CHAPTER II

GEOLOGY AND GEOMORPHOLOGY

" Straight my eye hath caught new pleasures
whilst the landscape round it measures."
John Milton (1608-74)

GENERAL

To facilitate the understanding of the problem of the present investigation, the author has touched upon the geology and geomorphology of the Bhadar basin. The Saurashtra Peninsula is one of the three major physiographic divisions of Gujarat. Two third of the surface area of this Peninsula is occupied by the trappean basalts. These rocks rest on Juro-Cretaceous sediments (Dhrangadhra and Wadhhwan formations), which are well exposed in the north eastern part. Coastal Tertiary (Gaj & Dwarka formations) and Quaternary (Miliolite limestones) sediments are bordering the trappean rocks (Fig. 2.1).

Basic geological knowledge of Saurashtra Peninsula owes to the pioneering works of Fedden (1884) who had mapped the whole region. Later on, workers from O.N.G.C. (Shrivastava, 1963,1968; Biswas 1971, 1987, 1988); G.S.I. (Foote, 1898; Pascoe, 1962; Krishnan, 1968; Verma, 1979; Verma and Mathur, 1978; Mathur, 1979); P.R.L. (Baskaran, et.al., 1989; Chakravarti and Baskaran, 1989; Baskaran, 1996) and academicians from Universities (Rajaguru and Marathe, 1977; Chiplonkar and Borkar, 1978; Merh, 1980, 1995; Merh and Ganapathi, 1985; Mahoney, 1988; Patel and Bhatt, 1995) have added knowledge to it. Among them, Shrivastava's (1963) and Merh's (1995) works are commendable. Merh (1995) has brought out a text book on geology of Gujarat in which he has dealt with the region as whole. The general stratigraphic sequence of Saurashtra Peninsula is furnished in Table 2.1. In the proceeding paragraphs, the geology of the study area is briefly discussed.

GEOLOGY

DECCAN TRAP FORMATION

The rocks of Deccan Trap form the basement, over which the younger coastal Tertiary and Quaternary sediments have deposited (Table 2.2). Within the limits of the Bhadar basin, the trappean rocks are exposed dominantly (Fig. 2.2) in the form of an elevated plateau with uneven topography, at times minor hills, fringing the basinal margin. Often, they are highly fractured and weathered to such an extent that thick black cotton soil cover is observed. Conspicuously, the hills are bordering the basin viz. Alech (298 m) in the north western part and Osham (314 m) in the southern part. The eastern fringe is occupied by central highlands rising to more than 300 m. from mean sea level.

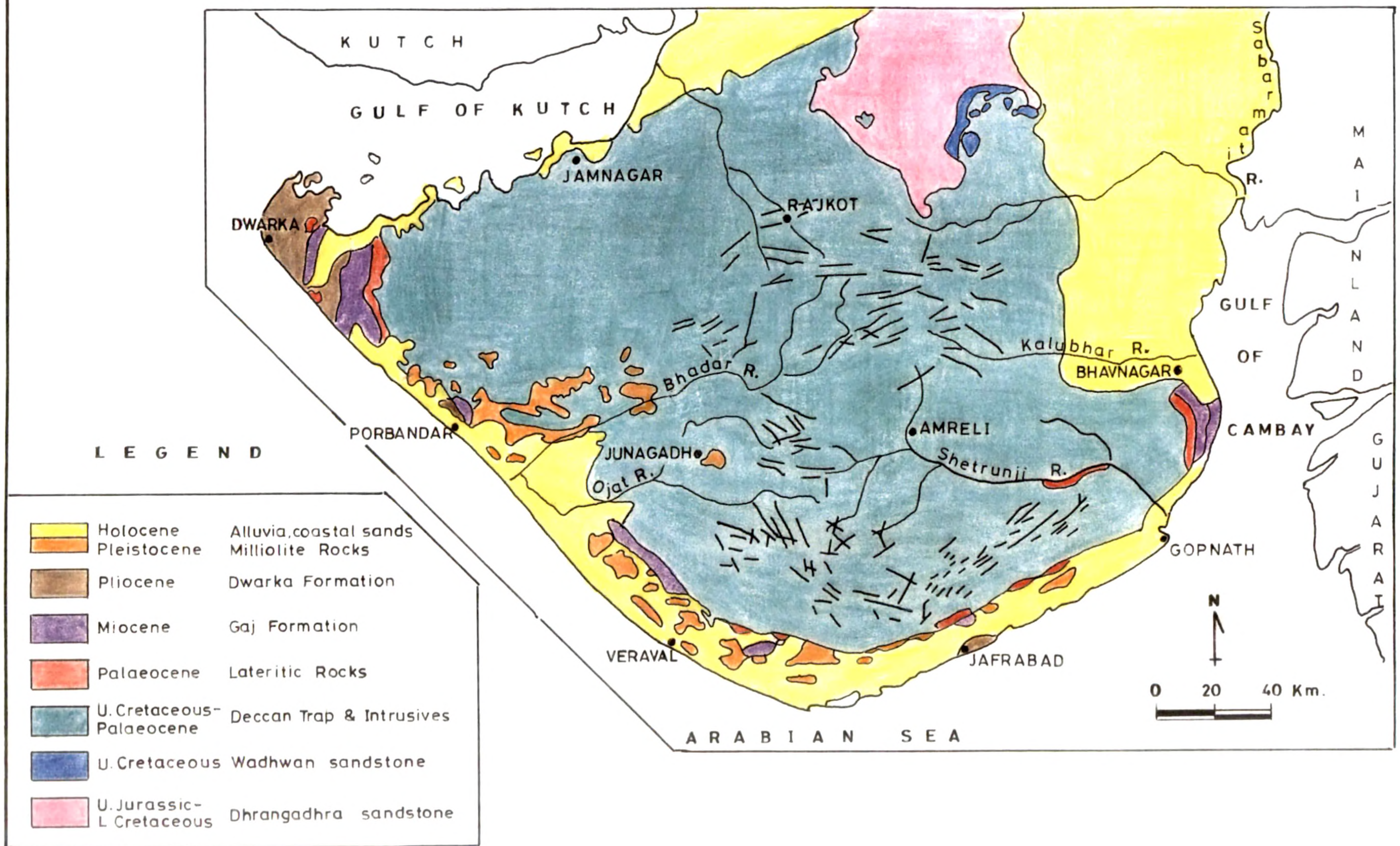


Fig.2.1: GEOLOGICAL MAP OF SAURASHTRA PENINSULA

Table 2.1 : Generalised stratigraphic sequence of the Saurashtra Peninsula (After Shrivastava, 1963)

AGE	FORMATION	LITHOLOGY	ENVIRONMENT
Recent and Sub-Recent	Recent Deposits	Alluvium, coastal dunes and beach sands. Rann clays, Mudflats, Soils, etc.	
		Unconformity	
Pliestocene to Sub-Recent	Agate conglomerate Formation	Agate conglomerates and associated ferrugineous sandstones	Fluviatile Littoral
	Miliolite Formation	Calcarenites, calcrudite, with intercalations of clay	
		Unconformity	
Upper most Miocene to Pliocene	Dwarka Formation Piram Beds	Dark brown silty clays, yellowish calcareous clays and limestone with gypseous clays Fossiliferous conglomerates, grits and sandy clays	Littoral to Epinerite
		Unconformity	
Lower Miocene	Gaj Formation	Variegated shales, sandstones, marls, conglomerates and impure limestones with intercalation of gypseous clays	Epinerite
		Unconformity	
Paleocene Cretaceous to Paleocene	Lateritic Rocks Deccan Trap Formation	Red, brown and yellowish brown laterites Plutonic masses and dykes intrusrve in the trap flows	
		Unconformity	
Middle Cretaceous (Albian to Cenomanian) Juro-Cretaceous (Tithonian to Albian)	Wadhwan Formation Dhrangadhra Formation	Red and brown colour sandstones with intercalation of Shales White and coloured felspathic sandstones with gritty layers, lenses of grey and yellowish shales and carbonaceous shales with coal layers and plant remains	Shallow marine Deltaic
		Base not exposed	

