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Quaternary tectonic history of northwest Himalaya

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Birbal Sahni's deduction that the Kashmir Himalaya did not form an effective barrier to movements of Palaeolithic–Neolithic man has been amply corroborated by recent neotectonic studies. Experiencing oblique compression and resultant large-scale thrusting, rotation and uplift of faulted blocks, the seismically active northwest Himalaya was a gentle terrain of low relief—possibly less than a thousand metres above sea level—enjoying mild climate. This is borne out by fossils of plants and large-sized heavy mammals, besides stone artefacts and unburnt wood entombed in the deposits of tectonically formed/related lakes in the Kashmir, Ladakh and Gilgit basins. It was only in the Holocene period that the terrain became difficult and formidable mountain barriers rose up rapidly due to block faulting. The Pir Panjal seems to have risen up by 2700–3000 m since the Middle Pleistocene at a rate ranging from 3.5 mm yr^{-1} to 10 mm yr^{-1}. In addition to 15 km lateral shift during the Quaternary period along an active transverse fault, the total uplift—tectonic accommodation—of the Nanga Parbat–Haramosh massif in the last 6–8 Myr is of the order of 15–25 km. The uplift of the massif is continuing at the rate of 5 mm yr^{-1}.

DRAWING on the streams of palaeontological, archaeological and structural evidence, Birbal Sahni[1,2] admirably summed up the Quaternary tectonic history of the Kashmir Himalaya: '... intercourse between these two ancient countries [India and China] was possible *by the direct route across the Himalayas*, which, during Palaeolithic and Neolithic times, were probably not so high as to form an effective barrier' to the movements of primitive man. It was only after the Stone-Age people had established themselves comfortably in settlements nestling in the then gentle terrain of low relief and mild climate—the Valley of Kashmir—that the Pir Panjal rose to its present height (3600–4600 m), terminating free intermigration between the North Indian plains and Tibet.

Sahni's[2] deduction is well confirmed through recent studies on neotectonism in the northwest Himalaya (Figure 1). The movements taking place on active faults[3–6] and the recurrent high seismicity[7] leave no

