

CHAPTER : III

GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

In order to set the scene for the presentation of the geological and geomorphological set up of the study area, a description of the regional set up of Baroda district is discussed before.

REGIONAL GEOLOGICAL SET UP :

The description of the regional geological set up has been compiled from the classic works of Bruce Foote [1898] and Gupta and Mukherjee [1938]. The geological succession in Baroda district is given in Table : 2 and the map in Fig. 2.

Aravallis :

Lower Aravallis :

The lower Aravalli sequence of rocks consist of a suite of older metamorphic rocks represented by granite-gneisses and caught up patches of meta-sediments such as phyllite, schists/gneisses and quartzites. Out-crops of Lower Aravallis found north-east of Koba in Pavi-Jetpur taluka, are represented by greyish grained gneisses with caught up patches of meta-sediments. The gneisses and schists exposed around the north and eastern side of Jambugam at the core of an anticline consist mainly of quartz, felspar, biotite and hornblende. Due to profuse lit-par-lit injection of granitic material into the meta-sediments in Orsang river bed, north and north-east of Chhotaudepur, the original characteristics of the

TABLE : 2

GEOLOGY OF BARODA DISTRICT
[Modified after Bruce Foote 1898]

Recent and Sub-recent	-	Soil	
Recent and post Tertiary	-	Kankar, calcareous conglomerate, alluvium etc.	
- - - - -		Erosional unconformity	- - - - -
Lower to Eocene to	-	Deccan Trap, complex basic, acidic lava	
Upper Cretaceous		flows, basic and alkaline dykes	
- - - - -		Eruptive unconformity	- - - - -
Middle to Upper	-	Infratrappean, Bagh bed, Nimar sand	
Cretaceous		stone	
[Mesozoic]			
- - - - -		Erosional unconformity	- - - - -
Post Delhi	-	Granite and gneisses with associated	
		pegmatites and quartz veins	
- - - - -		Erosional unconformity	- - - - -
	[Upper]	Quartzite, phyllites, calcareous quartzite,	
		calc-gneiss and limestone	
Champaners	- - -	Erosional unconformity	- - - - -
[Pre-Cambrian]			
	[Lower]	Quartzite with phyllitic intercalation,	
		crystalline limestone, dolomitic limestone	
- - - - -		Erosional unconformity	- - - - -
	[Upper]	Intercalated sequence of quartzites and	
		grits, mica schists and phyllites, conglomerate	
Aravallis	- - -	Erosional unconformity	- - - - -
[Pre-Cambrian]			
	[Lower]	Conglomerate, grits, quartzites, mica-	
		schist, biotite-schist and gneisses	

meta-sediments have been obliterated and they have been transformed into arterite [Bruce Foote, 1898]. Quartzites of Lower Aravalli age are exposed as low ridges trending NW-SE, north-east of Surkhed.

Upper Aravallis :

The pre-Champaner schistose sequence exposed to the south-west of Jambughoda [Panchmahals district] and around Muvada in Pavi-Jetpur taluka of Baroda district, comprises of basal conglomerate, well bedded quartzites, mica schists, and phyllites. Primary sedimentary structures are well preserved in the arenaceous unit.

The conglomerate at the base of the upper Aravallis occurs as discontinuous bands in the area east of Muvada and around Jetpur. The pebbles and boulders of conglomerate consist of quartz, quartzites, and mica-schist embedded in a dark schistose and gritty matrix.

Champaner Series :

A major part of the Champaner Series is exposed in Panchmahals district, and only a part of it occurs around Pani mines east of Muvada and Chhotaudepur in Baroda district.

The Champaner Series is essentially composed of arenaceous and argillaceous meta-sediments which are represented by quartzites, phyllites and mica-schists with bands of dolomite and limestone. The Jaban conglomerate which divides the series into Upper Champaners and Lower Champaners, occurs as lenses, and contains pebbles of quartzite, mica-schists, limestone, gneisses and granite. The quartzite and schists on either side of the conglomerate are very similar in nature and are conformable. The conglomeratic horizon can be traced laterally through the sinuous fold pattern northwards up to west of Pani mines, where a distinct angular unconformity is found to separate the Lower and Upper Champaners. Original sedimentary structures like bedding are found in the

meta-sediments at several places.

Lower Champaners :

In Baroda district, the Lower Champaners are found to the north of Chhotaudepur and are represented by crystalline limestone around Deohati, east and north-east of Deohati and south of Dungarvant, where they are intruded by younger granites and basic intrusions. The colour of the limestone is generally whitish, but locally exhibits a brown colour. Serpentine bands of about 1 cm to 20 cm thickness are commonly seen. In the Orsang river bed north-east of Surkhed, these bands are distinct, imparting a light green shade to the crystalline limestone. The presence of tremolite is observed in a few out-crops. Towards the north and north-east of Deohati, the colour of the limestone is light brown and it is dolomitic. Along the contact of the intrusives, the limestone is converted to a fine-grained white marble. The dolomite occurring around Deohati extends over a strike length of 8 km, with a maximum width of 2300 mt.

Upper Champaners :

The composition of sediments of Upper Champaners appears to have been changed from the earlier dominantly arenaceous sequence to a mainly argillaceous sequence later on. The Jaban conglomerate which separates Upper Champaners from the Lower Champaners, is of the nature of a graywacke conglomerate. The conglomerate is followed by quartzite and grits with phyllitic intercalations. This quartzite with phyllitic intercalations is followed upwards by a phyllitic group, at the base of which there is a discontinuous horizon of siliceous limestone. At the contact between quartzites and the overlying phyllite, there are manganiferous phyllites, the most prominent of which are exposed at Shivrajpur in Panchmahals district and Pani mines in Baroda district. Calcareous quartzites and calc-gneisses are found occurring at the top of the sequence. The rocks of Upper Champaner which are exposed to the

north and east of Pani mines in Baroda district are quartzites, phyllites, calcareous quartzites, calc-gneiss and limestone. The quartzite being more resistant to weathering forms low ridges in the area. The quartzites are manganiferous at places. The phyllites are dark grey in colour and vary in hardness and fissility. Magnetite in the form of veinlets and grains are present in the phyllite. Limestone bands interbedded with phyllite are situated just west of Pani village and around Chhotaudepur. The limestone contains argillaceous impurity and is traversed by stringers of quartz veins which stand out prominently on weathering.

Post Delhi :

The metasediments belonging to Pre-Cambrian age have been intruded, on a large scale, by different types of granites. The intrusive granites occupy a wide stretch of area extending from north-east of Godhra in Panchmahals district upto the border of Madhya Pradesh in the south-east and again from about 10 km south of Bodeli in Baroda district.

The granite separating the Champaner schist belt from the Aravallis have been mapped by various workers as two or three distinct types. The varieties noticed are a medium to coarse grained, non-porphyritic, grey granite, and a somewhat similar pinkish variety which is more potassic and porphyritic. In the south-eastern and central parts of the area, the normal sequence of plutonic differentiation is illustrated by compositional change from a sodic variety, almost granodioritic in composition, to a normal grey granite composed of microcline, microperthite, quartz and subordinate albite. Occassionally showing intrusive relationship with these, is the more potassic variety richer in microcline. The pegmatites and quartz veins which represent a pneumatolytic phase of igneous activities associated with granite, traverse the granites and meta-sediments at a number of places. The pegmatites occurring north of Chhotaudepur, are seen traversing the dolomites, schists, and gneisses and consist of microcline and quartz.

