



ISSN 2345 - 4997

Available online at: [www.geo-dynamica.com](http://www.geo-dynamica.com)

Vol. (1) - No. 03- Winter 2014  
3<sup>rd</sup> Article- P. XXVI to XXXIII

**GRIB**

*Geodynamics Research  
International Bulletin*

# Drainage Anomalies and Absence of Intermontane Valleys Characterize the Outermost Structural Discontinuity and Tectonic Boundary in the Nahan Salient of Western Indian Sub-Himalayas

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**Article History:**  
Revised: Mar. 08, 2014

Received: Feb. 18, 2014  
Accepted: Mar. 13, 2014

Reviewed: Feb. 25, 2014  
Published: Mar. 16, 2014

## ABSTRACT

Direct evidences of faulting along the Himalayan mountain front are very rare. The most conspicuous indicators of the presence of a structural discontinuity and an active tectonic boundary are manifested in the geomorphology. In most cases, a topographic break defines the outermost Himalayan thrust fault i.e. Himalayan Frontal Thrust (HFT). However, the nature of this tectono-geomorphic boundary tends to vary significantly along the strike of the mountain belt. In some sectors, it is marked by the presence of elongated intermontane valleys popularly known as 'duns', whereas other sectors are conspicuous by their absence. The Nahan sector of the Western Indian Himalaya is one such area that is characterized by the absence of intermontane valley. Here, in this article we emphasize that the absence of intermontane valleys in the Nahan sector gives rise to a distinctive geomorphic expression of the active tectonic boundary. In the Nahan sector, active slip along the underlying thrust faults and splays has resulted in the accumulation of high relief spread over a relatively smaller area. This led to the absence of the duns in this area. Also, the topographic boundary closely corresponds to a number of drainage anomalies establishing the active tectonic nature of the HFT. The drainage anomalies mainly include the deflection of streams, widening of channels and increase in their sinuosity as they approach the mountain front. The increase in the sinuosity of the channels is also marked by degradation activity and presence of broad flat terrace surface that confirm to the tectonic uplift in this area.

**Keywords:** DEM; Drainage; Closed Depressions; Hydrology; Watershed.

## 1. INTRODUCTION

Almost ubiquitous absence of any direct evidences of faulting along the Himalayan Frontal Thrust (HFT) do not undermine the presence of a structural discontinuity and an active tectonic nature of the postulated outermost Himalayan thrust fault (Nakata, 1972; Yeats et al., 1992). Geomorphology is the most important and convincing expression. However, nature of this tectono-geomorphic boundary tends to vary significantly along the strike of the mountain belt at all scales (Andronicos et al., 2007; Singh et al., 2012). In some sectors, the HFT zone and adjoining mountain belt is marked by the presence of elongated intermontane valleys popularly known as 'duns', whereas other sectors are conspicuous by their absence eg. Nahan sector. In this article, we investigate the geomorphic expression of HFT,

manifestations of active tectonics and absence of the 'dun' in the Nahan sector.

It is now well established that relief distribution and drainage patterns are indispensable to active tectonic investigations (Keller and Pinter, 2000; Burbank and Anderson, 2001). In the present study, the relief distribution basically refers to abrupt break in slope whereas drainage patterns refer to the geometry of the stream network.

## 2. THE STUDY AREA

### 2. 1. GEOLOGY, TECTONICS, SEISMICITY AND CLIMATE

The Sub-Himalaya is the southern outermost belt of the Himalayan orogen, limited by tectonic boundaries (thrusts) towards north and south (Fig 1). The northern boundary, known as the Main Boundary

Thrust (MBT), brings the Lesser Himalayan rocks over the Sub-Himalayan rocks. The Western Sub-Himalaya in India is marked by the sinuous trace of

the Main Boundary Thrust (MBT) clearly demarcating two reentrants interposed by a salient (Fig. 1).

