19. Seiler, E., *Nat. Res. Dev.*, 1989, **25**, 92–110.
20. Dent, D., *ILRI, Publ. No. 39*, Selbstverlag, Wageningen, 1986.
21. Costigan, P. A., Bradshaw, A. D. and Gemmell, R. P., *J. Appl Ecol.*, 1981, **18**, 865–878.

ACKNOWLEDEMENTS. Funding for this study was provided by the Meghalaya State Pollution Control Board, Shillong. We thank Professor R G. Michael, Department of Zoology, North-Eastern Hill University, Shillong, for valuable suggestions in planning the study. We are also thankful to Dr R. Uma Shaanker, Department of Crop Physiology, UAS, GKVK, Bangalore, for critical comments on the first draft of this paper.

Received 19 March 1993; revised accepted 5 May 1993

K/Ar cooling ages from Zanskar Himalaya: implications for the tectonics and exhumation of Higher Himalayan metamorphic complex

Rasoul B. Sorkhabi*@†, Arvind K. Jain, Tetsumaru Itaya‡, Susumu Nishimura*, Rm. Manickavasagam** and Nand Lal§**

* Department of Geology and Mineralogy, Faculty of Science, Kyoto University, Kyoto 606, Japan
** Department of Earth Sciences, University of Roorkee, Roorkee 247 667, India
‡ Hiruzen Research Institute, Okayama University of Science, 1-1 Ridai-cho, Okayama 700, Japan
§ Department of Physics, Kurukshetra University, Kurukshetra 132 119, India
@ Present address: Department of Geology, Arizona State University, Tempe, AZ 85287-1404, USA

New K/Ar ages determined on biotite, muscovite and hornblende separates from the Higher Himalayan Crystalline (HHC) rocks in the Zanskar region, NW India, are presented. The implications of these Cenozoic ages on the timing of regional metamorphism, exhumation history of the HHC and extensional tectonics within the Higher Himalaya are discussed.

OF all the domains of the Himalaya (Figure 1), the Higher Himalayan Crystalline (HHC) belt with many snow-capped peaks of >6000 m height represents the greatest uplift and denudation history. The HHC rocks are separated from the Lesser Himalaya to the south by the Main Central Thrust (MCT) system[1,2] and from the overlying Tethyan sedimentary rocks by a normal fault of regional dimension, called the Zanskar Shear Zone (ZSZ)[3], Trans-Himadri Fault[4], North Himalayan Normal Fault[5] and South Tibetan Detachment System[6]. The HHC rocks form the main metamorphic belt of the Himalaya, exhibiting Barrovian regional metamorphism with polyphase deformation related to the India–Asia collisional tectonics[7–11]. These rocks were once deep-seated, but now occupy high summits. Geologists' interest in the HHC (variously called the Central Crystalline in Kumaun and the Tibetan Slab in Nepal) dates back to the 19th century, but in the recent decade, there has been a focus on quantitative analyses of the HHC towards a better understanding of the tectonic and petrologic processes that have shaped the Himalaya. Isotopic ages providing the time–temperature pathways of rocks constitute an important component of such a database.

Here we report new K/Ar ages determined on biotite, muscovite and hornblende separates from metamorphic and granitic rocks in the Zanskar region of the Higher Himalaya, northwest India (Figures 1 and 2), and discuss the geologic implications of our age data.

Tectonic setting of Zanskar Himalaya

Zanskar Himalaya offers well-exposed sections of the HHC and the Tethyan sedimentary sequence (Figure 2). The geological setting, metamorphic history and plate-tectonic evolution of the region have been presented by several researchers[11–29].

The HHC belt is about 10–15 km thick, with Proterozoic to Early Paleozoic crystalline complex of gneisses, schists, amphibolites, deformed two-mica granites and migmatites. Rb/Sr isochrons determined for the Himalayan crystalline rocks in NW India have revealed three major plutonic events of 1800–2000, 1100 and 500 Ma (refs. 30, 31) like the northern parts

