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Zinc isotope dichotomy and the origin of volatile elements in the terrestrial planets

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Determining the provenance of volatile elements in the terrestrial planets is critical for understanding a possible pathway for the emergence of habitable planets. A planet may accrete volatile elements from its major building blocks or, alternatively, an exogenous source that otherwise contributed only little of a planet's mass. Distinguishing between these possibilities requires assessing as to whether there is a genetic link between a planet's major building material and the source of its volatile elements. Here we show that the moderately volatile element zinc exhibits an isotopic dichotomy between non-carbonaceous (NC) and carbonaceous (CC) meteorites, which likely derive from the inner and outer Solar System, respectively. This allows determining the provenance of moderately volatile elements in Earth and Mars, by comparing their Zn isotope compositions to those of the NC and CC reservoirs. Terrestrial Zn has an intermediate isotopic composition [1-3], demonstrating that ~70% of Earth‘s Zn derives from its main inner solar system building blocks, while ~30% derive from CC-like objects. Using literature data, we find the same proportions for the more volatile elements H and N, suggesting Earth's volatile elements predominantly derive from inner solar system objects and not, as often assumed, from the outer solar system. Unlike Earth, the Zn isotope composition of Mars is similar to that of NC and distinct from CC meteorites. Like for non-volatile elements, Mars' Zn isotope composition is intermediate between that of enstatite and ordinary chondrites, demonstrating that Mars acquired volatile elements predominantly from its inner solar system building blocks. The Zn isotope data limit the contribution of CI chondrite-like material to Mars to 4% by mass at most and show that Mars accreted less CC material than Earth. The origin of these disparate CC fractions is unclear, but can place constraints on how and when CC-type material was delivered to the inner solar system.

References: [1] Steller T. et al. (2022), Icarus 386, 115171. [2] Savage P. et al. (2022), Icarus 386, 115172. [3] Martins R. et al. (2023), Science 379, 369-372.