Geomorphic indicators of neotectonic activity around Srinagar (Alaknanda basin), Uttarakhand

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Fluvial terraces, entrenched stream courses, landslide-induced ponding, and active and stabilized landslide deposits are some of the morphological evidence of late Quaternary seismicity in the Alaknanda Valley around Srinagar, Uttarakhand. We attribute their development to the activity along the North Almora Thrust (NAT) that marks the northern boundary of the study area and its sympathetic E–W and NW–SE trending lineaments. The existing chronological data on the terrace sequence when viewed in conjunction with field data suggest that the NAT and the associated lineaments were active during the late Quaternary period.

Keywords: Fluvial terraces, late Quaternary period, neotectonic activity, North Almora Thrust.

The topography, geologic structures and recurrent seismicity of the Himalaya are a consequence of the continued northward progression and collision of the Indian plate with Eurasia. The convergence is accommodated by the active thrusts and faults and is expressed in associated geomorphic features. The rolled topography and less rugged mountains in the lesser Himalaya bounded by the Main Central Thrust (MCT) in the north and Main Boundary Thrust (MBT) in the south, suggest relatively mature topography. However, the recent tectonic activity within the Lesser Himalaya is common and is evident in the form of changing river courses (fossil valleys), entrenched meanders, river gorges, raised aggradational and degradational terraces. Valdiya envisaged reactivation along WNW–ESE trending faults (dip-slip to oblique-slip displacement) in the recent and sub-recent time to explain the formation of these young morphological features. Besides this, presence of deep gorges, debris avalanches and uplifted terraces (active and stabilized) are attributed to the recent movement along the North Almora Thrust (NAT). The southern segment of NAT which is endowed with young morphological features is supposed to have emerged in recent times. Though terrain instability in the vicinity of NAT has demonstrated a comprehensive record of late Quaternary tectonics, it is still illusive. Here an attempt has therefore been made to document various tectonically formed morphological features in the Alaknanda valley around Srinagar, Uttarakhand and to ascertain their relationship with the major and minor structural elements of the area.

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The Alaknanda river, after originating from the Bhagirath Kharak and Satopant glaciers, is joined by many tributary streams before meeting the Bhabrithu river at Devprayag to form the Ganga river. Along its course, the river traverses through the Tethyan sedimentary, higher Himalayan crystallines and the lesser Himalayan meta-sedimentary rocks (Figure 1a)

The present study, the area investigated lies in the Lesser Himalaya segment of the Alaknanda basin around Srinagar (30°12′–30°15′N and 78°45′–78°50′E). After emerging from a narrow valley in the upstream of Srinagar, the Alaknanda river becomes a wide, highly sinuous meandering river which flows through a wide valley of ~8 km (Figure 1b).

The climate of the area is sub-tropical (mean annual rainfall 100–150 cm) with 80% of the rainfall occurring between mid-June and mid-September. This is also the period during which the Alaknanda carries maximum suspended load contributed both by the glacier melt and south-west monsoon precipitation.

Lithologically, the area is dominated by low-grade upper Proterozoic phyllites which merge with the flaggy quartzites towards north (Figure 2). The phyllites, which are tightly folded and fractured, are intercalated with sills and dykes of metabasites. Contact between the phyllites and flaggy quartzites is marked by southerly dipping NAT, which is characterized by a wide shear zone around Srinagar. NAT becomes vertical or even north-dipping at places.

Gentle undulating slopes that are covered with ancient and recent landslide debris dominate the valley around Srinagar. The Alaknanda river enters into the basin through a gorge near Koteshwar and then takes a NE–SW straight course for about 500 m, followed by a southward swing into a wide-open valley between the Swit and Kirtinagar (Figure 3). Near Koteshwar, NAT has been laterally displaced by the NNE–SSW trending lineament (Figures 2 and 3). The Alaknanda river becomes sinuous with the development of scroll and point bars between the confluences of Swit Nala and Kirtinagar (Figures 1b and 3). The fast cascading and deeply incised seasonal streams are concentrated towards the northern flank (proximal to NAT) in the basin (Figure 1b). The major lineament trends (E–W and NW–SE) not only govern the course of the Alaknanda river, but also facilitate development of fluvial landscape around Srinagar (Figures 2 and 3).

Six generations of aggradational fluvial terraces on either side of the Alaknanda river could be seen resting on plant surfaces carved on phyllites. These terraces are developed on either flank of the Alaknanda river (Figure 4). Fluvial terraces represent former valley floors and flood plains that were abandoned with time. Terrace sequence between Koteshwar and Kirtinagar shows convergent relationship, indicating deposition along the meander loop (scroll bar). The terrace sediments are poorly sorted and dominated by boulders and pebbles with subordinate sand (Figure 5). Each terrace is separated by a scarp that varies between 5 m for the youngest (T_1) to 45 m for the oldest
Figure 1.  

