A Rayleigh model of cesium fractionation in granite-pegmatite systems

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ABSTRACT

The K/Cs ratios of K-feldspars from granitic pegmatites are compared to models derived from the Rayleigh equation. The K/Cs and K/Rb ratios of K-feldspars and micas exhibit decreasing values when plotted against their Cs or Rb contents across cogenetic suites of granites and pegmatites and from margin to core of individual bodies. The trends in elemental ratios conform to Rayleigh fractionation for the crystallization of feldspars and micas from a silicate melt. Within two individual pegmatite bodies, the K/Cs ratio of K-feldspar initially falls more rapidly than the Rayleigh model predicts. That might reflect a local increase in the concentration of Cs relative to K due to the pile-up of incompatible elements in a boundary layer of melt adjacent to the crystal growth front. The addition of an aqueous solution to the Rayleigh model (i.e., the simultaneous crystallization of K-feldspars from melt and from aqueous solution) predicts high and increasing K/Cs ratios of K-feldspars that are not observed in natural rock suites, except when K-feldspars crystallize in mioralitic cavities or when primary K-feldspar recrystallizes to microcline perthite in an open hydrothermal system. In those cases, the Cs content of K-feldspars falls to nil because of the high solubility of Cs in aqueous solution and low compatibility of Cs in K-feldspar. Otherwise, the observed patterns of K/Rb or K/Cs in K-feldspar and micas in pegmatites conform to crystal-melt fractionation in which an aqueous solution plays no part. From the viewpoint of the geochemistry of Cs in pegmatites, these observations give support to the model proposed by Cameron et al. (1949) and endorsed by Jahns (1953a, 1953b).

Keywords: Cesium, Rayleigh fractionation, pegmatite, K-feldspar

INTRODUCTION

Ever since early work by Černý (e.g., Černý et al. 1985), the K/Rb and K/Cs ratios of K-feldspars (reported as a ratio of weight) and of micas have been widely used as monitors of the extent of fractional crystallization of granites and the pegmatites they produce. When graphed as K/Rb vs. Rb, K/Rb vs. Cs, or K/Cs vs. Cs, the resultant patterns exhibit exponentially decreasing trends (e.g., Roda-Robles et al. 2012; Hulsbosch et al. 2014; Marchal et al. 2014; Brown et al. 2017), or decreasing linear arrays in log-log plots (Černý et al. 1985).

Shearer et al. (1992) utilized the K, Rb, Ba, and Cs contents of K-feldspar samples from Harney Peak granite and surrounding pegmatites and compared them to a Rayleigh model for the fractionation trends across the pegmatite district. Their results are mostly compatible with Rayleigh fractionation, although they note that the rare-element pegmatites are displaced from the trends in trace-element content that link the Harney Peak granite to the tens of thousands of common pegmatites that emanate from it. Kontak and Martin (1997) observed that trace-element variations in K-feldspar from the South Mountain batholith, Nova Scotia, closely fit modeled Rayleigh fractionation trends, although the results for Cs in K-feldspar were erratic. They attributed this variability to the volatility of Cs in an aqueous solution (Carron and Lagache 1980), implying that the scatter of data reflected variable degrees of recrystallization of the primary K-feldspar and loss of Cs in an open hydrothermal system.

Roda-Robles et al. (2012) demonstrated that the K/Rb and K/Cs ratios of K-feldspars and micas in the granite-pegmatite system of Pinilla de Ferronoselle, Spain, conform to a Rayleigh fractionation trend. Hulsbosch et al. (2014) plotted their analytical data for a field of pegmatites in Rwanda against modeled curves calculated by the Rayleigh equation, and they concluded that the good fit between modeled and actual values was evidence that the crystallization of K-feldspar from melt followed a Rayleigh fractionation process (Fig. 1). London et al. (2012, 2020a) likened the pattern of K/Cs in K-feldspar vs. distance from pegmatite margin to core to a Rayleigh fractionation process. London et al. (2012, 2020a) observed outliers with anomalously high-K/Cs ratios that were attributed to the recrystallization of K-feldspar in an open hydrothermal system.

In their summary of pegmatite geology, Cameron et al. (1949) concluded that zoned pegmatite bodies crystallize from their margins to center as essentially closed systems. If that zonation is fully symmetrical about the central plane of the body, then the distance from margin \((F = 1)\) in the Rayleigh equation) to center \((F = 0)\) is a proxy for the fraction of melt \((F)\) that has crystallized, or \(1 – F\), in the Rayleigh equation. For this reason, the fraction of melt crystallized, \(1 – F\), is plotted in the figures presented here where values of K/Cs of K-feldspar are normalized to \(1 – F\) based on their distance from margin to center.

In these few studies to date, the Rayleigh models and their close correspondence to observed trace-element patterns in K-feldspar apply only to fractionation between minerals and melt, because the partition coefficients utilized are derived from

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