

The sandstone pebbles derived from the Dagshai-Kasauli start appearing in the Tatrot Formation of Patiali Rao (dated about 2.5 m.y.), increasing in number upwards and attaining dominance in the Boulder Conglomerate (dated approximately 0.6 m.y.). The deposition of the Boulder Conglomerate in this region was accomplished mainly by the foredeep-fed fluvial system.

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# Uplift and geomorphic rejuvenation of the Himalaya in the Quaternary period

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Until Neolithic times in the middle Holocene, the populated Lesser Himalaya was a gentle terrain of low relief, less than a thousand metres above sea level, and the Stone-Age people freely migrated across the Himalayan domain, both to north and south. Still earlier, even large-sized heavy mammalian animals like hippopotami, rhinos and elephants lived in and around the lakes, which were formed due to neotectonic movements on faults in Kashmir, Kathmandu, Jammu Siwalik and Potwar basins, now separated by very high mountains. The lofty mountain barriers developed after the Neolithic times, obviously due to Recent movements—at the rate of 3.5 to 10 mm/yr in Pir Panjal Range—on faults of the Main Boundary Thrust Zone. Likewise, the Great Himalayan rampart emerged as a consequence of rapid movements at the rate of 0.7 to 1.1 mm/yr along imbricating thrusts of the Main Central Thrust Zone. The old, mature terrain of the Lesser Himalaya was lifted up episodically leading to its geomorphic rejuvenation.

The Siwalik Zone in the south is being squeezed up at

a rate of 0.8 to 1.0 mm/yr between the very active Main Boundary Thrust and Himalayan Frontal Fault and on faults and thrusts which split the Siwalik. Intermittent movements on these faults have resulted in ponding of rivers and formation of lakes upstream of active faults. Rapidly filled up lakes of this kind are now represented by intermontane flat stretches called the 'duns'. Tilting and faulting up—at least in three episodic pulses—of these 'duns' of Upper Pleistocene to Holocene ages imply very recent movements.

The neotectonism of the Himalaya is attributed to northward push of the Indian plate underthrusting the Himalayan province, which reactivated the intra-crustal boundary thrusts and faults.

## Mature topography of Lesser Himalaya

Looking from a high point in the Lesser Himalaya sprawling between the lofty Great Himalaya and Siwalik ranges one is struck by its remarkably gentle

topography. The terrain is characterized by wide flat stretches of undulating plains 1300 to 1500 m above the sea level, rounded mountains having striking evenness of summit levels and very gentle slopes (Figure 1) and extraordinarily wide valleys in which streams flow windingly or even tortuously (Figures 2 and 3). The gentler slopes and undulating tracts wear thick mantles of soil that once supported lush vegetation. These features indicate the advanced stage of peneplanation the Lesser Himalayan subprovince had attained not in a distant geological past when climatic conditions were quite congenial.

### *Populated since pre-historic times*

It is but natural that such a gentle terrain, with thick productive soils and having congenial climate should be populated by humans. What is significant is that this terrain has been populated by people since possibly the Palaeolithic times. This is borne out by the finds of stone artefacts, cave dwellings stone-hearths with pieces of charcoal, animal bones, and burial sites over extensive region stretching from Swat-Dardistan in Pakistan to West Nepal. The archaeological remains of

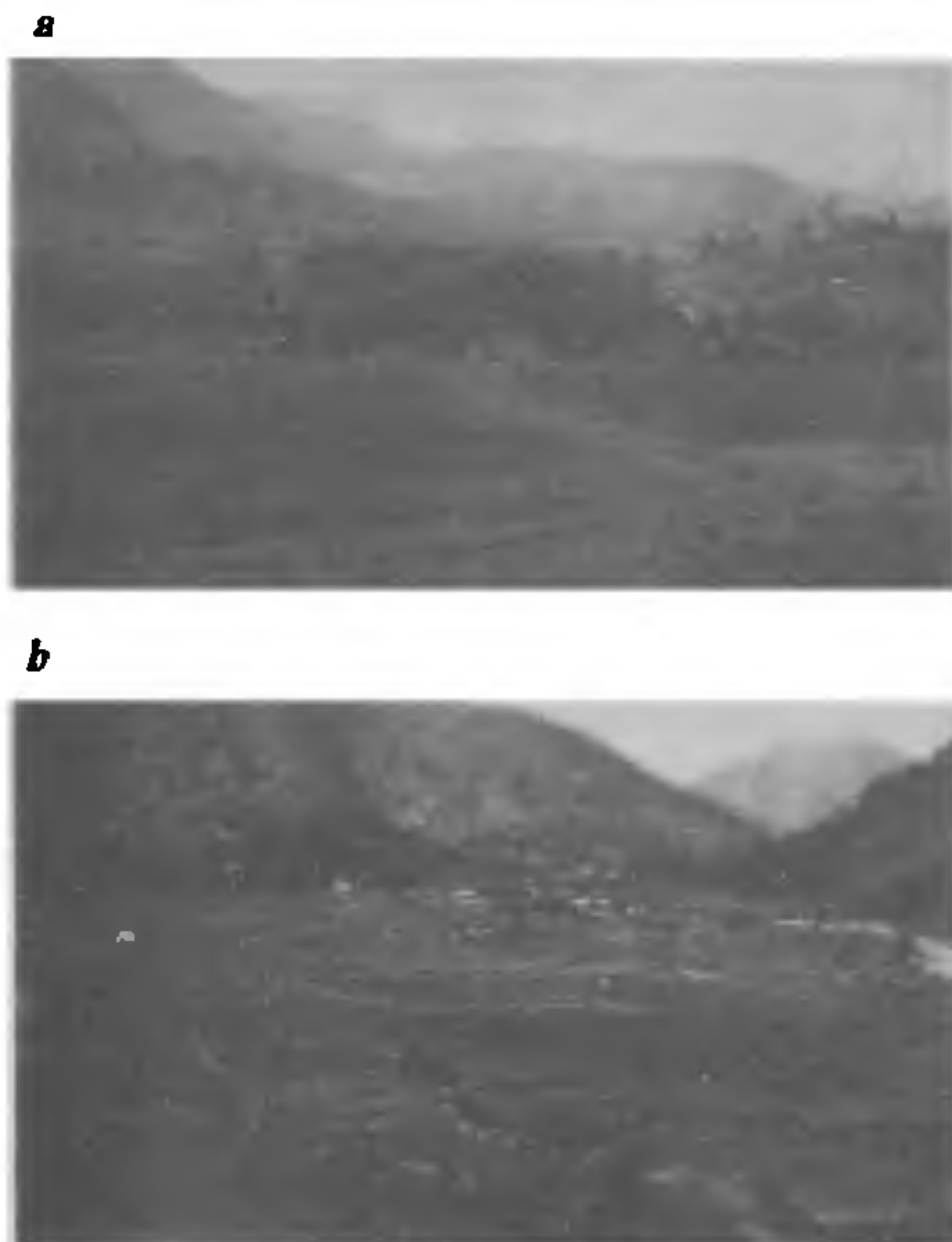


Figure 1. Wide stretches of undulating plains and wide valley bottoms have thick soil cover. *a*, Naini-Saini (Sor) Valley, Pithoragarh District. *b*, Upper reaches of the Kosi valley, Almora District.

