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Lithogenesis of Hydrothermal Clays as Reflection of Deep Metalliferous Fluids Influence (Southern Kamchatka)

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ABSTRACT

The lithological structure of the hydrothermal clays of the main thermal fields of the Pauzhetka hydrothermal system and the Koshelevsky volcanic massif located on the southern tip of the Kamchatka Peninsula (Russia) was studied in detail by means of pits and core holes. Hydrothermal clays form a single geological body and have a layered-block structure, an average thickness of 1.5-3.0 m and a length of more than 500-1000 m. The composition of hydrothermal clays depends on the composition and structure of primary (initial) rocks, hydrodynamic type of hydrothermal system, temperature, geochemistry of thermal waters and other factors. Mineralogical and geochemical criteria were defined for differentiation of horizons of the hydrothermal clay mass: both general and separate ones for the thermal fields of the area. A model of transformation of rocks into hydrothermal clays incorporating the influence of deep-seated metalliferous fluids on the hypergenesis zone of a modern hydrothermal system is suggested.

1. INTRODUCTION

Argillized rocks and hydrothermal clays, in particular, were in focus of many studies because these hydrothermal-metasomatic new formations widely occur in volcanic areas and they convey much information (Eroshev-Shak, 1992; Naboko, 1980; Rusinov, 1989; Hemley, Jones, 1964; Reyes, 1990). Based on a detailed layer-by-layer study of hydrothermal clays forming a single sufficiently thick and extended mass on thermal fields, the team of authors established a special role of such an “independent” geological body. The mass acts as an upper water-confining stratum, a heat shield and a complex geochemical barrier within the structure of the modern hydrothermal systems and geothermal fields (Rychagov et al., 2009). By the example of the main thermal anomalies and separate thermal fields of the Pauzhetka-Kambalny-Koshelevsky geothermal (ore) region of South Kamchatka, a comparative description of the structure and formation conditions of the clay mass is provided with consideration of its mineralogy, micro- and nanostructure, and geochemistry; separate lithological sections are demonstrated (Rychagov et al., 2012). At the same time, the long-term studies enabled the team to gather a great deal of data on the lithology of hydrothermal clays, which is the basis for understanding the conditions for the formation of argillized rocks and their mineral (ore mineral) associations. This work summarized the data on the lithological structure of the hydrothermal clays and argillized rocks of the Nizhne-Koshelevsky thermal anomaly and the East Pauzhetka thermal field.

2. LITHOLOGICAL STRUCTURE OF MASS OF HYDROTHERMAL CLAYS OF NIZHNE-KOSHELEVSKY THERMAL ANOMALY

The thermal anomaly is located on the western slope of the Koshelevsky volcanic massif (a complex volcano of the Quaternary age) and is confined to the central part of the largest in Kamchatka and widely known Nizhne-Koshelevsky vapour-dominated geothermal field (Pisareva, 1987; Rychagov, 2014). The geological setting of these sites **(Figure 1)** has been described in many papers, therefore we will dwell directly on the properties of the mass of hydrothermal clays. The thermal anomaly is located in an oval-circular negative geomorphological structure stretching to 500 m along a deep ravine cut by the Gremuchy creek **(Figure 2)**. Based on about 40 entries (pits and core drilling wells), it was established that the mass forms a single geological body extending over the geomorphological structure for a distance of more than 500 m. The thickness of deposits in hot areas ranges from 1.5-2.0 to 3.0 m. The base of the mass is a roof (eluvium) of lava flows of andesites: fragments of these rocks prevail in all cross-sections. The mass of hydrothermal clays is mainly layered: varied composition horizons are extended along the strike of the thermal anomaly (from east to west). High-amplitude (up to 110-130 cm) vertical displacements of horizons are observed across the strike of the anomaly and at separate thermal manifestations such as Bolshaya Sukhaya Voronka (‘Large Dry Funnel’), Central and West areas. Such displacements (downthrows?) probably occur due to the active underground circulation of water streams and a vapour-gas mixture around thermal lakes and ridges, as well as due to the manifestation of landslide processes on the steep slopes of the V-shaped valley of the Gremuchy creek.