Infratrappeans :

The Palaeozoic era, following the deposition and development of the Archeans and the Puranas, is entirely unrepresented in the area. Patchy formations belonging to the upper systems of the Mesozoic group, overlies the ancient metamorphics with a marked unconformity. The eroded surfaces of these, again have been over-run by the lava flows of the Deccan Trap. The Infratrappean formations are generally thin and lenticular. They form irregularly eroded horizontal shelves capping the ancient metamorphics and often crop out from below the Deccan Trap. The Infratrappeans are characterised by considerable heterogeneity of composition and variability of respective thickness of the component beds from place to place. Instances of considerable lateral variation in the lithological characters of the beds are also common and it is indeed difficult to draw up an accurate succession of the series.

Infratrappean [Nimar-Baghs] occurring as elongated out crops in the Narmada valley, around Naswadi in the north and elsewhere in the district are considered to be the marine equivalent of Lametas [fresh water] found in Madhya Pradesh. They comprise of an intercalated sequence of pebbly conglomeritic sandstone and fossiliferous limestone with shaly intercalations. The gritty sandstone found at the base of the sequence is termed as Nimar sandstone, while the overlying limestone, shale and sandstone are considered as Bagh beds. The typical exposures of Nimar-Bagh sequence occur around Naswadi, Ambadungar and Mohan Fort in Chhotaudepur taluka.

North of Naswadi, Cretaceous sediments comprising of conglomerate, felspathic gritty sandstone and calcareous chert lie unconformably over Upper Aravalli meta-sediments. Exposures of these sediments are also found in the Deo river where they show dips ranging from 4° to 40° towards the north-west. In the southern part, around Naswadi and adjoining parts of Bharuch district, the Infratrappeans occur as large elongated exposures trending ENE-WSW with dips varying from 8° to 15° towards SSE. South

of Naswadi they lie unconformably over either Pre-Cambrian meta-sediments or granites [Erinpura]. In the western part of the area inliers of infratrappeans are exposed towards east of Tilakwada.

The basal sandstones which are marked by a conglomeratic horizon imperceptibly grade upwards into coarse-grained sandstone. However, a thin band of purple shale which separates the two sandstones, suggest their shallow water deposition. However, occurrence of fossiliferous shaly limestone at the top of the sequence exposed north-east of Tilakwada in the Narmada river bed indicates a deepening of the basin during the later phase of deposition of Infratrappeans. The shaly limestone carries rich assemblages of marine fossils which are too ill-preserved to help specific identification but they appear to belong to the oyster bed horizon of the Bagh beds. The sedimentary sequence of Bagh-Nimar comprising gritty sandstone [Nimar] overlain by Bagh limestones, shales and sandstones near Ambadungar have witnessed intense faulting and Deccan Trap volcanism. The Bagh-Nimar in the area are exposed as inliers within basaltic flows of Deccan Trap. In the adjoining areas of Ambadungar near Mohan Fort, the Bagh-Nimar are represented by medium - to fine - grained and gritty sandstones with two intercalated beds of ferruginous clay. The sandstones strike almost east-west and show dips towards the south, but along the northern boundary they show northerly dips, which is perhaps due to proximity of the fault. South of Kanwant, sandstones are overlain by thinly bedded calcareous shales and arenaceous limestones which have yielded one Cretaceous ammonite and several fossil shark teeth. The occurrence of thin beds of conglomerate north-west of Kanwant resting unconformably over Pre-Cambrians and separating them from the overlying lava flows, perhaps suggests the northern limit of the Cretaceous basin in the area. The progressive increase in the thickness in sediments southwards and preponderance of limestone in the Ambadungar area suggests the deepening of the basin southwards. The Bagh sediments occurring in the Narmada valley have been subjected to a system of faults, sympathetic to the main Narmada rift in a ENE-WSW and NE-SW direction. The WSW trend of the Narmada river in the eastern part is deflected north-westward from Surpan

upto about 6 km north-west of Tilakwada and then reverts south-westwards upto Bharuch. This deflection is attributed to the N-S to NNW-SSE faults in the Deccan Traps and alluvium. This north-westerly deflection of the Narmada river, along the north-westerly trending faults with downthrows towards the south-west has obviously resulted in confining Bagh sediments and Deccan Trap exposures to the north-east bank. The other major rivers - Heran, Ashwan and Men together with Orsang, as also a number of rivulets, flow along fault zones parallel to the main ENE-WSW trend of the Narmada river. A number of cross faults run in a NW-SE direction, some of which have brought about considerable displacement of the Bagh sediment. One such major displacement appears to be along the Narmada river itself.

Deccan Trap :

The Deccan Trap suite of rocks comprises basic and acidic lava flows and the associated dykes and sills which occur as intrusives into lava flows. The intrusives are chiefly dolerite, trachy-basalt, gabbro, granophyre and alkaline rocks like nepheline-syenite, phonolite, ijolite and lamprophyre. In the northern part of the district, the outcrops of Deccan Traps are few and scattered among which the Pavagadh hills, which though occupying a very little portion of the district deserves special mention because of the diversity of rocks exposed. Important exposures of the Deccan Trap suite of rocks occupy the southern and south-eastern parts of the district around Phenaimata, Ambadungar, Kanwant, Mohan Fort etc. The Deccan Trap in this area forms a comparatively rugged topography. In the area around Naswadi and Chhotaudepur the volcanic activities have taken place on a large scale. The Decan Traps which occur around Naswadi comprise fine-grained, amygdaloidal and porphyritic lava flows. In the Phenaimata Hill and adjoining areas, there occurs trachy-basalt, gabbro, granophyre and nepheline-syenite which have intruded into the earlier formed Trap flows.

The Ambadungar and adjoining areas have witnessed intense volcanic

activities and exhibits a variety of rock types.

There are two main rock types in the area viz. the Cretaceous sedimentary sequence of Nimar-Bagh age and the succeeding volcanic intrusives belonging to the Deccan Trap suite. Included in the latter area are a suite of igneous rocks such as basalt flows, dykes of dolerite, basalt and granophyre, breccias, agglomerate and tuffs, dykes and plugs of alkaline rocks like nepheline syenite, phonolite, ijolite and lamprophyre. The carbonate rocks around the centre of the Ambadungar structure consist of different rocks such as coarse, white, calcite rocks, veins of aegirine - augite, calcite, fine-grained calcareous rocks with chert bands and fine-grained calcareous rocks which are ferruginous and manganiferous.

In the Kadipani - Ambadungar area, the Cretaceous sediments are exposed by a domal uplift and accompanying faulting. The centre is a depression in which basalts have been exposed. The carbonate rocks, which forms the main host rock for fluorite mineralisation and associated breccia around the centre of the dome at Ambadungar reach heights upto 625 meters. Numerous dykes of different composition and having trends mostly in a E-W to ENE-WSW direction occur in Ambadungar and Mohan Fort.