† For correspondence

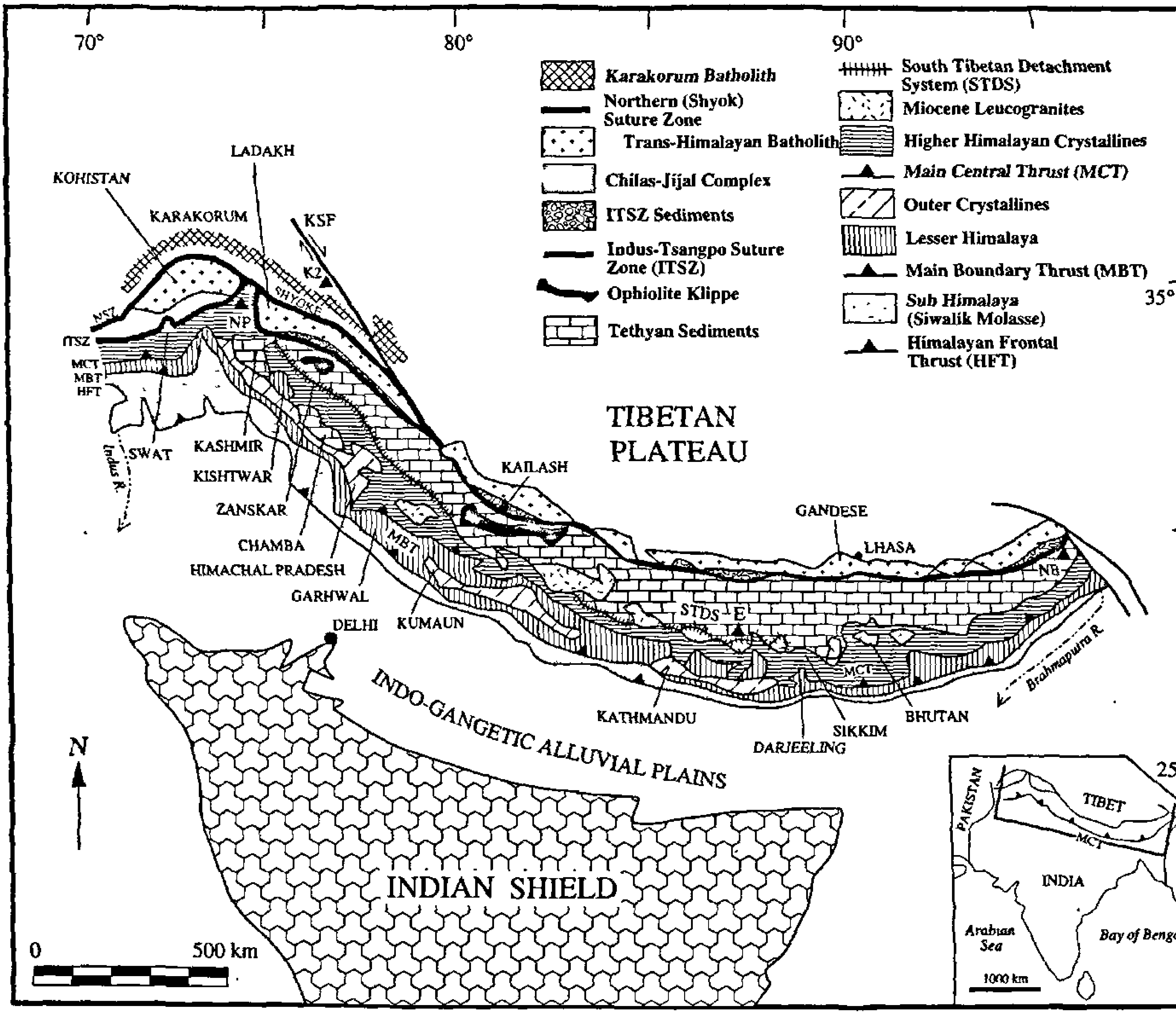

Figure 1. *Geological map of the Himalaya (modified after Windley*[8] *and Gansser*[53]*). KSF: Karakorum strike-slip fault; NP: Nanga Parbat; E: Everest; NB. Namche Barwa.*

of the Indian shield. From the Zanskar region itself, a few age data are available which put time constraints on the emplacement of the granitic gneisses. Honegger *et al.*[16] extrapolated a Rb/Sr isochron for two samples from the Suru valley as 500 Ma. Pognante *et al.*[32] reported a Rb/Sr isochron (549 ± 70 Ma) for a metagranitoid and a U/Pb concordia of zircon and monazite (472^{+9}_{-6} Ma) for an orthogneiss from southeast Zanskar–Lahaul region.

Intruding the Higher Himalaya are also two-mica (often tourmaline-bearing) Tertiary leucogranites which originated from anatectic melts of the crystalline basement[33,34]. Detailed geochronologic and geologic data on the Zanskar leucogranites are lacking.

A thick sequence of the Cambrian to Early Eocene sediments of the Tethyan zone forms a synclonorium in Zanskar and is the northwestern extension of the Lahaul–Spiti basin into Kashmir. This sedimentary sequence represents the shelf and shelf-edge facies of the northern continental margin of the Indian Plate. The lower part of this sequence is made up of low-grade metamorphosed quartzite, green–grey slates and phyllites, but for the most part the Tethyan sedimentary rocks have escaped the regional metamorphism affecting the Himalaya.

The contact between the Tethyan sediments and the HHC is defined by the northeast-dipping Zanskar Shear Zone (ZSZ)[3] having a complex geological history of an

