Normal faults near the top of footwall of Ramgarh Thrust along Kosi River valley, Kumaun Lesser Himalaya

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Conjugate sets of normal faults formed in the Quaternary fan sediments lying near the top of footwall rocks of the Ramgarh Thrust are analysed. These faults are recognized on left hillslope of Kosi River valley, Kumaun Lesser Himalaya. The Ramgarh Thrust marks the mountain front of the uplifted Central Crystallines, which have been under thrust along the Ramgarh Thrust by its footwall of the Nagthat Formation belonging to the Lesser Himalayan Sequence. The existence of a regional-scale footwall anticlinal structure along the Kosi River suggests that the compressional stress regime is active in the subsurface region related to the Himalayan thrust tectonics. Analysis of structural data reveals that the normal faults have been formed by pure shear due to gravity. The WNW–ESE trending normal faults are recognized within the Quaternary fan deposit and also at the top of the country rocks just below and adjacent to the fan deposit. Therefore, it is interpreted that the deformation related to N–S extensional tectonics has taken place at the uppermost crustal level due to gravity, where influence of the Himalayan subsurface compressional tectonics is no more significant.

Keywords: Fan sediments, footwall rocks, Kumaun Himalayas, normal and ridge faults, thrust tectonics.

PRESENCE of normal faults in the stratified Quaternary sediments resting on the eroded surface of inclined country rocks raises questions about how they have developed in an on-going continued compressional regime, and about their genetic relationship with the tectonic structures formed in the underlying rocks. Such an observation is made in the Kosi River valley where three closely spaced, NW–SE trending neotectonic faults in Betalghat–Basgaon–Bhujan section of the Kumaun Himalaya have been mapped[1,2]. Near Betalghat (Figure 1 *a*), the offset of Quaternary marker bed along a NNE–SSW trending fault has been interpreted to be a result of active transverse faulting due to oblique convergence of the Indian plate towards the Himalaya[3]. In the study area, brittle normal faults have been observed in the Quaternary deposit[4]. The transverse N–S trending Garampani Fault (Figure 1 *a*) has been shown with uplifted western block relative to eastern block[5]. Similarly, in Logar village area of the southeast Kumaun Sub Himalaya, the Main Boundary Thrust (MBT) shows active normal faulting that has cut the top surface of fan deposit and has formed a 40 m high NE-facing fault scarp[6,7]. In the same region, the normal faults developed parallel to the MBT have formed Shyamal Tal and other associated lakelets[8]. The top of footwall of the MBT has uplifted with a faster rate than its hanging wall[9]. Later on the basis of tectonic geomorphological study across the MBT in Logar and surrounding areas, the development of normal faults offsetting the surface of the Quaternary colluvial fan has been interpreted to be due to subsurface active tectonics[10,11]. In the surrounding area of Logar, including along the mountain front, the Quaternary normal faulting event took place after 17 Ka (ref. 12), and other normal faults that resulted in the formation of palaeolakes and lakelets south of the MBT[8] were formed before 1 Ka (ref. 12). Towards north, on the basis of field observations and analysis of anisotropy of magnetic susceptibility of rocks, the existence of a series of normal faults in the trailing terminal of a transverse Chaukhutiya Fault offsetting the North Almora Thrust in the inner Kumaun Lesser Himalaya has been described[13]. In the NW Himalaya, mesoscopic normal faults are recognized in the Panjal Thrust Zone in Dalhousie area, including the Bhadarwah Normal Fault between the Higher Himalayan Crystallines and Chamba syncline[14]. The characteristic of frequency-dependent attenuation indicates the presence of high degree of tectonic heterogeneities within the crust of the Kumaun Lesser Himalaya, where the low Q values of body waves (Q_p and Q_s) suggest seismic active region[15]. Based upon the thermochronological data in the Kumaun Himalaya, the second cycle of in-sequence thrusting was initiated during the Pliocene–Pleistocene from the Vaikrita Thrust to Berinag Thrust[16,17], and reactivation of the Main Central Thrust (MCT) as out-of-sequence thrusting during this time[18]. Based upon the fault plane solutions of small-to-moderate sized ($1.5 \le M_L \le 5.4$) earthquakes that occurred in Garhwal–Kumaun Himalaya during 2005–08, the occurrence of normal fault-related earthquakes is attributed to local structures and flexure of the Indian plate[19]. In Indian and Nepalese Himalaya, the presence of regional normal

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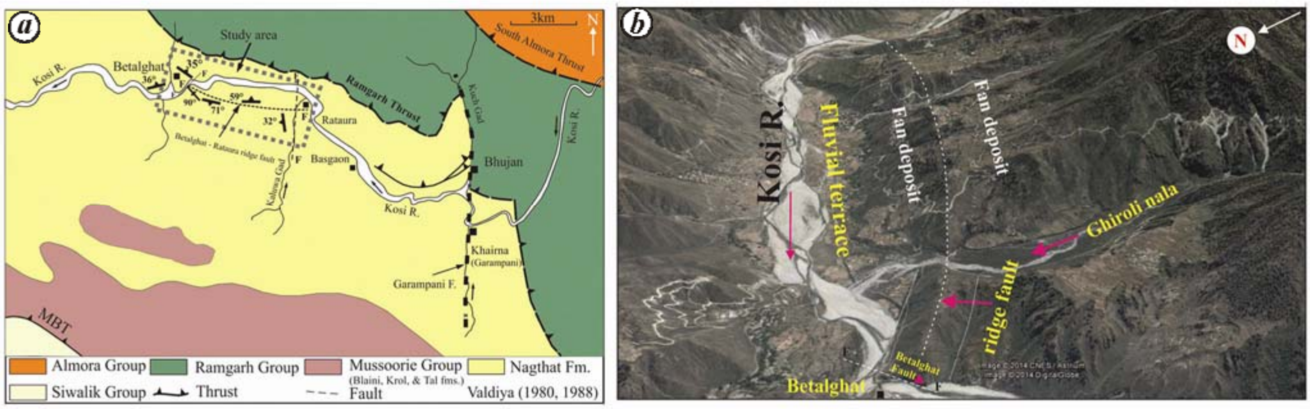