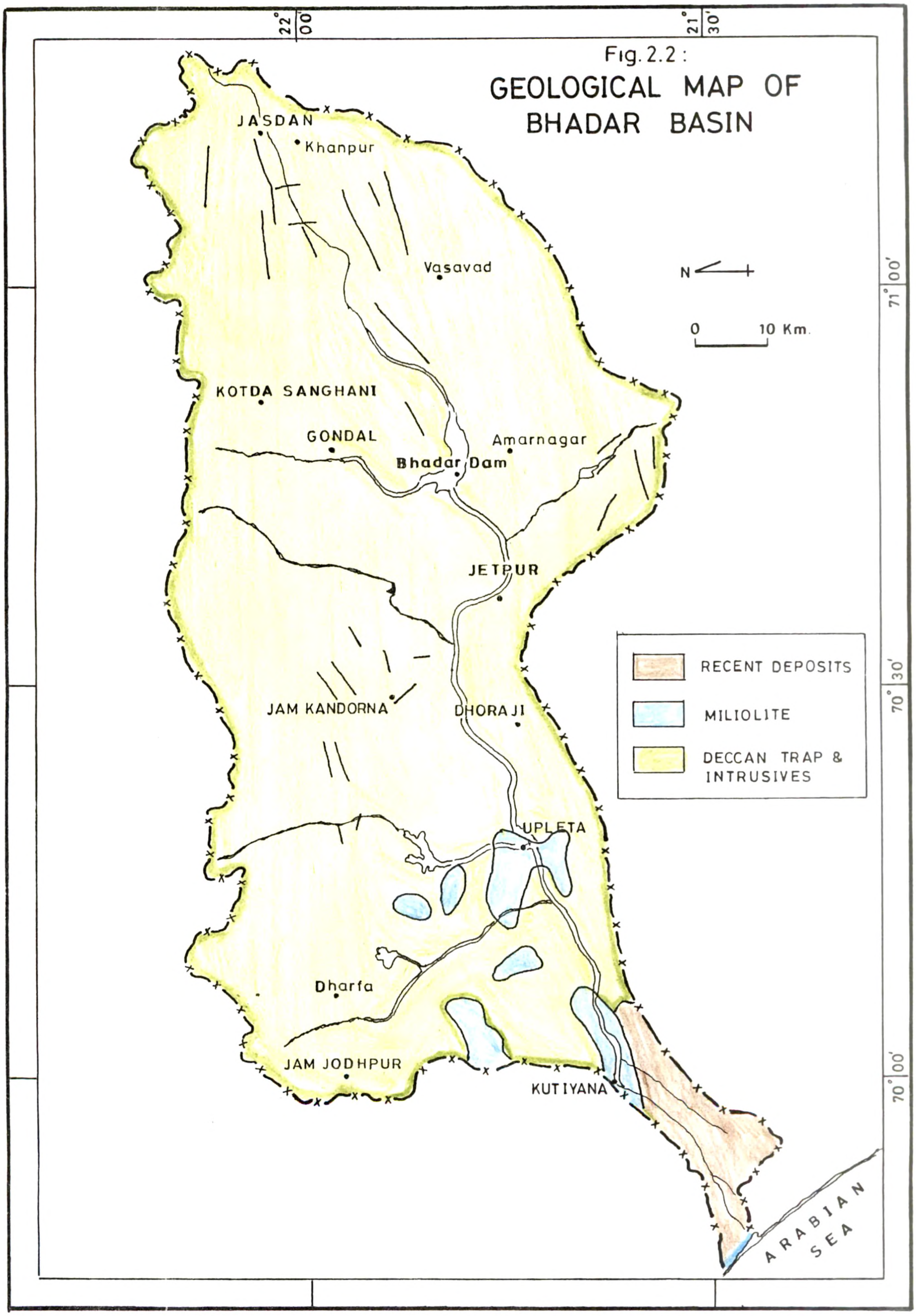


Fig. 2.2 :
GEOLOGICAL MAP OF BHADAR BASIN
22° 00'
21° 30'
71° 00'
70° 30'
70° 00'
N
0
10 Km.
JASDAN
Khanpur
Vasavad
KOTDA SANGHANI
GONDAL
Amarnagar
Bhadar Dam
JETPUR
JAM KANDORNA
DHORAJI
UPLETA
Dharfa
JAM JODHPUR
KUTIYANA
ARABIAN SEA
RECENT DEPOSITS
MILIOLITE
DECCAN TRAP & INTRUSIVES

TABLE 2.2 SURFACE STRATIGRAPHIC SEQUENCE OF BHADAR RIVER VALLEY
(After Shrivastava 1963)

Age	Formation	Lithology
Recent and Sub-Recent	Recent deposits	Alluvium, coastal dunes and beach sands, Rann clays, mudflats, soils etc.
------ Unconformity ------		
Pliestocene to Sub-Recent	Miliolite Formation	Calcarenites, calcrudite with intercalations of clays
------ Unconformity ------		
Cretaceous to Paleocene	Deccan Trap Formation	Plutonic masses and dykes intrusive in the trap flows
------ Base not exposed ------		

It has been estimated that the thickness of trap is more than 400 m. (Biswas, 1987). Based on the DSS profile along Navibandar - Amreli (south of the basin), Kaila et al. (1981) have calculated the trappean thickness, varying from between 900 m. and 1300 m. to the west of Junagadh to 350 m. to the east of it. This suggests the variable thickness of the basaltic flow in Saurashtra. The trap, generally comprises a successive lava flows of theoliitic basalt (Mahoney, 1988).

The most common rock type of the traps is fine to medium grained, compact, dark greyish basalts. But varieties in colour and textures as well as in composition are not uncommon. The vesicular and amygdaloidal varieties contain secondary minerals such as quartz, crypto-crystalline quartz, calcite, zeolites etc.

Osham hill consists of felsites where as Alech hill comprises rhyolite and felsite with occasional dolerite rocks. Conspicuously, these hills show a variety of igneous rocks intruding within the lava flows. Often, the dykes are seen cutting across the basalt in three major directions viz. ENE-WSW, NW-SE and E-W. The dykes are more dominant in the eastern part of the study area. Compositionally they are generally doleritic.

The longest dyke is exposed NE of Vavdi which could be traced for about 22 km having an average width of 5m and orientation of N70°E - S70°W. Yet another dyke was encountered SW of Khirasara and to NE of Charel. South east of Bhayavadar and South of Moj reservoir, dykes have been observed in N35°W- S35°E trend.

The basalts are highly fractured and jointed and their pattern coincides with the bounding faults of the Saurashtra Peninsula (Merh and Ganapathi, 1985 and Biswas 1987). The lineament map of the basin (Fig. 2.3) was prepared from Landsat FCC Imagery Band No. 234 year 1990,1991 and

