Helium diffusion and (U+Th)/He thermochronometry of titanite

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Recent developments in the (U+Th)/He-dating method of apatite demonstrate the potential of this method to record cooling histories of rocks through low temperatures and to constrain rates of a variety of near-surface geologic processes (e.g. Wolf et al., 1996a,b; Farley et al., 1996). In an effort to expand the (U+Th)/He-dating method to other minerals and ranges of closure-temperatures we have been investigating the use of the method for, and characteristics of He-diffusion in, titanite (sphene).

He-diffusion in sphene

We have performed a series of temperature-cycled, incremental step-heating experiments on sphenes from a variety of geologic environments and cooling rates, measuring 4He abundances in each extraction step using 3He isotope dilution and quadropole mass-spectrometry. These experiments indicate that sphene has a greater retentivity for He than apatite, and suggest two discernible trends of slightly different slopes in a plot of ln(D/a2) vs 10^4/T.

He-diffusivity in initial low-temperature extractions (prior to heating above approximately 490°C) is slightly higher than in extractions following heating above higher temperatures. Following relatively high-temperature heating-steps, step-heating extractions show good linear

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**Fig. 1.** Example of cycled step-heating diffusion experiment on MH-10 sphene (sample provided courtesy of M. Heizler). Initial low-temperature extractions indicate higher He-diffusivity than successive extractions. Following high-temperature heating-steps, all further extractions show a highly linear correlation between ln(D/a2) and reciprocal temperature, yielding a closure temperature of about 195°C.
correlation in a $\ln(D/a^2)$ vs $10^4/T$ plot (Fig. 1), yielding a closure temperature of about 190–210°C for a cooling rate of 10°C/Ma (compared with 75°C for apatite). These characteristics are observed for a range of sphene grain sizes. This behaviour may indicate more than one diffusion domain for He in sphene, whereby some fraction of the total He resides in a relatively less-retentive domain and is extracted at relatively low temperatures. If a closure-temperature of about 190-210°C is applicable, it would provide useful thermochronometric age constraints comparable to ages from K-feldspar-40Ar/39Ar, as well as zircon-fission-track, methods.

**Sphene (U+Th)/He ages**

(U+Th)/He dating of sphene is somewhat simpler than that of apatite, both because its higher U and Th concentrations allow dating of single crystals or crystal fragments, and because larger crystal sizes reduce or obviate the need for corrections for alpha ejections from crystals (Farley et al., 1996). Quantitative He extraction from sphene is accomplished by heating the sample to approximately 1150–1190°C, and 4He abundances are measured using either quadrupole (with 3He isotope dilution), or sector mass-spectrometry. Sphene crystals are then retrieved, spiked with a 230Th and 235U solution, and dissolved in hot HCl + HF; U and Th abundances are measured using isotope-ratio ICP-MS measurements.

(U+Th)/He-ages of five quickly-cooled sphenes from the Fish Canyon Tuff, Colorado, range from 27.6 to 32.0 Ma (mean = 29.5 Ma, estimated uncertainty = 2.3 Ma), in good agreement with the accepted age of 27.8 Ma. Five sphenes from the Chain of Ponds pluton, Maine (samples MH-10 and MH-42), used by Lovera et al. (1989) for determining the multiple diffusion-domain character of K-feldspars, yield ages of 200–244 Ma (mean = 223 Ma, estimated uncertainty = 17.8 Ma). If these ages represent cooling through about 190–210°C, this implies a slower cooling history for the pluton than previously interpreted from 40Ar/39Ar-dates of amphibole, biotite, and K-feldspar (Heizler et al., 1988). These ages are consistent with 40Ar/39Ar-dates implied by some of the smallest domain-size Ar fractions in K-feldspar however, which were interpreted as unreliable age-indicators by Lovera et al. (1989). More work on the He-diffusion characteristics of sphene and more sphene (U+Th)/He-dates from the pluton are required before these results can be fully interpreted.

We are also working on sphene (U+Th)/He ages from a suite of granitic samples from the Gold Butte Block, a tilted Proterozoic crustal section representing about 17 km of palaeo-crustal depth. Sphene He-dates will provide useful comparisons to previous apatite fission-track dates from the section (Fitzgerald et al., 1991), and should indicate the usefulness of this method for dating slowly-cooled rocks in uplifted crustal blocks.

**References**