(a) Generalized lithology and structure of the Alaknanda basin (modified after Ahmad et al.).  
(b) Morphology of Alaknanda basin around Srinagar. Note the gently sloping northern flank with high concentration of young streams.

Figure 2. Lithology and structures around the study area. Two sets of lineaments follow the trend of the North Almora Thrust (NAT), except near Koteswar where the NE-SW trending lineament has displaced the NAT.

(T_e) terrace and width varies from a few metres to hundreds of metres (Figures 4, 6a and b). The terraces are best developed in areas which are proximal to the E-W trending lineaments (between Swit and Chorhas, and Srinagar and Uphalda; Figure 4). Further, development of terraces was observed around the concave meandering loop on the northern and southern flanks and mimic scroll-bar morphology (Figure 3).

Scroll bars are usually formed in a laterally migrating river forming entrenched meanders. The valley morphology and confinement of the terraces along the meanders suggest their formation during phases of landscape stability. Consistent growth with distinct vertical offsets in terraces suggest ingrown meander morphology, which develops with...
increasing sinuosity due to pulsating tectonic activity. Vertical offset in the terraces is attributed to change in river gradient caused due to differential movement along the E–W lineaments.

Fossil valleys are well developed both at the entry and exit points of the Alaknanda river in the Srinagar valley (Figure 4). At these places the valley is invariably associated with raised rocky surfaces (strath) which are unpaired, for example, downstream of Supana and near Uphalda village, where these rocky planar surfaces rest 10 and 15 m above the river level respectively. Formation of fossil valley and strath surfaces is attributed to damming of the
river course either by moraines or landslide debris. The present-day features are epigenetic gorges that are formed due to topographic and structural control. In view of the fact that no appreciable fluvial sediment thickness is found plugging these valleys, it can be suggested that shift in the river course was caused by the sudden upliftment of the river bed. Considering their proximity to the NE–SW and WNW–ESE lineaments, we attribute their formation to the activity along these lineaments (Figure 4).

Distribution of seasonal stream pattern in the study area shows high concentration of first- and second-order streams on the right bank, incising deep gorges on quartzites and phyllites during their short traverse (2–5 km). Unlike the graded river where stream power remains fairly constant along its course, the lower-order streams usually show steeper gradients (due to their youthful stage) and are sensitive to minor changes in the terrain. In the study area, these streams are fed by seasonal precipitation and meet the Alaknanda river at right angles (Figure 1). However, between 600 and 700 m amsl (contours between which NAT passes), minor eastward displacement of streams (Figure 1) and deep entrenchment can be seen in the field. Pile of sediments thus eroded by the first- and second-order streams emanating from the right flank is seen on the otherwise fast-eroding convex meander of the Alaknanda river (Figure 3).

In addition, distinct knick points were observed on the stream courses draining through the right bank (Figure 7).

![Figure 5](image1.png)  
**Figure 5.** Stratigraphy of T₃ terrace at Choras. Note dominance of clast-supported fabric. Similar sedimentary succession with thickness variability can be found in other terraces as well.

![Figure 6](image2.png)  
**Figure 6.** *a.* Field photograph of Choras area showing six levels of terraces (marked T₁ to T₆). *b.* Terrace sequence showing vertical offsets drawn along the A and A' transect.

![Figure 7](image3.png)  
**Figure 7.** Two major streams emanating from the northern flank show marked deflections in the course near NAT.
Knick points transmit the fall of base level to all points along the stream network and are generated by sudden change in base level. And with time they migrate upstream depending upon the material property, efficiency of sediment transport, erosional process and competition between erosional intensity above and below the knick point\(^1\). Terraces on the right flank are dissected by first- and second-order streams, compared to this the left flank terraces are less degraded (Figure 4). This suggests that episodic uplift rejuvenated the lower-order terraces of the area that are manifested in knick-point development, channel incision, preferential deflection in streams and steepening of stream gradient\(^1\).

In the study area signatures of temporary ponding of lower-order streams are common. These streams appear to have been blocked before meeting the Alakananda river. Field relationship with the terrace sequence indicates that ponding occurred after the deposition of T\(_4\) and T\(_5\) terraces. Sedimentological evidence suggests that narrow courses of streams were clogged by landslide debris mixed with fluvial gravels. One such lake at Swit was investigated for sedimentological and geomorphological study (Figure 8\(a\)).

