CHAPTER - III

TECTONIC SETUP AND STRUCTURAL CONTROLS

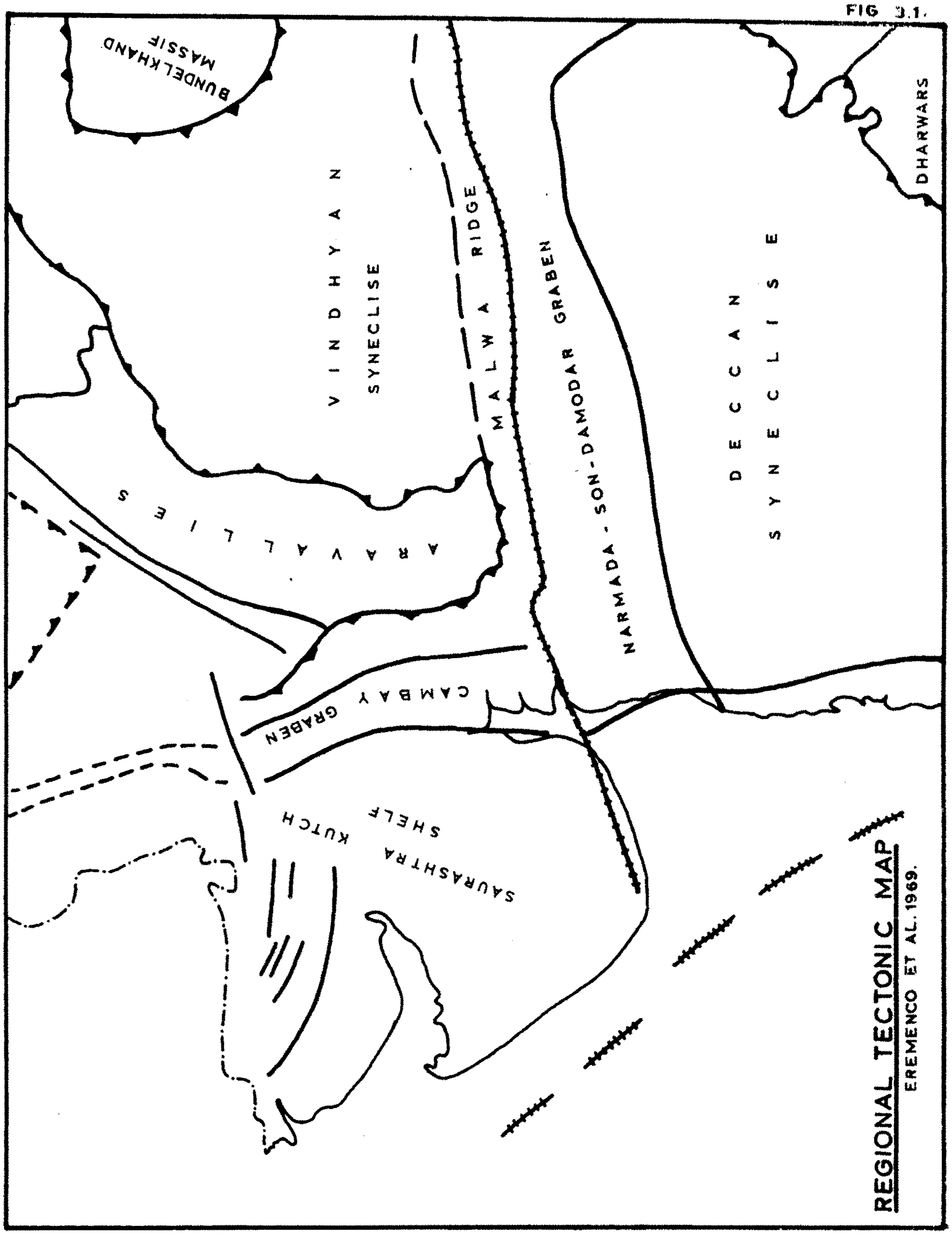
GENERAL FEATURES

A study of the tectonic aspects of this predominantly hard rock area of Heran basin is essential to give an insight into the major permeability directions and disposition of the groundwater conduits in an otherwise impermeable media. Fractures, cracks and fissures developed due to numerous tectonic processes provide these underground conduits. As has already been stated, to in earlier pages that the Heran river basin comprises a sub basin of the large Narmada river basin which is essentially controlled by geological events related to the tectonism of the Narmada Rift System. Interestingly, almost all parameters that have effectively been responsible for the development and evolution of Heran river basin, ultimately could be traced back in time to the tectonism, volcanism and sedimentation related to the Narmada geofracture. From Cretaceous period onwards the geological history of central and southern Gujarat, including tectonism, sedimentation and volcanism, has been directly or indirectly the manifestation of the control excersied by the Narmada geofracture. The evolution of the Heran river basin has therefore to be viewed in this light. The formation of the basalt hills and the deposition of Cenozoic sediments and their subsequent erosion, are all related to Narmada tectonism. The topography and the various channels provided for the Heran river and its various tributaries thus reveal the intimate relationship between the physiography and the channel characteristics of the basin and the structural features induced by the Narmada tectonism.

REGIONAL TECTIONIC SET UP

The Heran basin forms a part of the lower Narmada basin, which in turn comprises the extreme western part of the "Narmada-Son-Damodar Graben" of Eremenko et al, (1968). This first order structure is a major lineament with a ENE-WSW trend (Fig. 3.1), and extends across the central part of the

FIG 3.1.



REGIONAL TECTONIC MAP
EREMENCO ET AL. 1969.

Indian sub continent. Tectonically, the basin may be classed as a 'graben' which is filled up by Mesozoic sediments and is aligned roughly parallel to the present course of the Narmada river. The Narmada graben is the manifestation of tectonic forces operative over a zone of weakness in the Precambrian basement. The southern slope of the Malwa plateau which marks the northeastern boundary of the graben comprises a system of 'en' echelon' and step faults. The southern boundary of the graben is marked by a similar 'en'echelon' fault system.

Auden (1949) considered that this line of weakness divides the Indian shield into two parts and is a major crustal feature of ancient origin. West (1962) suggested that this line may have been a line of weakness from early times, and the same at one time marked the southern limit of the Vindhyans and at a later time marked the northern limit of the Gondwana's. Chaubey (1962) on the basis of detailed tectonic and geomorphological analysis considered the lineament to be a typical 'rift valley' of a segment of the Peninsular Shield by regional tensional force. Chaubey (1970) considered the broad peninsular arching as the main cause of the fracture, much larger than the rift structure. According to him the uparching of the peninsular shield was concomitant with the Himalayan tectonics and the Narmada rift was formed by regional tensional forces in the

Peninsular Shield following compressions of Tertiary folding in the north. According to Yellur (1967) the course of the Narmada river and its tributaries is governed by a superimposed fracture system comprising three sets of faults. Yellur, has further postulated that the Narmada valley was a region of great crustal weakness where deep crustal fractures accentuated volcanic activity.

The ENE-WSW trending pre-existing faults of the Narmada graben played a significant role in controlling the outcrop patterns of the Cretaceous sediments. The strikingly NE-SW trends of the hills, the rivers, the faults and the outcrops in the study area have all been controlled by the major fault of the Narmada graben.

The deposition of the Bagh Group and the Lameta formation was followed by a period of stress release possibly concomitant with the reactivation of the Narmada weak zone. This created the set of NE-SW trending parallel faults. This major faulting movement resulted in differential uplifts, erosion and removal of a major thickness of the sediments; and created a definite pattern in the outcrops which continues to the present day without being much affected by the subsequent cycles of faulting. The faults oblique to this trend, represented by the N-S, NNW-SSE and NNE-SSW faults and are younger in age, minor in nature and came into existence during subsequent reactivation of the existing faults and possibly prior to the Deccan trap lava flow activity. This is inferred from the basaltic dykes in the western part that trend obliquely to the NE-SW trend.

After the block faulting and uplift along dominant NE-SW trends and removal of the major thickness of the sediments, the Deccan volcanics erupted through the weak zones and flowed over the area towards the topographic lows. The amount of the lava flow accumulation was controlled by the existing topography. Near absence of basaltic rocks in the northern portion of the western part suggests that the topography was much higher than the rest of the area and possibly only a thin lava flow covered this part. The area was subsequently subjected to another cycle of tectonic movement and erosion which resulted in complete removal of the lava flows from the northern portion of the western part and partial removal from the rest of the area which was topographically much lower. A third cycle of tectonic activity, possibly neotectonic affected the study area.

