LESSER HIMALAYAN GEOLOGY: CRUCIAL PROBLEMS AND CONTROVERSIES

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ABSTRACT

The Lesser Himalayan domain is demarcated by intracrustal thrusts (MBT and MCT), marked by multiple thrusting, repetition of rock-units and strong shattering or mylonitization. In the north the Main Central Thrust (MCT) has brought up highgrade metamorphics of the basement and uplifted to soaring heights of the Great Himalaya, the vertical stratigraphic throw being of the order of 20 km. The Main Boundary Thrust (MBT) in the south seems to be geodynamically still active, being the plane of underthrusting of the Indian plate under the Himalayan.

Between the boundary thrusts, the autochthonous Proterozoic sediments are thrust over by sheets of successively, the Palaeozoic sediments (the Krol and its northerly extension the Berinag nappes), the epimetamorphics associated with ~ 1800 m.y. old porphyritic granites (the Ramgarh and its extension the Chail nappes), and the mesometamorphics intruded by the ~ 550 m.y. old tonalite-granodiorite-granite-suite (the Almora nappe and its analoques the Munsiari-Jutogh). The origin of the epimetamorphic nappes is attributed to tight folding, overturning and multiple splitting followed by southward thrusting of the oldest stratigraphic formation of the autochthonous sedimentary succession the Rautgara along with its granitic basement.

The blocking of southward translation along the Krol Thrust of the sedimentary pile, resulted in the evolution of tight folds, their splitting along crestal planes, and upwarp of the basement in the northern part. These faults divided the synclinorial Krol basin into two synclinal sub-basins the southern comprising full Palaeozoic succession (Chandpur-Nagthat-Blaini-Krol-Tal) and the northern of only the Lower Palaeozoic (Chandpur-Nagthat) units. This phenomenon related to the upwarping of the northern part reflects presumably a phase of the Caledonian orogeny.

The Outer and Lesser Himalayan belts are cut into blocks and segments by numerous transverse tear faults. Crustal accommodation, consequent on continuing continental convergence as the northward advancing Indian plate presses the Tibetan block, is taking place by strike-slip movements on these tear faults. This is corroborated by the seismicity pattern.

The lowermost part (Chakrata and Rautgara) of the sedimentary succession is constituted of flysch, emplaced by turbidity currents flowing NW, N and NE from a provenance that lay to the south in the Peninsular India presumably in the Aravali domain. In the succeeding carbonate formation (Deoban-Shali) prolifically developed algal-built columnar-branching stromatolites indicate Middle Riphean age (between 1350 ± 50 and 950 ± 50 m.y.). Radiometric dating of the rocks below and above this carbonate horizon corroborate this age deduction. The Deoban is characterized by very rich lentiform deposits of very coarsely crystalline magnesite intimately associated with talc and sulphides of Cu, Pb and Zn. The origin of magnesite is attributed to diagenetic replacement during sedimentation of early formed carbonates by Mg of the sea waters in the barred basins formed as a result of the development of algal bioherms. The uppermost protean

formation (Mandhali) also exhibits development of stromatolites, suggesting Upper Riphean to Vendian age (950 ± 50 to 570 m.y.).

In the allochthonous Krol Belt, following the shallow-water littoral sedimentation of the Nagthat,tectonic condition became abnomral, and greywacke and diamictites and pink limestone of the Blaini were emplaced not by glaciers, but as a result of submarine slides and current activities in warmer water. The solitary spined productid recently discovered in the uppermost horizon of the Krol Formation points to its Upper Palaeozoic age. The succeeding Tal, comprising the lower marine member of diamictite-greywacke phosphorite-black, and the upper continental member of coal and plant-bearing arkosic sandstone, is regarded as a Gondwana unit in the Lesser Himalayan framework, and placed in the Permian period. There was no sedimentation thereafter until the end of the Mesozoic, the retreat of the sea being marked by transition of the marine to continental sedimentation.

The sandy oolitic limestone disconformably resting upon the Tal and unconformably underlying the Lower Eocene (Subathu) is recognized as a separate formation of Danian-Palaeocene age—the Bansi—marking the return of the sea towards the close of the Upper Cretaceous times.

INTRODUCTION

IN an attempt, some 25 years ago, to find the identity of an organosedimentary structure and explain the inverted sequence of sedimentary rocks in a small area near Pithoragarh in eastern Kumaun, I got involved in a major venture of unravelling the stratigraphic and structural complexities of the region which, as the time progressed, encompassed the entire Kumaun Himalaya stretching 300 km from the western frontier of Nepal to the eastern border of Himachal Pradesh. Geologically very crucial, this central sector of the Himalayan arc happens to be the epitome of the whole of the Himalaya mountain, structurally and stratigraphically. This solo venture has led to construction of a geological framework, comprising stratigraphic order of rock formations and structural design that is applicable to the whole of the Lesser Himalaya. Although my views and deductions have generated acute and often very animated controversies—some of which defying solutions—these have nevertheless evoked questions promising to open horizons of more profound problems. In the following pages I touch on the problems and studies in which I have been deeply involved in the last two decades.

SOUTHERN TECTONIC BOUNDARY OF LESSER HIMALAYA

Nature and Extension: The mature though rejuvenating lithotectonic subprovince of the Lesser Himalaya, constituted of early Precambrian crystallines and late Precambrian and Palaeozoic sedimentaries, is separated from the youthful Outer Himalaya made up of Cenozoic sediments (including the Siwalik) by the Main Boundary Thrust (MBT) (figure 1). Departing from the old concept[1,2,3,] I redefine[4] the MBT as a series of at least five different and variably inclined (20–60° or more) thrusts which have brought disparate Lesser Himalayan formations over and against the Outer Himalayan Cenozoic sedimentaries comprising the Sirmur and Siwalik groups (figure 2). In Kumaun, as in adjoining Himachal, the Krol Thrust has brought one or the other of the six rock-formations of the Krol Belt succession over the Siwalik or locally the Subathu, so that it is this Krol Thrust that serves as the MBT in the central sector. To the northwest in the Mandi area the Drang Thrust bringing Precambrian Shali rocks over the Siwalik represents the MBT; and in Jammu the Murree Thrust between the Lesser Himalayan upper Palaeozoic rocks and the early Tertiary sediments is designated as the boundary thrust. In West Nepal the Precam-

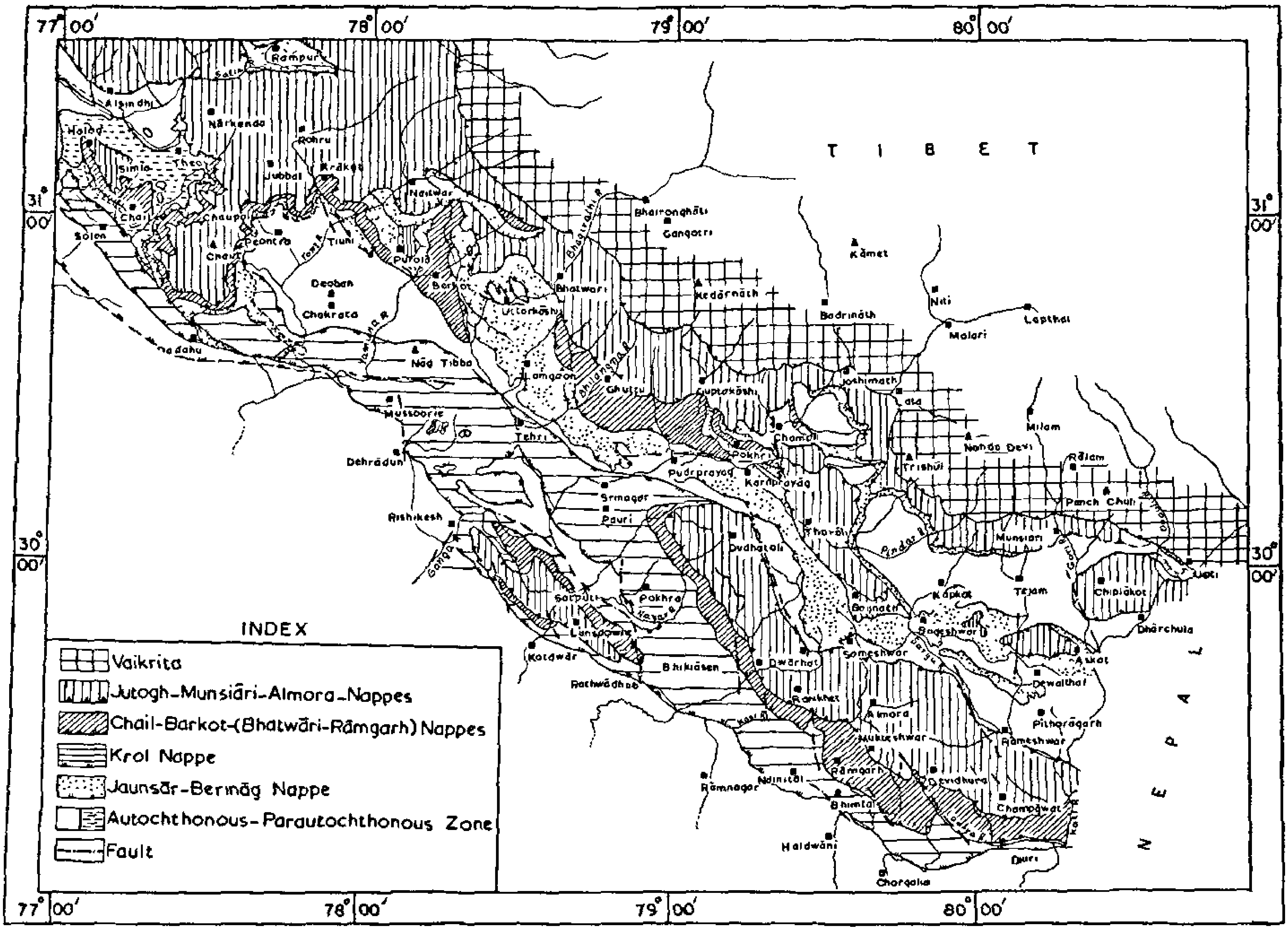

Figure 1. The Lesser Himalayan lithotectonic subprovince is delimited by intracrustal main boundary thrust (MBT) and Main central thrust (MCT). The precambrian and Palaeozoic sedimentaries have been thrust over by vast and thick sheets of metamorphics and associated granitic rocks[27].

brian rocks have advanced over the Siwalik. While in central Nepal the metamorphics of the Mahabharat Range (Bhimphedi) along with the sandwiched Gondwana rocks have moved along the Mahabharat (= Kathmandu) Thrust. Beyond the Kosi valley throughtout eastern Himalaya the Gondwana sediments have been thrust over the Siwalik, the plane of movement denoting the MBT.

