

Trace element partitioning between anhydrite, sulfate melt, and silicate melt

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ABSTRACT

Anhydrite has become increasingly recognized as a primary igneous phase since its discovery in pumices from the 1982 eruption of El Chichón, Mexico. Recent work has provided evidence that immiscible sulfate melts may also be present in high-temperature, sulfur-rich, arc magmas. In this study we present partition coefficients for 37 trace elements between anhydrite, sulfate melt and silicate melt based on experiments at 0.2–1 GPa, 800–1200 °C, and $f_{\text{O}_2} > \text{NNO}+2.5$.

Sulfate melt–silicate melt partition coefficients are shown to vary consistently with ionic potential (the ratio of nominal charge to ionic radius, Z/r) and show peaks in compatibility close to the ionic potential of Ca and S. Partition coefficients for many elements, particularly REE, are more than an order of magnitude lower than previously published data, likely related to differences in silicate melt composition between the studies. Several highly charged cations, including V, W, and Mo are somewhat compatible in sulfate melt but are strongly incompatible in anhydrite. Their concentrations in quench material from natural samples may help to fingerprint the original presence of sulfate melt.

Partition coefficients for 2+ and 3+ cations between anhydrite and silicate melt vary primarily as a function of the calcium partition coefficients ($D_{\text{Ca}}^{\text{Anh-Sil}}$) and can be described in terms of exchange reactions involving the Ca^{2+} site in anhydrite. Trivalent cations are dominantly charge-balanced by Na^{1+} . Most data are well fit using a simple lattice-strain model, although some features of the partitioning data, including $D_{\text{La}}^{\text{Anh-Sil}} > D_{\text{Ce}}^{\text{Anh-Sil}}$, suggest the occurrence of two distinct anhydrite Ca-sites with slightly different optimum radii at the experimental conditions.

The ratio $D_{\text{Sr}}^{\text{Anh-Sil}}/D_{\text{Ca}}^{\text{Anh-Sil}}$ is shown to be relatively insensitive to silicate melt composition and should vary from 0.63–0.53 between 1200–800 °C, based on a simple, “one-site” lattice strain model. Comparison to $D_{\text{Sr}}^{\text{Anh-Sil}}$ and $D_{\text{Ca}}^{\text{Anh-Sil}}$ calculated for natural anhydrite suggests that in most cases, including the S-rich eruptions of Pinatubo and El Chichón, the composition of anhydrite is consistent with early crystallization of anhydrite close to the liquidus of silicate melt with a composition approximately that of the bulk erupted material. This illustrates how anhydrite (and perhaps sulfate melt) provides a mechanism to transport large quantities of sulfur from significant depth to the eruptive environment.

Keywords: Sulfate melt, arc magmas, anhydrite, trace element partitioning, experimental petrology