The Conditions of Core formation on Earth

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Recent high pressure metal-silicate partitioning data have demonstrated that the contents of some siderophile elements, notably Ni and Co in the Earth's mantle are only consistent with segregation of the core under extremely high pressure conditions (greater than 30 GPa). This has led to the deep magma ocean hypothesis by which sinking iron droplets continuously equilibrate with the molten mantle until they form a thick layer above the solid lower mantle. The iron layer becomes gravitationally unstable and sinks rapidly as large diapirs to the core.

I have refined and extended this model in the following ways. Firstly, I have corrected the metal-silicate partitioning data for the effects of carbon capsules. It is well-known from the metallurgical literature that carbon has pronounced effects on trace element activities in iron and these need to be accounted-for. Secondly, I have collected data on a much wider range of weakly and strongly siderophile elements -V,Si,Mn,Ni,Co,W,Ga and P. Thirdly, I have used literature thermodynamic data to constrain the effects of temperature on partitioning, only using the high pressure data to estimate pressure dependencies.

The results are extremely interesting. Partitioning of V and Si depends strongly on temperature but hardly on pressure. So these elements give us constraints on temperature of core formation. Ni is strongly pressure-dependent, providing a constraint on pressure. If we assume that the core formed at the current Fe content of the mantle then the temperature of core formation should be 3750K and the pressure 40 GPa. However, these conditions are well above the peridotite liquidus, which seems impossible at the bottom of the magma ocean and the Si content calculated for the core (14%) is implausibly high.

In order to explain the composition of the mantle we must then accept that the core formed over changing pressure-temperature conditions at variable Fe content (and oxygen fugacity) of the mantle. I find that the mantle compositions are well-fit if the bottom of the magma ocean is forced to stay on the peridotite liquidus as the Earth grew, providing that the oxygen fugacity increased during accretion. Thus, the earth began life as a small reduced body and the oxygen fugacity increased during growth and core segregation. Various mechanisms for increasing oxygen fugacity during growth can be envisaged, including dissociation of H_2O and accretion of oxidised asteroidal bodies.