

POTASSIUM ISOTOPIC COMPOSITIONS OF MARTIAN METEORITES – IMPLICATIONS FOR A “DRIER” EARLY MARS THROUGH ACCRETIONAL VOLATILE LOSS. Z. Tian¹, T. Magna², J.M.D. Day³, K. Mezger⁴, E.E. Scherer⁵, K. Lodders¹, P. Koefoed¹, H. Bloom¹, and K. Wang¹, ¹Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University in St. Louis, One Brookings Drive, St. Louis, MO 63130, USA (t.zhen@wustl.edu), ²Czech Geological Survey, Klarov 3, CZ-118 21 Prague, Czech Republic, ³Scripps Institution of Oceanography, La Jolla, CA 92093, USA, ⁴Institut für Geologie, Universität Bern, Baltzerstrasse 1+3, 3012 Bern, Switzerland, ⁵Institut für Mineralogie, Universität Münster, Corrensstr. 24, D48149 Münster, Germany.

Introduction: Determining the abundances and distributions of volatile elements within inner Solar System differentiated parent bodies is one of the fundamental goals of cosmochemistry. Previous studies have shown that the volatile depletion of terrestrial planets is systematic [1]. Nevertheless, the mechanisms for such volatile depletion (*e.g.*, distinct isotopic precursors, accretionary loss, magma ocean degassing) remain unsettled [2-3]. With recent improvements in the precision of K isotope measurements, the stable K isotope system has become a powerful tool for assessing the moderately volatile element history [4].

Unlike the Earth-Moon system, there is no strong evidence that Mars was subjected to a high-energy giant impact that may have affected its volatile inventory. Furthermore, its distinct geochemical differentiation history and the existence of water on early Mars make it an intriguing object for inter-planetary comparison. The currently available high-precision K isotope data for martian meteorites are limited to only three samples [2]. We have conducted a systematic investigation of martian meteorites, with the aim of examining planetary/surface processes on Mars, and to provide a more complete picture of the volatile depletion of terrestrial planetary bodies.

Samples and Methods: A previous study has shown the complicating effects on K isotopes of terrestrial contamination or alteration in hot desert meteorite finds [2]. For these reasons, we mainly focused on meteorite falls and Antarctic finds. Twenty martian meteorites (23 subsamples in total) were analyzed, covering a wide range of martian lithologies represented in the meteorite collection (*Fig. 1*). We analyzed two basaltic shergottites, three lherzolitic shergottites, five olivine-phyric shergottites, one picritic shergottite, seven nakhlites, one chassignite, and one basaltic regolith breccia.

The sample dissolution and chemical purification procedures for K are described in detail elsewhere [5]. High-precision K isotopic analyses were performed using a *Thermo Scientific Neptune Plus MC-ICP-MS*. The enhancement of sensitivity and the suppression of hydride and oxide species were accomplished using an *Elemental Scientific APEX omega* equipped with a desolvation membrane. The sample-standard bracketing

technique was applied using the NIST SRM 3141a reference material.

Typical within-run reproducibility was $\pm 0.05\%$ (2SE). The long-term reproducibility was evaluated by periodic analysis of BHVO-2 reference material in each analytical session and is reported here to be $\pm 0.11\%$ (2SD) over ~ 20 months [5].

Results: The K isotopic compositions of 20 martian meteorites range from -0.59 to -0.08% . There are no significant differences between the mean values of each lithology (*i.e.*, basaltic shergottites, lherzolitic shergottites, olivine-phyric shergottites, nakhlites, chassignites, and basaltic regolith breccia).

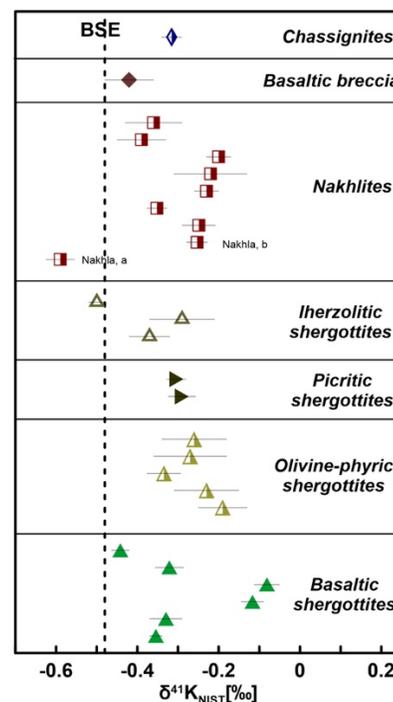


Figure 1. The K isotopic compositions of martian meteorites. Data are compiled from [2] and this study. Dashed line represents the K isotopic composition of the bulk silicate Earth (-0.48%).

