogenic-ore centre. In all, the centre is presently a large oval-circumferential structure (from 60 to 70 km in diameter) with a long history of tectonic, magmatic and volcanic processes. The eastern part of this centre is distinguished on account of the localized formation of large intrusive-subvolcanic complexes of the Middle and Upper structural stages. We distinguish here the Yagodninskaya-Bannaya hydrothermal-magmatic system with the centre of magmatic, hydrothermal ore-forming and geothermal activity which is located between the valleys of the Yagodnaya and Bannaya rivers (**Figure 3**). This relatively small area (6 x 6 km) has deposits of various useful resources (zeolite, geothermal, epithermal ore-forming), thermal-mineral springs with balneology properties, and widely-spread silicified potentially ore-bearing rocks.

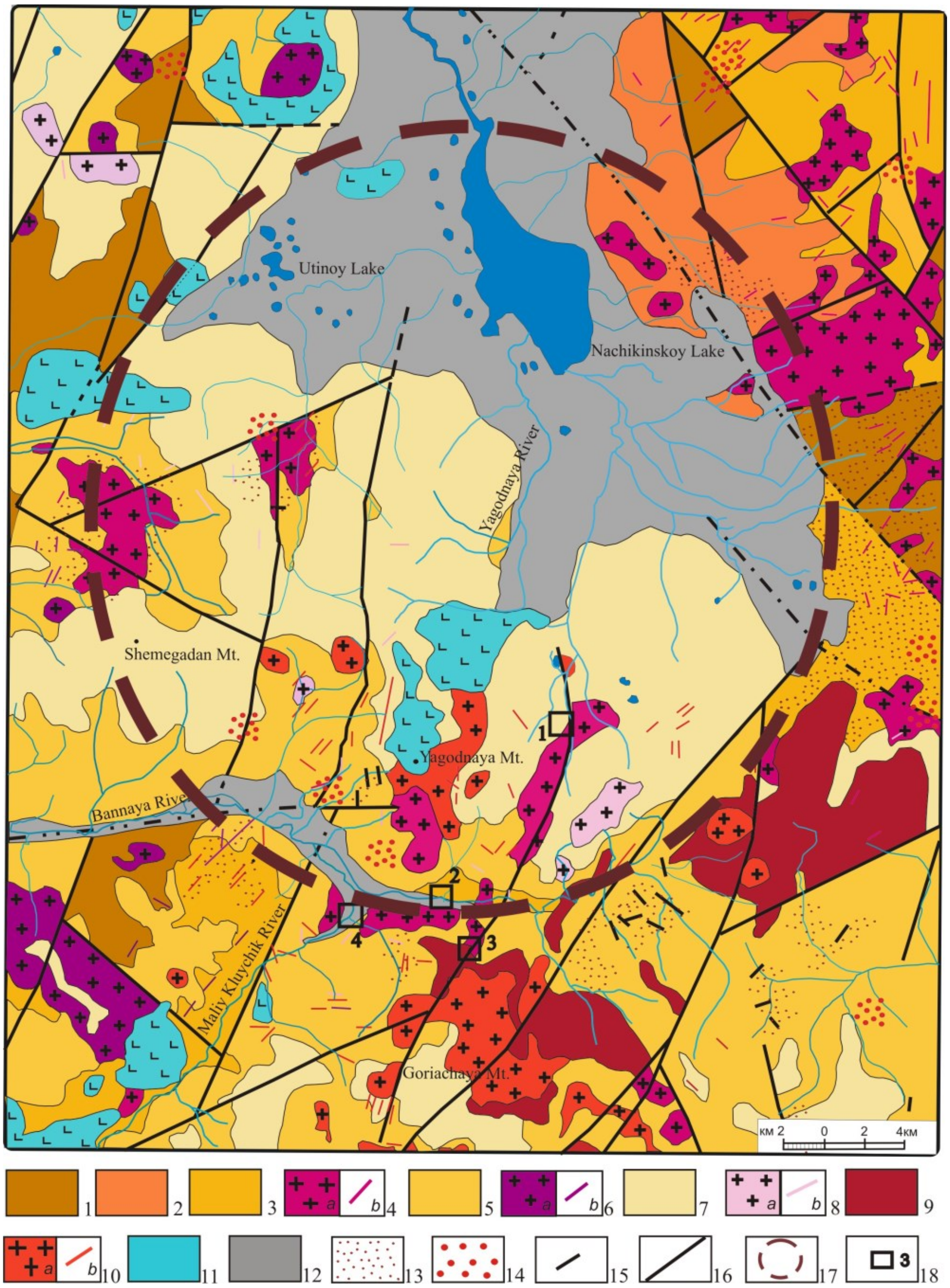

Figure 3: A schematic geological map of Yagodninskaya-Bannaya hydrothermal-magmatic system. Used the dates of state-run geological surveys (edited by Borovtsev, A.K., 2002). (1) volcano-sedimentary rocks of Low stage (Zhirovskoi complex of area - on West and Mutnovskii – on East); (2-6) the rocks of Middle stage: (2) sandstones, tuffites and tuffs by middle to acid chemical composition (Poperechensky complex), (3) – lavas, tuffs, and tuffs-conglomerates from andesite to andesite-basalts (Yuzhno-Bystrinsky complex), (4) subvolcanic intrusions (a) and dykes (b) of Yuzhno-Bystrinsky complex, (5) ignimbrites and rhyolite tuffs of Karymshinskii complex, (6) subvolcanic intrusions of dacite-riodacite (a) and dykes (b) of this complex; (7-12) the rocks of Upper stage: (7) andesite and basalt lavas and tuffs of Nachikinskii complex, (8) subvolcanic intrusions (a) and dykes (b) of this complex, (9) lavas, tuffs and ignimbrites of rhyolite Balaganchik complex, (10) extrusive-subvolcanic bodys (a) and dykes (b) of this complex, (11) basalts of Middle-Upper Quaternary age, (12) modern alluvial deposites; (13) fields of hydrothermally-altered rocks: propilytes, secondary quartzites, argillites; (14) fields