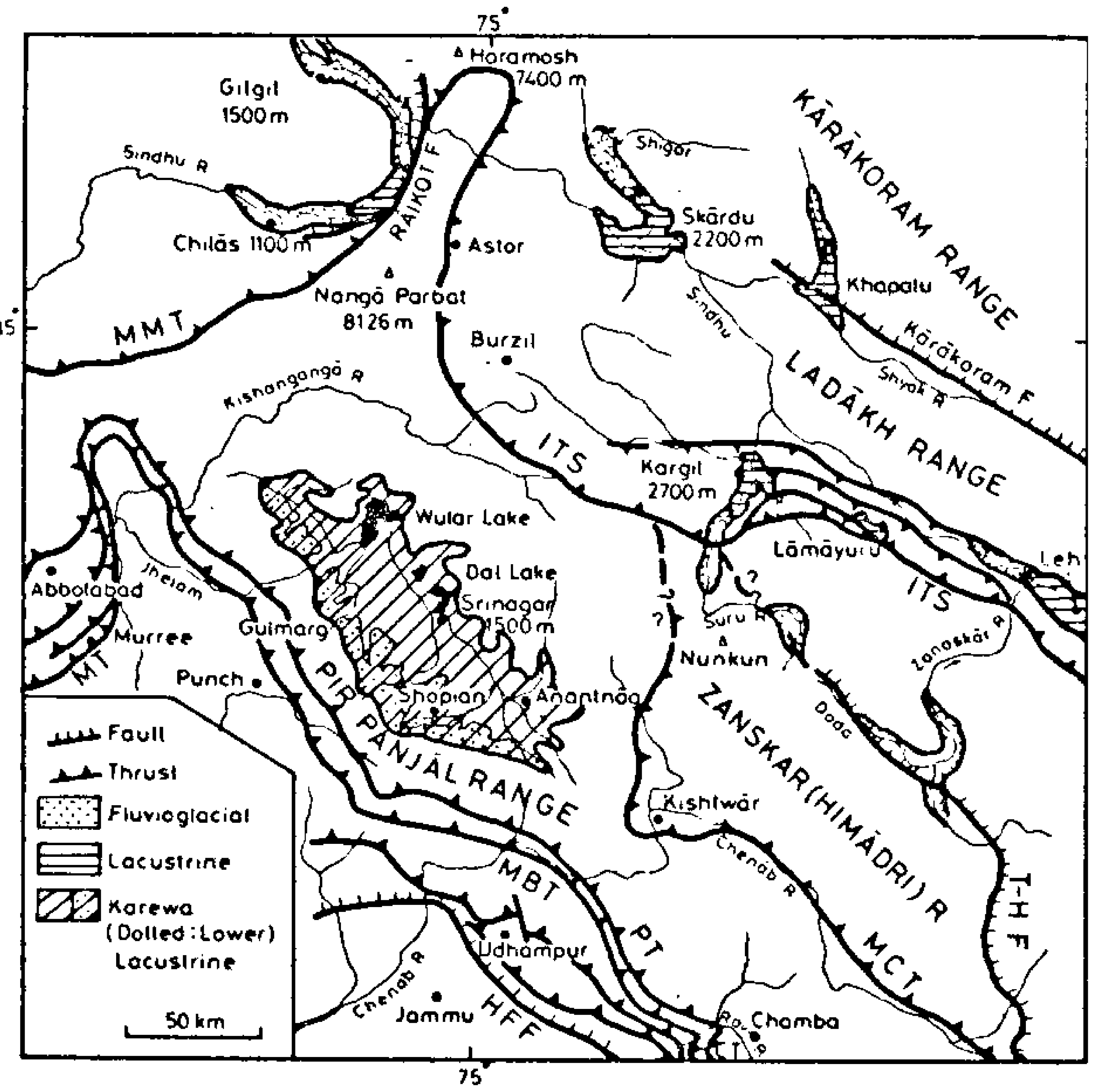


Figure 1. Tectonic set up of the northwest Himalaya and location of lacustrine and fluviolacustrine/fluvioglacial deposits of the Quaternary period. (HFF, Himalayan Frontal Fault; MBT, Main Boundary Thrust; MT, Murree Thrust; PT, Panjal (≡ Chail) Thrust; MCT, Main Central Thrust; T-HF, Trans-Himadri Fault; ITS, Indus-Tsangpo Suture; and MMT, Main Mantle Thrust.) (Based on Valdiya[5,6], Thakur[29], Thakur *et al.*,[30] and Bürgisser *et al.*[31])

doubt that this crucial segment of the Himalayan convergence zone is experiencing oblique compression and resultant large-scale thrusting, rotation and uplift of lithotectonic blocks (Figures 3 and 4). Stone-Age man was a witness to the rapid movements which converted a once gentle terrain of low relief and congenial environment into one that is formidable and inhospitable.

Karewa lake: origin and obliteration

Situated 1700–1800 m above sea level between the ruggedly lofty Zanskar (Himadri 4500–6100 m) and Pir Panjal (3600–4600 m) ranges, the Kashmir Basin is a product of ponding of a pre-existing river system. The damming occurred due to tectonic movements of the Pir Panjal along active faults of the Main Boundary Thrust (MBT) zone (Figures 1, 3, 4). The resultant lake was rapidly filled by sediments eroded from the steepened slopes of the uplifted mountain ranges. Beginning about 4 Ma, the 1300-m-thick succession of lacustrine and fluvio-deltaic sediments, described as the *Karewa Group*[8–12] was deposited at a rate (Figure 2) varying from 16 cm 1000 yr^{-1} to 64 cm 1000 yr^{-1} (ref. 13).

The quiet lacustrine sedimentation was frequently interrupted by violent, though sporadic, episodes of debris avalanches and slides—represented by conglomerates (Figure 2)—on the north-facing slope of the Pir Panjal (i) 3.5–3.0 Ma, (ii) 2.7 Ma, (iii) 2.1 Ma and (iv) 1.7 Ma (ref. 13).

The tectonic events in the mid-Olduvai epoch (in the magnetic polarity scale) at 1.6–1.7 Myr are particularly significant as they caused reversal of drainage from SW to NE in the Karewa Basin. Probably these were the events which led to emplacement of an enormous volume of very coarse debris of the Upper Siwalik Boulder Conglomerate in the Jammu region to the south of the uplifted Pir Panjal. Significantly, the base of the Boulder Conglomerate is dated 1.6 Myr (ref. 14).

