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Three terrane-defining thrusts of the Kumaun Himalaya: controversies on position and nomenclature*

K. S. Valdiya
Jawaharlal Nehru Centre for Advanced Scientific Research
Bangalore 560 064, India
(Email: nehrucen@jncasr.ac.in)

ABSTRACT

Three of the five thrust fault systems defining the boundaries of four lithotectonic terranes of the Himalaya and involved in controversies related to their positions and nomenclature, are the objects of discussion in this paper. Youngest of the five terrane-defining faults, the *Himalayan Frontal Fault* (HFF) is a series of reverse faults that demarcates the boundary of the Siwalik front of the Himalayan province with the alluvial expanse of the Indo-Gangetic Plains. Over large tracts, it is either concealed under younger sediments or has as yet not reached the ground surface and is therefore a blind fault. The nature of this frontal fault varies along its length. Where the hidden ridges of the Indo-Gangetic basement impinge the Himalaya, the mountain front is ruptured and the HFF is repeatedly reactivated. In the sectors intervening these ridges, it is not expressed on the surface, but the ground of the adjoining Indo-Gangetic Plain is sinking, the rivers are shifting their courses and large tracts of land are waterlogged and characterised by marshes or ponds and by strong seismicity.

The Vaikrita Thrust is the plane that marks pronounced metamorphic break and abrupt change in style and orientation of structures within the succession of crystalline rocks that build the bulk of the snowy ranges in the Kumaun Himalaya. Not only is there a jump of pressure of the order of 4 kb and a temperature rise of >200 °C, but also is there a conspicuous change of neodymium isotope value across the tectonic plane that separates the low-grade metamorphics in the lower part from the high-grade metamorphic rocks of the upper part of the Great Himalayan succession. The Vaikrita Thrust is therefore recognised as the *Main Central Thrust* (MCT). While the basal low-grade metamorphic assemblage comprises 1900±100 Ma old highly tectonised porphyritic granite characterised by low initial strontium isotope ratio, the upper high-grade metamorphic group is intruded by 20±1 Ma old anatectic granites characterised by garnet, kyanite, sillimanite and cordierite, and a high but variable value of strontium isotope ratio. Moreover, the anatectic Lower Miocene granites are singularly absent in the succession of the Lesser Himalayan nappes. Probably it is this thrust that has flexed downwards the plane of decoupling and displacement between the underthrusting Indian plate and the overlying Himalayan mass.

The terrane-defining fault between the high-grade metamorphics with granitic rocks of the Himadri (i.e., Great Himalaya) and the Tethyan sedimentary pile was recognised as the *Malari Thrust Fault* in the northern Kumaun Himalaya in the early seventies, as the *South Tibetan Detachment System* in southern Tibet adjoining north-eastern Nepal in the early eighties and as the *Zanskar Shear Zone* in north-western Himachal Pradesh in the late eighties. Not only is there an abrupt change in the metamorphic grade across the tectonic plane, but also an attenuation and wholesale elimination of some lithostratigraphic formations of the hanging wall besides the difference in the style of deformation. Exhibiting predominant dip-slip movement in the central sector of the Himalayan arc, the *Trans-Himadri Fault* (T-HF) was formed as a consequence of the Tethyan sedimentary cover detaching from its rigid foundation of the basement complex that was squeezed up following blocking or slowing down of tectonic movements related to India-Asia convergence. The sedimentary cover lagging behind the thrust-up basement complex slid down and toppled over northward and gave rise to back-folds and back-thrusts. In Kashmir, western Himachal Pradesh, central Nepal and north-western Bhutan, in sharp contrast, there was very strong compression, so that the Tethyan sedimentary rocks–along with a slice of the low-grade metamorphic basement in the hanging wall – advanced southwards across the Himadri and were emplaced as nappes and klippen south of the Main Central Thrust. The T-HF movement occurred approximately around 20.9 Ma, although the movement had started quite earlier in some places. Quaternary reactivation resulted in river ponding and development of huge lakes such as the Garbyang palaeolake in the Kali valley and the ~ 40,000 year-old Goting palaeolake in the Western Dhauli Valley.

TERRANE BOUNDARIES OF HIMALAYA

Within the 300 to 400 km wide expanse of the Himalayan province, four physiographically distinctive and lithotectonically contrasted terranes are recognisable, particularly between the Ravi and Arun rivers (Fig. 1). The northern boundary, defined by the zone of collision of India with Asia, is known as the *Indus–Tsangpo Suture* (I-TS). This 50 to 60 km wide zone of continental junction displays a very gentle topography, but at an elevation of 3600 to 5000 m above the sea level. South of the I-TS lies the domain of the Tethys Himalaya, made up of sedimentary succession

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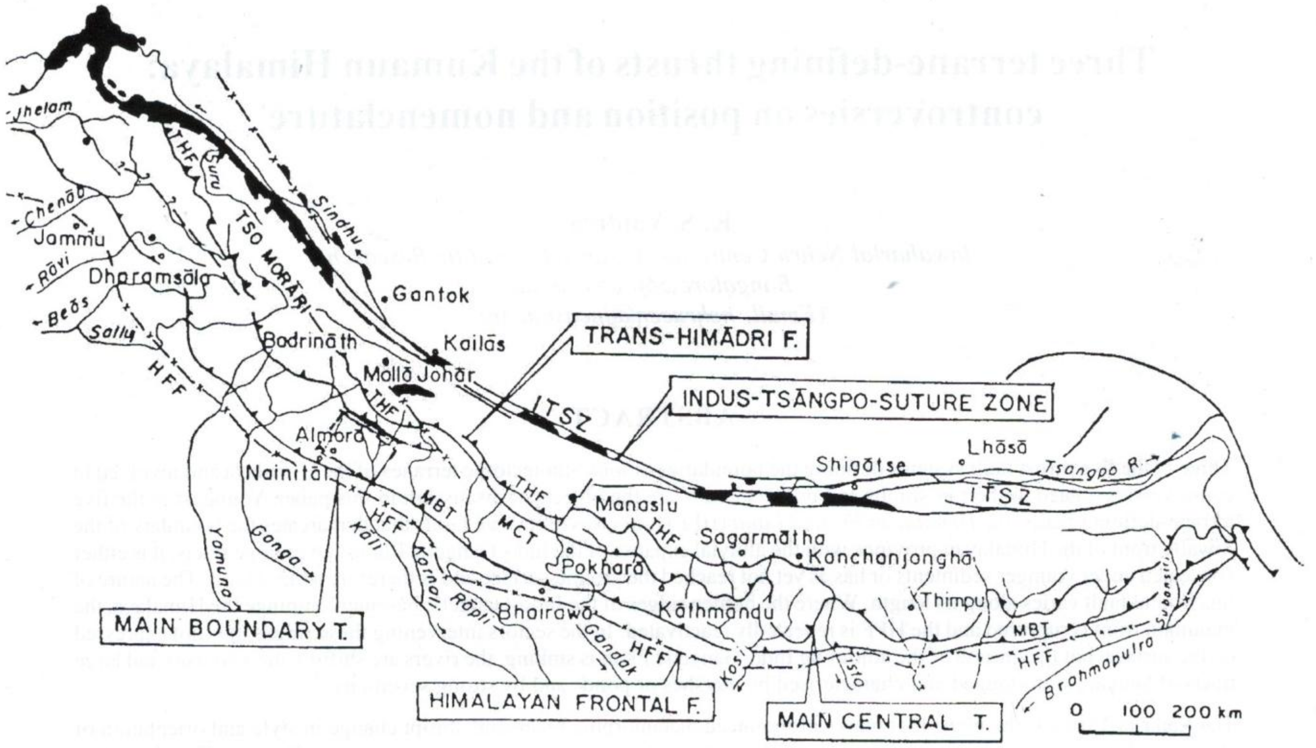


Fig. 1: The generalised map showing four physiographically distinct and lithologically contrasting terranes of the Himalayan province defined by the boundary faults and thrusts (Validya 1998)

that ranges in age from Late Precambrian to Lower Eocene as observed in the Tingri–Kampa area in Southern Tibet. The rugged terrane of the Tethys is separated from the Himadri or Great Himalaya terrane by what has been described as the *Trans-Himadri Fault* or *South Tibetan Detachment System*. The perennially snow-covered extremely rugged Himadri terrane rises from 3000 m to more than 8000 m in altitude. Made up of high-grade metamorphic rocks and granites of Pan-African and Early Miocene ages, the Himadri served as the basement of the Tethyan succession. This basement complex overrides and overlooks the Lesser Himalayan rocks to the south. It is the *Main Central Thrust* that has brought the Himadri rocks over and above the 600–2500 m high Lesser Himalayan terrane made up of Proterozoic to Lower Cambrian sedimentary rocks overlain by nappes and klippen of low- to medium-grade metamorphic rocks associated with mylonitised Palaeoproterozoic granites. It may be emphasised that the Palaeoproterozoic granites and mylonites occur within the typically Lesser Himalayan phyllites and sublitharenites of the Ramgarh sheet and its northerly extension Bhatwari–Barkot–Chail nappe, which lie structurally below the Munsiari–Almora sheet (Valdiya 1978) (Fig. 8). Obviously, the Palaeoproterozoic is not a part of the Great Himalayan succession.

The *Main Boundary Thrust* defines the boundary of the Lesser Himalaya against the Siwalik terrane. Made up of fluvial-alluvial Cenozoic sedimentary rocks, the 250 to 800 m high Siwalik Hills overlook the Indo-Gangetic Plains to the south. The *Himalayan Frontal Fault* (HFF) or *Main Frontal Fault* (MFF) separates the Siwalik terrane from the vast expanse of the Indo-Gangetic Plains, representing the latest foreland basin of the Himalayan province.

Of the five terrane-defining thrust systems, three are involved in controversies related to position and nomenclature. These are the objects of discussion in this paper.

INDO-GANGETIC PLAINS – HIMALAYA BOUNDARY

Demarcating the southern boundary of the Himalaya against the alluvial expanse of the Indo-Gangetic Plains, the Himalayan Frontal Fault is the youngest of the five terrane-defining fault systems of the Himalayan orogen (Figs. 1 and 2).

The southern boundary of the Himalaya has been described by different names by different workers–as a thrust demarcating the edge of the Himalaya at Haridwar by Talukdar and Sudhakar (1972); as Foothill Fault by Karunakaran and Ranga Rao (1979) and Thakur (1993); as Main Frontal Thrust by Gansser (1991); as Himalayan Foothill Boundary by Raiverman et al. (1993). The author (Valdiya 1984, 1992, 1998) adheres to the nomenclature proposed by

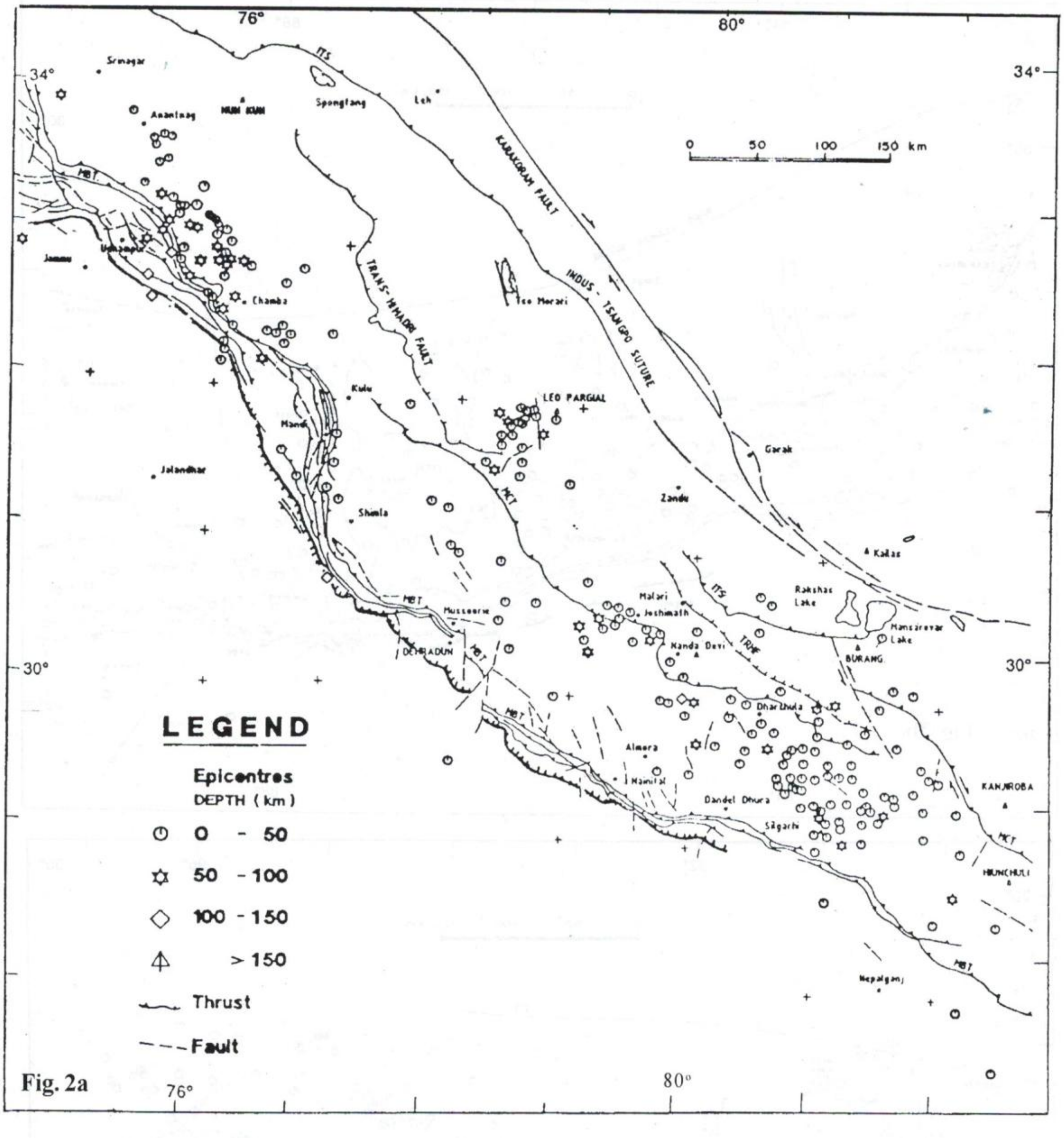


Fig. 2a

Fig. 2: Delineation of the Himalayan Frontal Fault (in three pieces – of western, central and eastern sectors) by the author (Valdiya 1992) on the basis of published works of a number of workers. Note the distribution of epicenters of earthquakes of magnitude M ≥ 5. There is practically no seismicity in the proximity of the HFF in the central and western sectors.

T. Nakata (1972) who first recognised and characterised it in the south-western Uttaranchal Himalaya between the rivers Ganga and Yamuna (Fig. 3).

The Himalayan Frontal Fault (HFF) originated in the Later Pleistocene between 1.5 and 1.7 Ma when the foreland basin in front of the emergent Himalaya was intensely compressed, resulting in its breaking up into the rising hilly Siwalik domain and the subsiding Sindhu–Ganga–Brahmaputra depression (Valdiya 1998). The entire Siwalik domain from Potwar in northern Pakistan to the Dihing valley in Assam was overwhelmed by excessive influx of gravels and mud coming from the fast-rising Himalaya. Understandably, the mountain front was affected by a very strong tectonic upheaval that triggered massive landslides and debris flows on the slopes of the destabilized mountain.

