CHAPTER 3

GEO MORPHOLOGICAL
STUDIES
3.1 INTRODUCTION

Geomorphology is the study of landforms, their description and interpretation. It may also be stated in the simplest form that geomorphology is the study of the evolution of landforms and their relationship with the underlying rocks. The science of geomorphology has its importance not only as an academic discipline but in the present world it has more practical applications in the field of soil science, economic geology, geohydrology, military geology, engineering geology and for rural and urban planning. For the development of agricultural resources, the terrain assumes special significance. so far as agricultural planning is concerned, regional geomorphological studies become of greater importance. In an agricultural country like India, the application of geomorphology in the field of land-utilization particularly for agriculture, horticulture, forest development; selection of sites for construction of dams, transport and communication and human habitation may be of great help. Proper understanding of the present as well as past geomorphological processes is imperative for careful planning and evaluation of earth's natural resources.

Aerial photographs provide a three dimensional synoptic over view of a large terrain and help to delineate the regional geomorphology. Both macro and
micro landforms as well as their details can easily be studied from aerial photographs. In general, most of the landforms are best seen on aerial photographs than on the ground due to their dimension and antiquity.

3.2 Geomorphology of the study area

Geomorphologically, the area depicts a mature topography, since it has been exposed to erosional processes from palaeozoic onwards. Among the exogenic geomorphic processes, mainly the fluvial processes have played a significant role in the terrain evolution. The present day landscape of the study area is carved out by Sonar, Koppa, Sajali and the Gadheri rivers. The erosional processes are still active, eroding the loose and poorly consolidated alluvium, shales and hard rocks like sandstone and limestone exposed along the banks and periphery of river valleys. Bhagavan & Rao (1985) has studied an area 1000 sq.kms. in Cuddapah and Nellore district of Andra Pradesh to bring out the different landforms and other geomorphic features, their material content and distribution, the process that have acted and are acting in the evolution of landscape and ultimately to get an idea of geomorphic history of the area, with the help of Landsat imagery, aerial photographs and field checks.

Lithology is related to landforms and being an important factor has played an important role in shaping the landscape. The older hard and resistant rocks stand out prominently as high hill ranges in the eastern and western part of the area, the less resistant ones form
low relief hills and pediment at the foot of hill ranges, whereas the least resistant ones form the low lying planes. Murthy & Pofali (1984) has analysed Landsat imagery for the texture, shape, size and pattern to study the different landforms developed under different climatic environments of Gujarat state.

Seven geomorphic units and seven landforms with erosional processes have been identified after detailed study of aerial photographs and Landsat imagery. These are shown on a detailed photo-geomorphological map (No.3.1) on 1:50,000 scale, prepared from the aerial photographs with selected field checks. Present studies also includes weathering characters of different rocks, quantitative analysis of drainage basins, evolution of drainage, adaptation of drainage to the underlying structure, valley deepening and valley widening, erosional surfaces, neotectonic activity and geomorphic history and evaluation of topography. Chopra (1986) has carried out the photo-geomorphological mapping in parts of the lower reaches of Jadukata-Umngi river valley in the southern fringe of Meghalaya. He divided the area into five geomorphic units with the help of aerial photographs. Singh (1987) has also studied the photo-geomorphology of Bist Doab Tract, Punjab lying between the two rivers viz., Beas and Sutlej on two sides and the Siwaliks range on the third side. He has analysed the Landsat imagery and False Colour Composite to study the different geomorphic units developed under different geological periods and environments. Singh & Goel (1984)
has also studied the various photo-geomorphological features associated with fluvial processes of the river Satluj are mapped using photo-interpretation techniques with a view to assess the environmental status of the area in the north-east of Ludhina (Punjab).

Each geomorphic units and landforms are being discussed with regards to its characteristic feature and distribution. Different geomorphic units in chronological order, landform and erosional processes are given below:

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<thead>
<tr>
<th>Geomorphic units</th>
<th>Geomorphic forms &amp; process</th>
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</thead>
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<td>1. Flood plain</td>
<td>1. River Bluff</td>
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<tr>
<td>2. Young alluvial plain</td>
<td>2. Point bar</td>
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<td>5. Old alluvial plain</td>
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<td>6. Pediment</td>
<td>6. Mesa</td>
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<tr>
<td>7. Denudational hill</td>
<td>7. Gully erosion</td>
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</tbody>
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3.3 GEOMORPHIC UNITS

3.3.1 Flood Plain

The flood plains (Map No.3.1) are depositional landforms created by the processes of stream meandering and over bank flooding. In the study area the flood plain is youngest unit and Sonar and
Kopra rivers have formed strips of flood plains along their courses.

The flood plain is composed primarily of horizontally layered reddish silt, silty sand, sand and pebble having fine to medium texture. Two landforms recognised in this unit (i) point bar (ii) cut-off meander.

Point bar is a low arcuate ridge of sand developed on the inside of a growing meander or convex side of a river by lateral accretion (Wolman and Leopold 1957). These point bars have a relative relief between 1.5 m to 2 m from the present river bed level near Aslana, Shahpur, Ankkhera.

The flood plain is easily recognised on the aerial photographs, by its characteristic light grey tone and fine texture as well as some phenomenon of bank cutting which enables separation of this unit on the imagery. On False Colour Composite, it shows light yellow tone.

3.3:2 Young Alluvial Plain

The alluvial plain (Map No.3.1) is the next younger unit and is characterised by the recent alluvial plain built by Sajali, Sonar and Kopra river at a lower level near their banks at NW of Dhigsar, north of Mandla on Kopra river, Hinotaghat, Khirya, Shahpur on Sonar river and Kevlari, Sasa on Sajali river. It is distinguished by the presence of a palaeochannel (Bari, NE of
Khojakheri, NW of Hinota, Chirola, SSW of Bansakalan, South of Bhainsa and South of Khejra) which indicate lateral shifting of the Kopra and Sonar river courses. It consist of grey clay, clayey silt, silt and sand and provide good agricultural land.

On aerial photographs, this unit shows medium grey tone, fine to medium texture, external drainage and low drainage density. On False Colour Composite, it appears yellowish blue in tone.

3.3:3 Terraces

Terraces (Map No.3.1) are topographic platforms, flat, treads or steps in the river valley that usually represent former levels of the valley floor or flood plain. They may have little or no alluvium on them and thus be classed as bed rock terraces in contrast to alluvial terraces, which consists of gravel, sand and fine alluvium. The individual terraces are separated by low bluffs, rises of scraps. The terrace analysis is useful for delineating the geologic history and climatic evolution of the region in which the valleys are cut.

Terraces may be located at more or less constant height above the present flood plain or valley flat. Though, it is generally presumed that the highest terraces are the oldest. This may not always be so since at place there are older buried terraces which might be exhumed.

River terraces are produced by surges of erosion
along river valleys and hence reflects periods of rejuvenation which affected streams. Cotton (1940) classified river terraces into (i) cyclic terraces (ii) Non cyclic terraces.

Cyclic terraces are paired and represent former valley floors formed during periods when valley deepening had largely stopped and lateral erosion had become dominant. Non cyclic terraces are unpaired and represent continued down cutting accompanied by lateral erosion.

In the present area of study noncyclic terraces are observed which are both depositional as well as erosional in nature. These are briefly discussed below:

(A) Depositional Terraces

The depositional terrace forms as a result of deposition of coarse, medium and fine alluvial material from bottom to top. Three depositional terraces are noticed at Kasreti and Jhira village having terrace bluffs of 2 to 2.5 m high. Two level of terrace is also noticed near Aslana and Rajghat Pipariya. Poor layering is observed in the terrace bluffs. The terraces are impaired, which indicates a slow and rejuvenation of the area.

(B) Erosional Terraces

The erosional terraces noticed on the bed rock (called rock cut terraces) as well as on old alluvial plain. Three levels of the rock cut terraces are
observed at Kasreti and Jhira having bench height of 2.5 m, at Chanua Khurd the bench height is 5 m, and at Ghograshat, Shahpura and Bansa Tarkheda the bench height is between 2.5 m to 3 m. The terraces have developed on limestone and shales by lateral cutting process.

Erosional terraces developed on old alluvial plain near the banks of Kopra and Sonar rivers are noticed at Datpura, Harduwani and Hinota village from the aerial photos.

3.3:4 Ravinous Terrain

Ravinous terrian (Photo No. 52) comprises fine grained semi-consolidated alluvium or soft litho units. They are small, narrow, deep depressions, smaller than a gorge but larger than a gully usually carved by running water. In study area, the ravinous lands occur in small patches along the banks of Sonar and Kopra and on the low lying areas of upper Bhandar sandstone on the southwestern side of Damoh.

On the basis of degree of dissection the ravines (Map No.3.1) are classified under the following heads:

<table>
<thead>
<tr>
<th>Category</th>
<th>Depth in mts.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow ravines</td>
<td>more than 2 metres</td>
</tr>
<tr>
<td>Moderate ravines</td>
<td>more than 3 metres</td>
</tr>
</tbody>
</table>

On aerial photographs, it shows light to medium tone on silty clay and dark tone on clay and a medium to coarse texture. On False Colour Composite, ravinous land shows bluish green tone.
Development of ravines is partially controlled by the slope, lithology and climate but mainly by the joints in country rock. Development and reclamation of ravinous land is discussed in detail later in land use chapter.

3.3:5 Old Alluvial Plain

Major part of the study area is covered by this unit and has formed as a result of deposition by drainage system of Sajali, Kopra and Sonar rivers, over an undulating topography developed from the Vindhyan sediments before the onset of fluvial activity. Due to this, the thickness of old alluvium (Map No.3.1) is not uniform in the area. The thickness is more in the central part than to the eastern or western side. The process of erosion is still active and effective, area under cultivation is getting reduced considerably day by day. This unit is under agricultural use due to the top soil preserved in the interfluvial areas.

On aerial photographs, it shows medium grey to dark tone, medium texture subparallel and subdendritic drainage, palaeochannel landform. On False Colour Composite, it gives reddish yellow tone.

3.3:6 Pediment

The pediment (Map No.3.1) occupies a small part of the area, restricted to the foot hills in the northwest, southwest and southeast. Where a thin veneer of soil has developed over Lameta limestone, upper Bhandar sandstone and Ganurgarh shale. It is characterised by
broad, gently sloping rock floor, erosional surfaces of low relief covered with thin veneer of detritus. It depicts a rugged and rolling topography. The origin of pediment is normally attributed to the retreat of scraps exposed to subaerial erosion in a semiarid region.

