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TWO METAMORPHIC EVENTS OF THE NEPAL HIMALAYAS PRIOR AND POSTERIOR TO INDIA-EURASIA COLLISION

by

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(with 3 text-figures and 2 tables)

Abstract

K-Ar ages were newly determined on biotite from a pelitic gneiss and on hornblende from a calcareous gneiss both from the Higher Himalayas in Nepal. The corresponding ages, 56.7±2.8 Ma and 61.5±3.1 Ma, respectively, are quite old compared with their fission-track ages.

We made a synthesis of the various isotopic ages from the Nepal Himalayas available so far, and attempted an analysis on the age versus closure temperature basis. The findings suggest that the Higher Himalayas have undergone two major reheating episodes, during the Himalayan orogeny, which are reflected in two different cooling trajectories roughly corresponding to late Cretaceous to Eocene and Eocene-Oligocene to the present times. A possible two-stage model involving two metamorphic events, which occurred prior and posterior to the India-Eurasia collision, is proposed, and the subsequent cooling histories are discussed. Implication of the (re-) magnetization events revealed by paleomagnetic data on the Nepal Lesser Himalayas to the model is also considered.

Introduction

The Himalayas represent a collisional product between Indian and Eurasian continents (Gansser, 1964: Powell and Conaghan, 1973: Le Fort, 1975). Most of the metamorphic and deformational features found in the Himalayas are considered to have been formed during the Himalayan orogeny, which resulted from the collision started in Eocene age (Frank et al., 1973: Le Fort, 1975), although some, especially in the Higher and Lesser Himalayas, show relics of an extensive pre-Himalayan tectono-metamorphism. At least three major intracontinental thrusts can be traced all over the Himalayas. From north to south, they are: Main Central Thrust (Gansser, 1964), Main Boundary Thrust (Gansser, 1964) and Himalayan Frontal Thrust (Nakata, 1972) with the related thrust activities progressively becoming younger in age towards the south. The Main Central Thrust is considered to be Miocene or older in age.

Isotopic geochronological studies on the Himalayan rocks reveal that the deter-

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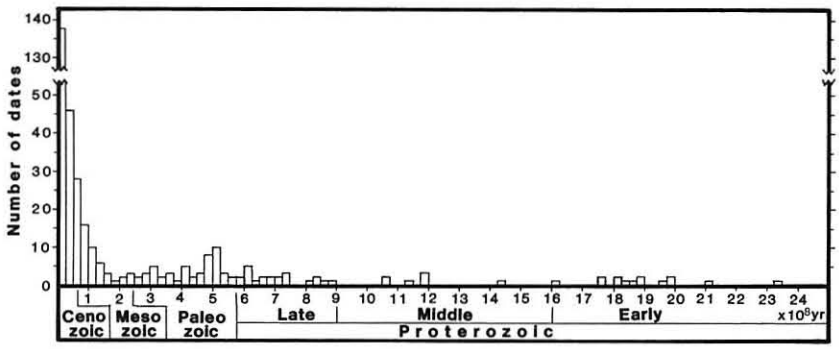


Text-fig. 1 Histogram of isotopic ages determined by various methods in the Himalayas. Data are cited from the papers which are shown in references with star or double stars.

mined ages are concentrated mainly into the Tertiary, especially Miocene age (Text-fig. 1). At the same time, they also prove the Himalayas to have undergone a poly-metamorphism or poly-orogeny since the Precambrian (Crawford, 1981). The poly-metamorphism and poly-orogeny were inferred from the geological and petrological points of view (Hashimoto et al., 1973 : Arita, 1983 : Caby et al., 1983 : Brunel and Kienast, 1986).

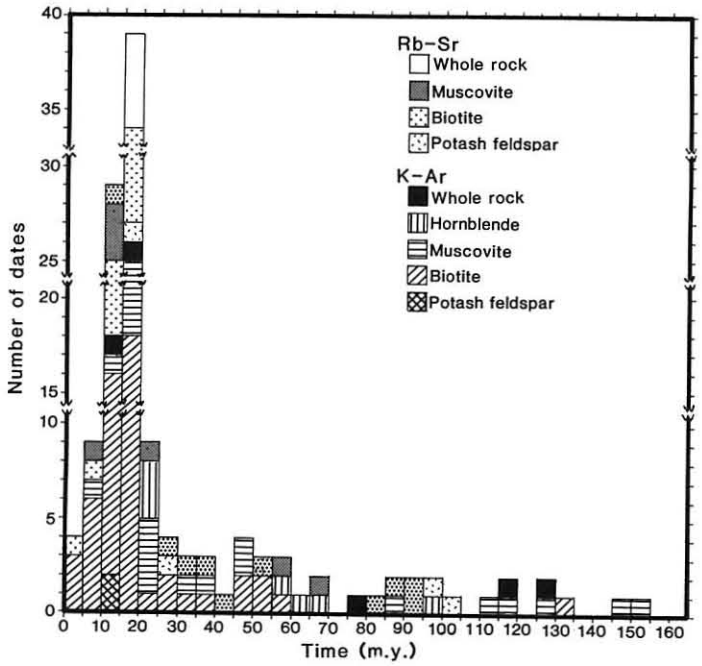
Mehta (1980) compiled the isotopic dating ages, and divided the Cretaceous-Tertiary Himalayan orogeny into three phases : (1) 75—50 Ma ; folding and metamorphism, (2) 40—25 Ma ; uplift, and (3) 25—10 Ma ; major uplift, thrusting and regional retrogression.

