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$^{40}Ar/^{39}Ar$ Dating of Himalayan Rocks from the Mount Everest Region

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Abstract. $^{40}Ar/^{39}Ar$ dating results for one granitic and four metamorphic rocks from the Everest region suggest that the initiation of the major uplift of Everest occurred about 17 m.y. ago. The surrounding area has been involved in subsequent orogenic events in this region.

On the basis of present results and other geochronological data for this region, the Himalayan orogeny is suggested to have occurred a few tens of m.y. after the collision of the Indian plate with the Asian plate.

Key words: $^{40}Ar/^{39}Ar$ age – Everest – Himalaya – Orogeny – Granite – Metamorphic rocks – Plate-collision – Uplift – Excess Ar

Introduction

The Himalayas are regarded as one of the typical examples of mountain building due to the collision between two continents (Dewey and Bird 1970). Although the collision of the Indian plate with the Asian plate is estimated to have occurred about 45 m.y. ago, the uplift of the Himalayas seem to have been initiated later (Powell and Canaghan 1973). To clarify the mechanism of mountain building due to the continental collision, it is necessary to know the time relationship between the various stages (e.g., the time of collision and that of mountain building).

So far, Himalayan rocks have been dated by the K – Ar, Rb – Sr and fission track methods, with ages ranging from a few m.y. to more than 1000 m.y. (e.g., Hamet and Allègre 1976; Krummenacher 1961, 1971; Mehta 1977; Virk and Koul 1977). However, most samples show ages less than 75 m.y. Further, we cannot eliminate the possibility that some of the samples dated might have been affected by secondary disturbances or by the occurrence of excess Ar or of Ar loss. In order to examine these cases and to investigate the age of mountain building of the Himalayas, the $^{40}Ar/^{39}Ar$ method has been applied to one granitic and four metamorphic rocks, which were collected from the Everest region. We expected that the application of the $^{40}Ar/^{39}Ar$ method to these rocks would clarify the fine structure of the tectonic events in this region.

Samples

More than 100 samples were collected by one of us (M.K.) from the eastern part of Nepal during the Japanese Mount Everest Expedition 1970. The samples include granitic, metamorphic and sedimentary rocks. Among them, five samples from the Everest region were selected for the present analysis, three of which (JE 121, 126 and 131) were collected directly from Everest itself.

Sample JE 131 is a greenschist, collected at an altitude of about 8200 m on the southwest ridge of Everest and is considered to be typical of samples forming the upper part of the mountain. Samples JE 121 (granite) and JE 126 (schist) were collected at an altitude of 5350 m at the northern flank wall of Khumbu glacier, below the Lho-la pass where the Makalu granite is in intrusive contact with the overlying schist (Bordet 1961). The Makalu granite is named after Makalu, a peak located about 20 km southeast of Everest, but it is also abundant in the Everest massif (Bordet 1961).

Sample JE 117 is a gneiss collected on the southwestern flank of Nuptse bordering the Khumbu glacier, at an altitude of 5120 m. Sample JE 065 is also a gneiss, but was collected at Pakie, about 50 km to the southwest of Everest. This sample is located farthest away from Everest among the samples dated in this study. The sampling localities are shown in Fig. 1 and their latitudes and the longitudes given in Table 1.

As shown in Table 1, these rocks contain K-rich minerals such as biotite, muscovite and K-feldspars. The K-contents of the total rocks range from 3% to 5% as determined by X-ray fluorescence analysis. Some samples contain plagioclase, but in small amounts compared with other minerals. Hence, their Ca content is generally low, less than 1%, except for the sample JE 126 whose Ca content is estimated to be about 1.7% by X-ray fluorescence analysis.

Experimental Procedures

Total rock samples of grain size 35 to 60 meshes were wrapped in Al foil and stacked in air in quartz ampoules ($10\phi \times 70$ mm) with standard samples at both ends. They received a total fast neutron flux of about 2×10^{18} n/cm^2 in the core of the Japan Material Test Reactor, Tohoku University. USGS standard LP – 6 (biotite) was used as the age monitor, which has the K – Ar age of 128 m.y. (Engels and Ingamells 1973).

