Redistribution of noble gases during magma ocean crystallization

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Recent measurements of Xe isotopes place the formation of high $^{3}He/^{4}He$ mantle to within the first 80 Ma of solar system history. This timeframe coincides with Earth's accretion, leading to the hypothesis that a magma ocean concentrated materials that now comprise the high $^{3}He/^{4}He$ source. We have initiated an experimental study to better constrain the distribution of noble gases within the solid Earth during magma ocean crystallization and the petrogenesis of high $^{3}He/^{4}He$ mantle. We report the Ar contents of minerals (bridgmanite, periclase) and liquids (silicate and Fe metallic melts) salient to magma ocean crystallization that were synthesized in the presence of Ar-rich fluids at high pressure. Our initial experiments are conducted with Ar because it is the middle noble gas, so its behavior is most representative of the bulk elemental group. Experiments were conducted using laser-heated diamond anvil cells (DAC) and multi-anvil (MA) apparatus and were analyzed by microprobe and laser ablation techniques.

The Ar contents of the large majority of bridgmanite and periclase analyses in the MA experiments were at or below the WDS detection limit. Detection limits are calculated from counting statistics and nominally approached 20 ppm Ar for longer duration analyses. Saturation of an Ar-rich fluid in the MA experiments was confirmed by high Ar concentration blebs throughout the recovered samples. Laser ablation analyses on a MA experiment yielded highly variable Ar concentrations in bridgmanite, ranging from 450 to 10 ppm. Given the observation of Ar-rich blebs in the MA experiments, we interpret the lower range in Ar concentration as our current best estimate of Ar solubility in bridgmanite. The Ar contents of samples from DAC experiments were more variable, but large areas of laser-heating spots on bridgmanite contain Ar contents at or below the detection limit by EDS microprobe (~100 ppm Ar). Bridgmanite disproportionated to (Mg,Fe)O and SiO_2 in some higher temperature heating spots. These phases also had undetectable Ar concentrations. In a parallel series of experiments, we have also quantified the concentration of Ar dissolved into silicate and Fe metallic liquids at 15 GPa using a DAC. Preliminary measurements by EDS yield Ar concentrations of 4000 ppm for the silicate liquid and Ar concentrations below detection in the Fe metallic liquid. This concentration is similar to previous determinations of Ar solubility in silicate liquids at transition zone pressures.

Our results imply that noble gases are strongly concentrated in silicate liquids over minerals and liquid Fe during magma ocean episodes. High $^{3}He/^{4}He$ mantle is associated with unradiogenic noble gas signatures. Given this, we suggest that the petrogenesis of high $^{3}He/^{4}He$ mantle is related to the fractionation of a silicate liquid during a magma ocean episode.

Keywords: noble gases, magma ocean, volatiles