of hydrothermally-altered rocks with sulphides and other ore mineralization; (15) quartz and quartz-carbonate veins; (16) faults; (17) boundary of Yagodninskaya-Bannaya hydrothermal-magmatic system by cosmic photo; (18) deposites: (1) Yagodninskoye deposite of zeolite materials, perlites and active mineral additives, (2) Bolshebannoye geothermal deposite, (3) Bolshe-Bannoye ore epithermal deposite, (4) thermal springs Maliye Banniye.

3. HYDROTHERMALLY-ALTERED ROCKS AND ORE-FORMATION

Hydrothermally-altered rocks widely occur in the evolution area of the Yagodninskaya-Bannaya hydrothermal-magmatic system and along its boundaries: propylites, secondary quartzites, monoquartzites, argillites, quartz and quartz-carbonate veins (See Figure 3). These formations are mainly connected to the most common here rocks of the Middle structural stage and form thick fields confined to large intrusive-subvolcanic (extrusive-subvolcanic) complexes of medium and acid composition. As a rule, the fields of the hydrothermally-altered rocks have a zoned structure (from the periphery to the centre): propylites – secondary quartzites – monoquartzites – quartz-adularia metasomatites – quartz and quartz-carbonate veins, argillization is confined to high fracturing zones (See Figure 3). The latter is usually an indicator of the final phases of hydrothermal-metasomatic transformations of rocks which is especially vividly manifested in the history of the evolution of the Bolshebannoye geothermal deposit. Ore mineralization develops in all types of rocks in the area (**Table 1**).

Table 1. Ore minerals and accompanying them in various rocks of area

Rocks type	Minerals
Volcanic rocks	Ilmenite, magnetite, Ti-magnetite, pentlandite, pyrrhotine, hematite, iron hydrooxides
Hydrothermal alterations	Ilmenite, magnetite, hematite, rutile, sphene, apatite, calcite, pyrite, chalcopyrite, covelline, chalcosine
Veins	Quartz, carbonate, adularia, hydromica, pyrite, chalcopyrite, galena, sphalerite, bornite, covelline, faded ore, hessite, argentite, hematite, iron hydrooxides, native metals

