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$^{40}Ar/^{39}Ar$ geochronology of the Main Central Thrust (MCT) region : Evidence for late Miocene to Pliocene disturbances along the MCT, Marsyangdi River valley, west-central Nepal Himalaya

Rebecca M. Edwards
Departmernt of Geology, Williams College, Williamstown, Massachusetts, USA

ABSTRACT

A series of $^{40}Ar/^{39}Ar$ radiometric age data on biotites and muscovites from the MCT zone in the Marsyangdi River valley in west-central Nepal indicates that disturbances along the MCT occurred in the late Miocene to Pliocene, significantly post-dating the major deformation event of ~20 Ma. The biotite and muscovite cooling ages from within 5 km on either side of the MCT range from 2.6 Ma to 9.4 Ma. Biotite cooling ages as young as 2.9 and 3.1 Ma have been found within one km of the MCT. Other ages are younger than 5 Ma, and almost all cooling ages from the area are younger than 9.4 Ma.

INTRODUCTION

The Himalayan mountain arc formed as a result of the collision of India and Eurasia, which started at approximately 50-40 Ma, and culminated in the Himalayan Orogeny (Molnar, 1984). The Main Central Thrust (MCT) is understood to have accommodated the majority of post-collisional convergence of the Himalayan Orogeny (Hubbard, 1989; Hubbard et al., 1991). The MCT is characterized less by a clear shear plane than by a shear zone, usually referred to as the "MCT zone," which can be as narrow as one km or as wide as 5 km (Pecher and Le Fort, 1986). Although a major ductile south-southwest directed thrusting event along the MCT in Nepal has been dated to have occurred between 21 and 18 Ma, later stages of activity along the MCT remain poorly understood. Studies such as those by Macfarlane (1993) and Copeland et al. (1991) have obtained young $^{40}Ar/^{39}Ar$ ages that suggest late-stage metamorphism and deformation in some regions of the MCT zone. $^{40}Ar/^{39}Ar$ Muscovite cooling ages from Macfarlane (1993) from the MCT zone in central Nepal suggest late-stage brittle faulting. $^{40}Ar/^{39}Ar$ cooling ages from Copeland et al. (1991) from the MCT zone in central Nepal suggest early Pliocene hydrothermal activity along the MCT. In this study, $^{40}Ar/^{39}Ar$ radiometric age data on biotite and muscovite samples taken from the MCT zone in the Marsyangdi River valley provide evidence for late-stage activity along the MCT in west-central Nepal.

SAMPLE REGION DESCRIPTION

The Marsyangdi River valley provides an excellent study area because it cuts through the Lesser Himalayan Sequence, the MCT zone and the Greater Himalayan Sequence. The Lesser Himalayan Sequence in the sample region of this study is characterized by phyllite, quartzite, pebble conglomerate, a variety of schists, dolomitic marble and pelitic gneiss. The MCT zone is visible around the hamlet of Bahundanda, and a brittle shear zone follows the trail that passes through this village. Modern hot springs are present along the river in the Greater Himalayan Sequence, just upsection of the brittle fault zone, giving further evidence for the presence of the MCT. The Greater Himalayan Sequence is comprised of biotite-muscovite-garnet-kyanite/sillimanite gneisses, various schists and an abundance of migmatites. A variety of metamorphic fabrics are present throughout the field area including abundant boudinage, folding (especially south-vergent), and *s-c* foliations.

SAMPLING

Figure 1 shows the geographical location of each sample. Samples were collected from within 5 km on either side of the MCT. Samples 93RE2, 93RE5 and 93RE6 came from the Lesser Himlayn Sequence. 93RE2 is quartz-chlorite schist; 93RE3 is a calcareous biotite schist; 93RE5 is gneissic with biotite and feldspar rich layers; and 93RE6 is a marble with phlogopite. 93RE7, a garnet-biotite schist, came from the MCT zone. Samples 93RE8, 93RE9, 93RE10 and 93RE11 came from the Greater Himlayn Sequence. 93RE8 is a migmatitic garnet-kyanite-biotite schist; 93RE9 is a garnet-kyanite-muscovite-biotite schist; 93RE10 is a gneiss with some migmatites; and 93RE11 is a sillimanite-garnet-muscovite-biotite schist.

