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Rb-Sr Geochronology of the Rocks of the Himalayas, Eastern Nepal
Part I
The Metamorphic Age of the Himalayan Gneiss

By

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Abstract

Rb–Sr isotopic measurements were carried out for whole rock and small sliced rock from the Himalayan gneiss which constitues the metamorphosed basement of the Tethyan sediments. The results of the measurements on whole rock from the Barun migmatite, the Barun gneiss and the Irkhua gneiss indicate that complete Sr isotopic redistribution occurred about 520 m.y. ago. This age is interpreted as the time of the regional metamorphism.

The analytical results of the small sliced slabs of the Himalayan gneiss indicate that Sr isotopic redistribution occurred among the sliced slabs 33.3 ± 13.2 m.y. ago. This age is interpreted as the time of the metamorphism in the sillimanite-amphibolite facies.

The high initial $^{87}Sr/^{86}Sr$ ratio of 0.7372 ± 0.0031 from the Barun migmatite of the Himalayan gneiss suggests the Precambrian origin of the source rocks. The analytical results on the sliced slab of the Barun migmatite indicate that the original age of the rocks is about 800 m.y. The rock is interpreted as the remobilized Precambrian crustal rock. The high initial $^{87}Sr/^{86}Sr$ ratio of the Barun gneiss and the Irkhua gneiss of the Himalayan gneiss (0.7234 ± 0.0013) indicates also the Precambrian origin of the source rocks.

I. Introduction

The Himalayas which extend for about 2500 km from the east to the west with the width of 300 km are the greatest mountain chains in the world. The geologic structure of the range is one of the typical examples of the orogenic belts.

The Himalayan gneiss is composed mainly of the various gneisses which occupy the bulk of the high ranges of the Himalayas. The rocks represent the highly metamorphosed and tectonic basements of the Paleozoic and Mesozoic Tethyan sediments (Bordet, 1961; Hagen, 1969).

A few geochronological data of the gneiss, now available, range from 500 to 600 m.y. and from 10 to 28 m.y. (Laboratory of Isotopic Geology, Kweiyang Institute of Geochemistry Academia Sinica, 1973; Metha, 1977). According to them, the Cambrian to Precambrian ages obtained by Rb–Sr whole rock isochron indicate the time of the regional metamorphism, while the Tertiary ages of biotite are attributed to a strong thermal event and rapid uplifting of the range. Many of the early investigators took the Precambrian age for the Himalayan gneiss for granted. The position below the Paleozoic sediments of the Tibetan zone and a broad similarity with Indian shield rocks invited this conclusion (GANSSER, 1964; SAXENA 1971; WADIA, 1975).

However, Le FORT (1975) linked the main phase of the metamorphism with the Tertiary deformation based on petrographic and structural analyses and advocated that the lack of a clear stratigraphic or metamorphic break between the gneiss and the Tethyan sediments provided evidence for the Tertiary metamorphism. The 28 m.y. age obtained by Rb–Sr whole rock dating of the Manaslu granite was considered as the minimum age of the metamorphism (HAMET and ALLÉGRE, 1976). Thus, the age of the metamorphism of the Himalayan gneiss is presumed to be later than the Mesozoic by some investigators (BORDET, 1961; POWELL and CONAGHAN, 1973; Le FORT, 1975; HAMET and ALLÉGRE, 1976).

It is needed to define the age of metamorphism to construct the evolutional history of the Himalayas. In the past decade, Rb–Sr geochronology on metamorphic rocks has progressed. The geochronological studies on metamorphic rocks by DAVIS *et al.* (1969) revealed that Rb and Sr isotopes migrated only within a few tens of centimeters during metamorphism. Rb and Sr isotopic analyses on small sliced rock samples succeeded in clarifying the age of the metamorphism (HOFMANN and GRAUERT, 1973; GRAUERT *et al.*, 1974). It is hopeful of dating the metamorphic rocks of the Himalayas by applying the same method.

The present study focuses to establish the isotopic age of the metamorphism. Rb–Sr isotopic analyses were made on the samples from the Himalayan gneiss in the eastern Nepal. The field survey was performed by the present author in 1973 and 1975.

The results from the Rb–Sr isotopic analyses on the rock samples are reported and discussed in the following sections.

