

Geomorphic expressions of the Main boundary fault: A study of the Kasauli ridge area (Shimla hills, Himachal Pradesh)

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Abstract

The Himalayas are a seismically active zone with innumerable faults. Faulting commonly has topographic expression. This is a study of the geomorphic expressions of the Main Boundary Fault in the Himalayas in the vicinity of the Kasauli Ridge area, Shimla Hills, from the Survey of India topographical sheet: 53 B/13. An intensive study was made of the drainage, springs, and the river terraces; slope analysis of the study area was done and profiles made for topographic interpretation. The evidence of the Main Boundary Fault was seen in the extreme steepness of slope and presence of scarp faces in the proximity of the Fault, the angular bends in the streams, the sudden breaks in slope in the longitudinal profiles of the rivers, the significant difference in slope on either side of the fault and presence of springs and terraces.

Introduction

The Himalayas are one of the most seismically active regions of the world. The Main Boundary Fault (MBF) is one of the more active faults in this mountain range (Valdiya, 1998). This fault was first recognized and named in southeastern Himachal by Medlicott (1864). Active faults are zones prone to earthquakes and they pose complex geologic problems particularly related to correct interpretation of the diastrophic history of a region (Thornbury, 1969, p. 234). Thus their identification is vital.

This study is concerned with the geomorphic expressions of the MBF in the Himalayas close to the Kasauli Ridge and the Pinjore Dun in the Shimla Hills, Himachal Pradesh.

Methodology

The topographic effects of faulting include:

- i. Elevated, lowered, tilted or horizontally displaced blocks of the earth's crust;
- ii. Crushed or brecciated zones which are more easily eroded than surrounding rocks; and
- iii. Weak and strong rocks in contact with each other making differential erosion possible on the two sides of the fault.

Accordingly, a geomorphological reconnaissance of the study area was attempted from the Survey of India topographical sheet: 53 B/13 on 1:50,000 scale.

In order to identify the geomorphic expressions of the MBF Zone, the following steps were followed:

- i. Demarcation of the fault-line.
- ii. Assessment of the drainage, springs, and the river terraces within the study area.
- iii. Regional slope analysis using Wentworth method and analysis of stream profiles and Transverse profiles. Also the slope along either side of the MBF was analysed.

The Study Area

The study area has been delineated with the Kasauli Ridge (Lower Himalayas) forming the eastern boundary and the Pinjore Dun forming the southern and western boundaries. The Balad Nadi forms the northern boundary. The study area is roughly oval-shaped with its elongate axis lying in a northwest-southeast direction. It extends between $76^{\circ} 45' E$ and $77^{\circ} 0' E$ and between $30^{\circ} 45' N$ and $31^{\circ} 5' N$. The length of the study area is 16 kilometres and its width varies between 3 kilometres to 6 kilometres. The areal extent of the area is 75 square kilometres.

The Main Boundary Fault (MBF)

The major line of the MBF runs right across the study area from north to south. It runs for a distance of 9 kilometres and its width is 3.25 kilometres. The orientation of this fault is $N 20^{\circ} W$. The secondary fault, which is in the northern part of the study area, is less than a quarter of a kilometre in length and its orientation is $N 15^{\circ} W$. It has

a displacement varying from a few meters to tens of meters.

Ridges

The Kasauli Ridge is one of the three ridges in the study area. At the base the ridge is 11 kilometres. The study area covers only the western slope of the ridge. Its orientation is $N 20^{\circ} W$. The profile of the crest of the Ridge consists of three peaks, which are at 1926 meters, 1913 meters (Manki Point) and 1910 meters. The ridge acts as a water divide for rivers flowing to the east and west. All rivers originate on the southern slopes of the Kasauli Ridge. The second ridge runs in a northwest-southeast direction, starting from the northwest corner of the study area. The orientation of this ridge is $N 45^{\circ} W$. Its crest reaches a maximum height of 1235 meters. The third ridge is in the southern part of the study area. Its orientation is $N 30^{\circ} W$. It reaches its maximum height of 1125 meters. It has seasonal streams on both eastern and western slopes; the degree of dissection by the drainage lines is low to moderate.

