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Trace-element segregation to dislocation loops in experimentally heated zircon

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Abstract

To evaluate the mechanisms driving nanoscale trace element mobility in radiation-damaged zircon, we analyzed two well-characterized Archean zircons from the Kaapvaal Craton (southern Africa): one zircon remained untreated and the other was experimentally heated in the laboratory at 1450 °C for 24 h. Atom probe tomography (APT) of the untreated zircon reveals homogeneously distributed trace elements. In contrast, APT of the experimentally heated zircon shows that Y, Mg, Al, and Pb+Yb segregate to a set of two morphologically and crystallographically distinct cluster populations that range from 5 nm tori to 25 nm toroidal polyhedra, which are confirmed to be dislocation loops by transmission electron microscopy (TEM). The dislocation loops lie in {100} and {001} planes; the edges are aligned with <100>, <101>, and <001>. The largest loops (up to 25 nm diameter) are located in {100} and characterized by high concentrations of Mg and Al, which are aligned with <001>. The $^{207}Pb/^{206}Pb$ measured from Pb atoms located within all of the loops (0.264 ± 0.025; 1σ) is consistent with present-day segregation and confirms that the dislocation loops formed during our experimental treatment. These experimentally induced loops are similar to clusters observed in zircon affected by natural geologic processes. We interpret that differences in cluster distribution, density, and composition between experimentally heated and geologically affected zircon are a function of the radiation dose, the pressure-temperature-time history, and the original composition of the zircon. These findings provide a framework for interpreting the significance of clustered trace elements and their isotopic characteristics in zircon. Our findings also suggest that the processes driving cluster formation in zircon can be replicated under laboratory conditions over human timescales, which may have practical implications for the mineralogical entrapment of significant nuclear elements.

Keywords: Zircon, radiation damage, APT, TEM, dislocation loop, annealing