Recent and sub-recent :

The Recent and sub-Recent formations are represented by kankar and soils. Nodular, concretionary lime, commonly known as kankar is often met with in the soil, covering the crystalline rocks in the areas adjoining the Trap. Dark grey cotton soil covers the elevated plains adjoining the Trap mounds and ridges. It is extremely fertile and prosperous agricultural villages flourish on it. Over the metamorphic regions the alluvial mantle varies widely in thickness. The granite and gneisses on disintegration yield rather poor sandy soil. The crumbling schists, on the other hand, are invariably covered with fertile soil derived from their own disintegration and support rich vegetation. The western half of the district is covered by a thick pile of alluvium which is underlain by sediments

of Tertiary age.

REGIONAL SEISMIC BLOCKS AND EARTHQUAKES :

This description has been compiled from the works of Chaubey [1968], Eremenko et al. [1968], Mathur et al. [1968], Sudhakar et al. [1973], Rao and Talukdar [1982], Biswas [1982, 1987], Biswas and Deshpande [1983] and Agrawal [1985].

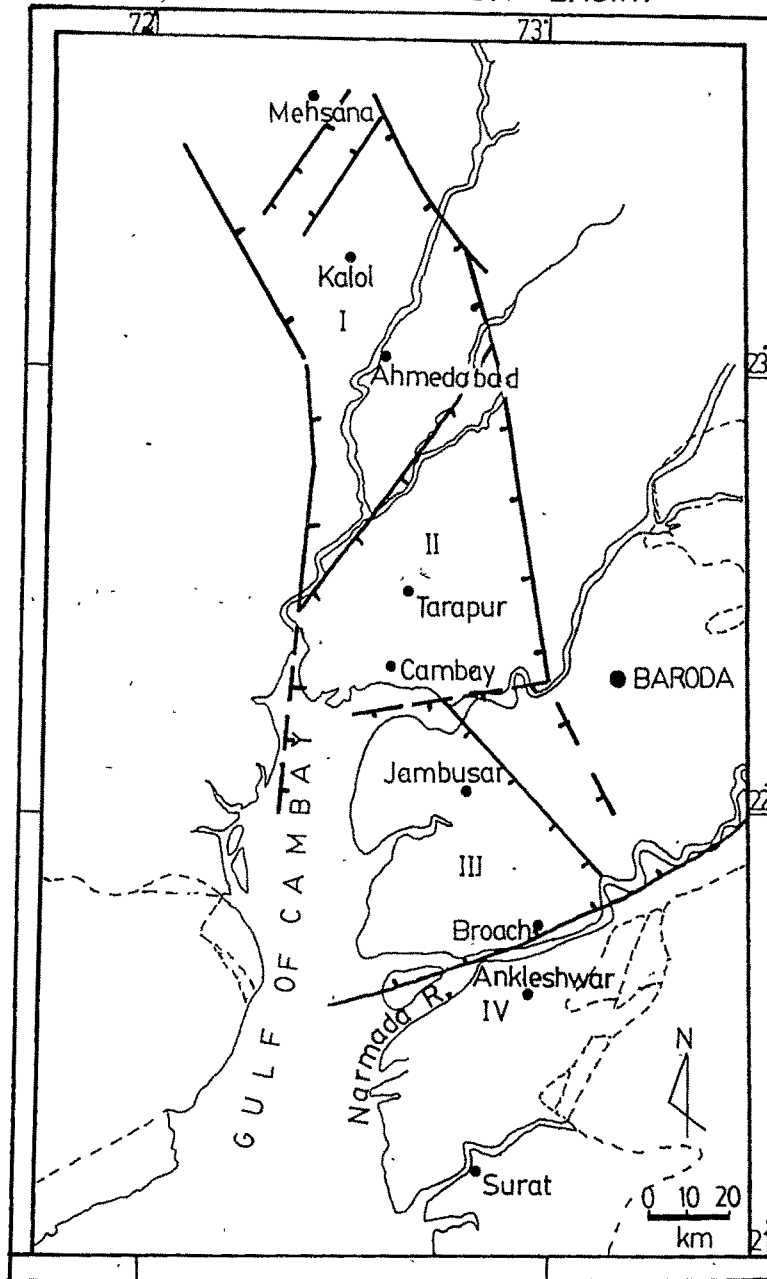
The Gujarat State can be divided broadly into four tectonic units.

- [i] The Saurashtra - Deccan Trap plateau in the west.
- [ii] The Kachchh - Ahmedabad - Surat belt in the centre.
- [iii] The Banaskantha - Sabarkantha - Panchmahals metamorphic igneous terrain in the north-east and east, and the Ambadungar - Rajpipla - Songadh Deccan Trap plateau in the south-east.
- [iv] The zone of rift systems coinciding with the course of the Narmada and the Tapi rivers in the south-east.

Among these units, the Kachchh - Ahmedabad - Surat belt is sandwiched between the relatively stable areas of Saurashtra in the west and metamorphic and igneous terrains of Banaskantha - Sabarkantha - Panchmahals and part of Baroda and Bharuch in the south-east which is tectonically unstable.

This unit falls in the Cambay graben area which is thought to have been formed as early as lower or upper Palaeozoic times along with the development of the Sindh - Rajasthan geosyncline. During the period of Deccan Trap activity, there appears to have been considerable tension in this region resulting in the development of inter-cratonic graben between the Saurashtra craton in the west and Aravalli hills in the east and Deccan

FIG.3-TECTONIC MAP OF CAMBAY BASIN.



(after Mathur et al, 1968)

- I Ahmedabad-Mehsana block,
- II Cambay - Tarapur block,
- III Jambusar-Broach block,
- IV Narmada block.

Trap massifs in the south-east. The site of this graben is a zone of deep seated crustal weakness. Two almost N-S aligned faults have been recognised on the eastern and western margins of the graben from Mehsana to the Mahi river, which may continue southwards. The structurally complex graben containing several domes and basins have been divided into four structural blocks separated by major faults [Fig. 3]. The blocks are named :

[i] Ahmedabad - Mehsana, [ii] Cambay - Tarapur, [iii] Jambusar - Broach and [iv] Narmada blocks from north to south, and are separated by faults roughly aligned with the courses of the Sabarmati, Mahi and Narmada rivers respectively. The thick deposits of sub-Recent times present just east of the mouth of the Mahi and Narmada rivers, which occur here almost at sea level, confirm that the tectonic activity has continued in this belt at least till the sub-Recent times. Further, the geomorphological evidences like the alluvial cliffs and the occurrences of moderate earth tremors indicate that the tectonic activity in this area continues. The zone of rift system coinciding with the west and WSW flowing Tapi and Narmada rivers also appears to be tectonically unstable. The ENE extension of links of weakness of the Narmada zone, the stretch between Bharuch and Tilakwada run into the courses of the tributaries, viz. Orsang, Heran, Men etc. Thus, there are two active tectonic systems in the region, the Kachchh - Mehsana - Surat graben with its folds and faults, and the fault system coinciding with Narmada and Tapi rivers. As such, these and neighbouring regions are potentially seismic.

