Trace element constraints on core formation in the Moon and Mars

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The physical and chemical conditions during metallic core formation in terrestrial planets are still not well constrained. We modeled the pressure, temperature and oxygen fugacity conditions under which it would be possible to match the observed siderophile element depletions of moderately siderophile elements Ni, Co, W, Mo, P, V, Cr and Ge in the silicate reservoirs of the Moon and Mars, using new constraints on their metal-silicate partitioning behaviour. We characterize the dependence of the metal-silicate partition coefficients (D) on temperature, pressure, oxygen fugacity, and composition of the silicate melt and the metal.

To study lunar core formation we use published partitioning data in the lunar pressure range (1 atm - 5 GPa). If the core is assumed to consist of pure iron, core-mantle equilibration conditions that best satisfy lunar mantle depletions of five siderophile elements—Ni, Co, W, Mo and P - are a pressure of 4.5(±0.5) GPa and a temperature of 2200 K. The lunar mantle depletions of Cr and V are also consistent with metal–silicate equilibration in this pressure and temperature range if 6 wt% S is incorporated into the lunar core. Our results therefore suggest that metal–silicate equilibrium during lunar core formation occurred at depths close to the present-day lunar core–mantle boundary. This provides independent support for both the existence of a deep magma ocean in the Moon in its early history and the presence of significant amounts of sulfur in the lunar core (Rai and Van Westrenen, 2014).

For Mars, our results show that it is impossible to simultaneously account for the martian mantle depletions of siderophile elements if the martian core sulfur content exceeds ~10.5 wt% at reducing conditions. At ~10.5 wt% core S, the conditions that best satisfy martian mantle abundances of the siderophile elements are a pressure of 13(±1) GPa at 2330 K, corresponding to the presence of a ~1025 km deep magma ocean on Mars during core formation (Rai and Van Westrenen, 2013).

One key outcome of these studies is that D parametrizations should be based on experiments performed within the likely pressure range of core-mantle equilibration in the planetary body of interest. Experiments at pressure exceeding those in the center of the Moon should not be used to constrain metal-silicate partitioning in the Moon. Similarly, low-pressure experiments should not be used to constrain metal-silicate partitioning in Mars (or the Earth).

References

Rai N, van Westrenen W (2014) Lunar core formation: New constraints from metal-silicate partitioning of siderophile elements. Earth and Planetary Science Letters 388, 1-10.

Rai N, van Westrenen W (2013) Core-mantle differentiation in Mars. Journal of Geophysical Research: Planets 118, 1195-1203.