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Wetting Properties of Fe-Ni-Co-Cu-O-S Melts against Olivine: Implications for Sulfide Melt Mobility

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Abstract

The effects of transition metal content and the fugacities of oxygen (fO_2) and sulfur (fS_2) on the wetting behavior of molten sulfide against forsteritic olivine have been investigated in this study. Wetting behavior, or the mobility of a liquid phase within a coexisting solid matrix, is quantified by the dihedral angle, Θ, which is a function of the relative solid-solid and solid-liquid surface energies. In order to determine sulfide wetting behavior, experiments were performed at 1,300°C using a vertical tube furnace employing C-O-S gas mixtures to control fO_2 and fS_2. Samples consisted of mixtures of San Carlos olivine and Fe + (Ni, Cu, Co; 0–30 wt %) + S melts equilibrated for 24 to 168 hr. Experimental conditions ranged from $fO_2 = 10^{-8}$ to 10^{-10} and fS_2 from $10^{-1.2}$ to 10^{-4} in accordance with values appropriate for basalt petrogenesis. Results of our experiments revealed that dihedral angles exhibited a marked increase with decreasing fO_2, and variable dependence on melt metal composition. At $fO_2 = 10^{-8}$, all sulfide melt compositions were found to be wetting (i.e., $\Theta < 60°$), whereas only those with <~15 wt percent added Cu, Co, or Ni were wetting at $fO_2 = 10^{-9}$, and no wetting compositions were encountered at $fO_2 = 10^{-10}$. In agreement with the results of other investigators, we found that values of Θ decreased as the mole fraction of oxygen in the melt increased, suggesting that metal oxide species in the melt are more likely to be surface-active with respect to olivine.

In light of our experimental data, it is expected that the wetting behavior of natural sulfide liquids will depend on both the identity and quantity of nonferrous metal and the abundance of dissolved oxygen. Because of this latter effect, the prevailing conditions of both fO_2 and fS_2 are therefore likely to dictate sulfide melt mobility. In terms of the potential for sulfide melt metasomatism in the upper mantle, consideration of the range of fO_2 reflected by natural sulfide liquids, mafic lavas, and upper mantle source regions reveals that conditions for sulfide melt mobility encompass much of this spectrum, even for many Ni- and Cu-rich natural liquid compositions. Thus, such liquids may be potent agents for redistributing siderophile and chalcophile elements in the upper mantle.

Sulfide melt wetting behavior will also play a role in the final sulfide distribution on solidification of mafic-ultramafic magmas that achieve saturation in an immiscible sulfide liquid. Efficient sulfide segregation may occur in reduced magmas only by early sulfide settling through a largely liquid medium, inasmuch as late-formed sulfide liquid will become trapped in the solid silicate matrix. For the case of relatively oxidized magmas, the wettability of sulfide liquid at these conditions, combined with a low viscosity and high density, suggests that efficient compaction-driven sulfide segregation is possible, even over the relatively short cooling intervals likely for high level mafic intrusions.