30. George, M. T., Harris, N. B. W. and Butler, R. W. H., The tectonic implications of contrasting granite magmatism between Kohistan island arc and the Nanga–Parbat–Haramosh massif, Pakistan Himalaya. *Geol. Soc. London, Spec. Publ.*, 1993, **74**, 173–191.

ACKNOWLEDGEMENTS. I am grateful to Prof. Wolfgang Frisch for providing facilities for research work and Prof. Wolfgang Siebel for guidance and help in geochronological data generation at the Institute of Geosciences, University of Tuebingen, Germany. I thank the Alexander von Humboldt Foundation, Germany for providing AvH Fellowship (2003–04); Dr Heinrich Taubald and Gisela Bartholoma for help in geochemical data generation and the staff of Tuebingen University, Germany for assistance during research work. Authorities of BSIP, Lucknow, WIHG, Dehradun and DST, New Delhi are thanked for financial support during the 1995, 1996 and 2002 field excursions in northern Ladakh. Thanks are due to Prof. C. C. Pant, Head, Department of Geology, Kumaun University, Nainital for providing facilities for research within the framework of the SAP and FIST programmes. Thanks are also due to the anonymous reviewers for constructive comments.

Received 3 May 2007; revised accepted 5 May 2008

Morphotectonic evolution of the Binau–Ramganga–Naurar transverse valley, southern Kumaun Lesser Himalaya

Pradeep K. Goswami* and Charu C. Pant

Department of Geology, Kumaun University, Nainital 263 002, India

The transverse river valleys in Kumaun Lesser Himalaya provide excellent transects to understand the neotectonic activities along various criss-crossing faults/thrusts. Digital analysis of remote sensing data and field investigations have been carried out to understand the morphotectonic evolution of the Binau–Ramganga–Naurar river valley in southern Kumaun Lesser Himalaya. The study reveals that the basal thrusts of crystalline nappes as well as the transverse Bhikiyasain Fault are neotectonically active and directly influence the morphology and landscape of the valley.

Keywords: Geomorphology, morphotectonic evolution, neotectonics, transverse faults.

A REMARKABLE feature of the Lesser Himalayan topography in the Kumaun–Garhwal region is the development of transverse valleys along the courses of antecedent rivers[1]. These exhibit marked deflections and striking morphological variations along their length, being narrow and straight at some places, while meandering and wide elsewhere. The youthfulness and reshaping of the landscape in these valleys during Quaternary times is indicated by the development of uplifted river terraces, triangular fault facets, rapids and falls along streams, elevated pot holes and water marks, and river ponding/palaeolakes. Being transverse to the mountain ranges, these valleys are cut across by many longitudinal faults/thrusts and thus provide excellent transects to understand tectonic movements along transverse as well as longitudinal faults/thrusts, and ascertain their specific role in geomorphic development of the region. The study also bears seismotectonic implication as the recurrent seismicity in the region is ascribed to strike-slip movement along transverse faults[2,3].

The present communication deals with the various tectonic and geomorphic features observed along the Binau–Ramganga–Naurar valley of Kumaun Himalaya. The study is intended to mainly understand the role of tectonic movements on morphological variations and landscape development along the Binau–Ramganga–Naurar valley. The investigations include mapping of major lineaments and their analysis in conjunction with structures and landforms of the area. The lineaments and landforms have been identified and demarcated through analysis, in Geographic Information System (GIS), of common terrain characteristic features like drainage pattern, slope, slope aspect, relief, river profiles, etc. and digital processing and interpretation of the satellite imagery of 4 March 2004 from IRS P6 LISS III sensor. Information on landforms has also come from detailed field work and interpretation of stereopair B&W aerial photographs, on 1 : 40,000 scale, of 2 October 1973 under zoom stereoscope. However, smaller landforms like terraces, landslides, etc. could not be mapped owing to limitations of the scale of aerial photographs (1 : 40,000) and spatial resolution of imagery (23.5 m).