Relatively clear mineralogical and geochemical criteria were obtained for identification of three horizons of hydrothermal clay mass **(Figure 3)**. The clays of the sulphuric acid leaching zone are differentiated by high concentrations of Ti, Al, Fe, and low concentrations of basic alkaline elements and silica. This distribution of chemical components correlates with the mineral composition: low content of silica minerals and sulphides and high content of sulphates of several metals. The horizon of intensively pyritized clays, so called “blue clays”, is distinguished in all sections of the thermal anomaly. Its thickness reaches 1.3–1.5 m (0.8–1.0 m on average). “Blue clays” have average values of most of the chemical and mineral components shown in the diagram (see Figure 3). This horizon is of particular interest in terms of studying the conditions of transport of ore elements in the mass of hydrothermal clays. In general, the entire thickness of hydrothermal clays of the Nizhne-Koshelevsky thermal anomaly, in contrast to the Pauzhetka thermal fields, is marked by a high content of pyrite and other sulphides (marcasite, cinnabar, and

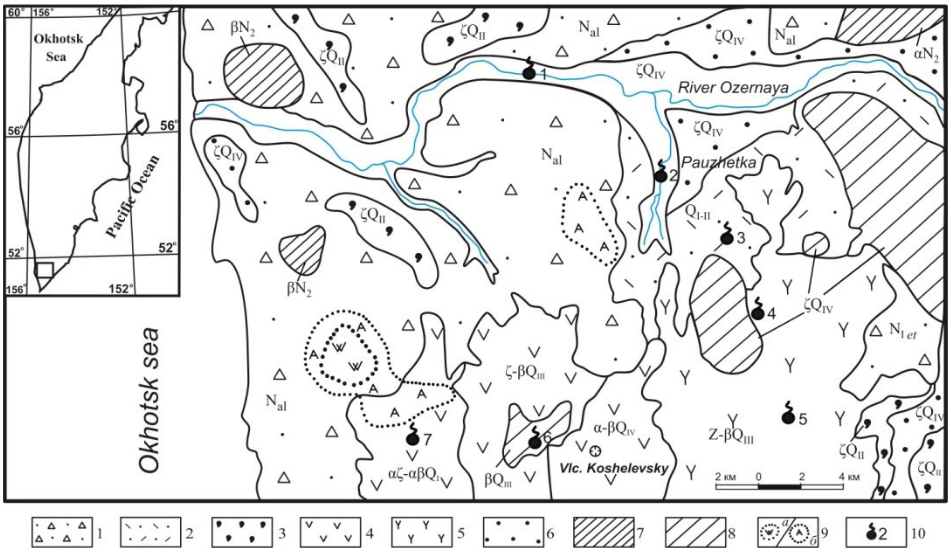

Figure 1: A schematic geological map of the Pauzhetka-Kambalny-Koshelevsky geothermal (ore) region of South Kamchatka. The map is plotted based on compilation of data obtained from scientific research and state geological surveys on a scale of 1: 200 000. 1 - lavopiroclastic deposits of the basement (N_{al}, Alneyan suite, Neogene); 2 - volcanogenic-sedimentary deposits (tuffites) of the Pauzhetka suite of the Lower Middle Quaternary age (Q_{I-II}); 3 – Middle Quaternary ignimbrites (Q_{II}); 4 - Koshelevsky volcanic magma complex array: Quaternary age andesidacites – andesibasalts of western part ($\alpha\zeta$-$\alpha\beta Q_I$), Middle Quaternary dacites – basalts of central portion (ζ-βQ_{III}), Upper Quaternary andesibasalts of eastern part (α-βQ_{IV}); 5 – lava-extrusive complex of rocks from dacite to basalts of the Kambalny volcanic ridge (ζ – βQ_{III}); 6 - pumiceous deposits of dacites – rhyolites of Upper Quaternary age (ζQ_{IV}); 7 – subvolcanic and extrusive bodies of the essential composition of Neogene age; 8 – same of contrasting composition (from basalts to dacites) of Middle-Upper Quaternary age (βQ_{III}, ζ – βQ_{III}, ζQ_{IV}); 9 – fields of secondary quartzites (a) and argillisites (b) in the area of the Tret'ya Rechka Paleohydrothermal System; 10 – main geothermal anomalies: 1 – Perviye Goriachiye Kluchy (Pioneer Camp), 2 – Vtoriye Goriachiye Kluchy (Pauzhetka geothermal field), 3 – Severo-Kambalny, 4 – Tsentralno-Kambalny, 5 – Yuzhno-Kambalny, 6 – Verkhne-Koshelevsky, 7 – Nizhne-Koshelevsky.