Drainage

The drainage system of the study area has evolved during the post-Middle Pleistocene times. The Kasauli Ridge is the origin of many streams including Shilu Khurd Nadi. The streams of the study area are part of the Sutlej River System. All the south-westward flowing streams join the Sirsa Nadi eventually. The north-eastward flowing streams join the Balad Nadi, which, in turn, empties into the Sirsa. The other south-westward flowing streams of the study area

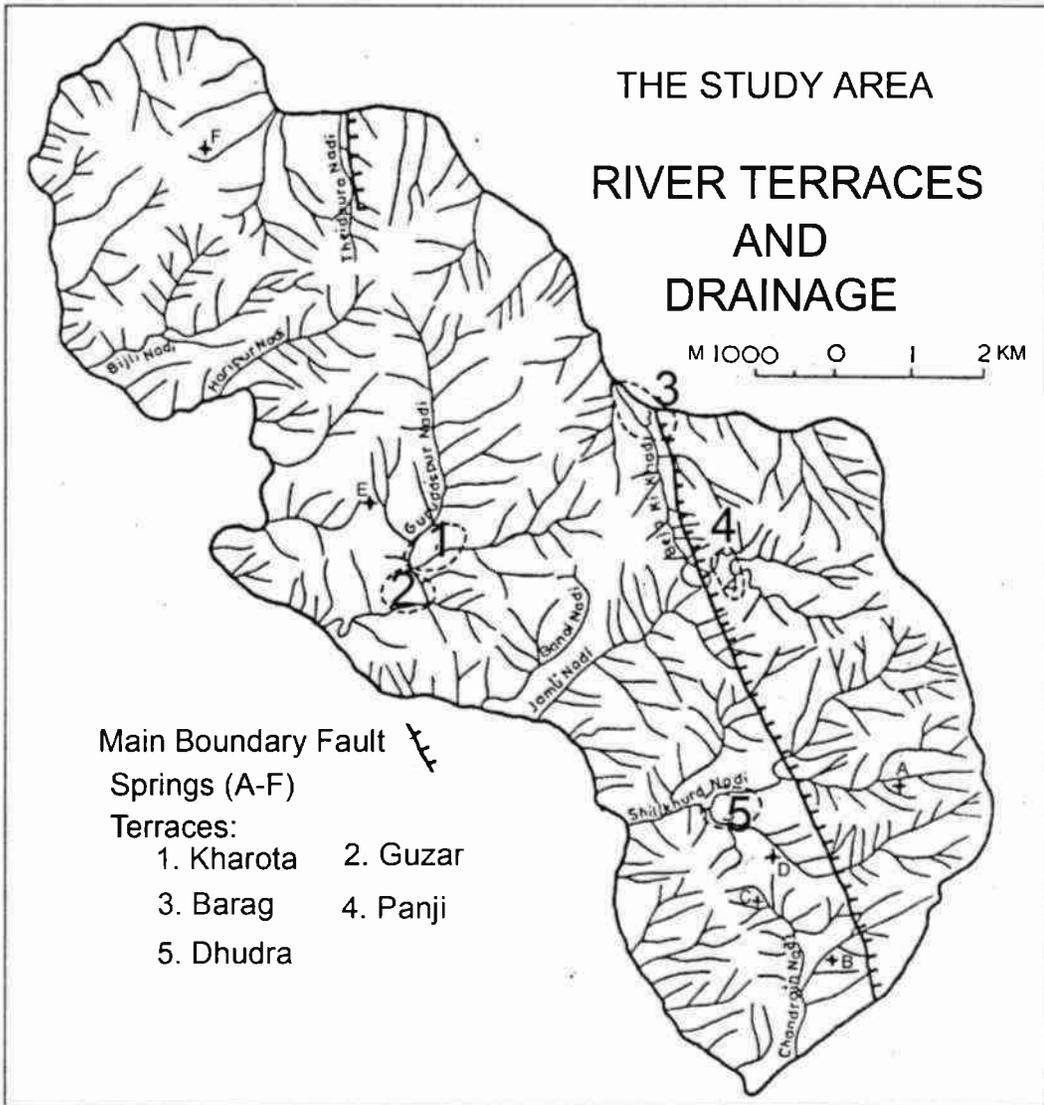


Fig. 1: River Terraces and Drainage

are the Bijli Nadi, the Haripur Nadi, the Gurdaspur Nadi, the Banoji Nadi and the Jamli Nadi. The Chandrain Nadi flows due south and the Theidpura Nadi due north. The northward flowing Beja Ki Khad is a tributary of the Balad Nadi, which forms

the northern boundary of the study area. Almost all the streams are seasonal with the exception of the Gurdaspur Nadi, the Shilu Khurd Nadi, and the Beja Ki Khad (Fig. 1).

