Variable helium diffusion in fluorite

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(U-Th-Sm)/He thermochronology is a valuable technique for studying low-temperature processes which take place close to the surface of the Earth. Understanding the diffusion characteristics of helium in crystals is crucial for this method. Apatite and zircon are the most frequently dated minerals having very low closure temperatures (T_c) and their diffusion parameters are already well understood [1] [2].

Hydrothermal veins and related ore deposit provide some of the most important evidence for localized fluid flow and thermal anomalies within the Earth's upper crust. Datable minerals from such deposits, however, are typically rare or absent. A challenging field for the geoscience community is to determine the age and/or duration of such hydrothermal processes. The common occurrence in ore deposits and its sensitivity to thermal events below 200 °C makes fluorite a prime candidate for (U-Th-Sm)/He thermochronolgy beyond apatite and zircon. However, previously published diffusion characteristics and T_c of the fluorite (U-Th-Sm)/He thermochronometer yielded contrasting values. Evans et al. [3] experiments point to 90 ± 10 °C T_c while Pi et al. [4] reported evidence for T_c up to, or even above 200 °C.

We have performed 34 stepwise degassig experiments on 14 fluorite samples with different chemical compositions. Our results indicate that despite the fact that the CaF_2 content of natural fluorites in most cases exceeds 99 weight percent, the diffusion characteristics are highly variable. The calculated T_c for the fluorite (U-Th-Sm)/He thermochronometer varies between ca. 45 and 170 °C. Our helium diffusion data suggests that minor substitutions of calcium by rare earth elements and yttrium (REE+Y) together with sodium for anionic charge compensation significantly impact the diffusivity of helium in fluorite. Higher Na and REE+Y concentrations are inducing higher T_c. This dependence might be explained by narrowing and blocking of the major diffusion pathways in the fluorite crystal lattice caused by incorporation of ions of different size and charge.

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