It is now realized[4,5] that the MBT in fact is a 2–7 km wide schuppen zone characterized by multiple thrusting along axial planes of isoclinal or overturned folds developed in the frontal part of the advancing thrust masses (figure 2). This has caused repetition and inversion of stratigraphic units and intense shearing and shattering of rocks, leading to serious instability of hillslopes. This bewildering situation witnessed throughout the extent of the Himalaya is responsible for varied interpretation of stratigraphic order and structural setting.

My view is quite at variance with the notion of the many workers that the southern tectonic boundary of the Lesser Himalaya is demarcated by a deep-seated fault rather than an intracrustal thrust that becomes gently inclined in depth.

Neotectonic Activity: Offsetting of the courses of rivers and streams, abandonment of old channels as a consequence of recent faulting, vertical displacement of subrecent river-terraces or bed deposits, lateral displacement of subrecent landslide debres and screes as seen near Naintal[6], the 150 to 200 m uplift of the Dun-fans on the southern slope of the Mussoorie Hills, the 135-m advance of the Palaeozoic Chandpur rocks over the Dun gravels between Rishikesh and Dehradun, and the transportation of the Eocene

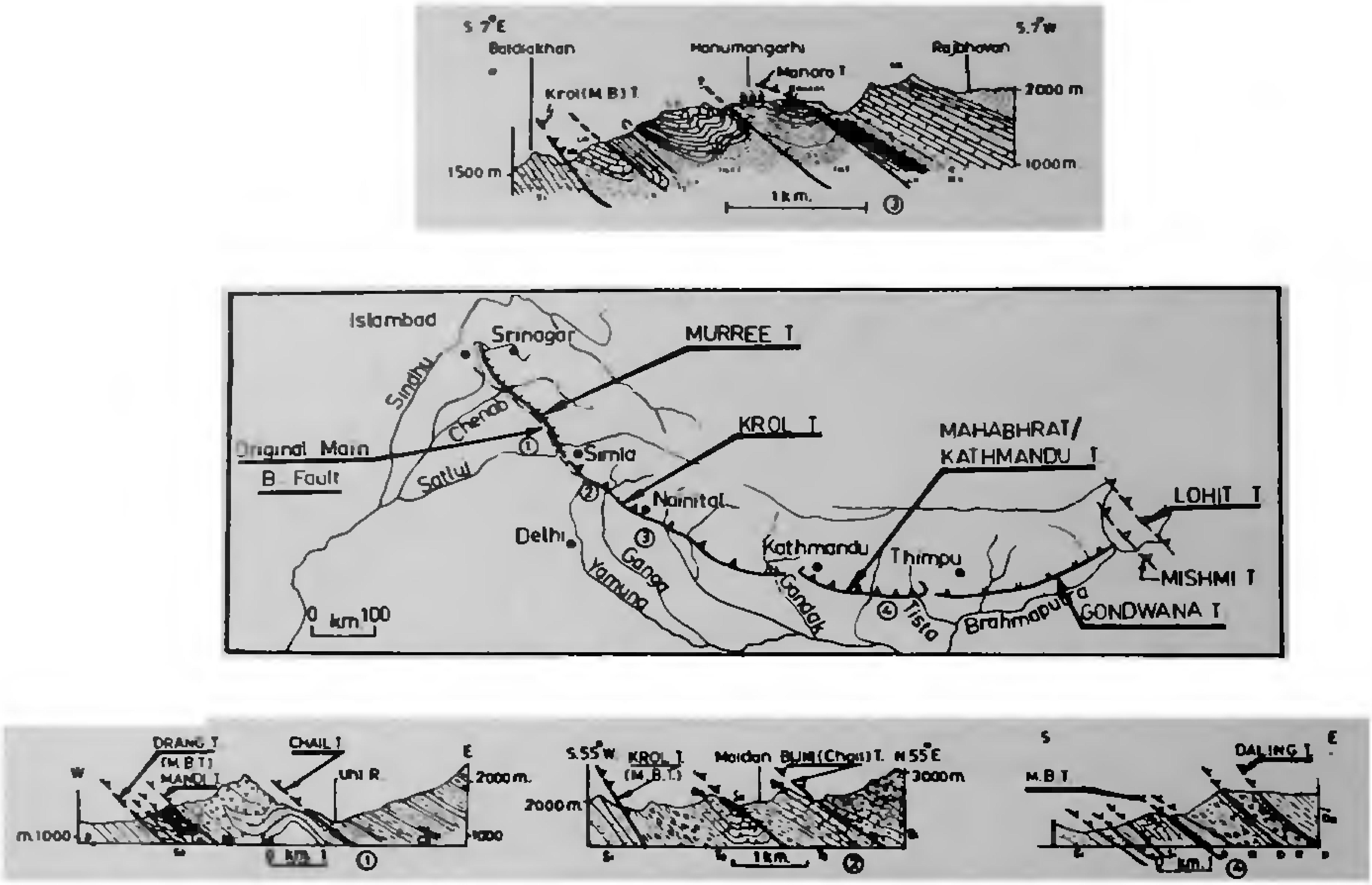

Figure 2. The MBT is a series of five different thrusts that have brought different rock-formations of the Lesser Himalaya over the early Tertiary and/or Siwalik sedimentaries (Si = Siwalik; Lk, Mk, Uk = Lower, Middle, Upper Krol; Inf = Infra-Krol (Blaini; Sh = Shali; Lo = Lokan (salt beds); M = Mandi Volcanics; S = Sundernagar; Ch = Chail; Ta = Tal; Su = Subathu; Bi = Bijni (= Chail); D = Damuda; R = Rangit Conglomerate; Da = Daling (= Chail).

(Subathu) over the recent scree in the Tons valley, bear testimony to neotectonic movement along the MBT[5]. Geodetic measurements carried out in the Tons and Beas valleys corroborate the geomorphic evidence. These continuing tectonic movements explain the great height of the Dhauladhar-Krol Mahabharat ranges in the frontal part of the Himalaya.

Some seismologists[7-9] attribute the seismicity of the Himalaya, particularly the rarely occurring stronger phases, to the movement along the MBT, consequent on the slipping of the Indian plate under the Himalayan crust at a shallow angle[10] of 15° ± 5°. Superficially, the dip-slip movement takes place on planes inclined 30° to 70° northwards[7]. Thus the MBT, a zone of intracontinental crustal underthrusting, is seismotectonically a sensitive belt.

STRUCTURAL SETTING OF KUMAUN LESSER HIMALAYA

Allochthonous Berinag Sheet: A vast stretch of the Kumaun Lesser Himalayan terrain is covered by thick piles of quartzarenite interbedded with basaltic lavas and tuffs, and locally with small lenses of mylonitized gneisses. Immediately beneath this succession of the Berinag Formation over a long strike-wise distance I had noticed stromatolitic dolomite either forming inverted sequence, folded isoclinally or split by minor thrusts (figure 3)—some of the lithologic units being attenuated or absent[12,37]. The Chandpur Formation forms a thick base of the Nagthat (Berinag) Formation in the outer belt in Garhwal, but is wholly missing in the inner belt. The still older Mandhali (Tejam) rocks are likewise eliminated or attenuated considerably in many areas, so that the Berinag (Nagthat) rests directly