ANALYTICAL METHODS

Mineral separations consisted of physical and magnetic separations at Williams College and final hand picking to ensure >99% purity at the Massachusetts Institute of Technology (MIT). The biotite and muscovite samples of 100 to 300 grains each, ranging in weight from 20 to 41 mg, were encapsulated in aluminum foil and stacked in an aluminum canister before irradiation in a reactor core with a cadmium shield for 7 hours at 14MW-Hrs at the Nuclear Reactor Facility of MacMaster University, Hamilton, Ontario. J-values for these samples were determined through the use of flux monitors and salts to correct for interfering nuclear reactions. The irradiated samples were analyzed at the MIT $^{40}Ar/^{39}Ar$ radioactive dating lab facility. Standards of known isotopic ratios were run to calibrate the mass spectrometer before dating the samples. The samples were run through the mass spectrometer in a series of heating steps on either a 7 or 10 step heating schedule; each step was run for 5 mass cycles at approximately 80 second intervals. Standard correction factors were used in determining the ages. Age isochrons were determined using the York 2 least square regression technique and age plateaus were determined using standard method. Possible sources of error include impurities in the mineral separates and errors in the calibration of the mass spectrometer, although these problems are usually detected by the running of monitors.

$^{40}Ar/^{39}Ar$ RESULTS

The age data are presented below and summarized in Table 1. A complete set of data can be obtained from the author upon request. Age

Table 1 : Compiled age data (estimated ages, MSWDs and $^{40}Ar/^{36}Ar$ are determined using the York 2 isochron method).

Sample	Mineral	Steps in Isochron	MSWD	$^{40}Ar/^{36}Ar$	Estimated Age (Ma)	Age Plateau
93RE2.bt	Biotite	1-9	0.9	280±30	13.5±0.4	
93RE3.bt	Biotite	2-9	1.7	410±40	2.8±0.1	
93RE5.bt	Biotite	1-7(All)	1.5	290±20	2.9±0.1	
93RE6.bt	Biotite	1-5,7	1.2	300±10	3.1±0.1	
93RE7.bt	Biotite	1-7(All)	1.1	280±10	9.4±0.4	
93RE7.ms	Muscovite	1-9(All)	1.9	290±20	6.2±0.2	age plateau, steps 3-6, 6.0±0.1 Ma, 74.2% ^{39}Ar
93RE8.bt	Biotite	1,3-7	0.6	280±20	9.4±0.4	age plateau, steps 3-7, 9.0±0.2 Ma, 85.8% ^{39}Ar
93RE9.ms	Muscovite	1-4	0.1	400±260	2.6±0.1	
93RE10.bt	Biotite	1-7(All)	2.2	270±10	4.6±0.2	
93RE11.bt	Biotite	1-7(All)	0.9	300±50	8.6±0.4	age plateau, steps 5-7, 8.5±0.4 Ma, 67% ^{39}Ar