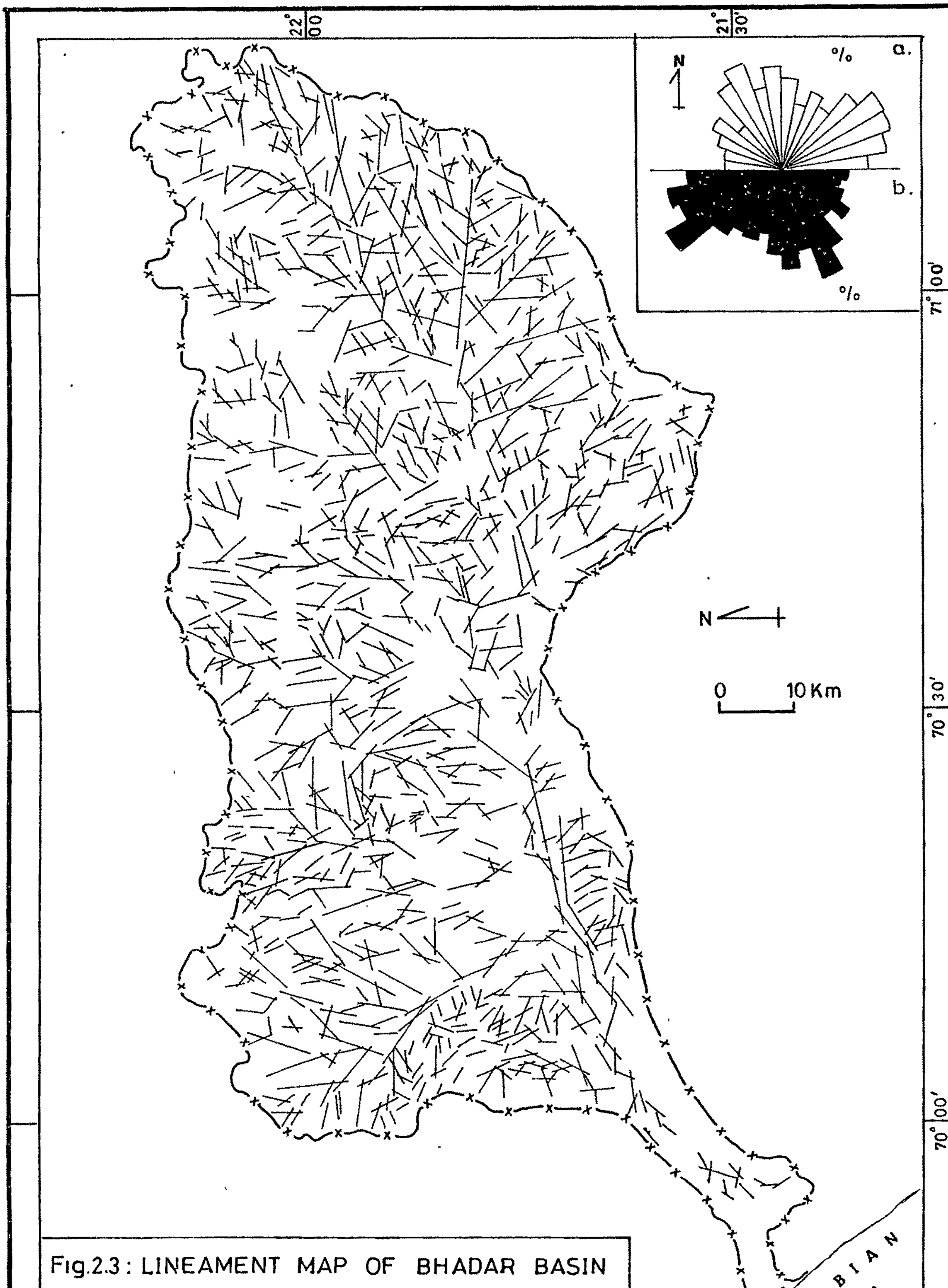


Fig.2.3 : LINEAMENT MAP OF BHADAR BASIN

Inset : Lineament rosette a) Frequency b) Magnitude toposheet No. 41 K/G/O/N/J of scale 1:250,000, and also author's observation in the field. The lineament rosettes (frequency and magnitude - based) drawn from the map conform to the findings of earlier works (Fig 2.3 a & b). It is interesting to observe that all major rivers are draining along one or other major structural lineament (Sood et al., 1981 and Ganapathi et al., 1985a).

GAJ FORMATION

The rocks of Gaj Formation (Lower Miocene - Ganapathi et al., 1985a) are not exposed on the surface within the limits of study area, but can be observed at Pharer and Bantwa, south of the basin. Within the basin, these Tertiaries are concealed below the Quaternary sediments and lie unconformably over the Deccan Trap. The Gaj rocks comprise variegated shales, sandstones, marls, conglomerates and impure limestone with intercalations of gypseous clay which have been deposited under shallow marine conditions (Srivastava, 1963).

MILIOLITE FORMATION

Rocks of Miliolite Formation rest conformably either over the Tertiaries or the traps. Within the basin, they are exposed along the coastline more or less parallel to the shore. They are also seen occurring along the Bhadar river upto Upleta. They occur as a sheet in the valley whereas south of Jam Jodhpur they occur as echo dunes. The coastal rocks are either a sheet (beach rocks) or a coastal dune, having morphology of various dune shapes (barchans, parabolic, longitudinal). The rocks essentially comprise biogenic beach sands and occur as shallow marine deposits (Mathur, 1978 and Verma, 1979) or as deposits, reworked by the aeolian processes (Patel, 1991a; Patel and Bhatt, 1995). Radiometric age determination has revealed the age of Miliolite ranging from 200 to 50 K.Y. (Baskaran et al., 1989) and appears to have been deposited during the Pliestocene in a successive stage of still and transgression or regression sea (Patel, 1991b), coupled with neo-tectonic activities (Merh and Ganapathi, 1985).

RECENT DEPOSITS

Recent deposits are represented by a variety of unconsolidated sediments of beach, dune, estuarine, fresh-water and sub-aerial origins.

GEOMORPHOLOGY

Geomorphologically the Saurashtra Peninsula can be divided into (1) Trappean highlands, (ii) Pediments and (iii) Coastal plains (Fig. 2.4). Many workers have discussed one or other area or the aspects of various landforms (Sood et al., 1981; Ganapathi et al., 1985b; Nayak et al., 1988 ; Ganapathi and Merh, 1987; Merh et al., 1991). Obviously, the lithology, structure, dynamic processes control the development of various landforms and drainage. To know the better hydrogeological conditions of the Bhadar basin, the over view of the geomorphic aspects are given in the forthcoming pages.

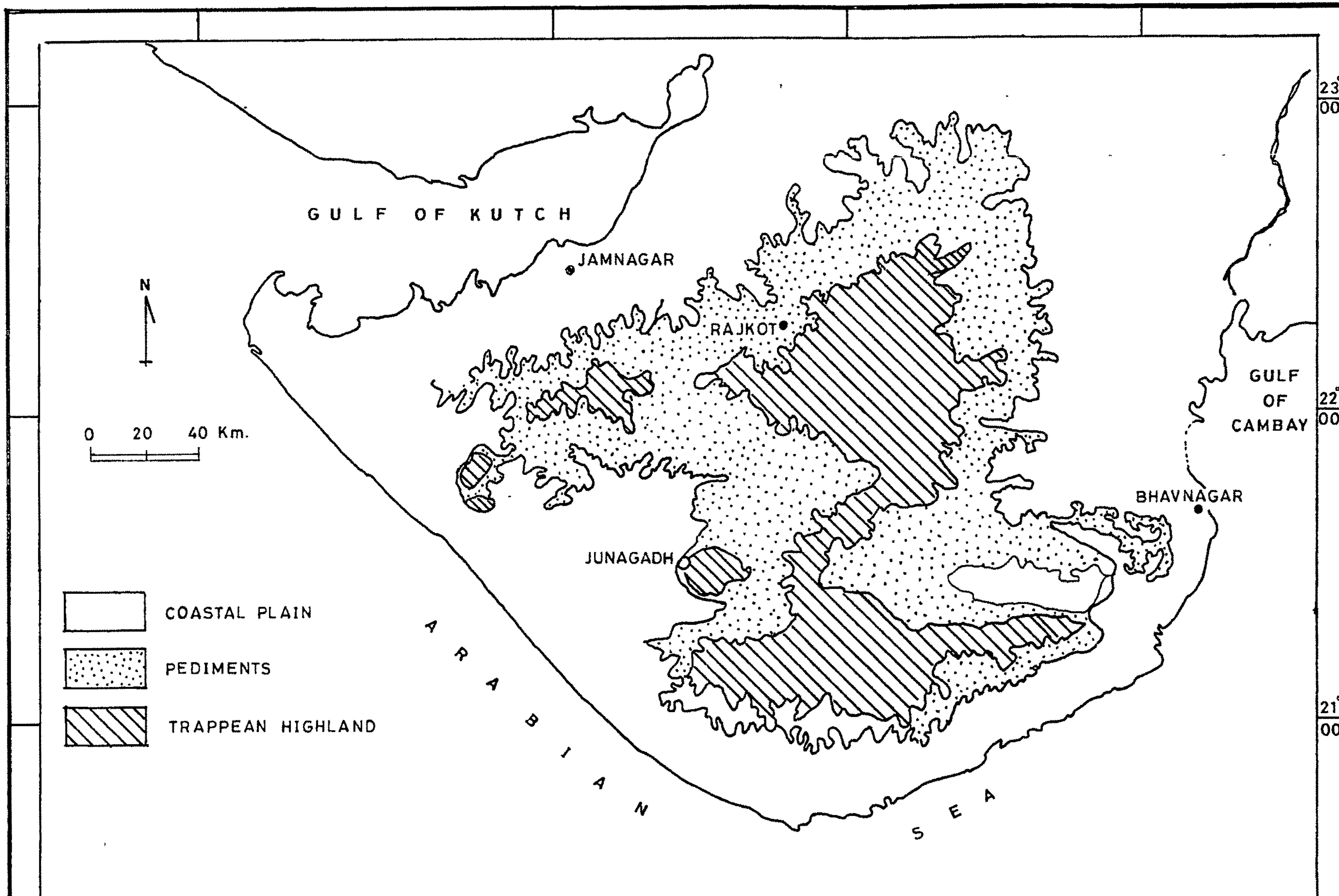


Fig.2.4: REGIONAL GEOMORPHIC MAP OF SAURASHTRA

DRAINAGE :