Earthquakes :

The western and south-western parts of the Baroda District form a part of the Cambay graben, falling in the Jambusar - Bharuch structural block, while the Cambay - Tarapur structural block lies to the north-western border of Baroda District. The northern and the eastern parts of the district are relatively stable areas. The Cambay basin and adjoining areas experienced a number of earthquakes in last 285 years. However, in recent

years, the Bharuch earthquakes of 23rd March, 1970, deserves a special mention. This quake was felt in an area of 27,000 sq.km, from beyond Baroda in the north to Surat in the south, and covering Bhavnagar and Ukai-Rajpipla areas in the west and east respectively. The earthquake was experienced by the city of Bharuch and the surrounding villages at about 7.25 a.m. on 23rd March, 1970. Two mild shocks followed immediately, and two more occurred subsequently at 10.20 a.m. and 10.37 a.m. As a result, 150-175 houses collapsed or became un-inhabitable and an additional 2,000-2,500 houses were partially damaged, twenty six persons died and a hundred persons received minor injuries. Slight damage to the Narmada railway bridge was observed but the traffic continued. Fissures developed in the ground at several places and water and sand ejected from them on the southern bank of the Narmada river. Mild after shocks took place on 26th March, 1970 at 9.25 a.m. and 26th April, 1970 at 6.48 p.m. The effect of this earthquake was most experienced in the western, south-western and north-western parts of Baroda District. The affected areas of the district fall in the Isoseist IV. The boundary between Isoseists III and IV passes between Baroda and Samlaya and east of Navagam dam site in the north-eastern and eastern sides respectively. While the boundary between Isoseists IV and V in the district passes between Padra and Jambusar and between Palej and Miyagam. The major part of the district experienced an earthquake equivalent to Isoseist IV where the quake was felt by most persons who were inside their houses and generally two shocks were felt. The building structures were observed to be vibrating. The sensation was that of a small electric drill being worked on the outside of the wall or that of the passing of a heavily loaded truck. Generally no appreciable effect on the materials of construction was noticed.

GEOLOGY OF THE STUDY AREA :

The entire study area is composed of a thick pile of alluvium comprising of a Quaternary sequence of sediments consisting of conglomerates, clays, kankars, sand, gravels and soils, mostly belonging to the major groups

of inceptisols, vertisols and entisols. The four major rivers viz. Mahi, Mini, Vishwamitri and Dhadhar, which flow through the study area are mainly responsible for the deposition. Some beautiful scarp sections are exposed along their banks and the study of these have thrown some light on the establishment of a stratigraphic succession in the study area.

This alluvial sequence belonging to the Quaternary times has been greatly influenced by climatic variations, sea-level fluctuations, tectonic events and various phases of fluvial rejuvenation which can be attributed to dynamic, anatectic and static conditions. Studies of the alluvial facies of the Narmada, Mahi rivers vis-a-vis climatic variation have been carried out by several workers viz. Zeuner [1950], Sankalia [1964], Dikshit [1970], Allchin et al [1970, 1971], Khan [1971], Rajaguru [1973], Kale and Rajaguru [1985], Merh [1987] etc. Based on studies of palaeolithic tools, gravels, clays, dunal materials as well as the presence of palaeosol horizons exposed within the terraced horizons, these workers have postulated a repeated oscillation of the climate between the arid and the humid.

The ONGC has carried out deep drilling at three sites in the heart of the City [Fig. 4] and the following stratigraphical succession has been established [after Ramanathan and Mukherjee, 1982] :

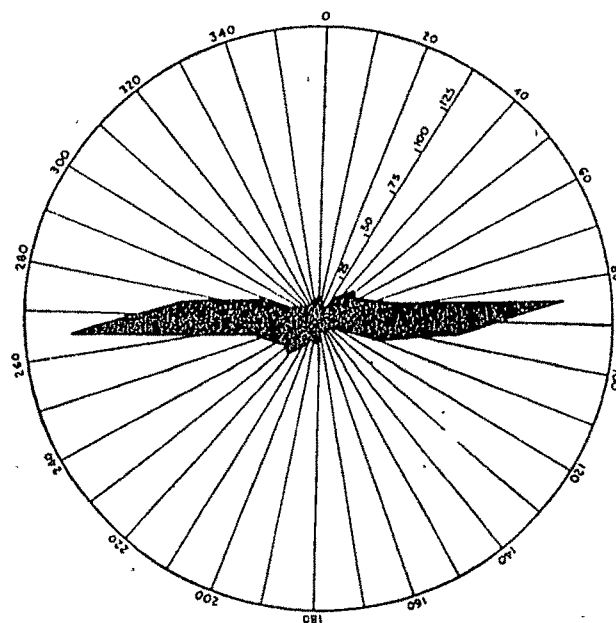
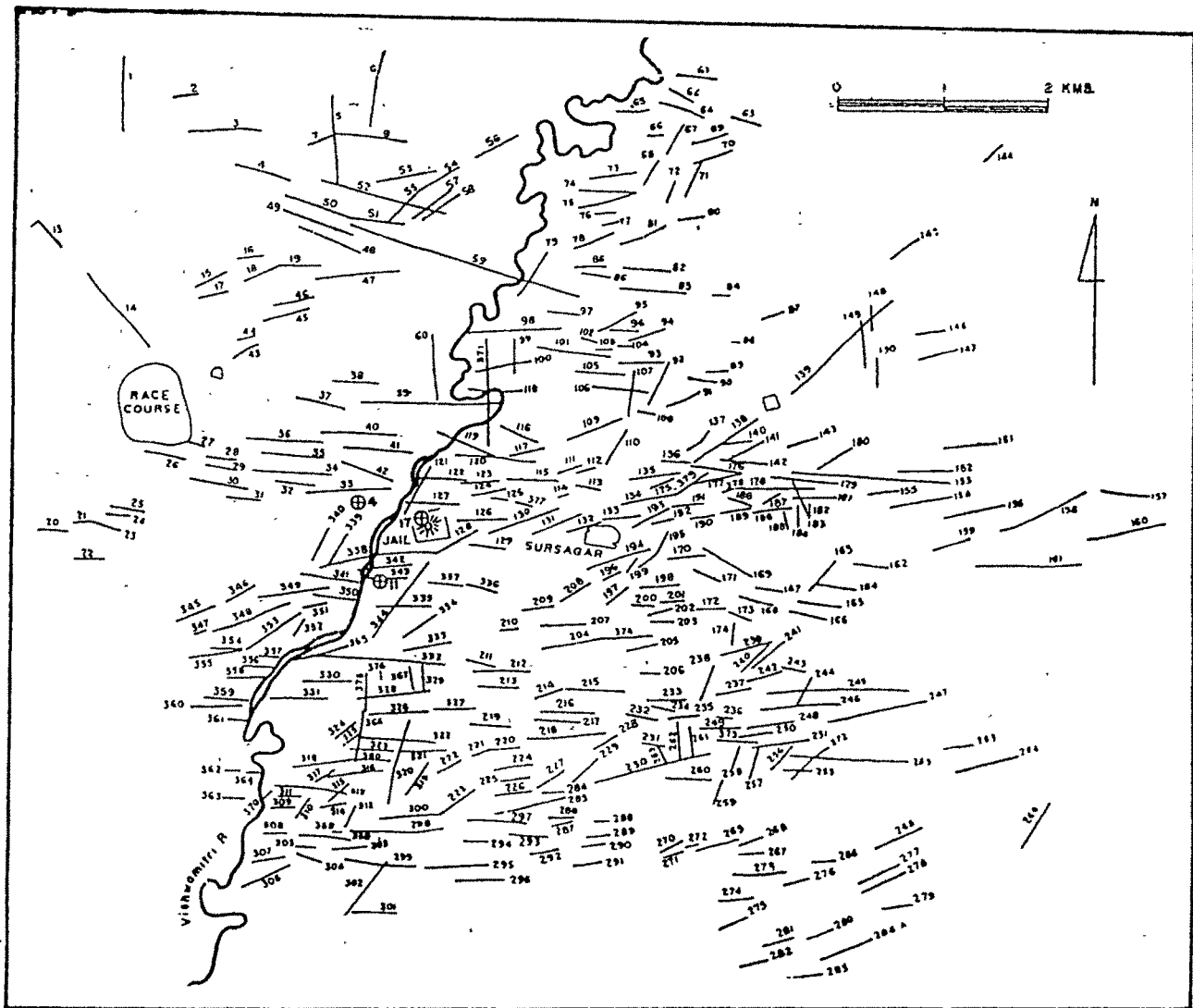
AGE	DEPTH IN METERS			LITHOLOGICAL DESCRIPTION
	BH NO.4	BH NO.11	BH NO.17	
Sub-Recent	3-27	3-27	3-27	Loose alluvium, coarse grained with kankars, pebbles and gravels.
Mio-Pliocene	27-172	27-182	27-164	Terrestrial sediments mainly brown coloured, variegated plastic clay with a few coarse to medium grained gravelly sands with Trap wash at base underlying Kaolinitic clay band.
Cretaceous	172-180(+)	182.5- 187.5(+)	164.5- 186.5(+)	Trap, light green in colour of basaltic composition, vesicular with flow structure.