II. Geology

The Himalayan gneiss is a polymetamorphosed crystalline complex composed of the various gneisses and schists. It occupies whole length of the high range of the Himalayas (Fig. 1). Its lower boundary is the MCT (Main Central Thrust) which has an E–W trend common in the Himalayas. The MCT separates the gneiss from the metasediments of the Midland (GANSSER, 1964). Tethyan sediments from the Cambrian to the Eocene in age overlie the metamorphic rocks on the north of the gneiss. The gneiss represents the basement rocks of the sediments (HAGEN, 1969; BORDET, 1961; HASHIMOTO *et al.*, 1973).

The geology of the studied area of the eastern Nepal is described below, mainly based on BORDET (1961), GANSSER (1964) and HASHIMOTO *et al.*, (1973) (Fig. 1).

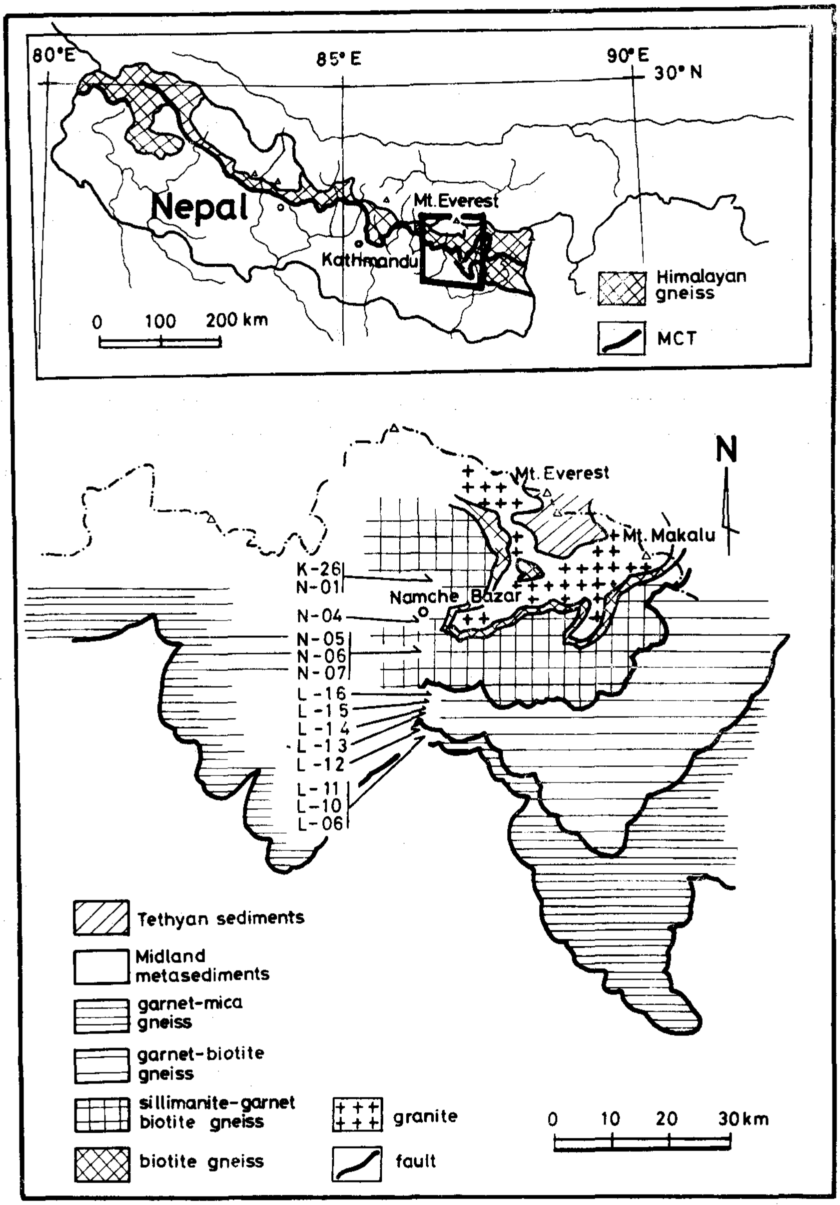


Fig. 1. Geologic map of the eastern Nepal, after Bordet (1961) and Hashimoto *et al.* (1973).