On aerial photographs, it shows light to medium grey tone and medium texture. The drainage texture is medium to coarse and drainage pattern subparallel and subdendritic. Pediment on the False Colour Composite, shows bluish yellow tone.

3.3:7 Denudational hill

In the study area, all the hills occupy are denudational hills (Map No.3.1). The Deccan Traps and upper Bharder sandstone constitute these hills having high relief of the order of 440 to 500 m.

On aerial photographs, they show light to moderate tone, medium texture, subdendritic drainage pattern and high to moderate resistance to erosion. These hills are the prominent landforms recognised on aerial photographs. On False Colour Composite, these hills shows dark red tone having thick vegetation and light red tone which have scanty vegetation.

3.4 LANDFORMS AND PROCESSES
3.4:1 River Bluff

River bluff are the cliffs developed at the banks of Sonar and Kopra rivers due to undercutting and lateral erosion on the outer side. These are liable to
cave in during or shortly after floods and thaws. These are noticed near Padrai, Mandla, Chakerighat, Hingwani (Map No.3.1). This unit could not be clearly identified on aerial photographs. But it has been confirmed by field checks.

3.4:2 Point Bar

The point bars are areas of sediment accretion on the convex banks of the meandering streams. These features possess light grey tone, coarse texture and slight relief on aerial photographs. The topography consists of a system of low ridges, aligned parallel to the depositional convex bank of the river. Their gradient is gentler towards the active part of channel. The point bars are noticed on the bank of Sonar river near Aslana, Shahpur and Ankkhera.

3.4:3 Cut-off meander

Cut-off meanders are formed during flood season due to increased flow of water when only a narrow neck of land is left between the adjoining ends of the loop. The water finds a new and shorter coarse across the narrow neck and abandons the meander. Cut-off meander in the study area are noticed near Parsoriya (Map No.3.1).

3.4:4 Palaeochannel

Palaeochannels are identified on aerial photographs, by their conspicuous relief, sinuous trend and vegetal and tonal contrasts. They exhibit a sub-parallel disposition to the main channel to which they
can be related on the evidence of their geometry. Their winding nature and numerous abandoned meander loops, scars and scroll exhibit successive changes in the river course. The scrolls, exhibiting successive changes in the old channel, may be the old point bars, however, their point bar topography can be perceived from channel cuts observed near Bari, south of Datpura.

Near the bank of Sonar and Kopro rivers on young alluvial plain and also away from the river on old alluvial plain, the palaeochannels are recognised on the aerial photographs by their darker tone and linearity. Palaeochannels on young alluvial plain are noticed near north of Khojakheri and west of Chirola and on old alluvial plain at Hinota, south of Bansakalan and north of Khirya (Map No.3.1).

3.4:5 *Mesa and Butte*

*Mesa and Butte* are Spanish terms. *Mesa* is (Photo No. 31) used for an isolated table land area with steep sides, formed as a result of a horizontal capping of hard strata having resisted denudation. In the course of time with continued erosion on the sides, a mesa is reduced to a smaller flat topped hill called a butte (Photo No. 31). *Mesa* and *Butte* occur in groups and may be regarded as of late stage in the dissection of a region of horizontally layered rocks.

Practically all the Deccan Traps hills in the study area are showing mesa topography at height of 460 m and also at 500 m. *Mesa* is also noticed on the
south-west of Damoh, having almost horizontal capping of upper Bhander sandstone at 460 m. height with steep scraps (Map No.3.1).

Butte is developed on second flow of Deccan Trap on the north-east of Mangarh at 460 m height.

3.4:6 Gully Erosion

Gullies (Photo No. 51) are the smallest drainage features can be seen on aerial photographs and may be as small as a metre wide and hundreds of metre long. Gullies resulted from the erosion of unconsolidated material by runoff and develop where rainfall can be adequately percolate into the ground, but instead collects and flows across the surface in small rivulets. These initial rivulets enlarge and adopt a particular shape characteristic for different lithologies. Short gullies with v-shaped cross sections tend to develop in sand and gravel, gullies with gently rounded cross sections tend to develop in silty clay and clayey soils. These two types of gullies are dominant in the area and are mainly confined to the Kopra, Sajali and Sonar drainage system (Map No.3.1).

3.5 STUDIES FROM LANDSAT IMAGERY

The interpretation of Landsat imagery is a modern technique in remote sensing. Imagery means photolike images obtained by scanning earth surface feature from a satellite. The Multispectral Scanner System (MSS) in the LANDSAT Satellite records reflected energy from visual to near infrared and far infrared
regions of electromagnetic spectrum. These regions of spectrum are divided into four different bands viz., 4, 5, 6 and 7 representing green, lower red, upper red and lower infrared and far infrared respectively. MSS band 4 was assigned to the region from 0.5 - 0.6 μm, and band 5 from 0.6 - 0.7 μm, band 6 from 0.7 - 0.8 μm and band 7 from 0.8 x 1.1 μm region. The resolution of Landsat data is 57 mts. x 79 mts on the ground.

Landsat imagery provides a good deal of information and certain regional details which could not be observed from aerial photographs or on the ground.

3.5:1 **Visual Interpretation**

For visual interpretation important towns recognised and annotated. Different terrain features were interpreted visually and having the knowledge about the area from aerial photographs and field observations. **False Colour Composite (F.C.C.)** on band 234 of Landsat image on 1:50,000 scale were used.

Band 5 of Landsat imagery displays good details regarding structural hills, escarpment, pediment, old alluvium, point bar, and lineaments. Band 7 of Landsat imagery displays good details regarding structural hills, escarpment, ravinous zone, young alluvium, inselburgs and lineaments. The F.C.C. is comparatively better than the above the shows the details more clearly. With the help of different photo characters like tone, texture, drainage, land use, landforms and lithology a photo-geomorphological map of the area under study has been
prepared (Map No.3.1). Salient features of the study made from F.C.C. are given below:

(i) The Deccan Traps which occupy the NNW and SW portion of the study area is recognised on the Landsat F.C.C. by dark red tone due to presence of vegetation.

(ii) The Lametas which occurs on the low lying area at the base of the Deccan Traps is recognised on Landsat F.C.C. by bluish yellow tone.

(iii) The upper Bhandar sandstone which constitutes the denudational hills on the south-eastern part of Damoh is recognised on the Landsat F.C.C. by their Brownish red tone.

(iv) Ganurgarh shale is recognised by reddish yellow tone, and Bhandar limestone by greenish blue tone.

(v) The upper Rewa sandstone is recognised by dark reddish blue tone.

(iv) Pediments occupy the toe regions of hills with rock cut surface and thin veneer of soil are identified by its bluish yellow tone.

(vii) Old and young alluvial plains identified by their reddish yellow and yellowish blue respectively.

(viii) Lineaments could be traced by their linear alignment and tonal contrasts.

(ix) Ravinous area was identified by their bluish green tone.
(x) The point bars were identified by its light yellow tone near the banks of Sonar and Kopra rivers.

3.6 DRAINAGE

Drainage has an important place in geomorphology. The way it develops, the texture it comes to possess, the patterns it shows and the system it forms - all these throw light on the erosional history, the properties of the rocks, the structure of the rocks, the regional slope and even the climate. Therefore, a systematic analysis of the patterns in the drainage net-work as well as the morphometry of the basins were undertaken.

Stereoscopic examination of aerial photography may prove helpful in identification of the lithology, soils and rock structure of an area. Of the various factors that are considered, drainage is an important element acting as a tool in air photo-interpretation. Drainage, although not reliable as a single factor, may be of great help when used in conjunction with other elements of photo-interpretation. The drainage pattern and texture seen on aerial photographs are indicators of landforms and bedrock type and also suggest characteristics and site drainage condition.

Ghosh (1989) has done a drainage analysis in Jharia coalfield, with the help of aerial photographs, which according to her, helps a lot in knowing its soil
texture, mainly its porosity, permeability, grain size & compactness. These observations may be used as a guide for land use planning over the area. She has also studied drainage pattern and drainage texture on aerial photographs.

3.6.1 Drainage Pattern

Several authors (Zernitz, 1932; Lobeck, 1939; von Engeln, 1940; Parvis, 1950; Howard, 1965) have described certain types of drainage patterns which are considered as basic patterns. A drainage pattern is the planimetric arrangement of streams, etched into the land surface by a drainage systems. The drainage patterns generally reflect the influence of such factors as initial slopes, inequalities in rock hardness, structural controls, recent diastrophism and geomorphic history of the drainage basin. Because drainage patterns are influenced by so many factors they are extremely helpful in the interpretation of geomorphic features and their study represents one of the more practical approaches to an understanding of the structural and lithologic control of landform evolution.

The pattern of drainage in the study area is of three types:

(A) Dendritic Drainage Pattern

The term first used by L.C. Russell (1898) was later defined by Cleland (1916) as a non-systematic or treelike (branching), pattern of valleys extending in many direction in a region of horizontally bedded rocks.
This type of pattern (Map No.3.2) may be noticed in the north-western, north-eastern and south-western parts of the study area. The only guiding factor for this pattern is the initial slope of the land. The Deccan Trap flows are more or less horizontal or have only a slight tilt towards north. The general flow direction of the important rivers are also from SW to NE. To some extent, in the areas of the Deccan Trap, the development of the drainage pattern also depends on the resistance of rocks to weathering. In the study region, three flows have been reported and each flow has its own characteristics. Due to the exposure of different flows along the fractures and joints in basalt, small rivulets have carved out their valleys, and the general patterns of these streams are dendritic. In Deccan Trap region around Bamori, Tetwara and Kharmau villages the dendritic drainage pattern are very well seen.

In the region of Upper Vindhyan formations around Muriya village, Denchri Nala, ESW of Garhakota, the general pattern of drainage is again dendritic. The study of stream courses show that they are following the belts of structural weakness (fractures and joints). At places, they are also found flowing along the soft and easily erodable beds of Sirbu shales. In most cases, they have developed their courses due to headward erosion. In the areas of the Lameta beds also, the general pattern of drainage is dendritic. Due to the presence of fractures on them the streams develop easily on them.
(B) Parallel Drainage Pattern

From the drainage map (Map No.3.2) of the studied region, it becomes clear that the major rivers, viz., Sonar and Kopra, flow more or less parallel to one another and show a parallel pattern rather than a dendritic one. The striking features of drainage pattern may be seen around Piprodha, Jortalala, Pura and also around Aslana villages, the drainage have the parallel pattern. The rock formations are mainly the Ganurgarh and Sirbu shale. The most helping factor for the development of parallel pattern is the general slope of the area towards north-east. All the streams descent along the slope in a parallel fashion. It also appears in most cases that they are flowing along the joints or cracks of rocks.

