Differential unroofing and inherited radiogenic strontium in the Western Himalaya

M.T. George *Department of Geology, University of Wales, College of Cardiff, Cardiff, CF1 3YE, UK.*

S.M. Reddy *Department of Earth Sciences, University of Liverpool, Liverpool, L69 3BX, UK.*

Introduction

In the western Himalaya, the Nanga Parbat-Haramosh massif (NPHM; Indian continental crust) has been differentially exhumed relative to the adjacent Kohistan island arc terrane (Zeitler 1985). This study aims to constrain the detailed cooling history of the region by using both Rb-Sr and laser probe $^{40}Ar/^{39}Ar$ dating of muscovite and biotite from closely-spaced samples. Such a study should also help to evaluate the resolution of mineral ages in determining cooling rates in regions of rapid exhumation. Samples dated include granite sheets and their metamorphic country rocks, and come from the NPHM, the Kohistan arc, and from the intervening steeply-dipping, high-grade shear zone.

Analytical techniques

All analyses were carried out at the Open University. Laser $^{40}Ar/^{39}Ar$ ages were determined by ablating different hand-picked mineral grains using a continuous Spectron SL902CW YAG laser and a MAP 215-50 noble gas mass spectrometer. Rb and Sr concentrations of mica separates were determined by isotope dilution using a VG Isomass 54E single-collector mass spectrometer, whilst whole-rock rubidium and strontium concentrations were determined by XRF. $^{87}Sr/^{86}Sr$ ratios were determined on a Finnigan MAT 261 multi-collector. All Rb-Sr ages were calculated by regression between mica and whole-rock, and therefore their interpretation is based on the simplifying assumption that at the time of closure to strontium, muscovite or biotite were in isotopic equilibrium with the whole-rock.

Results

$^{40}Ar/^{39}Ar$ ages from Kohistan lie mostly in the range 18.5–22.2 Ma for muscovite and 16.6–17.4 Ma for biotite. $^{40}Ar/^{39}Ar$ ages for muscovite and biotite from the NPHM are overlapping, and lie in the range 3.6–6.9 Ma. Rb-Sr ages from Kohistan lie in the range 23.0–26.6 Ma for muscovite and 12.9–16.8 Ma for biotite. Rb-Sr ages from the NPHM lie in the range 2.8–7.7 Ma for muscovite and 1.4–3.4 Ma for biotite. Rb-Sr ages for samples from the shear zone are extremely variable. Three pelitic gneiss samples yield duplicated muscovite ages of 26, 64 and 293 Ma, respectively. The majority of other muscovite Rb-Sr ages from the shear zone lie in the range 11.9–20.4 Ma. Gneisses from the shear zone yield biotite Rb-Sr ages in the range 5.8–11.7, whereas two metabasic samples yield older biotite ages of 16.6 and 23.7 Ma.

Discussion

With rare exceptions, the mineral ages from granite sheets are concordant with the mineral ages from both their proximal and distal metamorphic country rocks. This suggests that the granites were mostly intruded at depth into relatively warm rocks, and thus the majority of granite ages are interpreted as exhumation-related cooling ages. Muscovite and biotite $^{40}Ar/^{39}Ar$ and Rb-Sr cooling ages all decrease systematically from Kohistan into the NPHM, and furthermore, the separation between ages from the same area recorded by different isotopic systems also decreases, indicating that the exhumation of the NPHM has occurred both more rapidly and more recently than the exhumation of Kohistan. Given the extreme topographic difference which also exists between the NPHM and Kohistan, the differential exhumation is probably strongly related to differential surface uplift.

Surprisingly, biotite Rb-Sr ages obtained from the NPHM are consistently younger than the biotite $^{40}Ar/^{39}Ar$ ages for the same samples. The cause of the age discordancy is unknown, but may reflect the different diffusivities of argon and strontium in the dated biotite samples, or the preferential leaching of ^{87}Sr from the biotite during a brief period of fluid circulation (Kwan *et al.* 1992). Cooling paths for the region are poorly defined, even for closely-spaced samples, due to poorly constrained closure temperatures, the discordancy between biotite Rb-Sr and $^{40}Ar/^{39}Ar$ ages, the rapid rates of cooling, and the lack of geochronological data from other phases other than muscovite and biotite.

Mineral ages from the shear zone separating the NPHM and Kohistan terranes are highly variable, but may clearly be correlated with structural level or lithology. Mineral ages decrease across the Darchan valley from west to east, as the NPHM is approached, suggesting a later time of exhumation for those samples closest to the NPHM. An unusually young Rb-Sr biotite age determined for a granite sheet near Sassi may reflect late intrusion of this granite. Rb-Sr biotite ages determined for two metabasite units at Sassi yield unusually old ages, which may reflect the relatively late-stage incorporation of Kohistan material into the shear zone without causing isotopic re-equilibration. Pelitic gneisses collected from both the shear zone and from the core of the NPHM, yield 'mixed' Rb-Sr muscovite ages (26–293 Ma) due to the varying presence of inherited radiogenic strontium. In contrast, co-existing biotite in two of the pelite samples appears to have been completely reset, due to the lower closure temperature for strontium diffusion in biotite. P-T studies indicate that the dated samples were last equilibrated at temperatures and pressures of 600–750°C and 7–10 kbar. Given the high metamorphic temperatures relative to the approximate closure temperature for strontium in muscovite, it is surprising that strontium isotopic homogenisation in the pelitic lithologies did not proceed to completion in Himalayan times. It is possible that the dated muscovite samples are characterised by unusually high strontium closure temperatures. Alternatively, it is possible that the P-T data record an ancient (? Precambrian) metamorphic event, which has not been entirely overprinted during a lower temperature Himalayan event. However, the latter explanation is considered unlikely, given the documentation of late-Himalayan zircon and monazite U-Pb ages for the NPHM (Zeitler *et al.* 1993), and the lack of evidence for polymetamorphism from studies of garnet compositional zoning.

References

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