The Bhadar river originates from the central highlands near Jasdan, flows in the south western direction for nearly 260 km distance, before meeting the Arabian Sea at Navibandar. Numerous tributaries such as Gondli nadi, Vasavari nadi, Survo nadi, Galoliya nadi are joining the mainstream in the upper reaches itself, whereas Champarvadi nadi, Phophal nadi, Moj nadi, Vinu nadi in the mid-stream between Jetpur and Kutiyana (Fig. 2.5). Beyond Kutiyana, the Bhadar becomes defused and branch out into various distributary channels and appear to debouch into the marsh land. In the year 1964, a dam was constructed at Navagam village on the Bhadar river about 22.5 km to the upstream of Jetpur. This, in turn, has changed the eco-system as well as the natural flow of the river.

The river Bhadar, the largest of the Saurashtra rivers, mainly flows through the basalt of uniform resistance and shows a "dendritic pattern". Though its overall drainage pattern is dendritic, erroneously suggesting lack of structural control, detail examination of the trunk stream as well as various tributaries and lower order channels, all reveal a complex intersection of fracture direction, related to various major lineaments.

MORPHOMETRIC ANALYSIS

Morphometric analyses of the micro-water sheds of the study area were carried out to decipher and understand the various factors responsible for the development of river patterns. Keeping in mind, the factors that control the drainage patterns (i.e. structure, lithology and slope), the author analysed the important morphometric parameters of drainage evolution (Horton, 1945) which inturn has helped in understanding the hydrogeological aspects of the basin.

The drainage characteristics have been investigated from 1:50,000 scale toposheets of the Survey of India. Various sub-basins were selected for carrying out more detail investigation (Table 2.3). The following parameters were calculated to evaluate the comparative study of different sub-basins.

Stream Order : The method outlined by Strahler (1957) has been followed for assigning the stream order. The smallest finger tip tributaries are designated as order 1; where two first order streams join, a stream segment 2 is formed; where two of order 2 join, a segment of order 3 is formed and so forth.

Length : Total length of individual stream order.

Area : Area of the individual basin.

Bifurcation ratio : The ratio of first order to second order, second to third and so on (Horton, 1945)

Drainage density : The average length of stream within the basin per unit area (Horton,1932).

Stream Frequency : The number of streams per unit area (Horton, 1945).

Horton's (1945) law of stream numbers states that the numbers of stream segments of each order form an inverse geometric sequence with order number. The plots of the stream order versus number on a semi-logarithmic paper (Fig. 2.6) show a straight line graph. The maximum deviation,