Discussion

Expressions of the MBF can be identified through a series of features such as 1. the steep Kasauli Ridge and scarp faces, 2. steep valley sides, 3. angular bends in streams, 4. streams flowing along faults, 5. presence of springs and river terraces, besides the drainage pattern. In order to substantiate the evidence profiles were drawn and slope analysis was conducted for the study area.

The steep Kasauli Ridge and scarp faces

Kasauli Ridge attains its maximum height within a very short distance – within $\frac{1}{4}$ kilometer it reaches a height of 1900 meters from 900 meters at the base. The crest of the ridge runs for about $\frac{3}{4}$ kilometer. The slope of the Kasauli Ridge is very sharply dissected by the streams that drain its slopes. The streams have steep, almost vertical valleys at many places. The area also exhibits several scarp faces that could be attributed only to the faulting. This fault is mainly responsible for the extreme steepness of slope in this area. From the fault-line, which is at an average height of 900 meters, to the Kasauli Ridge (which forms the eastern boundary of the study area), the land reaches to a height of 1900 meters within a short distance of about $\frac{1}{4}$ kilometre.

Steep sided valleys

On the whole, the river valleys in the east of the study area are steeper because of the greater amount of available relief due to faulting. Towards the north the valley side slopes in the study area become relatively gentler.

The streams of the study area flow through steep-sided valleys, which are at times almost vertical e.g. the valleys of the Shilu Khurd Nadi and the Beja Ki Khad. The Shilu Khurd Nadi has about 2.5 kilometres of such steep-sided valleys while the Beja Ki Khad has approximately 3.5 kilometers of valley with similar conditions. The Theidpura Nadi flows parallel to this fault-line. The valley side of this stream is quite steep especially when it is compared with the otherwise general relief of the area.

Right angle bends and stream flow along faults

The rivers flowing across the Main Boundary Fault show angular bends in their courses as they cross the fault line. These rivers are the Shilu Khurd Nadi, the Jamli and the Beja Ki Khad. The last named river flows along the fault line for a considerable distance in addition to exhibiting the prominent right-angled bends in its course. One of the reasons for its course following the line of the fault is that it has excavated the weak and shattered lithology of the faulted zone and carved its bed. Thus the structural and lithological control exhibited by the fault is evidenced in the peculiarities of the river courses along the fault line.

The Drainage Pattern

There is an almost infinite variety in the patterns formed by any drainage system in areas of different rock-type, geological structure, climatic regime and erosional history. It is useful to make a classification of the more obvious patterns; however, it should be remembered that, in nature,

perfect examples of these patterns are not readily encountered.

The study area reflects a trellis drainage pattern with the streams being parallel to subparallel. The subparallel pattern comprises a series of streams, which run approximately parallel to each other. A parallel pattern indicates the presence of a major fault that cuts across an area of steeply folded bedrock. Such patterns are especially characteristic of areas of uniformly dipping rocks where geological conditions and/or the time factor have not yet permitted the development of a more complex pattern. A subparallel pattern is therefore essentially an initial drainage pattern.

Springs

The Himalayan region is characterized by fault-springs, which are formed as a direct result of an impermeable bed of rock being brought into juxtaposition with a permeable bed by virtue of faulting.

Of the six springs in the study area, five are located on the Siwalik formations which lie juxtaposed with the Kasauli formations, which are harder than the former.

Five of the springs are located in the vicinity of the Main Boundary Fault-line i.e. springs A-D and F. Spring A is found to the right of the fault-line on the harder Kasauli rocks. All springs are within 100 meters of the rivers in the study area (fig.1).

- Spring A is at a height of 1300 meters and is located with 50 meters of a seasonal tributary of the Shilu Khurd Nadi.

- Spring B is at a height of 850 meters and is within 10 meters of the river channel of the seasonal Chandrain Nadi.
- Spring C is also along the Chandrain Nadi, it is about 100 meters from the river channel and at a height of 920 meters.
- Spring D is along a perennial tributary of the Shilu Khurd Nadi. It is at a height of 980 meters and is 130 meters from the river channel.
- Spring E is along the Gurdaspur Nadi, along one of its seasonal channels. It is at a height of 740 meters and is located on a south-ward facing slope.
- Spring F is along one of the seasonal tributaries of the Balad Nadi. It is about 10 meters from the river channel, at a height of 800 meters and on a northeast-ward facing slope.

