

REASSESSING THE DEPLETIONS IN K AND Rb OF PLANETARY BODIES. N. Dauphas¹. ¹Origins Laboratory, Department of the Geophysical Sciences and Enrico Fermi Institute, The University of Chicago, Chicago IL, USA (dauphas@uchicago.edu).

Introduction: Planetary bodies are variably depleted in moderately volatile elements (MVE), including K and Rb [1-3]. The extent to which those depletions reflect nebular (incomplete condensation or evaporation) or planetary processes (impact-induced evaporation) is uncertain. Isotopic analyses of K and Rb have provided new insights into the processes that controlled the depletions in those elements [4-6] but significant questions remain. The degree of depletion for these elements in large planetary bodies such as Earth, Moon, Mars, or Vesta, is not straightforward to assess because these bodies have experienced magmatic differentiation and the compositions of the rocks exposed at the surface of a planetary body are not necessarily representative of its bulk composition. The degree of depletion in moderately volatile elements K and Rb is traditionally assessed by taking the ratio of those elements to another lithophile element of similar incompatibility but which is refractory rather than volatile [3 and references therein]. Uranium has been used for K normalization because both elements are often reported in rock analyses and those two elements can be measured remotely by space probes. For example, the MESSENGER mission constrained the K/U ratio of the surface of Mercury to a value that is ~4.4 times lower than CI chondrites [7]. Strontium has been used for Rb normalization because those two elements are part of a radioactive decay system (^{87}Rb - ^{87}Sr ; $t_{1/2}=49$ Gyr) and high-precision Rb/Sr ratios are available in the literature. By examining K/U and Rb/Sr ratios, Davis [3] established a relative scale of MVE depletion among planetary bodies. Knowing precisely the level of depletions in K and Rb, and the K/Rb ratios of planetary bodies is critical to develop a quantitative understanding of the processes that gave rise to those fractionations. For this reason, I have reassessed the abundances of K and Rb in planetary bodies, taking advantage of the large amount of concentration data available in the literature. Below, I focus on the depletions of K and Rb in the Moon relative to the Earth, as they are key constraints to scenarios of lunar formation [8-10].

Lunar K and Rb depletions: High precision concentration data are available in the literature from studies of lunar samples returned by the Apollo mission. The challenge with these samples is that they represent products of magmatic differentiation. In particular, the Moon retains chemical vestiges of the crystallization of the lunar magma ocean (LMO). In the course of the crystallization of the LMO, some minerals (mostly anorthite but

also clinopyroxene) could have incorporated some K and Rb, such that K and Rb did not behave as perfectly incompatible elements and their abundances relative to other elements could have changed. In particular, formation of plagioclase flotation crust could have changed the K/U and K/Rb ratios of the residual melt that contributed to the source of mare basalts, as shown by the complementary Eu anomalies of anorthosites and mare basalts. In order to disentangle the effect of lunar magmatic differentiation on the abundances of K and Rb, I use another element, Ba, which presents some affinity for plagioclase [11], is also lithophile, but is refractory. If LMO crystallization fractionated the K/U ratio, then it should have fractionated the Ba/U ratio. Because both Ba and U are refractory lithophile elements, one expects their ratio in a bulk planetary body to be more or less chondritic. In Fig. 1, I plot the K/U and K/Rb ratios as a function of the Ba/U ratio in bulk lunar basalts and KREEP-rich soils and breccias from Apollo 14. The data points define correlations. The case was made previously that the K/U ratio of lunar samples was more or less invariant because the two elements have the same incompatible behaviors [12]. Figure 1 shows that in detail, this is not the case. The K/U vs. Ba/U correlation passes near the origin (0,0 coordinate), meaning that the K/Ba ratio is almost constant [13]. The correlations can be interpolated to the CI-chondrite Ba/U weight ratio of 275 g/g to estimate the bulk lunar K/U and K/Rb ratios. Doing so, I estimate that the K/U ratio is a factor of 30.0 ± 2.4 smaller than CI and that the K/Rb ratio is a factor of 1.71 ± 0.20 higher than CI, meaning that Rb is more depleted than K in the Moon. The degree of K depletion relative to CI (~30) inferred from Fig. 1 agrees overall with previous values [1-3,12-15] but is more tightly constrained, as is the K/Rb ratio. For comparison, the terrestrial K/U ratio is fractionated by a factor of ~5.3 relative to CI and the K/Rb ratio is ~1.61 times CI. This means that the Moon is depleted by a factor of ~5.6 in K relative to the Earth but despite this greater depletion, the K/Rb ratio is very similar.

