

THE SOLUBILITY OF SULFUR IN A DEEP TERRESTRIAL MAGMA OCEAN. E.S. Steenstra¹⁻³, O. Lord⁴, S. Vitale¹, E.S. Bullock¹, A. Shahar¹, M. Walter¹ ¹The Geophysical Laboratory, Carnegie Institution for Science, Washington D.C., United States, ²Vrije Universiteit Amsterdam, the Netherlands, ³Institute of Mineralogy, Münster University, Germany, ⁴University of Bristol, United Kingdom (esteenstra@carnegiescience.edu)

Introduction: The variation in the sulfur content at sulfide saturation (SCSS) in silicate melts is key for understanding the (highly) siderophile- and chalcophile element geochemistry of planetary mantles [1–5], including that of the Earth [6]. Although the variation of the SCSS as a function of pressure-temperature (P - T) is well constrained at the low pressure conditions (<5 GPa) relevant to the Moon and asteroids [e.g., 1,2,5,7], high pressure ($P > 25$ GPa) data relevant for a deep terrestrial magma ocean is largely unavailable. Current models of the SCSS applied to the terrestrial magma ocean therefore usually rely on extrapolations of low-pressure data, although significant structural transitions in silicate glasses occur within the 1 atm - 35 GPa pressure range [8].

To investigate the SCSS in a deep terrestrial magma ocean, we performed high P - T experiments in which sulfide liquids and silicate melts were chemically equilibrated using a diamond anvil cell (DAC).

Methods: Sulfide liquids and silicate melts were equilibrated at pressures of 35–40 GPa and T between 3925–4600 K in a DAC. Experiments were performed using 250 μm culet diamond pairs in conjunction with Re gaskets. Gaskets were preindented to 25 GPa prior to sample loading, while using ruby grains as pressure calibrants. Circular sample chambers approximately 85 μm in diameter were laser-drilled in the indentations of the Re gaskets. Chambers were loaded with synthetic silicate and sulfide powder wafers. The silicate powder consisted of a finely-ground, synthetic equivalent of a mean MORB basaltic composition [9]. The sulfide alloys consisted of predominantly FeS and 1-2 wt.% of trace elements Se, Te, Cu and/or Cd. Synthetic mixtures were compressed to wafers and subsequently loaded in the hole of the Re gasket using a sandwich-type layering (MORB-FeS-MORB) to promote the availability of sulfide close to the heated spot.

Heating was performed using a double-sided continuous wave laser heating system with a wavelength of 1070 nm at the University of Bristol. Peak pressure was considered to be the average between pre-heating pressures and post-heating pressures. Temperatures were measured using standard spectroradiometric techniques. Recovered experimental run products were mounted on Si wafers. Cross-sections of experimental charges were made using FIB-SEM at the Geophysical Laboratory. Run products were carbon-coated and analyzed using EPMA at the Geophysical Laboratory.

Results: Fig. 1 shows a typical experimental run product. The silicate melt was clearly sulfide-saturated, reflected by the presence of abundant FeS micron and sub-micron quenched droplets [e.g., 1,2] throughout the heated spot.

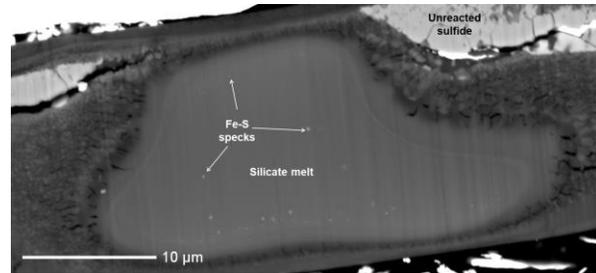


Fig. 1: Backscattered electron images of typical run product. Note the minute sulfide specks in the silicate melt that are consistent with sulfide-saturation of the silicate melt at peak conditions [e.g., 1].

Variation of the SCSS at high P - T : The upper panel in Fig. 2 shows the newly derived SCSS values as a function of FeO content of the silicate melt. Although there is some scatter in the data (presumably due to variable P - T conditions of the experiments), it is clear that the newly derived SCSS values vary with FeO contents in a way that is consistent with previous observations from low P - T experimental data (Fig. 2).

