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ACKNOWLEDGEMENTS. We are grateful to Prof. V. K. Gaur, Secretary and Shri H. P. Rajan, Director, Department of Ocean Development, New Delhi for sponsoring the work in Antarctica. The help rendered by Maj. Gen. Lalji D. Singh and Dr A. K. Hanjura is gratefully acknowledged.

Received 1 August 1992, accepted 15 September 1992

K/Ar hornblende ages from the Higher Himalaya: implications for the India–Asia collision and Himalayan metamorphism

Rasoul B. Sorkhabi, Arvind K. Jain*, Susumu Nishimura, R. M. Manickavasagam* and Edmund Stump**

Department of Geology, Arizona State University, Tempe, AZ 85287-1404, USA

*Department of Earth Sciences, University of Roorkee, Roorkee 247 667, India

**Department of Geology and Mineralogy, Faculty of Science Kyoto University, Kyoto 606, Japan.

Two amphibolite samples from the Higher Himalayan Crystalline (HHC) belt from the Suru Valley, Zanskar, have yielded Eocene K/Ar hornblende cooling ages between 40 and 45 Ma, thus indicating much older peak metamorphic conditions in northern parts of the Indian Plate. These ages are in conformity with almost identical ages from metamorphic complexes across the Nanga Parbat syntaxis in Pakistan and reveal a 65 to 70-Ma collision phase of the Indian indentor in the NW-Himalaya.

WITH the loftiest summits on Earth, the Himalaya is the epitome of mountains formed by continent-to-continent collision of the Indian and Eurasian plates during the Cenozoic[1–3]. Timing of the orogenic events of the Himalaya constitutes an important aspect of Himalayan geology. In this regard, isotopic ages provide a valuable tool. In this paper, firstly we report two hornblende K/Ar ages from the Higher Himalaya in the Zanskar region, N.W. India, and secondly, we synthesize the hornblende K/Ar and Ar40/Ar39 ages reported throughout the Higher Himalaya and analyse the data to put time constraints on the early stages of the thermo-tectonic evolution of the Himalaya.

The fundamental principle in applying radioactive clocks to thermotectonics is that while radioactivity itself is not affected by temperature, the stability of its record for various decay systems and mineral phases is mainly temperature-controlled[4]. The concept of closure temperature has been helpful in reconstructing the metamorphic and cooling history of orogenic belts, e.g. the Alps[5]. In high-grade metamorphic rocks where the thermal peak exceeds 550° C, K/Ar or Ar40/Ar39 ages on hornblende reveal the cooling history following the thermal peak of metamorphism[6]. This is due to the high closure temperature of hornblende, i.e. 525 ± 25 (ref. 7). This approach can be used to decipher the early history of the Himalayan orogeny.

The Higher Himalayan Crystalline (HHC) rocks (Figure 1) constitute the backbone of the Himalaya[8]. In the Himalayan orogeny and during the post-collisional period, the HHC has not only experienced the maximum uplift and crustal shortening but also forms the main metamorphic belt of the Himalaya[9], where deep-seated rocks now occupy high topography. These rocks have been well-exposed in the Zanskar region, Jammu and Kashmir State, where two amphibolites were collected among many samples during the field trip of summer 1987.

Hornblende separates from these rocks were dated by the K/Ar method at the Teledyne Isotope Laboratories. The analytical results are given in Table 1. The

