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“Magmatism of the Earth and related strategic metal deposits”. Proceedings of XXXIV International Conference. Miass, 4-9 August 2017/Editors V.A. Zaitsev & V.N. Ermolaeva.-M: GEOKHI RAS, 2017. 345 p. - ISBN 978-5-905049-21-7.

The mineral deposits of strategic metals are vulnerable to political and economic changes, and their availability is essential for high-technology, green energy, and other applications. The most of them are related to the deep-seated alkaline magmas.

This book offers a collection of papers presented at the 34th International Conference on Magmatism of the Earth and Related Strategic Metal Deposits held from August 4th to 9th 2017 in Miass, Russia. The conference articles are focused on understanding of the geological processes that produce high concentrations of critical metals in geological systems such as the transport of metals in the mantle and crust and enrichment processes, hydrothermal and metasomatic processes leading to the formation of such significant deposits. Papers in this book give a representative overview including mineralogy, geochemistry and origin of strategic metals deposits.

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The cover pictures are geological map of the Urals and «Ridges of Ural» of E.V. Nikolsky

Evgeny Vasilyevich Nikolsky (1917-1978) was a famous Russian artist who lived in Miass. The main theme of his artworks was Ural landscape. He had been making his paintings in different styles and techniques, but most of all he liked to paint with watercolours. In 1969 with this type of paint he had made an artwork “Ridges of Ural” which was painted in the mountains of Southern Ural. Nowadays, this artwork is being kept in local museum of Miass. This year we celebrate the centenary of the birth of this artist.

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MINERAL ORE FORMATION IN ARGILLIZATED ROCKS OF PAUZHETKA HYDROTHERMAL SYSTEM OF SOUTH KAMCHATKA

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Argillizated rocks are widely developed in the volcanic regions. The study of formation conditions for such rocks and study of argillization processes' impact on origin of mineral deposits was addressed in research papers of many leading scientists of the world: D.S. Korzhinsky, S.I. Naboko, V.L. Rusinov, V.A. Eroshev-Shak, J. Hemley, W. Jones, A. Reyes et al. The authoring team focused on a special role of hydrothermal clays in the Quaternary and modern volcanism regions: they form extended strata in the upper layers of thermal anomalies (thermal fields) and act as a water-confining stratum and a thermal insulator within the structure of hydrothermal systems; a compex geochemical barrier is confined to the stratum of hydrothermal clays (Rychagov et al., 2009). It is demonstrated that these rocks represent a long-lived (throughout Holocene or longer) highly dynamic mineralogical-geochemical system that functions at macro-, micro, and nano-levels (Rychagov et al., 2010). In addition, the basis of clays stratum is especially interesting because mineral ore associations, never previously diagnosed in the research practice, are formed there (Rychagov et al., 2015). The objective of this work is to define composition, structure and conditions of mineral associations' origin in the zones that we studied in East-Pauzhetka thermal field (th/f).

East-Pauzhetka th/f is situated on the slope of the Kambalny volcanic ridge that is characterized as a resurgent tectonic magmatic high in the Pauzhetka caldera of the Quaternary age (The long-lived…, 1980). The thermal field is among the large zones where hydrothermae discharge within the structure of Pauzhetka system (Fig.1) but it has not been adequately studied due to a remote location of producing sections of the geothermal deposit. Th/f is confined to a ring tectonic magmatic high 400-500 m in plan size (Structure of geothermal..., 1993). The central section is distinguished by steaming soils heated up to 105ºC; steam-gas jets and boiling water-mud pots. The waters that are discharged on the surface are acid sulphate and low-acid hydrocarbonate-sulphate with wide cation composition and a general mineralization of ≥ 0.8-1.0 g/l. The steam condensate has a similar chemical composition.

