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Experimental study of sulfur evaporation under reduced conditions — Implications for sulfur diffusion and isotopic fractionation within magma oceans

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The abundance and distribution of sulfur at the surface and among the reservoirs of rocky planets were shaped by planetary processes and impact events during planet formation. As sulfur is both volatile and incompatible, it was likely particularly affected by magma ocean outgassing and ingassing. Such processes may lead to isotopic fractionation, and affect the sulfur isotopic composition of magma oceans. The oxidation state of magma oceans and their overlying atmosphere control sulfur speciation, and therefore its solubility, diffusivity, partitioning and isotopic fractionation between the silicate and the gas phase. In this study, we experimentally determine the effects of temperature and oxygen fugacity on sulfur behavior.

Experiments were designed to reproduce the evaporation process in a gas-mixing furnace, under reduced conditions representative of magma oceans. A silicate glass containing 5000 ppm S was melted at various temperatures (1400 to 1600°C), fO_2 conditions (IW-2, IW, IW+2), and durations (5 to 90 minutes). Sulfur concentration and isotopic composition profiles were measured by Secondary Ion Mass Spectrometry (SIMS) after investigating the effects of reduced sulfur speciation on Instrumental Mass Fractionation (IMF) and the S content calibration curve, using 13 newly synthetized reduced reference materials. Based on comparison with values determined using oxidized MORBs (SO_4^{2-}), such analytical effects are negligible. Sulfur concentration profiles were also studied using the Electron Probe Micro-Analyzer (EPMA) after Johnson et al. (2024)'s method, which show perfect agreement with SIMS data.

Both EMPA and SIMS measurements revealed complex concentration profiles, encouraging us to obtain two-dimensional S maps of our samples. The acquired maps suggest that diffusion is not the sole process controlling sulfur distribution. Convection seems to play a role in S transport, particularly in 5 minutes experiments. Diffusion was mainly observed at lower temperatures, mostly under high fO_2 conditions. At low fO_2, for durations ≥ 20 minutes, samples appear homogeneous, with very low sulfur contents, implying more advanced and probably faster evaporation.

These observations highlight the complex interplay between diffusion and convection in controlling sulfur distribution. More chemical and isotopic data, currently being acquired, should provide a better understanding of the underlying mechanisms.