The traverse method was used for soil mapping of the study area. The detailed description is given in Chapter : IV. The occurrence and distribution of the various soil types is given briefly below. Detailed and technical terminology is not used here, but is included in Chapter : IV as mentioned earlier.

Dark coloured, swampy clays and highly oxidised red, silty sand are the two main lithological units which occur extensively in the area, dividing it into two distinct terrains. The area west, north-west and north of the Baroda urban complex is characterised by the occurrence of oxidised sand at the top excepting at places where it is covered by a top accretion of grey/yellowish grey silt which constitute the alluvial deposits of the Mahi and Vishwamitri rivers. The main lithological constituents are fine particles of quartzite, phyllite, schist, etc. belonging to the Aravalli group of rocks which are regularly exposed to the north and north-east of Baroda [Fig. 2]. A major part of Baroda city falls on this grey silt. Urban constructions have obscured the surface and near surface deposits. This oxidised sand and yellowish grey silt broadly fall within the three major soil groups viz. Vertisol, Inceptisols and Entisols. The area east, south-east and south of the urban complex is characterised by the occurrence of dark coloured, swampy soils and represent the flood plains of the Mahi and Vishwamitri rivers. The main lithological constituents are fine particles of Deccan Trap which are exposed to the north, north-east and east of Baroda [Fig. 2].

The stratigraphic contact between these two soil units viz. dark coloured, swampy, clay and highly oxidised, red, silty sand is observed by the accretion of the grey silt, but the stratigraphic position with reference to the older units appears to be identical. Microlithic tools have been collected from the surface of both these units. According to B. Subbarao [1952], these archaeological evidences are indicative of a pre-Microlithic age [roughly earlier than 5,000 years ago]. Soils composed of darkish coloured clays belong to the inceptisol group. Deposition of this clay might have started in a swampy condition in a palaeo-deltaic terrain,

FIG:- 4-LINEAMENTS AND ROSE DIAGRAM (OF LINEAMENTS) AROUND BARODA CITY.



(after Ramanathan et al,1982)

possibly in the early Holocene period and continued till upto the recent past. The Quaternary sequence of sediments [Pleistocene to Recent] is well preserved in the Mahi river section near the railway and road bridges, south of Vasad. Alternating clay [pedogenised] and conglomerate beds belong to the earliest visible phase of sedimentation during the Quaternary period. Palaeolithic pebble tools have been reported by Subbarao [1952], from these conglomerates, which indicate that their age must be Pleistocene. Subsequent to these sediments, red clay [with pedalfer pedogenesis], aggradational sand, red, silty sand and the top accretional grey silt occur in stratigraphic order from bottom to top.

QUATERNARY LINEAMENTS AROUND BARODA :

Ramanathan and Mukherjee [1982], have demarcated 379 Quaternary lineaments [Fig. 4] around Baroda city with the help of aerial photographs, satellite imagery and topographical maps. The lineaments which are inferred from the aerial photographs are not actually seen on the Quaternary surface, but are interpreted from the alignment of different physiographic features. The drainage course of the Vishwamitri is along a NE-SW lineament, reactivated during the Quaternary. The expression of the lineaments are sharper around Baroda because of this sediment cover over the Trap surface, which is known to have a number of fractures and lineaments, which have been reactivated during the Quaternary, the traces of which are picked up on the alluvium surface today. The fact that the Mio-Pliocene and younger sediments have been subjected to an intense later Quaternary movement is amply borne out by the fact that the outcropping Mio-Pliocene sediments of the Jhagadia anticline [near Rajpipla, Baroda District] have been steeply folded, with the sediments in the northern flank dipping at angles of 45-50°. It is also significant that the Trap-alluvium and Trap-Tertiary contact is faulted in this area and is almost a straight line. The apparent expression of these lineaments are almost in all directions [Fig. 4]. The rose diagram, however, drawn for these lineaments [Fig. 4], brings out clearly the concentration of these lineaments in an almost E-W direction which confirms the influence of the

Satpura alignment over the sediments of Quaternary period in the study area.

REGIONAL GEOMORPHIC SET UP :

In order to set the scene for a detailed description of the geomorphology of the study area, a regional geomorphological study of Baroda District has been done.

The Mahi-Narmada inter-river alluvial terrain has a long history of geomorphic evolution. The present day physiographic configuration is the manifestation of the regional tectonic framework and local exogenic processes which were active during the Quaternary period. The Mahi and Narmada rivers, the sea coast and the foot hills mark the major physiographic features exhibiting tectonic control. The large variety of small-scale land forms within the study area represent the complex processes of erosion and deposition under the influence of fluctuating sea-levels and neotectonism. This is a case of terrain development under Quaternary dynamics, confined within well defined tectonic blocks.