The present paper discusses two events of metamorphism and the subsequent cooling history during Cretaceous to Tertiary age in the Nepal Himalayas based on newly determined K-Ar isotopic ages and zircon fission-track ages (Arita and Ganzawa, unpub. data) together with other isotopic ages already reported by various methods. Findings of the paleomagnetic research into the Lesser Himalayan rocks in the Tansen area (Gautam, 1989a ; 1989b) are also discussed to support, though indirectly, the two-stage model.

Radiometric ages in the Nepal Himalayas

In Nepal, more than 160 age determinations measured by Rb/Sr and K/Ar methods have so far been reported mainly from the Higher Himalayas. A histogram of these ages, except for 36 older ages corresponding to Paleozoic to Precambrian time, is shown in Text-fig. 2. There are three distinct concentrations around 100—85 Ma, 70—45 Ma and 40—5 Ma. It is noteworthy that the trends of the histogram for the Nepal Himalayas closely resemble to those recognized by Mehta (1980) for the Himalayas as a whole.

Fifteen zircon fission-track ages, which were newly obtained from the Himalayan gneisses collected from the Higher Himalayas of central Nepal, are



Text-fig. 2 Histogram of isotopic ages from Cretaceous to Quaternary time determined by various methods in the Nepal Himalayas. Data are cited from the papers which are shown in references with double stars.

very young and range between 2.1 Ma and 0.6 Ma, except for one sample which is 7.7 Ma (Arita and Ganzawa, unpub. data).

Further, in an effort to establish the thermal history during the Tertiary, K-Ar age determinations were carried out on biotite from a pelitic gneiss and hornblende from a calcareous gneiss both collected from the upper stream of the Modi Khola river in central Nepal. The pelitic gneiss, which occurs in the upper part of the lower argillo-arenaceous unit of the Himalayan gneiss (Arita et al., 1982), consists mainly of kyanite, garnet, biotite, plagioclase and quartz. The calcareous gneiss,

Table 1 K-Ar ages on hornblende and biotite of the Himalayan gneisses in the Higher Himalayas, central Nepal.

Sample No.	Mineral	K (%)	$^{40}Ar^{*}$ (10^{-5}scc/gm)	Atm. ^{40}Ar (%)	Age (Ma)
HA80101624	Hornblende	1.29	0.322	76.6	61.5±3.1
		1.29	0.305	90.4	
HA7831510B	Biotite	7.32	1.63	84.5	56.7±2.8
		7.24	1.63	91.3	

$^{40}Ar^{*}$ is radiogenic argon. Ages were calculated with $\lambda_\beta = 4.962 \times 10^{-10}yr^{-1}$, $\lambda\varepsilon = 0.581 \times 10^{-10}yr^{-1}$, $^{40}K/K = 1.167 \times 10^{-4}$atom % and $^{40}Ar/^{36}Ar$ atmosphere=295.5. Determined by Teledyne Isotopes, N. J., United States.

exposed 1 km upward from the pelitic gneiss, is collected from the lower part of the middle calcareous unit of the Himalayan gneiss (Arita et al., 1982), and is mostly composed of garnet, hornblende and plagioclase with small amount of calcite. These gneisses which gave fission-track ages of 2.1 and 2.2 Ma, respectively, yield K-Ar ages of 56.7±2.8 Ma and 61.5±3.1 Ma (Table 1). These ages are far older than those expected to be 20 to 10 Ma.

Closure temperatures of various geochronological methods

The closure temperature below which an isotopic clock of mineral or rock ceases from working is one of the most important factors in deciding the cooling history of rock, and is dependent on kinds of the age determination method and mineral. Many theoretical, experimental and geological studies have been carried out to settle the closure temperatures of different chronometries and different minerals (e. g., Dodson, 1979 : Dodson and McClelland-Brown, 1985 : Harrison, 1981 : Harrison and McDougall, 1980). These studies show that the closure temperature is variable with variations of even up to 100℃ or more due to the influence of many factors such as differences in kinematic behavior and grain size of minerals, and to hydraulic effects of pore fluids. However, the estimates of closure temperatures shown in Table 2 are commonly adopted (Jäger, 1979 : Harrison and McDougall, 1980). The temperature of 230℃ is used for the closure temperature of the zircon fission-track dating.