Near Swit, a 250 cm thick lake succession punctuated by landslides was observed that overlies the T\(_4\) terrace sequence. In the field three events of ponding separated by four events of landslide debris could be seen (Figure 8\(b\)). Ponding events are marked as II, IV and VI, whereas landslide events are marked as I, III, V and VII (Figure 8\(b\)). In addition, a weakly developed flame structure (seismite)\(^1\) was observed in ponding event II (Figures 8\(c\)), pointing to a palaeoseismic event in the region\(^1\). The E–W trending lineament in the basin seems to be active and thus caused sudden westward swing in the Swit Nala (Figures 2 and 4), and incised a 50 m deep gorge on phyllites just before meeting the Alakananda river. As NAT is also nearby, we attribute development of ponding conditions to movements along the E–W trending lineament and NAT. Physical stratigraphy of the lake succession suggests that there could be four events of seismically induced landslides during the existence of the lake (Figure 8\(b\)).

The structural set-up of the area around Srinagar suggests that the valley was carved on the over-riding hanging wall of NAT. In case of a nappe, traces of thrusts are often affected by topography and high sinuosity, rendering it more difficult to measure offsets if the direction of fault motion is not well defined\(^1\). In the study area upstream of Koteshwar, the trend of NAT is roughly NW–SE, which becomes wavy but broadly E–W after crossing the Alakananda river (Figures 2 and 3). The dip angle varies from 40° to nearly vertical at places. It has been observed that upstream of the axis of the uplift, the channel gradient and valley-floor slope steepness are reduced, whereas below the axis slope, steepness increases. If the river gradient changes slowly, rivers tend to dissipate their energy through increasing sinuosity; but in case of drastic change braiding accompanied by incision takes place\(^1\). The morphology of the Alakananda river upstream of Kirtinagar and differential movement along a well-defined NW–SE lineament near Uphalda led to increasing sinuosity and deposition upstream.

Neotectonic activity along this NW–SE lineament is further indicated by the presence of strath terraces and fossil valleys. However, development of flight of fluvial terraces is attributed to neotectonic activity along the E–W trending lineaments.

Considering that the master structure is a thrust fault (NAT) in which maximum compressive stress is horizontal, the amount of displacement dies out towards the thrust tip. As a consequence, the hanging wall is typically folded adjacent to the thrust tip and with continued seismic activity a hanging-wall anticline is generated\(^1\). The Alakananda river flows through the rocks of Dudatoli syncline\(^7\) and the river channel is largely controlled by the E–W trending splay of NAT (Figure 2). However, in the anticlinal part (present-day valley slopes), bending moment stresses can generate out-of-syncline thrust due to compression (phylite). The NAT plane ramped on steeply tilted and more competent quartzite, which led to the diversion of stress along the weak bedding planes of phyllite rocks. With progressive compression, closely spaced lineaments were created.

![Figure 8](image-url)

**Figure 8.** a. Schematic representation of landslide-induced lake formation. b. Lithostratigraphy of the lake succession at Swit. Phases of landslide events are marked by open bars and odd Roman numbers. Lacustrine phases are marked by filled bars and even Roman numbers. c. Field photograph of flame structure.
by way of flexure slip faults, which develop due to weak inter-beds that act as slip surfaces\textsuperscript{19}.

In Figures 2–4, only master E–W and NW–SE lineaments are shown, however, a series of parallel lineaments may have developed due to flexure slip south of NAT. Six levels of fluvial terraces differentiated by vertical scarp of varying magnitude (Figure 6) indicate progressive compression along NAT during the late Quaternary that was released by flexure slip faulting. Geotectonic sympathetic to the trend of NAT. Development of a knick points on the streams emanating from the right flank, incision of gorges and landslide-dammed fluvio-lacustrine deposits together suggest that the Srinagar valley has been seismically active since the late Quaternary.

There is a complete paucity of chronometric data on river terraces from the study area. An indirect age estimate\textsuperscript{21} based on erosion rate suggests that the oldest terrace $T_6$ was deposited $< 20$ ka, whereas the younger terrace $T_1$ was deposited around 10 ka. This would imply that NAT and its sympathetic splays have been active prior to 20 ka and $< 10$ ka. This is important considering that the area has experienced massive earthquake during 1803. This earthquake is considered as the largest one reported so far from the Central Himalaya, whose epicentre was close to Srinagar\textsuperscript{22}. The study is preliminary in nature; nevertheless, it demonstrated the relationship between the major and minor structural elements and late Quaternary landscape development around Srinagar. However, a more quantified picture awaits chronometric studies that are in progress.

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