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Molybdenum Stable Isotope Constraints on Planetary Core Formation

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Traditionally, the conditions of core formation in planetesimals and terrestrial planets have been constrained by comparing the observed abundances of siderophile elements in the silicate portion of planetary bodies to the results of metal-silicate partitioning experiments [e.g., Wood et al. (2006)]. However, for many bodies the mantle compositions are not well known, thus limiting the informative value of this approach to constrain the conditions of core formation. Mass-dependent Mo isotope fractionation between metal and silicate might provide a new approach that is independent of the precise knowledge of mantle concentrations and partition coefficients. Significant Mo isotope fractionation between liquid metal and liquid silicates as determined in a companion study [Hin et al. (2012)] exists, demonstrating that Mo isotopes can potentially constrain the conditions of core formation in planetesimals and terrestrial planets.

Here we present Mo stable isotope data for a variety of meteorites, including chondrites, iron meteorites, eucrites, angrites and a martian meteorite as well as lunar and terrestrial samples. Chondrites and iron meteorites define a common δ98/95Mo, most likely representing the Mo stable isotope composition of bulk planetary bodies in the inner solar system. The Mo isotopic compositions of the silicate samples are heavier to variable degrees, which at least in part reflects Mo stable isotope fractionation during core formation. However, as is evident from the heavy Mo isotopic composition of one angrite (NWA 4801) and one shergottite (DaG 476), other processes such as terrestrial weathering have overprinted the Mo isotope signatures of core formation in some samples. Nevertheless, when excluding samples whose Mo isotope signatures were modified during weathering, the temperatures of metal-silicate equilibration during core formation can be estimated. Assuming metal-silicate equilibrium and instantaneous core formation, temperatures of $\approx$2000 °C (Earth and Moon) and $\approx$1700 °C (angrite parent body) are obtained, consistent with metal-silicate equilibration in a magma ocean. For the Earth, these new results may suggest that core formation did not occur at the base of a deep magma ocean, but rather took place at a shallower depth, either during descent of metal droplets through the magma ocean or by metal-silicate equilibration in Earth's precursor bodies. However, at present we cannot exclude that post-core formation processes have modified the Mo isotope composition of the examined terrestrial samples, in which case the temperature of metal-silicate equilibration cannot easily be determined from the Mo isotope data. This is exemplified by our Mo isotope data for eucrites, which are heavier than those of the other examined silicate samples. This may indicate core formation by percolation at lower temperatures ($\approx$1000 °C) or additional post-core formation Mo isotope fractionation within the eucrite parent body. In conclusion, our study demonstrates that once the different processes that can fractionate Mo isotopes at high temperatures are fully understood, Mo isotopes provide a powerful tool to investigate the conditions of core formation in planetary bodies.

References: Wood et al. 2006: Accretion of the Earth and segregation of its core. Nature 441,825-833. Hin et al. 2012: Equilibrium fractionation of molybdenum isotopes between liquid metal and liquid silicate. EMPG Meeting, Kiel.