

Critical melt fraction for percolation of core-forming materials

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The segregation of an iron-rich core from silicate mantle was a major event in the early history of the Earth. In a homogeneously accreting Earth, silicates and metal alloys would have at first been intimately mixed and core formation would require a mechanism for separating and mobilizing the iron alloy. There are two major modes of segregation of iron alloy from silicate mantle; grain boundary percolation and settling of iron droplets controlled by Stokes law. As for the former case, there has been much interest in the wetting properties of liquid iron or alloy melts in silicate matrix. Previous experimental studies concerned with the wetting behavior of alloy melts show large dihedral angles of over 90 degrees for Fe metal in an olivine-rich matrix, suggesting a non-wetting property of iron-rich melts. Although it seems reasonable from statistical angle measurements to conclude that the metal-rich melts cannot have segregated from a crystalline silicate mantle, a certain amount of liquid metal will connect along grain boundaries even when the dihedral angle is above the critical value of 60 degrees. In this case, the excess of Fe-rich melt over some critical melt fraction (CMF) can segregate from the silicate matrix, and residual melts become trapped at grain boundaries and as inclusions in silicates. Therefore, it is important to determine the CMF for Fe-alloys in mantle rocks, and to evaluate when melt connectivity occurs in 3 dimensions.

To determine the CMF for melt permeability in 3 dimension, we performed three types of experiments over a range of metal/alloy mass fraction up to 0.7 in San Carlos olivine + sulfide. Electrical conductivity of a part of the retrieved sample was measured by digital voltmeter to access metal/sulfide connectivity under room condition. From the above analysis, the lower bound of the CMF was determined.

1. The powder mixtures were hot-pressed using a piston cylinder apparatus at 1573K and 1.5 GPa. Electrical conductivity of a part of the retrieved sample was measured by digital voltmeter to access metal/sulfide connectivity at room conditions.

2. Electrical conductivity of a part of the retrieved sample was measured in the multi-anvil press under high pressure condition at room temperature.

3. Electrical conductivity of a part of the retrieved sample was measured in the cubic-anvil press under high pressure and high temperature condition.

There is a power law correlation between volume fraction and conductivity. CMFs determined by 1 to 3 methods are 20, 10 and 3-6 volume percent, respectively. Compared with results of method 1 and 2, CMF determined by method 1 is higher than that of method 2. This difference indicated that determining connectivity at room conditions may be artificially limited to 20 volume percent, perhaps due to a possible presence of microcrack generated by pressure release. Compared with results of method 2 and 3, CMF determined by method 2 is higher than that of method 3. Pressurization at room temperature not only leads to reconnection of sulfide phase but also leads to unavoidable failure of sintered sample. Therefore, method 3 is the best solution to determine the CMF.

Based on the CMF obtained by method 3, we assume 5 volume percent as a CMF for percolation. The volume fraction of metal in proto-planets and planetesimals is considerably more than 5 volume percent, indicating core comprises approximately 15 volume percent of Earth, so percolation of metal alloys from an olivine-rich mantle is possible. If so, formation of proto core due to the grain boundary percolation would influence the whole process of core formation and chemical evolution of the Earth such as absolute and relative abundance of siderophile elements in the Earth's mantle.