Ar gas was extracted and purified by conventional procedures and analysed on a Reynolds type mass spectrometer. Details of the experimental procedure have been described before (Kaneoka and Aoki 1978).

Since the samples were analysed 3 years after neutron irradiation, ^{37}Ar, a measure for the Ca-concentration, had already decayed below the detection limit. As a consequence, Ca-derived contributions to ^{36}Ar and ^{39}Ar could not be corrected for. However, as shown in Table 2, the samples have relatively high K-contents (3–5%) and high K/Ca ratios (2.9–10.4). Therefore, the effect

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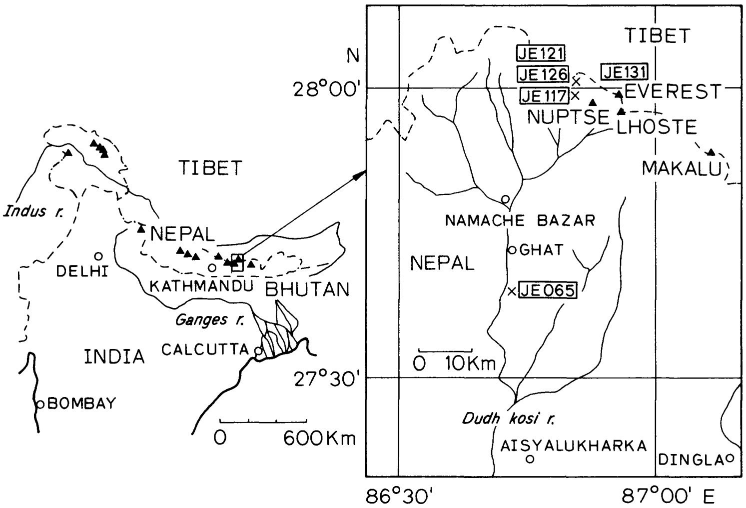

Fig. 1. Schematic map of sampling localities

Table 1. Samples used for $^{40}Ar/^{39}Ar$ analyses

Sample No.	Sampling locality				Rock type	Forming minerals[a]
	Location	Latitude	Longitude	Altitude		
JE 131	Southwest ridge above the South Col	27° 58.9′^{N}	86° 55.9′^{E}	8200^{m}	Green schist	Bi, Mu, Qz, Pl, To, Zi, Ch
JE 126	Beneath the Lho-la Peak	28° 00.6′	86° 50.9′	5350	Schist	Bi, Mu, K-feld, Qz, Pl, Zi
JE 121	Beneath the Lho-la Peak	28° 00.6′	86° 50.9′	5350	Granite	Bi, Mu, K-feld, Qz, Pl, Zi, Ap
JE 117	Nuptse, beneath the 5325 m Peak	27° 59.0′	86° 50.8′	5120	Gneiss	Si, Bi, K-feld, Mu, Pl, Qz, Ap, Zi
JE 065	Pakie	27° 38.9′	86° 43.5′	2550	Gneiss	Bi, Mu, K-feld, Qz, Pl, Ga, Zi, Ap, Il

[a] Bi = biotite, Mu = muscovite, Qz = quartz, Pl = plagioclase, To = tourmaline, Zi = zircon, Ch = chlorite, K-feld = K-feldspar, Ap = apatite, Si = sillimanite, Ga = garnet, Il = ilmenite

