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Fragmentation, mixing, and chemical equilibration in a magma ocean - Insights from fluid dynamics experiments

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Hf/W chronometry and the excess of siderophile elements in the silicate Earth both indicate significant chemical interaction between iron and silicates during accretion of the Earth and formation of the core. Recent studies have shown that the interpretation of W isotope anomalies in terms of a core formation timescale depends criticaly on the degree of metal-silicate chemical re-equilibration. Physical models of mixing and chemical interactions during core formation are needed to precise the exact signification of the $^{182}W/^{184}W$ anomaly. We focus here on estimating the degree of mixing between the metal and silicate phases during the settling of an impactor core in a magma ocean.

A first serie of experiments is devoted to the study of fragmentation in jets of silicon oil in water. Turbulent fragmentation is observed in experiments at high Reynolds and Weber number. Ambient water is entrained within the jet and mix with the silicon oil to form an emulsion. In a second serie of exeriments, we assume that the iron phase is indeed efficiently fragmented, and we model the impactor core as a cloud of dispersed iron drops. We report results from laboratory experiments where a concentrated cloud of dense particles (representing iron drops) is released from above in a spherical container filled with water (representing the magma ocean). We find that the regime of metal-silicate separation and the degree of mixing depend mostly on the non-dimensional parameter $\mathcal{R} = (R_m w_s)/B^{1/2}$, where B is the buoyancy of the impactor core, R_m the radius of the silicate melt region, and w_s is the settling velocity of individual iron drops. $\mathcal{R}$ is the ratio of the settling velocity of the particles to the particle cloud velocity. The initial evolution of the particle cloud is found to be very similar to that of buoyancy driven 'thermals' as observed in laboratory experiments : the particle cloud grows during its fall by turbulent entrainement of ambient fluid. The impact of the particle cloud on the container floor and the subsequent inertia driven flow promotes further mixing if $\mathcal{R}$ is larger than a critical value of $\mathcal{O}(1)$ (*i.e.* if the particles are kept in suspension by the internal circulation of the particle cloud). The experimental determination of the degree of mixing as a function of $\mathcal{B}$ provides a basis to discuss the importance of chemical reequilibration as a function of the protoplanet size and thermal state, impactor size, and efficiency of fragmentation of the impactor core.