The comparison of the new data with compiled low P - T data shows that the newly derived SCSS values obtained at high P - T are significantly higher than those derived at low P - T conditions. Given the well-established decrease of the SCSS with pressure [e.g., 2,3,10], the new results imply that T exerts the major control on sulfur solubility in silicate melts. An increase of the SCSS with increasing temperature is consistent with many previous experimental studies [1–3]. However, the observed temperature effects are likely minimum values as increasing pressure nominally decreases the SCSS [2,3,10].

Discussion and conclusions: Using the new data and the outcome of more planned experiments, the SCSS will be parameterized using high P - T data only and compared with previous SCSS parameterizations. We will use the new SCSS model to re-evaluate the evolution of the SCSS during terrestrial magma ocean solidification. These results, and its implications for establishing the depletions of chalcophilic elements, will be reported at the meeting.

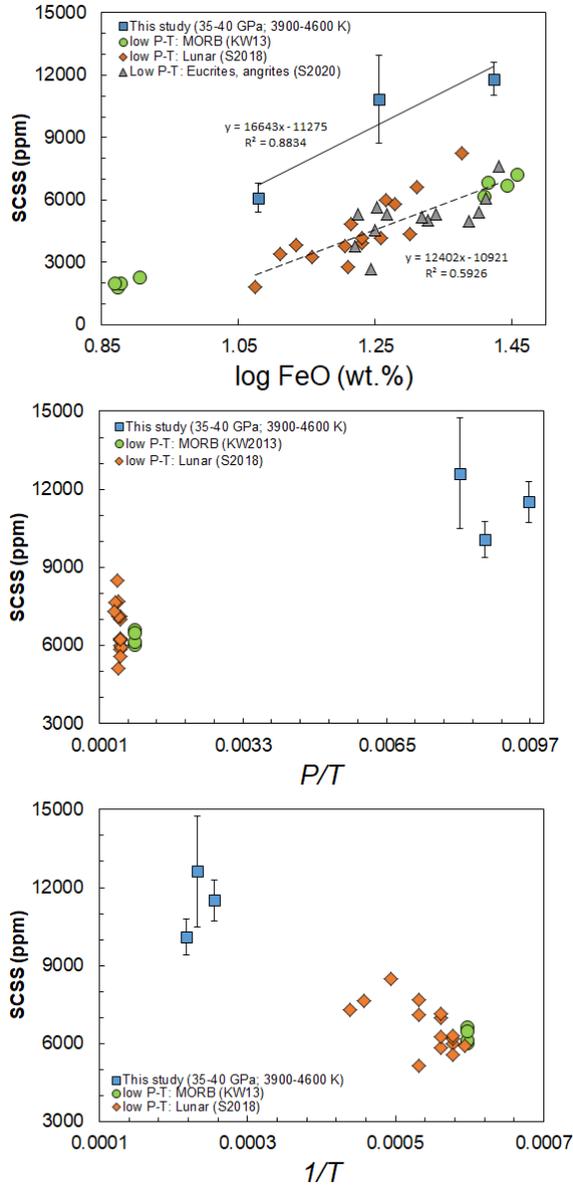


Fig. 2: Summary of derived SCSS values (a) as a function of FeO content for low (1–2.5 GPa and 1673 K) and high (35–40 GPa; 3900–4600 K) P-T conditions. Previous data was obtained for MORB [11] and primitive lunar or asteroidal basaltic compositions [12,13].

References: [1] Ding et al (2018) *GCA* [2] Steenstra et al (2018) *GCA* [3] Smythe et al (2017) *AM* [4] Steenstra et al. (2020) *this meeting* [5] Brenan et al. (2019) *Nat. Geosci.* [6] Kiseeva and Wood (2015) *EPSL* [7] Steenstra et al. (2020) *GCA* [8] Sanloup et al (2013) *Nature* [9] Gale et al. (2013) *Geochem. Geophys. Geosyst.* [10] Mavrogenes & O'Neill (1999) *GCA* [11] Kiseeva and Wood (2013) *EPSL* [12] Steenstra et al., under review [13] Steenstra et al. (2020) *GCA*