Figure 1. ***a***, Lithotectonic map (after Valdiya[1,2]) showing major thrusts. ***b***, Google satellite imagery showing linear ridge-fault along Kosi River valley, Kumaun Lesser Himalaya.

faulting along the hanging wall of the south-verging MBT has been described[20,21]. On the basis of the study of thermal history of expression of regional landform in hinterland region of the Bhutan Himalaya, the existence of an extensional normal fault of Pliocene–Quaternary age is revealed[22].

Thus a normal sense of movement of rocks along faults has been revealed across the northern boundary (or the MBT) of the Tertiary rocks of the Sub Himalaya. But towards hinterland region, this observation is less reported and analysed as mentioned above[3]. Moreover, no structural detail of normal faults was studied. In the present article, we analyse the geometry and kinematics of faults recognized in the Quaternary fan and underlying country rocks near the top of footwall of the Ramgarh Thrust that separates the Central Crystallines from the Lesser Himalayan Sequence (LHS) along Kosi River valley, Kumaun Lesser Himalaya, to understand their relationship with the structural set-up of the underlying rocks and also to infer the recent status of ongoing deformation due to convergence of the Indian plate towards the Himalaya.

Geological background

The study area lies between Betalghat and Kaluwa Gad along the left bank of Kosi River valley, Nainital district, Uttarakhand, Kumaun Lesser Himalaya (Figure 1 *a*). In the study area the Kosi River valley trends E–W. Towards north two major thrusts are situated, namely the South Almora Thrust (SAT) and the Ramgarh Thrust. The SAT has thrust the medium-grade rocks of the Almora Group over the low-grade rocks of the Ramgarh Group. Along the Ramgarh Thrust, the Ramgarh Crystallines have thrust over the LHS comprising quartzites, metabasics and phyllites of the Nagthat Formation. Sporadic outcrops of fine-grained slaty and coarse-grained crystalline limestone of the Deoban Formation are also found in association with the Nagthat quartzite and phyllites. The Ramgarh Thrust has been interpreted to be an out-of-sequence thrust, i.e. its reactivation postdates the folding event in its footwall[23]. It has been dextrally offset by about 10 km long N–S trending Garampani Fault[1,2,24]. It has thrust the basement granite porphyry (1765 ± 60 to 1875 ± 90 Ma) of upper crustal origin[25] of the Ramgarh Group and metamorphosed basal flysh (Nathuakhan or Rautgara Formation) over the rocks of the Nagthat Formation[1,2,24]. Towards south along the MBT, the pre-Tertiary LHS has thrust over the Tertiary Siwalik Group of rocks of the Sub Himalaya. In Figure 1 *a*, two subsidiary thrust faults within the quartzite and metabasic sequence of the Nagthat Formation are shown (figure 20 of Valdiya[2]) near west of Bhujan village. In the study area the country rocks comprise of mainly quartzite, slaty phyllites, phyllites and locally large outcrops of well-bedded slaty and crystalline limestones. Towards north the Ramgarh Thrust is a major thrust that separates the Lesser Himalayan low-grade rocks (phyllites, mylonitized biotite gneisses and orthogneisses of the Ramgarh Group) from the metasedimentaries (quartzite, phyllites and associated metabasics) of the Nagthat Formation of the LHS[24].

Present structural study

The Kosi River valley is located near the top of the footwall of the Ramgarh Thrust that forms the leading physiographic front of the Central Crystallines. Foliation-parallel shears with down-dip stretching lineation developed on foliation planes of quartzite suggest the presence of subsidiary thrusts within the footwall, as shown by Valdiya[2]. In the east, the Garampani Fault[2] is traced from south of Garampani (or Khairna) to along the straight course of Kuch Gad near north of Khairna (Figure 1 *a*). Along the Khairna–Betalghat transect in Kosi River valley, a sequence of multicoloured quartzites, slates, slaty phyllites, phyllites, metabasics and limestones is encountered. In the middle part of the transect, the lenticular beds of slaty limestone and coarse-grained crystalline limestone of the Deoban Formation dip 46–71° towards north. Across the western extremity of the transect at Betalghat, the NW striking beds are nearly vertical on the left bank of Kosi River, whereas on opposite bank the slaty limestone beds (1–6 cm in thickness) with down-dip lineation dip from 27° to 45° towards N to NE direction. This discordance in attitude of beds across the river indicates the presence of a fault along the river course (Figure 1 *a*).

