FLUID FILTRATION TROUGH ACID MAGMAS: PETROLOGIC AND GEOCHEMICAL EVIDENCE OF METAMAGMATISM

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High-F Acid Rocks (HFAR) produced in a variety of environments (at different depths, in relation to various magmatic series, in different times, etc.) display several major- and trace-element compositional similarities that suggest their similar genetic conditions. REE fractionation and some characteristic variations in the chemistry of the biotite in HFAR suggest that the main factor in the alterations of these magmas was their enrichment in fluorine (and, in some instances, also chlorine). Reconstructions of HFAR degassing [1, 2] indicate that crystallization of these magmas in the main chamber resulted in fluid flows toward the upper, partly solidified portions of the plutons. This led to fluid filtration under gradients of temperature and pressure through magmas in the apical parts. Calculations of the dynamical parameters of the model [3, 4] indicate that, during the degassing of large acid intrusive chambers, the following dynamic relations are valid: (1) the dynamic velocity of the fluid is higher than the rate of diffusional F exchange between the fluid and magma and (2) the rate of mass-transfer is higher than the rate of heat transfer during fluid--magma interaction. This means that chemical equilibrium with respect to F between the filtering fluid and magma in apical parts is attained much faster than the thermal equilibrium. As the fluid ascends and the temperature decreases, the HF solubility in it decreases. Because of this, the HF concentration in the magma, which plays the role of a fluid-permeable matrix, increases. Since the Cl solubility in magmas decreases with decreasing pressure [5], this mechanism is able to efficiently concentrate Cl in acid magmas in situations with pressure gradients. This receives support from facts of simultaneous F and Cl enrichment in subvolcanic HFAR [6, 7].

As fluid interacts with magma, the cooled fluid is characterized by other fugacities of volatile components, i.e., high filtration velocities cause the preservation of the overall composition of the fluid, and gas reactions in it proceed virtually instantaneously (as compared with the fluid/magma exchange rates). Hence, if the variations in, for example, the oxygen fugacity in a fluid of arbitrary composition with changes in temperature and/or pressure are calculated, it is possible to identify the tendencies in the variations in this parameter in a magma conduit in the course of fluid ascent. A simulation of this process demonstrates that there can be two possible scenarios for the metamagmatic action of the fluid on the conduit melts. If the original oxygen fugacity is higher than QFM + 1, fluid filtration along a T gradient gives rise to high-F oxidized melts ($fO_2 > QFM + 1$), while the filtration of a fluid whose original oxygen fugacity was lower than QFM + 1 produces reduced high-F melts ($fO_2 < QFM + 1$).

Metasomatism results in a change in the bulk composition of the melt, REE redistribution, and enrichment of Rb and Y. High F concentrations lead to the redistribution of LREE and HREE between the percolating fluid and melt. The higher solubility of LREE in a fluid causes a decrease in their concentrations in the melt. Data on the REE distribution in HFAR minerals and glasses indicate that minerals of these magmas crystallized from melt already depleted in Eu, and the process of this depletion was not related to plagioclase fractionation from HFAR. Plagioclase is a mineral with the lowest Eu concentrations, which suggest that the Eu concentration in the plagioclase was controlled by the fluid/mineral equilibrium [8]. Hence, the most typical features of HFAR are low La/Yb ratios and depletion in Eu, which result from the scavenging of components from melt by a high-F fluid [9].

The long-lasting percolation of fluid through roof rocks leads to their metasomatic alterations [10] and subsequent melting. The complex of metasomatic phenomena manifests itself in the growth of K-feldspar megablasts, recrystallization of biotite, and the development of granophyric quartz-feldspar aggregates. Temperature estimates and geochemical evidence indicate that melting starts in the rear zone of the metasomatized rocks. Detailed observations of melting in roof rocks [11] demonstrate that the leading mechanism of this process is magmatic replacement, with acid, high-F, geochemically homogeneous melt replacing all rocks regardless of their original chemistry.

Modeling of the dynamics of heat and mass transfer suggests that an open degassing magmatic system evolves through the following sequence of stages: (1) the development of a dome of partly or fully crystalline granite in the roof of a massif and the onset of eutectic magma crystallization in the central portion of the chamber; (2) fluid filtration (2-1000 years) at a temperature gradient results in high-F magmas, whose concentrations of F and related components progressively increase in the upper part of the dome (conduits); (3) after 5000-10000 years, fluid filtration results in the heating of the conduit to a temperature corresponding to the magma temperature in the central part of the chamber, which gives rise to the loss of F and related components from the heated high-F magmas to the overlying cooler parts of the column or to the intrusion of these magmas to either subvolcanic depths or the surface in the form of dikes of ongonites or topaz rhyolites and ignimbrites; (4) as the degassing process deteriorates within the main chamber, the high-F magmas in the dome start to crystallize, which leads to the origin of unusual mineralized acid magmas (Li-F granites, granites of the normal geochemical type, etc.) and genetically related ore mineralization.

Hence, fluid percolation through magma in the apical parts of magmatic chambers and roof rocks under temperature and pressure gradients fundamentally modifies the major- and trace-element chemistry of these magmas and their f O2 and X_{melt}^{HF}. These two parameters (the oxygen activity and concentration of halogens in magmas) are the most strongly related to the types of mineralization in granitoids [12]. Oxygen fugacity controls the partition coefficients of Mo, W, Cu, and Sn between melts and crystals and eventually predetermines the removal of particular elements from the magmas by fluids percolating through them [13].

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