Experimental investigation of the affect of pressure on the oxidation state of a terrestrial magma ocean

H. L. ZHANG[1], M. M. HIRSCHMANN[2], M. J. WALTER[3], O. T. LORD[3], E. COTTRELL[4]

[1]School of Earth and Space Sciences, University of Science and Technology of China, Hefei 230026, China. hongluo@ustc.edu.cn

[2] Dept. of Earth Sciences, University of Minnesota, Minneapolis, MN 55455, U.S.A.

[3] Dept. of Earth Sciences, University of Bristol, Bristol, BS81RJ, UK

[4] National Museum of Natural History, Smithsonian Institution, Washington, DC 20560, U.S.A.

The magma ocean (MO) stage was pivotal during early terrestrial planetary evolution. The oxygen fugacity (fO_2) of the MO controlled the speciation and solubility of volatile elements (C, N, S and H) at depth, and their degassing to the primitive atmosphere. The volatiles in turn affect MO crystallization and its subsequent geodynamic evolution. The oxidation state of the MO also affects the initial state of the solid mantle, which has a key influence on processes such as magma generation and differentiation, element partitioning, rheology, and volcanic degassing. However, the oxidation states of terrestrial MOs are poorly constrained.

Magmatic $Fe^{3+}/\Sigma Fe$ ratios are directly linked to MO oxidation state as iron is the most abundant multi-valent element in silicate melts. In a vigorously convecting, well-mixed MO, magma-metal equilibration will impose the $Fe^{3+}/\sum Fe$ ratio. Piston cylinder and multi-anvil experiments show that the $Fe^{3+}/\sum Fe$ ratio decreases with increasing pressure and with increasing temperature up to 7GPa and 1750 °C. This suggests that a shallow MO with fixed $Fe^{3+}/\Sigma Fe$ becomes more reduced relative to the iron-wüstite (IW) buffer toward the surface for both large and small planets, including Earth and the Moon (Zhang et al. 2017).

Theoretical calculations show, however, that compression in silicate liquids leads to a continuous increase in average ion coordination state, mimicking the discontinuous transitions that occur in solids (Stixrude and Karki, 2005). Consequently, further increases in pressure may favor Fe^{3+} stability relative to Fe^{2+}, such that a deep MO may become more oxidized relative to IW toward the surface. To test our hypothesis, we performed laser heating diamond anvil cell experiments up to 75 GPa and 4000 K using PtFe alloy to controll the fO_2 and obtained $Fe^{3+}/\Sigma Fe$ ratios in silicate melts through μ-XANES. Results are presented here and a revised thermodynamic parameterization is also in progress.