Physiographically, the area is bounded between the two major rivers viz. Mahi in the north and Narmada in the south. The boundary of the alluvial plain marks the western border and the line of rocky exposures defines its eastern limit. Thus the area can be broadly divided into two major physiographic units.

1. Coastal Alluvial Plain
2. Eastern Piedmont Zone

The general slope is towards WSW.

Rivers :

The area lies in between the lower reaches of the Mahi and Narmada

ivers, which are two of the major westerly flowing rivers of peninsular India. The regional set up of the Mahi-Narmada drainage system is shown in Fig. 5. The Dhadhar river flows in between these two major rivers, while draining a major part of the major inter-river alluvial terrain.

Sinuuous winding of the Mahi and Narmada river courses is quite conspicuous. The Mahi river exhibits frequent meandering, with the meander near Dabka as quite outstanding. The Dhadhar, which is a seasonal river, in contrast, does not have striking land form features. Microlevel course winding and meandering in the central part of the Mahi and Narmada river lengths are very significant features.

Landforms :

Regionally, the landscape has preserved within it admirable and well defined imprints of various landforms. Babu [1977] studied the Quaternary geology of the Cambay basin and prepared a geomorphological map. Based on depositional processes, he classified the landforms into four different groups viz. aeolian, marine, fluvial and sub-aerial denudational.

Bedi [1978], Bedi and Vaidyanathan [1982] studied the geomorphology of the lower reaches of the Narmada and Mahi rivers.

Techniques :

LANDSAT Thematic Mapper False Colour Composites [TM FCC Band 2, 3 and 4, Path/Row D 147, 148 - O 44, 45 March 86, 87] satellite imagery on a 1:2,50,000 scale were visually interpreted using light table and high magnification enlarger. The interpretation has been done at Indian Space Research Organisation [ISRO], Space Application Centre [SAC], Ahmedabad.

All landform features of the area have been broadly classified into two groups viz. depositional and erosional [Fig. 5]. The identification key [Table : 3] was prepared based on studies of aerial photographs

FIG. 5. REGIONAL GEOMORPHOLOGY

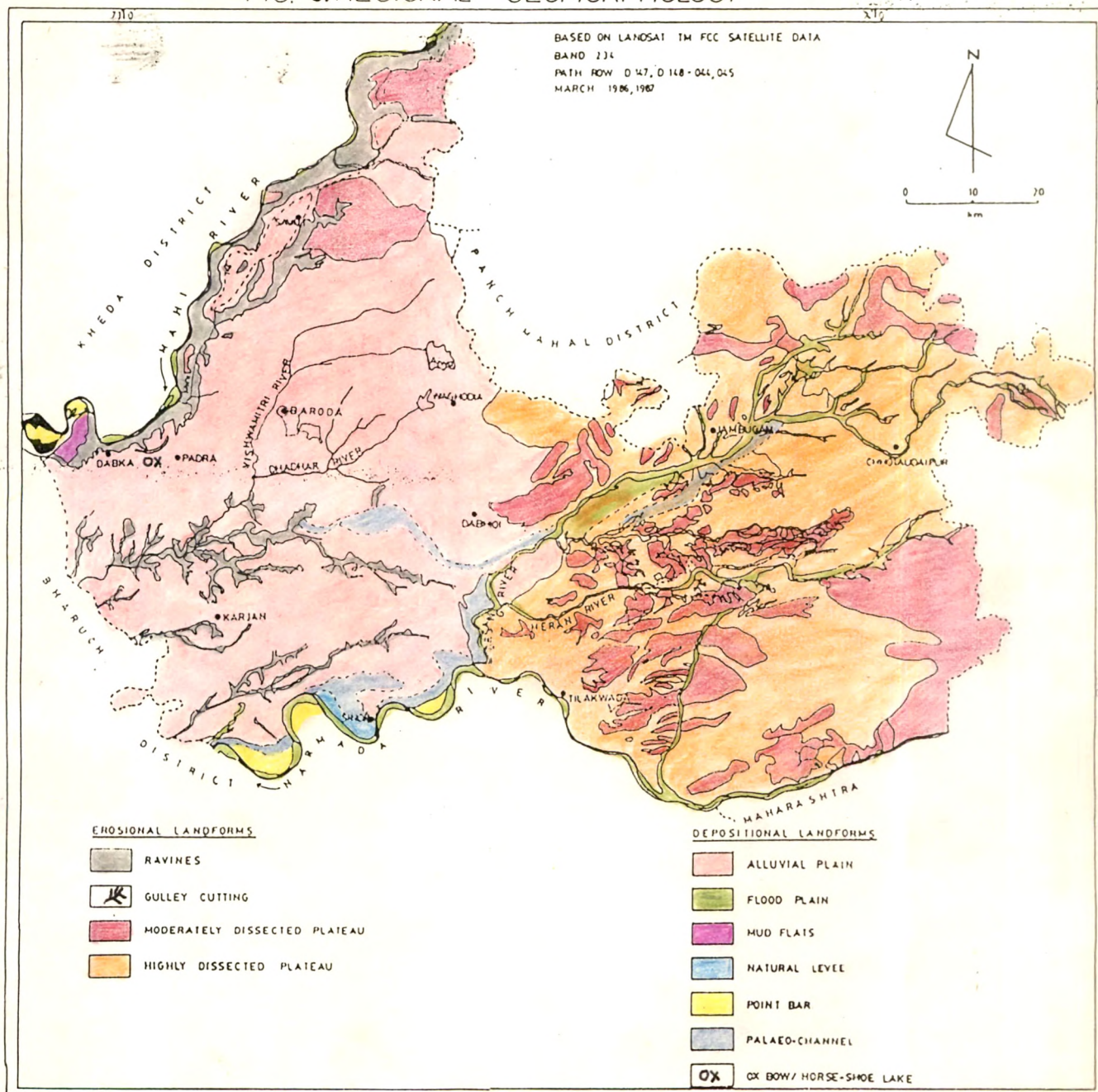


TABLE : 3

IDENTIFICATION KEY FOR GEOMORPHOLOGICAL
CATEGORISATION FROM LANDSAT SATELLITE DATA

SR. NO.	CLASS	TOPE	TEXTURE	OCCURRENCE
1.	Alluvial plain	Bluish with reddish tinge	Smooth	South of Baroda
2.	Flood plain	Bright red	Rough	Parallel to the Narmada and Orsang rivers.
3.	Mud flats	Pale blue to greyish blue	Rough	On the right side of Mahi meandering.
4.	Natural levee	Bright red	Smooth	Along the meander of the Narmada river.
5.	Point bar	Reddish tinge	Rough	Along the meander of the Narmada and Mahi rivers.
6.	Palaeochannel	Tonal change	-	Parallel to Narmada and Orsang rivers.
7.	Bad land/ ravines	Dull white	Slightly rough	Along the eastern bank of Mahi river, both the banks of Dhadhar river and at the mouth of western bank of Orsang river.
8.	Gulley cutting	Off-white	Rough	In dissected plateau.
9.	Highly dissected plateau	Greyish black	Rough	Between Orsang and Narmada rivers.
10.	Moderately dissected plateau	Off-white with bluish and reddish spot	Rough	Northern and western margin of the Baroda district.
11.	Ox-bow lake	Light black	Smooth	Curved, cut-off portion of meander, near Mahi river course.