Figure 2.5

DRAINAGE MAP OF BHADAR BASIN

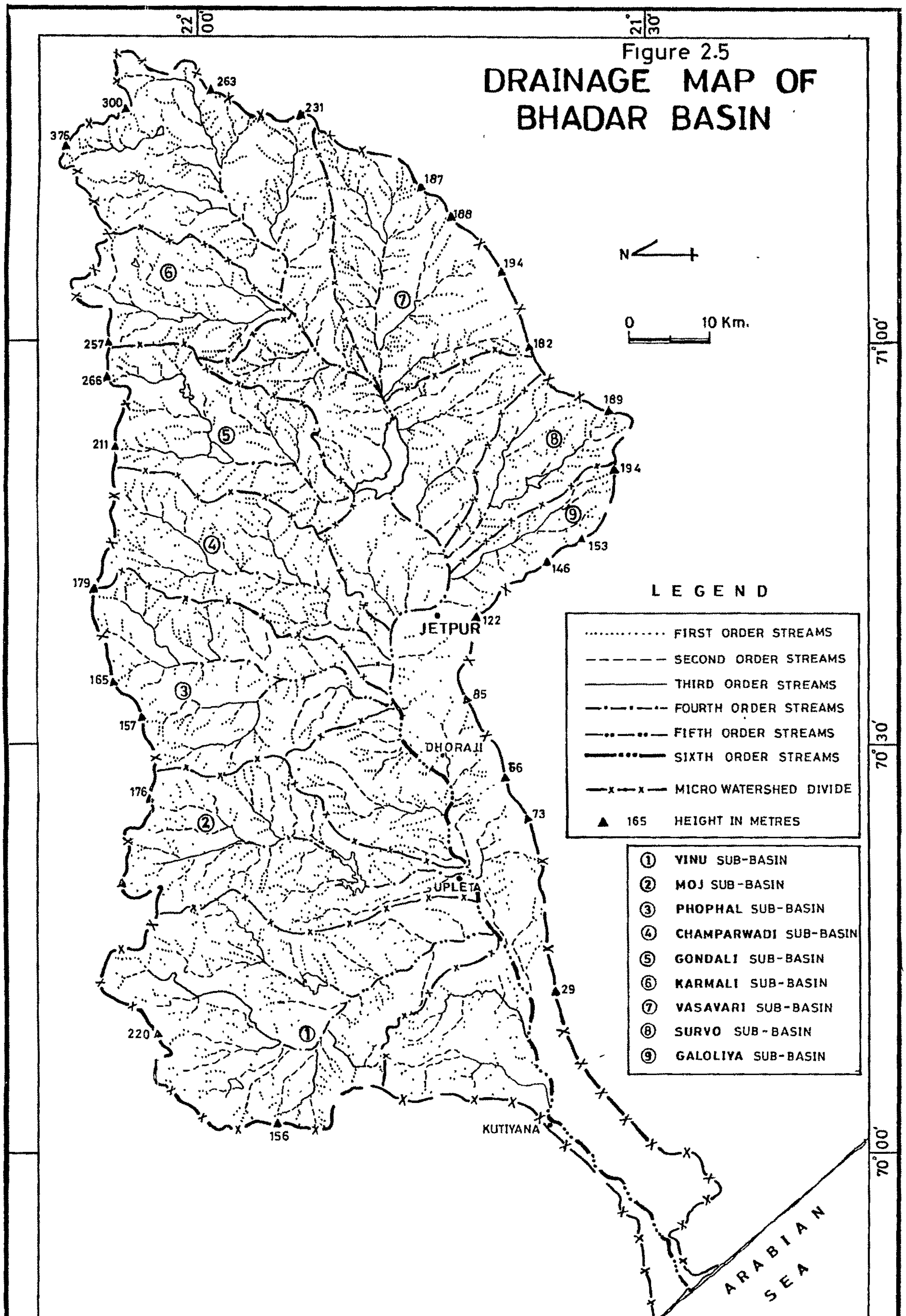


Table 2.3 : Morphometric Analyses

Basin Name	Stream Order	No. of Stream	Bifurcation Ratio	Total length of Stream(km)	Avg. length of Stream (km)	Total area Basin in Sq. km.	Drainage density	Stream Frequency
Vinu nadi	1	145	5 00	365 00	2.52	926.31	0 65	0 20
	2	29	4.83	132 50	4 57			
	3	06	3.00	55 00	9 17			
	4	02	2 00	25.00	12 50			
	5	01	-	21 25	21.25			
Moj nadi	1	83	4 61	227 50	2 74	548 06	0 70	0 19
	2	18	6 00	105 00	5 83			
	3	03	3 00	20 00	6.67			
	4	01	-	30 00	30 00			
Phophal nadi	1	100	4.35	290 00	2 90	569.56	0 77	0 23
	2	23	3.83	75 00	3 26			
	3	06	3 00	37 50	6 25			
	4	02	2 00	20 00	10 00			
	5	01	-	15 00	15 00			
Champaivadi nadi	1	88	5 50	242 50	2 76	449 13	0 75	0 24
	2	16	5 33	40 00	2 50			
	3	03	3 00	27 50	9 17			
	4	01	-	26 25	26.25			
Gondli nadi	1	73	3 65	185 00	2 53	440 94	0 64	0 22
	2	20	5 00	47 50	2 38			
	3	04	4 00	30.00	7 50			
	4	01	-	20 00	20 00			
Karmali nadi	1	52	4 73	150 00	2 88	280.50	0.80	0 24
	2	11	5 50	042 50	3 86			
	3	02	2 00	030 00	15 00			
	4	01	-	002 50	2 50			
Vasavari nadi	1	107	5 35	262 50	2 45	524 31	0 73	0 25
	2	20	4 00	062 50	3 13			
	3	05	5 00	037 50	7 50			
	4	01	-	022 50	22 50			
Survo nadi	1	47	6 71	125 00	2 66	249 13	0 72	0 23
	2	07	3 50	017 50	2 50			
	3	02	2 00	030 00	15 00			
	4	01	-	007 50	7 50			
Galoliya nadi	1	35	5 00	82 50	2 36	155 81	0 80	0 28
	2	07	7 00	25 00	3 57			
	3	01	-	17 50	17 50			

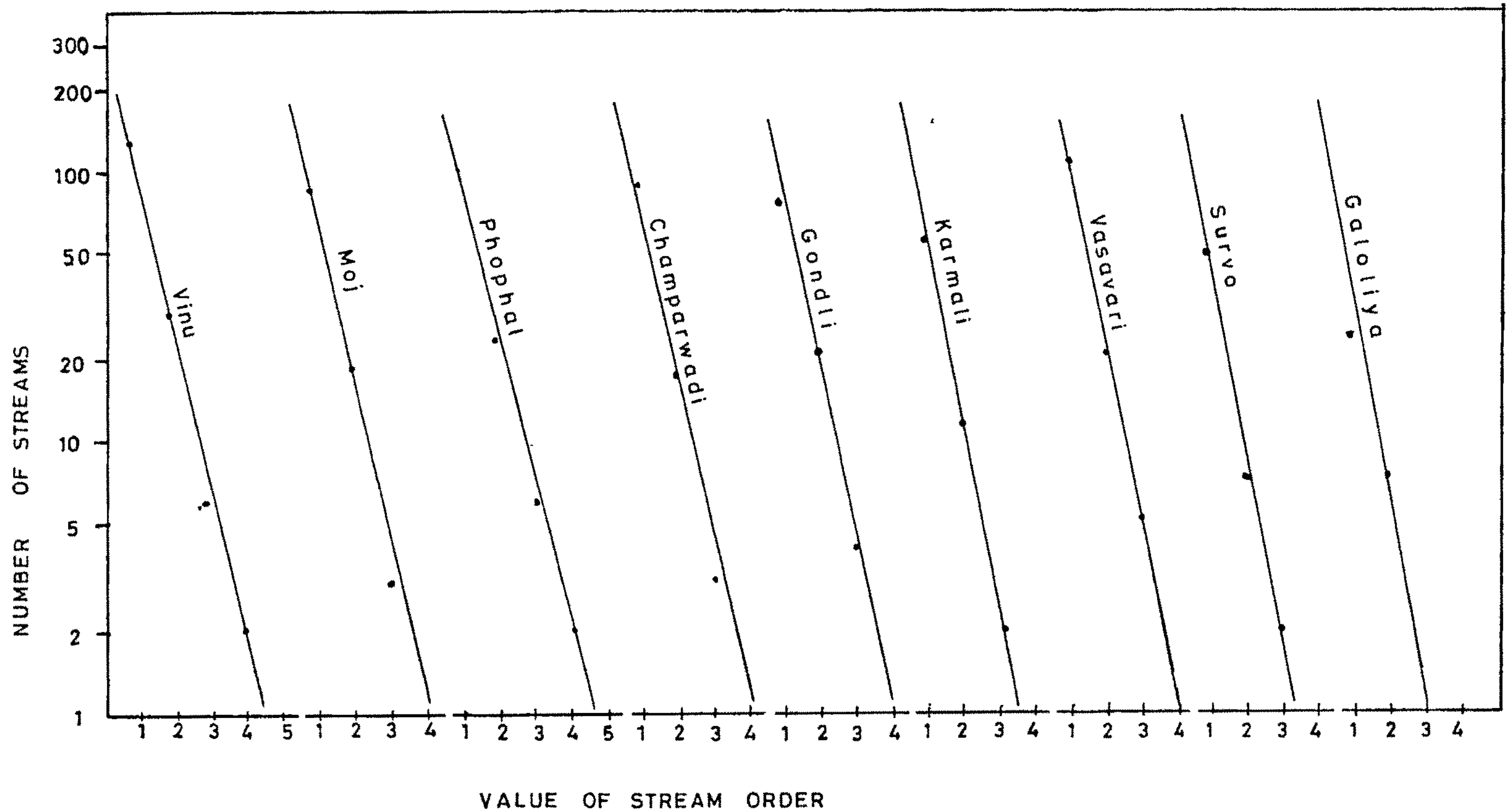


Fig. 2.6 : Relation of stream order to number of streams in different sub-basins.

observed in the high order of all basins, is generally suggestive of decrease in number of high orders. This could be reasonably attributed to the phenomena of rejuvenation of the main trunk.

Horton's (1945) law of stream lengths states that the average length of stream segments of each order forms a direct geometric sequence with order number. Except the Vinu nadi, the plots of stream order versus average length of the other rivers, however, do not show such linear relationship (Fig. 2.7). The discrepancies, seen in the lower orders, imply that before the first order streams unite and become second order within their own catchment, they attain a higher stream frequency and density, whereas, the second order streams attains lower stream frequency and density. This phenomena shows a deviation from Horton's law and obviously points to a structural control of these small low order streams that flow along various joint sets (Horton, 1945 p. 303). The summation of areas of the sub-basin points to a very large catchment area.

Bifurcation ratios of low order streams in all sub-basins vary from 3 to 7; this high value is on account of the fact that the streams are flowing through the distinct fractures in the trappean terrain, reflecting highly dissected drainage basin. Low bifurcation ratios for higher order streams (4 and above), on the other hand, are pointing to the flat or rolling topography (Horton, 1945, p. 290). This also confirms with slope angles (Fig. 2.8 a,b,c).

The values of drainage density vary between 0.6 and 0.8. This low values indicate the presence of highly resistant rocks on the surface (Karanth, 1990 p. 381). The low values of stream frequency points to low precipitation, high relief and high resistant rock. This also confirm with the slope angle (Fig. 2.8 a b c), rainfall data and basaltic terrain.

SLOPE

Slope of the ground is one of the important controlling factor in the hydrogeological aspect because of the gravity flow. It is controlled by the lithology, structure and climatic conditions.

Bhadar basin has uniform lithology and falls in semi-arid climatic zone, but has many joints, fractures and intrusives. Owing to this, the basin shows varied slopes from steep to sub-horizontal. To understand landform, land-use categorisation, run-off and recharge of ground water, one has to study in detail about the slope. Accordingly, the author has prepared the slope map (Fig. 2.8 a,b,c) of the Bhadar river basin by using simple trigonometric formula,

$$\tan\theta = \frac{V.I}{H.E}$$

where V.I = Vertical interval/contour interval

H.E. = Horizontal equivalent/distance between two adjacent contours

Based on slope angles, Young (1972) classified the slopes into 7 sub-divisions. Among the