Table 2. Summary of $^{40}Ar-^{39}Ar$ ages of samples from Himalaya

Sample (Weight)	K (%)[a]	K/Ca[a]	$^{40}Ar-^{39}Ar$ ages (m.y.)				
			Total	Minimum	Maximum	Plateau	Plateau range
JE 131 (1.465 g)	4.34	10.4	15.3	3.3 ± 0.1	19.0 ± 0.6	16.7 ± 0.5	1,100°–1,300° C (50.4% of ^{39}Ar released)
JE 126 (0.559 g)	4.88	2.87	21.1	16.7 ± 0.5	72.3 ± 6.3	16.9 ± 0.4	900°–1,100° C (40.0% of ^{39}Ar released)
JE 121 (1.465 g)	4.13	9.90	23.2	15.1 ± 0.5	185 ± 3	16.8 ± 0.3	900°–1,150° C (62.6% of ^{39}Ar released)
JE 117 (1.053 g)	3.15	3.00	56.8	11.8 ± 0.2	360 ± 4		
JE 065 (1.006 g)	3.87	5.45	25.3	5.2 ± 0.1	751 ± 41		

[a] K content and K/Ca ratio of samples were determined by the X-ray fluorescence method with the precision of about 5%
° Error Figures: 1σ (standard deviation)
° $\lambda_e = 0.581 \times 10^{-10}\ yr^{-1}$; $\lambda = 5.543 \times 10^{-10}\ yr^{-1}$ (Steiger and Jäger 1977)

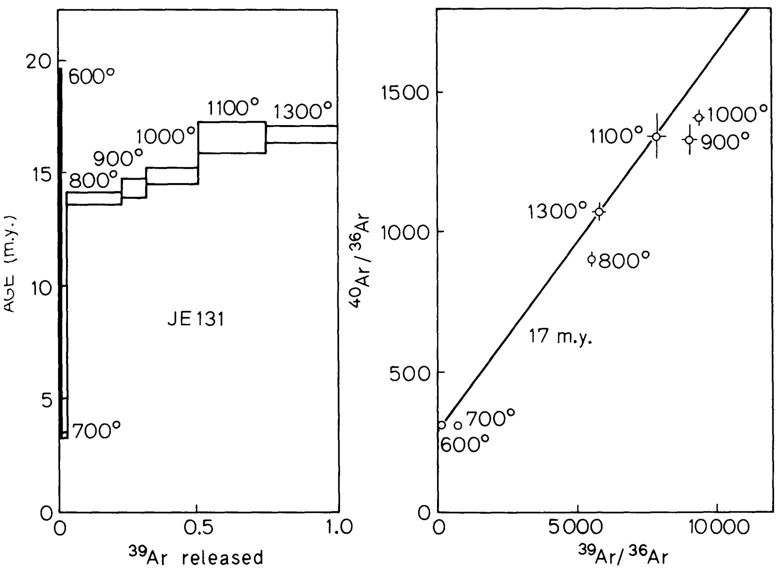

Fig. 2. Sample JE 131. $^{40}Ar/^{39}Ar$ age spectra as a function of ^{39}Ar released *(left)* and $^{40}Ar/^{36}Ar$ vs. $^{39}Ar/^{36}Ar$ isochron diagram *(right)*. The band in the $^{40}Ar/^{39}Ar$ spectra diagram indicates the $\pm 1\sigma$ (standard deviation) envelope about the calculated age of each temperature fraction. In the isochron diagram, a reference isochron of 17 m.y. is drawn which goes through the atmospheric $^{40}Ar/^{36}Ar$ value. All temperatures are given in degrees Celsius

