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Dynamics of magmatic sulfide droplets and silicate melts during transport in partially molten rocks and implications for magmatic sulfide ore formation

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Magmatic Ni-Cu sulfide deposits are generally considered as partial melts that originated from the mantle, but processes of ore metal source and transport in the asthenosphere have remained poorly understood. We report results from an investigation and theoretical calculations on topotaxy and rates of liquid migration and extraction within partially molten regions of the mantle using a piston-cylinder press and a 5GPa Griggs-type deformation apparatus to constrain the dynamics of the ore process. The starting material consists of polycrystalline olivine or pyrolite and 1.4 wt% Fe-Ni-Cu sulfide. Hydrostatic and deformation experiments were conducted at a pressure of 1.5 GPa and a temperature of 650-1250℃. Under hydrostatic conditions, our results show that the apparent dihedral angle of sulfide melt in an olivine matrix (~96°) is much larger than that of silicate + sulfide melt in pyrolite (14-25°). The sulfide liquid pockets appear mostly as blobs surrounded by the silicate melt in quadruple junctions indicating that silicate melt shields sulfide liquid. The permeability (k=Φ2.6d2/58 for silicate melt) is 10^{-15}-10^{-14}m^2 with melt fraction (Φ) of 0.08-0.15 (1250-1300℃). The local Reynolds number (Re=ρmvr/η) is far lower than 1(10^{-12}) meaning slow laminar flow around sulfide droplets. Therefore, silicate melt can be easily expelled from the thin films that separate one drop from another, and once the film is thin enough, the drops coalesce and the diameter increases. We calculated the melt transport velocity(v=kΔρ1g/Φη) ~ 7 to 18μm/day, but after silicate melt porously flows, sulfide drops would be stranded in the system under static conditions. Applying this to the natural world, the permeability and velocity of silicate melt are 10^{-10}-10^{-9}m^2 and 0.6-1.6m/day, respectively. Under deformation conditions, EBSD phase mapping analyses reveal strong shape preferred orientations (SPO) of sulfide liquid in the 45, 90, and 135 degree directions and elongated oriented sulfide liquid (10-20μm) for axial deformation. Several sulfide-rich bands can be observed in shear deformation samples, which consist of aligned, elongated (5-20μm) liquid pockets (Φ~0.05), indicating high-permeability pathways, and between the sulfide-rich bands there are rows of small sulfide droplets (Φ~0.01). Thus, anisotropic distribution of sulfide liquid suggests anisotropic permeability (k=$\Phi^{3.6}d^2/12$ for sulfide liquid) ~ 10^{-19} m^2 (rows of sulfide droplets) to 10^{-16} m^2 (sulfide-rich bands) and liquid transport velocity (v=kΔρ2g/Φη) ~ 9μm/day (rows of sulfide droplets) to 596μm/day (sulfide-rich bands). Permeability and velocity are 10^{-14}-10^{-11}m^2 and 0.8-53.7 m/day in nature, respectively. Hence, a possible mechanism of deep-seated staging magma chamber formation is that silicate melt rises from ore source area in mantle via porous flow, and then static-isolated sulfide liquid can be also transported into the magma chamber under specific tectonic setting, such as the transition from extension to compression or mantle plume, and this process may only take thousands of years.