III - GEOMORPHOLOGY
III GEOMORPHOLOGY

3.1 Introduction

Thornbury (1891) defined geomorphology as the science of landforms. According to him one of the important aspects of geomorphology is to delineate the diverse types of landforms. Geomorphic features can be very easily identified on a satellite image as they provide a large synoptic coverage. The indigenous remote sensing IRS LISS III satellite data provides the actual information on landforms as they are observed on a aerial mode. However for the more detailed study of the key area, higher spatial resolution IRS satellite data of LISS IV sensor is found to be appropriate. This data provides the in-depth information of the terrain and helps to delineate the sub-surface structural framework in the area under study. Of late the availability of very high spatial resolution satellite data available on the internet has added a new dimension in the study of landforms to the researchers and geomorphologists. Especially the three dimensional terrain information with its ease to handle maneuvers virtually takes the observer over the area under observation and helps him to visualize the relief and landforms from different aspects.

A typical landform is formed due to the interaction of processes of tectonic activity, erosion and deposition, that is well exemplified by the geomorphic feature of the area. Dun is a broad open syncline which is expressed geomorphologically as the “Dun valley” (Thakur and Pandey, 2004), however due to the thick accumulation of the Dun gravels in the synclinal region the flat-lying Siwalik strata of the synclinal depression is not exposed, but the seismic profile across the Dun show the horizontally layered Siwaliks to be present in this synclinal depression (Raiverman, Srivastava et al., 1994).
The southern part of the study area (Figure 3.1) comprising of western part of the Dun intermontain depression is also locally known as the “Kiarda Dun” is drained by Bata river, while the eastern part of this “Kiarda Dun” is drained by the Bata river. Thus the central high ground of the Kiarda forms first order continental level water divide between the Indus river system draining into the Arabian sea in the west and the Gangatic river system draining into the Bay of Bengal in the east. Locally this water divide separates the Bata river of the Gangatic system in the east from the Markanda river of the Satluj in the west (Figure 3.2). This water divide also forms the lowest part of the tectonically prominent Ropar – Narkanda mega-lineament.

The valley portion extends from the banks of Yamuna river in the east to Nahan town in the west. In the north of the study area is the structurally controlled valley formed by a series of east–west trending parallel faults and thrusts. Nossin (1971) observed that the adjoining Doon valley has been uplifted by 314 m to 420 m due to differential movement along the MBF and Krol thrust. He recognized different levels of fans in the adjoining valley that consists of Doon gravel of Pleistocene and recent age.

3.2 Methodology:

The appearance of any satellite image varies either on colour monitor or in hardcopy paper prints, because most satellite and airborne sensors are designed to accommodate a wide range of illumination conditions like the poorly lit undulating hilly region to high reflectance snow and barren rocky region. Electronic images and film or paper copies of original image data are often low in contrast, with many features of interest very hard to identify and in order to enhance the interpretability digital image enhancement techniques are applied to the satellite imageries.
Digital image enhancement technique is a group of operations that improves the visual or electronic detectability of the target or categories. To delineate different geomorphic units under various land cover conditions, the satellite data was subjected to different digital enhancement techniques, as no single image enhancement technique was found to be comprehensive in itself.

These operations included linear enhancement, root enhancement, equalise enhancement, infrequency enhancement, edge enhancement and others.

Linear enhancement; In this enhancement, more expressive details of the image are pronounced by uniformly expanding the range of grey level say from (51 to 153) to fill the range of the display device value of (0 to 255). This type of grey level reassignment is called a linear enhancement.

Root enhancement; is also known as the logarithmic transform, is particularly effective with images whose grey level distribution exhibit right skewness. This enhancement stretches the dynamic range of the low end of the image while compressing its high end. It tends to lend an overall brightening of the resultant image.

In Equalise enhancement: the image grey value level are assigned to the display level on the basis of their frequency of occurrence. More display value and hence more radiometric detail are assigned to the frequently occurring portion of the histogram.