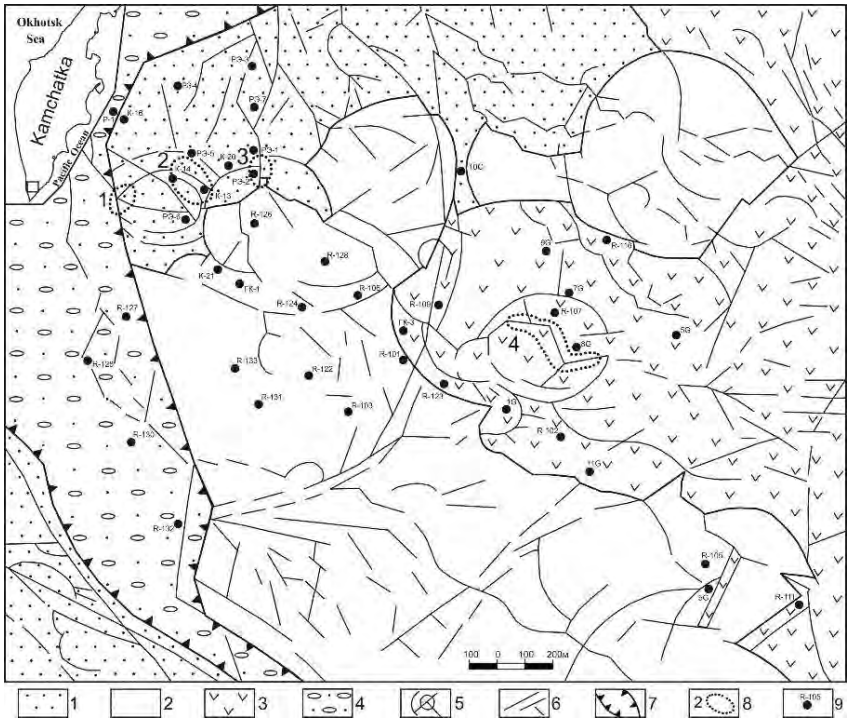

Fig. 1. An approximate geological map of Pauzhetka hydrothermal system.
1 – tuffites and tuffs of the Upper-Pauzhetka sub-suite of the Upper Neogene-Lower-Quaternary age; 2 – lava-extrusive complex of acid rocks of the Middle Quaternary age; 3 – andesites and andesibasalt of the Middle Quaternary age; 4 – alluvial boulder-cobble deposits; 5 – ring tectonic faults; 6 – linear tectonic faults; 7 – Pauzhetka trough of the Upper Quaternary age; 8 – thermal fields: 1 – South-Pauzhetka, 2 – Upper-Pauzhetka, 3 – Lower-Pauzhetka, 4 – East-Pauzhetka; 9 – drill holes.

The thickness of clays was established through prospecting pits (up to a depth of 4.0 m) and core drilling (up to 8.9 m). The stratum is characterized by zonal structure. The following layers with clear boundaries are distinguished (up – down): 1) clays of sulphuric-acid leaching composed of kaolinite and the minerals of alunite group (natroalunite, minamiit, ammoniojarosite, ammonioalunite, alunite, jarosite) contain iron oxides, pyrite, α-quartz, native sulphur; clays of dense and medium dense consistence; 2) clays composed of well-crystallized kaolinite, α-quartz, opal, feldspars, pyrite and marcasite (in subordinate quantity); these clays sharply differ in terms of consistence from overlying and underlying

ones: from stiff-high-plastic to very soft clay; 3) "blue clays" (saturated with pyrite and other sulphides) composed of kaolinite and smectite in comparable amounts as well as pyrite, α-quartz and opal: firm breccia-like clays due to solid fragments presented by silicified material; composed of smectite, pyrite, quartz, opal and others; the layer is transition to the firm basis of the stratum – fractured argillizated lavas of andesites. In general, it was found that the whole stratum of hydrothermal clays was formed *in situ* owing to hydrothermal-metasomatic changes of andesite lavas of the Kambalny volcanic ridge.

The layer of "blue clays" has a flat-dipping zone concordant with the general structure of the stratum and including mineral ore associations. The zone is missing in the clay stratum cross-cut of the Central (hot) area. At the boundary of the Central area, the zone consists of two layers (veins) with clear boundaries: the lower one is presented by siliceous-carbonate-sulphide deposits, the upper one is presented by phosphate-alumosilicate-sulphide ones. Both layers contain a large amount (up to 1-2 volume %) of regular round or flattened particles (globules) often forming aggregates by composition similar to the ground mass of the stratum from which they were singled out (Rychagov et al., 2015). The zone structure changes at a distance of 15-30 m from the area boundary: there, it has a single vein, thickness increases (from 0.4 to ≤ 0.6 m), chemical and mineral compositions become significantly more complicated. The vein globules are often flattened and form concretions-aggregates up to 25 mm in size. The aggregates are dense and massive. Their composition includes the following: carbonates, clay minerals, pyrite, quartz (and other silica minerals), iron oxides (mgnetite and titanomagnetite) and titanium (ilmenite), amphiboles, pyrite (up to 25 volume %). Based on data of infra-red spectroscopy, the main minerals, apart from pyrite, are magnesian calcite and smectite.

Microstructure of globules is varied (Fig. 2). The matrix is composed of pyrite (aggregates of crystals often have the ideal regular cubic shape, Fig. 2a), carbonates (banded microstructures, Fig. 2b) and smectite that forms cellular and globular shapes. Well-crystallized elongated phosphate crystals (most often apatite) in association with smectite and carbonates (Fig. 2c) are distinguished. A high content of other phosphates and pyrite micro crystals in the mass of alumosilicates is distinctive (Fig. 2d). A microglobular structure (Fig. 2e) and microbanding (Fig. 2f) of the surface of pyrite crystals due to formation of other mineral phases are revealed.