NATURE OF THE HFF

Over large tracts, the HFF is either concealed under the gravel deposits of the piedmont zone or has not yet reached the ground surface (Fig. 2). Moreover, it is not a continuous fault–it represents a series of reverse faults and thrusts that

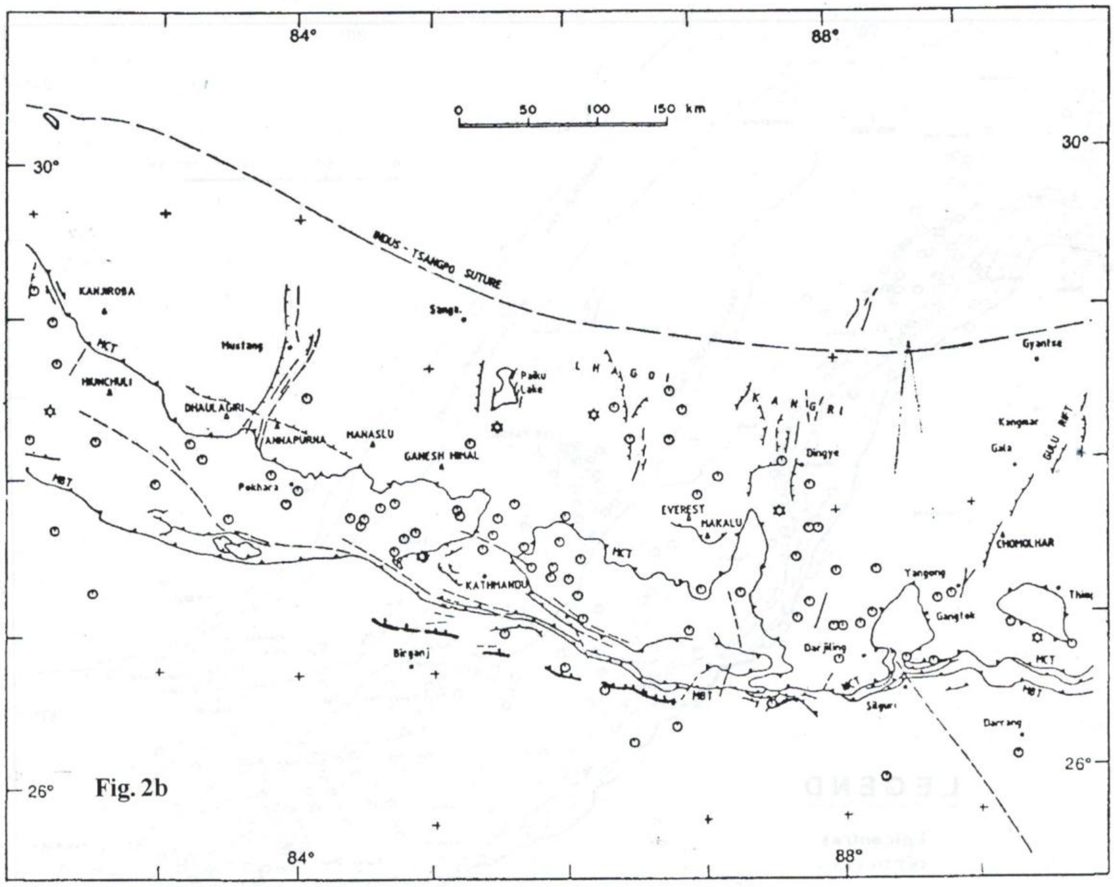


Fig. 2b

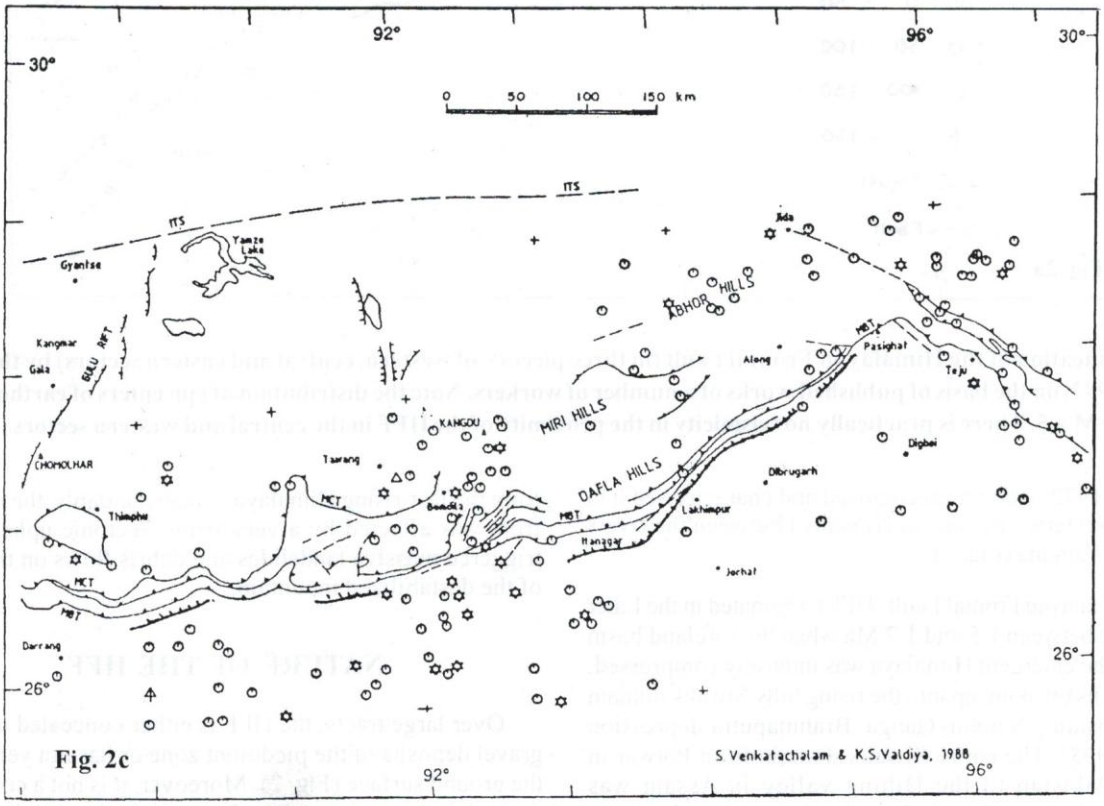


Fig. 2c

Fig. 2: Contd...

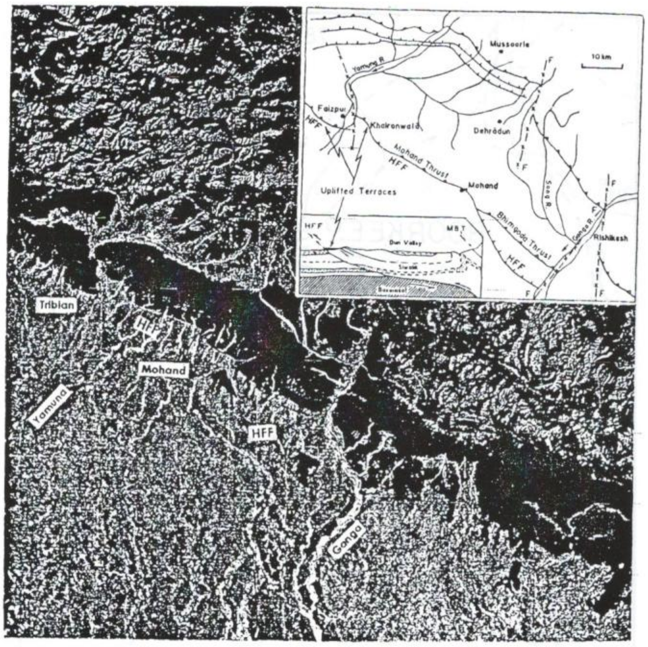


Fig. 3: Satellite imagery shows the HFF as a remarkably sharp, nearly linear boundary of the Siwaliks with the alluvial expanse of the Ganga–Yamuna rivers. Dark grey tone shows the forested Siwalik front, and the light grey-white part represents the apron of gravel fans at the foothills. (Courtesy: NRSA, Hyderabad). The inset shows simplified structural map of this area, based on Yeats and Lillie (1991).

have brought about attenuation of the Siwalik terrane, truncating its folds and faults and placing the Tertiary assemblage of rocks of the Siwalik terrane against the Quaternary sediments of the Indo-Gangetic Plains of the Sindhu–Brahmaputra–Ganga Basin (Fig. 2). The Siwaliks terrane in the west comprises three structural units, and just one (northern) unit east of Kaladhungi (79° longitude) all through the extent of the Siwalik up to the Brahmaputra (Valdiya 1984). This situation is attributed to the truncation of the Siwalik terrane by movements on the fault bounding it against the Indo-Gangetic Plains.

The nature of the HFF varies along its length from east to west. In the tract between the Sharada and Ganga rivers, it is of the nature of a thrust (Fig. 2a). In the type area in south-western Uttaranchal, the HFF is a low-angle (~30°) fault – a thrust that is blind, its surface expression being the Mohand Anticline and the downdip part becoming a decollement horizon (Yeats and Lillie 1991). Between the Ganga and Ravi valleys the reverse fault is of variable inclination, and is affected by strike-slip movements. In the foothills of the Kashmir Himalaya between the Ravi and Jhelam rivers (Fig. 2a), the faulting is not clearly expressed - it is either concealed under the cover of young sediments or is a blind fault that has yet not reached the surface of the ground.

According to Raiverman et al. (1993) the variation of the nature and attitudes of the HFF is due to a strong influence of the transverse structural elements (hidden ridges and faults) in the floor of the Sindhu–Ganga–Brahmaputra Basin (Fig. 7). In the Nepal sector (Fig. 2b) there is no clear expression of the HFF over a large tract. In the Arunachal foothills (Fig. 2c), a reverse fault demarcates the Upper Siwaliks from the Brahmaputra alluvial plain.

Strongly negative gravity anomaly (up to -150 mgal) near the foothills of the Siwaliks is indicative of a great thickness of the Quaternary sediments adjacent to the boundary between the two domains. This implies considerable sinking of the floor of the Ganga Basin adjacent to the mountain front.

ONGOING SLIP ON HFF

Holocene movements on the HFF have lifted up the gravelly terraces dated older than 3663±215 yr B.P. to 20–30 m above the stream level (Wesnousky et al. 1993). The uplift (at the rate of ≥6.9±1.8 mm/yr and the resultant slip at the rate of 13.8±3.6 mm/yr) is geomorphically expressed in the development of scarps. Slope failure is quite common on the scarps as seen west of Mohand (Fig. 3).

In the foothills of south-central Kumaun, the HFF is related to a 60–90 m high escarpment, locally broken by triangular facets that are devoid of rills and gullies. The smooth planar scarps resulted presumably from sheet slides. On the scarps are exposed the Late Pleistocene Dun Gravel grading upwards into younger fluvial gravel deposit, the younger deposits being lifted 8 to 20 m above the stream level (Valdiya 1992; Valdiya et al. 1992). The Dun Gravel is tilted 10–15° northwards in the Ramnagar–Jim Corbett National Park region as clearly discernible along the Kosi Valley (Fig. 4). In the southern periphery of the Jim Corbett National Park small streams crossing the outer Siwalik range have carved slit canyons that are deeply entrenched, bearing testimony to the continuing uplift of the Siwalik front (Valdiya 1992). Significantly, the subrecent gravel terraces, though horizontal, indicate two pulses of uplift subsequent to the tilting of the Late Pleistocene Dun Gravel.

IMPACT OF ACTIVENESS OF HFF ON INDO-GANGETIC PLAINS

The northern part of the Indo-Gangetic Plains could not have escaped the upheavals related to the reactivation in the recent time of the HFF. This is manifested in the development of ridges and depressions, paralleling the Himalayan ranges, in the flat expanses of the Plains.

In the south-central Kumaun foothills (Fig. 2a) where the HFF is untraceable, the Gaula flowing past Haldwani is deeply incised into the 15–56 m thick mass of fluvial and debris-flow deposits (Shukla and Bora 2003). This implies mild continuing uplift of the piedmont zone. To the west as the Ganga enters the Indo-Gangetic Plains, it passes through a zone of erosion, where the soil development is in a poor state. The degree of soil development increases from north to south, implying the

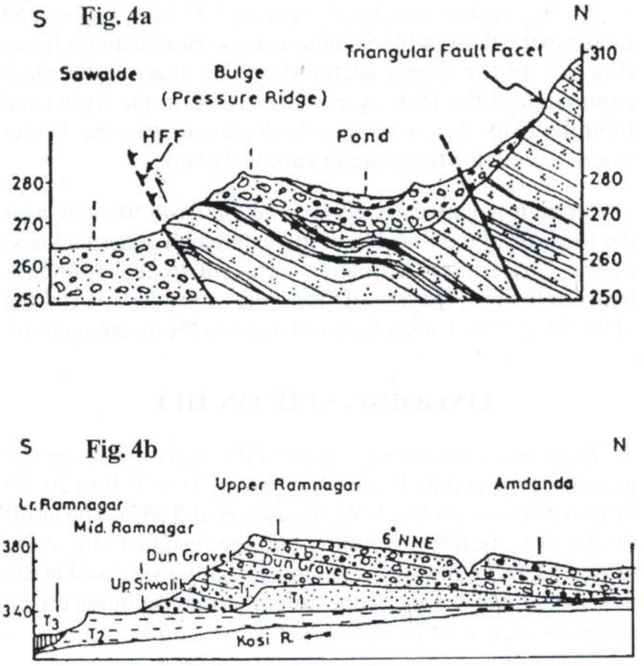


Fig. 4: (a) Deformed fluvial gravel of subrecent age (resting on the Siwaliks) at Sawalde, west of Ramnagar. (b) Dun Gravel of Late Pleistocene age is tilted 10–15° northwards in the Kosi Valley. However, the younger gravel terraces, indicating two pulses of uplift, remain horizontal. (From Valdiya 1992).

rise of the northern part (Kumar et al. 1996). Significantly, the tilting of the ground is testified by progressive shifting of the Ganga and Yamuna rivers (Fig. 5), and the variations in the degree of soil development.

On either side of the Yamuna River (Figs. 2a and 3) there is a pronounced geomorphic development related to ground swelling. The Dehradun–Roorkee road shows one such bulge between Mohand and Chhutmalpur. West of the Yamuna, a 9 m high scarp in the E–W direction, cutting through the alluvial gravel, is manifested in the shifting of a small stream (Wesnousky et al. 1999).

The Nepal foothills (Fig. 2b) over 180 km long stretch between the Rapti and the Saptkosi, the ground is subsiding rapidly (Mohinder and Parkash 1999), resulting in impeded drainage and ponding of streams on a large scale (Fig. 6). This has led to the formation of marshes that remain under water for eight months in a year. Another result of the ground subsidence and tilting is the continuing shifting of rivers. The Gandak, for example, has shifted eastward by 105 km over its megafan in the period 1935–1975 (Mohinder and Parkash 1994), and the Kosi moved 112 km in the span of 218 years from 1736 to 1964 (Gole and Chitale 1996). The subsidence of the ground has forced the rivers to migrate (through avulsion and cut-off and extensive overbank flooding), resulting in the development of back swamps and lakes (Sinha 1996).

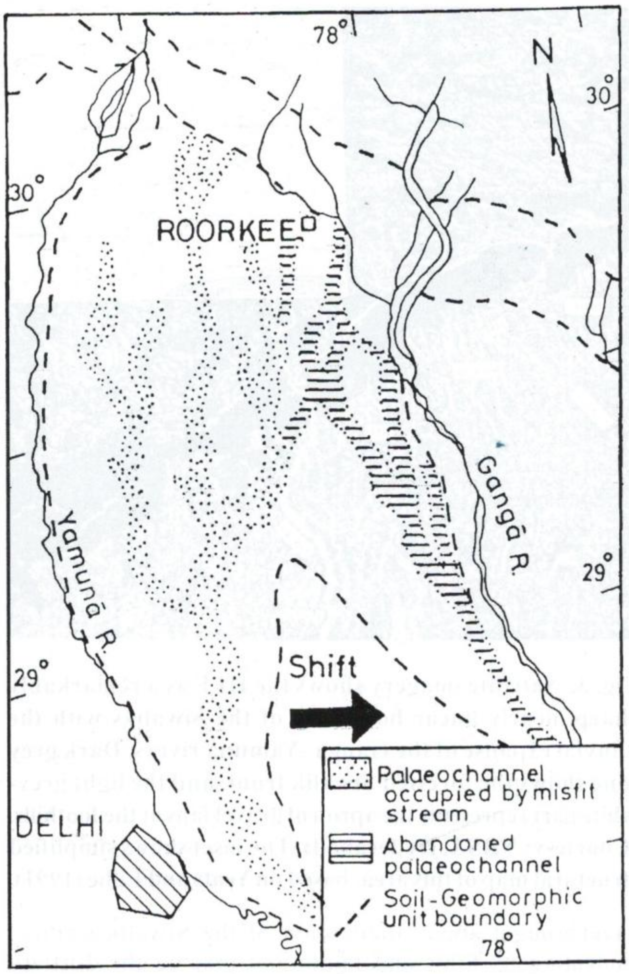


Fig. 5: Shifting channels of the Ganga and Yamuna rivers due to tilting of the ground surface close to the HFF (after Kumar et al. 1996)

In the foothills of central Bhutan (Fig. 2c) the ground just south of the foothill has subsided, and a little south risen 30–35 m up, forming an E–W ridge (Nakata 1972). The depression is characterised by ponds, lakelets and marshes, due to impeded drainage. East of the Chel River in the Sikkim–Darjeeling sector, the ground surface has risen up 80 m along an E–W fault (Fig. 6) while there is upwarping and southward tilting in the west (Nakata 1972).