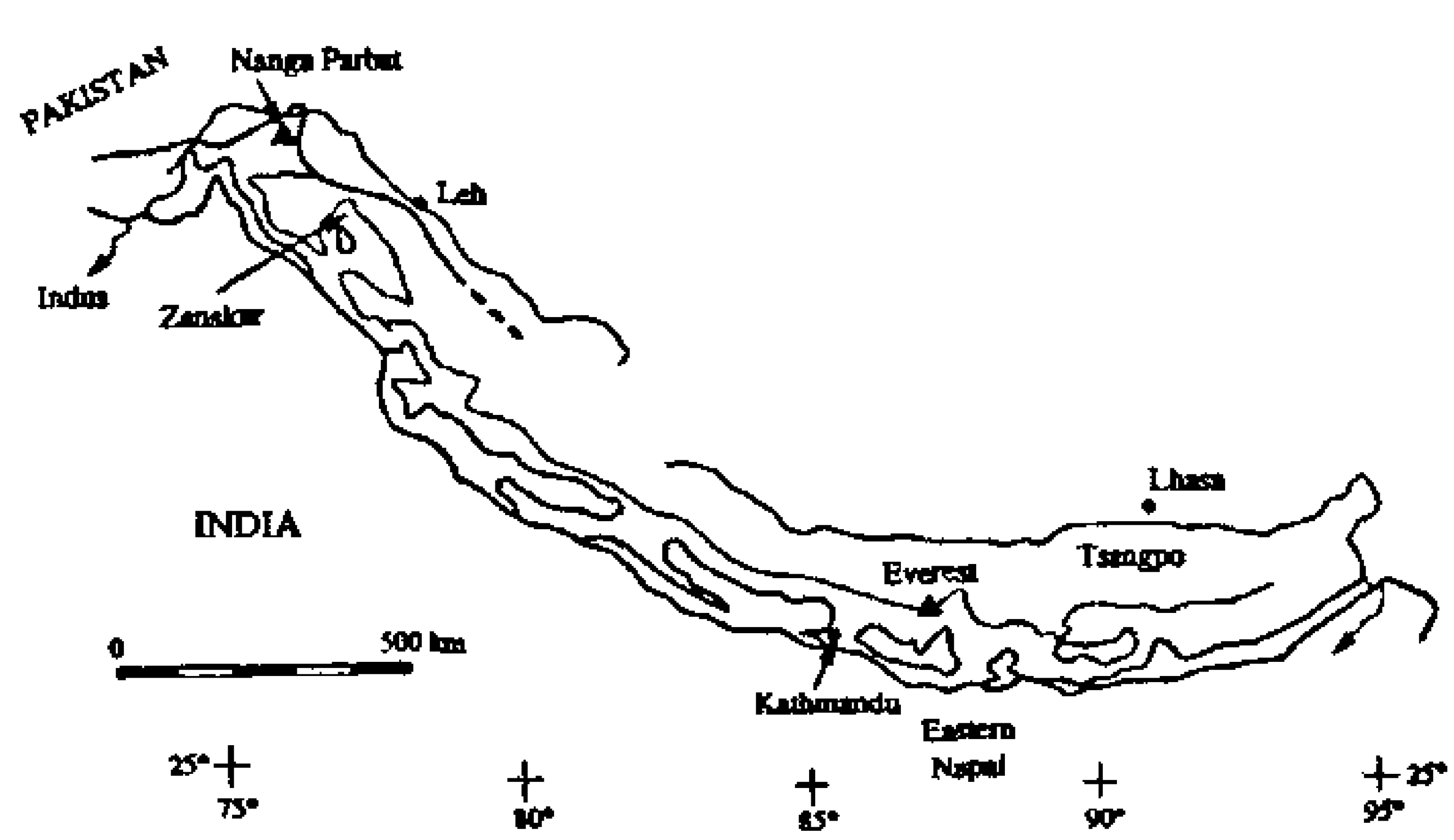

Figure 1. Sketch map of the Himalaya showing the Higher Himalayan Crystalline rocks.

Table 1. K/Ar analytical data of hornblende separates from two Higher Himalayan amphibolites in Zanskar, N. W. India.

Sample	Rad. Ar40 (scc/g × 10^5)	Non-radiogenic Ar (%)	Potassium (%)	Age (Ma)
S16-1				
	0.076	32.6	0.42	45.9 ± 3.2
	0.073	40.9	0.42	44.2 ± 3.3
	0.072	20.6	0.42	43.6 ± 3.3
	0.074	26.0	0.42	44.8 ± 3.2
				44.6 ± 3.3
S10F-1				
	0.112	63.1	0.57	49.9 ± 2.1
	0.117	65.1	0.58	51.2 ± 2.1
				50.5 ± 2.1

The age calculated for each sample and shown in bold is the arithmetic average of analyses.

obtained ages are 44.6 ± 3.3 Ma (for sample S16-1) and 50.5 ± 2.1 Ma (sample S10F-1). It is meaningful to consider these ages in the context of hornblende K/Ar and Ar40/Ar39 ages reported by other workers from the HHC rocks.

Some of the reported hornblende ages are pre-Himalayan and widely scattered (belonging to Mesozoic, Palaeozoic and even Precambrian times[10,11]). These ages are not necessarily indicative of thermotectonic events because they may carry excess argon. Moreover, if the samples are taken from low-grade rocks, the temperatures would not have been high enough to reset the K/Ar isotopic system. However, Ar40/Ar39 dates of 1800–2000 Ma on hornblende reported by Treloar and Rex[11] from basement gneisses may be indicative of a thermal event during the Proterozoic thermal event in the Indian terrain which has been well-documented by Rb–Sr isochrons[12].