STRUCTURAL FRAMEWORK OF THE BASIN AREA

The overall basin has mixed structural characteristics of four lithostratigraphic units of different generations viz; Precambrian crystallines, Bagh sedimentaries, Deccan volcanics and Quaternary alluvium. All the four units have significantly contributed to the structural complexity of the rocks. Precambrians being the oldest, have provided the depositional surface to Bagh sedimentaries, further, both together have furnished conduits and paths for the Deccan basalts to pour out. The prolonged denudation of these three under the influence of neotetonic uplifts along numerous faults have givenrise to the present configuration of basin and accumulation of thick alluvium. The trend of Heran river being more or less identical to that of Narmada and the continuity of occurrence of NW-SE and N-S trending fractures originating from Narmada northward upto Heran and beyond has imparted a characteristic tree like configuration to this basin. The landform nature and distribution are closely related with the occurrence of various litho-units and their structural elements.

The three major geomorphic divisions of the basin viz; upper, middle and lower are significantly controlled by different sets of structural elements. Divisionwise structural details are described below.

<u>UPPER BASIN</u>

The rocks of the upper basin consist of Precambrian crystallines, Bagh sedimentaries and the Deccan basalts;

the last one predominates. The Precambrian metamorphics form the peneplained basement on which the Baghs rest unfonformably. The metamorphics occurs as elongated hills striking NW-SE in the northern extremity (i.e. north of Panvad) of the area. The Baghs occur as elongated patches forming inliers and outliers; these show faulted contact with the Deccan traps.

The aerial photostudies and field checks reveal that the area between Panvad-Kawant had been tectonically a much disturbed zone because today they are seen riddled with numerous dykes and faults. Two fracture zones are seen to exist (i) ENE-WSW (F_1-F_1) along the Heran river bed; parallel to the strike of the Baghs and (ii) NW-SE (F_2-F_2) following the river Kara conforming to the stike of the metamorphics (Fig.3.2).

The various intrusions in the form of dykes follow these fractures. Most of the ridges and hills viz; Panchwada, Kavchia, Bandhan, Phenai Mata, etc. proved as intrusives (Sukheswala and Sethna,1964; Sukheswala, <u>et al.</u>, (1965), also have the same trend, the magma having come along these major fracture planes. Moreover the lower grounds surrounding these hills and the south of Panchwada as far as Dongargaon are littered with dyke intrusives suggesting a number of minor fractures developed parallel to the major faults. Panchwada is possibly a major faults of the region with a considerable downthrow to the north (Sukheswala and Sethna, 1969). The Heran river fault (F_1-F_1) to its south produces an 'en' echelon' pattern. As a result the Baghs (dipping SE at 30°) reappear to the south at far distance from its northern exposure at Karali. From Narmada northwards, regular step-faulting seems to have occurred with downthrow to the north. Rivers-Heran, Unchch, Orsang and other major streams, follow that direction. The Heran river shows many indications of faulting. Primarily, the course of the river is parallel to the fracture direction of the region, part of which is filled by Phenai Mata intrusives. Along its course, exposures of breccia are seen. Several other dykes following the river trend are seen in bed of the river. At many places the southern bank of the river presents steep scarps with flat lands to the north (Plate III.1). A ENE-WSW fault (F_3-F_3) at the village Karajwat has repeated the Baghs just where they come in contact with the traps with a downthrow to the north. The large outcrops of the Baghs at higher levels in contact with the trap at Khandibaru, Amalwat, Kakanpur etc. also appear to be due to a major fault which runs near the village Kawant.

A subsidiary NW-SE fracture zone (F_3-F_3) is established on the basis of the following field evidences. (i) Some larger rivers, viz. Banganga, Kara, Rami and several others nullahs flow in this direction. (ii) Narmada and Heran have also similar prominent bends (ii) Several minor and major dykes follow these trends (iv) Kara and Banganga rivers with their slickensided north-eastern scarps, and a number of dykes along their courses appear to be major fault zones. (v) Two minor fractures along Tokri and Wanta streams are suspected because of the slickensiding in the rocks along their banks. (vi) The elevated situations of Dungargaon and Towa may be the result of such movements. (vii) The local westernly dips of about 15° (regional dip is southerly) and the disappearance of Baghs along their strikes with an 'en'-echelon' arrangement may be the result of such movements.

The combined effect of the ENE and NW fracture pattern to a certain degree, controls the trellis arrangement of many subsidiary streams.

The ENE-WSW fractures are equally dominant in the southern part of the upper basin. To the area south and southeast of Kawant, the Bagh inliers occur within the Deccan trap terrain. In the Chikli inlier, the metamorphics are exposed in the southern part, presumably because of a fault of greater displacement. Unlike the outliers of Bagh beds in the lower Heran valley, the inliers are not bound on both sides by clearly observable faults. Only the Galesar and the Mohanfort-Raisingpur inliers are bound to the north by faults. Here the Bagh sediments are lowly dipping with dips usually ranging from sub-horizontal to 10° towards southeast to southwest.

It has been observed that, the Baghs have been affected by number of faults out of them two are major. First one (F_4-F_4) is trending ENE-WSW with minor offsets in NE-SW and is located to the northern boundary of the Galesar inlier. The downthrow of the fault is towards SSE. The second fault (F_5-F_5) that passes through the Artiya inliers, (west of Siriwasan inlier) and the western part of the Mohanfort-Raisingpur inlier has a downthrow towards north. A fault which has a trend of NNE-SSW is located north of Kawant with its downthrow to the ESE.

MIDLLE BASIN

Looking to the straight course of the Heran river in this part of the basin it will not be wrong to conjecture that the river flows along an E-W fault.

The Precambrians which occur as inliers show general trend of N40° W to N60° W with dips towards SW. These meta-sedimentaries though highly jointed, do not appear to have influenced the drainage.

In this part of the basin, the Bagh beds trend due N60°E to N80°C and show dips of 15° to 30° towards SSE. They exhibit several sets of joints, but these are tight and filled with silica and red clay; no influence of these joints on the drainage is observed. The Deccan lava flows in the southeastern portion of the central part of the basin exhibit a general flow trend in N 60°E direction with low dips (10° to 14°) towards SSE.

The rocks in this part of the basin are seen affected by a series of parallel to sub-parallel ENE-WSW and NW-SE trending faults. Displacement of dykes, abrupt ending of dykes against faults, repetition of Bagh beds and juxtaposition of traps by the Baghs are the clear indications of faulting. Slickensides, brecciation and shattering of rocks along fault zones and intense close jointing are also noticed. The WSW trending principal drainage represented by Heran and a major nullah to its north are carved along such faults. The other ENE-WSW and NW-SE trending rivulets that flow parallel to these two main streams also follow similar faults of lesser magnitudes or major joints.

The various faults are described as follows:
A fault (F_6-F_6) runs in a zig-zag manner along which a major nullah flows from southwest of Chalamali to east of Kosindra.

This fault is offset by a NW-SE fault near Naniwant, which extends for a distance of nearly 20-22 km. Parallel to the latter fault, runs the main Heran river fault from Tokri to south of Lalpur. The fault is very well exposed near Rangpur Ashram where the E-W displacement of dykes provides a very conclusive evidence of the faulting (Plate III.2). An off-shoot of this fault runs south of Wanta village and ideally shows displacement of dykes and shearing in the Rami river bed (Plate III.3) Other faults of lesser magnitude are recorded on either side of the Heran river fault. A second fault (F_7-F_7) of reverse type strikes from east of Thargaon to WNW of Navagam. Its continuity further WSW is obscured; beneath the alluvium but, it is again observed in the Men river (northwest of Amroli) where its trend is seen to be WNW-ESE and is evidenced by the abrupt occurrence of an upthrown outcrop of sandstone.

A third fault (F_8-F_8) also of reverse type, strikes from south of Artiya to south of Devliya (in adjoining Men river basin) for over 20 kms. This fault together with its subsidiary dislocations has been responsible for exposing a thick sequence of Baghs, all along the fault from Devliya Andhali to Bagaliya and south of Artiya.

Faults of lesser magnitude parallel or sub-parallel to the faults mentioned above are seen in the areas to the

Plate III.1 Field photograph showing a prominent fault scarp on the left bank of Heran river. (Loc. Heran bridge near Panvad).

Plate III.2 Field photograph showing E-W dislocation of dyke on account of F_1 -F_1 fault (Loc.Heran river bed near Rangpur Ashram).

Plate III.3 Field photograph showing displacement of micro dyke in the basaltic flow, due to $F_1 - F_1$ fault (Loc. Rami river bed near Wanta).

north of Bhildha south of Wankaner, southwest of Artiya. In the northwestern part of the area, a prominent NW-SE trending fault has been responsible for the NW kinking of Heran river and for a major nullah further northwest in the area east of Kosindra. In the southeastern hills a number of NE-SW trending cross faults have been deciphered with the help of air photo study.