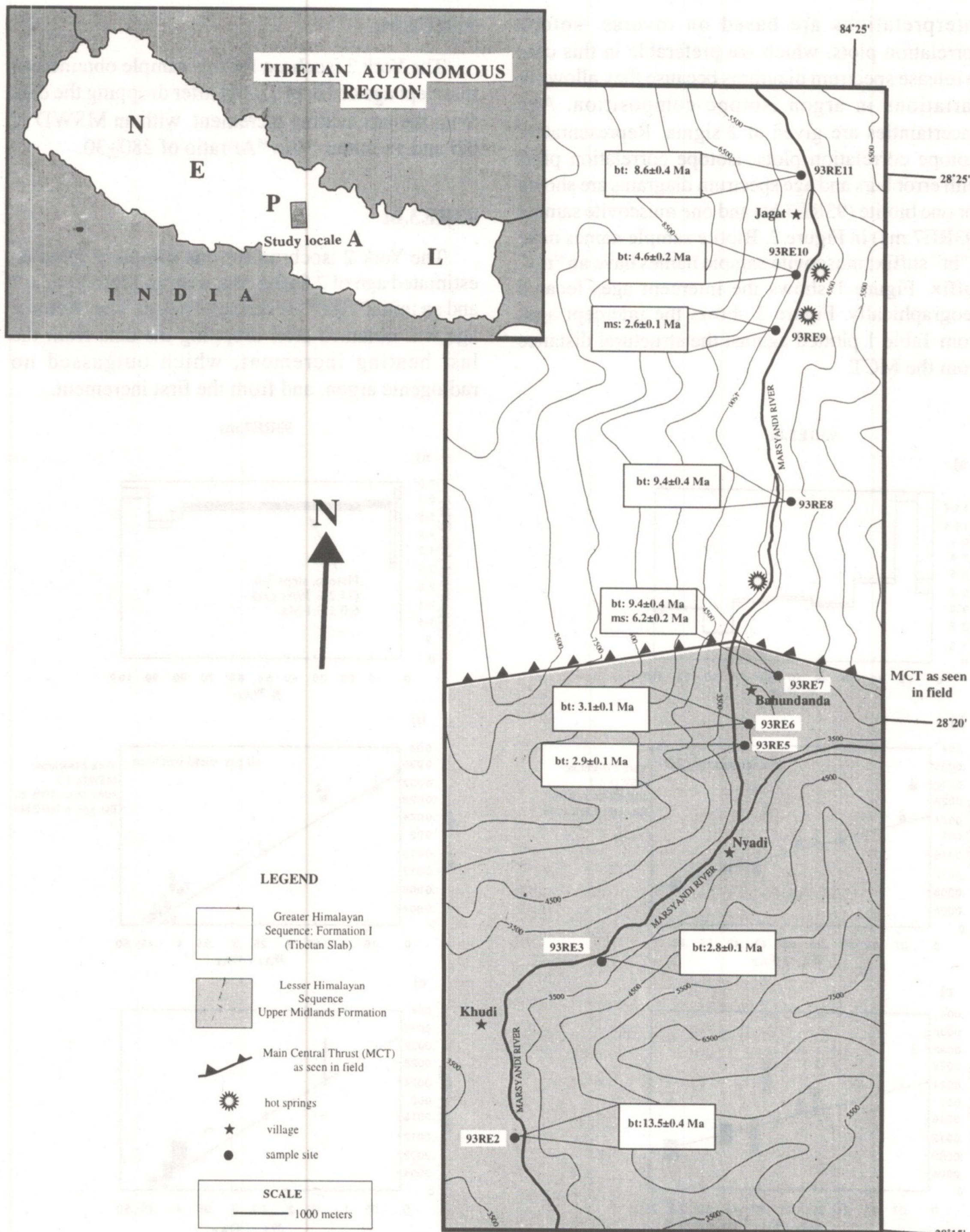

Fig. 1: $^{40}Ar/^{39}Ar$ age data for the Marsyangdi River valley MCT zone, Annapurna region, west-central Nepal (Isochron ages are included in boxes, bt = biotite sample, ms = muscovite sample).

interpretations are based on inverse isotope correlation plots, which are preferable in this case to release spectrum diagrams because they allow for variations in argon isotope composition. Age uncertainties are given at 2 sigma. Representative isotope correlation plots, isotope correlation plots with error bars and age spectrum diagrams are shown for one biotite (93RE3.bt) and one muscovite sample (93RE7.ms) in Figure 2. Biotite sample names have a "bt" suffix; muscovite sample names have an "ms" suffix. Figure 1 shows the intercept ages located geographically. Figure 3 shows the intercept ages from Table 1 plotted against the structural distance from the MCT.

93RE2.bt

The York 2 isochron for this sample obtained an intercept age of 13.5±0.4 Ma after dropping the data from the last heating increment, with an MSWD of 0.9 and an initial $^{40}Ar/^{36}Ar$ ratio of 280±30.

93RE3.bt

The York 2 isochron for this sample yielded an estimated age of 2.8±0.1 Ma, with an MSWD of 1.7 and an initial $^{40}Ar/^{36}Ar$ ratio of 410±40. The intercept age was obtained after dropping the data from the last heating increment, which outgassed no radiogenic argon, and from the first increment.