[wherever available]; LANDSAT satellite imagery, topographic maps, followed up by ground-truth checking.

The important depositional landforms interpreted are alluvial plains, flood plains, mudflats, natural levees, point bars, buried channels, etc. The erosional landforms mainly include gullies, ravines and scarps and the landforms of the eastern piedmont zone. A brief description of each landform is given below.

Depositional Landforms :

Alluvial Plain :

The vast open land between the Mahi and Narmada rivers forms the alluvial plain which is almost flat with a very gentle slope towards WSW. The surface is covered by fertile black cotton and sandy loam soil types. Development of drainage in this plain is very poor. The monotony of flatness is broken by the centrally flowing Dhadhar river along a general depression.

Flood Plains :

These plains represent the surface being constructed by the river and usually run parallel to the river. They are subject to periodic overflow of river water. The Mahi and Narmada rivers have heavily drained their vast catchment areas, continuously shifted their courses, leaving sediments on either banks with the development of alluvial flood deposits. They are present all along the Mahi and Narmada river courses, and are differentiated by their elongated shape and the presence of dense vegetation picked up in the LANDSAT TM FCC satellite data.

Mud Flats :

2-3 km wide mudflats have been developed along the right bank meander

of the Mahi river near Dabka. At a few places they are in the form of featureless, barren areas characterised by salty, waste land. Patches of younger alluvium are also seen within these mud flats. Their differentiation can be clearly done on the basis of their tone and texture which may be due to a particular type of sediment constitution. The main constituents are fine-grained silt and clay of fluvial origin which may have been deposited by the process of flocculation. An important land-use characteristic of these mud flats is that they are often used for agricultural purposes.

Natural Levees :

Natural levees forming striking ridge-like elevations are found along the Narmada river. They are highest near the river and gradually merge into the adjacent alluvial flood plains. The complete development of local drainage has been inhibited by these levees, which has resulted in the swinging of the local drainage away from the main river. They can also be termed as overbank or top-stream [vertical accretion] deposits. Presently, this landform is extensively used for agricultural purposes.

Point Bars :

Point bars are found distributed all along the banks of the Narmada river and represent the most important component of lateral accretion. Bloom [1979] has explicitly described the development of point bars. When a meandering channel migrates across a flood plain, the steep bank on the concave side is undercut and eroded. As it collapses, the derived bed-load is carried a short distance downstream and deposited as a submerged bar, usually on the convex side of the stream. The result is a cross-stratified deposit with a subdued relief consisting of islands and bars that may have the record of many episodes of meandering channel migration. Usually the crests of the point bars approach the level of the former flood plain on the cut bank side. The Mahi has one such point bar near Dabka, while the Narmada has several point bars along its meandered segment.

Palaeo-channels :

Old river courses and cut-off parts of meanders, ox-bow lakes, etc. are found associated with river course migration. A prominent palaeo-channel scar is seen in the Orsang and Narmada rivers. This actually represents the edge of the river terrace, formed due to slow and continuous rejuvenation with lateral erosion. These palaeo-channel scars can be attributed to early Holocene transgression or uplift or both [Nayak et al 1988]. There are several natural linear depressions in the area which may possibly mark the traces of older palaeo-channels. A prominent ox-bow lake is seen in the south on the right bank of the Mahi river, which may be indicative of a change in the river course, attributable to tectonic activity [Nayak et al 1988].

Erosional Landforms :

Ravines and Gullies :

The soft sediments with a uniform texture forming the levee along the immediate banks of the Mahi, Dhadhar and at the mouth of western bank of Orsang, rivers are prone to typical gully formation. This is characterised by a steep or vertical sided ephemeral stream with a steep head that is actively eroding headward, usually on the water gathering wash slopes. In comparison to the quantity of water flowing through the streams excessive material is eroded, producing characteristic ravines. Gullies grow rapidly headwards, showing a tendency of capturing adjacent streams and the development of a branching network of tributaries.

Eastern Piedmont Zone :

The general landscape of the eastern piedmont zone constitutes of a low relief and a subdued topography. Both erosional and depositional characters are present and seen. The major landforms are confined to an elevational range between 40-60 m and are located in a narrow strip

between Savli in the north and Tilakwada in the south. On the basis of the degree of dissection of the exposed rocks, this area has been divided into three geomorphic units :

- [a] Moderately dissected plateau
- [b] Highly dissected plateau
- [c] Small scale depositional features

The striking erosional landforms are residual bedrock terraces, scarps, cliffs, cascades, rapids, etc.

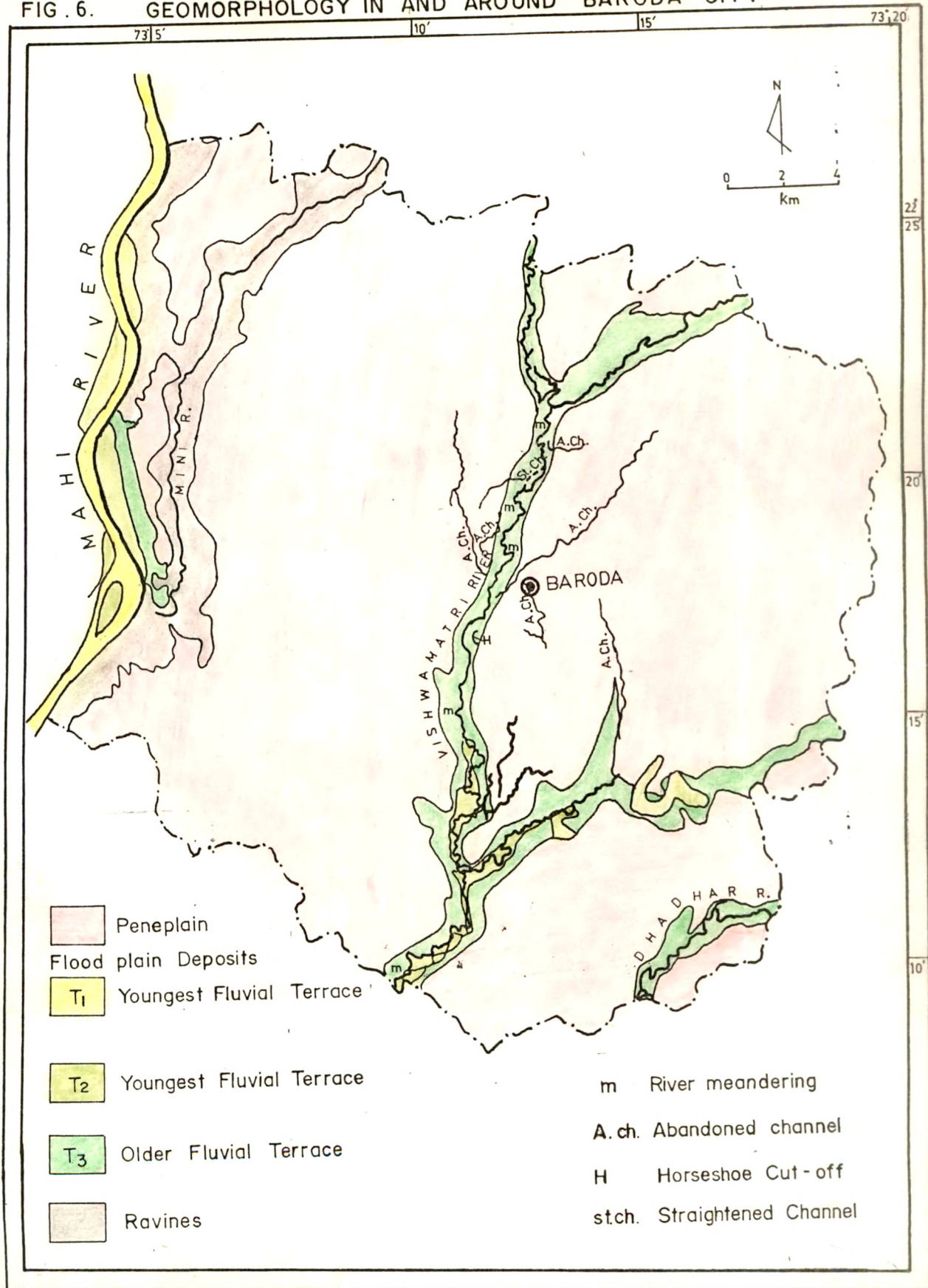
A thin veneer of alluvial deposits in transit from higher to lower levels are seen developing small sized aggradational features. The most notable depositional features are valley fills, low terraces, alluvial veneer on badlands, etc.