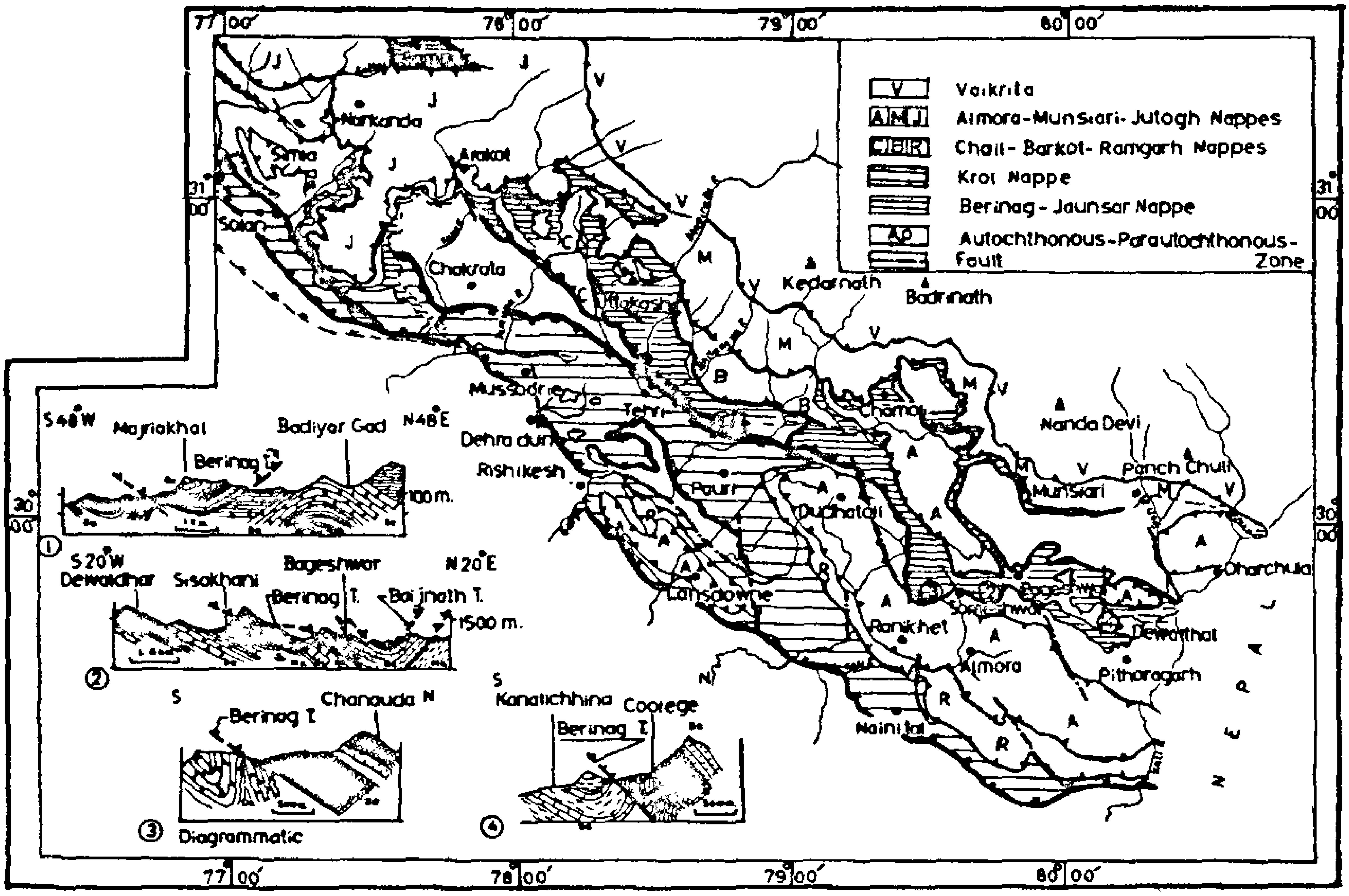

Figure 3. The Berinag sheet consisting of quartzarenites and basic volcanic belonging to the Nagthat Fm is the northerly extension of the larger Krol Nappe, but without the lower two and upper three formations. The sections of the areas north of Shrinagar (Alaknanda valley), near Bageshwar(Saryu valley), north of Someshwar (Kosi valley), and Kanalichhina, north of Pithoragarh, clearly bring out the thrusting of the Berinag over the folded and/or inverted Deoban dolomites (Be = Berinag = Nagthat; Ra = Rautgara; De = Deoban; Ma = Mandhali).

on the older Deoban dolomites—isoclinally folded, inverted or multiply split. These facts unequivocally indicate existence of the Berinag Thrust and imply that the quartizite-volcanics association represents an allochthonous sheet—the Berinag Nappe—which joins up westward in Himachal with the Jaunsar sheet[13].

My later studies[14-16], indicated that the Berinag sheet is the northerly extension of the Krol Nappe that thickly covers the outer belt between Nainital and Solan (Himachal), but with the difference that the normal Krol succession (Mandhali-Chandpur-Nagthat-Blaini-Krol—Tal formation) not develope in the inner belt in the Berinag Nappe, which is constituted exclusively of the Nagthat rocks. The proposition of the allochthonous nature of the Berinag has not found favour with many workers, and there are even fewer takers of my notion[14,15] that the Berinag sheet represents northerly prolongation of the Krol Nappe, *sans* its basal and top formations.

Faulted Krol Nappe: The sourthern flank of the Krol Nappe is affected by long, deep faults commonly developed along crestal planes of the tight anticlines. This is seen in the lake basin of the Nainital Hills, in the Nayar valley in Pauri District, in the Aglar valley in Tehri District, and in the Giri valley in Sirmaur District of Himachal Pradesh. There are quite a few faults parallel to the main ones. The crestal faults have brought up older rocks of the autochthon forming anticlinal cores and juxtaposed them against the younger rock-formations. The Nayar Fault in the tributary of the Ganga, for example, has lifted up by 1500-3000 m the early Riphean Chakrata rocks and placed them adjacent to the

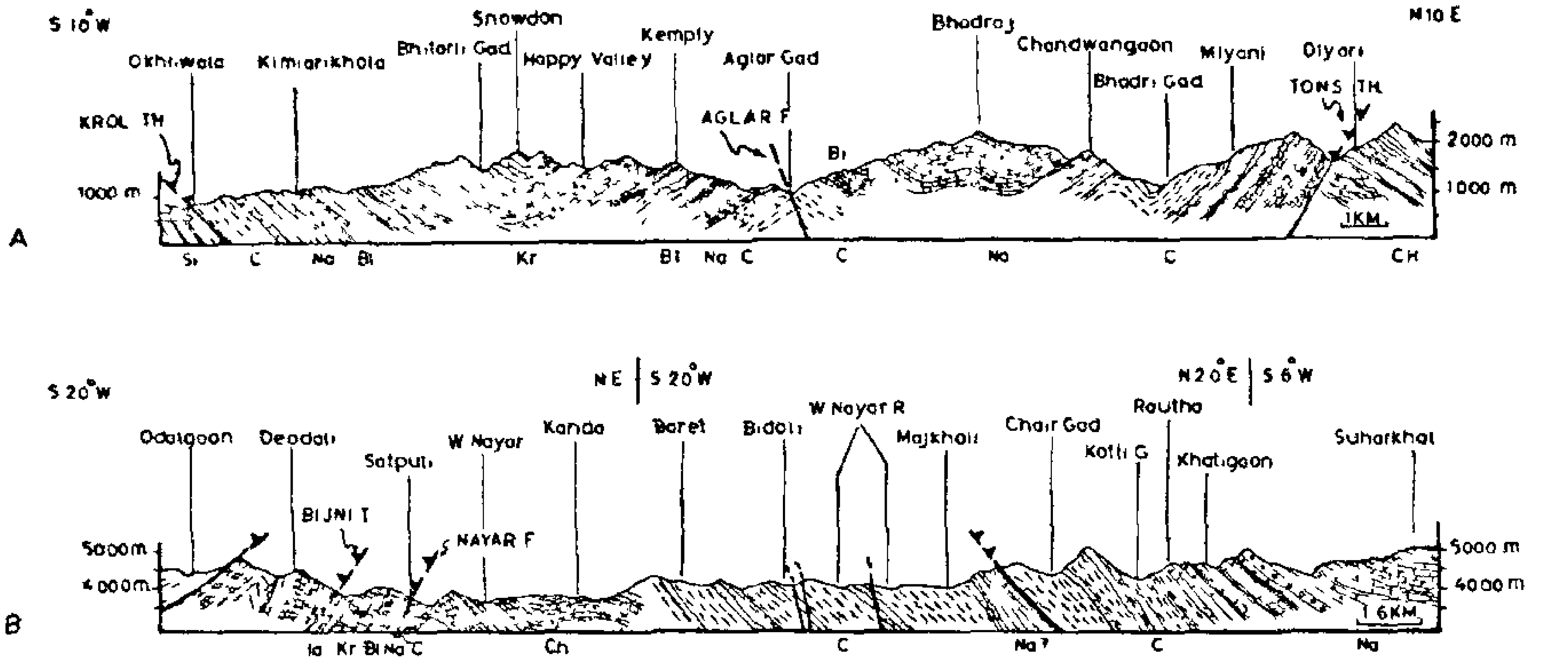

Figure 4. Cross sections across the synclinal Mussoorie-Lansdowne and Nag Tibba-Pauri ranges[16] showing division of the synclinorial Krol Nappe by deep faults developed along anticlinal crestal planes. (C = Chandpur; Na = Nagthat; Bl = Blaini; Kr = Krol; Ch = Chakrate; Ta = Tal; Bi = Bijni (= Chail); (La = (Sa) = Lansdowne Crystallines (= Almora)).

Palaeozoic rocks of the Krol succession, opening a vast tectonic window in this process[5,16]. It seems that these faults are genetically related to the southward advance of the Krol Nappe along the Krol Thrust. The blocking of horizontal translation must have resulted in the evolution of tight folds, their splitting along the crestal planes and progressive uplift of the northern blocks.

Differentiation of Krol Basin: These faults divide the synclinorial Krol Nappe into two distinctly different synclinal parts—the southern part embracing the synclinal hills of Ayarpatta (Nainital), Lansdowne, Mussoorie and Jaunsar made up of the full succession of the Krol Belt, namely the Mandhali, Chandpur, Nagthat, Blaini, Krol and Tal and the wider northern part forming the synclinal mountain of Nainital, Pauri and Nagtibba and constituted only of the older formations—the Chandpur and Nagthat. This implies that in the northern part of the Krol Basin, sedimentation came to an end immediately after the Nagthat times, presumably as a consequence of upwarping of the northern part—a precursor of development of the anticlinal crestal faults[5,16]. The progressive thinning of the Chandpur and Nagthat on the northern flank of the southern synclines (*e.g.* Landowne) is suggestive of the upwarping of the northern part of the basin[17].

These facts lead to the surmise that there was an epeirogenic movement after the Nagthat times but before the Blaini. Significantly, in the still interior part, in the Berinag belt, even the Chandpur is absent. The Chandpur is made up of flysch rocks, the deposition of which was presumably restricted to the relatively deeper southern part of the Krol Basin. Thus the tectonic interpretaion indicates differentiation of the Krol basin into three sub-basins with varied environmental conditions prevaling in them as a consequence of tectonic movement that occurred presumably in the lower Middle Palaeozoic times. This event may possibly be related to one of the phases of the global Caledonian orogeny.

Origin of Nappes of Epimetamorphics: The middle of the succession of three nappes consists of low-grade metamorphic (green schist facies) rocks, incorporating highly sheared or mylonitized and commonly spectacularly porphyritic granites 1960 ± 65 m.y. old[35]. This is the Ramgarh Nappe[36] which extends through Bhatwari and Barkot northwest into Himachal to join up with the Chail Nappe[13] and further northwest in the Dhauladhar-Pirpanjal ranges. In the east, its equivalents are known as the Daling[32]

TABLE 1.

