MAJOR RESEARCH PROJECT

Entitled

‘Quaternary Geology and Geomorphometric Characteristics of Sindphana River Sub-basin in Beed-Parbhani Districts of Maharashtra’

Submitted to

UNIVERSITY GRANTS COMMISSION (UGC), NEW DELHI

Submitted by

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2012-15

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ACKNOWLEDGEMENTS

At the outset, I would like to express my indebtedness for the affection and blessings from my parent, who had been and will remain a constant source of inspiration throughout my life.

I am indebted to by UGC New Delhi, for the valuable research grant sanctioned (F. No. 41-1026/2012 (SR) Dated 23 July 2012) and the Research Fellow sanctioned to me under the scheme. I am unable to express sincere thanks to UGC in formal words.

Prof. R.D. Kaplay, School of Earth Sciences, Swami Ramanand Teerth Marathwada University, Nanded, who deserve the pride of place, as he inspired me for the research work to be carried out and gave me all the required support from the School of Earth Sciences S.R.T.M. University.

The ever-inspiring words of Dr. P.L. More, Principal and Dr. Sandhya S. Kadam Vice-Principal, D.S.M. College, Parbhani and Dr. R.B. Muley, (Head, Department of Geology) of this college are not less significant to me. I find in them the motivational forces for my research activities.

Similarly, I am also thankful to Mrs. R.S. Ghatge (Lecturer, Department of Geology, D.S.M. College, Parbhani) and Mr. Govidaro Shinde for help in the laboratory work. I express my deep sense of gratitude to them.

I take an opportunity to thank my Project Research fellow Mrs. Snehal Indrasen Jadhav for her sincere, hard working and competent to perform diverse duties assigned to her from time to time during the project tenure. I also would like to thanks Mr. Gurav Chandrakant (Research Student) and Students of Geology Department in the context of help received during the field work. It is noteworthy that in spite of their own work they took pain to assist me in the field work. I also would like to thanks all those who directly or indirectly helped me during this endeavor.

Place: Parbhani

Date: 26/03/2016

(Dr. Shaikh Md. Babar)

Principal Investigator

Chapter 1

INTRODUCTION

Studies on Quaternary geology and geomorphology assumed the great significance and have been receiving attention of geologist in the recent years. From the detailed Quaternary geological mapping and geomorphological studies of the area I would like to establish the prominent stratigraphic position of the upper middle portion of the Godavari valley. The earliest descriptions of Quaternary geology of the Godavari River basin were made in the fluvial regime, Quaternary geology and geomorphology of rivers in western Maharashtra. However, not much work has been carried out in this field in eastern Maharashtra and particularly in Marathwada area. The Quaternary deposits in Marathwada area are primarily fluvial and are confined to main river valleys as narrow belts. The present research work is aimed to discuss the Quaternary geology with reference to the soil stratigraphy, morphostratigraphy and lithostratigraphy. The geomorphic studies include drainage pattern, stream orientation pattern, linear –aerial aspects of drainage system, stream bifurcation ratios, sinuosity parameters, valley development, basin asymmetry characteristics of different geomorphic surfaces and landforms. In this research the evidences of structural control on the drainage pattern such as straight courses of streams, sudden change in the path of streams, tributary streams flowing in upstream directions before joining the main stream and offset drainage are discussed. To study the Quaternary geology of the area the detailed sedimentary sections (lithologs) are studied and to determine the age of the sediment the dating of some samples is carried out.

Fluvial systems in Western India are highly affected by the highly seasonal monsoonal climate. Peak discharges in most of the rivers are about ten times greater than the average flows, but occur only for some period of hours to days (Mishra, 1970). During the Quaternary period rapid and frequent changes in climate are well documented (Mishra et al., 2003). In the present study the river

originates and flows in semi-arid climate with bed rock being the Deccan trap basalt. In spite of the limited extent and volume of the alluvium, some localities have preserved Early Pleistocene sequences (Mishra et al., 1999) and even remnants of Pre-Quaternary sediments have been identified (Mishra, 1995; Mishra et al., 2003).

Quaternary sediments are concentrated as narrow fringe along the River valleys e.g. Godavari, Pravara, Sindphana, Purna and Manjra River valleys. The Godavari valley sediments in the western Upland Maharashtra are 2-3 meter thick consisting of entirely coarse grained unconformably rest on the rocky bench 3-20 meter above the present bed of the River. These sequences consist of rounded to sub-rounded pebbles and cobbles of basalt, chalcedony, jasper, agate, chert and quartz set in a matrix of granular sand and silt showing cross bedding and local inverse grading (Dole *et al.,* 2002).

Considering the lack of data on either the Quaternary deposits or fluvial regime in Marathwada area the Godavari river basin has been undertaken for the study with following objectives:

1.1. OBJECTIVES

The main objectives of the study carried out are as follows:

1. Identify and classify the Quaternary deposits of Sindphana river with reference to soil stratigraphy, morphostratigraphy and lithostratigraphy.
2. Documentation and delineation of Quaternary geomorphology and stratigraphy of the Sindphana valley.
3. To study the terrain characteristics such as shape, area, altitude, slope and profiles of the land and to explain the overall evolution of the basin.
4. To evaluate the Quaternary stratigraphic events of the area the detailed sedimentary sections are to be dated.

In the Deccan Peninsular India Quaternary deposits are primarily fluvial. They are confined to very narrow belts along rivers with not much recognizable landscape features. These deposits are often discontinuous, generally unfossiliferous and lack suitable material for radiometric dating, further more; the deposits lack proper preservation of pollen and proper sedimentological record. In the present study, an attempt has been made for the studies on Quaternary Stratigraphy and depositional environment of Sindphana River in Maharashtra state. The emphasis has been given to identify soil stratigraphy, morphostratigraphy and lithostratigraphic units, their lateral correlations and reconstruction of the depositional environment.

1.2 STUDY AREA

The proposed area of study is located in Marathwada area of Maharashtra and falls within the Deccan Volcanic Province (DVP) of peninsular India. Although, the lava flows have been studied extensively in terms of their petrological characteristics and geochemistry, studies on their structural aspects, geomorphological and Quaternary stratigraphy are virtually nonexistent with reference to the area specific. The alluvial deposits in western uplands of Maharashtra have been studied in details with respect to Quaternary palaeoclimatic changes and archaeological significance. However, the Sindphana river basin has remained neglected in spite of its potential for delineating the Quaternary Stratigraphy of this part of the DVP.

The study area, Sindphana River in Beed district drains total area of 3972.70 sq km and spread in DVP of Maharashtra. The course of the Sindphana River is from west to east for it major length and acquired the northern flow for the stretch of 8 km before joining the mighty Godavari river (Fig. 1.1). The area has a semiarid climate and receives rainfall primarily from SW monsoon between June and September. In this chapter besides the national and international status of research in Quaternary Geology and geomorphology, the aspects of location and the physiography, demography and climate are discussed.

Several researches on fluvial regime, Quaternary geology and geomorphology of rivers in western Maharashtra in Deccan Trap terrain are carried out by (Rajaguru, 1969, Dikshit, 1970, Corvinus *et al.,* 1973, Kajale, 1976, Rajaguru and Kale 1985 and Rajaguru *et al*., 1993). However, not much research has been carried out in this field in eastern Maharashtra and particularly in Marathwada area except few including Wardha valley (Tiwari 1985), Tapi and Purna valley (Tiwari 1996), Narmada valley (Tiwari and Bhai 1997a and b) Purna valley (Tiwari et al 1996; Tiwari and Bhai 1998) Central Indian Rivers including Godavari valley (Tiwari 1999) and Quaternary geology and geomorphology of Purna River a tributary of Godavari river (Babar and Kaplay, 1999 and Babar 2008).

In the present study, an attempt has been made for the studies on Quaternary Stratigraphy and depositional environmental of Sindphana River in Maharashtra state (Fig. 1.1). The emphasis has been given to identify soil stratigraphy, morphostratigraphy and lithostratigraphic units, their lateral correlations and reconstruction of the depositional environment.

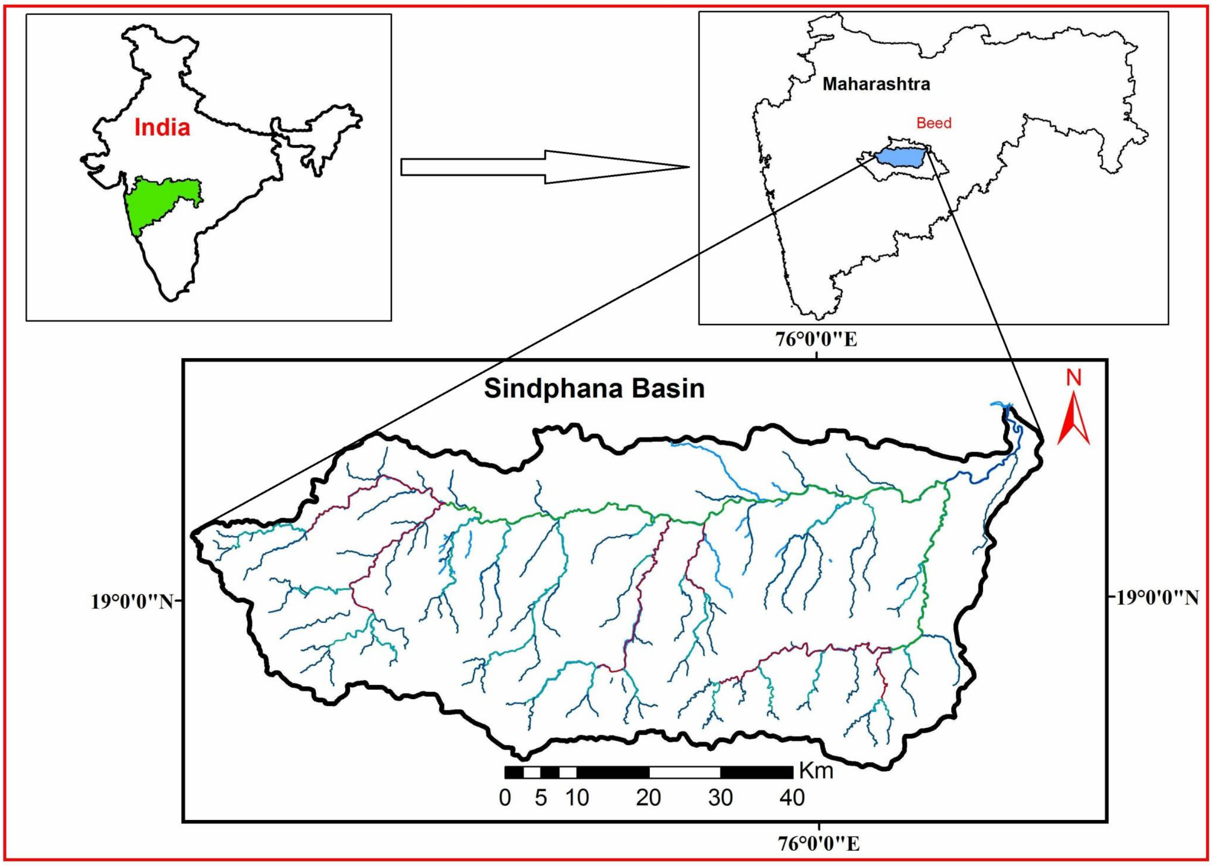


Fig. 1.1: Location map of the Study area.

The DBP of India is considered as tectonically stable even though a few damaging earthquakes occurred here. An increase in seismicity in peninsular India during the last few decades has reinforced the need for identifying seismogenic structures and their behaviour. Even though few earthquakes occurred at well defined structures many of them occurred at unexpected locations. For example the Killari earthquake occurred in a region that has not been known for previous seismic activity; however studies subsequent to the earthquake have lead to the identification of pre-existing faults that have activated in the past (Rajendran and Rajendran, 1999). Studies in the peninsular India also show that the damaging earthquakes occur on pre-existing faults with a recurrence period of tens of thousands of year (John and Rajendran, 2009).

The attempt has been made to study the signatures of Neotectonics in the Quaternary deposits of DBP of Sindphana basin. However, recognizing active structures in the cratonic areas is not easy. The difficulty stems primarily from the fact that the active faults are not easy to be detected and are characterized by low rates of stress accumulation and smaller slip rates as they are isolated from plate margin interactions. Therefore, the faults generally do not develop any dramatic fault scarps in the region. Furthermore, weathering and erosion would tend to destroy any remnant of physiographic evidence of faulting. However, such deformation in regard to active tectonics can be identified from careful, geomorphological studies using topographic maps aerial photographs, satellite images and by field investigations. Here we prefer to use the term neotectonics in place of active tectonics owing to the low-strain tectonic environment.

Geomorphometric characterization of the tectonic properties of a landscape is an extremely complex task. It is well recognized, however, that the commonly-used geomorphic indices of active tectonics are powerful reconnaissance tools to evaluate the relationship between tectonics and basin morphology on the regional or basin scale and to identify geologically recent deformation (Bull and McFadden 1977; Keller and Pinter 1996; Burbank and Anderson 2001). These relief, areal, shape and gradient parameters particularly provide useful information about the ongoing tectonics in regions underlined by the same rock-type (Keller and Pinter 1996). The digital elevation model (DEM) is represented in Fig. 1.2. The Deccan Basalt Province is highly suitable for this type of geomorphometric analysis and for making meaningful comparisons between basins and fluvial systems.

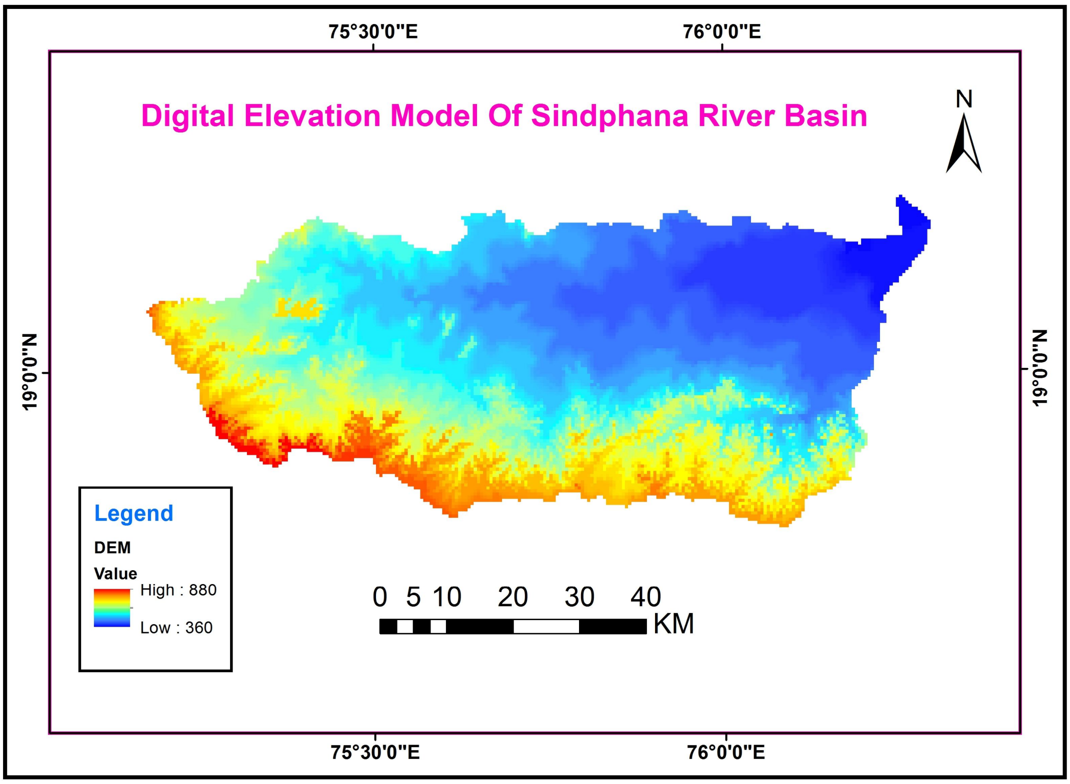


Fig. 1.2. DEM of upper Sindphana river basin

Chapter 2

MATERIALS AND METHODS

The present area is studied from the point of view of quantitative geomorphology using the Survey of India (SOI) topographical maps No. 47M/4, 47M/8, 47M/12, 47M/16, 47N/5, 47N/9, 47N/13, 47N/15, 56A/4 and 56B/1 supplemented with IRS-P6 LISS-III satellite imagery (FCC-geocoded) on the scale 1: 50,000. The detailed morphometric analysis of sub-basins is carried out in order to understand the drainage pattern, nature of topographic contour, basin shape, spot heights, slopes and altitude. Data on Quaternary sediments was collected from the exposures in the river banks, sediment surge deposits, quarries and well sections.

The present chapter also highlights the tools and techniques available, digital image processing, information extraction and image classification. It also highlights the functionality, components and analysis of GIS, spatial information and integration of remote sensing.

In order to evaluate the role of lithology and structural features on the geomorphology of the area the extensive field studies will be undertaken. The identification and classification of the Quaternary deposits of Sindphana valley will be made with reference to soil stratigraphy, morphostratigraphy and lithostratigraphy. Similarly geomorphic surfaces will be classified into various units (landforms) based on the topographic features and morphological characteristics. The following methodology is used to work out the geomorphic evolution of the Sindphana river.

1. Collection and appraisal of literature relevant to the present study. A critical review of the available geologic and structural information and geophysical data will be done to understand the overall geologic setup of the area in a regional context.
2. Lineaments and mega-geomorphic features will be identified using satellite data which will also help in identification of sites or segments of importance.
3. Detailed field mapping of Quaternary sediments will be carried out by preparing vertical lithologs of the sediments exposed along the incised cliffs and lateral facies mapping. A composite lithostratigraphy of the Quaternary sediments of the Sindphana sub-basin will be reconstructed based on presence and identification of key horizons/markers.
4. The steps required for morphometric analysis of the drainage basin are: (i) preparation of drainage map, (ii) stream ordering, (iii) stream orientations in the form of rose diagram, (iv) anomalous behaviour of streams, (v) stream sinuosity parameters, (v) valley development and (vi) basin characteristics.

5. Field studies will be carried out to study the sedimentary section by taking some trenches along the Sindphana River. The samples would be taken from these trenches for sediment analysis and age dating will be carried out at the renowned institutes in India and the expenses will be made through the funds of the project.
6. The data generated in the field and lab will be critically evaluated and synthesized reconstruct a model of Quaternary geomorphic evolution of the Sindphana valley.

IRS P6 LISS III 2006 data was used to delineate Quaternary litho units of the Sindphana River. Sections were logged and sedimentary structures were described in the field following the fieldwork. Five soil types have been recognized on the basis of colour, texture, structure, consistency, concretions and nature of soil profiles (Fig. 2) following the methods of Buol et al. (1980).

For the present study we selected 26 sub-basins on both sides of the Sindphana river valley in the DVP. The selected sub-basins include 12 on northern side and 14 sub-basins on the southern bank of the Sindphana river. The present study is based on the calculation of five commonly used geomorphic indices of active tectonics such as the basin elongation ratio (Re), the basin asymmetry factor (AF), the stream gradient-length ratio (SL), the hypsometric integral (HI) and the valley floor width-height ratio (Vf). The procedures used to calculate the indices are given below:

a) **Basin Elongation ratio:** It is the ratio between the diameter of a circle of the same area as the drainage basin and the maximum length of the basin (Schumm 1956). The formula used for the present study is $Re = (2\sqrt{A} : \sqrt{\pi})/LB$ *where,* A = basin area *and* LB = length of the basin (Bull and McFadden, 1977).
b) **Basin Asymmetry Factor (AF**): The AF is defined as $AF=100(Ar/At)$, where Ar is the area of the basin to the right (facing downstream) of the trunk stream and At is defined as the total area of the drainage basin (Keller and Pinter 1996).
c) **Stream Gradient-Length Ratio (SL):** It is calculated using the ratio $SL = (H1 - H2)/(\ln L2 - \ln L1)$ where, $H1$ and $H2$ are the elevations of each end of a given reach $L1$ and $L2$ are the distances from each end of the reach to the source (Hack 1973).
d) **Hypsometric Integral (HI):** Hypsometric analysis (Strahler, 1952) is related with ground surface and altitude. A hypsometric curve is the graphical representation showing the basin areas on abscissa situated above various altitudes. For the present study the hypsometric integral is calculated using, $HI = (Em - Emin)/(Emax - Emin)$,

where, Em = mean elevation, Emax = maximum elevation and Emin = minimum elevation (Bull and McFadden, 1977).

e) **Valley floor Width-Height Ratio (Vf):** We further calculated Ratio of valley floor width to valley height, which differentiate between broad floored valleys and V shaped valleys. The ratio of valley floor width to valley height (Vf) may be expressed as = 2Vfw/ (Eld-Esc)+ (Erd-Esc), where Vf is the valley floor width to height ratio; Vfw is the width of valley floor; Eld and Erd are elevations of the left and right valley divides, respectively, and Esc is the elevations of the valley floor (Bull and McFadden, 1977).

To identify possible tectonic signatures in the Deccan Basalt Province, the five indices of tectonics were derived for all the twenty six selected rivers. The indices were then assessed and supported by field observations of the occurrence of knick points, incised meanders, gorges, etc., as markers of active tectonics. In addition to this, statistical analysis of the geomorphic indices data was carried out to test the hypothesis that no significant differences exist between the geomorphometric parameters on either side of the Sindphana river. Identification of areas of steeper reaches (knick points or zones) could not be achieved. Therefore, the knick points identified in the field or reported in earlier studies have been mapped and discussed.

The geomorphic study carried out was based on the satellite data, Survey of India (SOI) topographic maps and extensive field survey. Fluvial terraces have been deliberated in terms of bedrock strath and overlying alluvial cover. The thickness of the alluvial cover was measured using measuring tapes at the outcrop. The data presented are based on the field observation on several outcrops, where a representative section has been discussed in detail. The relative abundances of the constituent lithologies of the bed load of the presently active river bed (Terrace T0) are derived after the field observations. IRS P6 LISS III 2006 data was used to delineate Quaternary litho units of the Sindphana River. Sections were logged and sedimentary structures were described in the field following the fieldwork. The basin boundary is superimposed on the google image (Fig. 2.1) in order to understand the correct position of the terrain in present day situation.

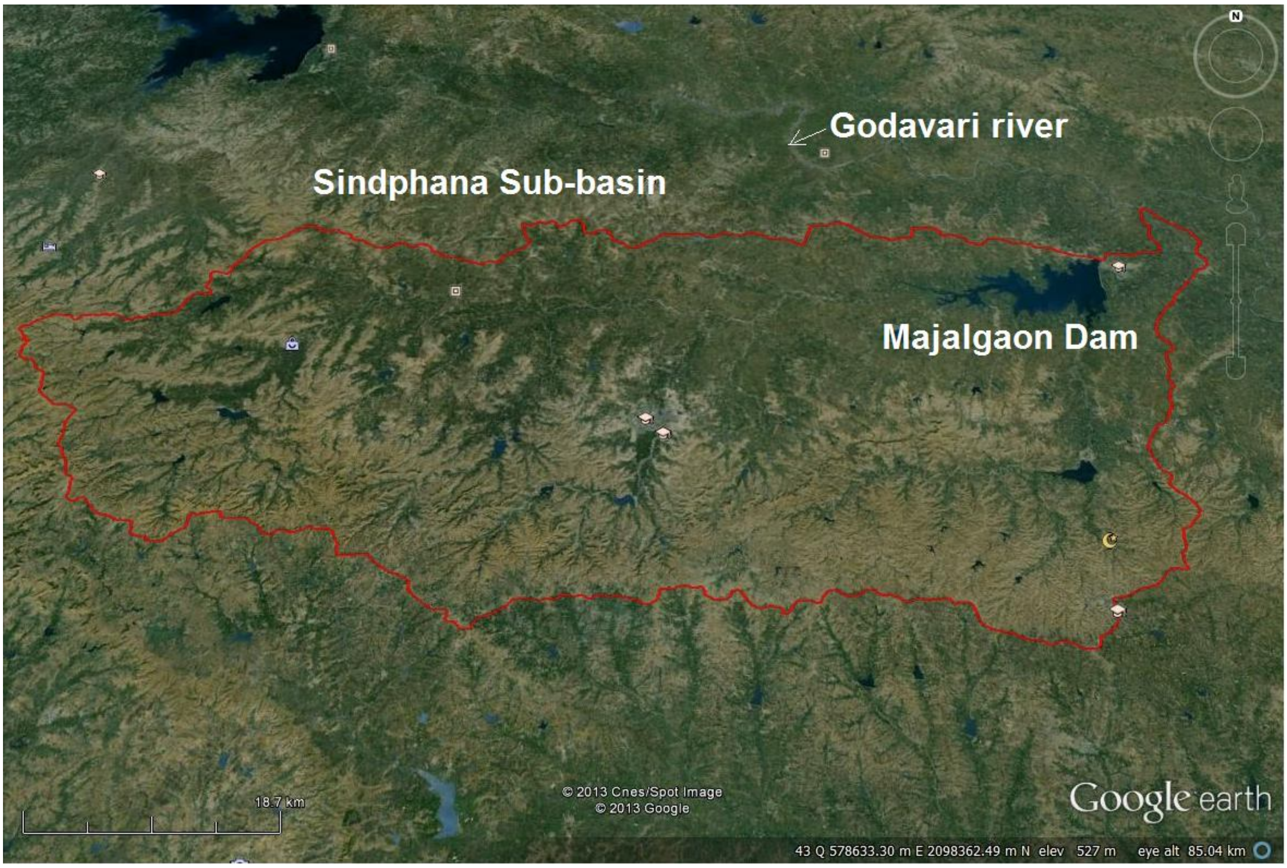


Fig. 2.1: Sindphana river sub-basin superimposed on Google image.

Chapter 3

GEOLOGY

Geologically, the entire study area Sindphana river in Beed district is covered by Deccan Basalt formations comprising nearly horizontal lava flows (Fig. 3.1). These flows have been considered to be a result of fissure type of lava eruption during late Cretaceous to early Eocene period. The types of basalt occurring in the area are compact basalt, vesicular-amygdaloidal basalt and red bole beds (Tachylitic bands) as observed in the natural exposures and well sections.

3.1 BASALT FLOWS

As the basalts are formed by cooling and solidification of the lava, they contain gas cavities and also joints which are the contraction cracks developed during cooling of the lava. But all the basalt flows do not contain gas cavities and joints and therefore on the basis of presence or absence of gas cavities, basalt flows are grouped into two categories:

i) Vesicular amygdaloidal basalt (Pahoehoe type).

ii) Non-vesicular or compact basalt (aa type).

The two basalt flows have distinct field characters i.e. vesicular amygdaloidal basalt (Fig. 3.2) and compact basalt (Fig. 3.3) and structural features including lineaments are described in detail in this chapter.

Deccan volcanism is considered to be a manifestation of original tectonic regime developed within the continental lithospheric plate (Chandrasekharam, 1995; Cox, 1991 and Bose, 1996). The stress conditions in the Indian peninsula initiated formation of fissure swarms and with increasing intensity and developed miniature Continental rifting. The Killari (Latur) 1993 earthquake rejuvenated the debate over the existence of rift valleys underneath the DBP (Valdiya, 1993 and Kailasam, 1993).

The Deccan Traps, which cover an area of more than 600,000 sq km of western and central India, consist of a number of flows ranging in thickness from a few meters up to about 100 m with the successive flows being separated by red bole or Intertrappean beds and are characterized by compact basalt at the bottom part succeeded by a vesicular zone (Gupta and Dwivedi, 1996). The Deccan basalt flows are broadly horizontal in disposition and exhibits gentle gradient towards ENE and SE. Chief rocks identified are Compact basalt (Fig. 3.2), Vesicular-Amygdaloidal basalt (Fig. 3.3), and green bole beds (Fig. 3.4). Quaternary sediments are concentrated as narrow fringe along the Sindphana river valley.