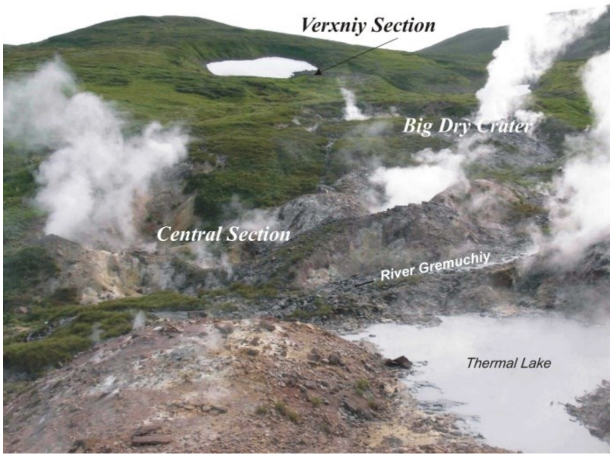

Figure 2: Main part of Nizhne-Koshelevsky geothermal anomaly. View from SW to NE. Photo by S.N. Rychagov.

sphalerite are detected) "infested" with Au, Ag, As, Cu, Hg and other elements. Elevated concentrations of many chemical elements in pyrite are probably the result of the influence of the Koshelevsky hydrothermal system on the zone of hypergenesis of deep-seated metal-bearing solutions saturated with reduced gases. The base of the mass is an eluvium or breccia of lavas of andesites and is distinguished by high values of silicic acid, alkali and rare earth elements. Silica minerals precipitate in intensely fissured and brecciated andesites from the hydrotherms rich in dissolved and colloidal silicic acid, basic and rare alkalis, and rare earth elements. It is known that the minerals of the smectite group and other mixed-layer minerals have a high sorption capacity and ability for cation exchange. These properties of clay minerals largely justify the enrichment of the base of the clay mass with alkaline and rare metals.

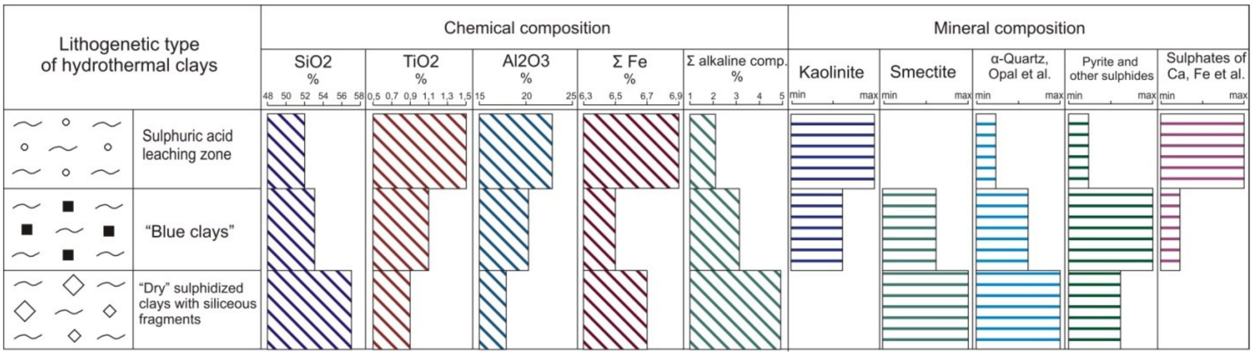

Figure 3: Lithogenetic types of hydrothermal clays and criteria for their identification.

