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The Degree of Undercooling and Critical Metal Mineralization Potential of Granitic Pegmatites

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Granitic pegmatites are notorious amongst many other geologic systems for their ability to concentrate critical metals (e.g., Li, Ta, Be) to mineable abundances. However, the petrologic processes that concentrate these metals to economic abundances in granitic pegmatites have not been fully determined. Undercooling, or crystallization below the liquidus, has been shown experimentally to cause saturation and associated critical metal mineralization (i.e., form distinct critical metal phases) at much lower concentrations than in more typical (i.e., minimally or nonundercooled) haplogranite systems at 700°-750°C. This process can theoretically explain the formation of pegmatites enriched in critical metals, but undercooling is difficult to demonstrate in natural systems. Previous research has demonstrated undercooling with textural evidence, such as unidirectional growth textures, the presence of graphic granite, and other skeletal growth forms, in addition to a number of case studies that used a variety of geothermometers to quantify undercooling. However, comparing results obtained from the latter is difficult as a result of the variable zones that were sampled, the different thermometers used, and heterogeneity between pegmatite types and classifications.

This study presents a compilation of crystallization temperatures from over 100 granitic pegmatites classified via the Černý and Ercit (2005) pegmatite classification scheme. These temperatures were estimated using several different geothermometers, including fluid and melt inclusion microthermometry, two-feldspar solvus and other mineral exchange thermometers, Ti-in-mineral, O-isotope, and mineral saturation thermometry, and phase-assemblage relationships. In addition to the pegmatite type and thermometer used, the pegmatite zone sampled was also noted to determine the effect of sampling location on temperature of crystallization. Preliminary data from this study show that more than 75% of pegmatites with reported crystallization temperatures have a lithium-cesium-tantalum (LCT) affinity, the rare element class has the most reported crystallization temperatures by more than twice any other pegmatite class, and fluid inclusion microthermometry is the most widely utilized thermometer in these systems. Plotting all of the data from individual thermometers together (ignoring the effect of pegmatite class and zone) yields ranges of primary crystallization temperatures of ~275°C for Ti-in-quartz thermometry, ~200°C for two-feldspar thermometry, and ~500°C for primary fluid inclusion microthermometry. On average, pegmatite classes that host significant critical metal mineralization (i.e., rare element and miarolitic classes) experienced ≥100°C of undercooling, whereas barren pegmatites (i.e., abyssal and muscovite classes) experienced little to no undercooling. LCT pegmatites yield crystallization temperatures that average ~100°C lower than the niobium-yttrium-fluorine (NYF) pegmatite family. Different pegmatite zones (i.e., border-wall, intermediate, and core zones) yield variable crystallization temperatures that both increase and decrease from the outer zones inward. The range of primary intrapegmatite crystallization temperature, or the crystallization temperature range between pegmatite zones, may act as a significant control on critical metal mineralizing potential. This is exemplified by the Tanco pegmatite, one of the most well-documented highly evolved granitic pegmatites known, which records a 300°C range in crystallization from margin to center, much larger than any other pegmatite in this study. This suggests that intrapegmatite crystallization temperature may be a useful criterion for identifying granitic pegmatites with high critical metal mineralizing potential.