Radiation damage and helium diffusion kinetics in apatite

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Experimentally determined diffusion coefficients for 39 different samples of apatite demonstrate that the closure temperature (T_c) for helium retention in apatite spans a wider range than previously recognized: from 44 ± 4 ^oC to 116 ± 18 ^oC (for 10 $^oC/Myr$) and correlates with the radiogenic ^4He concentration ([^4He]) in a given sample. We find no correlation between helium diffusion kinetics and apatite chemistry, including the F/Cl ratio. We argue that [^4He] is a measurable proxy for the radiation damage which accumulated within each crystal over geologic time. As the volume density of lattice damage sites increases, apatite becomes more helium retentive. This implies that helium retentivity, and hence the effective helium diffusion kinetics, is an evolving function of time. Measured diffusivities thus reflect a snapshot in time and cannot alone be applied to the thermochronometric interpretation of a given sample.

Calibrated with diffusion kinetics of 39 different samples of apatite, we present a simple, quantitative *trapping model* which relates diffusivity to both temperature *and* [^4He]. This previously proposed model [1] consists of two Arrhenius relations: one for volume diffusion through undamaged mineral lattice and one for the release of helium from the damage traps back into the undamaged lattice. The model predicts much of the observed log-linear correlation between T_c and [^4He]. By inserting this function into a ^4He production-diffusion calculation, the *trapping model* predicts: (i) that the effective ^4He closure temperature of apatite will vary with cooling rate *and* effective U concentration (*eU*) and may differ from 70 ^oC by up to ±15 ^oC, (ii) the depth of the ^4He partial retention zone will depend on accumulation time and on *eU*, and (iii) samples subjected to reheating after the accumulation of substantial radiation damage will be more retentive than previously expected. These predictions are consistent with recent observations of unexpected apatite (U-Th)/He ages in some settings, most noteably [2].

References

[1] Farley (2000) *JGR,* **105**, 2903-2914
[2] Flowers et al., (2006) *GCA* (This volume), Goldschmidt 2006