In the same way on SSW of Garhakota i.e. Hardi, Madho, Sanjra village, the drainage pattern is parallel on upper Rewa sandstone, small streams have developed narrow valleys due to the headward erosion. The slope the escarpment is very steep. The streams develop from watershed and descend downwards along the slope in parallel fashion.

(C) Radial Drainage Pattern

Radial pattern (Map No.3.2) corresponds to a pattern in which stream design is similar to that of a wheel. In the study region the radial drainage pattern found:

(i) Around Jamuniya, Sojanwar, Chopra villages
(ii) Around Kumrai village
(iii) On the south-eastern side of Damoh
(iv) Around Barpati Talab near Athai village

In the study area, the Radial pattern is seen on the scraps of the upper Bhandar sandstone. Here streams originating at the periphery or the flanks of the hill slopes flow down the hills. The radial drainage on the flanks of the hills is therefore of consequent type.
3.7 MORPHOMETRIC ANALYSIS

The word *morphometry* as refers to the measurement of the linear, areal and altitudinal aspects of the drainage basins, treating the latter as fundamental geomorphic units. This quantitative and hence more meaningful, approach to the drainage basins owes its initiation to *Horton* (1945) who injected new blood to a sick science by writing nearly a hundred pages on the *Erosional Development Of Streams*. Such a line of study has received a tremendous impetus in recent years and this increased attention that it has attracted, can be traced to the greater need to understand the geometry of the drainage basins in the tangible terms and compare them with others, with a view to establishing some existing, but hitherto un unravelled, relations among them and their attributes.

After Horton, a good number of workers *Strahler* (1952, 1954, 1958), *Chorley* (1957a,b, 1958a,b), *Clarke* (1967) and *Dury* (1952) to mention only a few have helped to build up an elaborate methodology, so much so that it is a veritable problem today which of the methods to employ. The collection of morphometric data involves such tedious, laborious procedures that there is no unanimity over the value of these techniques among geomorphologists. Some like *Hettner* (1921), seem to be highly sceptical about the final outcome while others, like *Clarke* and *Orrell* (1958) are not quite certain if the results would be commensurate with the time and labour spent on such a strenuous analysis.
The present analysis is based on the results of different morphometric methods which have been applied to bring out clearly the characteristics of drainage and the nature of scope of the drainage basins. These methods have also helped in identifying various erosional surfaces. These features together provide sufficient clues to visualise and reconstruct the geomorphic history of the region. This analysis has also helped to pin point those areas where drainage or relief features need intensive investigation. To confirm the validity of the morphometric analysis, several methods have been used for the analysis of a single feature, and results have been compared. For example, in the study of erosion surface different morphometric methods have been applied and their results have been compared, and it is found to a great satisfaction, that the results, obtained by different methods tally to a great extent. The results have been further checked from the large scale maps and also in the field to ascertain their authenticity.

The employment of radar imagery in place of landsat F.C.C. has attracted much attention to analyse drainage basins because of the varied opinion on its usefulness. The classic study undertaken by McCoy (1969) confirmed the potential of K-band SLAR (Wave-length about 1 cm.) for the identification, mapping and measurement of such hydrologic parameters as drainage area, stream length, stream order, basin perimeter and ratios of bifurcation, length and circularity. McCoy
found that the radar imagery at a scale of 1:200,000 could produce drainage information comparable to that derived from a 1:62,500 topographic map. Mekel (1972) also noted the considerably less detail of drainage patterns in the radar image than in the high altitude aerial photographs.

**METHODODOLOGY**

The drainage basin area may be defined as the area which contributes water to a particular channel or set of channels (Leopold et al. 1964). The delimitation of sub-basins in this area under investigation has been done on the basis of perennial streams marked on the separate tracing paper sheet and all other streams of each order. The measurements for the morphometric analysis has been done from the topsheets of Nos. 55M/1 and 55M/5 on 1:50,000 scale.

The whole area under investigation has been divided into sub-basins (Map No.3.2) of the major tributaries by marking of water-divides. There are four sub-basins in this area namely (i) Sonar-Gadheri basin (ii) Sonar basin (iii) Kopra basin (iv) Sajali basin.

**3.7:1 Stream 'Orders'**

The streams are ordered to measure the position of the stream in the hierarchy of the stream network and it is useful in ascertaining the dimension of the river basin. Stream order of highest number indicates the main river, where as the first order includes the stream in headward erosion.
After marking the boundaries of the four basin on the separate drainage map (Map. No. 3.2) the streams were ordered. Stream order is defined as a measure of the position of a stream in the hierarchy of tributaries (Leopold et al., 1964). Out of the four systems of ordering the streams, that are available (Gravelius, 1914; Horton, 1945; Strahler, 1957 and Scheidegger, 1970), Strahler system, which is in fact a slight modification of Horton's, has been followed because of its simplicity. Accordingly, the smallest of the streams without any tributaries were designated the first order streams, and those that were formed by the confluence of two such unbranched streams were assigned the second order and so up the order.

In this ordering the Sonar river and the Sajali river were found to be the sixth order stream and the Koprha river was found to be a fifth order stream (Table No. 6).

3.7:2 Bifurcation Ratio

The bifurcation ratio (Rb) is the ratio between the number of stream segments of a given order (NU) and the number of stream segments of the next higher order (NU+1) (Horton, 1945). This can be found by the following equation:

\[ Rb = \frac{NU}{NU+1} \]

These bifurcation ratios have been determined and mentioned in Table 6.
It will be seen that out of 15 bifurcation ratios calculated for the four drainage basins under study, 11 fall between 3.42 and 4.85. The unusually high ratio of 6, 8 and 9 was obtained between third, fourth and fifth order streams in Sonar-Gadheri basin, Sonar basin, Kopra basin and Sajali basin. This is because there is only one fifth order stream in each Sonar Basin, Kopra basin and Sajali basin and one fourth order stream in Sonar basin even though there are as many as 23 fourth order stream in the three basins and 8 third order stream in Sonar basin.

3.7:3 Stream Numbers

The number of stream segments present in each order were then counted and tabulated (Table 6).

It will be seen from the Table 6 that the number of streams decreases as the order increases. Graphical representation of these data on semi-logarithmic papers gives straight-line plots (Fig.3.1A, B). The best fitting regression equation of the exponential form are also given for the plots in this figure. The regression were found out by using the basic from \( \log Y = a \pm bx \), where 'a' is the value of the point of intersection of the plotted line with the logarithmic ordinate, i.e., the value of Y and X equals zero and 'b' the regression coefficient, which expresses the slope of the plotted line, its sign indicating whether there is a direct (+) or inverse (-) relationship between X and Y. In the graph, the stream order is independent variable and is on the arithmetic abscissa and the stream number, which
FIG 31A: PLOT OF STREAM ORDER AGAINST STREAM NUMBER

KOPRA RIVER BASIN

SAJALI RIVER BASIN

\[ \log y = 3.9797 - 0.66x \]

\[ \log y = 3.010 - 0.99x \]

Stream Orders

Stream number
FIG 3.1B: PLOT OF STREAM ORDER AGAINST THE STREAM NUMBER
is dependant variable, is on the logarithmic ordinate. The slope of the plotted line is obtained (as its tangent) by considering the value of its intersection on the abscissa.

These plots satisfy Horton's (op.cit.) first law of stream numbers which states that "the number of streams of different orders in a given drainage basin tend closely to approximate an inverse geometric series in which the first term is unity and ratio is the bifurcation ratio."

3.7:4 Weighted Mean Bifurcation Ratio And Regression Coefficient

To arrive at a more representative bifurcation number Strahler (1953) used a weighted mean bifurcation ratio obtained by dividing the product of bifurcation ratio x No. of streams involved in ratio in total to the No. of streams involved in ratio in total. Schumm (1956) has used this method to determine the mean bifurcation ratio the value 4.87 of the drainage of Perth Amoby, N.J. The values of the weighted mean bifurcation ratio thus determined are close to each other (Sonar-Gadheri basin 4.37, Sonar basin 4.88, Koprabasin 3.75 and Sajali basin 3.75, Table No.6). Morisawa (1959) while conducting research on geomorphology of the basin of the Appalachian plateau region found that the bifurcation ratio was constant for different drainage basin.

Maxwell (1955), showed that the bifurcation
### TABLE No. - 6

#### QUANTITATIVE CORRELATION OF DRAINAGE BASINS

<table>
<thead>
<tr>
<th>Drainage Basin No.</th>
<th>Order</th>
<th>No. of streams</th>
<th>Bifurcation Ratio</th>
<th>Log 10 NW</th>
<th>No. of streams involved in ratio</th>
<th>Product of bifurcation ratio × No. of streams involved in ratio</th>
<th>Weighted mean bifurcation ratio</th>
<th>Total of column 7</th>
<th>Total of column 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SONAR-</td>
<td>1</td>
<td>640</td>
<td>1:2 = 4.29</td>
<td>2.80618</td>
<td>789</td>
<td>3384.81</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GADHERI</td>
<td>2</td>
<td>149</td>
<td>2:3 = 4.65</td>
<td>2.1731863</td>
<td>181</td>
<td>841.65</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RIVER</td>
<td>3</td>
<td>32</td>
<td>3:4 = 4.00</td>
<td>1.50515</td>
<td>40</td>
<td>160</td>
<td>4.37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BASIN</td>
<td>4</td>
<td>8</td>
<td>4:5 = 8.00</td>
<td>0.9030899</td>
<td>9</td>
<td>72</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1</td>
<td></td>
<td>0.000</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Total= 4458.46</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>SONAR</td>
<td>1</td>
<td>170</td>
<td>1:2 = 4.85</td>
<td>2.2304489</td>
<td>205</td>
<td>994.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RIVER</td>
<td>2</td>
<td>35</td>
<td>2:3 = 4.37</td>
<td>1.544068</td>
<td>43</td>
<td>187.91</td>
<td>4.88</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BASIN</td>
<td>3</td>
<td>8</td>
<td>3:4 = 8.00</td>
<td>0.9030899</td>
<td>9</td>
<td>72</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1</td>
<td></td>
<td>0.000</td>
<td></td>
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<td>Total= 257</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>KOPRA</td>
<td>1</td>
<td>462</td>
<td>1:2 = 3.42</td>
<td>2.664642</td>
<td>597</td>
<td>2041.74</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RIVER</td>
<td>2</td>
<td>135</td>
<td>2:3 = 4.65</td>
<td>2.1303338</td>
<td>164</td>
<td>762.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BASIN</td>
<td>3</td>
<td>29</td>
<td>3:4 = 4.8</td>
<td>1.462398</td>
<td>35</td>
<td>168</td>
<td>3.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>6</td>
<td>4:5 = 6</td>
<td>0.7781512</td>
<td>7</td>
<td>42</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1</td>
<td></td>
<td>0.000</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Total= 803</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Total= 3014.34</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAJALI</td>
<td>1</td>
<td>561</td>
<td>1:2 = 3.59</td>
<td>2.7489629</td>
<td>717</td>
<td>2574.03</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RIVER</td>
<td>2</td>
<td>156</td>
<td>2:3 = 3.9</td>
<td>2.1931346</td>
<td>196</td>
<td>764.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BASIN</td>
<td>3</td>
<td>40</td>
<td>3:4 = 4.44</td>
<td>1.60206</td>
<td>49</td>
<td>217.56</td>
<td>3.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>9</td>
<td>4:5 = 9</td>
<td>0.9542425</td>
<td>10</td>
<td>90</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1</td>
<td></td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total= 972</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total= 3645.99</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ratio can be equated to the antilogarithm (regression coefficient) of the slope of the regression of logarithm of number of stream segments of a given order. The regression of logarithm of stream number of each order in these has been plotted (Fig.3.2). In general, all the four basins have almost similar characteristics between the first and fifth order streams. The regression coefficient (tangent of the angles formed by the lines on the abscissa) of the Sonar-Gadheri basin 1.37, Sonar basin 1.19, Kopra basin 1.27, Sajali basin 1.35).

