

Experimental constraints on metal percolation through silicate: How did early cores form?

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Core formation on small planetary bodies, e.g., early-formed planetesimals, asteroids, planetary embryos etc., occurred over very short timescales $\sim 1\text{-}5$ Myr [e.g., 1], yet the mechanics of metal segregation on bodies that were potentially too cold for complete silicate melting, i.e., no magma ocean, is not well understood. The overarching scenario invoked is core formation by percolation of metallic melt through a solid silicate matrix; difficult as Fe melt has a very high dihedral angle ($\Theta > 90^\circ$) [2-5], and does not wet grain boundaries. In order to enhance the percolative ability of the metallic melt, several modifications have been proposed:

1. Increase the volume of metallic melt present to $>5\text{-}10$ vol.% [5-7],
2. Add light elements (S [3,4,8-15], S-O [5,13-18], Si [19,20]) that reduce Θ ,
3. Increase silicate partial melts [9,10,21] with $\Theta < 45^\circ$ that wet grain boundaries.

The effect of C addition to the metallic phase has not been studied, nor has the combined effect of several light elements, e.g., S+C+O, where metal immiscibility occurs.

Two sets of piston cylinder experiments were conducted to determine the 1) Θ of C-bearing metallic melts, and 2) percolation conditions of metal segregation. All experiments used San Carlos olivine-pyroxene mix as the silicate matrix placed in MgO containers. Experiments were held at P (1.0-3.0 GPa) and T (1400-1800 °C) for 6-24 hrs. Dihedral angle experiments consisted of ~ 5 vol.% Fe-C mix. Percolation experiments consisted of layers of metal-free silicate and metal-bearing silicate, where the metallic phase was Fe-C or Fe-C-S. Compositions and textures of the quenched metallic liquids and silicate phases were determined with EPMA and SEM. Dihedral angles were measured from 2-D images (apparent Θ).

The dihedral angle experiments showed that carbon has little to no effect on the Θ of the metallic melt, measured apparent Θ of Fe-C alloys range from ~ 110 to 122° . With increasing silicate melt fraction (~ 2 to 15% from 1400 to 1600 °C), the metal droplets were completely enclosed in silicate melt pockets ($\Theta \sim 26^\circ$), precluding Θ measurements of the metallic phase. A similar situation occurs in the Fe-S-C system, where metal-metal immiscibility causes separation of FeS and an Fe-C phase. As the interfacial energy between the olivine and FeS is lower than that between olivine and the Fe-C phase, the FeS 'wets' ($\Theta \sim 90^\circ$) and encloses the Fe-C phase.

In both systems, the Fe-C phase sits in the interior of the silicate melt or FeS 'channels'. Depending on the relative size and densities of each of these phases, complex core formation scenarios can be envisioned, along with specific trace element signatures of the metallic and silicate phases. It is clear that carbon alone cannot enhance the wetting ability of metallic melt; however, a mix of volatiles (immiscibility), and/or the presence of a silicate partial melt may create channels that allow an interior metallic phase (in this case Fe-C) to flow to the core.

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