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Geometric analysis of radiation damage connectivity in zircon, and its implications for helium diffusion

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Abstract

Geometrical modeling of radiation damages zones from α recoil and fission that accounts for their elongate nature provides new estimates of the doses required to reach percolation and full connectivity in zircon. Alpha recoil track damage percolates at doses from 2.5–3.1 × 10^{16} α/g based on our calculations, about two orders of magnitude lower than previous estimates, with the difference partially due to elongation and partially due to decay chains creating pre-made networks of connected tracks. This dose level is far below that required for metamictization, and suggests that α recoil track percolation has no effect on macroscopic or unit-cell properties, at least as measured to date. However, fission tracks percolate at a dose of approximately 1.9 × 10^{18} α/g, the approximate level formerly ascribed to α recoil damage percolation and correlating with various transitions in material properties, such as an inflection in the relationship between dose and macroscopic swelling. Consideration of the undamaged regions between damage zones indicates that *c*-axis-parallel channels are frequently interrupted, at the micrometer scale at very low doses and tens of nanometers at usual doses in natural zircon, with the probable effect of decreasing diffusivity anisotropy. The percolation and further interconnectivity of α recoil damage corresponds with a general minimum in diffusivity and maximum in closure temperature in zircon, indicating that α recoil damage percolation does not make a grain "leaky", but instead quite the opposite. Instead, the onset of poor He retentivity at high damage levels correlates with fission-track percolation. Some of these results are non-intuitive with respect to the trapping model of He diffusivity reduction, and the alternative mechanism of tortuosity is discussed.

Keywords: Zircon, radiation damage, percolation, alpha recoil, fission track, diffusivity, (U-Th)/He