Metamorphics Built Nappes of Himalaya

Nappe	Kashmir	Himachal	Kumaun	Western Nepal	Eastern Nepal	Darjeeling Sikkim	Bhutan	Arunachal
High-grade metamorphics	Giambal	Central Gneiss	Vaikrita	Annapurna Gn. Complex Up Crystallines	Khumbu, Barun	Darjeeling	Thimpu	Sela
			MCT					
Mesometamorphics	Atholi	Jutogh	Munsiari (Root) Almora(Nappe) Thrust	Lr. Crystallines	Arun	Chungthang Paro	Paro	Bomdila
Epimetamorphics	Salkhala	Chail	Ramgarh(Nappe) Bhatwari (Root)	Bhimphedi	Tumlingtar Sanguri	Daling	Shumar Samchi	Tenga Siang

(Darjiling-Sikkim), the Samchi[33] (Bhutan) (figure 8) and the Tenga[34] (West Arunachal) (table 1).

The root of the Ramgarh (with its mylonitized porphyritic granites) is involved in complicated schuppen structure immediately under the Main Central Thrust zone. I have suggested[36] that the Ramgarh Nappe represents the overthrust prolongation of the lithologically similar Rautgara Formation—which in the normal state occurs at the bottom of the sedimentary succession of the autochthon. The deeper part of the Rautgara with the porphyritic granite basement involved in tight folding, overturning and multiple splitting along axial planes, was thrust southwards along with the basement granitic rocks to give rise to the Ramgarh. The Chail likewise originated from the Sundernagar Formation exposed in the middle reaches of the Satluj and Beas rivers. Similarly, the Daling and Samchi sheets are granite embracing far-travelled overthrust parts of the early Riphean Sinchula-Jainti (Phuntsholing) with elements sliced off from the overlying carbonate unit.

Petrogenesis of Granites in the Mesometamorphic Nappes: Comprehensive petrological study of the Champawat Granodiorite a batholithic pluton in the mediumgrade metamorphic succession of the Almora Nappe in Kumaun[11] demonstrated that this composite body is constituted predominantly of syntectonic granodiorite-tonalite association of trondhjemitic suite, emplaced into presumably moist sediments during the main phase of tectonic deformation. It was intruded by a suite of leucocratic adamellite, aplite and granite later during post-tectonic phase, the leucocratic magma coming towards the end of a protracted period of emplacement. Recent studies[35] have shown that the main syntectonic granodiorite as well as its extension the Almora Granite were emplaced 575 ± 25 m.y. ago, while the leucocratic adamellite-aplite intruded a little later (560 ± 40 m.y.)

TEAR-FAULTED TERRAIN

The Outer and Lesser Himalayan terrains are cut by numerous faults and fractures (figure 5)

TABLE 2.

Tectonic Succession in Kumaun Lesser Himalaya

Tectonic Unit	Outer Belt		Inner Belt	
			Vaikrita Group	
			Main Central Thrust	
Almora (=Jutogh) Nappe	Almora Group		Munsiari Formation	
	Almora Thrust		*Munsiari Thrust*	
Ramgarh (=Chail) Nappe	Ramgarh Group		Bhatwari Formation	
	Ramgarh Thrust		*Bhatwari Thrust*	
	Sirmur Group	Subathu Fm Bansi Fm		
Krol Nappe	Mussoorie Group	Tal Fm Krol Fm Blaini Fm		
	Jaunsar Group	Nagthat Fm Chandpur Fm	Berinag Formation	
	Tejam Group	Mandhali Fm		
	Krol Thrust		*Berinag Thrust*	
		Subathu Fm	Tejam Group	Mandhali Fm Deoban Fm
Allochthon	Damtha Group	Rautgara Fm Chakrata Fm	Damtha Group	Rautgara Fm Chakrata Fm

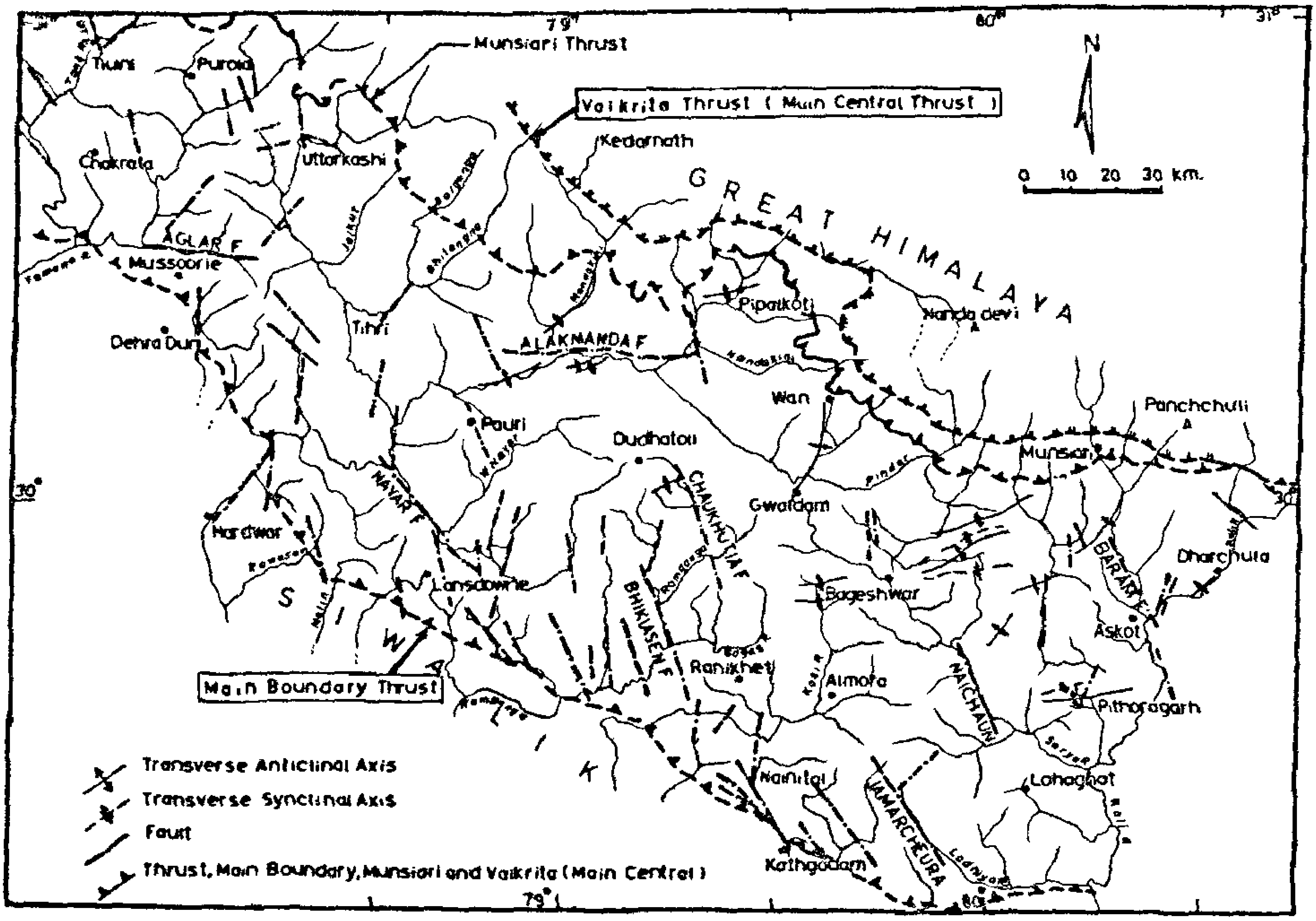

Figure 5. The tear-faulted terrain of Kumaun Lesser Himalaya[5]. The faults constitute conjugate pairs trending NNW-SSE and NNE-SSW.

oriented transversely in the NNW/N-SSE/S and NNE/NE-SSW/SW directions[18]. The tear faults have caused predominantly right-lateral offsetting of the order of 4–12 km even of so young features as the MBT and colluvial fans. North of Nainital the deposits of the Ramgarh stream have been vertically lifted. In some areas these tear faults are linked with the anticlinal crestal faults mentioned in the preceeding section, implying that the evolution of these transverse faults is related to the southward advance (overthrusting) of the Lesser Himalaya.

Locally the tear faults coincide with the thrust planes delimiting the Almora Nappe and its klippen of the crystalline rocks. This fact led some workers to deny the allochthonous nature of the crystalline sheets and speculate on existence of deep normal faults bringing up as horsts the basement crystalline rocks[19-22]

Tear Faults and Seismicity: The linearity in the northerly direction of the distribution of epicentres of earthquakes (M 5-6 or even 7.5) in the tear-faulted Dharchula-Bajang area[24] in northeastern Kumaun and adjacent Nepal—which incidently registers highest number of shocks annually anywhere in Himalaya—and the pattern of distribution of foci in the vertical planes up to the depth of 33 to 60 km or more, implies to my mind[5] that the shallow and recurrent seismicity of the terrain is related to strike-slip movement on the tear faults. The transversal areas of high seismicity in the quantitative seismicity map[23] coinciding with fault clusters lends a strong support to this proposition (figure 6). This view contradicts the deductions of the seismologists[9,24,25] whose fault-plane solutions indicate predominant thrust movements on the MBT and MCT. However, the MCT is now almost inactive; therefore part of the movements may be attributed to