LOWER BASIN

All over the lower Heran valley, the Precambrians and Bagh beds are seen outcropping as isolated patches within the alluvium, the Baghs are either resting over the Precambrians or as outlier within the alluvium. The low southerly dipping Bagh beds rest unconformably over the steeply (about 45°) dipping quartzites, phyllites and phyllitic schists of Champaner Series. The angular unconformity between Champaners and the overlying Bagh beds is very well seen in the present area in these outliers at a place near Ghantoli village in the Heran river bed. The Bagh sandstones show gradded bedding in which the basal part is conglomeratic.

In this lower part of the Heran basin are encountered a series of faults, either observed or inferred. As stated earlier, in this part of the basin also, the ENE-WSW trending fault system of the Narmada graben has played a significant role in controlling the tectonic setting. This is apparent from the NE-SW trends of the outliers and faults. Four major faults, all trending NE-SW, and two minor faults, one trending N-S and other trending NNW-SSE have been observed.

Fault (F_9-F_9) located between Songir hill outlier and Chosalpura-Chameta outlier has a downthrow towards north (Songir hill). From west to east the trend of the fault changes from ENE-WSW to NE-SW to ENE-WSW.

The fault (F_{10}-F_{10}) trends NE-SW and shows several fault plane evidences. Its presence is also clear from stratigraphic observations that the magnitudes of movement along these two faults F_9-F_9 & F_{10}-F_{10} are different, the displacement along F_9-F_9 being less pronounced than along F_{10}-F_{10}.

Fault (F_{11}-F_{11}) located south of Vajiria hill outlier has been interpreted from field evidences, i.e. on the basis of the different altitudes of the positions of basal conglomeratic layers in the two outliers.

A fault (F_{12}-F_{12}) passes through Indral, Songir and north of Lachharas and has a downthrow towards north and has been inferred on the basis of Precambrians contact with alluvium.

A minor fault (F_{13}-F_{13}) trending N-S with downthrow towards east.

Another minor NNW-SSE trending fault (F_{14}-F_{14}) with downthrow towards east.

ANALYSIS OF FRACTURE LINEAMENT

Based on satellite imagery, aerial photo interpretation, drainage pattern and field checks, an integrated fracture lineament map has been prepared (Fig. 3.3), and an attempt has been made to classify these fracture lineaments with a view to understand their genetic relationship, chronologic events and the control excersied by them over geomorphic features. Fractures have been grouped under four categories (Table 3.1).

The basement fractures have been referred to as first order fractures; fractures related to Deccan volcanism as second order fractures; those related to the cooling history and diagenesis of sediments as third order fractures; and those related to neotectonic activity (including reactivation of basement fractures) as fourth order fracture lineaments.

(i) First order fractures: These fracture lineaments controlled by basement tectonics (Precambrian) are reflected in the topography as major drainage lines. The basement fractures by their reactivation have influenced the geologic and geomorphic evolution of the basin area. As already metnioned, these first order fractures are sympathetic to Narmada Rift System. These are aligned in ENE-WSW and E-W directions. Continued tectonism along the Narmada rift and associated fractures during Tertiary and Quaternary periods, has evidently given rise to the fractures related to second and fourth orders. Reactivation of a few first order faults appear to have given rise to several sets of 'en'-echelon' faults. Dimensionwise, these fractures have regional extent being of the order of several km. Their displacement is mostly vertical such that the southern banks of the fracture controlled Heran and other major tributaries, show steep scarps. Majority of the landforms, trunk streams, dykes are aligned along these fractures and 5th and higher order streams are influenced by them.

Hydrogeologically these fractures regulate the entire flow of the basin. They form major productive linear aquifers and provide conduits for dynamic flow of the groundwater in the upper reaches.

(ii) Second order fractures forms a conjugate set of NW-SE ~~and~~ and NE-SW pattern, in which former is dominant. These fractures appear to have developed at the time of Deccan Trap activity. Their displacement is mostly lateral/ oblique. These fractures are regional as well as local and extend for about a few tens of kilometres to a kilometre. Their influence on geomorphic evolution of the basin is seen in the control exercised in them on the development of local landforms of intermediate height. The flow in lower reaches of Kara and Rami rivers and streams of second to fourth order are controlled by these fractures. The pinnate and rectangular drainage pattern are the results of their criss-cross nature.

Hydrogeologically they provides sparsely productive linear aquifers, but they mainly act as zones of recharge.

(iii) Third order fractures are aligned in N-S and E-W direction. The N-S trending fractures are more dominant and upto a certain extent they are related to the cooling history. They have influenced the fractures of the second order, whose effects are very pronounced in the upper part of the basin area. The E-W fractures are also related to the cooling history of the basaltic flows which ultimately resulted to a major joint direction. Quite a large numbers of these fractures (E-W) are manifested by steep slopes. They are very local having an extent of few hundreds of metres only. In the total picture of the geomorphic evolution of the basin, the effect of the fractures on landforms is insignificant but, highly significant rather from the point of view of evolution of drainage net of the basin as they have imparted a very fine texture to the basin drainage system.

These third order fractures are by far ubiquitous and important from the point of view of groundwater development. In the crystallines they are represented by joints and in the metamorphics by fracture cleavage, tensile and shear joints. They do not form any productive aquifers but act mainly as recharge streaks.

(iv) <u>Fourth order fractures</u>, though they are localised and confined to a smaller part of the basin, they have a very significant holdon the groundwater conditions. These fractures are the manifestation of neotectonic activity, which has given rise to typical landforms in the alluvial tracts of the lower basin. On account of neotectonism the second order fractures of NE-SW and probably first order fractures (E-W) which have been covered beneath the alluvium get exposed on the surface. The development of present drainage system of Ajna river is the product of this Quaternary phenomenon and perhaps, the last major tectonic activity within this basin area. These fractures are of very local extent and the displacement is dominantly vertical of a few metres only with a small lateral component. Their generation has caused incised topography.

Hydrogeologically they forms major productive aquifers of semi-confined nature.

STRUCTURAL CATEGORISATION

It is observed that the nature, intensity and dimension of the structural elements show a vital control over the groundwater conditions. Largescale structures with linear extensions have significantly contributed towards the development of aquifer system. The smallscale local structures have regulated the initial drainage lines, thereby augmenting infiltration and enhancing weathering process. Of course, directly they do not form any aquifer system.

Apart from fault and fracture systems which have been enumerated earlier, the different stratigraphic units have got their own inherent structural features. Precambrians, though their occurrence is sporadic are characterised by foliations, local folds, faults, joints and shear zones. The Bagh beds with variable dips show conspicuous inter-bedding, cross beddings, joints etc. The Deccan Trap basalts are characterised by a thick succession of lava flows. Apart from openings afforded by interflow surfaces and major joints and fracture pattern, a wide variety of small scale flow-wise and area wise structures like columnar joints, vesicular cavities, tuff-beds, breccias and red boles etc.

have been observed to effectively control groundwater infilteration, migration and accumulation. In the lower Heran valley where the terrain is mainly occupied with unconsolidated alluvium, the hydrofractures extending from hard rock areas in the east, though concealed under the alluvial cover are the major sources of recharge in the lower reaches of the basin. Besides these structures of various lithostratigraphic units, the dyke intrusions have played significant role towards the development of hydrogeologic regime of the basin. As these fall in both the categories, stratigraphic unit as well as structure, the later category is more important from the hydrogeologic point of view.

Based on the above discussed characteristics and their influence on groundwater, these structures have been categorised as under:

(i) <u>Major structures</u> have a regional extent, regulate groundwater flow and form linear aquifer systems of semiconfined.

