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Metal-silicate segregation in small bodies of the Solar System: an experimental study of the geometry in a three-phase system.

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Differentiation of small bodies (diameter < 100 km) is likely to have occurred within 3 Ma of CAI formation (e.g. [1-2]). Meteorites record various stages of this process: from undifferentiated (chondrites) to fully differentiated (iron meteorites), while the intermediate step (incipient differentiation) is typically illustrated by primitive achondrites (e.g. Acapulco & Lodran). Most studies up to now have used a two-phase system with a metallic / sulfide melt segregating in a crystalline silicate matrix. However, this simplistic model is unable to account for the meteoritic record (e.g. Acapulco and Lodran-like meteorites), as percolation velocities are too low [3] and primitive achondrites have produced up to 20 vol.% of silicate melt [4]. The addition of a third phase (silicate melt) allows the experimental charges to be more realistic; it also leads to segregation timescales in agreement with partially or fully differentiated meteorites. One way to quantify the mobility of a melt is to measure its dihedral angle, the angle at the junction of a melt with two grains. In a two-phase system the interconnection threshold (volume fraction above which a phase forms an interconnected network) can be predicted from the dihedral angles [5]. In a three-phase system, the interconnection threshold cannot be predicted, it has to be determined experimentally.
In order to better understand the formation of partially differentiated meteorites and their characteristics (melt fraction extracted, presence or absence of sulfide or feldspar), the present study aims at determining equilibrium geometries (dihedral angles and interfacial energy) in a 3-phase system: a metal (molten or not), a solid silicate matrix and a silicate melt. Experiments were performed in a reduced environment, below and above the melting point of nickel ($\log(fO_2)$ = -8.5, T = 1440 and 1470 °C) to simulate conditions before and after differentiation is triggered.

Results show that the measured dihedral angles depend significantly on the magnification: the dihedral angle of the melt decreases and dihedral angles of olivine and nickel increase at high magnification compared to low magnification. A steady value is obtained at a magnification of x3000. Sorting the interfacial energies leads to: $\gamma_{\mathrm{Ol-Melt}} < \gamma_{\mathrm{Melt-Ni}} < \gamma_{\mathrm{Ol-Ni}}$. Using data with sulfide [6] gives the following sequence: $\gamma_{\mathrm{Melt-FeS}} < \gamma_{\mathrm{Melt-Ol}} < \gamma_{\mathrm{Ol-FeS}}$. Thus, interconnection threshold for sulfide is lower than for pure metal. In a differentiating small body, sulfide therefore easily forms an interconnected network and is likely to segregate quickly. The metallic residue remains isolated, and trapped in the silicate matrix. These results help to better understand how incipient differentiation can come to a halt.

References:
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