Analysis of normal faults within Quaternary deposit

Thick fan deposit rests on the hillslope (Figure 1 *b*). This hillslope mass lies on the eroded surface of underlying moderately inclined to sub-vertical beds of country rocks. These stratified Quaternary deposits consist of coarsening upwards sequence of thick layers of coarse sand, large rounded boulders, pebbles and gravels of predominantly quartzites, and subordinate phyllites, hornblende schist, some metabasics and limestone, and thin muddy and sandy layers as matrix in between. This fan material belongs mainly to the Nagthat Formation. Normal faults are observed within fan deposit (Figure 2 *a*). Rotation and alignment of boulders of quartzite lying within crushed material of fault zone suggest dragging along the fault (Figure 2 *b*). In the upper part of the section, the Quaternary stratification dips >20° towards north (Figures 2 *a* and 3 *c*). Faulting has developed imbricated fault planes within boulders and some of them have been truncated, thus exposing new and fresh fault facets (Figure 3 *a*). These boulders have been rotated and are aligned parallel to fault zone. Fault facets formed in boulders dip 70° towards south. Some boulders are less rotated with their polished fault facets dipping 35° towards SSW direction. Longer dimension of large boulders (up to 34 cm in length) and pebbles is perfectly aligned parallel to the fault planes. Flat facets (dipping 63° towards S39W direction) of boulders are aligned parallel to closely spaced imbricated fault planes. Conjugate set of normal faults with imbricated pebbles (Figure 3 *b*) dips towards south. The presence of conjugate set of normal faults suggests that they have been formed under the condition of vertical pure shear mechanism.

Within the Quaternary deposit, a distinct marker bed of sandy layer (67–130 cm thick) is offset by an E/ESE–W/WNW trending normal fault dipping steeply 64–70° towards south to SSW direction (Figure 3 *d*). Thus, strike of fault is E/ESE–W/WNW. The mean dip of hanging wall beds of normal fault is 16° towards N58E direction, where the mean dip of footwall beds of normal fault is 8° towards N71E direction (Figure 2 *a*). As a result of normal

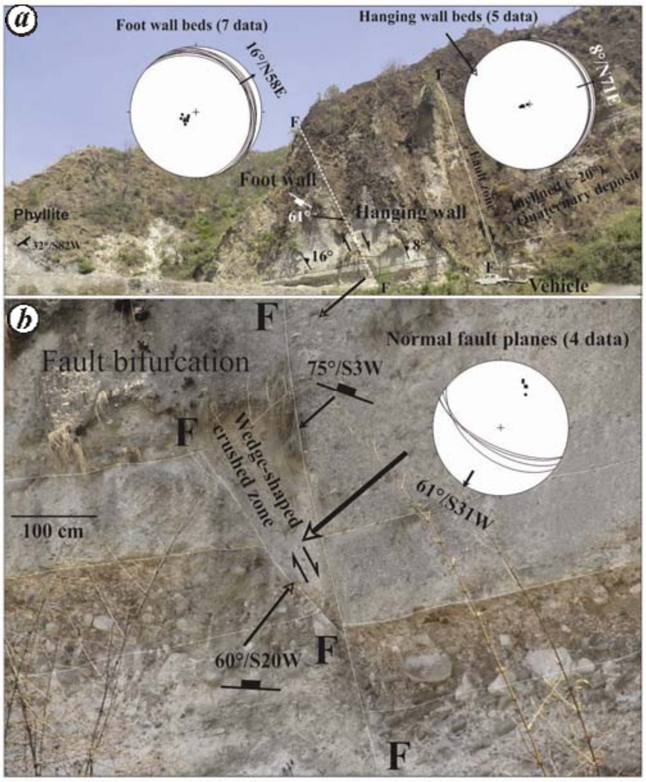

Figure 2. ***a***, Normal fault within Quaternary deposit with equal area stereo net diagrams illustrating bedding planes and their poles, including their means. Footwall rocks dip 16° towards N58E, whereas hanging wall rocks dip 8° towards N71E. ***b***, Enlarged portion of normal fault of (***a***) and fault bifurcation. Mean dip of normal faults is 61° towards N31W. The other normal fault dips 60° towards S20W.

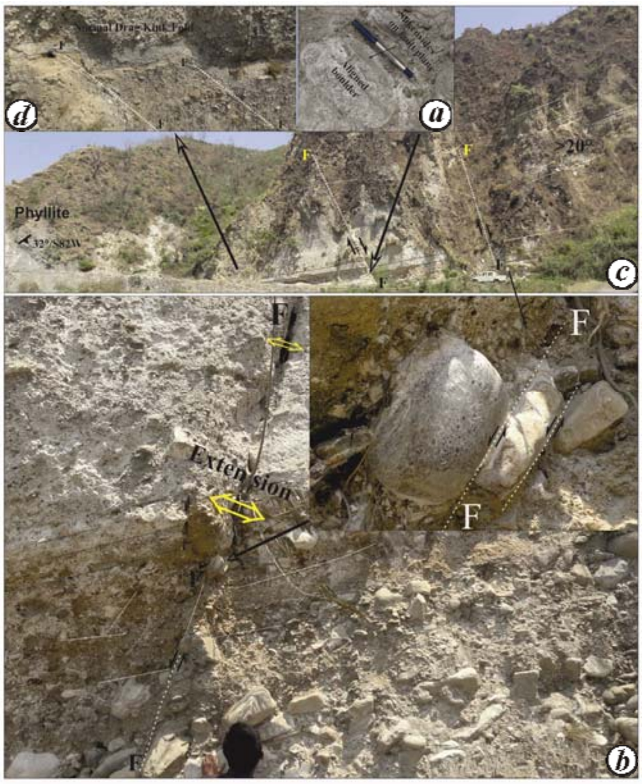

Figure 3. ***a***, Slickensides in fault surface developed in boulders that are reoriented along fault trace. ***b***, Normal fault-related kink fold. ***c***, Stratification of fan deposit dips >20°. ***d***, Conjugate fault showing extensional fractures and related fault imbrication between pebbles.