3.7:5 Stream Length

The length of the entire stream segments of the different orders were measured by Rotameter. The total length of the streams for each order as well as the mean length of the streams of each order were found out. The length ratio, which is the ratio of mean length of the streams of a given order to the mean length of the streams of next lower order, was then calculated for each pair of orders.

It was found that the mean lengths of the streams increased with the increasing order number in Sonar-Gadheri basin and in Sajali basin. This exponential relation is well brought out by the graphical plots on the semi-logarithmic paper (Fig.3.3A, B). Best fit regression equations here obtained as before. The total and mean length as well as length ratios for the four drainage basins are tabulated in Table 7.
FIG. 3.2 REGRESSION OF NUMBERS OF STREAM SEGMENTS ON STREAM ORDER OF TABLE 1
FIG33A: PLOT OF STREAM ORDER AGAINST MEAN LENGTH

SONAR GADHERI
RIVER BASIN

SONAR
RIVER BASIN

Log \( y = 4.140 - 3.6 \times x \)

Mean length (in Kms)

Stream Orders
FIG. 3.3B: PLOT OF STREAM ORDER AGAINST MEAN LENGTH

KOPRA
RIVER BASIN

SAJALI
RIVER BASIN

Log y = 2.86 - 2.6 x

Mean length (in Kms)

0 1 2 3 4 5 6 7 8
Stream Orders
<table>
<thead>
<tr>
<th>Drainage Basins</th>
<th>Order No.</th>
<th>No. of streams</th>
<th>Total length</th>
<th>Mean Stream Length</th>
<th>Length ratio</th>
<th>Weighted mean length ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>SONAR-</td>
<td>1</td>
<td>640</td>
<td>324</td>
<td>0.506</td>
<td>1.79</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>149</td>
<td>135</td>
<td>0.906</td>
<td>2.40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>32</td>
<td>70</td>
<td>2.18</td>
<td>2.52</td>
<td>1.91</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>8</td>
<td>44</td>
<td>5.5</td>
<td>1.727</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1</td>
<td>4</td>
<td></td>
<td>1.85</td>
<td></td>
</tr>
<tr>
<td>SONAR</td>
<td>1</td>
<td>170</td>
<td>128.5</td>
<td>0.755</td>
<td>2.70</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>35</td>
<td>71.5</td>
<td>2.04</td>
<td>1.55</td>
<td>2.57</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>8</td>
<td>25.5</td>
<td>3.18</td>
<td>4.71</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1</td>
<td>15</td>
<td></td>
<td></td>
<td>2.98</td>
</tr>
<tr>
<td>KOPRA</td>
<td>1</td>
<td>462</td>
<td>295</td>
<td>0.638</td>
<td>2.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>135</td>
<td>177</td>
<td>1.31</td>
<td>2.38</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>29</td>
<td>90.5</td>
<td>3.12</td>
<td>0.746</td>
<td>2.06</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>6</td>
<td>14</td>
<td>2.33</td>
<td>2.57</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1</td>
<td>6</td>
<td></td>
<td></td>
<td>1.93</td>
</tr>
<tr>
<td>SAJALI</td>
<td>1</td>
<td>561</td>
<td>230.5</td>
<td>0.410</td>
<td>1.23</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>156</td>
<td>79</td>
<td>0.506</td>
<td>3.45</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>40</td>
<td>70</td>
<td>1.75</td>
<td>2.21</td>
<td>1.72</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>9</td>
<td>35</td>
<td>3.88</td>
<td>1.03</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1</td>
<td>4</td>
<td></td>
<td>1.98</td>
<td></td>
</tr>
</tbody>
</table>
The semi-logarithmic plots of the mean length are more or less straight lines and therefore satisfy Horton's (op. cit.) second law which states that "the average lengths of streams of each of the different orders in a drainage basin tend closely to approximate a direct geometric series in which the first term is the average length of stream of the first order".

However, since Strahler’s method of ordering has been followed which differ fundamentally from Horton’s with respect to the length of the stream segments of different orders (see Fig. 3.4), log-log plots of the total stream lengths (Fig. 3.5A, B) were also made as suggested by Strahler (1956); these satisfy a revised law of stream lengths (Chorley, 1957b) which states that

\[
\frac{1}{2} \sqrt{1} \quad \frac{2}{2} \sqrt{1}
\]

Strahler's method
Horton's method

Fig. 3.4

"the total length of streams of each of the different orders in a drainage basin tend closely to approximate an inverse logarithmic series in which the term is the total length of streams of the highest order".

3.7.6 Drainage Frequency

A study of drainage frequency (Map No. 3.3) of streams is an expression of the spacings of the smallest drainage lines both intermittent and perennial. According to Horton (1945) what are referred to as drainage texture includes both drainage density and
FIG. 35A: PLOT OF THE TOTAL STREAM LENGTH AGAINST THE STREAM ORDERS

SONAR GADHERI RIVER BASIN

SONAR RIVER BASIN

\[ \log Y = 2.518 - 3.2X \]

\[ \log Y = 2.696 - 2.4X \]

Total stream length (in Kms)

Stream Orders
FIG 35B: PLOT OF TOTAL STREAM LENGTH AGAINST STREAM ORDER

KOPRA RIVER BASIN

\[ \log y = 2.9294 - 3.6 \times x \]

SAJALI RIVER BASIN

\[ \log y = 2.2041 - 3.4 \times x \]

Stream Orders

Total stream length (in Kms)
drainage frequency. The drainage frequency is calculated by the total number of streams in a drainage basin divided by the area of the drainage basin, or the drainage frequency is calculated by the total number of streams in a unit area given drainage basin (Horton, 1945).

\[ \text{Fs} = \frac{N}{A} \]

Fs represents drainage frequency, N equals total number of streams in a unit area and A represents the unit area.

**Method of Study**

The drainage map of the whole area on the scale two centimetres to one kilometre, was first divided into 2 cm. sq. The total number of streams in each square was then plotted in the centre of the square. Isopleth at two-stream interval were drawn. The resulting map of drainage frequency brings out the regional variation very clearly (Map No.3.3). The study of drainage frequency of all the four basins has been undertaken to identify the regions of varying drainage frequency into different categories of high, medium or low. The study of this map reveals that the frequency of streams in all the four basins, depends upon a number of variable factors, which may be divided into two categories:

(A) **Natural factor**

(B) **Map factor**

(A) **Natural Factors**

The important factors which have effected the drainage frequency of all the basins are as follows and
the relative importance of these factors varies from place to place:

(i) Climate

(ii) Lithological and structural characteristics of rocks

(iii) Relief

(iv) Infiltration capacity

(v) Vegetation

From the isopleth map of the drainage frequency of Sonar-Gadheri basin, Sonar basin, Kopra basin and Sajali basin, it is clear that in general, the Sajali river basin and the Sonar-Gadheri basin has a high frequency than that of the Sonar basin and the Kopra basin. This higher frequency may be attributed to the high rainfall and the lithological and structural characteristics of upper Vindhyan rocks (Bhander Group) having sufficient relief. To some extent climate also plays a role in the development of drainage. As this part of the basin receives heavy rains for 3 to 4 consecutive months, it influences directly the quantity and character of run-off.

Structure, lithology and relief are also important factors, in the development of drainage. All the four basins are comprises of Deccan Traps, Lametas, upper and lower Bhander sandstone, Sirbu shales, Ganurgarh shales and upper Rewa sandstone with joints and fractures. Greater relief along the watershed presents favourable conditions for the development of
numerous streams.

Although the Sajali basin and the western part of the Sonar Gadheri basin is thickly covered with vegetation, its effect in the development of drainage however, less perceptible in comparison to that of relief, lithology and structural contours.

In some part of the Sonar-Gadheri basin on the western side, the drainage frequency is between 10-12 per sq. km. This high frequency is mainly due to dissection of Ganurgarh shale which give rise as small hills and gave a helping hand in the development of numerous stream.

In the Kopra basin and Sonar basin the drainage frequency over a large area is between 2 to 6 per sq.km., except of few places where drainage frequency is 0 to 2 only. This is only due to lack of relief and absence of impermeable rocks on the surface. But in some parts of the Kopra basin, the frequency varies between 6 to 8. The reason for this is mainly the surface rocks and the local relief.

Some parts of the Sonar-Gadheri basin (bottom of the basin) falls in the Deccan Trap region. These areas have a drainage frequency between 6 to 10. Areas of such frequency increase towards the watershed part in the east.

(B) Map Factor

In the study of drainage frequency, the effect of map factor is also of a great significance. In the
map, the most important factor in determining the frequency of the drainage is the scale of the map and accuracy of the mapping. Needless to mention, with large-scale maps one will get a more accurate picture of drainage frequency than from the small scale ones. Considering all these points, the drainage analysis of the basin has been done on 1:50,000 toposheet.

3.7.7 Drainage Density

Horton (1945) has described the drainage density as the total length of streams in a basin divided by the area of drainage basin:

\[ D_d = \frac{L}{A} \]

Where \( D_d \) represents the drainage density, \( L \) represents the total length of the streams and \( A \) the total area of the basin.

Method of study

The drainage map on the scale 2 cms to one kilometre was first divided into 2 cms sq. In the centre of the square was plotted the total length of the streams in each square. Isopleth map of the drainage density has been drawn at the interval of 1 km/sq.km.

