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Investigating how deformation and pressure influence the behavior of helium in apatite

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Apatite (U-Th)/He thermochronology is widely utilized to infer the low-temperature thermal histories of rocks related to landscape evolution and tectonic processes. However, apatite (U-Th)/He dates from individual samples are often overdispersed, which limits the thermal history information that can be inferred. This date overdispersion cannot be fully explained by well-documented effects of grain size, parent nuclide zonation, or radiation damage on helium diffusion kinetics. Here, we investigate the potential of deformation in apatite to modulate helium diffusion behavior and therefore to differences in helium retention across different apatite grains. We deformed single-crystal Durango apatite under either compression (low stress) or torsion (high stress) in a Paterson gas-medium apparatus at 300 MPa confining pressure and 1100 ºC for 5 hours. We crushed deformed crystals into smaller shards and irradiated the shards with protons to generate a uniform, high concentration of ^{3}He. We measured the ^{3}He and ^{4}He degassed from individual irradiated shards in stepwise heating experiments using the same prograde heating schedule in both experiments. The sample deformed in compression yields a common unimodal gas release, while the Durango shards deformed to higher stress exhibit bimodal helium release peaks. The first release peak occurs at similar temperatures and cumulative ^{3}He release fractions as the unimodal release peak observed in experiments on undeformed Durango apatite shards, while the second release peak occurs at higher temperatures and cumulative ^{3}He release fractions. This bimodal behavior is comparable to continuous ramped heating (CRH) measurements of some natural apatite samples, and suggests that deformation-induced dislocations in apatite can function as sinks that can trap helium over a sample's geologic history. We also observed that a fraction of the naturally-occurring, radiogenic ^{4}He was retained in the deformed shards, despite the high temperatures reached in the deformation experiments. We attribute this primarily to the often neglected pressure term in the Arrhenius equation commonly used to quantify the kinetics of volume diffusion.