

Ti isotope constraints on late accretion to Mars

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The isotopic compositions of several elements in the solar system show a dichotomy in nucleosynthetic isotopic anomalies. Specifically, carbonaceous chondrites (CC) derived from the outer solar system show systematically larger isotopic anomalies than non-carbonaceous (NC) meteorites from the inner solar system. Nucleosynthetic isotope anomalies arise from the heterogeneous distribution of presolar phases and ultimately reflect that the Solar System incorporated material from different stellar sources[1][2]. It can be used as a tracer for the origin of building blocks of the terrestrial planets.

Mo isotopes analysis of combined Martian meteorites indicated that Mars is a mixture of NC and CC materials[3]. However, a recent high-precision Cr isotope study revealed the nucleosynthetic isotope heterogeneity among Martian meteorites[4]. Specifically, Martian meteorites enriched in incompatible trace elements such as enriched shergottites and nakhlites tend to have higher $\mu^{54}\text{Cr}$ values (i.e., more CC-like) than depleted shergottites. This finding is considered to reflect that CC materials accreted to Mars after NC materials accumulated and formed the Martian embryo. Such late accretion may be the origin of volatiles including water in Mars. Yet, the nature and size of the late accreted CC materials remain poorly constrained.

In this study, to better constrain the late accretion to Mars, we report a high-precision Ti isotope analysis of Martian meteorites. While Ti isotope compositions of Martian meteorites were previously reported [1][5], high-precision data are restricted to depleted and intermediate shergottites. By contrast, samples analyzed in this study cover a range of Martian meteorites: depleted and enriched shergottites (NWA 13190, Yamato 980459, Zagami), and one nakhlite (Yamato 000593). Ti isotopes were measured using MC-ICP-MS after Ti separation using column chromatography described in Hibiya et al. [6]. The data reveal that all samples have identical $\varepsilon^{50}\text{Ti}$ values within analytical uncertainty.

Our results, combined with the previously reported Cr isotope data [4], provide constraints on the nature of the late accreted materials and the origin of geochemical diversity in shergottites. There are two major theories regarding the formation process of shergottites. One is that there is an enriched mantle closer to the crust and a depleted mantle at depth, and enriched and depleted shergottites formed by partial melting of these mantle sources, respectively. The other theory is that there is only one shergottite source mantle and enriched shergottites are formed by crustal assimilation by the parental magma of depleted shergottites. If the former theory is correct, then the Cr isotope variation between depleted and enriched shergottites requires that late accreted CC materials mixed selectively into an enriched mantle. If the latter is the case, the effect of the late accretion would be restricted onto the crust. By considering mixing of various CC materials with Martian crust and mantle, we examined which theory and what kind of CC material can explain the Cr-Ti isotopic data. We found that mixing of any carbonaceous chondrites with the mantle cannot account for the Ti and Cr isotopic data, supporting the latter theory for the shergottite origin. By contrast, mixing of CI, CB, or CR chondrite with depleted shergottite magma can reproduce the Ti-Cr isotopic trend. The proportions of the carbonaceous chondrites mixed with the magma are further estimated to be ~20% for CI, ~25% for CB, and ~15% for CR chondrites.

Reference

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キーワード：火星、Ti同位体、後期集積、shergottite、Cr同位体、核合成起源同位体異常

Keywords: Mars, Ti isotope, late accretion, shergottite, Cr isotope, nucleosynthetic isotope anomaly