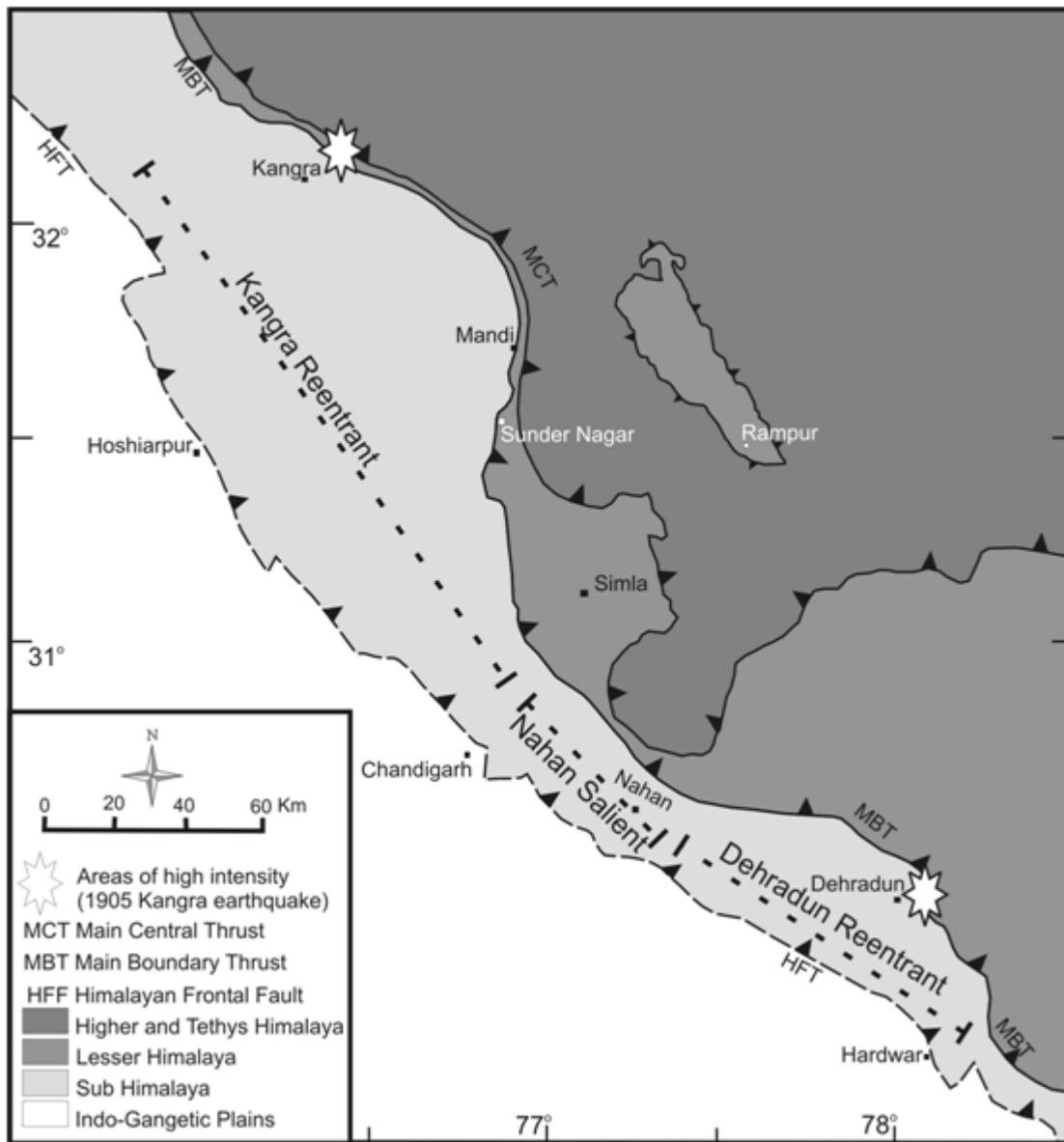


Fig 1. Geological map of the NW Himalaya showing the major lithological units and structural features. The sinuous trace of the MBT gives rise to the variable thickness of the Sub-Himalayan that defines the salients and reentrants. The salients and reentrants are a distinctive feature of the Sub-Himalayan belt. The map also shows the areas of maximum intensity during the 1905 Kangra earthquake (modified after Seeber and Armbruster, 1981).

