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Core formation in deforming terrestrial planets and planetesimals

Geoffrey D. Bromiley (1), Simon A.T. Redfern (2), Madeleine Berg (1), Yann Le Godec (3), and Su Ying Chien (2)

(1) School of GeoSciences/CSEC, University of Edinburgh, Edinburgh, UK (geoffrey.bromiley@ed.ac.uk), (2) Dept. Earth Sciences, University of Cambridge, Cambridge, UK, (3) IMPMC, Paris, France

Our understanding of the processes by which metallic cores formed in the terrestrial planets is constrained by knowledge of the mechanisms of metal-silicate segregation. It is widely held that significant melting of the silicate portion of the early Earth, i.e. the formation of a silicate magma ocean, is required for differentiation of a metallic core to have occurred. This view is partly based on the results of a wealth of experiments conducted to determine the permeability of Fe-rich liquids in solid silicate matrices. These experiments, typically conducted in static systems over a range of conditions, generally preclude that metallic cores could have segregated efficiently from a crystalline silicate mantle by grain boundary percolation alone. By contrast, only a handful of experiments have been conducted in 'dynamic systems' to investigate whether plastic deformation can aid segregation of metallic melts from solid silicate matrices. This is in spite of the seeming importance that deformation might have in young, hot terrestrial bodies undergoing rapid accretion. To date, such studies have been performed at relatively low pressures, largely due to constraints in conducting deformation experiments at higher pressures.

Here we present the results of experiments performed to determine whether deformation could have provided a mechanism for segregating Fe-rich melts during formation of the terrestrial planets. Experiments in the system olivine-Fe3S have been conducted using the recently developed rotational Paris-Edinburgh Cell (roPEC) in a series of in-situ experiments conducted at the ID27 High-Pressure beamline at the European Synchrotron Radiation Source (ESRF), Grenoble, France. The roPEC uses rotation of opposed carbide anvils to impart controlled, variable torque on samples held at simultaneously high pressures and temperatures (currently up to 6 GPa, 2000 K). Design of the apparatus allows samples to be imaged in-situ, with sample volumes of sufficient size to permit additional detailed and statistically meaningful textural analysis of recovered samples using high resolution X-ray tomography and electron microscopy. Results from experiments performed at 2.5 GPa demonstrate that plastic deformation provides a highly effective mechanism for segregating Fe-melts over a wide range of temperatures, through the development of melt channels. This has previously been observed in deformation studies performed at lower pressures. However, as well as demonstrating that this mechanism operates at the higher pressure conditions of planetary differentiation, we also demonstrate that this mechanism also operates at much lower temperatures than previously suggested. Plastic deformation can, in fact, aid segregation of Fe-rich melts at temperatures below the Fe-S liquidus. This may be relevant to core-segregation on bodies much smaller than the Earth, for which the presence of a silicate magma ocean has been hypothesised but is less well supported. Plastic deformation during the early stages of planetary accretion may have led to the formation of Fe-rich (S-poor) cores before heating (due to ongoing accretion and breakdown of short-lived isotopes) had risen the temperature of early terrestrial bodies above the Fe-S solidus. This may be of relevance to core-formation in the early Earth, as it greatly increases the likelihood that larger bodies accreting to the Earth were already differentiated, and suggests that core composition may have been variable and dependent on size of the body.