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Enrichment of manganese to spessartine saturation in granite-pegmatite systems

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Abstract

The enrichment of manganese in peraluminous (S-type) granitic melts beginning with the anatexis of metapelitic rock and ending with the crystallization of highly evolved pegmatites is explained using experimentally derived mineral-melt partition coefficients and solubility data for Mn-rich garnet. Mineral-melt partition coefficients for Fe, Mg, and Mn between garnet, cordierite, tourmaline, and peraluminous, B-bearing hydrous granitic melt were measured between 650 and 850 °C at 200 MPa_{H_2O}. The compositions of garnet and tourmaline synthesized in these experiments are similar to those found in nature. Garnets evolve from $Sps_{51}Alm_{23}Prp_{25}$ to $Sps_{81}Alm_{15}Prp_4$ with decreasing temperature. The Mn content of cordierite increases with decreasing temperature. The composition of tourmaline does not vary with temperature. Partition coefficients, $D_M^{\alpha/L}$, and exchange coefficients, $K_D^{\alpha/L} = D_M^{\alpha/L}/D_N^{\alpha/L}$ where α is a mineral, *L* is liquid (melt), and *M* and *N* are different elements, are presented for mineral-glass pairs. Partition coefficients for Mg, Fe, and Mn increase with decreasing temperature for garnet, tourmaline, and cordierite. The precipitation of garnet alone results in a progressive increase of MgO/FeO and a decrease of MnO/FeO in the melt. Crystallization of cordierite and tourmaline results in a decrease of MgO/FeO and an increase of MnO/FeO in melt. Tourmaline is most efficient at concentrating Mn in residual liquids. The trend toward increasing Mn/Fe in natural garnets in granites and pegmatites is not controlled by garnet itself, but instead by the crystallization of other mafic minerals in which Mg and Fe are more compatible than is Mn.

A Rayleigh fractionation model constitutes a test of the partition coefficients reported in this manuscript. The starting composition for the model is that of a liquid (melt inclusions) from an anatectic S-type source. Normative modes of cordierite and biotite are calculated from that composition and are similar to modes of these minerals in natural occurrences. The model consists of crystallization of a cordierite-biotite granite from 850 to 650 °C. The model predicts that ~95% crystallization of the starting composition is required to reach saturation in spessartine-rich garnet at near-solidus temperatures. The model, therefore, is consistent with the occurrence of spessartine as restricted to highly fractionated granite-pegmatite systems at the end stages of magmatism.

Keywords: Fractional crystallization, manganese, partition coefficients, tourmaline, garnet, cordierite