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K-Ar Dating of White Mica from the Lesser Himalaya, Tansen-Pokhara Section, Central Nepal: Implications for the Timing of Metamorphism

Lalu P. Paudel
Central Department of Geology, Tribhuvan University, Kirtipur, Kathmandu
e-mail:lalupaudel67@yahoo.com

Abstract

The Lesser Himalaya in central Nepal comprises low- to medium-grade metasedimentary rocks. Metamorphic studies show that they have experienced at least two metamorphic events (M_1 and M_2). However, exact timing of metamorphism is still controversial. In the present study K-Ar dating of white micas in shales, slates, phyllites, schists and gneisses from the Tansen-Pokhara section was carried out to understand the timing of metamorphism. The muscovite in gneiss from the MCT zone shows an age of about 1255 Ma representing the age of crystallization of parent granite. Detrital mica from the Bhainskati Formation gives an age of about 2441 Ma. Probably this is the age of crystallization of muscovite in its provenance. The recrystallized white micas from slate and phyllite show older ages (Early Paleozoic) in the southern part (279 to 458 Ma). Most probably this represents the timing of M_1. Age become gradually younger towards the north due to the mixing of older (M_1 related) and younger (M_2 related) white micas. Youngest age (10 Ma) was measured from the sample just below the Upper MCT. This age may be related to the M_2 which was due to the Late Miocene-Pleistocene reactivation of the Upper MCT.

Key words: geochronology, himalaya, K-Ar age, muscovite, Nepal.

Introduction

The Himalaya was formed by the collision of the Indian and the Eurasian Continents around 55-50 Ma along the Indus-Tsangpo Suture Zone (Le Fort 1996). Major intracrustal thrusts divide the Himalaya into four tectonic zones, i.e., the Tethys Himalaya, Higher Himalaya, Lesser Himalaya (LH) and Sub-Himalaya (Siwaliks), from north to south, respectively (Gansser 1964) (Fig. 1). Each of these zones is morphologically distinct and shows contrasting lithostratigraphy and tectonic style.

The LH is a tectonic wedge lying between the Upper Main Central Thrust (Upper MCT) in the north and the Main Boundary Thrust (MBT) in the south. The LH in central Nepal is divided into the inner (north) and outer (south) belts by the Bari Gad-Kali Gandaki Fault (Arita *et al.* 1982, Sakai 1985). The outer belt is a parautochthonous unit overlain by the Palpa Klippe. The inner belt consists of two thrust sheets, i.e, Thrust Sheets I (TS I) and Thrust Sheet II (TS II). They are divided by the Phalebas Thrust (Upreti *et al.* 1980). The northernmost part of the LH is an extremely sheared and mylonitized MCT Zone. The MCT Zone is bounded by the Upper MCT in the north and by the Lower MCT in the south.

The rocks of the LH are basically grouped into the pre-Gondwana Nawakot Complex (Stöcklin 1980) and the Gondwana and post-Gondwana Tansen Group (Sakai 1983). The Nawakot Complex is more than 10 km thick and comprises low- to medium-grade metasedimentary rocks of Late Precambrian to Early Paleozoic. The Parautochthon, TS I, TS II and the MCT zone are composed of the Nawakot Complex rocks. The Tansen Group is distributed only along a narrow belt in the Tansen area (Fig. 1).

Illite crystallinity, b-spacing and petrographic studies show that the area has suffered at least two metamorphic events, an anchizonal burial metamorphism (M_1) overprinted by a garnet-grade dynamothermal metamorphism (M_2) (Paudel & Arita 2000, 2006a, 2006b). Paudel and Arita (2000) on the basis of textural relationship suggest that M_1 is pre-Himalayan activity). However, the exact timing of M_1 and M_2 in the LH is still unclear.

The only way to know the timing of metamorphism is radiometric dating of minerals in the rock. Absolute age of parent material is established by measuring the amount of radioactive decay of a radioactive isotope with a known half-life A number of radioactive isotopes are used for this purpose. K–Ar dating is based on measurement of the product of the radioactive decay of an isotope of potassium (K) into argon (Ar). Potassium is a common element found in white mica (Ms). The timing of crystallization/recrystallization can be calculated by measuring the ratio of the amount of ^{40}Ar accumulated to the amount of ^{40}K remaining in Ms.

