

Sulfur extraction during decompression melting of a heterogeneous mantle

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Sulfur (S) plays a crucial role in various geological and biological processes, including microbial anaerobic respiration, oxidation of the Earth's surface, short-term climate variation, redox change of the Earth's mantle, and ore deposit formation. The S inventory of Earth's surface is mainly controlled by the input through sulfur degassing at volcanic arcs and at intraplate volcanoes, and by the output through sulfur burial and subduction back into the deep Earth. Sulfur extraction from the Earth's mantle by partial melting, therefore, is the fundamental process determining the sulfur input to the surface. Compilation of the total S concentration from minimally degassed global primitive mid ocean ridge basalt (MORB), ocean island basalts (OIB), and parental arc magmas indicates that the sulfur concentration in the parental magmas varies by more than a factor of six. The underlying question is what controls the significant variation of sulfur contents in the magmas derived by mantle partial melting.

Total sulfur concentration in the parental OIBs varies from ~1000 ppm, similar to that in global MORBs, to ~ 5000 ppm, as high as some sulfur-enriched arc magmas. This considerable S variation in the parental OIBs is accompanied by the mantle heterogeneity underneath different ocean islands, with some mantle domains having much higher mantle potential temperatures (T_P), others experiencing extremely low or high degrees of partial melting (F), and some others having high oxygen fugacity (fO_2). Therefore, sulfur budgets in the primitive OIBs can be probes in understanding different scenarios of sulfur extraction through mantle partial melting.

To reconstruct the sulfur budgets of different OIBs, we modeled the behavior of sulfur and copper, a sulfide-loving trace element, during decompression melting of peridotite mantle at $T_P=1450-1650^\circ\text{C}$. We employed the most recent models of sulfur concentration at sulfide saturation (SCSS) and sulfur concentration at anhydrite saturation (SCAS). Variation of fO_2 is implemented in the model by using different $S^{6+}/\sum S$ ratios in the partial melts. Partial melts relevant to OIB generation have high SCSS because of the positive effect of temperature and fO_2 on SCSS. Calculation of SCSS along melting adiabats at $T_P=1450-1650^\circ\text{C}$ with different $S^{6+}/\sum S$ ratios in the magma and variable initial S contents of peridotite indicates that a sulfide-enriched peridotite mantle source is not required to explain the sulfur enrichment (1500-4000 ppm) observed in some parental OIBs, for example, from Hawaii and Canary island. Instead, the high T_P and high fO_2 combined with low F is critical to producing the observed sulfur and copper inventory in these magmas. Mixing of partial melt derived from low-degree melting of subducted sediments with peridotite partial melts may be necessary to produce the measured S and Cu contents in extremely low- F Samoan basalts. Our analysis suggests that the sulfur contents in the parental OIBs result from the interplay between SCSS, the degree of melting, and S inventory in the mantle. This framework can be further applied to understand the sulfur extraction through arc volcanos, which contributes the majority of the global sulfur outflux from Earth's interior to the surface.