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Severo-Paramushirskaya Hydrothermal-Magmatic System: Interaction of Modern Volcano Ebeko, Severo-Kurilsky Geothermal Deposit and Metallogenic Fluids

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ABSTRACT

Case study of the Severo-Paramushirskaya (North-Paramushir) hydrothermal-magmatic system demonstrates paragenetic and genetic connection between the main components of this geological structure located in the northern part of the Vernadsky volcanic ridge: sub-intrusive bodies as heat sources and deformational tensions in their endo- and exocontacts, ascending fluxes of metal-bearing fluids in deep-seated fault areas, thick sections of boiling solutions and therefore formed geochemical barriers and quartz-adularia metasomatites with ore mineralization, active Ebeko volcano and rock decompaction zone underneath.

Introduction

The Paramushir Island is one of the largest islands in the Greater Kuril arc. Social and economic activities of the Sakhalin's North-Kuril district are concentrated on this island. The district experiences some problems related to heat and power supply due to absence of own sources. Geothermal heat may become a reliable source of energy for the island. Based on past exploration data, predicted resources of the Severo-Kurilsky (North-Kuril) geothermal field adjacent to the town of the same name are no less than 60-100 MW of electrical power calculated for 100 years of exploitation (Belousov et al., 2002). These resources exceed area's development demand many times. The geothermal resources are associated with the high-temperature Severo-Paramushirskaya (North-Paramushir) hydrothermal-magmatic system the central part of which is topped by the active Ebeko volcano (Figure 1). Deep drilling reached subintrusive bodies. Thick sections of boiling hydrothermae, geochemical barriers and ore mineralization form in endo- and exocontact zone of these bodies (breccia mantle). Present-day metal-bearing solutions are discharged on surface above deep-seated faults (the Yur'ev river, the crater are of Ebeko volcano) (Rychagov et al., 2001). Thus, there is paragenetic and, possibly, genetic connection between hydrothermal-magmatic system, the active volcano and flows of metallogenic fluids within single geological structure of the Vernadsky ridge. Some issues of this interaction are dealt with in this paper to specify geothermal and mineral resource potential of the Severo-Kurilsky (North-Kuril) district.

Severo-Paramushirskaya (North-Paramushir) Hydrothermal-Magmatic System

The Paramushir island is deemed a relatively uplifted block of the earth's crust and an extension of the southern Kamchatka's Pribrezhny ("coastal") horst (Aprelkov, 1971). Other authors distinguish anticline of the north-east strike in the northern end of the island which has existed as a structural high since the late

Figure 1. The north part of Paramushir Island. Photo by V. N. Dvigalo. 1989 year.