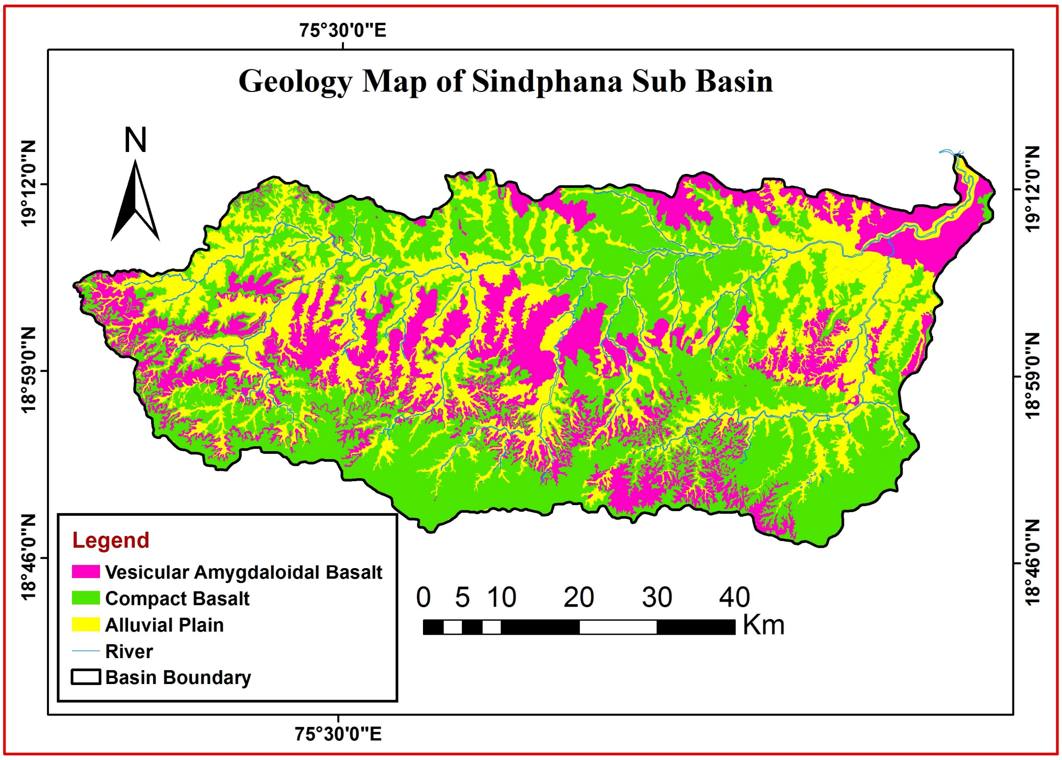


Fig. 3.1. Geological Map of Study Area.

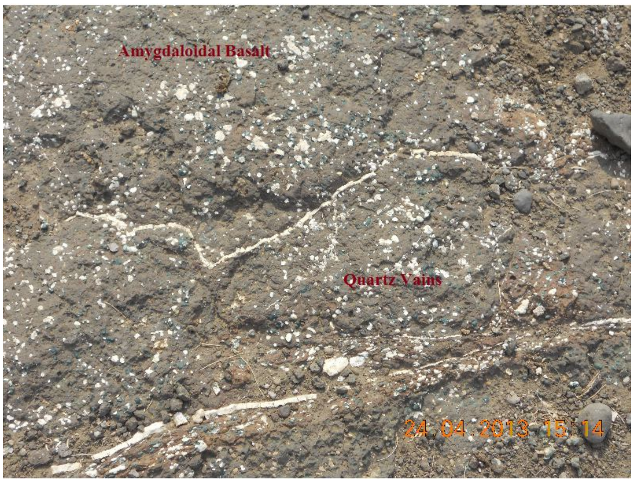


Fig. 3.2. Jointed Compact Basalt along

Fig. 3.3. Amygdaloidal Basalt along with

Sindphana River at Hingni village. **Quartz veins at Sandas Chincholi**

Total number of 38 flows of basalt (Fig. 3.5) of which 17 compact (massive) and 21 vesicular-amygdaloidal basalt flows are developed in the study area from the source of the river to the confluence with the mighty Godavari river within the elevation difference of 872 to 389 m amsl. The flows can be demarcated by the presence of ropy lava at the top (Fig 3.6 a) and the presence of pipe amygdules at the bottom of flow (Fig. 3.6 b). These flows have different characteristics which are described below:

i) Flow No. 55: This flow belongs to Deccan Trap - Sahyadri Group, Upper Ratangarh Formation and consist of Vesicular basalt rocks.

ii) Flow No. 56: This flow belongs to Deccan Trap - Sahyadri Group, Upper Ratangarh Formation and consist of Vesicular basalt rocks.

iii) Flow No. 84: This flow belongs to Deccan Trap - Sahyadri Group, Ajanta Formation and consist of Compact (massive) basalt rocks.

iv) Flow No. 86: This flow belongs to Deccan Trap - Sahyadri Group, Ajanta Formation and consist of Vesicular basalt rocks.

v) Flow No. 88: This flow belongs to Deccan Trap - Sahyadri Group, Ajanta Formation and consist of Vesicular basalt rocks.

vi) Flow No. 89: This flow belongs to Deccan Trap - Sahyadri Group, Upper Ratangarh Formation and consist of Vesicular basalt rocks.

vii) Flow No. 91: This flow belongs to Deccan Trap - Sahyadri Group, Ajanta Formation and consist of Massive basalt rocks.

viii) Flow No. 93: This flow belongs to Deccan Trap - Sahyadri Group, Ajanta Formation and consist of Vesicular basalt rocks.

ix) Flow No. 94: This flow belongs to Deccan Trap - Sahyadri Group, Ajanta Formation and consist of Massive basalt rocks.

x) Flow No. 95 This flow belongs to Deccan Trap - Sahyadri Group, Ajanta Formation and consist of Vesicular basalt rocks.

xi) Flow No. 97: This flow belongs to Deccan Trap - Sahyadri Group, Ajanta Formation and consist of Massive basalt rocks.

xii) Flow No. 98: This flow belongs to Deccan Trap - Sahyadri Group, Ajanta Formation and consist of Vesicular basalt rocks.

xiii) Flow No. 99: This flow belongs to Deccan Trap - Sahyadri Group, Ajanta Formation and consist of Vesicular-amygdaloidal basalt rocks.

xiv) Flow No. 100: This flow belongs to Deccan Trap - Sahyadri Group, Ajanta Formation and consist of Vesicular basalt rocks.

xv) Flow No. 104: This flow belongs to Deccan Trap - Sahyadri Group, Ajanta Formation and consist of Vesicular basalt rocks.

xvi) Flow No. 105: This flow belongs to Deccan Trap - Sahyadri Group, Ajanta Formation and consist of Massive basalt rocks.

xvii) Flow No. 109: This flow belongs to Deccan Trap - Sahyadri Group, Ajanta Formation and consist of Massive basalt rocks.

xviii) Flow No. 160: This flow belongs to Deccan Trap - Sahyadri Group, Chikhali Formation and consist of Vesicular-amygdaloidal basalt rocks.

xix) Flow No. 162: This flow belongs to Deccan Trap - Sahyadri Group, Chikhali Formation and consist of Vesicular-amygdaloidal basalt rocks.

xx) Flow No. 164: This flow belongs to Deccan Trap - Sahyadri Group, Chikhali Formation and consist of Vesicular basalt rocks.

xxi) Flow No. 165: This flow belongs to Deccan Trap - Sahyadri Group, Chikhali Formation and consist of Massive basalt rocks.

xxii) Flow No. 166: This flow belongs to Deccan Trap - Sahyadri Group, Chikhali Formation and consist of Vesicular-amygdaloidal basalt rocks.

xxiii) Flow No. 168: This flow belongs to Deccan Trap - Sahyadri Group, Chikhali Formation and consist of Vesicular-amygdaloidal basalt rocks.

xxiv) Flow No.169: This flow belongs to Deccan Trap - Sahyadri Group, Chikhali Formation and consist of Vesicular-amygdaloidal basalt rocks.

xxv) Flow No. 174: This flow belongs to Deccan Trap - Sahyadri Group, Buldhana Formation and consist of Vesicular basalt rocks.

xxvi) Flow No. 176: This flow belongs to Deccan Trap - Sahyadri Group, Buldhana Formation and consist of Vesicular basalt rocks.

xxvii) Flow No. 177: This flow belongs to Deccan Trap - Sahyadri Group, Buldhana Formation and consist of Massive basalt rocks.

xxviii) Flow No. 178: This flow belongs to Deccan Trap - Sahyadri Group, Buldhana Formation and consist of vesicular basalt rocks.

xxix) Flow No. 180 This flow belongs to Deccan Trap - Sahyadri Group, Buldhana Formation and consist of Vesicular basalt rocks.

xxx) Flow No. 182: This flow belongs to Deccan Trap - Sahyadri Group, Buldhana Formation and consist of Massive basalt rocks.

xxxi) Flow No. 202: This flow belongs to Deccan Trap - Sahyadri Group, Mahabaleshwar Formation and consist of Massive basalt rocks.

xxxii) Flow No. 204: This flow belongs to Deccan Trap - Sahyadri Group, Mahabaleshwar Formation and consist of Massive basalt rocks.

xxxiii) Flow No. 205: This flow belongs to Deccan Trap - Sahyadri Group, Mahabaleshwar Formation and consist of Massive basalt rocks.

xxxiv) Flow No. 206: This flow belongs to Deccan Trap - Sahyadri Group, Mahabaleshwar Formation and consist of Massive basalt rocks.

xxxv) Flow No. 207: This flow belongs to Deccan Trap - Sahyadri Group, Mahabaleshwar Formation and consist of Massive basalt rocks.

xxxvi) Flow No. 208: This flow belongs to Deccan Trap - Sahyadri Group, Mahabaleshwar Formation and consist of Massive basalt rocks.

xxxvii) Flow No. 209: This flow belongs to Deccan Trap - Sahyadri Group, Mahabaleshwar Formation and consist of Massive basalt rocks.

xxxviii) Flow No. 210: This flow belongs to Deccan Trap - Sahyadri Group, Mahabaleshwar Formation and consist of Massive basalt rocks.

3.2. LINEAMENTS

Lineaments represent a group of several mega and intermediate lineaments with a NNW to northwesterly trend extending over the Deccan Plateau and include Pranhita-Godavari section with a NNW-SSE trend (Rajurkar, et al, 1990 and Powar, 1993). The lineament (Fig. 3.7) cuts across the Deccan lava flows and is characterised by the linear feature with straight stream courses.

Fig. 3.4. Weathered Amygdaloidal Basalt and green bole beds occurring at Sandas Chincholi along right bank of Sindphana river.

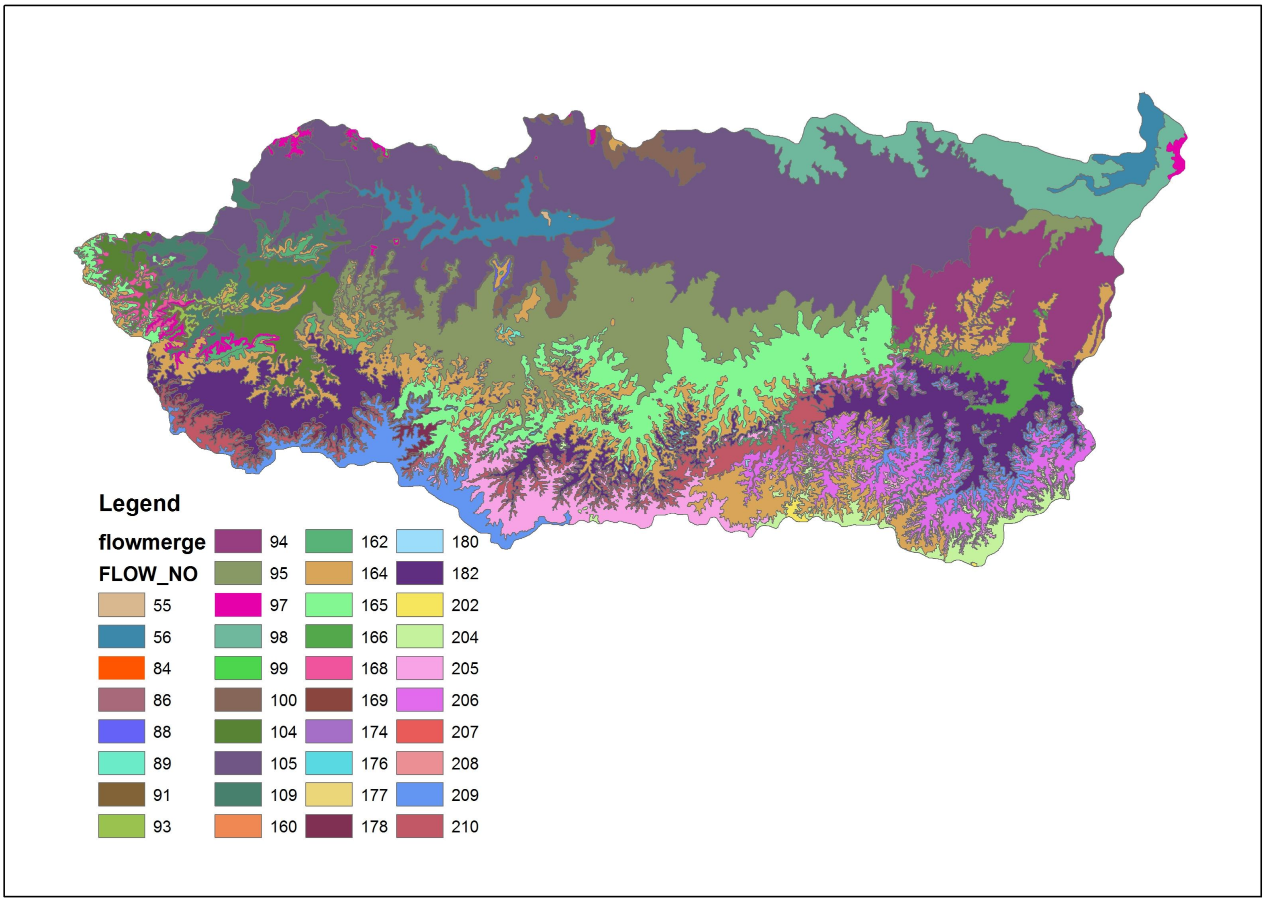


Fig. 3.5: Basalt flow wise Geological Map of Sindphana sub-basin

Fig. 3.6a: Ropy lava illustrating the top of the of the lava flow at Sakshal Pimpri.

Fig. 3.6b: Pipe amygdules a part of bottom of the lava flow at Majalgaon.

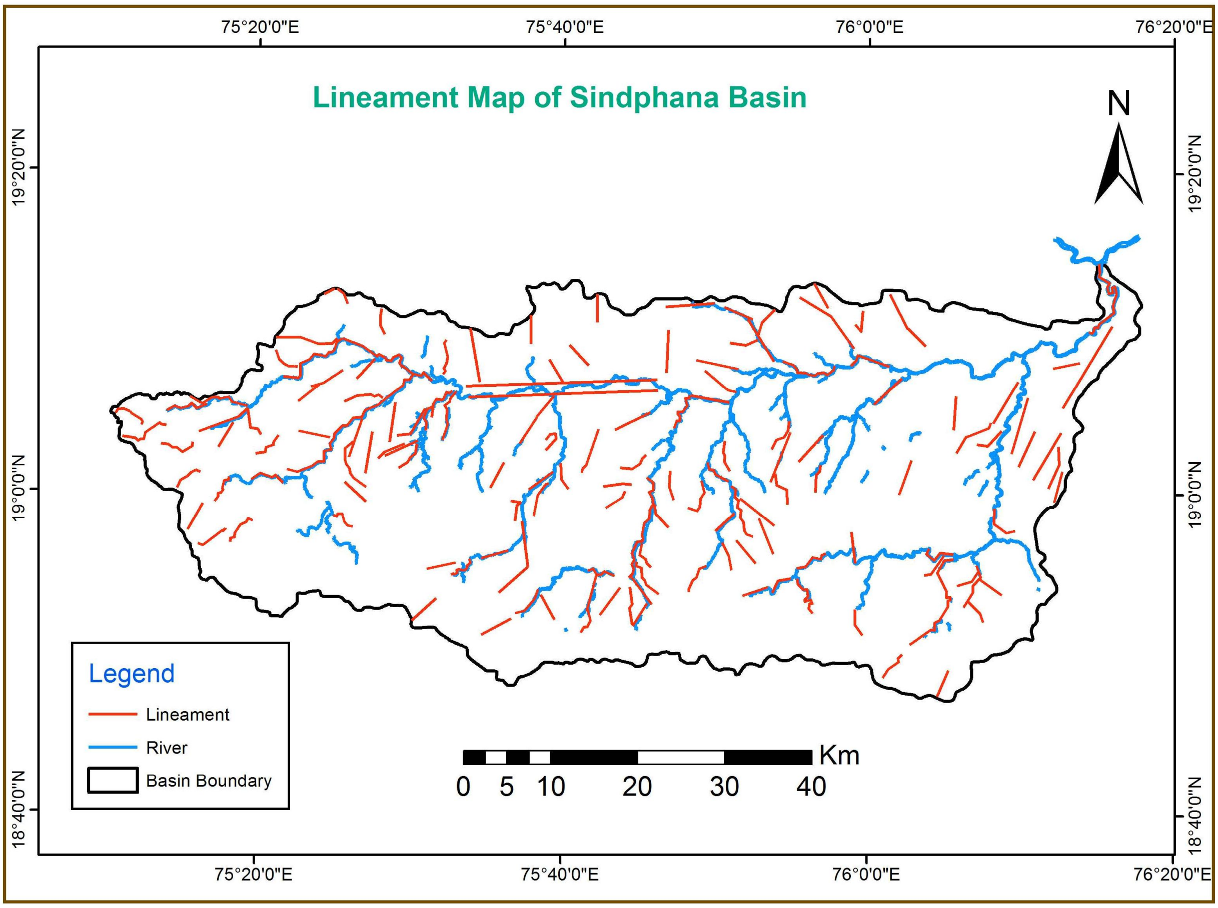


Fig. 3.7. Lineament map of the upper Godavari river basin

Lineament analysis of the area has been carried out by visual interpretation of IRS LISS III P6 images in conjunction with the SOI toposheet. Lineaments have been picked up on the basis of morphological features, structural alignments, textural contrasts and tonal differences. The lineaments correspond to the three major structural trends like NW-SE, WNW-ESE, N-S and E-W in the present area.

3.3. GEOLOGIC SETTING OF THE AREA

Different parts of Sindphana basin bear distinct geological formations. The entire basin mainly comprise Basalts which form part of the Deccan traps. These are extruded from fissures type of volcanoes during the Late-Cretaceous to Early Eocene age. The Deccan traps, not being porous are incapable of holding or transmitting water in their primary stage. The basaltic lava, however, developed a vesicular character on the top layer due to escaping of steam and gas. Similarly the cooling lava had produced various joint systems in hard flows.

Quaternary sediments are concentrated as narrow fringe along the river valley. The Sindphana valley sediments in the upper reaches are 2-3 meter thick and consisting of entirely coarse grained unconformably rest on the rocky bench and consisting of angular to subangular fragments. In middle and lower reaches of the river the Quaternary sequences consist of rounded to sub-rounded pebbles and cobbles of basalt, chalcedony, jasper, agate, chert and quartz set in a matrix of granular sand and silt showing cross bedding and local inverse grading. The cross sections along Sindphana river at two places i.e. near Ranjegaon and Sakshal Pimpri to illustrate the terrace characteristic are described in next chapter.

The deposits are complex in nature and might have resulted from the vertical stacking and amalgamation of low sinuosity channels dominated by massive bedded gravels. This suggests the rivers of low sinuosity channels of braided streams (Kale 1989 and Rajguru *et al* 1993). The high proportion of cobbles indicates high energy river, with wide shallow channel and prevalent bed load transport. Atkinson *et al* (1990) obtained an age of about 145000 years BP for the sandstone facies from gravel bed of Godavari river near Paithan by using a U/Th series date of the cementing material.

Chapter 4

QUATERNARY GEOLOGY

Quaternary deposits of India constitute a major geological unit in different parts of the country, study of which is invested with much interest and significance because of its relevance to present and its contribution towards understanding the past environment. Studies on Quaternary Geology and geomorphology assumed great significance and have been receiving attention of geologist since last two decades. Several researchers from fields of geology, geography and geoclimatology are working in different river basins in Peninsular India. These studies include those on fluvial regime, Quaternary Geology and geomorphology of rivers in western Maharashtra. However, not much work has been carried out in this field in eastern Maharashtra and particularly in Marathwada area. The Quaternary deposits in Marathwada area are primarily fluvial and are confined to main river valleys as narrow belts. These deposits are generally discontinuous, unfossiliferous and lack suitable material for radiometric dating.

In the Deccan peninsular India Quaternary deposits are primarily fluvial. They are confined to very narrow belts along rivers without much recognizable landscape features (Dikshit, 1970). These deposits are often discontinuous, generally unfossiliferous and lack suitable material for radiometric dating, further more; the deposits lack proper preservation of pollen and proper sedimentary features (Rajaguru, 1969). Several researches on fluvial regime, Quaternary geology of rivers in western Upland Maharashtra in Deccan Trap terrain are carried out by (Rajaguru, 1969, Dikshit, 1970, Corvinus *et al.,* 1973, Kajale *et al*, 1976, Rajaguru and Kale 1985; Rajaguru *et al*., 1993, Widdowson and Cox 1996; Widdowson 1997; Subrahmanya 1998; Widdowson and Mitchell 1999; Gunnell 2001; Dole *et al*, 2002; Gokarn *et al* 2003; Mishra *et al* 2003; Tiwari *et al* 2006; Catherine *et al* 2007 and Sheth 2007). The research is also carried out in eastern and northwestern Maharashtra including Wardha valley (Tiwari 1985), Tapi and Purna valley (Tiwari 1996), Narmada valley (Tiwari and Bhai 1997a and b) Purna valley (Tiwari and Bhai 1998) and Central Indian Rivers (Tiwari 1999). However, diminutive research has been carried out in this field in Marathwada area in eastern Maharashtra except few including Quaternary geology and geomorphology of Purna River a tributary of Godavari river (Babar and Kaplay, 1999 and Babar 2008) and on Godavari river (Babar *et al* 2010).

In present chapter the Quaternary Geological formations of Sindphana river are described based on morphostratigraphy and lithostrtigraphy. In this chapter Quaternary stratigraphy of the Sindphana valley is studied based on synthesis of the above data sets supplemented with relative age data. The stratigraphic succession is given in Table 4.1.

4.1. MORPHOSTRATIGRAPHIC UNITS

Geomorphic study along the Sindphana River near Nanded indicates the presence of three levels of terrace surfaces. These are terrace T2 (oldest), T1 and the youngest being the active channel, termed as terrace T0, that lies at 430 m amsl (above mean sea level). From T2 to

T0 the river shows north to south shift of ~400 m (Fig.4). The stratigraphy of alluvial cover was

studied to determine the palaeoclimatic conditions and temporal changes in bed load conditions. Based on grain size, matrix, bioturbation and color, the following four lithofacies were identified:

Sedimentary deposits of the Sindphana river shows 3 terraces namely, T0, T1, and T2 in increasing order of elevations (Table 4.2). These terraces were described as suggested by Tiwari and Bhai (1997a) with reference to the soil types and soil characteristics.

Three morphostratigraphic units present in the area are described below:

Terrace (T2):

The oldest terrace T2 is the developed in the pediplains of the basin at Ranjegaon and has an elevation range of 446 m in north to 424 m in south indicating a drop of 22 m. It covers most of the alluvial plain. T2 terrace is preserved along the northern valley margin in the western part of the study area. It consists of dark grey sand and silts with grey brown clay. This formation belongs to the early Upper Pleistocene age.

Terrace (T1)

T1 terrace has a general southern slope with elevation of 425 m in the north to 389 m above msl in south, showing a drop in elevation of 36 m. This terrace usually comprises grey sand and brown calcareous silt. This is the morphostratigraphic unit consisting of sediments of the older depositional terrace with development of vertisol. This formation belongs to the late Upper Pleistocene age.

Terrace (T0)

It comprises sands of lower point bar, channel bars and grey sand and silt of present flood plains. The sediments are unoxidised and non-calicfied. Unconsolidated cobble and gravels are predominant in the channels. This morphostratigraphic unit is associated with sediments having young and loosely developed soil. This formation belongs to the Holocene age. Older depositional terrace consist of two formations separated by a palaeosol. Palaeosol has a dark grey clayey ‘A’ horizon and deep brown mineralized ‘B’ horizon with stress and iron cutans.

Table 4.1: Stratigraphic Succession of the Study Area (modified after Tiwari, 1999).

Era	Period	Epoch	Formation	Beds	Lithology
Cenozoic	Quaternary	Holocene	Shirasmarg	Dark grey silt formation in Present Floodplain (T0)	Uncalcified Silty Sand, Gray Silty Clay and Black Soil
		Late Upper Pleistocene	Manjrath	Light grey silt formations in Older Floodplain (T1)	Light Grey Silty and Grey to dark Grey Calcareous Silty Clay
		Early Upper Pleistocene	Ranjegaon	Grey silt formation in Pediplain (T2)	Grey to Dark Grey Calcareous Clay
Cenozoic and Mesozoic	Tertiary-Cretaceous	Early Eocene to Late Cretaceous	Base of Deccan Trap Basalt at Hingani	Basalt flows	Compact (Dense) & Amygdaloidal Basalt Flows

Table 4.2: Morphostratigraphy of Sindphana Alluvium

Terrace	**Origin**	**Soil Type**	**Soil Characteristics**	**Av. Elevation m asl**
T0	Depositional	Entisol (I)	Dark Gray Sand and Silt	395.5
T1	Depositional	Inceptisol (II) Bisequel (III)	Gray Sand and Silt Grey Sandy Silt and Clay	408.7
T2	Depositional	Vertisol (IV)	Dark Gray Sand and Silt with Gray Clay	422.4

4.2. LITHOSTRATIGRAPHIC UNITS:

The lithostratigraphic formations have been identified on the basis of nature of sediments, sedimentary structures and pedogenic characters. Thus we have four lithostratigraphic formations viz. Shirasmarg, Manjrath and Ranjegaon (Table 4.3). The oldest grey silt formation at Ranjegaon is correlated with tephra bearing the Beneta formation of early Upper Pleistocene (75 ka to 118 Ka). The light grey silt formation at Manjrath is correlated with upper Hirdepur formation of late upper Pleistocene age (13 ka to 25 ka). The dark grey silt formation at Shirasmarg is correlated with the Ramnagar formation of Holocene period (Tiwari 1999).

Table 4.3: Lithostratigraphy of Quaternary Formations of Godavari Basin

Formations	Beds	Lithology	Soil Characteristics	Morphostratigraphy

			and (Type)	
Shirasmarg	1. Dark grey silt formation	Uncalcified silty sand and gray silty clay	Gray, fine silty clay (Entisol)	T0 – Present Floodplain
Manjrath	2. Light grey silt formations	Light grey silty and brown to grey brown calcareous silty clay	Dark brown clayey (Vertisol)	T1 – Older Floodplain
Ranjegaon	3. Brown silt formation	Brown to dark brown calcareous clay	Dark brown clayey (Vertisol)	T2 – Pediplain

For the present study the lithologs of the Quaternary sediments of the Sindphana River was studied from fourteen localities (Fig. 4.1) viz. Ukkadpimpri, Sakshalpimpri, Shirasmarg, Ranjegaon, Nathapur, Hajipur, Hingani, Hirapur, Shirpur, Majalgaon, Manur, Depegaon, Sandas Chincholi, Shimpe Takali and Manjrath village. The pebbly gravels are followed by grey sandy silt layers with calcretes and thick massive sandy silt with silt layers. The sandy silt layers show the presence of cross bedding structures.