The Himalayan gneiss of the area is subdivided structurally and lithologically into three units from the bottom upward; the garnet-mica gneiss, garnet-biotite gneiss and sillimanite-biotite gneiss. The rock-type of the lowermost section of this area is the garnet-mica gneiss with conspicuous banded structure. The garnet-mica gneiss is termed the Irkhua gneiss by HASHIMOTO *et al.* (1973). The rock thrusts over the metasediments of the Lower Himalayas. The Barun gneiss overlying the Irkhua gneiss is garnet-biotite gneiss. Its banding consists of thin feldspar-rich layers alternating with dark biotite bands. The sillimanite-biotite gneiss of granitic composition thrusts over the Barun gneiss. The rock is termed the Barun migmatite by BORDET (1961). The Barun migmatite contains characteristically porphyroblastic potassium feldspar. The migmatite is composed of two rock types; leucocratic migmatite and potassium feldspar augen gneiss rich in biotote.

The melanocratic gneiss rich in fine-grained biotite termed the Black gneiss by BORDET (1961) overlies the Barun gneiss. It is inferred that both rock units were originally in unconformable contact in consideration of the similarity in the degree of the metamorphism (YIN and KUO, 1978). The Everest series of the Tethyan sediments overlie the Black gneiss. The Black gneiss and the Tethyan sediments are separated by intrusive granite.

There is fairly a good homogeneity of the gneiss all along the Himalayas with regard to metamorphic phases and mineral species represented (HASHIMOTO *et al.*, 1973.) The metamorphic grade increases from the south to the north and its maximum is attained in the Himalayan gneiss. Chloritoid, staurolite, kyanite and sillimanite are the typical metamorphic minerals found in sufficiently aluminous rocks. The metamorphism is a medium pressure type.

The metamorphism of the eastern Nepal has been investigated by HASHIMOTO *et al.* (1973). They recognized three metamorphic episodes: (1) During the first metamorphism the Himalayan gneiss recrystallized and achieved NNE–SSW trending mineral lineation in them. (2) The second metamorphism is characterized by local migmatization of the gneisses. The event is linked to the intrusion of granite. (3) The intrusion of granite gave a contact metamorphism to the Tethyan sediments.

The structure formed by the first metamorphism was recognized in Middle Paleozoic sediments of Nepal (HAGEN, 1969). The age of the metamorphism is earlier than Middle Paleozoic (HASHIMOTO *et al.*, 1973). The second and the third metamorphism are associated with the intrusion of the granite. The age of the granite is supposed to be Tertiary (HAGEN, 1969). The intrusion is related to tectonic movement which caused W–E trending fold system prevailing to the present Himalayas.

Today the majority of the investigators agrees on the final episode to be the Tertiary, but the existence of the pre-Tertiary event is still a matter of debate. POWELL and CONAGHAN (1973) and Le FORT (1975) suggested the absence of the pre-Tertiary metamorphism. They recognized that the metamorphism was later than old deformation event that affected the Mesozoic formation in the Tethyan sediments in North-West Himalayas.

III. Analytical Procedures and Precisions

Analytical method consists of three procedures, such as sample preparations, chemical separation and mass spectrometry. The analytical procedures in this study essentially followed those of ISHIZAKA (1966). Only a brief description of the procedures different from ISHIZAKA (1966) is given below.

Whole rock and small slab are prepared from the rock specimen about 2 to 5 kg in weight. The rock specimen was cut into two blocks. The large block was crushed and was reduced to the sample of whole rock. The small block was cut into sliced rocks about 1 to 2 cm^3 as shown in Fig. 2. The sliced rock was pulverlised and was reduced to sample of small slab.

Eleven replicated analyses of JG–1 and nine analyses of Eimer and Amend $SrCO_3$ were made to define the long term precision of machine. The average concentrations of Rb and Sr of JG–1 are 181.2 (181.3) ppm and 190.0 (184.1) ppm, respectively and the average $^{87}Sr/^{86}Sr$ ratio of JG–1 is 0.7109 ± 0.0007 (0.7114). The values in the parentheses are average values (ANDO et al., 1974). The average $^{87}Sr/^{86}Sr$ ratio of Eimer and Amend is 0.7082 ± 0.0007. Contribution of ^{87}Rb to ^{87}Sr peak during the mass spectometery was negligible for all samples and corrections for blanks were unnecessary both for Rb and Sr. The probable error in Rb/Sr ratio is believed within 2% and the error in $^{87}Sr/^{86}Sr$ ratio is within 0.2%.