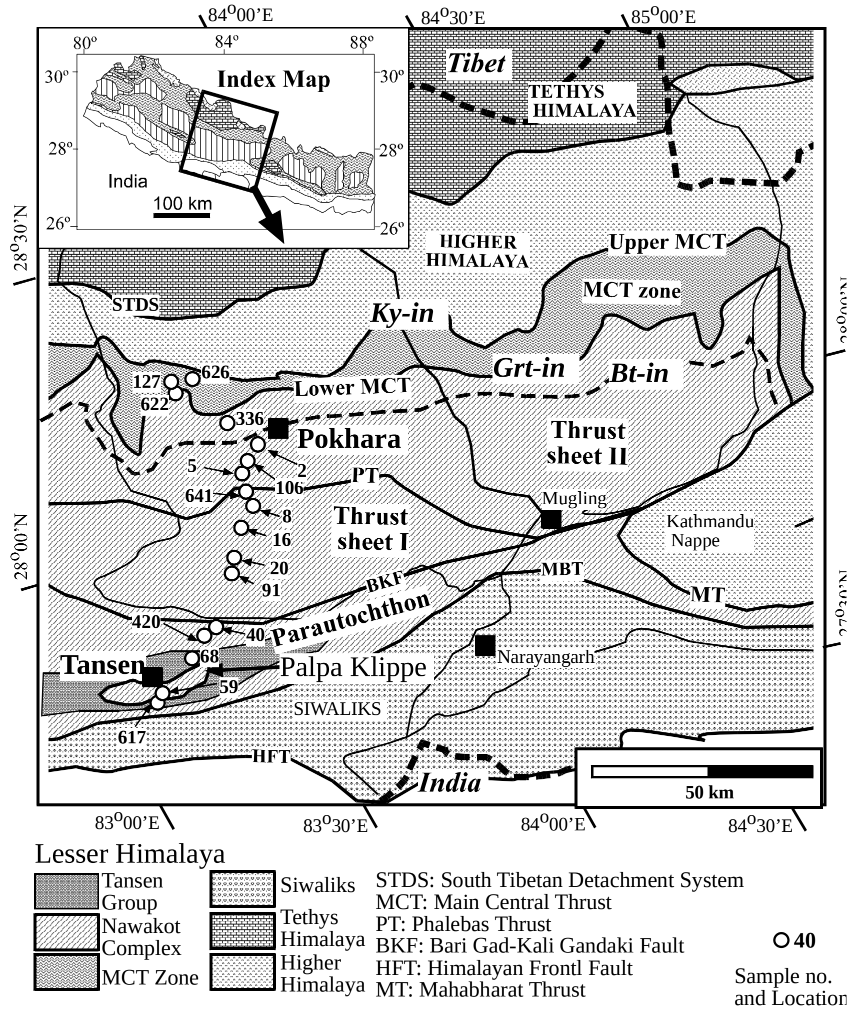

Fig. 1. Tectonic map of central Nepal showing the sample locations (map modified after Paudel and Arita, 2000). Bt: Biotite, Grt: Garnet, Ky: Kyanite.

In the present study K-Ar dating of Ms in the metasedimentary rocks of the Tansen-Pokhara section was carried out to understand the possible ages of metamorphism of M_1 and M_2. This paper presents the results of K-Ar dating of Ms and their implication for the timing of metamorphism in the LH.

Methodology

Sample description

Altogether 17 pelitic rocks (shale, slate, phyllite, schist and gneiss) with well-developed foliation with shining surfaces, and containing abundant phyllosilicates were collected along the Tansen-Pokhara motor road and the Modi Khola Valley (Fig. 1). Such a selective sampling helped to reduce the inter- and intra-sample variations. Among them 3 samples belong to the MCT zone, 4 samples belong to the TS II, 6 samples belong to the TS I, 2 samples belong to the Parautochthon, 1 sample belongs to the Palpa Klippe and 1 sample belongs to the Tansen Group.