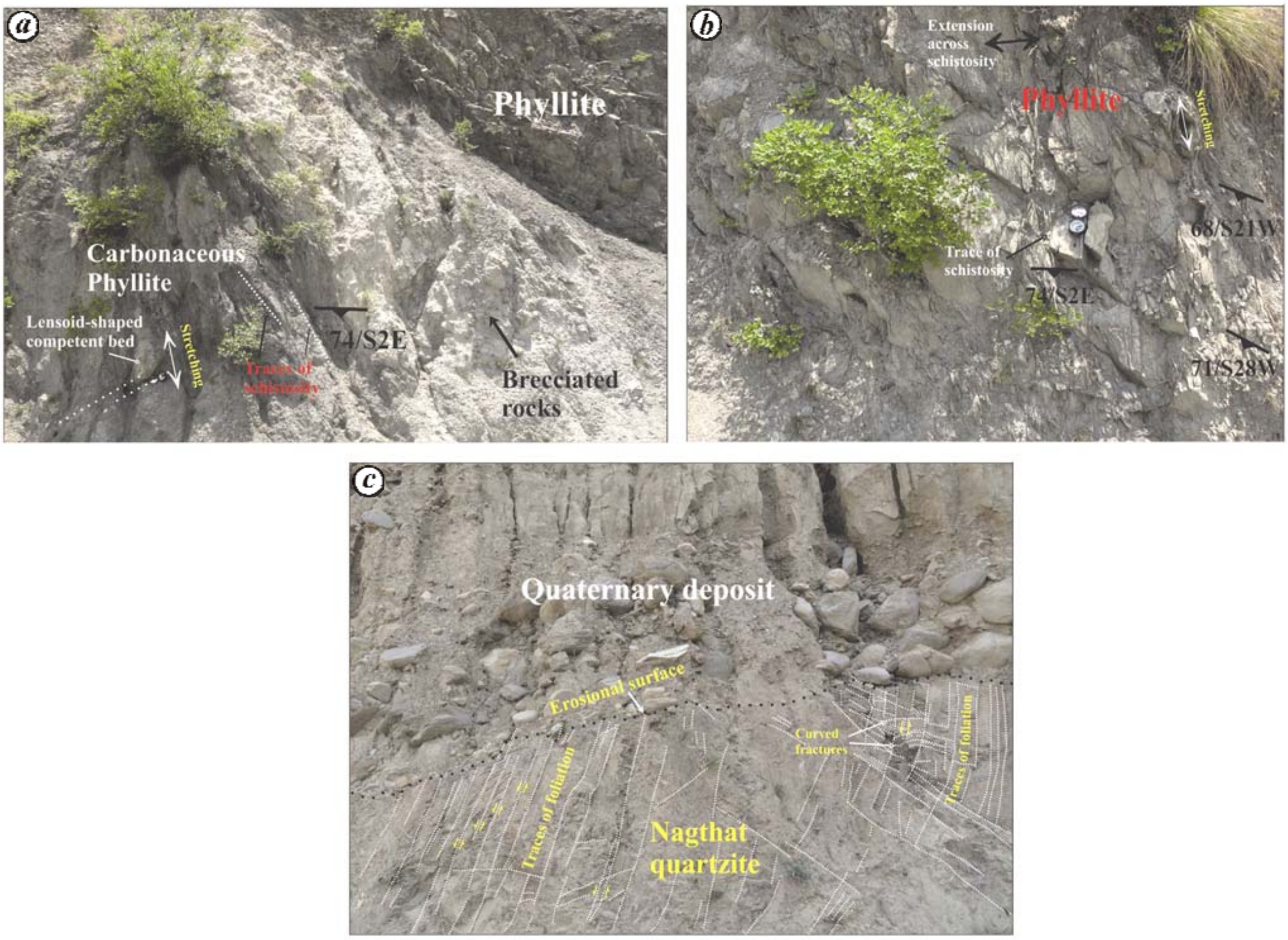

Figure 4. ***a***, Brecciated rocks showing schistosity-parallel stretching. ***b***, Extension across schistosity planes. ***c***, Steeply-dipping schistosity-parallel normal sense of shearing in the underlying Nagthat quartzite adjacent to the overlying fan deposit.

faulting, the hanging wall shows less dip amount than its footwall. The mean dip of normal fault surface is 61° towards S21W direction. Brecciated and crushed material has been formed within the fault zone. Offset of marker bed or fault slip is 110 cm. A 93–120 cm wide normal fault zone has developed as a result of fault bifurcation. One branch of fault dips 60° towards S20W direction, and the other branch dips 75° towards south. Locally, the rotation of hanging wall beds is noticed due to listric nature of fault plane. Some small, closely spaced faults have developed within the fault zone. Normal drag folds have developed in the vicinity of fault. This kink fold is formed by a sandy layer (Figure 3 *d*), indicating normal sense of movement. Extensional fractures (up to 7 cm wide) with small relative displacement have developed parallel to the normal fault. This is an extensional conjugate fault of the main normal fault. The other conjugate fault dips 78° towards N29E direction and has formed imbricated pebbles (Figure 3 *b*). Along this fault boulders of quartzite have been rotated and are truncated by the fault. Offset of marker beds of mud is 18 cm.