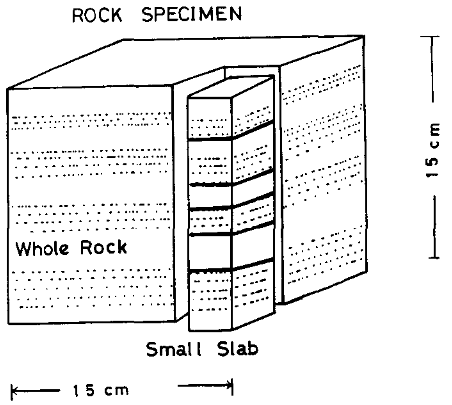


Fig. 2. Schematic sketch of whole rock and small slabs. The dotted layer is rich in biotite and the white layer is rich in quartz and feldspar. The large block is crushed and analyzed for whole rock. The small block is cut along thick line and analyzed for small slab.

The decay constant of ^{87}Rb used for calculating the Rb–Sr age is $\lambda = 1.39 \times 10^{-11}\ yr^{-1}$. The calculation of a best fit isochron through the data points is followed to the treatment of YORK (1966). The standard errors of initial Sr ratio and Rb–Sr age are $\pm 1\sigma$.

IV. Results

Rb–Sr isotopic measurements are made on samples from the Barun migmatite, the Barun gneiss and the Irkhua gneiss which are typical, widely occurring Himalayan gneiss.

The analytical results for whole rock and small slab of the Himalayan gneiss are shown in Table 1.

Table 1. The analytical data for the Himalayan gneiss

Sample No.	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr \pm 1\sigma$
Barun migmatite				
N-04 wr	219.0	104.6	6.114	0.7842±0.0029
N-05 wr	262.6	49.28	15.65	0.8536±0.0027
N-06 wr	221.7	104.5	6.203	0.7814±0.0019
N-07 wr	264.8	55.60	13.96	0.8380±0.0026
N-05-A sr	209.2	50.33	12.23	0 8602±0 0027
N-05-B sr	211.3	59.80	10.50	0.8530±0.0028
N-05-C sr	389.1	38.13	29.99	0.8634±0.0025
N-05-D sr	258.6	44.70	17.00	0.8592±0.0043
N-05-E sr	180.4	43.43	12.20	0.8532±0.0023
N-05-G sr	373.7	70.96	15.65	0.8582±0.0023
Leucocratic Barun migmatite				
N-01 wr	191.1	181.2	3.067	0.7581±0.0026
K-26 wr	210.7	65.94	9.766	0.8377±0.0029
K-26-A sr	249.5	85.05	8.589	0.8233±0.0028
K-26-B sr	238.2	96.70	7.197	0.7987±0.0022
K-26-C sr	223.0	137.0	4.744	0.7762±0.0027
K-26-D sr	225.0	132.7	4.941	0.7765±0.0028
Barun gneiss				
L-13 wr	217.3	259.0	2.463	0.7403±0.0019
L-14 wr	106.8	32.48	9.917	0.7912±0.0020
L-15 wr	86.32	63.64	3.944	0.7554±0.0018
L-16 wr	167.8	303.0	1.607	0.7364±0.0014
Irkhua gneiss				
L-10 wr	147.2	123.4	3.452	0.7483±0.0027
L-11 wr	158.2	100.0	4.603	0.7585±0.0028
L-12 wr	61.09	61.62	2.880	0.7418±0.0011
L-06 wr	214.7	68.40	7.295	0.7669±0.0019
L-06-A-1 sr	212.7	92.98	6.660	0.7663±0.0033
L-06-A-2 sr	223.2	74.26	8.761	0.7790±0.0014
L-06-A-3 sr	218.3	91.47	6.963	0.7702±0.0016
L-06-A-4 sr	218.3	91.47	6.953	0.7702±0.0016

wr; whole rock, sr; small slab.