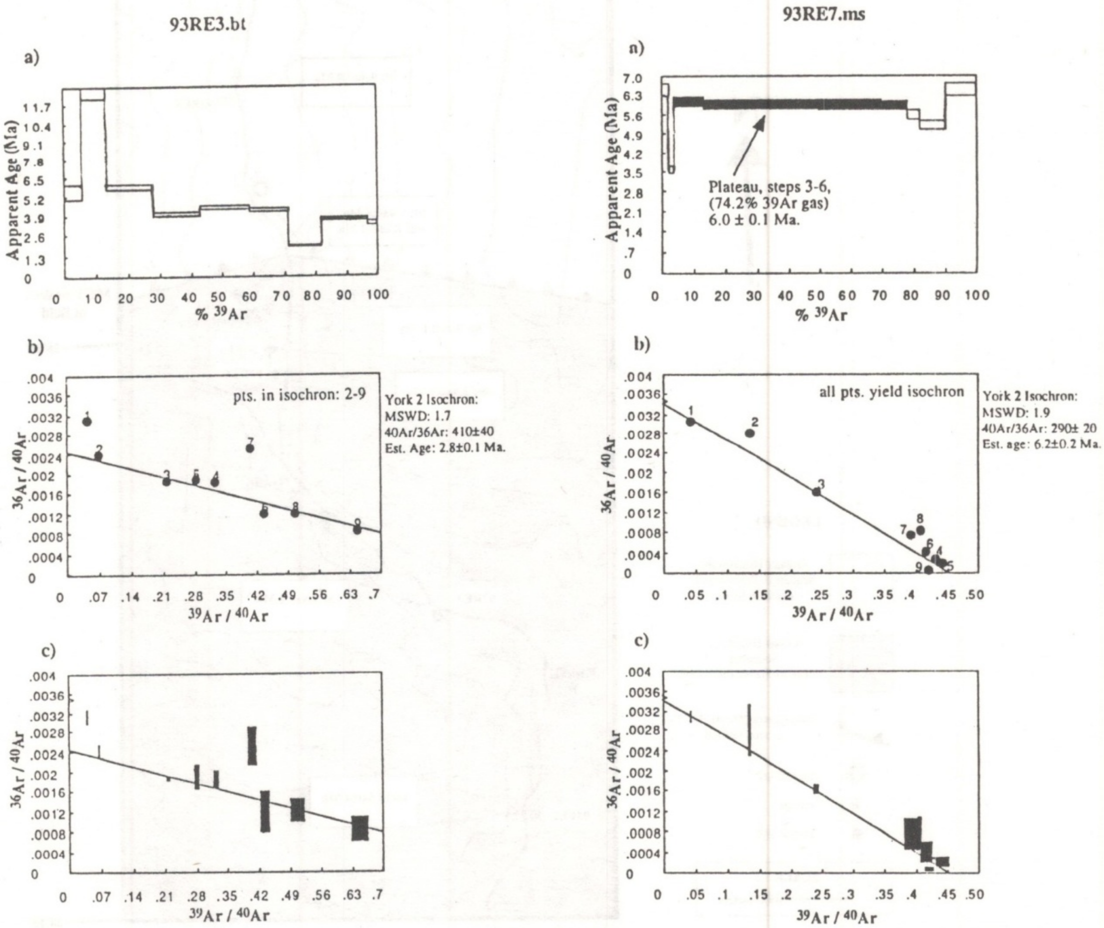

Fig. 2: Representative age spectra (a), isotope correlation plots (b) and isotope correlation plots with 2 sigma errors (c) for a biotite (93RE3.bt) and muscovite (93RE7.ms) sample. York 2 isochrons are drawn on figures b) and c). Age plateaus are filled in black on the age spectra.

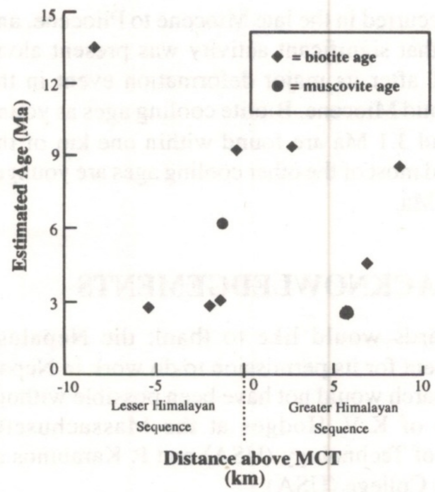

Fig. 3: ^{40}Ar/^{39}Ar intercept ages versus the structural distance from the MCT.

93RE5.bt

This sample yielded a York 2 isochron with an intercept age of 2.9±0.1 Ma, an MSWD of 1.5 and an initial ^{40}Ar/^{36}Ar of 290±20.

93RE6.bt

The York 2 isochron for this sample yielded a slightly questionable intercept age of 3.1±0.1 Ma, with an MSWD of 1.2 and an initial ^{40}Ar/^{36}Ar ratio of 300±10. The data from the second-to-last increment were excluded in the calculation of the intercept age, which is somewhat problematic, bcause it outgassed a significant amount of radiogenic argon.

