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Assimilation of xenocrystic apatite in peraluminous granitic magmas

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Abstract

Apatite is a ubiquitous phase in granite plutons and in most adjacent country rocks, thus contamination of a granite magma with wall-rock material results in two genetic types of apatite in the magma: cognate and foreign. These two textural and chemical varieties of apatite undergo textural and compositional changes to reach physical and chemical equilibrium (perfect assimilation) in the melt. Our experiments replicate the conditions in such contaminated granites. The starting materials consist of a peraluminous synthetic SiO_2-Al_2O_3-Na_2O-K_2O (SANK 1.3) granite gel with A/NK of 1.3, synthetic F-apatite, synthetic Cl-apatite, and natural Durango apatite. Initial experiments in cold-seal hydrothermal pressure vessels at magmatically realistic temperatures of 750 °C and pressures of 200 MPa produced negligible reactions, even after run times of 2000 h. Instead, we used an argon-pressurized internally heated pressure vessel with a rapid-quench setup at temperatures of 1200 °C, pressure of 200 MPa, and run durations of 192 h. An advantage of this high temperature is that it exceeds the liquidus for quartz and feldspar; therefore, apatite is the only solid phase in the run products. The starting composition of each run was 90 wt% SANK 1.3 granite gel and 10 wt% crushed apatite (consisting of one, two, or three varieties), with and without 4 wt% added H_2O. Run products were examined by SEM for texture and by EMPA and LA-ICP-MS for composition. The starting synthetic granite composition contains no Ca, F, Cl, or REEs thus, in every run, apatite was initially undersaturated in the melt. In all experiments, most large apatite grains consisted of anhedral shards with rounded corners, most small apatite grains were round, and a small proportion of apatite grains developed one or more crystal faces. In experiments with two or three apatite compositions, the run-product apatite grains had compositions intermediate between those of the starting-material grains, and they were homogeneous with respect to Cl, and probably F, but not with respect to REEs. The processes to reach textural equilibrium consist of dissolution until the melt is saturated in apatite, followed by Ostwald ripening to eliminate small grains and to develop crystal faces on larger ones. The processes to reach chemical equilibrium consist of dissolution of apatite, diffusion of cations (Ca, P, REE) and anions (F, Cl, OH) through the silicate melt, and solid-state diffusion in the undissolved apatite grains. The halogens approached chemical equilibrium in all experiments, but in the experiments containing Durango apatite, the REEs have not. Models involving radial diffusion into spherical apatite grains at the temperatures of the experiments show complete re-equilibration of the halogens, but changes in the REE concentrations affecting only the outer few micrometers. We conclude that the rate of chemical equilibrium for the halogens is greater than the rate of physical equilibrium for texture, which in turn is greater the rate of chemical equilibrium for REEs. We illustrate these processes with a natural example of contaminated granite from the South Mountain Batholith in Nova Scotia. Given that all granites are contaminated rocks, we propose that future petrogenetic studies focus on developing techniques for a minerals-based quantitative estimation of contamination (QEC).

Keywords: Apatite, granite, chlorine, fluorine, REE, diffusion, equilibration, South Mountain Batholith; Experimental Halogens in Honor of Jim Webster