The neotectonic movements of the Pir Panjal not only caused folding and northward tilting of the Lower Karewa and development of 'margs' at the elevation of 3000–3500 m (ref 10), but also the shrinking of the Karewa Lake and its confinement to the northern part. Continuing movements in the Late Pleistocene ($\sim$ 200,000 yr BP) culminated in the opening of the Baramula gorge[11] and final obliteration of the lake.

The undisturbed Upper Karewa sediments are covered by a mantle of eolian loess—25 m thick on the

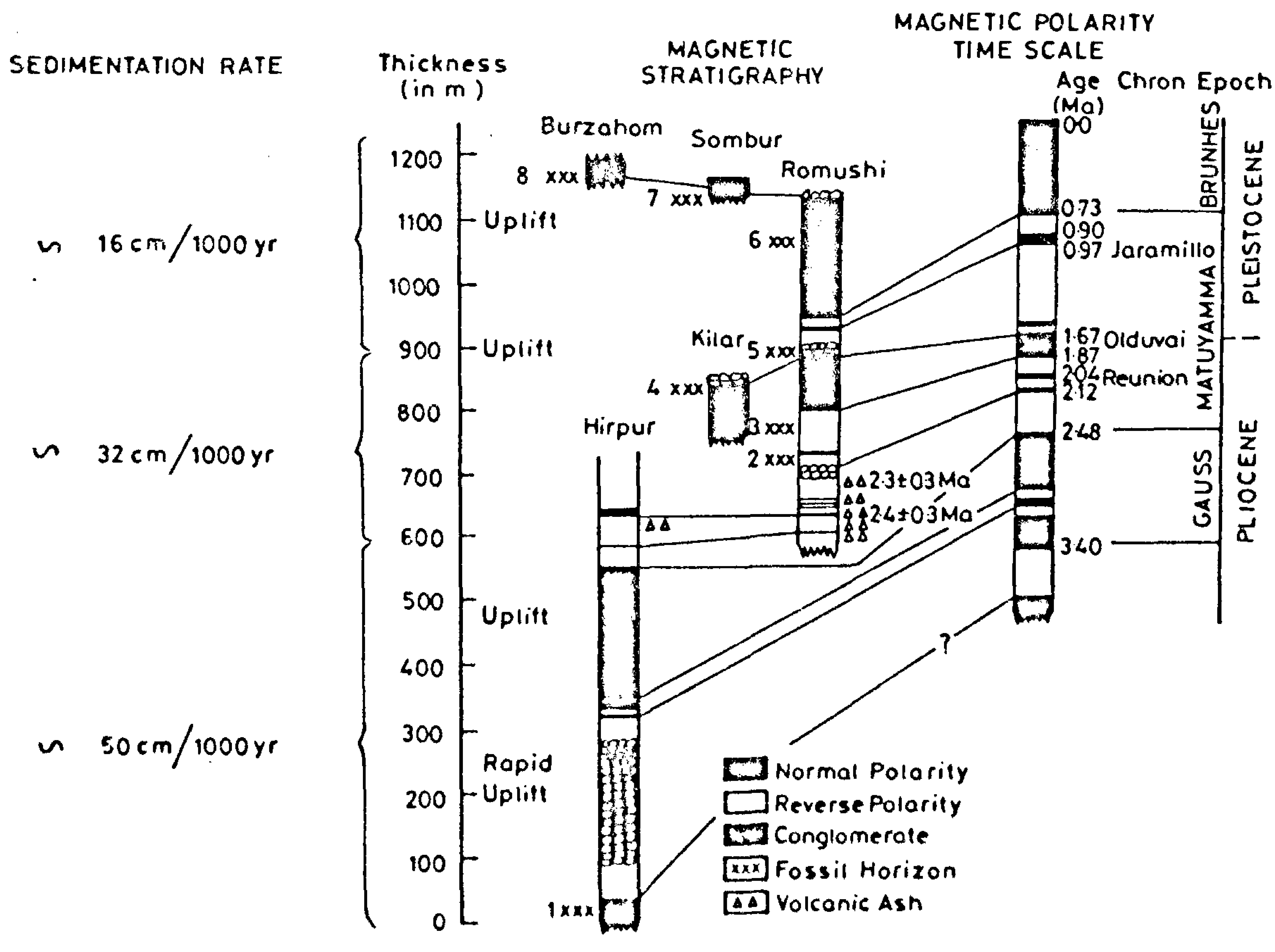
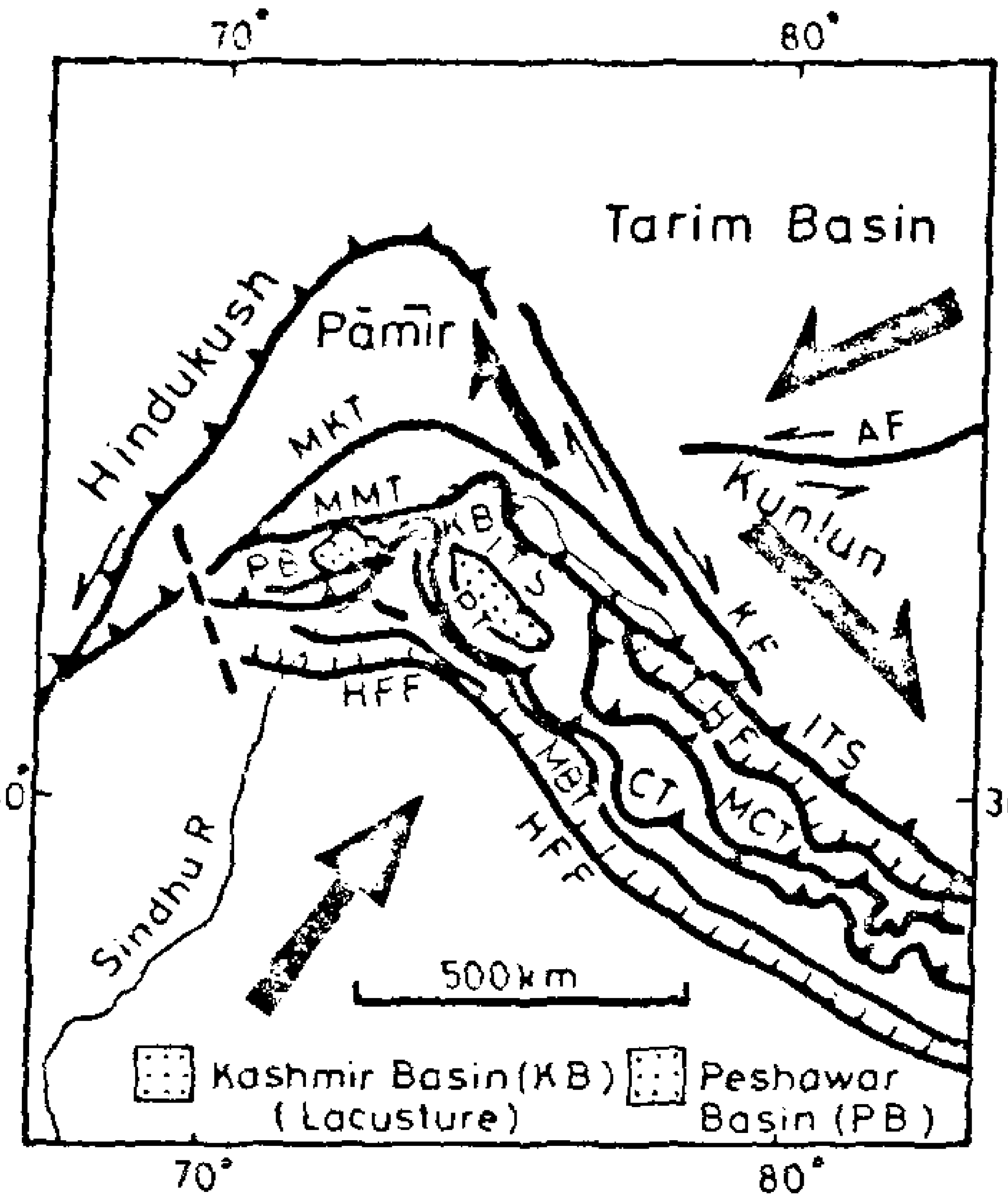


Figure 2. Correlation and chronostratigraphic positions of the horizons of crucial vertebrate fossils in the Karewa Group, Kashmir Basin. The conglomerates represent events induced by sudden uplift of the Pir Panjal Range. (Localities: 1, *Hexaprotodon*; 2, *Cervus punjabiensis*; 3, *Equus sivalensis*; 4, *E. sivalensis*; 5, *Cervus sivalensis*; 6, *Elephas hysudricus*; 7, *E. hysudricus*; 8, *Canis vitastensis*.)