Primary-magmatic minerals, mainly, iron and titan oxides as well as sulphides were found in the host rocks that were not affected by hydrothermal-metasomatic alterations. They occur in the form of fine inclusions or ore fines in the main glassy mass of erupted rocks and in the form of idiomorphic (hypidiomorphic) “large” (up to 0.5 mm) crystals in subvolcanic and extrusive rocks. A reddish-brown colour of ignimbrites and tuffs which is most frequently observed in rocks near subvolcanic intrusions can be explained by oxidization of these ore minerals during cooling of the rocks. Hydrothermally-altered rocks are characterized by significant diversity of ore minerals, including oxides and sulphides Fe, Ti, Cu and others. Intensive pyritization zones evolve in these rocks (up to 10% of volume in separate lenses and subtabular bodies), silicification and quartz-adularia mineralization with tellurides, fahlore, sulphides Zn and Cu, native metals. This type of mineralization was identified in silicified host rocks in the apical parts of subvolcanic intrusions, namely, of the complex of syenite-diorites-dacites which is communicated with Bolshe-Bannoye epithermal ore deposit. There have been delineated over 30 7-meter-thick 200-meter-long quartz and quartz-adularia vein bodies at the deposit. Host rhyolite tuffs and lavas of dacites enclose a developed stockwork system of fine veins and veinlets. Ore mineralization (See Table 1) is in the form of disseminated shots in veins of various composition which have massive, striped and breccias-type textures. The richest ore mineralization is related to quartz-adularia crypto-crystalline aggregates, vague-striped structures in the quartz-adularia mass and manifested by fine (< 0.1 mm) grains of fahlore, argentite, native metals. On the whole, the deposit has not been studied enough and, in our opinion, has a great potential for discovery of rich ore bodies at depth and in an exocontact zone of subvolcanic activity. The top of this intrusion was penetrated by geothermal wells at a depth of 250-400 m which was indicative of the fact that the northern block of the intrusive massif was submerged to a depth of 500-600 m when the quaternary trough of the Bannaya River was being formed. The drilling revealed hydrothermally-altered rocks and signs of ore mineralization and elevated concentrations of many micro-components in thermal waters (see below). Therefore, the interior of the Bolshebannoye geothermal deposit is expected to host ore bodies.

3. YAGODNINSKOYE DEPOSIT OF ZEOLITE MATERIALS, PERLITES AND ACTIVE MINERAL ADDITIVES

The deposit is connected with a paleovolcanic structure of the Yagodnaya mountain (Serezhnikov, Zimin, 1976) and directly confined to the extrusive-subvolcanic complex of elevation 1081 (Nasedkin, Nasedkina, 1980), see Figure 3. Rocks in the area are confined to deposits of the Middle and Upper structural stages. Lavas and tuffs of andesites, dacites and rhyolites prevail in the area (**Figure 4**). The final (Pleistocene-Holocene) phase of evolution is manifested by lavas and basalt dykes. The complex of elevation 1081 is a composite edifice which is built by a series of lava flows, pyroclastic flows, pyroclastic deposits and extrusive bodies of dominantly acid composition. The edifice is underlain by dacites, zeolitized tuffs of rhyolite composition from pelite to psephite varieties. Tuffs are overlain by lavas of rhyolites. The central part of this volcanic massif has a complex structure which is characteristic of the crater vicinity of differential (of contrast composition) extrusive-subvolcanic complexes: a series of cutting bodies composed of spherulitic rhyolites and volcanic glasses (perlites) has been identified here. A vent facies manifested by agglomerate lavas, tuffs and tuffites penetrated by basalt dikes (stocks) has been identified. The Yagodninskoye deposit is connected with a stratum of zeolitized litho-vitro-crystalloclastic tuffs of rhyolite composition which form three flows from the centre of elevation 1081: Northern, South-Western and South-Eastern (See Figure 4). Based on results of drilling, the thickness of the tuff stratum is 100 m and more. The rocks have a distinct light colour. Acid glass prevails in the composition of the main mass, whereas lavas of dacites, glass, pumice, crystalloclasts of various rock-forming minerals prevail in fragments. First of all, the microlites and glass of the main mass as well as pumice and glass fragments are affected by hydrothermal-metasomatic alterations. **Figure 5** shows a variety of rocks enclosing the Yagodninskoye deposit. Among hydrothermal-metasomatic alterations the dominants ones are zeolitization and argillization of acid tuffs. Zeolitization bears an areal character. Vitroclastic tuffs contain most significant amounts of zeolites (up to 80%). Finely-grained clinoptilolite (up to 65% in separate layers) and acicular mordenite (up to 40%) are prevalent, while sheaf-like radial-fibrous heulandite aggregates are less common (up to 25%). Along with zeolites, sheet silicates such as hydromica and clay minerals of a montmorillonite group are developed on volcanic glass. A 60% increase in growth of contents of mineral clays in some layers is related to excessive fissuring of initial rocks in these zones. A significant number of silica minerals (opal and quartz – up to 26%) as well as lavas and perlites are observed in the zones of intensive fissuring of tuffs. Several perlite phases have been identified.