TECTONICS OF HFF

The Indian Plate, with the prisms of Siwaliks and Indo-Gangetic sedimentary assemblages, is sliding under the Himalaya at a rate of 20±4 mm/yr along the Main Boundary Thrust – the Siwalik-Himalaya boundary plane (Freymueller et al. 1996). The foothill belt is not behaving uniformly all through its extent. Some parts are ruptured and resurgent seismotectonically, others are showing signs of neotectonic movements and

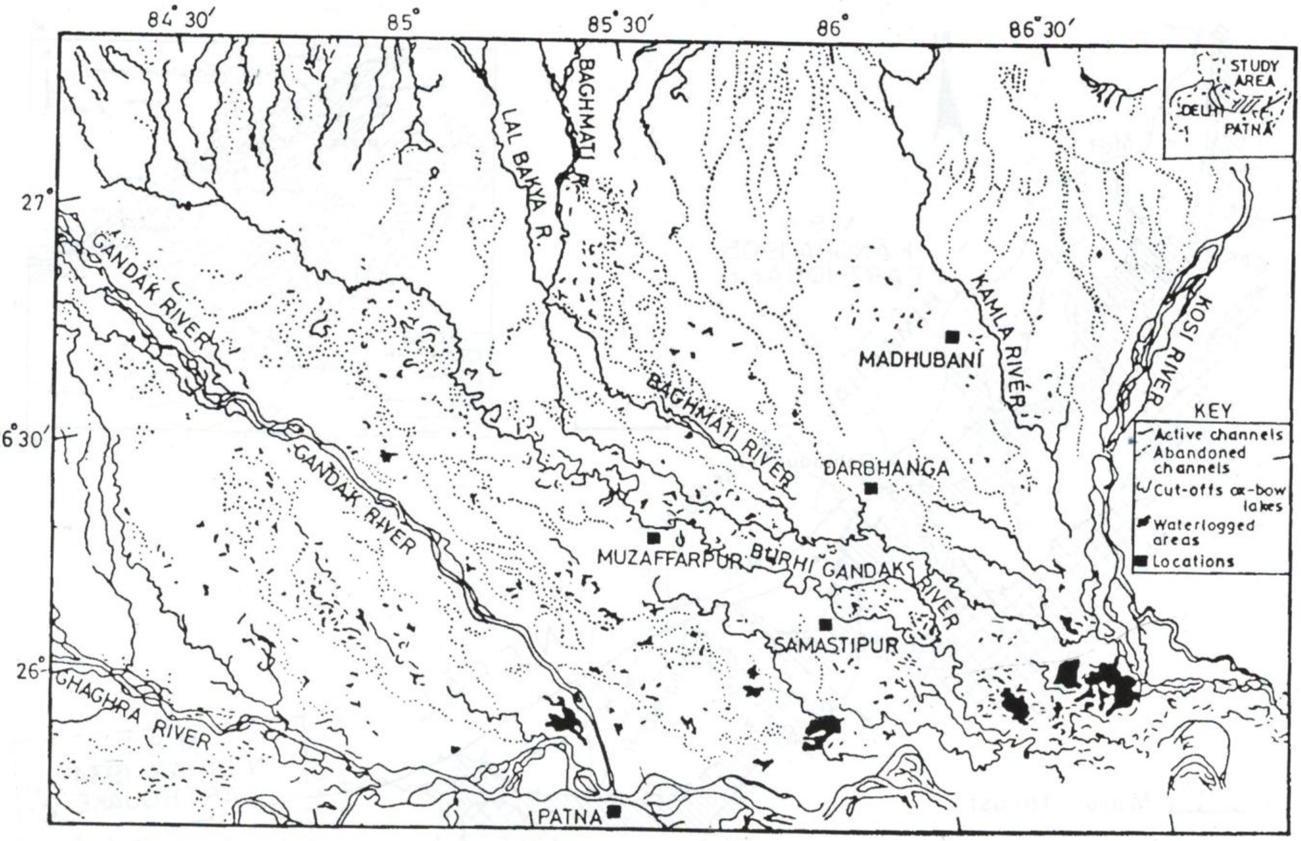


Fig. 6: Ground surface of northern Bihar is subsiding, resulting in progressive shifting of rivers and development of waterlogging, swamps, and lakes due to impeded drainage (From Sinha 1996).

some others remain unaffected. It seems that where the ridges in the basement of the Indo-Gangetic Basin (Raiverman et al. 1993) such as the Aravali–Haridwar High, the Satpura–Munger–Saharsa High, the Meghalaya–Mikir High (Fig. 7) impinge the Himalaya, the mountain front is ruptured (Fig. 2a and 2c) and the HFF is active. In the intervening sectors between these hidden ridges, the HFF is not expressed – at least not on the ground surface (Fig. 2b). Presumably the frontal boundary is a blind fault in these sectors, and the ground is sinking owing to continuing slip deep underground. This is particularly evident in northern Bihar where the ground has subsided maximally and continues to sink at a rate of 0.2 to 0.3 mm/yr (Sinha 1996), the rivers are continually changing their courses, and the land is recurrently ravaged by floods. It is here where the thickness of the Quaternary sedimentary accumulation is maximum (1500–2500 m). These sectors have thus served like depocentres, now known as Sharada and Gandak Depressions (Fig. 7). Palaeoliquefaction studies in the Motihari–Sitamarhi–Madhubani region in northern Bihar show that in addition to the recorded 1883 and 1934 great earthquakes (M ≥8.0), there were two more seismic events of equal magnitude – one between 1700 and 5300 yr BP and the other earlier than 25,000 yr BP (Sukhija et al. 2002). This seismically active region covering more than 12000 km² area has been described as the "slump belt".

MAIN CENTRAL THRUST

Boundary between Lesser Himalaya and Himadri

The Main Central Thrust (MCT) in Kumaun (Uttaranchal) Himalaya is a terrane-delimiting thrust that separates the Lesser Himalaya from the Great Himalaya (Himadri). It not only separates the two lithotectonically distinctive terranes but also forms the boundary between physiographically contrasted terrains that the geographers recognise. The thrust that Heim and Gansser (1939) recognized and depicted (Fig. 1 and 8) in their classic work as the MCT separates the lower-grade metamorphic rocks with their tectonised Precambrian granites from the Proterozoic sedimentary rocks of the Lesser Himalaya terrane (Fig. 2 and 8). According to them, the MCT is "a nicely traced thrust with gentle dip (20–35°)" separating "the crystalline central zone" from the underlying "sediments of the Tejam zone with quartzite as its uppermost division" (p. 221). This definition embodies the idea that "the synclinal crystalline zones or outliers

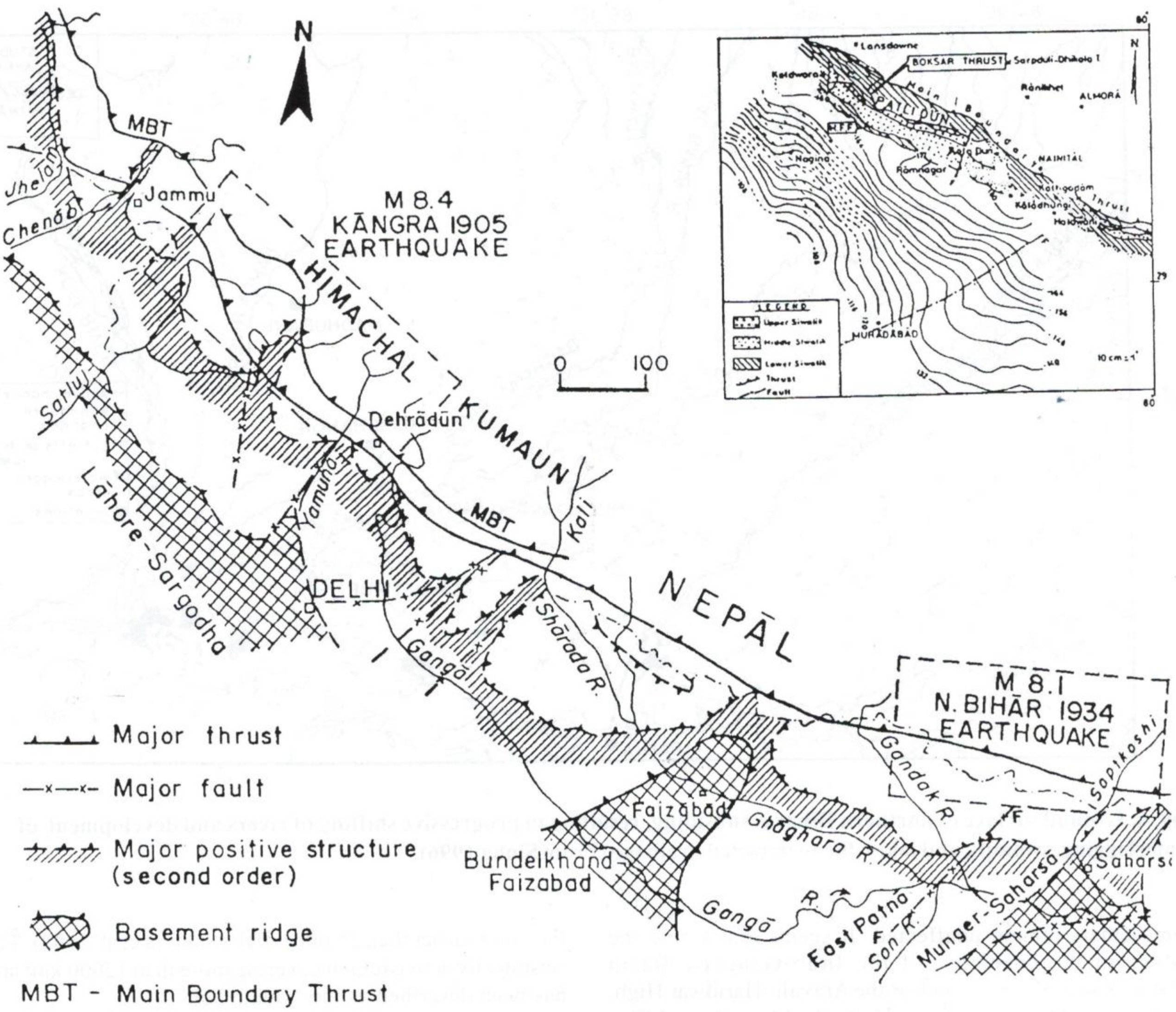


Fig. 7: Uncovering of the thick mass of Quaternary sediments would reveal northward extension of the Precambrian ridges, faults and intervening depressions in the basement of the IndoGangetic Basin. The inset shows extension of the subsurface Moradabad Fault towards central Kumaun Himalaya (After Raiverman et al. 1993).

in the Lower Himalaya are apparently the prolongation towards SW of this MCT mass, which have undergone secondary folding after the main horizontal displacement" (p. 225).

The definition of the MCT by Heim and Gansser (1939) and Gansser (1964) was favoured by practically all investigators, but not the present author. For, he noticed a pronounced metamorphic break and abrupt change in style and orientation of structures across a plane (Fig. 9) higher up in the succession of the crystalline rocks that build the bulk of the snowy mountain range in the Kumaun Himalaya, and designated it as Vaikrita Thrust (Valdiya 1976a, 1976b, 1979, 1980a and 1980b). The Vaikrita Thrust (VT) is thus a terrane boundary – a tectonic surface that delimits the boundary of the Great Himalaya and the Lesser Himalaya. And the tectonic surface separating the low-grade metamorphic rocks with tectonised granite from the underlying Proterozoic sedimentary rocks of the Lesser Himalaya was renamed as Munsiari Thrust. The thrust surface separating the sedimentary rocks from the crystalline rocks succession–the Munsiari Thrust and its analogues elsewhere–cannot be accepted as the terrane-defining Main Central Thrust for several reasons as explained in the following paragraphs.

The synclinal nappes and associated klippen of crystalline rocks in the Lesser Himalaya terrane are considered to be the remnants–or detached pieces–of the overthrust MCT sheet that Heim and Gansser (1939) recognised. For, its frontal part reaches 95–110 km in the

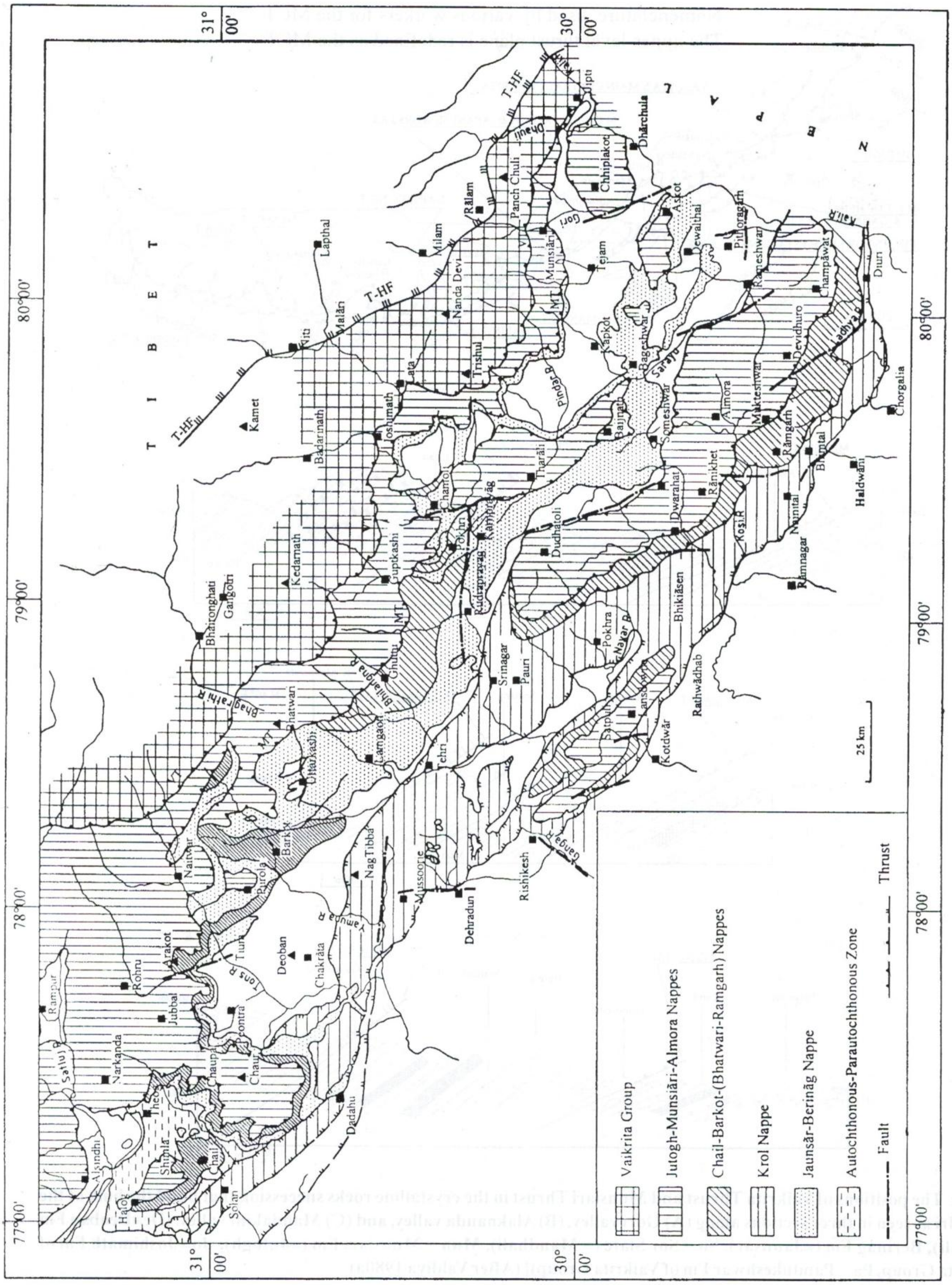
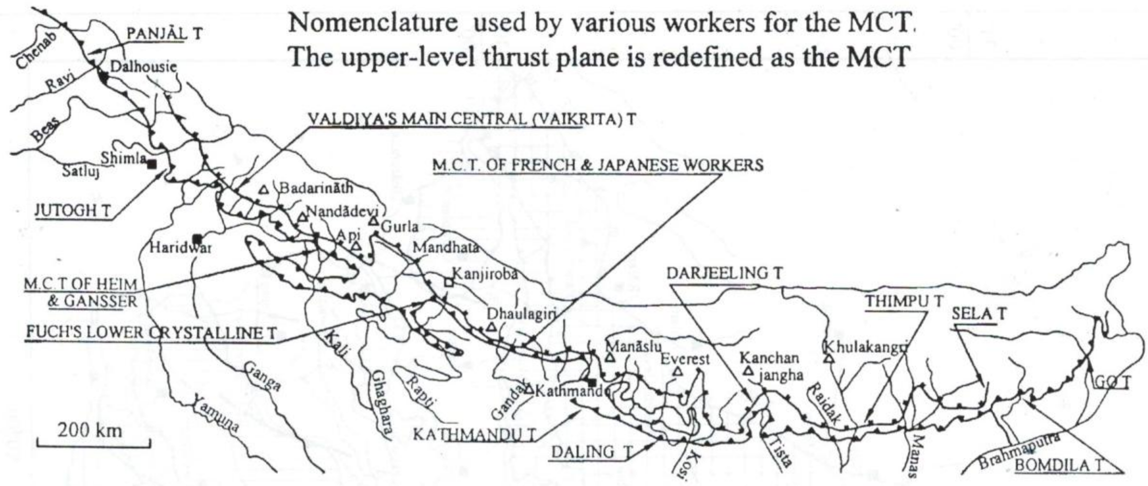


Fig. 8: Simplified tectonic map of Kumaun Himalaya (Uttaranchal) (Valdiya 1976b, 1979) showing various terrane boundaries including Vaikrita Thrust, Munsiari Thrust and Main Boundary Thrust. What Valdiya described as Munsiari Thrust was earlier recognized and designated as MCT by Heim and Gansser (1939). Vaikrita Thrust remained undetected until Valdiya (1976b, 1979, 1980a) identified and depicted it. The synclinal nappes and klippen in the Lesser Himalaya terrane are shown as the prolongation of the Munsiari unit lying below the Vaikrita Thrust.



