# 2D FOUR-PHASE NUMERICAL MODELLING OF THE MELTING AND DIFFERENTIATION OF PLANETESIMALS

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**Introduction:** Planetesimals of the early Solar System were subject to internal differentiation from a primitive chondritic composition, to a differentiated interior. This differentiation occured if the interior underwent sufficient heating and melting, due to the decay of short-lived radioneuclides such as $^{26}$Al [1]. Magmatic differentiation of planetary interiors are mechanically controlled by multi-phase fluid dynamics, and phase changes (i.e. melting and crystalisation) by multi-component thermochemistry. In the context of differentiating planetesimals, silicate and core-forming metal phases melt and mobilise, segregating the interior into a core, mantle and crust due to the relative buoyancy of the phases.

Meteoritic evidence of $^{128}$Hf-$^{128}$W isotope ratios, where the parent lithophile $^{128}$Hf decays to the siderophile $^{128}$W constrain the timing of core formation in planetesimals to within 6 million years of Solar System formation [2]. There are two mechanisms proposed for metal-silicate partitioning in planetesimals which represent the low to high melt fraction end-members at different stages of the planetesimal development. Early-stage porous flow of molten metal through a permeable solid matrix may occur at low melt fractions, and the rainfall of immiscible metal droplets and residual solids within a magma ocean (Figure 1). Meteorite observations give us insight to the timescales and in-situ conditions of the Solar System, however, numerical geodynamic models are required to infer global-scale processes across a planetesimal from small scale-meteorite observations.

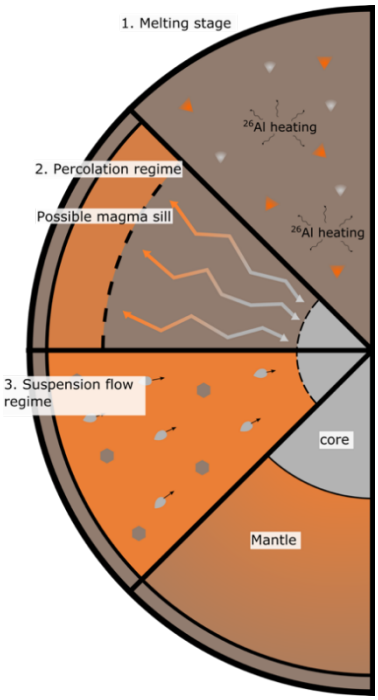


*Figure 1. Schematic illustration of the mechanisms of metal-silicate partitioning during different stages of planetesimal differentiation.*

**Methods:** The model uses the multiphase reactive transport modelling framework, which calculates fluid mechanical phase segregation and phase transfers of melting and crystallisation for multiphase igneous systems [3]. Previous 1D pilot modelling of planetesimal differentiation has modelled phase changes and segregation of a 2-phase silicate solid+liquid system [4]. My model expands the domain into 2D and adds two additional solid and liquid Fe-FeS for a total of four phases.

We calculate the phase changes of meting and crystallization for the silicate and iron phases separately using computationally generated phase diagrams. We construct the iron system phase diagram with a single phase loop between pure Fe and FeS limits [5]. The silicate phase diagram is created and calibrated based on simulations of enstatite chondrite melting using the alphaMELTS software [6]. Pressure dependence of the melting has been omitted as initial calculations of pressure for a low-gravity 100s km scale planetesimal quantify maximum internal pressures as less than 5 kbar. The components of each phase diagram are also subject to fractionation due to density heterogeneity (e.g. mafic silicate components and felsic components). Using the lever rule, the equilibrium phase fractions of solids and liquids for the silicates and iron can be outputted at any given temperature.

The multiphase fluid dynamics and phase segregation rates are calculated dependent on the relative phase fractions of the four phases. We use specifically calibrated permission functions which collapses the phase segregation rates into appropriate fluid mechanical regimes dependent on the relative phase connectivities at any combination of phase fractions. For example, at low melt fractions but above a liquid percolation threshold, the liquids form interconnected networks between solids and segregate via percolation, described by Darcy's law. At high melt fractions, the solids and immiscible iron melt phases individually move through the background as particle suspensions, and described by the Stoke's particle settling velocity.

Our model will be useful for a range of planetary deodynamic applications at different fluid-mechanical regimes. We also plan on introducing stable isotope partitioning into our model so that our model results can be compared to geochemical observations of meteorites.

**References:** [1]Sahijpal S. et al. (1995) *Proc. Indian Acad. Sci. (Earth Planet Sci.) 104, 555–567.* [2] Qin, L. et al. (2008). *Earth and Plan Sci. Letters*, *273*(1-2), 94–104. [3] Keller, T., & Suckale, J. (2019). *Geophys.219*(1). [4] Lichtenberg T. et al. (2019). *EPSC 507*, 154–165. [5] Fei, Y. et al. (1997). *Science*, *275*(5306), 1621-1623. [6] Smith, P.M. & Asimow, P.D. (2005), *Geochem. Geophys. Geosyst.* 6, Q02004