The data of the Barun migmatite are plotted in Fig. 3. The data points of the whole rock define an isochron corresponding to an age of 525±20 m.y. with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7372±0.0031.

The data of the Barun gneiss and the Irkhua gneiss are shown in Fig. 4. The whole rock age is 512±20 m.y. and the initial $^{87}Sr/^{86}Sr$ ratio is 0.7234±0.0013. The ages of the Himalayan gneiss are identically about 520 m.y.

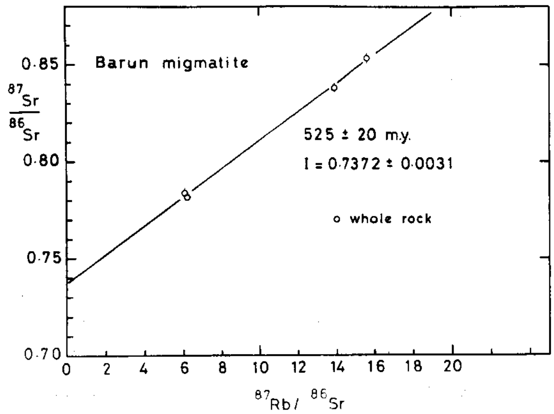


Fig. 3. Isochron plot of the Barun migmatite. Vertical bar represents analytical error.

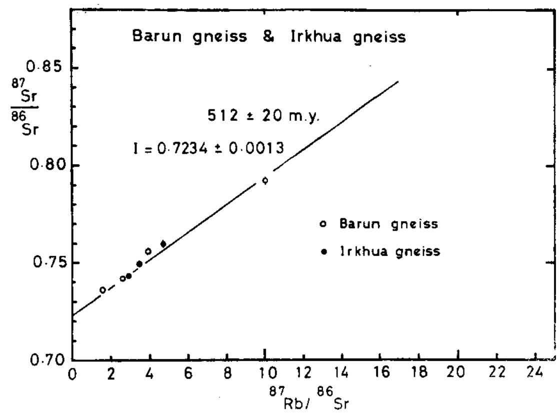


Fig. 4. Isochron plot of the Barun gneiss and the Irkhua gneiss. Vertical bar represents analytical error. open circle; the Barun gneiss, closed circle; the Irkhua gneiss.

The Himalayan gneiss was also examined by the small slab method proposed by Davis et al. (1969). This method usually gives the age of the oveprinting of metamorphism. The whole rock isochron indicates that the rock has remained closed to Rb and Sr isotopes for the isochron age. If complete Sr isotopic redistribution occurred among the small slabs, the analytical data of the small slabs define a linear line on Rb–Sr evolution diagram. The slope of the line corresponds to the time when complete Sr isotopic redistribution occurred among the small slabs. HOFMANN and GRAUERT (1973), GRAUERT *et al.* (1974) and MONTOGOMERY and HURLEY (1978) succeeded to define metamorphic age by the same methods.

The slab sample of the leucocratic Barun migmatite is schematically shown in Fig. 5. The analytical data of the migmatite are shown in Fig. 6, in which the closed circle represents ordinary whole rock, while the open circle represents the small slab prepared from a hand-sized specimen. The slope of the regression line corresponds to 847±47 m.y. and the intercept on the $^{87}Sr/^{86}Sr$ ratio is 0.7193±0.0044. The results suggests that the leucocratic Barun migmatite has remained closed to Rb and Sr isotopes.

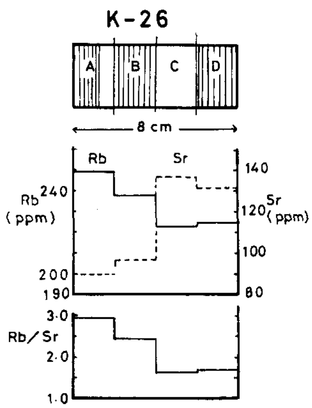


Fig. 5. Cross-section of the leucoratic Barun migmatite, K–26, show ing variations of concentrations of Rb and Sr along a section normal to the layering. The vertical striped layers are rich in biotite. The white layers are rich in feldspar and quartz. The section is about 1 cm square.