The River Terraces in the Study Area

The river terrace may be described as a portion of the former flood plain of river, now abandoned and left at a higher level. Some may have little or no alluvium on them and may thus be classed as bedrock terraces in contrast with alluvial terraces.

Distribution of Terraces

The distribution of terraces in the study area is related to (1) the easily erodible Siwalik rocks; (2) the steep slopes, which accelerate their own denudation and retreat; (3) the middle and Upper Pleistocene periglacial climatic conditions (reflected in the fluctuations in the stream discharges); and (4) the widespread local tectonic events,

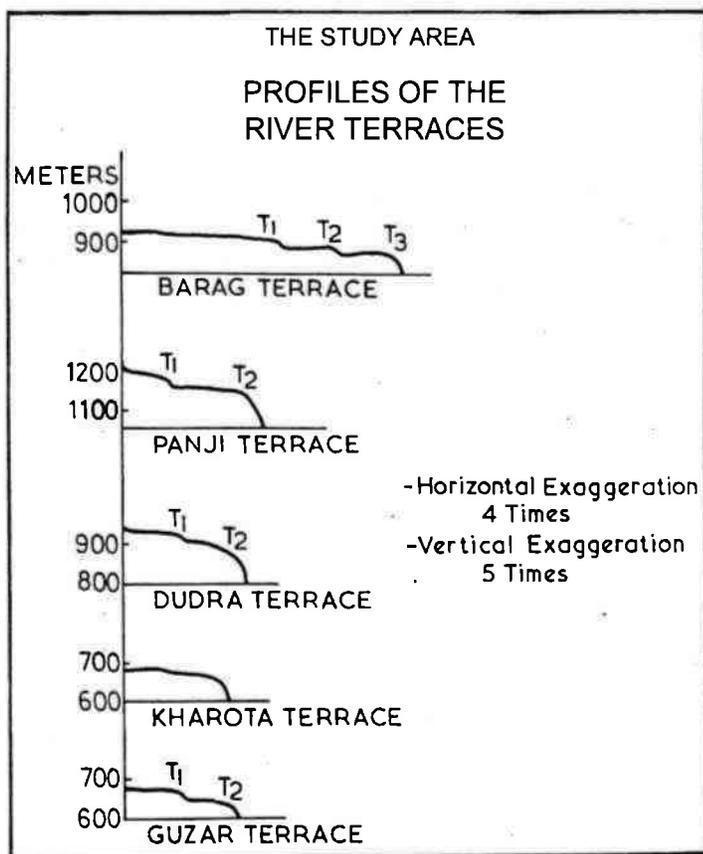


Fig. 2: The profiles of the river terraces

primarily faulting. In the Himalayas, the river terraces are found only on the concave side of the meanders. They are non-paired and non-cyclic terraces. This implies that there was continued down cutting accompanied by lateral erosion. Non-paired terraces also imply continued slow uplift of the land.

Three terraces, the Kharota, the Guzar, and the Dudra lie to the west of the Main Boundary Fault, while the Panji and the Barag terraces are to the east of the fault-line.

Site of the Terraces

The terraces are located on the inner side of the river bends/meanders. Generally the convex side of the bend is having a sharply steep slope and the concave side is having the terraces. The Kharota terrace is formed at the confluence of the Nadi whereas the Guzar terraces are located on a meander of Gurdaspur Nadi.

The Dudra terrace is formed at the confluence of the two major tributaries of the Shilu Khurd Nadi.

The Barag and the Panji Terraces occur along the Beja Ki Khad River. The Panji is formed on the inner side of a meander of the stream. The meander forms distinct right angles due to the faulting in the area. The Barag terrace occurs at the confluence of two tributaries of the river.

Profiles of the Terraces

The terraces of the study area are rather small in size. A maximum of three terrace levels has been observed (Fig. 2).

- The Barag terrace is the longest terrace and is located at a height of 920 meters. This terrace has three levels, with the first level being the longest having a length of 500 meters. The second and third levels are about 200 meters in length.
- The Panji terrace is at a height of 1200 meters. It has two levels with the first one being 190 meters in length and the second 250 meters.
- The Dudra terrace is situated at an elevation of 940 meters above mean sea level, with two terrace levels. The older terrace is 200 meters long and the younger one is 130 meters in length.
- The Guzar terrace is located at a height of 680 meters and has two levels of a length of 180 meters and 140 meters respectively.
- The Kharota terrace can be sited at a height of 680 meters and has only one level of a length of 270 meters.