Nomenclature used by various workers for the MCT. The upper-level thrust plane is redefined as the MCT

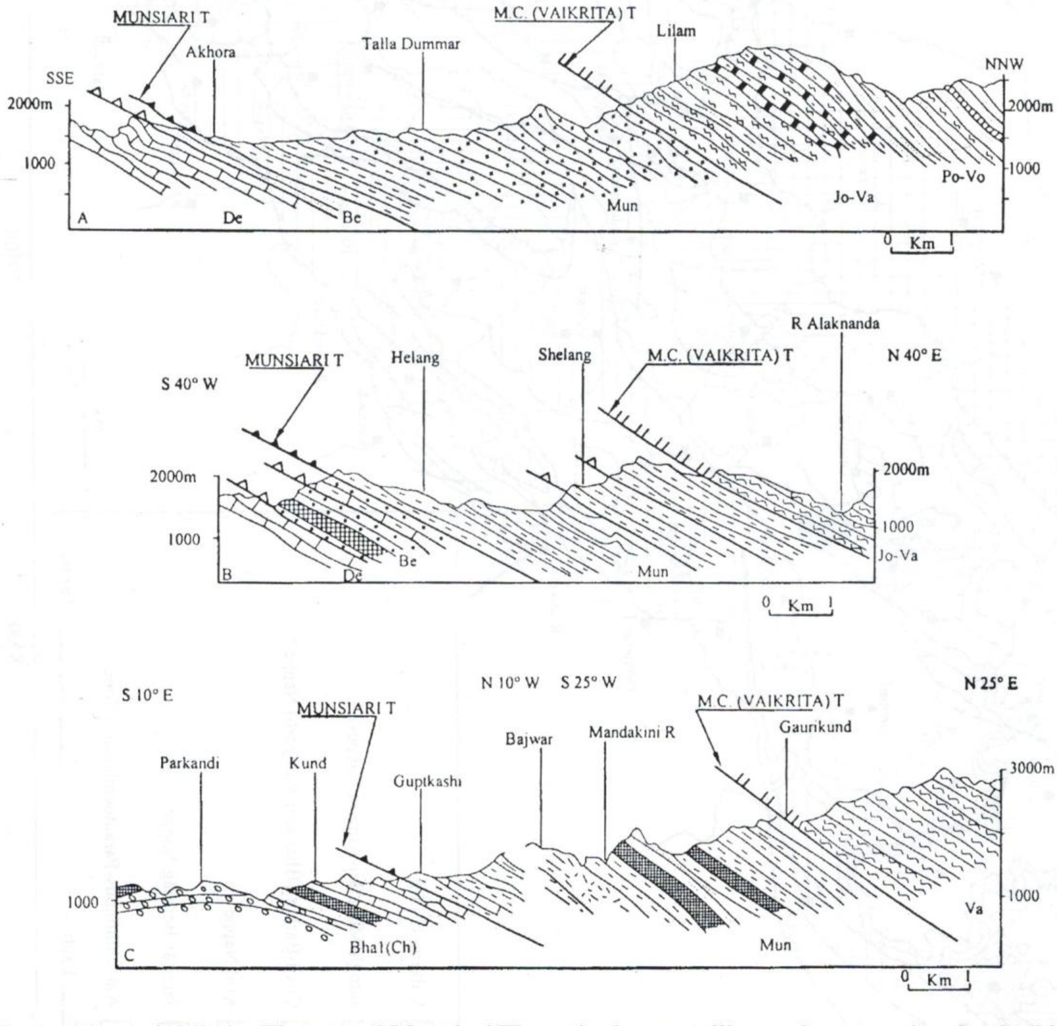


Fig. 9: The positions of Vaikrita Thrust and Munsiari Thrust in the crystalline rocks succession that build the bulk of the Himadri as seen in three sections along (A) Gori valley, (B) Alaknanda valley, and (C) Mandakini valley. [De≡Deoban Fm (≡ Shali), Berinag Fm (≡Jaunsar), So = Sor Slate (≡ Mandhali), Mun = Munsiari Fm (≡Jutogh), Jo≡ Joshimath Fm of Vaikrita Group, Pa = Pandukeshwar Fm of Vaikrita Group)] (After Valdiya 1980a)

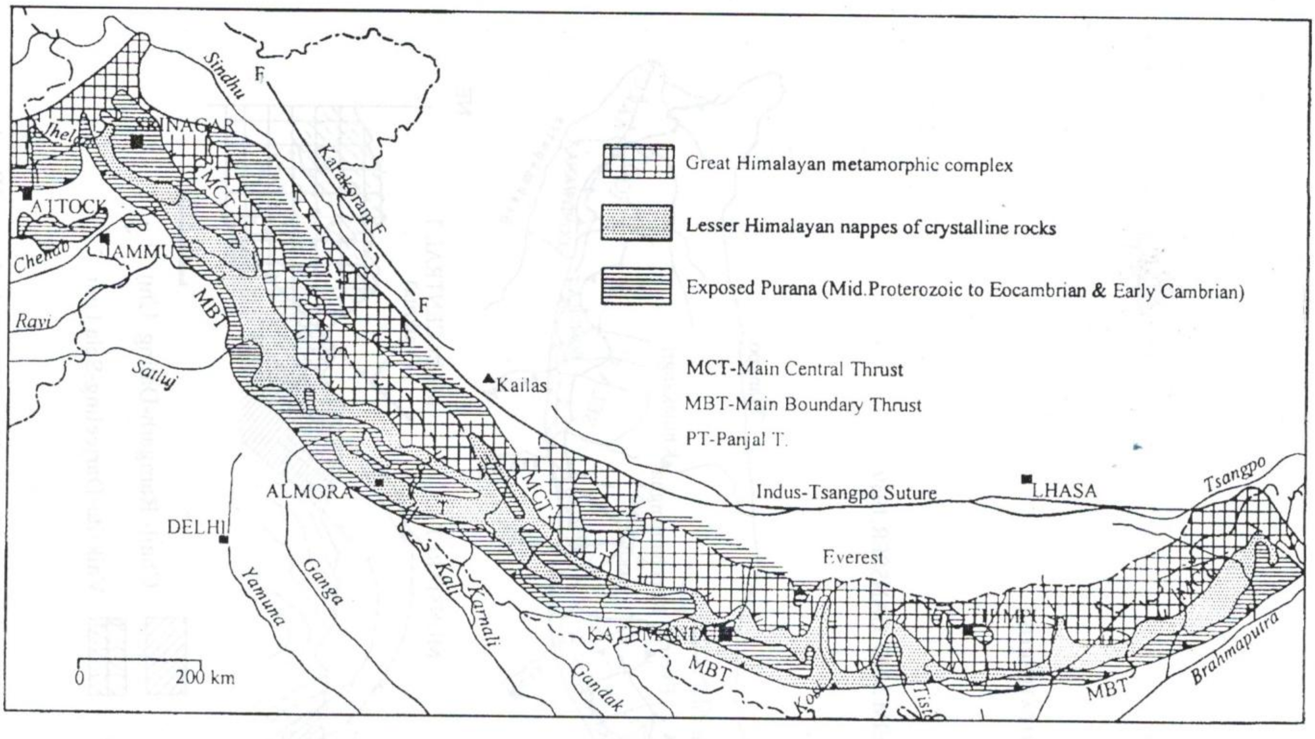


Fig. 10: The Great Himalayan (Himadri) terrane comprises high-grade metamorphic rocks associated with 500±25 Ma old porphyritic and 20±1 Ma old anatectic granite. It is delimited at the base by the Vaikrita Thrust — which the author regards as the Main Central Thrust. The Lesser Himalayan lower-grade metamorphic rocks associated with 1900±100 Ma old highly tectonized granite porphyry and 500±25 Ma porphyritic granite constitute the Munsiari sheet and its nappes and klippen. The nappes and klippen rest upon and are concordantly folded with the underlying Proterozoic–to-Early Cambrian sedimentary rocks of the Lesser Himalaya (Valdiya 2001).

Outer Lesser Himalaya. In Nepal (Upreti 1999) and further east the front comes close to the Main Boundary Thrust (Fig. 10) which delimits the boundary of the Siwalik terrane against the Lesser Himalaya. A thrust plane that is traceable close to the Siwalik terrane boundary and defines klippen or a nappe detached from its root and comprising essentially Lesser Himalayan rocks cannot be called the Main Central Thrust, the recognised tectonic boundary between the lithologically distinctive and phyiographically contrasted terranes of Great Himalaya and Lesser Himalaya.

The uniquely and unambiguously Vaikritan high-grade metamorphic rocks such as kyanite-sillimanite psammitic gneisses, garnet-biotite-kyanite-quartz schist, calc-silicate rocks, biotite-porphyroblastic calc schist, anatectic leucogranite and migmatites do not occur (Figs. 8, 9 and 10) in the succession of the larger and small nappes in the Lesser Himalayan domain (Figs. 10 and 11). This fact implies that the crystalline rocks of the Lesser Himalayan nappes and klippen and not the uprooted parts of the Vaikrita complex of the Himadri.

The 25 to 15 Ma (Le Fort 1988; Trivedi 1990) old tourmaline-bearing anatectic leucogranites and associated migmatites of the Great Himalayan Vaikrita complex are nowhere discernible in the Lesser Himalayan nappes and klippen (Fig. 12), implying that the Lesser Himalayan crystalline rocks escaped the climactic thermodynamic phase of the Himalayan orogenic cycle which overwhelmed approximately 20±1 Ma ago the whole of the Great Himalaya and gave rise to, among other things, the anatectic granites and migmatites. In other words, the Lesser Himalayan nappe rocks do not represent the prolongation of the Vaikrita complex.

It may be pointed out that there is a clear distinction in tectonostratigraphic setting between the Palaeoproterozoic (1900±100 Ma) and the Cambro–Ordovician (500±25 Ma) granites and mylonites in Nepal. The former are present within the Lesser Himalayan rocks and the latter only within the Great Himalayan rocks, as demonstrated by mapping and structural analysis (DeCelles et al. 2001), structurally controlled Nd-isotope geochemistry (Robinson et al. 2001), and more than 3000 U–Pb ages (Parrish and Hodges 1996; DeCelles et al. 2000, 2001). However, in Kumaun and Himachal Pradesh the 550±25 Ma granites occur in the Lesser Himalayan nappes made up exclusively of lower-grade metamorphic rocks (even phyllitic)–the Dalhousie (456±50 Ma) and the Mandi (518±100 Ma) in Himachal, and the Almora at Ranikhet (485±55 Ma), Almora (560±20 Ma) and Champawat (565±22 Ma) in south-central Kumaun (Trivedi et al. 1984; Trivedi 1990; Valdiya 1995). According to Le Fort et al (1986) these were formed under dry conditions and resulted from

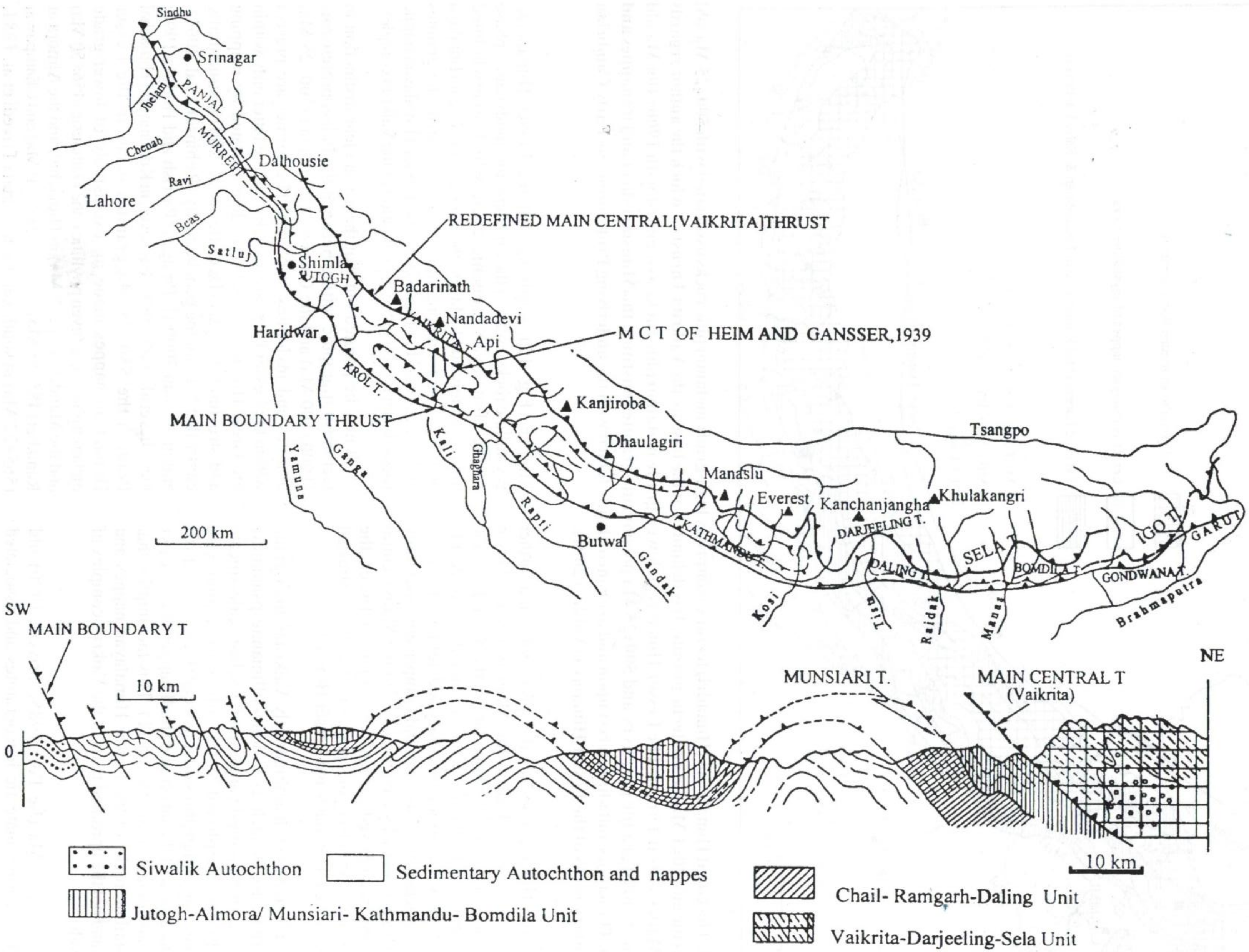


Fig. 11: Diagramatic map and cross section of the Kumaun Himalaya showing that the nappes and klippen of the crystalline rocks in the Lesser Himalaya terrane are made up of rocks indistinguishable from the rocks of the Munsiari unit lying below Vaikrita Thrust at the base of the snowy range but are singularly destitute of unambiguously Great Himalayan high-grade metamorphic rocks with anatectic granite and migmatites (Valdiya 1980a).