Representative samples were studied in thin-sections under petrological microscope. Almost all metapelitic samples contained 'Ms+Chlorite+Albite+Quartz' as unique mineral assemblages. The samples from the Parautochthon, TS I and TS II show two foliations, S_1 parallel to bedding and S_2 oblique to the bedding. They are defined by microcrystalline authigenic Ms (Fig. 2a). Some samples contain detrital Ms (Fig. 2b). Schist samples from the MCT zone are strongly sheared and recrystallized showing only S_2 foliation defined by recrystallized Ms (Fig. 2c). The gneiss sample comprises sheared and deformed porphyroclasts of Ms (Fig. 2d).

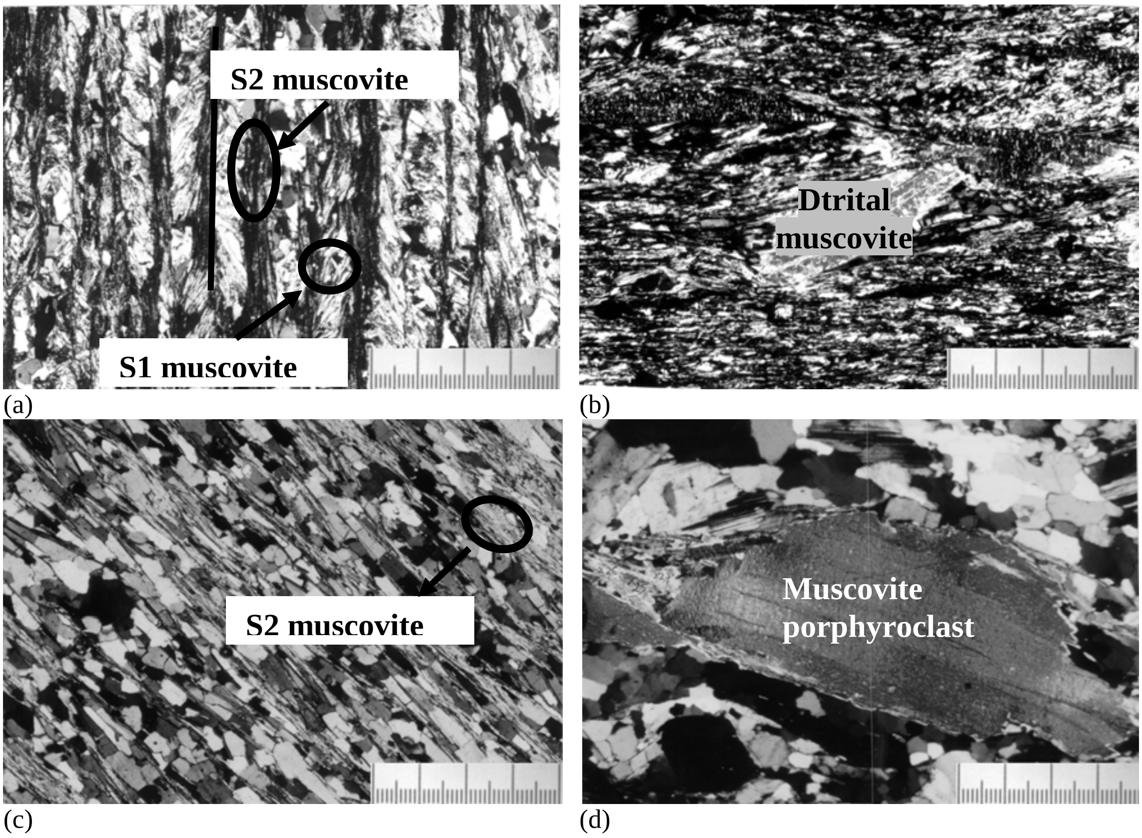

Fig. 2. Representative photomicrographs of the rock samples used for dating. (a) Sample No. 2 from the TS II with white micas defining two cross-cutting foliations. (b) Sample No. 617 from the Bhainskati Formation of Tansen Group with detrital white mica. (c) Sample No. 622 from the MCT zone with only S_2 foliation. (d) Sample No. 127 from the MCT zone with muscovite porphyroclast.