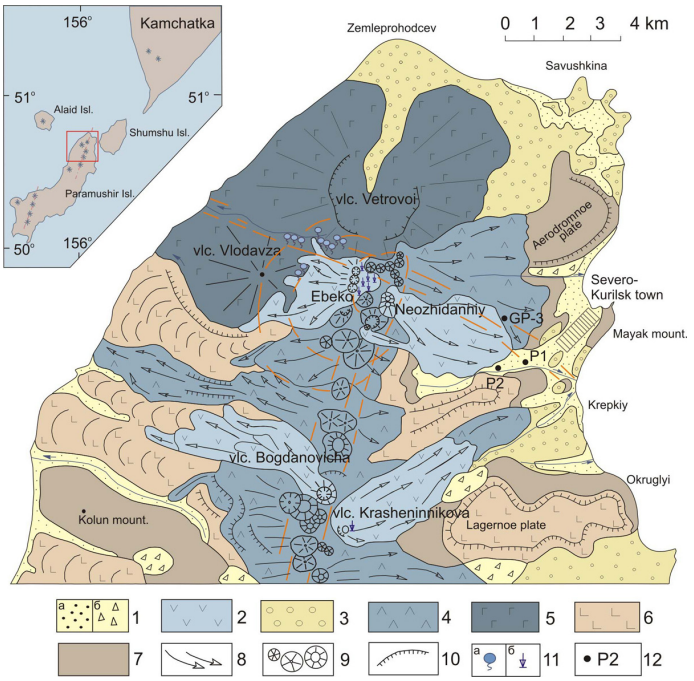

Figure 2. The schematic geological map of the northern part of Paramushir Island (Present-Hydrothermal..., 1998). 1 – present alluvial, marine and lacustrine strata (a) and tallus (b); 2 – andesitic, andesibasaltic lavas (Q_4); 3 – glacial deposits (Q_3^4); 4 – andesitic lavas (Q_3); 5 – andesitic, andesibasaltic lavas ($N_2^2 – Q_1$); 6 – basaltic lavas, tuffs, tuff-breccias (Q_{1-2}); 7 – undivided volcano-sedimental deposits and subvolcanic bodies ($N_1^3 – N_2$); 8 - centers of volcanic eruptions; 9 – small volcanoes, lava and cinder cones located in axial zone of the Vernadsky ridge; 10 – displayed in the relief scarps and erosional limits of calderas; 11 – thermal springs (a) and fumaroles (b); 12 – drill holes.

Miocene. With that, Paramushir's folding is considered to be an exception to the islands of the Great Kuril ridge (Sergeev, 1976). Thus, the anticlinal structure of the North-Kuril islands can be an extension of the South-Kamchatka anticlinorium. The northern end of the island is composed of Upper-Pliocene to modern rocks (Figure 2). The basement comprises volcanic-sedimentary rocks of the Paramushir complex of suites: volcanomictic sandstones, tuffs and tuff gravelites of the Okhotsk suite with a total thickness of 1400 to 3000 meters, as well as nongraded conglomerates, breccias, coarse-grained sandstones of the Ocean suite 900-1000 meters thick. Deposits of these suites are concordant or discordant with dykes, sills, other exhumed intrusive and subvolcanic bodies and composed of diabases (the Mayak Mountain situated in the center of Severo-Kurilsk town). The large magmatic body "Aerodromnoye Plateau" is of interest in view of the fact that it is a probable equivalent of present-day intrusions of gabbro-diorites presumably feeding the Severo-Paramushirskaya (North-Paramushir) Hydrothermal-Magmatic System. We demonstrated non-homogenous distribution of physical-chemical properties of rocks and breccia-block structure of magmatic (subvolcanic?) body's margins (Belousov et al., 2002). Probably, the margins of such bodies may be cross-flow zones for hydrothermal fluids at depth (Structura…, 1993), and near the surface – infiltration zones for meteoric and mixed thermal waters. The Okhotsk and Ocean suites are overlain by Upper-Pliocene andesite lavas forming a plateau in the southern end of the island. Of the most ancient effusives, basalt lavas of presumably lower-Mid-Pleistocene age are exposed in the northern end of the Paramushir Island. Probably, of the same age is a thick (over 200-300 meters) rock mass of tuffs of neutral to acid composition and two-pyroxene andesites called interglacial (Gorshkov, 1967). Krasheninnikov, Bilibin, Bogdanovitch, Neozhidanny (Unexpected), Ebeko and other Quaternary volcanoes form elongated volcanic-tectonic structure – the Vernadsky volcanic ridge in the interior of which an andesite-basalt magma had been migrating for a long time. Therefore, in the northern part of the Vernadsky ridge there is a long-lived hydrothermal-magmatic system deemed by authors to be at the progressive stage now (Rychagov, 2003).

Ebeko Volcano

Ebeko volcano is one of the most active ones in the Northern Kuril islands (Menyailov et al., 1985). Its periodically repeated phreatic-magmatic eruptions in the historical time (until 1934-35) and phreatic (1967-71 and 1987-91) eruptions along with strengthened fumarolic activity with single ash plumes happening from 1998 until now are directly hazardous to the town of Severo-Kurilsk, air and maritime traffic, fishing operations, etc. At the