Edge enhancement; is an analytical technique that sharpens object boundaries in an image.
Out of the above enhancement technique infrequency enhancement was suited the best for the structural study, this technique which is also termed as “histogram inversion” produces an image in which the high (bright) pixels represent those grey levels in the original image which were infrequent (that is accounted for a small proportion of the entire image). The look up table function is derived from an inverted (upside down) histogram of the input image data values.

This function was useful as it highlighted the rare and small features in the image which were otherwise unnoticed. This enhancement technique was especially useful for detecting the lineaments or edges which, owing to the thinness of their dimension were unclear.

Digital image enhancement technique such as band rationing and image interpretation is generally useful for separating out the different geomorphic units of the study area.

After the aforesaid enhancement techniques, on screen visual image interpretation was carried out. This thematic information derived using the enhancement technique was integrated with the other derived layers which included the lithology, slope, drainages, lineaments etc. Taking into account this integrated information, the following six geomorphic units were finally delineated as per the national standard codes designed by Space Applications Centre technical document (SAC, 1997). The work flow methodology is shown in (Flow chart Ch-3.1).
Flow Chart 3.1 Procedure for preparation of Geomorphological map

1. Satellite Data at 1: 50,000 scale
2. SOI Topographic sheet at 1:50,000 scale
3. Visual Interpretation
   - Drainage
   - Lithology
   - Lineament

4. Preparation of pre-field maps
5. Ground Truth Survey
   - Preparation of post-field maps (Map updation)

6. Scanning and Digitization of final maps
7. Editing and Building topology in GIS environment
   - Polygon maps from digital and geocoded satellite data
     - Lithology, Lineament density, Drainage density
   - Polygon maps from Survey of India maps
     - Slope percentage, slope aspect, DEM
8. Geomorphological map
3.3 Geomorphological Classes

Different geomorphological classes in the adjoining eastern part into Siwalik range, Doon valley and the Himalayan front has been described by (Nossin, 1971). Nakata (1972) suggested that the valley was formed by an intricate superimposition of alternate depositional and erosional phase caused by climatic changes and crustal movement. However Doon valley is the largest intermontane synclinal longitudinal valley in the sub Himalayan region, the geomorphology with respect to stratigraphy of the Siwalik group of Dun and adjoining frontal Siwalik range is also described by (Karunakaran et al., 1979). Kumar, Ghosh et al. (2003) have stated that the Pinjor Formation (sandstone dominated) and Boulder Conglomerate Formation (conglomerate dominated) sub groups forms an upward-coarsening succession of an alluvial fan system.

Jha (1995) divided the area geomorphologically into Denudo-structural hill, Structural hill, Residual hill, River terrace and Flood plain. On the basis of the study of satellite images, drainage pattern, slope, lineament and lithology the following geomorphic classes were delineated in the study area. The geomorphic terms for the individual units have been taken as per the Technical Guidelines – National Remote Sensing Agency, Department of Space, Hyderabad.

- Structural Hills
  - Ridge type structural hills
  - Cuesta type structural hills
  - Residual hill
  - Piedmont Zone
  - Alluvial fans
  - River Terraces
3.3.1 Structural Hills

Structural hills are defined as linear to arcuate hills showing definite structural trend (NRSA, 1995). Structural hills in the study area are observed in the satellite image by the presence of structure controlled sharp crested ridge lines, straight segments of bedding traces, straight ridges and parallel valleys and network of rectangular drainage pattern. In the present study area structural hills are observed in the lower Siwalik sandstones in the north of “Kiarda Dun” as well as in the middle Siwalik sandstones in the southern part of the study area. This is shown by the geomorphological map (Figure 3.1).

In the northern region its altitude ranges between 680 to 1800m in the eastern region it ranges between 640m to 1200m and in the southern region it ranges between 640- 1000 m. Field observations also indicates the presence of control of strikes of the rock formations on the trend of the ridges and valleys. Steep scarps and landslides along the thrust are also observed especially in the northern aspect (Plate III-b).