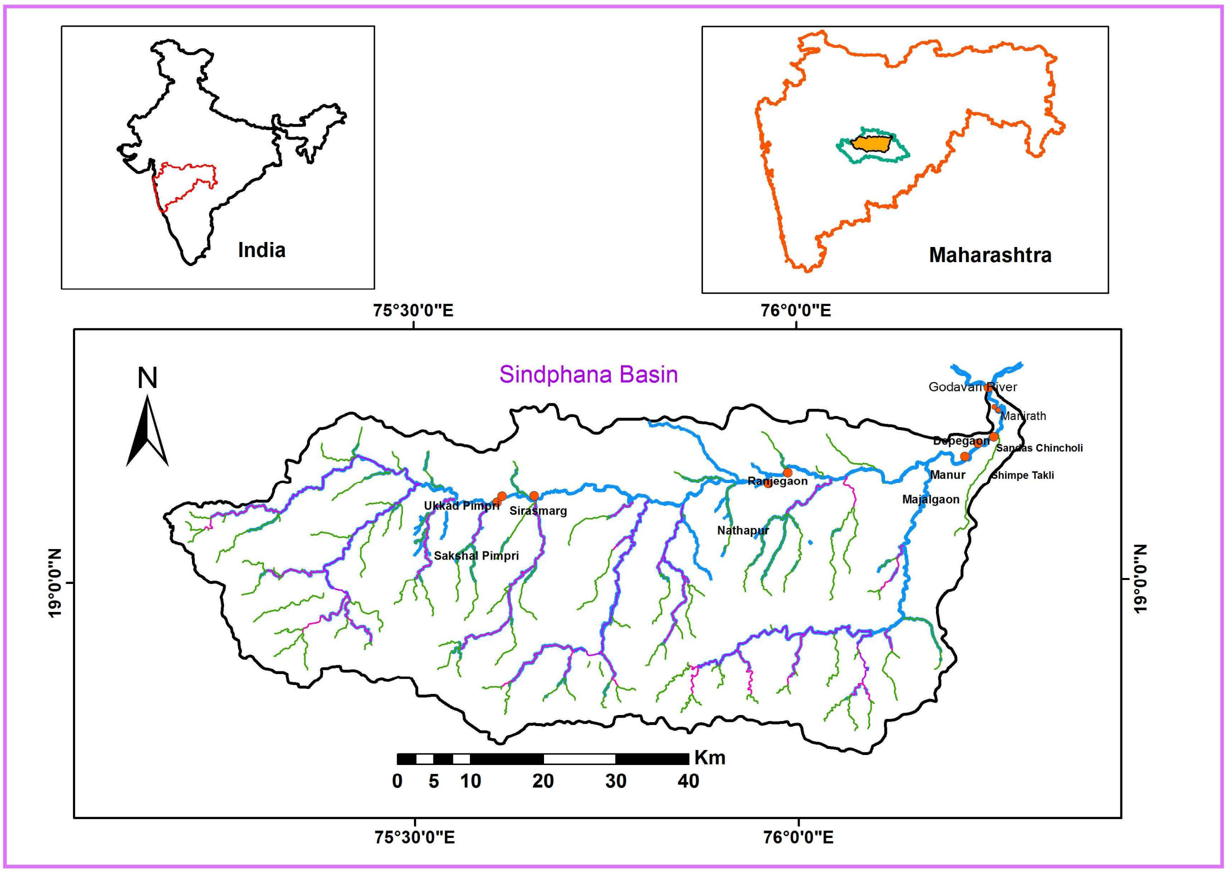


Fig. 4.1: Location map of sites where the lithologs are studied.

The details of the lithologs are given in the Table 4.4.

Table 4.4: Lithologs along the Sindphana river.

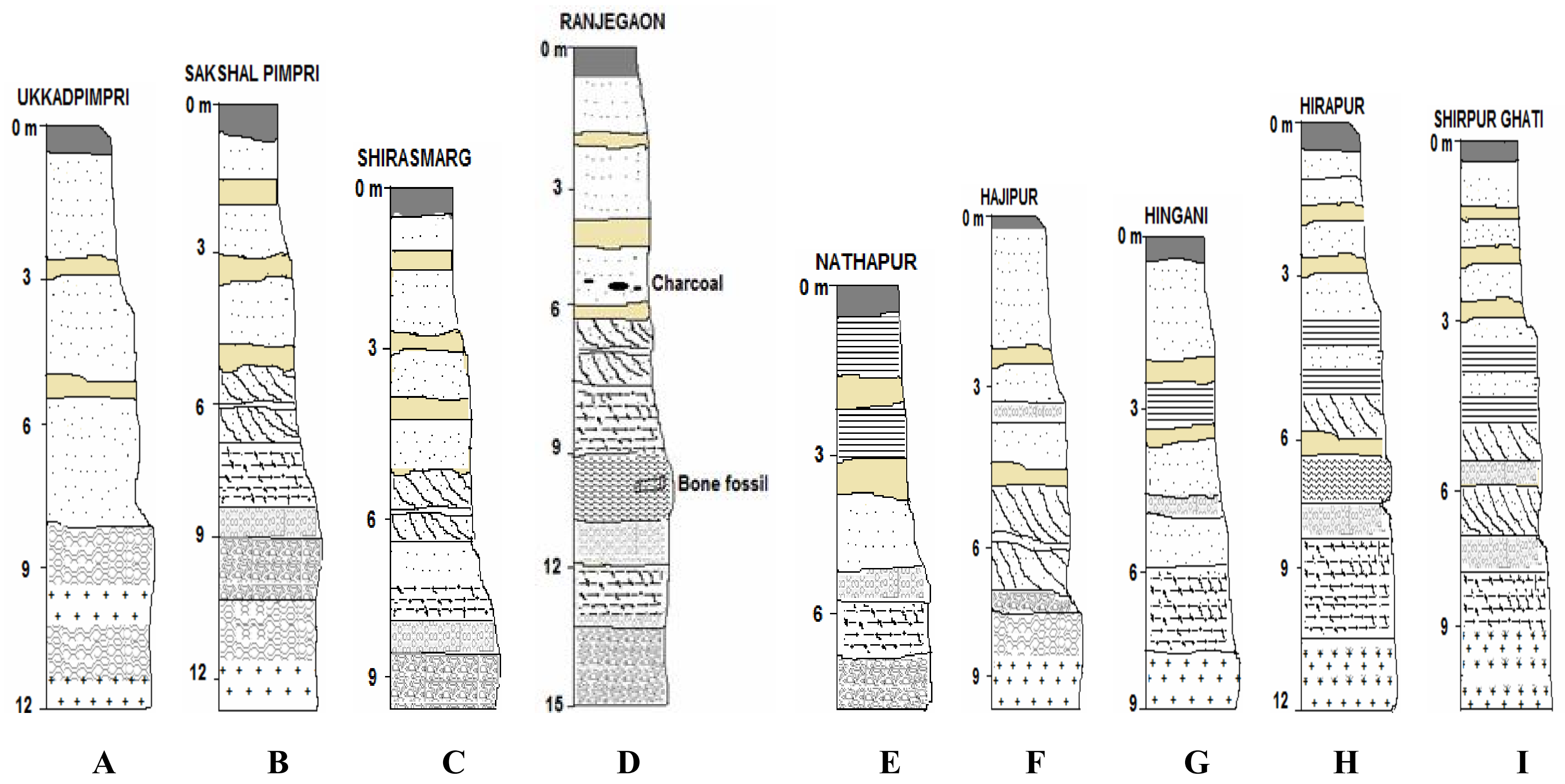
Sr. No.	Location	Latitude	Longitude	Lithology	Thickness (m)	Total Thickness (m)

1	Ukkadpimpri	19º06'24"N	75º36'50"E	Top black clayey	0.6	12.0
				Dark grey sandy silt	1.9	
				Clay	0.5	
				Dark grey sandy silt	1.9	
				Clay	0.5	
				Dark grey sandy silt	2.4	
				Vesicular-Amygdaloidal	1.4	
				Compact Basalt	0.9	
				Vesicular-Amygdaloidal	1.1	
				Compact Basalt	0.8	
2	Sakshalpimpri	19º06'13"N	75º36'22"E	Top black clayey	0.6	12.8
				Dark grey sandy silt	0.9	
				Clay	0.5	
				Dark grey sandy silt	1.0	
				Clay	0.5	
				Grey Sandy silt	1.4	
				Clay	0.5	
				Cross beded Sandy silt	1.6	
				Silty clay with calcretes	1.6	
				Gravel with sand	0.6	
				Pebbly gravel	1.2	
				Vesicular-Amygdaloidal	1.3	
				Compact Basalt	1.1	
3	Shirasmarg	19º06'32"N	75º39'49"E	Top black clayey	0.5	9.5
				Dark grey sandy silt	0.8	
				Clay	0.4	
				Dark grey sandy silt	0.9	
				Clay	0.4	
				Grey Sandy silt	1.0	
				Clay	0.4	
				Grey Sandy silt	1.0	
				Cross beded Sandy silt	1.1	
				Grey Sandy silt	0.9	
				Silty clay with calcretes	0.6	
				Gravel with sand	0.6	
				Pebbly gravel	0.9	
4	Ranjegaon	19º08'22"N	75º59'08"E	Top black clayey	0.5	15.0
				Dark grey sandy silt	1.3	
				Clay	0.2	
				Dark grey sandy silt	1.9	
				Clay	0.5	
				Grey Sandy silt	1.4	
				Clay	0.2	
				Cross bedded Sandy silt	1.2	
				Silty clay with calcretes	1.8	
				Sandy silt stone	1.8	
				Silty clay with calcretes	1.2	
				Gravel with sand	1.3	
				Pebbly gravel	1.7	
5	Nathapur	19º07'44"N	75º57'39"E	Top black clayey	0.5	8.1
				Greyish brown silty clay	1.2	
				Clay	0.4	
				Greyish brown silty clay	0.9	
				Clay	0.6	
				Sandy Silt	1.8	
				Gravel bed with sand	0.5	

				Silty clay with calcretes	1.2	
				Pebbly gravel	1.0	
6	Hajipur	19º06'40"N	75º33'10"E	Top black clayey	0.3	9.5
				Sandy Silt	2.1	
				Clay	0.4	
				Sandy Silt	0.6	
				Gravel bed with sand	0.4	
				Sandy Silt	0.9	
				Clay	0.4	
				Silty clay with calcretes	1.9	
				Pebbly gravel	0.5	
				Vesicular-Amygdaloidal	1.0	
				Compact Basalt	1.2	
7	Hingani	19º07'03"N	75º45'48"E	Top black clayey	0.4	9.0
				Sandy Silt	1.9	
				Clay	0.4	
				Silty clay	0.7	
				Clay	0.3	
				Sandy Silt	0.9	
				Gravel bed with sand	0.4	
				Sandy Silt	0.9	
				Silty clay with calcretes	1.9	
				Compact Basalt	1.2	
8	Hirapur	19º06'53"N	75º44'32"E	Top black clayey	0.6	12.0
				Sandy Silt	1.1	
				Clay	0.3	
				Sandy Silt	0.7	
				Clay	0.3	
				Sandy Silt	1.0	
				Silty clay	0.5	
				Sandy Silt	0.4	
				Silty clay	0.5	
				Cross bedded Sandy silt	0.6	
				Clay	0.4	
				Sandy silt stone	1.4	
				Gravel bed with sand	0.6	
				Silty clay with calcretes	2.2	
				Compact Basalt	1.4	
9	Shirpur Ghat	19º06'53"N	75º33'20"E	Top black clayey	0.4	10.5
				Sandy Silt	0.8	
				Clay	0.2	
				Sandy Silt	0.4	
				Clay	0.3	
				Sandy Silt	0.6	
				Clay	0.3	
				Sandy Silt	0.4	
				Silty clay	0.5	
				Sandy silt	0.4	
				Silty Clay	0.5	
				Cross bedded Sandy silt	0.8	
				Gravel bed with sand	0.4	
				Cross bedded Sandy silt	1.2	
				Gravel bed with sand	0.7	
				Silty clay with calcretes	1.1	
				Compact Basalt	1.5	
10	Majalgaon	19º09'26"N	76º11'35"E	Top black clayey	0.2	9.5

				Sandy Silt Silty Clay Sandy Silt Clay Sandy Silt Gravel bed with sand Sandy Silt Clay Cross bedded Sandy silt Silty Clay Pebbly gravel Silty clay with calcretes Compact Basalt	0.8 0.5 0.9 0.3 0.6 0.4 0.7 0.4 0.8 1.4 0.4 1.5 0.6	
11	Manur	19º10'01"N	76º14'36"E	Top black clayey Sandy Silt Clay Sandy Silt Gravel bed with sand Sandy Silt Silty Clay Sandy silt stone Pebbly gravel Compact Basalt	0.3 1.3 0.4 0.5 0.3 0.4 1.1 0.6 1.7 0.6	7.2
12	Depegaon	19º12'46"N	76º15'36"E	Top black clayey Silty Clay Clay Sandy Silt Clay Gravel bed with sand Silty Clay with Charcoal Gravel bed with sand Silty clay with calcretes Pebbly gravel	0.6 1.1 0.5 1.0 0.6 0.7 0.8 0.5 1.1 0.7	7.6
13	Sandas Chincholi	19º13'00"N	76º15'50"E	Top black clayey Sandy Silt Clay Sandy Silt Clay Sandy Silt Vesicular-Amygdaloidal Compact Basalt Vesicular-Amygdaloidal Compact Basalt	0.3 0.9 0.4 0.9 0.2 0.8 1.8 0.9 1.5 1.3	9.0
14	Shimpe Takali	19º10’30”N	76º15’02”E	Top black clayey Silty Clay Clay Sandy Silt Gravel bed with sand Silty Clay Sandy Silt Gravel bed with sand Sandy Silt Pebbly Gravel Sandy Silt Pebbly Gravel Compact Basalt	0.5 0.7 0.4 0.8 0.5 0.4 1.4 0.4 1.6 1.0 1.9 2.2 1.1	12.9

15	Manjrath	19º15’59”N	76º45’37”E	Top black clayey Sandy Silt Clay Sandy Silt Clay Sandy Silt Silty Clay Cross bedded Sandy silt Silty Clay Gravel bed with sand Sandy Silt Stone Pebbly Gravel Silty clay with calcretes Pebbly Gravel Compact Basalt	0.7 1.5 0.6 1.6 0.4 0.9 0.6 0.7 1.5 0.6 0.8 0.9 1.2 2.1 1.2	15.3


UKKADPIMPRI
SAKSHAL PIMPRI
SHIRASMARG
RANJEGAON
Charcoal
Bone fossil
NATHAPUR
HAJIPUR
HINGANI
HIRAPUR
SHIRPUR GHATI
A
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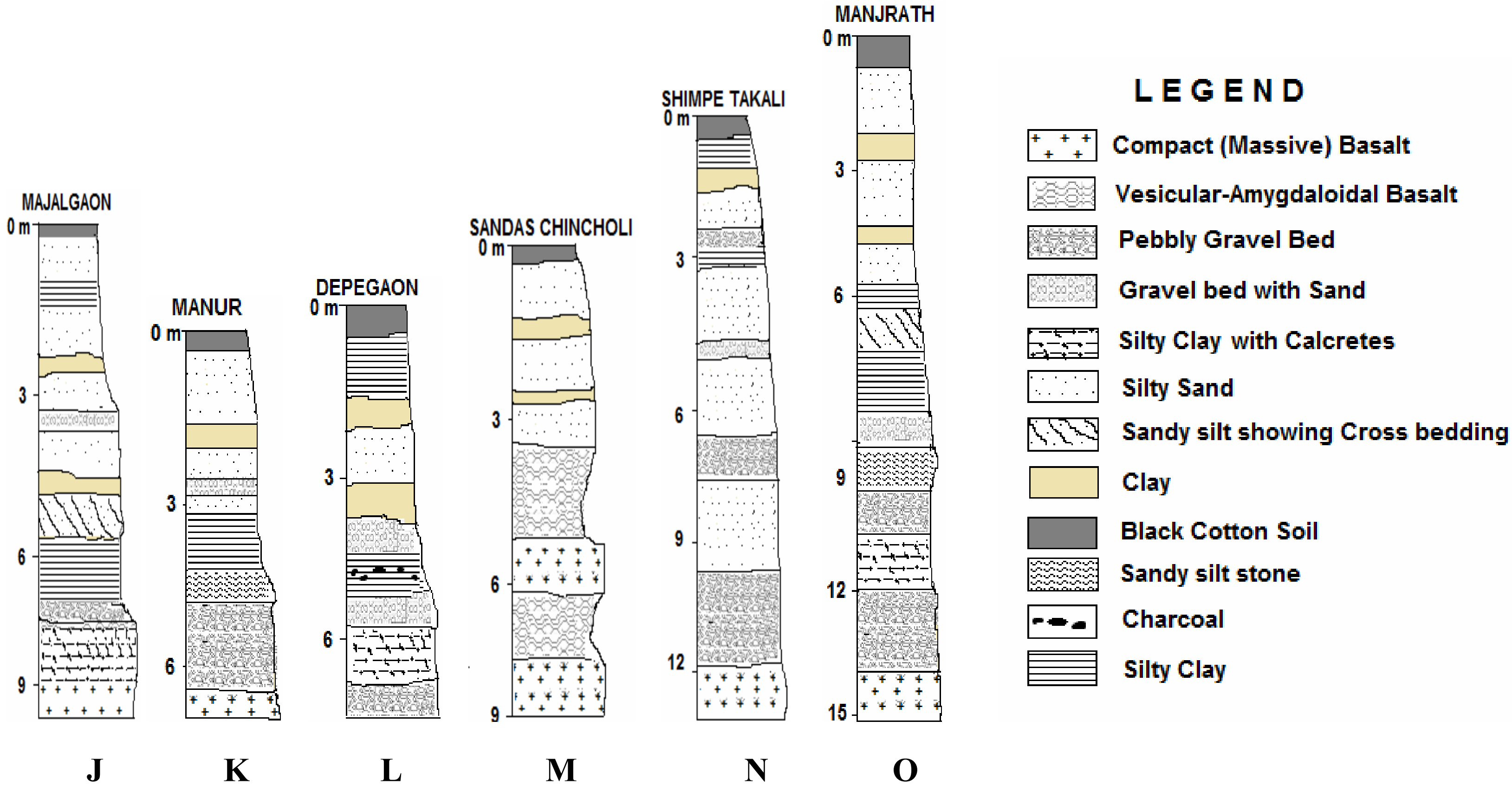


Fig. 4.2. Lithologs (A to O) occurring along the Sindphana river in Beed District

4.2.1: Ukkad Pimpri:

The Quaternary sequence at Ukkad Pimpri (Fig.4.2 A and Table 4.4) is the 7.8 m thick sediment consisting of dark grey sandy silt intercalated with clay layers. Due to low channel gradient the depositional activity is dominant. The river cut exposed is 12.0 m thick, of which, the lower 4.2 m is consisting of 4 flows of alternate compact basalt and amygdaloidal basalt flows followed by three layers of dark grey coloured sandy silt layers having total thickness of about 6.2 m. Three sandy silt layers are separated by tow clay layers each of 0.5 m thickness. Topmost layer is 0.6 m black clayey soil popularly known as black cotton soil.

4.2.2: Sakshal Pimpri:

At Sakshal Pimpri (Fig. 4.2B and Table 4.4), the section shows gradual fining upward trend, which is typical of the point bar deposits. The lowest part is marked by two basalt flows in the sequence from lower to upper i.e. compact basalt (1.1 m) and amygdaloidal basalt (1.3 m). The hard rock basalts are followed by pebbly gravel layer at base, which is overlain by gravel with sand, silty clay showing calcrete (Fig. 4.3) followed by sandy silt showing cross bedding structure. Towards the top there are three layers of dark grey sandy silt alternating with three layers clay. The topmost layer consists of grey black clay.

Mishra et al (2003) studied 3.0 m sequence of sediment from which the dates of bivalve shells and gastropods is obtained as 14200±90 years with calibrated age as 17020 years indicating beginning of agradational phase in the area at Sakshal Pimpri. Number of dates of OES fragment derived from pebbly gravel bed from the same sections was obtained 14.2 ka belonging to late Pleistocene period,while upper layer yielded age of 7.8 ka. These investigations suggest that the aggradations were rapid between 14.2 to 17.0 ka when over 3 m of silty sand was deposited, while 2.4 m of sandy silt was deposited between 7.8 and 4.2 ka (Mishra *et al*, 2003). The date obtained from the Sakshal Pimpri area of 7 m thick sandy silt containing the bivalve shells is about 7800±100 indicating the aggradations were rapid between 7.8 to 8.6 ka.

The area at Sakshal Pimpri showing the pebbly gravel bed along with the presence of bone fossil (Fig. 4.4). Fluorine: Phosphate ratio derived for determination of age of the bone fossil indicates the age of the fossil is Early Holocene.

Fig. 4.3: Photo showing development of calcretes in silty clay layer and sandy silt at the base

Fig. 4.4: Photo showing the pebbly gravel alongwith the presence of bone fossil along left bank of the Sindphana river at Sakshal Pimpri.

4.2.3: Shirasmarg:

The Quaternary sediments along left bank of Sindphana valley at Shirasmarg (Fig. 4.2 C and Table 4.4) illustrates the pebbly gravel overlies the Deccan traps and is overlain with an erosional unconformity, by gravel with sand followed by calcareous silty clay showing development of calcretes and sequence of grey sandy silt with cross bedding structure (Fig 4.2 C). The river cut exposed is 12.8 m thick, of which, the lower 1.8 m is light to dark grey coloured and marked by loosely packed pebbles (Fig. 4.5), gravel and sand having subrounded to rounded pebbles, gravels of basalt, agate, chalcedony and zeolites (e.g. natrolites). The later part shows three layers of dark grey sandy silt intercalated with three layers of clay and the black clayey soil at the top. The section at Shirsmarg show slump structure at pebbly gravel bed and bone fossil possibly transported type (Fig. 4.6).

Fig. 4.5: Sedimentary section exposed at right bank of Sindphana river at Shirasmarg

4.2.4: Ranjegaon:

The sediments at Ranjegaon are found to overlie the Deccan basalt and underlain by older alluvium of Sidphana river. It is the well established section having total thickness of 15 m and illustrating gradual decrease in grain size from bottom to top and development of calcrete layers in lower level. The pebbly gravel bed (Fig. 4.7) is about 1.70 m thick and occurs at the bottom layer. The development of sandy silt stone of 1.8 m thickness (Fig. 4.8) is the prominent feature of this sequence. The hard silt stone layer consists of bovid bone fossils (Fig. 4.9). Sandy silt deposits also show the presence of Charcoal layer (Fig. 4.10) along the right bank of the Sindphana river. The sequence consists of three layers of Grey brown sandy silt with alternating clay (Fig. 4.11), development of calcretes and Gravel bed at the base (Fig. 4.2 D and Table 4.4).

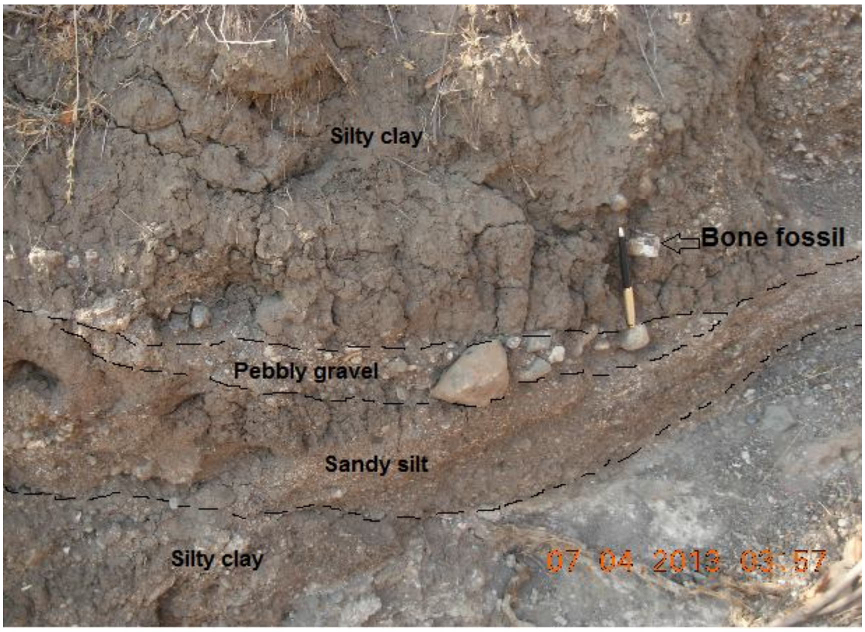


Fig. 4.6: Sedimentary section showing slump structure and bone fossil along right bank of Sindphana river at Shirasmarg

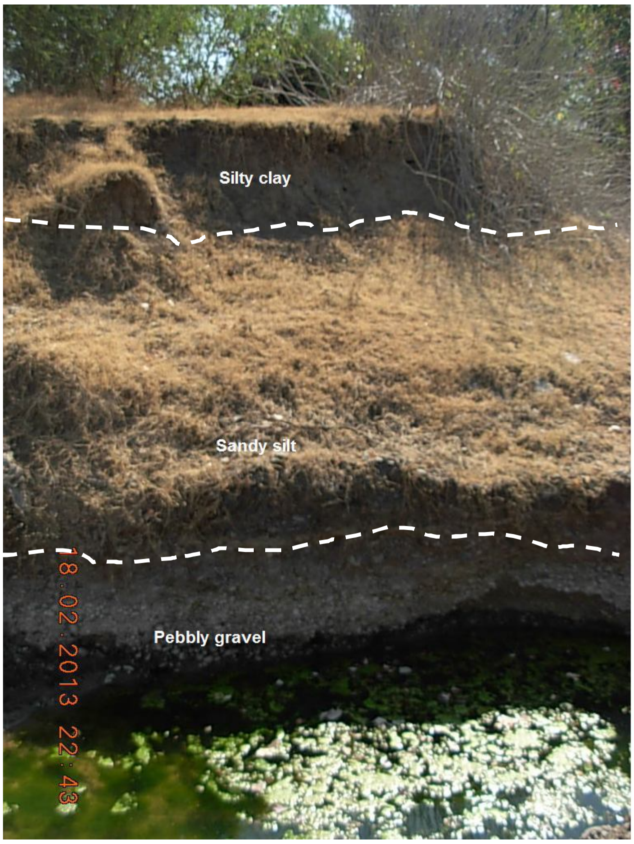


Fig. 4.7: Pebbly gravel at the base at Ranjegaon

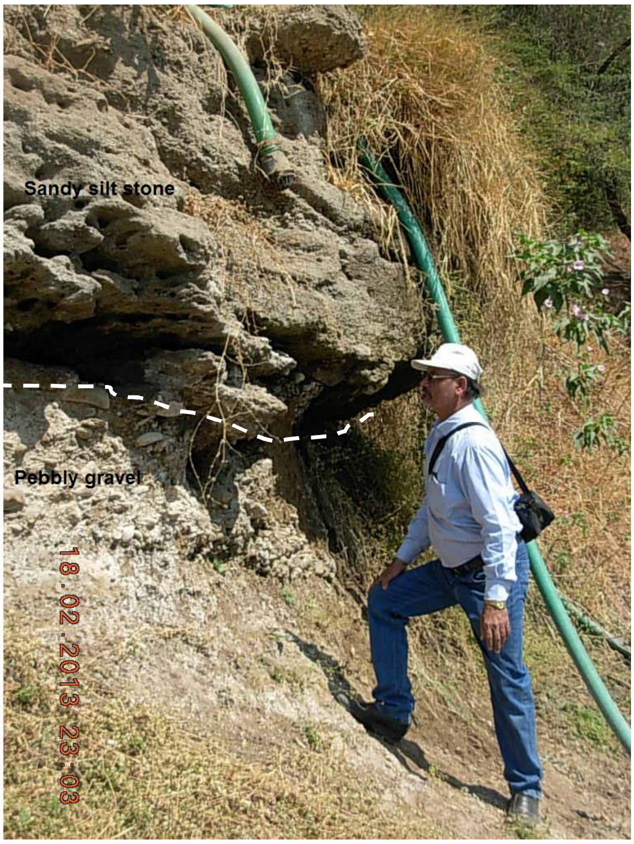


Fig. 4.8: Sandy silt stone formation at Ranjegaon

Similar to Sakshal Pimpri Mishra et al (2003) studied 7.0 m sequence of sediment from which the dates of bivalve shells is obtained as 7800±130 years with calibrated age as 8590 years. These investigations suggest that the aggradations were rapid in the area at Ranjegaon between 7.8 to 8.6 ka. The shells were collected from the top of the terrace and show the human activity in collection and discarding of the shells on terrace top.

