A self-consistent model of radiation damage annealing and its control on helium diffusion kinetics in apatite

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(U-Th)/He thermochronometry in apatite is widely used to study surface processes and the development of topography through geologic time. This thermochronometric system depends on a quantitative description of the diffusion kinetics of ^{4}He across a range of temperatures, timescales, and geologic scenarios. Empirical observations demonstrate that He diffusion in apatite is not solely a function of temperature, but also depends on damage to the crystal structure from radioactive decay processes, including alpha decays and fission events. Commonly-used models that account for the influence of thermal annealing of radiation damage on He diffusivity assume the net effects evolve in proportion to the rate of fission track annealing, although the majority of radiation damage is caused by alpha recoil. While this assumption adequately represents the net effects of damage annealing in many geologic scenarios, previous empirical work suggests that the annealing rates of the two damage types differs substantially. Here, we present the results of a new model that quantifies the influence of thermal annealing on He diffusivity in apatite without relying on the assumption that all radiation damage anneals in the same way. We present an empirical fit to experimentally-determined diffusion kinetics data and incorporate this fit into a model designed to interrogate the competing effects of radiation damage accumulation and annealing on He diffusivity in apatite through geologic time. We compare the results of this new model framework with existing models and demonstrate that in certain, but not all, geologic scenarios, the interpretation of low-temperature thermochronometric data can be strongly influenced by which model of radiation damage annealing is assumed. Using hypothetical time-temperature (*t-T*) paths chosen to demonstrate differences between models, we highlight the influence of damage annealing on data interpretation. Geologic scenarios involving 1-2 km of sedimentary burial, such as in the Grand Canyon, are especially sensitive to the assumed rate of annealing and its influence on He diffusivity.