The reentrants and salients are limited towards the south by the Himalayan Frontal Thrust (HFT) that brings the Sub-Himalayan rocks over the Indo-Gangetic alluvium (Nakata, 1972; Yeats et al., 1992). Geologically, the Himalayan Frontal Thrust (HFT) zone comprises of the Siwalik Group of rocks that have been thrust over the Indo-Gangetic alluvial plains. The Siwalik Group has been classified into three subgroups based on lithology and magnetostratigraphic ages (Table 1).

Although the HFT rarely shows any direct evidence of thrusting all along its strike, it has been referred as one of the most active thrust fault all along the strike of the Himalayan orogen (Lave and Avouac, 2000). Its active nature has been demonstrated by the significant rates of slip/uplift in different sectors of the Himalaya (Wesnousky et al., 1999; Lave and Avouac, 2000). GPS measurements (Banerjee and Burgmann, 2002) also indicate to the continuous slip along the HFT that accounts for a total shortening of about 4 km observed in different areas of the Sub-Himalayan belt in India (Powers et al., 1998).

Table 1: Stratigraphy of the Sub-Himalaya of the Nahana Salient.

Main Units	Formation	Lithology	Geological age (approx.)	Magneto. ages
Post-Siwalik Deposits	Alluvium/Piedmont	Fluvial unconsolidated sands, silts and clays of floodplain deposits. -----Unconformity-----	Recent	
	Terraces	Fluvial deposits poorly sorted and unconsolidated, consists of silts, sands, gravels, clays with variable proportion of gravels. -----Unconformity-----	U. Pleistocene	<0.7 Ma.
	U. Siwalik	Coarse boulder conglomerate comprised of cobbles, pebbles, clasts which are either clast or mud supported with inclusions of sand, grit or clay nodules.	L. Pleistocene	0.7-5.77 Ma.
	M. Siwalik	Sandstones, siltstones and clays comprise bulk of the lithology. Well bedded bright buff coloured clays towards top and gray clays towards bottom. -----Unconformity-----	Upper to Mid. Pliocene	5.77-7.88 Ma.
Siwalik Group	Lower Siwalik	Sandstones comprise bulk of the lithology, with minor shales, clays and few pseudoconglomerates. Siltstones grayish-green to yellow-brown. Well bedded thick sandstone units. -----Unconformity-----	Mid. Miocene to L. Pliocene	<10 Ma.
Lower Tertiaries	Subathu	Earthy yellow to red shales, olive green splintery shales and greenish-gray sandstone.	Eocene	

Continuous tectonic activity along the HFT also contributes to seismicity of the entire Himalayan belt (Khattari, 1987; Bilham et al., 2001). Some significant earthquakes ( $M > 7$ ) in the past century have affected this mountain belt (Seeber and Armbruster, 1981; Ambraseys and Bilham, 2000). The Western Himalaya was a site of at least one of the great earthquakes in the past century, the 1905 Kangra earthquake. On the basis of instrumental data this earthquake was assigned a magnitude of  $M = 8.4$  by Richter (1958). The most interesting observation about this earthquake was that it was characterized by two distinct areas of high intensity separated by a gap of around 100 km (Fig. 1). This gap spatially corresponds with the area of present investigation in the Nahana Salient. Therefore, present study becomes even more significant. It appears that most of the slip along the HFT in this area contributes to the process

of continuous landscape evolution rather than abrupt and episodic seismic activity.

Climatically, the Western Indian Sub-Himalaya lies in the monsoonal climatic regime and therefore can be considered uniform at the scale of investigation. It receives about 1600 mm/yr of rainfall, most of which (75-85%) falls in the months of July through September (Mohindra et al., 1992).

**3. MATERIALS AND METHODS**

The topography of the Nahana Salient has been investigated using the Survey of India (SOI) topographic maps, published geological maps, Landsat TM images and digital elevation models (DEM). The details of dataset used are provided in Table 2. All the dataset have been integrated into a GIS environment and used in the present investigation.

Table 2: Details of dataset used in the present study.

