CHAPTER

V

GEOMORPHOLOGY: COASTAL LANDSCAPE AND LANDFORMS

GENERAL
SAURASHTRA BLOCK
BHAL BLOCK
MAINLAND BLOCK

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GENERAL

The different parts of the Gulf coastline are geomorphically quite distinct from one another. On account of the controls exercised by the factors of geology (structure and lithology), sea level changes, climatic variations (rainfall and wind) and strong tidal currents, which have acted in a variety of combinations, the different coastal segments exhibit a wide variety of erosional and depositional landforms. The Saurashtra coast with its landforms is quite different from the Mainland Gujarat coast. Whereas the coastal areas on the Saurashtra side consist of landforms related to the Tertiary and Quaternary periods, those on the Mainland are exclusively within the Quaternary deposits. The different combinations of fluctuating sea level and differential tectonism along some major lineaments appear to be the factors responsible for generating contrasting landscapes. Secondly, the onshore terrain characteristics have been considerably influenced by the offshore processes and for a full understanding of the coastal landforms specially their evolution, it is most essential to study the Gulf of Khambhat in totality.

In this chapter the present author has highlighted the landscape diversity of the coastal areas and has given blockwise account of the various coastal landforms. While describing the landforms he has also attempted to explain their genetic aspects. The total geomorphic picture that has emerged, throws significant light on various geo-environmental parameters prevailing within the Gulf during the Late Quaternary times.

From the landscape point of view, the Gulf coast is divisible into three blocks, comparable to those based on geological factors, viz. Saurashtra, Bhal and Mainland. The geomorphic characteristics of the various segments into which the three blocks are further divisible as under, reveal a lot of information on the coastal processes:

A. Saurashtra block

   (a) Methla-Gopnath segment

   (b) Gopnath-Ghogha-Bhavnagar segment

   (c) Bhavnagar-Dholera segment

B. Bhal block

   Dholera-Khambhat segment

C. Mainland block

   (a) Khambhat-Dahej segment

   (b) Hansot-Hazira segment

In the following pages the author has given morphology of the landforms and their modes of origin, and has attempted to acquaint the reader adequately with the help of written words, sketches and photographs.

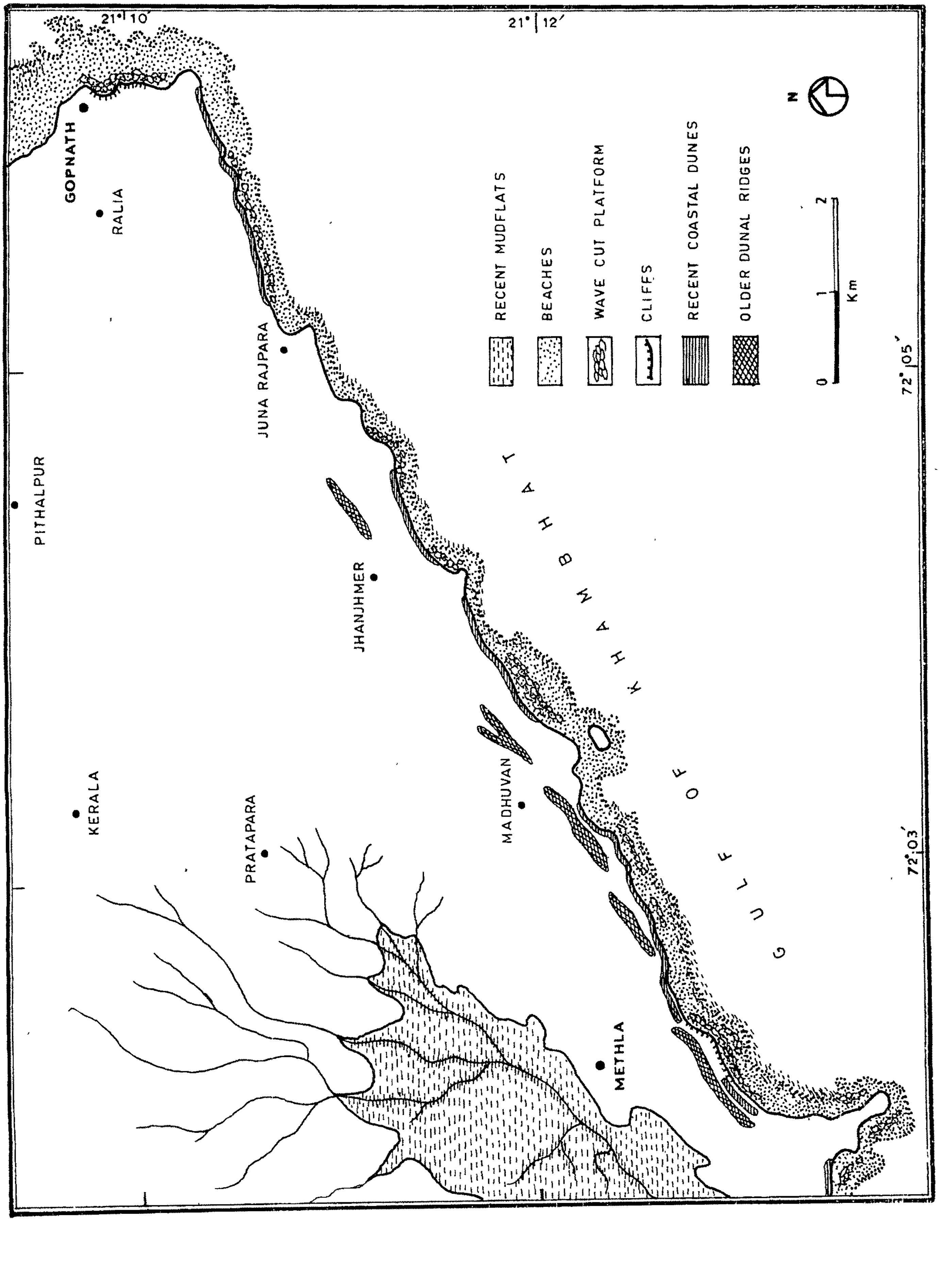
SAURASHTRA BLOCK

The Saurashtra coastal block is divisible into three segments each segment characterised by its own set of landforms. It is observed that the factors which have imparted geomorphic characteristics of the respective segments are essentially tectonic. The NW-SE Shetrunji Fault (Ganapathi, 1981) demarcates the Methla-Gopnath segment from the Gopnath-Ghogha-Bhavnagar segment. Similarly the Kalubhar River Fault separates the latter from the Bhavnagar-Dholera segment. Shetrunji Fault has controlled deposition of miliolites to its south; these rocks are absent to the north of it. This fact is ideally reflected in the coastal landforms. The Bhavnagar-Dholera segment shows a distinct subsidence in comparison to the Gopnath-Ghogha-Bhavnagar segment such that the entire coastal area to the north of Kalubhar river does not have any outcrops of Deccan trap, and instead the entire segment consists of unconsolidated fluviatile and marine coastal plain deposits of Late Quaternary.

The METHLA-GOPNATH segment (Fig. V.1) forms a straight coast trending almost N 60°E. It is an essentially rocky coast with narrow sandy beaches flanked by steep cliffs. In detail, it is seen to comprise a number of projecting headlands with crescentic sandy beaches in between. It marks an emergent coast with a geomorphic history revealing strandline fluctuations and related erosional and depositional landforms as under have been observed:

1. Wave cut platform
2. Cliffs and stacks
3. Backshore Miliolitic dune complex
4. Backshore paleodunes
5. Recent coastal dunes

FIG.V.1



GEOMORPHIC MAP OF METHLA-GOPNATH SEGMENT

6. Beaches
7. Mudflats

Almost all along the length of the coastal segment the littoral and a part of the supratidal zone is characterized by a miliolitic rocky platform. Obviously it is a product of wave action and is almost horizontal to very gently sloping rocky surface. Essentially an intertidal marine terrace, it varies in width from 50 m to 300 m. At several places it lies buried beneath thin covers of beach sands, but its continuous presence is easily recognised by numerous exposures all along the length of the coastline. Good examples of this wave cut platform are seen near Gopnath and Methla village (Plate V.1a & b). The erosional surface ideally reveals horizontal dissection of ancient coastal miliolite dunes, revealing traces of well defined aeolian cross-bedding.

Cliffs and stacks are the erosional features rising above the high waterline. These are eroded remnants of consolidated coastal miliolitic dunes (Plate V.2a&b).The cliffs occur almost all along the coast upto Gopnath flanking the beach and the platform rising upto heights of 6 to 15 m. These cliffs form almost vertical faces. Steep aeolian bedding characterize the cliff faces. The base of the cliffs more or less forms the high water line, and

Plate V.1a. Wave cut platform of Gaj rocks at Methla.

Plate V.1b. Rocky platform of miliolite with a cliff at Gopnath.

Plate V.2a. Cliffy headland and a crescentic beach at Gopnath.

Plate V.2b. Cliffs formed by wave action on consolidated dune of miliolite at Methla.

at many places strong surf action has given rise to the formation of caves near the base (Plate V.3). The cliffs are better developed at the various projecting headlands; five such projecting headlands have been recognised in this segment. Detached portions of cliffs along the headlands forming isolated projections provide good example of stacks. Two such stacks have been observed near the villages Methla and Madhuban (Plate V.4).

The various depositional landforms characterising this coastal segment are seen to belong to three generations, in all probability related to the three strandline levels. Related to the earliest high strand line are the miliolitic dunes which form consolidated dunal complex in the backshore area and represent the oldest depositional features (Ganapathi, 1981). In fact, the miliolitic cliffs mark the sea-facing eroded flanks of these old dunes. A linear belt about 2 km wide near Methla village and 5 km near Gopnath behind the cliffs, is occupied by this dunal complex forming an undulating topography consisting of numerous mounds rising upto 5 m above the interdunal depressions. These consolidated dunes, which represent the earliest coastal aeolian accumulation support a number of stone quarries (Plate V.5).

Plate V.3. Development of cave in Gaj rocks by strong wave action. Miliolite dunes resting over Gaj rocks form cliffs at Methla.

Plate V.4. A miliolite stack at Madhuban.

Plate V.5. A miliolite quarry in a consolidated dune near Jhanjhmer.

Plate V.6. A well developed beach with sandy ridge in the background near Methla.

Dunes of the next younger generation also of miliolitic material, rest over the older dunes and are only partly consolidated supporting some vegetation. These mostly occur nearer to the high water line and form longitudinal ridges either parallel to the coast or oblique to it. To the south of Methla village the partly consolidated dunes occur as a continuous 2 km long coastal ridge. Whereas east of Methla upto Jhanjmer such dunes are represented by discrete oblique ridges several hundred metres long. The semiconsolidated dunes are perhaps the products of the regressive phase of the last higher (Flandrian) strandline.