Fig. 4.9: (A) Pebbly gravel bed showing bone fossil (B) Sandy silt stone formation on top and occurrence of bone fossil in pebbly gravel bed at Ranjegaon

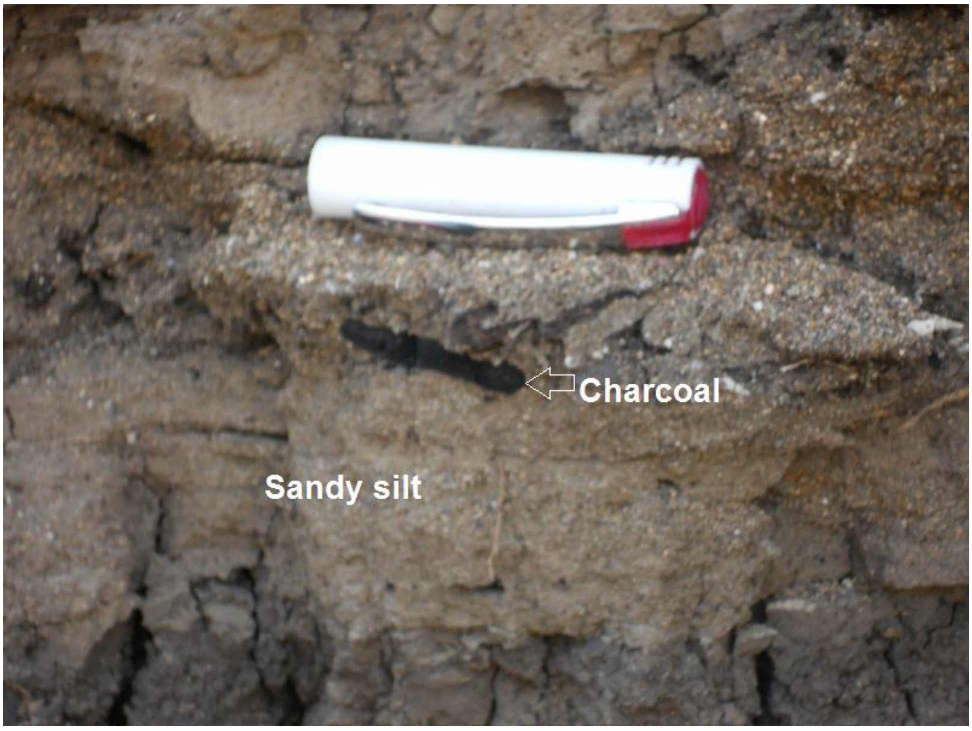


Fig. 4.10: Sandy silt layer along right bank of Sindphana river at Ranjegaon showing Charcoal just beneath the layer of gravel with sand.

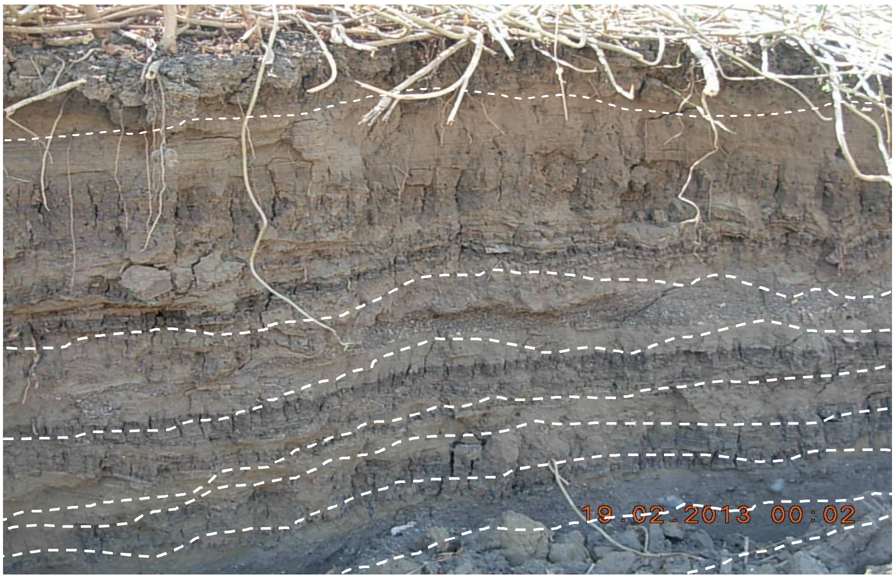


Fig. 4.11: Alternate layers of Sandy silt and clay at Ranjegaon

4.2.5: Nathapur:

The sedimentary section along right bank of the Sindphana valley occurring at Nathapur (Fig. 4.2 E and Table 4.4) consists of the gravel bed with loosely packed rounded to sub-rounded pebbles and gravels of basalt and quartz grains mixed with thinly bedded clays showing warping followed by silty clay with the development of calcretes and gravel sand. It is overlain by sandy silt layer and two layers of dark brown silty clay (Fig. 4.12) intercalated with greyish brown clay and thin layer of black cotton soil on top. The sequence found in the area is 8.1 m thick dominated by silty clay layers separated by thin dark grey clay layers towards top.

Fig. 4.12: Silty clay layers along left bank of Sindphana river at Nathapur

4.2.6: Hajipur:

The sediments at Hajipur are found overlies the Deccan trap and underlain by older alluvium of Sindphana river. They consist of Grey sandy silt layers with development of calcretes in the lower portion. Hence the sediments may belong to late (upper) Pleistocene age. This section is 9.5 m thick with lower 2.2 m basalt flows and 7.3 m arenaceous to argillaceous in nature and shows the pebbly gravel (0.50 m) at the base (Fig. 4.2 F and Table 4.4). Above this section there is silty clay (1.9 m) with cross lamination structure (Fig. 4.13), clay (0.40 m), light grey sandy silt (0.90 m), gravel bed with sand (0.40 m), two layers of sandy silt (0.60 m and 2.10 m) separated by thin clay layer (0.40 m) in upward succession and top most grey black clayey soil (0.30 m).

4.2.7: Hingani:

The Quaternary sediments along left bank of Sindphana valley at Hingani (Fig. 4.2 G and Table 4.4) illustrates the Silty clay with calcretes (1.90 m) overlies the Deccan traps (compact basalt 1.20 m thick) and is overlain with an erosional unconformity, by sandy silt (0.90 m), gravel with sand (0.40 m) followed by sandy silt (0.90 m), clay (0.30 m), silty clay (0.70 m), clay (0.40 m), sandy silt (2.10 m) and black clayey BCS at top (Fig 4.2 G). The river cut exposed is 9.0 m thick, of which, the lower compact basalt is 1.20 m and upper Quaternary sediments are 7.80 m thick.

4.2.8: Hirapur:

Along right bank of Sindphana valley at Hirapur (Fig. 4.2 H and Table 4.4) the Quaternary sediments exemplify the Silty clay with calcretes (2.20 m) overlies the Deccan traps (aa flow/compact basalt 1.40 m thick) and is overlain with an erosional unconformity, by gravel with sand followed by compacted sandy silt stone (Fig. 4.14), calcareous clay and sequence of grey sandy silt showing development of calcrete (Fig 4.15), silty clay, sandy silt, silty clay and three layers of sandy silt separated by three layers of clay. The river cut exposed is 12.00 m thick, of which, the lower 1.40 m is igneous and upper 10.60 m is sedimentary. The later part shows four layers of dark grey sandy silt intercalated with one layer of silty clay and three layers of clay (Fig. 4.16), while the black clayey soil is at the top.

Fig. 4.13: Silty clay layers mixed with sandy silt shows several generation of cross lamination and current bedding structure along left bank of Sindphana river at Hajipur

Fig. 4.14: Compacted sandy silt stone along left bank of Sindphana river at Hajipur

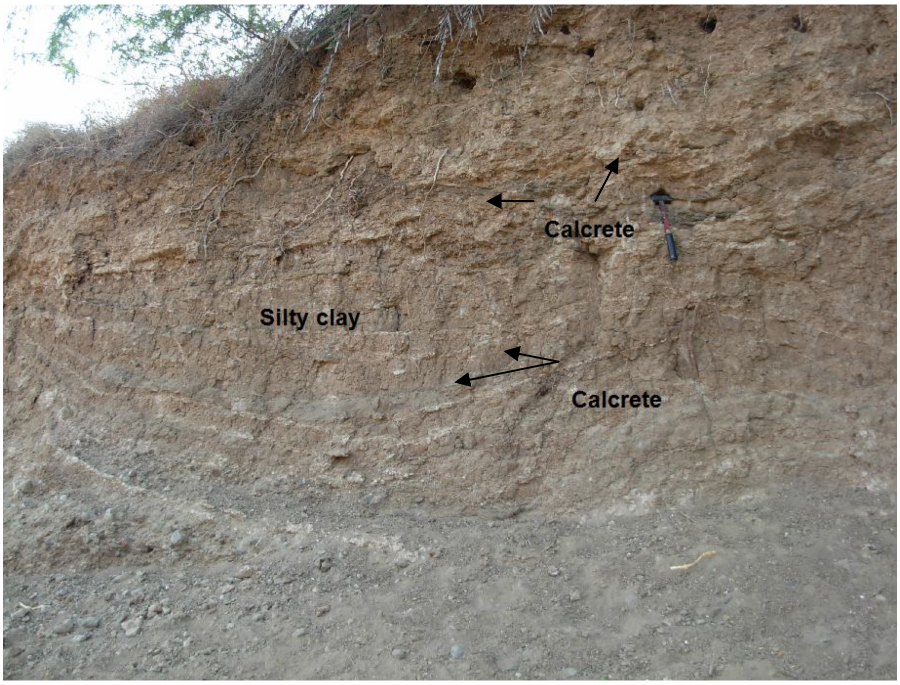


Fig. 4.15: Development of calcrete in silty clay along left bank of Sindphana river at Hirapur


Fig. 4.16: Silt clay showing layers of clay along right bank of Sindphana river at Hirapur

4.2.9: Shirpur Ghat:

The Quaternary sediments along right bank of Sindphana valley at Shirpur Ghat (Fig. 4.2 I and Table 4.4) illustrates the Silty clay with calcretes (1.10 m) overlies the Deccan traps (compact basalt 1.50 m thick) and is overlain with an erosional unconformity, gravel with sand (0.70 m), by cross bedded sandy silt (1.20 m), followed by gravel with sand (0.40 m), cross bedded sandy silt (0.80 m) (Fig. 4.17). These layers are followed by five layers of sandy silt alternating with two layers of silty clay in lower part and three layers of clay towards top and black clayey BCS at the top (Fig 4.2 I). The total river section exposed is 10.50 m thick, of which, the lower compact basalt is 1.50 m and upper Quaternary sequence is 9.00 m thick.

4.2.10: Majalgaon Near Dam:

The Quaternary sediments exposed along the channel of Sindphana valley at Majalgaon near Dam in Beed district (Fig. 4.2 J and Table 4.4) consists of Compact basalt (0.60 m) at the base followed by Silty clay with calcretes (1.50 m), pebbly gravel bed (0.40 m), light grey silty clay (1.40 m), Cross bedded Sandy silt (0.80 m), clay (0.40 m) followed by four layers of sandy silt deposits separated by layers of gravel bed with sand (0.40 m), clay (0.30 m) and silty clay (0.50 m) in upward succession and BCS at the top (0.20 m). The exposure of silty clay is shown in Fig. 4.18 and pebbly gravel and sandy silt are represented in Fig. 4.19.

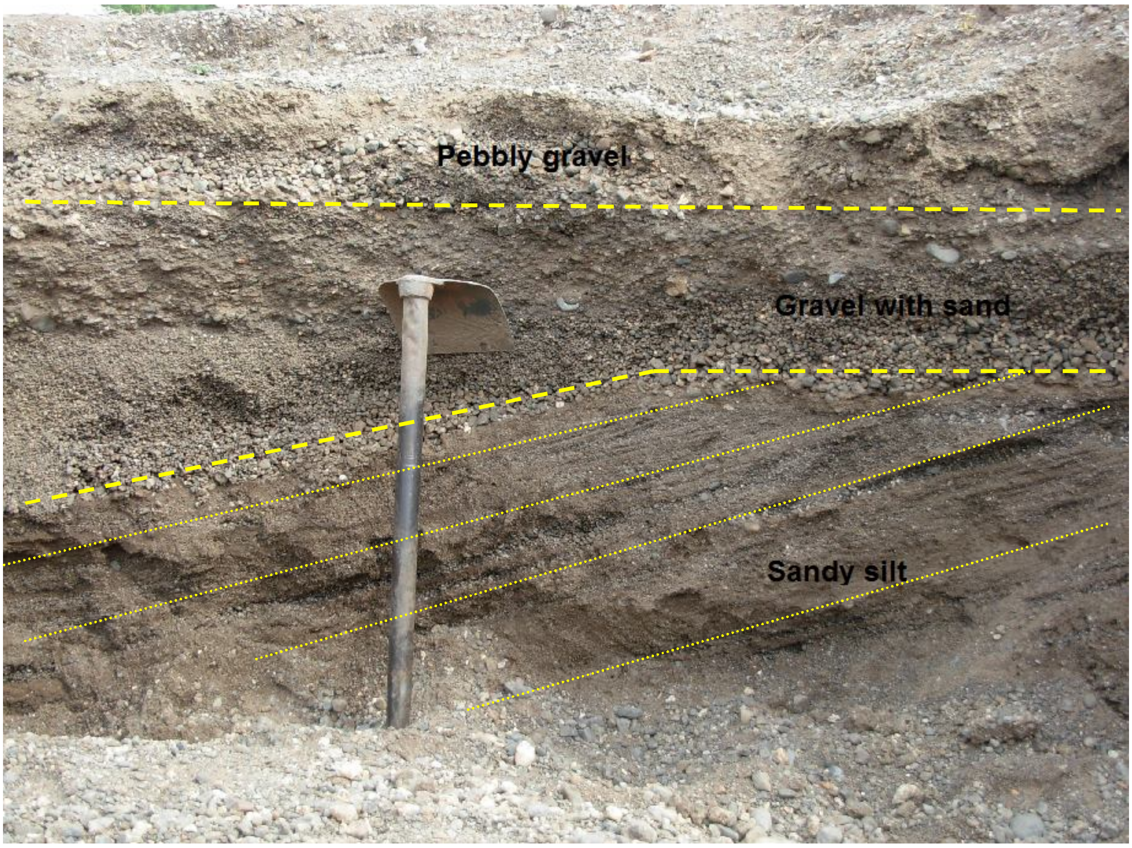


Fig. 4.17: Layers of pebbly gravel, gravel with sand and cross bedded sandy silt at Shirpur

Fig. 4.18: Silty clay at right bank of Sindphana at Majalgaon

Fig. 4.19: Sandy silt and pebbly gravel at right bank of Sindphana at Majalgaon

4.2.11: Manur:

The Quaternary sediments along right bank of Sindphana valley at Manur (Fig. 4.2 K and Table 4.4) illustrates the pebbly gravel (1.70 m Fig. 4.20) overlies the Deccan traps (compact basalt 0.60 m thick) and is overlain with an erosional unconformity by sandy silt stone (0.60 m), followed by silty clay (1.10 m), sandy silt (0.40 m), gravel with sand (0.30 m), sandy silt (0.50 m), clay (0.40 m), sandy silt (1.30 m Fig. 4.21) and black clayey BCS at the top. The total river section exposed is 7.20 m thick, of which, the lower compact basalt is 0.60 m and upper Quaternary sequence is 6.60 m thick.

Fig. 4.20: Pebbly gravel at the base observed in the Stream bed of tributary of Sindphana river at Manur

Fig. 4.21: Sandy silt observed along the right bank of Sindphana river at Manur

4.2.12: Depegaon:

Fig. 4.2 L and Table 4.4 illustrates the Quaternary sediments along left bank of Sindphana river at Depegaon consists of the pebbly gravel (0.70 m) at the base followed by silty clay with development of calcretes (1.10 m), gravel with sand (0.50 m), silty clay with charcoal (0.80 m Fig. 4.22A), gravel with sand (0.70 m), clay (0.60 m), sandy silt mixed with shells (1.00 m Fig. 4.22B), clay (0.50 m), silty clay (1.10) and black clayey BCS (0.60 m) at the top. The total river section exposed is 7.60 m thick, which is totally Quaternary sequence. The area is also characterized by presence of charcoal layers and molluscan shells (Fig. 4.22) and the bovid tooth fossil (lower molar) in the bed of the Sindphana river as a transported material in form of pebbles (Fig. 4.23).

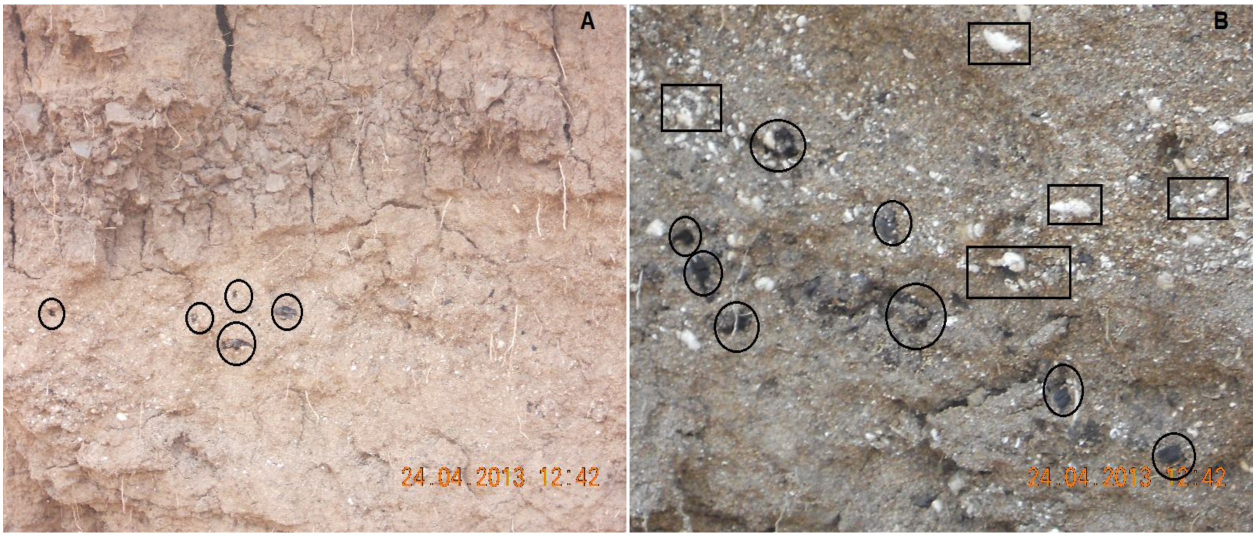


Fig. 4.22: (A) Silty clay layer along right bank of Sindphana river at Depegaon showing Charcoal in circles, (B) Sandy silt layer along right bank of Sindphana river at Depegaon showing Charcoal in circles and shells in rectangles.

Fig. 4.23: Lower molar teeth fossil of Bovid found as transported in the bed of Sindphana river at Depegaon.

4.2.13: Sandas Chincholi:

The litholog occurring at the right bank of Sindphana valley at Sandas Chincholi (Fig. 4.2 M and Table 4.4) illustrates four layers of Deccan traps (compact basalt 1.30 m, Vesicular-Amygdaloidal 1.50 m, compact basalt 0.90 m and Vesicular-Amygdaloidal 1.80 m with total thickness of 5.50 m from bottom to upward direction) and is overlain with an erosional unconformity by Quaternary sediments consisting of three layers of sandy silt separated by two layers of clay and black clayey BCS at the top as shown in Fig 4.2 M. The total river section exposed is 9.00 m thick, of which, the lower Deccan basalt is 5.50 m and upper Quaternary sequence is 4.50 m thick.

4.2.14: Shimpe Takli:

Along right bank of Sindphana valley at Shimpe Takli (Fig. 4.2 N and Table 4.4) the Quaternary sediments represent the Pebbly gravel (2.20 m Fig. 4.24 A) overlies the Deccan traps (aa flow/compact basalt 1.10 m thick) and is overlain with an erosional unconformity by sandy silt (1.90 m), pebbly gravel (1.00 m) followed sandy silt (1.60 m), gravel with sand (0.40 m), sandy silt (1.40 m), silty clay (0.40 m), gravel with sand (0.50 m), sandy silt (0.80 m), clay (0.40 m), silty clay (0.70 m) and top layer of grey black cotton soil. The river section exposed is 12.90 m thick, of which, the lower 1.10 m is igneous and upper 11.80 m is sedimentary. Layers of silty clay and clay are shown in the Figure 4.24 B.

4.2.15: Manjrath:

The Quaternary sediments exposed along right bank of Sindphana river at Manjrath (Fig. 4.2 O and Table 4.4) embody the Pebbly gravel (2.10 m Fig. 4.25A) overlies the Deccan traps (aa flow/compact basalt 1.20 m thick) and is overlain with an erosional unconformity by silty clay with development of calcretes (1.20 m Fig. 4.25B), pebbly gravel (0.90 m), compacted sandy silt stone (0.80 m) gravel with sand (0.60 m) followed by silty clay (1.50 m) and sequence of grey sandy silt with cross bedding structure (0.70 m), silty clay (0.60 m) and three layers of sandy silt separated by two layers of clay. The river cut exposed is 15.30 m thick, of which, the lower 1.20 m is igneous (Deccan basalt) and upper 14.10 m is sedimentary. The later part shows three layers of dark grey sandy silt intercalated with one layer of silty clay and two layers of clay, while the black clayey soil (BCS) is at the top. The sediments excavated for sand mining in the river bed also illustrated two generation of cross bedding structures (Fig. 4.26).

Fig. 4.24: (A) Pebbly gravel layer at base along right bank of Sindphana river at Shimpe Takali, (B) Silty clay and clay layers along right bank of Sindphana river at Shimpe Takali.

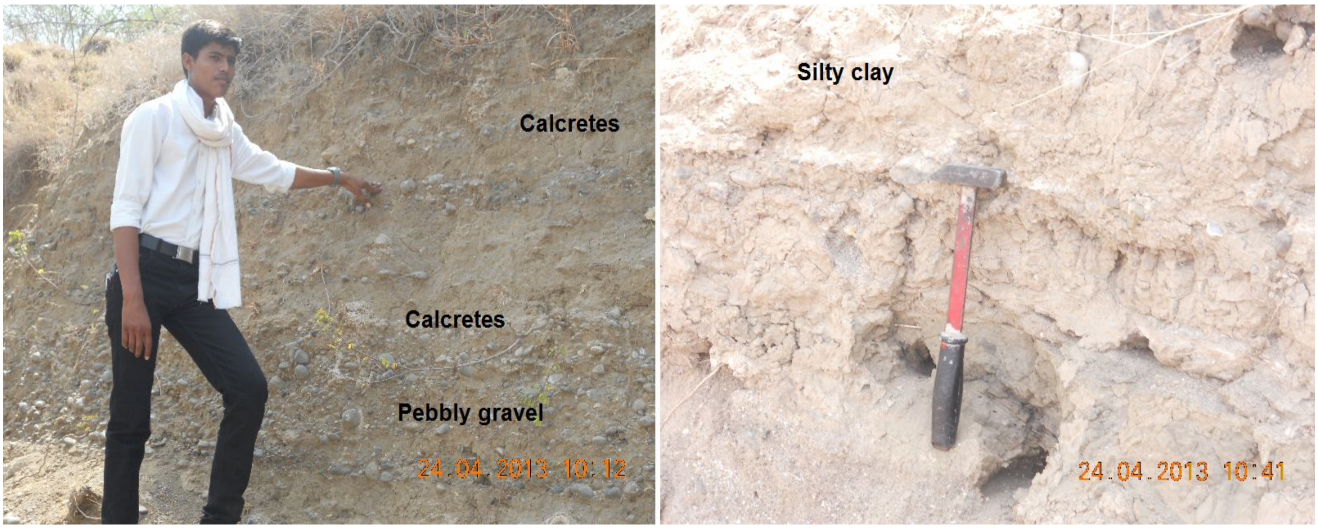


Fig. 4.25: (A) Pebbly gravel layer at base followed by sandy silt with development of calcretes along right bank of Sindphana river at Manjrath, (B) Silty clay layers along right bank of Sindphana river at Manjrath.

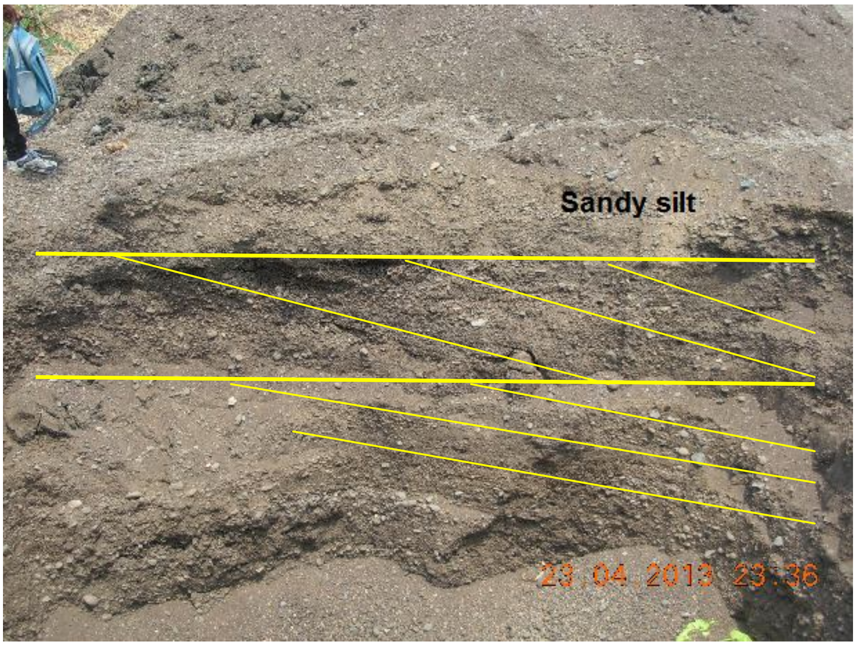


Fig. 4.26: The pit in the bed of Sindphana river at Manjrath showing the cross bedding structure in the sandy silt mixed with pebbles

4.3. FLUVIAL SEDIMENTATION

The fluvial systems in the semi arid areas are subject to wide fluctuation in discharge. The fluvial forms and processes are closely associated with the morphogenetic regions. Although river channels can be classified as meandering or non meandering or bed load or wash load dominant, the nature of the semi arid rivers is complex because the rivers are subject to marked fluctuation in water and sediment discharge. In spite of this it is the fact that development of sediments depends on several factors such as sediment supply, climate, tectonic stability etc.

The general predominance of coarse sediment in semi arid rivers is responsible for less stability and more mobility of sediments. Such channels are therefore, unstable and dynamic and are characterized by constant channel migration. Further the semi arid rivers respond fast to the changes in the hydraulic regime because of the higher average rate of motion of coarse sediments. In the present study the depositional environment have been deduced on the basis of the sedimentological characters of the fluvial deposits of the Sindphana river. Sindphana River comprises rounded to sub rounded pebbles and cobbles of basalt, chalcedony, agate, chert, zeolites and quartz set in a matrix of granular sand and silt, whereas in lower reaches (i.e. in Sakshalpimpri, Majalgaon etc.) The sediments are medium to fine grained sandy silt and silty clay). The deposits are complex in nature and might have resulted from vertical stacking and amalgamation of number of low sinuosity (nonmeandering) channels (Babar, 2008; Babar and Kaplay, 1999 and Babar et al., 2010).

Three main types of fluvial formations in the Sindphana basin are as follows:

1. Sandy Silt – weakly calcified
2. Silty Sand – moderately to strongly calcified
3. Pebbly gravels sediments

Sandy Silt – Poorly Calcified

This Quaternary sedimentary deposit is represented mainly by less calcareous, faintly laminated brownish silt or sandy silt with thin (~ 2m) intercalated with patches of pebbly gravels, has developed a distinct terrace (6 to 8 m above modern bed level) cut into the older terrace surface developed on the calcareous alluvial fill at an average elevation of about 15 to 20 m above modern bed level. These deposits are found in younger floodplain areas of Sindphana River at Nathapur (Fig. 4.27), Shimpe Takli, Majalgaon, Manur, Sandas Chincholi, Dipegaon and Ranjegaonon (right bank) areas. These are younger sediments compared to the moderately to strongly calcified deposits.

Fig. 4.27. Sandy Silt – non Calcified on right bank of Sindphana river at Nathapur with Pebbly gravel at base. The photo facing east.

Silty Sand – Moderately to Strongly Calcified

These deposits are generally 5 to 10 m thick and are the most prominent Quaternary formations in the valley. However, only the upper 15 m section is generally available for examination on the banks of the Sindphana river and along its tributaries. It is observed that these deposits are laid down in channels, near channel and floodplain environments. The silty sand deposits occur either as inter-fingering layers with gravels and sands or as uniform, more or less massive or faintly laminated sedimentary units in the upper part of deposits are brownish in colour and are traversed by calcareous bands i.e. calcretes (Fig. 4.28) and concretions. Sorting is poor and lamination is poorly preserved probably due to post diagenetic changes. Dissection cracks in the sediments indicate the periodic drying after the deposition in the channel to overbank environment, were also observed in the sections at Sakshalpimpri, Shirasmarg, Ukkad Pimpri, Rajegaon (Left bank) and along the Sindphana River at Manjrath (Fig. 4.28). The presence of clay deposit below the sandy pebbly gravel in some of the sections suggests the existence of local back swamp conditions in the abandoned floodplain of the Sindphana. These deposits yield the faint inclined bedding and some cross bedding structures. The deposits suggest their settling under low current velocities and overbank accretion. These deposits perhaps developed under waning bed load and suspension sedimentation processes on overbank floodplains. The vertical uniformity and regularity of grain size in the silty sand unit suggest that the stream flow responsible for the agradational sequence was much less flashy.

