Water Diffusion in Olivine: Experiments and Application to Phenocrysts

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The figure below illustrates the primary results from this study, currently in preparation for publication. This arrhenius plot illustrates the diffusivity of H in olivine as a function of temperature, as determined in previous studies and this one (stars). The central question is why H diffusivity varies over so many orders of magnitude at any one temperature, from the slowest rate ([Si], H associated with Si vacancies in pure forsterite) to the fastest (proton-polaron diffusion in San Carlos olivine, SCol). Our work demonstrates that in SCol, H can leave Si vacancies at a rate orders of magnitude faster than Si or Mg vacancy diffusion, by reaction and exploitation of the proton-polaron path. Thus, the diffusivities determined for Fe-free olivine (the colored lines on this figure) are too slow and largely irrelevant to natural olivines. Our dehydration experiments on olivine from the 1959 eruption of Kilauea Iki are the first for a natural volcanic phenocrysts (as opposed to mantle or synthetic olivine). Here the bulk diffusivity is an order of magnitude slower than SCol, but still several orders of magnitude faster than that for pure forsterite.

The lines with identified defect associates ([Si], [Ti], [Mg]) are average diffusivities for pure Fo (from Padron-Navarta et al., 2014). Thin black lines show anisotropy for a single mechanism (related to Mg vacancy-diffusion in pure foresterite, green field, from Demouchy & Mackwell, 2003) and the proton-polaron mechanism in San Carlos Fo90 olivine, grey field, from Kohlstedt & Mackwell (1998). The orange box shows the bulk H diffusivity in SCol (parallel to [100]) during dehydration from 1 to 68 hours, from this study. The starting material was natural SCol that was hydrated by the proton polaron mechanism (800°C for 17.5 hours at 1 GPa and NNO). Yellow stars indicate the initial dehydration diffusivities of the [Ti] and [Si] H-associates at 1 atm and QFM-2; arrows show the change in diffusivity over 68 hours of dehydration. Purple star is dehydration of Kilauea olivine at 800°C for 8 hours at 1 atm and QFM-2, parallel to [100].