Sample preparation

The gneiss sample (No. 127) contains Ms grains larger than 1 cm. This sample was broken by hammer and Ms grains were hand-picked and cleaned with water. In the case of schist samples (Nos. 622, 626, 336), approximately 1 kg of each sample was crushed in a jaw crusher to less than 200 mesh in size and sieved to provide a mesh fraction size range of 280-330 mesh. These sieved fractions were then washed to remove adhering powder residues, and the heavy materials were separated out by decanting. An isodynamic magnetic separator was used to remove most of the impurity minerals such as chlorite, biotite, albite and quartz. The Ms concentrates were then treated with dilute HCl solution to dissolve the remaining chlorite and Fe contaminations. Then the samples were washed with dilute acid repeatedly.

The remaining sampels were very fine-grained and it was impossible to get Ms concentrates from those samples. About 500 g of each sample was broken into small chips and then washed and dried. About 200 g chips were then crushed in a mortar and pestle, and passed through 2.38 mm and 0.59 mm sieves. The fine fraction (<0.59 mm) was discarded to reduce any influence from weathered material. About 200 g of the 2.38-0.59 mm fraction was then ground for 3 minutes in a mortar and pestle, and passed through a 100-mesh (0.149 mm) sieve. <2µm powder fraction was separated from <0.149 mm powder by centrifuge from sample 106, 5, 8, 91, 40, 68 and 59. Powder fractions of the size range 4-6, 2-4 and 1-2 µm were separated from sample 2 and 641 with the help of sedimentation cylinders. Similarly, 05-1, 1-2 and 2-4 µm size fractions were separated from sample 16, 20, 420 and 617.

The powder fractions were examined with X-ray diffraction techniques to access the contaminant minerals in them. Almost all of the samples contained the minerals Ms, chlorite, quartz and albite. Minerals other than Ms do not contain K and thus do not affect the K-Ar ages (Itaya & Takasugi 1988). Therefore, K-Ar dating of the powder fractions represent the age of Ms in the samples.

K-Ar Analysis

The Ms concentrates as well as the powder fractions were analyzed for K and Ar at Okayama University of Science, Japan and calculations of age and errors were performed using the methods described by Nagao *et al.* (1984) and Itaya *et al.* (1991). K was analysed by flame photometry using a 2000 ppm Cs buffer that has an analytical error within 2% at the 2 sigma confidence level. Argon was analysed on a 15 cm radius sector type mass spectrometer with a single collector system using isotopic dilution method and an argon 38 spike (Itaya *et al.* 1991). The error of analysis of Ar is about 1% at the 2 sigma confidence level. The decay constants for ^{40}K to ^{40}Ar, and ^{40}Ca and ^{40}K content in potassium used in the age calculation are from Steiger and Jäger (1977).

Results and Discussion

K-Ar ages of the Ms concentrates as well as different size fractions are given in Table 1 and Fig. 3. The Ms in gneiss show an age of about 1255 Ma. Probably this is the age of crystallization of Ms in its parent rock (granite). The shale of Bhainskati Formation also shows very old age (850, 930, 1045 and 2441 Ma). Probably this is the age of detrital Ms present in shale. DeCelles et al. (1998) have obtained similar U-Pb ages (~2.5 Ga) on detrital zircons from the Tansen Group.

The slates, phyllite and schists show wide variation in age ranging from 10 Ma (Sample No. 626) to 458 Ma (Sample No. 420). Rocks of the MCT zone show younger ages (10 to 64 Ma) compared to the samples from other tectonic units. Within the sample, finer fractions have relatively younger ages compared to the coarser fractions (Table 1). This is because the finer fractions are dominated by authigenic Ms of younger ages whereas the coarser fractions may have been contaminated by detrital Ms of older ages.