3.3.2 Ridge type Structural Hills

Ridge type structural hills are defined as a narrow linear or curvilinear resistant ridges formed by resistant rocks like quartzite bed, dykes etc.
This geomorphic unit of the structural hill is situated along the higher crestline of the Siwalik range running in the west to east direction upto village Kaludeo and then runs in the NW – SE direction. Further down it branches into two hill ranges running almost parallel in the Himalayan trend. The altitude of these hill ranges between 550 m to 701 m. Eastward it occupies the higher crest line and runs in the north west south east direction. Its altitude ranges between 500 m and 600 m. The insitu rocks comprises of the middle and upper Siwalik rock formations. The lineament density is high, the slope percentage is of the order of 5. The drainage patterns is dendritic and the present land cover is predominantly forest cover.

Sharp water divide ridge lines are also observed in the satellite data as well as in the field especially along the Jhande ki dhar crestlines (Plate III-1a) This also give rise to the sharp water divide to the north east and south west flowing ephemeral rivers. Also across the Giri river it occupies the higher hill crest line and litho – units comprises of Krol Formation. However across the Jalal river the crest line comprises of the Infra-Krol Formation (Plate III-1b).

3.3.3 Cuesta type Structural Hills

Cuesta type structural hills are group of hills formed by gently dipping (5° – 15° degree) sedimentary beds having escarpments or steep slopes on one side and gentle slope on the other sides (NRSA, 1995). Cuesta type structural hills are marked by the difference in erosional pattern of the rocks, due to the differential erosional work, dip slope and escarpment are exposed and each flank is represented on one side by escarpment with intervening broad valleys. These structural hills are observed between the Nahan ridge line and the Jalal river valley. Another set of Cuesta type structural hills are observed across the Giri river (Plate-III 2a) in the Infra-Krol and Krol Formation. These are observed to be developed on the inclined strata of the Subathu and Dharamshala rock formation in the north Plate-III.
2(b) and are developed on the inclined strata of the Siwalik formation in the south of the study area. Another set of these hills are observed between the Indo-Gangetic plain in the Siwalik hill ranges in the south of the study area.

Towards the central region the cuesta topography is pronounced due to the high inclination of the beds giving rise to shorter slopes. The higher degree of inclination in these Tertiary rocks which forms a part of the narrow Nahan Salient is due to the development of imbricate thrusts (Raiverman, Srivastava et al., 1994) and (Power, Robert et al., 1998) that has given rise to the cuesta type topography.

In the mid region that is between the Jalal – Giri and Jhande – Ki Dhar ridge line, the cuesta hills comprise of tilted strata of the Subathus and Dharmshalas in the west and comprise of the Siwaliks in the east. This is a zone of Main Boundary Thrust which marks a sharp tectonic boundary between the upper and the lower Tertiary Formation, which is geomorphologically expressed by a sharp break in slope across the thrust that has resulted in the marked difference in the erosion pattern of the rocks.

At places the slope surface along the MBF is gently sloping for example in the western sector north of Nahan and at the other places especially around Baila it is steeply inclined (Plate III-2a). This is attributed to the reactivation of the fault by neo-tectonic events (Valdiya, 1992). The lineament density is quite high and runs in the east-west direction. The drainage pattern is rectangular and follows the strike direction of the rock formation. The land cover as per the satellite data is Forest and scrub dominated with occasional pockets of agriculture. These agricultural regions are observed to orient itself in the east-west direction along the strike controlled valleys and parallel to each other. The average slope is gentle at 5 percent.
3.3.4 Residual Hill

Residual hills are group of hills occupying comparatively smaller area than composite hills ranging from 2×2 sq. Km. to 10×10sq. Km. in extent (NRSA, 1995).

