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Exploring ^{4}He diffusivity in highly radiation-damaged zircons for the (U-Th)/He system

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The geologic utility of zircon (U-Th)/He thermochronometry relies on a robust understanding of the ^{4}He diffusion kinetics in zircon. ^{4}He diffusivity in zircon is influenced by the accumulation and annealing of radiation damage, which, for zircon grains with well-characterized thermal histories, can be related to a crystal's calculated alpha dose. However, ^{4}He diffusion kinetic data for highly radiation-damaged zircon crystals above the damage-diffusivity threshold is presently scarce, limiting the available constraints for damage-diffusivity models at and above ~ 1–2 × 10^{18} α/g. In addition, questions remain on the exact alpha dose (or at least the approximate range of alpha dose) that marks the damage-diffusivity threshold, where diffusivity begins to increase with increasing radiation damage. This study presents new diffusion kinetic data for c-axis-oriented slabs of Sri Lankan zircon samples with high levels of alpha dose and radiation damage, derived from step-heating experiments. Our samples include specimens GZ8 (1.63 × 10^{18} α/g), G168 (2.12 × 10^{18} α/g), G4 (3.51 × 10^{18} α/g), GZ5 (4.03 × 10^{18} α/g), and G3 (4.88 × 10^{18} α/g). We report new kinetic parameter values of E_a = 120.67 kJ/mol and D_0 = 4.49 × 10^{-3} cm^2/s for G168 and E_a = 111.19 kJ/mol and D_0 = 1.53 × 10^{-2} cm^2/s for G3. These diffusion kinetic parameters correlate strongly with observed E_a and D_0 data trends from previous experiments on well-characterized natural zircon samples. We also report preliminary diffusion kinetic parameter values of E_a = 56.30kJ/mol and D_0 = 1.30 × 10^{-4} cm^2/s for GZ5, which deviate from observed E_a and D_0 data trends. We highlight that the consistency in the diffusion kinetic parameters of samples G168 and G3 with previous studies shows that the present damage-diffusivity model remains coherent. However, we acknowledge that further investigation is required to assess the cause of E_a and D_0 deviation for GZ5. Furthermore, we propose that three-dimensional investigations of zircons through methods such as the atom probe tomography could reveal the behavior of ^{4}He and/or other trace elements in zircon within amorphous, radiation-damaged domains, which remains elusive.