The terraces of the study area reflect the complex geological history of the region. The formation of the three-terrace level

is indicative of rejuvenation the area has experienced due to tectonic movements. The older terraces consist of older alluvium, which is compact and cemented and brown in colour. These older terraces also have a higher proportion of calcarious material as compared to the younger ones. The younger terraces are formed of newer alluvium, which is of a lighter shade than the older deposits.

Profiles - Transverse Profiles

Six transverse profiles across the study area drawn in a west to east direction and one profile (No. 7), running in the northeast-southwest direction are shown in fig.... All the profiles from 1-6 show an increase in height and slope as one move from west to east (Fig. 3).

The northernmost profile (number 1) shows little relief as compared to the others. Profiles 2 and 3 have peaks at the ridge in the east. Profiles 4, 5 and 6 all rise suddenly towards the west to mark the Kasauli Ridge (Fig. 4).

The long profiles of the rivers of the study area

The shape of the river long profile can be described as its slope or gradient, which is the graphic representation of the ratio of the fall of the channel to its length over a given reach. It is the configuration of the channel bed or bottom in longitudinal view. The characteristic features of the general shape of the long profile of rivers include concavity and convexity, graded (equilibrium) and un-graded forms.

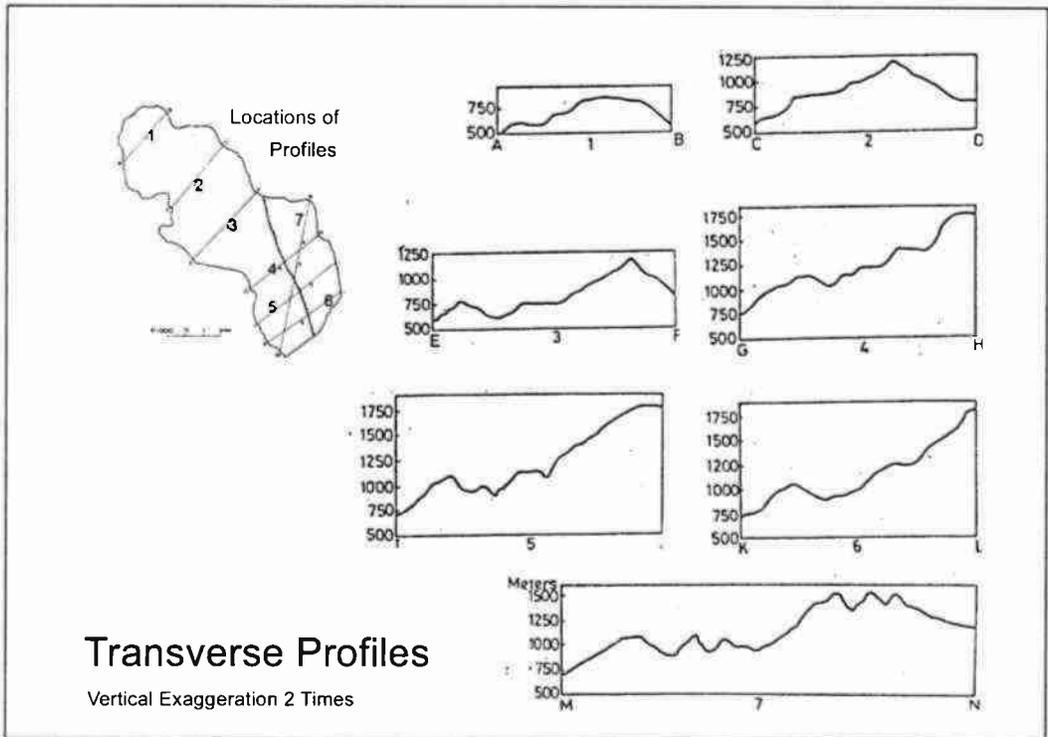


Fig. 3: Transverse Profiles

This, in most cases, and particularly in humid regions, is concave – upwards towards the sky. This shape is also described as the graded profile or the profile of equilibrium. The features which complicate the general concave, upwards – towards the sky (smooth) curve of river beds include waterfalls, cataracts, rapids and knickpoints, which are also among the most prominent erosional features along river courses.

All the rivers in the study area originate at a height of about 1000 meters and they leave the region at a height of about 520 meters. The fall in height in the slope facets for the different rivers varies between

1120 and 340 meters. The length of the streams varies from 7.7 kilometres (Beja Ki Khad) to 1.5 kilometres (Theidpura Nadi) (Fig. 6).

