Analogue benchmark for simplified planetary differentiation models

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We conduct simple column experiments using an ice-sand slurry and compare them with mathematical models to explore the physical differentiation of small planetary bodies in the early solar system. The equations solved include mass conservation, linearized momentum conservation and energy conservation, with equation of state and constitutive relations

It is widely accepted that planetary bodies such as Ceres, with low densities ($\sim$ 2077 kg/m^3) may contain large amounts of H_2O [1]. Furthermore, it is widely accepted that high abundances of short-lived radiogenic isotopes, such as ^{26}Al in the early solar system led to interior melting and differentiation on many of the first planetesimals [3, 4]. Despite the general consensus regarding the high water content in some rocky planetesimal bodies and presence of radiogenic heat, it is not obvious how physical sedimentation processes within the interiors of planetesimals contributed to differentiating rocky planetary bodies with significant H_2O water-ice content in the early solar system. Depending on the amount of heating due to gravitational forces and decay of radioactive isotopes, the physical differentiation of the planetary body may be a two or three phase flow problem.

We conduct analogue column experiments to explore the sedimentation of silicate material in an ice slurry. We mix shaved ice and sand using a wide range of initial volumetric ratios. The column is placed on top of a hot plate inside a walk-in freezer. The top of the column, represents the planetesimal "surface" and is left open, while the column is gradually heated from below. The walls of the column are double paned and sealed air-tight with a vacuum drawn between the column walls. This disallows heat conduction from the sides of the experiment to the surrounding freezer in an attempt to create a temperature profile throughout the column that replicates a slice of a small planetary body.

As the ice slurry melts, the sandy portion of the matrix collapses, eventually reaching a stable, grain supported configuration. Depending on the ice to sand ratio, an array of physical processes may occur in the partially molten regions of the column. If the water to sand ratio is high and the water becomes molten quickly, the sand descends as a sediment front according to hyperbolic conservation laws [2, 5]. In the case where the water to sand ratio is low and melting is slow, the sandy matrix compacts slowly and there is no discernible sedimentation front.

Although this analogue model does not capture the local heat sources introduced by short-lived radiogenic isotopes, we hope to benchmark future theoretical models for planetary differentiation with simple end-member cases from our analogue experiment. The results of our simplified model can be extended to include factors such as radiogenic-isotope decay, density changes, release and storage of latent heat due to phase changes. Our benchmarks will allow a more well-informed scaling analysis and parameterization of future planetesimal formation models.

References

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