Radiometric ages from the low-grade metamorphic rocks of the LH are relatively scarce compared to those from the higher grade rocks. Macfarlane *et al.* (1992), Vannay and Hodges (1996), Hubbard and Harrison (1989) and Copeland *et al.* (1991) have measured ^{40}Ar/^{39}Ar ages of Ms from the rocks of the MCT Zone (Table 2). The ages range from 3 Ma in the Buri Gandaki Valley to 14 Ma in the Kali Gandaki Valley. These young ages are comparable with the K-Ar ages from sample No. 622. The K-Ar ages of detrital Ms and sericite given by Krummenacher (1961, 1966) range from 728 to 1280 Ma. Those ages are similar to that measured in the detrital Ms in the shale of Bhainsakti Formation. The whole rock K-Ar age of Benighat Slate measured by Khan and Tater (1970) range from 540 to 560 Ma. In the present study, dating was carried out in the finer fractions (<4 ìm) of slate. Therefore, the present ages are little bit younger (<450 Ma) compared to the ages by Khan and Tater (1970).

Table 1: Results of K-Ar dating of white mica from the Lesser Himalayan rocks along the Tansen-Pokhara section, central Nepal.

Specimen No.	Distance from MBT (Km)	Tectonic Unit	Formation	Lithology	K(wt%)	Radiogenic Ar (10-8 ccSTP/g)	K-Ar Age (Million years)	Non. Radiogenic Ar
Muscovite oncentrates								
626	75	MCT Zone	Lower Unit (Pelitic and Psammitic Schist)	Pelitic Schist	8.18±0.16	324±3	10±0	6.8
127	74	MCT Zone	Lower Unit (Pelitic and Psammitic Schist)	Orthogneiss	7.992±0.16	56258±66	1255±21	1.5
622	73	MCT Zone	Lower Unit (Pelitic and Psammitic Schist)	Pelitic Schist	6.89±0.14	915±9	34±1	3.1
336	68	TS II	Kuncha Formation (Nawakot Complex)	Pelitic Schist	5.83±0.12	1467±14	64±1	1.3
< 2 micron fractions								
106	63	TS II	Kuncha Formation (Nawakot Complex)	Phyllite	6.49±0.13	1757±21	68±2	11.2
5	60	TS II	Kuncha Formation (Nawakot Complex)	Phyllite	5.30±0.11	1604±17	76±2	4.2
8	51	TS I	Nourpul Formation (Nawakot Complex)	Phyllite	6.59±0.13	2378±27	91±2	9.6
91	34	TS I	Nourpul Formation (Nawakot Complex)	Phyllite	5.15±0.10	7870±82	356±7	1.2
40	21.5	Para.	Benighat Slate (Nawakot Complex)	Slate	5.84±0.12	7799±0.1	315±7	1.6
68	16	Para.	Bhainskati Formation (Tansen Group)	Shale	1.04±0.02	20964±23	2441±31	0.6
59	5.5	Palpa	Nourpul Formation (Nawakot Complex)	Phyllite	6.57±0.13	8352±88	301±6	1.4
4 to 6 micrn fractions								
2	64	TS II	Kuncha Formation (Nawakot Complex)	Phyllite	6.92±0.14	2337±27	85±2	0.6
641	55	TS I	Nourpul Formation (Nawakot Complex)	Phyllite	8.05±0.16	4434±42	137±3	0.2
2 to 4 micron fractions								
2	64	TS II	Kuncha Formation (Nawakot Complex)	Phyllite	7.44±0.15	1637±16	56±1	1
641	55	TS I	Nourpul Formation (Nawakot Complex)	Phyllite	8.14±0.16	3711±35	114±2	0.3
16	46	TS I	Nourpul Formation (Nawakot Complex)	Phyllite	6.68±0.14	11650±109	401±8	1
20	38	TS I	Benighat Slate (Nawakot Complex)	Slate	4.533±0.09	8575±81	432±9	0.7
420	19	TS I	Nourpul Formation (Nawakot Complex)	Phyllite	5.19±0.104	10495±99	458±9	0.8
617	4	Para.	Bhainskati Formation (Tansen Group)	Shale	1.854±0.03	10183±10	1045±18	2.6
1 to 2 micron fractions								
2	64	TS II	Kuncha Formation (Nawakot Complex)	Phyllite	6.67±0.13	1323±13	50±1	2.1
641	55	TS I	Nourpul Formation (Nawakot Complex)	Phyllite	8.13±0.16	2918±28	90±2	0.3
16	46	TS I	Nourpul Formation (Nawakot Complex)	Phyllite	7.39±0.15	10789±10	342±7	0.1
20	38	TS I	Nourpul Formation (Nawakot Complex)	Slate	5.51±0.11	8977±85	378±8	0.8
420	19	TS I	Nourpul Formation (Nawakot Complex)	Phyllite	6.45±0.13	10527±99	378±8	0.7
617	4	Para.	Bhainskati Formation (Tansen Group)	Shale	1.77±0.04	8388±82	930±16	4.4
0.5 to 1 micron fractions								
16	46	TS I	Nourpul Formation (Nawakot Complex)	Phyllite	7.55±0.15	8849±83	279±6	0.2
20	38	TS I	Benighat Slate (Nawakot Complex)	Slate	6.54±0.13	9398±89	337±7	0.7
420	19	TS I	Nourpul Formation (Nawakot Complex)	Phyllite	7.26±0.14	11087±10	356±7	0.3
617	4	Para.	Bhainskati Formation (Tansen Group)	Shale	1.82±0.04	7659±76	850±15	5.3