(ii) <u>Minor structures</u> do not form any significant aquifer pattern, but they play an important part in enhancing weathering and contributing towards groundwater recharge. The various structures with respect to their nature and hydrogeologic characteristics are listed as under:

Major structures	Minor structures
Fracture zones	Bedding planes.
Faults and shear zones.	Foliations.
Lithologic contacts	Conjugate joints, columnar joints
Interflow surfaces	Vesicular cavities
Dykes	Red bole layers
Master joints	Local fractures.

divided into following three main morphological units:

(a) The Trappean Highlands (Upper part of the basin)

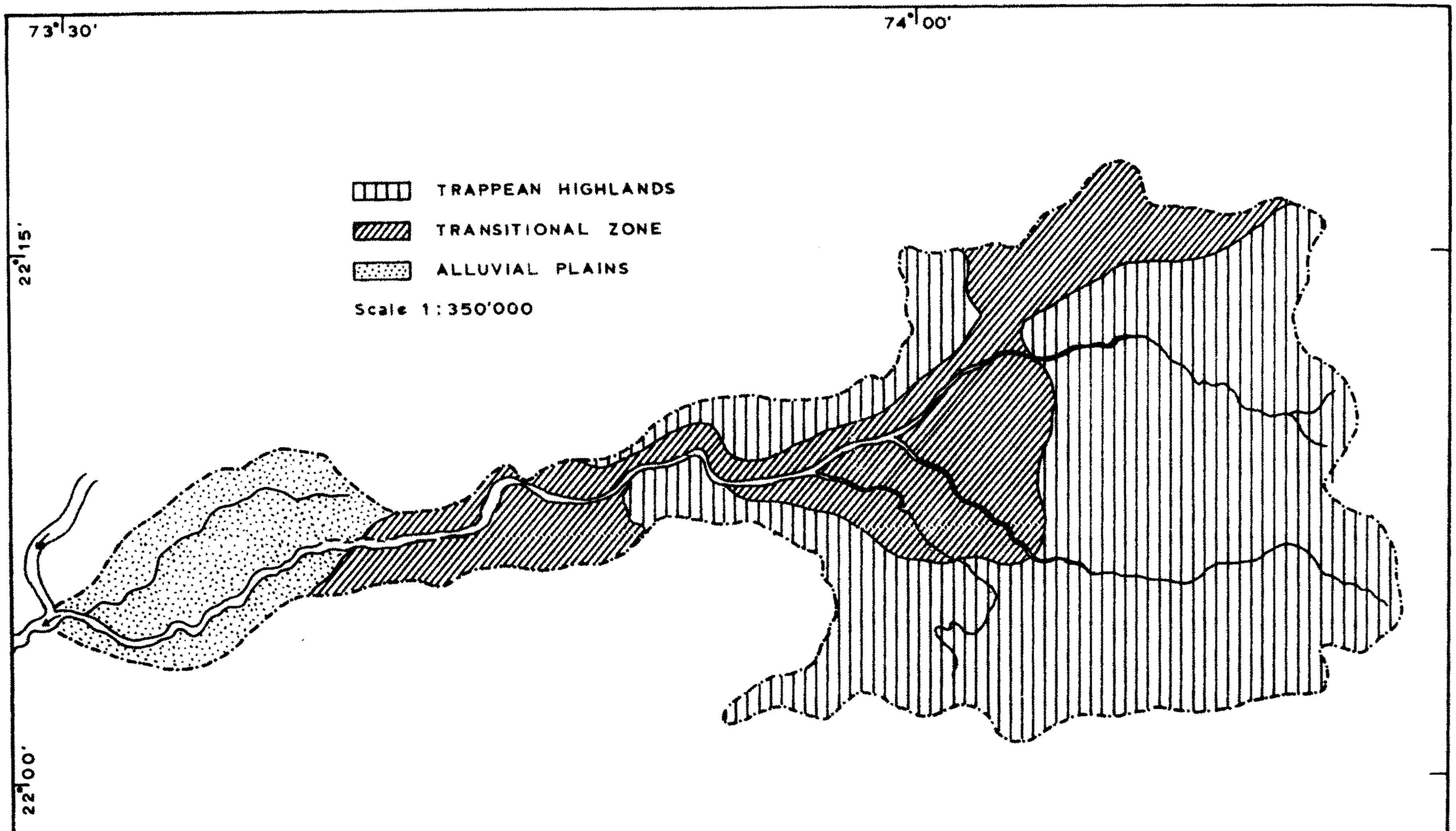
(b) Transitional Zone (Middle part of the basin)

(c) Alluvial Plains (Lower part of the basin)

The distribution and areal extent of these morphological units are shown in (Fig.4.1). The units in turn, show considerabl terrain diversity within each of them depending upon the contributing factors of lithology and structure etc. The hummocky terrain of crystalline rocks at many places has been rendered rugged and rough due to rising hills and deeply dissected valleys.

The areal extent, surface coverage and percentage distribution of the three units are tabulated as under:-

Unit	Location	Altitude Range (m) AMSL	Surface Coverage (Km^2)	Percentage distribut-ion
Trappean highland	Upper basin area upstream of Heran Kara rivers confluence.	180-540	783	59
Transitional Zone	Central part of the basin between Rang-pur and Chalamali	80-160	254	19
Alluvial Plains	Lower (western) part of the basin between Kosindra and Bhilodiya	40-80	288	22



DISTRIBUTION OF GEOMORPHIC UNITS IN THE STUDY AREA

TRAPPEAN HIGHLANDS

The upper part of the basin i.e. upto the river Heran-Kara confluence, is characterised by a rocky terrain made up of Deccan lava flows and Precambrian crystallines riddled with dyke ridges. The ENE-WSW trend of the ridges typically characterises the regional fracture directions more or less parallel to the Narmada geofracture.

The entire eastern and southern boundary of the basin is marked by steeply sloping basaltic hills and ridges. The northern border of the highland is occupied by the Precambrian Banded Gneissic Complex forming a series of round topped peaks rising at an average height of 260 m above mean sea level (AMSL). The central part around Ambasota, Ghorda and Phulmal is highly undulatory and dotted with numerous dykes and intrusive mounds. This is characterised by rolling topography in the central part gradually dropping towards west and enriched by steeply rising chain of hill peaks. The dykes stand out rather prominently above the surrounding trappean pedeplain. The dykes ranging in length from 200 m to 5 km and attains mountainous height in the area around Bakhatgarh, Chaktala, Mathwad, Kawant and Siriwasan (Plate IV.1).

The highest elevation 540 m is seen in the south-eastern extremity of the area.

TRANSITIONAL ZONES

A terrain marked by transitional landforms extending into the upper as well as the lower parts of the basin. It shows a variety of topographic features; both erosional as well as depositional, and it is characterised by landform assemblages which have a strong element of transitional as well as independent genetic attributes. Essentially this zone is made up of landforms formed due to prolonged erosion and later on filled by a process of deposition of sediments. These intermontane valleys have rocky faces and sediment filled base. These features are encountered in the areas of trappean lithology, their linear trends being due to structural influence. The three major intermontane zones show following characteristics:

Zone No.	Location of occurrence	Approximate Dimension			River/ stream
		Length	Width	Thickness	
I	Bagaliya to Chalamali	7.00 km	2.00 km	10-15 m	Heran
II	Deri to Phenai Mata Hill	10.00 km	1.00 km	15 m	Rami-Heran
III	Kawant to Narukot-Dhanpur	8.00 km	12.00 km	8-10 m	Kara

The transitional zone of intermontane valleys (Fig.4.1) when traced westwards, gradually drop in elevation and ultimately marge into the alluvial plains.

ALLUVIAL PLAINS

This unit comprises thick alluvial deposits and forms about 30% of the total basin area. The deposits are made up of fluvial material brought by the rivers Orsang, Heran and Aswan. Alluvium is thickest in the southwestern part of the lower reaches of the basin. Its thickness varies from 30 m to more than 100 m and comprises mainly coarse sand with subordinate proportions of gravel and silt derived from the Heran and Orsang rivers.

These plains cover vast areas in the lower reaches of the basin and extend from Kosindra to Bhilodiya and Malpur. The horizontal nature of Bagh sedimentaries has imparted a flatness to these alluvial plains. One of the striking features of these fluvial plains is that, they are dominantly confined to northern bank of Heran and their sudden appearance near Vora in the southern part clearly suggests that the outcrops of Bagh beds from Kosindra to village Vora have prevented the spreading of the alluvial material. The Heran-Orsang course which is fault controlled, has obviously developed a local trough which has marked the site of a thick deposition of fluvial material along the northern bank of the Heran.

A scrutiny of several deep well sections has revealed that the alluvial material has been deposited over a variety of pre-existing basement rocks, viz. Deccan lava, Mesozoic sedimentaries (Infra-trappean) and Precambrian metacrystallines. The details of the bed rock over which the alluvium has been deposited, and related zones are as under:

Sr. No.	Zones based on location	Bed rock	Alluvium thickness m
1	Around villages Bihora and Akoti	Deccan Trap	30-90
2	Around villages Damoli and Songir	Bagh sediment-aries	15-40
3	Around villages Vora, Dudhpur, Malpur and Ratanpur	Precambrian metacrystallines	10-70

The evolution of these morphological units and their hydrogeological significance have been discussed in the subsequent chapters.

The alluvial plains show a number of river terraces along the stream courses. Terraces along the Heran river course are quite prominent to the downstream of Phenaimata hill. The most prominent terrace is of the nature of a typical levee between the village Bagaliya and Kosindra; possibly it could be the result of the river course shifting towards south and down cutting of the present river beds. This terrace is 10 km long in an E-W direction and spreads over 3 km width.