An isolated oval and elongated residual hill is observed on the right bank of Giri river within the Doon valley also locally known as the Garibnath hillock just at the base of the Jamota hill. The hill comprises of the loose gravel and boulder deposits. Its slope percentage is 5, that is the hill is steeply sloping at the upper reaches. At the western margin the slope percentage is 4 and in the eastern margin it is 3 percent and the south central hill top is relatively flat with slope of 2 percentage.

The drainage is sub-radial but in the eastern margin deranged drainage pattern is observed. In the satellite data this hill is conspicuously distinct from the surrounding topography and the hill is covered with forest and scrub vegetation with few pockets of forest blank at the hill top. This hill has probably been observed to be isolated from the adjoining hill (Plate III-4) probably due to the eastward migration of the Giri river owing to the tectonic activity of the Paonta or Markanda thrust in the vicinity.

3.3.5 Piedmont Zones

Piedmont zone are accumulation of deposits or sediments along the foothill zone due to sudden loss of gradient by rivers or streams in humid and sub hummid climate. Based on the thickness of the sediments deposited, it is further divided into three categories – 1) shallow (0-10m), 2) Moderate (10-20m), and 3) Deep (more than 20m) (NRSA, 1995).

In the study area the piedmont zone is developed on southern side of the Doon valley as continuous region along the foothills of the Siwalik where
it meets the alluvial plain. Most of these piedmont zone are developed on the south of the Paonta thrust due to the tectonic upliftment of the middle Siwalik Formation (Figure 3.1). Here the Piedmont zone is developed over the northern slope of the Upper Siwalik Formation. Singh, Prakash et al. (2001) has also observed that the dip controlled southern slope of the valley and the hog back of the gently NE dipping strata of the frontal Siwalik to be covered by an apron of piedmont fan.

In the extreme southern part of the study area these are developed along the north of the Himalayan Frontal Fault due to the upliftment of the Middle Siwalik formation. The broad channeled ephemeral drainage pattern are the most characteristic feature. Most of these piedmonts are observed to be dissected by the broad dry drainages having smooth surface texture. A large number of these piedmonts are covered with agricultural fields as observed on satellite imageries. This zone is preferred for agricultural practices owing to its loose soil and gentle slope.

On the basis of the slope gradient (Nossin,1971) has divided them into two units, the upper unit and the lower unit. Across the Yamuna he has delineated the fan into two parts the upper half is termed as the dissected part of the principal fan and the lower portion as the lower realms of the principal fan. However (Philips, 1996) has divided the area into three major fan surfaces on account of the recent intermittent tectonic impulses in the eastern margin of the adjoining Doon valley. In the study area the region has been divided into three different zones on the basis of their relative positions is as follows:-

This western piedmont zone is in the western part of the study area and is developed on the southern side of the Markanda/Poanta Thrust in the Middle and upper Markanda river valley. Due to the presence of northward dipping reverse fault the lower Siwaliks have been uplifted. This phenomenon has given rise to higher gradient in the north. The rock deposits comprises of the poorly sorted, coarse gravels and boulders of angular and sub angular
shapes. The slope is of the order of 5 percent that is steeply sloping surface towards the north. This zone is subsequently segmented by local streams arising out of the northern slope of the Upper Siwaliks. The higher gradient of these slopes are truncated at the bottom at the margin of the left banks of the Markanda river course giving rise to the broad river channels northwards (Figure 3.1). Owing to the steep slope and heterogeneous rock deposits the area is under forest cover.

In the central part of the area it is developed on the right side of the Bata river valley. This zone is also formed due to the northward dipping upper Siwalik Formation this has given rise to the steeper slopes towards the north comprising of the Upper Siwalik Formation comprising of the boulders, pebbles, cobbles etc. (Figure 3.1). Due to the steep to moderately steep sloping surface the zone is segmented by stream channels giving rise to slope categories of 3, 4, & 5%. The upper reaches of the zone represents the presence of typical dendritic drainage pattern, where as the lower western zone has parallel drainage pattern. This upper steeper zone is also under forest cover.

