

Turbulent metal-silicate mixing, fragmentation, and equilibration in magma oceans

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Much of the Earth was built by high-energy impacts of planetesimals and embryos, many of these impactors already differentiated, with metallic cores of their own. Geochemical data provide critical information on the timing of accretion and the prevailing physical conditions, but their interpretation depends critically on the degree of metal-silicate chemical equilibration during core-mantle differentiation, which is poorly constrained. Efficient equilibration requires that the large volumes of iron derived from impactor cores mix with molten silicates down to scales small enough to allow fast metal-silicate mass transfer. Here we use fluid dynamics experiments to show that large metal blobs falling in a magma ocean mix with the molten silicate through turbulent entrainment, with fragmentation into droplets eventually resulting from the entrainment process. In our experiments, fragmentation of the dense fluid occurs after falling a distance equal to 3-4 times its initial diameter, at which point a sizeable volume of ambient fluid has already been entrained and mixed with the dense falling fluid. Contrary to what has usually been assumed, we demonstrate that fragmentation of the metallic phase into droplets may not be required for efficient equilibration: turbulent mixing, by drastically increasing the metal-silicate interfacial area, may result in fast equilibration even before fragmentation. Efficient re-equilibration is predicted for impactors of size small compared to the magma ocean depth. In contrast, a much smaller re-equilibration degree is predicted in the case of large impacts for which the impactor core diameter approaches the magma ocean thickness.

