Zirconium isotope compositions of chondrites, eucrites and martian meteorites

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Introduction:

The isotopic composition of meteorites can reflect the initial distribution of different phases in the protoplanetary disk, processes in solar nebula (condensation/evaporation) and/or later accretional differentiation processes within planetary bodies. The isotopic composition of refractory lithophile elements, like Ca and Ti (50% T_C 1517 K and 1582 K respectively) [1], are little influenced by core formation, late veneer and vapour loss during accretion. They are condensed early under high temperature conditions, therefore providing useful information of processes occurred in the early stages of solar system [2, 3]. Previous studies on mass dependent Ca and Ti isotopic fractionations show CAIs have a large range of isotopic ratios for these two systems. Calcium-aluminum-rich inclusions are preferentially enriched in lighter Ca isotopes while they can be either isotopically heavier or lighter for Ti [4, 5]. Whereas different chondrite groups show indistinguishable Ti isotope compositions, the Ca isotopic variations among groups of chondrites can be attributed to either a heterogeneous distribution of CAIs or parent-body aqueous alteration.

Zirconium is the most refractory lithophile element (50% T_C of 1736 K) [1]. In addition, it is one of the least mobile elements during aqueous fluid alteration processes [6]. Thus Zr is a good candidate to provide a better insight into the early stages of planetary information.

It is shown that the precipitation of zircons during fractionational crystallisation exert a major control on the Zr isotope composition of terrestrial igneous rocks and Zr isotopes are potential tracers of magma differentiation [7-9]. The Zr isotope compositions of terrestrial mantle and crust has been fairly well defined. Understading how Zr isotope compositions distribute within different planetary bodies has also the potential to provide further insights into planetary differentiation.

In this study, a large set of bulk meteorite samples, including all groups of chondrites, martian meteorites, eucrites, as well as CAIs are studied to test whether the solar nebular evaporation/condensation induce Zr isotopic fractionations. Furthermore it allows constraint on the igneous history of these planetary objects relative to Earth .

Samples and methods: Four CV, 3 CK, 5 CM, 6 CO, 3 CR, 1 CI, 3 ungrouped (CM-like or between CI and CM) carbonaceous chondrites, 8 oridnary chondrites, 2 enstatite chondrites**,** 11 martian meteorites (shergottite, nakhlite, orthopyroxenite) and 2 eucrites, as well as 3 CAIs from the CV chondrite Allende were analyzed for Zr isotopic composition. Sample preparation and spiking, purification, and MC-ICP-MS analysis followed the protocol reported in [10]. The Zr isotopic anomalies were corrected based on [11].

Results and Discussion: The CV and CK chondrites are systematically isotopically lighter in Zr compared to the estimated composition of the bulk silicate Earth. The same is observed for CM but to a lesser extent. The CO chondrites have zirconium isotopic composition mostly similar to the BSE but some samples extend to lighter values. While the Zr isotopic compositions of CR fall between the range of CV-CM-CO and that of BSE, or similar to the BSE, CI, ordinary and enstatite chondrites are indistinguishable with the BSE. The Zr isotopic variations between the carbonaceous chondrites can be attributed to the variable distribution of CAIs between chondrite groups. The CAIs from Allende studied in this work are characterized by large Zr isotopic variations, which can be either isotopically heavy or light compared to bulk Allende. Considering that CAIs analyzed here have different Zr concentrations, their Zr-weighted average value is actually close to the isotopic composition of bulk Allende. In this way, Zr isotopes holds some similarities with Ca isotope systematics, yet, with the enphasis on the more robust record for Zr isotopes, as potential parent-body aqueous alteration seems not to affect the Zr isotope composition of carbonaceous chondrites. Combining Ca and Zr stable isotopes may have the potential to decipher between these two processes. The variations of Zr isotopic compositions of Martian meteorites and eucrites overlap with that of terrestrial basalts reported in [12], suggesting limited variations of Zr isotopic composition between terrestrial planets.

References:

[1] Lodders K. (2003) *Astrophys. J.* 591:1220-1247. [2] Simon J. I. and DePaolo D. J. (2010) *Earth Planet. Sci. Lett.* 289:457-466. [3] Deng Z. B. et al. (2018) *Geochim. Cosmochim. Acta* 239:409-419. [4] Simon J. I. et al. (2017) *Earth Planet. Sci. Lett.* 472:277-288. [5] Davis A. M. et al. (2018) *Geochim. Cosmochim. Acta* 221: 275-295. [6] Anderson S. P. et al. (1997) *Geol. Soc. Am. Bull.* 114:1143-1158. [7] Inglis E. C. et al. (2019) *Geochim. Cosmochim. Acta* 250, 311-323. [8] Guo J. L. et al. (2020) *Proc. Natl. Acad. Sci. U. S. A.* 117:21125-21131. [9] Ibañez-Mejia M. and Tissot F. L. (2019) *Sci. Adv.* 5: eaax8648. [10] Tian S. et al. (2022) *J. Anal. At. Spectrom.* 37:656-662. [11] Akram W. et al. (2015) *Geochim. Cosmochim. Acta* 165:484-500. [12] Inglis E. C. et al. (2019) *Geochim. Cosmochim. Acta* 250:311-323.