The drainage density (Map No.3.4) of the Sonar-Gadheri basin, Sonar basin, Kopra basin, Sajali basin are 1.89, 0.89, 1.08, 1.42. The Sonar-Gadheri basin show high drainage density due to weak rocks such as shales. The Kopra basin and Sajali basin show a region of medium density, while Sonar basin show a low density
<table>
<thead>
<tr>
<th>Drainage Basin</th>
<th>Drainage density</th>
<th>Drainage frequency</th>
<th>Constant of channel maintenance (I/D)</th>
<th>Distance of over land flow (1/2D)</th>
<th>Total area of the basin (in sq.kms.)</th>
<th>Total length of all the streams (in Kms.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SONAR-GADHERI RIVER BASIN</td>
<td>1.89</td>
<td>2.72</td>
<td>0.529</td>
<td>0.264</td>
<td>304.44</td>
<td>577</td>
</tr>
<tr>
<td>SONAR RIVER BASIN</td>
<td>0.89</td>
<td>0.79</td>
<td>1.12</td>
<td>0.561</td>
<td>268.265</td>
<td>240.5</td>
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<tr>
<td>KOPRA RIVER BASIN</td>
<td>1.08</td>
<td>1.18</td>
<td>0.925</td>
<td>0.462</td>
<td>534.415</td>
<td>580.5</td>
</tr>
<tr>
<td>SAJALI RIVER BASIN</td>
<td>1.42</td>
<td>2.61</td>
<td>0.704</td>
<td>0.352</td>
<td>292.88</td>
<td>418.5</td>
</tr>
</tbody>
</table>

Total Drainage Density of the study area = 1.29
Total Drainage Frequency of the study area = 1.74
Total Constant of Channel Maintenance of the study area = 0.775
Total Distance of over land flow of the study area = 0.387
due to coarse grained rocks such as sandstone. Chorley (1969) suggested "Drainage density is one of the most independent morphometric variable affecting both the hydrologic and physiographic development of drainage basin".

3.8 Discussion And Conclusion

As mentioned by Strahler (1968), the usefulness of the stream order system and bifurcation ratio depends on the premise that on the average, if a sufficiently large sample is treated, the order number will be directly proportionate to the size of the contributing watershed, to channel dimension and to stream discharge at that place in the system. Since order numbers and bifurcation ratios are dimensionless, two drainage networks differing greatly in linear scale can be compared with respect to corresponding points in their geometry through the use of order numbers and bifurcation ratio. Bifurcation ratios characteristically range between 3.0 and 5.0 for a watershed in which the geologic structures do not distort the drainage. The drainage material tends to display geometrical similarity. Therefore, it is not surprising that the ratio shows only a small variation from region to region. High bifurcation ratios are expected in regions of steep dipping rock strata where elongated strike valleys are confined between hogback ridges.

In the study region, the bifurcation ratios, particularly in the range of third order and fourth order streams, are higher in all the four basins. In
this case of Sonar-Gadheri basin, this may be accounted for the steep sloping Deccan Trap hills and presence of large vertical joints on upper Rewa sandstone at Abchand Reserve Forests. Similarly, for Sajali river basin, the high bifurcation ratio is due to presence of high steep sloping Deccan Trap hills on the western part of the region. In Sonar basin, the high bifurcation ratio due to presence of fractures and joints on Sirbu shale, Bhandar limestone and Ganurgarh shales. In Kopra basin this high bifurcation ratio may be due to the presence of master joints on upper Bhandar sandstone and where the bifurcation ratio is lower in all the four basins may be due to drainage falls in the plains and unjointed portions.

In the study region, the Sonar river has been divided into two basins because of the peculiar difference between the Sonar-Gadheri basin and Sonar basin. It is very clear that, the Sonar-Gadheri basin has a less infiltration capacity and more run-off because it has very fine or closely spaced drainage network than the Sonar basin which has coarse drainage and more infiltration capacity. This Sonar basin has also much thick deposits of alluvium. The Sonar-Gadheri basin shows much structural disturbances i.e. presence of steep sloping Deccan Trap hills, large vertical joints, fracturing and higher relief than the Sonar basin. The Sonar basin also show low frequency and density due to near flat plains. It may be said that the areas which gradually decrease in relief the number
of streams per square kilometre also decreases.

Summarising the above results, the quantitative analysis of streams in drainage basins in different lithologies have been considered. In the area under study stream order, stream number, bifurcation ratio, stream length, weighted mean bifurcation ratio, weighted mean length ratio, drainage density and drainage frequency have been tested. Various laws are helpful in explaining the behaviour of drainage in the area. It is noticed that mostly Horton's law holds good, but sometimes sizeable departure are noticeable, due to the different lithologies in the region under study. Since the four basin have many uncommon factors, influencing their drainage network i.e., underlying lithology and structure, a perfect similarity can not be expected in these drainage basins.

3.9 The adoption of drainage to the underlying structure

Practically, all the tributaries of the major rivers are subsequent streams. Generally they flow parallel to the strike of the country rock and change their direction according to the outcrops of underlying rocks. From the study of drainage pattern on Deccan Trap terrain, it has become clear that the structure of the underlying rocks has affected the drainage pattern. The study of toposheets reveals that the present drainage intensity and pattern are gradually organised in accordance with initial slope and the underlying
structure of Deccan Trap.

In the Deccan Trap region, the development of streams is controlled by the pattern of the joints of the basaltic rocks. During cooling and consolidation of the lava, there had been a considerable contraction giving rise to a large number of cracks and joints. In general, the joints in the volcanic rocks run in all directions. Along these joints and cracks, countless gullies develop in the rainy season and due to a long continued action of the running water, they have carved out their valleys. Numerous short tributaries and gullies are extending themselves along joints and fractures by headward erosion and developing a dendritic pattern. The channels followed by streams as a whole are narrow and shallow, and the number of streams per unit area is quite high in the marginal areas of the study area. These drainage characteristics are observed in the early mature stage in the cycle of erosion.

From the drainage frequency map (Map No.3.3) and drainage pattern (Map No.3.2) in the Vindhyan country it may be observed that the relation between the underlying structure and drainage pattern is very close. The study of toposheets reveals that the present drainage has gradually organised in accordance with the underlying structure of the Vindhyan formations. In the study area on the Vindhyan country, the development of streams is controlled by the pattern of joints and fractures (belts of structural weakness) or flow along the soft and
easily erodible beds of shales.

The parallel pattern of drainage developed by the Kopra river is the beautiful example of adoption of drainage along the major joints and fractures. Sajali, Sonar and Kopra rivers have adopted awkward courses at the junction of shales and sandstone. Near Ghogra Ghat Sonar river has turned nearly 90 degrees to avoid the hard resistant limestone. There are many similar streams whose courses are controlled by the geological structures and in many places, they have adopted very awkward courses to avoid the resistant sandstone and limestone.

3.10 Evolution Of Drainage

The thick deposits of the outliers of the Deccan Trap in Damoh district and even in Son valley (Rao, 1967) indicate that at the end of the lava eruption, the whole region must have been completely covered with the volcanic material and it had completely obliterated the mature Vindhyan topography. When the eruption of lava had finally ceased, a few major consequent streams must have developed on the initial surface of the lavas, guided probably by the general slope of the lava flows. In the absence of any controlling structure in the nearly horizontal lavas, the drainage development subsequently must have been largely through a multitude of inequivalent streams branching dendritically. The fluvial cycle presumably ran its whole course and brought the country to the base level.
A new drainage started developing over these slopes. As the cycle progressed, more and more of the lava material got removed, so much so that the underlying upper Vindhyans got exposed to view once more at places. This exhumation must have taken place within a short time after for commencement of this cycle of erosion, because, the difference between the highest elevation reached, on the upper Vindhyans, nearly 460 m. and on the Deccan Traps in the study area, nearly 500 m. above M.S.L. is only 60 metres. The drainage line must have been confronted by these newly emerged hard upper Vindhyans here and there. The smaller among the streams must have adopted themselves to the changed environment by avioding the upper Vindhyans and flowing over the relatively soft basalts. The bigger rivers must have tried to keep their original courses over the upper Vindhyans also and got superposed over the harder and older rocks.

3.11 WEATHERING

Ever since the consolidation of earth's crust and formation of water upon the earth, after it has sufficiently cooled, the rocks have been subjected to the wearing effects of geological agencies like running water, wind, sea, waves, glaciers etc. The rocks have been attacked and bit by bit they have been made smaller and smaller. The worn down particles are then taken away from the place of their formation to be deposited elsewhere and their gradual consolidation makes the
sedimentary rocks. Weathering involves the process of breaking of rocks to smaller particles and decomposition of rocks.

The combined effect of weathering processes results in either weakening, fragmentation or decomposition of the bed-rock at or near the surface of the earth. Deep weathered soil cover and the presence of the laterite cover are characteristic feature not only of the hill tops but also of several areas scattered here and there in the study area. It may be added that while in the Vindhyan rocks physical weathering is dominating and on the Deccan Trap, the effect of chemical weathering is more marked.

The various factors which affect weathering are:

(i) Climate,
(ii) Petrological and lithological characteristics of rocks types,
(iii) Structure, and
(iv) Vegetation.

Amongst the physical elements, the role of climate, particularly of rainfall, has great importance in the rate of weathering. All these factors have played an important role individually and collectively, but to what extent each factor has influenced weathering would be difficult to assess. It is true that structure and lithology have a great role to play in the intensity and extent of weathering. The well-developed joints and fractures in the upper Vindhyans are the weakest parts
where the effect of the physical weathering is observed first. It is noticed that in the upper Bhander Sandstone and the upper Rewa sandstone, where the joints are present. Mechanical weathering starts along the joints and proceeds downwards. The roots of the trees penetrating along the vertical joints split the rocks and as the roots penetrate deeper, the joints and fractures of the rocks are windened.

Climate and Mechanical Weathering

The climatic factor, especially temperature and rainfall decide to a great extent the nature and intensity of weathering. Due to climatic variation, one or the other process of weathering predominates in the region.

It may be mentioned here that the area under study is crossed by the Tropic of cancer and the analysis of the data of temperature and rainfall shows that the region may be placed under the monsoon type of climate. The climatic conditions of the study area have already been discussed in the first chapter.

The nature of Weathering

The major climatic variations in temperature, rainfall and humidity affect the rate of weathering directly or indirectly. The temperature conditions mainly decide the type of physical weathering. The repeated process of heating and cooling of sandstone and shales which are poor conductor of heat, gives rise to stress and strain in the upper layers of the rock mass
and in long course of time, with the same changes in temperature, the rocks scale along the joints and bedding planes into thin layers.