Analysis of faults in underlying rocks

About 40 m away from the main normal fault, underlying outcrops of rocks are exposed, with development of brecciated olive green and carbonaceous phyllites (Figure 4 *a*). The predominantly developed schistosity of carbonaceous phyllite dips 68–74° towards south to SSW direction. Presence of boudins and lensoid bodies of competent layers lying between incompetent layers suggests schistosity-parallel stretching (Figure 4 *a*). This resulted in the formation of lenticular schistosity due to simple shearing parallel to schistosity planes. The extensional fractures recognized in phyllite are parallel to those developed in the overlying fan deposit (Figure 4 *b*). This implies that there is an intimate relationship between faults formed in underlying country rocks and fan deposit. Parallelism of attitudes of underlying phyllites and the normal faults formed within the overlying fan deposit, and associated extensional fractures (within underlying country rocks) suggest the schistosity-parallel normal faulting-related shearing developed due to layer-parallel

Figure 5. ***a***, Extension of Betalghat–Rataura ridge fault. The *en echelon* ridge fault segment and narrow-gorged Kosi River are also shown. ***b***, ***c***, Gentle and vertical-dipping beds across Betalghat Fault. ***d***, Extension of ridge fault towards west across Kaluwa Gad.

simple shearing. Thus, we were unable to show displacement of marker beds. Analysis of structures along the left and right banks of Kosi River indicates a large anticlinal structure around Betalghat region. Southern limb dips 74° towards S39W direction, whereas northern limb dips 36° towards NNE direction, implying that the fold plunges gently towards NW direction, which is the general strike of the country rocks.

Betalghat–Rataura ridge fault

A distinct and slightly curved E–W trending elongated topographic ridge running from Betalghat to Rataura along the hillslopes of the left bank of the Kosi River is delineated from satellite imagery (Figures 1 *b* and 5 *a*). This ridge is interpreted as the Betalghat–Rataura ridge fault that is concave towards the Kosi River course and is sub-parallel to its wide course, which has deeply incised top of the footwall rocks of the Ramgarh Thrust. From satellite imagery it is clear that the Betalghat–Rataura lineament has developed a linear sharp topography forming a ridge across which a relief of 225–300 m from Kosi River bed has developed. Western extremity of fault ridge is truncated by a local fault named Betaghat Fault along the Kosi River at Betalghat (Figure 1). Across the Betalghat Fault, towards south, the beds of slaty limestone are vertical, whereas towards north the beds are gentle-dipping 27–45° towards N and NE directions with development of down-dip striations (Figure 5 *a* and *c*); this suggests simple bedding-parallel shearing. The ridge fault is bounded by lineaments on its both flanks near Betalghat. At the tip of the fault at Betalghat, the thickness of the Quaternary deposit is less. Along the fault length, attitude of beds is variable. Extensional fractures associated with normal faults have formed along diverging axial planar cleavages of kink folds developed in the fault ridge. West of Betalghat, the general attitude of schistosity planes of phyllitic rocks is 36° towards NNW direction, where Valdiya[2] has mapped a WNW–ESE trending Amel Fault.

Optically stimulated luminescence dating

The optically stimulated luminescence (OSL) samples were collected from the fan deposit. In the TL/OSL lab, Wadia Institute of Himalayan Geology, Dehradun, under subdued red light conditions, the sample processing includes treating with 1 N HCl and 30% H_2O_2, sieving (to obtain 90–125 μm size fraction) and separation of heavy minerals, quartz and feldspar grains (using sodium polytungstate solution). The extracted quartz grains were etched for 80 min in HF and subsequently treated with HCl and washed in distilled water and re-sieved. The HF treatment also removes any feldspar contamination and the purity of the etched quartz was tested using infra-red stimulated luminescence (IRSL) technique. The etched quartz grains were then fixed into the centre of stainless steel discs (i.e. about 3 mm diameter mono layer of samples in 10 mm diameter steel discs) using silicon oil (adhesive agent) to determine the radiation energy received by the sample after its burial (i.e. palaeo dose or equivalent dose). About 30–35 aliquots were prepared per sample and the single aliquot regeneration (SAR) protocol[26] was used for equivalent dose (De) determination. The OSL measurements (pre-heat = 240°C for 10 sec, cut heat = 160°C; test dose = ~15% of expected De; blue light stimulation = 40 sec at 125°C) were carried out in an automated Riso TL/DA 20 reader equipped with blue LED. The equivalent dose values were calculated using

Table 1. Quartz optically stimulated luminescence ages of sediment samples collected as shown in Figure 6 *a* and *b*. Elemental concentration (XRF) and moisture content used for dose rate calculation and equivalent dose are also given

Lab no.	Sample no.	Sample depth from surface (m)	U (ppm)	Th (ppm)	Potassium (%)	Moisture content (%)	Equivalent dose (De) Gy	Dose rate (Gy/ka)	Age (ka)
LD1458	KLA-8	~20	0.8	15.9	2.89	1.3	148.2 ± 15.82	4.0 ± 0.30	36.6 ± 4.7
LD1459	KLA-9	~20	0.8	13.8	2.9	1.2	153 ± 14.3	3.9 ± 0.30	39 ± 4.6
LD1460	KLA-10	~10	2.14	10.9	2.61	2.1	126.06 ± 11.2	3.7 ± 0.27	33.9 ± 3.9