The geological set-up of the Kumaun–Garhwal Lesser Himalaya has been discussed in detail by Valdiya[1]. In southern Kumaun, the Lesser Himalaya is made up of three distinct lithotectonic–stratigraphic units; from bottom to top, these are Krol, Ramgarh and Almora nappes (groups)[1,4,5] (Figures 1 and 2 *a*). The Almora Nappe is a thick synclinal sheet of meso-grade metamorphics intruded by trondhjemitic suite of granites. Its northern and southern flanks are called the North Almora Thrust (NAT) and South Almora Thrust (SAT) respectively[1,5] (Figure 1). Along the NAT, the Almora Nappe is placed over the autochthonous Proterozoic clastic–carbonate sedimentary succession, whereas along the SAT it is thrust over the very low-grade metamorphics with mylonitized porphyroids of Ramgarh Nappe. The Ramgarh Nappe is thrust southward over the Proterozoic–Early Cambrian clastic–volcanic–carbonate sedimentary succession of the Krol Nappe, along the Ramgarh Thrust (RT)[1,6] (Figure 1). The entire succession is then thrust along the Main

*For correspondence. (e-mail: drpgoswami@yahoo.com)

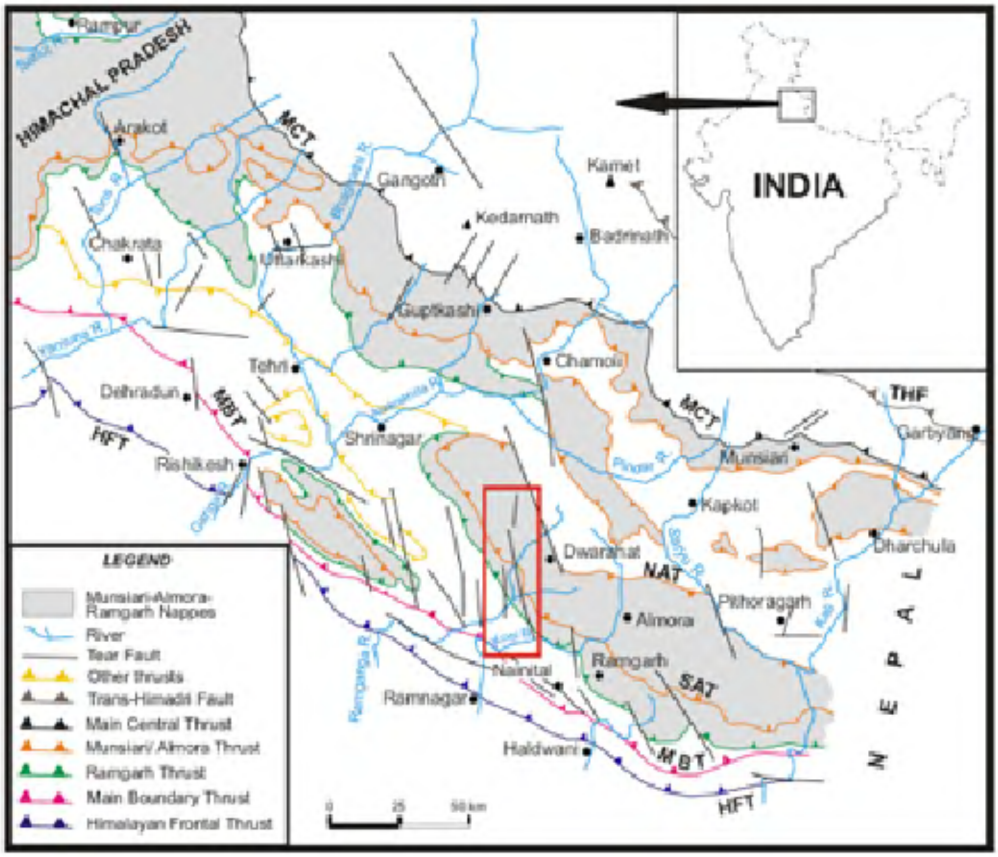

Figure 1. Map showing major thrusts and tear faults of the Kumaun–Garhwal Himalaya (after Valdiya[1,11,12]); THF, Trans-Himadri Fault; MCT, Main Central Thrust; MBT, Main Boundary Thrust; HFT, Himalayan Frontal Thrust; NAT, North Almora Thrust; SAT, South Almora Thrust. Red box shows the location of the study area.