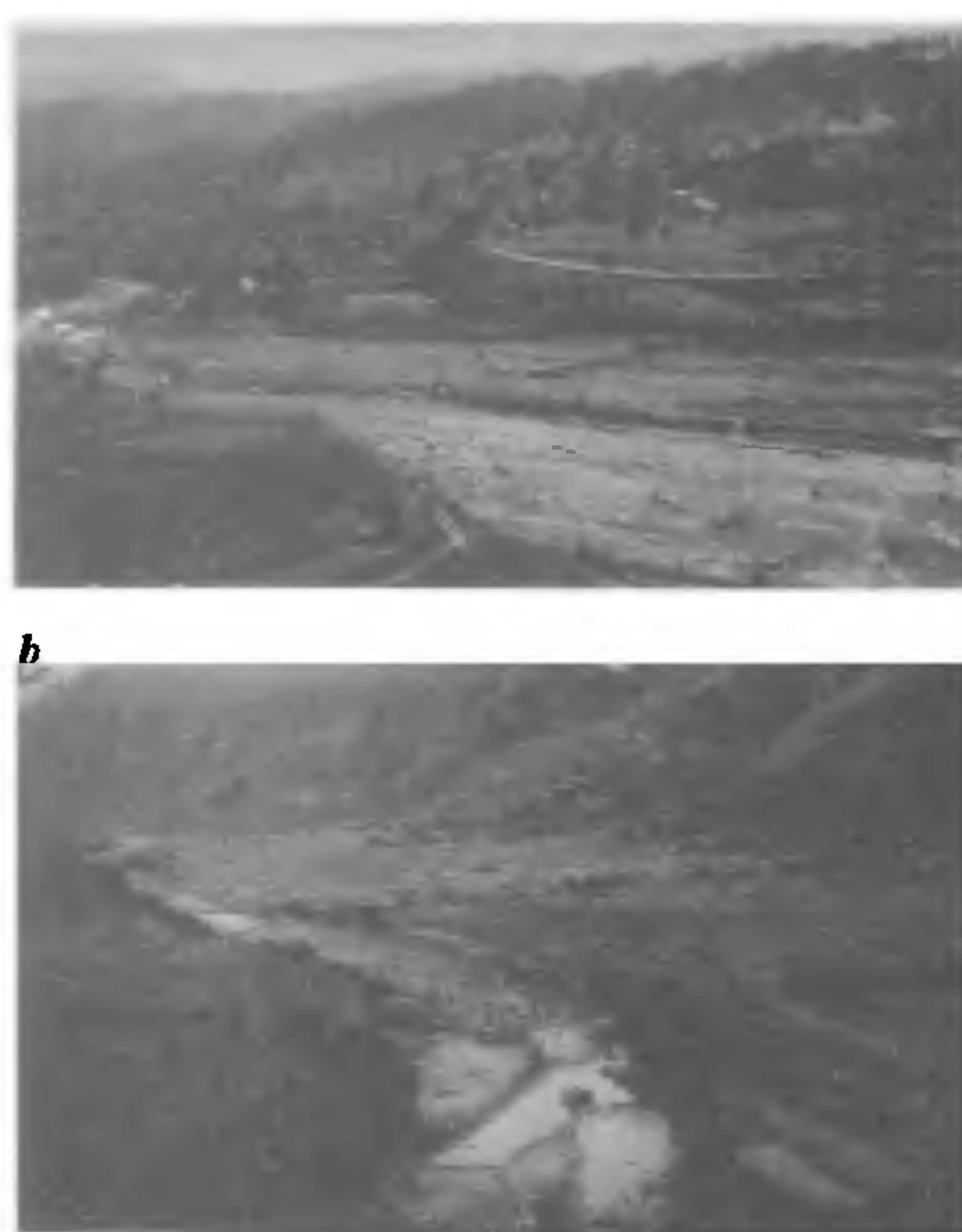
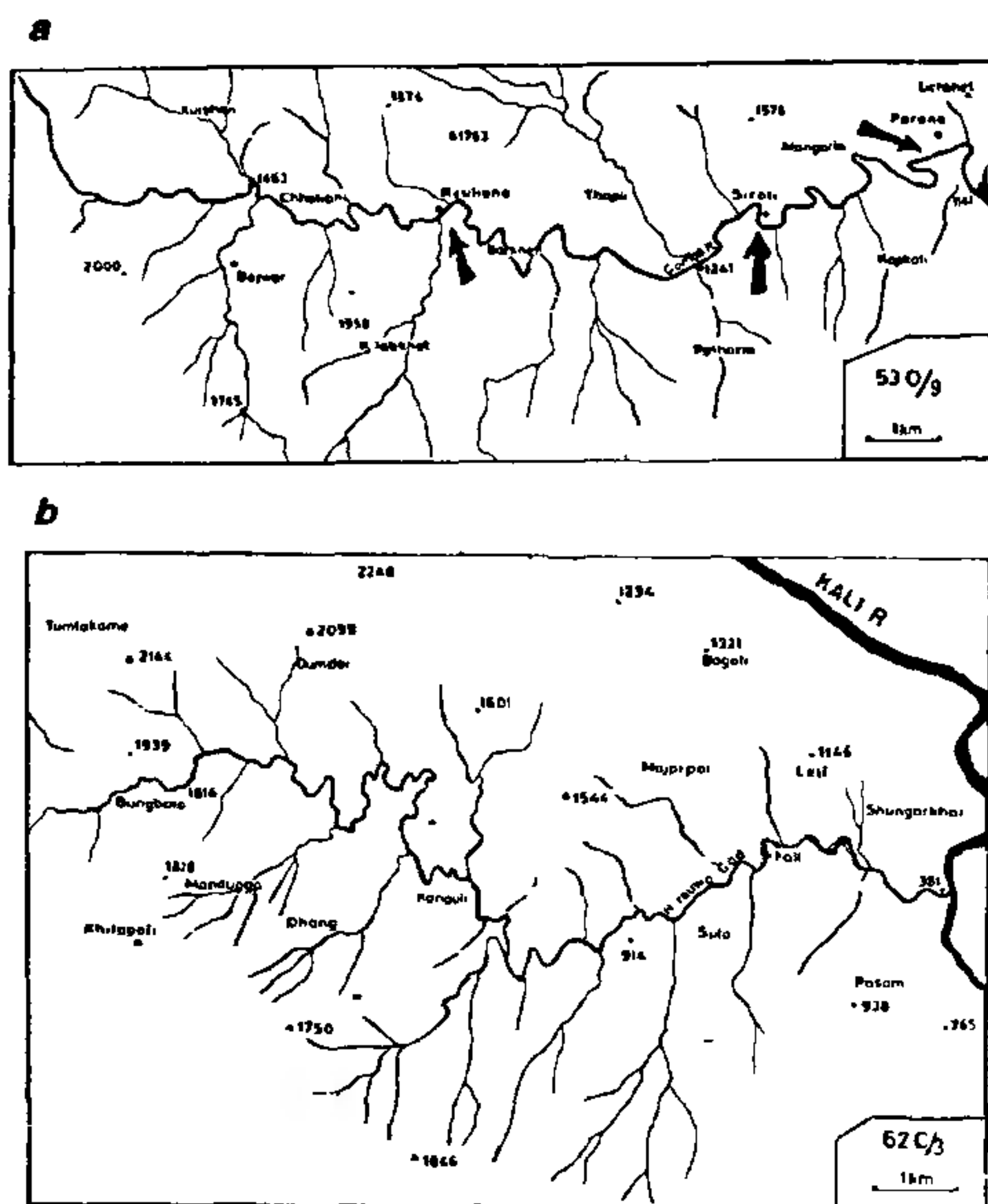


Figure 2. Wide valleys and winding or meandering streams of the mature old terrain in the Lesser Himalaya: *a*, West of Dangoli-Wajyula (Bajinath) area in central Kumaun. *b*, Kosi River near Someshwar, District Almora.

the Palaeolithic civilization have been found in the second fluvial terrace near Shrinagar in the Alaknanda valley (Figure 4) in Garhwal<sup>1</sup>, and near Pahalgam in the Liddar valley (Kashmir) and in the Soan valley in Potwar (Pakistan)<sup>2,3</sup>. Likewise, in the southern Siwalik terrain Palaeolithic finds have been located near Dera Kharauni and Chandi Mandir in the Ghaggar valley, near Nalagarh in the Sirsa valley, near Guler in the Banganga valley in Kangra district (Himachal Pradesh), and at a number of places in the Kathua area (Jammu).

The now desert expanse in western Rajasthan supported widespread human civilization in the Mesolithic times<sup>4</sup>. Contemporary stone implements have been found in the outer Siwalik terrain of the Soan valley (Potwar), in the Kangra area (H. P.) and in West Nepal<sup>5</sup>. The Neolithic people lived in pits with wooden superstructures of sort on the Karewa terraces in the Burzahom-Pampur-Anantnag belt in Kashmir. The charcoal pieces recovered at Burzahom are dated  $4325 \pm 115$  yr B.P.<sup>7</sup>. Remains of the contemporary civilization in the Siwalik terrain have been located in the valleys of Tarnah, Ben, Chenab (Akhnoor), Beas (Dehra and Nadaun), Ravi (Karrow), Banganga (Ror) and Sirsa (Pinjaur-Nalagarh); and in the Lesser Himalayan belt in

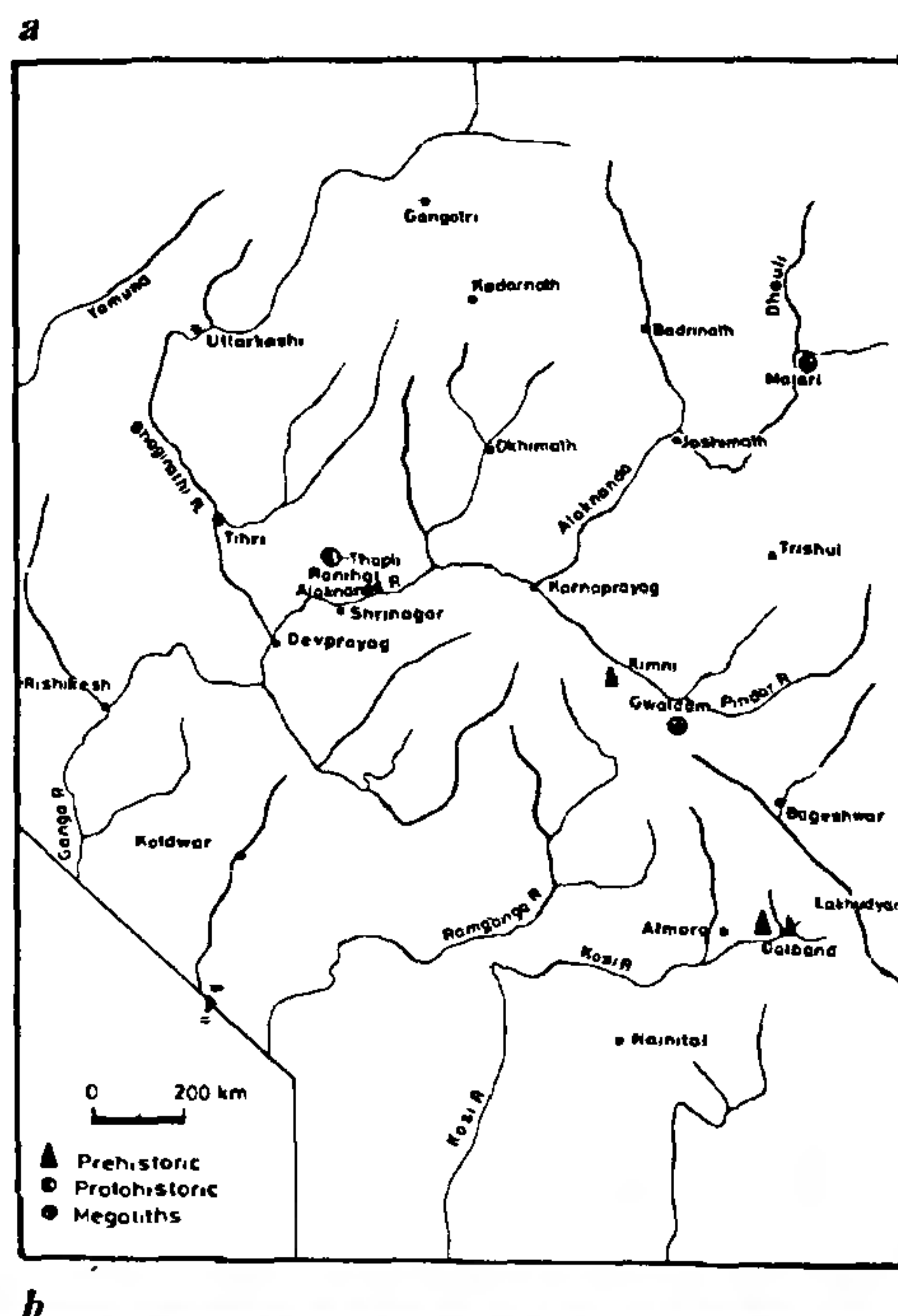


**Figure 3.** Winding streams flowing in wide valleys characterized by twists and curves in deeply dissected (rejuvenated) terrain, the arrows indicating meander loops. *a*, Gomati, a tributary of the Saryu River in central Kumaun. *b*, Hirkua, a tributary of the Kali River in Lohaghat area, eastern Kumaun.

the Alaknanda valley (Ranihat, Shrinagar) and the Suyal valley (Kumaun). Rock shelters with wall paintings at Dalband and Lakhu Udyar in Kumaun<sup>8,9</sup> and Kimni in Garhwal (Figure 4) together with burial cists at Gwaldam (Pindar valley), Baijnath (Gomati valley), near Devidhura and Ladyuna, Koormand and Bechandhar in the Ramganga valley<sup>10</sup> in Kumaun are highly significant.