Table 2. Published white mica K-Ar and $^{40}Ar/^{39}Ar$ ages from central Nepal Lesser Himalaya.

Ar-Ar Method			
MCT zone			
Langtang Valley	Muscovite isochron	8.86±0.16	Macfarlane et al. (1992)
	Muscovite isochron	8.49±0.16	Macfarlane et al. (1992)
Kali Gandaki	Muscovite isochron	13.9±0.6	Vanny & Hodges (1996)
Everest region	Muscovite isochron	12.0±0.2	Hubbard & Harrison (1989)
Buri Gandaki Valley	Muscovite-isochron	3.1±0.2	Copeland et al. (1991)
K-Ar Method			
Parautochthon (Tansen-Pokhara-Kali Gandaki section)			
Benighat Slate	Whole rock slate	540±17	Khan & Tater (1970)
Benighat Slate	Whole rock slate	559±18	Khan & Tater (1970)
Tansen Group	Detrial sericite	1280	Krummenacher (1966)
TS I			
Kunchha Formation	Detrital Muscovite	728±20	Krummenacher (1961)
Kunchha Formation	Detrital Sericite	1280	Krummenacher (1966)
Kunchha Formation	Detrital Muscovite	872	Krummenacher (1966)

Present K-Ar Ms ages have been also plotted against the structural distance of the sample from the MBT (Fig. 3). It also shows a uniform trend of decreasing ages from south to north towards the Upper MCT. Samples from southern part mostly show older ages (279 to 458 Ma). There is sharp drop in age from 10 km south of the PT (drops below 100 Ma) and gradually decreases to 10 Ma nearby the Upper MCT (Sample No. 622). This trend, i.e., ages getting older southward, is quite similar to the trend shown by the $^{40}Ar/^{39}Ar$ Ms ages as a function of distance along a N018ºE section in central Nepal (Bollinger *et al.* 2004) (Fig. 4). The $^{40}Ar/^{39}Ar$ Ms ages also appear to approximately follow a linear trend with ages getting older southward.