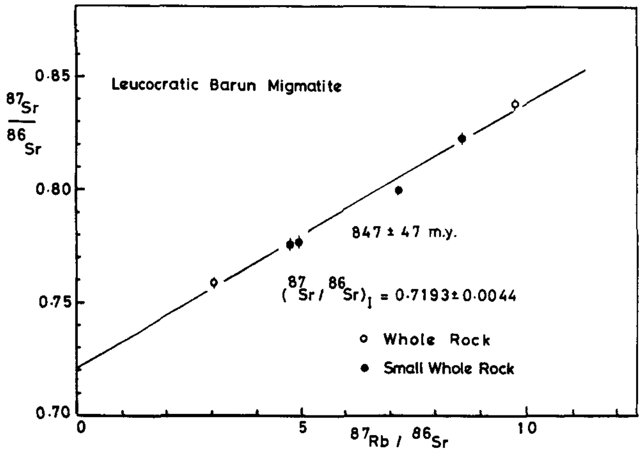
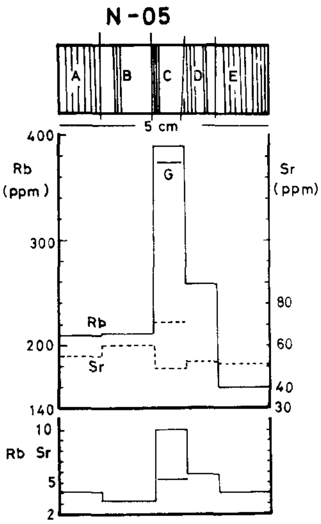


Fig. 6. Rb–Sr evolution diagram for the small slabs of the leucocratic Barun migmatite. Vertical bar represents analytical error. open circle; whole rock, closed circle; small slab.



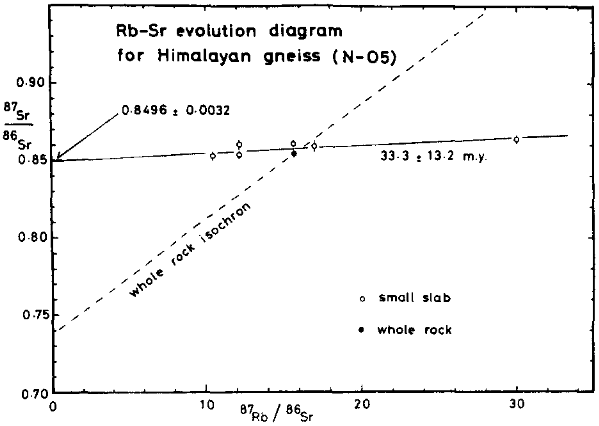
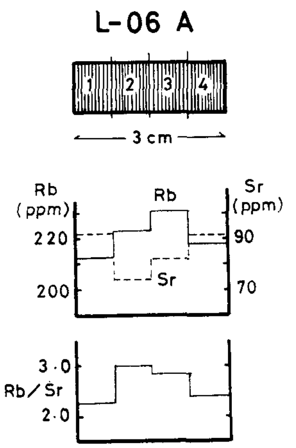


Fig. 8. Rb–Sr evolution diagram for small slabs of the Barun migmatite, N–05. The dashed line is whole rock isochron of the Barun migmatite. Vertical bar represents analytical error. open circle; small slab, closed circle; whole rock.

Fig. 7. Cross-section of the Barun migmatite, N–05, showing the variations of concentrations of Rb and Sr along a normal to the layering. The vertical striped layers are rich in biotite. The white layers are rich in quartz and feldspar. The sample, N–05–G, is cut from the neighboring column. The section is about 1 cm square.



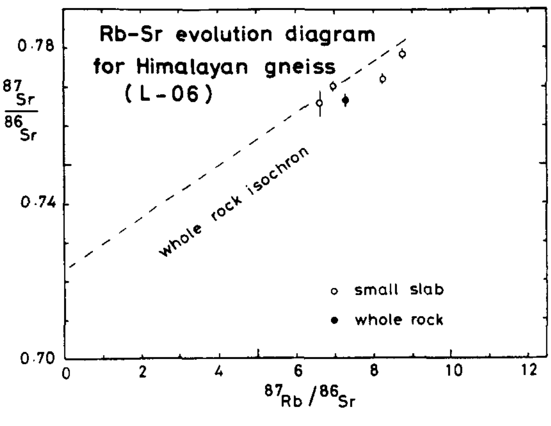


Fig. 10. Rb–Sr evolution diagram for small slabs of the Irkhua gneiss. Vertical bar reprents analytical error. The dashed line is whole rock isochron of the Barun gneiss and the Irkhua gneiss. open circle; small slab, closed circle; whole rock.