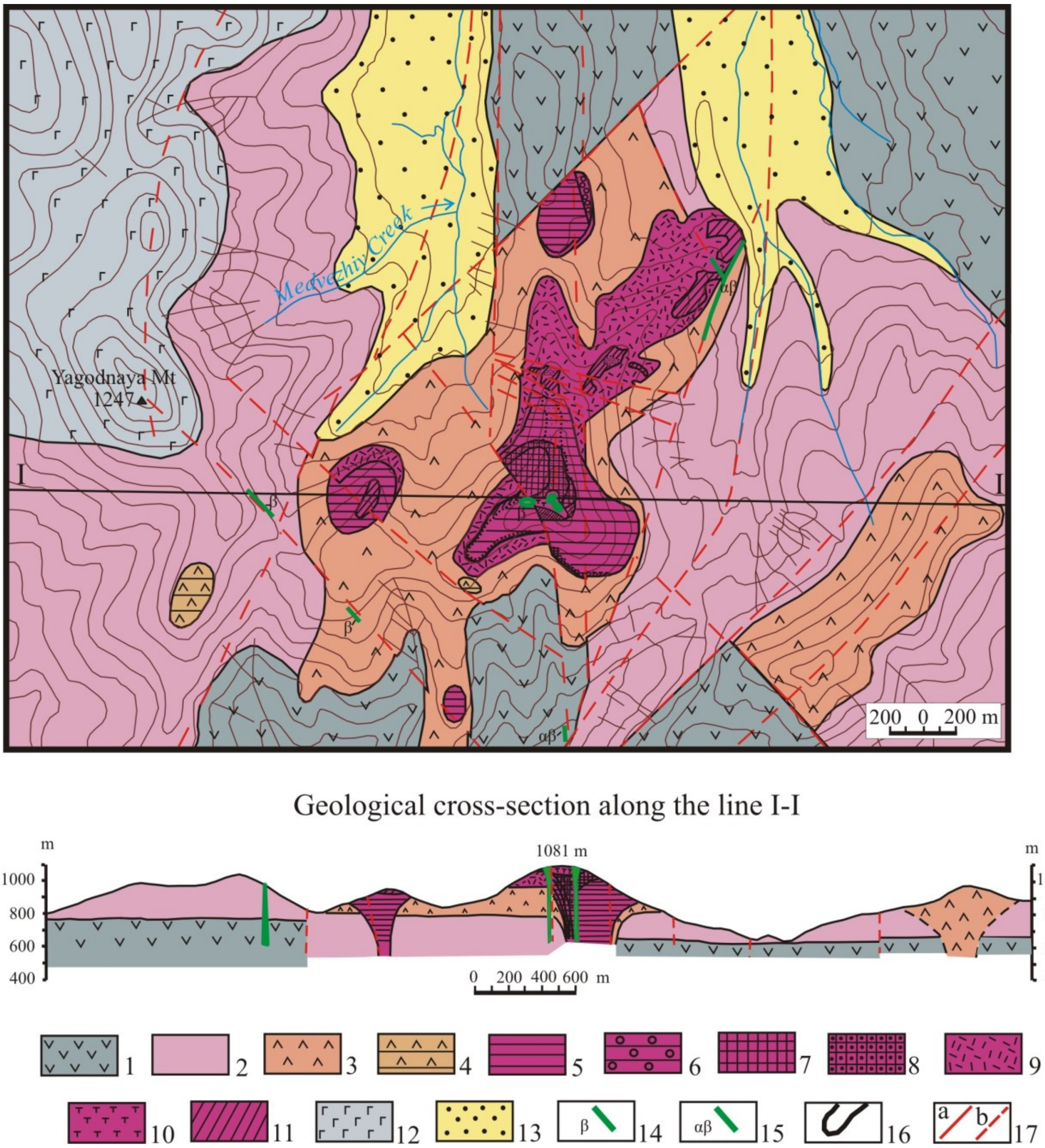

Figure 4: A shematic geological map of the area of Yagodninskoye deposite of zeolite materials, perlites and active mineral additives (Nasedkin and Nasedkina, 1980) with modifications and additions. (1) andesite, andesitic tuffs; (2) rhyolite; (3) dacite lavas; (4) dacite extrusions; (5) banded rhyolites; (6) spherulitic rhyolites; (7) brown perlites; (8) brown spherulitic perlites; (9) perlites with zeolites; (10) tuffs, tuffites, and tuffs-breccia; (11) gray and green perlites; (12) basalts; (13) alluvial deposits; (14) basalt dykes; (15) andesite-basalt dykes; (16) perlite breccia with zeolites; (17) faults: installed (a), prospective (b).