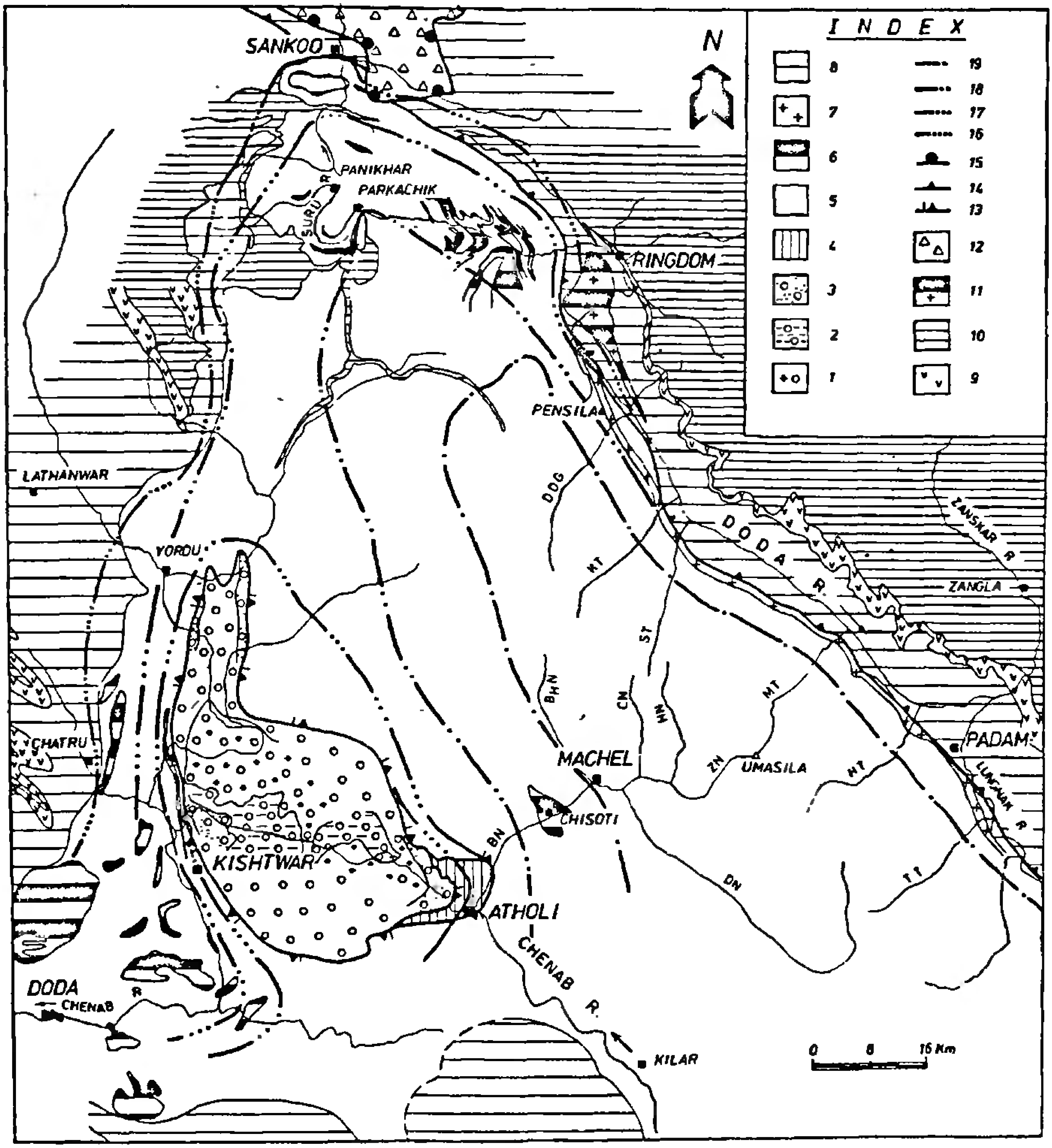

Figure 2. Simplified geological map of Zanskar and surrounding regions in NW Himalaya, India, showing major tectonic units and regional metamorphic isograds. Lesser Himalayan Proterozoic Foreland (Autochthon Kishtwar Window) Kishtwar Group: 1, Woil Formation (granitic gneiss); 2, Phyllite, schist; 3, Dul Formation (quartzite, metavolcanics); 4, Carbonaceous Phyllite. Higher Himalayan Crystallines (Allochthonous) 5, Schist-gneiss, migmatite, amphibolite; 6, granitoid intrusives; 7, leucogranite. Tethyan sedimentary zone: 8, Haimanta Group, 9, Phe Volcanics, 10, Lilang Group; 11, Granite. Indus Suture Zone: 12, Dras Volcanics. 13, Main Central Thrust; 14, Zanskar Shear Zone, 15 Dras Thrust. Metamorphic isograd boundaries. 16, garnet; 17, Kyanite-staurolite; 18, Sillimanite-muscovite; 19, Sillimanite-K-feldspar. BHN, Bhazuan Nala, BN, Bhot Nala; CN, Chirang Nala; DDG, Durng Glacier, DN, Dharlang Nala, HHC, Higher Himalayan Crystalline, HN, Hangshu Nala, HT, Haptal Tokpo, KT, Kange Tokpo; MCT, Main Central Thrust, MT, Mulung Tokpo; ST, Sumche Tokpo, TT, Temasa Tokpo, ZN, Zanskar Nala, ZSZ, Zanskar Shear Zone. (Based on our own observations and those of Herren[1], Honegger et al [16], Srivastava[17], Vohra et al [18] and Staubli[24])

early overthrusting towards the southwest and a later-superposed extensional tectonics[11, 29].

Geological mapping and petrologic studies of the HHC across the Chenab, Suru and Doda valleys (Figure 2) have identified Barrovian-type metamorphism ranging from biotite grade (middle greenschist facies) through sillimanite-K-feldspar grade (upper amphibolite facies)[35]. The garnet zone is observed near the MCT surrounding the Kishtwar Window, the sillimanite–K-feldspar zone exists towards the deeper structural and higher topographical levels to the northeast, and the metamorphism again lowers to garnet zone along the ZSZ in the Suru–Doda valleys. Our data on mineral paragenesis and pressure (P) and temperature (T) in the Suru valley (Figure 2) demonstrate maximum T and P of 700°C and 950–1100 MPa for the sillimanite–muscovite grade between Tangol and Parkachik, and these gradually decrease to around 450°C and 650 MPa in the basal parts of the Tethyan sedimentary sequence around Ringdom. Thermobarometric analysis of metamorphic samples from Zanskar has also been carried out by Gilbert (1986) (cited in Le Fort[36]), who estimated peak metamorphic conditions of $T = 700$°C and $P = 780$ MPa, by Pognante *et al.*[32], who reported $T = 650$–750°C and $P = 600$–800 MPa, and by Searle *et al.*[28], who obtained $T = 700$–750°C and $P = 800$ MPa. Temperature data are conformable but pressure shows large variations, probably due to uncertainties inherent in the activity models[37].

Samples for this study were collected from the HHC of the Zanskar region along the Suru River from Sankoo to Pensi La (Figure 2) during the summer of 1987. These include orthogneiss, paragneiss, mica schist, granite and amphibolite from various metamorphic zones. Figure 3 shows sample sites and lithology along with a plot of the obtained ages.

Results and discussion

Table 1 shows the analytical data on K/Ar ages (15 biotite, 9 muscovite and 2 hornblende) obtained in this study.

