CHAPTER - VI

TECTONIC CONTROLS ON LANDSCAPE AND FLUVIAL SYSTEM

The satellite imageries and toposheets of the alluvial plains of Gujarat were studied for identifying the major landforms followed by field checks. The main objective of the study was to work out the detailed Quaternary geomorphology and to delineate neotectonic features responsible for the evolution of the present landscape of the Gujarat alluvial plains. Correlation of the surface geomorphic features with the known subsurface structures have also been attempted. Though it can be stated at the outset that the direct evidences of the subsurface structures are not observed, however, several indirect evidences suggest a very obvious influence of the

subsurface structures. The drainage seems to be highly influenced by the subsurface horsts, anticlines, faults etc.

The area depicts a flat landscape with minor undulations and is drained by major rivers like the Banas, the Sabarmati, the Mahi, and the Narmada. The Banas river debouches into the Great Rann of Kachchh while the other rivers join the Gulf of Cambay. The landscape of the area is the result of the neotectonically controlled fluvial activities of these rivers.

A number of geomorphic anomalies are observed in the basinal area. They are identified on the satellite imageries by tonal contrasts and drainage characterstics. The anomaly trends are in confirmation with the dominant structural trends. Straight courses of the streams and their pattern mostly follows the morphostructural trends.

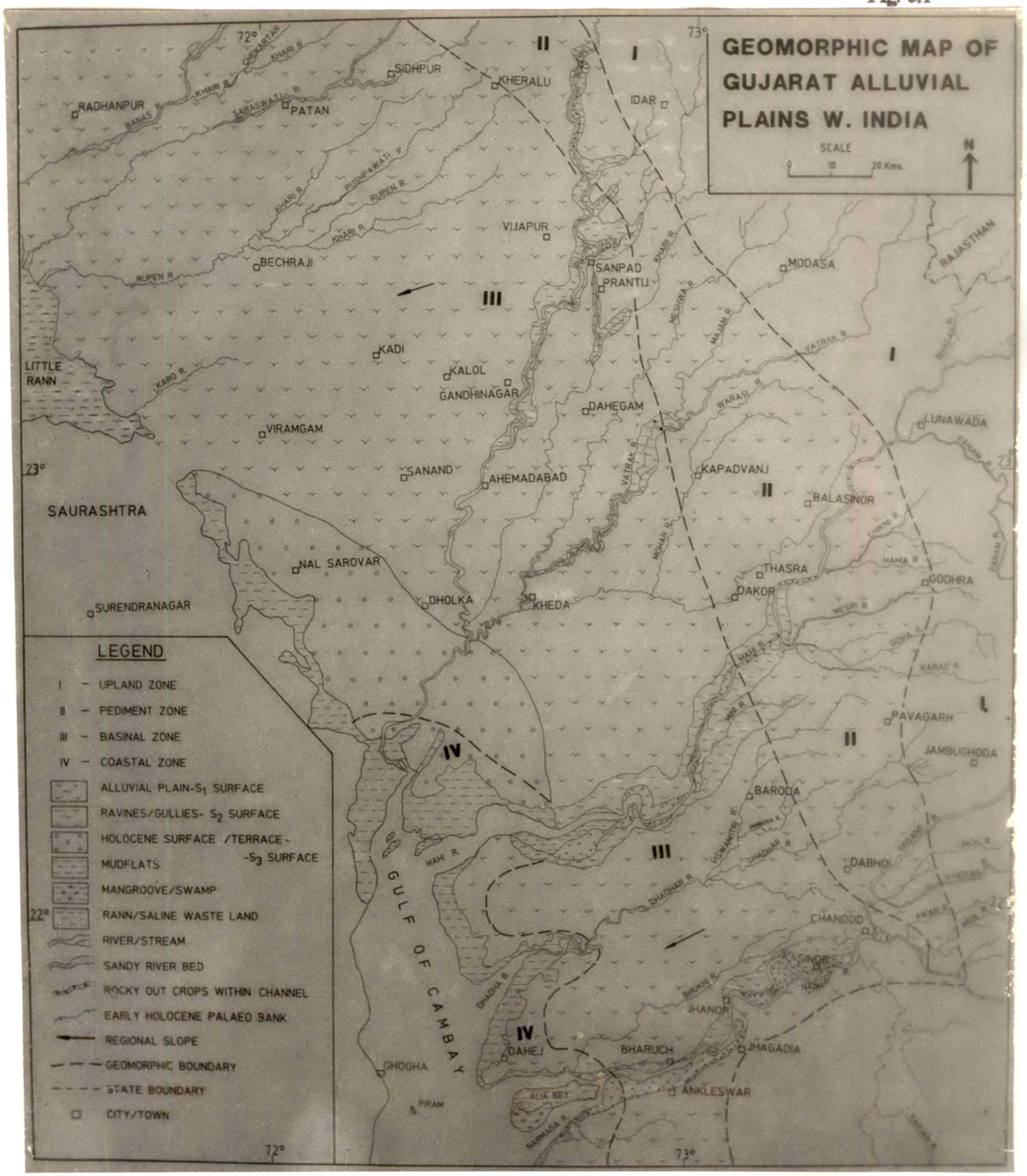
GEOMORPHIC UNITS

The various geomorphic features observed have been classified into several categories (Fig. 6.1). The categorisation has been made keeping in mind the objectives of the study. Instead of classifying the structures genetically, the categories have been formed in such a way that the geomorphic features reflect their tectonic units. For this purpose the geomorphic studies were carried out in the light of the available subsurface data.

The major tectono-geomorphic units recognised throughout the area are as follows:

1. The upland zone
2. The pediment zone

Fig. 6.1


GEOMORPHIC MAP OF GUJARAT ALLUVIAL PLAINS W. INDIA
SCALE
0 10 20 Kms.
N
72°
73°
23°
22°
SAURASHTRA
LITTLE RANN
GULF OF CAMBAY
RAJASTHAN
SIDHPUR
KHERALU
IDAR
RADHANPUR
