Multi-anvil experimentation applied to planetary differentiation

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Planets undergo differentiation that includes segregation of metal from silicate at high temperatures and pressures ranging from deep planetary core pressures (>300 GPa for Earth) to very shallow conditions of asteroids (<100 MPa). The multi-anvil solid media apparatus accesses the middle part of this range from 3 to 30 GPa – pressure relevant to the interior of Mercury, Venus, Earth, Earth's Moon, and Mars. Early planets are thought to have experienced high temperatures from a combination of heat sources including radioactive decay, gravitational and accretional heating, and impact processes. These heating events led to melting of mantles and cores, thus requiring an understanding of solid-liquid equilibria in metal-silicate systems. In 2006 we established a multi-anvil facility at NASA-JSC combining an 880 ton press and a Kawai/Walker type module from Rockland Research. Our high PT work has been greatly facilitated by use of the COMPRES multi-anvil assemblies (1). Our recent work has included studies of element partitioning between liquid metal and liquid silicate (e.g., 2), as well as between minerals and melts (e.g., 3), both of which have led to better constraints on the timing and conditions of planetary differentiation (e.g. 4). Several examples involving sustained efforts will be summarized below and for the presentation.

The distribution of siderophile (iron-loving) elements between core and mantle is controlled by metal-silicate equilibrium across a wide range of pressures. Therefore, experimentation across this pressure range helps to calibrate elemental partitioning models that can be applied to planets, and used to predict mantle chemistry and composition during planetary differentiation. Our studies have focused on a wide range of siderophile elements (refractory Ni, Co, W, Mo; volatile P, Ga, Cu, Sn, Sb; highly siderophile Au, Pd) that have constrained partitioning, valence, and isotopic fractionation, and applied to Earth, Moon, and Mars.

When molten mantles (magma oceans) cool enough to initiate crystallization, the solids precipitate at depth and in large planets this involves high pressure phases like garnet, majorite, akimotoite, and ringwoodite. As these solids precipitate they can segregate from liquid by density contrasts, thus causing elemental fractionation which can be used to decipher timing of differentiation. Mineral/melt and metal/silicate equilibria in our lab have helped to better understand high pressure fractionation of isotopic parent/daughter pairs Hf/W, Mn/Cr, Pd/Ag, Pt/Os, Re/Os, and U/Pb, and their application to Earth, Moon and Mars.

There remains great potential for multi-anvil experimentation to shed light on many pressure–dependent aspects of planetary evolution such as core formation, high pressure phase equilibria, redox equilibria, and volatile evolution and storage.

References

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