· 3. Neotectonic movements in the northwest Himalaya—a of continuing convergence of the Indian and Asian plates. Altyn Tagh Fault; MKT, Main Karakoram Thrust; KF, Kara- Fault; MMT, Main Mantle Thrust; ITS, Indus-Tsangpo ; T-HF, Trans-Himadri Fault; MCT, Main Central Thrust; anjal Thrust; CT, Chail Thrust; MBT, Main Boundary Thrust; Himalayan Frontal Fault.)

western side and 10 m on the northeastern[15,16]. al horizons of palaeosols within the loess ssion indicate prolonged spells of warm humid tions. The last three palaeosol horizons fall in the of 25,000 years[17].

Testimony of plant fossils

The occurrence of remains of temperate plants in the Karewa sediments[18] implies that the lake basin lay at a lower altitude, and had mild temperate climate in the Plio-Pleistocene times. Across the Zanskar Range, the Sindhu Valley likewise had warmer moist conditions, obviously at a considerably lesser altitude. This is borne out by the occurrence of palms like *Sabal major* and *Livistona*, besides charophytic gyrogonites in the Hemis Conglomerate of the Oligocene age[19,20]. Likewise, the fan palm, *Trachycarpus*, recovered from the Liyan (≡ Kargil) Formation[19], further corroborates this deduction. As the modern analogues of these plants do not occur above 2100 m, their presence at the present elevation of over 5000 m implies uplift of the order of 3000 m since the upper Oligocene times.

Evidence of vertebrate fossils

The vertebrate fossils corroborate even more tellingly the uplift of the Sindhu and Karewa Basins. The large-sized heavy mammals such as *Hexaprotodon* (hippopotamus) found at the base of the Lower Karewa (Figure 2), *Rhinoceros*, *Sivatherium* and *Elephas* in the sediments encompassed by the uppermost Matuyama–Brunhes epoch (~ 0.9 to 0.6 Ma[21] could not have lived and flourished except in a low-altitude gentle terrain enjoying humid hot climatic conditions. The beginning of colder period in the Middle/Late Pleistocene, and the occurrence of Holarctic elements (arvicolids) such as *Kilarcola* and *Microtus*[21] followed the accelerated