In the orogenic belts that have experienced high-grade regional metamorphism, discordant radiometric ages imply the closure of various radiometric systems for mineral phases at different times and thus record the cooling of rocks subsequent to the acme of metamorphism[38, 39]. The cooling age represents the time when the rock passed through a certain temperature threshold (i.e. closure temperature) below which the radiogenic stable isotope in a given mineral could be retained[40]. Thus, K/Ar mineral ages obtained reveal the cooling history of the HHC rocks in the Zanskar Himalaya. We assume the following closure

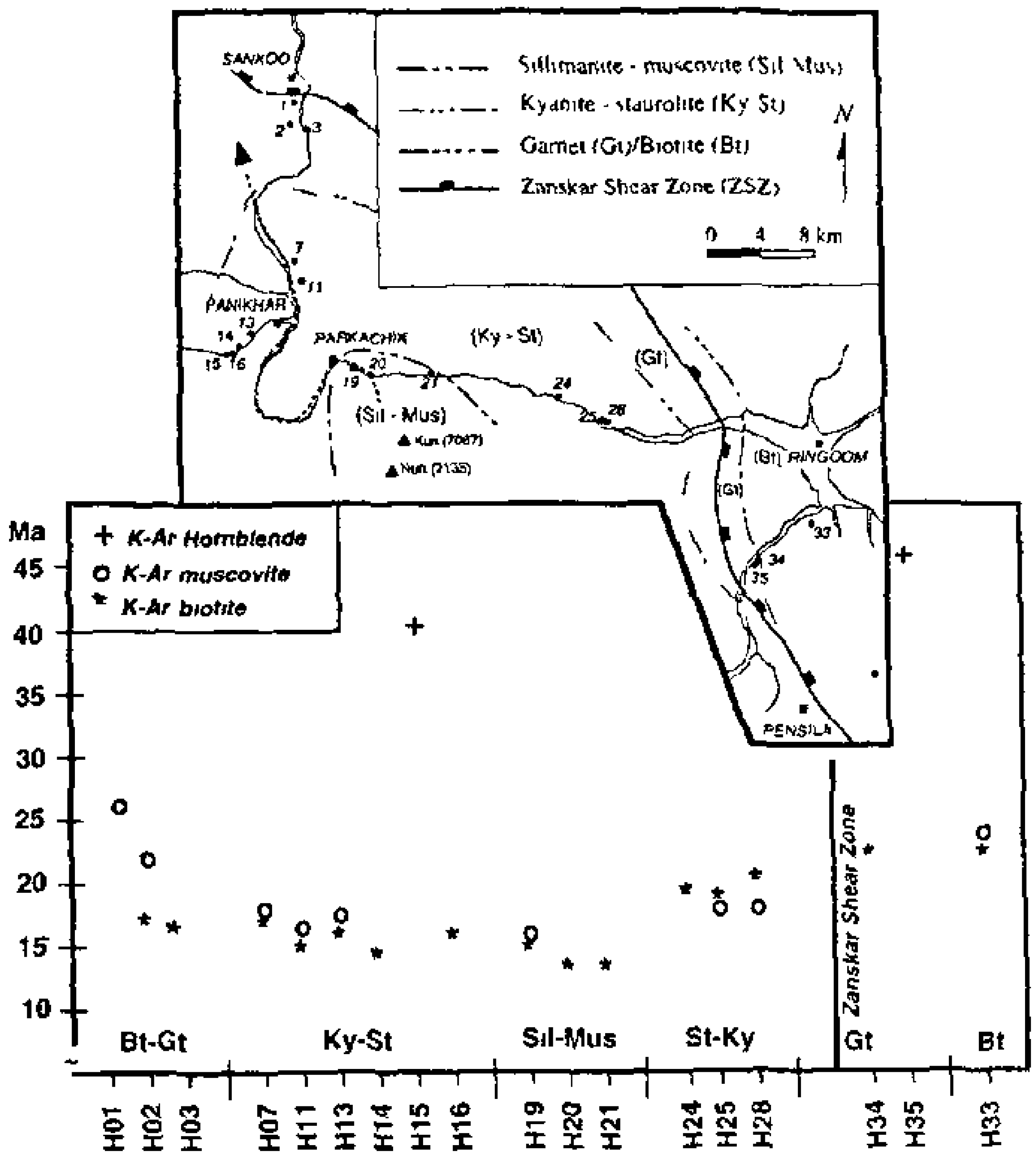

Figure 3. Sample sites and metamorphic zoning along the Suru River. Dotted line with an arrow shows the axis of the Suru refolded dome. Rock types include gneiss (H7, H13, H16, H19, H20, H21, H25, H28), schist (H1, H11, H14), granite (H2, H3, H24, H33, H34) and amphibolite (H15, H35). Plot of the K/Ar obtained from the HHC in Zanskar.

temperatures for K/Ar system: 300 ± 50°C for biotite; 350 ± 50°C for muscovite and 525 ± 25°C for hornblende[41–44].

Palaeomagnetic data[45, 46] and palaeontological evidence[47, 48] indicate that the collision of the northwestern Indian Plate with Asia occurred at 55+ Ma or closer to the Cretaceous–Tertiary boundary (65 Ma). The K/Ar ages from the HHC rocks in Zanskar, being of Cenozoic age, imply that the northern edge of the Indian Plate was reactivated, metamorphosed and deformed during the Cenozoic Himalayan orogeny.

K/Ar hornblende ages from two amphibolites (H14, 40.5 ± 1.3 Ma and H35, 45.5 ± 2.3 Ma) suggest that the thermal peak of the Barrovian-type regional metamorphism in the upper parts of the HHC in Zanskar was reached in the early Eocene, which is similar to the data and interpretation given for the HHC stacks in the Swat region in Pakistan Himalaya[49].