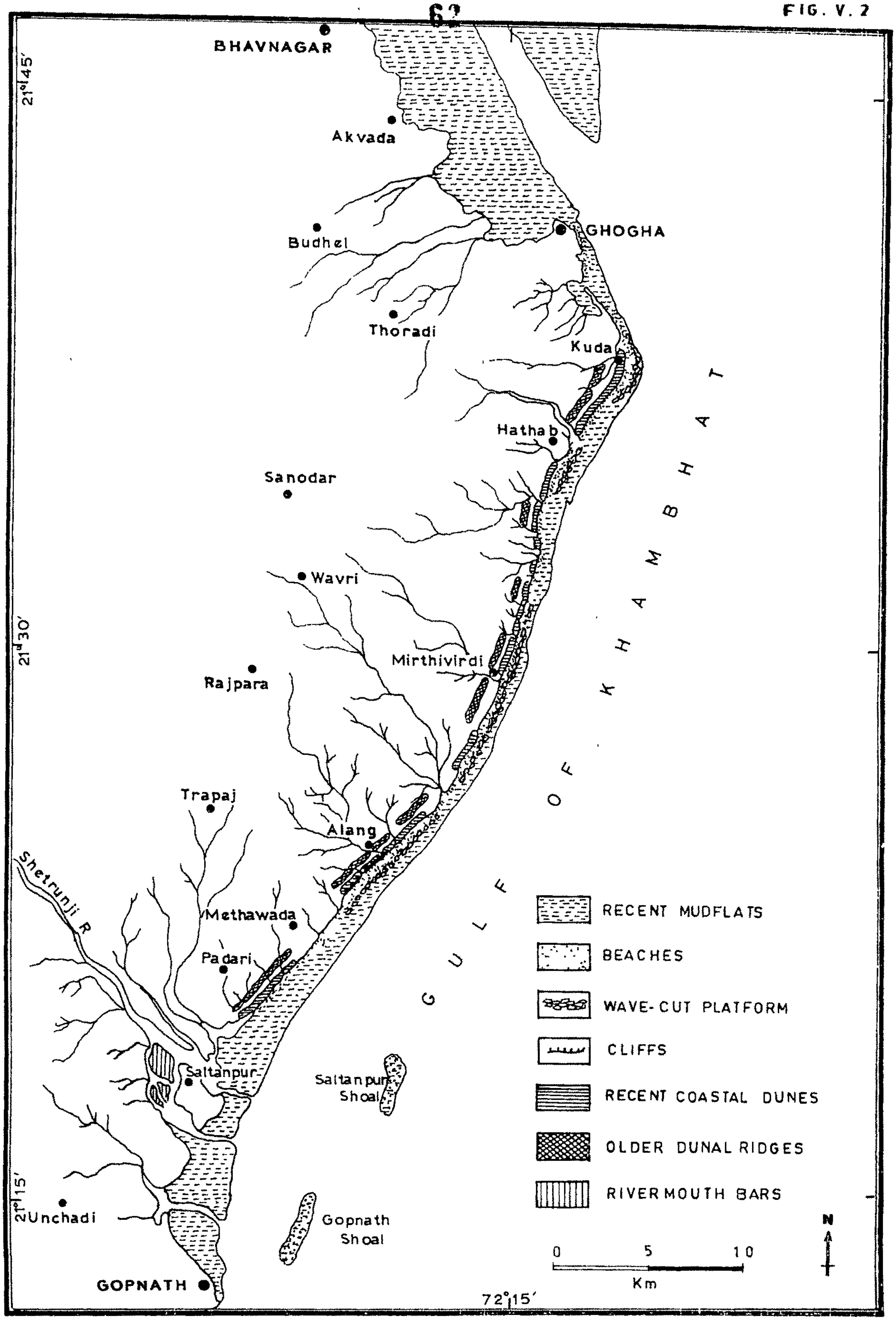
The youngest aeolian accumulations of carbonate sands are seen to comprise unconsolidated dunal heaps which are transient and keep on shifting and changing forms on account of the action of wind. These dunes represent present day beach material.

Beaches occur almost uninterruptedly all along the length of the coast and are observed to form a blanket over the rocky intertidal platform (Plate V.6). The thickness of the sand accumulation is variable, at places it could be several meters thick while at other it is only a few centimeters in thickness so much so that rocky platforms commonly peep out. The beach development is more or less restricted to crescentic coasts between the various headlands. At most places the beach sands abut against the rocky cliffs.

Mudflats are scarce along the actual coastline. However a part of the extensive mudflat deposit of the Methla creek (west of Methla village) falls within the limit of thé study area. The Methla mudflats occupy about 8 sq.km and represent a lagoonal creek.

The GOPNATH-GHOGHA-BHAVNAGAR segment (Fig.V.2) from the point of view of landforms and their genesis, is quite distinct from the other two segments. Its southern end marks the Shetrunji river mouth and represents an estuarine delta; the latter forms a broad triangular mouth of the Shetrunji river which after flowing for a considerable distance along a straight channel, abruptly debouches itself ~~debris~~ in the Gulf. Today the river is somewhat depleted in water (partly because of the Shetrunji dam) but in the recent geological past it must have been carrying a lot of water. Ganapathi (1981) has described in detail the various landforms of this estuarine delta. Based on his work, the present author has divided the Shetrunji river delta plain complex into subaquous and subaerial delta. The subaquous delta represents the area below high water line and the subarial delta is the portion of the land slightly higher than the high water line. The landforms like distributary channels, river mouth bars, barrier ridge complex, intertidal mudflats, raised mudflats, lagoons, relict alluvium and

FIG. V. 2



GEOMORPHIC MAP OF GOPNATH-GHOGHA-BHAVNAGAR SEGMENT terraces are observed in this estuarine deltic region. The morphology and evolution of various landforms reveal that the river has laterally shifted its course several times during the recent geological past. Here the estuarine delta plain above the high water line is dissected by several distributary channels. A prominant mouth bar is seen developed and according to Ganapathi (1981) three different sea levels can be recognised, two as offshore features (Saltanpur and Gopnath Shoals). The Saltanpur shoal is older than Gopnath shoal. The youngest mouth bar is the one on which the village Saltanpur is located and which is presumed to have grown during the Flandrian transgression. An elongated sandy ridge which extends upto Methawada village separates the coastal plain from a narrow backshore lagoon and the raised mudflat area. This sandy ridge is 6 km long and its width varies from 50 m to 1000 m. This barrier ridge complex is now seen to consist of (i) beach, (ii) spit and (iii) dunal ridges. The foreshore of the Shetrunji delta is more or less horizontal, and the area between the high and low water lines marks intertidal mudflats, the width of which varies from 1 km to 2.5 km. The area to the north and south of the two Shetrunji main distributary channels, gently rise above the high water line upto a height of 6 to 8 m and form raised mudflats.

The coastal geomorphology to the north east of Shetrunji towards Ghogha is different, essentially dominated by non-miliolitic deposits and lacking in well defined cliffs and dunal material. The coastline features here comprise erosional landforms like, backshore rocky undulating terrain, cliffs, wave cut platforms, and depositional landforms like backshore alluvial plains, coastal dunal ridges, beaches, river mouth spit bars and mudflats.

The erosional features are on the whole less pronounced. The backshore coastal plains provide an undulating rocky landscape (Plate V.7) consisting of numerous randomly occurring mounds and low hills. They are either of laterites and Lakhanka rocks in the southern part (Methawada to Hathab), or of Gaj rocks in the north (Hathab to Ghogha). The average elevation of the ground is about 20 m with numerous hillocks rising as high as 20 to 25 m above the ground. This rocky coastal plain slopes down with a steep gradient towards the shoreline, forming cliffs, occasionally, but mostly merging gradually into the intertidal rocky platform.

The intertidal rocky platform is broad, of the order of 200 m to 1 km. Ganapathi (1981) has described it as a very gently seaward sloping rocky plain excavated out of

Plate V.7. A panoramic view of the undulating rocky backshore coastal plains near Alang.

laterites, Gaj and Lakhanka rocks. Good examples of this wave cut platform are seen near Ghogha, Kuda and Alang (Plate V.8a.b) The platform at most places is seen covered by a thin cover of mud throughout the year except during monsoon and immediately after it, during which period the muds are washed out into the sea.

The depositional landforms are equally varied. The backshore to the south of Methawada typically marks an alluvial plain formed by the material brought by the Shetrunji river. In this part of the coast another very striking depositional landform is that of the longitudinal dune ridges, although taken as a whole, the phenomenon of dune formation is comparatively not so pronounced. But even then two generations of backshore dunal ridges are observed, (i) a recent dune ridge immediately behind the beach, and (ii) an ancient beach and dune topography just at the backside of the present day dunes. From Methawada village to as far north as a little beyond Kuda guest house, recently formed coastal dune ridge complex is observed parallel to the shoreline. This coastal dune accumulation is seen cut at various places by a number of inflowing streams. The width of this dune complex varies from 10 m to 50 m and height from 3 m to 20 m and its top surface shows a characteristic undulating topography.

Plate V.8a. Rocky platform with a steeply inclined lateritic cliff at Alang.

Plate V.8b. Rocky platform of Gaj rock at Kuda.

An older dune beach complex is seen to have developed just behind the present day dunes. These ancient dunes with remnants of associated beaches are observed to extend from north of Padari village upto Hathab Bungalow, and provide evidence of a past higher strandline.

From Ghogha to Methawada beaches occur as a continuous coastline feature. Inlandward, the beaches abut rather abruptly against the recent coastal dunes, while seaward they die out under a thin cover of mud (Plate V.9) or terminate against rocky platform in the littoral zone. The beach width varies from a few meter (in the south) to as much as 500 m near Kuda village. The beach slopes are gentle and vary from 30 minutes to 3 degrees. The sands are composed mainly of quartz, agate, chalcedony with subordinate proportions of shell and rock fragments, and their grain size varies from very fine sands to very coarse pebbles and gravels.

Mudflats are also prominent and occur continuously from Gopnath to Bhavnagar. All along the coastline these rest directly either over the beach sands or over the rocky platform of Gaj, laterite or Lakhanka formation. Up to Ghogha, they are rather increasing in thickness towards the low water line. Between Ghogha and Bhavnagar the mud accumulation is thicker. The width is variable,

Plate V.9. A panoramic view of the backshore coastal dunes, beach and intertidal mudflats at Hathab Bungalow.