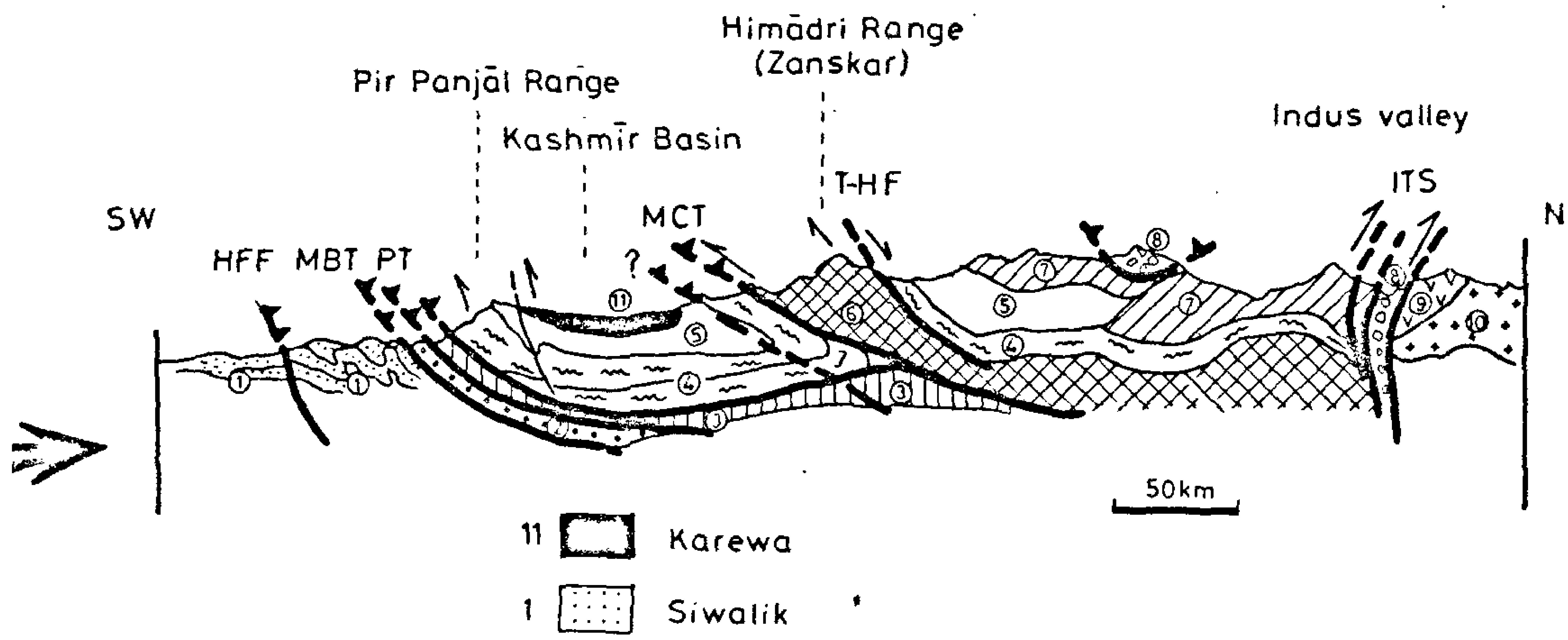


Figure 4. Diagrammatic cross-section of the northwest Himalaya (based on Thakur[29]) explaining neotectonism. (1, Siwalik; 2, Murree; 3, Palaeozoic of Kashmir Basin; 4, Salkhala-Haimanta epimetamorphics; 5, Palaeozoic-Mesozoic succession of Tethys Himalaya; 6, Vaikrita Zanskar crystallines (basement); 7, Lamayuru Nindam succession (Triassic-Cretaceous); 8, Ophiolites and ophiolitic melanges of the obduction zone; 9 and 10, Volcanics and plutonics, respectively, of the collision zone. HFF, Himalayan Frontal Fault; MBT, Main Boundary Thrust; PT, Panjal Thrust; TT, Tethys Thrust; MCT, Main Central Thrust; T-HF, Trans-Himadri Fault; I-TS, Indus-Tsangpo Suture.)

tectonic movements along faults of the MBT zone around 1.7 Ma.

Likewise, in the Sindhu Valley in Ladakh the occurrence of terrestrial vertebrates, including ctenodactyles, rodents, boid snakes, artiodactyles (*Cryptomeryx* and *Lophiomeryx*) and small to medium-sized mammals in the basal part of the Oligocene Kargil molasse, not only implies prevalence of congenial environmental conditions, but also their migration from or to Eurasia[22].

Interestingly, the Kargil molasse bears remarkable lithological and faunistic similarities with the Murree Group of the Jammu Hills; and the Nagrota Formation of the Upper Siwalik contains—like the Karewas—large-sized heavy mammals like *Hexaprotodon, Stegodon, Archidiskodon, Elephas*, etc[23]. This indicates that the Karewas of the Kashmir Basin and the Upper Siwalik of the Jammu region were probably at the same altitudinal level, enjoyed similar climatic and environmental conditions, and were easily accessible and mutually connected during the period ending 0.22 Ma.

Witness—Stone-Age man

As adumbrated by Birbal Sahni[2], the Upper Palaeolithic to Neolithic artefacts in the Upper Karewas at Pampur (near Srinagar) indicate that the tectonic upheaval lifting up the lacustrine sediments to great heights was witnessed by Stone-Age people. The human settlements must have thrived during optimum (subtropical to temperate) climatic conditions[12].

Thin layers of 6710 ± 130-yr-old charcoal with unburnt wood in the fireplace (stone 'chulha') and with pieces of animal bones embedded in the fluvial sediments near Gaik in the Sindhu Valley (100 km east of Leh)[24] demonstrate that the primitive human settlements extended as far north as Ladakh, and were presumably linked with the contemporary civilization in China and Central Asia.

