Hydrothermal-Magmatic Systems of Insular Arches and Some Geotechnologycal Problems

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Abstract

The purpose of this work is creating the complex geological-geochemical model of evolution of a typical long-living (beginning from thousands and up to hundreds of thousands years and even more) hydrothermal-magmatic ore-generating system of the Kuril-Kamchatka insular arch. This model is considered as the basis for development of estimation and safety use of the richest thermal, water and mineral resources of recent and ancient volcanism areas. Specific examples were used to ground existence and show formation stages of hydrothermal-magmatic ore-generating systems of the area of ocean-continent transition. The hydrothermal-magmatic system geological structure is studied and thermo-controlling zones as well as ore-controlling ones are distinguished. The structure of areas of near-surface and abyssal solution intensive mixing and water boiling as well as geochemical barrier zones is shown. New conceptual models of hydrothermal-magmatic ore-generating systems are offered. The work has been done with a financial support of the Russian Fund of Fundamental Research (project 06-05-64689a), Presidium of Far East Division RAS (projects 06-III-A-08-332 and 06-III-B-08-371) and Russian Association of Geothermal Energy Society.

Introduction

Studies, exploration and exploitation of geothermal deposits have been long conducted in many countries. In large, this trend of fundamental science and technology – the study and exploitation of geothermal deposits – has good social and economic prospects worldwide. Russian scientists gained a significant experience in study and exploitation of near-surface low temperature therms and vapor hydrotherms deposits. Nevertheless, exploration and exploitation of deposits in Russia are still at the level of pilot production. Beside general economic reasons, it is due to instability of many parameters of near-surface deposits and the complicated structure of hydrothermal systems in the deep levels. Near-surface geothermal deposits are characterized by low P-T parameters and limited resources with a heat carrier having aggressive properties. These factors induce fundamental science and geothermal energy operations to study the deep levels of hydrothermal systems. However, the researches are carried on is specialized, that does not give possibility to create complex model of evolution of long-existing ore-forming hydrothermal system. The development of conceptual models for formation conditions of epithermal ore and geothermal deposits, deep drilling of present-day hydrothermal systems and data on the composition of a restored endogenic fluid allowed to make the definition of volcanic-magmatic-hydrothermal systems (Giggenbach et al., 1990). Based on a large joint team research work at volcanoes and hydrothermal systems of present-day and ancient island arcs, we located long-living ore-forming hydrothermal-magmatic systems.

The Hydrothermal-Magmatic System Types

The high-temperature hydrothermal-magmatic systems under study belong to the systems associated with insular-arch andesite volcanism according to the geological-hydrochemical classification by R. Henley and A. Ellis (Henley, Ellis, 1983). The near-surface geological structure and local hydraulic gradients are of great importance for the formation of high-temperature system discharge centers. At the same time it is well known that the hydrothermal cell abyssal part is concentrated around subvolcanic bodies (intrusions?) located within the boundary of the tectonic-magmatic structure axial zones (the Vernadskogo and Karpinskogo volcanic ridges in Paramushir island, the Ivana Groznogo volcanic ridge in the central part of Iturup island and the Kambalny one in the south of Kamchatka). The series of geologists studying the recent and paleohydrothermal ore-forming systems mark out two types of high-temperature ($T>150^0$) hydrothermal systems as per sulphur oxidation condition: low sulfidation and high sulfidation (Hedenquist, Houghton, 1987). Majority of recent hydrothermal-magmatic systems belongs to the “low sulfidation” type. There H_2S is a dominant sulphur-containing compound in the convective cell upper part. The temperature in hydrothermae is $170\text{-}270^0$ C at the depth 50-1000 m. The diluted chloride hydrothermae are the basic type of solutions in such well-studied systems. In the chemical composition of hydrothermae chlorine in a dominant anion and it is accompanied by

Na^+, K^+, Ca^{+2} and silica as well as by gas with varying concentrations (mainly by CO_2 the quantity of which can prevail over chlorine and H_2S) and there are small concentrations of other elements including metals. Research of the systems of high sulfidation type was started due to exploring auriferous epithermal deposits. Enargite, pyrit, tennantite-tetrahedrite, covellite and/or alunite and often porous quartz that is the product of hydrolytic leaching are found in the hydrothermally altered rocks of this deposits. The ore zones which are strictly localized by the structural elements and connected with the breccia formed by phreatic eruptions occur everywhere in the narrow interval of depths – often within first dozens of meters. Gradual transition from leached residual silica to quartz-alunite, quartz-kaolinite, clays (illite-montmorillonite and smectites) and propylitization zone is observed (Stoffregen, 1985). Kaolinite, dickite, pyrophyllite, diaspore, K-mica, native sulphur, barite and anhydrite are the important compound in the enclosing rock. In the whole sulphate and chloride-sulphate hydrothermae are dominant there. Low pH (less than 2), the facts indicating that there are solutions with high mineralization (brines) and relatively oxidized conditions, high hypsometric marks of volcanogenic structures et al. are the evidence that magmatic fluid quotas in the composition of solutions of "high sulfidation" type is great (as per isotopic data it varies from 5-7 up to 9-12 %). These systems are located in the upper part of complex andesite volcanoes such as Ebeko (Paramushir island) and Koshelevsky (South Kamchatka).