Fig. 4.28. Photograph of silty sand showing the development of calcrete. Photo facing east on right bank of Sindphana river at Manjrath.

Pebbly Gravels Sediments

These are bouldery-pebbly, sub-rounded, crudely stratified, well-consolidated gravels with a maximum thickness of about 5 m. They occur on an eroded valley flat surface of basalt at an elevation of about 10 m above the modern bed level of the Sindphana. Exposures of these gravels (Fig. 4.29) are found at the right bank (e.g.at Manjrath near confluence of river Sindphana with the river Godavari). The surface of this gravel forms a distinct high ground at an elevation of about 384 m above sea level. Lithologically, the pebbly gravel comprises fragments of compact basalt and multi-coloured cherts. The matrix is of silt and fine sand and the cement is calcareous and argillaceous. The pebbly gravel is moderately sorted but poorly graded and is inter-layered with well laminated granular gravel. The sediment thickness ranges in size from 2 to 8m. The pebbly gravels capped plateau has been dissected and the alluvial fills are found to be resting against the eroded slopes of the gullies. It is therefore, apparent that there is a clear cut erosional disconformity between the pebbly gravel beds (Fig. 4.29) and the alluvial fills of the Sindphana River. The pebbly gravels are lenticular, discontinuous bodies and are cemented by secondary calcite. Pebble lithology is represented by compact, porphyritic basalts, cherts, chalcedony, secondary silica and zeolites. The gravels are subrounded, moderate to well sorted but generally poorly graded suggesting their deposition as channel bars in as seasonal flooding stream. All these field characters suggests that the lower gravels were deposited in the high energy upper flow regime of channel environment by a stream having a peak discharge for a short duration only. Similar types of pebbly gravel beds have been observed in the same stratigraphical relationship with the alluvial fill further upstream at Nevasa in the Pravara valley (Ansari and Pappu, 1975) and downstream at various localities such as Nandur Madhmeshwar, Hiradpuri, Dharangaon, Apegaon along the Godavari River (Babar, 2011).

Fig. 4.29. Photograph of Pebbly gravel beds A) right bank of Sindphana river at Manur B) right bank of Sindphana river at Manjrath Photo facing east.

The pebbly gravels are grey to dark grey, yellowish and reddish brown, poorly sorted and matrix-supported. In most cases, the matrix comprises medium to coarse grained sands, argillaceous and carbonaceous materials. They are polymictic, texturally immature and crudely stratified or massive. The pebbly gravel units were deposited most probably as small lenticular bodies of channel lag or low sinuous streams (Reineck and Singh, 1980). They might have been deposited as debris flow deposits. Some of the siliceous pebbles display surface cracks due to weathering. Signs of weathering and iron staining are seen along micro joints. In the sediments the imbrications, grading and stratification are not seen conspicuously. These sediments have yielded faunal remains of Bos sp., elephus sp. and wood (Corvinus, 1981). Stratigraphically and geomorphologically they have tentatively dated to the late-middle Pleistocene period (Rajaguru and Kale, 1985). The pebbly gravel sediments are correlated with the Godavari formation by Kale (1988). The coarseness of sediments, poor sorting, lack of grading and stratification and general absence of cross bedding are suggestive of deposition by nonmeandering, shallow and wide streams.

4.4. DEPOSITIONAL ENVIRONMENT OF GODAVARI SEDIMENTS

Semi arid regions of lower latitudes are having strong imprints of humid tropical climate of the Neogene (Rajaguru *et al*, 1993). The fluvial systems in the semi arid areas are subject to wide fluctuation in discharge. The fluvial forms and processes are closely associated with the morphogenetic regions (Stoddart, 1969). Although river channels can be classified as meandering or non meandering or bed load or wash load dominant (Schumm, 1977), the nature of the semi arid rivers is complex because the rivers are subject to marked fluctuation in water and sediment discharge (Baker and Kochel, 1988, Rajaguru *et al*, 1993 and Kale *et al*, 1994). In spite of this it is the fact that development of sediments depends on several factors such as sediment supply, climate, tectonic stability etc. The sediments are derived from the pebbles and boulders of the basalt rock fragments and quartz, chalcedony, jasper, agate and zeolites. The later sediments are found in the gas cavities of the amygdaloidal basalt in the form of amygdules and after weathering the pebbles and gravels are formed. The upland of source region of the Sindphana river produce the rounded to sub-rounded and coarser sediments.

The general predominance of coarse sediment in semi arid rivers is responsible for less stability and more mobility of sediments (Rajaguru and Kale, 1985 and Rajaguru *et al*, 1993). Such channels are therefore, unstable and dynamic and are characterized by constant channel migration. Further the semi arid rivers respond fast to the changes in the hydraulic regime because of the higher average rate of motion of coarse sediments. In the present study the depositional environment have been deduced on the basis of the sedimentological characters of the fluvial deposits of the Sindphana river. The deposits of sediments in the upper reaches of Sindphana river comprises rounded to sub rounded pebbles and cobbles of basalt, chalcedony, agate, chert, zeolites and quartz set in a matrix of granular sand and silt, whereas in lower reaches the sediments are medium to fine grained sandy silt and silty clay. The deposits are complex in nature and might have resulted from vertical stacking and amalgamation of number of low sinuosity (non-meandering) channels.

A comparison of the present channel deposits and older sediments of Upper Pleistocene reveals that the former are sandy pebbly in nature and thus are coarser than the later ones. This fact indicates that the rivers during the closing phase of Pleistocene had relatively low competence. The climatic control is quite evident in the basin. The phases of erosion are linked to warm and wet periods while the episodes of deposition are associated with cold and dry phases. Besides this several factors such as sediment supply, nature of transporting sediments, tectonic stability etc also plays an important role in the formation of pedofacies. Morphostratigraphic studies indicates that older sediments of Terrace T2 are finer and consisting of dark grey sand and silts with grey brown clay, terrace T1 are medium grained and include those grey sand and brown calcareous silt while the terrace T0 are coarse grained and comprising of grey sand and silt along with unconsolidated cobble and gravels. It is observed that due to high relief and steeper gradient the erosional activity is dominant and courser sediments are dominant, while in the lower reaches of the river due to low channel gradient the depositional activity is dominant in the Sindphana river basin.

Chapter 5

GEOMORPHOLOGY

Geomorphology has been defined as the scientific study of surface features of the earth's surface involving interpretative description of landforms, their origin and development and nature and mechanism of geomorphological processes which evolve the landforms with a view that " all landforms can be related to a particular geological process, or set of processes, and that the landform thus developed may evolve with time through a sequence of forms dependent in part, on the relative time a particular process has been operating" (Esterbrook, 1969). In a simple way geomorphology is also defined as the systematic description and analysis of landscapes and the processes that changed them (Bloom, 1979).

The rapidly evolving discipline of geomorphology has undergone vast change since 1945 in methodology and approaches to the study of landforms and related processes when Horton (1945) introduced quantitative methods for the analysis of morphometric characteristics of fluvial originated drainage basin. In fact, the morphometry incorporates quantitative study of the area, altitude, volume, slope, profile of the land and drainage basin characteristics of the area concerned (Singh, 1972).

The present study involves the morphometric analysis of the Sindphana river a sub-basin of Godavari river and include the assessment of various parameters like bifurcation and length ratios, basin configurations, drainage density, stream frequency, length of overland flow and relief aspects (Channel gradient, relief ratio, ruggedness number and hypsometric integrals) of the sub-basin.

5.1. GEOMORPHIC SETTING

The Sindphana subbasin comprises area in the Beed district, which originates at Chincholi hills at the north-western apex of the Balaghat plateau in the Patoda tahsil. From the site of origin the river flows in a northeasterly course past Amalner, a small village in the Patoda taluka. About a kilometre below Chavarwadi it makes a right-angular turn to follow a north-westerly direction flowing to Sindphana village, where the Sindphana dam sits across the river. Here, it resumes its north-easterly course once again. After the confluence of another tributary, the Kinha, the Sindphana has a fairly long easterly course flowing alongside the villages Yelamb, Pimpari and Hirapur beyond which it is joined by one of its tributaries – Bindura river. Its flow is interrupted by the Majalgaon dam at Majalgaon, where after it flows north-eastwards and northwards to join the

Godavari at Manjarath village, Pathri taluka in Parbhani district at an elevation of 407m. The interior of the basin is a plateau divided into a series of valleys sloping generally towards east and north.

The study area covers an area of 8519.41 sq. km from its origin to the confluence with Godavari river in Deccan plateau of Maharashtra and occupying 80% of area of Beed district. The only important tributaries of the Sindphana river on its left bank are the Ad, the Belpar and the Kinha in the western part. In the eastern part the tributaries on the left flank flowing from the north are very small sized streams.

The *Ad* rising on the northern slopes of the Chincholi hills flows by Kotan in a north-easterly direction to fall into the backwaters of the reservoir created by the Sindphana dam.

The *Belpar* also rises on the northern slopes of the Chincholi hills to the west of the Ad. After flowing past Hatola, it makes a short sojourn outside into Ahmednagar district and after re-entering the district flows by Pimpalner to join the Sindphana at Gomalwada. The Belapara Project Lake is situated on this river.

The *Kinha* river (alternately Sina) rising in the hills to the west of Pangri village, flows in an easterly and north-easterly course sometimes within and sometimes outside the district and joins the Sindphana just above Nimbgaon. The Kinha has several small tributaries such as the Manakarnika flowing by Manur, and the Nandidara flowing by Ukirda.

There are innumerable right flank tributaries of Sindphana flowing from the Balaghat slopes, the more important of which, in order from west to east are the *Uthola* flowing by Raimoha, the *Utawal*i flowing by Khokarmoha and Khalapuri, the *Dombri* flowing by Dombri, Ukhanda and Rajuri and joining the Sindphana opposite to Shirasmarga, the *Bindusara*, the *Takur* rising on the eastern slopes of Pimpalgaon Ghat, the *Pimpalner* river and the *Kundalika*. Of these the Bendsura and the Kundalika are of considerable size and length and require some detailed consideration.

Bindusara: The Bindusara rises near Waghera, 2 kilometres north-west of Limba Ganesh and has a fairly long course on the northern slopes of the Balaghat plateau first flowing northwards and after Kadamwadi eastwards to Pali village, receiving a number of tributaries on both banks comprising a fairly large catchment area of 183 square kilometers. This has been taken advantage of for the Bindusara project. About 8 kilometres below Pali the river flows through Beed town with a north-north-east course to join the Sindphana. The head ward erosion of this comparatively large sized stream must have been so considerable that the watershed to the south has migrated farther south here than at other places.

The *Kundalika*, called very often by the shortened form Kundka, rises to the north-east of Neknur and flows first in a north-easterly direction and then in an easterly direction up to Nagjheri after which it has a general northerly course to join the Sindphana a few kilo-meters upstream of Majalgaon.

5.2. GEOMORPHOMETRIC ANALYSIS

5.2.1 Drainage Pattern:

The river that drains the study area is the Sindphana, a tributary of Godavari river. The drainage network of streams of Sindphana sub-basin (Fig.5.1) shows dendritic to subdendritic and sub parallel.

The dendrite drainage pattern is the network of streams of various orders and magnitudes joining the trunk master streams and resembles the branches of a tree. The development of dendritic to sub dendritic drainage in the sub-basin indicates the area of massive rock types, gently sloping to almost horizontal terrain and low relief.

The sub parallel drainage pattern shows relatively less parallelism than the basic parallel pattern (Zermitz, 1932). In Fig.5.1 the streams show the sub parallel type of drainage pattern. It has been suggested that the parallel drainage in Deccan Basalt terrain is initiated due to the step like nature of the Deccan traps which is joined by subsequent lateral ravines giving a sub-parallel pattern (Dhokarikar, 1991).

5.2.2 Morphometric Analysis

The morphometric analysis include the assessment of various parameters like bifurcation ratio, length and area ratios, basin configurations, drainage density, stream frequency, length of overland flow and relief aspects (Channel gradient, relief ratio, ruggedness number and hypsometric integrals) of the Sindphana sub-basin.

i) Bifurcation Ratio:

The first step in morphometric analysis of sub-basin is determination of stream order following the method of Strahler (1957). Accordingly the Sindphana sub-basin is of Eighth order. The ratio of number of stream segments of a given order (Nu) and the number of stream segments of next higher order (Nu + 1) is known as the bifurcation ratio (Rb). The values of bifurcation ratio of the subbasin are between 2.00 and 4.56 (Table 5.1) indicating that the geological structures do not distort the drainage system (Strahler, 1964).

The number of streams of each order is plotted against the corresponding stream order of the Sindphana sub-basin (Fig 5.2). The plot shows that the number of streams of given orders in the sub-basin forms an inverse geometric sequence by decreasing systematically with increasing order in conformity to the Horton's (1945) 'law of stream numbers'.

ii) Length Ratio:

The lengths of the various stream segments were measured order wise and the total lengths as well as the mean stream length for each order were computed. The length ratio, which is the ratio of the mean length of the streams of a given order to the mean length of the streams of the next lower order, was then calculated for each pair of order (Table 5.1). The plot of mean stream length of each order against stream order (Fig.5.3) gives exponential form around the regression line.

It is apparent from the plots that the average length of streams of a given order forms a direct geometric sequence by increasing systematically with order and thus conforms to Horton's (1945) 'law of stream length'.

Table 5.1: Bifurcation ratio, length ratio and area ratio of Sindphana sub-basin

Stream order	No. of streams	Bifurcation Ratio	Stream length (Km)	Mean stream length	Length Ratio
1	8954		5015.30	0.56	
		4.32			1.55
2	2073		1800.00	0.87	
		4.56			2.43
3	455		961.13	2.11	
		4.29			2.39
4	106		535.66	5.05	
		3.93			1.52
5	27		207.32	7.68	
		4.50			3.07
6	6		141.39	23.56	
		3.00			2.55
7	2		120.18	60.09	
		2.00			0.39
8	1		23.56	23.56	
	11588		8519.41		

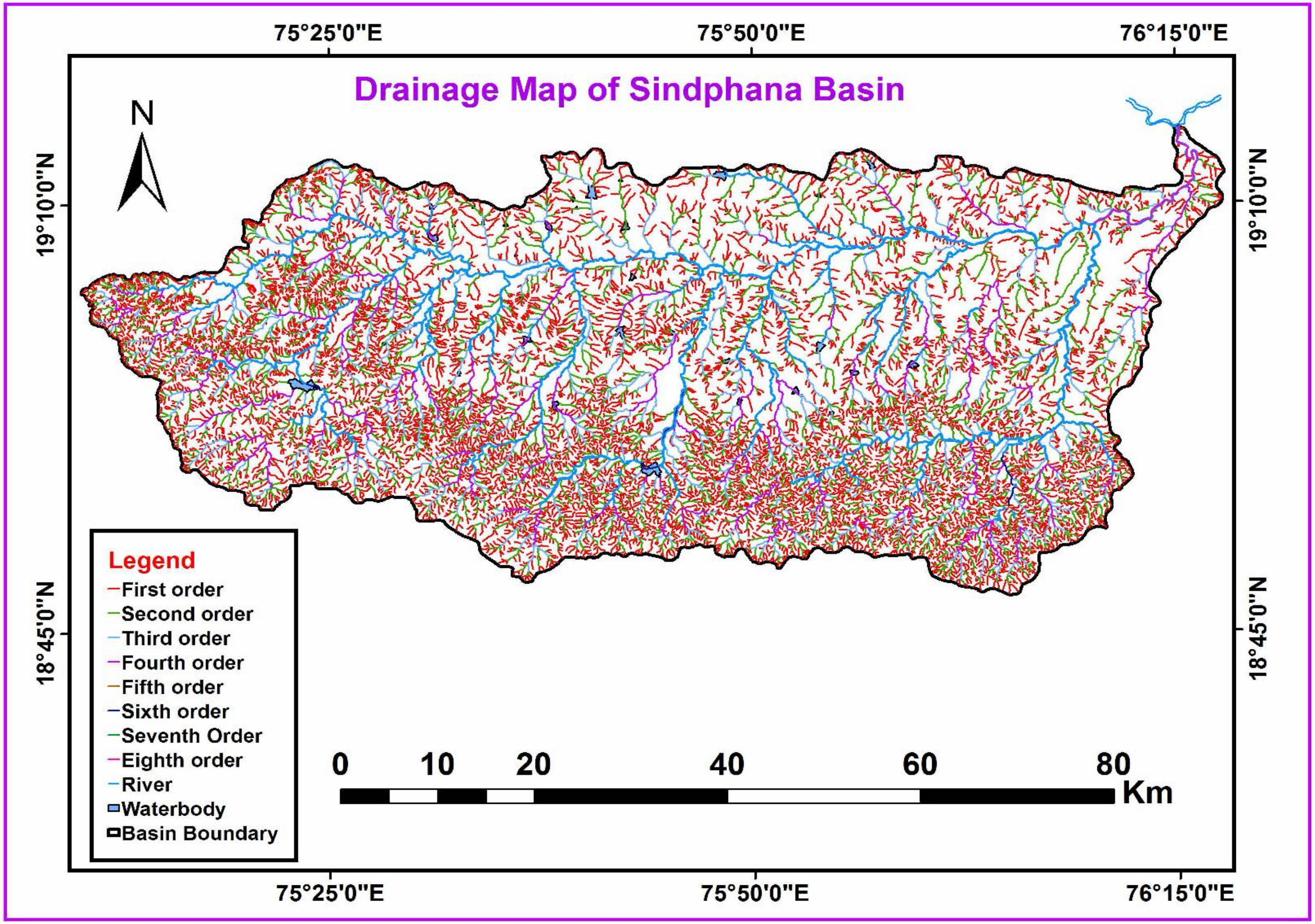
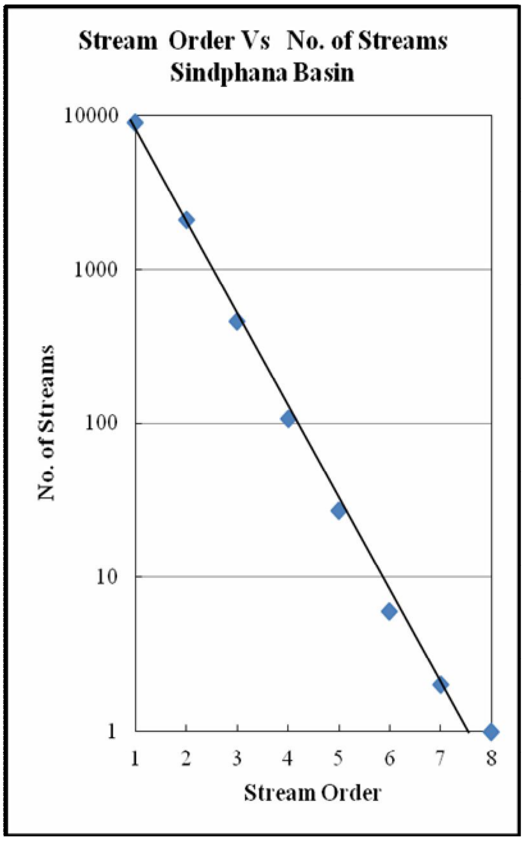


Fig. 5.1: Drainage map of Sindphana river Sub-basin.



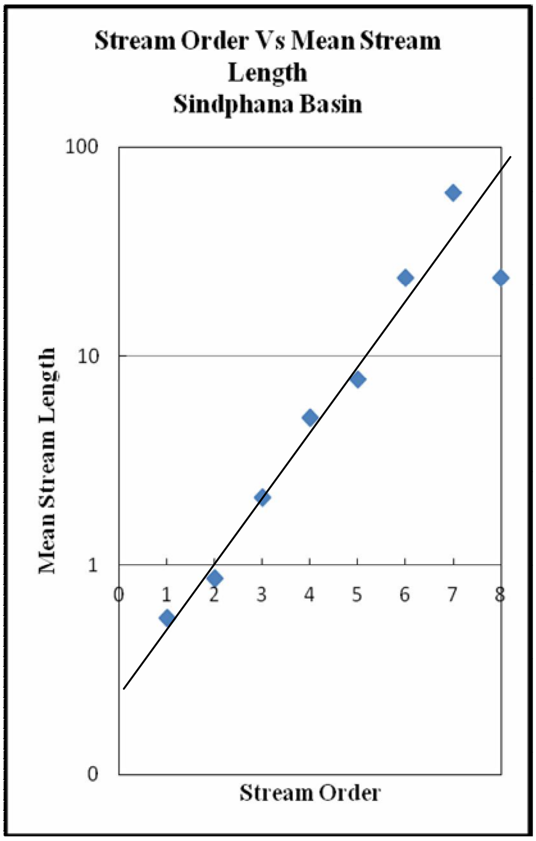


Fig. 5.2: Stream Order Vs Number of Streams of Sindphana Basin

Fig. 5.3: Stream Order Vs Mean Streams length of Sindphana Basin

iii) Basin Configuration:

For determining the shape of the drainage basin, a quantitative study of the Sindphana sub-basin is made using following three dimensionless ratios:

The form factor (F) suggested by Horton (1932) and Strahler (1968) is the ratio of the basin area to the square of the basin length and the value is 0.28 (Table 5.2).

The circularity ratio (Miller, 1953) is the ratio of the area of the basin to the area of a circle having the same circumference as the perimeter of the basin. The obtained value is 0.41. Same is the value of compactness ratio of the sub-basin.

Elongation ratio (Schumm 1956) is the ratio between the diameter of a circle of the same area as the drainage basin and the maximum length of the basin. The value thus obtained is 0.60.

The values of circularity ratio and elongation ratio indicate that the basin is moderately elongated. The circularity ratio is a significant ratio, which indicates the stages of dissection in the study region. Its value (0.41) can be correlated with the early mature stage of the cycle of the erosional development. In comparison with Strahler (1964) the value of elongation ratio (0.60) suggests that the basin is associated with moderate relief and gentle ground slope.

Table 5.2. Morphometric parameters of Sindphana River Sub-basin.

Parameters	**Values of Total Basin**
Total stream length-L (Km)	8519.41
Total basin area-A (Km^2)	3972.70
Total no. stream-(N)	11588
Basin perimeter-P (Km)	350.77
Maximum basin length - MBL(Km)	118.48
Form factor-F	0.28
Elongation ratio-E	0.60
Circularity ratio-Rc	0.41
Drainage density (Km/Km^2)	2.14
Stream frequency-(Streams/Km^2)	2.92
Highest point on the basin perimeter (m)	892
Height of the basin mouth (m)	397
Maximum basin relief (H) meters	495
Relif ratio – H/MBL	0.0037
Length of overland flow (L) Km.	0.23
Infiltration Number	0.74
Hypsometric Integrals %	43.81
Compactness Ratio ($K= 4 \pi A/P^2$)	0.41

iv) Drainage Density:

Drainage density is defined as the lengths of streams per unite area (Horton, 1932) and is obtained by dividing the total channel segment lengths (L) by the total area of the basin (A). The drainage density obtained is 2.14 km/km^2, which is moderate value and indicate the area of weak impermeable subsurface rock or soil with sparse vegetation and mountainous relief in the source region.

v) Stream Frequency:

The stream frequency (Fs) refers to the number of streams per unit area (Horton 1945) and is calculated by dividing the total number of streams (N) by the drainage basin area (A). The stream frequency thus obtained is 2.92 streams/km^2.

The factors affecting the drainage density and stream frequency are the erodibility of the rock and climate. Moderately higher values of drainage density and stream frequency as compared to Karpara, Dhamuda and Pingalgad sub-basins of Purna river basin (Babar, 1998) reveals that the Sindphana sub-basin belongs to the region of high rate of precipitation and hilly terrain.

vii] Length of Overland flow:

Horton (1945) used this term to refer the length of the run of the rainwater on the ground surface before it gets localized into definite channels. Horton for the sake of convenience had taken it to be roughly equal to half the reciprocal of the drainage density. Calculated thus, the length of overland flow for the Sindphana sub-basin is 0.23 km which means that the rainwater has to run over this distance before getting concentrated in stream channels and corroborate the lower drainage density derived for the sub-basin.

5.2.3 Relief (Gradient) Aspects of Sub-basin:

A) *'Charnel gradient'* refereed to Strahler (1964) the total drop in elevation from the source to the month is found out for the watershed and the horizontal distances are measured along its length. The value of gradient from this is 4.18 m/km. The longitudinal profile of the Sindphana sub-basin is drawn (Fig.5.4).

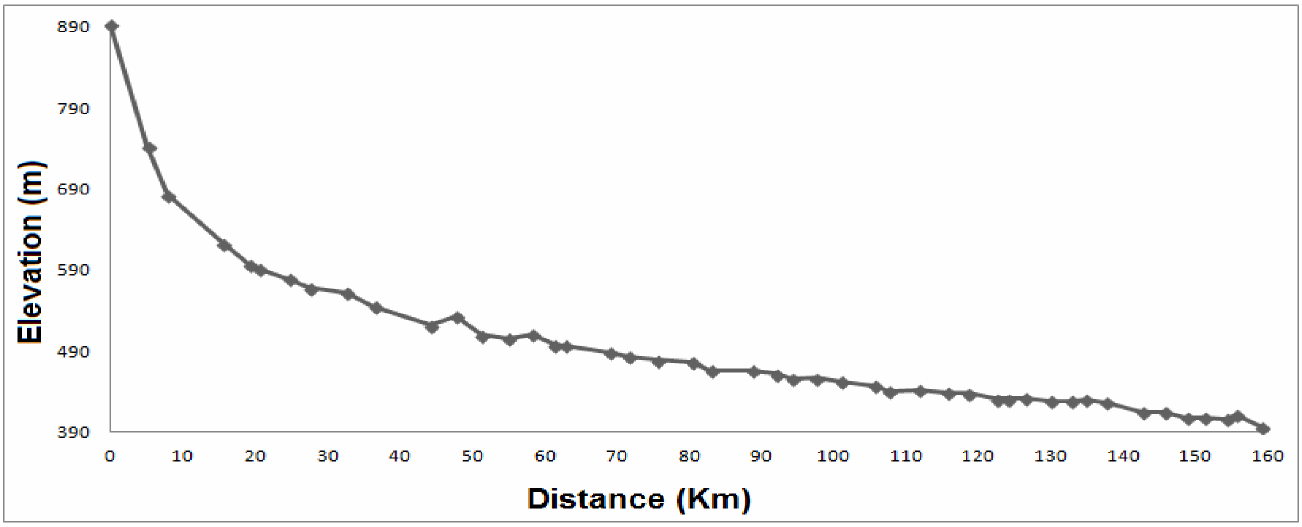


Fig. 5.4: Longitudinal profile of the Sindphana sub-basin

B) The *'Maximum basin relief'* is the elevation difference between basin mouth and the highest point on the basin perimeter. The calculated value of maximum basin relief is 495m. Using the relief (H), a 'relief ratio' is computed as suggested by

C) Schumm (1956), by dividing the relief by maximum measured length of the drainage basin. The value of relief ratio is 0.004.

D) Strahler's (1968) '*ruggedness number*' is the product of the basin relief and the drainage density where both terms are in the same unit. The calculated value is 1.06.

E) The '*Slope of the ground surface*' (Sg) from water divide to stream is obtained by the equation Sg = H x 2D and the value obtained is 2.12 m/km. The relief measures for Sindphana sub-basin are higher i.e. maximum basin relief of 185 m, relief ration of 0.004, ruggedness number 1.06 and slope of the ground surface 2.12 m/km all indicating that the basin lies within hilly terrain and has youth stage of erosional development. The ruggedness number is also indicative of a region of high to moderate relief.

F) **Hypsometric Analysis:**

Hypsometric analysis (Strahler, 1952) is related with ground surface and altitude. A hypsometric curve is the graphical representation showing the basin areas on abscissa situated above various altitudes. The data presented in Table 5.3 is graphically plotted keeping a/A on the abscissa and h/H on the ordinate (Fig.5.6). The hypsometric integral obtained by measuring the area below the curve is 43.81%. This area below the curve stands for the volume of the landmass yet to be removed by erosion.

