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The Effects of Radiation Damage as Measured by Raman Spectroscopy on Apparent (U-Th)/He Ages and He Diffusion in Zircon

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Zircon is one of the most commonly used minerals in (U-Th)/He thermochronometry, based on He ingrowth from the alpha decay of U, Th, and Sm. Helium retention in zircon is characterized by a closure temperature of ca. 180°C (dT/dt of 10°C/m.y.) and a partial retention zone between ca. 140-200°C. However, several studies have shown that zircon (U-Th)/He (ZHe) ages are significantly affected by radiation damage. The emission of the alpha particle and the recoil of the parent nuclide, as well as spontaneous 238U fission, create defects in the crystal lattice which accumulate over time. Despite a large number of published step-heated, fractional-loss He diffusion experiments in zircon, most studies only use uniform values for He diffusion kinetics without consideration of the potential for variations due to accumulation of damage. An understanding of variations in diffusion kinetics is therefore imperative for the reliable interpretation of thermochronometric data. Several case studies from the North African Tethys Margin (Gulf of Suez and Western Desert, and Morocco) show strong correlations between apparent ZHe cooling age and effective uranium concentration (Ue, as proxy for maximum accumulated radiation damage) within individual samples; i.e., low Ue (less damage) yield older apparent ZHe ages than high Ue grains that exhibit systematically younger ages. The spread of ages obtained from Pan-African rocks is commonly ca. 400 m.y. Furthermore, obtained apparent ZHe ages occur in clusters around known regional tectonic events, such as the East African Orogeny, Hercynian Orogeny, Neotethyan rifting, or Santonian inversion. These data demonstrate unequivocally a strong and systematic relationship between radiation damage and He diffusion kinetics in zircon. We use Raman spectroscopy to directly measure accumulated damage within each grain, followed by U-Pb LA-ICP-MS measurements to remove the effects of inheritance from our data in detrital zircons, and finally ZHe age dating and low-T He diffusion experiments to quantify the correlation between total accumulated damage, diffusion kinetics, and apparent (U-Th)/He age and allow the use of zircon as a thermochronometer capable of measuring more robust and continuous thermal histories.

Keywords: zircon, thermochronology, U-Pb, Egypt