The Hydrothermal-Magmatic System Stages

The systems of progressive stage of development. According to geological and hydrogeological researches, the hydrothermal system of Baranskiy Volcano is characterized by high temperatures of a heat conductor (300-320^{0}C at a depth of 1000-1100 m, in some blocks - 200^{0}C already at a depth of 50 m), by large gradients of temperatures (up to 50^{0}C/100 m), by a significant heat flow in two localities – Starozavodskoye Pole and the Kipyashchaya Rechka (up to 71,000 kcal/sec total capacity). The hydrothermal-magmatic system of Baranskiy Volcano is situated on the southwestern slope of the Late Quaternary andesite volcano of the same name at the center of the Middle-Late Pleistocene (?) Kipyashchaya caldera. The data presented above suggest that an active of hydrothermal and metasomatic alteration is going on in the volcanic, volcano-sedimentary, and intrusive rocks of the Baranskiy hydrothermal-magmatic system under the effect of high-temperature (300^{0}C or more), fissure and fissure-pore H_2S-CO_2-SO_4 and Cl-Na-CO_2-NO_2 waters. The medium- and high-temperature propylites (300-450^{0}C) of the quartz-chlorite-albite-mica composition occur at the base of the sequence (more than 500 m below the surface) or in the contact aureole of the inferred large diorite body. At higher levels they are replaced by low- to medium-temperature quartz-chlorite-calcite-zeolite propylites. The process of propilitization is terminated by the formation of quartz-calcite-zeolite-hydromica rocks with abundant mixed-layer illite-smectite minerals and montmorillonite. The liquid-vapor transitions zone is formed under different thermodynamic and geochemical conditions. The hydrothermal mineral formation occurs there in a wide temperature range, from 300-250 to 200-170^{0}C and lower. This fact indicates an abrupt drop of rock temperature in the course of hydrothermal boiling due to adiabatic expansion. The onset of boiling may initiate the inflow of cold meteoric or sea water through open faults. These zones are geochemical barriers for Au, Ag, K, As, base metals, and rare alkalis (Rychagov, 1993), which record P and T drops along with changes in the composition and phase state of the fluid. Metallic elements may amount to high concentrations in lenses and veins varying from a few centimetres to tens of meters in thickness. The zones of liquid-vapor transition are commonly found in horsts **(Fig. 1)**.

The systems of extremal stage of development. Mutnovskaya hydrothermal-magmatic system (the South Kamchatka) it´s the typical system of extremal stage of development. Geology and structure of the Mutnovsky geothermal area are defined by its disposition in graben-syncline of the South Kamchatka. Palaeogene-Neogene volcanogenic and volcanogenic-sedimentary rocks, having high fracture permeability, constitute a water-bearing complex, the structure of which is distinguished by a significant complexity in section and on the strike. Pliocene-Quarternary formations are less permeable except for lava flows, dissected by contractional fractures. The rocks of Pliocene-Quarternary age often occur upon layers of loose or weakly baked pyroclastics, compacted by ancient hydrothermal processes, or upon volcanogenic-sedimentary and sedimentary deposits. These layers and deposits act as a relative upper water-confining stratum. The structure of the upper water-confining complex is complicated, its continuity is disrupted by numerous dykes, extrusions, maars, diatremes and fractures. These geological bodies intricately influence the structure of the water-confining complex. Silicification and argillization of rocks significantly reduce permeability of magmatic bodies included into the

