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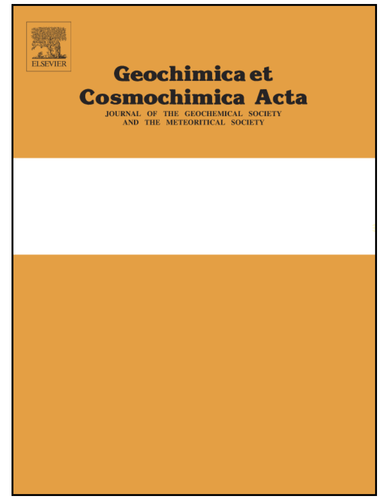

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Helium diffusion parameters of hematite from a single-diffusion-domain crystal

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Abstract

This contribution reports new parameters for helium diffusion in hematite useful for interpretation of cosmogenic ^{3}He and radiogenic ^{4}He chronometry. Fragments of a coarse, euhedral single crystal of hematite from Minas Gerais, Brazil were subjected to bulk step-heating helium diffusion experiments after proton irradiation to make a uniform distribution of ^{3}He. Aliquots of three different grain sizes ranging from ~300 to ~700 μm in equivalent-sphere radius yielded helium diffusion activation energies E_a~170 kJ/mol, very similar to previous estimates for E_a in hematite. Uniquely in this specimen, diffusivity varies with the dimensions of the analyzed fragments in precisely the fashion expected if the diffusion domain corresponds to the physical grain. This contrasts with previous studies that concluded that the analyzed hematites consist of polycrystalline aggregates in which helium migration is governed by the size distribution of the constituent crystallites. These new data permit a direct estimate of the helium diffusivity at infinite temperature for hematite of $\ln(D_o) = -0.66 \pm 0.35$ cm^2/sec.

The major implication of the new diffusion parameters is that hematite is very retentive of helium even at very small crystal sizes. For example, a 20 nm radius hematite crystal, at the smallest end of the size range so far described in dated polycrystalline hematite specimens, will retain more than 99% of its ingrown He over 1 Myr at 30^{o}C, and more than 90% over 100 Myr. Under most conditions, hematite is close to quantitatively helium-retentive on the Earth's surface, simplifying radiogenic and cosmogenic helium dating of this phase. In a system cooling at 10^{o}C/Myr, the 20 nm hematite crystal has a He closure temperature of ~70^{o}C, similar to a typical ~100 μm apatite crystal.

Helium is likely held tightly in hematite owing to its dense hexagonal closest packing structure and absence of migration-enhancing channels. The isostructural minerals corundum and sapphire are likely to be similarly helium retentive.

1. Introduction

Hematite is increasingly a target for He-based dating using either radiogenic ^{4}He or cosmogenic ^{3}He. For example, (U-Th)/He dating has been used to establish the timing of oxide cap hematite formation in a copper porphyry deposit (Cooper et al., 2016), to constrain the age of faulting using hematite-mineralized fault surfaces (Ault et al., 2015), and to date iron oxide deposition during hydrothermal fluid flow (Evenson et al., 2014). By combining (U-Th)/He dating with ^{4}He/^{3}He