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3D diffusion of water in melt-inclusion-bearing olivine phenocrysts

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Rapid diffusion of hydrogen (as H^+ ions) through the olivine crystal lattice can help and hinder the interpretation of volatile concentrations in the crystal record. Rapid diffusive re-equilibration obscures the melt inclusion record, but it can also be an exciting chronometer that can track magmatic processes that occur hours to even minutes before eruption, such as final magma ascent. Many studies often use spherical or 1D models to track melt inclusion dehydration that fail to account for complex geometries, diffusive anisotropy and sectioning effects. We have developed a finite element 3D diffusion model for H^+ in olivine using FEniCS. The model includes physical domains for a spherical melt inclusion and the surrounding host olivine. The boundary between these domains accounts for olivine-melt partitioning behaviour and ensures conservation of flux, whilst an external degassing boundary condition can be imposed. We use the model to examine the fidelity of the water content of melt inclusions based on inclusion size, position, crystal size, diffusive anisotropy in olivine, olivine-melt partition coefficients and for different magma decompression rates. We then use the model to fit 2D observations of water profiles in olivine measured by SIMS from the 1977 eruption of Seguam volcano, Alaska. Our model is one of the first to account for the natural shape of olivine, and to include the diffusive properties of both olivine and melt. The model is also novel in that multiple melt inclusions can be modelled in a single crystal. We find that the presence of multiple melt inclusions can buffer the water composition of inclusions in the center of the crystal. This ‘shielding’ effect may have important implications for estimating magma storage depths or primary water compositions. By reducing uncertainties associated with crystal morphology and sectioning we hope to better reconcile short-term petrological and geophysical observations.