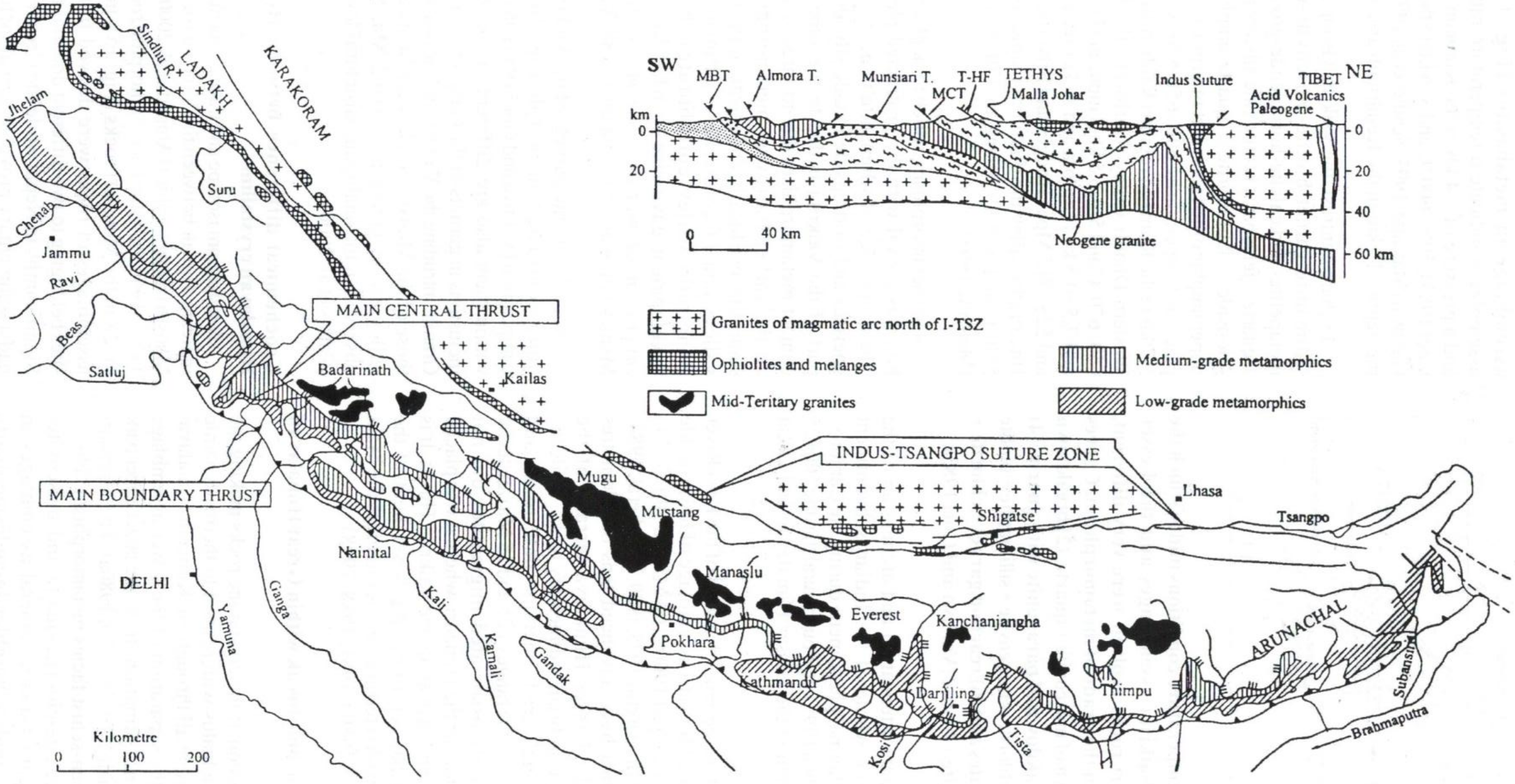


Fig. 12: Sketch map of the Himalayan terranes showing the predominantly 20±1 Ma-old (25–15 Ma range) anatectic leucogranite restricted to the Himadri terrane and the basal Tethyan sedimentary succession. These granites are singularly absent in the Lesser Himalayan nappes made up of lower-grade metamorphic rocks with 1900±100 Ma.-old tectonised and Cambro-Ordovician porphyritic granite (Valdiya 1983).

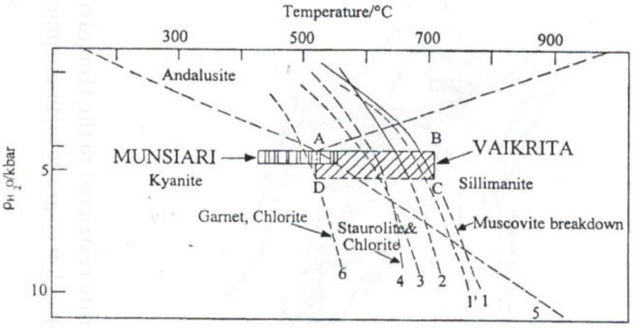


Fig. 13: Pressure-temperature conditions under which the Great Himalayan Vaikrita assemblages and the Lesser Himalayan Munsiari rocks evolved were very different, indicating a hiatus in the grade of metamorphism. Curves refer to (1) breakdown of muscovite + quartz, (2) breakdown of staurolite, (3) breakdown of paragonite with quartz, (4) reaction staurolite + chlorite = muscovite + sillimanite + biotite + quartz, (5) Al-silicates and (6) reaction garnet + chlorite + muscovite = sillimanite + biotite (Valdiya and Goel 1983).

extension and attendant attenuation and arching up of the continental crust. The whole of the Indian subcontinent experienced tectonothermal phenomena during the Cambro–Ordovician time (Valdiya 1995). It is but natural that the 500±25 Ma granites occur both in the Lesser Himalayan and Great Himalayan terranes.

The author, therefore, believes that west of the Kosi River (in Nepal) it is only the Munsiari assemblage of lower-grade metamorphics with tectonised 1900±100 Ma and 500±25 Ma old porphyritic granites (Bhanot et al. 1975, 1980; Trivedi et al. 1984; Singh et al. 1986) that have advanced tens of kilometres southwards over the Lesser Himalaya terrane of the Proterozoic-to-Early Cambrian sedimentary rocks, while the Vaikrita pile with high-grade metamorphic rocks and dominant 20±1 Ma old (in the range of 25 and 15 Ma) anatectic granite with intimately associated migmatites did not advance beyond the foot of the Himadri, where it was placed over the Munsiari assemblage along the Vaikrita Thrust. It is this Vaikrita Thrust that constitutes the lower limit of the Great Himalaya (Himadri) terrane, and is therefore the Main Central Thrust (Valdiya 1980a, 1981, 1988, 1998).

Pronounced metamorphic break within Great Himalayan succession

Within the succession of the crystalline rocks making the bulk of the Himadri a hiatus with respect to thermodynamic conditions is discernible all through the Kumaun Himalaya. This is the basis of the separation of the lower assemblage of rocks– the Munsiari Formation–from the larger upper part, the Vaikrita Group (Valdiya 1976b, 1979, 1980a). The Munsiari rocks exhibit the green-schist facies metamorphism. This is evident from the sericite-chlorite-quartz and muscovite-chlorite-chloritoid-garnet-quartz mineral assemblages in metapelites and the epidote-hornblende-andesine-quartz assemblage in metabasites (Fig. 13). The Munsiari assemblages indicate a temperature range of 250°–450 °C and a pressure of ~ 4 kb in the Kumaun region (Valdiya and Goel 1983), 500°–600 °C and 3–6 kb in the Bhagirathi valley in Garhwal (Matcalfe, 1993; Scaillet et al, 1993) and 500°±20 °C at the depth <15 km in the Kedarnath area (Singh et al. 1997).

In sharp contrast, the Vaikrita Group comprising kyanite/sillimanite-garnet-biotite-muscovite-quartz-plagioclase metapelites and calcite-hornblende-grossularite-labradorite ± quartz ± feldspar ± biotite calc silicate rock and hornblende -diopside ± labradorite ± quartz amphibolite indicate the upper amphibolite facies metamorphism (Fig. 13) which took place at temperatures 600–650/670 °C and pressures 5 to 5.7 kb in the Kumaun region (Valdiya and Goel 1983). In the Western Dhauli valley (Garhwal), the PT conditions were 650–670 °C and 5.5–6.5 kb (Gupta and Dave 1979), 645±50 °C and 7.5±0.5 kb (Gairola and Ackermann 1988) and > 780 K and 523–317 Mpa (Hodges and Silverberg 1988) while in the Bhagirathi valley the thermodynamic conditions were 640–550 °C and 8–9 kb, rising to 770 °C and 12 kb at the top (Metcalfe 1993).

The metamorphism, which took place at a depth of 19–20 km, was coeval with the protracted phase of deformation. The occurrence of sillimanite in pelites and psammopelitic gneisses and of diopside in calc silicate rocks in the upper part of the Vaikrita is due to the superimposition of later contact metamorphism due to large-scale granite intrusion on the earlier Barrovian metamorphism. Occurrence of staurolite and locally andalusite in the Gori and Bhagirathi valleys and of cordierite ± sillimanite at Harsil in the Bhagirathi valley corroborates this inference. This development gave rise to what has been described as *inversion of metamorphism* (Arita 1983; Jain and Manickavasagam 1993; Valdiya 1988; Valdiya et al. 1999).

Not only are the garnets of the Vaikrita and the Munsiari quite contrasted in morphology and trace elements composition (Valdiya and Goel 1983), the monazite inclusions within them also are different in age. While the monazite inclusions in garnets of the Gangotri Granite and the Shivling Granite intruding the Vaikrita in Garhwal are 20.2±0.6 Ma old, those of the Munsiari rocks near Bhatwari in the Bhagirathi valley are as young as 5.9±0.2 Ma. Similar situation is observed in the analogous structural levels in central Nepal (Catlos et al. 2000).

Geochemical difference between Himadri and Lesser Himalayan crystalline

Neodymium isotope and trace element data unambiguously indicate a break between the Vaikrita rocks and the underlying Munsiari metamorphics (Ahmad et al. 2000). The ε_{N}d value is –14 to –19 in the Vaikrita metamorphic rocks compared to –23 to –28 in the Munsiari rocks (Fig. 15), implying that the two assemblages of rocks were derived from entirely different sites belonging to two different domains (Ahmad et al. 2000). Significantly, in Nepal while the Great Himalayan sequence had a sedimentary provenance that included a major source

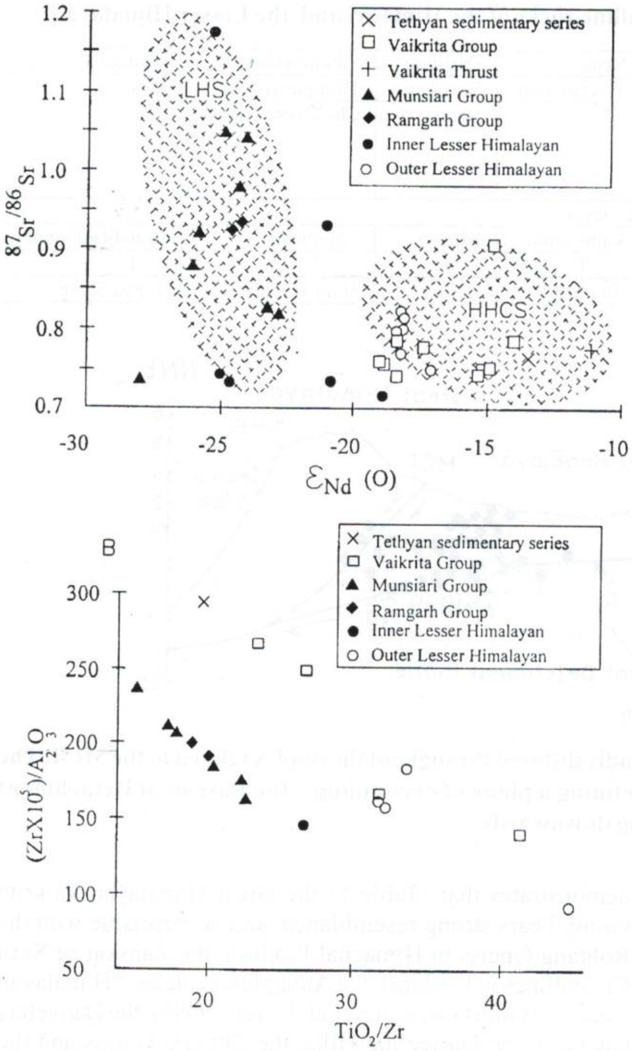


Fig. 14: (A) The relationship of neodymium isotope value – strontium istotope ratio clearly distinguishes the Vaikrita metamorphic rocks of the Himadri from the Munsiari rocks of Lesser Himalayan affinity. (B) Zircon-alumina and titania-zircon ratios clearly bring out the separation of the Munsiari and Lesser Himalaya nappe rocks from the high-grade metamorphic rocks of the Vaikrita of the Himadri domain (From Ahmad et al. 2000).

of 0.8–1.0 Ga zircons, the source of the Precambrian part of the Lesser Himalayan sequence contained 1.87–2.60 Ga zircons; and in contrast to the Great Himalayan rocks having ε_Nd values between –14.6 and –18.5, the Lesser Himalayan counterparts had ε_Nd values between –21.4 and –25.9 at 21 Ma (Parrish and Hodges 1996). This fact provides a very strong support to designating the Vaikrita Thrust as the terrane-bounding MCT. The Nd isotopic study coupled with trace element data (Fig. 14) further demonstrate a strong similarity of the crystalline rocks of the Munsiari Formation with those of the Lesser Himalayan nappes. Significantly, Robinson et al. (2001) have similarly distinguished the rocks of the Lesser Himalayan nappes from those of the Great Himalaya in Nepal— the average ε_Nd(o) value being –21.5 in the Lesser Himalaya and –16 in the Great Himalaya.

Different granites of Himadri and Lesser Himalaya

Across the Vaikrita Thrust (the MCT) the granitic component of the crystalline succession are radically different. The 500±25 Ma old Cambro-Ordovician porphyritic granite is, however, common to the Vaikrita, the Munsiari and the Lesser Himalayan nappes. This granite is thus a non-Himalayan element in the sense that its origin and emplacement is unrelated to the Cenozoic Himalayan orogenic cycle. On the other hand, the intrusive bodies (batholiths, laccoliths, sills, dykes, etc.) of strikingly leucocratic adamellite and granite in the upper part of the Vaikrita succession (and also intruding into the basal Tethyan sedimentary rocks) (Fig. 12) are singularly Himalayan rocks that formed 21±1 Ma ago. This age is deduced on the basis of fission-track dating of zircon and apatite, 39Ar/40Ar age of hornblende, U-Pb age of zircon and Th-Pb age of monazite (references in Valdiya 2001). Characterised by the occurrence of sillimanite, kyanite and cordierite, these granites are a product of partial melting or anatexis of high-grade metamorphic rocks of the Vaikrita (Powar 1972; Gupta 1979; Valdiya and Goel 1983). These granites are further characterised by high though variable values of strontium ratio – 0.746 to 0.785 and by low neodymium isotope ratios < 0.5119 (Stern et al. 1989; Scaillet et al. 1993; Searle et al. 1993).

The anatectic granites are intimately injected *lit-par-lit* into the metapelites, giving rise to migmatites on a large scale (Valdiya and Goel 1983; Valdiya 1988, 1998). The anatectic granites and migmatites are altogether absent in the Munsiari sheet and in the Lesser Himalayan nappes of the crystalline rocks as already pointed out. This clearly shows that the Great Himalayan Vaikrita does not extend south of the base of the Great Himalaya – beyond the Vaikrita Thrust (Fig. 12).

In great contrast, the Munsiari Formation and the crystalline nappes in the Lesser Himalaya comprise in the basal part 1900±100 Ma old granite (Bhanot et al. 1975, 1980; Singh et al. 1986) that are spectacularly porphyritic and notably rich in biotite and quartz, and invariably tectonised. Severe cataclasis has converted the granite into augen mylonite, ultramylonite and porphyry schist (Valdiya 1988). Much of the sericite schist seems to be phyllonite. These Proterozoic granites show low (0.706) initial strontium ratio, usually varying from 0.703 to 0.725 (Singh et al. 1986). Very similar granites in predominantly the Ramgarh unit of the crystalline rocks succession in the Lesser Himalayan nappes have the initial strontium ratio of 0.746±0.14 to 0.7325±0.0035 (Trivedi 1990).

Seismic expression of Vaikrita Thrust

Most of the epicentres lie just south of the surface trace of the MCT. With a few exceptions, most of the fault-plane solutions indicate thrust movements. The hypocentres at the depth from 15 to 25 km are broadly scattered throughout

Table 1: Correlation of the rock formations of the crystalline rocks of the Himadri and the Lesser Himalaya

Terrane	Kashmir	Himachal	Kumaun	Nepal	Darjiling	Sikkim-Bhutan	Arunachal
Himadri (Great Himalaya)	Zanskar/Suru Crystalline	Rohtang Gneiss Vaikrita	Vaikrita Annapurna Gneiss, Himalayan Gneiss, Khumbu/Barun Gneiss	Tibetan Slab	Darjiling Gneiss	Thimpu Gneiss, Chasilakha Gneiss	Sela
Main Central Thrust							
Lesser Himalaya	Salkhala	Jotogh	Almora	Kathmandu	Paro	Chunthang	Bomdila /Dirang
		T	T	T	T	T	T
		Chail	Chail	Bhimpedi	Daling	Shumar/Samchi	Tenga/Siang

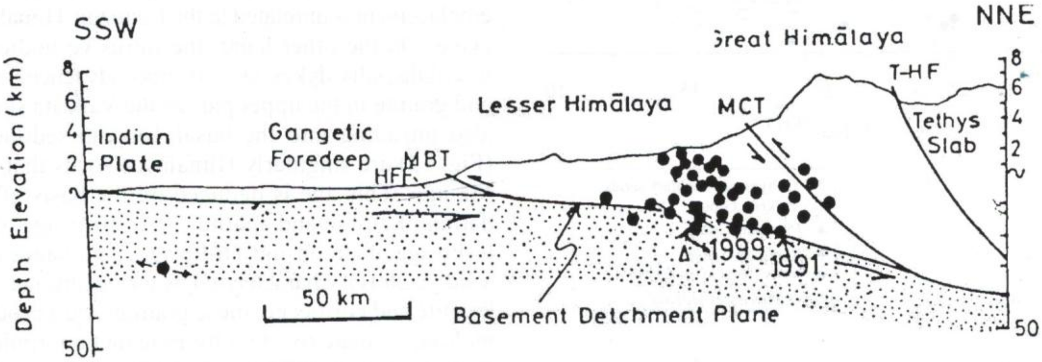


Fig. 15: Hypocentres of small and moderate earthquakes are broadly diffused throughout the duplex related to the MCT. The pattern of hypocentral distribution has been interpreted as defining a plane of decoupling – the Basement Detachment Thrust (BDT). The Vaikrita Thrust (MCT) has caused its flexing downwards.

the duplex related to the MCT, implying continuing activity of the thrusts within the duplex. The pattern of hypocentral distribution (Fig. 2) has been interpreted as defining the interface (Fig. 15) between the underthrusting Indian plate and the overlying Himalayan mass. This interface is known as the Basement Detachment Thrust (Molnar and Chen 1982; Ni and Barazangi 1984; Jackson and Bilham 1984; Khattri 1987; Cotton et al. 1996; Kayal 1996; Narula et al. 2000). This is the plane on which the Himalayan rock mass is sliding southwards. It seems that the Himalayan orogenic wedge is both sliding southwards along the main detachment and shortening internally by folding at depth and faulting (P.G. Delelles, per. com., 2004). This is obvious from the G.P.S. studies (Bilham and Gaur 2000).