The morphologic details of the major river terraces encountered in this units are tabulated as under:

Terrace	Location of occurrence	Approximate dimension			Bed rocks
		Length	Width	Thickness	
I	Kwant to Dhanpur	5.50 km	600 m	8-10 m	Basalt
II	Rangpur to Kosindra	15.00 km	200-2000 m	10-15 m	Basalt
III	Wasna to Taleti	4.00 km	200-500 m	6-8 m	Sandstone
IV	Vora to Asodara	12 km	200-500 m	20 m	Schist & Phyllite
V	Deri to Wanta	3.00 km	500 m	15.00 m	Basalt

DRAINAGE

The total length of the Heran river as has already been alluded to earlier is divisible into upper, middle and lower parts. The behaviour of this river in its three segments though essentially controlled by the factors of structure, lithology and slope, show well marked diversity in details. The upper reaches of the river i.e. from its source upto the point where it emerges out of the hills near village Narukot the river dominantly performs erosion along a network of lower order streams which owe their origin to fracture pattern. Of course, relatively higher gradient enables the water to cause vertical erosion rather than deposition. On the other hand along the middle segment of the river, although the river flows along some major joint planes, its erosive power is very much reduced on account of the lack of gradient. In this part the river doesn't erode much and doesn't deposit much. However in the past, in this part depositional activity must have been relatively more pronounced. This is revealed by the narrow flood plains. Some lateral shifting of the river channel is evidenced by the formation of a levee on the right bank. The total alluvial deposits however are relatively thin. The lower segment of the channel i.e. from village Kosindra to its confluence with Orsang, points to a sequence of substantial deposition followed by a recent rejuvenation. In this part the Heran river flow within its own alluvium. The study of bore hole data have also revealed a thickness of about 100 m fluvial/alluvial deposits in the lower part. Though a substantial proportion of thin alluvium appears to be a product of Orsang deposition, some of it especially the upper part appears to have been deposited by the Heran river. An interesting feature of this channel segment is the abundant development of ravines and a badland topography, especially on the right bank. The channel of the principal stream i.e. Heran also shows a very conspicuous incision of the order of 25-30 m (Plate IV.2). This phenomenon of entrenchment together with the development of ravines along tributaries is attributable to a neotectonic uplift.

The development and evolution of the river Heran and its three major tributaries has been governed by litho-structural and geomorphic characteristics of the terrain. The drainage patterns show considerable diversity and reveal many interesting facts vital for a proper understanding of the basin evolution. Various geological factors in conjunction with the hydro-climatic processes and topographic features have controlled the development of the drainage system. The hydrometeorological factors being constant for the limited study area, the principal controls of lithology and structure for the development of the present drainage system have been discussed herewith. Obviously, the drainage has played a major role in controlling the hydrogeological conditions of the basin. The factors that

Plate IV. 1 Field photograph showing a view of the dyke ridge in the trappean upland area. (Loc. Near village Rendi).

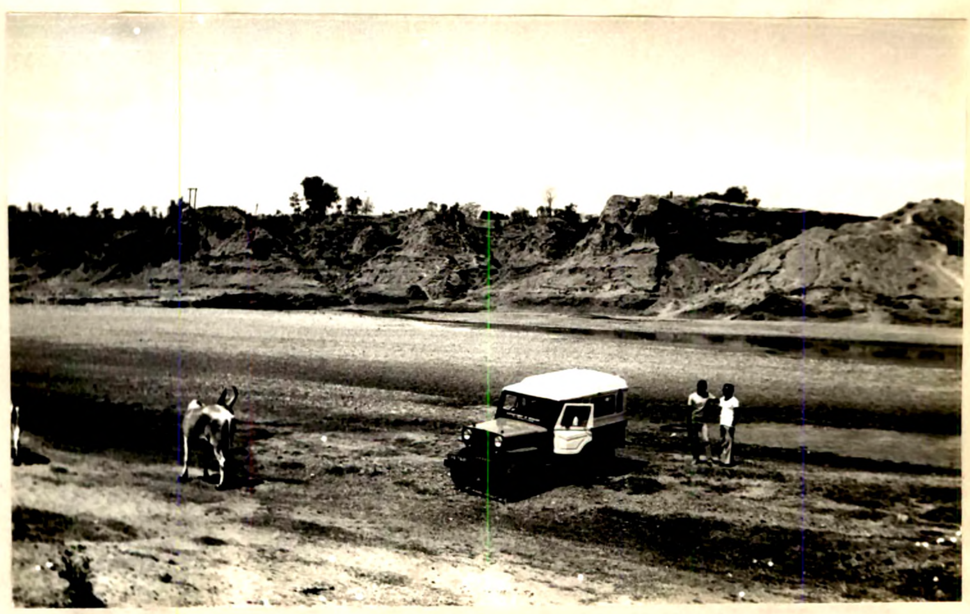


Plate IV. 2 Field photograph showing a close view of the Heran river terrace. (Loc. Near village Vora) have relevance are listed as under:-

a - <u>Tectonic control</u>: This comprises the regional fracture pattern vis-a-vis major stream alignments.

b - <u>Structural control</u>: The effect of the joints, fractures, faults, folds, foliations, beddings and unconformity etc.

c - <u>Lithologic control</u>: Variation of rock types, their composition and texture and response to fluvial action.

The development of smaller streams of the basin and its neighbourhood has also been controlled by the above facts. It has been observed that fracture pattern and joint planes have considerably influenced the development of the total drainage pattern. These in combination with the actions of natural weathering agencies have resulted in the formation of soils and a topography has profoundly affected the distribution and movement of surface and subsurface water. The combined effect of the geologic, topographic and pedologic features have influenced the landforms, slope stability and drainage density. In general low drainage density is favoured in regions of highly resistant or highly/ permeable subsoil material under dense vegetation where the relief is low. High drainage density is developed in the regions of weak or impermeable subsurface materials, sparse vegetation and high relief.

The streams owe their courses either to structural lineaments (fault-joints) or to the general slope of the terrain. Except the main channels of Heran, Kara and Rami river the majority of the streams is seasonal and has only restricted wet channels, the periods of water flow, gradient and bed rock being the main agents which have greatly influenced the development of the stream channels and stream beds.

In the upper reaches of the streams, as the streams originate on the higher ground they flow along the hill slopes. Due to higher gradient the amount of erosion is more in which downward cutting is significant. On account of this phenomenon the channels are narrow with steeply sloping sides. In the highly fractured rocks, the shape and size of streams are controlled by the size and direction of the fractures and the intensity of jointing. Along the stream beds occur localised occurrences of water pools formed due to break in the gradients or on account of local obstacles and barriers.

In the middle reaches, where the streams flow on gently sloping round the bed characteristics are different. The channels are rather wide and without any significant gradient. The streams are affluent in nature and their beds are filled with heterogenous material consisting of boulders, cobbles and sandy gravels.

The lower reaches of the basin the stream courses, except those which are structurally controlled, are wide and curved. The beds do not show any significant erosional features and are influent in nature. Deposition being dominant, the stream beds are full of sediments.

