American Mineralogist, Volume 98, pages 1779–1787, 2013

The diffusion behavior of hydrogen in plagioclase feldspar at 800–1000 °C: Implications for re-equilibration of hydroxyl in volcanic phenocrysts

Elizabeth A. Johnson[1,2,3,*] and George R. Rossman[2]

[1]Department of Geology and Environmental Science, James Madison University, 395 S. High Street, MSC 6903, Harrisonburg, Virginia 22807, U.S.A.
[2]Division of Geological and Planetary Sciences, California Institute of Technology, MS 170-25, Pasadena, California 91125-2500, U.S.A.
[3]Department of Earth and Space Sciences, University of California Los Angeles, Los Angeles, California 90095, U.S.A.

Abstract

To use structural hydroxyl (OH) concentrations preserved in volcanic phenocrysts to constrain magmatic water contents prior to eruption, it is first necessary to understand the diffusive behavior of hydrogen in plagioclase. In this study, diffusion coefficients for a natural OH-bearing plagioclase feldspar ($Ab_{66}An_{31}Or_3$) are determined from a series of integrated loss heating experiments performed at 800–1000 °C and 1 atm under air, nitrogen gas, and a CO_2-H_2 mixture at the FMQ oxygen buffer. Hydrogen diffusion is found to be isotropic within analytical error. Using a one-dimensional diffusive loss model for an infinite slab, the diffusion behavior for hydrogen in plagioclase is described by the diffusion parameters $\log D_0 = -1.62 \pm 0.31$ (m^2/s) and $E_a = 266 \pm 77$ kJ/mol, and $\log D_0 = -0.97 \pm 0.35$ (m^2/s) and $E_a = 278 \pm 90$ kJ/mol for experiments only conducted under nitrogen gas. Nearly complete (83–97%) loss of OH from the andesine was achieved in 900 and 1000 °C heating series, except for the 900 °C FMQ buffer experiment in which only 64% of the total OH was lost after 21.6 days of cumulative heating. The diffusion rates of hydrogen in the plagioclase after 800–1000 °C are similar to interpolated diffusion rates for sodium diffusion in An_{30} feldspar, implying that Na^+ and H^+ both diffuse via Frenkel defects involving the large cation sites and interstitial ions. The diffusion coefficient (D) values for hydrogen in plagioclase are lower than most reported diffusion data for hydrogen in nominally anhydrous minerals, and are most similar to D reported for pure forsterite, unaffected by iron redox reactions. Based on the hydrogen diffusion parameters in this study, a 1 mm spherical plagioclase phenocryst experiencing dehydration under lowered water activity during ascent and eruption at 800 °C retains 50% of its initial OH concentration after 34 days. At 900 and 1000 °C, a 1 mm phenocryst retains 50% of its initial OH concentration after only 1.3 days and 0.25 day, respectively. OH concentrations in plagioclase are therefore most indicative of magmatic water contents during the latest stages of ascent and eruption.

Keywords: IR spectroscopy, OH in plagioclase, diffusion, H in plagioclase, high-temperature studies, igneous petrology