This extensive spread of the Stone-Age civilization in the northwest Himalaya in the period 4200–7000 yr BP means that the climatic conditions were very congenial and the terrain was hospitably gentle—peneplaned surface of low relief just less than a thousand metres above the sea level.

Geomorphological evidence shows that until major fault movements occurred during the Pleistocene times, the Tibetan plateau also was a peneplaned surface of low relief, just a few hundred metres above the sea level, with humid climatic conditions[25]. Neotectonic uplift of the fault blocks resulted in the development of antecedent drainage, shaping of the present rugged terrain and ushering the frigidly cold climate of the high plateau.

It is obvious that until the Neolithic times, not only the Tibetan plateau but also the northwest Himalaya, including Jammu–Potwar region in the outer belt, were readily accessible to primitive people and large-sized heavy mammals which migrated along negotiable pathways. It is only in the Holocene period that the terrain became difficult and forbidding, as formidable mountain barriers rose up rapidly due to block faulting.

Movements on active faults

The northwest Himalaya is seismically one of the most active parts of the Himalayan province. Kashmir has been rocked by major earthquakes in very recent historical times—1669, 1780, 1828, 1885, 1937 (Srinagar), and 1947 (Bhadarwah). The one that occurred at Badgam 25 km west of Srinagar in 1885 had the intensity of IX or X on the MM scale. The disastrous April 4, 1905 Kangra earthquake (M 8.6) occurred on the southeasterly extension of the Pir Panjal.

The Nanga Parbat–Haramosh massif in the northwestern extremity of the Zanskar Range (Figure 1) has risen up in the geologically recent times—quite after the establishment of the Sindhu drainage of geomorphic maturity. This is evident from the folding, overturning and under-thrusting of even the youngest fluvioglacial sediments in the Sindhu Valley crossed by the Raikot Fault[4,26]. According to Madin *et al.*[4], "as much as 15 to 25 km of uplift has been accommodated across a zone that averages 20 to 40 km wide and locally is as narrow as 10 km". The total uplift in the last 6–8 Myr is of the order of 15–25 km, in addition to 15 km lateral offset in the Quaternary period of the Sindhu River across the active Raikot Fault[4]. The uplift is still continuing at the rate of 5 mm yr^{-1} (ref. 27).

The movements on active faults triggered big landslides and debris glacial avalanches on an extensive scale. This phenomenon resulted in damming up of river courses and formation of lakes upstream in the Gilgit, Hunza, Sindhu and Zanskar Valleys (Figure 1). The lacustrine deposits in Skardu, for example, represent temporary impoundment some time between 3.2 and 0.7 Ma, of the Sindhu River in the faulted Karakoram terrain[3]. The Lamayuru lake at an altitude of 3600 m in Ladakh was created by a landslide more than 35,000 years ago[28]. The 200-m-thick sediments of the lake (which persisted until 500–1000 yr BP) entomb such Karewa-like remains as charophytes, ostracodes and gastropodes, which indicate strong biological activity in presumably more congenial climatic conditions. Rossettes of gypsum in the sediments indicate prevalence of intermittent evaporitic conditions[28].

The Pir Panjal Range, as already explained, has been rising as a result of movements along the faults of the very active MBT zone[5,6]. On the north-facing flank of the Pir Panjal, the altitudinal differences between the elevated-tilted remnants of the Lower Karewa and the Lower Karewa of the downstream Romushi Valley imply movements of the order of the 1400 to 1700 m, and thus an inferred uplift of 2700–3000 m since the Middle Pleistocene at a rate varying between the 3.5 mm yr^{-1} and 10 mm yr^{-1} (ref. 13). Comparable is the rate of uplift of the Nanga Parbat–Haramosh massif, that is, 5 mm yr^{-1} (ref. 27).

The uplift of the northwest Himalaya is due to oblique compression across the plate margin, causing large-scale underthrusting and rotation along the boundary thrusts such as the Main Boundary Thrust, Main Central Thrust, Trans Himadri Fault, Indus-Tsangpo Suture (Figures 1, 3, 4). The thrusting on these thrusts is translated into dextral strike-slip movements along transverse faults, and attendant uplift of the overthrust blocks (Figure 4).

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