

Insight into the volatile content of Mars from the zinc isotopic composition of SNC meteorites

M. Paquet¹, P. Sossi² and F. Moynier¹, ¹Université Paris Cité, Institut de Physique du Globe de Paris, CNRS, 1 rue Jussieu 75005 Paris (paquet@ipgp.fr, moynier@ipgp.fr), ²Institute of Geochemistry and Petrology, ETH Zürich, Clausiusstrasse 25 CH-8092 Zürich (paolo.sossi@erdw.ethz.ch).

Introduction: Barring a sample return mission to Mars, martian meteorites are the sole tangible records of its crust. These samples provide insights into the composition of Mars, as well as the processes that led to its accretion and differentiation. Relative to CI-chondrites or the Sun, terrestrial planets are depleted in moderately volatile elements (MVE) [e.g., 1]. Recent work showed that martian meteorites have systematically heavier K isotopic compositions than the Bulk Silicate Earth (BSE), suggesting a greater volatile depletion and stronger K isotope fractionation relative to their potential precursor materials [2]. However, this interpretation is in contrast with the abundances of other volatile elements, such as Zn or Rb that are present in greater abundances in the martian mantle than in the BSE [3]. Zinc, like K, is a moderately volatile, lithophile element, whose isotope composition provides independent constraints on volatile delivery and loss during planetary accretion [4]. Previous Zn isotopic data for martian meteorites range from $\delta^{66}\text{Zn} = +0.13$ to $+0.35\text{‰}$ [5], values that are not resolvable from that of the BSE ($\delta^{66}\text{Zn} = 0.16 \pm 0.06\text{‰}$, [6]) within error. To better evaluate the Zn isotopic composition of Mars, we present new high precision Zn isotope data for ten martian meteorites, spanning the major petrologic types. Combined with previous measurements, this new dataset permits a precise assessment of the martian mantle Zn isotope composition, representative of the Bulk Silicate Mars (BSM), and to test if the model proposed for volatile depletion based on K isotopes [2] holds for Zn.

Samples and Methods: Zinc isotope compositions were measured in ten martian meteorites: seven shergottites (depleted: Allan Hills [ALHA] 77005, Dar al Gani [DaG] 476, Elephant Moraine [EETA] 79001, Tissint; enriched: Larkman Nunatak [LAR] 06319, Roberts Massif [RBT] 04262, Zagami), two nakhlites (Miller Range [MIL] 00346, MIL090032) and one orthopyroxenite (ALH 84001). Zinc isotope compositions, measured using a Thermo Scientific Neptune Plus Multi-Collector Inductively Coupled Plasma Mass Spectrometer following a standard-sample bracketing method together with Cu-doping, are reported as the permil deviation from the JMC-Lyon Zn standard [7].

Results and discussion: Martian meteorites measured in this study span a range of $\delta^{66}\text{Zn}$ from $+0.18 \pm 0.02\text{‰}$ (Tissint) to $+0.52 \pm 0.02\text{‰}$ (ALHA 77005), with an average value of $+0.36 \pm 0.08\text{‰}$, consistent with previous work [5]. Nakhlites, enriched and depleted shergottites are, in average, indistinguishable within error ($+0.36 \pm 0.05\text{‰}$ [n=3], $+0.35 \pm 0.06\text{‰}$ [n=6] and $+0.38 \pm 0.12\text{‰}$ [n=6], respectively). The martian samples with the lightest $\delta^{66}\text{Zn}$ values tend to exhibit lower MgO content, opposite to what is observed for terrestrial basalts [6], however there is no correlation with the Zn abundances.

Extrapolation of the shergottite array (with the exception of Tissint which plots within the BSE range) to the MgO content of the martian mantle of 32.8 wt.% [3] yields a $\delta^{66}\text{Zn} = +0.51 \pm 0.10\text{‰}$ for the BSM, distinctly heavier than that of the Earth ($+0.16\text{‰}$; [6]). If the mantle had higher MgO contents, as allowed by the preservation of Fo₈₅ phenocrysts in olivine-phyric shergottites [8], the $\delta^{66}\text{Zn}$ estimate would only further diverge from that of the BSE.

The Earth's Zn composition is interpreted as deriving from the accretion of material that experienced chemical and isotopic fractionation in the solar nebula likely during chondrule formation [10], similarly to what carbonaceous chondrites experienced but to more volatile-depleted extremes [6]. With a Zn/Mg of 3.34×10^{-4} (MgO = 32.8 wt.% and Zn = 65.9 ppm [3]) and an estimated composition of $+0.51\text{‰}$ for the BSM, Mars plots off the carbonaceous chondrite array [9, 10]. Thus, the Zn isotope composition of Mars would rather argue in favor of volatile loss by evaporation from a precursor akin to Earth, leading to an enrichment in heavier isotopes, which is consistent with other volatile elements such as K [2].

References: [1] Palme H. and Jones A. (2003) *Treatise on geochemistry*, 1, 711. [2] Tian Z. et al. (2021) *Proceedings of the National Academy of Sciences*, 118, 39. [3] Khan A. et al. (2022). *Earth and Planetary Science Letters*, 578, 117330. [4] Day J. M. D. and Moynier F. (2014) *Philos. Trans. Royal Soc. Math. Phys. Eng. Sci.*, 372, 20130259. [5] Paniello R. C. et al. (2012) *Nature*, 490(7420), 376-379. [6] Sossi P. et al. (2018) *Chemical Geology*, 477, 73-84. [7] Moynier F. et al. (2017) *Reviews in Mineralogy and Geochemistry*, 82(1), 543-600. [8] Usui T. et al. (2008) *Geochimica et Cosmochimica Acta*, 72(6), 1711-1730. [9] Luck J.-M. (2005) *Geochimica et Cosmochimica Acta*, 69, 22, 5351-5363. [10] Pringle E. et al. (2017) *Earth and Planetary Science Letters*, 468, 62-71.