The variation in mineral composition and diversity in colour of rock constituents of the Vindhyan sandstones have also considerably given a helping hand in the mechanical weathering of rocks. It is also noticed that the weathered material in the form of rock pieces or weathered soil produced by weathering is washed to long distance by water, and the new barren surface is exposed again.

3.11:1 The regions of intensive mechanical weathering in the study region

From the regional point of view, the region most affected by the action of mechanical weathering are:

(A) The Bhandar Escarpment
(B) The Hill tops
(C) The River banks.

It may be mentioned that the rest of the study area is mainly covered by transported soil and the underlying rocks are not exposed on the surface. On the contrary, field studies of the Deccan Trap region show that it is affected more by chemical weathering.

(A) The Bhandar Escarpment

The Bhandar escarpment runs in a north-east southwest direction. It's southern face, mainly the
upper half, has bare rock surface, covered only by scanty vegetation and is affected by mechanical weathering, particularly along the banks of rivulets. The presence of well-marked joints and fractures in the upper Bhander sandstone accelerates the physical weathering. At the foot of the scrap, the weathered and eroded material supplied from the crest of the escarpment, is deposited in the form of debris slope. This has covered the lower half of the scrap. The coarser material is deposited and the fine soil is washed away to a long distance. The author has also observed assorted rock pieces all along the crest of the scrap. In the same way along the hills to the east of Damoh, the bare surface is seen to be greatly affected by the weathering, thin layers of weathered rock breaking along the joints and fractures.

(B) The Hill Tops

The hill tops in the upper Vindhyan region are not completely flat being covered by a thin veneer of residual soil (Photo No. 38) varying in the colour from reddish brown to grey. It is noticed that the hills, running to the northeast and to the east of Damoh, are mostly devoid of vegetation except for thin grass cover and scanty shrubs. The rocky surfaces are exposed all along the hill sides and have been attacked by weathering. The scaled pieces are found strewn all over the surface. The pebbles, rock pieces and coarse sand are the characteristic deposits of these areas. The weathered material on hill tops, varies from a few
Photo No. 38: Showing weathering of hill tops of upper Bhandar sandstone.

Locality: Damoh.
centimetres to many centimetres in depth. The hills running, to the east of Damoh, are mainly composed of Sirbu Shales with the upper Bhandar sandstone as the covering rock. The shales and limestone, having some calcareous material, are more attacked by chemical weathering. The action of gully erosion become more vigorous in the rainy reason.

(C) The River Banks

The Gadheri river valley of the study area have cut across the rocky beds. The Gadheri river banks are often seen to standing like walls. The well-armed joints in the upper Rewa sandstone may be noticed along the banks. The growth of tree roots has aided in widening of the joints are fractures. The exposed surface of river banks is directly affected by changes of temperature and the surface rocks scale off in the form of weathered material. About 3 Km. north-west of Garhakota disc-like structure with diametres of 0.90 to 1.20 metres may be seen in Ganurgarh shales along the stream sections, which might have formed due to spheroidal weathering.

3.11:2 Chemical Weathering

There is no dividing line between the areas of physical and chemical weathering in the study area and it must be made clear that no rock is subjected merely to a single process. Both the processes act hand in hand, though their relative importance may vary from area to area.
(A) The Deccan Trap Basalt

The analysis of chemical composition and other lithological and structural features of the Deccan Trap basalt gives the idea that in this formation, chemical weathering is more active than mechanical weathering.

With the break of the monsoon, the vigorous action of chemical weathering in the Deccan Trap, starts in the characteristic form of spheroidal weathering. The water enters through cracks and joints and reaches to a considerable depth. As the water goes through the joints which are more or less in all directions, the edges and corners of the rocks are attacked by chemical action. The process of hydration and oxidation takes place with ferromagnesium and other mineral constituents of the basalts. The surface weathered material becomes soft and increases in volume; this further extents strain on the solid mass. This long-continued process of chemical weathering cause a slow rounding of the corners and converts the rock mass into numerous spheroidal boulders. As the process penetrates deep low, the weathered material is scaled off into concentric layers.

It may also be noted that in the rainy season, due to heavy showers, the water table of the region becomes high and it is possible that a considerable amount of chemical weathering takes place underground and rounded boulders and coarse materials are formed before they are exposed on the surface by weathering and
erosion. With the cessation of the rains, the water-table of the region falls gradually and in the long dry season from October to next June, mechanical weathering becomes more active.

The weathered material is of two types:

(i) The decomposed rock mass in the form of coarse to fine-grained clayey soil.

(ii) A large number of ball-like boulders varying in size from a few centimetres to many centimetres in diameter. The weathered material in the form of laterite may also be noticed on the hill tops of the region, which is the product of further action of chemical weathering.

The average rainfall is about 117.226 cms which is moderately high and comes in heavy showers. During such showers, the surface is completely submerged under water and the weathered material is washed in the form of sheet erosion and to some extent, the rills descending along the hill slope are flooded with dissowed and suspended material. As the distance increases from watershed, the erosive power of rills increases, thus the decomposed soil and rounded boulders are transported. But as soon as the water in the numerous rivuletts reaches to the lower part of the hills, where the velocity of running water is checked by low gradients, the rounded boulders are left on the foot hills and the coarse to fine material is washed away for a long distance. The scree thus formed is another
region of intense chemical weathering. The space between the boulders is filled by soil and is soaked with water. During the rainy season, this scree slope looks like a swamp. The boulders thus are further reduced in size, giving rise to the soil which could be removed by the running water. A large number of rounded boulders may be seen scattered along the foot hills and the hills sides which are to be removed, while the loose material between them has already been washed away. There is one very interesting fact i.e. the size of the boulders varies considerably according to the composition of different lava flows. The material of the first flow is weathered into small rounded boulders. In the same way, the material of the third flow, the top of which comes at height of 500 metres, is weathered into comparatively big boulders. It is also marked that rocks rich in iron content are subjected to the process of oxidation. They are attacked by water and oxygen. The dull reddish brown colour of the weathered material derived from the basalt has a characteristic colour produced by the action of chemical weathering (oxidation). The intense action of spheroidal weathering may be noticed 0.8 kms. west of Jamunia and by the side of cart track which passes through the gap between Sondni Reserve Forest and Nipania hill. To the west of Patharia village, on the hill tops, the weathered material in the form of reddish brown colour has been noticed up to a depth of more than 30 centimetres; while along the hill slopes, small rounded boulders are noticed forming a debris slope. This debris is further
weathered to finer detrital and is removed under erosion.

(B) Lameta

This formation is also heavily affected by chemical weathering. In this rock, calcium carbonate predominates, which is largely affected by the process of solution or carbonation. The carbon-dioxide derived from decaying of organic matter, acts as a weak acid which converts the calcium carbonate into calcium bicarbonate. This calcium bicarbonate, soluble into water, is taken away in the ground water.

In this way, outcrops of this rocks is directly affected by this processes. Due to long continuation of this process, rock masses become weak, the joints and cracks enlarge in size. Due to weathering and erosion, potholes have developed in the limestone. To the southwest of Nadrai village shales have formed prominent disc-like structures with diameter of 1 to 1.2 metres due to spheroidal weathering as seen in stream sections. To the west of Patharia Railway Station, about 1½ Km. away, big boulders of the Lameta beds are found lying on the foothills which have been detached from the rocks mass and have come down due to the force of gravity.

3.11:3 Biological Weathering

Biological weathering in the region is not so significant as the other two process of weathering. However, the effect of roots of trees penetrating along the joints of the rocks cannot be neglected. This type
of weathering is mostly noticed in highly-jointed rocks of upper Rewa sandstone in Abchand Reserve Forest especially along the Gadheri river (Photo No. 39) banks and also at Basari village where the roots penetrating along the joints in Bhandar Limestone (Photo No. 40).

3.12 VALLEY DEEPENING AND WIDENING

The valleys in the Deccan Trap regions are shallow and of open nature. They are still being deepened downward by vertical cutting. It has also been noticed that in the Deccan Trap region, in river Sonar, the flood plains are lacking in their upper courses, while along the hill ranges, a large number of gullies are developing and are extending by headward erosion. It is also marked that the rivers are more engaged in vertical than lateral erosion. The open nature of valleys in the Deccan Trap country may in course of time be affected by weathering, sheet wash and mass wasting on the valley sides. The rejuvenation of rivers in the pleistocene period has also helped in the deepening of the valleys.

The valley deepening and widening in the upper Vindhyan country is somewhat different from the Deccan Trap. It is noticed that the process of valley deepening is very active here. In this part, cross section of valleys is really the expression of the arrangement of rocks and the age of the valley. Due to the presence of hard resistant rocks, the valley sides are more or less vertical and are over steepened. The
Photo No. 40: Roots wedging in Bhander limestone example of Biological weathering.

Locality: Basari village.

Photo No. 39: Roots wedging in upper Rewa sandstone example of Biological weathering.

Locality: Abchand Reserved Forest along Gadheri River.
action of weathering, development of gullies and mass wasting has also given a helping hand in valley widening.

3.13 EROSION SURFACES

The term "erosion surfaces", synonymous with the term "Planation surface", has been frequently employed by British writers to describe the geographically the plain surface, which is the end product of the 'erosion surface'. The word erosional surface has remained a matter of controversy amongst the geomorphologists since the time of Davis (1902). Davis et al. (1902) suggested that cycles of erosion and peneplanation were active during period of uplift after which erosion continues until a new peneplain was formed. This forms a stepped landscape where various planation surface occur at different levels. Penck (1924) described the process of planation by periodic scrap retreat and King (1953) by a more simplified process of pedimentation. Spark (1922) described that any surface which is not an original structural or constructional surface, is an erosion surface. The term would thus include such forms as hill and mountain slopes and sea cliffs. But in practice it is applied essentially to surfaces of joint relief, the end products of complete or incomplete cycles of erosion. Subaerial erosion, marine planation, pediplanation and possibly others lead ultimately to erosion surfaces, which vary in form dependng upon the duration for which the process has been operating. By study of the height and origin of the erosion surface, it is possible to describe approximately what base levels and what
processes of erosion have been in operation, while the study of gentle warping of these surfaces sometimes adds to the knowledge of recent tectonic movements.

There still remains the problems of interpreting the surfaces, once they are established. This is an equally confounding problem, because, these surfaces may be peneplains (Davis, op. cit.), Pediplains (King, 1950), endrumbf (Penck, 1924), Panfans (Lawson, 1915), Panplains (Crickmay, 1933), etchplains (Wayland, 1934), marine plains (Barrell, 1920), cryo-plains, stripped or structural plains, or karst plains.

