Sulfur content at sulfide saturation of peridotitic melt at upper mantle conditions

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ABSTRACT

The concentration of sulfur that can be dissolved in a silicate liquid is of fundamental importance because it is closely associated with several major Earth-related processes. Considerable effort has been made to understand the interplay between the effects of silicate melt composition and its capacity to retain sulfur, but the dependence on pressure and temperature is mostly based on experiments performed at pressures and temperatures below 6 GPa and 2073 K. Here we present a study of the effects of pressure and temperature on sulfur content at sulfide saturation of a peridotitic liquid. We performed 14 multi-anvil experiments using a peridotitic starting composition, and we produced 25 new measurements at conditions ranging from 7 to 23 GPa and 2173 to 2623 K. We analyzed the recovered samples using both electron microprobe and laser ablation ICP-MS. We compiled our data together with previously published data that were obtained at lower P-T conditions and with various silicate melt compositions. We present a new model based on this combined data set that encompasses the entire range of upper mantle pressure-temperature conditions, along with the effect of a wide range of silicate melt compositions. Our findings are consistent with earlier work based on extrapolation from lower-pressure and lower-temperature experiments and show a decrease of sulfur content at sulfide saturation (SCSS) with increasing pressure and an increase of SCSS with increasing temperature. We have extrapolated our results to pressure-temperature conditions of the Earth’s primitive magma ocean, and show that FeS will exsolve from the molten silicate and can effectively be extracted to the core by a process that has been termed the “Hadean Matte.” We also discuss briefly the implications of our results for the lunar magma ocean.

Keywords: Peridotitic melts, sulfur solubility, high pressure, high temperature, magma ocean

INTRODUCTION

Sulfur solubility in silicate melts is important for understanding several geological processes such as the formation of magmatic sulfide deposits (Simon and Ripley 2011), volcanic degassing during eruptions (Black et al. 2018), and planetary core-mantle differentiation and late-accretion scenarios (Rubie et al. 2016). The sulfur content at sulfide saturation (SCSS) represents the maximum concentration of sulfur that can be dissolved in a melt at a given pressure and temperature, and as such provides an upper limit to the concentration of sulfur present in melts under reduced conditions. Indeed, at oxygen fugacities below the quartz-fayalite-magnetite buffer, S2− in the silicate replaces O2− in the anion sublattice (Fincham and Richardson 1954). There have been numerous studies of the relation between SCSS and melt composition (e.g., Fincham and Richardson 1954; Haughton et al. 1974; Holzheid and Grove 2002; Liu et al. 2007; Mavrogenes and O’Neill 1999; Fortin et al. 2015; Mysen and Popp 1980; Smythe et al. 2017). The effects of pressure and temperature have also been studied since the early 1980s. The first study that determined the effects of P and T on SCSS is that of Wendlandt (1982), which showed that SCSS decreases with increasing pressure and increases with increasing temperature. This study was limited to pressures of ≤3 GPa and temperatures up to about 1800 K, but the temperature effect was later confirmed by Mavrogenes and O’Neill (1999). Holzheid and Grove (2002) performed an experimental study of the effect of P and T on SCSS up to 2.7 GPa and 1873 K, respectively, which verified that SCSS increases with T and decreases with P. Laurenz et al. (2016) performed multi-anvil experiments to study the effect of sulfur on the partitioning of highly siderophile elements. They derived a simple relation between SCSS and pressure and temperature that verified the increase of SCSS with T and decreases with P. Recently, Smythe et al. (2017) constructed a model that encompasses a very broad range of compositions for both the sulfide and the silicate phases that could reliably reproduce the value of SCSS for hundreds of natural and experimental data. The vast majority of experimental data used in that study was obtained below 6 GPa and 2073 K, with only three data points above those values for pressure and one for temperature.

The evolution of SCSS at high P and T for peridotitic melt is important for understanding the fate of sulfur in a magma ocean. Indeed, S will exsolve from a magma ocean if its concentration exceeds SCSS. Understanding how the mantle acquired its final concentration of sulfur is still a matter of debate and has been the subject of several recent studies (e.g., Rose-Weston et al. 2009; Boujibar et al. 2014; Rubie et al. 2016; Suer et al. 2017). The objective of the current study is to extend our knowledge of SCSS of peridotitic melt to high P-T conditions. To achieve this,