At the macroscopic level, the rocks have a massive brecciated and spherulitic structure and a greenish-gray colour. At the microscopic level, perlites include spherulitic and fan-like aggregates of alkali feldspar and crystobalite. Probably, they were formed due to cooling of a magmatic melt. Spherulites composed of zeolites (heulandite, mainly) and silica minerals have been identified, they are formed at the stage of hydrothermal-metasomatic transformations of rocks. Metamorphosis of the glass takes place along fractures that develop around "perlitic bulbs" and spherulites; see Figure 5. Entire replacement of the main mass of the rocks with formation of montmorillonite, hydromica, mordenite and clinoptilolite may occur. A content of highly-siliceous zeolites amounts to 70%. Thus, the Yagodninskoye deposit is referred to as a rich deposit of high-quality raw material which can be nurtured to various industries, agriculture and to resolve environmental issues.

4. BOLSHEBANNOYE GEOTHERMAL DEPOSIT

Bolshiye Banniye ('Large Sauna') boiling springs and Maliye Banniye ('Small Sauna') hot springs were first described by S.P. Krasheninnikov, a famous Russian explorer, in the 18th century, later on they were studied by B.I. Piip and other researchers. In the1960th, detailed scientific and prospecting and exploration activities took place, heat capacities of geothermal anomalies were estimated, based on drilling results the Bolshebannoye deposit of superheated waters was established (Krayevoy et al., 1976). Maximum temperatures of hydrothermal waters at a depth of 500-600 m are 170^{o}C and forecast temperatures at a depth of over 1 km are above 200^{o}C. An electric capacity of the deposit has been estimated 51 MW calculated for 100 year long operation (Strategiya razvitiya…, 2001). The deposit is located in the deep-cut valley of the Bannaya river and it has a large catchment basin at the river head (See Figure 3). The host rocks are sediments of the Middle structural stage: lavas, tuffs and ignimbrites. An intrusive-subvolcanic facies plays a great part in the geological cross-section: insignificant intrusions and dykes of basic to medium composition. The deposit is of a vein-fracture type: circulation of superheated waters and precipitation of meteoric and mixed waters happen via a system of subvertical fracture zones between blocks of low-permeable rocks, via subvertical fracture-breccia zones inside the blocks and via boundaries of subvolcanic (intrusive) bodies. **Table 2** shows the main types of natural waters that are formed in the area of the Yagodninskaya-Bannaya hydrothermal-magmatic system and immediately in the geothermal deposit area.