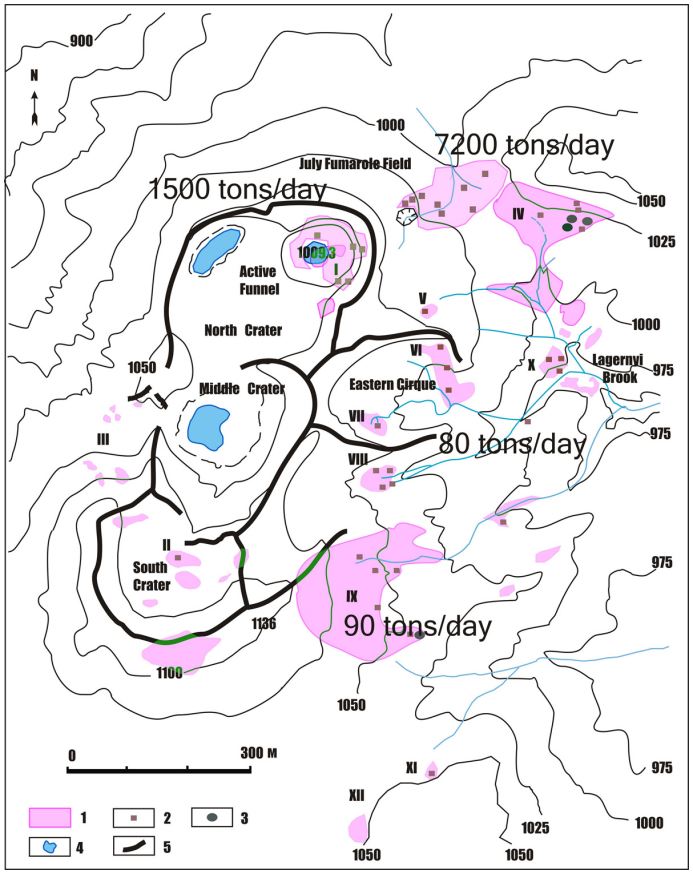

Figure 3. The crater zone of Ebeko volcano. 1- Map of Ebeko volcano thermal fields, after V.N. Dvigalo (1989) and supplemented by these authors: (1) thermal fields, (2) fumaroles, (3) pots of thermal water, (4) crater lakes, (5) rims of major craters. Roman numerals denote thermal fields: (I) Active Funnel, (II) South Crater, (III) West Field, (IV) Northeastern Field, (V) Gremuchaya fumarole field, (VI) Florenskii fumarole field, (VII) First Eastern Field, (VIII) Second Eastern Field, (IX) Southeastern Field, (X) Lagernyi Brook field, (XI) Second Southeastern Field, (XII) Third Southeastern Field.

Figure 4. Eruption from Active crater of Ebeko volcano. Photo by L. Kotenko 07.02.2009.

same time, study of the volcano is useful for description of a cognominal geothermal field adjacent to the town with an implication that there is genetic connection between these two geological units (Rychagov et al., 2001; Belousov et al., 2002). The summit of Ebeko volcano has three adjoining craters with diameters 250-300 m each. Heat efflux and discharge of hydrothermae within the crater area take place on solfataric and fumarolic fields and on other heated sites on an area of ≥ 1 km^2 (Figure 3). A new fumarolic field titled Iyulsky ("Of July") having temperatures of gases up to 500^0C was formed due to the activation of the volcano in the recent years (Kotenko et al., 2007). Estimation of heat discharge in the volcano crater area demonstrated that the highest thermal flux was confined to the connection of two fumarolic fields – Iyulsky (Of July) and Severo-Vostochny (North-Eastern) and to Active Funnel of the Severny (Northern) crater. Sites with elevated radon levels in soil-pyroclastic cover had been also confined to these same areas before the Iyulsky fumarolic field emerged. These anomalies were identified with surface steam hydrothermae vents and steam hydrothermae vents covered by loose pyroclastics along zones of rock fracture and tectonic faults. Since January 2009 the volcano has entered a new stage: phreatic eruption from the Active Funnel has begun. Periodical eruptions of fine resurgent ash reach up to 2.5 – 3.0 km in altitude (Figure 4). Some increase of Cl/SO_4 ratio in acid thermal waters discharged in the crater area has occurred. Heat efflux immediately from the Active Funnel has increased approximately by one order.