HERAN RIVER

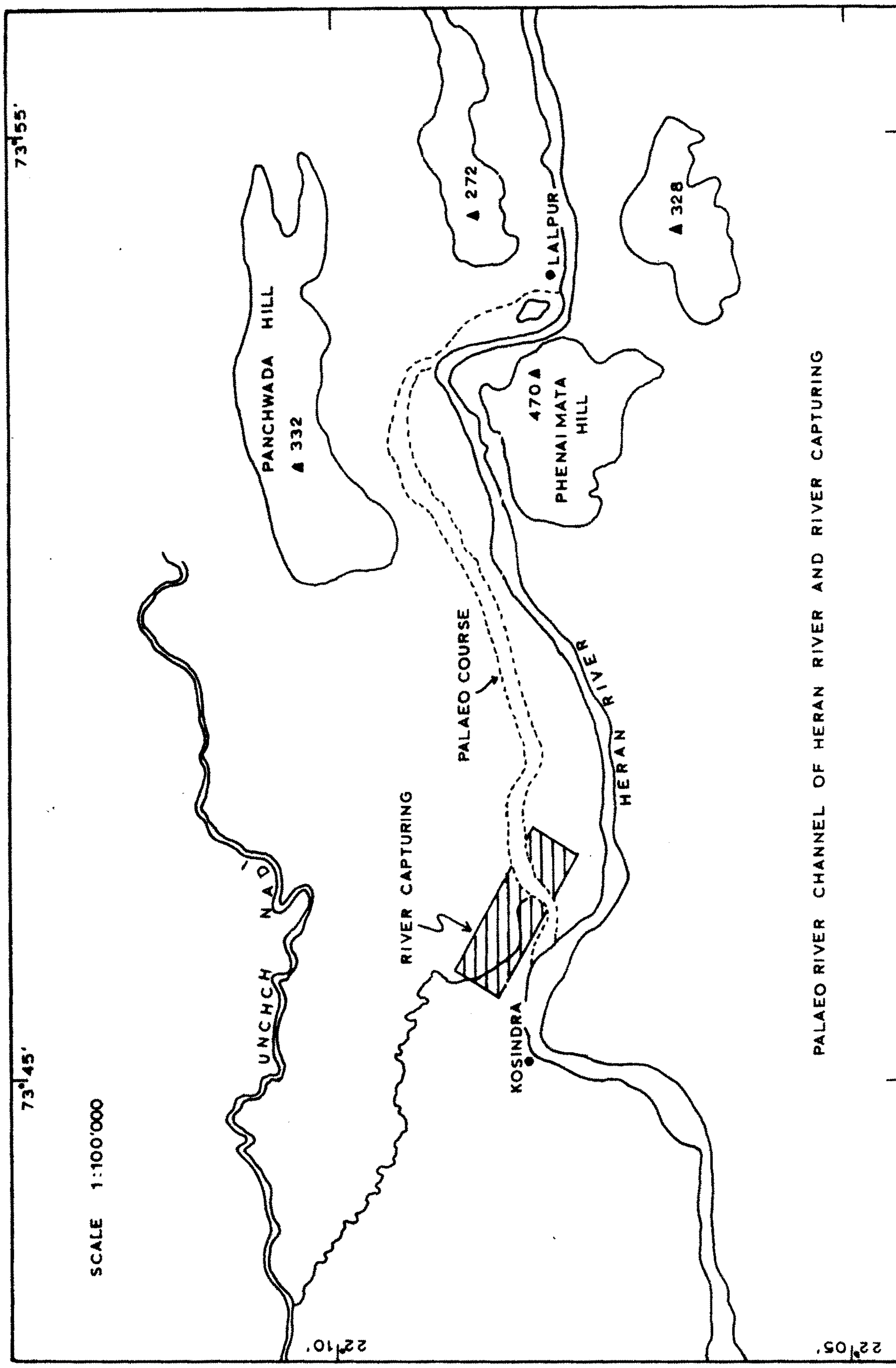
The Heran river which forms the principal stream flows westerly, its main course is controlled by a series of en-echelon type of faults which extend parallel to the Narmada rift system, having a trend of ENE-WSW. It originates in the trappean highlands near the village Untvali. From its source, it flows down first in a WNW direction and then northwesterly draining the steep hills of basalt with a gradient of 1:75. Upto the village Ghorda it flows due NW and then takes a turn to WSW direction. All these abrupt changes and straight segments appear to be controlled by faults and fractures. Near Phenaimata hill the abrupt 90° change towards north in the river course could best be explained by a combination of two factors, one is the obstacle provided by the hill and the other being a NNW-SSE trending cross fault. The fault zone is evidenced by the presence of a palaeochannel which is existing about

350 m to the east of the present channel (Fig. 4.2).

The river bed from Rangpur to Bagaliya is riddled with intrusions of numerous dykes. These dykes show two trends, the prominent one being ENE-WSW with the subordinate NNW SSE trend. Obviously, the dykes have arisen along fractures and conform to the fracture pattern of the basalts. The Heran river bed from its source upto the village Wasana a distance of 68 km, points to dominantly erosional process and shows affluent characters i.e. groundwater table on the bank areas being higher than its bed level, the river is fed by the groundwater. On the other hand the area further west of beyond Wasana, the river is marked by a depositional bed and the river flow feeds the groundwater in the bank areas, thereby changing its nature from affluent to influent. Thus the basin, upstream of Wasana forms a recharge zone while its downstream forms the discharge zone. Beyond Wasana the river bed becomes very flat with a gradient of 1:750, and the channel is full of gravel and sands till it meets the Orsang near Bhilodiya.

The course of Heran further downstream of Bagaliya has shifted to south. The airphoto studies have revealed this facts ideally. A palaeochannel is presently existing below the extensive elongated levee from Bagaliya to Kosindra. This patch forms a rich agriculture land with

FIG 4.2



PALAEO RIVER CHANNEL OF HERAN RIVER AND RIVER CAPTURING very high groundwater potential.

Main Tributaries of Heran

The main tributaries of Heran and their interesting stream characteristics are briefly discussed below.

(i) Kara: It originates in the hills of Atta village at an elevation of 540 m in the Madhyapradesh and enters Gujarat near Bakhatgarh. It flows in a northwesterly direction for about 25 km and meets Heran near Narukot, dropping its elevation to 160 m. Faults control its entire course. In the upper and lower reaches the flow is controlled by NW-SE fault, which are sympathetic to Narmada Rift System. The classic example of NW-SE fault's control over the course has been observed on the Mathwad Nullah, which originates near Mathwad and meets Kara near Wajipura.

The dyke control over the river course observed near the village Burma, Bhirata and Kawant. Near Burma and Bhirata the dyke control is such that river almost takes abrupt 'W' and 'U' turns in its course (Plate IV.3).

The Kara travelling mostly through a high relief terrain with average gradient of 1:75 is characterised by an erosional rocky river bed and a narrow channel with steep banks. In the upstream part alluvial pockets are observed, wherever the stream encounters obstacles (mainly dykes) which break the velocity of the water. Good examples of such alluvial pockets are recorded near the village Bhirata, Burma, Bakhatgarh, upstream of Kawant (Plate IV.4 & IV.5). The downstream beyond Kawant the bed gradient is flattened to 1:250 such that sizable alluvial terraces have formed.

The annual average flow as recorded by the state irrigation department at Kawant gauge site is of the order of 132.50 Mm^3.

(ii) Rami : It originates near the village Saidivasan at an elevation 380 m and flows due northwest for about 16 km and meets Heran near Wanta by dropping its elevation to 120 m. The Rami course is also controlled by major fractures trending NW-SE. Also some deflections in the channel course is due to dykes. Rami has got one tributary stream viz. Huktu, originating near Watda at an elevation of 440 m and travelling for about 8 km, meets Rami near Deri village. The stream course of Huktu follows a N-S trending fault.

Plate IV. 3 Field photograph showing a prominent dyke, controlling the Kara river flow by giving a 'U' turn. (Loc. Near village Burma and Bhiratha).

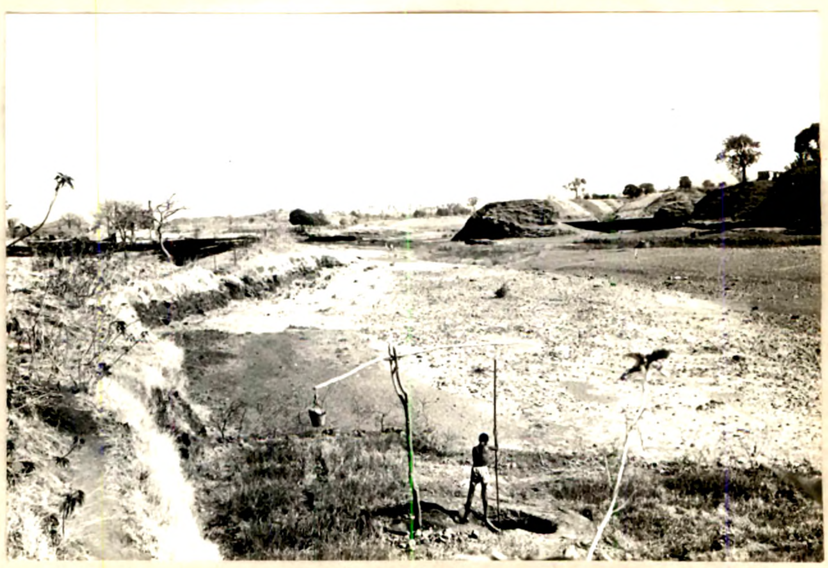


Plate IV. 4 Field photograph showing dyke obstacle diverting the Kara river flow. The other side of the dyke, alluvium pocket are seen. (Loc. Near Kawant).

Plate IV.5 Field photograph showing fluvial terrace deposits along Kara river (Loc. Near Kawant bridge)

(iii) Ajna : It originates near Kankuva at an elevation of 70 m and flows southwesterly for about 20 km before meeting the Heran near Erniya. It shows a drop of 30 m in its elevation. This stream drains the alluvium area with an average gradient of 1:700, shows ENE-WSW alignment, almost parallel to the trunk stream. Obviously, this stream which is excavating the Heran alluvium is a subsequent stream.