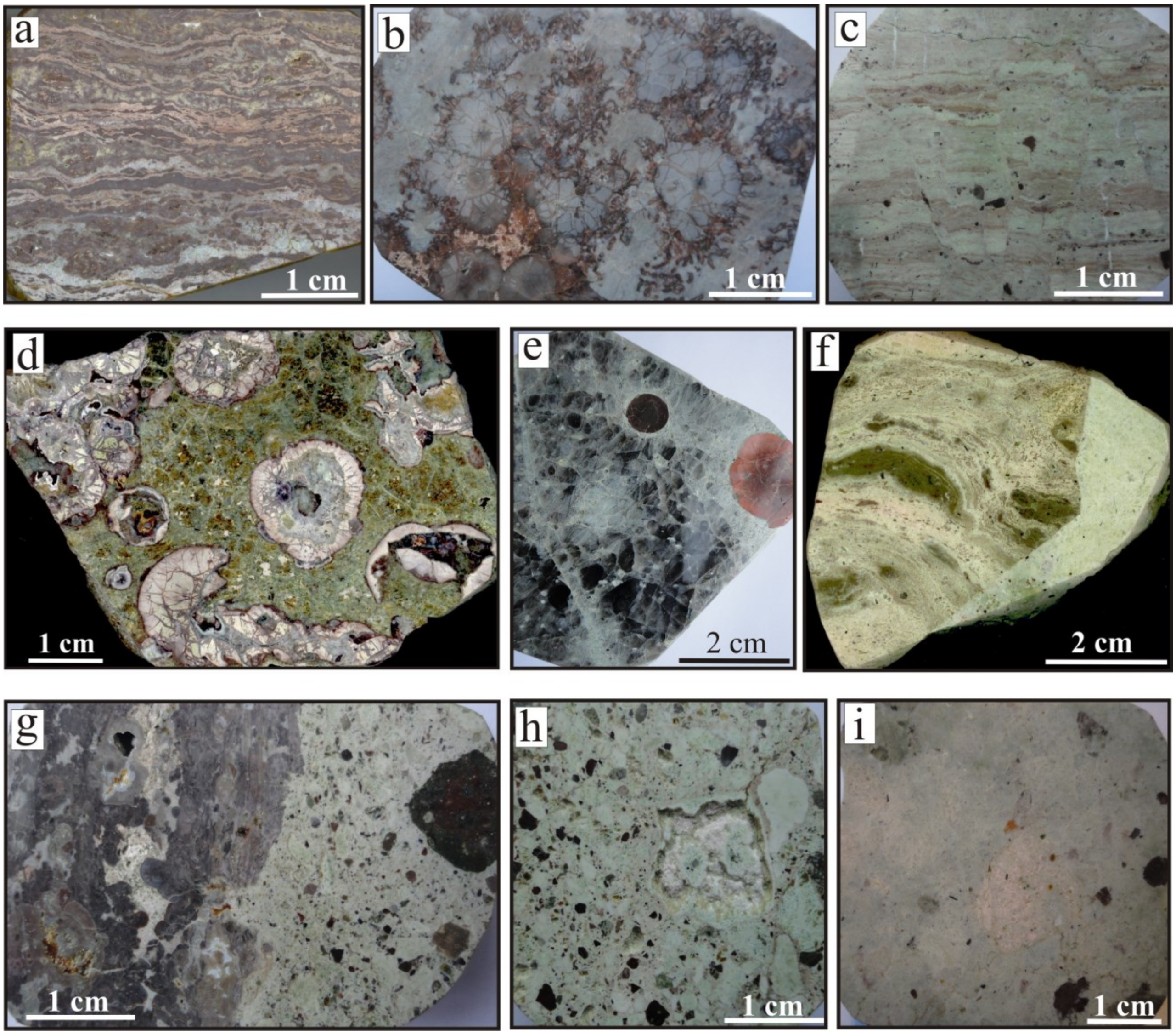

Figure 5: Types of Yagodninskoe deposit rocks. (a) striped rhyolite; (b) spherulitic rhyolite; (c) zeolitized rhyolite; (d) spherulitic perlite; (e) feldspar spherulites in glass; (f-i) zeolitized rhyolite tuffs of various structure.

Table 2. The natural water characteristics of Yagodninskaya-Bannaya hydrothermal-magmatic system

Physical and chemical properties	River waters	Subsoil pressure waters	Unloadings on thermal fields	Deep waters of Bolshebannoye deposit	Thermal waters of Maliye Banniye
pH	7.0	7.1	7.2	7.2	7.3
Eh	+90	+50	-23	+240	+65
T^oC	8.0	8.3	93.0	99.0 (on a mouth)	72.3
Content of components, mg/L					
HCO_3^-	9.8	24.4	59.8	109.8	110.0
F	<0.1	<0.1	6.3	8.8	4.0
Cl^-	2.1	1.9	90.8	120.5	51.1
NO_3^-	1.5	1.4	0.0	0.0	0.0
SO_4^{2-}	0.9	0.7	365.0	490.0	192.1
Na^+	3.6	3.4	222.3	311.3	167.8
K^+	2.1	3.5	14.4	22.7	4.8
Ca^{2+}	3.3	3.8	34.5	48.1	6.0
Mg^{2+}	1.0	1.3	0.0	0.0	0.0
H_3BO_3	<0.3	<0.3	8.7	13.6	3.7
$H_4SiO_{4\ soluble}$	32.0	81.6	195.5	164.0	124.1
$H_4SiO_{4\ colloidal}$	0.0	0.0	70.8	197.0	14.9
Mineralization	56.3	122.0	1068.1	1485.8	678.5

Note: Analytical works are executed in the Institute of Volcanology and Seismology FEB RAS, analyst S.V. Sergeeva.