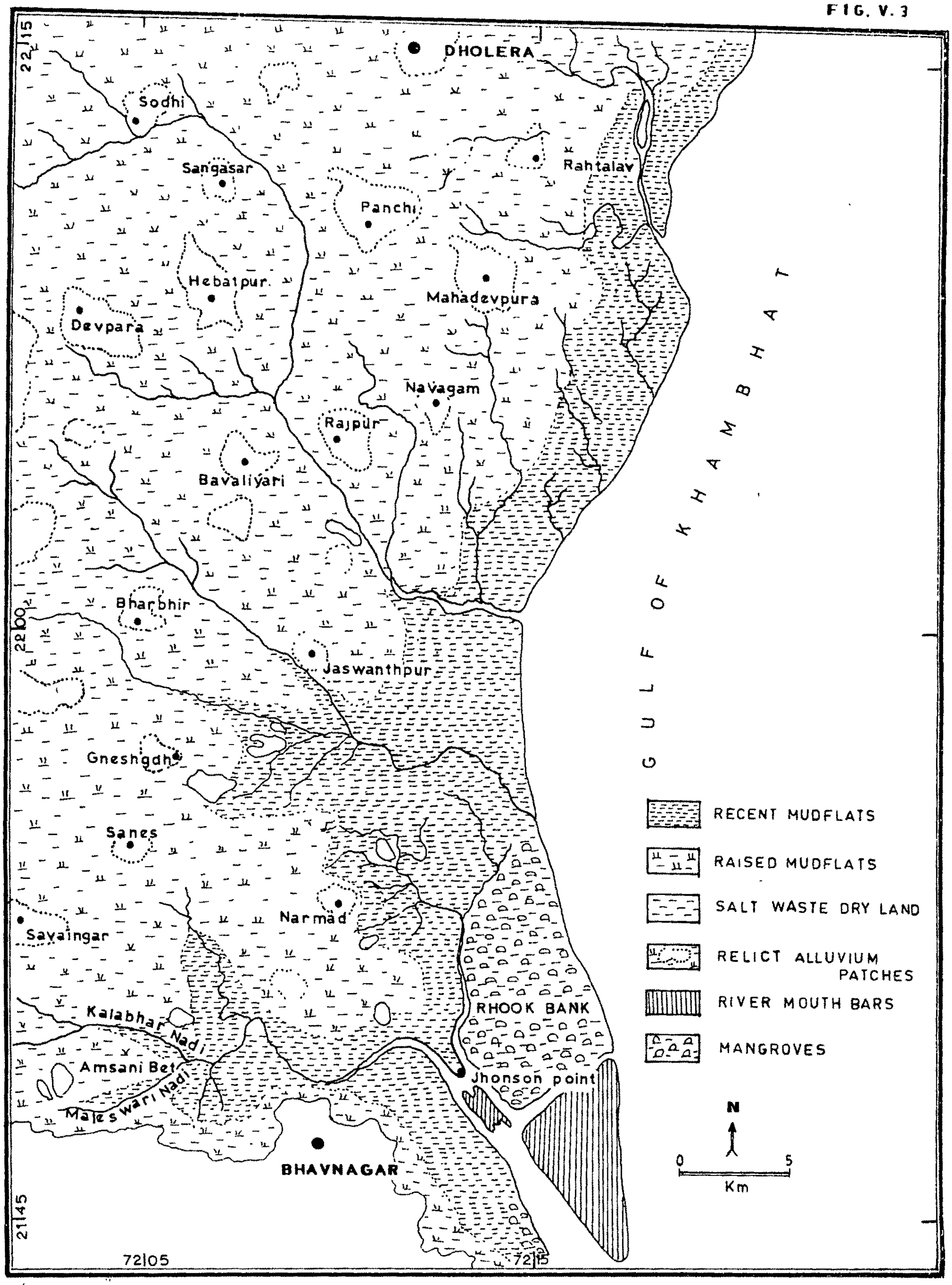
more between Ghogha-Bhavnagar and Methawada, and near Kuda it nearly disappears. The mudflats between Hathab to Kuda show numerous small tidal channels normal to the coast.

The BHAVNAGAR-DHOLERA segment is in fact that part of the Gulf coast which represents a merger and transition of Bhavnagar creek with Sabarmati river mouth. This segment is quite different from the earlier described segments, consists of landforms of unconsolidated sediments related to the fluctuating strandline of the Late Quaternary (Fig. V.3). From the point of view of landforms, this segment is divisible into (a) the tidal creek of Bhavnagar and (b) the coastal areas north of the Bhavnagar creek upto Dholera. Bhavnagar creek provides a complex assemblage of tidal landforms flanking the rocky terrain to its south and essentially comprising river mouth of Kalubhar river.

The tidal creek of Bhavnagar (Plate V.10) constitutes the mouth of Kalubhar river. This river flows along an E-W fault, named as Kalubhar Fault by Ganapathi (1981). In this extensive creek, recent mudflats, raised mudflats, mangrove swamps, point bars and islands and offshore bars are observed.

During high tides the Gulf waters enter through this creek and flood vast inland portions, as the whole

FIG. V. 3



GEOMORPHIC MAP OF BHAVNAGAR- DHOLERA SEGMENT

Plate V.10. View of Bhavnagar creek showing a small tidal channel in the foreground and extensive mudflats with mangroves in the background.

area is low and almost gradientless. The tidal waters have been bringing a lot of suspended sediment from the Gulf and deposit them in the intertidal area to give rise to the mudflats. As the river Kalubhar carries very little water except during monsoon months, increasing siltation of this creek has been observed. Raised mudflats inlandward are seen rising gradually above the present high water line upto heights of 6 to 8 meters, supporting a few shrubs and grasses. These represent an earlier littoral zone when the sea level was a few metres higher than the present.

On both sides of the Bhavnagar creek, mangroves are seen to grow in the littoral zone mud. Extensive mangrove swamps are observed on the Rhook Bank in between the Bhavnagar creek and Malcolm's Channel and also on either side of the Bhavnagar jetty.

The mudflats are dissected by numerous tidal channels which also happen to be the mouths of various rivers flowing from the west. A number of point bars and islands are seen within the creek. Jhonson Point provides a good example of a point bar which extends almost NW-SE. A bar island is also seen near the mouth of the Bhavnagar creek.

Mudflats represent the most dominant landform stretching continuously from Bhavnagar to Dholera and beyond across Sabarmati river mouth to as far as Khambhat. Restricted between the low and high waterlines the mudflats are several kilometers wide at most places, onshoreward gradually merging into the raised mudflat or entering inlandward through tidal creeks and channels (Plate V.11). The inner limit of the mudflats is highly crenulated whereas seaward they end up into numerous shoals and mud-banks. Being under the constant influence of tides, these mudflats are criss-crossed by a network of tidal channels. At many places the flats are seen supporting growth of mangroves, some time quite luxuriant.

Six tidal river channels dissect the coastal mud flowing from the west or north west. These are essentially ancient tidal channels ~~related~~ and today they represent low gradient inflowing streams which carry little water except during monsoon. Through these openings seawater enters for several kilometers and deposits tidal mud along their flanks.

A major portion of the backshore area, beyond the present day tidal influence comprises ancient mudflats which are now above the high water line. These are seen as vast featureless wasteland (Plate V.12) with very negligible gradient such that during periods of strong monsoon and

Plate V.11. Tidal creek of Baniya Khadi near Golatalav, raised mudflats in the background.

Plate V.12. A view of gradientless mudflats at Motitalav near Bhavnagar which gets inundated under monsoonal stormy conditions.

stormy conditions they get flooded under knee deep water. These flats do not support any vegetation. Altitudewise, these plains rise only a few meters above the normal H.W.L. The deposits of these raised mudflats are dominantly silts with small percentages of fine sands and clays.

The most interesting feature of this coastal segment is the occurrence of discrete patches or 'bets' of alluvium rising above salt wasteland. These 'bets' are easily recognised in the field by their vegetation. It is observed that these alluvial patches show a slightly higher elevation, a difference of as much as 2 to 5 meters above the ground level. It is on such alluvial islands that the various sparsely populated villages and hamlets are located. Although the soil is no doubt somewhat saline but because of its coarser texture it supports reasonably good agriculture based on monsoonal rains. It is obvious that these irregularly shaped alluvial islands represent an older dissected alluvial topography which was inundated by the last sea transgression.

The landforms of this coastal segment point to their genesis closely related to a fluctuation of the Quaternary strandline.

BHAL BLOCK

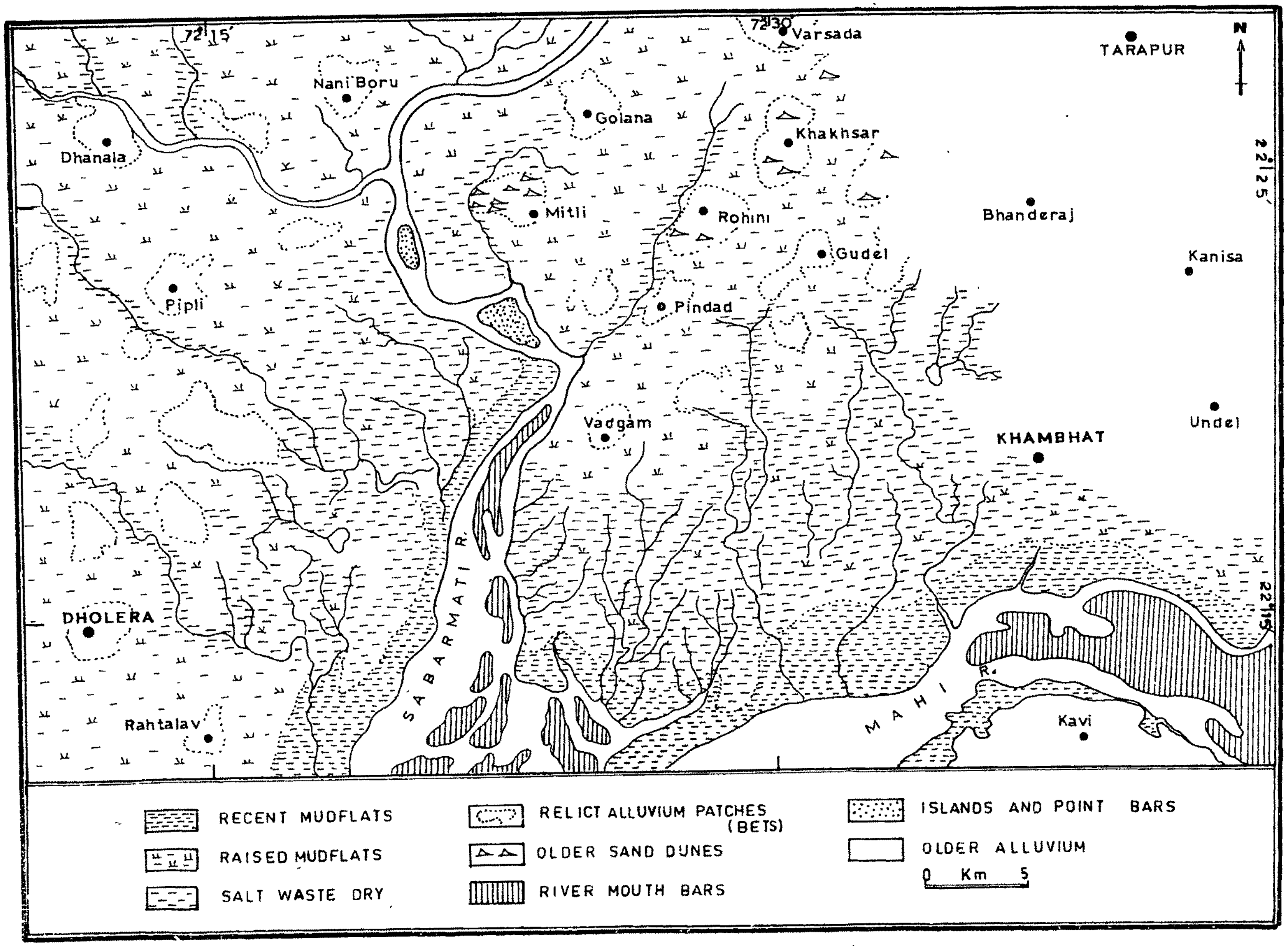
The limits of the Bhal block are marked by Bhadar river on the Saurashtra side and the town of Khambhat in the