Boundary Thrust (MBT) over the Cenozoic sedimentary succession of the Siwalik (Sub-Himalaya)[1,4,5] which, in turn, is thrust southward over the Ganga Plain sediments along the Himalayan Frontal Thrust (HFT)[7–9]. Moreover, whole of the Ganga Plain–Siwalik–Lesser Himalaya terrane in southern Kumaun is traversed by a number of other neotectonically active longitudinal and transverse faults[1,2,7–13].

The Binau–Ramganga–Naurar valley is developed in the Almora and Ramgarh nappes along the Ramganga River and its tributaries. Most of the rivers/streams flowing into the valley are lineament-controlled and render a rectangular drainage pattern (Figure 2 *a* and *b*). Morphological variations along the length of the valley are striking. In the north is the valley of the Binau River which originates in the >2200 m amsl high Dudhatoli mountains and flows towards SE in its upper reaches. At Bharsoli, the Binau meets another tributary stream and then flows towards south into ~800 m wide valley. Further downstream it flows towards SSW into an anomalously ~2.25 km wide valley at Syalde. Downstream of Syalde, it takes an open 'S' bend between Timil and Taltai, and then flows southward in a deep and <100 m wide gorge until it merges with the Ramganga River at Burhakedar. In the satellite imagery, the S-bend is seen to be controlled by E–W and almost N–S trending lineaments. Downstream of Burhakedar, the Ramganga flows towards SSE up to Bhikiyasain, where the NNW-flowing Naurar stream joins it. At this place it takes a sharp bend and flows towards SSW along a NNE–SSW trending right-lateral strike-slip fault[14].

Earlier workers have shown that the Binau–Ramganga–Naurar valley is formed along two transverse faults[1,2,14]; one is the NNW-SSE trending Bhikiyasain Fault (BF)[1,2] that extends between Syalde in the north and Bhatronjkhan in the south, and the other is the NE–SW trending fault between north of Deghat and Bamankhola. The present investigation reveals that both these faults are vertical to steeply (>75°) eastward dipping and in the satellite imagery they are seen joined by a NE–SW trending lineament, between Bamankhola and Syalde (Figure 2 *a*). The southern limit of the BF extends to the south of Bhatronjkhan up to the northern face of the Saonchalia ridge. An active landslide zone along its trace near the Amdali village and falls of 25 and 35 m along nearly NW-flowing second and third order streams respectively, on

