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Versatile monazite: Resolving geological records and solving challenges in materials science

Diffusion of helium in natural monazite, and preliminary results on He diffusion in synthetic light rare earth phosphates†

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Abstract

Diffusion of helium has been characterized in natural monazite and synthetic LREE phosphates. Polished slabs of natural monazite and flat growth faces of synthetic phosphates were implanted with 100 keV ^{3}He at a dose of 5×10^{15} ^{3}He/cm^2 and annealed in 1 atm furnaces. ^{3}He distributions in monazites following experiments were measured with nuclear reaction analysis using the reaction ^{3}He(d,p)^{4}He. For diffusion in monazite we obtain the following Arrhenius relation for diffusion normal to (100)

$$D = 1.60 \times 10^{-7} \exp(-150 \pm 8 \text{ kJ/mol}/RT) \text{ m}^2/\text{s}.$$

Diffusion in natural monazite exhibits little diffusional anisotropy, as diffusion normal to (001), (100), and (010) appear similar, as do diffusivities of He in natural monazites from two different localities. Over the investigated temperature range, these diffusivities are similar to those of Farley and Stockli (2002), and values obtained for some of the monazite grains analyzed by Boyce et al. (2005), obtained through bulk-release of He by step heating, and are bracketed by diffusivities obtained by Farley (2007) for monazite-structure synthetic REE phosphates.

Helium diffusion measured in synthetic REE phosphates ($LaPO_4$, $NdPO_4$, $SmPO_4$, and $EuPO_4$) with the monazite structure appears to behave systematically, with diffusion in the lighter REE phosphates slightly faster than in the heavier REE phosphates. This trend is in broad agreement with the findings of Farley (2007), but the difference in diffusivities among the REE phosphates is smaller than that reported by Farley (2007). Activation energies for He diffusion in the synthetic LREE phosphates are similar to that for natural monazite measured in this study, but He diffusivities in synthetic $LaPO_4$ are about an order of magnitude faster than in the natural monazites.

The differences in He diffusivities among the natural monazites and synthetic REE phosphates may be a consequence of the density and distribution of interstitial apertures in the crystal structure, which may result in differences in He migration rates. The similarities in He diffusivities for natural monazites containing varying mixtures of rare-earth elements, as well as differences in Th contents, however, indicate that the above Arrhenius relation is most relevant for describing He diffusion in monazite in nature.

We use this Arrhenius relation to evaluate He retentivity in monazite experiencing thermal events, using both the closure temperature formulation of Dodson (1973) and recently developed expressions (Watson and Cherniak 2013) for prograde thermal events and heating and cooling trajectories. Calculations indicate that monazite is relatively retentive of He compared with accessory mineral phases.

Keywords: Monazite, xenotime, rare-earth orthophosphates, helium, diffusion, nuclear reaction analysis, thermochronology