3. LITHOLOGICAL STRUCTURE OF MASS OF HYDROTHERMAL CLAYS OF EAST PAUZHETKA THERMAL FIELD

The East Pauzhetka thermal field is situated on the eastern flank of the Pauzhetka geothermal field at a distance of up to 2 km from the production sites **(Figure 4)**. It was established earlier that the field development did not change the temperature and geochemical regime of the thermal field (Feofilaktov et al., 2017), unlike the central part of the hydrothermal system (Structure ..., 1993). Due to preservation of the natural regime and the original structural-geophysical and mineralogical-geochemical data obtained in recent years, the East-Pauzhetka thermal field presents a considerable interest. 21 mine entries were made to study the structure and composition of the rocks that compose the thermal field. The mass of hydrothermal clays and argillized rocks at the base of the cross-section was intersected. The mass has a stratified structure **(Figure 5)**. The upper horizon is represented by typical clays of the sulphuric acid leaching zone. The clays are composed of kaolinite, hydroxides and iron oxides, sulphates of Fe-Ca-Mg-..., pyrite, marcasite (traces), and opal. Native sulphur is observed. The clays are non-homogeneous due to the presence of a large number of lenses, spots and other similar structural fragments with different mineral composition and physical properties. A layer of black and red hematitized clays of semi-solid consistency with an inherited pseudomorphic block structure of the original rocks, that of andesite lavas, is identified at the base of the horizon. The horizon is extended over the entire area of the thermal field with thickness increasing from 50-80 cm in the hot area to more than 300-350 cm at the edge. The horizon of the montmorillonite clays of the carbon dioxide leaching zone underlies it. The horizon is also extended along the strike and in the thermal field cross-section (it is wedged out at separate hottest areas – near thermal pots and vapour-gas jets). The average thickness of the layer is 150 cm, sometimes reaches 250 cm. The clays are composed of montmorillonite (kaolinite is rarely observed), α-quartz, opal, pyrite, marcasite. Many crusts, lenses, films and thin veinlets of opal and α-quartz, and much finely disseminated pyrite scattered in the mass typically occur. Pyrite also forms monomineral veinlets. The clays have special physical properties, i.e. high plasticity: from semi-solid to soft-plastic and hidden soft consistency. As noted earlier, the horizon of soft clays acts as an excellent water-confining stratum and a thermal insulator, and it plays a crucial role in the formation of mineral ore associations within the structure of the East-Pauzhetka thermal field (Rychagov et al., 2017).

Figure 4: Pauzhetka geothermal field and East-Pauzhetka thermal field (in the foreground). Photo by M.S. Chernov.

The horizon of “dry” sulphidized clays is extended along the strike of the thermal field and has a thickness of 20–150 cm in the hot area and up to 200 cm in the “cold” one. The sediments are smectite clays; there is transition from kaolinite to smectite and an abundance of relatively uniformly dispersed coarse-crystalline (up to 2-3 mm) pyrite and semi-decomposed andesite fragments in the upper layers of the horizon. Presence of a large amount (up to 15-25% by volume) of fragments similar in shape to fragments but saturated with siliceous matter is characteristic. The distribution of such fragments is uneven: they form interlayers, lenses, “spots” in the main clay matrix, and are characteristic of the hottest area of the thermal field. Most likely, the fragments are formed metasomatically by replacement of the fragments of andesites with silica minerals and smectites. Deposits are represented by typical “blue clays” (largely sulphidized) at the edge of the thermal field with the thickness of the horizon increased. The tendency of the horizon thickness increase from hot to colder areas is also observed in the other cross-sections. The clay substrate of these deposits is distinguished by a high open fracture-pore permeability and the presence of a large amount of minerals (Fe, Cu, Zn sulphides, as well as iron oxides) with elevated electrical conductivity (Feofilaktov et al., 2017). The horizon includes vein zones with mineral ore associations: phosphate-aluminosilicate-sulphide, siliceous-carbonate-sulphide and combined more complex composition (Rychagov et al., 2017). Below is a horizon that differs from “dry” sulphidized clays by presence of a large amount of semi-decomposed debris (fragments) of andesites and small (up to 1-2 cm) fragments and lenses composed of opal (α-quartz, chalcedony) and smectites. The clays are lumpy and drier, which indicates an increase in the temperature of soils to the base of the cross-section (up to 105°C and higher). The horizon of these argillizites extends along the strike of the thermal field with the thickness sharply increasing in the cooling area.

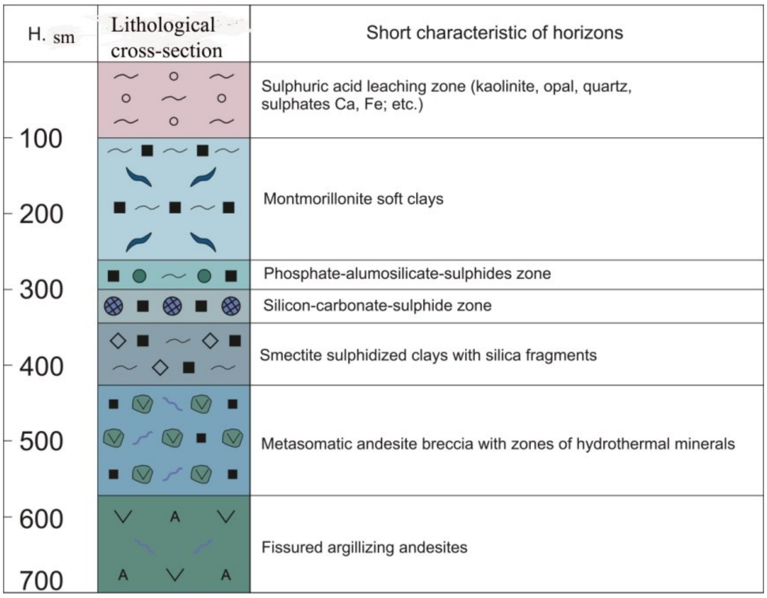

Figure 5: Section of the mass of hydrothermal clays of the East Pauzhetka thermal field.

