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Helium diffusivity measurements under hydrothermal conditions indicate high retentivity of helium in goethite at surface temperatures

BEN THYER[1], KENNETH A. FARLEY[2] AND JONATHAN TREFFKORN[1]

[1]Caltech

[2]California Institute of Technology

Presenting Author: bthyer@caltech.edu

(U-Th)/He and cosmogenic ^{3}He geochronology of goethite provide quantitative constraints on the timing of surface processes such as weathering and erosion, but whether and under what conditions of temperature and goethite crystallinity, composition and grain size He is adequately retained for geochronology remains uncertain. He retentivity in minerals is usually established from vacuum step-heating experiments that reveal the temperature dependence of He diffusivity. However, recent work (Farley et al, submitted 2024) demonstrates that the vacuum heating approach cannot be applied to goethite because in such experiments He mobility is controlled not by diffusion but by the decomposition of goethite to hematite + water.

To overcome this problem, we have been exploring a method to stabilize goethite by sealing it in a helium-permeable silica glass tube along with a small amount of water. The tube is then heated in vacuum in the same way a bare sample is analyzed; during heating He permeates the walls of the glass tube and is accumulated for analysis, while water remains in the tube. This approach allows the experiment to be undertaken at temperatures of at least 300^{o}C at P_{H20} dictated by the vapor saturation PT curve. While these conditions likely do not achieve thermodynamic stability of goethite, it is apparent that goethite dehydration proceeds far more slowly under these conditions than in vacuum. He diffusivities computed from a "glass tube" step heat experiment on a massive botryoidal goethite are ~8 natural log units lower than computed “diffusivities” from step heats on the same sample in vacuum. While the vacuum experiments show complex Arrhenius plot behavior, the glass tube results are consistent with a thermally activated polycrystalline domain model for helium migration indicating an activation energy of ~160 kJ/mol. These data predict very strong retention of He in this specimen at Earth surface conditions, consistent with its measured ^{4}He/^{3}He spectrum that indicates only a small amount of ^{4}He loss in nature. This method may be applicable to other goethite specimens, allowing investigation of what factors may affect He loss from goethite in nature.