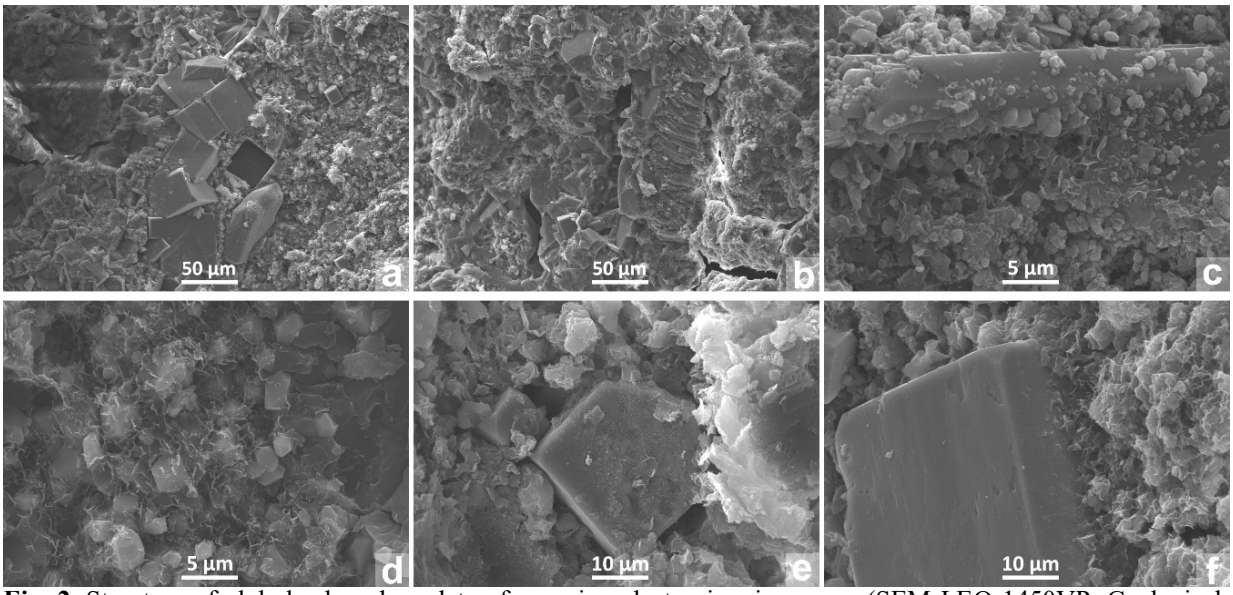

Fig. 2. Structure of globules based on data of scanning electronic microscope (SEM LEO 1450VP, Geological faculty of M.V. Lomonosov State Moscow University).

The studies by means of VEGA 3 scanning electronic microscope equipped with energy-dispersion spectrometer (EDS) X-MAX 80 with AZtec firmware (Institute of Volcanology and Seismology of FED RAS, Petropavlovsk-Kamchatsky, operator T.M. Filosofova) identified even larger variety of structures and composition of the globules (Fig.3). Many particles have a breccia-like structure of the ground mass (Fig. 3a): the cement is presented by carbonates and alumosilicates, whereas "chips" are presented by smectite, quartz, opal, iron and titanium oxides, phosphates and others. The most typical is a relatively homogeneous structure of globules, which is governed by dominance of carbonates in the ground mass. The carbonates include crystals of other minerals or pores lined with smectite, phosphates, oxides and others (Fig. 3b). A system of micro fissures in crystals and in the main matrix is pronounced. A zonal sequence caused by the mineral phases of titanium is also characteristic; the zone sequence of the ground mass is governed by distribution of phosphates (hydrous phosphates Al, Fe, Ca, Na and others) (Fig. 3d); the zone sequence in carbonates is governed by an elevated content of Mn (до 12-15 %) in separate microbands (Fig. 3e). Phosphates form micro-nanoglobular structures (Fig. 3f). Rare earh mineralisation in the form of miniscule (up to 5 µm) crystals that are concentrated around pores and micro fissures (Fig. 3g) is detected. Large crystals (up to 1.5 – 2.0 mm) of edenite amphibole (Fig. 3h) are identified. Edenite was also diagnosed based on X-ray powder diffraction and electron-probe microanalysis performed in the resource centres of St. Petersburg State University (operator E.S. Zhitova).

In general, the mineral composition of ore zone depositions include calcite, magnesian calcite, manganocalcite (the content of Mn reaches 12-15 wt. %), smectite, kaolinite (in subordinate quantity among alumosilicates), quartz and opal, epidote, K-feldspar, amphibole (edenite), apatite, sphalerite, chalcopyrite, ilmenite, rutile, titanite, magnetite and titatomagnetite, zircon, hydrous phosphates (the most probable are phosphates Al, Na, Ca, Fe, Mn: variscite, metavariscite, the minerals of wicksite group). Based on data of ICP MS (quadrupole mass-spectrometer Agilent 7500ce, Geochemistry institute SB RAS, Irkutsk, research associate G.P. Sandimirova), higher contents (up to 1 order) of rare alkaline (Li, Rb, Cs) and base alkaline elements (Na, Mg, K, Ca), As, Ba, rare earth and other metals (La, Ce, Nd, Eu, W, Tl, Th) in the composition of both the globules and ground mass of the zone are detected.