For most samples for which we have two different aliquots (*e.g.*, Shergotty, Zagami), their K isotopic compositions are in good agreement. However, two Nakhla aliquots show a resolvable K isotopic difference. Given

that Nakhla is a fall, we interpret these variations to reflect aqueous alteration of nakhlites on Mars [6]. Two processes could potentially introduce K isotopic variabilities: 1) alterations in a suite of hydrous minerals (*i.e.*, iddingsite) within olivine, and 2) modification of glassy mesostasis.

Discussion: Figure 2 shows a “summed Gaussian” distribution of $\delta^{41}\text{K}$ among samples from the available terrestrial planetary bodies (*i.e.*, the Earth, Moon, Mars, and asteroid 4-Vesta). The majority of the martian meteorites show a clear offset towards heavier K isotopic compositions relative to the bulk silicate Earth (BSE). The bulk silicate Moon, and to a more extreme extent, samples from 4-Vesta, are more enriched in heavy K isotopes compared to Mars [2,7].

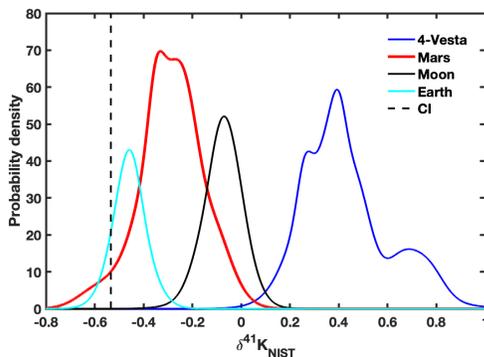


Figure 2. The “summed Gaussian” plot of the $\delta^{41}\text{K}$ distributions among four parent bodies (the Earth, Moon, Mars, and asteroid 4-Vesta, data compiled from [2,7]). The dashed line refers to the $\delta^{41}\text{K}$ of CI chondrite Orgueil [4].

Among the four bodies, the mean $\delta^{41}\text{K}$ values increase with decreasing mass, with the Earth being similar to CI chondrites. These observations are given in Fig. 3 where the average K isotope compositions of all four differentiated terrestrial planetary bodies are plotted versus their radius, mass, escape velocity, and surface gravity (Fig. 3). A tight negative correlation is observed for all parameters and K isotopes indicating some gravity control of K loss. Intriguingly, the average planetary K isotopic compositions do not correlate with their K/U ratios (or other elemental ratios characteristic for planetary volatile element depletions, such as Rb/Sr). Nevertheless, the strong control of planetary gravity for K isotopes suggests that the K isotopic fractionation in planetary bodies likely occurred via volatile escape during accretionary growth of planetesimals, as proposed for the alkalis in these four objects [8] and Mg isotopes in the Earth [9]. Therefore, these new results suggest that the estimate of the initial volatile budget of Mars needs to be revisited and Mars is likely more volatile-depleted

than previously thought, being intermediate between Earth and the Moon.

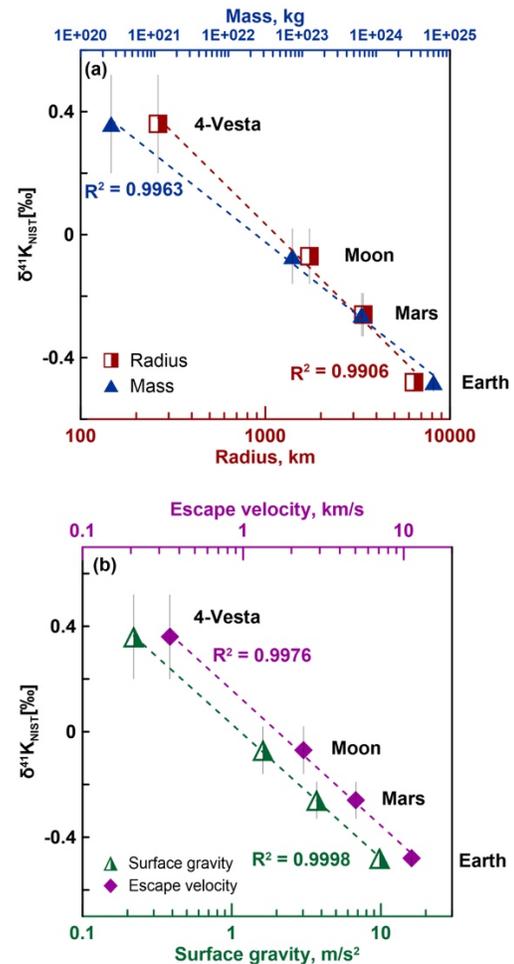


Figure 3. The K isotopic compositions of the four parent bodies vs. their corresponding radius, mass, surface gravity, and escape velocity in log scale.

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