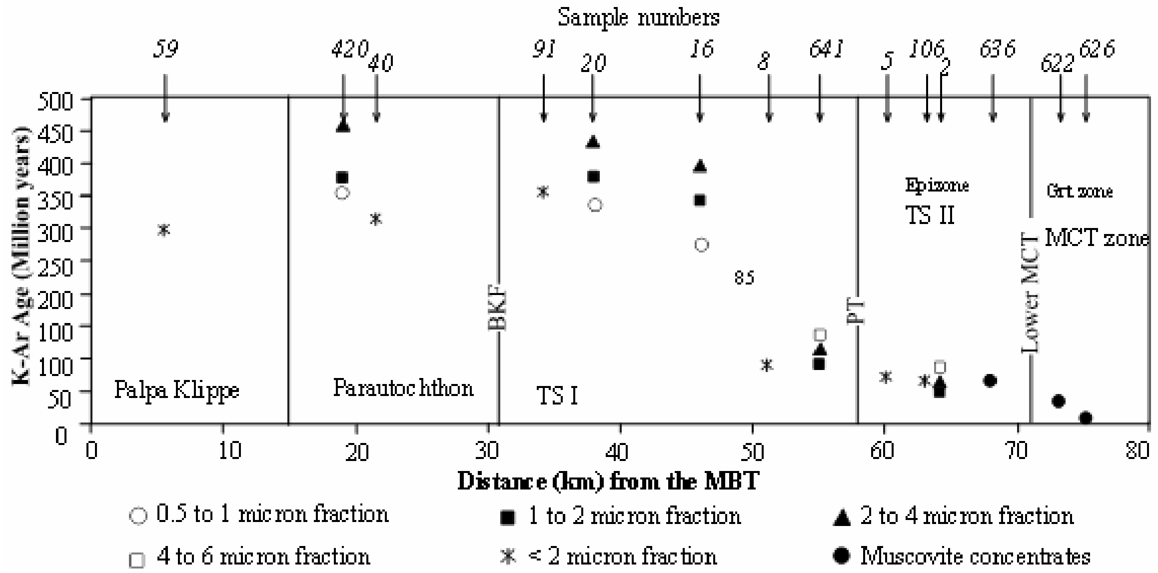

Fig. 3. Plot of present K-Ar ages as a function of structural distance of the sample location from the Main Boundary Thrust. The data show northward decreasing trend of ages.

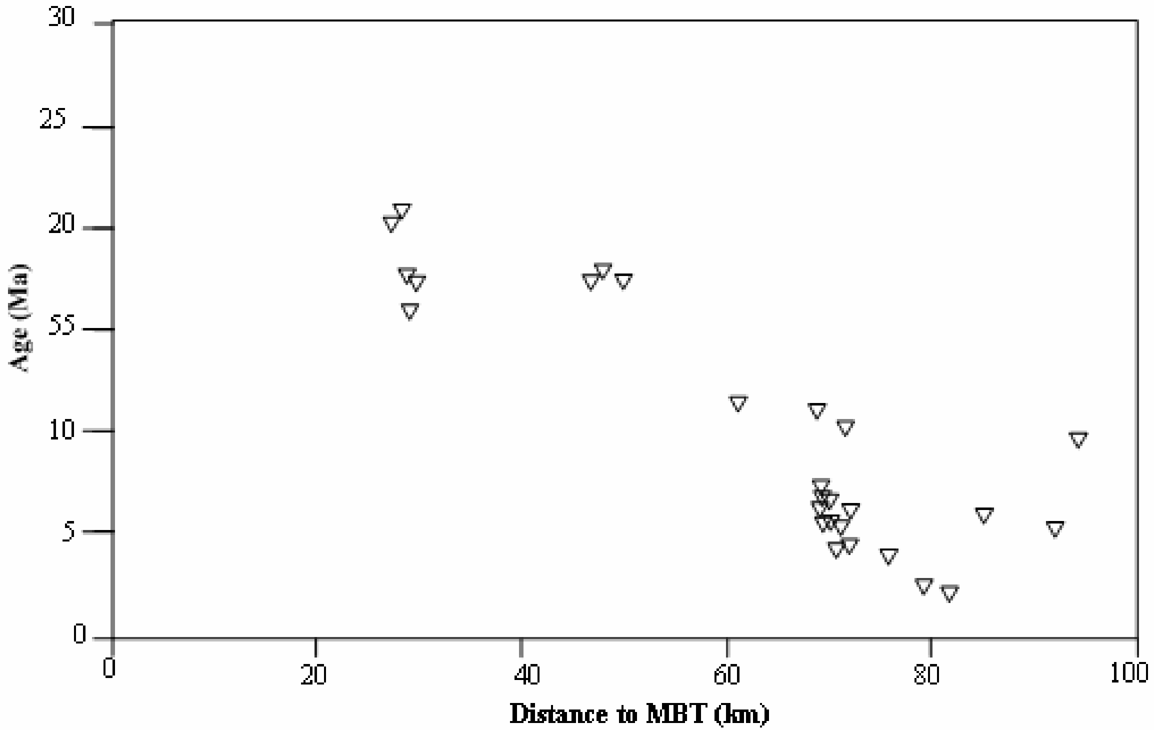

Fig. 4. Plot of $^{40}Ar/^{39}Ar$ muscovite ages in central Nepal as a function of distance along a N018°E section. The origin is taken at the Main Boundary Thrust. The muscovite ages appear to approximately follow a linear trend with ages getting older southward. (Figure modified from Bollinger *et al.* 2004).