DRAINAGE PATTERN

An analysis of the various types of subpatterns developed in the basin has revealed that the overall pattern shows a mixed control of lithological types and structural elements. However, it is interesting to observe that the structural features have very much dominated over the lithology in imparting the overall pattern. The analysis of drainage patterns vis-a-vis fracture lineaments and faults points to a significant structural control. The Heran river course, as well as those of its major tributaries are seen following major fractures and those segments of the river which shows straight courses point at a consistant parallelism with the existing fracture lineaments.

The linearity of the segments of major rivers and the smaller tributaries have parallelism with the regional fracture/structural pattern and are essentially identical to the tectonic lineaments which control the course of Heran river and its major tributaries.

The overall drainage shows a dentritic pattern. However, the main (trunk) stream shows trellis to rectangular pattern. The streams originating from the highlands deceptively point to a slope control but, on a closer observation it becomes evident that structural features have significantly regulated the stream paths. These subsequent streams draining through the trappean country meet the ENE-WSW trending main river channel at an angle of about 45°. Also, the lower streams, mainly of 1st and 2nd order, draining the trappean terrain show a typical rectangular drainage pattern, suggestive of their directions being controlled by joints.

The radial pattern of drainage system has been observed only at two locations and is due to the domal shape of the plutonic hill masses viz. Amba Dongar and Phenaimata. Amba Dongar domal intrusion forms a part of the watershed dividing the Heran basin from the Narmada main basin.

The present author has followed Howard (1967) who studied the inter-relationship of geological parameters and drainage patterns, and classified various drainage patterns into five basic and ten modified basic patterns, showing geological significance of each type of pattern. Following

Horward the present author has tabulated the stream features and their significance (Table 4.1) and prepared a composite drainage map of the basin (Fig. 4.4).

Some interesting details of drainage characteristics in the different parts of the basin, have been highlighted in the following lines.

1. The thin veneer of the residual clayey soils overlying the Deccan Traps, shows following significant control on the drainage.

   (a) The large surface run-off has resulted into a finer texture of drainage and higher drainage density.

   (b) On account of the thinness of the soil cover the lineaments of the underlying Deccan Trap get reflected in the surface streams.

2. In Kawant-Bakhatgarh-Panvad region, the drainage is strongly influenced by the structural elements, though, lithological control is also evidenced at places. The drainage is angulate to rectangulate type with pronounced linear segments tending NW-SE though, other fracture lineaments also have influenced the development of drainage. In majority of tributary basins the development of drainage reflects the underlying structural lineaments.

Occasionally the drainage shows a sub-dendritic with trellis influence. In the northern part of Panvad the drainage is dominantly dendritic which is a result of lithologic control. The area around Tokri and Pipli is influenced by a pinnate pattern in which tributary streams indicate a stage of tectonic re-adjustment.

3. A case of river capturing has been observed near village Rajbodeli, where a nullah which flows parallel to Heran for quite a distance, suddenly takes a northwesterly turn and flows away from Heran, meeting the Unchch river. It is obvious that originally this streamlet was discharging its load in Heran river, but due to a lateral shifting of the Heran southward and a levee formation, it has been beheaded and captured by Unchch river. This phenomenon might have been initiated by the development of a NW-SE fracture in the alluvial area, possibly due to reactivation of an underlying fault and the resulting NW flowing nullah that is meeting Unchch, on account of headward erosion progressively captured the former (i.e. one which was flowing parallel to the Heran river). A small relict stream of this nullah still exists and has a very insignificant contribution to Heran (Fig.4.2)

4. Several nick points have been observed in the Heran course from Rangpur to Ghantoli, and these are due to either fault

zones or dykes. These nick points have developed several water pools. Some of the water pools viz. those at Rangpur, Jharoi, Moradongar, Chalamali and Ghantoli are of significant sizes, ranging in dimension from 2500 to 10,000 sq.m (Plate IV.6).

5. The Heran is of affluent nature in the area from its source up to Rajwasana. As the river bed is lower that the existing groundwater table of the bank areas, springs feed the river. On the other hand, the area downstream of Rajwasana is characterised by an influent nature of river and here the river bed level is elevated in comparision to the water table, as a result the water of the river feeds the aquifers.

LONGITUDINAL PROFILES

In order to fully understand the channel characteristics and evolutionary controls of the Heran drainage system, the author has prepared the longitudinal profiles of the main river as well as its principal tributaries, viz. Kara, Rami and Ajna. Development of longitudinal profile according to Leopold et.al. (1969), is a function of important variables such as (i) discharge, (ii) load delivered to the channel, (iii) size of debris, (iv) flow resistance, (v) velocity (vi) width, (vii) depth and (viii) slope etc. From the inter-relationship of these variables they derived a relation between fall in elevation to distance along the channel.

Plate IV.6 Field photograph showing formation of water channels along less competent dykes due to differential erosion. Presence of Knick point has developed water pool. (Loc. Heran river bed Between Rangpur Ashram and Jharoi).

The longitudinal profiles of the major streams plotted by the author are given in (Fig. 4.3). Nearly all the longitudinal profiles are concave upwards except for the river Ajna.

The various breaks have been found to be on account of either faulting and rejunvenation or due to abrupt change in lithology and relief.

BASIN ANALYSIS

Morphometric analysis of drainage basins of the study area (Fig. 4.4) was carried out to decipher and understand the various factors responsible for the development of the stream pattern. The drainage characteristics have been evaluated from the 1:50,000 scale Survey of India Toposheets. Majority of the drainage sub-basins either flow over basaltic terrain or Bagh sedimentaries except river Ajna sub-basin, it flows all over its course through alluvium. A comparative study of the different sub-basins was under taken applying the Horton's Laws of Morphometry, and various relevant parameters were computed (Appendix 4.1).

A comparison of the various morphometric parameters for each of these river sub basins reveal some significant variations. Bifurcation Ratios of first order to second order streams ranges from 3.53 to 4.44, ratios of second order to third order stream range from 3.54 to 5.22, ratios of third order to fourth order stream range from 2.00 to 5.14, ratios of fifth order to sixth order of stream range from 1.50 to 7.00 and ratios of sixth order to seventh order of stream range from 1.00 to 2.00, and there values are in confirmity with the usual characteristics, fully substantiating a lithological control.

The values of Drainage Density (Dd) vary between 1.52 to 2.56. The lower value in Ajna river sub basin is because the stream has flowed over softer formations. The higher Dd 2.56 for Kara river sub basin indicates that the river has flowed throughout its course in hard rock area of Deccan Trap.

