

RUBIDIUM ISOTOPIC COMPOSITIONS OF THE EARTH AND THE MOON. N. X. Nie¹ and N. Dauphas¹.

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Introduction: The Moon and the Earth share isotopic anomalies for refractory elements, placing important constraints on scenarios of lunar formation [e.g., 1-4]. An important difference between the two bodies is that the Moon is more depleted in volatile elements compared to the Earth [5-7]. This depletion most likely took place in the aftermath of the giant-impact, but considerable uncertainties remain as to what is the underlying mechanism for this depletion [8-10]. Isotope measurements of moderately volatile elements (MVEs), such as K, Rb and Zn, can provide important clues on the nature of this mechanism [8-10].

Among MVEs, K and Rb are of particular interest. The two elements are both alkali metals, lithophile and incompatible, and they behave very similarly in various geochemical processes. Recently, Wang and Jacobsen [10, 11] measured K isotopic compositions of some terrestrial and lunar rocks, and found that the lunar rocks were enriched in heavy K isotopes by $+0.4 \pm 0.10$ ‰ compared to the Earth. Pringle and Moynier [9] reported Rb isotopic compositions of terrestrial rocks and seven lunar rocks, including three low-Ti mare basalts, three high-Ti mare basalts and one norite. Rubidium isotope measurement of lunar samples is tricky in that Rb is a trace element and it is in very low abundance (~1 ppm in mare basalts) and separating it from matrix elements is not straightforward. Furthermore, the difference in the isotopic composition of Rb between the Moon and the Earth is small. Therefore, here we measured new high-precision Rb isotopic data of terrestrial basaltic rocks (geostandards), and of five lunar basalts including two high-Ti mare basalts and three low-Ti mare basalts. The goal of this study is to re-assess the degree of Rb isotope fractionation between lunar and terrestrial rocks using a novel purification method that gives a clean Rb separation.

Methods: About 50 mg for each terrestrial rock and about 100 mg for each mare basalt were digested using a combination of HF, HNO₃, and HCl. Bomb digestion was used if the open beaker digestion left behind some undissolved residue. Rubidium is in trace amount (~1 ppm) in mare basalts and separating it from matrix elements, especially from K, is challenging. We therefore developed a chromatographic method to purify Rb, so that every matrix element in the final Rb solution has a concentration lower than that of Rb. The total blank of the entire procedure is around 0.1 ng, which is very low (less than 1 ‰) compared with the total Rb extracted from rock samples (tens of ng or more). The yield of the

purification procedure is ~95-105 %. The purified Rb solutions were measured for isotopes using the Thermo Finnigan Neptune MC-ICPMS at the University of Chicago. A SIS spray chamber was used as the sample introduction system, and Rb was introduced in dilute HNO₃ medium. Standard sample bracketing was used to correct for the instrumental fractionation.

Results: The Rb isotopic compositions are reported as $\delta^{87}\text{Rb}/^{85}\text{Rb}$ relative to the NIST reference standard SRM 984. Fig. 1 shows the Rb isotopic compositions of measured terrestrial geostandards and the average compositions of the low-Ti and high-Ti mare basalts. Terrestrial geostandards BCR-2, BHVO-2, BEN, W-2 and AGV-2 have negative Rb isotopic compositions of -0.16 ± 0.03 ‰, -0.12 ± 0.02 ‰, -0.11 ± 0.03 ‰, -0.15 ± 0.02 ‰ and -0.14 ± 0.02 ‰, respectively. The three low-Ti mare basalts have an average value of -0.01 ± 0.07 ‰, and the two high-Ti basalts show a slightly positive average value of $+0.07 \pm 0.06$ ‰.