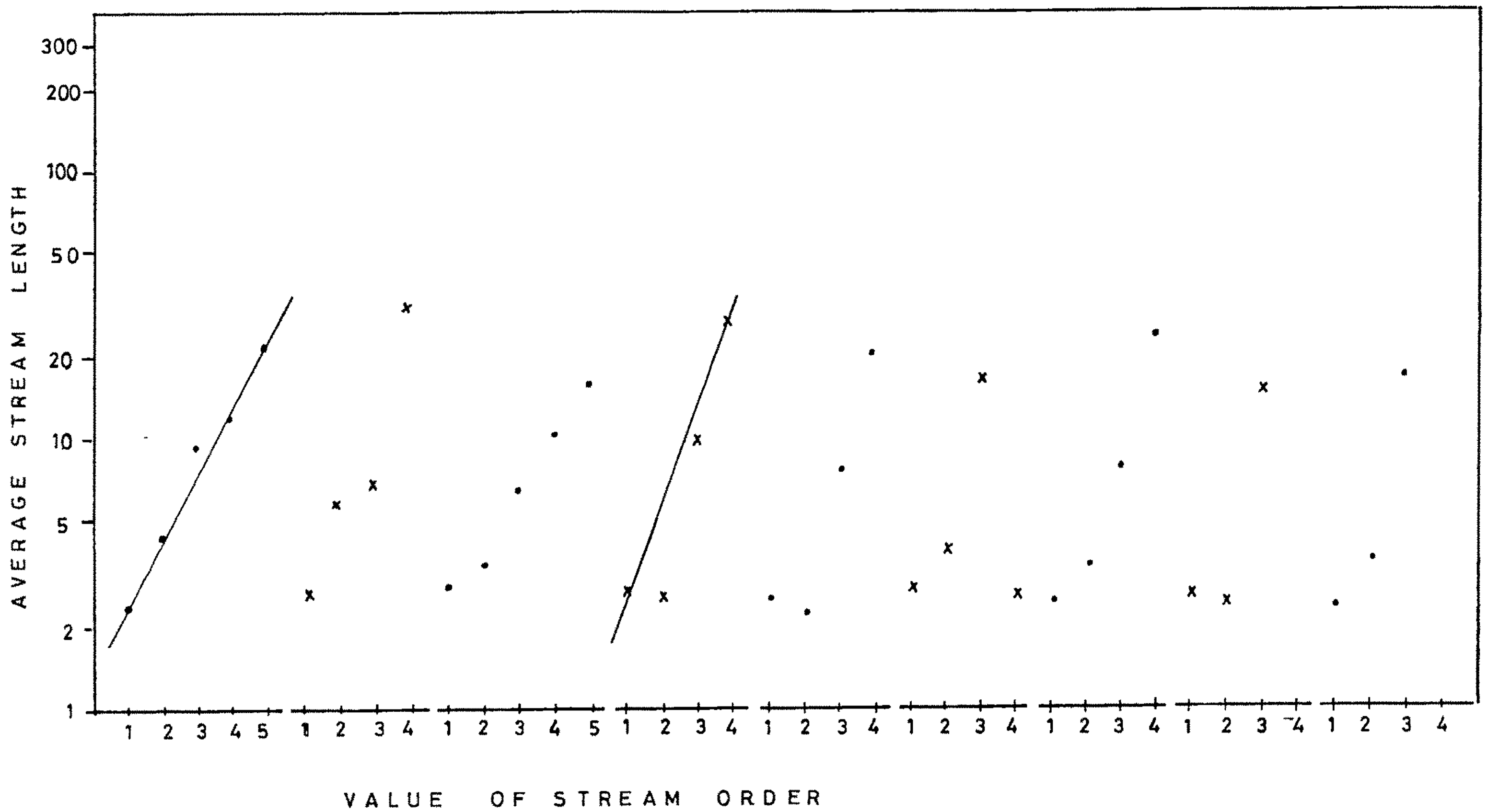
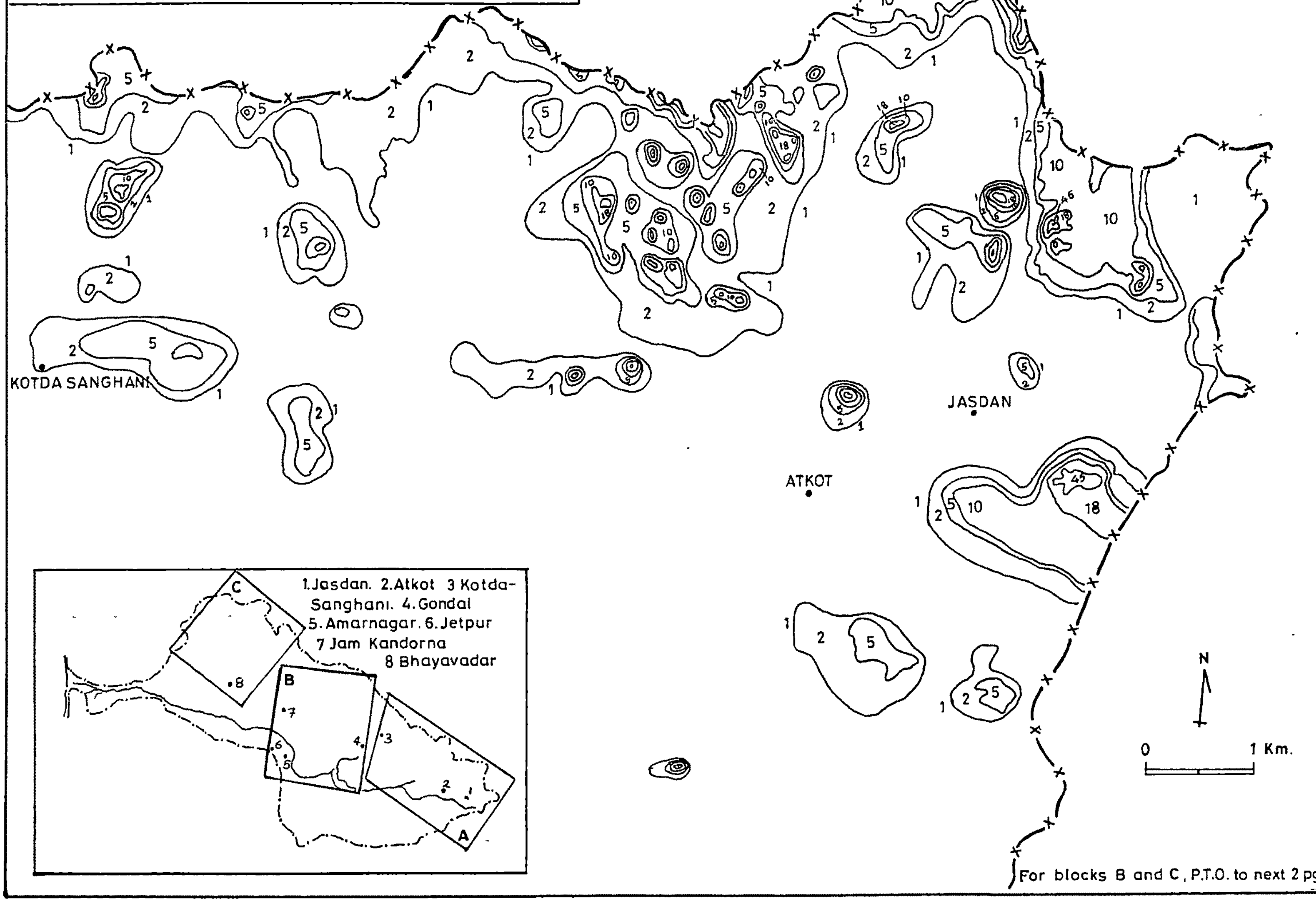
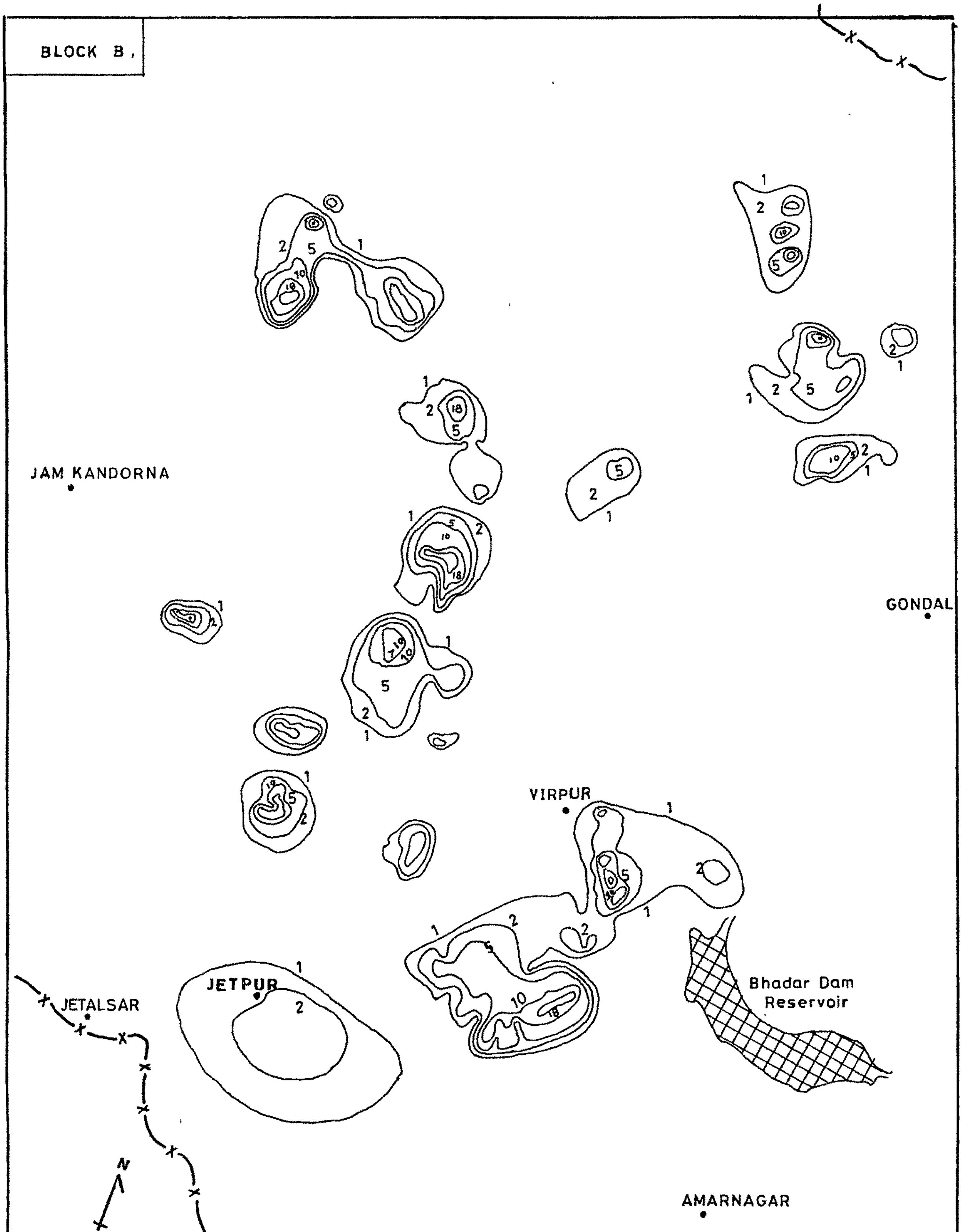