All the mica ages in Zanskar date back to early–middle Miocene (25–15 Ma). In a few cases, biotite obviously carries excess argon, as it has an apparent age larger than that of muscovite from the same rocks (e.g. sample H28 in Table 1). Such excess argon in biotite is not uncommon and has been reported from other orogenic belts[50]. This is a shortcoming with the

Table 1. K/Ar age data from the Higher Himalayan crystalline rocks in Zanskar, NW India

Sample	Fraction (mesh size)	Sample weight for Ar (g)	Potassium (weight %)	Radiogenic ^{40}Ar (10^{-8} ccSTP/g)	Nonradiogenic Ar (%)	Age (Ma)
Biotite						
H02	80–100	0.1197	6.91 ± 0.14	472.3 ± 7.7	34.4	17.5 ± 0.5
H03	100–150	0.1305	7.18 ± 0.14	450.7 ± 5.2	13.5	16.1 ± 0.4
H07	60–100	0.1165	7.41 ± 0.15	487.5 ± 5.5	13.1	16.9 ± 0.4
H11	32–80	0 1087	7.20 ± 0.14	421.1 ± 4.9	12.2	15 0 ± 0.3
H13	32–80	0.1483	7.52 ± 0.15	476.6 ± 5.2	9.6	16.3 ± 0 4
H14	60–80	0 2336	7 61 ± 0.15	417.8 ± 4.2	4.4	14.1 ± 0.3
H16	32–80	0.2200	7.56 ± 0.15	450.6 ± 4.7	8.2	15.3 ± 0.3
H19	60–100	0.1212	7.26 ± 0 15	428.5 ± 4 4	4.6	15.2 ± 0.3
H20	60–100	0.1545	7.88 ± 0 16	413 3 ± 4.4	7.9	13.5 ± 0.3
H21	60–100	0.1224	7.60 ± 0.15	402 6 ± 4.4	10.2	13.6 ± 0.3
H24	60–100	0.1042	7.35 ± 0 15	572 9 ± 6 0	6.8	19.9 ± 0.5
H25	80–150	0.1158	7.57 ± 0.15	556.5 ± 5.9	7.6	18.8 ± 0.4
H28	100–150	0.1133	7.57 ± 0.15	609 6 ± 6.5	7.5	20.6 ± 0.5
H33	100–150	0 1212	7 54 ± 0 15	663.9 ± 7.0	7.8	22.6 ± 0.5
H34	80–150	0.1501	7.43 ± 0.15	654 4 ± 6.8	7.3	22.5 ± 0.5
Muscovite						
H01	100–150	0.1557	8.42 ± 0.17	855.1 ± 8.4	2.2	25.9 ± 0 6
H02	100–150	0.1071	9.00 ± 0.18	790.7 ± 7.9	2.4	22 5 ± 0 5
H07	32–60	0.1402	8 92 ± 0 18	623.9 ± 6.2	2.8	17.9 ± 0 4
H11	32–60	0.1049	6.75 ± 0.14	432.5 ± 4.6	6.8	16.4 ± 0.4
H13	60–80	0 1293	8 89 ± 0.18	604.4 ± 6.4	9.1	17.4 ± 0.4
H19	60–80	0.1194	7.63 ± 0.15	467.6 ± 4.9	6.0	15.7 ± 0.4
H25	80–100	0.1615	8.92 ± 0.18	631.8 ± 6.4	3 8	18 2 ± 0.4
H28	100–150	0.1000	9.23 ± 0.18	633 3 ± 6.7	3 9	17.6 ± 0.4
H33	100–150	0.1218	9.12 ± 0.18	850.3 ± 8.5	4 4	23.9 ± 0.5
Hornblende						
H15	80–150	0.5347	0 62 ± 0 02	98.3 ± 1.1	11.8	40.5 ± 1.3
H35	80–150	0.5553	0.42 ± 0.02	75.5 ± 0.9	19.6	45.5 ± 2.3

K/Ar experimental procedure: Samples were sieved and washed in ion-exchanged water to remove powder residue. Separation and purification of biotite, muscovite and hornblende were carried out by decanting, tapping and a Franz magnetic separator K/Ar dating was carried out at the Hiruzen Research Institute, Okayama University of Science Itaya *et al.*[59] have given the detailed laboratory procedure The equations for calculating the age and error follow Cox and Dalrymple[60]. The constants used follow Steiger and Jager[61]. Potassium content was determined by flame photometry using a 2000 ppm Cs buffer. Mineral separates (each weighing 0 05–0 08 g) were decomposed for the K-analysis by treatment with HF and HNO_3 in a teflon beaker. Multiple runs (along with the unknown samples) of a working chemical standard showed the uncertainty of the K analysis to be within 2%. An average value of double runs for each sample was used in the age calculation. Samples for argon analysis were wrapped in Al foil, preheated at 150–200°C for about 24 h in vacuum. Argon was extracted in an Mb crucible at 1500–1600°C in an ultrahigh vacuum line. Clean-up of the reactive gases was done by a Ti–Zr scrubber. Argon was analysed on a 15-cm-radius sector-type mass spectrometer using isotopic dilution method and ^{38}Ar spike. The mass discrimination was checked with the atmospheric argon once every day. The double analysis of the age standard JG-1 (91 Ma) along with the unknown samples ensured the uncertainty of the age data to be within 2%.

conventional K/Ar age data. However, the ages reported here are useful for an approximate geologic discussion. These ages are similar to Rb/Sr biotite ages[16] and K/Ar, $^{40}Ar/^{39}Ar$ mica ages[28] reported from Zanskar as well as those from Nepal[51] and Pakistan[49]. Early–middle Miocene marks a rapid phase of uplift and exhumation in the Himalaya[52].