Other planetary bodies: I have used similar approaches to reassess the depletions of K and Rb in other planetary bodies. The main challenge is with angrites, which are extremely depleted in K and Rb [16]. This makes it challenging to measure the concentrations of K and Rb precisely so few data are available in the literature. A second challenge is that due to the great depletions of those elements in angrites, they are prone to contamination during residence at the Earth's surface.

All angrites except one are meteorite finds, meaning that their K and Rb concentrations are unreliable. With only Angra dos Reis available, it is impossible to properly assess the extent to which its K/U and K/Rb ratios are representative of the bulk body. I compiled high-precision (mostly isotope dilution) K, Rb, U, and Sr analyses of Angra dos Reis to constrain the degree of depletions of K and Rb in the angrite parent-body (APB). I thus estimate K to be depleted by a factor of ~ 700 relative to CI but the K/Rb ratio is only 1.67 (similar to Earth and Moon).

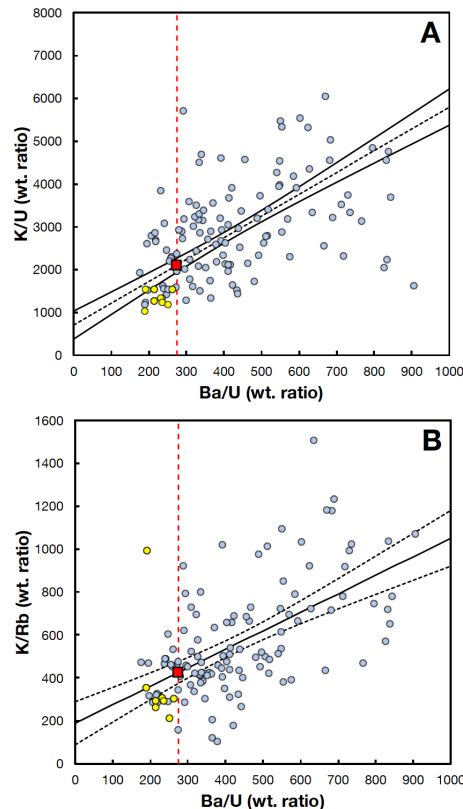


Fig. 1. Correlations between K/U (A), K/Rb (B), and Ba/U in mare basalts (pale blue dots) and KREEP-rich samples from Apollo 14 (yellow dots) (data from the Lunar Sample Compendium and other sources). The red dashed vertical line marks the CI Ba/U ratio. The red squares are the estimated K/U and K/Rb ratios of the Moon (this study).

Discussion: Large planetary bodies display a range of depletions in K from ~ 3 in Mars to ~ 700 in the APB. For comparison, chondrites display K enrichments reaching 30% in EH (*i.e.*, $K/U = CI/0.7$) to K depletions reaching ~ 3.5 in CV [17], overlapping with the depletion measured in Mars. Most K/Rb are close to CI, except EH and EL, which could be slightly enriched in K relative to Rb. The K/Rb ratio in large scale planetary bodies does not follow any systematic relationship with the degree of depletion. Overall, natural samples point

to Rb being more volatile than K, which is consistent with some experiments but not all, calling for an experimental reassessment of the volatilities of these elements. The fact that the K/Rb ratio does not correlate with the K/U ratio in bulk planetary bodies is puzzling. One possibility is that some of the depletions do not reflect simple evaporation/condensation processes but also involve mixing with chondritic (undepleted) material. Another possibility is that some of the depletions may have been achieved through batch processes while others may have been subjected to Rayleigh processes. A third possibility is that K and Rb were evaporated from a partially crystallized melt in which some K and Rb had partitioned into minerals like plagioclase. In such a scenario, the melt would be left with a lower Rb/K ratio than the bulk, leading to more efficient evaporation of Rb relative to K.

Conclusion. I have reassessed the degrees of K and Rb depletions using published concentration data for a variety of planetary bodies. This analysis shows that K and Rb show slightly different behaviors, providing another means of assessing the cause of MVE depletion in planets.

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