Method of study

For the recognition of the erosion surfaces in the region, different morphometric techniques have been applied and subsequently an extensive field work has been undertaken to collect the field evidences. The prominent geomorphic features suggest intermittent uplifts in the region in different periods which have found expression in the erosion surfaces on the upper Vindhyans and the Deccan Traps.

Superimposed profiles

From the 1:50,000 scale toposheets, a series of profiles along the latitudes have been drawn at two kilometres interval with a vertical scale of one centimetre to 50 metres. In this manner, the profiles are drawn in west-east direction and all the serial profiles have been superimposed. From the general uniformity of levels of various profiles at different
heights, the plains of different erosion surfaces can be identified (Fig. 3.6).

Altitude Frequency Histogram

The summit height data have been collected from the whole area of 1400 sq. kms. with uniform distribution of grids. From the grids of 3.8 x 3.8 cms. drawn on the 1:50,000 scale toposheets, one reading of maximum height has been noted. Where the peak points were not available, the points of maximum height have been calculated with reference to contour lines or the adjacent height point.

The summit heights are represented by histograms at the height intervals of 20 metres (Fig.3.7).

The author is well aware of the limitations in the application of these techniques for the study of erosion surfaces, as the coincident surfaces, as revealed by such techniques, may be due to other innumerable factors. Rich (1938) and Fenneman (1936), have not emphasised the validity of erosion surfaces as they are revealed in the even skyline or the projected profiles (similar to the superimposed profiles in the present case). They refused to accept the validity of such factors without adequate field evidence. Rich concludes that by projecting hill tops, ridge and sloping surfaces on to one vertical plane, undue emphasis is given to the appearance of horizontality which results in a deceptive view. Similarly, viewing the evenness of skyline may lead to the illusion of
FIG. No. 3.7: ALTITUDE FREQUENCY HISTOGRAM
apparent optical horizontality and may be misleading. It is, therefore, that a double sided approach has been made in the recognition of various surfaces. The comparision of the results of the above techniques shows a clear coincidence of certain definite surfaces at different levels. In addition, the evidence gathered from toposheets, aerial photographs, and from the field have also been taken into account to interpret these levels as being planation surfaces or otherwise.

**Views of the earlier workers**

Choubey (1967 and 1969), Rai (1970), Dube (1970), Dixey (1971), Pandey (1972) and Subramanyan (1973), have worked in adjacent areas. In total, they have described more than ten surfaces to exist in Central India (Table No. 9).

Choubey (1967 & 1969) has described three erosion surfaces to exist in Sagar, Damoh, Narsinghpur and Jabalpur districts and explained them to have developed as a result of peneplanation. Based on the criteria of the few summit heights of the sub-horizontal Vindhysans and other basement rocks and considering the heights of junction of the Trap lava flow with the underlying rocks, he has described an extensive peneplain developed at 1950 feet level. This surface has been shown to extend over the Archaeans, Bijawars, Vindhysans and Gondwanas in Central India representing a complete cycle of erosion as delineated by Davis (1922). He believes that the same level was uplifted to form an
initial surface of the later cycle of erosion at 1750 feet. Applying the criteria of the Deccan Trap - Gondwana junction at different levels he has established many more erosion surfaces to exist in the Satpura region at 2000, 3000, 3500 and 1450-1400 feet levels to be erosion surfaces existing before the eruption of Deccan Trap lava flows.

Dixey (1971) has indicated the existence of six erosion surfaces in Central India, more or less at same levels as mentioned by Choubey (1967 & 1969) but with different designations.

Rai (1970) has also described five erosion surfaces at different height levels in the Sonar-Bearma basin (parts of Sagar, Damoh and Jabalpur districts) and adjoining region. He has suggested that these surfaces here associated with the Himalayan uplift in the various geological periods. Similarly, Dube (1970) has described four erosion surfaces from the Rewa region.

Pandey (1972) appears to have been influenced so much by Rich's (op.cit.) criticism of almost all geomorphologist's who have written on erosion surfaces that he has concluded against the existence of any erosion surface in the region except Dixey's Jabalpur surface with which he agrees.

Subramanyan (1973) has described six erosional surface around Sagar. There is good agreement between the Subramanyan's and Dixey's (op.cit.) finding in relation to the first three surfaces. Dixey's fourth
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<td>Erosion surface on the Rewa Plateau</td>
<td>Erosion cycles in Central India</td>
<td>Sleemanabad</td>
<td>Sagar area</td>
<td>Around Damoh</td>
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**South of Narmada Valley:**

1. 4300 ft.- Dissected higher erosion surface.
   - 1. 1900 ft.- Cretaceous & eohumed Vindhyan surface.
   - 2. 1900 ft.- Late Eocene surface.
   - 3. 1750-1450 ft.- Middle Miocene surface.
   - 4. 1300-1200 ft.- Pleistocene surface.
   - 5. 1000 ft.- Recent surface.

2. 3500 ft.- Younger Erosion surface on the Gondwanas.
   - 1. 2350-2000 ft.- Bhandar surface.
   - 2. 1660-1350 ft.- Panna surface.
   - 3. 1150-1000 ft.- Rewa surface.
   - 4. 500-350 ft.- Trans Yamuna surface.

3. 3000 ft.- Erosion surface on the Gondwana.

4. 2000 ft.-

**North of Narmada Valley:**

1. 1950 ft.- Cretaceous peneplain.
2. 1750 ft.- Initial surface of later cycle of erosion.
3. 1750-1440 ft.- Sub-Basaltic erosion surface.
4. 1450-1400 ft.- Late cretaceous erosion surface.

1. 2300-1950 ft.- Bhandar erosion surface.
2. 1750-1450 ft.- Sub-Trap surface.
3. 1450-1400 ft.- Early Post Trap cycle.
4. 1325-1000 ft.- Jabalpur surface.
5. 1200 ft.- Marble rock & above valley cycle.
6. 1150 ft. Quaternary and above surface.

1. 1350-1100 ft.- Jabalpur surface.
2. 2050-1900 ft.- Rewa surface.
3. 1650-1450 ft.- Post-Deccan Trap surface (II).
4. The quaternary surface.

1. First surface (460-500 Mts.)
2. Second surface (380-440 Mts.)
3. Third surface (350-370 Mts.)
surface, viz., the Jabalpur surface, also appears to be a southerly continuation of the Subramanyan's post Deccan Trap surface (II).

The techniques and criteria which have mostly been used by the above workers in fixing these levels are the projected profiles, attitude frequency histograms, evenness of skyline, height of the Trap-Lameta and Trap-Gondwana junction, truncation of deformed strata and accordance of summit levels and ridge tops.

3.13:3 Erosional surfaces of the study area

The study region has remained buried under the Deccan Traps till the recent past. The Traps have kept buried the upper Vindhyan rocks for a quite long period. The Traps have been removed from the eastern part of the study region, but the western areas still carry thick pile of Deccan Traps. Submerging the earlier Cretaceous relief below them and subsequent removal of the Traps causing resurrection of the pre-Trap topography. There are traces of atleast three erosional surfaces in the study region (Fig.No. 3.6).

(i) First surface (460-500 metres)
(ii) Second surface (380-440 metres)
(iii) Third surface (350-370 metres)

First surface (460-500 metres)

It's has already been surmised that at the close of the Cretaceous period, the mature topography of the upper Vindhyan was completely buried beneath the thick deposits of the Deccan Trap. It may be supposed that
the Deccan Trap lava must have extended to a much wider area than what it is noticed today. As soon as the lava cooled, the lava surface came under the influence of denudational agents. As the denudational cycle proceeded, the upper flows of the Traps were removed exposing the exhumed upper Vindhyan surface once again.

The presence of waterfall along Sonar river near Garhakota and the presence of the deep gorges in the Gadheri river, suggests that there has been uplift in the recent periods. The analysis of the superimposed profiles, altimetric frequency histogram and field evidences also support the view that this surface has a wide extent on the Deccan Traps and upper Vindhyan. The deposits of the laterites on the flat tops of the Deccan Traps, west of Patharia also strengthen the presence of this surface.

This surface seems to be an equivalent to the Panna surface (Dube, 1968). Choubey (1970) is of the opinion that this surface is a sub-basaltic erosion surface and it is an etch plain. But considering the time available for the development of this surface, deposits of laterite and the wide extent of surface indicate that it is peneplained surface rather a etch plain which has been upraised in the middle miocene period (Rai, 1968).

**Second surface** (380-440 metres)

This surface is represented by the summits capped by the upper Bhandar sandstone in the eastern
part of the study area. In this surface the whole region must have been upraised and the rivers were rejuvenated and a fresh cycle of erosion must have been started. The presence of the lowest Deccan Trap flow at the height of 440 metres and in Jamuniya and Amata, the presence of sill in the upper Bhandar sandstone at the height of 420 metres, suggest that the region was not completely peneplained, when the volcanic activity occurred.

This is another extensive surface and a major section of the river valleys has been carved out during this cycle. Although the deposits of laterite and weathered material on younger surfaces do not seem to be very thick, yet it appears that they are mainly the result of the erosion of the uplifted earlier surface. The development of this surface is definitely followed by the parallel retreat of the southern side of the north-western scrap towards north of the Sonar river and the retreat of the northern face of the Bhandar scrap. A few important villages viz., Patharia, Garhakota, Amata, Jamuniya, Sukha and Lakhrauni are situated on this surface. It is generally covered with alluvium but here and there low hills of the upper Vindhyans are exposed on the surface.

**Third surface** (350-370 metres)

From the study of the superimposed profiles, it is clear that in the region astride the major rivers, recent surface is in developing stage the rivers are
still deepening their valleys. From the study of the superimposed profiles and the field observations, it is clear that this surface is developing at the expense of the second surface. The old surface has been destroyed along river valleys and its remnants are only noticeable on northern and south side of the Sonar river. It seems that the third surface is only a local surface, which is not very extensive in the adjoining region.

This surface is not fully developed on the Deccan Trap. It may be explained by the fact that this part of the Deccan Trap country comes too close to the watershed and the cycle in which this surface was formed could not produce an erosional surface up to the upper reaches of rivers. It appears that the last upheaval of the Himalaya (Rai, 1968) was also experienced by this region and this surface was upraised a new cycle started on this surface.

The presence of waterfall indicate that the region has been uplifted in recent times. Due to uplift, the streams are still deepening their valleys and developing the new surface which is still under process of formation and it is difficult to say how much time it will take to attain its mature stage. This surface is equivalent to the Rewa surface of Dube (1970).