The river profiles reveal three distinct segments: the upper, middle and lower. The upper segment is concave, the middle is planar and steeper, and the lower segment gently concave to planar and gentler than the middle. A few of the river profiles exhibit, at some places, a break in slope, which could be interpreted as knickpoints. Some of the profiles also contain depressions, which could be due to a number of factors. At least some profiles suggest the jutting out on the

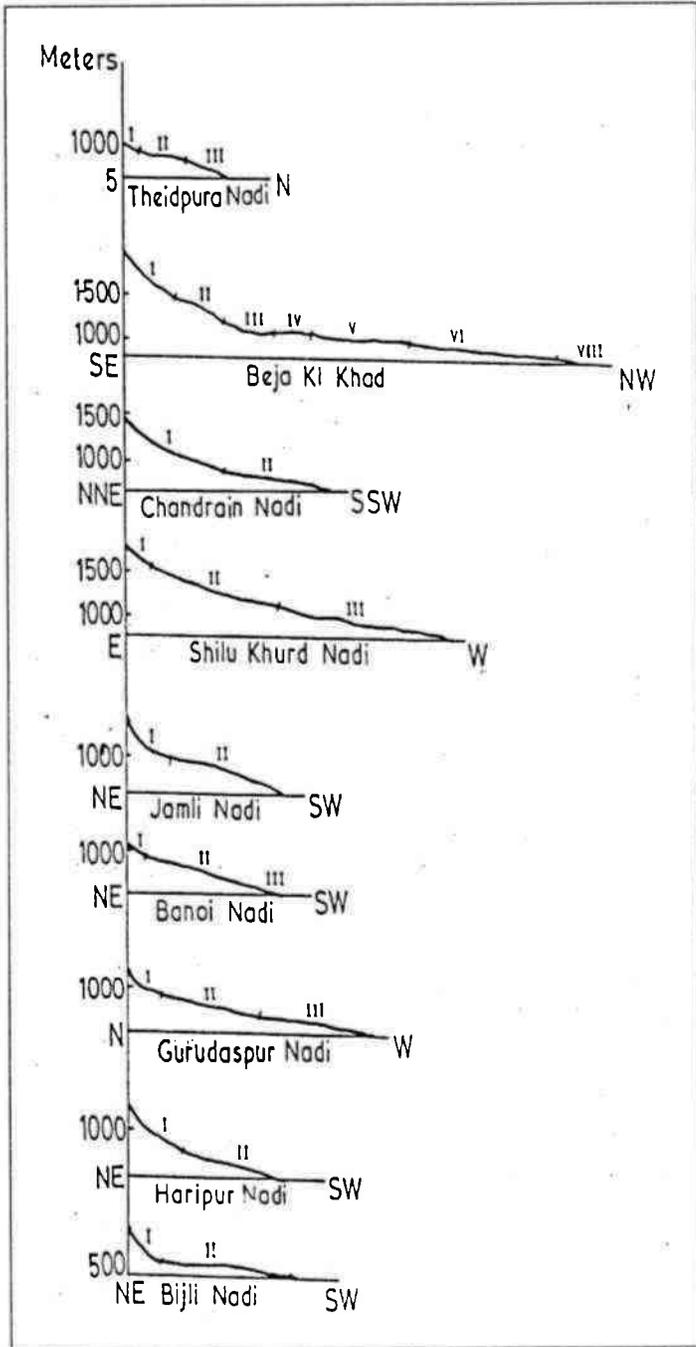


Fig. 4: Longitudinal Profiles

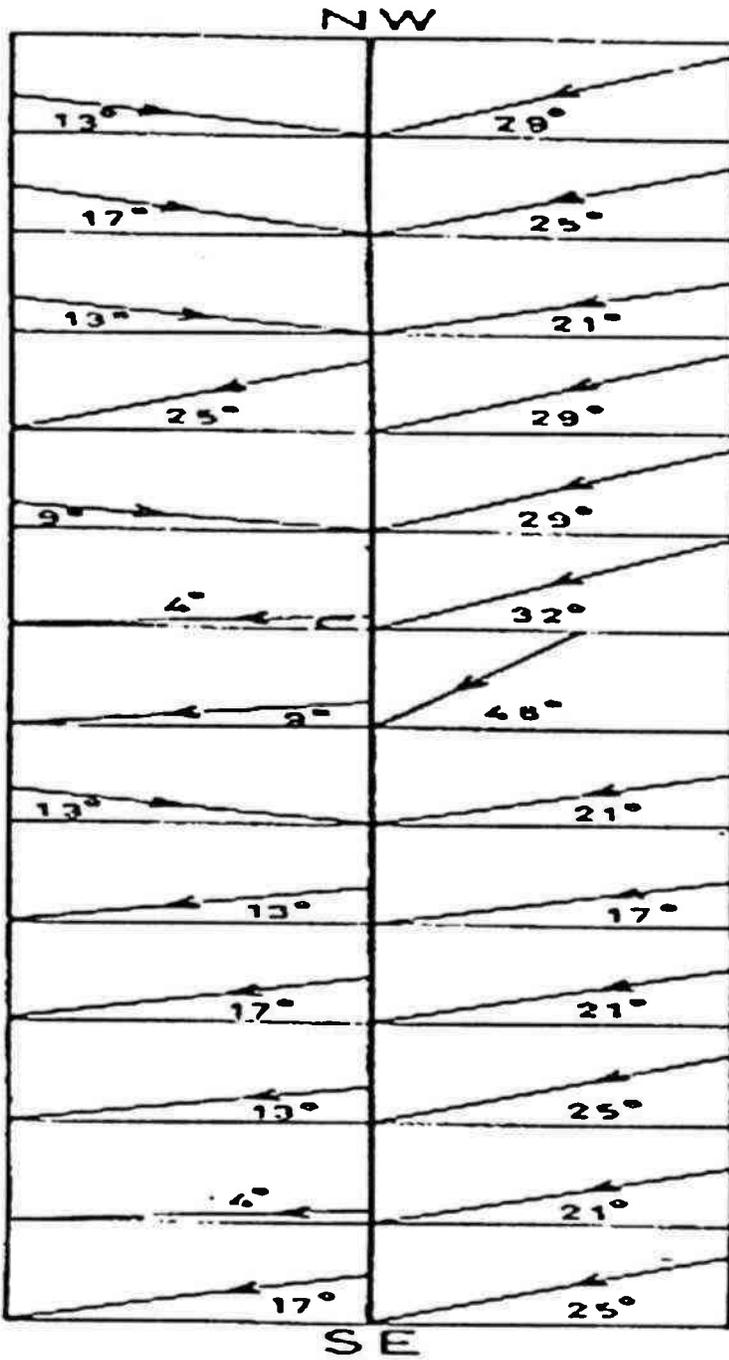


Fig. 5: Slope on either side of MBF

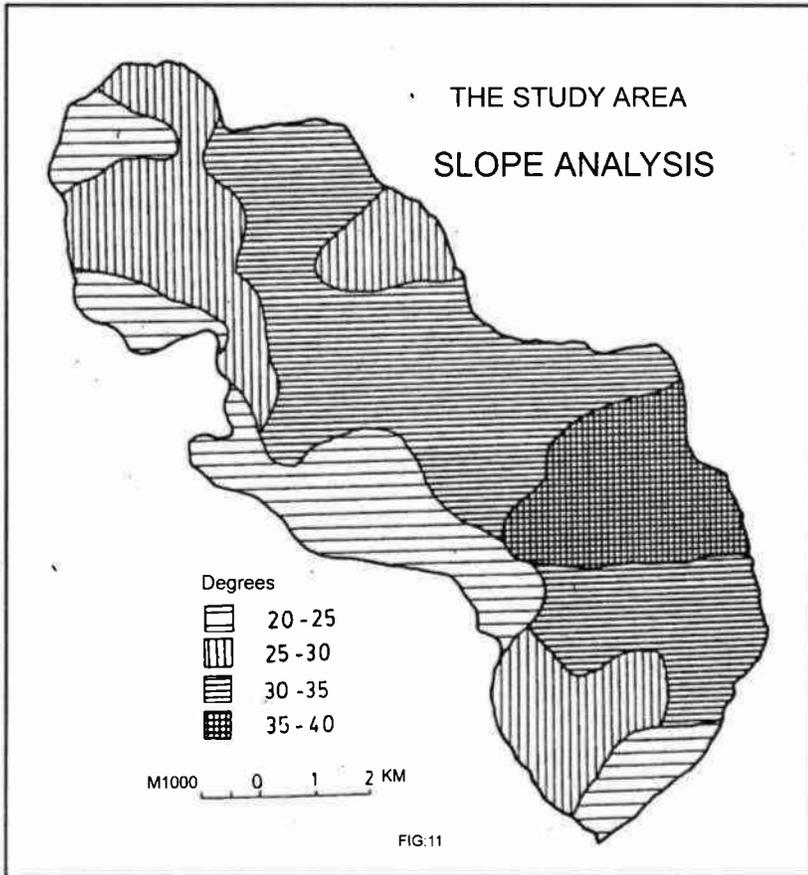


Fig. 6: The study area slope analysis

riverbeds of hard bedrocks and also a state of disequilibrium and un-graded reaches.