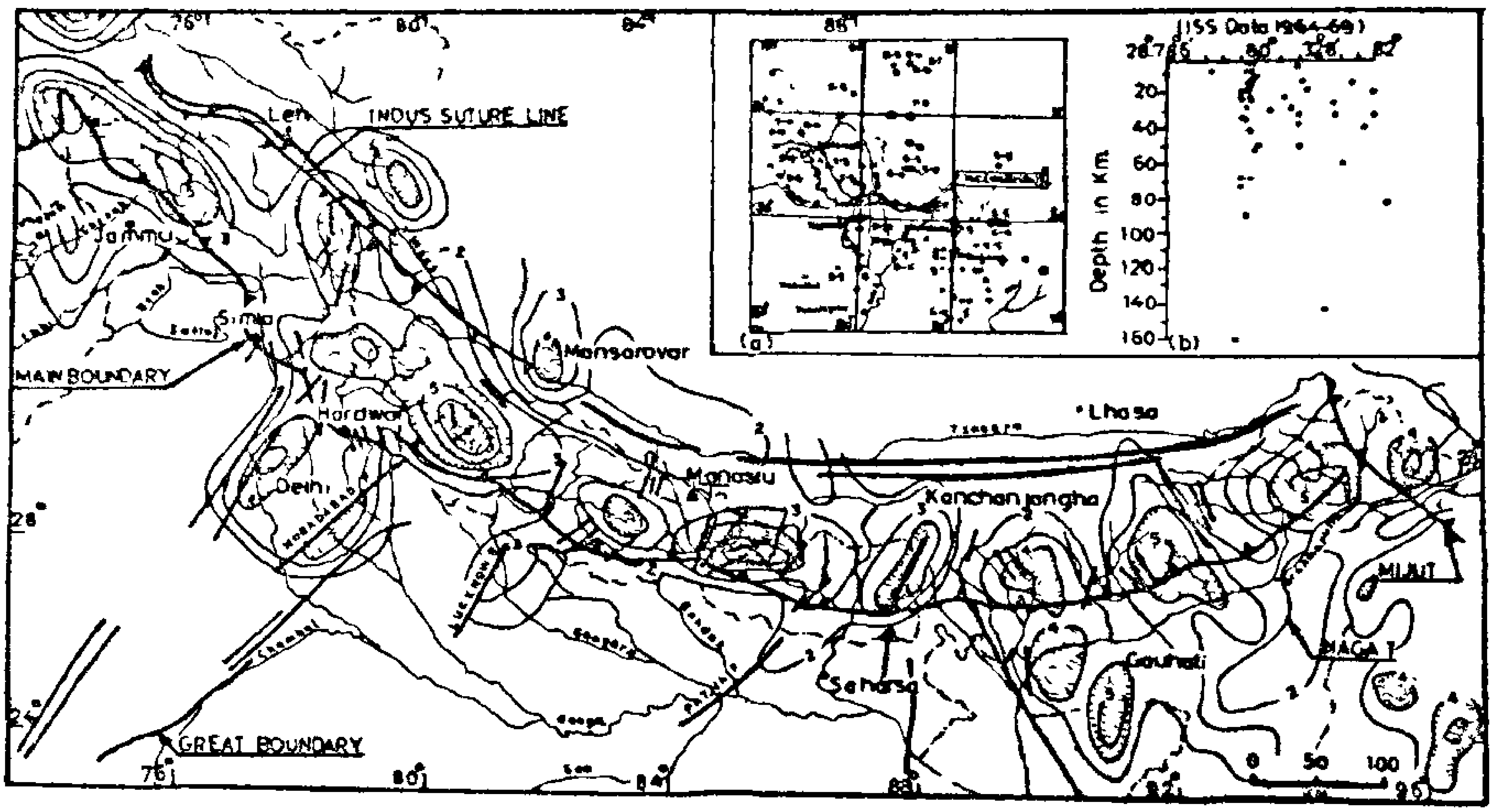

Figure 6. The high-seismicity areas in the quantitative seismicity map[23] coincide with area riven[5] with faults. The inset shows spacial and vertical distribution of earthquake foci in northeastern Kumaun and adjacent Nepal.

the transverse taults.

The crustal accommodation consequent on continental convergence (as the advancing Indian plate presses the Tibetan block) is taking place by strike-slip movements on the faults that tear the Himalayan arc into segments and blocks[5,18].

NORTHERN TECTONIC BOUNDARY OF LESSER HIMALAYA

Nature: The tectonic plane that separates the sedimentary rocks of the Lesser Himalaya from the overlying metamorphics with augen gneisses and the gneissose granodiorites has been taken unquestionably as the boundary between the Lesser Himalaya and the Great Himalayan domain and designated as the Main Central Thrust (MCT)[26,27]. However, my interpretations[15] have created a controversy, for I place this boundary up the succession at a higher altitude where there is an abrupt change from the low-grade metamorphics (dominantly greenschist facies) to higher-grade amphibolite and lower-granulite facies, and the sudden change in the style and orientations of mesoscopic structure. Tentatively named as the Vaikrita Thrust, the MCT in Kumaun dips 30–45° northwards, serves as pathways of hot waters from the deeper level as the location of numerous thermal springs in its proximity implies, and is associated with a zone of multiple thrusting, repetition of rock-units and extreme shearing and mylonitization and attendant retrograde metamorphism (figure 7). This baffling situation is at the root of the problem of real identity and delineation of the MCT. It is in fact a zone (a few km to 30 km wide) of mylonitized rocks sandwiched between the gently-dipping Munsiari Thrust (which other workers describe as the MCT) and the upper moderately inclined (30°–45°) Vaikrita Thrust (which I recognize as the MCT). The pervasively affected rocks of ths zone have been squeezed and pushed tens of kilometres southwards, giving rise to the Almora-Jutogh nappes and their many detached pieces (klippen) that cover the Lesser Himalayan sedimentry domain.

The MCT has been traced northwestward to near Karchham in the Satluj valley in Himachal,

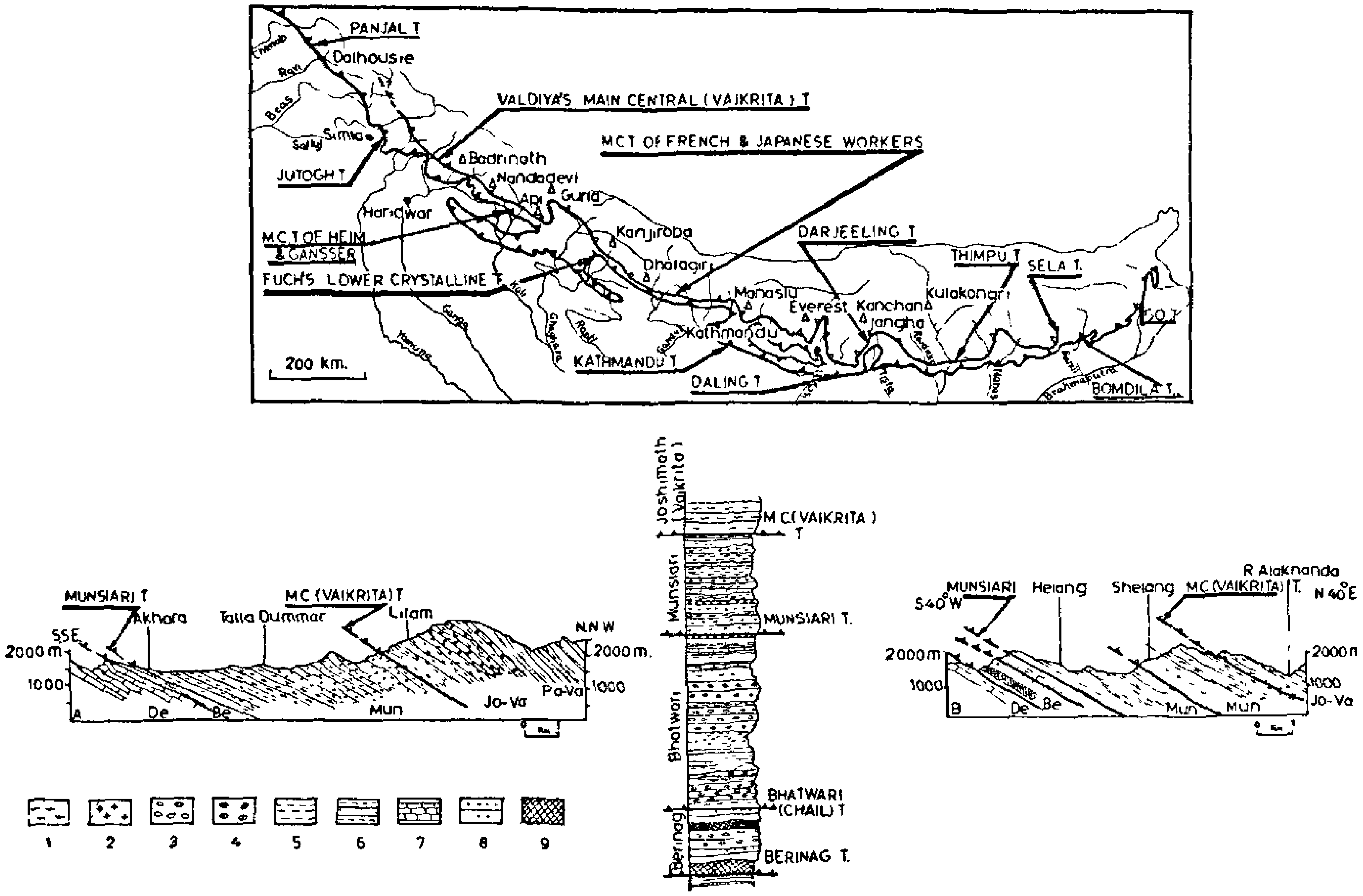

Figure 7. The positions of the Main Central Thrust as defined by Valdiya[4] and the Main Central Thrust recognized by the majority of workers. Sections are along the Gori and Alaknanda valleys. The lithostratigraphic column[4] relates to the Mandakini valley (1 = Kyanite-sillimanite-garnet-mica psammitic-gnesis and schist; 2 = Gneissose granodiorite granite; 3 = K-felspar-bearing granite porphyry (~1800 m.y.); 4 = Sheared porphyry; 5 = Sericite-chlorite schists; 6 = Phyllite and fine-grained quartizite; 7 = Marble and calc-phyllite; 8 = Coarse-grained and pebbly quartzarenite and basic volcanics (Berinag); De = Deoban dolomites; Be = Berinag; Mun = Munsiari; Jo = Joshimath Fm; Pa = Pandukeshwar Fm; Va = Vaikrita Group).

and its easterly extension in West Nepal defines the base of the so-called Tibetan Slab of the Vaikrita rocks against tectonic slices[28,29]. Further east this is known as the Khumbu or Barun Thrust in east Nepal[30,31], the Darjeeling Thrust in Darjeeling-Sikkim Himalaya[32], the Thimpu Thrust in Bhutan[33]; and the Sela Thrust in Kameng[34] (figure 8).