During the study of erosion surfaces of the region, the author has tried to keep in view, the factors such as rock resistance. It may be suggested that the erosion surfaces of this region must have been
formed by subaerial erosion, retreat of scraps and widening of valley floors and surfaces have developed from lower courses of the river upstream.

3.14 NEOTECTONICS

The term "neotectonic" was originally proposed by V.A. Obruchev to the movements of earth's crust that have taken place during the Neogene and Quaternary periods, and which played a decisive role in the formation of the contemporary topography. The beginning of the neotectonic stage has been taken as the Miocene, i.e. the boundary between Palaeogene and Neogene by the majority of workers.

The immense alluvial plain of the Ganga basin are believed to have evolved through certain neotectonic activities. The southern part of the Ganga-Brahmaputra plain (delatic portion) is, however, shaped by the combined effect of Tertiary tectonism, eustatic changes and neotectonism. During the Quaternary geological mapping, a number of recent faults and reactivation along pre-existing faults have been mapped. Few of the important active faults are ENE-WSW Moradabad fault, NE-SW Lucknow fault and NE-SW Patna fault (Krishnaswamy, 1962; Krishnaswamy et al., 1970). Bajpai (1989) has studied both the surface and subsurface evidences exist along the longitudinal section of the Ganga river in Kanpur-Unnao region of Central Ganga Plain, indicating the effect of tectonic subsidence. He has studied the morphological pattern on both the banks
of the Ganga river supported by field checks. Further, for detailed studies of flood plain characteristics, resistivity soundings have been carried out by him, over a large abandoned channel. In addition, a surface panel diagram as a transverse section in reference to the Ganga river, has been prepared by him by using the tubewell, drillhole data. He used it for understanding basement topography, the nature of deposition in adjustment to the river and finally the aquifer disposition. The study has been carried out to present the surface and subsurface evidences.

**Methods of Investigation**

For the study of regional subsidence and accumulation, some of the geological methods which are used for determining old movements may be employed. These include "geomorphological methods" tracing of river terraces, planation surface, flood plains, ravinous tract, upland tracts and other geomorphological features and evidences of their formations. For establishing effectively neotectonic deformation of broad areas, the study of polygenetic erosion surfaces is necessary. Each of these levels includes the denudational surface and the corresponding accumulation area, formed by simultaneous erosion and deposition. Many neotectonic structures are inherited from older ones, whereas others were formed on their own.

3.14:2 **Evidence Of Neotectonic Activity In The Study Area**

(i) Palaeochannels which are old courses of the Sonar
and Kopra rivers indicate shifting in course of Sonar river near Chirola, SSE of Bansakalan, south of Bhainsa and south of Khejra and in Kopra river near Bari, NE of Khojakheri and NW of Hinota (Map No.3.1).

(ii) Unpaired depositional terraces noticed at Aslana, Kasreti, Jhira and Rajghat Pipariya (Map No.4.1).

(iii) Accelerated erosion due to gully erosion process in the study area (Map No. 4.1).

(iv) Unpaired erosional terraces noticed at Kasareti, Jhira, Chanua Khurd, Ghograghat, Shahpura and Bansatarkheda (Map No. 3.1).

(v) Cut-off meanders seen near Rajghat Pipariya is another likely evidence for the shifting of river course (Map No.3.1).

(vi) Development of ravines following the trend of old course of Sonar river near south of Khirya, north of Khejra and in Kopra river near east of Rajaiwari (Map No. 3.1).

(vii) Presence of waterfall on sonar river near Garhakota which indicate recent uplift in the area.

(viii) Two erosional surfaces over Deccan Trap and Bhandar group of sediments and one level of surface over the recent alluvium which indicate upliftment of the area during recent time (Fig.No.3.6).
3.14:3 Discussion

In the present area of study during the late Tertiary to Quaternary times the drainage system of palaeo Sonar and Kopra rivers (evidences of which are present in the area as palaeochannels) have cut the Vindhyan sediments of Bhandar group in the uplifted areas and have deposited in the lowlying areas upto 20-25 metres thick depending upon the undulating topography of depositional sites. The alluvium which was deposited by the Sonar and Kopra rivers have been cut now by the drainage system of Sonar and Kopra rivers itself to the extent that exhumed topography is exposed with in the ravines and at the banks of Sonar and Kopra rivers.

3.15 GEOMORPHIC HISTORY AND EVOLUTION OF TOPOGRAPHY

The geomorphic history of the study region, to a certain extent is the history of the work of the rivers and the changes which they have undergone. As soon as the lava cooled, the lava surface came under the influence of denudational agents, and as the denudational cycle proceeded, the upper flows of the Traps were removed exposing the upper Vindhyan surface once again. It may be stated that the present topography is mainly the product of the intermittent uplifts and differential erosion of the rocks differing in their geological structure. The conventional interpretation of the geomorphic history of the study region indicates that the region has experienced intermittent uplifts and
atleast three erosional surfaces have been identified in the region.

The evidence provided by the geological studies, reveal some very interesting features about the geomorphic history of this area. It's first chapter dates back to the Vindhyan era when argillaceous and arenaceous sediments were deposited on the coastal region of the sea. This is quite evident from the structure like ripple marks and current bedding. The high colouration of sandstone with its characteristic red tints provides evidence to the general conditions of aridity and semi-aridity prevailing in that era.

The epiergenic upheaval of the post Vindhyan times lifted the sediments from the sea floor to form a continental land area; this upheaval appears to have caused little or only slight tilting of strata. After prolonged weathering extending over millions of years depressions in the form of lakes must have been formed in which the Lametas were deposited.

Then perhaps the first flow of the lava overflowed the lakes and areas of depression and covered the sedimentary deposits. The cycle repeated in the present region, the two subsequent lava flows succeeded so rapidly that there was no time for erosive processes to work causing the accumulation of sediments in the interval or as is more probable the surface may have been converted into a uniform plane of basalt by enormous lava streams which were poured out. However,
it is difficult to say that actual position of the time as no traces of life have hitherto been found until the close of the volcanic activity.

The present relief of the area is distinguished by low lying plains divided by the zigzag chains of steep hills. It is quite evident from the study of the rock types that constitute the hills and those constitute the plains, that differential resistance to erosion has been a major factor in carving the topography of the area. The hills are exclusively composed of basalts and their tops consist of various platforms representing the tops of the different flows. They are made up of weathered boulders of the basalt, which are embedded in the residual black soil. The platforms are connected by convex slopes of moderate to high gradient, and they are mostly carved by rolled boulders from the top of the hills.

The hills have been carved mainly by two sets of streams flowing towards east and north and these directions seem to be broadly controlled by the two main joint patterns in basaltic flows. They have sculptured steep and winding types of valleys among the hills. The streams start their action from the top of the platforms along the two opposite slopes. Due to the headward erosion of streams, the valleys of the opposite slopes get united and thus the platform gets detached. At places the sides of the platform are denuded away and thus they are changed to conical shaped forms.
Further action of the streams is not prominent on the plains due to the lack of natural avenue for their development. The horizontality of beds, lack of favourable structural elements and low porosity of rocks of the Vindhyans which constitute the plains are some of the facts for the poor development of drainage system. As a whole the relief of the area may be said 'medium'.

Despite the differences in lithology, structure and topography, the upper Vindhyan region has shared a common geomorphic history. Some evidences of geomorphic history are as follows:

(1) The study of fluvio-geomorphic cycle in the study region helps in understanding the geomorphic features which have developed due to fluvial action. The present landform characteristics are the outcome of running water and weathering. The study of erosion surfaces has also helped in tracing the evolution of landforms and drainage. The evidences show that atleast one cycle has completed on the Deccan Trap, the remanents of that cycle may be seen at the height of 480 mts. and above. Since then atleast two cycles of erosion were interrupted due to the Himalayan orogeny (Rai, 1968). During that period, the landscape had almost reached the late mature stage. The old upper Vindhyan topography which was obliterated due to the outpouring of the volcanic lava is being exhumed during the various cycles of erosion. Though it is a fact that the upper Vindhyan region has shared somewhat similar geomorphic
history, yet there are variation in rock types, attitude or characteristic landforms.

(ii) The upper Vindhyan sediments were deposited in the stable platform.

(iii) The presence of waterfall along Sonar river near Garhakota and the presence of deep gorges in the Gadheri river, suggest that there has been uplift in the recent period.

(iv) The area underwent upliftment after the deposition of upper Vindhyan sediments. The upper Vindhyan rocks are gentle dipping to sub horizontal giving rise to plateau topography.

(v) Shifting of Sonar and KOPRA rivers as indicated by the presence of palaeochannels.

(vi) In recent times during semi-arid climate, the area has been subjected to gully erosion resulting into the development of ravinous topography.

(vii) Near Shahpur, the rock terraces are seen only on the right bank of the Sonar river, while on the left bank a vertical wall like bank of alluvium is found. Here river has formed meander. It is cutting its left bank and is depositing coarse to fine material on the right bank. Thus, these rock terraces which are noticed at different places along the banks of Sonar and Kopra, definitely indicate that the present valley bottoms of these rivers are much narrower in comparision to the
previous valleys whose remanents are seen in the form of these river terraces. Besides, this feature also indicates that the rivers are entrenching and cutting their own valley bottoms. Obviously the presence of waterfall is another evidence of vertical cutting.

(viii) Three major erosional surface brought out from the study of superimposed profiles and altitude frequency histogram indicate that there is successive upliftment in the area.

(ix) Geomorphic landforms such as cut-off meander, unpaired terraces, palaeochannels and ravines controlled by the old courses of Sonar and Kopra river indicate neotectonic activity prevailing in the area.

The active erosion, therefore, is finding expression in the form of gullying, rocky bottoms, waterfalls and river terraces. These features are not in harmony with the general landscape, overall nature of streams and their valleys. It seems that after the uplift in the second erosion surface (380-440 mts.), the added erosive power of the rivers might had given rise to these features. It may be added here that during the study of erosion surface, a new surface was found developing astride the main streams in their lower courses around 350 metres (IIIrd surface). This erosional surface is in a developing stage and emerging at the expense of immediately older surface viz., the
second surface 380 to 440 metres.

The synthesis of geomorphic characteristics of the study region brings us to the conclusion that during the last cycle of erosion, this part had passed the late mature stage and was entering into the old stage. But a new cycle starting after the pleistocene uplift (Rai, 1968) had put this region again in a little earlier period in cycle of erosion. How far this region will be reverted back in the cycle is difficult to assess? Because the Kopra is the tributary of Sonar and the Sonar is the tributary of Ken river and unless an intensive geomorphic study of the whole Ken basin of even further is undertaken, this prediction will be hypothetical rather than a factual one.