In this paper, we concern ourselves with the Cenozoic hornblende ages. Maluski and Matte[13] have reported two Ar40/Ar39 hornblende ages of 44.7 ± 1 and 39.7 ± 1 Ma from the HHC rocks in Pakistan. From the same region, Treloar and Rex[11] have reported the following hornblende ages: 37, 53 ± 2, 35 ± 2, 40 ± 2, 65 ± 2, 48 ± 2, 63 ± 2 Ma. And recently, Chamberlain *et al.*[14] have reported two Ar40/Ar39 hornblende ages of 42.6 ± 1.1 and 39 ± 2.5 Ma from Pakistan. The hornblende ages determined by us for the amphibolites from the Zanskar region are concordant with those reported from Pakistan.

All these data indicate that the HHC rocks in the northwestern Himalaya were experiencing palaeotemperatures of 500–550° C during the Palaeocene and early Eocene times. However, most of the hornblende ages reported from the HHC rocks in eastern Nepal are younger. Krummenacher *et al.*[10] have reported two K/Ar hornblende ages of 20.2 ± 1 and 24 ± 1 Ma from the Everest region, and Hubbard and Harrison[15] have reported two Ar/Ar hornblende ages of 22.7 ± 4.4 and 20.9 ± 0.2 Ma. Figure 2 shows the histogram of the Cenozoic hornblende ages available for the HHC rocks. A question arises as to why such young hornblende ages are not found from the northwestern Himalaya in India and Pakistan.

We believe this has an important tectonic implication for the India–Asia collision and the Himalayan metamorphism. Considering the high grade metamorphism of the HHC rocks (amphibolite facies with thermal peaks of 650–750° C determined from thermobarometric methods[3]), the hornblende ages record cooling shortly after the thermal peak of metamorphism. Therefore, it appears that the Barovian-type regional metamorphism in the northwestern Himalaya is older than that in eastern Himalaya.

Since the Himalayan metamorphism was related to the continental collision between the Indian and Asian plates, the pattern of the hornblende ages is consistent with a tectonic model in which the collision took place obliquely, with earlier impingement in the northwestern