GEOMORPHOLOGY OF THE STUDY AREA :

The Baroda urban complex and its surroundings have been studied using LANDSAT TM FCC satellite imagery to evaluate the present landforms and the dynamic processes which have controlled their geomorphic evolution. The current landforms are characterised by fluvial and aeolian surfaces, gullies, ravines, flood plains and reclaimed swampy land. The bed-rock topography is not reflected on the land surface. Hard rock exposures do not occur in the study area. Bed-rock depth is shallow in the eastern sector, whereas it is deep in the western sector, beyond the Vishwamitri river.

Physiographically, the study area is bounded by the Mahi and Dhadhar rivers in the NW and SSE respectively, while the alluvial plain marks the SSW and NE border. The study area can broadly be divided into three major geomorphic units [Fig. 6], using the same methodology used in the study of regional geomorphology described earlier.

FIG. 6. GEOMORPHOLOGY IN AND AROUND BARODA CITY



- [i] Central Alluvial Peneplain
- [ii] Flood Plains
- [iii] Bad-land or Ravines

Central Alluvial Peneplain :

The plain land in and around the Baroda urban complex is a featureless terrain. It is a highly oxidised peneplained surface and occupies a major part of the area lying to the east and west of the Vishwamitri river, at places dissected and filled up by material of later fluvial phases. The dark coloured, clay surface, extending from the eastern fringe of Baroda to the north-eastern boundary must have been formed under a swamp of the Vishwamitri, Surya and Dhadhar rivers. This central tract has witnessed large scale urbanisation over the past hundred years. Neotectonism must be responsible for the present course of the Vishwamitri river which flows through Baroda, dividing it into two [Ramanathan and Mukherjee, 1982]. Along the banks of the Vishwamitri, gullying is prominent, forming at some places, ravines. Few scattered mounds and depressions are noticed. The area has a gentle slope towards WSW.

Flood Plains :

The Mahi, Vishwamitri and Dhadhar rivers have heavily drained their respective vast catchments and have deposited large amounts of fluvial material to form the flood plains. The constant shifting of these river courses have left signatures on either banks. Three terraces have been identified in the study area on the basis of their elevations and topographic discontinuity [Plate : 2]. The present, or the most recent flood plain, represents the youngest of the three terraces present, and is denoted as T_3 . The main occurrences of this T_3 terrace are in the river beds of the Mahi, Vishwamitri [Plate : 3] and Dhadhar rivers. The next surface T_2 , is found along the banks of the Mahi and the southern flanks of the Vishwamitri. The oldest fluvial terrace T_1 , is found near the Vishwamitri and Dhadhar rivers. At times, this surface is covered by

PLATE 2 : VIEW OF THE TERRACES FORMED BY THE VISHWAMITRI RIVER.



PLATE 3 : CONSPICUOUS SINUOUS WINDING OF THE VISHWAMITRI RIVER IN BARODA CITY. THE THICK, DARK EFFLUENT-CONTAINING WATER IS ALSO NOTICED.



a top accretion of grey silt and sand.

Other features which are so conspicuous in the study area are the sinuously winding courses of the Vishwamitri and Dhadhar rivers, with the meandering of the Vishwamitri particularly eye catching. Several micro-point bars and ox-bow lakes [Plate : 4] are seen along the Vishwamitri river course. The presence of several natural linear depressions in the area might be indicative of the traces of older river channels of the Vishwamitri river.

Bad-land or Ravines :

The soft sediments present along the banks of Mahi, Mini, Vishwamitri and Dhadhar rivers are prone to gully formation. Vigorous and continuous gullying has lead to the development of bad lands [Plate : 5] or ravines [Plate : 6] as described earlier. This type of land is very conspicuous in the north-west of the Baroda urban complex, between the Mahi and Mini rivers. Though fertile, this land is of no economic use due to the ravine formation.

The above mentioned natural geomorphic features are rapidly being modified by human activity. The levelling of the ravines for agricultural and road building purposes are beneficial in nature. The straightening of the sinuous [Plate : 7] course of the Vishwamitri at many points, the cutting off of older meanders leading to the formation of abandoned channels [Plate : 8] and horse shoe lakes, are a few examples of artificially induced formation of new geomorphic features. The latter mentioned new geomorphic features have led to the inhibition of natural drainage [Plate : 9] resulting in the flooding of low lying areas of Baroda city during the monsoon.

PLATE 4 : PROMINENT OX-BOW FORMATION IN THE VISHWAMITRI RIVER



PALTE 5 : BAD-LAND BETWEEN THE MINI AND MAHI RIVER MARKING THE ONSET OF RAVINE FORMATION.



PLATE : 6 RAVINE FORMATION ALONG THE MINI RIVER. THORNY
VEGETATION IS NOTICEABLE. STEEL GRAY VISCOUS
EFFLUENTS IN THE STREAM CHANNEL IS CONSPICUOUS.



PLATE : 7 STRAIGHTENING OF THE VISHVAMITRI RIVER IN
KARELIBAUG AREA OF BARODA CITY TO COPE
WITH FLASH FLOODS DURING THE MONSOON.



PLATE 8 : HIGH-RISE BUILDINGS ALONG THE BANKS OF THE VISHWAMITRI
RIVER WHICH HAVE COME UP IN AN INDUCED ABANDONED
CHANNEL



PLATE 9 : INHIBITION OF NATURAL DRAINAGE BY CONSTRUCTION
OF GUIDE WALLS IN THE VISHWAMITRI RIVER.

'a'



'b'