Assuming an average geothermal gradient of 30°C/km, the age data indicate an exhumation of ~12 km of the HHC since ~20 Ma. The rapid exhumation of the HHC has occurred due to two processes: (i) deep crustal rampings and imbrication causing extensional tectonics across the HHC belt, and (ii) ensuing erosional unloading. Evidences for these

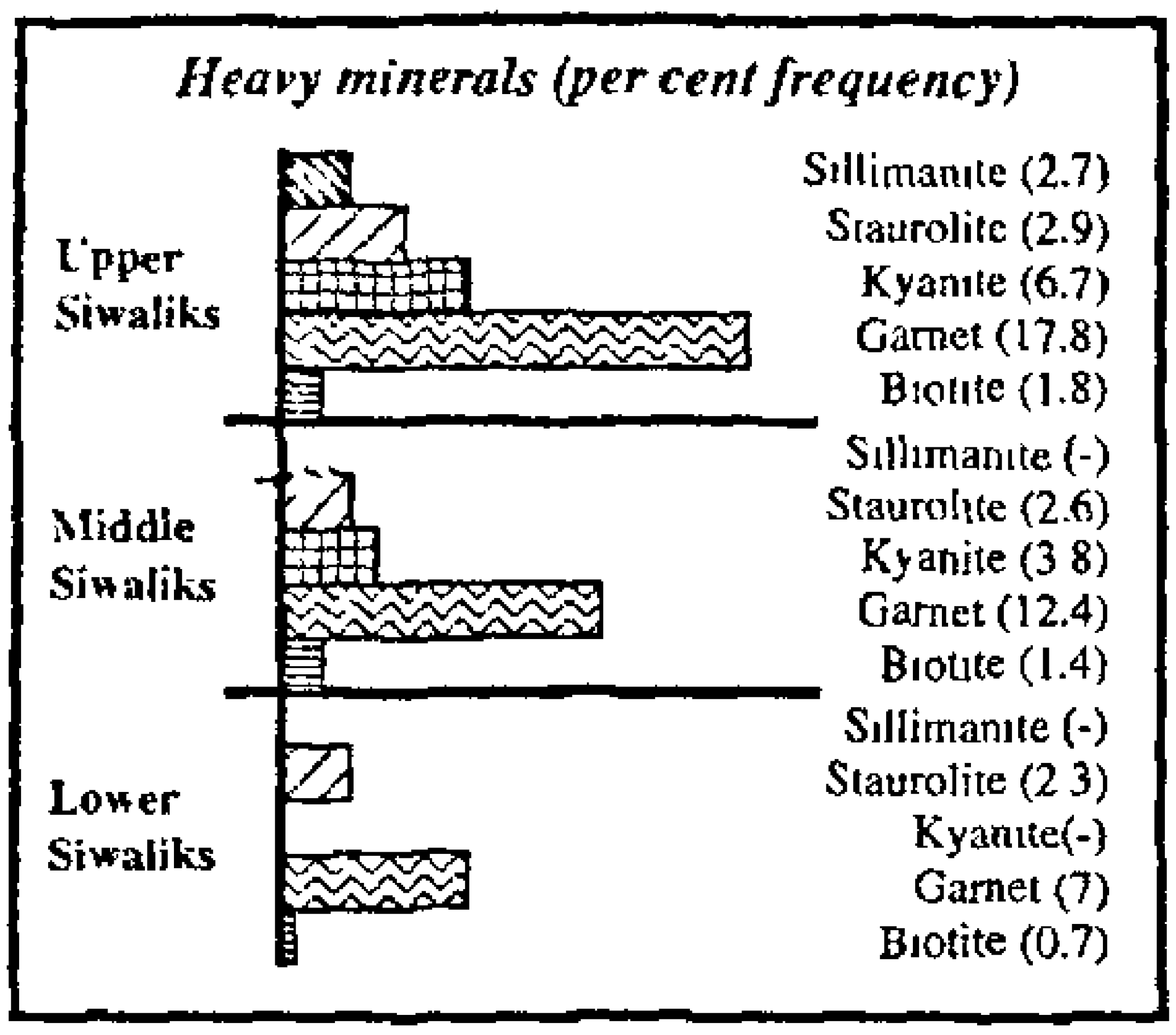

Figure 4. Relative abundances of metamophic minerals in the Siwalik Group averaged for Punjab and Kumaun (data from Chaudhri[58]).

processes are (i) tectonic displacements along the ZSZ and the MCT and (ii) the Siwalik molasse deposited in front of the rising Himalaya in Miocene–Pleistocene times[36,53,54]. Our samples collected across the ZSZ put time constraints on the activity of this extensional structure (Figure 3). Mica ages jump from 23 Ma (for samples H33 and H34) on the hanging wall to 18 Ma (samples H25 and H28) on the footwall of the ZSZ, demonstrating its activity in the early Miocene. Hodges *et al.*[55] also found similar ages (19–22 Ma) for the activity of the South Tibetan Detachment System in the Everest region of Nepal. Treloar *et al.*[56] interpreted fission track zircon ages of Zeitler[57] from the Swat region of Pakistan as timing the extensional phase of the Main Mantle Thrust at ~23 Ma. It thus seems that the extension between the HHC and the overlying Tethyan zone took place not only synchronously with the MCT compression at depth[55] but also simultaneously throughout some 2000 km of the Himalayan belt.