PATAN
VIJAPUR
BECHRAJI
SANPAD PRANTIJ
MODASA
KADI
KALOL
GANDHINAGAR
DAHEGAM
LUNAWADA
VIRAMGAM
SANAND
AHEMADABAD
KAPADVANJ
BALASINOR
NAL SAROVAR
THASRA
DAKOR
GODHRA
SURENDRANAGAR
DHOLKA
KHEDA
PAVAGARH
JAMBUGHODA
BARODA
DABHOI
CHANDOD
SINOR
JHANOR
DAHEJ
BHARUCH
JHAGADIA
GHOGHA
ANKLESWAR
I
II
III
IV
LEGEND
I – UPLAND ZONE
II – PEDIMENT ZONE
III – BASINAL ZONE
IV – COASTAL ZONE
ALLUVIAL PLAIN-S1 SURFACE
RAVINES/GULLIES- S2 SURFACE
HOLOCENE SURFACE /TERRACE- -S3 SURFACE
MUDFLATS
MANGROOVE/SWAMP
RANN/SALINE WASTE LAND
RIVER/STREAM
SANDY RIVER BED
ROCKY OUT CROPS WITHIN CHANNEL
EARLY HOLOCENE PALAEO BANK
REGIONAL SLOPE
GEOMORPHIC BOUNDARY
STATE BOUNDARY
CITY/TOWN

3. The basinal zone

4. The coastal zone

5. Ravines/Gullies

6. Valley fill terraces

The Upland Zone

The rocky upland areas border the eastern fringe of Mainland Gujarat. These comprise rocks belonging to Precambrian and Mesozoic age. The Precambrian rocks belong to the Aravalli supergroup while the Mesozoics belong to the Deccan Traps and Bagh and Lameta beds. The constituent rocks vary from igneous to sedimentary to metamorphic. The Precambrian rocks are complexly folded and consists of quartzites, schists, phyllites, gneisses and granites. The Deccan traps occupy the SE fringe of the area and comprise various types of basalts. The Cretaceous sedimentary rocks largely consists of different types of sandstones with limestones including fossiliferous limestones forming a minor part.

The uplands are known to have been rejuvenated during Quaternary. Various workers have reported evidences of rejuvenation from the Aravalli mountains (Sen and Sen, 1983) as well as the trappean highlands (Khan and Banerjee, 1989). According to Ahmad (1986) the Aravallis have been uplifted by around 300 m during Late Quaternary. The evidences cited are uplifted planation surfaces, terraces, escarpments, drainage characterstics, tilting of trappean flows and presence of hot springs. Some traverses taken by the author along various river valleys have revealed

deep entrenched meanders in hard rocks, lineament controlled drainage and raised terraces indicating rejuvenation of the rivers during Quaternary. Other geomorphic features indicative of neotectonic activity are the escarpments, colluvial fans, hogback ridges and the general youthful topography.