The base of the hydrothermal clays is represented by fractured and brecciated strongly argillized andesite lavas. Metasomatic breccias along andesites form a large block at the base of the clay mass in the eastern part of the field. We describe these rocks as metasomatic breccias according to the classification of M.M. Konstantinov (Konstantinov, 1977). Fragments of primary andesites are either rounded or with soft edges, and consist of smaller fragments displaced relative to each other due to the formed hydrothermal-metasomatic cement. The cement is the association of secondary minerals: smectites + chlorites + quartz + opal + carbonates + zeolites + sulphides. Separate rock sections consist of relatively less altered but fractured andesites. Macro cracks with a thickness of up to 10–15 mm are mostly filled with silica minerals and iron oxides, as well as carbonates, zeolites, and pyrite. Micro cracks can be traced due to staining with Fe hydroxides. The andesites of the base include lenses and geodes filled with a quartz-opal-carbonate-zeolite aggregate; in some cases, monomineral formations are observed. The lenses and geodes reach 20×50 mm in size. The wells also intersected zones entirely consisting of secondary minerals. The thickness of the zones is above 15-20 cm. The composition is complex and includes the secondary minerals listed above, as well as iron oxides; large pyrite crystals form on the walls of caverns; the green colour of the fragments is due to the occurrence of chlorite-smectites, chlorites and hydromica. In general, the base of the mass of hydrothermal clays is composed of fractured strongly argillized andesites including hydrothermal alteration zones. The thickness of zones and the intensity of hydrothermal alteration of andesites increase with depth.

The noted features of the composition and structure of the clay mass reflect the distribution of chemical composition of the deposits over the horizons. The horizon of argillized andesites is distinguished by high concentrations of alkali and alkaline earth elements, Mn, SiO_2; often – P; low – Ti and Al. The horizon of “dry” sulphidized clays including “blue clays” is primarily distinguished by high levels of phosphorus and, to a lesser extent, alkaline components and silicic acid. Montmorillonite plastic clays are characterized by low concentrations of iron, manganese, alkali, as well as by complex distribution of other components. The clays of the sulphuric acid leaching zone are marked by high contents of titanium dioxide and iron oxides, which is caused by subtraction of iron from the original rocks and by its concentrating in the form of limonite, goethite, and hematite in the oxidation zone. The increase of the content of Ca, Mg, Na, K and P (as well as rare alkaline, rare-earth and many other elements) with depth is probably due to the fact that the local conditions of increased fracture-pore permeability promote discharge of ascending mineralized thermal waters and smectite prevailing in clays is a good sorbent of many metals. This common trend is violated in the horizon of dark-grey “dry” clays, where the concentration of alkaline elements decreases to a minimum, the Al_2O_3 content increases (up to 30% versus an average of 15-22% for the stratum); the phosphorus content is largely variable. This is due to the fact that ore mineral associations form in this horizon.

4. CONCLUSION

The structure and composition of hydrothermal clays that form quite thick and extended masses on the surface of the thermal fields of South Kamchatka are studied. The base of the hydrothermal clay mass is composed of argillized rocks with zones of intensive hydrothermal alterations. The masses of hydrothermal clays of different thermal fields differ in their structure, chemical and mineral composition, which is governed primarily by hydrodynamic conditions, the duration of the influence of hydrotherms on host rocks, and the composition of a deep-seated fluid. A reduced hydrocarbon fluid impacts the thickness of the clay of the Nizhne-Koshelevsky thermal anomaly, the clays are intensively “washed” with steam condensate, and the sulphidized “blue clays” actively form. The mass of hydrothermal clays of the East Pauzhetka thermal field have been formed for a long time (probably during the Holocene), mineral ore associations are formed in the argillized base rocks of the mass due to the discharge of an alkaline metal-bearing solution. The most probable sources of phosphorus, alkali and rare metals are heat sources located in the depths of the Kambalny volcanic ridge that is the largest geothermal structure in Kamchatka.

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