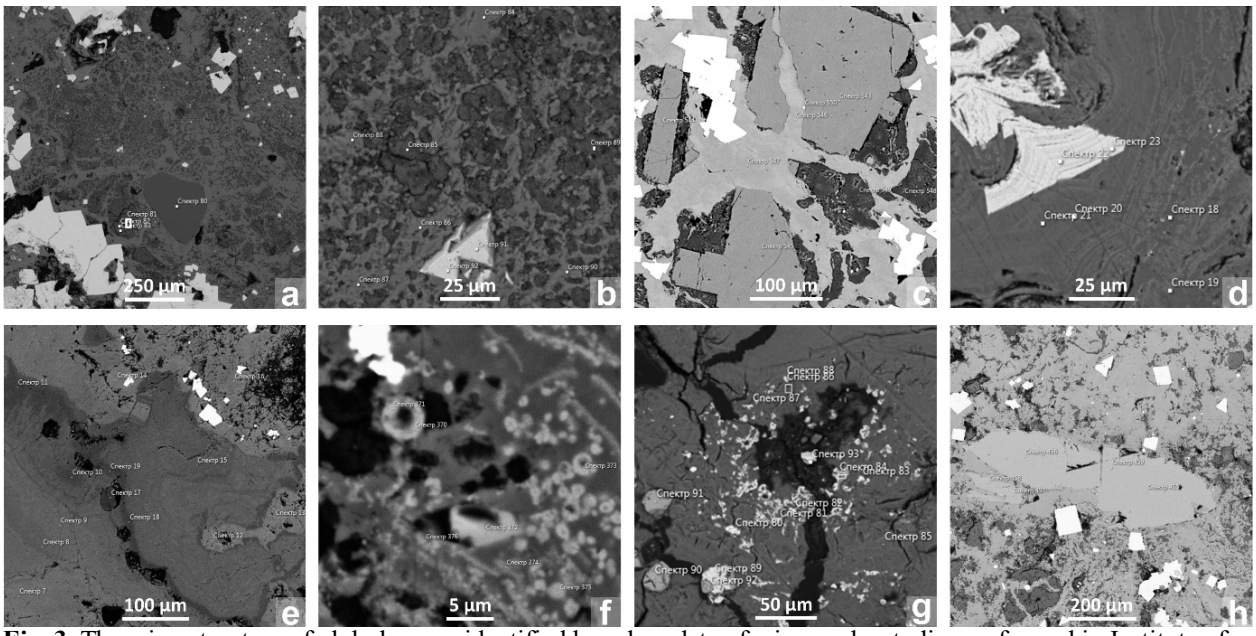

Fig. 3. The microstructure of globules was identified based on data of microprobe studies performed in Institute of Volcanology and Seismology of FED RAS.

On the basis of complex geological-geochemical and mineralogical studies, the following model of ore zone formation in the stratum of geothermal clays is suggested. In the hypergenesis zones of modern Pauzhetka hydrothermal system, bed rocks (andesite lavas) are altered into clays under the impact of acid sulphate and hydrocarbonate-sulphate waters. Long evolution of the field (probably, throughout the Holocene) resulted in the formation of a layer of ductile clays with the properties of the upper water-confining layer and heat-insulating layer. This served as an additional factor for formation of decompacted, penetrable for hydrothermae, zones in the basis of the clay stratum (as a rule, the basis of the stratum is confined to the foot or top of lava flows having a higher primary fracturing and brecciatedness of rocks). Introduction of a high temperature alkaline chloride-hydrocarbonate solution into the decompacted area caused its intense boiling, cooling and supersaturation with respect to silica minerals, carbonates, sulphides and formed the corresponding mineral association. Then, this solution mixed with near-surface sulphate waters, became supersaturated to other phases (phosphates, first of all) and phosphate-alumosilicate-sulphide association was formed. As a result, the ore vein with a distinct zone sequence formed. Apparently, the change of structure and complication of the ore vein composition along the strike from the thermal field's Central (hot) area to its boundaries and formation of the single zone can be attributed to a lateral spread of hydrothermae (Structure..., 1993) and further influence of an ascending alkaline hydrothermal fluid on the stratum of hydrothermal clays. The most probable source of phosphorous, alkaline elements, barium, arsenic, REE element and other rare elements are magmatic magma chambers of the Kambalny volcanic ridge.

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