Heat and Ore Feed Source for Hydrothermal-Magmatic System

Geophysical surveys did not reveal an earlier assumed magma chamber at the border, but right below the craters the existence of rock decompaction zone in the form of a vertical cylinder 1 km in diameter and 2.0-2.5 km deep was established. (Geological-geophysical Atlas…, 1987). This zone controls gas-hydrothermal volcanic processes, heat distribution and heat efflux. From low acid to ultra acid hydrothermal solutions of chloride-sulfate, sulfate and hydrocarbonate-sulfate mixed cation (Na-Ca-K-Mg-Fe-Al) composition are discharged in the crater area. Ultra acid hydrothermal waters of the Yur'eva River, heading from the volcano, are metal-bearing (Nikitina, 1978). Composition of fumarolic gas, in general, is stable and includes $H_2O>CO_2>SO_2>HCl>H_2S$, hydrogen, methane, helium etc. When activity of the volcano heightens ratios of S/Cl, H_2O/CO_2 reduce whereas ratio of H_2S/SO_2, increases, in other words, fumarolic gases bring more chlorine, carbon dioxide and, probably, hydrogen, hydrocarbons, etc. These data speak in favor of the existence of a gas-hydrothermal fluid-generating magmatic heat source under the volcano's craters and deeper than the rock decompaction zone. Key geological section represented by deep drilling well GP-3 (2,5 km deep) exposed the apical part of subvolcanic body of gabbro-diorites. It is composed of intrusive, automagmatic and other breccias (intrusive tuffs). Above this zone, boiling section of overheated fluids is formed within tectonic, hydrothermal-explosive and metasomatic breccias (Figure 5, overleaf). Secondary quartzites and their sulfide mineralization are paleostage indicators for the formation of the section. Present-day stage indicators include quartz-adularia metasomatites, open interstices (up to 50 volume% on some breccia sections) and peculiar ore mineralization: native metals, intermetallic compounds, alloys and solid solutions (Rychagov et al., 2002). Minerals often presented in the form of globules fill open pores and cracks thus witnessing in favor of their present-day origin.

Severo-Kurilsky (North-Kuril) Geothermal Deposit

Severo-Kurilsky (North-Kuril) geothermal field is situated in the northern end of the Paramishir Island on the eastern slopes of the Vernadsky ridge near the Ebeko volcano. As estimated by V.M. Sugrobov (Belousov et al., 2002), forecast resources of the deposit are 60-100 MW of electric power and no less than 120 GCal/sec of heat capacity. Two water-bearing layers are distinguished in the deposit (Rychagov et al., 2001). The lower one controls chloride-sodium neutral-alkaline high temperature hydrothermae and is confined to Neogene tuffs and tuffites. The upper one is a circulation zone for meteoric and mixed low acid-neutral waters of hydrocarbonate and hydrocarbonate-sulfate compositions in Quaternary lavas and tuffs. In some blocks,