In the eastern part of the area it is developed across the Giri river at the foot hills of the Siwaliks and ranges between 460m to 600 m. It comprises of the loose pebbles and boulders of the Lower Siwalik formation derived from the north the slope face is towards the south with slope percentage between 2 and 3 ie; gently sloping surfaces. Due to the gentle nature of the slope the streams are broad in their middle course. The upper reaches of the Piedmont zone exhibit a series of dendritic drainage pattern that gets terminated at the break in slope region due to the presence of heterogeneous formation downstream comprising of loose pebbles and boulders having angular to sub angular shapes.

The piedmont zone is formed due to the northward dipping eastward trending easternmost extension of the Paonta thrust (Figure 3.1). It is
observed that the upthrow side comprises of the lower Siwalik Formation and towards the north has given rise to the hills and valleys towards the south as a result due to the break in slope along the thrust. The area has developed piedmont zone along the foothill slopes due to erosion of lower Siwalik sediments from the steep sloping hills in the north. The satellite imageries shows the presence of sloping agriculture fields in the middle part were as the lower portion of the zone is occupied by dense sal forest and dense scrubland.

3.3.6 Alluvial fans

Alluvial fans are fan shaped mass of sediment deposited at a point along a river where there is a decrease in gradient (NRSA, 1995). Alluvial fans are observed across the Giri River especially at the base of the Piedmont zone where it meets the old river terrace. It is observed that the sediments are thickest at the top of the fan and thins out rapidly in the downstream region. The sediments comprises of loose sand, silt and clay materials brought down from the upper and middle Piedmont zone. Due to steep slope these fan deposits have sparse growth of scrubs and grasses which is evidently observed on the satellite data. These alluvial fans are formed due to decrease in stream gradient and by accumulation of secondary deposits of sediments derived from the middle piedmont zone located at the elevated region along the Paonta and Bata thrusts lying parallel to each other and also in close proximity to each other, the trend of the thrust is in the east - west direction.

3.3.7 River Terraces

River terraces are flat upland adjoining the river course, occurring at different levels and occupied by river borne alluvium. It indicates the former river floor (NRSA, 1995). River terraces are formed on either side of the river valleys at different elevations are clear indicators of the former level of flood plains, when the river flowed at relatively higher level. In the study area the
River terraces are formed as benches of small extent on either side of the Giri river, also as benches of moderate extent on either side of Bata river and as benches of of large extent on the older river beds of lower Giri–Yamuna river. The deposits comprises of the gravel, sand and clays. These terraces have been formed due to the initial phase of deposition of the sediments brought down by these rivers followed by tectonic upliftment along the Giri thrust, Paonta thrust and Yamuna tear fault zone and the later phase of erosion under different climatic conditions.

3.3.7.1 Giri river Terraces

A number of river terraces are developed along the course of the Giri river starting upstream at village Chandni it forms a large river terrace in the study area with an approximate area of 150 hectare. It has an average altitude of 630 m. It has very gentle slope towards the south with slope category of 0-1%. The deposits consists of alluvial material comprising of sand, silt and clay.

In the satellite image for the rabi season (Pre monsoon satellite data) the terrace represent flat agricultural land with smooth texture and pockets of habitations. Further downstream a smaller terrace at village Amboa with average elevation of 600 m with an area of 50 hectare is observed. It slopes towards the south. similar terraces at village Kuna, Bhujon and Manal are observed downstream.

At village Kuna the terrace spreads for about 500 hectare with very gentle slope category. The upper catchment shows deranged drainage patterns. At village Bhujon the terrace spreads for 450 hectares. With gentle sloping surface towards south. The average elevation is 520 m here the thickness of the sediments are quite high. The drainages above the terraces shows deranged pattern.
At Village Jhankar the terraces spread for 150 hectare and also exhibit deranged drainage patterns.