The HHC in Zanskar forms a large-scale refolded domal structure with the highest-grade rocks in the core and lower-grade metamorphics towards the flanks[11,16,22,26,35] along the Suru Valley, where metamorphic grade has reached up to sillimanite–muscovite around Parkachik (Figure 3). The mica ages show a trend conformable with this thermal structure. The ages become smaller towards the core of the Suru dome and are larger towards the lower-grade metamorphics on its flanks (Figure 3). It seems that the culmination parts of the Suru dome have undergone faster exhumation due to rapid uplift of the axis of the orogen. Note that highest peaks such as Kun and Nun (both >7000 m) along the Suru river from Sankoo as far as Pensi La occur in the sillimanite–muscovite zone for which youngest mica ages (13–15 Ma) have been obtained. We believe this pattern is real and testable and, although it is shown here only for the Suru Dome, it is worth the investigation in other structural domes of the Higher Himalaya.

Interestingly, the erosional and depositional record of the Higher Himalayan rocks preserved in the Siwalik molasse is consistent with the idea suggested above. Chaudhry[58] has carried out heavy mineral analysis of the Siwaliks in Punjab and Kumaun. Figure 4 shows the results of his study for metamorphic minerals. Note that the influx of metamorphic assemblage not only increases from Lower to Upper Siwaliks but also higher-grade metamorphic minerals become more abundant with the passage of time.

1. Heim, A. and Gansser, A., *Central Himalaya*, Denckenbergische Schweizerische Naturforschenden Gessellschaft, 1939, **73**, 1–245.
2. Valdiya, K. S., *Tectonophysics*, 1980, **66**, 323–348.
3. Herren E., *Geology*, 1987, **15**, 409–413.
4. Valdiya, K. S., in *Tectonics of Western Himalayas* (eds. Malinconico, L. L. and Lillie, R. J), Geol. Soc. Am. Spl. Paper 232, 1989, pp. 153–168.
5. Pecher, A., *Tectonics*, 1991, **10**, 587–598.
6. Burchfiel, B. C., Chen, Zh., Hodges, K. S., Liu, Y., Royden, L. H., Deng, Ch. and Xu, J., *The South Tibetan Detachment System, Himalayan Orogen: Extension Contemporaneous with and Parallel to Shortening in a Collisional Mountain Belt*, Geol. Soc. Am. Spl. Paper 269, 1992, p. 41.
7. Thakur, V. C., *Tectonophysics*, 1980, **62**, 141–154.
8. Windley, B. F., *Bull. Geol. Soc. London*, 1983, **140**, 849–865.
9. Le Fort, P., in *Collision Tectonics* (eds. Coward, M. P. and Ries, A. C.), Geol. Soc. Spl. Publ. 19, 1986, pp. 159–172.
10. Hodges, K. S., Hubbard, M. S. and Silverberg, D. S., *Philos. Trans. R. Soc. London*, 1988, **A326**, 257–280.
11. Jain, A. K. and R. M. Manickavasagam, *Geology*, 1993, **21**, 407–410.
12. Nanda, M. M. and Singh, M. P., *Himalayan Geol.*, 1976, **6**, 364–388.
13. Srikantia, S. V., Ganesan, T. M., Rao, M., Sinha, P. K. and Tirkey, B., *Himalayan Geol.*, 1978, **8**, 1009–1033.
14. Ganesan, T. M., Razdan, M. L., Razdan, R. K. and Muthu, V. T., *Contemp. Geosci Res Himalaya*, 1981, **1**, 177–188.
15. Fuchs, G., *Jb. Geol. B.-A.*, 1982, **125**, 1–50.
16. Honegger, K., Dietrich, V., Frank, W., Gansser, A., Thoni, M. and Trommsdorff, V., *Earth Planet. Sci. Lett.*, 1982, **60**, 253–292.
17. Srivastava, G. S., *Misc. Publ. Geol. Surv. India*, 1982, **41**, 259–271.
18. Vohra, C. P., Jangpangi, B. S., Mehrotra, P. C., Singh, D. P., Puri, V. M. K., Kaul, M. K. and Mehta, P., *Misc. Publ. Geol. Surv. India*, 1982, **41**, 56–63.
19. Baud, A., Gaetani, M., Garzanti, E., Fois, E., Nicora, A. and Tintori, A., *Eclogea Geol. Helv.*, 1984, **77**, 171–197.
20. Gaetani, M., Garzanti, E. and Jadoul, F., *Rend. Soc. Geol. It.*, 1985, **8**, 3–8.
21. Searle, M. P, *J. Struct. Geol.*, 1986, **8**, 923–936.
22. Kundig, R., *J. Metam. Geol.*, 1989, **7**, 43–55.
23. Pognante, U. and Lombardo, B., *J. Metam. Geol*, 1989, **7**, 9–17.
24. Staubli, A, *J. Metam. Geol.*, 1989, **7**, 73–93.
25. Thakur, V. C., Rawal. B. S. and Islam, R., *J. Himal. Geol.*, 1990, **1**, 11–25.
26. Gapais, D., Pecher, A., Gilbert, E. and Ballevre, M., *Tectonics*, 1992, **11**, 1045–1056.
27. Spring, L. and Crespo-Blanc, A , *Tectonics*, 1992, **11**, 978–989.
28. Searle, M. P., Waters, D. J., Rex, D. C. and Wilson, R. N., *J. Geol. Soc. London*, 1992, **149**, 753–773.
29. Patel, R. C., Singh, S., Asokan, A., Manickavasagam, R. M and Jain, A. K., in *Himalayan Tectonics* (eds. Treloar, P. J. and

