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^{40}Ar/^{39}Ar dating of tourmaline as a tool for high-temperature metamorphism thermochronology

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Tourmaline is an ubiquitous mineral, with properties making it ideal for studying metamorphic processes as well as a useful tool for a wide range of applications (e.g, magmatism, metasomatism, ore deposits [1]), mostly because it is not sensitive to chemical or mechanical alteration and is stable over a wide range of pressure–temperature conditions (up to 6 GPa and 850˚C [2]). Typical metamorphic tourmaline types include dravite and shorl which, along with elbaite, belong to the alkali group [1]. The alkali group is notable because tourmalines from this group tend to incorporate trace amounts of K_2O and therefore, can be dated using the ^{40}Ar/^{39}Ar technique.

In order to understand the maximum temperature below which the K/Ar chronometer stays closed to argon loss by thermally activated diffusion, we carried out temperature controlled furnace diffusion experiments on well-behaved ^{40}Ar/^{39}Ar plateau-forming Archean tourmaline of 2935 $\pm$ 9 Ma [3]. Each experiment yielded an Arrhenius profile (Do vs. 1/temperature) that shows that the ^{39}Ar data form two linear arrays with two distinct slopes. The first array only includes a few % of the total gas, has a shallow slope and shows very fast diffusivity at low temperature. We interpret these data as indicating very fast release of argon by cracks and defects. The second array of data points includes most of the gas of each experiment and forms a much steeper slope. These data yielded Ea (activation energy) values ranging from 120 to 157 Kcal/mol and D_0 (pre-exponential diffusion factor) values ranging from 1.9x10^6 to 2.5x10^9 cm^2/s for crystals with an average radius of 100 $\pm$ 25 μm. Three additional experiments using a laser (resulting in poor temperature control) suggest similar values although the latter experiments are considered semi-quantitative. The furnace experiments suggest that tourmaline has a weighted mean closure temperature of 804 $\pm$ 90 ˚C (1σ) for a cooling rate of 10˚C/Ma. Monte Carlo simulations using triangular and normal data distributions for Ea, D_0 and radius size values yielded a mean closure temperature of 764 $\pm$ 65 ˚C (1σ) and a skewed distribution mode of ca. 725 ˚C.

A closure temperature of 700-800 ˚C makes tourmaline the most retentive mineral that can be used for ^{40}Ar/^{39}Ar dating. Such a high closure temperature make tourmaline ideally suited for studying the high-temperature thermochronology of tourmaline-bearing metamorphic rocks. In particular, since tourmaline is more likely to grow during the prograde P-T history because of the exhaustion of boron liberation before the peak metamorphism [1], ^{40}Ar/^{39}Ar dating may provide information on the prograde history of a rock provided that the system stays below ca. 700˚C. Tourmaline is also well suited to access low-temperature hydrothermal histories.

[1] van Hinsberg, V.J., Henry, D.J., Dutrow B.L. 2011. Tourmaline as a Petrologic Forensic Mineral: A Unique Recorder of Its Geologic Past Elements. Elements 7, 327-332. [2] Dutrow B.L., Henry, D.J. 2011. Tourmaline: A Geologic DVD. Elements 7, 301-306. [3] Thern, E., Jourdan F., Evans N.J., McDonald B.J., Danisik M., Frew R.A., Nelson, D.R.. Post-depositional thermal history of the 4364–3060Ma zircon-bearing metasandstones of the Illaara and Maynard Hills granite greenstone belts Western Australia. in: Goldschmidt conference, Prague 2011.