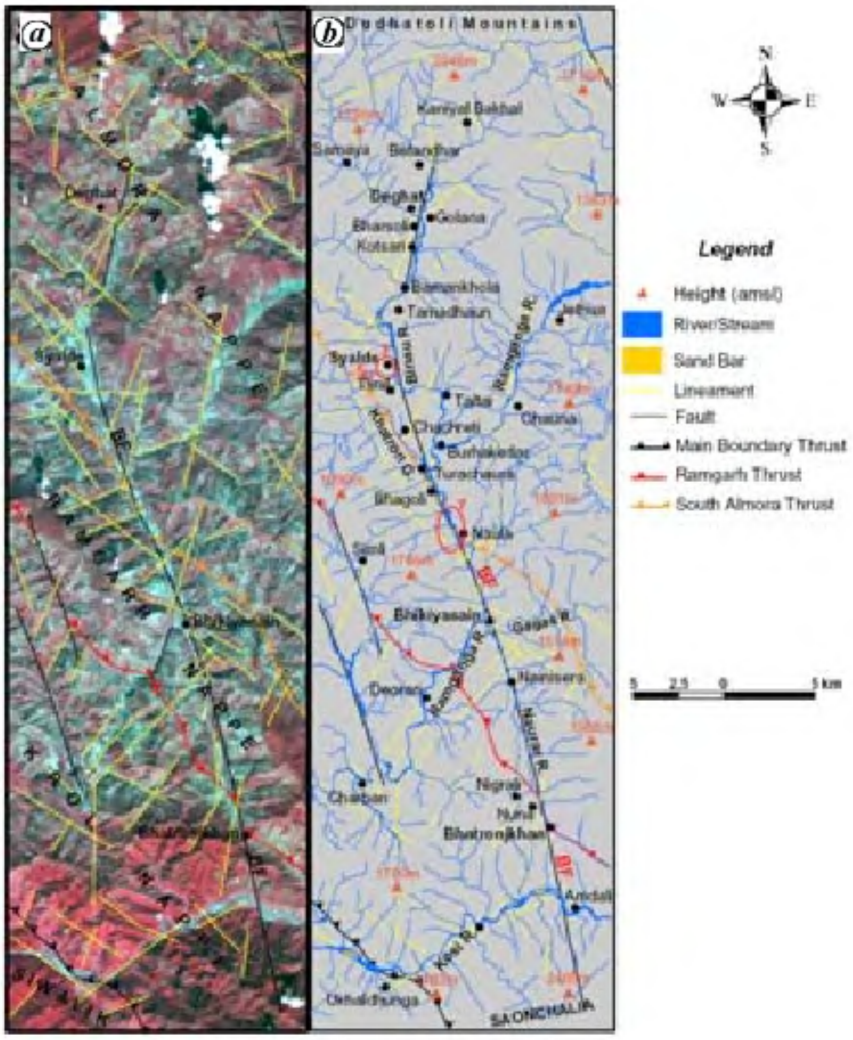

Figure 2. ***a***, Major thrusts that define various lithotectonic domains and lineaments of the area drawn onto the IRS P6 LISS3 imagery of 4 March 2004. ***b***, Rectangular-type drainage pattern in the area is controlled by various thrusts/faults and lineaments. Areas shown in red ellipses marked with numbers indicate locations of corresponding figures. BF, Bhikiyasain Fault; R, River and G, Gad (stream).

the northern face of Saonchalia ridge are surface expressions of BF in this part. Considered as a tear fault, the right lateral displacement of SAT and RT along BF is about 2.5 and 1.6 km respectively[1,2].

The entire Binau–Ramganga–Naurar valley is lined with paired and unpaired, discontinuous fluvial terraces, active and old landslide fans and debris that are often anthropogenically or naturally redistributed.

Between Golana and Bamankhola, five levels of fluvial terraces along the left bank (BnT_{L1} to BnT_{L5}) and three levels along the right bank of the Binau River (BnT_{R1} to BnT_{R3}) have developed. The elevation difference between successive terraces is not identical. For example, at Bharsoli three levels of terraces are developed along the right bank and two levels along the left bank of the river (with average elevation difference between successive terraces from the river bed to BnT_{R3} being about 6, 5 and 7 m respectively, whereas from the river bed to BnT_{L2} it is about 8 and 6 m respectively). Similarly, four levels of fluvial terraces are developed along the right bank (BnT_{R1} to BnT_{R4}) and three levels along the left bank (BnT_{L1} to BnT_{L3}) of the Binau River at Syalde (Figure 3). Here the average elevation differences between successive terraces from the river bed to BnT_{R4} are about 2, 2, 10 and 60 m respectively, and from the river bed to BnT_{L3} about 2.5, 4 and 6 m respectively. The right bank terraces are wider compared to the left bank terraces; the average width of the right bank is ~1.75 km, whereas that of the left bank is ~500 m.

A simple explanation for the development of terraces with unequal elevation difference could be that these were formed as fans by streams originating from adjacent

valley walls and later planed away by the main river. However, terraces along the Binau River are of fluvial origin, made up of channelized to sheet-type, clast to matrix-supported gravels of up to boulder sized rounded to sub-rounded clasts and a few sand horizons, and are morpho-stratigraphically comparable. The clasts generally show imbrication, indicating southwest- to south-directed palaeocurrent. It is, thus, most plausible to attribute the development of these terraces to vertical movements along the BF, which also causes right lateral displacement of NE-dipping lithounits for about 2.2 km between Bamankhola and Kotsari. The unequal elevation difference between successive terraces is considered to be a result of palaeotopographic characteristics of the depositional surface as well as deposition of terrace forming sediments in multiple episodes.