The BDT is flexed downwards, steepening to 10–15° under the Himadri (Fig.15), the flexing taking place ~ 50 km south of the Indus–Tsangpo Suture (Lyon-Cean and Molnar 1985). The zone of flexing down of the BDT coincides with the line below the surface trace of the Vaikrita Thrust–which the author recognises as the MCT. It seems that the Vaikrita Thrust is genetically related to the BDT which is responsible for the displacement of Himalayan rock mass due to continuing underthrusting of the Indian plate (Fig. 15).

Regional correlation

Regional correlation of the high-grade metamorphic rocks intruded by anatectic granite of Early Miocene age demonstrates that (Table 1) the Great Himalayan Vaikrita Group bears strong resemblance, and is correlable with the Rohtang Gneiss in Himachal Pradesh, the Zanskar or Suru Crystallines in Kashmir, the Annapurna Gneiss, "Himalayan Gneiss", Barun Gneiss in Nepal (Upreti 1999b), the Darjeeling Gneiss in the Darjeeling Hills, the Thimpu Gneiss and the Chasilakha/Takhtasang Gneiss in Sikkim–Bhutan and the Sela Group in western Arunachal Pradesh. The thrust planes defining the base of these gneissic units against other rocks below represent the extension of the Vaikrita Thrust that is the Main Central Thrust (Fig. 16) in the sense that it delimits the Himadri terrane against the Lesser Himalaya domain.

TRANS-HIMADRI FAULT: A DETACHMENT SYSTEM

Basement–cover relationship

The high-grade metamorphic rocks and associated 500±25 Ma and 20±1 Ma granites that build the bulk of the Himadri constitute the basement complex on which rests a great thickness of the Cambrian-to-Cretaceous Tethyan sedimentary succession throughout the expanse of the Himalaya Greisbach (1891), Auden (1937) and Heim and Gansser (1939) saw no clearly defined boundary between the Vaikrita of the Himadri and the overlying slates, phyllites and quartzites of the Haimanta System belonging to the Tethyan domain.

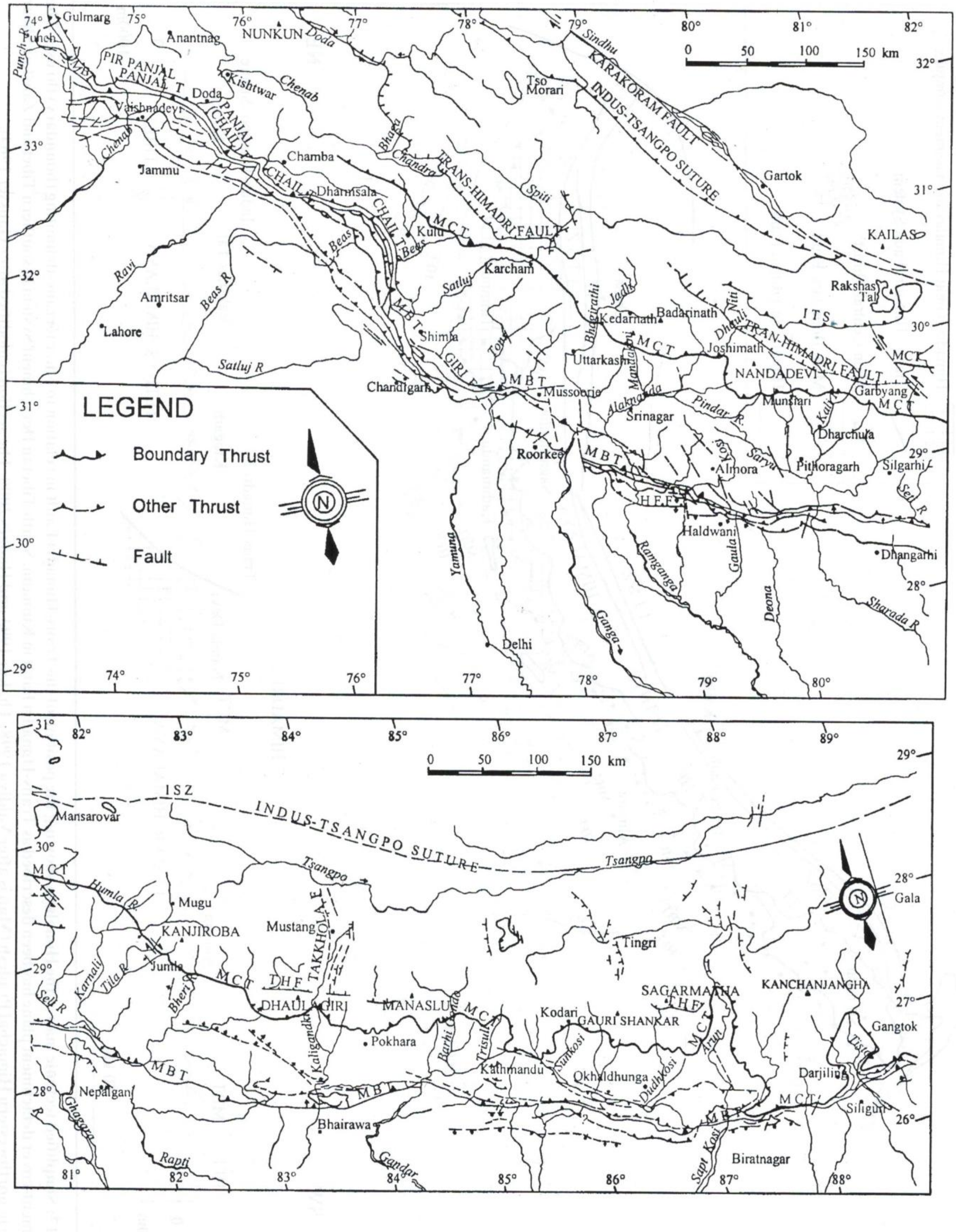


Fig. 16: Delineation of the Main Central Thrust in Kumaun, Himachal, Nepal, Darjiling and Sikkim Himalaya (Valdiya 1992)

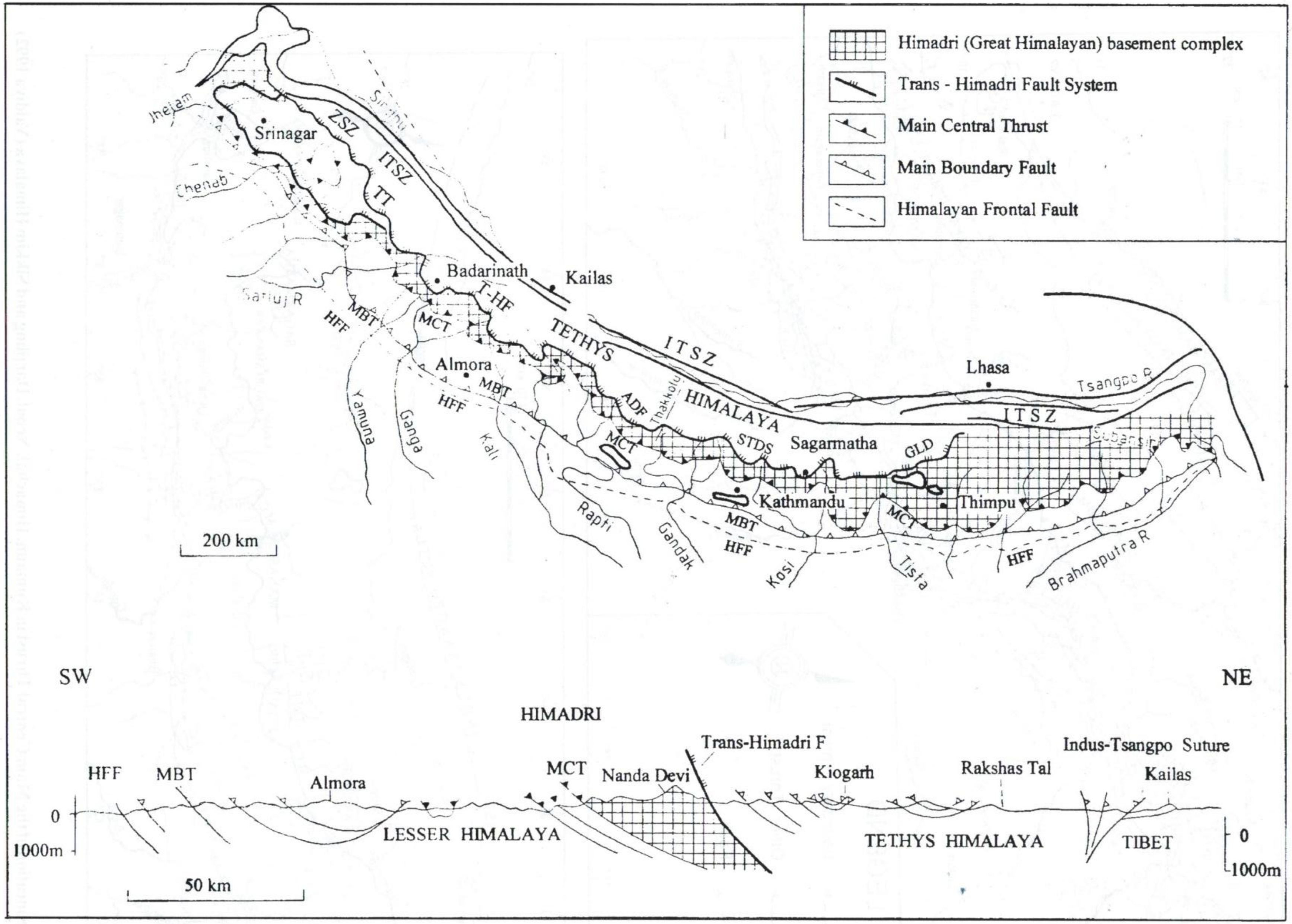


Fig. 17: Simplified tectonic map of the Himalaya showing the position of the Trans-Himadri Fault in relation to other terrane-delimiting (boundary) thrusts. The basement-cover detachment plane has been described as Trans-Himadri Fault in Kumaun, South Tibetan Detachment System in southern Tibet and Zanskar Shear Zone in northwestern Himachal Pradesh (Map is after Valdiya 1998; Thakur 1993 and Hodges 2000. The section is modified after Gansser 1964).

The author's observations are at variance with those of earlier workers. In the Kali Valley in northeastern Kumaun (Fig. 17 and 18) the Budhi unit of the Vaikrita Group comprising biotite porphyroblastic calc schist and calc silicate rocks is abruptly succeeded by a thick succession of Middle Ordovician dolomitic and argillaceous limestones with calcareous shales of the Garbyang Formation (Heim and Gansser 1939). The Budhi succession itself is split by a fault into two slices, one steeply dipping and another gently inclined (Powar 1972). Significantly, the intervening horizons (Martoli Formation and Ralam Formation) of the Tethyan succession are altogether missing in the Kali succession in sharp contrast to their development as 500–800 thick succession of greywacke-slate and 500 m conglomerate and quartzite in the Gori Valley nearly 80 km to the west respectively (Fig. 18). This situation of extraordinary superposition provides a clear case of elimination by faulting of two crucial horizons. It was designated as *Malari Thrust Fault* (Valdiya 1976, 1979, 1981, 1984). Realizing later that it represents a plane of decoupling of the cover rocks from their basement, it was renamed as *Trans-Himadri Fault* (Valdiya 1987, 1988, 1989) – the fault that is developed across the Great Himalayan snowy *Himadri* ranges of the Himalaya. The Himadri or Great Himalaya is thus bounded at the base by the gently north-dipping Main Central Thrust and at the top by the relatively steeply-hading Trans-Himadri Fault. It is a huge tectonic wedge that took shape during the climactic phase of the Himalayan orogeny.

The recognition and delineation in maps and cross-sections of the Kumaun Himalaya (Figs. 1 and 2) of a boundary fault of regional dimension in the central sector of the mountain arc (Valdiya 1976, Figs. 7 and 9; Valdiya 1979, Figs. 2 to 5 and 10; Valdiya 1981 Figs. 3 and 15; Valdiya 1984, Figs. 8.2, 8.3D, 8.11) was the negation of the widely accepted view that the high-grade metamorphic rocks of the basement pass transitionally upward without break into the sedimentary rocks of the Tethys terrane. Understandably, there were no takers to the proposition and portrayal of the author's Malari Fault. Even those who had noticed and described similar normal faults in southern Tibet to the north of the Everest region and in north-eastern Nepal, did not take cognisance of the author's recognition in Kumaun of the fault detaching the basement complex from its sedimentary cover.

Regional extension

Northwest of the Kumaun Himalaya in the Spiti region of Himachal Pradesh, Berthelsen (1951) depicted at Babeh Pass a fault– apparently of no consequence to him–between the Vaikrita metamorphic rocks and the Haimanta sedimentary succession. The fault seen south of Morang in the Satluj valley (Fig. 19) and the one south of Batal dipping 10–30° NE in the River Chandra in the Lahaul region between the "Central Crystallines" and the Tethyan sedimentaries was described by Sinha (1989) as *Tethys Thrust*. There is a pronounced break in the grade of metamorphism between the kyanite-sillimanite-bearing gneisses and schists characterized by three phases of folding of the footwall and the biotite-facies rocks in the hanging wall exhibiting only two episodes of deformation (Bhargava et al. 1991; Misra 1993; Sinha et al. 1997). Further northwest in the Doda valley the Vaikrita metamorphic rocks have a faulted contact with the Later Proterozoic phyllites (Fig. 20, lower section) of the Tethyan domain (Nanda and Singh 1977). In the Suru valley in the Zanskar region, a 45°–70° NE-dipping fault (Fig. 20 upper section) has brought the Early Permian to Triassic Panjal Volcanics against the Vaikrita rocks (Fuchs 1977; Baud et al. 1984), Interestingly, Fuchs (1977) did not believe in the existence of this fault, which later Pognate et al. (1990) described as *Zanskar Fault* dipping 45–50° NE, and which has locally deformed the leucogranites.

It will be obvious that the elimination of stratigraphic units due to faulting along the T-HF system increases from the Satluj valley northwestwards to the Suru valley (Fig. 20).

In the Zanskar region (Fig. 20), the T-HF system has been studied comprehensively. Described as *Zanskar Shear Zone* (Searle 1986; Herren 1987; Patel et al. 1993; Jain 1998; Steck et al. 1998; Jain and Patel 1999; Jain et al. 2002) or as *Tethys Thrust* (Sinha 1989; Thakur 1993; Sinha et al. 1997; Paul and Paul 1999), the T-HF is a 2.2 to 6.7 km wide ductile shear zone characterised by intensely mylonitised rocks and "telescoped metamorphic isograds within a 250 m wide strip" (Patel et al. 1993; Jain et al. 2002) in which there was southward thrusting in the initial phase and NE–SW oriented extension subsequently. The minimum horizontal and vertical displacements in the Zanskar Shear Zone were of the order of 16 and 19 km, respectively (Herren 1987; Patel et al. 1993). A significant feature noticed in the Zanskar Shear Zone is the occurrence of "melt-enhanced leucogranite veinlets, indicating close relationship between extensional tectonics, exhumation and decompression melting (Patel et al. 1993; Jain et al. 2002). Jain et al (2002) prefer to describe the whole stretch of the detachment plane in western Himalaya as *Trans-Himadri Shear Zone*.