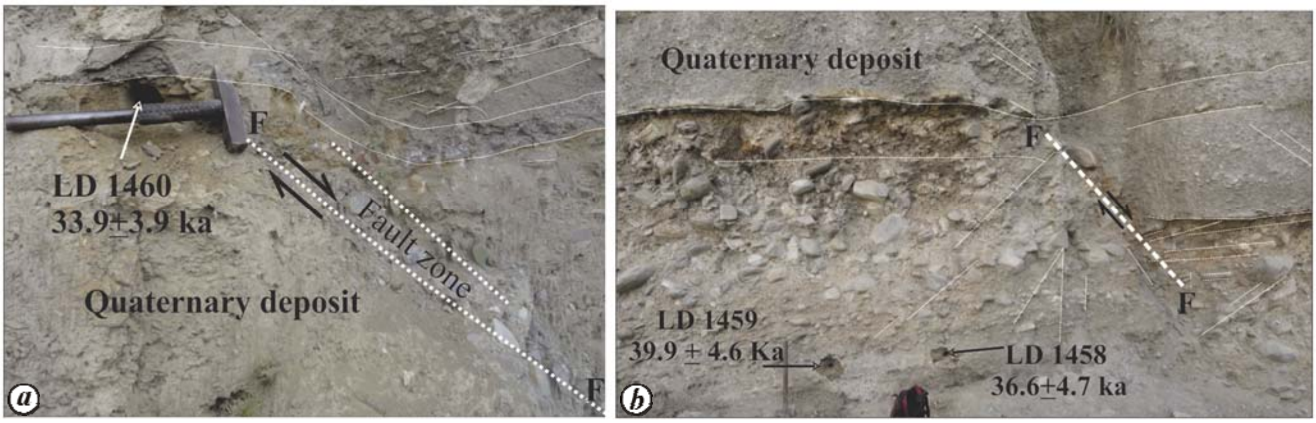

Figure 6. ***a***, Location of one optically stimulated luminescence (OSL) sample taken from adjacent kink fold as shown in Figure 3 *d*. ***b***, Locations of two OSL samples taken from footwall of normal fault as shown in Figure 3 *c*.

the initial integral (0.8 sec) of the OSL using Duller's Analyse software. For annual dose rate estimation, concentrations of uranium, thorium and potassium in the sediments were measured by XRF. Table 1 provides the ages thus obtained.

Three samples were collected from two sandy layers of the fan deposits in opaque pipes (Figure 6). Two samples were collected from the same layer (2 ft apart), while the third sample was taken from the sandy layer some distance apart where the vertical distance between the two layers measures about 5 m. The lower layer samples, LD 1458 and LD 1459, taken about 20 m from the surface give OSL age of 36.6 ± 4.7 and 39.9 ± 4.6 ka respectively; while the sample from the upper sandy layer that is about 10 m from the surface gives OSL age of 33.9 ± 3.9 ka. The contact between the fan deposits and the underlying country rocks is not seen at the location of field observation of normal faults. Similarly, it is practically not possible to collect dateable sediments from the uppermost horizon of fan deposits because of the presence of cliff. Therefore, only three samples were dated from two layers. Their OSL dates indicate that the normal faulting activity was at least post-34 ka.

Geomorphology

It is noticed that the spurs generally develop across the river course. However, in the present case an elongated uplifted ridge is developed almost parallel to the Kosi River course (Figure 1 *b*). This we interpret to be a fault ridge, which has been dissected by transverse tributaries joining the Kosi River. Towards its western extremity at Betalghat, the ridge is 262 m wide but becomes narrow towards its eastern extremity near east of Rataura village, where earlier E–W running Kosi River course becomes NW–SE-oriented. It runs from Betalghat to Kaluwa Gad, where it is terminated by a transverse N–S trending Kaluwa Gad. Fault mapped by Valdiya[2]. Continued deformation-related rock uplift has increased the gradient of Kaluwa Gad (Figure 5 *d*). Reworked fan materials by N–S tributaries joining the Kosi River have shifted its course further towards north. In a 70 m wide fault zone that imbricated the Quaternary deposit, the hillslope topography has become zigzag due to deep incision along closely spaced gullies (Figure 7 *a*).

Between Khairna and Basgaon, the Kosi River valley is NW–SE trending, whereas between Basgaon and Betalghat the river suddenly becomes E–W trending and its course is very wide (250–440 m); it becomes very narrow (30 m) and gorged at Betalghat. The sudden anomaly of trend of Kosi course is interpreted to be controlled by the presence of the Betalghat Fault along which the block is rotated resulting in vertical beds (Figure 5 *c*). Genetically associated parallel *en echelon* pressure ridge is interpreted to be oblique to Kosi River course near south of Betalghat (Figure 5 *a*). This implies that the fault moves

