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Partitioning of trace elements among coexisting crystals, melt, and supercritical fluid during isobaric crystallization and melting

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Abstract

The distribution of trace elements among coexisting crystals, melt, and supercritical fluid during melting and crystallization is a critical constraint for understanding the evolution of magmatic systems, including the origin and development of continental and oceanic crust. Although trace-element partitioning between crystals and melt during Rayleigh fractional crystallization or melting is well-known, partitioning among co-existing melt, crystals, and supercritical fluid during anatexis or crystallization is less explored despite the ubiquity of magmatic fluids. Here we develop the trace-element differential equations governing solid-melt-fluid equilibria for melting and crystallization under fluid-present conditions and provide analytical solutions for fractional and equilibrium crystallization and melting. A compilation of solid-fluid and melt-fluid distribution coefficients for about 30 trace elements in olivine, clinopyroxene, garnet, plagioclase, alkali feldspar, biotite, amphibole, apatite, and silicic melts is provided. Forward modeling demonstrates the conditions under which fluid-melt-solid partitioning will impact trace-element signatures in magmatic systems. We show that for trace elements soluble in aqueous fluids, the composition of a melt derived by fluid-present fractional crystallization or by fluid-present fractional melting will be significantly different than in otherwise comparable fluid-absent systems. Ignoring the partitioning of soluble elements into the fluid phase leads to large errors in concentrations (over 100%) and ratios and consequent misinterpretation of the trace-element character of source material and/or the processes of fractional crystallization and melting. Although significant in any setting involving fluid-present equilibria, this analysis may have a most profound influence on fluid-present subduction zone magma generation and the evolution of shallow level fluid-saturated silicic magmatic systems.

Keywords: Distribution coefficient, fluid-saturated magma, fluid-melt, solid-melt, trace element