Geodynamics: The MCT, which remains 150–175 km inside in the interior throughout the central and northwestern Himalaya, has significantly advanced close to the Siwalik frontier in the long belt east of the Kosi valley. This indicates greater underthrusting of the Indian plate in the northeast. Judging from the extent of deformation and metamorphic transformation in the MCT zone, it is surmised that there was strong and considerable underthrusting of the Indian plate under the MCT in the past. In the central sector, the 10000 m thick basement (Vaikrita) rocks, earlier buried under the 13000 m thick pile of Tethyan sediments, were uplifted to the soaring heights of more than 7000 m above the sea level, the vertical stratigraphic throw being of the order of 20,000 m[5]. A number of lines of evidence though indicate continuing rise of the Great Himalayan lithotectonic sub-province, the underthrusting of the crustal plate has now shifted south to the MBT.

STRATIGRAPHIC ORDER

Recognition of Datum Horizon: Working out the stratigraphy of the Lesser Himalayan formations has been a difficult task. Not only are these sediments completely barren of fossils, they are also affected by deformation and metamorphism variably. In attempting to untangle the stratigraphic confusion, help came from an

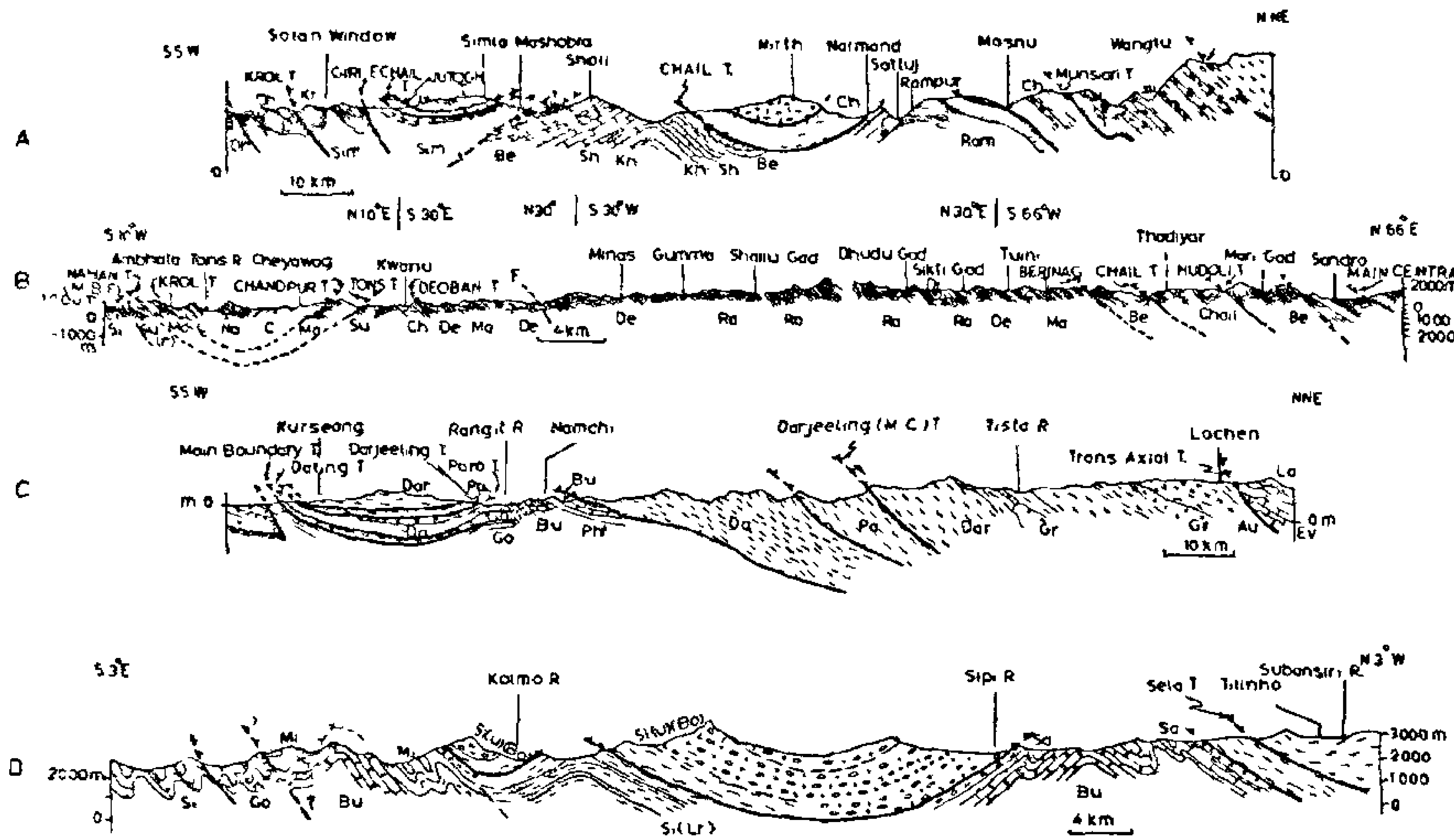

Figure 8. Cross sections across the Himalaya in east Himachal, Kumaun, Darjiling and eastern Arunachal illustrating the structural setting and tectonic succession[71] (Valdiya, in press).

unexpected quarter—the algal-built stromatolites. In 1960 I stumbled upon a couple of crucial forms of stromatolites, (then little known in India), developed prolifically and widely in the dolomites of Pithoragarh[37]. The identification of this organosedimentary structure built by seaweeds and bacteria not only initiated a new line of investigation but also helped to fix the age of the Deoban Formation in the Middle Riphean[41] time-span somewhere between 1350 ± 50 and 950 ± 50 m.y. which was earlier thought to be of Permo-Triassic age (270–180 m.y.). This age assignment and my reliance on the testimony of stromatolites were received with disconcerting skepticism. Recent radiometric dating of rocks below and above the Deoban dolomites[39,40] has however established the validity of the assignment of the sedimentaries of the autochthon to the Riphean era.

Riphean Sedimentaries of the Autochthon: The succession (figure 9) is divisible into four units of lithological formations: (i) The turbiditic flysch assemblage of alternating greywackes and shales making up the Chakrata Formation; (ii) the turbidites grade imperceptibly upwards into and locally laterally interfinger with a great succession of sublitharenites, muddy arenite and slates that constitute the Rautgara Formation, integrally associated with basic lavas and tuffs (Rudraprayag Volcanics) and dolerite intrusives, dated between 414 to 1190 m.y. by k-Ar method[39]. The Chakrata and Rautgara together make the Damtha Group[16,45]. The turbidites are not uniformly developed and seem to be confined to southeastern Himachal and southwestern Kumaun Himalaya. Elsewhere, the Rautgara is the oldest-basal—formation resting presumably on the basement of the 1860 ± 65 m.y. old porphyritic granites and porphyries. Table 3 shows the equivalants of the Rautgara in other parts of the Himalaya—Sundernagar in Himachal, Fagfog-Dandagaon-Nourpul in central Nepal, Jainti-Sinchula and Phuntsholing in Bhutan, and Miri in Arunachal Pradesh. (iii) The flyschoid group is succeeded without break by the argillocalcareous Tejam Group. The lower part, Deoban Formation, is made up dominantly of dolomites and limestones, and the cherty dolomites exhibit prolific and widespread development of columnar-branchings stromatolites represented by *Baicalia* with *Kussiella, Masloviella, Minjaria* and rarely *Conophyton*

TABLE 3

Regional Correlation of the Sedimantary Formations of Lesser Himalayan Autochthonous Zone

Probable Age	Kashmir	Himachal	Kumaun	Nepal	Darjeeling	Bhutan	Arunachal
Lr. Eocene	Subathu	Subathu	Subathu	Subathu			
Up. Cret. to Palaeocene		Kakara	Bansi (Singtali)	Tosh			
Lr. and Mid. Permian	"Agglomeratic Slate", S of Panjal Thrust			Damuda Barahkshetra Masem	Damuda Rangit	Damuda Diuri	Khelong (Bhareli) Rangit
Up. Riphean to Vendian		Basantpur	Mandhali (Sor)	Robang (?) Malekhu Benighat			Saleri
Mid. Riphean		Shali	Deoban	Dhading	Buxa	Buxa	Dedza
Lr. Riphean	?? Gamir[1]	Sundernagar[2]	Rautgara[3]	Nourpul Dandagaon Fagfog	Jainti Sinchula	Phuntsholing	Bichom (Miri)
			Chakrata	Kuncha			

* Basic volcanics thrust upon the "Agglomeratic Slates" is possibly (??) part of it. 2. With Mandi-Darla Volcanics. 3. With rudraprayag Volcanics. 4. With Abor Volcanics.

