Reconstructing asteroidal core formation using Cr stable isotopes

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Introduction: Most iron meteorites are interpreted to represent fragments of the cores of asteroids, hence their formation represents a significant stage of planetary differentiation. The formation and crystallization of these cores dates back to the first few million years of the solar system. Stable isotopes of siderophile elements, such as Cr [1, 2] may fractionate during metal-silicate equilibration, which can provide constraints for the reconstruction of the physicochemical environment of core formation processes. However, it is difficult to determine the original Cr isotope composition of iron meteorites, because exposure to cosmic rays can significantly modify the Cr isotope compositions of samples with high Fe/Cr ratios and long exposure times, leading to enrichments in ^{53}Cr and ^{54}Cr [3]. This can result in a negative correlation between Cr contents and δ^{53}Cr of iron meteorite metal [4]. Chromite and Fe-Cr sulfide (daubréelite) in iron meteorites have very low Fe/Cr ratios and thus, may better preserve the original Cr isotope composition of iron meteorites before irradiation [5]..

Samples and Methods: Seven chromite/daubréelite samples of iron meteorites, belonging to IIIAB (Cape York and Saint Aubin), IVA (Yanhuitlan and Duchesne) and IIAB (Agoudal, Sikhote Alin and NWA 11420) groups are investigated which, wereare from a previously studiedy for mass-independent Cr isotope variations [5]. We employed the Triton TIMS (Freie Universität Berlin) and double spike techniques to measure to their δ^{53}Cr values, with an external 2SD precision of better than 0.02 ‰. The detailed analytical method is described in [6].

Results: Two IIIAB chromites show the same δ^{53}Cr (per thousand ^{53}Cr/^{52}Cr ratios relative to NIST SRM 979) values of −0.08 ± 0.01‰ (2SD), while the chromite/daubréelite in IVA and IIAB iron meteorites show large δ^{53}Cr variation, from −1.29‰ to −0.74‰ and from −0.64‰ to −0.08‰, respectively. The bulk iron meteorites have variable Ni, Au and Ir contents, which are not correlated with the δ^{53}Cr values of the chromites.

Discussion and Conclusion: The Cr stable isotope fractionation of more than 1 permil for some chromites most likely reflects kinetic isotope fractionation, caused by diffusion processes during core crystallization and cooling. Two IIIAB iron meteorites with different Ni, Au and Ir contents (8.50%, 1.01 ppm and 2.90 ppm; 10.33%, 2.59 ppm and 0.02 ppm respectively) have chromites with the same δ^{53}Cr values of -0.08 ± 0.01‰. These data may reflect equilibrium isotope fractionation and the δ^{53}Cr value may be representative for the IIIAB iron meteorite parent body. However, during crystallization chromite can become enriched in heavy Cr isotopes by ~0.15‰ as was shown in relatively oxidized terrestrial rocks [7]. Hence, the IIIAB bulk iron meteorites may have a lighter δ^{53}Cr value relative to chromite (around ~−0.23‰). Since the chromites from these three iron meteorite groups have ordinary chondrite (OC)-like ε^{54}Cr values [5, 8, 9] and chondrites show heterogeneous δ^{53}Cr values [6], we assume that the δ^{53}Cr values of OCs (−0.10 ± 0.04‰; 2SD, N = 20) are representative of the bulk parent bodies of the iron meteorites [6, 10]. The δ^{53}Cr difference between IIIAB iron meteorites and OCs, $\Delta^{53}Cr_{IIIAB\text{-}OCs}$ = ~−0.13‰, potentially indicates Cr stable isotope fractionation during core formation of the IIIAB parent body.This observation is consistent with *ab-initio* calculations suggesting that the metal phase is enriched in isotopically light Cr compared to coexisting silicates during their segregation [11]. Indeed, silicates of the aubrite and ureilite parent bodies are enriched in isotopically heavy Cr, which suggests the asteroid cores should be dominated by isotoplically light Cr. When Cr stable isotopes are used for tracking planetary differentiation, core formation must be considered, especially for small planetary bodies [12, 13].

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