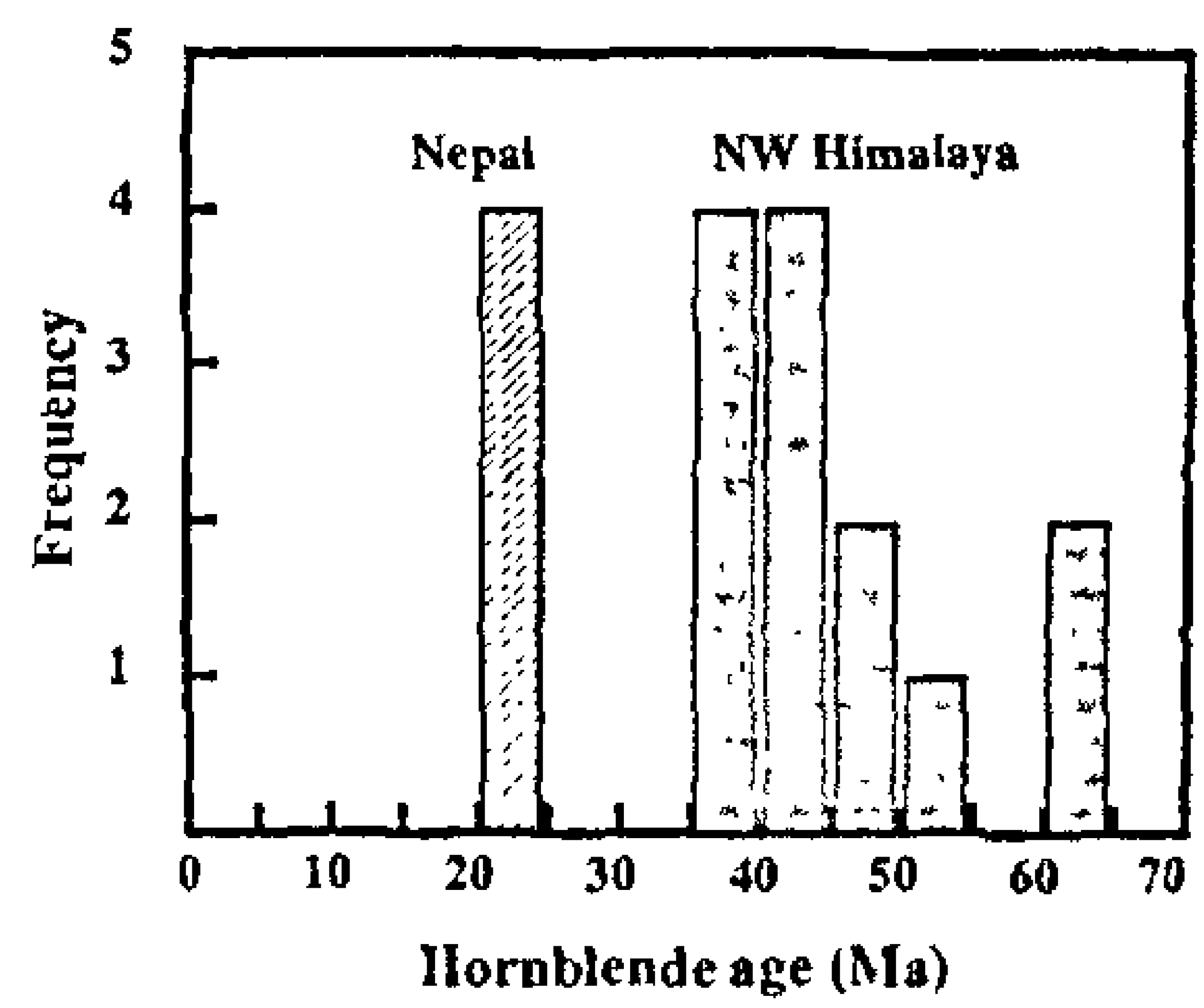

Figure 2. Histogram of the K-Ar and Ar40-Ar39 ages on hornblende reported from the Higher Himalayan Crystalline rocks. Only the Cenozoic ages are shown for the purpose of this paper.

Himalaya[16]. Palaeomagnetic studies also support such an interpretation. Recent palaeomagnetic data[17] for the northwestern Himalaya put the time of the India–Asia collision at ~60 Ma or even close to the K/T boundary as supported by palaeontological evidence for some link between India and Asia at that time[18,19]. Palaeomagnetic data for the eastern Himalaya demonstrate later collision at 45–50 Ma[20].

Assuming an early collision of the Indian plate on its northwestern margin close to the K-T boundary, an interesting point emerges from Figure 2. The peak of hornblende ages at 35–45 Ma for the northwestern Himalaya indicates that crustal thickening associated with the collision and subsequent thermal acme of the regional metamorphism were reached shortly after the collision. This interpretation has been given for the Indian plate crystalline stack in the Pakistan Himalaya[21]. The hornblende ages we report here for the HHC rocks in Zanskar agree with such a thermal history and can be explained considering the very fast drift of the Indian plate during the Cretaceous (18–20 cm/yr compared to the present rate of 4–5 cm/yr) and the substantial decrease in the drift rate during early Tertiary[17,20].

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ACKNOWLEDGEMENTS. This study was undertaken while R. B. S. was in Kyoto University, Japan. He would like to thank all friends in the Department of Geology and Mineralogy, Kyoto University, for kind hospitality, and members of the field party from University of Roorkee for a joyful trip to Zanskar.

Received 25 September 1992; accepted 30 September 1992

Ornithoid eggshells from Deccan intertrappean beds near Anjar (Kachchh), Western India

Sunil Bajpai, Ashok Sahni and S. Srinivasan
Department of Geology, Panjab University, Chandigarh 160 014, India

We describe here the ornithoid eggshell fragments from the Deccan intertrappean beds (Late Cretaceous) near Anjar, district Kachchh, Gujarat. The find assumes palaeobiogeographic significance as morphologically similar eggshells are known from the Late Cretaceous Nemegt Formation of Mongolia. Taxonomic affinities (dinosaurian/avian) of these eggshells cannot be established at present.

DOCUMENTATION of dinosaur (sauropod) egg clutches from Late Cretaceous Lameta Formation of central and western India has increased considerably in recent years[1–5]. However, the record of ornithoid (or avian-like[6]) eggshells was so far restricted to Pleistocene deposits where they have been referred to the ostrich *Struthio* cf. *S. asiaticus*[7]. Here we describe such eggshells from the Deccan intertrappean beds at a locality about 1.5 km SE of the village Viri (23° 4′ 50″ N: 70° 30′ E) near Anjar, district Kachchh, Gujarat (Figure 1). This record, of which a brief mention was recently made[8], follows the discovery of dinosaur bones in the same general area[9].

The eggshell-yielding bed comprises dark grey splintery shale containing stringers of chert. In the local flow stratigraphy[9], it occurs between the third and fourth lava flows, representing the third intertrappean level in the area (Figure 1). Screen-washing of these shales yielded a diverse assemblage of eggshell fragments including those of sauropod dinosaurs and geckonid lizards, besides the most abundant ornithoid