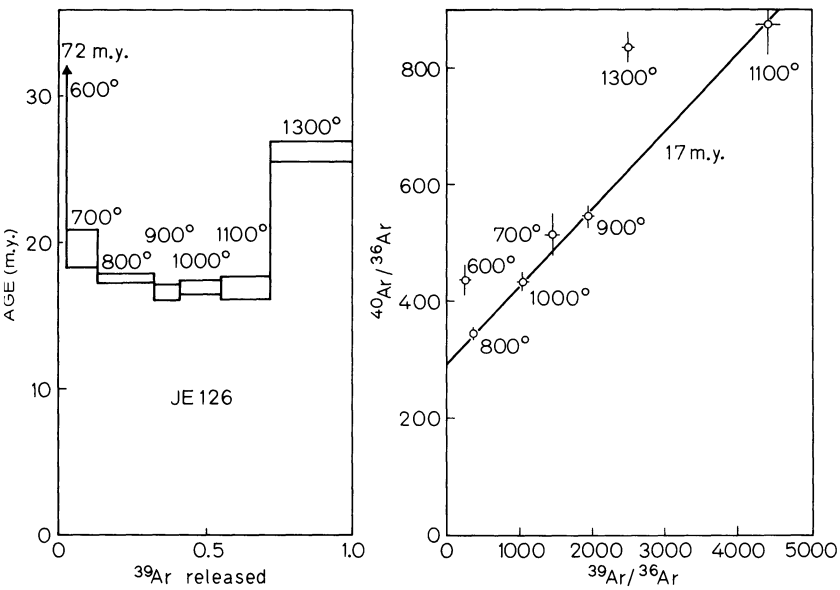

Fig. 3. Sample JE 126. In the age spectra diagram, the 900°–1,100° C fractions show almost similar ages of about 17 m.y. In the isochron diagram, a reference isochron of 17 m.y. is drawn assuming the atmospheric ratio for the $(^{40}Ar/^{36}Ar)_i$ ratio

of Ca-derived Ar isotopes on the age is estimated to be relatively small, less than 1 m.y. at the maximum.

Results and Discussion

The results are shown in Figs. 2–6 and summarized in Table 2. Sample JE 131 shows a typical stair-case pattern with higher $^{40}Ar/^{39}Ar$ ages at higher temperatures (Fig. 2). The apparent low $^{40}Ar/^{39}Ar$ ages at lower temperatures suggest partial radiogenic ^{40}Ar loss from this sample. On the other hand, the 1100° and 1300° C fractions indicate almost the same ages of 16.7 ± 0.5 m.y. and cover about 50% of total ^{39}Ar released. Although only two fractions are included in this case, this age may be regarded as a plateau age, considering the results of JE 126 and JE 121.

As shown in Figs. 3 and 4, samples JE 126 and JE 121 indicate saddle-shaped age spectra, which are typically observed in deep-seated samples with excess Ar (Kaneoka 1974; Lanphere and Dalrymple 1976). In such cases, the apparent lower $^{40}Ar/^{39}Ar$ age at the intermediate temperatures may represent the maximum estimated age for the thermal event affecting the sample and is sometimes very close to the age of the event (Kaneoka 1974; Lanphere and Dalrymple 1976). For the present samples, such an event is considered to have been some orogenic processes and the samples were affected at some depth. Hence, the occurrence of excess and/or inherited ^{40}Ar in these samples is quite likely. It is noteworthy that both samples have intermediate plateau ages of about 17 m.y. This age agrees well with the plateau age of sample JE 131 at higher temperatures. Since three samples from different sites and of different rock type show almost the same age, 17 m.y. seems to have geochronological significance. Since the Makalu granite has a relatively wide distribution in this region, it may be conjectured that the age represents the time of granite intrusion. As shown in Fig. 4, however, sample JE 121 (granite) shows $^{40}Ar/^{39}Ar$ ages above 17 m.y. in the lowest and highest temperature fractions with a total $^{40}Ar/^{39}Ar$ age of about 23 m.y. Hence, it is less likely that the age of 17 m.y. corresponds to that of the granite intrusion. Sample JE 126 (schist) also indicates a slight-