Moreover, the BnT_{L1} terrace developed near the temple in Syalde is of strath nature with fluvial gravels resting on the intensely fractured garnetiferous mica schist of the Almora Group, showing NW-plunging striations on slickensided surfaces. It also indicates that the left bank of Binau River has been uplifted and moved southward along the BF and thus, rocks of the Almora Group have been placed in juxtaposition with the Quaternary sediments. Downstream, to the east of Timil, the river crosses the BF so that the uplifting of the eastern block of the fault obstructed the flow of river water and thick gravel units were deposited in the channel upstream of Timil. In the profile of the Binau River, the trace of BF is manifest in the form of ~1.4 m high upwarp (Figure 4 *a*). Uplift of the eastern fault block accelerated downcutting by the stream and thus, a deep gorge has been carved downstream of Timil. The uplift of alluvium on the right bank of the river, on the other hand, is attributed to movements on the SAT passing through the west of the valley and moving the Almora Nappe upward and southwestward over the Ramgarh Nappe.

It is interesting to note that the beds of the BnT_{R4} terrace, just west of the Government Girls Inter College, Syalde, along the Syalde–Bhikiyasain motor road are dipping 21° → SW (Figure 5), whereas beds in lower-level terraces or even elsewhere in the same terrace are nearly horizontal. Such anomalous local disposition of beds of a particular terrace could most plausibly be again attributed to the palaeotopographic characteristics of the depositional surface.

Figure 3. Four levels of fluvial terraces developed on the right bank of anomalously wide valley of Binau River at Syalde. Abbreviations are same as used in the text (viewing towards west).

Development of the anomalously wide valley of the small Binau River at Syalde can thus be attributed to movements on SAT and BF; the former has caused en bloc uplift of the entire valley and progressively eastward migration of the river, whereas the latter has been responsible for facilitating deposition of thick gravel units by placing obstacles in the flow of the river (Figure 6). Deeply incised tributary streams joining the Binau River at right angles on both the banks also indicate *en bloc* uplift of the entire valley.

To the south of Syalde, the BF passes through the saddle just southeast of the Timil village. Further south, SAT and BF converge towards each other and ultimately SAT is dextrally offset for ~2.5 km along the BF between Bhagoli and Naula[2], indicating a younger age for the latter. To the south of Timil village, near villages Chachreti and Turachaura, fluvial gravels of the Khatron Gad are uplifted ~60 m from the stream bed as a result of movements along the SAT. The petty stream of Khatron Gad has carved a deep and narrow gorge, upstream of the region where SAT passes through, indicating accelerated downcutting in response to uplift of the terrane along SAT. The development of cliffs and active landslides along the trace of SAT, near Turachaura village also bear testimony to the activeness of the SAT.

The zone of crossing of the SAT and RT in Ramganga river valley is characterized by the development of paired fluvial terraces, debris fans and scarps. In the longitudinal profile of the Ramganga River distinct knick points are seen where BF and SAT pass through (Figure 4 *b*). Development of paired fluvial terraces along Ramganga River near Bhagoli is a result of uplift along the SAT passing though the western margin of the valley. In the downstream, the BF passes through the western margin of the valley and thus uplifting of the eastern fault block, along it and/or SAT has led to the development of three levels of paired fluvial terraces above the bed of Ramganga River near Naula village; the average elevation differences between successive terraces from the river bed being 1, 4 and 5 m on the right bank and 1.5, 7 and 25 m on the left bank. Interestingly, an abandoned channel is also seen on the upper terrace of the right bank. Moreover, the upper terrace on the left bank is transversely cut and its upstream part is uplifted by ~5 m along the SAT (Figure 7). Further downstream, the Ramganga River has carved a deep and ~50 m wide gorge along the BF. Consequently, upon uplifting of the eastern block along it, the second and third order tributaries joining the river from the east also flow into deep gorges and fluvial gravels are uplifted ~40 m above the river bed north of Bhikiyasain.