Similar funerary remains have been located across the formidable Himadri at Malari (Dhauli valley) in Garhwal (Figure 4*a*), in Lahaul (H.P.) and near Leh in Ladakh<sup>1</sup>. Some of these sites could have been merely temporary camps of migrants (per com. S. N. Rajaguru, G. L. Badam and R. K. Ganjoo). In the backdrop of caves in the uplifted riverine terraces, the finding of the  $6710 \pm 130$  yr old charcoal pieces in a stone-hearth with unburnt wood, and animal bones at Gaik (100 km east of Leh)<sup>11</sup> is extremely significant. The Burzahom burials are strikingly similar to those of the contemporary sites in Central Asia and NW China and in Swat and Dardistan in Pakistan.

It seems that the primitive Himalayan people, who had no skill of building bridges across rivers, and certainly no mountaineering gears needed for scaling



**Figure 4. a.** Stone-age sites in Garhwal-Kumaun region of the Palaeolithic through Neolithic to Painted Greywares times. A Cup-like depressions made by Prehistoric (2000–1000 yr B.C.) people are found in many place in Kumaun, (M. P., Joshi, pers. commun., 1991).

high mountains, ranged the Lesser Himalayan land extensively and had easy contact with their contemporaries in distant China, Central Asia, Dardistan, Potwar and Rajasthan. Moreover, why should they have chosen colder places when vast stretches of verdant plains were available? Understandably, there was uninhibited intercourse between the Stone-Age peoples of the distant places through direct routes across the Himalaya, which during the Palaeolithic-Neolithic

times were not so high as to form an effective barrier<sup>12,13</sup>.

The Painted Greyware finds (1100–800 yr B. P.) at Thapli in Garhwal (Figure 4) marking the advent of Iron Age and growth of urbanization<sup>1</sup>, suggest that the Lesser Himalayan people continued to have connections with the contemporary civilization that spread all over northern India. In the epic *Mahabharat* there are frequent references to places in the Himalaya. The vivid descriptions of climate, topography, flora, fauna and the tribals (e.g. Kiraats, Kinnars, Yakshas) show that until the *Mahabharat* times (4000–3500 yr B. P.), the Lesser Himalayan relief must have been gentle, and the climate quite inviting so that kings, warriors, and pilgrims freely frequented the Himalayan domain. This could have been possible only if the elevation of the terrain were not forbiddingly high as it is today. Evidently, the prehistoric Lesser Himalayan civilization (7000–4500 yr B. P.) extended across the mountains and the Lesser Himalayan terrain was a hospitably gentle peneplaned surface of low relief, possibly less than a thousand metres above the sea level<sup>13</sup>. Significantly, the Tibetan plate was also a peneplaned surface of low relief, only a few hundred metres above the sea level, with humid climatic conditions prevailing, until major fault movements during the Pleistocene elevated the landmass<sup>14</sup> to the present height (> 5000 m).

This deduction is at variance with the view of some workers that Himalaya had reached more or less the present height sometime after the Late Pleistocene<sup>15</sup> (per com. S. N. Rajaguru, G. L. Badam and R. K. Ganjoo).

### Geomorphic rejuvenation of terrain

The Lesser Himalaya, by and large, has a mature topography. Traversing the terrain one realizes that a once peneplaned land is greatly, and locally incisively, dissected by antecedent rivers. Both the Himadri and Siwalik ranges rise abruptly to great heights and have extremely rugged and youthful topography, implying their uplift and reshaping due to neotectonic movements<sup>16</sup>.

Various geomorphic features, such as changing courses of streams evidenced by abandoned channels, abrupt swings in their courses, entrenched meanders (Figure 5), uplifted fluvial terraces (Figure 6a), and colluvial fans, recently cut chasms (Figure 6b), besides flatter or gently sloping erosional terraces on transverse spurs (Figure 1) mantled thickly with residual soils<sup>18</sup> provide eloquent testimony of uplift of the Lesser Himalayan subprovince, mostly in the Holocene times. Representing the morphogenetic phase of Quaternary diastrophism, the rate of uplift is estimated at 5 mm/yr—five times faster than the rate measured in the Alps<sup>18</sup>.

a



b



Figure 5. Entrenched meanders in the Lesser Himalayan rivers. a, At Pathariya in the Kosi valley, south of Someshwar. b, Gomati River near Rauliana, upstream of Baijnath.

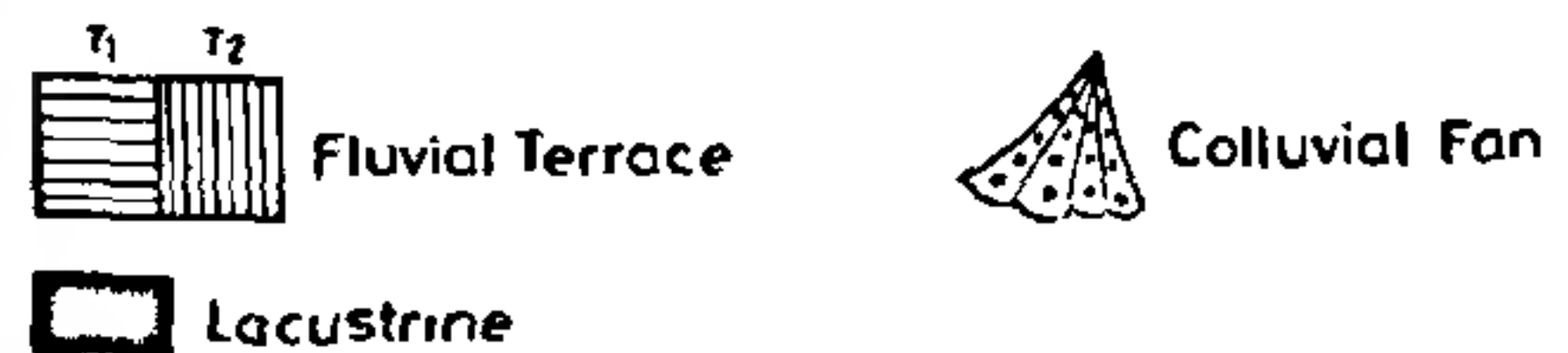
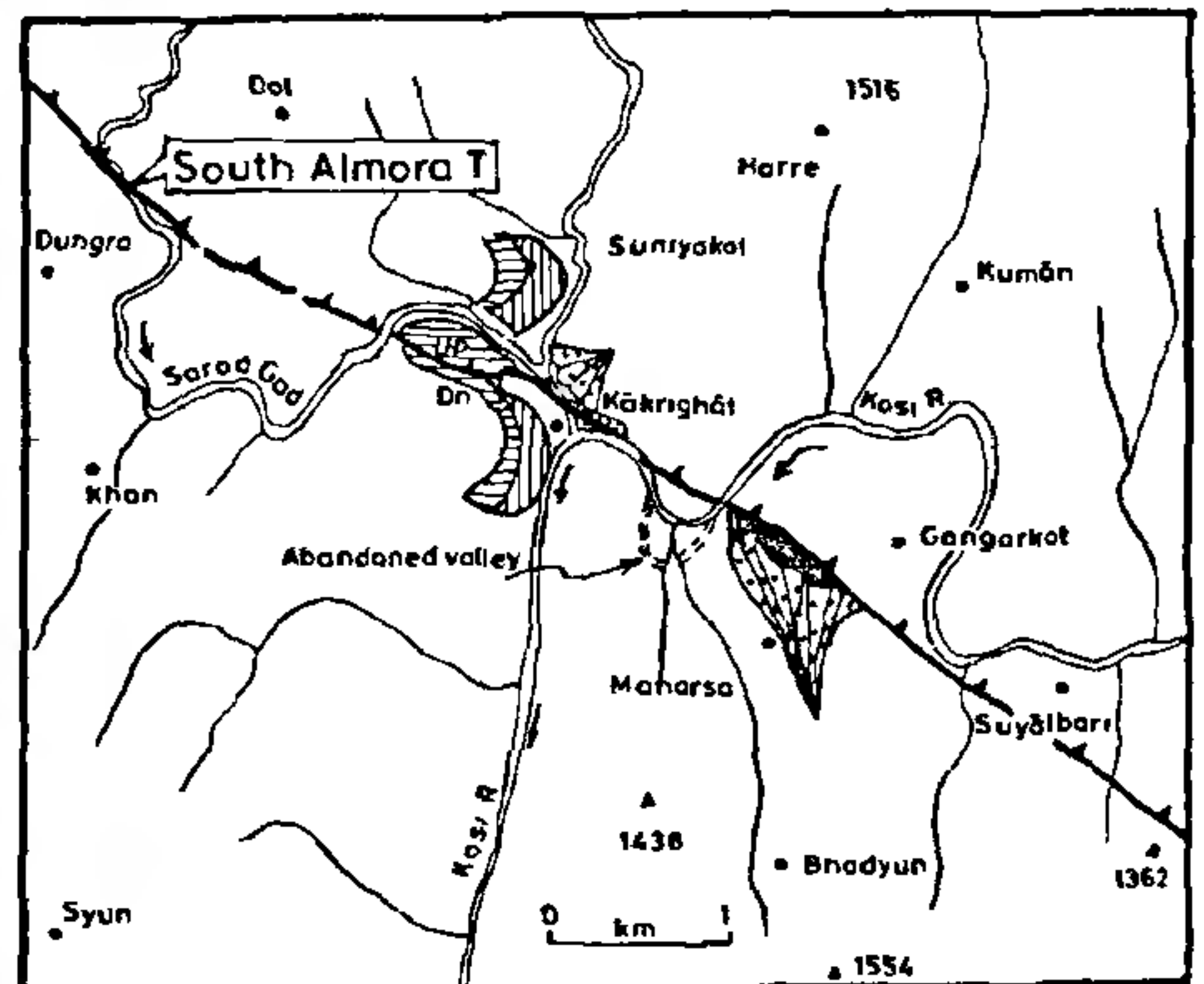
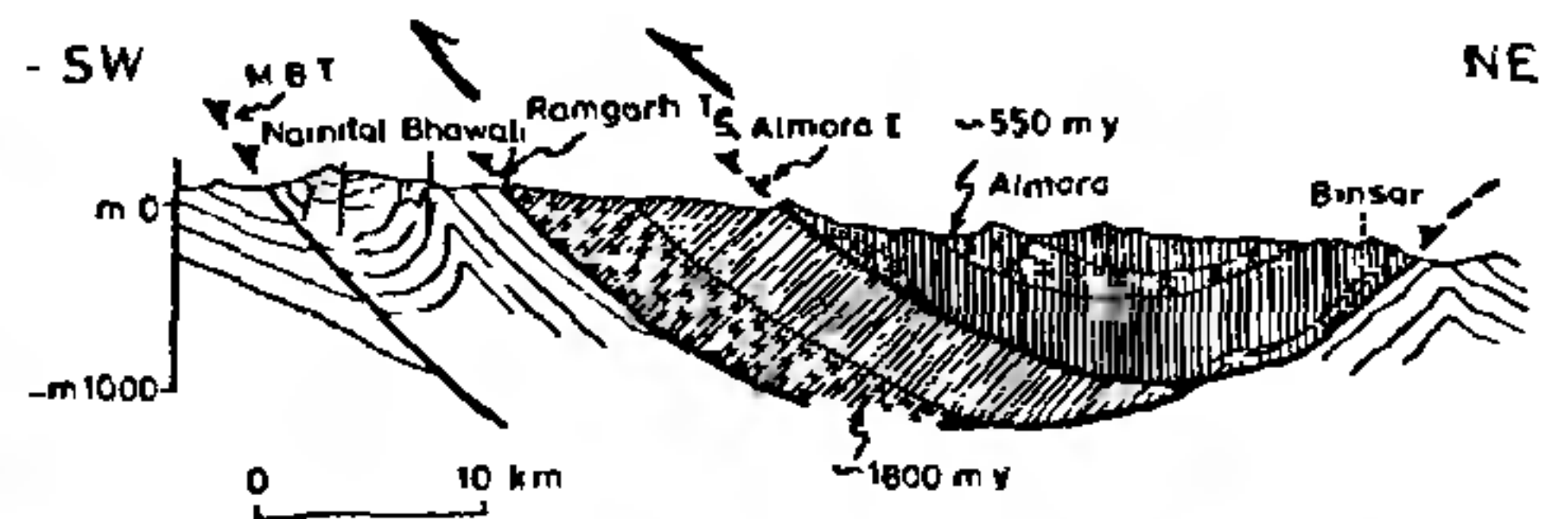
The consequence of fast uplift is the superimposition of youthful topography on mature relief of considerable antiquity. The 3 to 6 levels of depositional terraces in practically all major rivers and streams, but invariably upstream of active faults crossing the valleys<sup>19–22</sup> indicate as many pulses of uplift in the Quaternary as there are levels of terraces. It may be recapitulated that on one of these uplifted fluvial terraces near Shrinagar in the Alaknanda River lived the Stone-Age people (Figure 4). The primitives must have witnessed the episodic rise of the land of their settlements.