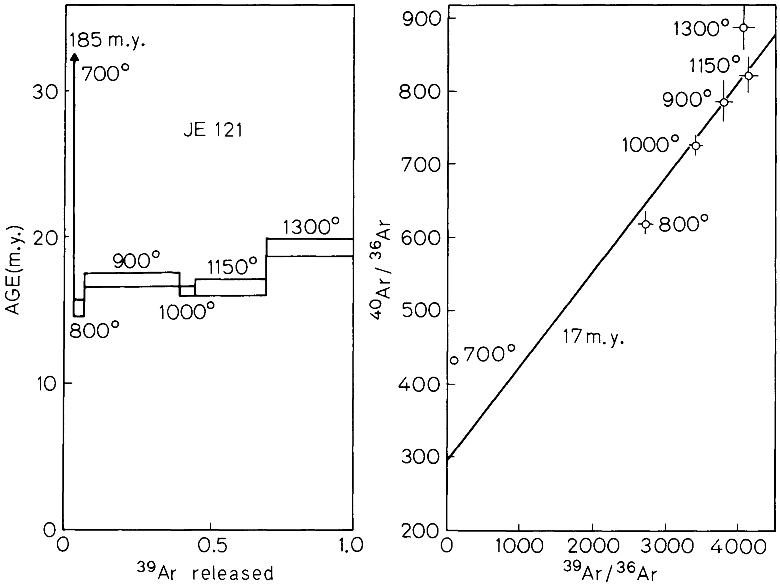

Fig. 4. Sample JE 121. The 900°–1,150° C fractions show almost similar ages of about 17 m.y. in the age spectra diagram. In the isochron diagram, an isochron of 17 m.y. is drawn as a reference which goes through the atmospheric $^{40}Ar/^{36}Ar$ ratio

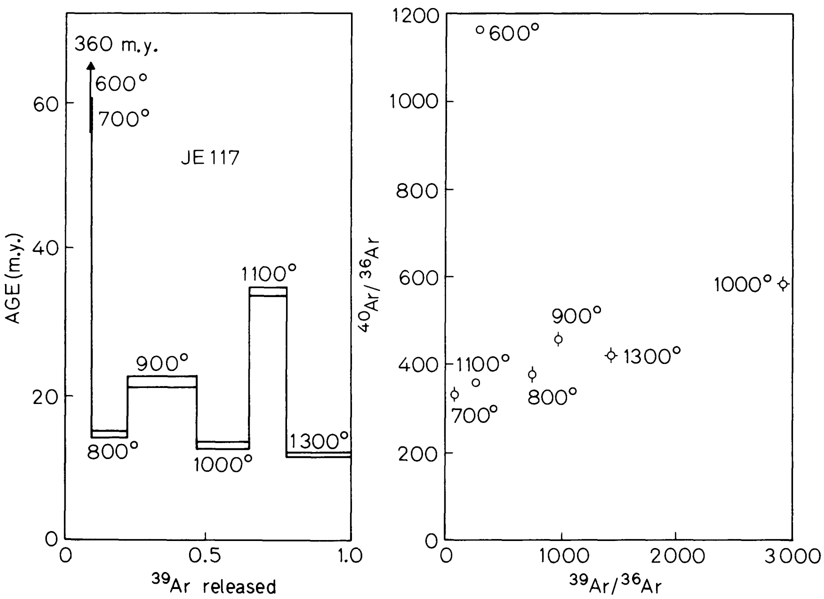

Fig. 5. Sample JE 117. The age spectra show disturbed pattern for this sample

ly older total $^{40}Ar/^{30}Ar$ age of about 21 m.y. These situations suggest that the age would probably correspond to a time when these samples began to keep a closed system with respect to Ar systematics after having been involved in an earlier orogenic process, or processes, in this region. Since these three sample belong to the main body of Everest itself and the elevated part would have cooled more rapidly than the lower part, these results might imply that the major uplift of Everest began about 17 m.y. ago.

If this is the case, then the lower part might have been further involved in the later orogenic processes in this region. In effect, sample JE 117 and JE 065 apparently show the evidence of such later event(s) in their age spectra. In the case of sample JE 117 (Fig. 5), the age spectrum is highly disturbed, but the 800°, 1000° and 1300° C fractions indicate $^{40}Ar/^{39}Ar$ ages of 12–15 m.y. The other four fractions show much higher $^{40}Ar/^{39}Ar$ ages with the total $^{40}Ar/^{39}Ar$ age of about 57 m.y., probably reflecting the presence of inherited and/or excess ^{40}Ar.

