Exploring the conditions of metal–silicate equilibration during and after giant impacts

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The compositions of the mantles and cores of terrestrial planets are dictated by the pressure, temperature, and oxygen fugacity conditions of planet formation and differentiation. Planet growth is a stochastic process, including one to several giant impacts. Most giant impacts transform planets into synestias, which have a complex internal structure. Earth-mass synestias are supercritical silicate bodies with no magma ocean surface. Planetary growth models have typically approximated equilibration as occuring under "average" conditions of mantle depth and temperature at the base of a partial-mantle magma ocean. However, it is unlikely that this approximation is valid.

Here, we use simulations of a range of giant impacts and results from shock experiments on silicates to develop a new approach to understanding core formation. Much of the impactor's core penetrates directly to the target's core without equilibrating with the target silicate. Metal that is left in the mantle will exist as either droplets within liquid silicate or dissolved in a supercritical metal-silicate mixture at low pressures. After most giant impacts, the silicate pressures are lower and temperatures are much hotter than considered in previous core formation models. As the vapor cools, the metal condenses out of the solution as metallic liquid, which falls through the vapor into the underlying silicate melt. We identify three major processes of metal-silicate equilibration which occur under different conditions: direct addition of some metal to the growing core, precipitation of metal out of the vapor at very high temperatures and low pressures, and continuous equilibration between liquid silicates and metal as the planet cools.

We use a Monte Carlo approach to systematically explore the competing effects of these different processes on the chemistry of the mantle and core. We explore many possible core-formation scenarios and compare our results with the major- and trace-element compositions of Earth's mantle.

Funding from NASA NNX15AH54G and DOE-NNSA DE-NA0003842.