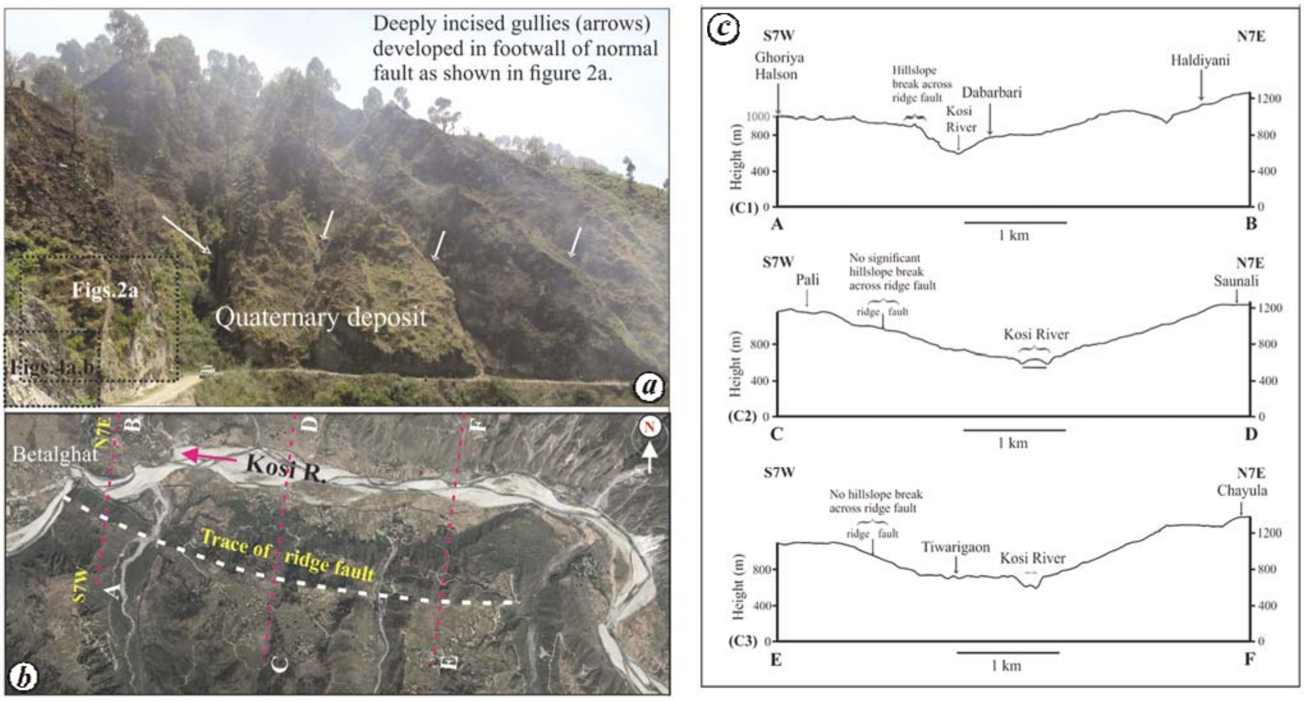

Figure 7. ***a***, Closely spaced, deeply incised gullies developed in normal fault zone as shown in Figures 2 *a* and 3 *c*. ***b***, Locations of three transverse profiles across Kosi River valley. C1–C3, Transverse river profiles drawn across Kosi River valley and across ridge fault showing knick points.

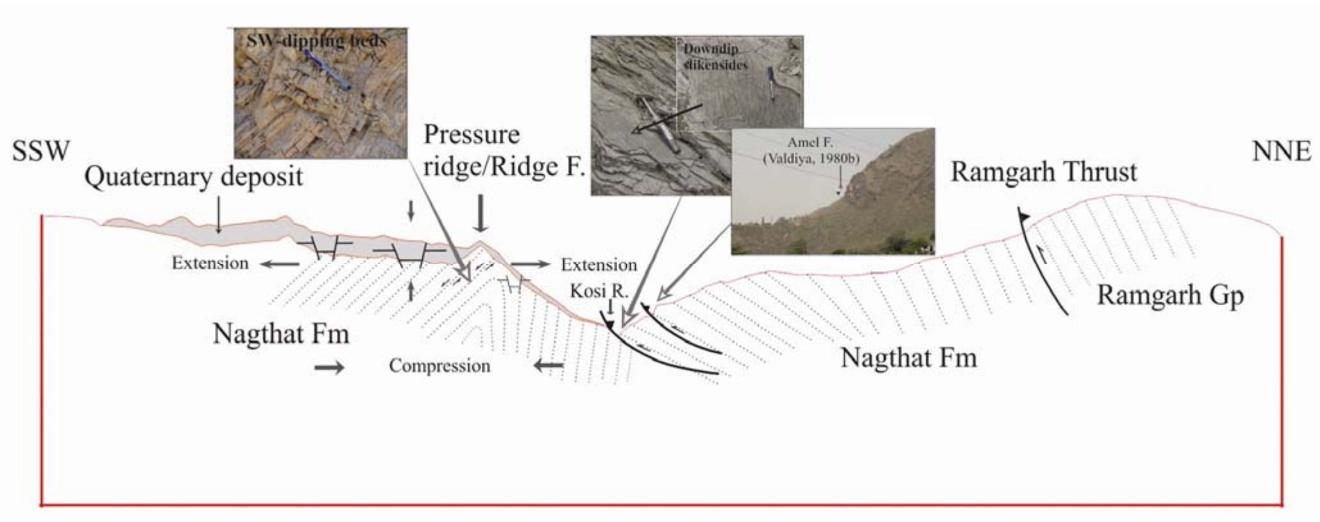

Figure 8. Schematic diagram depicting the formation of normal faults near the top of footwall of the Ramgarh Thrust.

