

# Multi-phase melt percolation during core formation

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## Abstract

The segregation of dense core-forming melts by porous flow is a natural mechanism for core formation in early planetesimals. It has long been thought that texturally equilibrated metallic melts reside in isolated pores that prevent percolation. It has recently been shown that hysteresis in the network connectivity allows melts that overcome the percolation threshold to drain almost entirely [1]. However, the drainage of metallic melts may occur in the presence of a silicate melt, in particular in S-poor planetesimals where higher temperatures are required to overcome the percolation threshold of metallic melts. Percolative core formation therefore likely involves the flow of two melts in a compacting medium. The dynamics of this complex process are currently poorly understood, both on the pore-scale and on the Darcy-scale.

## 1. Introduction

Experimental observations show that texturally equilibrated metallic melt does not wet the silicate grain boundaries and tends to reside in isolated pockets that prevent percolation [2]. This leads to a percolation threshold, a minimum melt fraction required to connect the pores and induce porous flow. Although typical planetesimals likely contain enough metal to overcome this threshold, it has been thought that melt segregation is prevented by a pinch-off at melt fractions slightly below the percolation threshold. Recently, it has been shown that texturally equilibrated melt networks experience significant hysteresis and remain connected down to melt fractions of only 1-2% [1]. This hysteresis in melt connectivity allows percolative core formation in planetesimals that contain enough metal to exceed the percolation threshold. Some primitive achondrite meteorites preserve metal distributions that are reminiscent of a connected network of metallic melt, suggesting that hysteretic melt segregation is a viable mechanism for core formation.

## 2. Two-phase melt percolation

If the partial melting of metallic melts and the silicate melts overlap, melt segregation requires multi-phase percolation and additional physical processes have to be considered. The overlap in the partial melting regimes depends strongly on the overall composition. In an ordinary chondrite assemblage, progressive internal heating initially leads to the formation of a metal-sulphide melt at the Fe,Ni-FeS eutectic at 988°C and later to the formation of a silicate melt at approximately 1050°C-1150°C, depending on composition and pressure [3]. In S-rich compositions up to 40% of the metallic melt may form at the eutectic temperature, before the onset of silicate melting. In S-poor bulk compositions more overlap in melting regions is expected.

### 2.1. Silicate melt as wetting phase

In the simplest case, the silicate melt is the wetting phase and the metallic melt is the non-wetting phase. In this limit, the silicate melt entirely coats the silicate grain boundaries and hence determines the shape and connectivity of the melt network. In this case, the metallic melt forms ganglions in the center of the pore space, as shown in Figure 1.

The dynamics of two-phase percolation introduce a

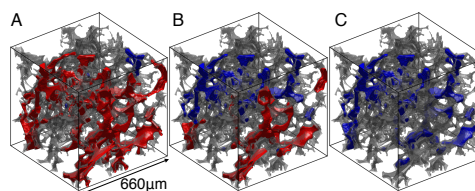


Figure 1: Trapping of non-wetting (metallic) melt during drainage, from left to right. Connected and mobile metallic melt is shown in red, while isolated trapped metallic melt is shown in blue. [4].

new phenomenon, called *capillary trapping*, currently not considered in literature on percolative core formation. This process is shown in Figure 1 and leads to the immobilization of up to 40% of the metallic melt. Capillary trapping might therefore prevent efficient percolative core formation in the presence of silicate melt.

However, the simulation shown in Figure 1 does not consider the simultaneous compaction of the pore space as melt segregation occurs. It is possible that metallic melt remains connected during compaction, because its connectivity is typically a function of the fraction of the pore space it occupies rather than its absolute volume fraction. Hence, if compaction reduces porosity as the metallic melt drains, its saturation and hence connectivity may remain the same and allow percolation. This has potentially been observed in centrifuged experiments of metal migration [5].

## 2.2. Mixed-wet three-phase systems

The wetting properties of the silicate and metallic melts are highly dependent on their composition. Experiments show that silicate melts do not wet the grain boundaries entirely [6]. In this case, the shape of the pore network itself becomes dependent on the volume fractions of the two melt phases (Figure 2).

Past work on such mixed-wet three-phase systems has assumed that connectivity of phases can be determined from the classical two-phase connectivity criterion [6]. The connectivity of the two-phase system depends only on the volume fraction of the melt and the dihedral angle [7]. In contrast, the three phase system has at least two additional parameters, the volume fraction and wetting angle of the second melt. This increased parameter space allows for many melt configurations, and their connectivity has not yet been explored. Such systems are also likely to exhibit significant hysteresis, similar to the two-phase system.

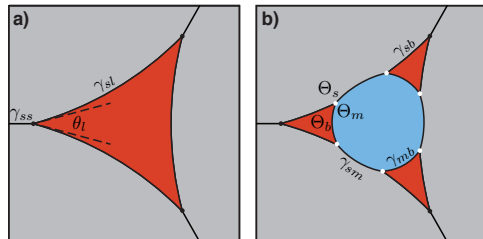


Figure 2: **a)** Two-phase textural equilibrium in 2D. **b)** Potential three-phase mixed-wet equilibrium configuration.

## 3 Conclusion

Despite recent improvements in our understanding of melt percolation, the effect of silicate melt on the mobility of core forming melts is unclear. The presence of a second melt phase introduces new capillary phenomena that determine melt mobility and hence the possibility of percolative core formation. Therefore, we are working to extend current two-phase pore-scale simulations for equilibrium melt distributions to mixed-wet three-phase systems.

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