Searle, M. P.), Geological Society Special Publication, 1993, pp. 445–459.
30. Bhanot, V. B., Pandey, B. K., Singh, V P. and Kansal, A. K., in *Stratigraphy and Correlation of Lesser Himalayan Formations* (eds. Valdiya, K. S. and Bhatia, S. B) Hindustan Publishing Corp , Delhi, 1980, pp 139–142.
31. Kwatra, S. K., Bhanot, V. B., Kansal, A. K., Kakar, R. K. and Hedge, C. E., in *Metamorphism, Ophiolites and Orogenic Belts* (ed. Saklani, P. S.), Today and Tomorrow's Printers and Publishers, New Delhi, 1989, pp. 277–289.
32. Pognante, U., Castelli, D., Benna, P., Genovese, G., Oberli, F., Meier, M. and Tonarini, S., *Geol. Mag* , 1990, **127**, 101–116.
33. Searle, M. P. and Fryer, B. J., in *Collision Tectonics* (eds. Coward, M. P. and Ries, A. C.), Geol. Soc. Spl. Publ. 19, 1986, pp. 185–201.
34. Pognante, U., *Mineral, Petrol.*, 1992, **46**, 291–313.
35. Searle, M. P. and Rex, A. R., *J. Metam. Geol.*, 1989, **7**, 127–134.
36. Le Fort, P., in *Tectonic Evolution of the Tethyan Region* (ed. Sengor, A.M.C.), Kluwer Academic Publishers, Dordrecht, 1989, pp. 289–386.
37. Essene, E., in *Evolution of Metamorphic Belts* (eds. Daly, J. S., Cliff, R. A. and Yardley, B. W. D.), Geol. Soc. Spl. Publ. 43, 1989, pp. 1–44.
38. Armstrong, R. L., in *Potassium Argon Dating* (eds. Schaffer, O. A and Zahringer, J.), Springer-Verlag, Berlin, 1966, pp. 117–133.
39. Zeitler, P. K., in *Evolution of Metamorphic Belts* (eds. Daly, J. S., Cliff, R. A. and Yardley, B. W. D.), Geol. Soc. Spl. Publ. 43, 1989, pp. 131–147.
40. Dodson, M. H., *Contrib. Mineral. Petrol.*, 1973, **40**, 259–274.
41. Wagner, G. A., Reimer, G. M. and Jager, E., *Mem. Ist. Geol. Mineral. Univ. Padova*, 1977, **30**, 1–27.
42. Dodson, M. H., *Nature*, 1981, **293**, 606–607.
43. Harrison, T. M., *Contrib. Mineral. Petrol*, 1981, **70**, 324–331.
44. Harrison, T. M., Duncan, I. and McDougall, I., *Geochim. Cosmochim. Acta*, 1985, **49**, 2461–2468.
45. Patriat, P. and Achache, J., *Nature*, 1984, **311**, 615–621.
46. Klootwijik, C., Gee, J. S., Peirce, J. W., Smith, G. M. and McFadden, P. L., *Geology*, 1992, **20**, 395–398.
47. Sahni, A., Bhatia, S. B., Hartenberger, J. L., Jaeger, J. J., Kumar, K., Suder, J. and Vianey-Liaud, M., *Soc. Geol. France Bull.*, 1981, **23**, 689–695.
48. Jaeger, J., Courtillot, V. and Tapponnier, P., *Geology*, 1989, **17**, 316–319.
49. Treloar, P. J. and Rex, D. C., *Tectonophysics*, 1990, **180**, 322–349.
50. Dallmeyer, R. D. and Rivers, T., *Geochim. Cosmochim. Acta*, 1983, **47**, 413–428.
51. Hubbard, M. S. and Harrison, T. M., *Tectonics*, 1989, **8**, 865–880.
52. Sorkhabi, R. B. and Stump, E., *GSA Today*, 1993, **3**, 85, 88–92.
53. Gansser, A., in *Zagros, Hindu Kush, Himalayan: Geodynamic Evolution* (eds. Gupta, H. K. and Delany, F. M.), American Geophysical Union Geodynamic Series, 1981, 3, pp. 111–121.
54. Valdiya, K. S , *Tectonophysics*, 1984, **105**, 229–248.
55. Hodges, K. V., Parrish, R. R., Housh, T. B., Lux, D. R., Burchfiel, B. C., Royden, L. H. and Chen, Z., *Science*, 1992, **258**, 1466–1470.
56. Treloar, P. J., Rex, D. C. and Williams, M. P., *Geol Mag.*, 1991, **128**, 465–478.
57. Zeitler, P., *Tectonics*, 1985, **4**, 127–151.
58. Chaudhri, R. S , in *Sedimentary Geology of the Himalaya* (ed Srivastava, R. A. K.), Today and Tomorrow's Publishers, New Delhi, pp. 1–14.
59. Itaya, T., Nagao, K., Inoue, K., Honjou, Y., Okada, T. and Ogata, A., *Mineral. J.*, 1991, **15**, 203–221.
60 Cox, A. and Dalrymple, G. B., *J. Geophys. Res.*, 1967, **72**, 2603–2614.
61. Steiger, R. H. and Jager, E., *Earth Planet. Sci. Lett.*, 1977, **36**, 359–362.

ACKNOWLEDGEMENTS. Japan's Ministry of Education is acknowledged for awarding a Monbusho Scholarship to R. B. S. to carry out this work as part of his Ph.D. thesis submitted to Kyoto University. R. B. S. is grateful to Messrs. T. Okada, H. Takeshita and S. Fukui of Hiruzen Research Institute, Okayama University of Science. Field work was made possible by the untiring help rendered by Messrs. Sandeep Singh, M. Dangwal, L. P. Singh, S. Misra and several residents in Zanskar. A. K. J. and Rm. M. acknowledge financial assistance from the Department of Science and Technology, New Delhi.

Received 10 May 1993; revised accepted 14 June 1993