Further downstream the terraces are also developed at Manal village with approximate area of 250 hectare with an average elevation of 500 m. It is gently sloping towards south with slope category 0-1%. Terraces are also observed at few places on the right banks of Giri river across village Manal. Here three different levels of terraces are observed as T-3, T-2 and T-1 however on the right bank only one level of Terrace namely T-1 level Terrace are observed on the left bank throughout the length of Giri river course. River terraces at higher elevation on either side of the Renuka lake (in close proximation to the study area) has also been reparted (Thapa, et al., 1998). The different level of Terraces are observed along the terraces of the Krol thrust, Main Boundary Fault and Renuka thrust zones at successive interval and are developed due to subsequent erosion by the Giri river (Raina, 1967), (Mazari.1992). (Plate III 5a & b, Plate III 7a & b).

3.3.7.2 Yamuna river Terraces:

The Yamuna river also exhibits two terrace levels on either banks of the river especially near the Yamuna tear fault zone. T-1 level terrace at lower altitude is observed at villages Paonta, Matrail, Devinagar, Kedarpur, Bata Mandi, Satiwala, Bahral. Terraces along the Yamuna river adjoining the Flood plain is seen in the (Plate III b).

3.3.7.3 Bata river Terraces:

On the left bank of Bata river two levels of terraces are observed in the upper stream area at village Bain Kuan, Jamun wala, Kundian, Dhoka etc. However in the downstream region of Bata, the remaining area shows only
one level of Terrace deposits. On the other hand the right bank exhibit only one level of river Terrace development along the lower Siwalik formation along the Paonta thrust.

### 3.3.7.4 Markanda river Terraces:

Large tracts of river terraces are developed on the northern region of the Markanda river. However only thin terraces are observed along the length of the river on the southern side of the Markanda river. These terraces are observed to be tilted north easterly at Sambhuwala due to the upliftment by the Markanda thrust in the south of Uttamwala (Figure 3.1).

### 3.3.8 Flood Plains:

Flood plains are alluvium deposited along the river or stream course due to repeated flooding. Based on the thickness of alluvium, it is classified into three categories – shallow (0-10m), Moderate (10-20m) and deep (>20m) as per the technical guidelines (NRSA, 1995).

Alluvial plains are formed by the deposition of soil on the banks of the river by the overflowing water during floods and flood plains are continuous stretch of flat land bordering a river mainly its lower reaches and consisting of alluvium deposited by the river. The large stretch of flood plains are formed by the Giri river downstream of Sataun to the point of its confluence with Yamuna river.

Yamuna river has developed the broadest stretch of Flood plain along its course in the present study area. Relatively narrow flood plains are those developed by the Bata and Markanda rivers respectively. These vast stretches of flood plains are developed due to the widening of the Doon valley due to
the tectonic upliftment of the downstream blocks by thrusts, Himalayan frontal thrust and lateral displacement of formation caused by Yamuna tear fault.

On the right bank alluvial deposits of Giri river comprising of the fluvial gravel and sand of Quaternary age are also reported by (Nossin, 1971). It is interesting to note that the lower river Terraces T-2 are observed across the high level terraces T-3 away from the right bank. This phenomenon indicates that the Giri river once flowed through the passage formed between the Garibnath hill and the Jamota hill. The migration of the course of the river eastwards to its present position is attributed to the reactivation of the Paonta and Bata thrusts.

Yamuna river develops sinuous bend along its course within the Doon valley in the south eastern part of the study area (Plate III-b). This meandering phenomenon is observed to be prevalent along the stretch within the valley upto its confluence with Bata river before entering the narrow channel of Yamuna downstream and finally into the Indo-Gangatic Flood plain.

The meandering have been developed as a result of the Yamuna river taking a preferred course, determined by very gentle gradient, cross sectional area of the Channel and lower ratio of the discharge to the load.