The tectonic resurrection is the result of horizontal strike-slip and vertical dip-slip recent to subrecent movements on the multiplicity of oblique and transverse thrusts and faults which cut the framework of the Himalaya<sup>16,21,23</sup> (also see ref. 27). Striking changes are discernible in the nature of the windingly flowing or meandering streams as they approach the fault planes—they plummet down 200–300 m into the main channels through deep gorges or chasms as seen on the sides of the Nainital massif<sup>21,24</sup> and the Devidhura-Dhunaghat Range in southeastern Kumaun. The

**a****b**

**Figure 6.** *a*, Multiple levels of fluvial terraces practically in all the Lesser Himalayan rivers and major streams near Bajnath on the Gomati River, a tributary of the Saryu. *b*, Deep chasm near Patibagar in the otherwise wide Kosi valley of gentle slopes.

regional thrusts, like the Ramgarh T and South Almora T in Kumaun and the Shrinagar (Tons) T in Garhwal, are associated with huge fans and tongues of debris avalanches, presumably triggered by large earthquakes. The earthquakes must have been related to movements on these active intracrustal thrusts (Figure 7). The Barigad Fault in West Nepal, for example, registers crustal shortening at the rate of 5 mm/yr—one tenth of the rate of plate convergence<sup>25</sup>. Significantly, the NW-SE trending tear faults—which bear striking parallelism with the Karakoram Fault<sup>26</sup>—Kopili-Bomdila lineament<sup>27</sup> in West Arunachal and Mishmi Thrust in eastern Arunachal (Figure 8) are more active than other faults<sup>21,23,26</sup>. However, in eastern Nepal and the adjoining Darjiling-Sikkim region, the NNE-SSW trending strike-slip faults are seismically very active<sup>27</sup>. This pattern of seismicity and change in the direction of relative motion is possibly a manifestation of northward drag of tectonic blocks between transcurrent faults and plate margins due to the convergence of the Indian and Asian plates<sup>28</sup>.



**Figure 7.** Recent movement on the South Almora Thrust in central Kumaun is evident from about 10 m displacement of a fluvial terrace at Ira (Naugaon) west of Kakrighat and tilting and deformation of the fluvio-lacustrine deposit, 2 km ESE of Kakrighat in the Kosi Valley.

### Rapid uplift of southern mountain front

#### Testimony of vertebrates

Overlooking the Siwalik subprovince, the extremely rugged and youthful PirPanjal-Dhauladhar-Krol-Nainital-Mahabharat Range abruptly and steeply rises to heights above 2500 m (3500 m in the NW). The southern front of the Lesser Himalaya is thus a lofty barrier, which isolates it from the Peninsular India.

North of this high mountain rampart are relatively gentler terrains with quite many flat stretches representing lakes that have been completely filled up with sediments. One such lake north of the PirPanjal (3500–3200 m) is represented by the Karewa group (Figure 9) in the Kashmir valley at an elevation of 1700 m–1800 m above the sea level<sup>2,6,29,30</sup>. A huge lake was formed as a result of ponding of the precursor of the River Jhelam, due to upward movement of the footwall

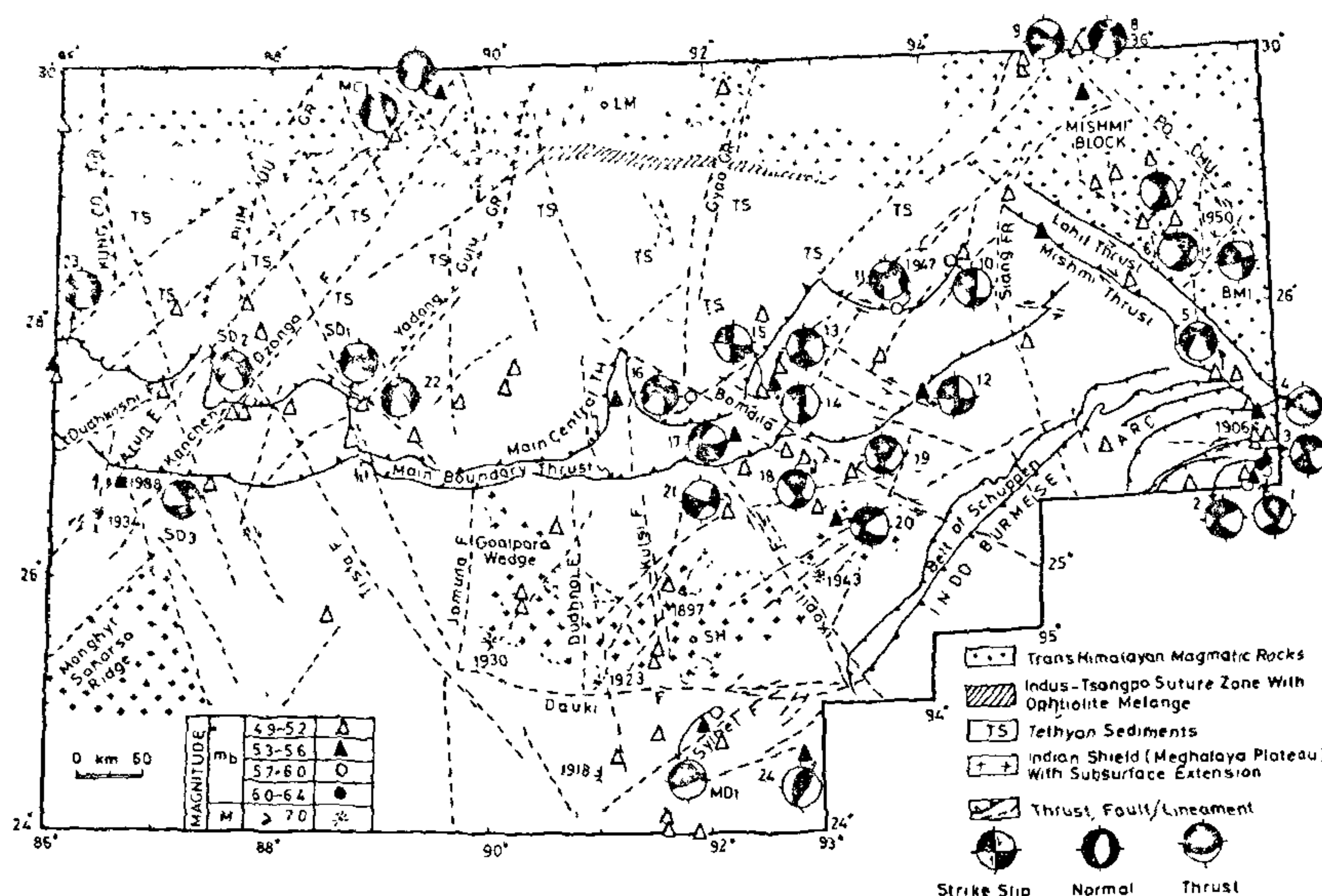


Figure 8. Eastern Himalaya, like other parts of the Himalaya, is cut by a multiplicity of faults, oriented parallel, oblique and transverse to the orogenic trend. Many of these are seismogenic (e.g. 1950 earthquake of  $M 8.7$  in the Mishmi Thrust zone) (After Nandy and Das Gupta<sup>28</sup>).