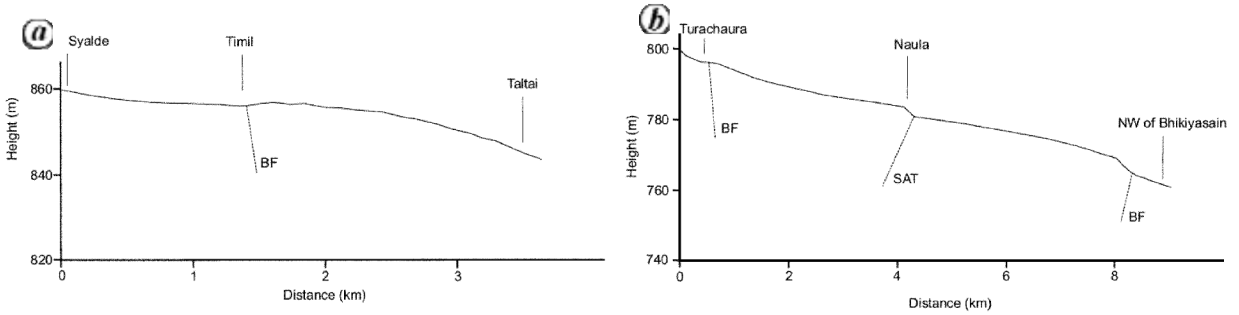

Figure 4. Longitudinal river profiles of ***a***, part of Binau River between Syalde and Taltai, and ***b***, part of Ramganga River between Turachaura and upstream of Bhikiyasain. Note the knick points at places where fault/thrust passes through. Tectonic lines are drawn freehand, irrespective of dip measurements, to highlight topographic expression of tectonic movements. Abbreviations are same as used in the text.

Figure 5. Tilted fluvial gravels and sand units are seen along the Syalde–Bhikiyasain Road, west of Government Girls Inter College, Syalde (viewing southwestward).

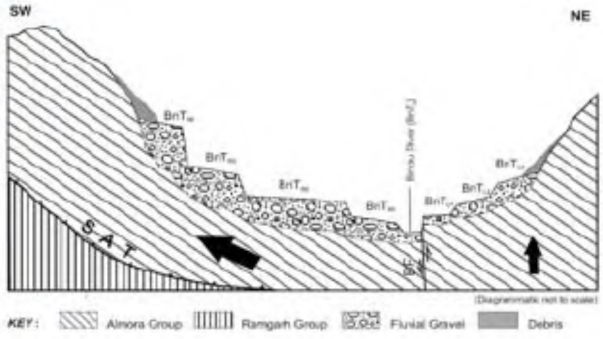

Figure 6. The anomalously wide valley of Binau River at Syalde as a result of movements along the SAT and BF. Abbreviations as used in the text.

Figure 7. Three levels of paired terraces developed along the banks of Ramganga River near Naula village. Note the abandoned channel on the uppermost right bank terrace and displacement of the uppermost left bank terrace along the SAT. T_L and T_R indicate left and right bank terraces respectively; the remaining abbreviations are same as used in the text (viewing towards north).

At Bhikiyasain, the WSW flowing Gagas and NNW flowing Naurar rivers meet and join the Ramganga River. Here, the Ramganga valley suddenly becomes wide, up to ~500 m, lined with three levels of fluvial terraces along the eastern margin (average elevation differences between successive terraces from the river bed being about 2, 8 and 30 m) and two levels along the western margin (average elevation differences between successive terraces from river bed being about 1.5 and 3 m) of the valley. Here the BF passes through the west of valley giving rise to triangular fault facets and planar hill-slope facets along the western valley wall. Thus, development of terraces at this place may be attributed to vertical movements along the RT.

South of Bhikiyasain, the Naurar River flows through a <160 m wide, remarkably straight channel. The right bank tributaries join the Naurar River through deep gorges, e.g. the lineament-controlled and <80 m wide meandering

channel of the Gagas River is deeply incised (up to 300 m) into the bed rock and shows development of >100 m uplifted, strath-type terraces along a few meander bends. The tributaries of the Gagas also flow through lineament-controlled deep gorges. These features indicate intense dissection owing to accelerated downcutting by streams in the uplifted eastern block of the BF passing just east of Bhikiyasain along the right bank of Naurar River.

