The Hadean matte, magma ocean solidification and Earth's late veneer

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Highly siderophile elements (HSE) are present in Earth's mantle in unexpectedly high concentrations and, except for Ru and Pd, in chondritic relative abundances. The classical explanation is that the HSE were strongly depleted in the mantle by core formation with presently-observed concentrations being added to the mantle after the end of core formation in a "late veneer" of oxidized chondritic material [1]. We have modelled this process by extending a combined accretion/multistage core formation model [2] to include the HSEs and S. We assume that all starting bodies in the protoplanetary disk contain CI concentrations of HSE and that S concentrations increase linearly from zero at ≤0.8 AU to 4.35 wt% at ≥6-7 AU. In addition to reproducing mantle HSE concentrations, we aim to create a model Earth with ~1.8 wt% S in the core and ~200 ppm in the mantle [3].

The classical explanation fails badly. First, at the end of core formation, the mantle contains high and strongly-fractionated concentrations of HSE. This is because, after each accretional impact, metal only equilibrates with a fraction of Earth's mantle (i.e. equilibration is localized) [2] and also the HSE are fractionated at high pressure [4]. Second, such localized metal-silicate equilibration is also inefficient at extracting S from the magma ocean so that mantle concentrations greatly exceed S saturation levels in silicate liquid [5,6]. Consequently, immiscible sulfide liquid (the "Hadean matte" of O'Neill [7]) must have segregated from the terrestrial magma ocean for much of Earth's accretion history. Core formation thus involved: a) localized segregation of the impactor's metallic core and b) segregation of a more widely dispersed immiscible sulfide liquid. The latter efficiently extracts Pt and Ir from the mantle but allows significant concentrations of Ru and Pd to build up in the mantle prior to the addition of the late veneer, based on new partitioning data [6]. Late veneer addition occurs after sulfide liquid segregation has ceased due to magma ocean solidification. This model reproduces well the suprachondritic Ru/Ir and Pd/Ir ratios of the mantle, reflecting incomplete removal of Ru and Pd from the mantle with core-forming sulfide liquids.

[1] Walker (2009) *Chemie der Erde* **69**, 101-125. [2] Rubie *et al* (2015) *Icarus* **248**, 89-108. [3] Palme & O'Neill (2014) *Treatise on Geochemistry* vol. 2, 1-39. [4] Mann *et al* (2012) *GCA* **84**, 593-613. [5] Mavrogenes & O'Neill (1999) *GCA* **63**, 1173-1180. [6] Laurenz *et al* (2015) this meeting. [7] O'Neill (1991) *GCA* **55**, 1159-1172.