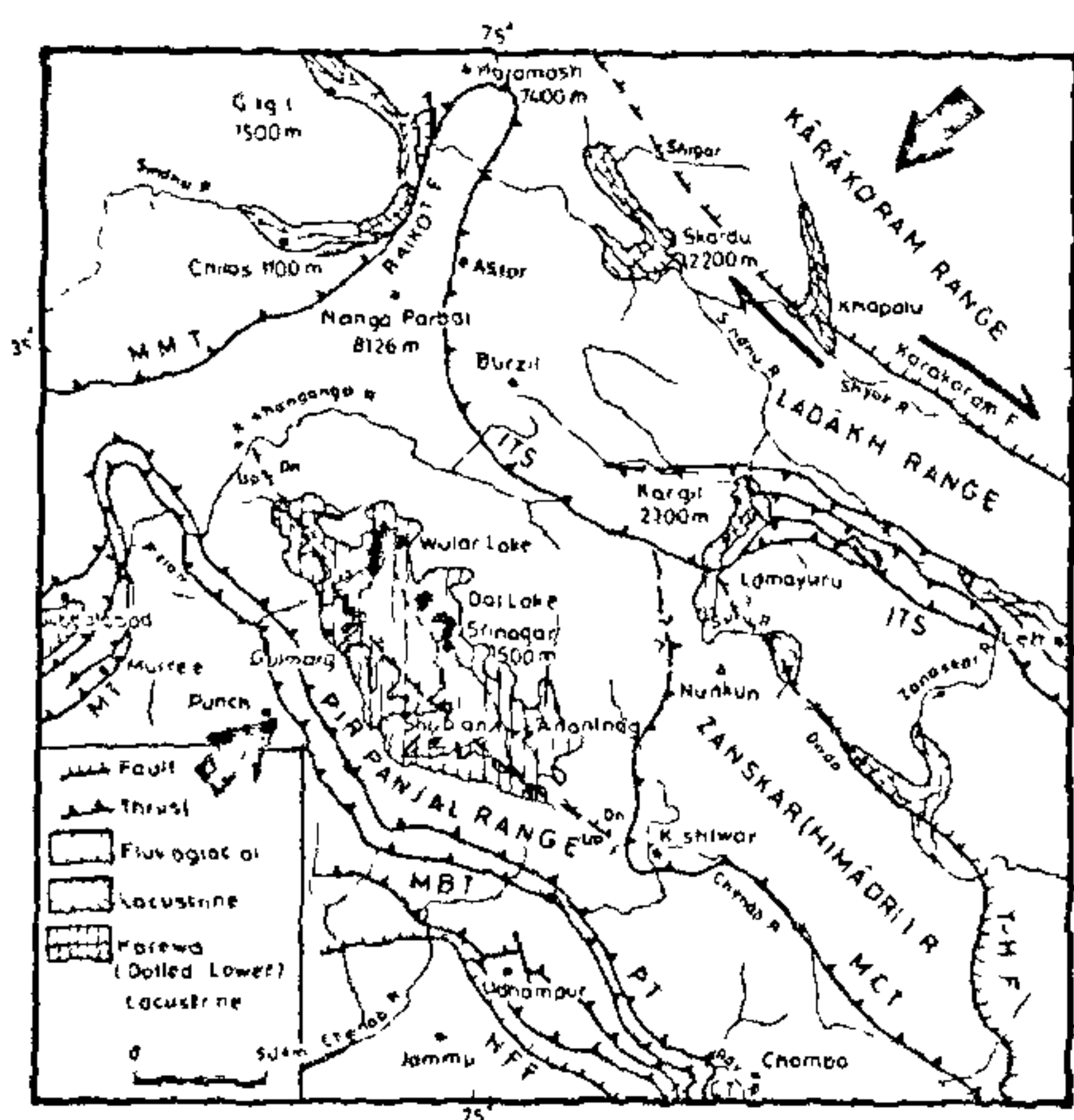


Figure 9. Karewa lake north of the PirPanjal is cut by an active E-W fault (based on Valdiya<sup>63</sup>, Thakur<sup>64</sup> and Burgisser et al<sup>65</sup>).

(PirPanjal) along one of the thrusts (Figure 10) of the Main Boundary Thrust (MBT) Zone<sup>13</sup>. If the plant remains in the middle level of the lithological column (Figure 11) indicate prevalence of temperate to warm moist climate<sup>31</sup>, the fossils of large-sized heavy vertebrates *Hexaprotodon* (hippopotomus), *Rhinoceros sivatherium* and *Elephas* at the base within the Brunhes-Matuyama epoch (0.9 m.y. to 0.6 m.y.)<sup>32</sup> are suggestive

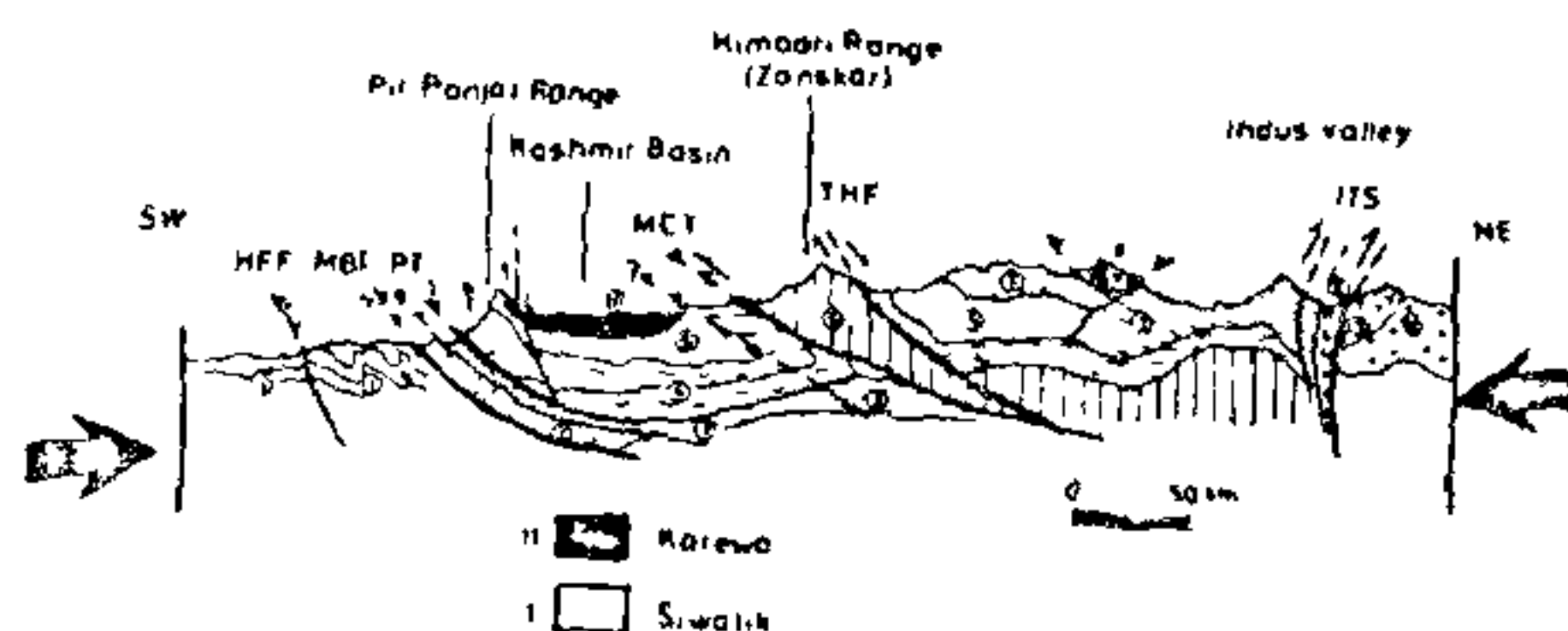


Figure 10. Rapid and repeated uplift of the PirPanjal on active faults and thrusts, due to compression of the Indian plate. (HFF: Himalayan Frontal Fault; MBT: Main Boundary Thrust, PT: Panjal Thrust, MCT: Main Central Thrust; T-HF: Trans-Himalayan Fault; ITS: Indus-Tsangpo Suture)

of marshland in a terrain of gentler relief, only a few hundred metres above the sea level<sup>13</sup>. Significantly, almost the same mammalian fauna lived in the Nagrota times in the Upper Siwalik of the Jammu region<sup>33</sup> across the PirPanjal. The faunal similarity implies mutual connection and free inter-migration of the bulky beasts of warmer moist climate.

The more than 500 m thick lake deposits of the Kathmandu valley (Figure 12) at the elevation 1360–1550 m above the sea level include 30,000 yr, 20,000 yr and 10,000-yr-old peat layers in the upper part, and fossils of *Elephas planifrons*, *E. hysudricus*, *Stegodon ganesa*, *Hexaprotodon sivalensis* and *Crocodylus* in the lower part belonging to the Gauss-Matuyama epoch<sup>34</sup>.

It seems that the Karewa Basin of Kashmir, the Kathmandu Basin of Nepal and the Upper Siwalik Basin of the Jammu foothills across the mountain barrier were at low altitudinal levels, enjoying nearly similar climatic conditions, and were easily accessible and mutually connected during the Upper Siwalik times. The mountain barrier must have developed after this period. This is attributable to the uplift on the thrusts and faults of the MBT Zone<sup>13</sup>. The lenticular horizons of conglomerates within the lacustrine Karewa succession<sup>30</sup> represent spasmodically emplaced gravels of debris avalanches triggered presumably by earth-

The great height of the Mahabharat Range in south-central Nepal is due to cumulative movements on the multiplicity of imbricating thrusts of the MBT zone<sup>26,37</sup>.

Atop the Karewa succession in Kashmir, the primitive people of the Neolithic period had established their settlements. They could not have chosen habitations but on an accessible place with congenially warm climate. Besides, they had free intercourse with people living in the Potwar plains in Pakistan and in the Jammu Basin in the south. Evidently, it was only after the Neolithic times when man had established himself comfortably in the Kashmir valley—and elsewhere in the Lesser Himalaya—that the PirPanjal rose to its present height (3500–3200), terminating their connections with the people living in the plains<sup>12,13,38</sup>.

The drainage pattern of the major rivers like the Brahmaputra, Kosi, Karnali, Kali, Ganga, Satluj and Sindhu is remarkably independent of the tectonic trend<sup>19</sup> controlled by the intracrustal boundary thrusts and faults. Without deflecting, these rivers cross the high (7000–8000 m) mountain barriers and enter the Lesser Himalayan domain through deep canyons. Not only are these gorges characterized by vertical to convex walls and utter ruggedness of ranges cut by south-facing stupendous scarps<sup>10</sup>, but also with very high gradient and knick-points of the rivers within the stretch of the Main Central Thrust (MCT) zone<sup>39</sup>. These features imply very brisk rate of uplift of the Himadri, 0.7 to 1.1 mm/yr. (Refs. in Valdiya<sup>10</sup>).