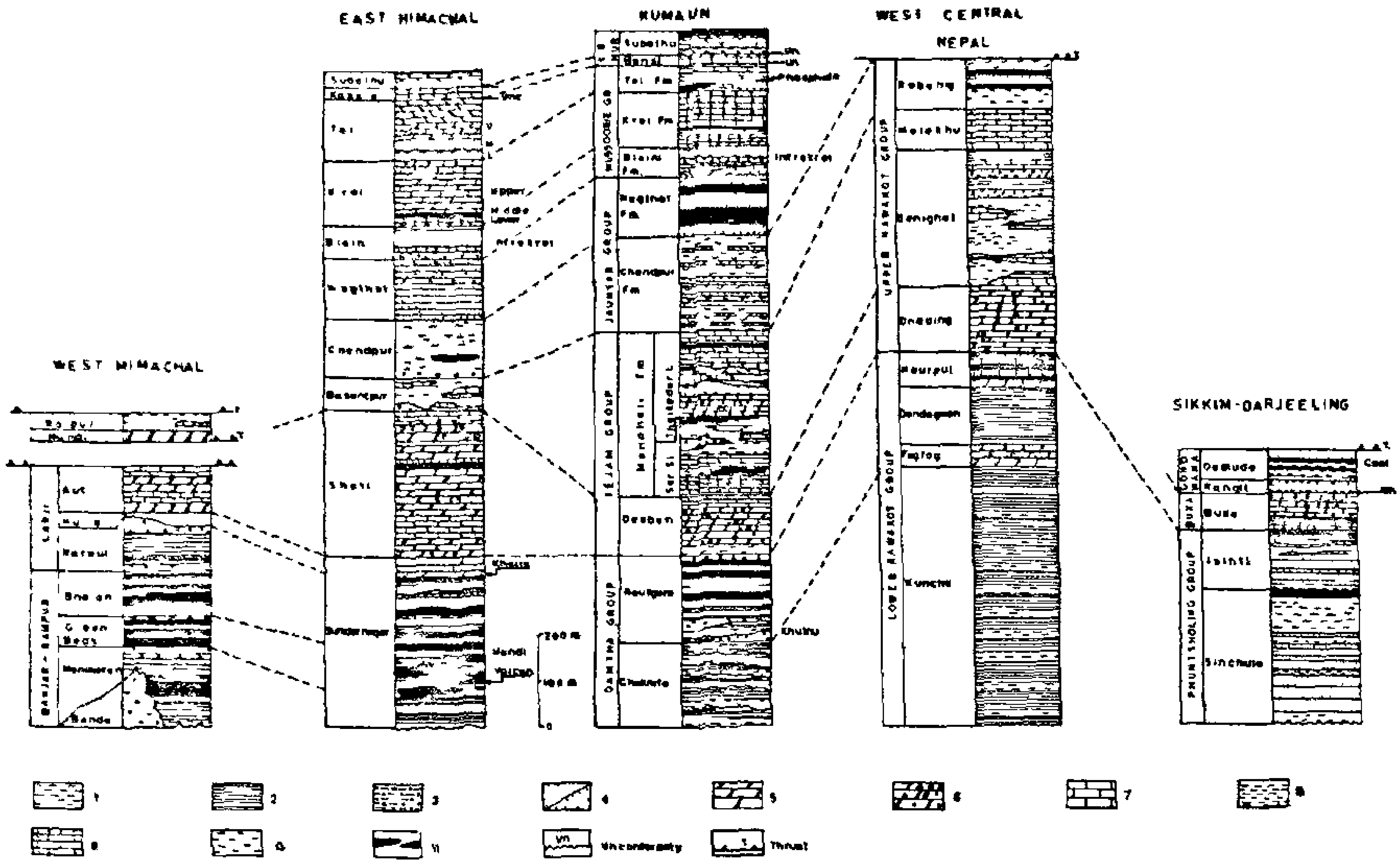

Figure 9. The lithostratigraphic order of sedimentaries in the Lesser Himalaya, and their correlation[72] (1 = Wackes and turbidites, 2 = Shales and slates; 3 = Conglomerates; 4 = Quartzarenites; and sublitharenites (fine-and coarse-grained); 5 = Dolomites; 6 = Cherty and stromatolitic dolomites; 7 = Limestones; 8 = Carbonaceous shales; 9 = Sandy limestone; 10 = Phyllite; 11 = Basic volcanics/phosphatic rocks/coal).

testifying to broadly Middle Riphean (1350 ± 50 to 950 ± 50 m.y.) age—more likely to upper part of the Middle Riphean[41]. Radiometric dating of the galena samples recovered from the top of the Jammu Limestone, which is a stratigraphic equivalent of the Deoban, gives the age of 967 m.y.[40], thus corroborating my earlier deduction[37]. A very significant feature of the Deoban and equivalents is the occurrence of lentiform deposits of economically reach coarsely crystalline magnesite, intimately associated with talc and stringers, veins, pockets and disseminations of sulphides of copper, lead and rarely zinc[16]. Although of variable thickness, this lithostratigraphic unit is persistently developed throughout the Lesser Himalaya: in north western part it is known as Jammu (Great or Sirban) Limestone, in Himachal as Shali, in Central Nepal as Dhading[42] and in eastern Himalaya as Buxa (table 3).

(iv) The dolomite unit is succeeded transitionally by a protean assemblage of pyritic-carbonaceous shale, marl varicoloured commonly marmorized limestone, dolomite, and local lenses of intraformational conglomerate. This is the Mandhali Formation, the dolomites of which are characterized by Upper Riphean to Vendian (950 ± 50 to 570 m.y.) stromatolites such as *Collenia parva, Jurussania, Newlandia* and *Irregularia*[41,43]. In the northwest in Himachal, the Mandhali is known as the Basantpur[44], and in Central Nepal it is represented by the Benighat Slates-Malekhu Limestone succession[42].

In the inner Lesser Himalayan autochthonous belt the Mandhali is the uppermost unit, thrust over by the Berinag quartzites belonging to the allochthonous unit.

Stratigraphic Succession of Krol Nappe: In the outer Lesser Himalayan belt, in constrast, the Damtha rocks of the autochthonous zone have been thrust over along the Krol Thrust by about 6000 m thick succession of sediments,including the truncated Mandhali at the base and the Tal

Formation at the top (table 2). The full succession comprises the Mandhali, Chandpur, Nagthat, Blaini, Krol and Tal formations divisible into the Jaunsar and Mussoorie groups[16]. Since the range of the Mandhali stretches up to the Vendian, and as I assign the Tal to the Permian[48], the Krol-belt succession represents the whole span of the Palaeozoic era—a postulation that is a clear repudiation of the universally accepted view that it spans the whole of the Phanerozoic times. If my deduction is correct then the full succession of sediments from early Riphean (somewhere between 1600 to 1400 m.y.) to the end of Permian (~225 m.y.)is developed in the Lesser Himalaya, while the whole of Mesozoic is unrepresented.

There are two strong reasons for placing the Jaunsar—Mussoorie groups in the Palaeozoic era. The uppermost limestone member of the Krol at Nainital has yielded solitary spined productid *Linoproductus*, suggestive of Upper Palaeozoic (Upper Carboniferous to Lower Permian) age[46]. The Tal that transitionally succeeds the Krol in Nainital, Lansdowne[48], and Sirmaur may be assigned to the Permian period on the basis of the occurrence of moravamminids in the phosphorites of Mussoorie[51], bryozoans, brachiopods, and algae in the lowermost Jogira member made up of conglomeratic greywacke-black shale in the Lansdowne Hills[48,52]. My Tal Formation is certainly not Medlicott's Tal series described from the Tal valley, but the one which conformably rests on the Krol and the one described as the "Volcanic Breccia" by Middlemiss[53] from the Dugadda area in the Lansdowne Hills. Among the fossils[54,56] recovered from this horizon are *Fenestella oculata, Polypora, Strophalosia, Eurydesma, Spirifer holdhausi, Spiriferina zewanensis, Chonetes orientalis, Neospirifer fasciger, Productus spitiensis.* But there is a dispute on the position of the Permian fossil-bearing horizon (Jogira member), which I take as the lower part of the Tal Formation, but almost all other workers as the Bijni[47]—an altogether different lithostratigraphic unit anomalously placed on the Krol succession. The intensity of controversy has been hightened by the finding by Azmi[57] in the basal phosphorite unit of the Tal in the Mussoorie Hills of conodonts of Cambrian-Early Oridovician age. Interestingly, from the same horizon, fossils—both animal and palynological of the Triassic-Jurassic range have been described by earlier workers. It is evident that there is no agreement amongst the palaeontologists about the identities and ranges of the Tal fossils.

Gondwana Element in Lesser Himalaya: Whether the Jogira is a part of the Tal Formation or not, it certainly represents the marine Gondwana element in the Lesser Himalaya, and is a part of the chain of marine diamictite horizon represented by the Barahkshetra Fm in southeastern Nepal[58], the Rangit Pebble-State in Darjeeling-Sikkim[32], the Diuri in Bhutan[59] and the Garu in Arunachal Pradesh[60]. Significantly, the marine diamictite is overlain without break everywhere by continental coal-and plant-bearing arkosic rocks such as the Maskhet in Lansdown Hills or the Damuda in eastern Himalaya. The remarkably strong lithological and palaeontological similarities of the Himalayan Gondwana units with those of Daltonganj (Bihar), Manendragarh and Umaria (Madhya Pradesh) are pointers to the linkage of the Himalayan basin with that of the Peninsular India.

*Palaeocene and Eocene Formations:*In the Lansdowne Hills the Tal (Jogira-Maskhet succession) is unconformably succeeded by a horizon designated as the Bansi (Singtali) of sandy oolitic limestone and calcareous sandstone characterized by a variety of bryozoans, calcareous algae, lamellibranchs and foraminifera indicating Upper Cretaceous to Palaeocene age[16,45,52]. This horizon, first recognized in the valley of the Tal stream in southeastern Lansdowne Hills and which has been identified and almost universally accepted as the real Tal Formation[61,62] should be equated in my opinion with the Kakara Formation exposed in the Gambhar valley, southwest of Simla[63].

The Bansi (Singtali) and Kakara formations are disconformably overlain by the Subathu Formation of Lower Eocene age. They consist of flysch and fossiliferous limestone.