Fig. 2.7 : Relation of stream order to average stream length in different sub-basins.

Fig. 2.8: SLOPE MAP OF BHADAR BASIN
(Inset: Blocks, within the basin, selected for detailed study)





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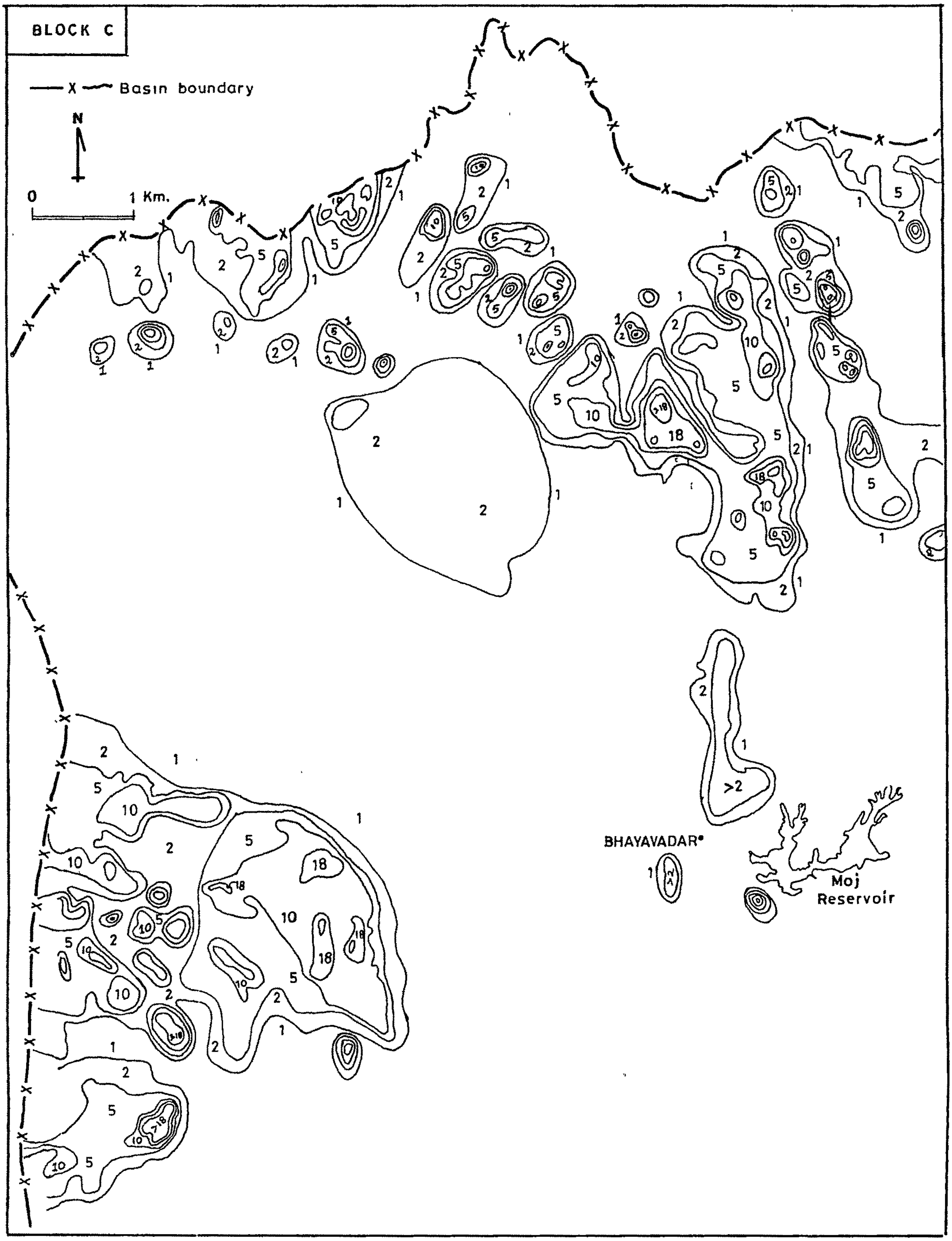
BLOCK C
Basin boundary
N
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1 Km.
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Moj
Reservoir

above 7 classes, class - 1 i.e. 0°-1°, almost the level slope, dominates on the rest. Class- 7 i.e. 30°-40° is totally absent. The slope classes of Young's coincide with different landforms encountered within the basin. Steep slopes rest within the denudational hills, moderate slopes represent the pediment landforms and very gentle to level slopes occupy the burried pediment and flood plains (Agnihotri, 1993).

As the slope angle increases, the gravity flow increases and they inturn increase the run-off of the water; whereas its decrease points to the increase in recharge/ infiltration (Karanth, 1990).

It is also observed that the angle of slope of the terrain has control on the land use categorization or landuse pattern. The gentle slope favours agricultural land/resident, whereas moderate slope angle encourage the grazing land or agriculture capability if precipitation is good.

LANDFORMS

Basaltic rocks cover the major lithology of the Bhadar basin, which exhibits conspicuously erosional landforms. However, along the Bhadar valley and its mouth, depositional landforms are seen. It is interesting to observe that development of these landforms is essentially controlled by structure, lithology, climate and weathering processes. A geomorphological map of Bhadar basin (Fig. 2.9) was prepared from IRS-1A, FCC Band 234, 16/3/90, 25;26/3/91; NRSA L3 MSS 5 and 7, 22/10/80 and Survey of India toposheets (1:50,000 scale). Ground truth was collected, checked and modified. The landforms were classified following King's (1964) method. In the proceeding pages, individual landforms are described, with the view to understand landuse pattern and the hydrogeological conditions.

