High spatial resolution Ar-Ar age profiles in micas - slow cooling in the Presidential Range, New Hampshire, USA

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Apparent age gradients in single crystals of muscovite have been detected in a sufficient number of cases to indicate that they are common. The various studies have suggested one or more dominant process controlling the development of 'fossil' age gradients in micas, including; volume diffusion, multipath diffusion, deformation, chemical variations, and heterochemical recrystallisation. If we can discriminate between age profiles formed by volume diffusion and those formed by other means, they may be very useful for evaluating thermal histories. Moreover, thermal histories, determined using high spatial resolution UV laser originate from single minerals and single grains, circumventing to a large extent the uncertainties resulting from the various estimates of closure temperatures.

The Presidential Range of New Hampshire, USA, offers an ideal site to study argon age profiles in muscovite. Regional geochronological studies and the depositional age of the Littleton formation, suggest the main stage of the Acadian metamorphism in the Presidential Range occurred in the interval 412-405 Ma. Rocks are exposed along the eastern flank of Mount Washington from the summit at 1917 m to the base at 411 m. In earlier work Eusden and Lux (1994) found 30 m.y. of variation in bulk-sample muscovite ages from the top to the base of Mt. Washington, from 305 Ma at the summit to 275 Ma at the base. Eusden and Lux interpreted these results to indicate the present day relief of Mt. Washington exposes ancient, deep crustal levels that passed through the argon closure temperature for muscovite (sensu stricto - Dodson 1973) during a 30 m.y. interval of post Acadian unroofing and cooling. Their results and previous studies by West and Lux (1993), and Harrison *et al.* (1993), corroborated a proposed slow cooling history in the Late Devonian to Permian time in portions of northwestern New England.

Eusden and Lux (1994) recorded argon release spectra deviating slightly from ideal plateaux though none recorded staircase which might be expected to indicate the effects of argon loss. Single crystal laser fusions yielded ages ranging from 267 ± 3 to 327 ± 4 Ma, an age range of 60 Ma, in a locality where Eusden and Lux recorded a total gas age of 304 ± 1.5 Ma. To further test the distribution of ages, micas were collected from a pegmatitic granite dyke chosen for their exceptional size (up to 1 cm) and clarity. A total of 31 spot fusions using an Ar Ion laser resulted in ages varying from about 390 to 305 Ma with a systematic age distribution from centre to edge. Ages reflecting early cooling from the Acadian metamorphism in the grain centre (380-390 Ma) gave way to ages reflecting late cooling at the grain edges though the spatial resolution of the Ar Ion technique prevented resolution of the age gradient in the outer 100 μm. Further work using a UV laser to achieve high spatial resolution close to the edge of one grain, revealed that ages varied by up to 50 Ma in the outer 100 μm of the grain (Fig. 1).

The larger grains yielded much older ages than the smaller grains analysed by Eusden and Lux (1994) so in order to study the effects grain size upon the ages we analysed some large grains with cores rich in fibrolitic sillimanite. The sillimanite needles acted as macroscopic analogues for smaller scale defects in

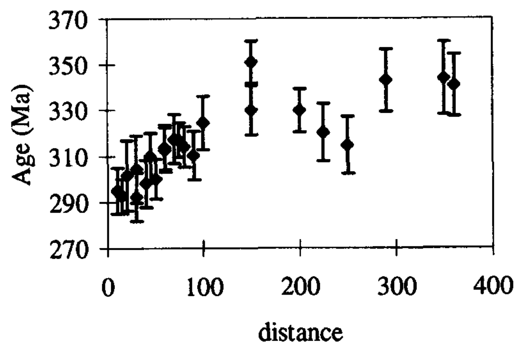

FIG. 1.

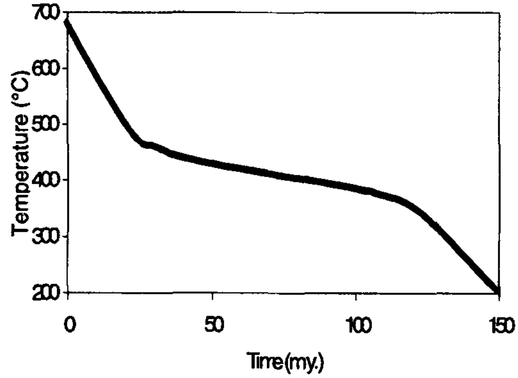

FIG. 2.

layers of the muscovite restricting the effective grainsize. UV-laser analyses along the outer millimetre of a large muscovite crystal with an inclusion free core confirms shows no systematic increase of ages towards the crystal core whereas crystals from the same sample without the sillimanite core do exhibit such variations. In summary, argon retention in muscovite is commonly a function of the physical grainsize though macroscopic to sub-microscopic features can affect argon retention.

Given the slow cooling in this section of the President Range of New Hampshire, closure temperatures as defined by Dodson (1973) are not valid. Dodson (1986) defined profiles which might be expected for minerals in slowly cooled terrains which indicate significantly younger ages at the grain margins. In fact this is theoretically the case in all terrains with a linear cooling history but the variations occur so close to the margins (less than 10 μm) that they can be discounted in more rapidly cooled rocks and the conventional closure temperature (Dodson 1973) is a good estimate for thermochronolgy. However, Wheeler (1996) modelled combined argon diffusion and argon loss (or gain) and showed that Ar-Ar age profiles could be used quantitatively to recover thermal histories asssuming that diffusive loss occurred by volume diffusion. Using the DIFFARG software (Wheeler, 1996) we have been able to model the age profiles in micas from the Presidential Range and derive thermal histories from 450 °C to 300 °C from single muscovite grains.

The fits of age profiles to the theoretical curves are remarkably good in these large clear micas and the thermal histories vary systematically from the top to base of Mt. Washington yielding a picture of the thermal structure of this section of crust over 50 m.y. of time.

References

Dodson, M.H. (1973) *Contrib. Mineral. Petrol.*, **40**, 259–74.

Dodson, M.H. (1986) *Materials Science Forum*, **7**, 145–54.

Eusden, J.D. and Lux D.R. (1994) *Geology*, **22**, 909–12.

Hames, W.E., Eusden, D., Lux, D. and Cheney, J. (1997) *Geol. Soc. Amer., Abst w. Prog.*, **29**.

Harrison, T.M. Spear, F.S. and Heizler, M.T. (1989) *Geology*, **17**, 185–9.

Kelley, S.P., Arnaud, N.O. and Turner, S.P. (1994) *Geochim. Cosmochim. Acta*, **58**, 3519–25.