WHY IS THE MOON DEPLETED IN MODERATELY VOLATILE ELEMENTS?

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Compared to chondrites, which all have somewhat similar K/U ratios (between ~0.3×CI in CV and 1.4×CI in EH), planets and differentiated meteorites are variably depleted in K, reaching a factor of ~500 lower than CI in the angrite parent-body [1-3]. Closer to us, lunar rocks are depleted in K and Rb by a factor of ~6 relative to terrestrial rocks [3]. The origin for this depletion is poorly constrained. It is unlikely to have been inherited from a volatile element depleted impactor. The reason is that it would require Theia to have contributed at least ~83% of the mass of the Moon if Theia was as potassium-depleted as the angrite parent-body but even then, it would fall short of explaining the greater depletion measured for Zn [4]. Most likely, this depletion reflects processes that occurred during or after the Moon-forming giant impact. Wang and Jacobsen [5] showed that the Moon was enriched in the heavy isotopes of K by ~+0.4 ‰ compared to Earth. Pringle and Moynier [6] also found hints of a heavy Rb isotope enrichment in lunar rocks relative to terrestrial rocks but the extent of this enrichment was uncertain. Recently, we have revisited this question by measuring the Rb isotopic composition of several lunar rocks to more precisely define the Rb isotopic composition of the Moon [7]. Wang and Jacobsen [5] interpreted the heavy K isotopic composition of the Moon to reflect evaporative loss of K under equilibrium conditions. *Ab initio* studies have shown, however, that the equilibrium K isotopic fractionation between monoatomic K vapor and condensate (K-feldspar, taken as a proxy for liquid) under temperature conditions relevant to lunar formation would be too small to account for the heavy K isotopic composition of the Moon [8,9].

We have re-evaluated the extent to which K and Rb are depleted in the Moon. While it is commonly assumed that K/U and K/Rb ratios are relatively unfractionated during magmatic differentiation, we have found that mare basalts and KREEP-rich samples display variations in those ratios that correlate with ratios of incompatible non-volatile elements. These variations must therefore reflect processes of magmatic differentiation most likely associated with crystallization of the lunar magma ocean [3]. Our reassessment of the degree of K and Rb depletions in the Moon [3], together with our determination of the Rb isotopic composition of the Moon [7] allow us to reassess the cause of depletion in moderately volatile elements of lunar rocks relative to Earth. The models put forward to explain those depletions involve (1) transport in the protolunar disk of condensed material across the Roche limit when most volatile elements remain behind in the inner disk [10], (2) partial condensation in a Synestia structure produced by a high-energy impact between the protoEarth and Theia [11], (3) drainage of vapor onto the Earth when the liquid remains in a disk orbiting the Earth [12], and (4) loss by evaporation from the lunar magma ocean. The scenarios that involve partial condensation cannot explain the heavy isotope enrichments because equilibrium isotopic fractionation is too small and kinetic isotope effects would produce condensates enriched in the light isotopes, which is opposite to what is observed [9]. It is also not clear whether a magma ocean could have led to sufficient loss of K and Rb, at least not if volatile escape operated under Jeans' regime [13].

At the meeting, we will evaluate these scenarios and show that the heavy K and Rb isotopic compositions of lunar rocks can provide new and critical constraints on the setting of lunar formation, specifically with regard to evaporative loss in the aftermath of the Moon-forming impact. We will show that the heavy isotope enrichements of K, Rb, and possibly Zn can all be quantitatively explained in the context of a single scenario.

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