Ar/Ar dating of hydrothermal minerals in the Southern Alps, New Zealand

D. A. H. Teagle
C. M. Hall
Department of Geological Sciences, University of Michigan, Ann Arbor, MI 48109-1063, USA

S. C. Cox
D. Craw
Department of Geology, University of Otago, Dunedin, New Zealand

The Southern Alps, New Zealand are an actively rising mountain belt formed along an obliquely convergent portion (~40 mm/yr) of the Australian-Pacific plate boundary. The uplift rate is difficult to quantify in this rugged region because there are no reliable Quaternary markers. The present study attempts to quantify uplift rate at two localities to the west of the Main Divide using Ar/Ar dating and fluid inclusion data from hydrothermal minerals.

The rapid uplift of the Southern Alps along the Alpine Fault has resulted in high geothermal gradients and vigorous hydrothermal circulation in the upper crust (Koons and Craw, 1991). These fluids deposit vein minerals, mainly quartz and calcite, with minor gold mineralisation, that cross-cut structures associated with the rise of the Southern Alps and must be late Cenozoic in age. Earlier endeavours using Ar systems in the Southern Alps were fraught with the recurrent problem of excess inherited argon (e.g. Adams, 1981). To address this problem a procedure has been developed to remove inherited Ar from minerals by liberating fluid inclusions prior to final analysis for dating.

We have attempted to date samples of adularia, muscovite and actinolite hosted by greenschist facies schists from near Almer Hut on the northern flank of the Franz Josef glacier. Porphyroblastic biotite forming a new foliation in garnet zone schist from near the junction of the Victoria Valley and Fox glacier has also been investigated. This locality is approximately 10 km south west of the Almer Ridge and is closer to the Alpine Fault.

Adularia from the Almer Ridge mineralized zone contains numerous large (~100 μm) primary, fluid inclusions that homogenize at 240–280°C. Adularia with bladed calcite commonly indicates boiling and vapour-rich fluid inclusions have been found in adularia and calcite in similar veins a few km to the northeast (Craw, 1997). This means that the adularia homogenization temperatures reflect true trapping temperatures, and a mineralisation depth of about 400–700 can be estimated from the liquid-vapour curve in p-T space (Craw, 1997).

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Mineral samples were irradiated and multiple grains of actinolite, biotite and muscovite transferred into sample wells for conventional laser step heating. Adularia grains were treated in a two stage process in order to liberate fluids trapped in inclusions that pilot studies had shown to contain a significant proportion of inherited Ar. Single grains of adularia were heated with a diffuse laser beam in two increments to burst fluid inclusions and liberate all the trapped gas, but without significantly disturbing lattice bound Ar. The vacuum was then broken and an outgassed flux bead was added to each sample well. The single grains of the pale, translucent adularia were melted with the aid of the flux bead, with a focussed high power laser beam.

Sixty three single grains of adularia have been analysed. There is a clear separation between the low and high temperature data sets with the low temperature points clustering at very low $^{39}Ar/^{40}Ar$ ratios (<0.03) and displaying $^{40}Ar/^{36}Ar$ spanning the range from atmosphere to extremely radiogenic values (>60,000). The high temperature points do not define an isochron and scatter in an elongate data cloud with a gentle negative slope (Fig. 1). Age constraints can be placed on these data by assuming that the analyses record mixing in a 3 component system bounded by atmosphere, an inherited Ar component as defined by the low temperature data, and Ar due to *in situ* radioactive decay. The youngest bounding line that will contain all data is ca. 880 kyr (Fig. 1), with older ages reflecting slight contamination by highly radiogenic inherited Ar as liberated from fluid inclusions in the low temperature analyses. The bounding line at 880 kyr represents a minimum age but due to the asymmetric nature of the data and the irregular contamination by inherited Ar precise error estimates cannot be assigned. The adularia

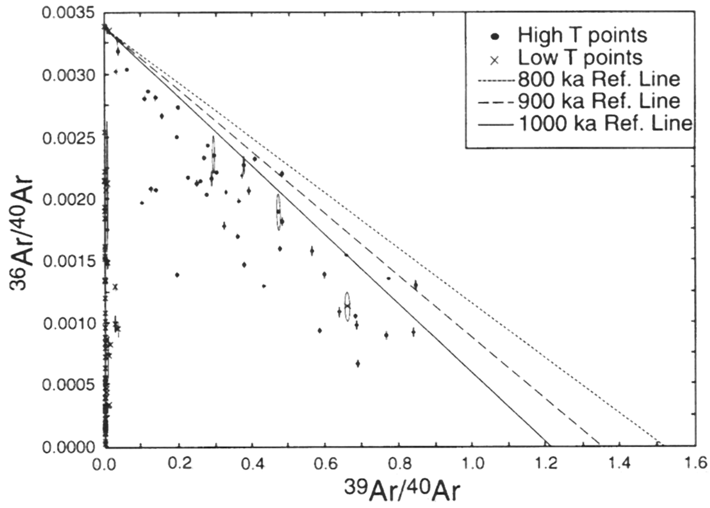

FIG. 1. Ar-Ar analyses of single grains of adularia from Almer Ridge, Southern Alps, New Zealand.

could conceivably be younger than 880 kyr if the samples that define the uppermost bounding line still contain inherited ^{40}Ar. However, after 63 analyses there is no evidence for younger ages. Whilst adularia is a common host for Ar-rich fluid inclusions it appears that Ar is not incorporated into the crystalline lattice during growth of the mineral.

Step heating of actinolite and muscovite did not yield useful age information. Conventional laser step-heating of late metamorphic biotite from garnet schists from the Fox Glacier yields an isochron age of 1.26 ± 0.02 Myr (MSWD = 0.54; n = 7). The isochron has a near atmospheric intercept indicating only a very minor inherited radiogenic component.

Discussion

The similarity between the Ar blocking temperature (200-250°C) and the fluid inclusion homogenization temperature suggests that the minimum age of 880 kyr yielded for the adularia samples most probably records the time of hydrothermal activity in the Almer Ridge mineralized zone. In contrast, the biotite isochron age most probably records the passage of the host garnet schist through the biotite Ar retention temperature (350–400°C for cooling >200°C/Myr). A pressure-temperature path for the uplift of the central Southern Alps has been estimated (Holm *et al.*, 1989), and combining this information with a range of Ar blocking temperatures for biotite (350–400°C) an uplift rate of between 4.8–8.8 mm/yr is estimated for the garnet schists from the Fox Glacier. This rate is rapid and similar to determinations based upon uplifted marine terraces (5-20 mm/yr; Simpson *et al.* 1994) and fission track dating of zircons (1–8 mm/yr; Tippet and Kamp, 1993).

The exposure of greenschist facies rocks from beneath metagreywackes to the east of the Alpine Fault implies uplift of the order of 5-10 km over the 2 to 3 Myr of orogeny, and uplift rates are expected to be significantly lower than near the Alpine Fault (~1.6–5 mm/yr). For the mineralized adularia veins at Almer Ridge the depth of formation (400–700 m) and the minimum age determined by Ar-Ar dating (880 kyr) constrain the uplift rate to be in the range of 0.45–0.8 mm/yr, and certainly an uplift rate less than 1mm/yr seems to be inescapable. Our new data quantifies an order of magnitude change in uplift rate over *c.* 10 km in the Southern Alps. Similar variations in uplift rates should be expected in all active collisional mountain belts and in exhumed metamorphic belts which formed beneath such mountain belts.

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