Ground head waters having physical-chemical characteristics (pH, Eh, T ^oC) similar to river waters differ from them by elevated contents of hydrocarbonate-ion and silicic acid and, it appears, they form under influence of hydrothermal vapours and fluids. The thermal waters that are discharged at the surface, deep-seated pressure waters (penetrated by drilling) and Maliye Banniye springs are of a sulphate-chloride-sodium composition with a high content of dissolved and colloid silicic acid. High concentrations of fluorine, boron, rare alkaline elements, arsenic and other have been detected in thermal waters (Krayevoy et al., 1976). Host rocks of intensive circulation of thermal vapours and fluids were discovered to contain native lead and copper (Nasedkin et al., 1988). Dissolved gas of the Bolshebannoye deposit mainly contains carbon dioxide (up to 61% of volume), whereas dissolved gas of Maliye Banniye springs mainly contains nitrogen (up to 98%). The deposit is closely confined to the intrusive-subvolcanic complex of syenite-diorites-dacites with which the Bannoye epithermal ore deposit is connected. It is considered that the large intrusion of Goriachaya Sopka is the source of geothermal heat (Krayevoy et al., 1976). We suppose that the complex of syenite-diorites-dacites and the Goriachaya Sopka massif belong to the same long-evolving magmatic centre at a certain development phase of which the Bolshe-Bannoye epithermal ore deposit formed and at the modern phase of which the Bolshebannoye geothermal deposit has formed. The main source of ore and rare chemical elements in thermal waters are zones of deep circulation of high-temperature solutions in the apical parts of intrusive-subvolcanic complexes and their enclosing alkaline metasomatites with quartz and quartz-carbonate veins and epithermal ore mineralization.

5. CONCLUSION

The evolution history of the Yagodninskaya-Bannaya hydrothermal-magmatic system covers a period from Eocene-Low Miocene to Holocene. The system is a dome-circumferential volcanic-tectonic structure whose diameter is about 30 km. The orogenic development phase which includes the Middle and Upper structural stages was accompanied by formation of large intrusive-subvolcanic (extrusive-subvolcanic) complexes of medium to acid composition. The formation of such complex in the area of Yagodnaya mountain and subsequent cooling of intrusive and host rocks on account of boiling of alkaline solutions under the conditions of constrained water exchange (in dense low permeable tuffs) caused the intensive zeolitization and argillization of the stratum of rhyolite tuffs having more than 100 meters in thickness. A similar setting is characteristic of the Valley of Geysers (Kamchatka) where zeolitization of ash tuffs took place under high heating conditions with constrained circulation of thermal waters in rocks with low filtration properties (Naboko, Glavatskikh, 1978). On the whole, zeolitized rocks are developed extensively across Kamchatka, zeolitic (copper-zeolitic) formation is observed (Petrachenko, 1968). It is assumed that there exists a long-evolving thick vapour-dominated pool at depth of the hydrothermal system of the Valley of Geysers. The vapour-dominated pool of the Yagodninskaya hydrothermal system was presumably formed in the above-dome area of the extrusive-subvolcanic complex whose interior and periphery are expected to contain hydrothermally-altered rocks of another type: secondary quartzites, monoquartzites, and vein-shaped bodies. Such rocks are typical for highly fissured and brecciated exocontact zones of subvolcanic intrusions. Penetration of mineralized thermal solutions in such zones was accompanied by formation of epithermal ore mineralization widely propagated by the periphery of the Yagodninskaya-Bannaya hydrothermal-magmatic system. At the modern phase of development, such geological structures feature near-surface and concealed discharge of superheated thermal waters and they are potentially productive in terms of discovery of large (> 50 MW of electric capacity) geothermal deposits. Our findings suggest that the Bolshebannoye geothermal deposit was formed at the conjunction zone of two large intrusive-subvolcanic complexes (Yagodnaya mountain and Goriachaya Sopka) complicated by the Upper-Quaternary trough of the Bannaya River. Such a favourable combination of geological and hydrogeological conditions predetermined the formation of a large circulatory hydrothermal system of the vein-fracture type.

Thus, the Banno-Karymshinskii geothermal (ore) region of South Kamchatka and the Yagodninskaya-Bannaya hydrothermal-magmatic system have large mineral and energy resources and are of a significant importance for future socio-economical development of Kamchatka Krai. The formation of a concept for such development involves compilation of the existing wealth of geological, geophysical and hydrogeological data along with new comprehensive scientific studies.

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