Mainland. It marks a transitional zone and for the most part comprises a terrain which comes under the influence of the fluvial regimes of the rivers Sabarmati and Mahi and strong tidal effects of the Gulf. Hundreds of square kilometers of this coastal block are made up of comparatively low and featureless terrain most of it being either tidal mud deposits or saline wastelands (Fig. V.4), In fact the Bhal area consists of sediments that were deposited along river mouths under fluctuating strandlines, and at present the various landforms mostly depositional are related to the depositional action of the rivers or that of the sea. Following coastal landforms have been identified:

1. Mudflats
2. Raised mudflats
3. Alluvial plains
4. Alluvial islands (Bets)

Mudflats are the most extensive landforms. These are replete with a number of tidal channels and are dissected by the irregular shaped estuarine river mouths of Sabarmati and Mahi. These river mouths themselves are highly muddy, the tidal waters entering for several kilometers inlandward. The river mouths themselves consist of a network of distributary channels so much so

FIG V.4



GEOMORPHIC MAP OF DHOLERA - KHAMBHAT SEGMENT that the actual mouths of the two river are almost choked with rows of linear mudbanks.

The ancient mudflats above the present high water line also constitute an important landform. Rising above the high waterline to as much as 10 meters above the mean sea level these are seen to occupy large areas of dry saline wasteland which usually get flooded during rainy season. These show an almost imperceptible slope towards the sea. On account of their flatness, during monsoon rain water or sea water during stormy conditions pushed landward, stagnates and causes waterlogging. This fact is better seen in the toposheets and on Landsat imageries in the form of a network of channels; these channels remain dry except during the monsoon. The raised mudflats either flank the present day tidal mud flats or occur as linear tracts flanking the river channels.

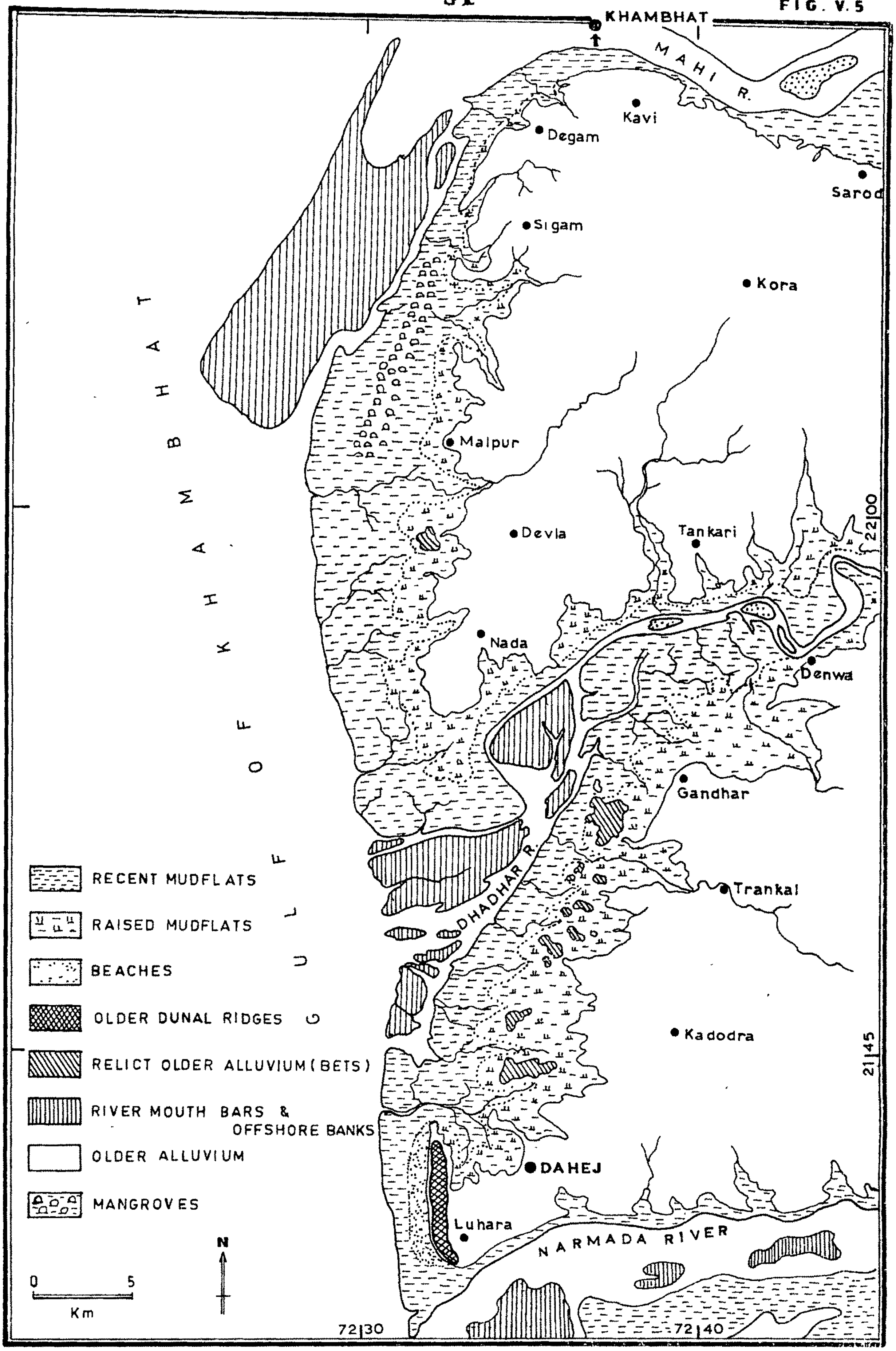
Within the raised mudflats occur patches of alluvium as 'bets' or islands. These rise 4 to 5 m. above the ground level and are easily recognised by the vegetation that they support. Villages have grown on these alluvial islands. Some cultivation is also supported.

The raised mudflats merge into the coastal alluvial plains. These alluvial areas are very fertile. An interesting feature of this alluvium is the occurrence of sporadic dunes resting over it, and made up of quartz sands with a fair proportion of foraminifera. A good cluster of east-west trending dunes are seen near the village Mitli. Similarly some scattered dunes are recorded on the areas at the villages Rohini, Varsada, Khakhsar etc. Interestingly these partly consolidated dunes are related to the sea inlets through a dissected alluvial terrain, the dunes having formed during the withdrawal of a transgressed sea (Patel & Merh, 1982).

MAINLAND BLOCK

A major part of the KHAMBHAT-DAHEJ segment (Fig. V.5) comprises a thick accumulation of Quaternary fluviatile sediments and its landscape provides good example of a drowned alluvial coast. Subsurface investigations by the workers of ONGC (personal communication) have established a thick accumulation (approximately 150 m) of Quaternary sediments that rest over the marine Pliocene rocks. Neotectonic subsidence has been responsible for the accumulation of such an enormous alluvial thickness. It is interesting to observe that the rivers Dhadhar and Mahi which deposited this thick pile of alluvium, were themselves later on responsible for carving out cliffy channels within their own deposits. This phenomenon of river rejuvenation has been attributed by Patel et al. (1985) to a major regression of sea. The

FIG. V.5



GEOMORPHIC MAP OF KHAMBHAT - DAHEJ SEGMENT present author would however not rule out some minor uplift as well in Sub-Recent times.

The following landforms are observed in this segment:

1. Estuarine river mouths
2. Foreshore mudflats and offshore mudbanks.
3. Older mudflats
4. Relict alluvial patches within mudflats (Bets)
5. Beaches and sandy ridges

The estuarine river mouths of Mahi and Dhadhar are broad, muddy and extend for several kilometers inland. During high tides, the sea water enters through the river mouths to fairly long distances, as a result of which extensive accumulations of tidal muds are encountered along the estuaries of the two rivers. The mouths of the river Mahi during low tides reveals vast stretches of muddy shoals across which the river flows through a network of braided channels. The width of the mudflats at the mouth of the river Mahi could be as much as 4 to 6 km. The Dhadhar river mouth provides a good example of the choking of the river due to increasing mud accumulation, so much so that the river meanders, bifurcates and then joins again while flowing within the muddy deposits. The N-S extension of the mudflats along this river mouth are of the order of

8 to 10 km in width at its western extremity. In both the cases, the tidal water enters inlandward to distances as much as 50 km.

The entire length of this segment is characterised by intertidal mudflats (Plate V.13). These flats are dissected by numerous unnamed tidal creeks and channels, the high water line being thus highly crenulated. The width of these flats vary from 500 m to as much as 8 km. Mangrove growth is also quite prominent in some places within the mudflats.

Another related feature of this coastal segment is the occurrence of offshore mudbanks and shoals. Mudbanks of variable diamensions and shapes occur in abundance between the mouths of Mahi and Dhadhar river. Most of the mudbanks near the Mahi river mouth are sandy and silty while those of Dhadhar are silty and clayey. Most of them get submerged during high tide. These mudbanks have been observed to change their configuration frequently in course of time or even seasonally depending upon the sediment supply and the pattern and intensity of the tide controlled depositional and erosional processes operating within the Gulf.

