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Metal-silicate fractionation and chondrule formation: Fe isotope constraints

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Recent studies have shown that considerable variations of Fe isotopes exist in both meteoritic and terrestrial materials, and that they are related, through mass-dependent fractionation, to a single isotopically homogeneous source[1]. This implies that the Fe isotope variations recorded in the solar system materials must have resulted from mass fractionation incurred by the processes within the solar system itself. The Fe isotope composition therefore in turn offers potential to address some important issues in solar system sciences. Metal-silicate fraction is a fundamental process during solar nebular evolution and planet formation, and chondrule formation represents an important event in the history of early solar system. As an element which is moderately volatile and has substantially segregated from silicates in various planetary materials, Fe isotope composition is expected to provide insights into process of metal-silicate differentiation. Samples used in this study include a carbonaceous chondrite Allende (CV3); ordinary chondrites Chainpur (LL3), Chandakapur (L5) and Forest City (H5); main group pallasites Imilac and Krasnojarsk; and a non-main group pallasite Eagle Station. The primitive chondrites Allende and Chainpur were analysed for bulk samples, matrices, chondrules, metal fractions and silicate residues. The equilibrated chondrites and the pallasites were analysed for metal and silicate fractions. The high-precision iron isotope results obtained in this study provide new insights into the mechanisms of metal-silicate fractionation and chondrule formation. They demonstrate that physical metal-silicate separation is the dominant process responsible for iron depletion in chondrules and for metal-silicate fractionation in the solar nebula, but evaporation also played an important role at least for some chondrules in carbonaceous chondrites. This study provides compelling evidence that chondrules even from a single meteorite may have formed by different processes and at different environments, which highlights the complexity of chondrule formation. More generally, this study shows that iron isotope composition of meteoric material is a powerful tool in distinguishing metal-silicate fractionation caused by physical removal of metal phases from that resulted from evaporation and condensation.

Reference

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Fe isotopes fractionation in experimental chondrules

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Natural chondrules show an Fe-isotopic mass fractionation range of a few δ-units [1,2] that is interpreted either as the result of Fe depletion from metal-silicate fractionation during chondrule formation [1] or as the reflection of the fractionation range of chondrule precursors [2]. In order to better understand the iron isotopic compositions of chondrules we conducted experiments to study the effects of reduction and evaporation of iron on iron isotope systematics.

About 80mg of powdered slag fayalite was placed in a carbon crucible and heated for various durations (ranging between 5 min. and 2hr) at 1450, 1500 and 1540°C. The oxygen fugacity was near the the C-CO buffer. Recovered charges were analyzed on the electron probe and by MC-ICPMS for Fe isotopic compositions.

The data obtained demonstrate that the formation of iron metal via reduction is efficient and occurs within 10 min. or less. The reduction does not induce any isotopic fractionation, as the isotopic composition of the metal remains constant and equal to that of the source material throughout all the experiments (within 0.1‰).

The chemical evolution the silicate portions of the charges indicates that, within the first 10 minutes of the experiments, more than half of the initial FeO was reduced to metal and that the remaining FeO is subsequently lost to evaporation).

This interpretation is confirmed by the isotopic composition of the silicate portion of the charge, which becomes heavier by up to 2.5‰ for $\delta^{57}Fe$ after 10 minutes at 1540°C and more gradually at 1500°C. As time progresses, however, the mass fractionation in the silicates gradually decreases. This must be due to an exchange between the vapor and the melt aided by the 1 atm. total pressure.

The behavior of Fe in the experimental charges thus follows the conclusion advocated by [3] that extensive Fe-loss during the formation of Renazzo chondrules was followed by its re-condensation.

References

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