Sample JE 065 also shows a saddle-shaped age spectrum (Fig. 6), but the minimum $^{40}Ar/^{39}Ar$ age observed in the 900° C fraction indicates an age of only 5 m.y. Since the 700° C fraction in this sample shows an apparent $^{40}Ar/^{39}Ar$ age of about 750 m.y. and the 1300° C fraction an age of about 46 m.y., this sample was clearly disturbed by later event(s). The age of the event(s) was probably less than 5 m.y. and is considered to have been an orogenic process, or processes, in this region. Although no mineral separates were analysed in this study, the consistent results on ages of the present samples will be regarded as geochronologically significant.

Krummenacher (1961) reported a K – Ar age of 18.2 ± 0.6 m.y. (recalculated after new decay constants (Steiger and Jäger 1977)) for a schist from an altitude of 8400 m on Everest. If we take into account the experimental uncertainty, there is no difference between the K – Ar age reported by Krummenacher (1961) and the present results. His data further suggest that K – Ar ages of

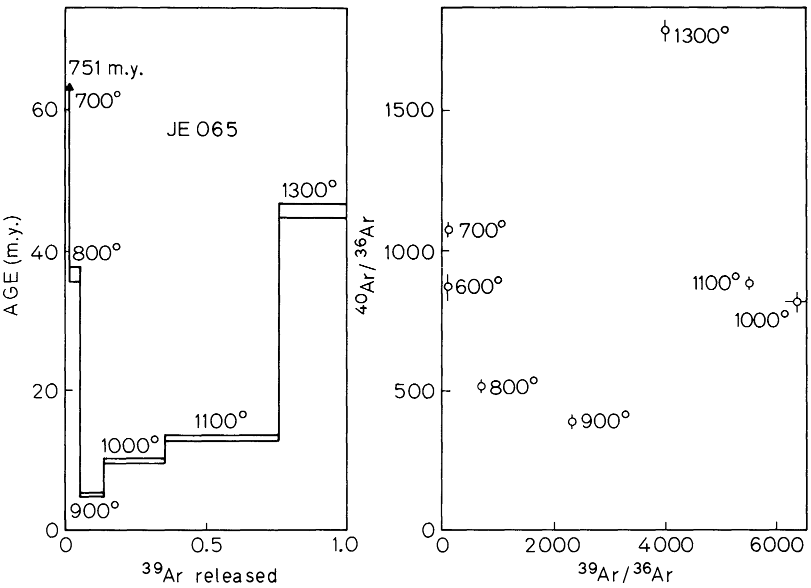

Fig. 6. Sample 065. The age spectra suggest some secondary effect on this sample about no more than 5 m.y. ago

biotites from rocks from the Nepal Himalayas range from about 10–18 m.y. On the other hand, fission track ages of Himalayan muscovites in Nepal range from about 3–23 m.y. (Virk and Koul 1977). The younger age probably reflects the relatively recent and less intense orogenic processes in this region and may correspond to the youngest result observed in sample JE 065. Hamet and Allègre (1976) reported a whole rock Rb-Sr age of about 29 m.y. for granites from central Nepal. Such differences in the apparent ages probably reflect the different sensitivity of each isotopic system to thermal events.

Since the collision of the Indian plate with the Asian plate is estimated to have occurred about 45 m.y. ago (Powell and Canaghan 1973), these geochronological results suggest that the major uplift of the Himalayas occurred a few tens of m.y. after the collision of both plates. Such a delay in the process of the uplift may be attributed to the possibility that the later deformation of continental lithosphere required some time. The present results imply that the Makalu granite might have intruded more than 20 m.y. ago. Although the major elevation of the Everest region occurred about 17 m.y. ago, the surrounding region has been involved in subsequent orogenic processes.

The analyses of gravity data in this region suggest that the Himalayas are not in isostatic equilibrium and are currently under the influence of large scale tectonic forces, probably due to the collision of the Indian plate with the Asian plate (Kono 1974; Molnar and Tapponier 1975). Thus, the younger orogenic processes reflected in the geochronological data probably correspond to the uplift of the Himalayas which is still in progress.

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