Older mudflats are seen to occur just above the present day high water line. These are the usual featureless barren areas characterising salty wasteland (Plate V.14). As

Plate V.13. Intertidal mudflats at Tankari.

Plate V.14. Raised mudflats at Devla.

compared to Saurashtra coast, the extent and width of these raised mudflats are much less. These saline barren flats inlandward show a well defined junction with the alluvium. At several spots these raised mudflats are now seen under cultivation (Plate V.15). Such cultivated patches represent portions which have been washed by rain water for a long period of time, as a result these are now used as agricultural land.

The backshore alluvial plains form almost a flat terrain. Between the rivers Mahi and Dhadhar these plains show a gradual southwesterly slope whereas to the south of Dhadhar river the slope is westward. Significantly these plains do not support any major consequent streams, the few that occur flow slopeward either meeting Dhadhar or Narmada. Only a very few flow westward scross the alluvium to meet the Gulf. The channels in all cases are invariably entrenched and cliffy, 2 to 3 meters deep.

Alluvial islands or 'bets' occurring within the mudflats comprise another conspicuous landform. These islands rise a few meters above the mudflats or the saline wasteland. Of irregular shape and size, these vegetated patches represent alluvial relicts of the past and point to a sequence of Quaternary sea level changes : an early regression followed by a late transgression of sea, the

Plate V.15. Raised mudflat now reclaimed into agricultural land at Devjagan temple.

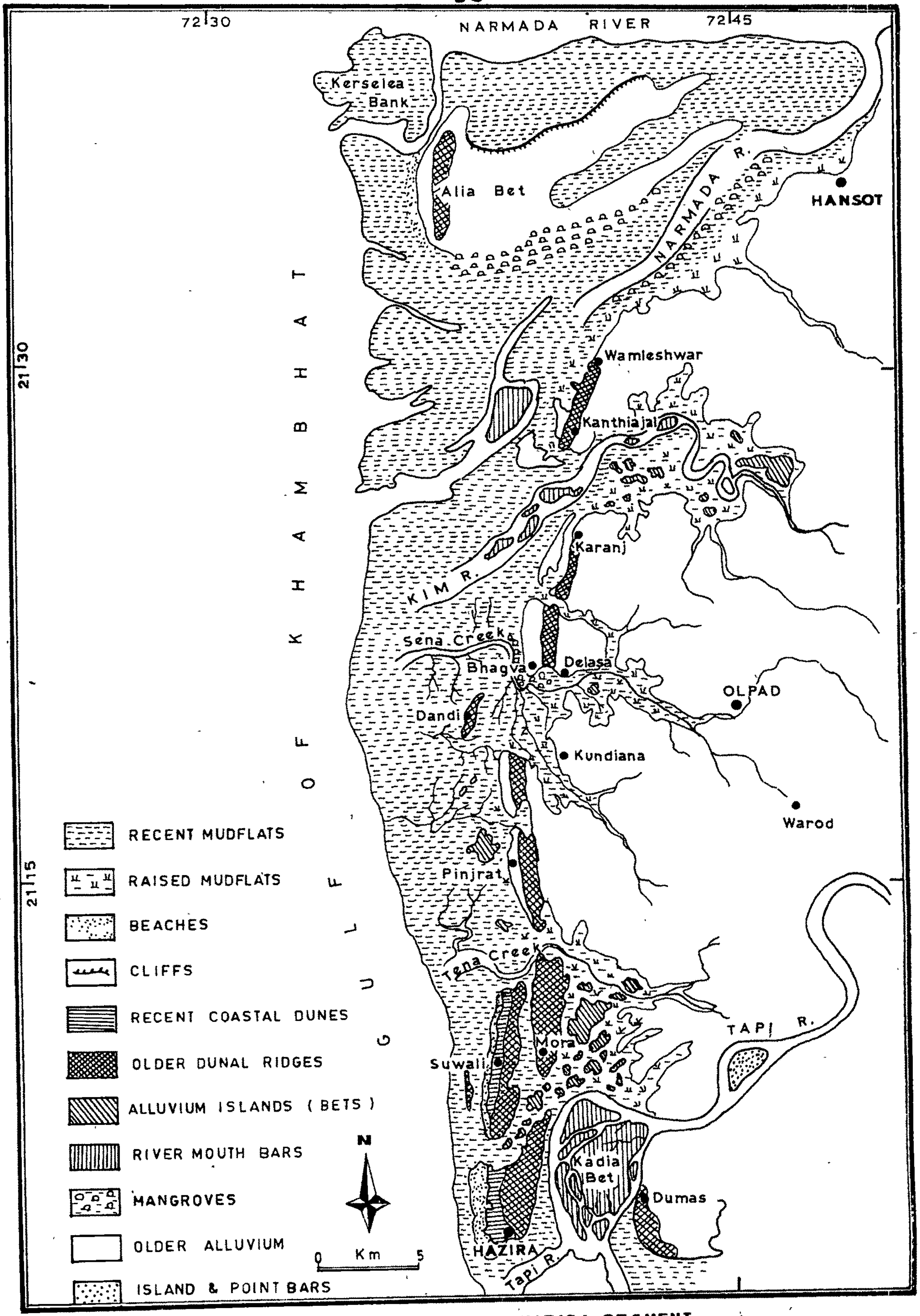
Plate V.16. Sandy beach at Dahej jetty.

relict patches representing an eroded alluvial topography of the period when a much lower strandline was located further in the west (Patel et al.,1985). The subsequent transgression (Flandrian) resulted into the drowning of the river valleys and encirclement of the elevated portion of a dissected alluvial coast by tidal waters. These alluvial islands support considerably good vegetation and are easily recognized in the field.

The phenomenon of sand accumulation as beaches and coastal ridges is negligible. Sandy beaches are restricted only between Dahej bandar and Luhara village (Plate V.16). These represent present day accumulation,about 500 m wide, and consist of an admixture of coarse to fine sand. An older sandy ridge is also encountered at the back of the beach which extends from south of Ghugaria creek (Dahej Bandar) upto Luhara light house at the Narmada river mouth. Varying from 200 to 500 m in width the ridge rises 5 to 10 m above the alluvial plain. This sandy ridge at present 8 to 10 m above the present sea level is correlatable to the last higher strandline.

The HANSOT-HAZIRA segment (Fig.V.6) is different from the northern Khambhat-Dahej segment both geologically and geomorphologically. Also the coastal marine processes like tidal currents, wave action etc. play a different role. As

FIG V.6



GEOMORPHIC MAP OF HANSOT- HAZIRA SEGMENT a result the coastal landscape and the various geomorphic features here are also different.

In this segment the thickness of the alluvial cover has been reported to be comparatively thin (about 100 m at its maximum near Narmada mouth) and rests directly over the Jhagadia Formation of Middle Miocene to Upper Miocene age (Agarwal,1984). The relatively smaller thickness of alluvial cover is in contrast to the great alluvial thickness of the Khambhat-Dahej segment. Located to the south of 'Narmada-Geofracture', tectonically this segment has been found to show much less vertical tectonism during the Quaternary period. Hence, its coastline features provide a better glimpse of the Late Pleistocene and Holocene sea level changes.

This coastal segment is characterized by the development of prominent sandy ridges parallel to the coast and a highly crenulated shoreline, replete with estuarine creeks which mark the mouths of numerous rivers, such as Kim, Sena and Tena. These rivers meet the Gulf after meandering through the alluvium, their mouths typically comprising tidal creeks which allow tidal waters to enter inland spreading over large areas. The southern limit of this segment is marked by a fault (Raju, 1968; Kaila, 1982) along which the Tapi river is flowing. The alluvial thickness increases progressively seaward, which ultimately goes below the ancient and present day mudflats. Landward the thickness decreases and dies out towards east and south.

The geomorphic features observed in this segment are as under :

1. Estuarine river mouths and tidal creeks
2. Recent mudflats
3. Raised mudflats
4. Sandy ridges
5. Beaches
6. Alluvial plains
7. Relict alluvial pacthes or 'bets'.

The rivers Narmada and Tapi (alongwith Mindhola) form the two major estuaries. The eustarine river mouths of smaller rivers Kim, Tena and Sena also form tidal creeks. The estuarine mouth of Narmada is funnel shaped with a very wide opening (about 25 km) and a well developed mouth bar of 'Alia Bet'. 'Kerselea bank' is another small bet near the mouth of Narmada. Alia Bet is a huge island having an area of approximately 48 sq.km a major portion of it, which is above the highwater line, supports a thick 'babul' forest. The areas which are under the influence of tides, are seen supporting a luxuriant growth of mangroves. A large part of Alia Bet goes under water during high tide. Mudflats are encountered in its eastern and southern parts, while in the western part, the littoral zone is sandy; the northern boundry is marked by 3 to 4 m high cliffs. The configuration of this island appears to be constantly being modified with passage of time. Nayak & Sahai (1985) on the basis of scrutiny of topographical maps and Landsat imagery have shown a distinct shifting of the bet southward in the course of last 100 years. The author has also personally recorded that during low tide, the Alia Bet today remains almost connected with the left bank of the river mouth.

The presence of a sandy ridge on the western flank of the Alia Bet, which appears to be in continuation with the ridge of Kantiajal, is also an intriguing phenomenon. Though the Alia Bet for all purposes typically resembles a mouth bar, its true nature is according to the author, not yet fully understood. It is not improbable that this depositional feature has something to do with the modification of the Narmada river course.

The Tapi estuarine mouth is comparatively smaller. Somewhat 'hook' shaped, it shows considerable complexity and heterogenity of coastline depositional and erosional processes. As a result of this, the total picture of this river mouth is quite confusing. The most significant feature is the mouth bar 'Kadia Bet' having an area of approximately 11 sq.km. The Kadia bet itself is criss crossed by numerous tidal channels thereby imparting a highly dissected shape to it. A striking feature of the Tapi river mouth is presence of the adjacent Mindhola creek to the immediate south which is dominated by a wide inland lagoonal mudflat. The alluvial patch between Tapi and Mindhola, perhaps formed an ancient sandy mouth bar and on it are located the famous holiday site of Dumas and the port of Magdalla. The actual bank of the river rises approximately 5 m above the water level.

