Accurate self-diffusion coefficients of hydrogen in olivine and implications for mantle electrical conductivity

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The evolution and dynamics of the Earth's upper mantle are governed by the physico-chemical properties of olivine, which are highly affected by the incorporation of hydrogen (H). Magnetotelluric studies allow investigation of the inaccessible upper mantle when combined with the electrical properties of olivine. Electrical measurements are highly sensitive to a number of properties such as temperature, anisotropy, composition and importantly the H content, making them a viable tool to probe the hydration state of the Earth's interior. However, electrical conductivity measurements of hydrous olivine reported from different laboratories have contrasting results.

In this study we investigated H self-diffusion in olivine along its 3 principal orientations ([100], [010], [001]). Oriented single crystals of San Carlos olivine were first heated to 1300˚C in a gas-mixing furnace at fO_2~NNO, to equilibrate the distribution of small polarons and metal vacancies. The single crystals were then hydrated at 2 GPa and temperatures between 700 and 950˚C in a piston cylinder apparatus, where the crystal was surrounded by liquid H_2O. Finally, deuterium (D) was exchanged with H in the crystal in a subsequent piston cylinder experiment at the same P-T conditions where a heavy water solution (D_2O+H_2O) was instead employed.

Precise diffusion profiles were determined using a NanoSIMS. The results indicate that H self-diffusion is highly anisotropic with diffusion coefficients that are over a magnitude higher along the [100] orientation than the [010] and [001] orientations. These results were used to calculate the electrical conductivity of hydrous olivine using the Nernst-Einstein formulation. Our model assumes that all H in the crystal conduct current by independently hopping between various sites while carrying a +1 charge. The new, accurate values are used to understand the effect of H on the magnitude and anisotropy of olivine electrical conductivity and interpret regional electrical conductivity profiles and the hydration state of the upper mantle.