The Theidpura Nadi can be divided into three segments. The uppermost has the maximum slope and shows a tendency towards concavity. The second segment has a gentler gradient and it also shows a tendency towards concavity. The third segment is planar and its slope is once again steeper than the previous segment.

Beja ki Khad has as many as seven segments in its profile. The first segment is concave and has a steep gradient. The second segment is planar with a tendency towards convexity. The slope in this segment is once again steep. The third segment has a gentle slope which is planar. The fourth segment has a convex slope. The fifth, sixth and seventh segments are all planar but there are breaks in slope that separate each segment. Most of these irregularities

are related to outcrops of bedrocks having differential erodibility and disposition - a feature common in complex folded geology.

The Chandrain Nadi has two segments – the first one being concave and steep and the second one being gentler and planar with a tendency towards convexity.

The Shilu Khurd Nadi has three segments – the first being steep and linear, the second being less steep and planar and the third having an even gentler planar slope.

The Jamli Nadi has two segments – the first one is steeper and has a concave slope while the second is less steep in comparison and its slope is planar to start with, but it becomes convex as we move on.

The Banoi Nadi has three segments. The first segment has a steep slope that is concave. The second segment has a relatively less steep slope, which is linear with slight tendency towards convexity. The last segment has a gentle slope and a planar profile.

The Gurdaspur Nadi has three segments. The first is concave and the second planar which has a slight depression as we move towards the third segment. This last one has a convex profile initially which straightens out as we move down.

The Haripur Nadi has a concave profile in its first segment and a planar profile in its second.

The Bijli Nadi has a pronounced concave profile in its first segment with the second being planar with a low slope angle.

Slope Analysis of the Study Area: Slope measurement on either side of the Main Boundary Fault

An exercise in the measurement of slope angles, for a distance of 250 meters on either side of the MBF reveals that the eastern side has a steeper slope than the western side. The differences between the angles on both sides are found to range from 4 to 39 degrees, with the average difference being 13.5 degrees (Table 1).

Table 1 : Slope difference on either side of

A	B
1	16
2	8
3	8
4	4
5	20
6	28
7	39
8	8
9	4
10	4
11	12
12	17
13	8

Main Boundary Fault: “A” Segment Number “B” Slope Difference

The average slope on the east is 26.4 degrees and on the west is 12.8 degrees. All these figures reinforce the previous findings on the profiles that the slopes were steep in the east and gentle in the west. The land to the east of the fault line was uplifted during the tectonic movements in the area. This partially accounts for the sudden

steepness in slope. Another explanation is the juxtaposition of the soft Siwalik rocks with the harder ones of the Lower Tertiary period.

Slope Analysis

The slope analysis for the study area was carried out with the Wentworth method. It was observed that the high angle slopes coincide with the Kasauli Ridge with 35-40 degrees of slope in the eastern part of the study area. This area contains almost vertical scarps.

The areas with the lowest slope (20-25 degrees) lay adjacent to the Pinjore Dun. This area has river valleys with contours fairly widely spaced.

The rest of the study area fell in the zone of intermediate slope varying between 25-35 degrees. The centre of the study area had a slope of 30-35 degrees with another such area lying in the southern part. The area with 25-30 degrees of slope has low-lying hills with not so steep slopes as compared with the rest of the study area. These hills are about 900 meters in height. The region with 30-35 degrees of slope consists of a ridge of a height of between 1100-1200 meters. In this area the contours get closer together as compared to contour spacing in the northwest.

Conclusion

The Himalayas being one of the most seismically active regions of the world contain several faults. The Main Boundary Fault is one of them. The geomorphic expressions of this fault have been assembled from the Survey of India topographical sheet: 53 B/13. Among the evidence of faulting that was observed was the rapid attainment of height by the Kasauli Ridge noted in the slope analysis for the study area and in the transverse profiles. In addition, the evidence included the angular bends in streams at the site of the fault, the sudden breaks in slope in the longitudinal profiles of the rivers and the difference in slope on either side of the fault. The presence of springs and terraces in the study area are also indicative of the presence of the Main Boundary Fault.

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