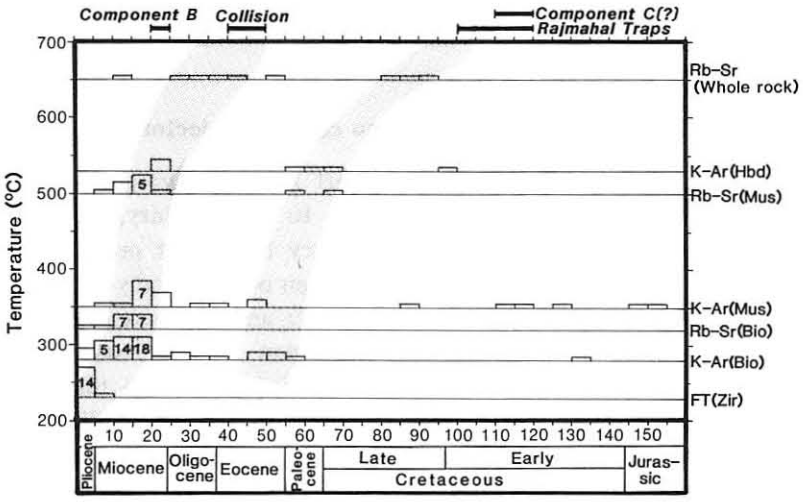
Table 2 Adopted closure temperatures (℃) for whole rock and various minerals by K-Ar and Rb-Sr methods.

	K-Ar method	Rb-Sr method
Whole rock	——	650
Hornblende	530	——
Muscovite	350	500
Biotite	280	320

Two metamorphic events and the subsequent cooling history in the Nepal Himalayas

The radiometric ages from the Nepal Himalayas are plotted against their closure temperatures (Text-fig. 3). These ages are obtained from central and eastern Nepal, and distributed in a wide area mainly of the Higher Himalayas. However, in the Himalayas it is well known that the rocks have undergone similar types of metamorphism and show monotonous and similar lithology especially in the Higher Himalays (Gansser, 1964 : Hashimoto et al., 1973 : Le Fort, 1975).

This suggests that the Himalayas as a whole have suffered similar thermal



Text-fig. 3 Plot of radiometric ages derived by various methods and minerals from the Nepal Himalayas versus their closure temperatures. Components B and C show magnetization and remagnetization events in the Tansen area of the Lesser Himalayas (Gautam, 1989b). The age bar for the Rajmahal Traps is after McDougall and McElhinny (1971) and Baksi et al. (1987). The closure temperature levels are shown as horizontal lines, and height of columns is proportional to the number of ages corresponding to the particular interval. For clarity, however, the exact number is indicated inside the bar if it exceeds five.

history throughout the region. Therefore, the ages from various areas in Nepal which, during the late Eocene to Oligocene through the Miocene to the present, show younging with a corresponding decrease in closure temperature, are supposed to represent a trajectory of cooling history. A rather broad width of the trajectory can be attributed to the minor regional variation in cooling history. Another trajectory, although not so clear as the former, is also traceable from the late Cretaceous through the Paleocene to the Eocene. Thus, two cooling history passes are appreciable in the Nepal Himalayas. Some K-Ar ages on muscovite and biotite are found between the two trends. They can be considered to be rejuvenized ages of the older trajectory. Most of the K-Ar ages older than 85 Ma are obtained from detrital sericite and muscovite in sandstone and calcareous schist (Krummenacher, 1966 : Krummenacher et al., 1978). The newly determined K-Ar ages for hornblende and biotite belong to the older trajectory. The estimated cooling rate based on these ages is 52℃/Ma. This value is twice as much as that of the Alps (Jäger, 1979). The cooling rate of the younger cooling pass is estimated to be almost the same to that of the older cooling pass.

In this paper, we consider the fission-track ages of 2.1 Ma and 2.2 Ma for gneisses to represent a later stage of the young cooling history. However, judging from the estimated cooling rate of about 50℃/Ma for the cooling trajectory, the ages appear to be young. In this context, it is worth noting that Gautam and Koshimizu (1988) suggested a possible strong thermal event around 5 Ma on the

basis of paleomagnetic and fission-track studies on the Ampipal alkaline massif in the Nepalese Lesser Himalayas.