Channel bar sand bar formed due to braided river course due to vertical accretion of sediments (NRSA, 1995). Channel bars are observed to developed within the flood plains near Paonta town and upstream these more or less oval and elongated deposits of loose gravels and sands are formed due to the network of active river channel in this zone the network of active river channels forms distributaries and tributaries at regular intervals due to the very low slope gradient of 1% slope.
Point bars sand bars formed at the convex side of the meandering river by lateral accretion of sediments (NRSA, 1995).

Downstream of Paonta valley Giri and Yamuna river course develops large point bar deposits. These point bars are developed on the left bank due to the presence of in-situ boulder conglomerates of the upper Siwalik formation exposed in the area.

The development of the meandering of river channel, channel bars and point bars developed within the Yamuna flood plain is attributed to the tectonic upheaval and upliftment of the downstream subsurface lower and upper Siwalik Formation along the Yamuna tear fault and the formation of the above features are a consequence of the Himalayan Frontal Fault lying to its southern margin.

Formation of Channel bars are also observed along the course of Jalal river (Plate III-8). Formation of point bar along the course of Giri river is also observed as represented by (Plate III 9 b).
FIG. 3.1
GEOMORPHOLOGICAL MAP OF THE NAHAN-SATAUN-PAONTA AREA, H.P.

LEGEND

GEOMORPHIC-UNIT
- RIDGE TYPE STRUCTURAL HILLS
- CUESTA TYPE STRUCTURAL HILL
- DISSECTED STRUCTURAL HILLS
- RESIDUAL HILL
- PIEDMONT ZONE
- ALLUVIAL FAN
- RIVER TERRACE
- FLOOD PLAIN

3 1.5 0 3 6 9 12 Kilometers
FIG. 3.2 LAND FORMS SHAPED BY THE NETWORK OF DRAINAGES
FIG. 3.3
DRAINAGE ORDER MAP IN
NAHAN - SATAUN - PAONTA AREA, H.P.

LEGEND
DRAINAGE ORDER

1
2
3
4
5
6

STUDY AREA
location point

Kilometers

3 1.5 0 3 6 9 12
(a) Jhande-ki-dhar ridge type structural hill running in the east-west direction it also forms the water divide between the Giri and the Bata river.

(b) Ridge type structural hill running in the NW-SE direction between the water divide of Giri and Tons river.
(a) Cuesta type structural hills developed due to differential erosion on the highly inclined formation in the Trans Giri region east of Barwas village. The stream follows the contact line between the Tal formation to the right and Infra Krol formation to the left.

(b) Moderate slope along the dip direction and steep slopes opposite to the dip direction developed in the cuesta type structural hills south of Jamota village.
(a) Extensively wide open valley with flood plain at the initial stage of Bata river as viewed south easterly from Uttamwala village.

(b) Structural hills east of Sataun village across the Giri river.
Residual hill amidst the old Giri river alluvial plain north of Haripur village. The hill is oriented in the NW-SE direction. The photograph is taken due north.
(a) Development of river terraces on the right bank of Giri river at different levels opposite Pedua village. Older terraces T-1 are observed at higher level, T-2 at lower level.

(b) River terraces on the left bank of Giri river at different levels Sataun is situated on the Older terraces T-1 at higher level as compared to T-2 at lower level.
Flood plain and channel bars formed by the Yamuna river. The view is taken towards west from its left bank.
(a) Thick accumulation of old river terraces (7 to 10m thick) amidst the fertile alluvial plain near village Rampur Ghat

(b) Old river terraces comprising of huge boulders of quartzites, about 3Km away from the present course of Giri river.
Formation of channel bars along the course of Jalal River near shiru village.
Plate III-9

(a) Alluvial fan formed due to the accumulation of Rock fall debris near village Tikkar west of Sataun village.

(b) Point bars formed on the inner curve of the Giri river at the region of low river gradient along its course.