EVOLUTION OF MAGMATIC FLUIDS IN ACTIVE VOLCANIC HYDROTHERMAL SYSTEMS: A THERMODYNAMIC MODEL (EBEKO VOLCANO, NORTHERN KURILES, PARAMUSHIR ISLAND)

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Evolution of fluids in igneous and hydrothermal activity is a key point in understanding magmatic processes. Overview papers on melt inclusions and quench glasses [1, 2] contain a collection of 5000 reliable analyses of volatiles. A large database has been obtained on high-temperature (>700°C) hydrothermal systems [3] in which gas composition approaches the composition of fluids in magmatic sources. All these data can be synthesized in a physical-chemical model.

Methods

We applied the program "Petrofluid" to estimate the fluid flow and the vertical distribution of temperature and pressure in rocks above the magmatic chamber [4] based on standard and specific parameters. The standard parameters included initial melt temperature, solidus, specific heat, thermal conductivity, density of melt and fluid, and nonuniform effective porosity and permeability of the wall rock; contents of volatiles in the melt and lithology of rocks above the source were used as additional specific parameters. The temperature and pressure computed with "Petrofluid", as well as the compositions of rocks, fluid, and meteoric water, were used in the thermodynamic model implemented as a software package «SELECTOR-WIN», in the flow reactor version [5]. The compositions were taken from our field data (several active volcanoes on Kamchatka) and from literature. The modelling results were checked against compositions of thermal solutions and rocks sampled on Ebeko and Karymsky volcanoes during the field seasons of 1998-2002.

Physical modelling

The model section over the magmatic source consisted of four layers of equal thicknesses with different porosities and permeabilities. We analysed two types of sections: with homogeneous (type I) and inhomogeneous (type II) lithologies. In the homogeneous section composed of tuffs and tuff breccias, porosity and permeability increase gradually towards the surface. The inhomogeneous section is capped by andesitic lavas, much less porous and permeable than the rocks below.

PT profiles were obtained for different depths of the source (1500, 2000, and 2500 m), and showed similar behaviour at all model depths. However, depth controls the cooling time of the intrusion, which, in turn, influences the life time of the magmatic hydrothermal system. The sections of the two types demonstrated similar temperature trends but different pressure profiles. In the section capped with lavas, pressure is high in the permeable layers below and decreases monotonically upwards. Note that this pressure distribution in type II sections occurs at the initial stage of the system evolution, and since 5000 years the pressure behaves in the same way as in type I sections.

Thermodynamic model

The first step in physical-chemical modelling was to locate the boiling aquifer. The front of the secondary boiling aquifer rises with time from the depth of 700 m at the age of 1000 years to 200 m at 10,000 years, and the boiling temperature also changes. The mass balance was estimated for a 5000 years old system, which corresponds to a hypothetical age of the hydrothermal system of Ebeko volcano. The fluid equilibrated with rocks in the source has an alkalic composition, and its alkalinity increases with cooling. Almost no mineral deposition occurs during the fluid ascent associated with changes in temperature and pressure. Degassing starts at the depth of 800 m from 0.1%, then 2% at 600 m, and at 400 m the fluid boils up and the system passes into the vapour state (97 %). Boiling is accompanied by abrupt changes in the redox potential of the system and in the acidity of residual melts. During further condensation, CO_2 no longer penetrates into the fluid, and the solutions remain acid.

We modelled three possible evolution scenarios of the fluid: the first two with separate migration of gas and solutions, and the third one implying their joint ascent and mixing with meteoric water. If gas separates during boiling and rises independently of solutions (first scenario), it condenses as it passes through meteoric water, which lowers the acidity of the mix solutions (pH=4) and the oxidation potential. In the case of separate migration of residual magmatic solutions (second scenario) no degassing occurs at mixing (1:100) and cooling, and the solutions are the least acid (pH=2.4). At

1:1000 dilution, calculated for comparison, the pH of the mix solutions did not exceed 3. In the third scenario, meteoric water was added to the original fluid in the proportion of 1:100, which caused abrupt cooling of the solution and secondary condensation. pH after mixing was about 3. Contents of anions in the model and natural solutions are of the same order of magnitude.

Conclusions

1. Modelling of temperature and pressure distribution in rocks above a magmatic source shows that time-dependent temperature variations along the fluid flow in hydrothermal systems with shallow sources are controlled by the source depth and the initial contents of volatiles in the magma, but are almost independent of lithology. At the same time, the behaviour of pressure depends on rock composition, especially at the initial evolution stage of systems.

2. The location of the secondary boiling aquifer depends on the age of the system, as the composition of volatiles released from the source changes with time and the rocks above the source heat up more uniformly.

3. The secondary boiling aquifer is a chemical barrier where the fluid changes its acidity and redox potential. As a result, some elements further migrate with gases and others with residual solutions.

4. Water solutions become ultra-acid after secondary boiling, and their mixing with meteoric water produces the amount of acid water three orders of magnitude greater than the original magmatic fluids.

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