American Mineralogist, Volume 105, pages 1078–1087, 2020

An experimental approach to examine fluid-melt interaction and mineralization in rare-metal pegmatites

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Abstract

Niobium and tantalum, rare metals and high field strength elements (HFSEs) that are essential to modern technologies, are concentrated among others in lithium-cesium-tantalum (LCT) pegmatites and rare metal granites. The most important hosts for Nb-Ta in these types of deposits are the columbite group minerals (columbite-tantalite), but at some ore deposits significant Ta is also contained in wodginite, microlite, and tapiolite. Previous solubility experiments of HFSE minerals have been limited to high temperatures because of the slow diffusivities of HFSEs in granitic melts. An experiment protocol is described herein that allows HFSE mineral solubilities to be determined at lower temperatures, more in line with the estimated solidus temperatures of LCT pegmatites and rare metal granites. This is achieved through the interaction of a melt that is enriched in high field strength elements (e.g., P and Nb or Ta) with a fluid enriched in a fluid-mobile element (FME, e.g., Mn). A starting glass enriched in a slow diffusing HFSE was synthesized, and HFSE mineral saturation is obtained via the diffusion of a FME into the melt via interaction with a fluid. This interaction can occur at much lower temperatures in reasonable experimental durations than for experiments that require diffusion of niobium and tantalum. The solubility product of columbite-(Mn) from the fluid-melt interaction experiment in a highly fluxed granitic melt at 700 °C is the same as those from dissolution and crystallization (reversal) experiments at the same *P*-*T* conditions. Thus, both methods produce reliable measurements of mineral solubility, and the differences in the metal concentrations in the quenched melts indicates that the solubility of columbite-(Mn) follows Henry's Law. Results show that columbite-(Mn) saturation can be reached at geologically reasonable concentrations of niobium in melts and manganese in hydrothermal fluids. This experimental protocol also allows the investigation of HFSE mineral crystallization by fluid-melt interactions in rare-metal pegmatites. Magmatic origins for columbite group minerals are well constrained, but hydrothermal Nb-Ta mineralization has also been proposed for pegmatite-hosted deposits such as Tanco, Greenbushes, and granite-hosted deposits such as Cínovec/Zinnwald, Dajishan, and Yichun. This study shows that columbite-(Mn), lithiophilite, and a Ca-Ta oxide mineral (that is likely microlite) crystallized from experiments in fluid-melt systems at temperatures as low as 650 °C at 200 MPa. It is important to note that HFSE minerals that crystallize from fluid-melt interactions texturally occur as euhedral crystals as phenocrysts in glass, i.e., are purely magmatic textures. Therefore, crystallization of HFSE minerals from fluid-melt interactions in rare metal granites and pegmatite deposits may be more widespread than previously recognized. This is significant because the formation of these deposits may require magmatic-hydrothermal interaction to explain the textures present in deposits worldwide, rather than always being the result of a single melt or fluid phase.

Keywords: Experimental petrology, rare metals, pegmatite, niobium, fluid-melt interactions