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The physical and chemical evolution of magmatic fluids in near-solidus silicic magma reservoirs: Implications for the formation of pegmatites

Juliana Troch[1,2,*,†], Christian Huber[1], and Olivier Bachmann[3]

[1]Department of Earth, Environmental and Planetary Sciences, Brown University, 324 Brook Street, Providence, Rhode Island 02912, U.S.A.
[2]Department of Mineral Sciences, Smithsonian Institution National Museum of Natural History, 10th Street & Constitution Avenue NW, Washington, D.C. 20560, U.S.A.
[3]Institute of Geochemistry and Petrology, ETH Zürich, Clausiusstrasse 25, 8092 Zürich, Switzerland

Abstract

As ascending magmas undergo cooling and crystallization, water and fluid-mobile elements (e.g., Li, B, C, F, S, Cl) become increasingly enriched in the residual melt until fluid saturation is reached. The consequential exsolution of a fluid phase dominated by H_2O (magmatic volatile phase or MVP) is predicted to occur early in the evolution of long-lived crystal-rich "mushy" magma reservoirs and can be simulated by tracking the chemical and physical evolution of these reservoirs in thermomechanical numerical models. Pegmatites are commonly interpreted as the products of crystallization of late-stage volatile-rich liquids sourced from granitic igneous bodies. However, little is known about the timing and mechanism of extraction of pegmatitic liquids from their source. In this study, we review findings from thermomechanical models on the physical and chemical evolution of melt and MVP in near-solidus magma reservoirs and apply these to textural and chemical observations from pegmatites. As an example, we use a three-phase compaction model of a section of a mushy reservoir and couple this to fluid-melt and mineral-melt partition coefficients of volatile trace elements (Li, Cl, S, F, B). We track various physical parameters of melt, crystals, and MVP, such as volume fractions, densities, velocities, as well as the content in the volatile trace elements mentioned above. The results suggest that typical pegmatite-like compositions (i.e., enriched in incompatible elements) require high crystallinities (>70–75 vol% crystals) in the magma reservoir, at which MVP is efficiently trapped in the crystal network. Fluid-mobile trace elements can become enriched beyond contents expected from closed-system equilibrium crystallization by transport of MVP from more-evolved mush domains. From a thermomechanical perspective, these observations indicate that, rather than from melt, pegmatites may more likely be generated from pressurized, solute-rich MVP with high concentrations of dissolved silicate melt and fluid-mobile elements. Hydraulic fracturing provides a mechanism for the extraction and emplacement of such pegmatite-generating liquids in and around the main parental near-solidus mush as pockets, dikes, and small intrusive bodies. This thermomechanical framework for the extraction of MVP from mushes and associated formation of pegmatites integrates both igneous and hydrothermal realms into the concept of transcrustal magmatic distillation columns.

Keywords: Magma reservoir, magmatic volatile phase, supercritical fluid, crystal mush, pegmatite, granite; Experimental Halogens in Honor of Jim Webster