Discussion: The five terrestrial basaltic rocks (four basalts BCR-2, BHVO-2, BE-N and W-2, and one andesite AGV-2) have very similar Rb isotopic compositions. Using their isotopic compositions to represent the bulk Earth (Rb is quite incompatible during mantle melting), the average value is -0.14 ± 0.06 ‰. The bulk Moon is estimated to have an isotopic composition of $+0.03 \pm 0.09$ ‰ if averaging together all high-Ti and low-Ti mare basalts. The two averaged values are very similar to those reported by Pringle and Moynier [9] of -0.12 ± 0.06 ‰ and $+0.05 \pm 0.12$ ‰ respectively, confirming that the Moon is isotopically heavier than the Earth. Pringle and Moynier [9] did not present the elution curve of their method of using a cation resin to separate Rb from K. We were not able to get a clean separation of Rb from K using the resin so we developed our own method. Despite of the difference in methods, the data appear to agree.

The measured Rb isotopic compositions show that the Moon is heavier than the Earth by $+0.17 \pm 0.11$ ‰. Heavy isotopic compositions of the Moon compared to the Earth have also been observed for other MVEs such as K and Zn. The Moon is heavier than the Earth by $+0.41 \pm 0.10$ ‰ and $+1.1 \pm 0.5$ ‰ for $\delta^{41}\text{K}/^{39}\text{K}$ and for $\delta^{66}\text{Zn}/^{64}\text{Zn}$ respectively [8, 10]. The heavy Zn isotopic composition of the Moon has been interpreted to be due to volatile loss during the giant impact or magma ocean degassing, and the heavy K isotopic composition was used as an evidence for incomplete condensation of the

Moon from the protolunar disk in a high-energy high angular momentum giant impact scenario [8, 10].

The heavy isotopic compositions of K, Rb and Zn in the Moon compared with the Earth do not reflect equilibrium isotope fractionation between gas and solids during Moon formation, because at the temperature relevant to Moon formation (3000-4000 K [12]) the equilibrium isotope fractionations should be near zero. Those heavy isotopic compositions cannot be explained by condensation of moonlets since condensation would enrich the condensates in light isotopic compositions. The heavy isotopic signatures of the Moon seem to be more consistent with evaporation being the major driving force for the depletion of the MVEs. Evaporation can occur under many different conditions, in the canonical giant impact scenario [13] and in the high-energy high-angular momentum giant impact scenario [12].

Conclusion: Terrestrial and lunar samples were measured for constraining the Rb isotopic compositions of the Earth and the Moon. The result shows that mare basalts are enriched in the heavy isotopes of Rb compared to terrestrial basaltic rocks. We estimate that the Rb isotopic composition of the Moon is heavier than the Earth by $+0.17 \pm 0.11$ ‰. This is consistent with literature data and with the heavy isotopic compositions of other MVEs in the Moon such as K and Zn. These heavy isotopic compositions of the Moon compared to the Earth most likely reflect evaporation. The context under which such evaporation could have taken place will be discussed at the conference.

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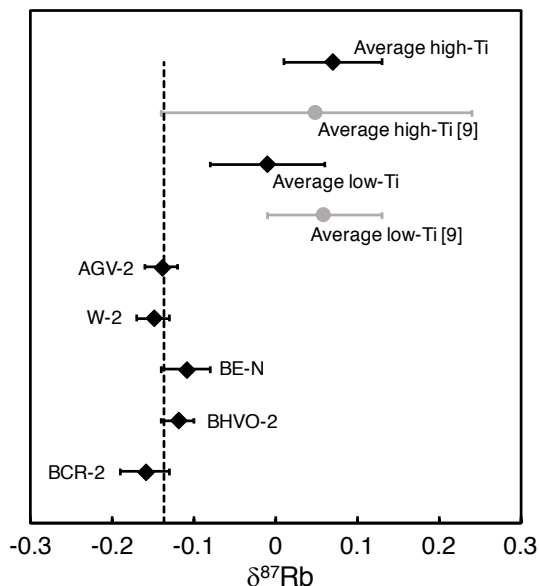


Fig. 1. Rubidium isotopic compositions of terrestrial geostandards and mare basalts (relative to NIST SRM 984, in ‰). The lunar samples are heavier than the Earth in terms of Rb isotopes.