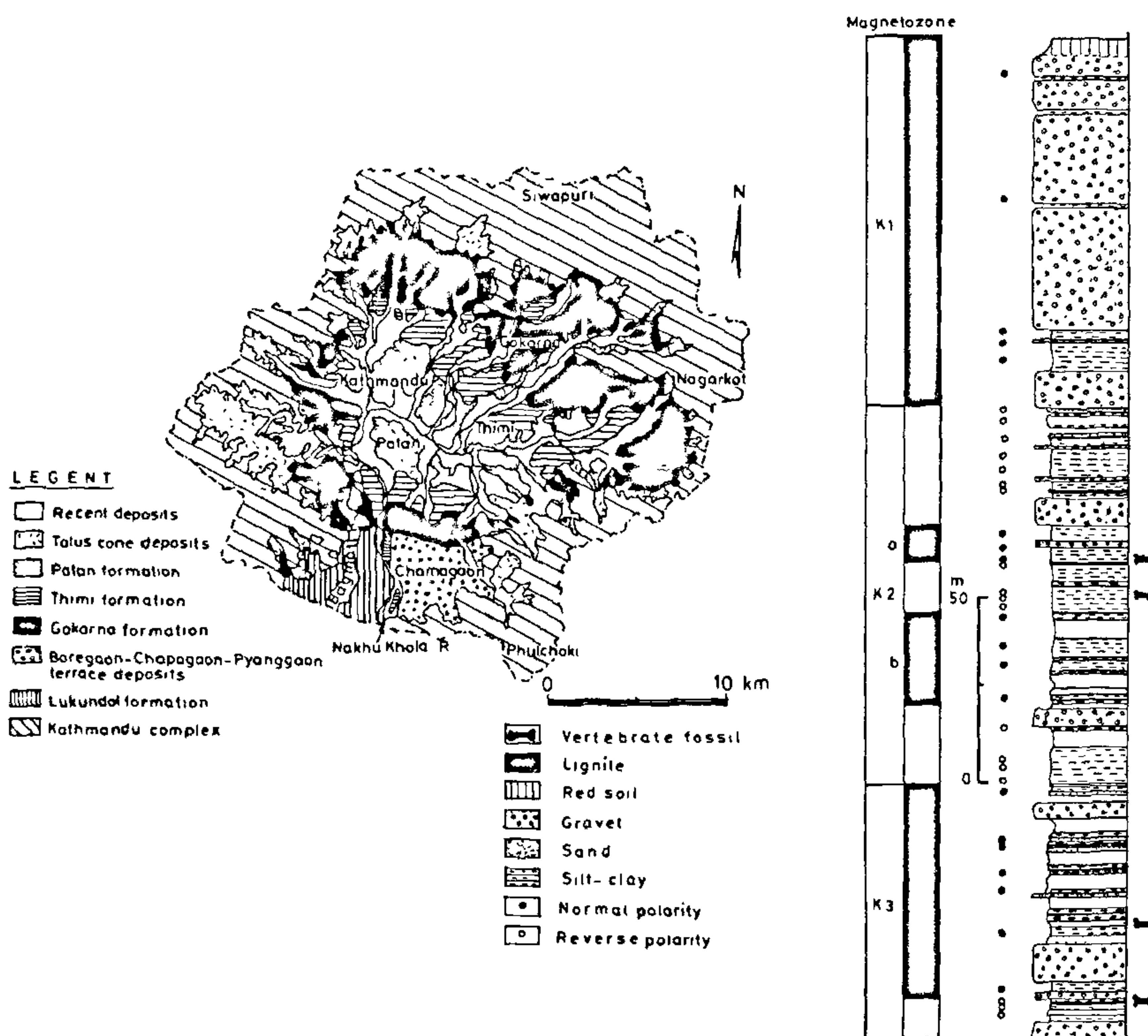


Figure 12. Kathmandu Basin, representing intermontane lake across the lofty Mahabharat Range, has also yielded large-sized heavy mammalian fauna (After Yoshida and Gautam<sup>34</sup>).

At the northwestern extremity of the Himadri the Nanga Parbat-Haramosh massif is cut by the active Raikot Fault (Figure 9). The massif has risen to the present eminence quite after the establishment of the Sindhu drainage of great geomorphic maturity and antiquity. This is evident from the awe-inspiring Sindhu gorge within the stretch of the massif<sup>38</sup>, the overthrusting of the river gravels by the Precambrian metamorphics, and the folding of the 50,000-yr old fluvioglacial sediments along the Raikot Fault<sup>40,41</sup>. The cumulative lateral offset of the Sindhu River along the Raikot Fault, is approximately 15 km in the Quaternary period<sup>40</sup> and the rate of continuing uplift of the massif about 5 mm/yr<sup>42</sup>.

The folded fluvial terraces in the Tsarap and Sumkhet streams in the belt of active TsoMorari-Puga Fault in southeastern Ladakh suggest movements 3850 yr ago<sup>43</sup>.

The movements on the active faults and attendant earthquakes triggered huge landslides on an extensive scale, resulting in damming up of rivers and formation of lakes in the Gilgit, Hunza, Skardu, Sindhu and Zaskar rivers<sup>44</sup> of the Indus-Tsangpo Suture (I-TS) zone (Figure 9)<sup>44</sup>. The 200-m thick sediments of the Lamayuru lake in Ladakh formed due to a landslide 35,000 years ago (and which persisted until 1000–500 yr B.P.) contain Karewa-like remains of charophytes ostracodes and gastropods, and also rosettes of gypsum<sup>45</sup>. The former indicate strong biological activities under presumably congenial climate, and the latter imply intermittently evaporitic condition. This is not possible at the present elevation of 3600 m above the sea level.

In the Sindhu valley the Liyan Formation (= Kargil Molasse) now at the altitude of 5400 m, contains fossils of fan palm *Trachycarpus*<sup>46</sup> and rhino skull (per.

com. A. C. Nanda, 1993). The Kargil bears remarkable lithological and faunistic similarities with the Murree Group of the Jammu-Potwar foothills. The Hemis Conglomerate of the Oligocene age, now at the elevation of 4000 m, contains besides charophytes and gyronites, plant fossils like *Livistona* and *Sabal major*<sup>47</sup>. The modern analogues of these palms are not found above the altitude of 1600–2100 m. This fact implies that there was an uplift of the order of 3000 m since the Upper Oligocene times.

Thin layers of  $6710 \pm 130$  yr old charcoal with unburnt wood<sup>11</sup> in a stone hearth embedded in fluvial sediments of the Sindhu terrace near Gaik (100 km east of Leh) demonstrate that the primitive human settlements—or their camps extended as far north as Ladakh and were perhaps linked with the contemporary civilization in China and Central Asia<sup>12,13</sup>.

Across the I-TS, the Karakoram Range rose up rapidly at the rate of 2 mm/yr<sup>48</sup>, as evident from large-scale warping of glacial deposits and the peneplaned Tibetan plateau was elevated to the present height (>5100 m) by movements on major faults since the Pleistocene times<sup>14</sup>. It is quite evident that neotectonic uplift of the fault blocks (Figure 10) resulted in the development of antecedent drainage, shaping of the present rugged topography, and ushering of the frigidly cold climate in the Himalayan-Tibetan highlands<sup>13</sup>.

## Squeezing up of the Siwalik

### MBT, the Northern Boundary

Characterized by imbricating thrusts and faults, the Main Boundary Thrust (MBT)<sup>16</sup> is a very active tectonic plane. This is evident from a variety of geomorphic and geological features and geophysical phenomena such as seismicity and radon gas emission<sup>49</sup>. In some segments the Siwalik has risen up 30–45 m relative to the Lesser Himalaya (Figure 13a), thus truncating and displacing fluvial terraces and younger colluvial fans, in other parts the Lesser Himalayan rocks have advanced over the Siwalik, mantled with recent fluvial gravels (Figure 13b)<sup>13,16,21,24,50–53</sup>. Geodetic measurements in southwestern Garhwal and south-central Himachal Pradesh establish beyond doubt that movements on the faults of the MBT zone are continuing<sup>54–56</sup>.

Immediately to the south of the MBT, the Siwalik Range abruptly rises to great heights (1700–1800 m). The rugged ranges are broken by awesome scarps, the northward hurrying streams descend down in rapids and unending waterfalls, and the steep slopes are covered with fans and cones of debris avalanches. Transverse rivers flow through canyons and have raised pointbar

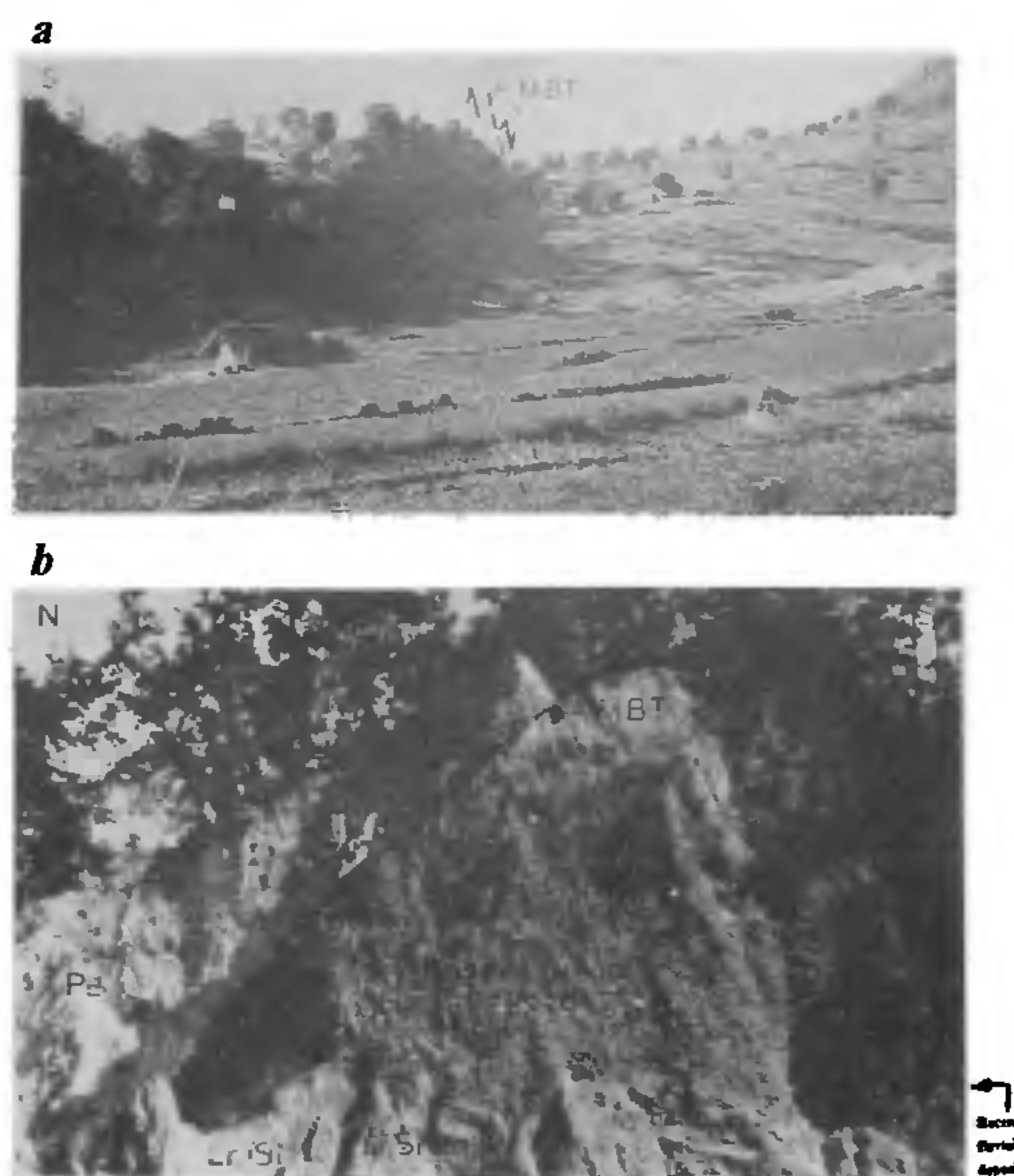


Figure 13. *a*, In southcentral and southwestern Kumaun the Siwalik has risen up relative to the Lesser Himalaya on the reactivated MBT as seen in the Lugal Gad valley, a tributary of the Gaula River, where the fluvial deposit of the footwall block (Siwalik) has risen up 45 m as evident from the scarp. *b*, Southward advance on the MBT of the crushed mass of Precambrian quartzites on the uplifted (70 m) recent gravel deposits at Shim in the Ladhiya Valley in SE Kumaun.

deposits<sup>57,58</sup>. Obviously, the northern belt of the Siwalik has risen up at a much faster rate.