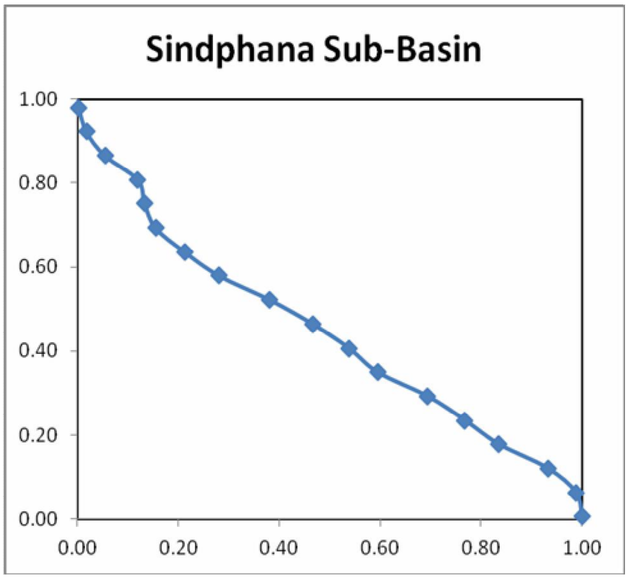


Fig. 5.6: Hypsometric curve of Sindphana sub-basin

Table 5.3: Hypsometric data of Sindphana river sub-basin

contour(m)	a (Sq. Km)	a/A	h (m)	h/H
880	0.02	0.000005	483	0.98
860	0.86	0.000216	463	0.94
840	2.01	0.000506	443	0.89
820	28.85	0.007262	423	0.85
800	48.06	0.012098	403	0.81
780	370.23	0.093194	383	0.77
760	417.74	0.105153	363	0.73
740	848.67	0.213625	343	0.69
720	984.73	0.247874	323	0.65
700	1189.77	0.299486	303	0.61
680	1334.28	0.335862	283	0.57
660	1476.57	0.371679	263	0.53
640	1643.27	0.413641	243	0.49
620	1830.50	0.460770	223	0.45
600	1839.61	0.463063	203	0.41
580	2392.58	0.602255	183	0.37
560	2626.74	0.661198	163	0.33
540	2752.57	0.692871	143	0.29
520	3023.84	0.761155	123	0.25
500	3355.95	0.844753	103	0.21
480	3679.65	0.926234	83	0.17
460	3741.06	0.941692	63	0.13
440	3956.10	0.995821	43	0.09
420	3972.55	0.999962	23	0.05
400	3972.68	0.999995	3	0.01

A= Total basin area (sq. km.) **H=** total height of the basin with reference to the same base (m)

5.3. GEOMORPHIC INDICES OF ACTIVE TECTONICS

During the last four decades different researchers have postulated or deduced sustained uplift along the western continental margin of India (Athavale and Anjaneyulu 1972; Kailasam 1975; Powar 1981; Ollier and Powar 1985; Powar 1993; Radhakrishna 1993; Widdowson and Cox 1996; Widdowson 1997; Subrahmanya 1998; Widdowson and Mitchell 1999; Gunnell 2001; Valdiya 2001; Gokarn *et al* 2003; Mishra *et al* 2004; Veeraswamy and Raval 2005; Tiwari *et al* 2006; Catherine *et al* 2007; Sheth 2007; Campanile *et al* 2008; Mukhopadhyay *et al* 2008 and Kale and Shejwalkar 2008).

Based on Bouguer gravity anomalies, Kailasam (1975) identified areas of uplift in Nasik and Sangola; and Power (1981) attributed the typical lineament pattern in DBP to regional uplift. In a recent paper, Leroy *et al* (2008) have inferred that volcanic margins, such as the western Indian margin, are characterized by 2–3 times higher uplift since the breakup and rifting than the non-volcanic margins. Furthermore, an adjustment in response to denudational isostacy and the resulting activation of faults and fractures has been suggested as the major contributory cause of sporadic seismic activity in the DBP over the past few decades (Mahadevan and Subbarao 1999; Widdowson and Mitchell 1999). John and Rajendran (2008) elucidated the geomorphic indicators of Neotectonism from the Precambrian terrain of Peninsular India from the Bharathapuzha Basin, Kerala.

The occurrence of early Tertiary high-level laterites at the present elevation (> 1000m ASL) in the Deccan Basalt Province (DBP) is considered as a strong evidence of post-Deccan Trap uplift (Widdowson 1997; Sheth 2007). It has been suggested that the present high-level laterite plateaux (the Mahabaleshwar and the Kas laterite plateaux for instance) are the remains of an extensive lateritic surface that was formed at lower altitude during the early Tertiary. It is hypothesized that this surface was then uplifted to its present-day altitude of up to ca. 1.4 km above sea level by late Tertiary (Widdowson 1997; Sheth 2007). On the basis of the reconstruction of lateritised palaeosurfaces, Widdowson and Cox (1996) have deduced significant post-Deccan Trap uplift in the Nasik region. They also speculate that this uplift has been responsible for reversal of the primary volcanic dips of the basalt flows in this part of the DBP. In addition, incised meanders and river systems on the Konkan lowland, and knick points and warped terraces along the Upland rivers have been considered as geomorphic markers of recent uplift in the DBP (Widdowson and Mitchell 1999).

Rivers are the most active and sensitive elements of the fluvial landscape. If uplift (tectonic/isostatic) has occurred in the Neogene and Quaternary times, it should be amply reflected in the drainage basin, valley and network properties of the Sindphana river. The main objective of this study, therefore, is to objectively ascertain the tectonic character of the Sindphana river sub-basin by deriving and mapping the widely used tectonic activity indices for 26 number of selected drainage sub-basins in Beed district including 12 sub-basins in the northern half of the basin and 14 in the southern half (Fig. 5.7 and Table 5.4).

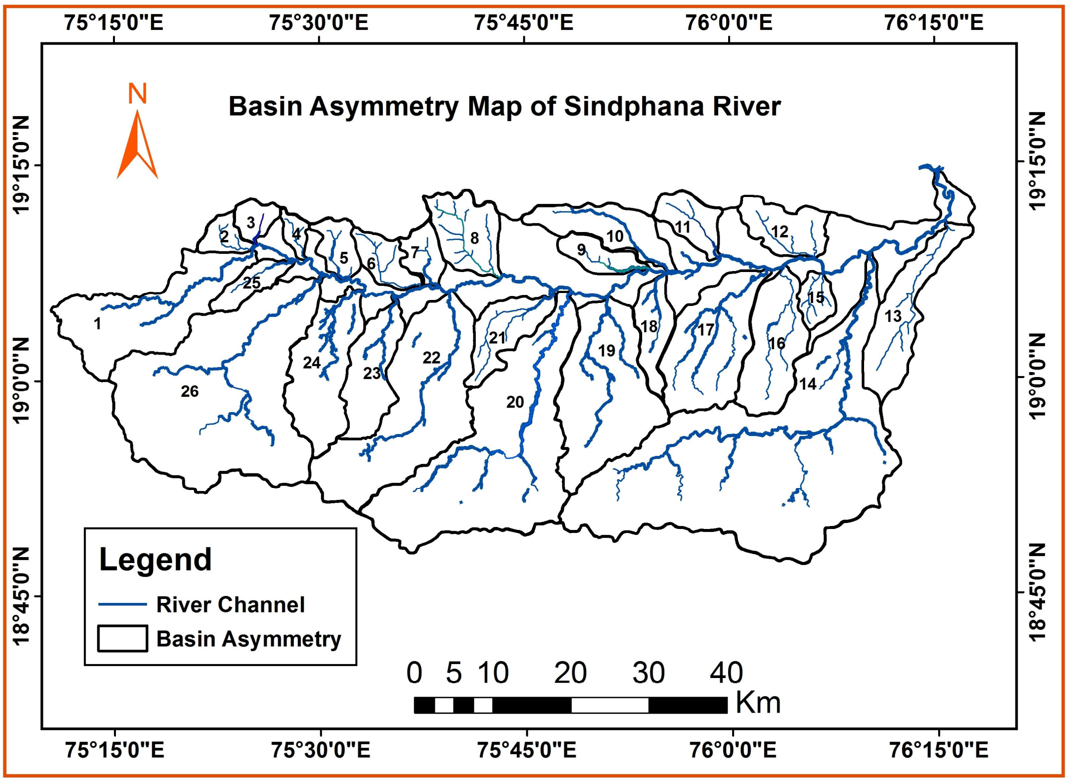


Fig. 5.7: Locations of Sub-Basins Marked as 1 – 26 and in Table 5.4 are: 1-Kinha, 2-Kharwandi, 3-Pargaon stream, 4-Mathor, 5-Anandwadi, 7-Phulsanghavi Stream, 8-Savargaon, 9-Pachegaon, 10-Khardi, 11-Bhend Khurd, 12-Talkhed, 13-Shimpe Takli, 14-Kundka, 15-Kadiwadgaon, 16-Pimpalkhed, 17-Manakarnika, 18-Adgaon, 19-Tukur, 20-Bindusara, 21-Malapuri, 22-Domri, 23-Dharwanta, 24-Uruli, 25-Ukarda and 26- Sindphana (upper) sub-basin.

Table 5.4. Morphometric attributes of Sindphana River Basin in Beed District

Sr. No.	Name of Sub-basin	Basin Elongation Ratio	Asymmetry Factors	Stream Gradient-Length Ratio	Hypsometric Integral %
Sub-basins in the Northern Part of the Sindphana Basin					
1	Kinha	0.56	36.30	2.92	44
2	Kharwandi	0.78	22.53	2.24	31
3	Pargoan	0.87	71.64	2.81	39
4	Mathor	0.58	48.75	2.85	44

5	Anandwadi	0.80	28.23	4.85	37
6	Phulsanhvi	0.60	35.35	9.05	39
7	Kolgaon	0.74	59.02	5.65	57
8	Savargaon	0.68	39.62	5.02	47
9	Pachegaon	0.54	40.06	2.92	46
10	Kharadi	0.52	52.95	3.59	50
11	Bhenkhurd	0.68	49.77	3.95	43
12	Talkhed	0.70	27.10	7.86	72
	Total	**8.05**	**511.32**	**53.71**	**549**
	Mean	**0.67**	**42.61**	**4.48**	**45.75**
Sub-basins in the Southern Part of the Sindphana Basin					
13	Shimpetakli	0.49	48.82	3.68	49
14	Kundka	0.68	75.45	3.33	56
15	Kadiwadgaon	0.75	67.81	8.11	72
16	Pimpalkhed	0.61	65.47	6.50	32
17	Mankarnika	0.63	68.64	7.12	32
18	Adgaon	0.52	46.31	7.05	52
19	Tukur	0.65	76.85	5.25	34
20	Bindusara	0.57	68.25	5.85	52
21	Malapuri	0.55	61.36	8.53	56
22	Domri	0.61	55.67	7.11	41
23	Dharwanta	0.55	60.31	6.33	32
24	Urauli	0.58	55.04	5.12	35
25	Ukarda	0.51	64.71	4.87	48
26	Sindphana	0.72	43.71	6.35	44
	Total	**8.42**	**858.4**	**85.20**	**635**
	Mean	**0.60**	**61.31**	**6.09**	**45.36**

5.3.1. Basin Elongation ratio

This is an areal morphometric variable that quantitatively describes the planimetric shape of a basin and, thus, indirectly provides information about the degree of maturity of the basin landscape. Bull and McFadden (1977) have shown that basins draining tectonically active areas are more elongated and become more circular with the cessation of uplift. Elongated basin shapes are also associated with high local relief and steep valley slopes (Molin *et al* 2004).

It is the ratio between the diameter of a circle of the same area as the drainage basin and the maximum length of the basin (Schumm 1956). The formula used for the present study is Re = $(2\sqrt{A} : \sqrt{\pi})/LB$ where, A = basin area and LB = length of the basin (Bull and McFadden, 1977).

In the study area, the Re except for Shimpe Takli sub-basin (0.49) is greater than 0.50 suggesting that all the sub-basins are moderately to highly circular. The Re mean value in northern part of the basin is 0.67 with minimum of 0.52 and maximum of 0.87 (Table 5.4) suggesting that all the sub-basins are moderately to highly circular. Similarly, the mean value of Re in southern part of the basin is 0.60 with minimum of 0.49 and maximum of 0.75 (Table 5.4) suggesting that all the basins except Shimpe Takli sub-basin are moderately to highly circular. The mean elongation ratios of 0.69 and 0.60 for sub-basins implying that the rivers are more elongated in both the half of basin which is as similar to the observations made by Kale and Shejwalkar (2007) in Plateau rivers. However, the mean value of the two parts of the river systems is not statistically significant (Kale and Shejwalkar 2007).

5.3.2. Basin asymmetry factor

This geomorphic factor was developed to detect tectonic tilting at basin scale or larger areas. The asymmetry factor (AF) is defined as $AF=100(^{Ar}/_{At})$

Where A_r in the area of the basin to the right of facing downstream the trunk stream and A_t is defined as the total area of the drainage basin. Like most geomorphic indices, the AF works best where each drainage basin is underlain by the same rock type (Keller and Pinter, 1996). For convenience for calculating AF we divided Sindphana River into 26 sub-basins of the river (Fig. 5.7). The calculated values of asymmetry factor are given Table 5.4.

The influence of tectonics on the drainage pattern is also reflected by the asymmetry of drainage basins (Molin *et al* 2004). AF is an areal morphometric variable that is used to detect the presence or absence of regional tilt on basin or regional scale (Keller and Pinter 1996). The mean value of AF of sub-basins in the northern half is 42.61% and in the southern half it is comparatively more i.e. 61.31% (Table 5.4). In northern part of the Sindphana river basin, the sub-basin No. 1, 2, 5, 6, 8 and 12 (AF < 40%) has shifted towards the downstream right side of the drainage, while sub-basin number 3 (AF > 60%) has more area to the downstream right of the parent stream. An interesting point is that the southern tributaries of Sindphana river show some unidirectional asymmetry. The anomalous basin asymmetry in southern part of the basin is found in the sub-basin numbers 14, 15, 16, 17, 19, 20, 21, 23 and 25 (>60%) while in none of the sub-basins have asymmetry factor <40%. For a stream network that formed and continuous to land in a stable setting, AF should equal about 50. The asymmetry factor of 26 sub-basins is given in Fig. 5.8 with respective values.

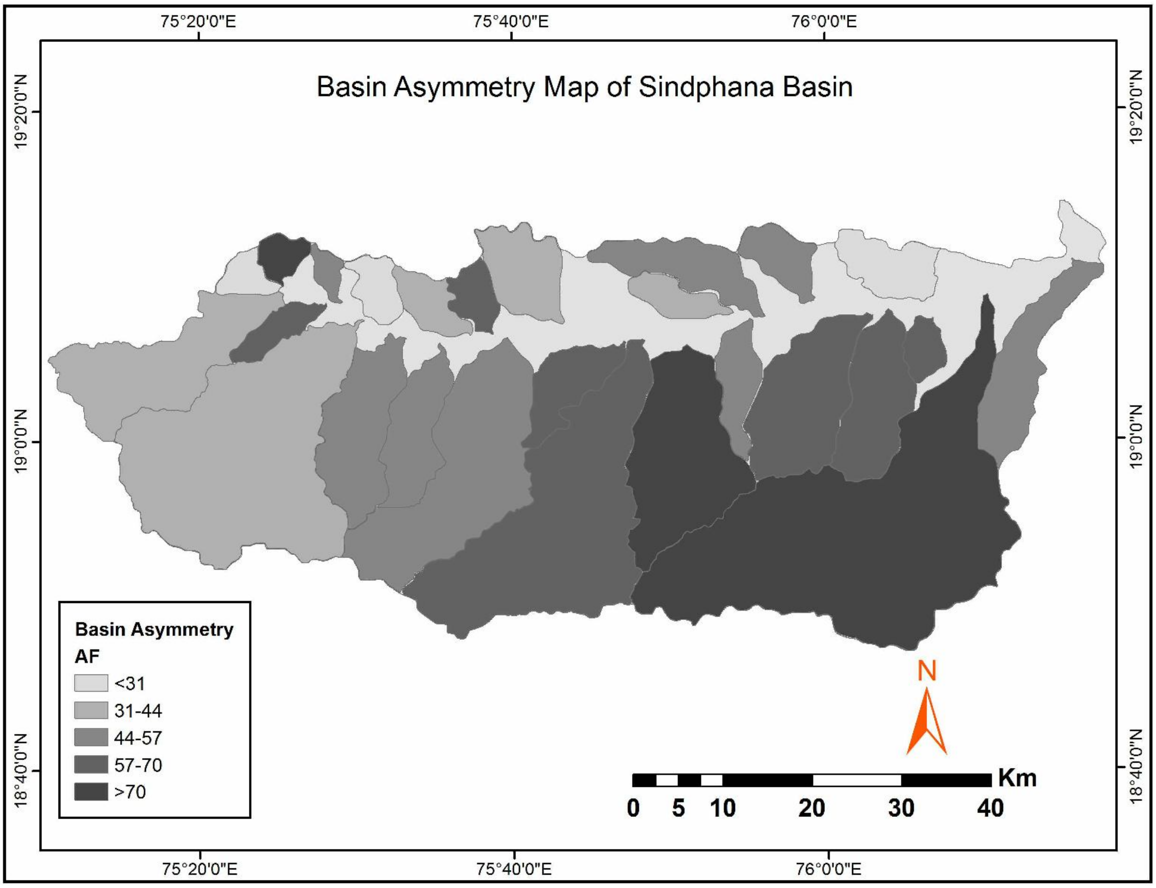


Fig. 5.8: Basin asymmetry map of Sindphana River basin for 26 Sub-basins.

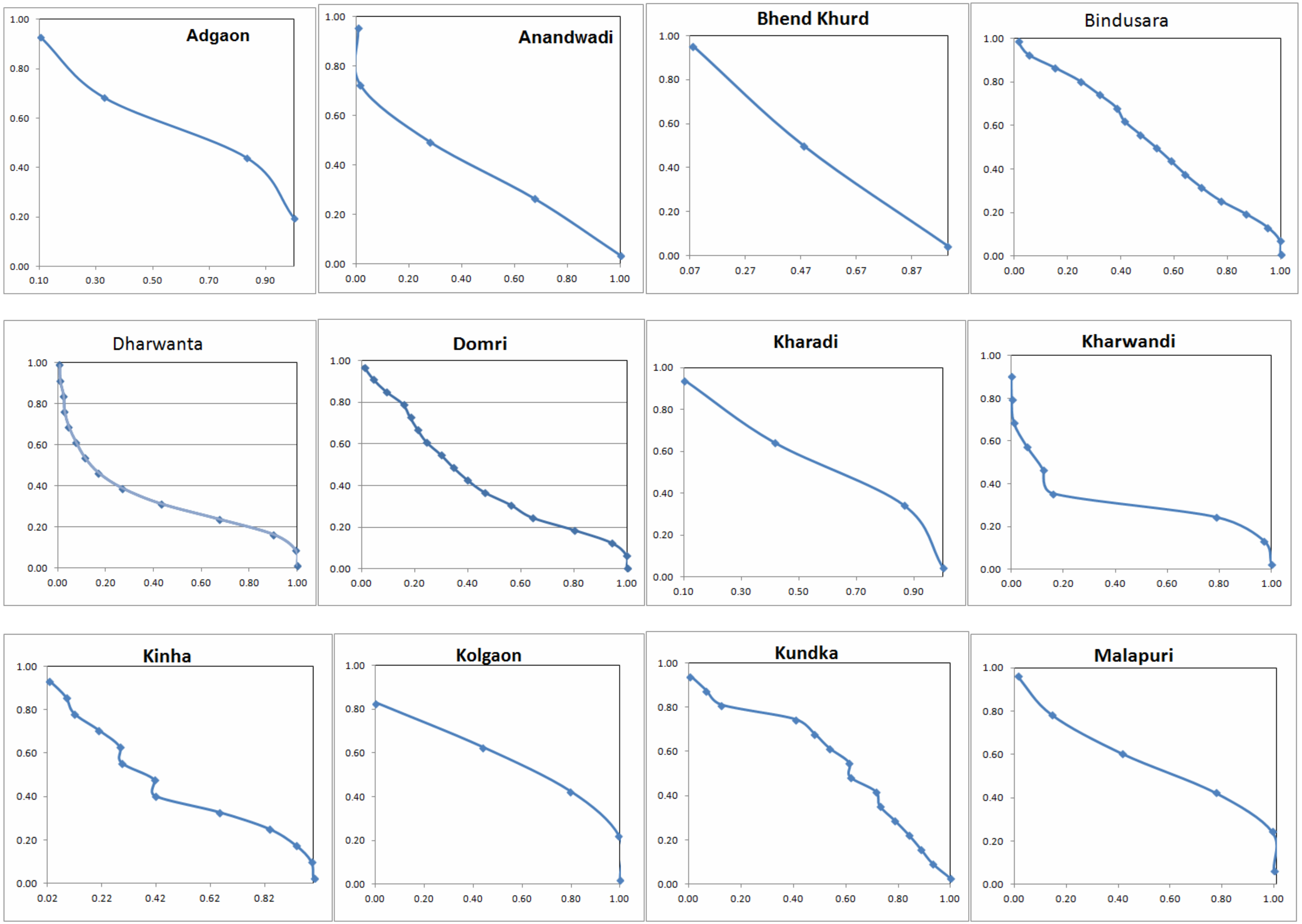
5.3.3Hypsometric Analysis of 26 Sub-basins

The hypsometric curve has been termed the drainage basin relief graph (Vladimirescu, 1978). Langbein (1947) appears to have been the first one to have used such a line of study to collect hydrologic data. Strahler (1952) popularized this method. Hypsometric data for entire basin is given in Table 5.3 and the curve is represented in Fig. 5.6.

In the present study of (percentage hypsometric integral method) two ratios are computed from map measurements of contour map. First one is a/A where, 'a' is the area enclosed between a given contour within the basin and basin boundary and A is the total area of the basin. The second ratio is h/H, where, h is the height of the contour above the base level of the stream mouth and H is the total height of the basin with reference to the same base. The graphs of a/A versus h/H are plotted for 26 sub-basins (Fig. 5.9). The area below the respective curves is measured and its proportion (in percentage) with reference to the total area of the graph is calculated. The hypsometric integrals thus obtained for sub-basins Sindphana river are given Table 5.4.

The value of the hypsometric integral and the form of the hypsometric curves taken together, help to identify the stage of the basin development (Strahler, 1952). This integral of the study area indicates that the sub basins are in early mature stage of erosional development.

Hypsometric integral is a relief variable that is widely used to measure the degree of fluvial landscape erosion and describes the distribution of elevations across the drainage basin area (Strahler 1952). It is a powerful tool to differentiate between tectonically active and inactive areas (Keller and Pinter 1996). Analysis reveals that the mean percentage integral for the sub-basins in the northern part of the river is (45.75 %) is nearly equal to the mean for the sub-basins in the southern part (45.36 %). The minimum value of hypsometric integral in northern part of the basin is 31 and maximum value is 72, while in southern part the minimum value is 32 and maximum is 72 which is similar to the values of northern part.


Adgaon
1.00 0.80 0.60 0.40 0.20 0.00
0.10 0.30 0.50 0.70 0.90
Anandwadi
1.00 0.80 0.60 0.40 0.20 0.00
0.00 0.20 0.40 0.60 0.80 1.00
Bhend Khurd
1.00 0.80 0.60 0.40 0.20 0.00
0.07 0.27 0.47 0.67 0.87
Bindusara
1.00 0.80 0.60 0.40 0.20 0.00
0.00 0.20 0.40 0.60 0.80 1.00
Dharwanta
1.00 0.80 0.60 0.40 0.20 0.00
0.00 0.20 0.40 0.60 0.80 1.00
Domri
1.00 0.80 0.60 0.40 0.20 0.00
0.00 0.20 0.40 0.60 0.80 1.00
Kharadi
1.00 0.80 0.60 0.40 0.20 0.00
0.10 0.30 0.50 0.70 0.90
Kharwandi
1.00 0.80 0.60 0.40 0.20 0.00
0.00 0.20 0.40 0.60 0.80 1.00
Kinha
1.00 0.80 0.60 0.40 0.20 0.00
0.02 0.22 0.42 0.62 0.82
Kolgaon
1.00 0.80 0.60 0.40 0.20 0.00
0.00 0.20 0.40 0.60 0.80 1.00
Kundka
1.00 0.80 0.60 0.40 0.20 0.00
0.00 0.20 0.40 0.60 0.80 1.00
Malapuri
1.00 0.80 0.60 0.40 0.20 0.00
0.00 0.20 0.40 0.60 0.80 1.00

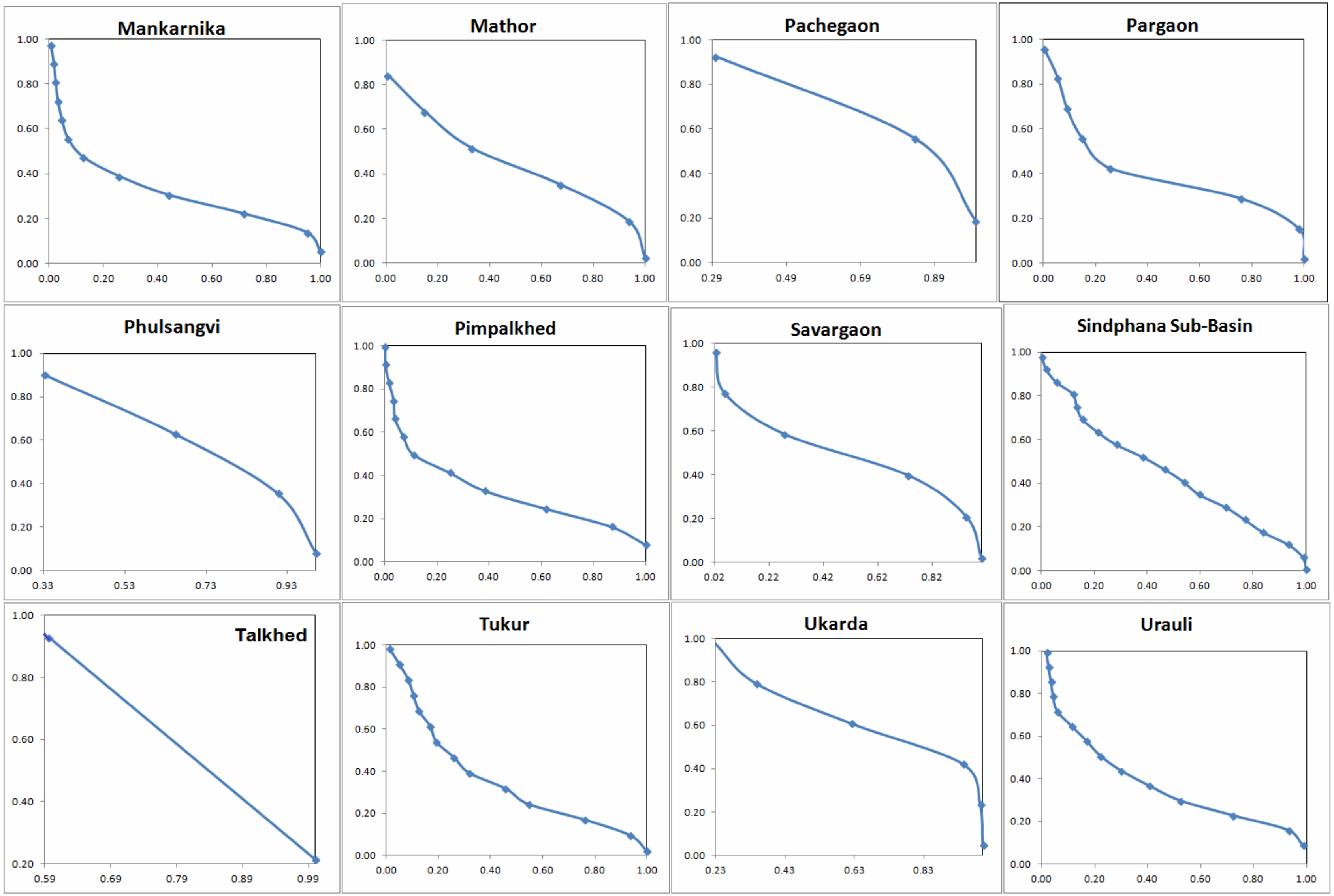


Fig. 5.9: Hypsomtric integrals of sub-basins of Sindphana river basin.

5.3.4. Stream Gradient Length Ratio (SL)

It is calculated using the ratio $SL = (H_1 - H_2)/(\ln L_2 - \ln L_1)$ where, H_1 and H_2 are the elevations of each end of a given reach L_1 and L_2 are the distances from each end of the reach to the source (Hack 1973). The data regarding the stream gradient index is given in Table 5.4.