Fig. 9. Cross-section of the Irkhua gneiss, L–06, showing variations of concentrations of Rb and Sr along a normal to the layering. The vertical striped layers are rich in muscovite. The section is about 1 cm square.

The small slab of the Barun migmatite (N–05) is shown schematically in Fig. 7. The data points of the small slabs are plotted on Sr evolution diagram in Fig. 8. The points fall on a linear line, whose slope corresponds to age of 33.3 ± 13.2 m.y. Although a large error of the age prevents from dating precisely, the linear line suggests that Sr isotopic redistribution occurred at relatively recent time.

The sample of the Irkhua gneiss (L–06) is sketched in Fig. 9. The data of the small slabs are plotted on Sr evolution diagram in Fig. 10. The data points do not fall on the whole rock isochron nor define another straight line, but are scattered along the whole rock isochron. The results suggest that the rocks have not maintained closed to Rb and Sr isotopes but Sr isotopic redistribution was not severe since 520 m.y. event.

V. Discussions

5–1) Eastimate of the original age of the Himalayan gneiss

The Himalayan gneiss is composed of three segments; (1) metamorphosed sediments of the Precambrian age, (2) instrusive granite and gneiss of a later period and (3) remnant of Precambrian granite, granulite, orthogneiss and schist (WADIA, 1975). The Barun gneiss and the Irkhua gneiss are supposed to be sedimentary origin by GANSSER (1964) and the origin of the Barun migmatite is not obvious.

The analytical result of the whole rock and small slab of the leucocratic Barun migmatite gives $847 + 47$ m.y. age. The result indicates that the leucocratic Barun migmatite has remained closed to Rb and Sr isotopes since that time.

Using the analytical results of the whole rock of the Barun migmatite, it is possible to estimate the original age of sedimentation or emplacement of the Barun migmatite if following assumptions are made (HURLEY *et al.*, 1962): (1) Each rock unit has remained closed to Rb and Sr isotopes since deposition or emplacement. (2) The observed initial $^{87}Sr/^{86}Sr$ ratio is a good average initial $^{87}Sr/^{86}Sr$ ratio of that unit. (3) The average whole rock $^{87}Sr/^{86}Sr$ ratio obtained from the present study represents the present-day $^{87}Sr/^{86}Sr$ ratio of that rock unit.

The isochron ages are plotted against its initial $^{87}Sr/^{86}Sr$ ratio in Fig. 11. The lines are defined by the initial ratio and the present-day $^{87}Sr/^{86}Sr$ ratio of the units. For each rock unit extrapolations are made to 0.70 on the $^{87}Sr/^{86}Sr$ axis. The intercept on the base line is 818 m.y. Although the age estimated from the Sr evolution diagram has large inherent uncertainities because of the simple assumptions, the age of 818 m.y. of the Barun migmatite is fairly concordant to the age of the leucocratic Barun migmatite.

HASHIMOTO *et al.* (1973) considered that the leucocratic Barun migmatite and the feldspar-porphyroblastic Barun migmatite composed the same stratigraphic and tectonic unit. If we follow the logic of HASHIMOTO *et al.* (1973), the concordance of the age of the Barun migmatite and the leucocratic Barun migmatite suggests that the age of about 800 is the time of original emplacement of them.

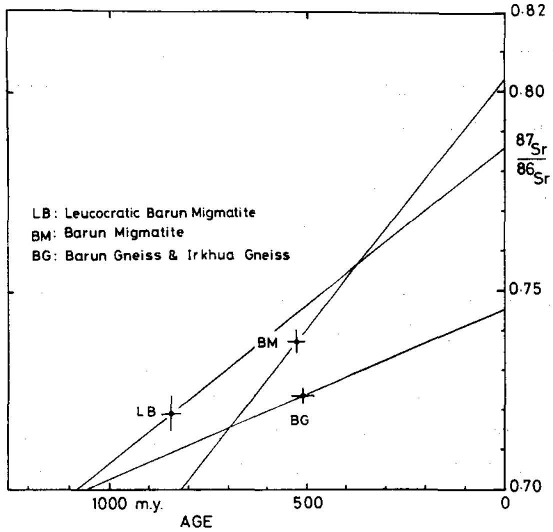


Fig. 11. $^{87}Sr/^{86}Sr$ evolution diagram for the Himalayan gneiss. BM; the Barun migmatite, BG; the Barun gneiss, LB; the leucocratic Barun migmatite.