93RE7.bt

This sample yielded a York 2 isochron with an intercept age of 9.4±0.4 Ma, an MSWD of 1.1 and an initial ^{40}Ar/^{36}Ar ratio of 280±10.

93RE7.ms

The York 2 isochron for this sample obtained an estimated age of 6.2±0.2 Ma, an MSWD of 1.9 and an initial ^{40}Ar/^{36}Ar ratio of 290±20. The data from the second increment were excluded because no radiogenic argon was outgassed. An age plateau was obtained on the release spectrum with an age of 6.0±0.1 Ma, containing steps #3-6 and 74.2% of the outgassed ^{39}Ar .

93RE8.bt

This sample yielded a York 2 isochron intercept age of 9.4±0.4 Ma, after omitting the data from the second increment, with an MSWD of 0.6 and an initial ^{40}Ar/^{36}Ar ratio of 280±20. An age plateau with an apparent age of 9.0±0.2 Ma, was obtained for the sample, which includes heating steps #3-7 and 85.8% of the outgassed ^{39}Ar.

93RE9.ms

In order to obtain a York 2 isochron for this sample, it was necessary to exclude the data from the first heating step, which outgassed no ^{40}Ar, as well as the data from the last two heating steps. The York 2 isochron estimated age is 2.6±0.1 Ma, with an MSWD of 0.1 and an initial ^{40}Ar/^{36}Ar ratio of 400±260.

93RE10.bt

The York 2 isochron for this sample yielded an intercept age of 4.6±0.2 Ma, an MSWD of 2.2 and an initial ^{40}Ar/^{36}Ar ratio of 270±10.

93RE11.bt

This sample yielded a York 2 isochron estimated age of 8.6±0.4 Ma, with an MSWD of 0.9 and an initial ^{40}Ar/^{36}Ar ratio of 300±50. This sample also yielded an age plateau with an age of 8.5±0.4 Ma, which includes temperature steps #5-7 and 67% of the outgassed ^{39}Ar.

DISCUSSION

The ^{40}Ar/^{39}Ar age data presented above provide clear evidence for a resetting event on the MCT post-dating the ~20 Ma deformational event. Two samples from within one km below the MCT date as young as 2.9 and 3.1 Ma; other cooling ages are younger than 5 Ma; and all of the cooling ages are younger than 9.4 Ma, except the sample taken furthest from the MCT (93RE2.bt), which yielded an age of about 13.5 Ma. From these data we can conclude that one or many resetting events occurred along the MCT in the late Miocene to Pliocene. $^{40}Ar/^{39}Ar$ mica cooling ages of 16-17 Ma obtained upsection in the Marsyngdi River valley (Coleman, unpublished data, 1993) suggest that the young ages in this study are confined to the MCT region.

In studies to date, only a few $^{40}Ar/^{39}Ar$ ages have been found along the MCT that post-date the major ~20 Ma thrusting event. Studies such as those by Copeland et al. (1991), in central Nepal, and Macfarlane (1993), in the Langtang region of central Nepal, have also found evidence of late Miocene to early Pliocene resetting events on the MCT, and provide a variety of explanations for these young ages. Copeland et al. (1991) suggest that hydrothermal fluids produced from activity on the structurally lower Main Boundary Thrust (MBT) travel to the surface using the MCT as a conduit. These hydrothermal fluids reheat the MCT rocks and produce young $^{40}Ar/^{39}Ar$ cooling ages. Macfarlane (1993) explains the young cooling ages to be the result of late-stage brittle shearing in and around the MCT. It is possible that the young ages obtained in this study can be accounted for by one of these models, or perhaps another explanation is required for the Marsyangdi River region MCT. In order to better ascertain the nature of these late-stage resetting events, further study needs to be done, both in the Marsyangdi River valley and other parts of the Nepal Himalaya. Nevertheless, this study asserts the need to consider late-stage $^{40}Ar/^{39}Ar$ resetting events as a significant component of the MCT fault system.

CONCLUSIONS

$^{40}Ar/^{39}Ar$ radiometric age data on biotites and muscovites from the MCT zone in the Marsyangdi River valley indicate that one or many resetting events occurred in the late Miocene to Pliocene, and suggest that significant activity was present along the MCT after its major deformation event in the early to mid Miocene. Biotite cooling ages as young as 2.9 and 3.1 Ma are found within one km of the MCT, and most of the other cooling ages are younger than 9.4 Ma.

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