S. no.	Data type	Source	Details	Specifications
1	Topographic maps	Survey of India (SOI)	53B/14, 53F/2, 53F/6 and 53F/7	1: 50,000
2	Geological maps	Published work	Raiverman et al. 1993	Lithological and structural features
3	Satellite imagery	USGS	Landsat TM	Path/Row – 147/039
4	DEM	Topographic map	Grid data	20 m * 20 m

**3. 1. TOPOGRAPHY OF THE NAHANA SALIENT**

The investigation of Sub-Himalaya in the Nahana Salient, via topographic maps, satellite images, DEM and geological maps was carried out as an initial step (Fig. 2 a, b, c, d). Topographically, it comprises a set of parallel to sub-parallel ranges with a prominent arcuate shape that bulges towards the south (Fig. 2a).

These ranges extend along the strike of the mountain belt and are variably dissected giving rise to different landforms and drainage patterns. Most conspicuous is the absence of any intermontane valleys popularly known as ‘duns’. These are common in most sectors of the Sub-Himalayan belt (Nakata, 1972; Powers et al., 1998).

The southern outermost boundary of the hills, adjacent to the alluvial plains, marks the boundary

between two basic geomorphic entities i.e. the hills and the plains. This boundary is referred to as the 'mountain front' of the Himalayan orogen (Fig. 2a). The low lying hills in the Nahan Salient attain summit elevations of about 1400 m that are approximately 1000 m in excess of the adjoining alluvial plains (Fig. 2b). The mountain front also shows a distinct change in the tone and texture across

the line that marks the mountain front, as seen on the Landsat image (Fig. 2c). Besides these, the line of the mountain front also marks an important boundary in terms of geological units as it separates the Siwalik Group from the Post Siwalik Quaternary sediments of the Indo-Gangetic alluvial plains (Fig. 2 d).