As shown in Fig. 11, the extrapolated line of the Barun gneiss and the Irkhua gneiss intercepts the base line at about 1069 m.y. The rock is presumed to be sedimentary origin by inclusion of marble (GANSSER, 1964). The age is a maximum one of deposition, and is not contradictory to the above mentioned view.

5–2) Metamorphic age

The Himalayan gneisses have had similar metamorphic histories. They have experienced a metamorphism of the amphibolite facies (HASHIMOTO *et al.*, 1973; LE FORT, 1975).

The geochronological evidences indicate that the Barun migmatite, the Barun gneiss and the Irkhua gneiss of the Himalayan gneiss have remained closed to Rb and Sr isotopes for 520 m.y., as far as large whole rock samples are concerned. The event responsible for this age is not obvious and the age may refer to (1) deposition of the original rocks or (2) recrystallization during a metamorphism.

The age of about 800 m.y. is the time for the emplacement of the Barun migmatite as suggested by the previous discussion. The age of 520 m.y. of metamorphic rocks would not correspond to the time of deposition, but correspond to that of metamorphic recrystallization of the rock. HASHIMOTO *et al.* (1973) considered that the first metamorphism of the Himalayan gneiss was probably early Paleozoic and that the event developed the NNE–SSW trending mineral lineation in them. Then, the early Paleozoic metamorphic event corresponds to the 520 m.y. event.

The analytical results for the small slabs indicate that the complete Sr isotopic redistribution had occurred among the small slabs of the Barun migmatite 33.3 ± 13.2 m.y. ago but that complete Sr isotopic redistribution had not occurred among those of the Irkhua gneiss.

The metamorphic grade increases from the latter to the former, i.e. from the greenschist facies to the amphibolite facies (HASHIMOTO *et al.*, 1973). DAVIS *et al.* (1969) found that Sr isotopic redistribution had occurred among the neighboring small slabs during the sillimanite-amphibolite facies metamorphism, but had not occurred during the low grade metamorphism. Thus, the event revealed by the data of the small slabs would correspond to the time of metamorphism of the Himalayan gneiss. Although further investigations are necessary to date the precise age, the present results support the high-grade metamorphism of the Himalayas in the Tertiary, as suggested by BORDET (1961), Le FORT (1975) and Hamet and ALLÉGRE (1976).

The Tertiary metamorphism is postulated by this study. The gradual decrease of the metamorphism from the Himalayan gneiss to the overlying Tethyan sediments would have been caused by the Tertiary metamorphism, as suggested by Le FORT (1975). The Tertiary metamorphism would have been strong enough to obscure the previous geologic relations of the Himalayan gneiss and the Tethyan sediments.

VI. Conclusions

The conclusions obtained from this study are summarized as follows:

1) The analytical data of the Himalayan gneiss define two regression lines with the same slope. One line is given by the Barun migmatite, the upper part of the Himalayan gneiss, the other line given by the Barun gneiss and the Irkhua gneiss, the lower part of the Himalayan gneiss. Their age of about 520 m.y. indicates the time of recrystallization of the rocks.

2) The analytical results for the small slabs of the Barun migmatite gneiss indicate that the Sr isotopic redistibution had occurred among the neighboring small slabs 33.3 ± 13.2 m.y. ago. The age would correspond to the metamorphism which formed the present-day mineralogy.

3) Initial $^{87}Sr/^{86}Sr$ considerations and the analytical results of the leucocratic Barun migmatite indicate that the rock is remnant of the Precambrian crustal rock and that the age of the original emplacement is about 800 m.y. Considerations of initial $^{87}Sr/^{86}Sr$ ratio of the Barun gneiss and the Irkhua gneiss also suggest the

Precambrian origin of them.

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