Hack's (1973) SL index is considered as an excellent measure of the stream power. Variations in the stream gradient index reflect the downstream variations in discharge and stream power, but more commonly the lithologic or tectonic controls on channel slope of a given reach. SL index has been widely used as a proxy to identify areas of anomalous uplift within a landscape.

The average stream length-gradient index value for 26 sub-basins of the Sindphana river is calculate and found significantly higher than the SL index of the sub-basins in the upper reaches of the Sindphana river (Table 5.4). This, of course, is not completely unexpected, given the peculiar geomorphic setting of the sub-basins of the Sindphana river.

5.4 GEOMORPHIC SURFACES

The geomorphic surfaces of the study area are classified into six different morpho-units (Landforms) on the basis of physiographic characteristics, morphological features, relief, slope, drainage density and lithology. Use of satellite imagery, topographical maps, profile study and visual field studies were also made in arriving at the classification and in delineating the boundaries of these morpho-units. Geomorphic surfaces of the study area have been classified into nine morpho-units (Fig. 5.10):

i. Alluvial plain
ii. Pediments
iii. Pediplains
iv. Highly Dissected plateau
v. Moderately Dissected plateau
vi. Denudational Hills
vii. Mesa
viii. Buttes
ix. Escarpment slopes

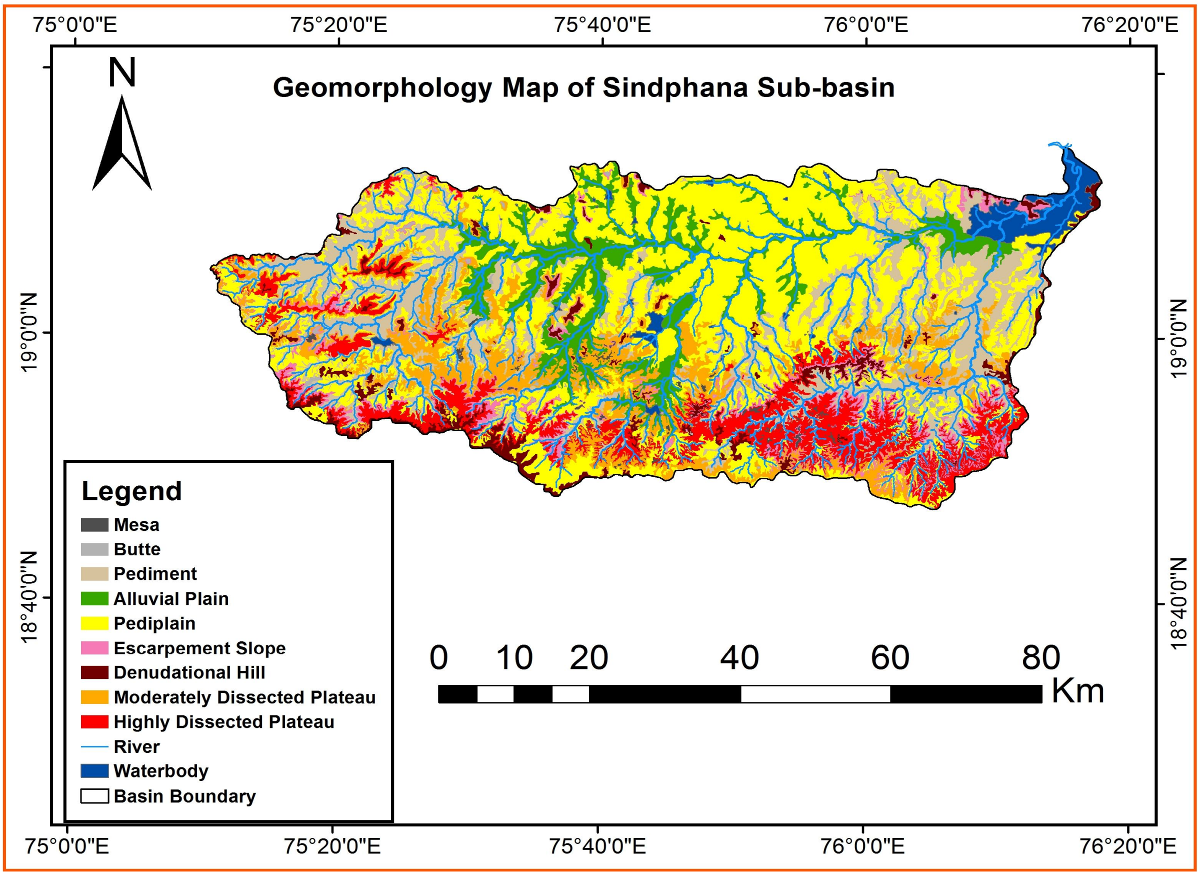


Fig. 5.10: Geomorphic surfaces of the study area

5.4.1 Alluvial plain

These are primary sediment storage areas, especially on wide valley floors (Dietrich et al, 1982; Nakamura, 1986 and Nakamura and Kikuchi, 1996). This geomorphic unit occurs on either side of the major rivers and their tributaries covering about 425.96 sq. km. (i.e. 10.72%) of the total geographical area of the basin. The alluvial plain features recorded in Present floodplains include the point bar (5.11) and channel bar deposits (Fig. 5.11). The younger alluvial plain has elevation range from 515 to 600 m above msl, while the older alluvium occurs with an elevation range from 400 to 510 m above msl. The characteristic features of the alluvial plain of study area are of low slope angle (0 to 10°) with almost flat surfaces, low drainage density (< 1 km/km^2), low stream frequency (1 to 1.5 streams/km^2) and low relative relief (< 5%).

The alluvial plain comprises the alluvium of 5 to 12 m. It consists of uncalcified silty sand and grey brown silty clay with presence of gravels and pebbles of basalt, quartz and chalcedony resting over the basalts. On the other hand the older alluvial plain is covered by soils which are very thick dark greyish brown to dark brown coloured, calcareous, moderately well to ill drained alluvium with high moisture retentive capacity. The groundwater in these units is brackish on account of leaching of salts and calcareous material i.e. calcretes (Fig. 4.28) is developed into the deeper horizons of these zones.

Fig. 5.11: Point bar deposits occurring along the Sindphana river.

Fig. 5.12: Alluvial plain deposits with two terraces occurring along the Sindphana river.

5.4.2 Pediments

Pediments are noted as a narrow strip adjoining the older alluvial plain at the foot of the moderately dissected plateau in the central and southern part of the basin parallel to the river channel (Fig. 5.13). Pediments occupy about 845.48 sq. kn. (i.e. 21.28 %) of the area of the basin. They range in elevation from 580 to 650 m above msl. Morphometric attributes of the pediments are gently sloping surfaces (20° to 35°) low gradient, coarse drainage density (~1 km/km^2), low stream frequency (1 to 2 streams/km^2) and relative relief is about 15 %. Sediments comprising the pediments are not very thick.

The soils occurring over this unit are dark greyish brown to black coloured, clayey, calcareous, ill (poor) drained colluvium and scree with high moisture retentive capacity. The gully erosion has dissected the pediments at several places.

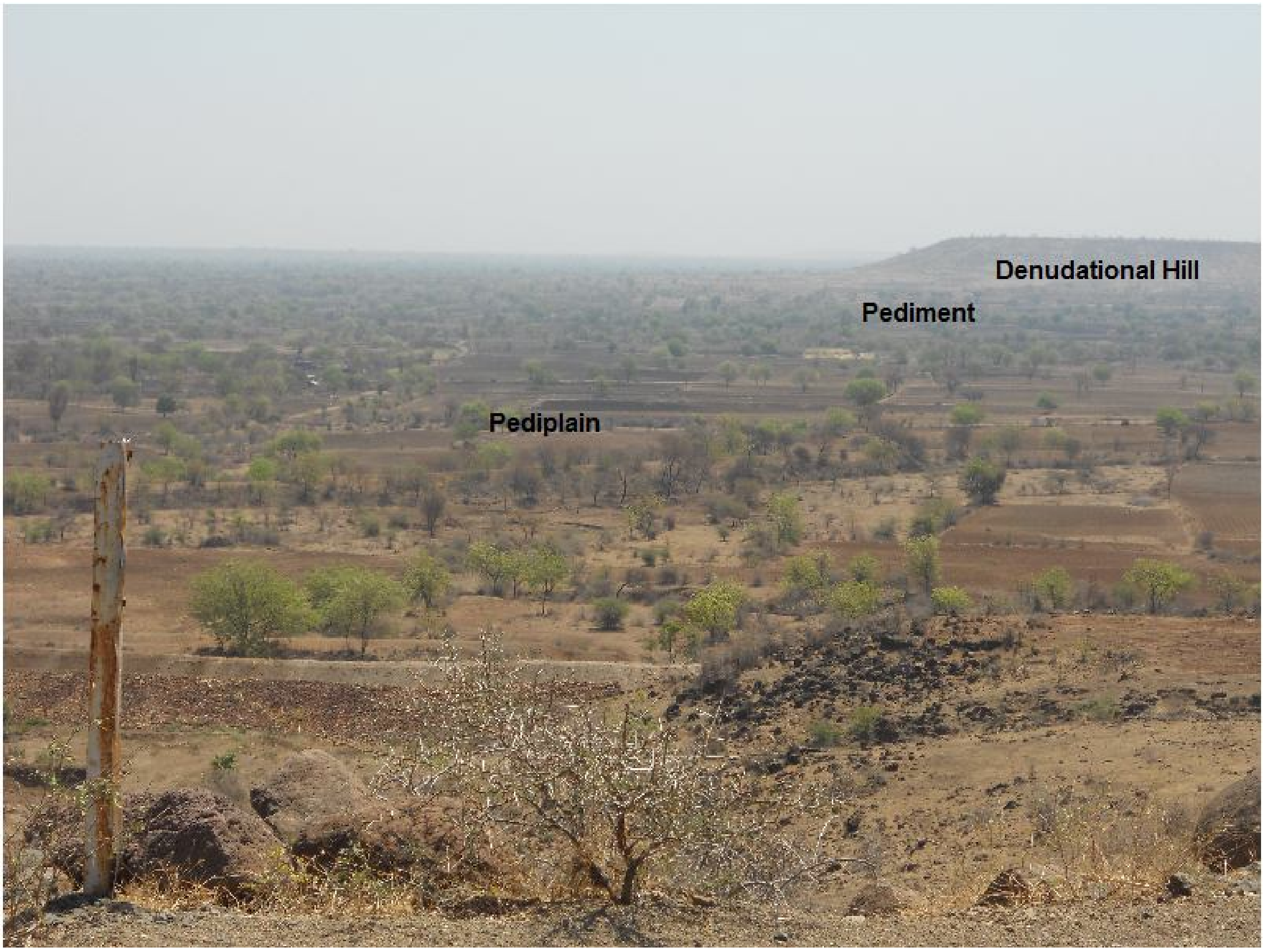


Fig. 5.13: Photo illustrating the exposures of Denudational hill, pediment and pediplain in the area around Beed.

5.3.3 Pediplains

Pediplains range in elevation from 440 to 580 m above msl covering about 1359.13 (i.e. 34.22 %) of the area of basin. The Pediplains are most dominant geomorphic units found in the basin. These are surface have good potentials for agriculture (Fig. 5.13).

Morphometric attributes of pediplains areas are: gently sloping to nearly flat terrain with gradient (5° to 30°), moderately coarse drainage density (1 to 1.5 km/km^2), moderate stream frequency (1.5 to 2 streams/km^2) and moderate relative relief (15%).

The materials comprising these surfaces, consists mainly of weathered products of the surrounding basaltic rocks, mostly comprise moderately thick gravels, pebbles, sand and silt. The soil cover over this unit consists of dark greyish brown to dark brown coloured, silty clay (calcareous), with high moisture retentive capacity.

5.4.4 Highly dissected plateau

This landscape unit is dominant in the upper reaches hilly terrain of river and in the southern part at the basin boundary and occupies about 417.37 sq km. (i.e. 10.51%) of the total geographical area of the basin. The lands of this unit are dissected by the streams of Sindphana river giving rise to a terrain consisting of flat topped ridges and steep scarps (Fig. 5.14a & b). This unit has elevation range of 620 to 740 m above msl.

Morphometric attributes of the highly dissected plateau include steep slopes (> 50°), rapid runoff, high drainage density (> 2km/km^2), high stream frequency (2.5 to 3.0 streams/km^2) and high relative relief. (>60%).

The soils over the plateau are dark brown to dark reddish brown in colour, clayey, skeletal, non calcareous in composition, well to excessively drained, low in moisture retentive capacity and underlained by weathered basalt.

5.4.5 Moderately dissected plateau

This landscape unit is dominant in the upper reaches hilly terrain of river and in the southern part adjoining the highly dissected plateau at the basin boundary and occupies about 439.82 sq km. (i.e. 11.08%) of the total geographical area of the basin. The lands of this unit are dissected by the streams of Sindphana river giving rise to a terrain consisting of flat topped ridges and steep scarps. This unit has elevation range of 620 to 740 m above msl.

Morphometric attributes of the moderately dissected plateau include moderate to steep slopes (30° to 50°), rapid runoff, moderate drainage density (2 to 2.5 km/km^2), moderate stream frequency (2.0 to 2.5 streams/km^2) and moderate relative relief. (50 to 60%).

The soils over the plateau are dark brown to dark reddish brown in colour, clayey, skeletal, non calcareous in composition, well to excessively drained, low in moisture retentive capacity and underlained by weathered basalt.

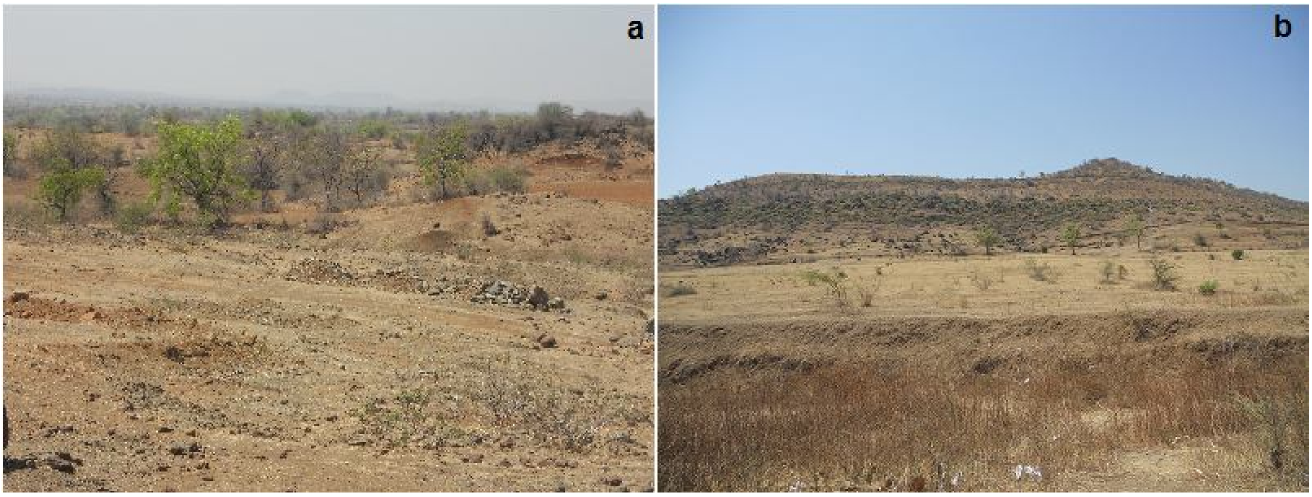


Fig. 5.14: (a) Highly dissected plateau and (b) Denudational hills observed in Beed area.

5.4.6 Denudational Hills

The hills in northern and western part of the basin in Osmanabad and Latur district are part of hills along margins of Balaghat plateau. The average elevation of these hills is about 650 m above msl. They occupy about 138.49 Sq. km. (i.e. 3.49%) of total geographical area. The hill tops have heights ranging from 720 m above msl to 820 m above msl. Apart from these, there are several isolated barren hills (Fig. 5.14b & 5.15a) scattered over the plains within elevation range of 640 to 750 m above msl.

These hills in the area have steep gradient (>60°), high drainage density (3 to 3.5 km/km^2), high stream frequency (4 to 4.5 streams/km^2), high relative relief (68%) and are characterized by rapid runoff.

The soil cover this geomorphic unit is very thin. The soils are rocky, clayey, non calcareous and underlain by weathered basalts. The flow characteristics of the basalts can be easily identifiable in the hills. The hills are sometimes barren and at places clothed with tropical dry deciduous forest.

5.4.7 Escarpment

An escarpment is an area of the Earth where elevation changes suddenly. Escarpment usually refers to the bottom of a cliff or a steep slope (Fig. 5.15a & b). Erosion creates an escarpment by wearing away rock through water. One side of an escarpment may be eroded more than the other side. The result of this unequal erosion is a transition zone from one type of rock to another. This geomorphic unit has less distribution in the basin and occupies about 4.60% of the total area. It has elevation range of 620 to 700 m above msl.

The morphometric attributes of the lateritic escarpment include moderate slope (25° to 50°), moderately coarse drainage density (1.5 to 2 km/km^2), moderate stream frequency (2 to 2.5 $streams/km^2$) and relative relief (25%).

5.4.8 Mesa

A mesa is a medium size flat-topped hill or mountain (Fig. 15b). Once a plain land, continuous erosion of surrounding areas makes it an elevated landmass and the top layer resists denudation of underlying rocks, thus giving it its characteristic shape. This geomorphic unit has less distribution in the basin and occupies about 14.91sq km (i.e.0.38%) of the total area. It has elevation range of 650 to 720 m above msl.

The morphometric attributes of the lateritic escarpment include steep slope (> 60°), coarse drainage density (2 to 2.5 km/km^2), high stream frequency (2.5 to 3 $streams/km^2$) and relative relief (>25%).

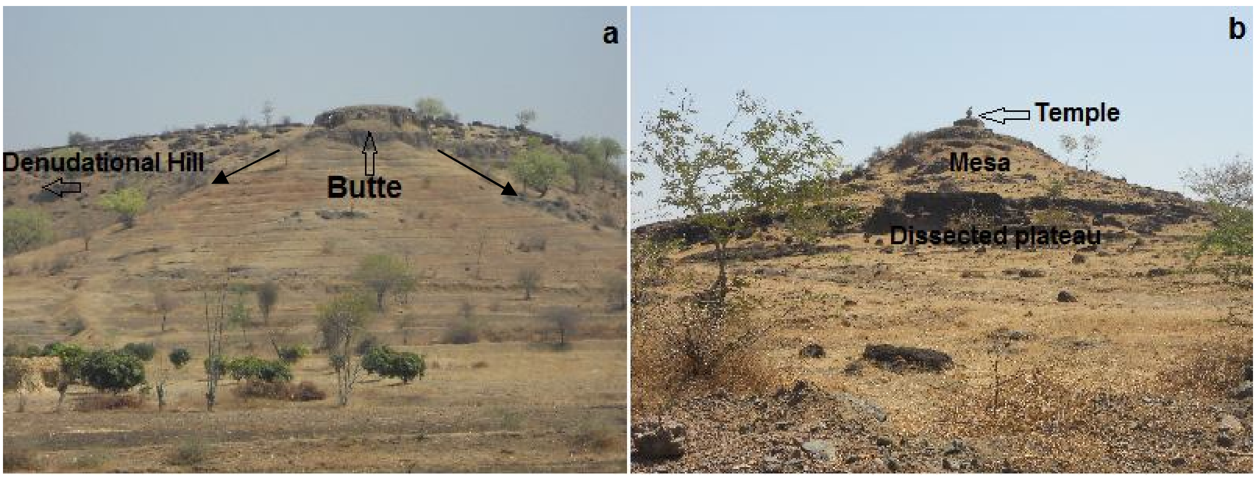


Fig. 5.15: (a) Denudational hill (in background) and Butte (in front) with escarpment slope (b) Mesa and dissected plateau in Beed area.

5.4.9 Butte

A butte is a small flat-topped or pointed hill or mountain (Fig. 15a). Continued denudation by water gradually reduces the Mesa into small flat hills called Buttes. This geomorphic unit has less distribution in the basin and occupies about 32.34 sq. km. (i.e. 0.81%) of the total area. It has elevation range of 620 to 700 m above msl.

The morphometric attributes of the lateritic escarpment include steep slope (> 60°), coarse drainage density (2 to 2.5 km/km^2), high stream frequency (2.5 to 3 streams/km^2) and relative relief (>25%).

Chapter 6

DISCUSSION

In this chapter the discussion is made on various aspects of the study including geology, structures, drainage pattern, drainage morphometry, and geomorphic surfaces of the area.

6.1 Geology

The Deccan Basalt in this area has been assigned to Ajanta formations which are stratigraphic equivalents of Upper Ratangad formations of Western Maharashtra comprising compound flows.

The two basalt flows have distinct field characters, which are described in detail in this chapter. On the basis of field characters it is observed that the major areas of the basin are developed on compact (Massive) basalt with amygdaloidal basalt in the subsurface flows.

6.2 Structures

Structural features like major and micro lineaments are recorded in the area from remote sensing studies using IRS P6 LISS III imageries. There are three mainsheets of lineaments trending in WNW-ESE, E-W and NW-SE directions.

6.3 Quaternary Geology

The scarcity of sand in the Deccan trap river originating and flowing through Deccan basalt terrain is attributed to the nature and the product of the weathering of the basalt. The low channel gradients of rivers must have facilitated the transport of silt and clay to a large extent than coarse

During the present study, the study area is divided into three Quaternary geomorphic units on the basis of break in slope, soil type, constituting material and nature of erosion in the landform. These units are:

1) Present Floodplain – To (Younger)
2) Older Floodplain – T1
3) Pediplains – T2 (Older)

It is seen that debris slope of the pediplains forms the valley margins. The older floodplain rests against the pediplain. The pediplains have steep slopes which gradually grades into the gentler surface of the floodplains. The younger i.e. present floodplain forms central part of the valley where the river channel lies and rests over older floodplain as well as overlies on the pediplains.

The sedimentary bluffs found in Quaternary sediments of the Sindphana river in general show evidences of deposition by river surges and are marked by alternating layers of coarse sands with cobbles and silty clay. The coarser layers may have been deposited during the floods and fine sediments during the leaner seasons. Texturally the sediments can be classified as clay loam, silty clay, sandy clay and sandy silt. These types of sediments have been noted for major rivers in Maharashtra and are categorized as flood loams or diluvium. These rivers are noted for highly fluctuating discharge and active channel migration.

The fluvial terraces carved out in the Upland area of Balaghat plateau by the Sindphana River show a well-developed bedrock strath overlain by colluvial and alluvial cover. Terrace T2 is marked by debris flows where the bed load is comprised of larger pebble size (8–20 cm) (Fig. 4.29), indicating high intensity episodic flood conditions in the Sindphana river channel that were generated in upper catchment. The fact that quartz and chalcedoney pebbles are relatively larger and lack comparable roundness suggests that the pebbles are not recycled from the older sedimentary fills but are produced and transported during the contemporary floods. The younger terrace T1 is characterized by braided river conditions punctuated by few episodic floods generating debris flows, however as compared to the T2 aggradation the intensity of these floods was reduced (reduced pebble size). Terrace T1 also shows aggradation under a braided fluvial regime. The presently active channel (T0) is also aggrading under braided conditions in the Middle reach of the Sindphana. The terrace configuration indicates that the river has undergone two phases of aggradation and incision that also suggests that the river has not been flowing under equilibrium during the Holocene.

The light grey silt formation is correlated with upper Hirdepur formation of late upper Pleistocene age (13 ka to 25 ka). The dark grey silt formation is correlated with the Ramnagar formation of Holocene period (Tiwari 1999). These formations are given in Table 4.3. The lithology and development of calcretes and ferricreted sediments of the Sindphana valley alluvium suggest that the Older Quaternary Alluvial deposits may be of Early Pleistocene age **(**Rajaguru, 1969**;** Rajaguru *et al*, 1993**)**.

6.4 Age Data

The presence of calcretes in the Quaternary sediments and presence of vertebrate fossils ‘Stegodon insignis’, ‘Bos nomadicus’, Elephas hysudricus’ and ‘Elephas sp’ from the Purna river at Yeldari dam pit (Rajaguru, 1968-69) suggests that the Older Alluvium is older than the sediments of Present floodplain and is possibly of Upper Pleistocene period. Similar fossils were also reported by Badam (1979) from construction trench at Jayakwadi project at Paithan on Godavari river and at Majalgaon dam site on Sindphana river in the present study area.

The aulluvial deposits of the Godavari basin, which have yielded a varied faunal assemblage, were earlier believed to be equivalent to the Narmada deposits (Pligrim, 1905). However, the recent bio-stratigraphical studies suggest that though the Upper Pleistocene sediments are well preserved in the shallow valleys of the Deccan trap region, there is no convincing evidence for the presence of middle and early Pleistocene formations in the Godavari and adjoining valleys (Badam, 1979). So far there is only a single C14 date of about 19,000 years B.P., for the upper part of the calcareous alluvium exposed around Paithan in Godavari valley (Covinus et al, 1973). The vertebrate fossil finds of ‘Bos nomadicus’ at Gangapur in upper Godavari valley and jaw of ‘Bos nomadicus’ (32,000 years B.P.), recovered from the buried channel of Mula river, a tributary of the upper Godavari, suggests that the age of the older alluvium is Upper Pleistocene (Rajaguru, 1970). Mishra et al (2003) dated the carbon sample from Sakshal Pimpri on the Sindphana river, tributary of the Godavari river, which originates in on the edge of the Ahmednagar plateau has given a record spanning the period of 14-8 ka.

In order to understand the stratigraphic history of the region we carried out the continued research in the major river of the Sindphana river the fossils were collected (Table 6.1). During this study the fossils were obtained from fossiliferous sites of the Quaternary sediments and dated using the Fluorine/Phosphate ratio (Table 6.2). A large number of fossils of *Elephus maximus, Bubalus bubalis, Cervus unicolour, Equus namadicus, Bos namadicus and Cervus duvauceli* were collected from the low energy over bank floodplain deposits of the Sindphana river at Sakshal Pimpri, Ranjegaom, Depegaon, Majalgaon, Manjrath etc. These fossils were identified with the help of earlier fossil records. The fossils collected are given in the Fig. 6.1.

The fossils identified in the present study as given in Table 6.1 are described below:

6.1 a: Auroch Tooth fragment (Upper) of *Bos* *nomadicus* from Ranjegaon area in the Sindphana valley. The tooth is found in sandy silt. This specimen is partially rolled and preserved with fine plates.

6.1 b: Distal Metatarsals of *Cervidae (Deer)* from sandy gravel of Ranjegaon area in the Sindphana valley. The broken edges of shaft are rolled.

6.1 c: Metatarsal fragment of *Bos nomadicus* from pebbly gravel of Ranjegaon area in the Sindphana valley. The bone is poorly preserved and covered with matrix of pebbly gravel crown.

6.1 d: Metatarsal fragment of *Bos nomadicus* from sandy gravel of Ranjegaon area in the Sindphana valley. The bone is poorly preserved, suffered long transport and broken.

6.1 e: Weathered right hemimandible teeth illustrating labial view of *Cervidae (Deer)* from sandy silt of Ranjegaon area in the Sindphana valley. Due to weathering the teeth are broken and poorly preserved.

6.1 f: Metatarsal fragment (right) of *Bos nomadicus* from sandy gravel of Shirasmarg area in the Sindphana valley. The bone is poorly preserved, suffered long transport and broken.

6.1 g: Distal Metatarsal fragment of *Cervidae (Deer)* from sandy silt of Shirasmarg area in the Sindphana valley. The broken edges of shaft are less rolled but well preserved.

6.1 h: Distal Metatarsal (left) of <u>*Bos nomadicus*</u> from sandy gravel of Shirasmarg area in the Sindphana valley. The bone is well preserved, but suffered long transport and broken.

6.1 i: Antler fragment of deer from sandy silt of Sakshal Pimpri village in the Sindphana valley. Having encrustation of matrix, the shape and broken section of a bone indicating absence of in cavity storage suggest being Antler fragment of deer.

6.1 j: Upper Auroch teeth of <u>*Bos nomadicus*</u> from Pebbly gravel of Depegaon village in the Sindphana valley. The teeth are preserved in coarse sediments covered by stubble matrix and suffered the long transport in the form of pebble on the river bed.

6.1 k: Tarsometatarsals (left) of *Bos indicus* from sandy gravel of Depegaon village in the Sindphana valley. It is good preserved and found in river bed.