Estuarine creeks, which receive waters from local rivers, are one of the most striking geomorphic features of this coastal segment. The vast stretch of the continuous mudflats extending from Narmada to Tapi, are flanked landward by these creeks, the prominent ones being those of Kim, Sena and Tena. The creeks extend for several kilometers onshoreward, through which tidal waters are pushed for long distances. Significantly the rivers do not carry much sediment load, and the estuarine deposits mainly consist dominantly of the reworked sediments of the littoral and offshore areas, brought by tidal waters and mixed with fluvial material transported by the rivers.

The merging of the tidal deposits of the various river mouths and the smaller estuarine creeks described above, has given rise to the broad stretches of mudflats encountered throughout the entire length of this coastal segment. On an average these mudflats are 4 to 5 km wide but occasionally their width is as much as 10 km. e.g. near Sena and Tena river creeks. The Kim river meanders for about 20 km within these mudflats before meeting the Gulf. Similar phenomenon is also shown by Sena and Tena rivers. These intertidal mudflats are characterised by numerous channels through which the water flows back with the receeding tide (Plate V.17). There are a few unnamed perennial channels which criss-cross the mudflats. Within the mudflats, occur submerged remnants of ancient sand ridges. Mangroves are also observed to grown in some places along the coastline. Occasionally the growth is seen to be very luxuriant, e.g. near the village Bhagva.

Raised mudflats, which are at present above the high water line are also observed in this coastal segment. These mudflats are seen increasing in prominence southward. Comprising typically barren areas made up of dry saline wasteland, these occur along the fringes of the tidal creeks and lagoons and occupy some of the interdunal depressions between the ancient sandy ridges. Essentially these are the remnants of older mudflats, products of the last higher

Plate V.17. A tidal channel within the mudflats at Dandi.

Plate V.18. Well developed sandy beach at Hazira.

strandline. The high sea level as recorded on the basis of these raised mudflats today is + 8 to + 10 m.

In comparison to the Khambhat-Dahej segment, sandy beaches are better developed. A good sandy beach 50 m to 300 m wide is located near Hajira (Plate V.18). The formation of the beach is mainly on account of the (i) destruction of the older dune ridges and (ii) onshore accumulation of sandy material by wind generated waves.

Interesting depositional landform restricted to this coastal segment are the older coastal sand ridges occurring within the mudflats or in the backshore (Plate V.19 & 20).

These sandy ridges have been reported to belong to several generations (Patel et al., 1985). These ridges give valuable information in respect of the past strandline. Three sets of almost parallel but discontinuous ridges are encountered. The two inner ones are quite prominent while the last outer one is fragmentary and represented by outcrops of smaller dimensions. The easternmost ridge is present throughout the coastline and varies in dimensions. From Wamleshwar to Kanthiajal, it is 6 m to 10 m high, from Karang to Delasa about 20 m high, between Sena and Tena creek, the average height is 6 m, and to the south of Tena creek up to Hazira the ridge is 6 m high. The ridge shows a variable width of 1 to 2 km. The next ~~ridges to its~~

Plate V.19. Stabilised older coastal dunes at Hazira.

Plate V.20. Eroded older dune ridges at Vasna. Windblown sand resting against these dissected dunes.

ridges to its west is smaller and rises only 2 m to 6 m and is separated from the former by raised mudflats. These two ridges appear to coalesce southward near Hazira keeping the average height of 6 m though the highest point could be as much as 10 m.

The relicts of the westernmost (offshoreward) ridge are fragmentary and sporadic, represent the oldest coastal dune deposits when the sea level must have been several meters lower than the present, and which got drowned during the Holocene transgression when the sea level went up for the last time by a few meters. Small projections of this ridge are seen rising above the present day mudflats and form elongated sandy 'bets'. The middle row of the three sandy ridges is obviously related to the present day shoreline while the easternmost ridge is related to the last tranggressive strandline of the past (Flandrian). It is interesting to observe that though the older sandy ridges themselves are fairly consolidated, their tops are covered with present day loose sand.

In contrast to the coastline to the north of Narmada, the alluvial plains in this coastline segment are less extensive and their vertical thickness has also been reported to be much less. The alluvium is reported to be directly resting over Miocene rocks. Near the coast, the alluvium forms cliffs only in the inner parts of the mouths of the rivers; Narmada, Tapi and Kim. At most places near the coastline, it tends to go below the raised mudflats. The alluvial plains show a very gentle slope seaward, showing an altitude difference of only 4 m to 5 m within a distance of approximately 20 km. All the streams in this segment follow the westward slope and meet the Gulf.

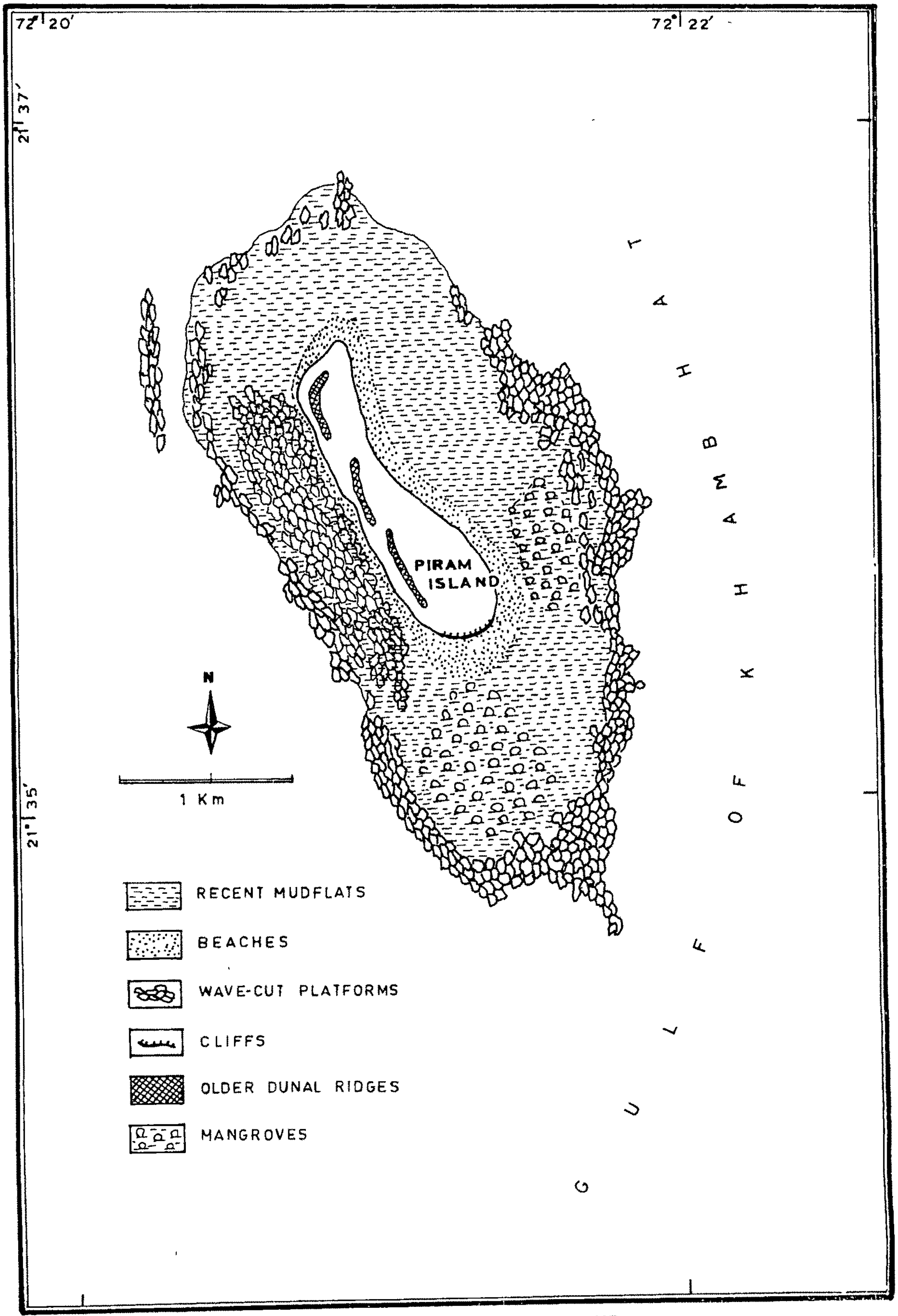
Alluvial islands within the mudflat (bets) are common and conspicuous enough, especially in the vicinity of Tapi and Tena rivers. As usual, they are easily recognised by the slight elevation and the vegetational cover.

PIRAM ISLAND

Besides all the above-described coastal segments, the offshore island of 'Piram' constitutes an independant geomorphic unit, which in the strict sense marks an offshore feature. Geologically it is important from the point of view of its mammalian fauna (Fedden, 1884; Rao & Jain, 1959; Datta, 1959) and also geomorphically for its landscape and landforms. The island (Fig. V.7) is elongated in NNW-SSE direction having area of 1.5 sq.km with approximately 7.5 sq.km. of intertidal area (Plate V.21 & 22). Essentially controlled by tectonics this island shows several landscape features, viz. beaches, rocky platforms, dunes and cliffs.

Mudflats form the most extensive feature, confined to the vicinity of low water line on all sides of the island. These mudflats terminate landward against rocky

FIG. V. 7



GEOMORPHIC MAP OF PIRAM ISLAND

Plate V.21. Northwestern part of Piram Island showing a vast intertidal rocky platform.

Plate V.22. Southwestern part of Piram Island showing rocky intertidal area.

platform of the Piram Beds and at some places against beaches. Rocky wavecut platforms occur along the west and south western littoral zone. These platforms are quite rich in mammalian fossil bones. Coarse to medium sized sandy beaches are seen to develop in the southern and eastern side of the island, the width being about 250 m in the south whereas in the west the beach is only a few meters wide. Growth of mangroves (Plate V.23) is seen to the east and south of the rocky island. The southern part of the island is marked by cliffs of about 5 to 8 m height (Plate V.24). The central part of the island shows a good development of stabilized sand dunes which are around 3 to 4 meters high above ground level. The entire island is covered by a thick 'babul' vegetation.