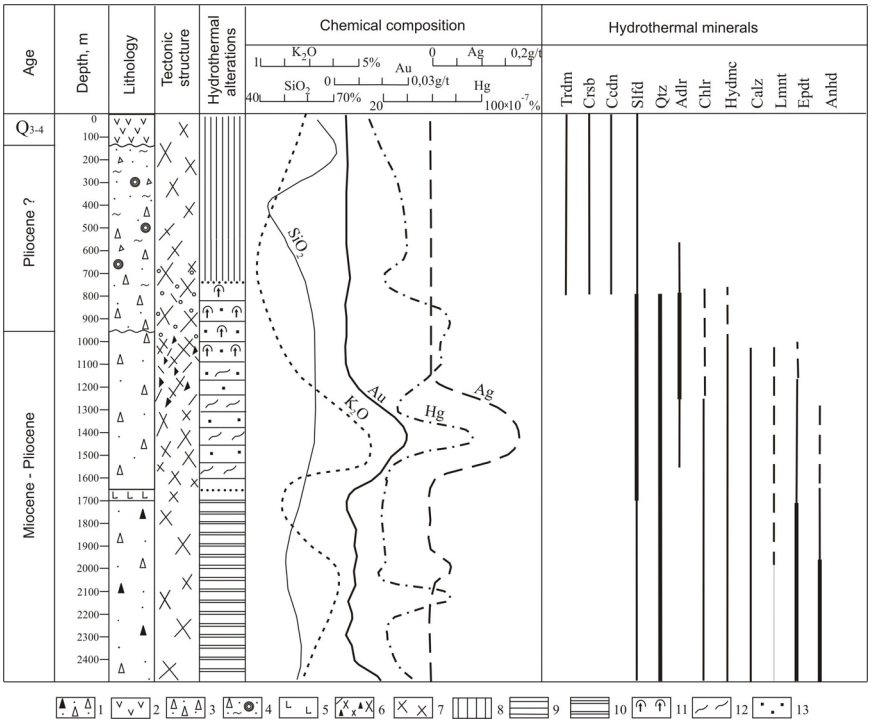

Figure 5. Deep geological-geochemical cross section of Severo(North)-Paramushirsky Hydrothermal-Magmatic System (well GP-3). 1 – lithocrystalloclastic intrusive tuffs of andesibasaltic; 2 – andesite lavas; 3 – multicoloured lithoclastic tuffs of andesite; 4 – tuffites with inclusions of a relic organic material; 5 – andesibasaltic lavas; 6 – tectonic and other breccias; 7 – cracks; 8 – low-temperature opal-cristobalite-tridymite-chalcedony metasomatites; 9 – low-middle-temperature quartz-adularia-hydromica metasomatites; 10 – middle-temperature quartz-chlorite-epidote-muscovite propylites; 11 – vapor-dominated zones (quartz-adularia metasomatites); 12 – quartz-chalcedonic veins with ore minerals; 13 – ore mineralization.

open tectonic faults enable active crossflow of waters from one complex to another thus forming solution mixture zones and thick (> 100 meters) boiling zones. Probably, there is one more water-bearing stratum having overcritical parameters of gas-hydrothermal fluid and overheated water steam and which is confined to subvolcanic intrusive endocontacts and exocontacts (Rychagov et al., 2002). In general, circulation zones of ascending deep-level, often metal-bearing, steam-hydrothermae are confined to the Vernadsky ridge crossaxial regional faults (graben-like faults) and to separate ring structures manifested above intrusive bodies or upstanding blocks. The authors believe that the geothermal field is hydrodynamically connected to the western part of the hydrothermal-magmatic system (the area of the Yur'ev and Gorshkov rivers). This part of the system probably has higher thermodynamic values inasmuch as it is enclosed in thick overlying (>500 m on the average) sheets of andesites and andesibasalts of Middle- and Upper-Quaternary age.

Conclusion

Geological-geochemical study of the Severo-Paramushirskaya (North-Paramushir) hydrothermal-magmatic system, its geological reference sections, hydrogeochemical features of solutions, state and structure of deep-seated sections of Ebeko volcano demonstrated that there was hydrodynamic connection of steam-hydrothermae and other type natural waters from the northern end of the Paramushir island with solutions discharged at the crater area (Rychagov et al., 2002). Thick zones of boiling metal-bearing hydrothermal fluids are formed above apical parts of subvolcanic intrusions therefore native metals, intermetallic and other compounds precipitate in cavernous quartz-adularia metasomatites. Based on deep drilling data derived from well GP-3, such zone is located within an interval of 700-1,200 meters from the surface. Sulfides of Fe, Pb, Zn, Cu and other elements were detected in secondary quartzites below this zone. The survey results correlate with the fact that many metals (Fe, Pb, Cu, As, etc.) are transported in sources located along the deep fault of the Yur'ev river (Zelenov, 1972; Nikitina, 1978). Thus, metal-bearing hydrothermal solutions possibly originating from subvolcanic bodies or from small intrusion of gabbro-diorite composition are discharged in the crater area of the Ebeko volcano. In our opinion, the case study of the Severo-Kurilsky (North-Kuril) geothermal deposit and the Severo-Paramushirskaya (North-Paramushir) hydrothermal-magmatic system suggests the following working conceptual model. (Hedenquist et al., 1996; Corbett, Leech, 1998; Rychagov, 2003). A high sulfidation fluid system is formed above the heat and ore source and in the crater area of the Ebeko volcano; a low sulfidation hydrothermal system and geothermal deposit are formed at the boundary of the geological structure in the zone of lateral flow of mixed hydrothermae and infiltration of meteoric waters (the zone may also include separate heat sources, in particular, areas of second heating and melting of rocks); mesothermal and epithermal gold-rare-metal-polymetallic ore in host rocks directly above intrusions or a bit away from them is formed; formation of Cu-Mo-Au-Ag… porphyry mineralization is possible in endocontact and exocontact zones of large multiple phase gabbro-diorite bodies.

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