6.1 l: Metatarsals (left) of *Cervidae (Deer)* found in sandy silt layer at Sandas Chincholi in the Sindphana valley. This is the bone metatarsal fossilized.

6.1 m: Piece of Metatarsals (left) of <u>*Bos nomadicus*</u> from sandy gravel layer at Shimpe Takali in the Sindphana valley. This is the piece of bone of fossilized metatarsal. It is the example of fluvial abrasion. The shaft shows fleet broken and which reveals abrasion in slope. All the articular facets and grooves are highly abraded.

6.1 n: Pelvic girdle bone Ilium of *Bos nomadicus/ Bubulus* from pebbly gravel of Manjrath in the Sindphana valley.

6.1 o: Part of Pelvic girdle bone of *Bos nomadicus/ Bubulus* from pebbly gravel of Manjrath in the Sindphana valley.

The fossils, dating back to the late Pleistocene period about 50,000 years ago, draw our attention to the amazing completeness of their skeletal remains. "The state of preservation rules out the possibilities of any prolonged pre-burial exposures to allow disintegration of skeletal elements by factors like scavengers, transportation by water currents or trampling under sub-aerial conditions" (Kshirsagar and Badam, 1990).

Table 6.1: Location and position of Fossils found in Sindphana valley

Fossil No.	Cranial/Dental/ Skeletal part	Genus / Species	Horizon / Locality	Probable age
6.1a. SF1	Auroch Tooth fragment (Upper)	*Bos nomadicus*	Sandy Silt/ Ranjegaon	Mid Holocene
6.1b. SF2	Distal Meta-tarsal	*Cervidae (Deer)*	Sandy gravel Ranjegaon	Late Holocene
6.1c. SF3	Metatarsal fragment	*Bos nomadicus*	Pebbly gravel Ranjegaon	Late Holocene
6.1d. SF5	Metatarsal fragment	*Bos nomadicus*	Sandy gravel Ranjegaon	Late Holocene
6.1e. SF6	Right hemimandible labial view	*Cervidae (Deer)*	Sandy Silt Ranjegaon	Late Holocene
6.1f. SM2	Metatarsal fragment (right)	*Bos nomadicus*	Sandy gravel Shirasmarg	Late Holocene
6.1g. SM3	Metatarsal fragment (right)	*Cervidae (Deer)*	Sandy silt Shirasmarg	Late Holocene
6.1h. SM4	Distal Metatarsal	*Bos nomadicus*	Sandy gravel Shirasmarg	Late Holocene
6.1i. SP1	Antler fragments	*Cervidae (Deer)*	Sandy silt Sakshal Pimpri	Early Holocene
6.1j. DPF2	Upper Auroch teeth	*Bos nomadicus*	Pebbly gravel Depegaon	Mid Holocene
6.1k. DPF1	Tarsometatarsals (left)	*Bos indicus*	Sandy Silt Depegaon	Late Holocene

6.1 l CH1	Metatarsal (left)	*Cervidae (Deer)*	Sandy silt Sandas Chincholi	Late Holocene
6.1m STF1	Piece of Metatarsal (left)	Bos nomadicus *Cattle*	Sandy gravel Shimpe Takali	Late Holocene
6.1n MJF2	Pelvic girdle bone Ilium	Bos nomadicus	Pebbly gravel Manjrath	Late Holocene
6.1o MHF1	Part of Pelvic girdle bone	Bos nomadicus	Pebbly gravel Manjrath	Late Holocene

The fossiliferous gravels (Photo 6.2), which yielded these fossils, are exposed laterally for a stretch of 1 to 2 kilometers in the hard sandy silt and pebbly gravel beds at Ranjegaon on the left bank of the Sindphana river. All the conditions indicate that there has been no displacement of these bones from their actual place of burial. This implies that all the stages in the life history of these fossils were confined to the same region.

The relative dating of bones is based on the principle that the bone buried in the soil absorbs fluorine and the content of fluorine increases with time. Modern bone gives F/P ration of 0.03, while fossil bone of terminal Pleistocene to Mid-Holocene may have values ranging from 1 to 2. The bones of the Late Holocene period usually have F/P ratio less than 1. Fluorine analysis of animal bones from the Quaternary deposits of India has been successfully attempted. Quaternary deposits in India often yield animal fossils. The fossil data helps to establish the biochronological sequence of the geological events.

The analysis of a number of animal bone samples of different periods and from different regions of India has proved this method to be useful for dating purposes (Joshi and Kshirsagar, 1986). The results are comparable with those for fossils of the Pleistocene and Holocene period. Oakley (1980) successesfully attempted the dates based on Fluorine/phosphate ratio from the British Isles, France, Hungary and Italy.

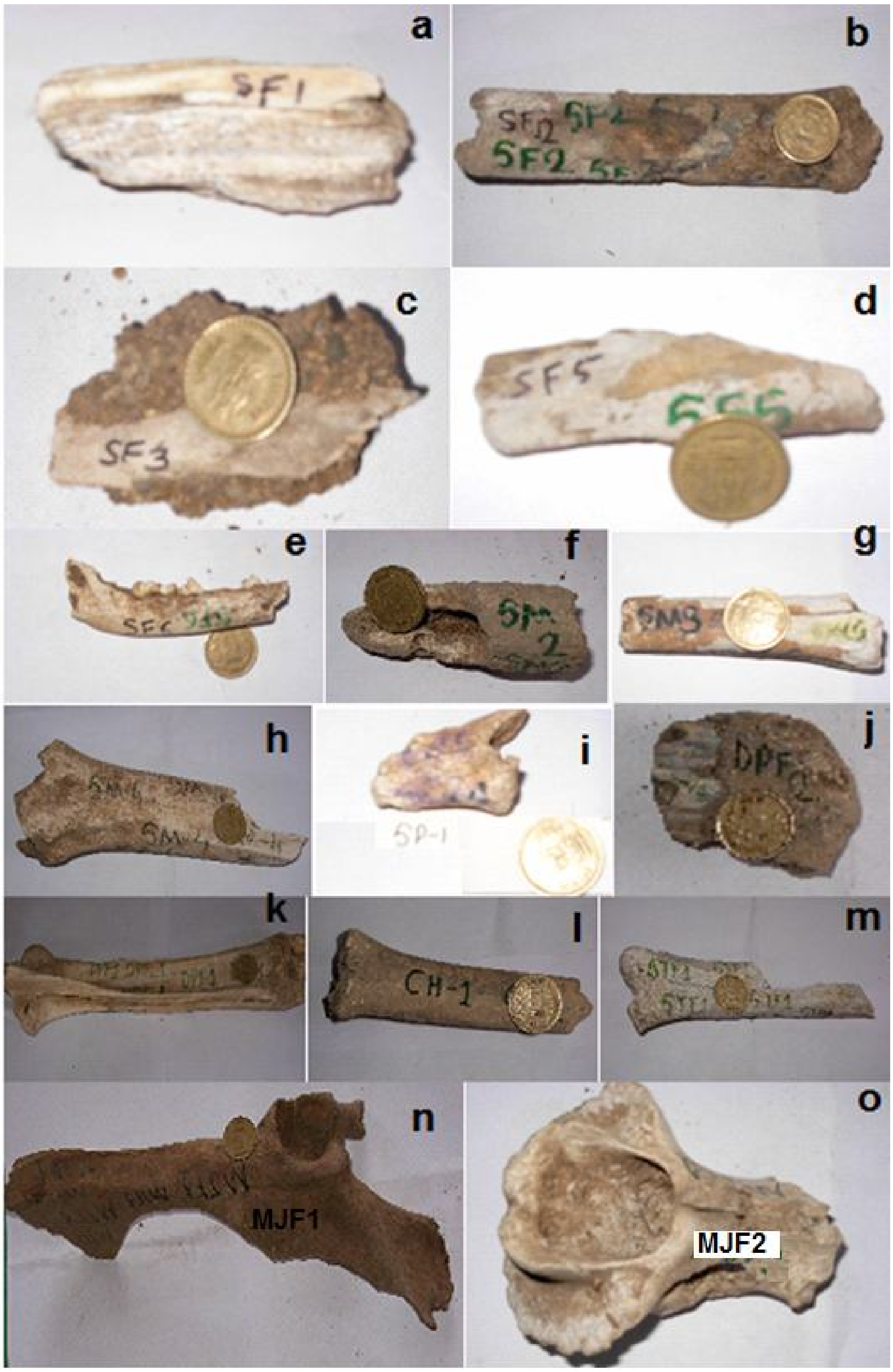


Fig. 6.1: Quaternary fossils of Sindphana river basin (a) Auroch Tooth fragment (Upper) of Bovid (b) Distal Meta-tarsal of deer (c) Metatarsal fragment Bovid (d) Metatarsal fragment Bovid (e) Right hemimandible labial view deer (f) Metatarsal fragment (right) of bovid (g) Metatarsal fragment (right) deer (h) Metatarsal (right) bovid (i) Antler fragments of bovid (j) Upper Auroch teeth bovid (k) Tarsometatarsals (left) bovid (l) Metatarsal (left) deer (m) Piece of Metatarsal (left) bovid (n) Pelvic girdle bone Ilium of bovid (o) Part of Pelvic girdle bone of bovid.

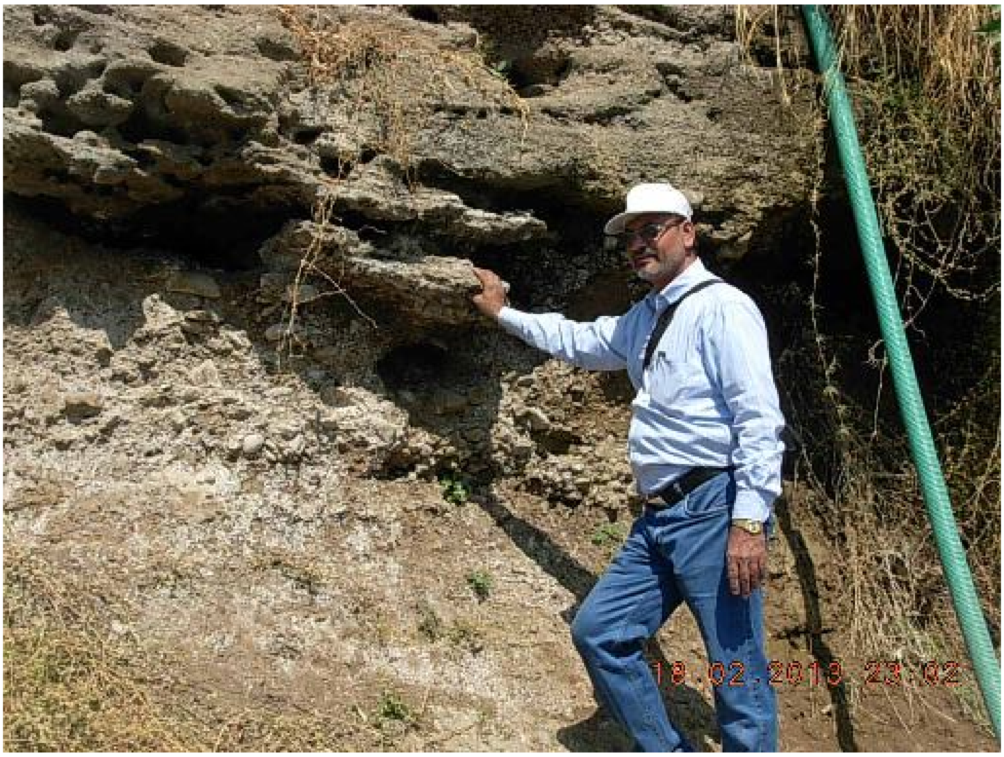


Photo 6.2. Fossiliferous sandy silt stone and gravel bed along Sindphana river at Ranjegaon in Beed district.

The complete sequence of animal bones from the Hunsgi-Baichbal valley from Karnataka, some fossils from central and Western India, revealed that in most cases chronology, based on faunal and stratigraphical considerations, is well supported by fluorine analysis (Kshirsagar and Badam 1990). This method was also used to establish the probable age of bones from Goa (Kale and Rajaguru, 1983), Uran, Maharashtra (Kale et al. 1984) and Poredam, Kerala (Rajendra and Kshirsagar 1993).

Table 6.2: Age dating of fossil bones using Fluorine Phosphate ratio

Sample No	Location	F %	P %	P2O5 % (p%*2.29)	100F/P2O5	Tentative Age
SF1	Ranjegaon	0.39	12.2	27.94	1.40	Mid Holocene
SF2	Ranjegaon	0.08	4	9.16	0.90	Late Holocene

SF3	Ranjegaon	0.14	8	18.32	0.79	Late Holocene
SF5	Ranjegaon	0.08	4.8	10.99	0.76	Late Holocene
SF6	Ranjegaon	0.11	5.5	12.60	0.88	Late Holocene
SM2	Shirasmarg	0.13	7	16.03	0.82	Late Holocene
SM3	Shirasmarg	0.11	5	11.45	0.98	Late Holocene
SM4	Shirasmarg	0.18	9.8	22.44	0.80	Late Holocene
SP1	Sakshal Pimpri	0.35	7.5	17.18	2.04	Early Holocene
DPF 2	Depegaon	0.27	9.5	21.76	1.24	Mid Holocene
DPF1	Depegaon	0.16	9.5	21.76	0.74	Late Holocene
CH1	Sandas Chincholi	0.19	8.8	20.15	0.95	Late Holocene
STF1	Shimpe Takali	0.15	8.5	19.47	0.77	Late Holocene
MJF2	Manjrath	0.17	10.2	23.36	0.71	Late Holocene
MJF1	Manjrath	0.18	9.5	21.76	0.83	Late Holocene

F = Fluorine P = Phosphorus P_2O_5 = Phosphate $100F/P_2O_5$ = Fluorine/Phosphate

Geological Age:

Late Holocene	Present to 2000 Year B.P.
Mid Holocene	4000 –2000 Years B.P.
Early Holocene	10,000 –4000 Years B.P.
Late Pleistocene	40,000 –10,000 Years B.P.

Late /Mid/Early Pleistocene/Tertiary 1,50,000 –40,000 Years B.P.

Flourine/ Phosphate Ratio:

1) Late Holocene (ratio <1)
2) Early Holocene /Terminal Pleistocene (ratio 2 to 3)
3) Upper Pleistocene (ratio 3-5)

4) Upper Paleolithic and 5-6
   In those form Middle Paleolithic.

5) Late middle Pleistocene and early, up to Tertiary Period.
   (ratio > 6.5 up to 8.12, the theoretical Saturation value)

Comparing the lithology and faunal assemblage of the Sindphana valley alluvium with the adjoining areas of Manjra and Godavari valley (Badam, 1979), it is inferred that the Older Quaternary Alluvial deposits may be of late Pleistocene to Holocene age.

6.5 Drainage pattern

The dendritic drainage pattern is the network of streams of various orders and magnitudes joining the trunk master streams and resemble the branches of a tree. The development of dendritic to sub-dendritic drainage in the basin indicates the area of massive rock types, gently sloping to almost horizontal terrain and moderate to low relief.

6.6 Morphometric Parameters:

The morphometric analysis includes the assessment of various parameters like bifurcation ratio, length and area ratios and basin configurations, drainage density, stream frequency and length of overland flow of Sindphana river.

Bifurcation ratio of Sindphana river in general ranges from 2.00 to 4.56 (Table 5.1) suggesting that the basin is not structurally controlled. The values of stream length ratios are relatively low for the basins of higher order. The higher bifurcation ratio for a lower order stream would mean that the stream has rapid networking of lower order streams resulting in the decrease in the mean stream length. This is also borne out by the lower values of stream length ratios, which suggests that the area is fairly well dissected and may have broad valleys (Badve et al, 1990 and Babar 2000).

The values of form factor (F) 0.28, circularity ratio (Rc) 0.41, compactness ratio 0.41 and elongation ratio (E) 0.60 of Sindphana river basin (Table 5.2) indicates that the basin is relatively elongated and occurs in the early mature stage of erosional development.

In general high drainage density and high stream frequency are characteristics of regions of incompetent and impermeable subsurface materials, sparse vegetation and mountainous relief (Babar 2000).

Factors affecting drainage density are the erodibility of rock and climate. The drainage density is generally low in semi arid and arid climates but comparatively high in humid terrain (Gardiner, 1980). The drainage density value for the Sindphana river basin is 2.14 km/km^2 and stream frequency 2.92 streams/km^2 (Table 5.3). The drainage density and stream frequency are moderate in the Sindphana river basin which is attributed to moderate rate of precipitation in the area in past.

The length of overland flow is an important element of runoff processes in drainage basin. The overland flow that is the surface runoff of rainfall until it is channelized into a channel or stream depends on the length of the slope and on the nature and state of the surface. The later is influenced to a great extent by the mode of land use and the type of cultivation. Overland flow disappears shortly after the rainfall, water being either absorbed by the soil or retained by the vegetation cover, or evaporated (Zavoianu, 1985). The concentration time Tc, which is the time needed by the water to travel from the remotest fall point to the nearest gauging station relates to the overland flow. This time interval can be divided into two parts. First of these is the time interval Tc1 required for rainwater after it falls on ground, to flow from its fall point until it gets into the channel. The other one is Tc2, required for stream flow (once formed in the channel network) to travel to the gauging station (Lambert, 1975). Therefore Tc = Tc1 + Tc2.

For Sindphana river basin the value of length of overland flow is low (lo = 0.23 km). Thus, the surface run of rain water, before getting concentrated in the stream channels is 0.23 km.

6.7 Relief:

Relief (gradient) is an important attribute of a terrain in general and the drainage basin in particular. The basin shows higher relief values in the hilly terrain and moderate to low relief in plains. The low relief measures of Sindphana river basin suggest that the erosional development has early maturity stage (Subramanyan, 1974).

Slope values like relief ratio for Sindphana river basin is 0.004, channel gradient is 4.18 m/Km and the ruggedness number obtained for Sindphana river basin is 1.06.

Based on the hypsometric curve (Fig. 5.6) the hypsometric integral for the Sindphana river basin is 43.81%. This hypsometric integral indicates that the basin is in the early monadnock stage, beyond the early mature stage of erosion and 43.81% area is yet to be removed by erosion. Hypsometric curves confirm the inference drawn on the basis of basin configuration and relief measures that the basin has reached maturity in the erosional cycle.

6.8 Geomorphic Surfaces:

Considering the importance, different geomorphic surfaces are mapped using the satellite imagery. The geomorphic surfaces obtained are: Alluvial plain, Pediments, Pediplains, Highly Dissected Plateau, Moderately Dissected Plateau, Denudational Hills, Escarpment, Mesas and Buttes.

6.9 Geomorphic Setting

The Sindphana river originates in the upland part of Ahemadnagar district of Maharashtra. The Sindphana river shows NW-SE, WNW-ESE, N-S and E-W lineament trend (Fig.3.7). A WNW-ESE trending structure seems to have overprinted on the E-W structures and as this study shows it has influenced the drainage pattern of the area. The Sindphana river has been maintaining a E-W trend even throughout its course. The presence of significant meanders is also an important observation here. We have carried out quantitative geomorphic analysis and integrated with the field observation. We employed the quantitative geomorphic parameters like basin asymmetry factor and ratio of valley floor width to valley height, which are widely used in the study of neotectonics. Both AF and Vf are generally used to detect the tilting of a region (Keller and Pinter, 1996). The present data do not show any preferred direction of regional tilt. However, the study identifies different zones where AF shows a greater anomaly (>65 and <35) the Vf calculated for different reaches indicate that the E-W segment of the Sindphana shows relatively low values in comparison to the upper reaches of the river. The low values of Vf in the E-W segment can be due to the rejuvenation of the river caused by the neotectonic adjustments of E-W structure.

Geomorphic indices of active tectonics such as the basin elongation ratio, the basin asymmetry factor, the stream gradient-length ratio and the hypsometric integral were used as reconnaissance tools to ascertain the level of tectonic uplift in a landscape and identify areas undergone the tectonic uplift. Synthesis of the results of several previous case studies indicates that landscapes undergoing tectonic uplift should display the following characteristics with respect to geomorphic indices of active tectonics indices (Bull and McFadden 1977; Keller and Pinter 1996; Matmon *et al* 1999; Burbank and Anderson 2001; Silva *et al* 2003; Molin *et al* 2004; Verrios et al, 2004; Peters and Van Balen 2007 and Kale and Shejwalkar, 2008).

- Very low elongation ratio for tectonically disturbed rivers.
- Anomalously high SL index values in regions underlain by uniform lithology.
- Asymmetry factor significantly greater or less than 50 suggesting tectonic tilt.
- High hypsometric integral indicating deep incision and rugged relief.

The values of hypsometric integral in the selected 26 drainage basins range from 31 to 72 with the highest being 72 (table 5.) indicating prevalence of mature or subdued topography. These values demonstrate absence of rapid valley down cutting and incision. There is also complete absence of any regional pattern in the occurrence of basin asymmetry. The distribution of basin area with reference to the trunk stream appears to be random and not related to any regional determinant factor. Similarly, the minimum elongation ratio is 0.43, suggesting that all the basins are not highly elongated, as expected in an uplift-dominated region. Thus, in view of the facts adduced in this study, it can be stated that the western DBP area belongs to the class of low tectonic activity. Another point that emerged in the present study is that southern DBP rivers, namely Varna, Panchganga and Dudhganga display some distinct basin characteristics in terms of GAT indices. These southern tributaries of Krishna show some unidirectional basin asymmetry. These rivers have more area to their downstream right indicating a tendency to migrate northward. This tendency is perhaps the manifestation of the influence of the well-established, low-angle northerly dip of basalt flows in the extreme southern part of the DBP (GSI 1976; Subbarao *et al* 1994). The tributaries of Tapi in the north also show a similar tendency (figure 2A) perhaps because these rivers are under the influence of the SONATA rift related system (Ravi Shankar 1991).

The rivers in the DBP are wide and flat and their box-shaped or U-shaped appearance often gives the impression of their being glacial in origin, which of course, is not plausible even remotely. The point is that for the development of such wide, flat-floored valleys (Vf = 7–61) it is of utmost importance that the regional base level remains undisturbed for a lengthy period. If the DBP was experiencing continuous and protracted uplift during Neogene. Quaternary, as postulated by many workers, formation of such large, box-shaped valleys is absolutely unlikely. Therefore, unless there is an alternative explanation, it is reasonable to suggest that a vast period of tectonic stability is indicated by the Upland valleys.

One of the alternative explanations is that phreatic processes, rather than fluvial processes, have played an important role in the formation of the valleys in Deccan Basaltic Province. Due to the nearly horizontal nature of the lava flows, the lava pile in the DBP displays a layer-cake structure (Gunnell 2001). In such settings, groundwater sapping is recognized as one of the effective geomorphic processes in the recession of valley-walls. Such sapping valleys exhibit very distinct valley plan forms. Sapping valleys are invariably steep walled and sinuous with a few short tributaries. The valleys are amphitheatre-headed and hanging tributary valleys are common

(Howard 1995; Lamb *et al* 2007). Such forms along with little dissection upstream have long been associated with groundwater sapping or seepage erosion (Lamb *et al* 2008).

Another possible explanation could be that the valley walls have receded by back wasting. If backwasting would have been the dominant process, the planform of the valleys would have revealed broad, shallow re-entrants, separated by sharp cusps, because the attack is areally uniform (Howard 1995).

In fact, all the morphologic characteristics suggest that the present-day valleys are the product of normal fluvial erosion. The valley heads are predominately V-shaped in plan (Kale and Subbarao 2004). Here it is pertinent to mention that serious doubts about the role of groundwater sapping or seepage erosion have been expressed even in the case of the amphitheatre-headed valleys of the Colorado Plateau and Hawaii, the so-called classic examples of groundwater sapping in bedrock, because of evidence for flash floods and plunge pool erosion (Lamb *et al* 2008).

Deeply incised bedrock meanders and a series of knick points at the gorge head occur in the Mandvi and Pravara (and its tributaries Mula-Kas) rivers (Kale and Rajaguru 1988) in the neighbourhood of the Malshej Ghat (figure 3B). Interestingly, the highest peak in the DBP (Kalsubai Peak; 1646m ASL) and the deepest embayment in the Western Ghat are also observed in the same area (figure 3B). The Pravara river and some of its tributaries are also featured by some of the thickest Quaternary deposits in the DBP. Incised or entrenched meanders and knick points are a common phenomenon in uplifted plateaux around the world and therefore, these features are considered as markers of regional or tectonic uplift (Matmon *et al* 1999). Whilst, the presence of these spectacular features cannot be contested, one cannot overlook the fact that the valleys immediately north (Godavari and Dharna) and south (Puspavati) are exceptionally wide even by Upland standard (figure 3B), with no sign of deeply incised bedrock channels. The co-existence of such contrasting geomorphic features is intriguing and puzzling. One obvious explanation could be that incised meanders and knick points may not always form by uplift and there may be other reasons for their development. Erosional disequilibrium between river systems has been commonly recognized as one of the causes of knick point formation and upstream migration (Hack 1973). Here it is pertinent to mention that the southern limit of the bedrock-meander-dominant area coincides with the Kurduwadi or Ghod lineament, a major regional structural feature (Powar and Patil 1980). Needless to say further work is required to improve our understanding of such anomalous geomorphic situations.

Chapter 7

CONCLUSION:

The Quaternary deposits of the Sindphana river are studied with reference to the morphostratigraphy and lithostratigraphy. In the Sindphana valley three terraces have been identified with the decrease in order of elevation from T2, T1 to T0. Terraces T2 and T0 are depositional while T1 is erosional. Three lithostratigraphic formations are studied viz: Shirasmarg, Manjrath and Ranjegaon formations. Dark grey silt formation formation of Shirasmarg is correlated the Ramnagar formation of Holocene period. Brown silt formation of Ranjegaon is correlated with the Beneta formation of early Upper Pleistocene. The light grey silt formation of Manjrath is correlated with upper Hirdepur formation of late upper Pleistocene age.

The depositional environment of coarse gravel sediment in bottom beds of Sindphana valley indicates that the streams are of relatively high energy with prevalent bed load transport; whereas fine clay and silt formations in the upper layers reflect that the streams are of low gradient and fluctuation of climatic conditions. The lithology and development of calcretes and ferricreted sediments of the Sindphana valley alluvium suggest that the Older Quaternary Alluvial deposits may be of Early Pleistocene age.

Considering the foregoing discussion it is concluded that:

- Occurrence of dominant compact basalt flows (aa type) along with vesicular – amygdaloidal basalt flows (compound pahoehoe) in the hilly terrain and in the other gently sloping to flat terrain reflects the lithological control on physiography and geomorphology of the area.
- The depositional environment of coarse gravel sediment in bottom beds of Sindphana valley indicates that the streams are of relatively high energy with prevalent bed load transport; whereas fine clay and silt formations in the upper layers reflect that the streams are of low gradient and fluctuation of climatic conditions.
- Three lithostratigraphic formations are studied viz: Shirasmarg, Manjrath and Ranjegaon formations.

- Dark grey silt formation formation of Shirasmarg is correlated the Ramnagar formation of Holocene period.
- Brown silt formation of Ranjegaon is correlated with the Beneta formation of early Upper Pleistocene.
- The light grey silt formation of Manjrath is correlated with upper Hirdepur formation of late upper Pleistocene age.
- Drainage pattern of the area is controlled by physiography and structures.
- Bifurcation ratio and length ratio of the river basin indicate normal development without structural control on drainage development.
- Evaluation of dimensionless ratios of basin configuration such as form factor, elipticity index, circularity ratio and elongation ratio indicate that basin is elongated and in the late mature stage of erosional development.
- The values of drainage density and stream frequency are moderate suggests the area of permeable soil with high moisture retentive capacity and low relief.
- Relief studies including channel gradient, longitudinal profile, relief ratio and ruggedness number reveal that the basin belongs to gently sloping to flat terrain.
- Hypsometric integrals indicate that the basin is in the monadnock stage, beyond early mature stage of erosional development and the area 43.81% below the curve is yet to be removed by erosion.
- Geomorphic surfaces identified are Alluvial plain, Pediments, Pediplains, Highly Dissected Plateau, Moderately Dissected Plateau, Denudational Hills, Escarpment, Mesas and Buttes.
- Highly dissected plateau, Denudational Hills, Escarpment, Mesas and Buttes have the problems of shallow soil cover, high relief, steep slope, rocky and rugged terrain difficult for agriculture, but have the potential for forestry and wild life preservation.
- Younger and older alluvial plain, pediplains and pediments are the fertile regions of the basin and have the problems of severe bank cutting and seasonal flooding.

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