Magma Ocean Differentiation

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Accretion theory depicts a violent and hot early Earth. The kinetic energy buried in proto-Earth from large impacts as well as the potential energy release from core formation could easily have raised temperatures high enough to melt the entire planet. During this ‘Hadean’ era, one or more global silicate magma oceans are likely to have existed. Crystallization of a magma ocean could potentially have resulted in gross chemical differentiation in the silicate mantle. Signals of such events may be preserved in primitive upper mantle (PUM) in the form of deviations in refractory lithophile element ratios from chondritic initial values. Recently, experimental data has become available to make strict tests for the amounts of fractionation permitted by the geochemistry of the upper mantle [e.g. 1-3].

Samples of PUM are remarkable in that many refractory lithophile element ratios are within ± 10% of chondritic values [4]. Further, the $^{176}Hf/^{177}Hf$ and $^{143}Nd/^{144}Nd$ isotopic compositions of modern volcanic rocks form an array that passes through the chondritic initial value, such that early mantle differentiation cannot have significantly perturbed Lu/Hf and Sm/Nd ratios [5]. A notable anomoly is the Mg/Si ratio, which is about 20% greater than chondritic in PUM. Also, the Ca/Al ratio is also apparently about 15% greater than chondritic [1]. Can either of these super-chondritic ratios be due to primordial mantle differentiation without upsetting other refractory element ratios in PUM?

Mineral/melt partition coefficients for a large group of major and trace elements at pressures extending into the lower mantle have been measured for pertinent liquidus phases [1-3]. Two liquidus phases, majorite at transition zone depths and Mg-perovskite at lower mantle depths, have sub-chondritic Mg/Si and could raise the Mg/Si ratio of the upper mantle via crystal fractionation. However, removal of copius amounts of either phase is required (> 50%), yet less than 5% removal can be tolerated before other refracotry element ratios (e.g. Ca/Al, Lu/Hf, Sc/Al) become fractionated beyond observed bounds in PUM. In contrast, 10 to 15% fractionation in the deep mantle of a mixture of Mg-perovskite, Ca-perovskite and ferropericlase (93:3:5 by weight) can reproduce the Ca/Al ratio of primitive upper mantle while maintaining other refractory element ratios within observed bounds. This amount of fractionation also produces complimentary reservoirs with Hf and Nd isotopic compositions that fall within the observed mantle array [1].

References

[1] Walter et al (2004) *GCA* **68,** 4267. [2] Corgne et al (2005) *GCA* **69,** 485. Hirose et al (2004) *PEPI* **146,** 249. [4] McDonough & Sun (1995) *Chem. Geol.* **120**, 223. [5] Salters & White (1998) *Chem. Geol.* **145**, 447.