Core-mantle fractionation of carbon in magma oceans of inner Solar System bodies: the role of sulfur

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Constraining carbon (C) fractionation between silicate magma ocean (MO) and Fe-rich alloy liquid during early differentiation is essential to understand the origin and early distribution of C between reservoirs such as the exosphere (crust + atmosphere), mantle, and core of the inner Solar System bodies such as Earth, Mars, the Moon, and 4 Vesta. Yet experimental data at high pressure (*P*)-temperature (*T*) on the effect of other light elements such as sulfur (S) in alloy liquid on alloy-silicate partitioning of C and C solubility in Fe-alloy compositions relevant for core formation are lacking. Here we present new multi-anvil experiments at 6–13 GPa and 1800–2000 °C to examine the effects of S and Ni on the solubility limit of C in Fe-rich alloy liquid as well as partitioning behavior of C between alloy liquid and silicate melt ($D_{\mathrm{C}}^{\mathrm{alloy/silicate}}$). The results show that C solubility in the alloy liquid as well as $D_{\mathrm{C}}^{\mathrm{alloy/silicate}}$ decreases with increasing in S content in the alloy liquid from 0 to 25 wt.%. Empirical regression on C solubility in alloy liquid using our new and previous experiments demonstrates that C solubility significantly increases with increasing temperature, whereas unlike in S-poor or S-free alloy compositions, there is no discernible effect of Ni on C solubility in S-rich alloy liquid.

Our modelling results confirm previous findings that in order to satisfy the C budget of BSE, the bulk Earth C undergoing equilibrium alloy-silicate fractionation needs to be similar to those of carbonaceous chondrites. For Mars, on the other hand, an average single-stage core formation at relatively oxidized conditions ($\log fO_2$~IW-1) with 10-16 wt.% S in the core could yield a Martian mantle with a C budget similar to that of Earth's BSE for a bulk C content of ~0.2-0.9 wt.%. If models of 4 Vesta's S-rich core are appropriate, then Vestan mantle also may be more C-rich than previously thought. Using our new data we also refine the model of establishment of C budget in Bulk Silicate Earth via merger of an S-rich, differentiated, late-stage impactor [1]. In this framework, our model calculations predict that the bulk C content in the impactor can be as low as ~0.5 wt.% for an impactor that is between 9 and 20% of the present-day Earth's mass.

[1] Li et al. (2016) *Nat. Geosci.* 9, 781-785.