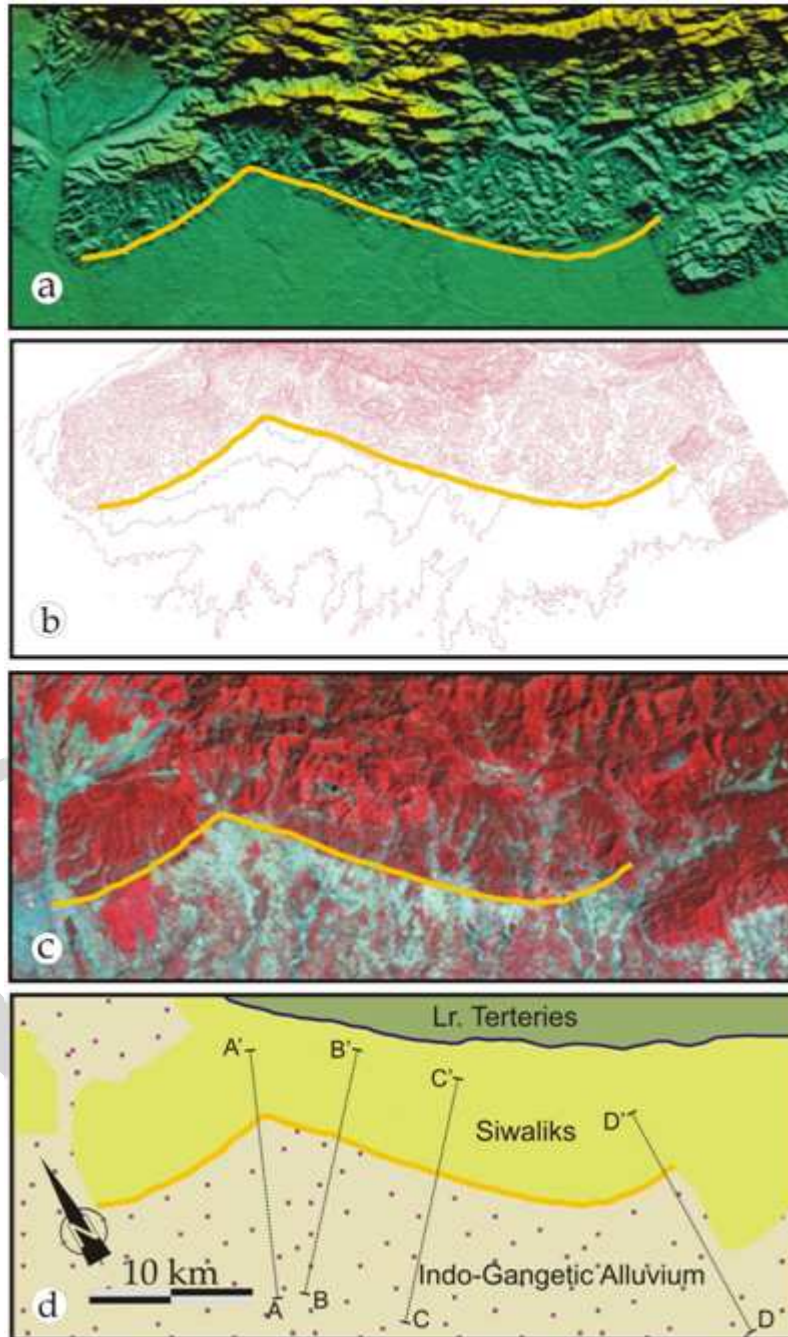


Fig 2. (a) Shaded relief of the Nahan Salient clearly showing mountain front of the Himalayan orogen, marked by a bold line, between the hills towards the northeast and plains towards the southwest. (b) The contour map of the same area showing the elevation distribution. The contour interval is 25 m. A sharp change in the contour spacing can be clearly seen across the line of the mountain front. (c) Landsat image of the same area shows an abrupt change in the colour, tone and texture across the line of the mountain front. (d) The line of the mountain front is also significant in the geological map. The Siwalik rocks that are older in age abut against the younger alluvium of the Indo-Gangetic plains, suggesting that the mountain front is also a tectonic contact. Topographic profiles have been drawn along line AA', BB', CC' and DD' (profiles shown in Fig. 3).

Topographic profiles drawn normal to the strike of the mountain front clearly demonstrate the break in slope across the mountain front (Fig. 3). The break in

slope is marked by small discontinuous scarps at a number of places in the field (Fig. 4).

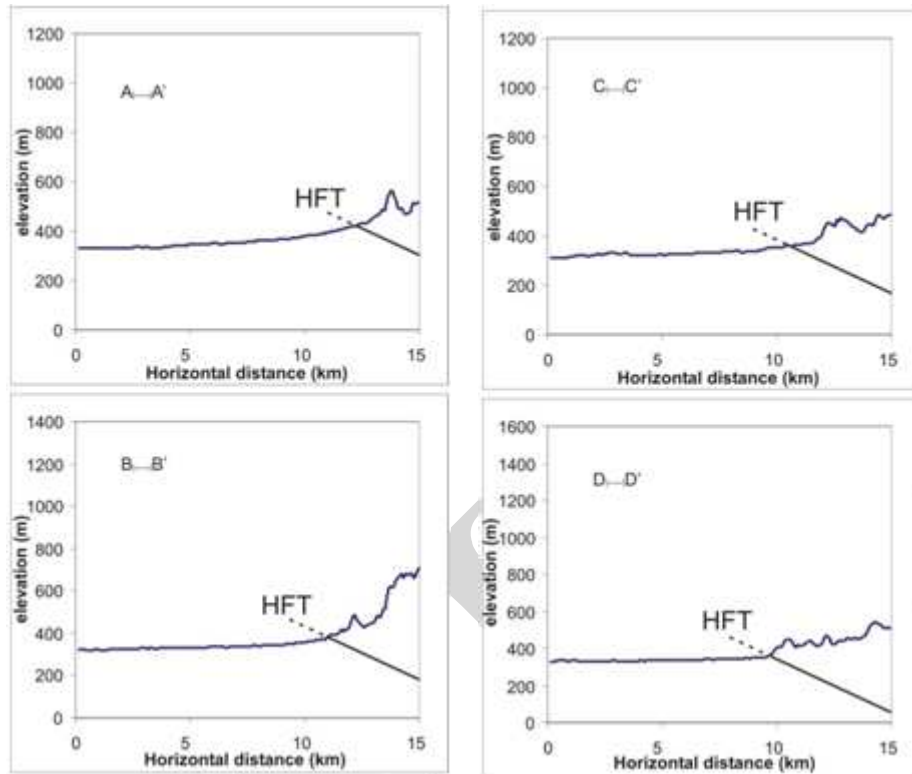


Fig 3. Topographic profiles drawn normal to the HFT (for locations refer Fig. 2). Each of the profile shows a distinct break in the topographic slope across the thrust, HFT. This break is also consistent with the line of mountain front emphasized in Fig. 2.