Going by the map of Thakur (1993), west of the Suru Valley the T-HF becomes a thrust (Fig. 20), bringing the Tethys pile upon the Zanskar crystalline rocks. Together with the slice of the basement complex (made up of low-grade metamorphic rocks of the Salkhala Formation was thrust southwards for considerable distance across the Himadri domain onto the Lesser Himalaya terrane. This development gave rise to emplacement of the Chamba and Kashmir nappes of the predominant Tethyan sedimentary formations (Figs. 17 and 20).

Turning east of the Kali valley, in south-central Nepal (Fig. 21) Bordet (1961) had schematically portrayed a decollement between the basement called "Tibetan Slab" of high-grade metamorphic rocks and the Tethyan sedimentary cover. It was noticed that the intervening horizon of phyllites, greywackes and acid tuff– the "Sanctuary Formation"– is considerably attenuated and overlain by a thick pile of middle Ordovician dolomites and limestones (Bordet et al. 1975).

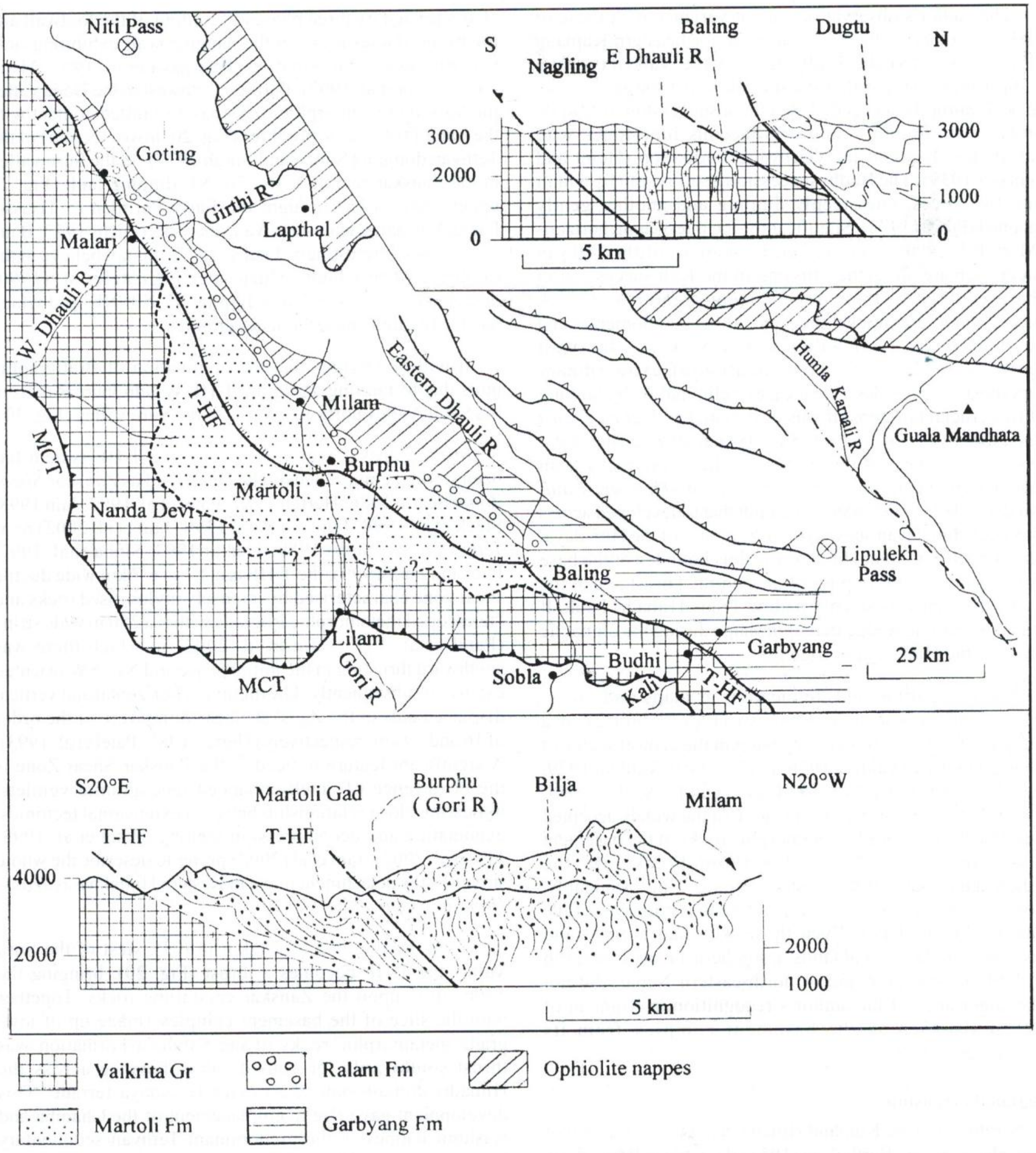


Fig. 18: Simplified tectonic map of northeastern Kumaun, showing truncation and attenuation of rock formations (such as Martoli and Ralam) by the Trans-Himadri Fault (T-HF). North of the T-HF, the Tethyan sedimentary succession is split into imbricating thrust sheets, and in the northeast is the Gurla Mandhata Dome made up of basement rocks that constitute the footwall beneath the T-HF (Modified after Valdiya 1979 which is based on Heim and Gansser 1939).

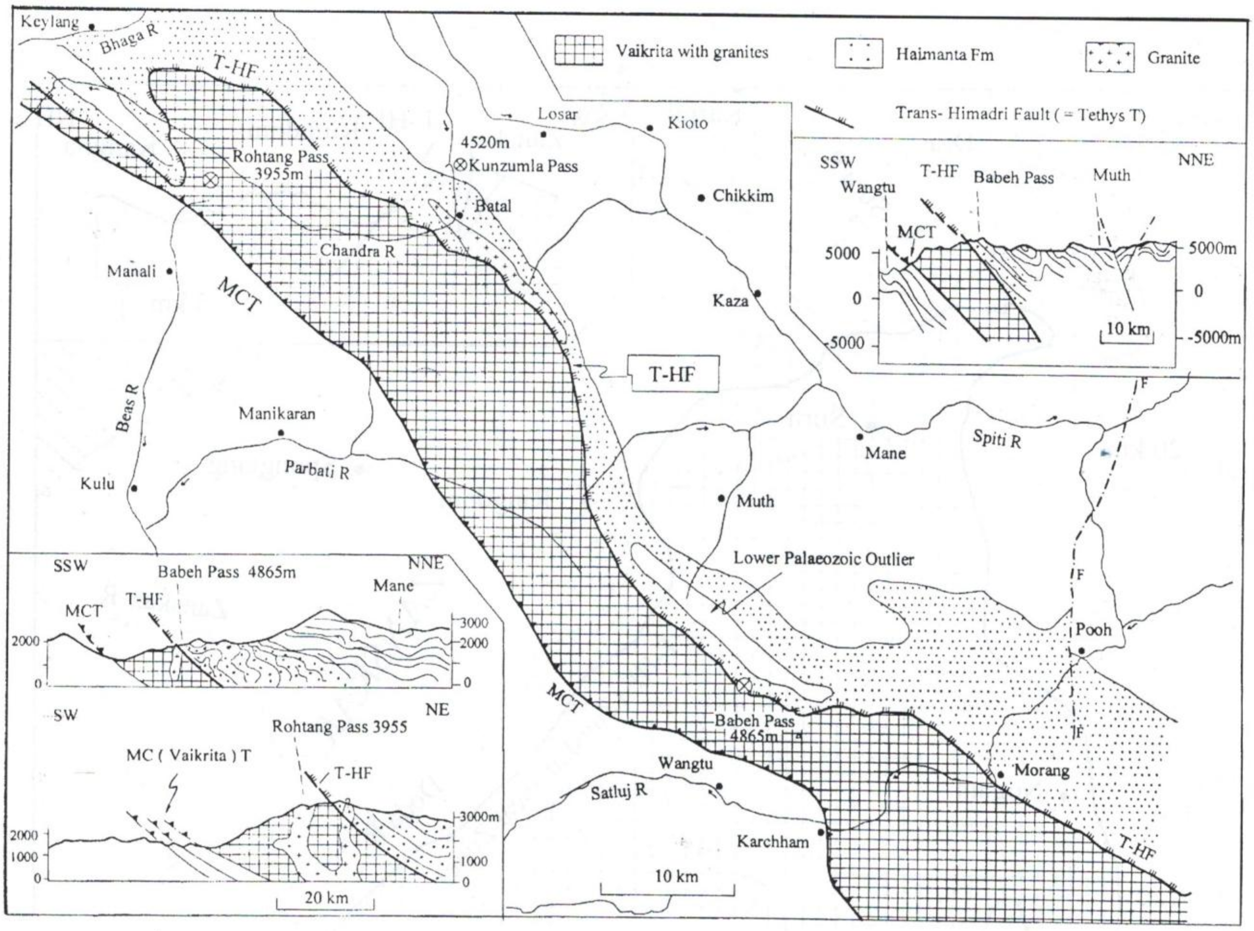


Fig. 19: Simplified tectonic map of the Spiti-Lahaul region of Himachal Pradesh (modified after Sinha et al. 1997) showing the T-HF in relation to the MCT and the Early Miocene Granite. *Upper Section*: In the Spiti region, the contact between the Vaikrita metamorphic rocks and the Tethyan sedimentary succession is shown by a thrust plane by Berthelsen (1951). *Middle Section*: The same locality as the above (after Sinha et al. 1997). *Lower Section*: Near Rohtang Pass in the northwestern part, Sinha et al. (1997) depict the T-HF as being cut by Early Miocene granite bodies.

Locally, disharmonic folding of incompetent beds disrupting the basement-cover continuity is quite obvious in the Kali Gandaki sector.

The above-mentioned plane of tectonic discontinuity has been described as *Annapurna Detachment Fault* by Brown and Nazarchuk (1993) and Godin et al. (1999). It is one of the many detachment planes – Madikhola Shear Zone, Machhapuchhare Detachment, Chame Detachment, Dudhkhola Detachment, Deorali Detachment – collectively representing the South Tibet Detachment System (Hodges et al. 1996).

In north-eastern Nepal, the basement detachment plane is represented by a gently dipping thrust associated with a breccia zone. It has been variously described–as *Main Himalayan Thrust* in southern Tibet north of the Sagarmatha massif (Wang and Zheng 1975; Chang and Pan 1981; Chang et al. 1986; Burg et al. 1984; Burg and Chen 1984) as *Chomolongma Thrust* or *Detachment* (Jaros and Kalvoda 1978; Searle et al. 1997; Searle 1999; Pognate et al. 1990; Pognate and Benna 1993) in the Sagarmatha (Everest) region in north-eastern Nepal, and as *South Tibetan Detachment System* (Fig. 22) in the Rongbuk valley in north-eastern Nepal and adjoining part of southern Tibet. (Burchfiel and Royden 1985; Burchfiel et al. 1986; Royden and Burchfiel 1987; Hodges et al. 1992; Burchfiel et al. 1992; Edwards et al. 1996; Carosi et al. 1998; Murphy and Harrison 1999). Hodges (2000) prefers to describe the whole extent of this decoupling plane as *South Tibetan Fault System*.

The 5–15° NNE dipping detachment is a zone of brittle faulting, marked by 3 to 10 km wide belt of brecciated rocks. The faulting brought the Ordovician limestone ("Everest Limestone") of the hanging wall over the mylonitised metamorphic rocks belonging to the amphibolite facies ("Everest Pelites") of the footwall. It is associated with a "complex array of synthetic and antithetic splay faults in the basal part of the hanging wall, giving rise to extensional risers" (Hodges 2000). The detachment plane has been traced

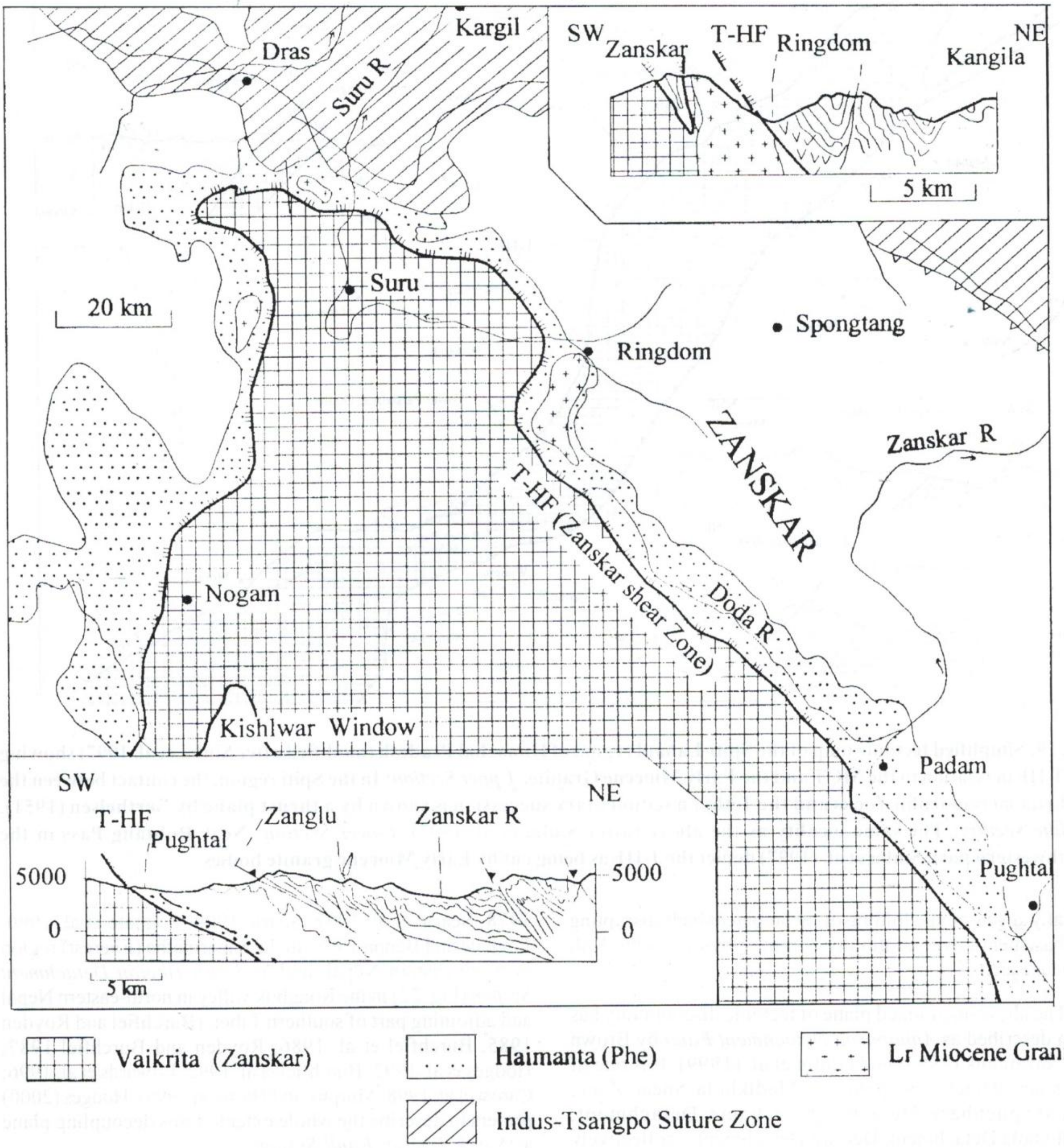


Fig. 20: Simplified tectonic maps of NW Himalaya, showing the stretch of the Zanskar Shear Zone– the northwestern extension of the T-HF system – in relation to the Indus–Tsangpo Suture and the Main Central Thrust. (Modified after Thakur 1993). *Lower section*: In the northwestern Himachal and adjoining Ladakh, the Zanskar Crystallines (basement rocks) are thrust over by the Tethyan sedimentary rocks, beginning with Upper Proterozoic Phe Phyllite (≡Haimanta) of the Pughtal unit. (Baud et al. 1984). *Upper section*: In the Suru Valley in Ladakh, the 20±1 Ma granite-intruded Vaikrita metamorphic rocks are faulted against the Lower Permian to Triassic Panjal Volcanics, much of the Palaeozoic formations having been eliminated altogether (Modified after Fuchs 1977).