### Intra-Siwalik thrusts and plains

The forested middle belt of the Siwalik has remarkably gentle topography, characterized by flat expanses called 'duns'. These flat expanses represent synclinal depressions filled up thickly with coarse gravels of the Upper Pleistocene to Lower Holocene and still younger times. The Siwalik has been cut by intrabasinal very active thrusts and faults. Holocene movements along them have given rise to intra-basinal horsts and grabens of lesser dimension, as seen in the Bhutan and Dehradun foothills<sup>59,60</sup>. The Sarpduli-Dhikala Thrust in southwestern Kumaun (which T. Tokuoka, pers. com. 1992, equates with the Central Churia Thrust of south-central Nepal) has caused uplift of the footwall block, resulting in the ponding of the Ramganga and Kosi rivers, and formation of lakes, respectively, in the Dhikala (Corbett National Park) and Garjiya area (Figure 14)<sup>47,58</sup>. Filled up very rapidly due to erosion of the rising mountains of the neotectonic belt, these lakes are now represented

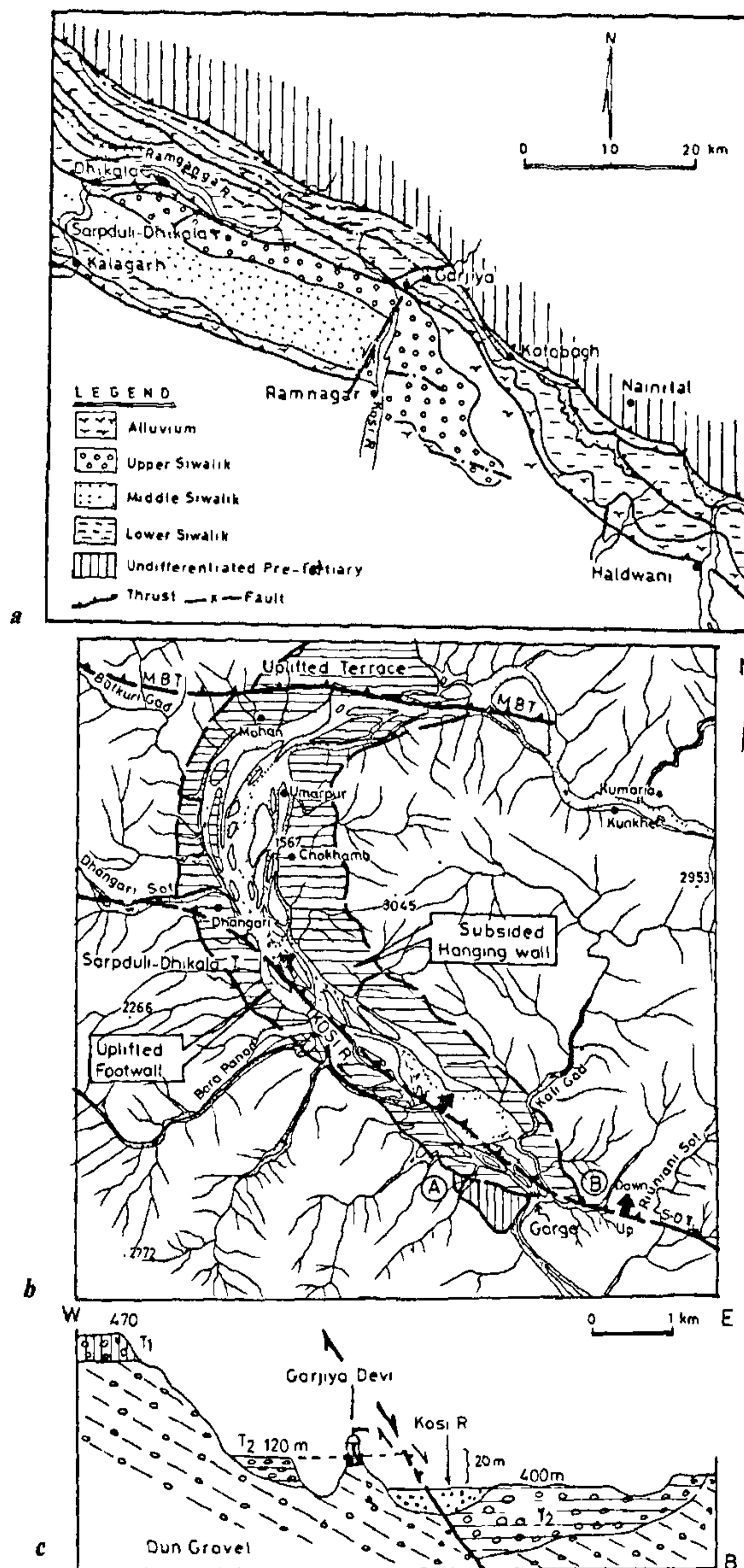


Figure 14. (a) Intermontane flat stretches in the Siwalik Terrain. (b) A lake formed in the Kosi River due to uplift of the footwall (downstream) block on the Sarpduli-Dhikala Thrust, and (c) Recent reactivation has lifted up by 20 m even the recent lake deposit.

by intermontane flat plains or newer 'duns' (Patli Dun, Kotabagh Dun) developed upon the tilted older Dun of the Upper Pleistocene (Figure 15). Significantly, these Holocene fluviolacustrine deposits have been vertically displaced 10–20 m, due to reactivation of the Sarpduli-Dhikala Thrust<sup>58</sup> (Figure 14c). In southeastern Kumaun, recent differential movements along intra-Siwalik faults have led to evolution of lakelets on top of the Sukhidhang Ridge, and also precipitated major landslides, now represented by huge fans and tongues of debris fringing the southern foot of the Siwalik. Right-lateral strike-slip movement on one of these E-W faults accounts for the 6 km westward deflection of the consistently south-flowing Kali (Sharada) River<sup>57,58</sup>. In the Darjiling foothills, the average rate of movements on these faults is of the order of 3–4 m/1000 yr<sup>26</sup>.

#### Siwalik front: active HFF

The Himalayan Frontal Fault (HFF) demarcating the tectonic boundary of the Siwalik against the Indo-Gangetic Plains<sup>16,21,59,61</sup>, is quite active<sup>25,26</sup>. Resting on the tilted Dun Gravels are three levels (35 m, 25 m, 100 m) of fluvial terraces in the Kosi valley (north of Ramnagar), implying three pulses of uplift in the Holocene times. The 66-m high oldest terrace at Kalagarh on the Ramganga (Figure 15a) contains wastes of a pottery factory of the historical (Kushan) times (per. com. K. P. Nautiyal, 1990), implying uplift in the last 1600 to 1800 years. The 6–15° N tilted Dun Gravel (Upper Pleistocene) (Figure 15b, c) is lifted 60–90 m above the plains<sup>57</sup>.