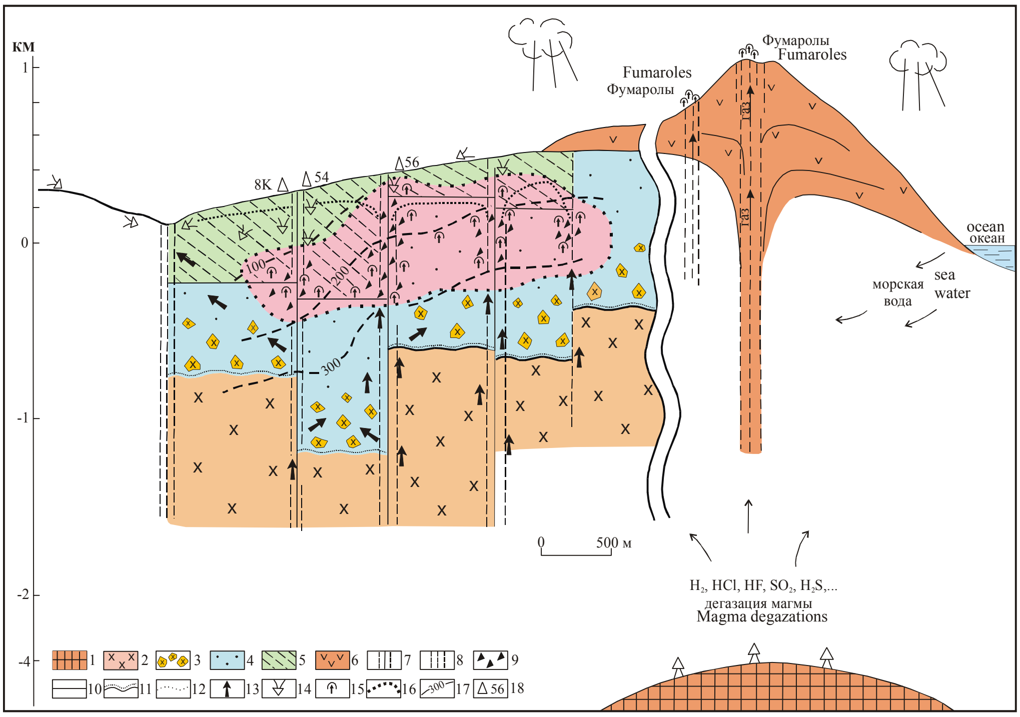

Fig. 1. The geological-geochemical model for the present-day (typical long-living ore-generating ?) Baranskiy hydrothermal-magmatic system (Rychagov, 2005). 1-Magmatic chamber; 2-subintrusive diorites; 3-intrusive tuffs (breccias); 4-Parus sequence; 5-Lebedin sequence; 6-Quaternary andesites; 7-tectonic faults, proved; 8-same, probable; 9-hydrothermal breccias; 10-lithological boundaris; 11-intrusive boundaries; 12-boundary of distribution of argillizities; 13-ascending flux; 14-descending flux; 15-vapor-dominated zones; 16-zone of ore mineralization. 17-isotherms; 18-boreholes.

structure of the water-confining complex of the Mutnovsky geothermal area. Holocrystalline intrusions of gabbro and diorites localized beyond tectonic deformation zones are practically impermeable too. Extrusion rocks transform into caolinite and montmorillonite clays or opalitic siliceous formations under influence of steam-heated hydrotherms (acid solutions of surface formation) or under influence of acid deep-level hydrotherms a significant part of which consists of high-temperature magmatic gases. These processes reduce permeability of the upper parts of extrusions, and they act no more as drains feeding deep-level water-bearing complexes with meteoric waters. Accordingly, nearsurface hydrothermal activity in the Mutnovsky hydrothermal area leads to formation of broad fields of argillized-opalitized rocks acting as an additional thick water-confining layer and a heat insulator.

The systems of regressive stage. Pauzhetka long-existing ore-forming hydrothermal-magmatic convective system (the South Kamchatka) is localized in the central part of the Koshelevsk-Pauzhetsk volcanogenic-ore center. The block structure of the hydrothermal-magmatic system is not homogenous. Ascending fluxes of hydrothermal fluid are confined to isometric elevated blocks of rocks. Thermal fields at surface mark the most heated sections. The thermal fields occur at the borders of tectonic uplifts or in their axial structures. Liquid-steam transition zones and zones of loosened rocks in the form of various breccias are formed in these isometric circular blocks. During evolution hydrothermal processes underwent the following successive stages of alterations: a) medium-temperature propylitization (chlorite + albite + epidote + pirite + leucoxene), within a range of temperatures of 350-330 to 280^{0}C; b) intensive and vast zeolitic (chlorite + lomontite + vairakite + analcime + prenite) and limited Transylvanian (illite + carbonate + quartz + chlorite + pirite + sphen) low-temperature propylitizations within a range of temperatures of 300-280 to 200^{0}C; c) hydrothermal argillization of propylites (mixed-layer minerals) within a temperature range of 200-150^{0}C. Quartz-adular, epidote-quartz-adular, vairakite-prenite-epidote-quartz-adular metasomatites at temperatures of 330-300 to 170-150^{0}C are formed in the liquid-steam transition zones during low-temperature propylitization and argillization: zones are the geochemical barrier. High-siliceous zeolites and dioctahedral smectite develop at a temperature of 150-80^{0}C in acid tuffs, andesites and dacites near surface. Under anomalous conditions when high-temperature isotherms were neared to surface due to intensive fracturing of rocks over the heat source, zeolitic propylites formed in the upper water-confining horizon. Clay-formation processes at temperatures below 100^{0}C occur in the thermal fields owing to chloride-carbon dioxide (dioctahedral smectite) and sulfur acid (caolinite) leaching. Successive stages of metasomatic alterations of rocks resulted in co-localization of high-temperature minerals with low-temperature ones. Thermobarogeochemical studies showed that the hydrothermal process had been multi-staged: mineral-formation occurred under conditions of temperature decreasing from 350-330 to 200-150 and to 100-50^{0}C in some separate blocks of the system. Concentrations of salts in solutions were decreasing at this. Low-temperature propylites are most common at the Pauzhetka geothermal deposit. Lomontite, i.e. intensively manifested zeolitic propylitization, marks the main ways of fluids movement. Blocks of rocks lacking mixed-layer minerals are somehow isolated from influence of the present-day fluids. Thus, hydrothermal-magmatic convective systems of the regressive development stage have certain peculiarities of geological structure evolution (as a rule, it is formation of thick caldera complexes and large artesian basins); they inherit the structure of hydrothermal-magmatic systems of the preceding stages (a contrast system of “hot” and “cold” blocks of rocks); gradual separation of magmatic and hydrothermal convective cells takes place in their interiors (cooling of intrusive and subvolcanic feeding bodies, degradation of an ascending flux of steam-hydrotherms, the intensive development of ore material re-distribution processes in separate blocks of the structure).