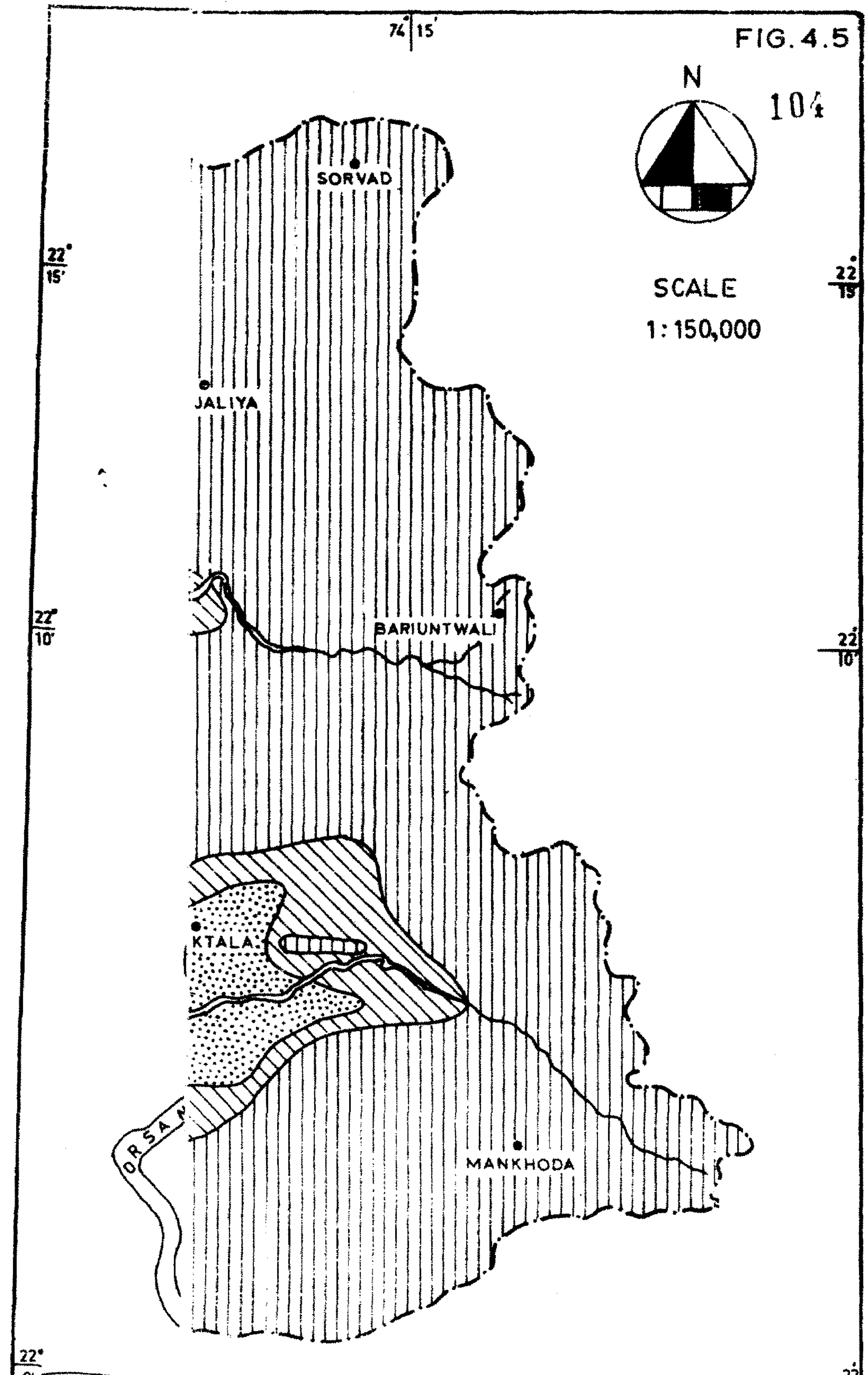
The values of Stream Frequency (Fs) vary between 2.98 to 4.15 and show a conspicuous relationship with lithology and structure. The streams flowing through softer formation and highly resistant rocks with structurally less disturbed terrain show low stream frequency. viz. Ajna and Heran river respectively. In contrast, the streams flowing through the hard and highly jointed lithology display a stream frequency values as high as 4.15.

SLOPE ANALYSIS

Geological maps have their obvious limitations for groundwater purpose and from toposheets it is erroneous to separate areas arbitarily for groundwater availability. Therefore, it is necessary to classify slopes on the toposheets and separate the zones where groundwater is not likely to occur and provide effective areas of groundwater basins where water level fluctuations take place.

The slope analysis of the area on 1:100,000 scale map has been carried out (Fig, 4.5). The iso-tangent contours have been plotted to divide the area into various slope categories. The amount of slope has been represented into tangents, degrees and percentage. The slopes of the entire basin area has been divided into three zones as under:-

Sr. No.	Area Characteristics	Percentile slope	zone
1	Steep hills, bold ridges and dykes	More than 4	III
2	Gently undulating terrain with scattered depudated hills and dissected pediments.	Between 2-4	II
3	Flat terrain with river alluvium, terraces and inter-montane valleys.	Less than 2	I



[ISO-TANGENT] MAP OF ERAN RIVER BASIN

WEATHERING

Rock weathering is one of the important parameters for the occurrence and movement of groundwater in hard rock areas. The geometry and magnitude of the bodies of weathered rock vary greatly with the rock type, climatic conditions, the history of weathered surface and neotectonic activity. Zones of deeper weathering usually elongate are developed along bands of readily decomposed rocks or along joint systems, while the porosity of the mantle varies with the depth. Weathering of most common rock types results initially in a profile containing a basal zone of disintegration, a middle zone of partial decomposition and an upper zone of total decomposition.

The factors that govern the depth and pattern of weathering are many. The most important of them are climate and lithology. In general, weathering is faster and occurs deeper in humid than in arid regions. Topography is another factor, especially with regards to the depth of weathered mantle.

In the study area a marked irregularity of the depth and pattern of weathering has been observed. For evaluation. of bore hole data have been collected from various agencies and field checks and observations by the present author have led to following important observations.

a) The mean depth of weathering in the basaltic area and Basement Complex is in the range of 10 m ± 6 m, the greatest depth of 30 m ± 10 m occurs when alluvium cover is present.

b) The process of rock weathering is controlled by random distribution of rock structure and rock types in space.

c) The typical deep-weathering (duricrust) profile is widespread, and occurs both in weathered basalt with little or no alluvial cover and in alluvium covered areas. In the later case, the profile does not continue into the underlying basalt/gneisses without marked break.

d) Weathering in sandstone is much less of the order of 2 m or so; may be due to its compactness and dominantly siliceous (quartzitic) composition.

e) Spheroidal weathering is most commonly observed, particularly on denudational hills and pediment zones.

Based on above observations an attempt has been made to quantify the probable depth of weathering by providing due weightage to the controlling factors, as under:

Factors		Zone	Basalt			Granite/Gneisses		
			Range	Mass-ive	Fractured	Range	Massive	Fractu-red
Relief	2 %	I	8-12 m	8 m	10-12 m	6-10 m	6 m	8-10 m
Drainage density	Poor							
Stream gradient	Low							
Relief	2-4%	II	5-8 m	5 m	7-8 m	3-6 m	4 m	5-6 m
Drainage density	Moderate							
Stream gradient	Intermediate							
Relief	4%	III	2-5 m	2 m	3-4 m	0-3 m	1	2-3 m
Drainage density	High							
Stream gradient	High							

GEOMORPHIC EVOLUTION OF THE HERAN BASIN

The evolution of the Heran river basin in all probability is a phenomenon of Quarternary period. However, in the absence of any undoubted Tertiary deposits this age has to be only conjectural. Although, the author does not rule out the possibility of a pre-Quaternary drainage, yet looking to the erosional and depositional landform as well as the thick accumulations of fluvial material deposited by this river as well as the Orsang. The existing configuration channel characteristics and landscape of this river basin must have originated during Late Quaternary.

The factors responsible for the evolution of the basin are essentially lithological, structural and climatic. The rock types of the basin area from east to west show very well defined lithological diversity which in turn comprise rock formations of different ages and different origins. The upper reaches of the basin are formed of the hard Deccan basalts of Cretaceous age. These have resulted into rugged terrain of considerable elevation. The middle part is comprised of Bagh sedimentaries and some very ancient metamorphics. These characteristically form low flat terrain with some isolated trappean hills. The lower reaches are as stated earlier made up of a thick pile of fluvial sediments most of which might have already pre existed. The author has visualised an original surface high in the east, low flat in the middle and shallow depressed in the west.

It was over such a topography, most probably during a wet phase i.e. during the Late Pleistocene, that the Heran river originated, by gathering its water in the eastern trappean hills and flowing across the middle segment, dumped its detritus over a partially filled alluvial depression and met the Orsang river. Of course, the river flowed along a progressively decreasing gradient but, its course was essentially controlled by a number of structural lineaments (fractures, joints etc).

The development of lower order streams (mostly second onwards) also show a structural control. Today the river does not carry as much water as it might have done in the past. Obviously the sediment load excavated, transported and deposited, today is comparatively much less. This fact appears to be related to two factors, (i) diminishing rainfall and (ii) some neotectonic uplift of the lower part of the basin.

GEOMORPHIC CATEGORISATION OF THE AREA

Based on the drainage and morphometric analyses (slope and relief) and aerial distribution of different lithologies, the Herab Basin can be divided into three geomorphic divisions namely Upper, Middle and Lower. These divisions may not be precisely correlatable with the tectonic history or the lithostructural characteristics, though the entire basin development is the function of these factors.

The characters of the three categories are summarised below:

Physiographic Division	Characteristics
Upper Basin (upto Heran-Kara confluence i.e. Narukot village)	Rocks: Precambrians 5%, Traps 85 % Sedimentaries 10% and Quaternary 5% of the total area. Slope: dominantly more than 4 % River Gradient 1:75 Drainage density : 2.0
Middle Basin (From Narukot to Kosindra)	Rocks: Precambrians 1%, Traps 60% Sedimentaries 20% and Quaternary 25% of the total area. Slope :Between 4 - 2 % River gradient : 1:300 Drainage density: 2.00
Lower Basin (Kosindra to Bhilodiya i.e. Heran-Orsang confluence)	Rocks: Precambrians 10%, Traps 1%, Sedimentaries 15% and Quaternary 75 % of the total area. Slope Less than 2% River gradient : 1:750 Drainage density : 1.00

A very close relationship exists between the terrain attributes of the above stated level categories and the groundwater conditions of the basin, and the aspect of geomorphic controls over the hydrogeological characteristics are discussed in the following chapter on Hydrogeology.