The Naurar valley upstream of Nainisera is covered with huge landslide fans and tongues covering a few square kilometre area. The debris is generally redistributed by streams as well as humans inhabiting the region, for the purpose of developing agricultural fields, and the Naurar River and its left bank tributaries, descending energetically from steep slopes, are deeply incised into it owing to downcutting into the loose material. In the upstream reaches of the valley, the RT is offset dextrally for about 1.6 km along the BF as observed by Valdiya[2], indicating a younger age for the latter. This zone is marked by the presence of a huge and thick landslide debris apron, extending downslope of Nuna and Nigrali, deeply cut on the sides by streams. South of Bhatronjkhan, the BF extends southeastward through a saddle and the RT trends WNW–ESE.

The above enumerated observations indicate that the basal thrusts of crystalline nappes as well as transverse faults of the region are neotectonically active. The landscape and morphology of the Binau–Ramganga–Naurar river valley is largely controlled by neotectonic movements along the SAT, RT and BF.

1. Valdiya, K. S., *Geology of the Kumaun Lesser Himalaya*, Wadia Institute of Himalayan Geology, Dehradun, 1980, p. 291.
2. Valdiya, K. S., Himalayan transverse faults and folds and their parallelism with subsurface structures of the northern Indian Plains. *Tectonophysics*, 1976, **32**, 353–386.
3. Kayal, J. R., Precursor seismicity, foreshocks and aftershocks of the Uttarkashi earthquake of October 20, 1991 at Garhwal Himalaya. *Tectonophysics*, 1991, **263**, 339–345.
4. Auden, J. B., Geology of the Krol Belt. *Rec. Geol. Surv. India*, 1934, **67**, 357–454.
5. Heim, A. and Gansser, A., Central Himalaya. *Mem. Soc. Helv. Sci. Nat.*, 1939, **73**, 1–245.
6. Pande, I. C., A geological note on the Ramgarh area, District Nainital, UP. *Q. J. Geol., Min. Metall. Soc. India*, 1950, **27**, 15–23.
7. Nakata, T., Geomorphic history and crustal movements of the foot-hills of Himalaya, Science Reports, 7th Series (Geography), Tohoku University, Japan, 1972, vol. 22, pp. 39–177.
8. Karunakaran, C. and Ranga Rao, A., Status of exploration for hydrocarbons in the Himalayan region – Contribution to stratigraphy and structure. *Geol. Surv. India, Misc. Publ.*, 1976, **41**, 1–66.
9. Valdiya, K. S., Rana, R. S., Sharma, P. K. and Dey, P., Active Himalayan Frontal Fault, Main Boundary Thrust and Ramgarh Thrust in southern Kumaun. *J. Geol. Soc. India*, 1992, **40**, 509–529.
10. Valdiya, K. S., *Geology and Natural Environment of Nainital Hills, Kumaun Himalaya*, Gyanodaya Prakashan, Nainital, 1988, p. 155.
11. Valdiya, K. S., Main boundary thrust zone of Himalaya, India. *Ann. Tecton.*, 1992, **6**, 54–84.
12. Valdiya, K. S., Reactivation of terrane-defining boundary thrusts in central sector of the Himalaya: Implications. *Curr. Sci.*, 2001, **81**, 1418–1431.
13. Goswami, P. K. and Pant, C. C., Geomorphology and tectonics of Kota–Pawalgarh Duns, Central Kumaun Sub-Himalaya. *Curr. Sci.*, 2007, **92**, 685–690.
14. Powar, K. B., Stratigraphy of the Lesser Himalayan sediments of Nainital–Almora area, Kumaun Himalaya. In *Stratigraphy and Correlation of the Lesser Himalayan Formations* (eds Valdiya, K. S. and Bhatia, S. B.), Hindustan Pub Corp, Delhi, 1980, pp. 49–58.

ACKNOWLEDGEMENTS. Prof. K. S. Valdiya, JNCASR, Bangalore encouraged us to undertake this study. We thank the two anonymous referees for their critical reviews and constructive comments which helped to drastically improve the quality of the manuscript. The facilities generated under DST, New Delhi-sponsored FIST programme and a research project (No. SR/S4/ES-131/2005) and UGC, New Delhi-sponsored SAP in the Department of Geology, Kumaun University, Nainital, have been fruitfully utilized.

Received 10 May 2007; revised accepted 2 April 2008