laterally across the trend of Kosi River course. The Ridge shows surface topographic expression that indicates the presence of an active fault. From the Survey of India toposheet of 1 : 50,000 scale, three profiles were prepared across Kosi River (Figure 7 C1–C3). A linear sharp knick has developed (Figure 7 C1) across the present geographic surface of hillslope across fault ridge, particularly towards east of Betalghat region. Top of ridge is at 998 m and river bed is located at 740 m amsl. Thus a relief of 258 m is across the ridge fault. Ridge line plunges towards NW direction and less amount of throw is interpreted towards eastern part of the fault (see cross-sections). River Kosi flows through the hinge zone of the anticline (Figure 7 C1). It is inferred that the ridge fault described above may be a pressure ridge because it is compressed from both sides (Figure 8).

Discussion

Thrust tectonics is a predominant mechanism for initiating thrust faulting in the subsurface region. In the present study the normal faults are parallel to the orogeny. This formation of faulting is interpreted to be as a result of southward propagation of active mountain front along with widening of the Himalayan arc[27,28]. Valdiya[2] has mapped three closely spaced faults towards south of the Ramgarh Thrust. The present study clearly delineates one (Betalghat–Rataura fault ridge) of these faults between Betalghat and Rataura. In hanging wall, the transverse extensional faults[29] have been developed due to inhomogeneous strain during late stages of deformation in the Tethys Himalaya of NW Himalaya[30]. In the present case normal faults are observed near the top of footwall of the Ramgarh Thrust. Agarwal and Sharma[31] have described the reverse fault-related Quaternary tilt–block tectonics in the eastern Kumaun Himalaya, but normal fault-related Quaternary tectonics has not been observed by these workers. Researchers have also reported normal faults at the top of footwall of the MBT or along the trace of the MBT[6,8,10,12]. But the present authors are of the opinion that these are faults are merely bedding-parallel shears. Kothyari *et al.*[10,11] interpreted active normal faults within the Quaternary fan as a result of subsurface active tectonics. The present authors do not agree with this interpretation, as a matter of fact, in the subsurface region of the MBT zone there must be compressional tectonics that formed the thrust faults.

Hillslope break is noticed across Betalghat (Figures 1 *b*, 5 *a* and 7 C1) at the western tip of the Betalghat–Rautaura ridge fault. It seems that the N–S compression imposed on the underthrust LHS beneath the Ramgarh Thrust is compensated by N–S extension near the top of the footwall of the Ramgarh Thrust. This mechanism has developed E–W trending ridge at the uppermost crustal level of the footwall. Thus in the Himalayan region the active thrusting and normal faulting might be broadly synchronous. Valdiya[2] has shown two subsidiary thrust faults north of Khairna within the quartzite and metabasic sequence of the Nagthat Formation. So recent uplift and subsidence seems to be contemporaneous near the top of footwall of the Ramgarh Thrust. As a matter of fact the Ramgarh Thrust is an out-of-sequence thrust postdating the main Himalayan deformation event in its footwall[23]. The E–W trending course of the Kosi River (flowing near the top of the footwall of the Ramgarh Thrust) is parallel to the trace of the Ramgarh Thrust in this particular part of the Kumaun Himalaya. Therefore, it is interpreted that this trend of river is affected by the footwall deformation. Faults observed in fan deposit are parallel to the Himalayan orographic trend (or Ramgarh Thrust), but dip in the opposite direction, i.e. towards SSW. Conjugate fault dips towards NE direction. Mehta and Sanwal[3] have also described the same normal fault. They have interpreted the active tectonics with the oblique transverse normal fault. But the analysis of structural data generated during field work by the present workers reveals that the normal fault trends E/ESE–W/WNW and not NNE–SSW as documented by Mehta and Sanwal[3]. Therefore, its tectonic activity cannot be associated with the oblique transverse normal fault as described by Mehta and Sanwal[3]. A schematic diagram has been shown to understand how normal faults have been developed near the top of the footwall of the Ramgarh Thrust (Figure 8). As a result of gravity, active pure shear formed the normal faults and associated extensional fractures. Details of this perception about normal faulting have been already described above.

Future scope of work

In the Lesser Himalaya region, the occurrence of recent normal faulting is observed within the Quaternary deposit resting on the eroded surface of inclined beds of uplifted rocks. As a matter of fact, the MHT or the detachment beneath the Lesser Himalaya is locked[32]. Therefore detailed analysis of structural aspect of these faults and associated surface deformation may give some clues to understand the deformation processes and for seismic hazard.

Conclusion

The Ramgarh Thrust represents the leading edge of the topographic front formed by the uplifted Lesser Himalayan Crystallines, which have been thrust over its footwall made of the Nagthat Formation of the LHS along the Ramgarh Thrust. The Quaternary fan sediment lying near and at the top of the footwall of the Ramgarh Thrust, is situated above the compressional stress regime that has been active in the subsurface region related to the Himalayan thrust tectonics. Because the normal faults are recognized within the Quaternary fan deposit and also within the country rocks just below and adjacent to the fan deposit located near the top of the footwall of the Ramgarh Thrust, therefore, it is revealed that this deformation related to N–S extensional tectonics has taken place at the uppermost crustal level due to gravity, where influence of the Himalayan subsurface compressional tectonics is no more significant.

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