Denudational Hills (DH)

Weathering and erosion have played an important role in shaping the various hills, such as Osham (314m) to the south of Upleta and Alech (298m) to the north of Kutiyana. Basically, these hills represent an intrusive nature, having granophyre and felsitic rock types, still they stand out prominently above pediment plains. These hills which are generally barren or scantily vegetated, with sudden rise from the surrounding, reflecting the processes of weathering, erosion and transportation, has been termed as denudational hills. These highlands show steep slopes greater than 18°; therefore, no significant soil horizons exist, which result into a fast run-off and very negligible percolation.

Pediment (PM)

Being semi-arid climatic zone with uniform lithology, the Bhadar basin is represented largely by pediment landform. It is an erosional landform of sloping surface, adjacent to a highland, with thin veneer of soil horizon developed due to periodic spreading of flood. It covers more than 15.47 .sq.km (Fig. 2.9), more or less on the north of the Bhadar river. It supports scattered vegetation, by and large represent a barren/waste lands, but changeable into a grazing land along the margins depending upon the amount of precipitation. Since the slopes are moderate (5°-10°), the run-off becomes quick, with little chance of infiltration.

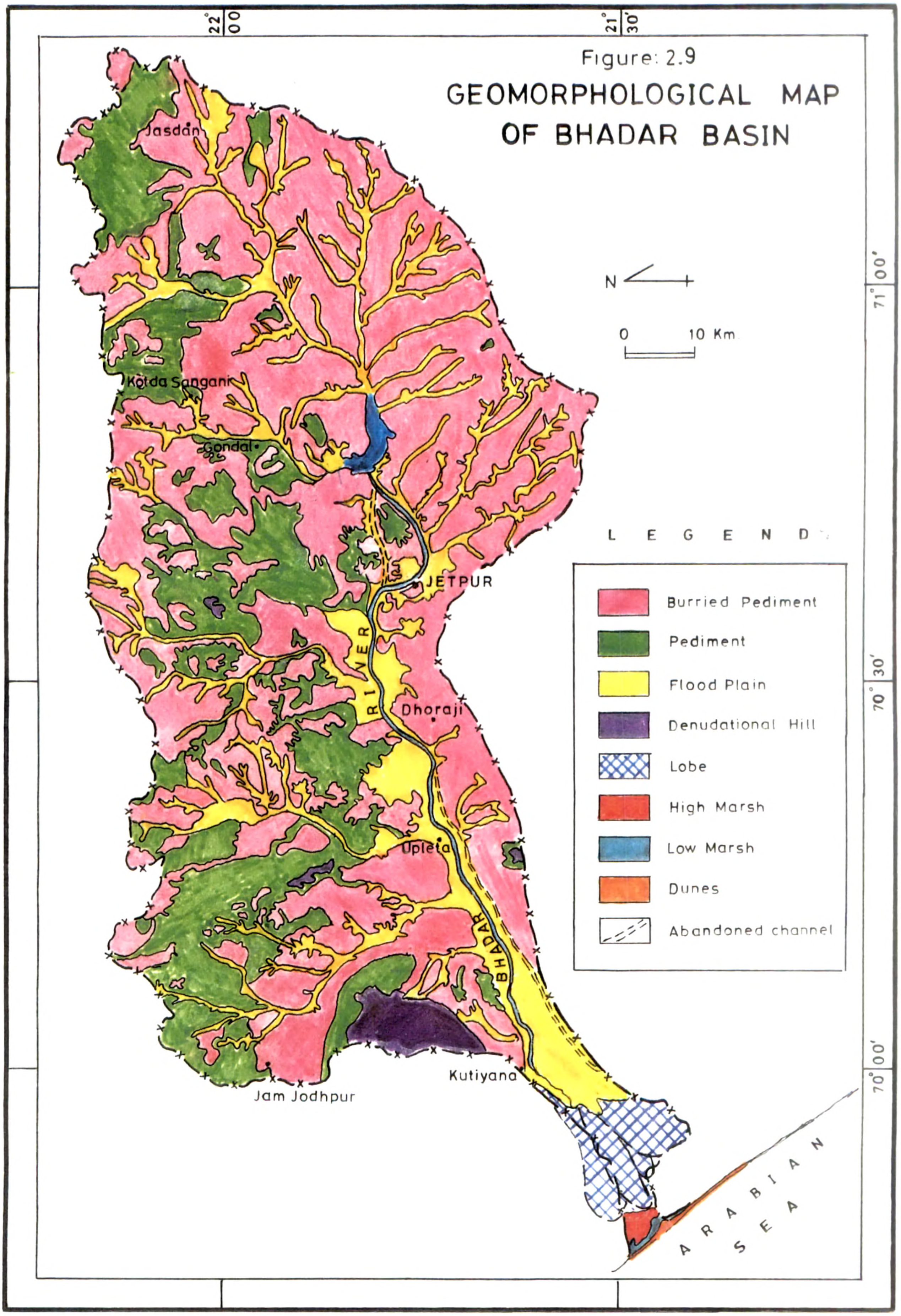

Figure: 2.9
GEOMORPHOLOGICAL MAP
OF BHADAR BASIN
N
0
10 Km
22° 00
21° 30'
71° 00'
70° 30'
70° 00'
Jasdan
Kotda Sangani
Gondal
JETPUR
RIVER
Dhoraji
Upleta
BHADAR
Kutiyana
Jam Jodhpur
ARABIAN SEA
LEGEND
Burried Pediment
Pediment
Flood Plain
Denudational Hill
Lobe
High Marsh
Low Marsh
Dunes
Abandoned channel

Burried Pediment (BPM)

In due course of development, the pediment slowly receive the sheet wash sediments at their margins. This, further, leads to the decrease of the slope angles (5°-2)°, increase in the sediment and soil cover (Fig. 2.9). Therefore, the landform is called as burried pediment. This landform occupies 3740 sq.km, and forms the largest unit. Being thick in vegetations, it represent usually the grazing land, but also includes agricultural land, depending on precipitation. It depicts less run-off and moderate to good percolation.

Flood Plains (FP)

Compared with earlier landform, the flood plains is restricted in aerial extent, usually along the tributary streams and the Bhadar river. Within the basin, it has developed primarily east of Jetpur (Fig. 2.9). However, the construction of dam during 1964 and consequent reduction in periodic floods have led to the reduction of further deveopment of these flood plains. Flood plains, often, are quite thick, however, in the tributary channel, the bed rocks are frequently exposed. Down stream beyond Upleta, alluvial capping is more thick and highly fertile and support major agricultural lands. The plain being more or less horizontal, good infiltration and less run-off act as good aquifer conditions.

Paleo-channels (PC)

Paleo-channels of Bhadar main stream were identified, one north of Jetpur and the other one, south of Upleta, their total length amounting to approximately 42.85 km.. These channels are the ideal sites and serve as good potential for recharge to ground water.

Lobes (L)

Between Kutiyana and Navibandar, the area depicts the lobe morphology, which is very clearly seen in the IRS- 1A FCC Band 234 imagery. The textural attribute and the tonal variation are amply different from the rest of the units. These lobes, represent the paleo mouth deposits of the Bhadar river, when the sea-level might have been little higher than the present, possibly during Flandrian times (Ganapathi et al., 1985b). However, at present, they are partly concealed below the recent marshes.

Dunes (D)

Recent and Paleo-dunes have developed along the coastline and comprise biogenic carbonate materials. They are often semi-consolidated, but the recent ones are either migrating or under the process of stabilization. The paleo-dunal area does have good vegetation and also human settlement (Gosa and Navibandar village). More details regarding this have been discussed in the forth coming chapter on hydrogeology.

Marshes (M)

Marshes have developed extensively at the mouth of the rivers Bhadar and Ojat. They run more or less parallel to the coast, having 7.2 km in length and 7.14 km in width (Ganapathi et al., 1985b). These marshes can be divided into high and low marshes, depending upon their indundation of the tidal water. At present, high marsh areas are under reclamation. The process of reclamation is very slow due to the dearth of good, fresh water. This whole belt suffers from saline water ingression.