MODEL OF SEDIMENTATION

Ancient Currents that Flowed Northwards: My detailed study of the sedimentaries of the Chakrata Formation (Western Kumaun) and Simla Slates (Himachal) demonstrated that these sediments were laid down by turbidity currents that originated to the south of the Himalayan domain from what might have been the prolongation of the Aravali hills[64]. This was a startling finding, for until then it was implicitly believed that the source of the Himalayan sediments lay in the north, presumably in the Great Himalaya. The enormous volume of sediments was carried to the sea by the turbidity currents that flowed in the NW, N, NE and ENE directions. Simultaneously ocean-bottom currents were active parallel to the coast and the bottom topography in the ENE to E direction but turning SE towards the Ganga Basin east of the Ganga Valley.

Later studies[16] indicated that throughout the Riphean and Palaeozoic times, that is until the end of Permian (Tal)—stretching from 1600–1400 m.y. to 225 m.y.—the Lesser Himalayan basin received its supply of clastic sediments from the southerly provenance in the Peninsular India as testified by the ENE-to NE-flowing palaeocurrents (figure 10).

Environment of Riphean Sedimentation: In the Lesser Himalaya the sedimentation commenced with the deposition of lithic wackes and mudstones in a rather deeper environment where northerly to easterly flowing turbidity currents and ocean-bottom currents were active. Towards the later part of that period, there were spasmodic floods bringing in their trails submarine slides, and thus giving rise to lentiform horizons of paraconglomerates integrally associated with the turbidites. Those resting over the

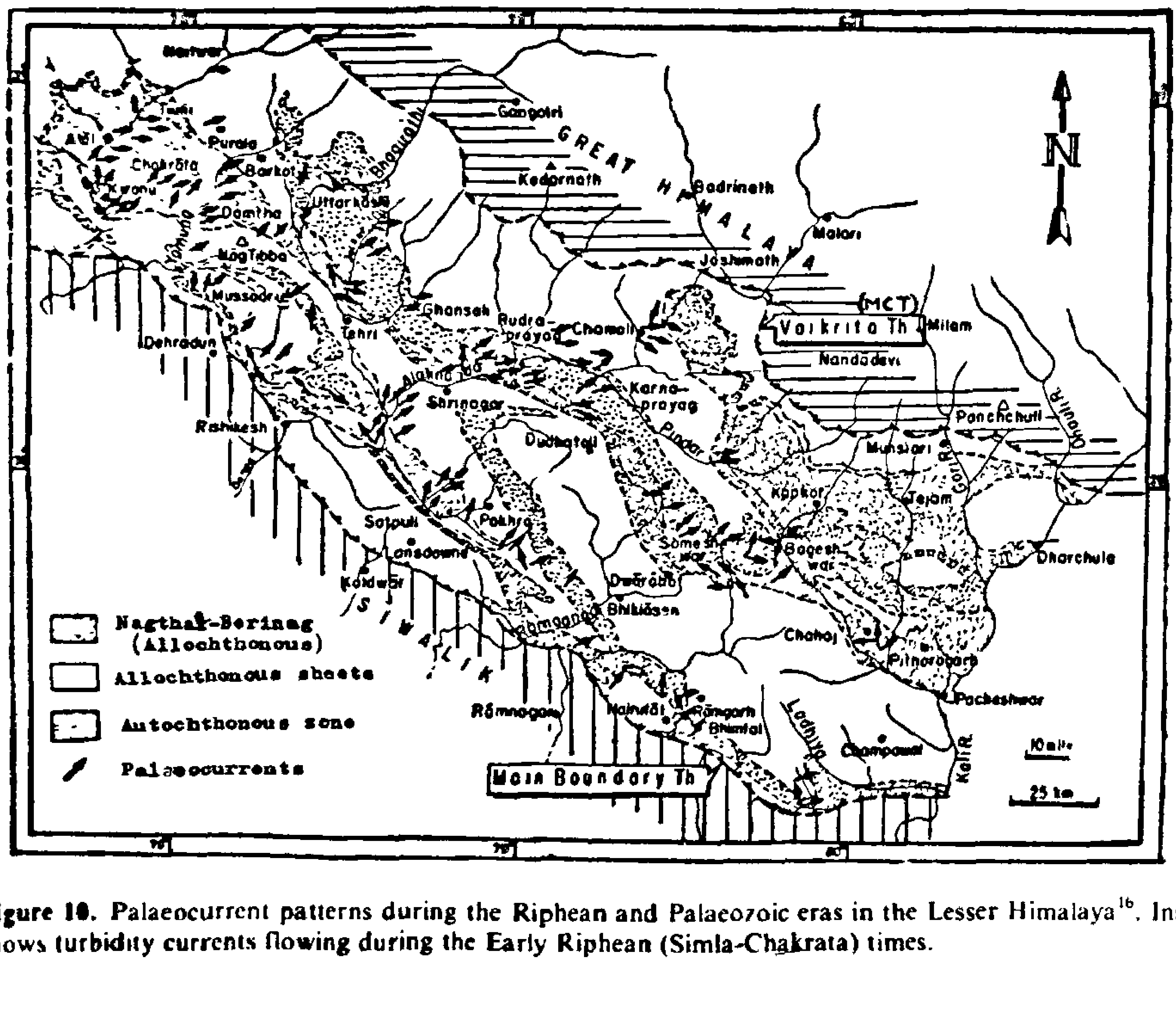

Figure 10. Palaeocurrent patterns during the Riphean and Palaeozoic eras in the Lesser Himalaya[16]. Inset shows turbidity currents flowing during the Early Riphean (Simla-Chakrata) times.

Simla Slates and Chakrata Formation have been in my opinion mistakenly described as the Blaini Boulder Beds[16,64,65]. The activities of the turbidity currents declined as the basin shallowed and sublitharenites, shales and quartzarenites of the Rautgara and Sundernagar formations were deposited.

The progressive shallowing of the basin is marked by the advent and eventual proliferation of the algal stromatolites that grew in platforms with very shallow, warm, clear and agitated waters during the Middle Riphean times. The biohermal growth led to development of lagoons and barred basins and embayments in which not only conditions for phosphatization of stromatolites were generated[66], but later under penesaline conditions thick lentiform deposits of magnesite were also formed[12], as a consequence of diagenetic replacement during sedimentation of early-formed calcite and dolomite by magnesium in water of the lagoons and barred basins in the back-reef shelves of the Deoban sea. It is conceived that the algae played a vital role in creating environmental condition conducive for the concentration of Mg in the water. The algal built biohermal barriers gave rise to barred basins in which Mg/Ca ratio progressively increased as a cumulative result of biogenic and inorganic precipitation of $CaCO_3$. Later during the Mandhali times local to widespread euxinic conditions developed and carbonaceous pyritic sediments were deposited. Occassionally, and locally such condition developed that produced intraformational conglomerates.

Sedimentation During Palaeozoic: The Mandhali sedimentation was followed by a period when non-turbidite flysch of the Chandpur Formation was laid down in a relatively deeper and shrunken basin in the southwestern belt. This was followed by widespread deposition of clean sands (quartzarenite and pebbly sands of Nagthat-Berinag formations) in very shallow littoral environment that stretched over vast part of the Lesser Himalaya. Simultaneously, penecontemporaneous lavas and tuffs (Bhimtal Volcanics) were deposited with the quartzose-sediments.

Then the tectonic conditions turned abnormal: the basin drastically shrank in dimension so that the sedimentation was restricted to the very narrow southern part. In this shrunken basin were deposited the paraconglomerates with greywackes of the Blaini Formation, not as a result of glaciation as commonly and widely believed[67-69] but as a consequence of submarine slides[16,65,70]. The second (upper) layer of the conglomerate associated with dolomitic limestone consists of rounded clasts exhibiting flow-imbrication, indicating that in the making of this horizon of conglomerate the currents in warmer waters have played a notable part[16]. Thus the origin of the conglomerate (boulder beds) of the Blaini is yet another matter on which I find myself in fundamental disagreements with a great majority of workers.

The sediments of the upper part of the Mussoorie Group Krol and Tal were laid down in a gradually shallowing basin as borne out by the algal bioherms and carbonate clastics—calcarenite and pelmicrite and intraclasts associated with them in the uppermost Krol. The beginning of the Tal witnessed recurrence of conditions that gave rise to formation of diamictites and phosphorites in the euxinic setting as represented by the Lower Tal (Jogira member) of the Lansdowne and Mussoorie Hills[49,50]. The marine conglomeratic or phosphatic sedimentation was followed by deposition of continental-type felspathic clastic sediments (Maskhet and Damuda units) containing Gondwana coal or plant fossil throughout the outermost belt of the Lesser Himalayas. The fast shallowing basin was completely efaced by the end of the Permian. It is notable that the retreat of the Palaeozoic sea took place by transition from marine to continental sedimentation.

The cessation of the sedimentation after the Permian, to my mind, marks the influence of hercynian diastrophis. And the Lesser Himalayan domain remained above seawater all through the Mesozoic era.

Harbinger of Himalayan Revolution: Towards the end of the Cretaceous the sea returned through narrow gulfs. And during the Danian-

Palaeocene interval in the high-energy shoals of the small restricted basins were laid down flyschoidal and fossiliferous calcareous sediments of the Bansi-Kakara formations. In the Lower Eocene times (55–60 m.y.) sedimentation took place in lagoons and tidal flats Post-Eocene transgressive sedimentation was widespread, but took place outside the Lesser Himalayan domain in the Outer Himalaya.

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ANNOUNCEMENT

ATOMIC ENERGY COMMISSION, INDIA

Dr. Raja Ramanna has been appointed Chairman of the Atomic Energy Commission and Secretary, Department of Atomic Energy. Dr. Ramanna succeeds Dr. H. N. Sethna who is retiring. Dr. Ramanna's scientific work has been on neutron thermalisation including design of reactors.

Dr. Ramanna had collaborated in the design, installation and commissioning of the research reactors Apsara, Cirus, and Purnima and the Cyclotron at Calcutta.