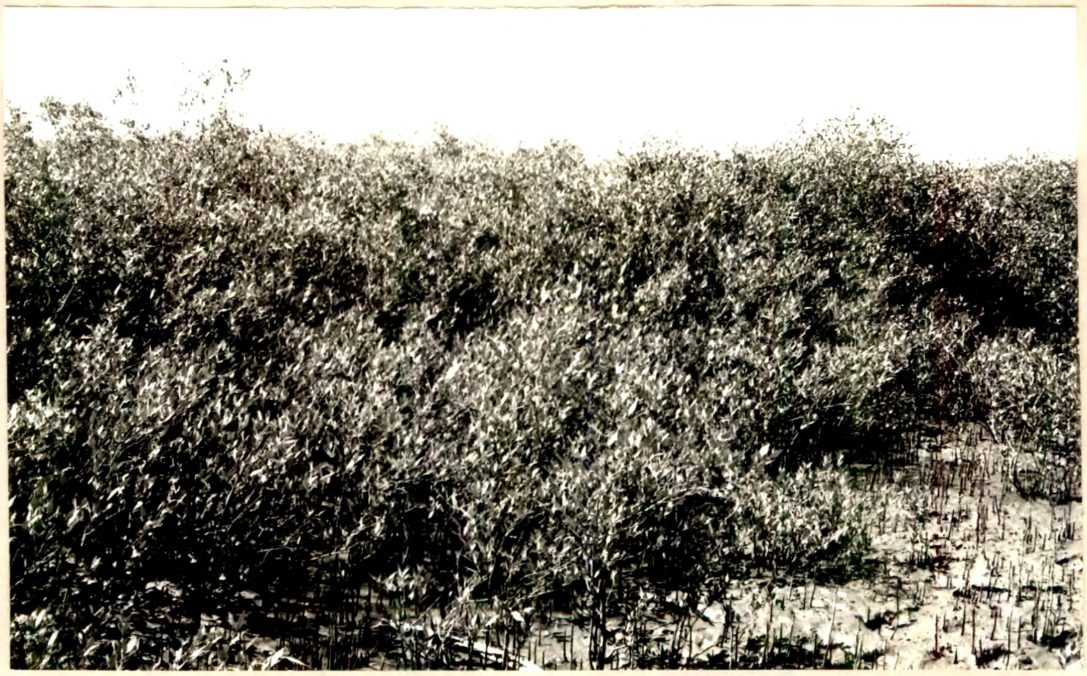


Plate V.23. Luxuriant growth of mangroves at South Piram.

Plate V.24. Well developed beach with a cliff at South Piram.

tributaries of Kalubhar River (E-W channels) and meet the trunk stream at right angles. Similarly, the southwesterly (to the north of Shetrunji river) and easterly and north easterly (to the south of Shetrunji river) flowing streams meet the Shetrunji river as its tributaries. As the area receives less rainfall (average 600 mm /year) its discharge is restricted only to the monsoon months.

Within the limits of the study area, however, a number of ephemeral slope controlled streams originating only a few kilometers inland from the shoreline, exist side by side with older and bigger streams.

Area between Bhavnagar Creek and Sabarmati River

On crossing the Bhavnagar creek, the entire landscape changes to an almost gradientless flat terrain, without any rock exposures and devoid of any rivers worthwhile or streams. Flowing across the barren wasteland are the sluggish rivers of Bhogavo, Bhadar and Sarasdi, which near the actual shoreline come under strong tidal influence. The western fringe of the raised midflats is seen truncating a large number of relict channels which tend to disappear in the saline wasteland of Bhal (Fig. VI.2). As already stated the drainage of this part of the coastal area typically reflects remnants of a drainage system related to the higher strandline. For most part of the year, these streams remain dry and near the coast the water is saline due to tidal influence.

Area between Sabarmati and Mahi rivers

The drainage of the area between Sabarmati and Mahi rivers is equally interesting. There are almost no worthwhile streams in this area. Although this region receives quite a good amount of precipitation (average 800 mm/year) the area is devoid of any significant stream. The high permeability of the horizontally deposited sediments of Sabarmati and Mahi rivers are responsible for the absorption of all precipitation. The area to the north and west of Tarapur village is however characterised by a few remnants of stream channels (Sabarmati paleo-channels) which now have been converted into ponds.

The area in the immediate neighbourhood of the coast is marked by small channels which cut across the salt waste land and fall into the Gulf. These are not the streams in the true sense, but consist of relict tidal channels. At present they carry water during monsoon months only.

Area between Mahi and Narmada rivers

From the drainage point of view the area between Mahi and Narmada is very peculiar. The northern half of this area i.e. between Mahi and Dhadhar though forming an alluvial plain that experiences moderate rainfall, does not have any well developed drainage system. There are few rivers and streams, and the drainage density is also very less.

It is observed that the few streams that exist, originate very near the river Mahi but instead of meeting it, they flow down straight to south, meeting the Dhadhar river. This phenomena points to the strong possibility of southward tilting of the Mahi-Dhadhar segment. The well marked entrenchment of Mahi and Dhadhar tributaries also points to tectonism.

The surface drainage in the area between Dhadhar and Narmada is not at all well defined. In the northern half which falls under the catchment of Dhadhar river, there are no major streams except Rupa Khadi which meets the Dhadhar river mouth near the village Manchhasra. Rest of the coastal segment right upto Narmada, does not have any stream worth mentioning. Almost 22 km inland a minor stream named Bhukhi river flows down in a WSW direction meeting the Narmada at Mehegam village. This stream and its tributaries appear to follow ENE-WSW fractures related to Narmada Rift. The entire portion clearly points to neotectonic uplift such that numerous abandoned relicts paleochannels are recorded at various places.

Area between Narmada and Tapi rivers:

In this coastal area, there are numerous west flowing rivers and streams meeting the Gulf. Here the stream density is quite high in comparison to the earlier described segments. These streams show an overall dendritic pattern and are slope controlled. Agarwal (1984) and Vyas (1984) who have studied some aspects of the drainage of this coastal segment, have stated that a combination of structural features, slope, neotectonism and sea level changes has considerably influenced the drainage development to the south of Narmada river.

PONDS

Ponds, all along the Gulf coast constitute an important source of sweet water, and these man-made storages play a very significant role in improving the living conditions of the coastal population. Essentially comprising impounded bodies of rain water, the ponds not only provide water for domestic needs but also considerably influence the behaviour of shallow phreatic aquifers along the coast. Locations of ponds in the coastal areas have been controlled by the geo-environmental factors of topography, nature of sediments and the rainfall, and local inhabitants have astonishingly identified the right spots for constructing ponds, around which the village have grown subsequently.

In the course of his investigations, the present author realised the importance of this environmental factor, and attempted to obtain as much data as was individually possible. It is worth mentioning that this vital source of fresh water in the form of surface storage and as an important contributor to the sub-surface sweet water supply, has not yet received attention from any developmental agency. No doubt, ponds comprise a relatively small and rather 'unimpressive' natural water resource, but they are very vital for the coastal areas.

It has been observed by the author that in a large portion of the Gulf coast, especially in the Bhal and Saurashtra, ponds are the only source of drinking water, and it is essential that a scientific and feasible programme of harnessing this resource is taken up.

The author visited most of the important ponds, to collect first hand information about their nature (Table 6.2).

CATEGORISATION OF PONDS

Broadly, the ponds fall into two main categories. To one category belong most of the ponds of the Mainland coastal areas, which represent reservoirs of impounded rainwater, built at suitable sites along paleo-channels.

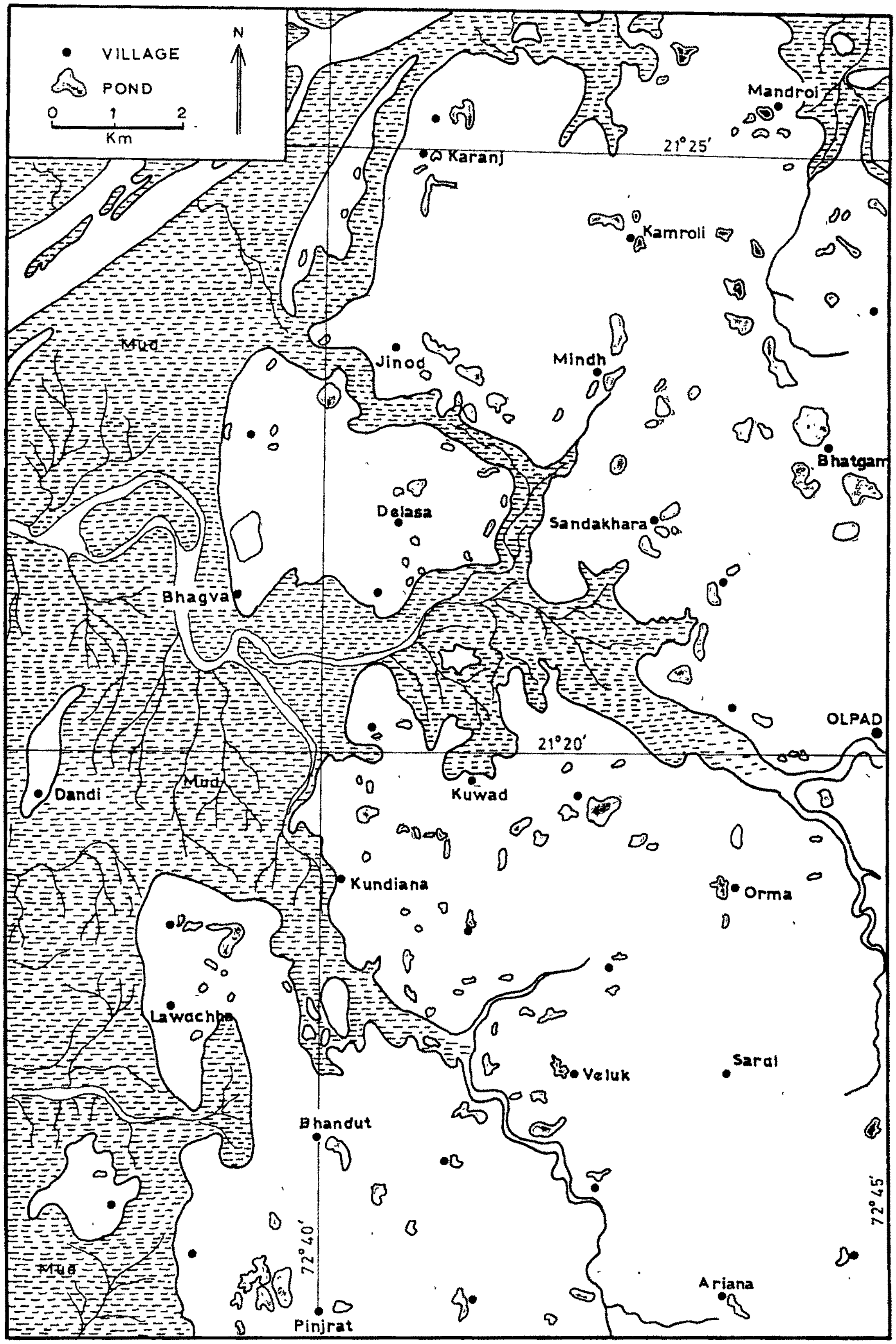
TABLE 6.2 INFORMATION ON PONDS

Block Number	Block area in sq.km	Total number of ponds	Pond density per sq.km	Av. Pond Dimension Area (Sq.km) Max.	Min.	Depth (m)	Type of ponds	Shape of ponds	Pond nature Perennial/ Ephemeral	Remarks
I	1375	84	0.061	340,000	2000	3-8	Dug ponds	Semi circular circular, eliptical oval etc.	Perennial	Ponds are dominantly bigger in size and made for agricultural requirements also
II	1000	85	0.085	90,000	2000	1-2.5	Dug ponds	Circular and semi-circular	Ephemeral	Ponds are located strictly near the village for domestic purposes only
III	1400	498	0.355	159,000	1500	1-6	Mostly dug ponds	Circular and oval	Ephemeral to perennial	East of Khambhat ponds are mostly perennial while in thewest these are mostly ephemeral and their occurrences are irrespective of habitation
IV	1050	270	0.257	125,600	2000	2-5	Mostly dug ponds	Oval circular, eliptical elongated etc.	Ephemeral to perennial	Dominantly located near the villages
V	900	287	0.318	300,000	5000	2-5	Mostly Palaeo channel type	Rectangul-ar, crescentic oval, senusoidal lensoid, elongated etc.	Perennial and Ephemeral	Bigger sized ponds common, occurrences are irrespective of habitation.