Conclusion

This way, in connection with the elaboration of conceptual models for formation conditions of epithermal ore and geothermal deposits and based on drilling material from deep and super-deep boreholes at present-day hydrothermal systems, new geological structures have been identified: long-existing ore-forming hydrothermal-magmatic convective system in the ocean-continent transition zone. These through-crust draining systems govern the transfer of thermal energy, melts, gases, hydrothermal solutions and chemical elements from the upper-mantle level to the near-surface horizons of the crust. These systems not only control heat mass fluxes in the ocean-continent transition zone but also generate energy and matter. The geological structure of a hydrothermal-magmatic system represents an hierarchic system of circular, oval-circular and differently-shaped blocks of rocks. Geological structure at each hierarchic level has the following pattern: blocks of rocks with contrasting physical-mechanical, petrologic, mineralogical-geochemical and other properties alternate laterally and in vertical profiles. They form a peculiar block-mosaic geological structure out of relatively monolithic (hard, dense, impermeable) and decompacted portions. The decompacted portions are most permeable for the fluxes of hydrothermal-magmatic fluids. Ascending fluxes of steam-hydrotherms and gases are, as a rule, confined to the central parts of hydrothermal-magmatic systems and are localized in axle zones and along the borders of relatively elevated isometric-circular blocks of rocks; meteoric waters and «exhaust» hydrothermal solutions infiltrate up-down through fissures and cause cooling of rocks in the submerged blocks. In this manner, a series of lesser size convective cells each of which includes both an elevated (hot, permeable) block and submerged (cooled, monolithic) block is formed within the hydrothermal-magmatic system. Such a structure governs the dynamics of gas and water fluxes, and, accordingly, allocation of ore-manifestations of various types: ore mineralization of the high sulfidation type – in the central part of a hydrothermal-magmatic system, and low sulfidation – at the periphery of systems and depths ≥ 1 – 1,5 km. Ore mineralization of the Au-Cu-…porphyry type is formed in the apical parts and brecciated mantle of large intrusive (subvolcanic) complexes, as a rule, multi-phase.

References

Giggenbach W.F., Garcia N.P., Londono A., et al. The chemistry of fumarolic vapor and thermal-spring disharge from the Nevado del Ruiz volcanic-magmatic-hydrothermal system, Colombia // J. Vol. Geotherm. Res., 1990. N 42. Pp. 13-39.

Hedenquist J.W., Houghton B.F. Epithermal gold mineralization and its volcanic environments. The earth resources Foundation the University of Sydney Taupo Vol. Zone, N.Z. 15-21 november, 1987.

Henley R.W., Ellis A.J. Geothermal systems, ancient and modern // Earth Science Reviews, 1983. N 19. Pp. 1-50.

Rychagov S.N. *Gidrotermal'naya sistema...* (The hydrothermal system of the Baranskogo volcano, Iturup is.: a model for geologica structure) // Vulkanologiya i seysmologiya. 1993. № 2. Pp. 59-74.

Rychagov S.N. Hydrothermal-magmatic systems as the basis source for energetic and mineral resources of recent volcanism areas // Proceedings World Geothermal Congress 2005. Antalya, Turkey, 24-29 April, 2005.

Stoffregen R.E. Genesis of acid-sulfate alteration and Au-Cu-Ag mineralization at Summitville, Colorado (including sections of supergen alteration and clay mineralogy of the deposit) // Unpublished Ph. D. Thesis, University of California, Berneley. 1985. 205 p.