Fig 4. Field manifestations of the slope break across the HFT. The small scarp seen here is not continuous all along the mountain front, rather it becomes diffused at most of the places (Singh et al., 2011).

### 3. 2. DRAINAGE NETWORK AND ANOMALOUS BEHAVIOUR

Drainage network has been identified as one of the most important tools that has been used to interpret subtle crustal/deformational processes (Schumm, 1993; Keller and Pinter, 2000; Singh and Jain, 2009).

Drainage network in the Nahan sector comprises mainly of the ephemeral streams that support intermittent flow of water. Only a few higher order streams are perennial in nature. The perennial streams are flooded only for a smaller part of the year i.e. during rainy season (July to September). In the summer months (March to June), they are reduced to small channels with very weak flow. The drainage network is parallel to sub-parallel in pattern and mostly drains normal to the mountain front, in a southwest direction. However, as the streams approach the mountain front, just north of the alluvial plains, they tend to behave anomalously.

The most common anomaly observed among these streams includes the deflection, from their usual NE-SW courses to transverse trends, that are as high as normal to their original courses i.e. almost parallel to the mountain front. Such deflections are observed at a number of locations along the mountain front (Fig. 5). The most conspicuous among them is the one between Bhud and Kambala. The stream here takes a

sudden diversion from its axial course i.e. NE-SW to a transverse one i.e. NW-SE. It flows roughly parallel to the trace of the HFT for about 3 Km, capturing the smaller streams in its way. A noteworthy phenomenon associated with the deflection of larger streams, from their original courses, is the presence of abandoned channels. These abandoned channels are usually wide and filled with river material of all sizes varying from large boulders to fine mud. They are commonly dry but may flow intermittently during peak discharges.

Another anomaly is related the widening of stream channels and their increased sinuosity. In most cases streams tend to meander or increase their sinuosity through meander loops. Such increase in the sinuosity of the stream channels has been observed along the Turan nala (NE of Mandlai village), Sangrel Nadi (between Bhud and Mauhliwala villages), Thattar ki Nadi (near Gobindpur village), stream between Mirpur and Mandton villages and stream near Bhola Kheri village (Fig. 5).

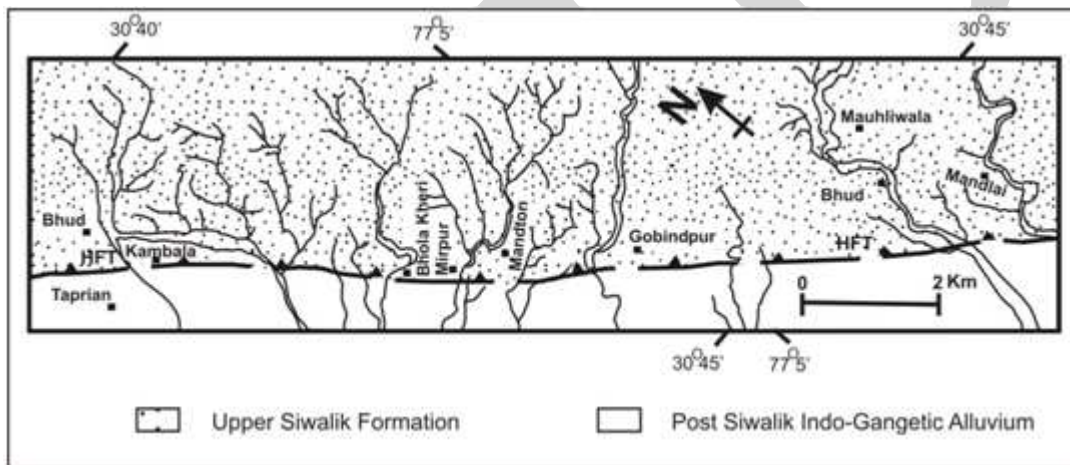


Fig. 5 Drainage network of the Nahan Salient. It forms a parallel to sub-parallel pattern at the mountain front, except for some prominent deflections and change in sinuosity of the stream channels. An abandoned channel is also present near Taprian, just south of the mountain front.