By damming rain water flowing along the otherwise dry channels, local inhabitants have constructed reasonably big ponds. Some ponds are so located that they receive water from several directions and are more or less perennial. Depending on the configuration of the channels occupied by these ponds, their shapes are also seen to be elongated, crescentic, sinusoidal etc. The practice of locating dug wells within the ponds and along the margins of these ponds, is very common, and these wells provide the main source of drinking water (Plate VI.1&2). These paleochannel based ponds are abundant in the area around Mahi river mouth and also all along the Mainland coast. Of course, their numbers and sizes vary from segment to segment. Best development of such ponds is seen to the south of Narmada, where the density of paleochannels is quite high (Fig. VI.4) and the rainfall is appreciable. As a result, the entire coastal plains are dotted with ponds which hold a lot of water.

In contrast, the areas to the north of Narmada, have lesser number of such ponds. The relative paucity of original channels is the primary factor. Instead, manually dug ponds along some relict channel features are more common. Obviously, the villagers have taken advantages of the rain gullies and similar features to locate their sites for ponds.

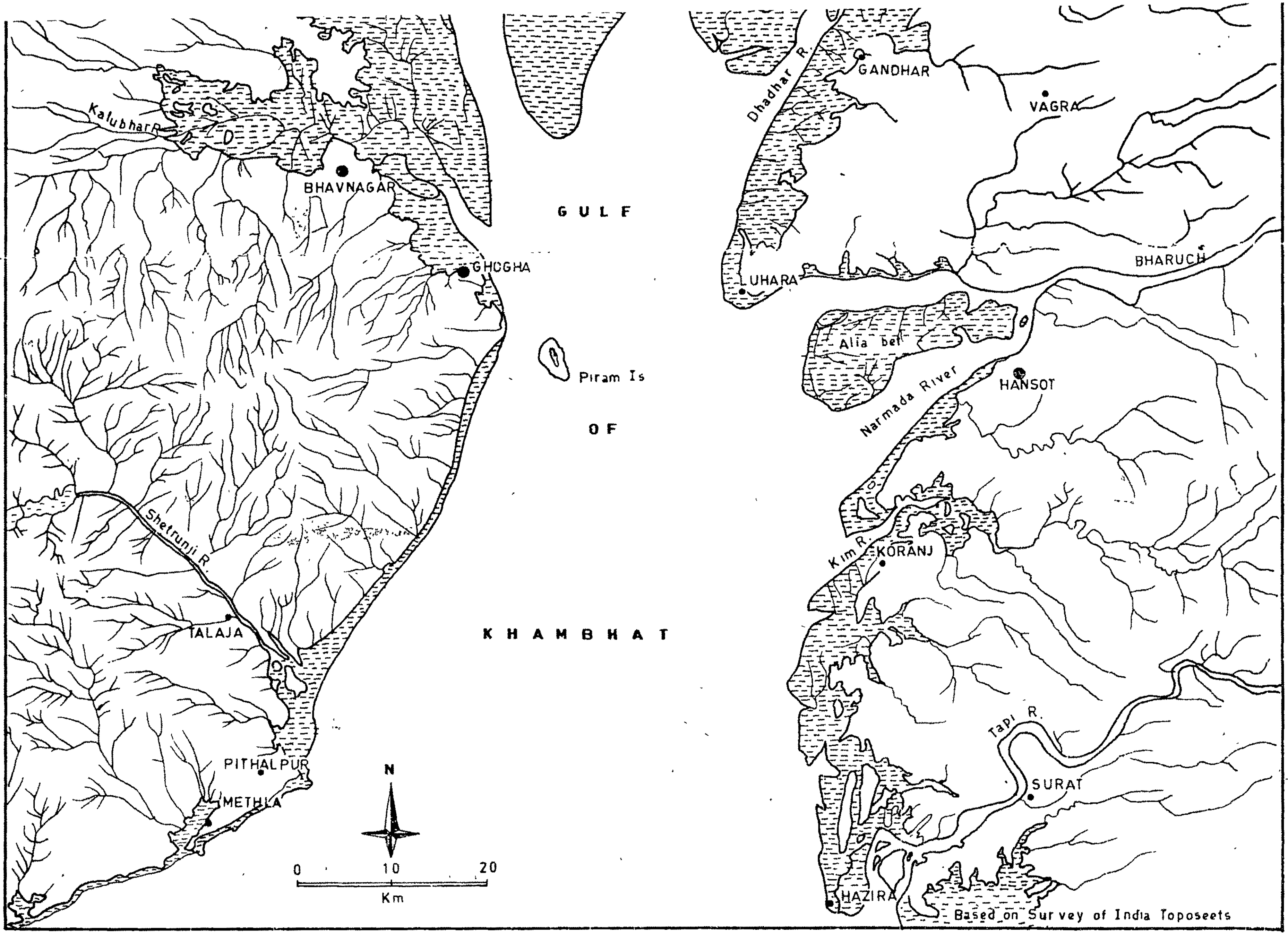
FIG. VI-4



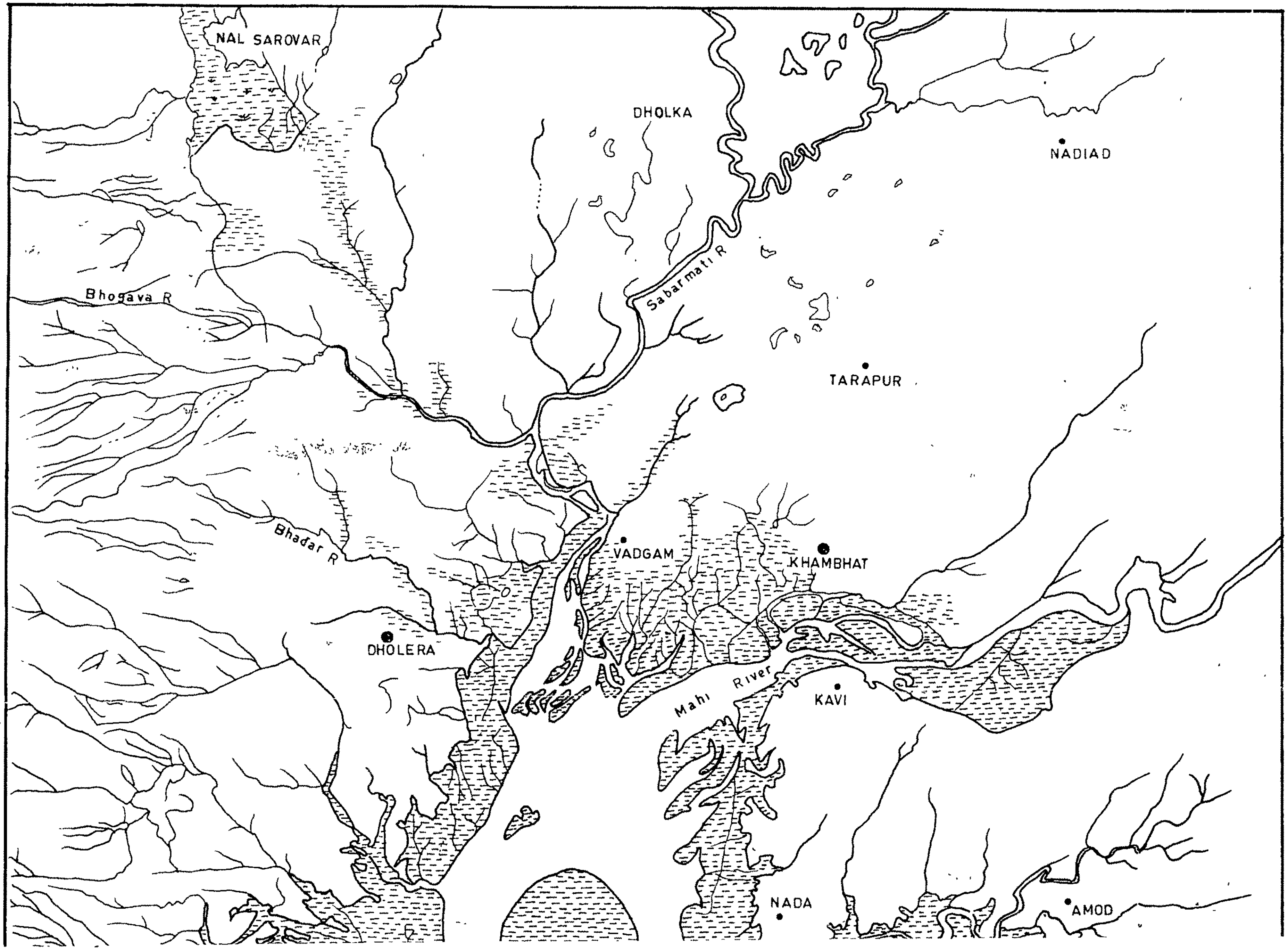
NATURE OF PONDS IN NARMADA - TAPI COASTAL SEGMENT

(Damming of The Palaeochannels)

FIG. VI.3



MAP SHOWING THE DIFFERENT TYPES OF DRAINAGE IN AND AROUND THE STUDY AREA


NAL SAROVAR
DHOLKA
NADIAD
Bhogava R
Sabarmati R
TARAPUR
Bhadar R
VADGAM
KHAMBHAT
DHOLERA
Mahi River
KAVI
NADA
AMOD