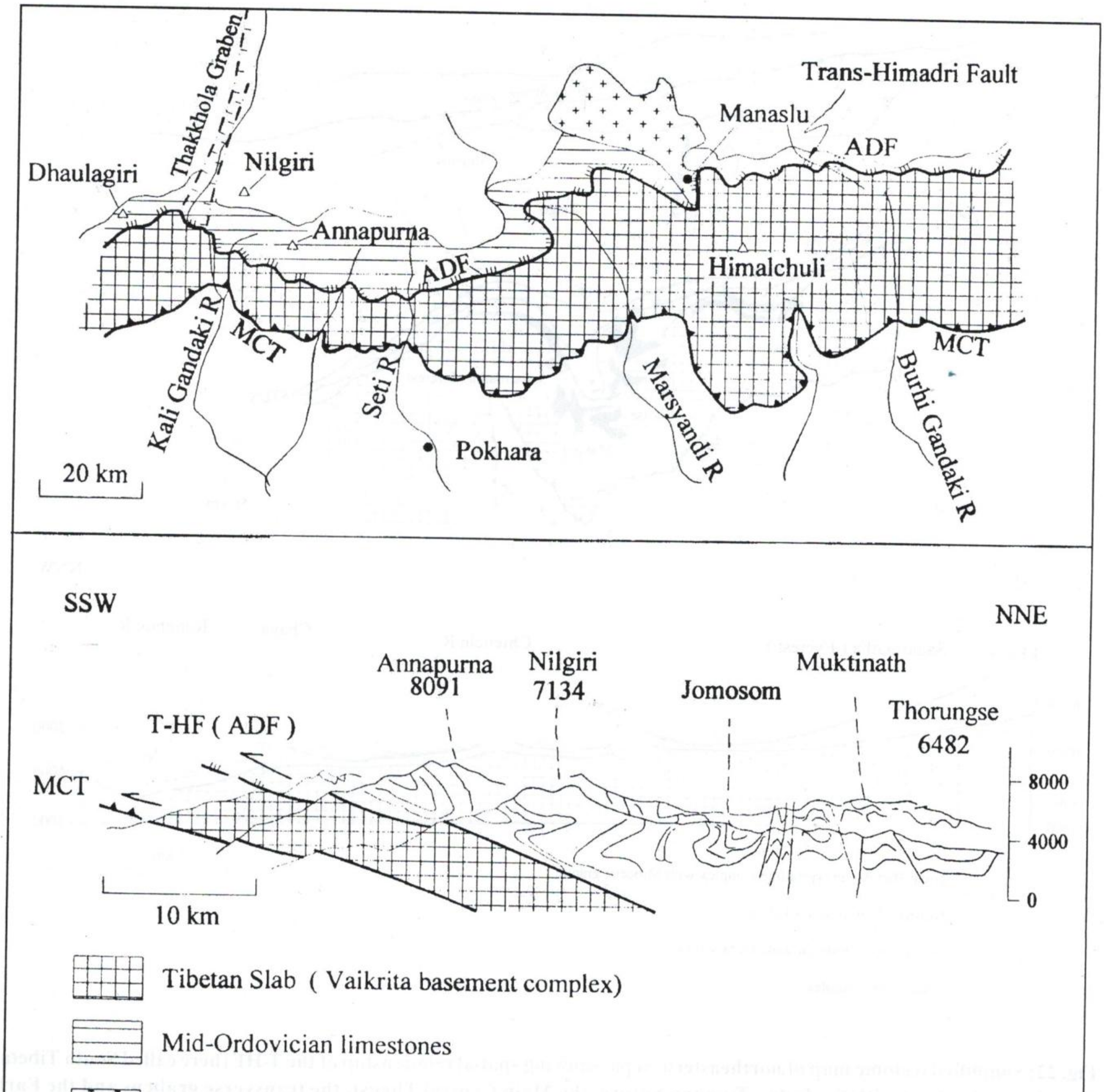


Fig. 21: The tectonic sketch map of south-central Nepal embracing the Dhaulagiri-Nilgiri- Annapurna massif shows the position of the Trans-Himadri Fault in relation to the Main Central Thrust and the transverse Thakkhola Graben and the Manaslu Granite.The cross section of the Annapurna Himalaya portrays north-verging back-folds and associated faults in the hangingwall (Modified after Brown and Nazarchuk 1993).

north in the Rongbuk valley in southern Tibet, where the shear zone is 850 to 1000 m thick and characterized by granite bodies (Murphy and Harrison 1999) unlike in the Sagarmatha region where the granite bodies do not cross the detachment plane. The minimum offset along the detachment plane is 35 km (Searle 1999), and the vertical displacement accommodation is of the order of 5 km (Carosi et al. 1998). The extension that developed in the root zone of the detachment system, and the normal slip along the South Tibetan Detachment System are attributed to gravitational collapse of the over-thickened crust (Lee et al. 2000).

Interestingly, in a seismic profiling the T-HF system is observed dipping nearly 12.5° NNE from the depth of 6 km

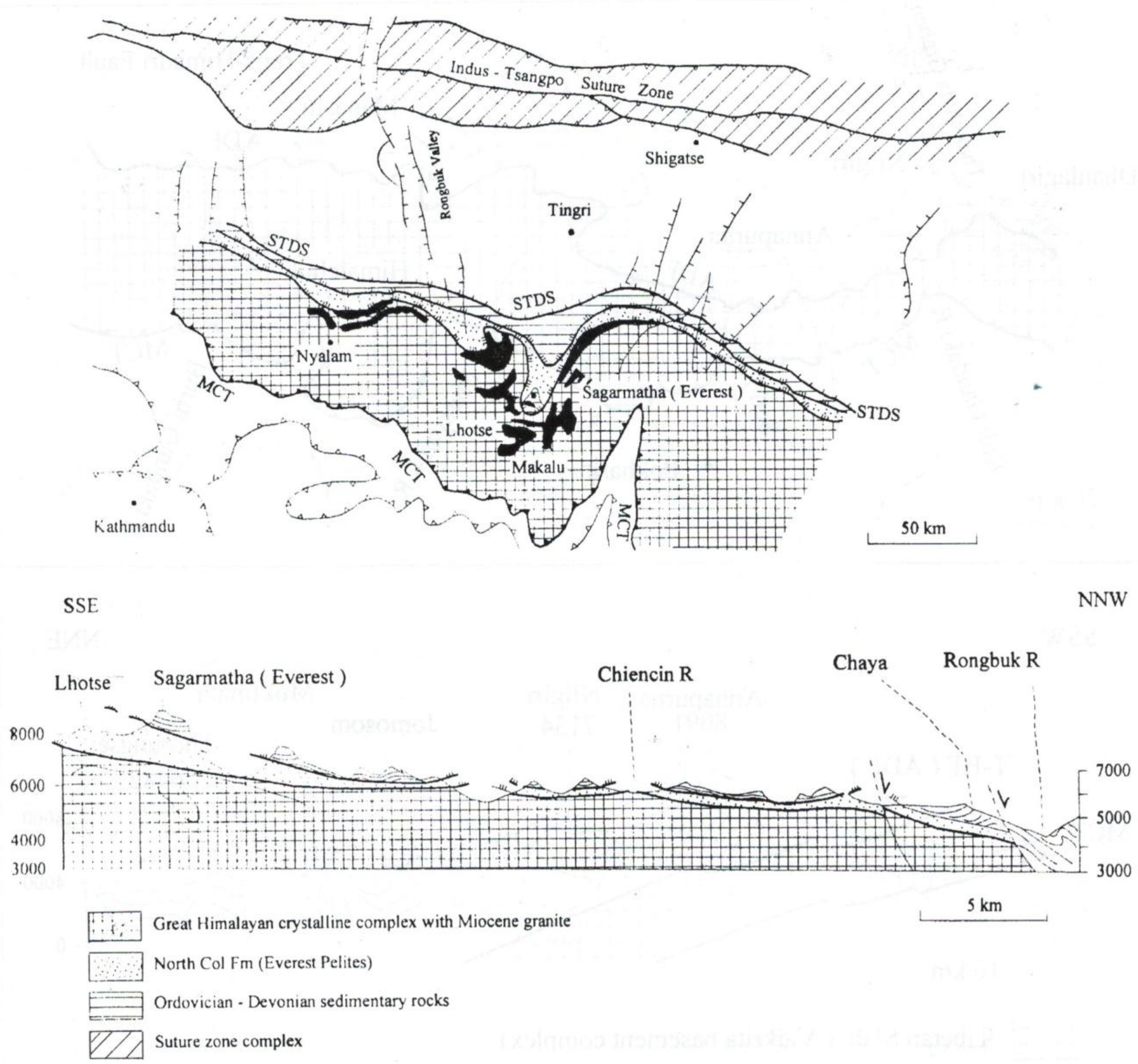


Fig. 22: Simplified tectonic map of northeastern Nepal showing spatial relationship of the T-HF (here called South Tibetan Detachment System) with the Indus-Tsangpo Suture, the Main Central Thrust, the transverse grabens and the Early Miocene granite bodies. The cross section of the Sagarmatha massif showing the Chomolongma Thrust, (also called South Tibet Detachment System) extends north upto the Rongbuk valley in southern Tibet (Modified after Carosi et al. 1998).

beneath the surface under south end to 27 km depth and then flattening to 2.5° NNE in the north (Makousky et al. 1996)

The South Tibetan Detachment System has been traced north-eastwards to the border of Bhutan. The 10° N dipping thrust (Fig. 23) that has placed the Tethyan black slates (along with the Chekha phyllites of the metamorphic basement) over the footwall of the Khula Kangri Granite of the Himadri domain, has been described as *Gonto La Detachment* (Edwards et al. 1996).

Neotectonics of the T-HF system

According to Hodges (2000), the STFS was formed around 20.9 Ma, nearly at the same time when the Main Central Thrust was formed, but has been active time and again.

Downstream of the point of crossing of the T-HF, the wide valleys of the Kali, Eastern Dhauli, Gori and Western Dhauli rivers become abruptly very narrow slit-shaped gorges. These gorges are characterized by nearly vertical to convex slopes implying very fast recent uplift of the footwall below the T-HF. The occurrence of thick lacustrine and

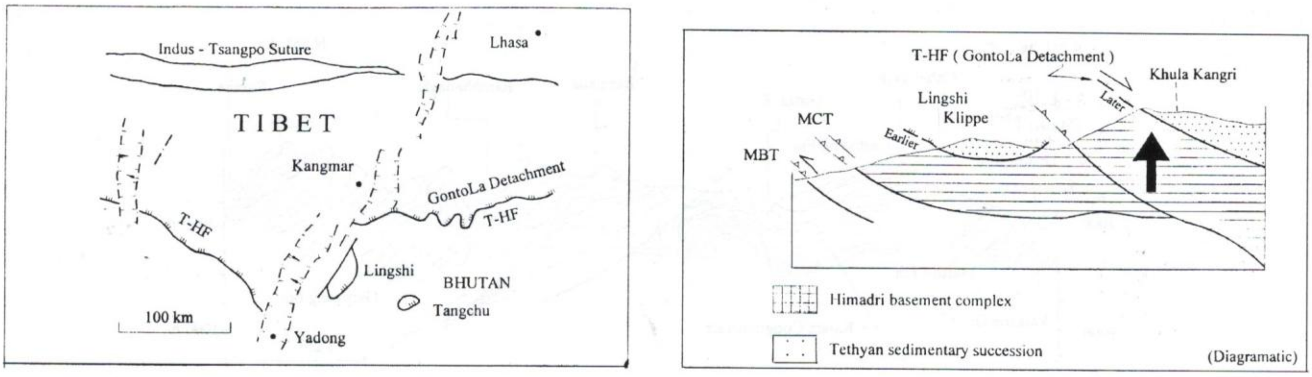


Fig. 23: ***Left*****: Sketch map of NW Bhutan showing the portion of the T-HF – called Gonto La Detachment – in relation to the transverse graben and the Indus-Tsangpo Suture.** ***Right*****: Cartoon shows how the Tethyan sedimentary succession detached from its foundation in the Khula Kangri mountain and subsequent displacement southwards across the high mountain range, gave rise to the tectonic klippen of the Tethyan rocks at lower elevation (Edwards et al. 1996).**

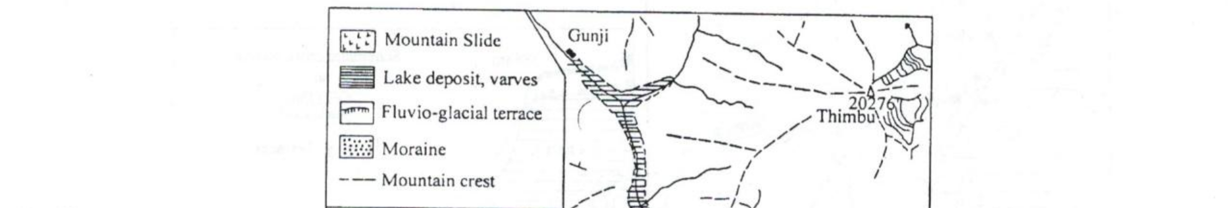


Fig. 24: (A) Extent of the Garbyang palaeolake formed upstream of the T–HF at the Chhialek gorge in the Kali Valley (B) Lithological succession of the Garbyang palaeolake (C) Deformation in the clay beds of the Garbyang palaeolake (Modified after Heim and Gansser 1939).

fluviolacustrine deposits upstream of the fault crossing within the wider valleys in the hanging-wall side is obviously the result of decrease in riverbed gradient and attendant stream ponding. The river ponding is attributed to the rising up of the footwall block and causing blockage (Valdiya 2001).

In the Kali Valley the Garbyang (Fig. 24) Quaternary succession of gravel (at the base), silt and clay has been described as glacial deposit upstream of a moraine dam (Heim and Gansser 1939; Gansser 1964; Valdiya 1979) and the Goting palaeolake in the Western Dhauli (Fig. 25) is thought

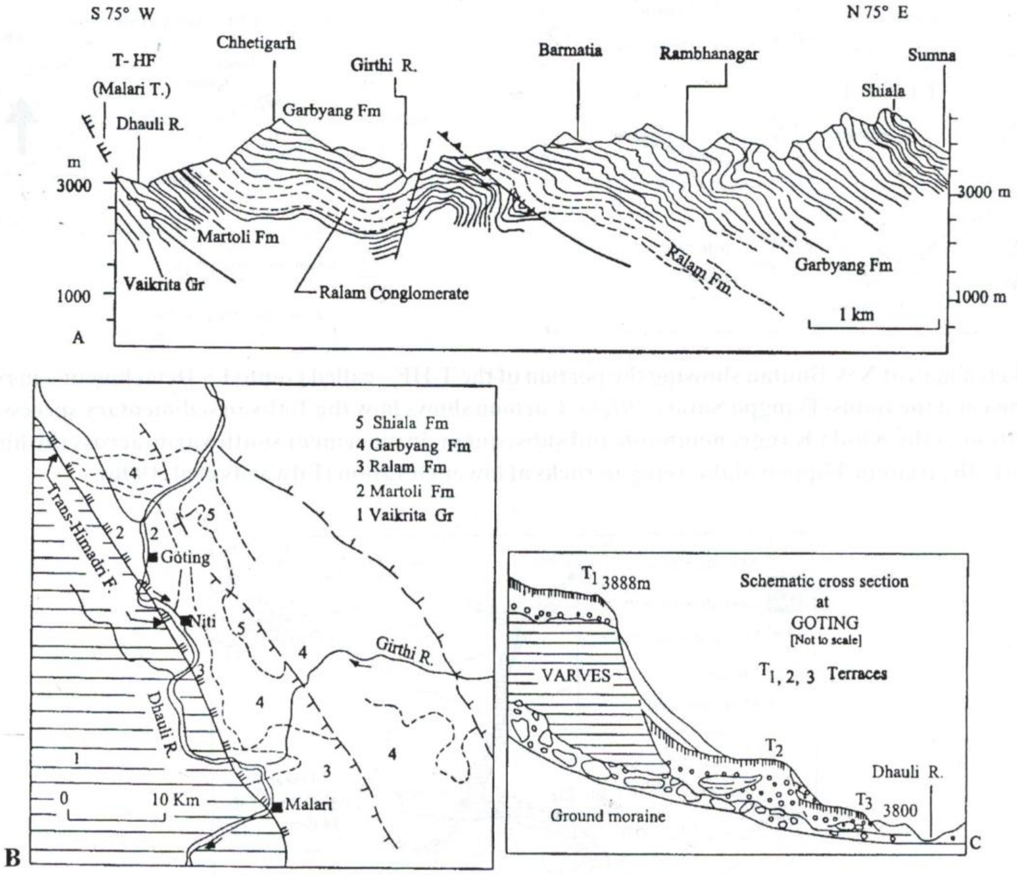


Fig. 25: (A) Section across Tethys zone in the Dhauli valley, showing the position of T-HF. (B) Simplified geological map of the Dhauli valley (modified after Pant et al. 1998) in which the Goting palaeolake formed upstream of the point of crossing of the T-HF at Malari. (C) Lithological succession of the Goting palaeolake and the younger fluvial terraces (after Pant et al. 1998).

to have developed behind the moraine dam (Pant et al. 1998). The Western Dhauli was ponded nearly 40,000 yr B.P., as borne out by radiocarbon dating of the carbonaceous material in the so-called "varvite" of the Goting palaeolake (Pant et al. 1998). The origin of the Garbyang and Goting palaeolakes is a Late Quaternary neotectonic phenomenon related to the reactivation of the T-HF (Valdiya 2001). The deformation features seen in the lacustrine deposits at Garbyang and Goting bear testimony to the continuing the movements on the Trans-Himadri Fault.

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