Tectonic significance of two cooling trajectories

The metamorphism in the Himalayas, apart from that in Paleozoic and Precambrian times, is generally designated in age to the Tertiary, especially to the Miocene. The metamorphism in the pre-Tertiary is not yet proved geologically. However, two episodes of metamorphism have been petrologically recognized in the Nepal Himalays (Arita, 1983). Caby et al. (1983) and Brunel and Kienast (1986) inferred that the main metamorphism of barrovian type had occurred prior to thrusting on the Main Central thrust zone. We infer that the thrust movement gave metamorphism to the rocks in and around the Main Central Thrust zone, and brought about granitic magma in the depth. The young cooling trajectory is indicative of the metamorphism related to the thrusting during Oligocene to Miocene age. The old one seems to represent the cooling history of the metamorphism prior to the thrusting. It is noteworthy that these tectono-metamorphic events took place before and after the collision between India and Eurasia which occurred during 50 to 40 Ma.

The events visualized by two cooling trajectories are supported by the paleomagnetic data on the Nepalese Lesser Himalayan rocks. In the Tansen area of central Nepal, complex multi-component magnetic remanence consisting of at least four components, designated as components A, B, C and D, was recognized in the Aulis volcanics (Gautam, 1989a). The first three components could also be isolated from the sedimentary rocks in the same area (Gautam, 1989b). A mean direction of component A magnetization is consistent with the present dipole field at Tansen, and is of recent field origin. Timing of other componets was inferred by comparing the paleolatitude values derived from the mean inclination with the calculated paleolatitude pattern at Tansen (27.9°N, 83.5°E) expected from the simulated Indian Apparent Polar Wander Path.

Component B, before any bedding tilt-correction, yields a most probable paleolatitude of 17°N suggesting its acquisition around 23 Ma. In volcanics, this component rests on a low Curie-temperature (360℃) mineral phase interpreted as (titano-) maghemite which represents a low-temperature (200—300℃) oxidation product of a Ti-rich magnetite. In red siderite and hematite-bearing sediments, this component rests on hematite which was probably formed due to oxidation of siderite during the time of the remanence acquisition. Thus, the Tansen area seems to have undergone a secondary moderate heating in the early Miocene, whereas the major folding or tectonic disturbance occurred prior to that time. This tectono-thermal picture might be a manifestation of the events responsible for the younger cooling trajectory in the Higher Himalayas.

Component C, of normal polarity, with thermally distributed unblocking temperatures up to 550—560℃ suggests a paleolatitude of about 50°S after bedding tilt-

correction, Component D, almost antipodal to component C and hence of reverse polarity, with thermally discrete unblocking temperatures close to 550—560℃ or above could be recognized only in few samples and so its quantitative estimation was rather poor. A high Curie-temperature (ca. 565℃) phase of Ti-poor magnetite carries the remanence corresponding to these componests.

Sakai (1983) correlated the Aulis volcanics with the Rajmahal Traps and the sedimentary rocks of the Taltung Formation with the intertrappean sediments in the eastern part of the Indian shield north of Calcutta on geological grounds. Recent K-Ar dating of the Rajmahal Traps and associated volcanics by Baksi et al. (1987) suggests that they were erupted ca. 115 Ma rather than 100—105 Ma based on previously determined K-Ar ages (McDougall and McElhinny, 1970). The high southern paleolatitude derived from component C and the occurrence of dual polarity componests (i. e. component C probably acquired during the early time of Cretaceous Normal Polarity Superchron and component D acquired prior to it?) suggest that the volcanic activities in Peninsular India and Nepal Lesser Himalayas are coeval. At this point, we speculate that such volcanic activity in the Nepal Lesser Himalayas and the tectono-metamorphic event in the Higher Himalayas initiating the older cooling trajectory might be genetically interrelated.

Concluding remarks

An analysis of the Rb-Sr, K-Ar and fission-track zircon ages from the Nepal Himalayas (including the newly obtained K-Ar isotopic ages from two gneiss samples) and study on the age versus closure temperature relationship reveal that:

1) The isotopic ages, except those reflecting Quaternary uplift, are chiefly concentrated around 100—85 Ma, 70—45 Ma and 40—5 Ma.

2) These ages reflect two major cooling histories: the old one of late Cretaceous to Eocene, and the young one of late Eocene-Oligocene to the present, Two metamorphic events occurring prior and posterior to the India-Eurasia collision are suggested, accordingly.

The younger metamorphism and the resultant cooling history were undoubtedly caused by the activities related to an intracontinental thrust (the Main Central Thrust) and the following uplift. As evidenced by the secondary remagnetization episode, the latest maximum reheating event in the Lesser Himalayas dates back to the early Miocene. The initiation of the tectono-thermal event responsible for the older metamorphism is possibly coeval with the Aulis volcanic activity in the Lesser Himalayas. It is, however, unclear how such a metamorphism took place on the northern margin of the northward drifting Indian continent before the India-Eurasia collision.

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