An isotopic age in metamorphic rocks indicates only the age of cooling from the thermal event, when each mineral become a closed system for certain isotopes after cooling under certain temperature (Dickin 1995). The problem is complicated if a rock undergoes polymetamorphism. If the latest metamorphic event is very strong, it will reset all the isotopic clocks in the rock. Then any geochronometry will give the cooling age after the latest metamorphic event. On the other hand, if the later event is weaker than the previous one, the isotopic clocks will be partially reset and one will get a range of ages. Those ages actually represent the mixed ages of no geological significance.

The K-Ar ages of phyllites and slates from the Nawakot Complex that contain only authigenic Ms vary greatly. However, the ages seem to become younger towards the north. The peak metamorphic temperature of the M_2 increases from about 300°C in the Parautochthon and TS I to 400°C in TS II and (Paudel 2000). This temperature is below or around the Ar closure temperature for Ms (350°C). Therefore, the K-Ar clock in Ms related to M_1 must have not been affected or only partially reset during the M_2. Therefore the K-Ar Ms ages from south of the MCT represent only the mixed ages of two generations (M_1 and M_2) of Ms. Therefore, it is difficult to tell the exact time of M_1 metamorphism. However, the age data from the southernmost part of the LH which are little affected by M_2 range from 279 to 458 Ma. It indicates an Early Paleozoic age for M_1. Evidence of pre-collisional orogeny and metamorphism in the LH has also been documented in the Kumaun Himalaya of India (Johnson and Oliver, 1990; Oliver et al., 1995) and in Pakistan (Baig *et al.* 1988, Chaudhry & Ghazanfar 1989).

The metamorphic temperature in the MCT zone during the M_2 event has been estimated to be about 400-500°C with a rapid increase up to 600-650°C near the Upper MCT (Kaneko, 1995). This temperature is above the Ar closure temperature for Ms. Therefore, Ms from the MCT zone are completely reset by M_2 and the ages represent the timing of M_2. The youngest age determined in the present case is about 10 Ma. Harrison et al. (1997) have measured *ca.* 6 Ma Pb-Th monazites in garnets of the MCT zone of the Gorkha area, central Nepal. Monazite appears in pelitic rocks at about 500°C (Kingsbury *et al.* 1993) which is below the closure temperature for U-Pb system in monazite (≥700°C, Copeland *et al.* 1988). Harrison *et al.* (1997) interpret that the M_2 occurred in the LH in the Late Miocene-Pleistocene due to the reactivation of the Upper MCT. Gautam and Koshimizu (1989) have also suggested a possible strong thermal pulse around 5 Ma on the basis of paleomagnetic and fission-track studies on the Ampipal alkaline complex, central Nepal.

The LH in central Nepal is affected by at least to metamorphic event (M_1 and M_2) evidenced by two cross-cutting foliations (S_1 and S_2) defined by recrystallized white micas (Ms). K-Ar dating of Ms separated from 17 rock samples along the Tansen-Pokhara section was carried out to access the timing of M_1 and M_2. The Ms in gneiss from the MCT zone show an age of about 1255 Ma. Probably this is the age of crystallization of Ms in its parent rock (granite). The shale of Bhainskati Formation of Tansen Group also shows very old age (850 to 2441 Ma). Probably this is the age of detrital Ms present in shale. The phyllite and schists from the southernmost part of the LH are not affected by M_2. The Ms from those samples show older ages (Early Paleozoic) in the southern part (279 to 458 Ma) and most probably represents the timing of M_1. The ages become gradually younger towards the north and youngest age (10 Ma) was measured from the sample just below the Upper MCT. This age may be related to the M_2 which was due to the Late Miocene-Pleistocene reactivation of the Upper MCT.

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