It is interesting to note that these sinuous reaches are marked by the presence of broad flat surfaces commonly referred as terraces (Fig. 6). The terraces form as a result of degradation caused by streams

along their sinuous reaches. The terraces are usually elongated parallel to the streams and mark the sites of degradation whereas aggradation is observed on their either side (Singh et al., 2011).



Fig. 6 Field photograph showing the presence of flat broad terrace surface near Mauhliwala village. These terrace surfaces are characteristic of the sinuous reaches. In the hills these surfaces provide nice flat land that is suitable for cultivation and habitation (Singh et al., 2011).

#### 4. RESULTS AND DISCUSSION

The Nahans Salient exhibits typical geomorphic features characteristic of an active mountain belt (Fig. 2, 3, 4, 5, 6), marked by small discontinuous scarps and drainage anomalies. There is a close spatial correspondence of the mountain front with the geological boundary between Siwaliks and the Post Siwalik Quaternary alluvium, thereby corroborating the postulation of an active structural discontinuity.

Continuous convergence and the resultant uplift have led to anomalous drainage patterns which are not in line with the regional topographic slope. Where the streams cannot counter the actively uplifting topography, they tend to get deflected, capture smaller streams on the way to attain more power and finally get across the uplifting surface. This is clearly evident in the channels that are abandoned in doing so. In addition, the presence of flat elongated surfaces (terraces) along the stream courses reflect the degrading nature of streams where they cut across their own deposits now lying at a higher base level. Similar examples of drainage diversion by rising topographic structures have been cited in many fold-thrust belts (Jolley et. al., 1990; Burbank and Verges, 1994).

The rising front also tends to increase the topographic slope in the hanging wall block. The change in the topographic slope induces the base level to fall (Keller and Pinter, 2000; Singh, 2008) that in turn increases the potential energy of the stream system. The increase in the potential energy disturbs the equilibrium condition between the discharge and sediment load (Keller and Pinter, 2000). In such a case, the stream responds by widening of stream channels and increasing sinuosity of its channel in order to maintain the equilibrium between discharge and sediment load (Keller and Pinter, 2000).

The presence of the sinuous reaches in the hanging wall block just across the mountain front suggests that these streams are trying to make adjustments to the changes brought about by the fall in the base level and increase in channel slope. The sinuous reaches are marked by the presence of flat terraces within the hills that are indicative of a degrading system. This is also supported by the presence of an aggrading system on both sides of these sinuous which clearly indicates that these sinuous reaches are actually the sites of an active uplift/deformation (Ouchi, 1985).

#### 5. CONCLUSIONS

The Sub-Himalayan belt in the Nahans Salient responds to active thrusting along the HFT by topographic uplift in the hanging wall block as demonstrated by the surface relief and slope break at

the mountain front. This is manifested in the drainage network as anomalies that closely correspond to the spatial location of the HFT and its hanging wall. The widening of channels, increase in sinuosity of streams and presence of broad flat terraces along the sinuous reaches is clearly indicative of active thrusting along the HFT and related tectonic uplift. Further, in view of the low seismicity in Nahans Salient, it is proposed that the active slip along the underlying thrust faults and splays has resulted in accumulation of high relief spread over a relatively smaller area thereby explaining the absence of intermontane valleys i.e. 'duns' in this particular area.

#### ACKNOWLEDGEMENTS

Authors thank for facilities provided by Scientist-in-Charge, CSIR-Centre for Mathematical Modelling and Computer Simulation, Bangalore. The initial financial support for the work was provided by Department of Science and Technology (Government of India) vide grant no. SR/FTP/ES-52/2006 to TPS.

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