Between the MBT and the HFF, the Siwalik

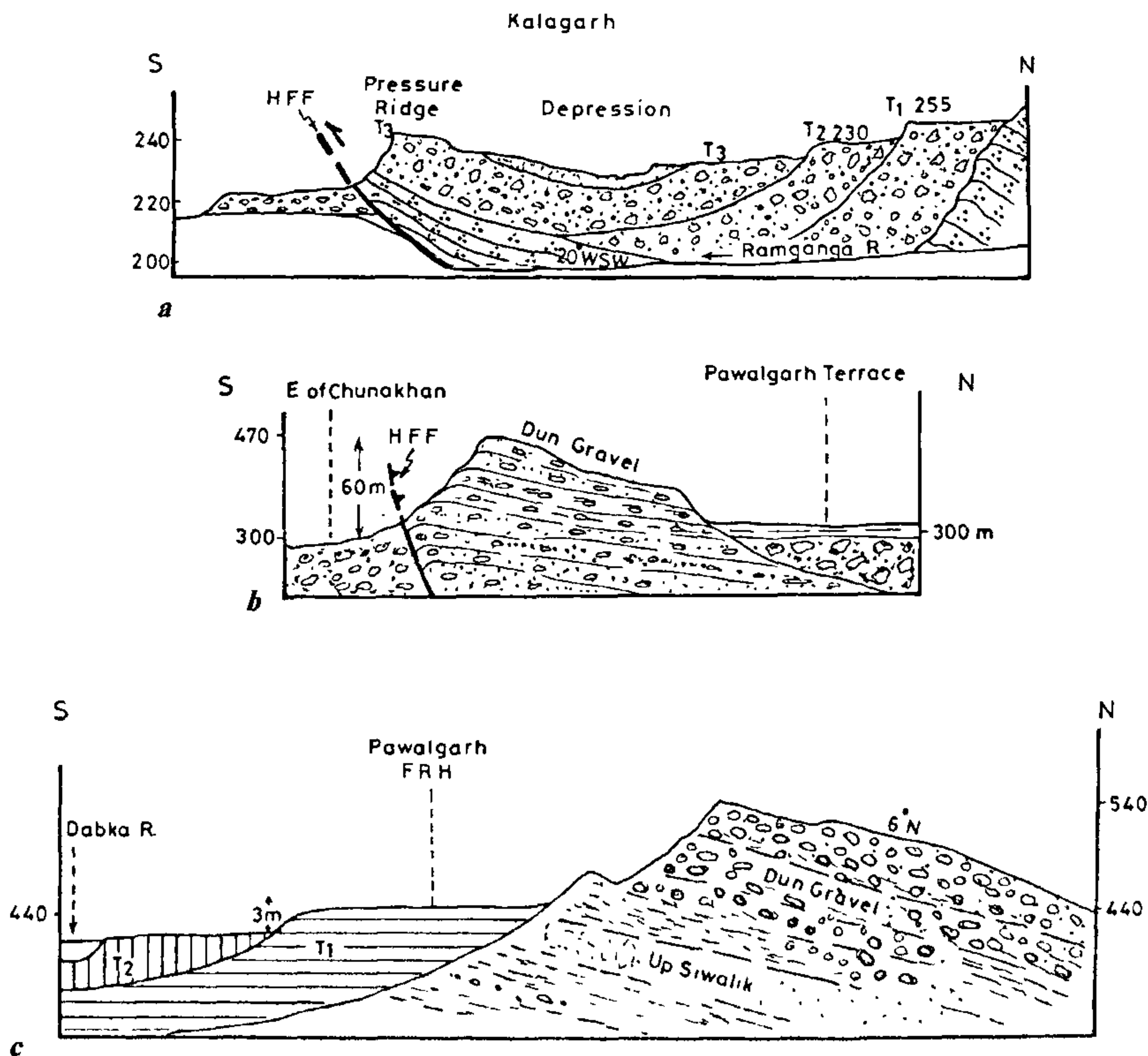


Figure 15. Recent movement on the HFF is evident from: (a) Deformation of the T<sub>3</sub> (youngest) fluvial terrace northwest of Kalagarh in the Ramganga valley. (b) Tilting of the Dun Gravel (later Pleistocene) north of Belparao-Chunakhan (c) Tilted Dun Gravel at Pawalgarh (Dabka valley) is overlain by three levels of younger fluvial terraces, implying three pulses of uplift in the Holocene times

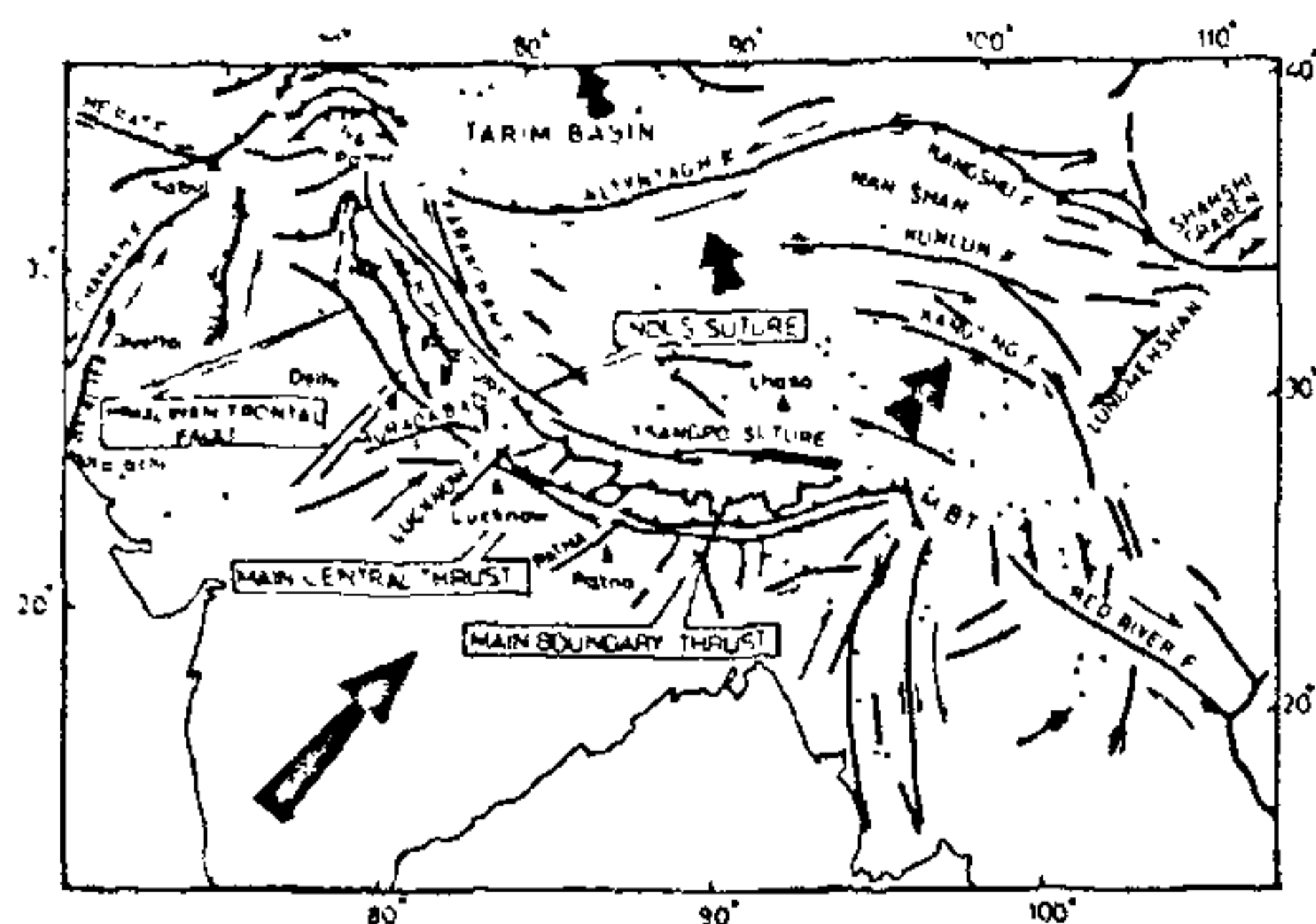


Figure 16. Persistent push of the northward drifting Peninsular India has brought about splitting of the framework of the Himalaya as represented by intracrustal faults and thrusts (From Valdiya<sup>63</sup>).

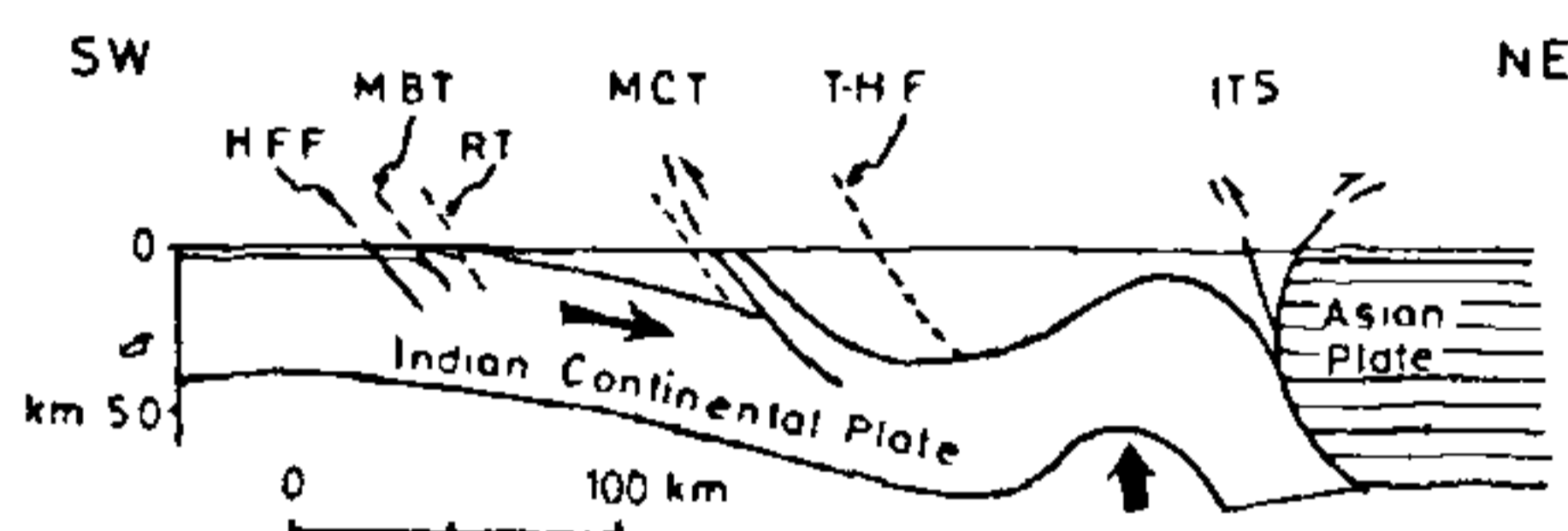


Figure 17. Cartoon explains that reactivation of intracrustal boundary thrusts and related faults is responsible for the neotectonic movements (Valdiya<sup>16</sup>).

subprovince has been rising at a fast rate—0.8 mm/yr to 1 mm/yr<sup>62</sup>. The 1905 Kangra earthquake caused 13.4 cm uplift of the ground of the Dehradun township and 10.3 cm of the Mohand Anticline<sup>62</sup> adjoining the HFF.

### Geodynamic implication

The underthrusting of the Indian plate is causing differential movements of the disjointed block in the mountain domain—rotating slightly as they moved up and slipping along the strike of the boundary thrusts like the MBT. The tectonic tumult has not only rejuvenated the once old mature topography of low relief and kept it in a ruggedly youthful state, but also made it the highest mountain of the world. Since the movements have been faster and repetitive on the MBT and MCT zones, the Great Himalaya and the southern front of the Lesser Himalaya have attained formidable heights. The impact of the continuing northward push of the drifting Indian plate (Figure 16) is also manifest in the repeated reactivation of the intracrustal boundary thrusts (Figure 17), the rise and subsidence of the ground of the Indo-Gangetic Plains, reactivation of the many transcurrent faults in the Peninsular India,

including the Karnataka Craton, and the epeirogenic uplift of the western coast stretching from Kachchh to Kerala.

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# Seismic gaps and likelihood of occurrence of larger earthquakes in Northern India

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On the basis of seismicity pattern in and structural setting of the Himalaya, seismic gaps have been identified. These gaps are the likely locales of future great earthquakes. The extents of the gaps are defined by the structural discontinuities that exist in the subducting Indian crust.

## Introduction

NORTHERN India is subject to considerable hazard due to earthquakes, which occur mostly in the Himalaya—the site of collision between the Indian and Eurasian plates.

In the past the earthquakes have played considerable havoc in this region<sup>1–8</sup>, where there has been a phenomenal increase in population density and also development programmes. It is important that the seismic hazard be assessed realistically in order to provide a sound basis for earthquake hazard reduction to the planners and administrators.

The strain energy release in the form of earthquakes at the plate boundaries is due to the relative motion of the plates. They release from time to time by rupturing and relative slip of the plates in the sections of the plate boundaries with the accompaniment of great earthquakes.