The Pediment zone

The eastern part of the study area is dominantly a shallow buried pediment. The pediment zone is uncharacteristically very wide and for the most part is very shallow, especially in the southern parts. The shallow nature of the pediment is indicated by the presence of outcrops of hard rocks within the river channels. Such rocky outcrops within the river channels of Vatrak, Mahi, Dhadhar, Orsang and the Narmada are encountered long before the upland region starts. The subsurface data and the open wells observed provide evidence for the wide and shallow nature of the basement. The rock types exposed within the river channels belong to one or the other formations exposed in the uplands.

In the Sabarmati river, first the sandstones belonging to the Himmatnagar Sandstone Formation are exposed beyond which the metamorphics and intrusives belonging to the Aravalli Super Group are exposed. In the Mahi river, first the trappean rocks are encountered followed by sandstones belonging to the Lameta beds. Further upstream the trappean rocks and Aravallis are alternately encountered within the channel. In the Narmada valley, the extrusive rocks belonging to the Deccan Trap Formation are exposed.

The Quaternary sediments are seen directly overlying these rocks within the pediment zone (Plate 6.1). The exposed Quaternary sediment coloumn is stratigraphically comparable to the upper part of the sediment coloumn exposed in the downstream part of the rivers. Such a relationship between the exposed sediments is observed in the lithosections described by Chamyal and Merh (1992) and Merh and Chamyal (1997). This indicates that the pediment was formed in the later stages of deposition. The formation of a wide pediment is attributed to a period of tectonic stability (Mayer, 1986).

The presence of soil horizons in the exposed sediment coloumn (Chamyal and Merh, 1992; Merh and Chamyal, 1997) are further indicative of tectonically stable conditions during the formation of pediment. On the surface the topography corresponds to a flat alluvial topography. The only break in the flatness of the terrain is seen in the form of various sand hills composed of aeolian sand comparable to the aeolian sediments in the down stream area. These sand hills are formed by deposition of sands against some minor obstructions within the topography which further increased in size as the deposition continued.

The Basinal Zone

This geomorphic unit forms the main basinal part which constitute the bulk of the sedimentary fill. This sedimentary fill is confined by deep seated basinal faults. The sediments have been brought from the Aravalli ranges and deposited by various rivers during Quaternary. Outside the Cambay basin the Quaternary deposits directly

Plate 6.1 Photograph showing Quaternary deposits overlying basement rocks in the pediment zone (Loc. Vanoda).

Plate 6.2 Photograph showing dunal topography north of Banas in north Gujarat.

overlie the basement rocks. The alluvial plain is a featureless flat terrain. The thickness of the Quaternary sediments exceeds 800 m. The rivers have carved out a conspicuous meandering course across the alluvial plains marked by cliffy banks.

The area around Sidhpur and Himmatnagar is dominantly a shallow buried pediment. Further north the arid landforms become more and more common (Plate 6. 2). Wind erosion deflation and deposition caused the development of hollows and disintegration of drainage system. The region around Tharad, Diodar, Dhanera and Palanpur are all covered by sand dunes. Most of these are consolidated (stabilised) longitudinal dunes and appear to be deposited by SW winds. Around Palanpur numerous sand hills are present formed by deposition of wind blown sand against the low lying mounds of hard rocks. The Banas river apears to be a dividing line between highly dunal area to the north and the less dunal area to the south. The area west of Sabarmati shows presence of several raised mounds which are infact stabilised dunes.

In the central plains, except for a small hilly area in the northern part of Kapadvanj and Vadasinor, the topography is that of an alluvial plain gently sloping to the SW. Anamolous slopes deviating from the regional slope are seen near Kapadvanj. The area around Matar is characterised by two large areas of depression. The topography around Mehmadabad is gently undulating plain with a downward slope from NE to SW and a few sand hills to the north. Around Cambay, the area is flat and open. The soil is saline and water becomes brackish at very shallow depth.

The area between Shedhi and Mahi is the richest agricultural zone of Gujarat and is locally known as the Charotar plain. The area between the Little Rann and the Gulf of Cambay is a low lying land and at various places it is marshy and salt waste land (Plate 6.3). This low lying area is waterlogged for a major part of the year. It appears that the Gulf of Cambay and the Rann were once connected by a shallow sea. The Nal and the lower course of Bhogavo river represent the arm of this sea. Due to the gradual silting up, the area has now been converted to a saline wasteland. This silting up was possibly accompanied by some uplift. The occurrence of the stabilised dunes decrease gradually southwards, though they are found to occur right upto the Narmada river. These aeolian features have imparted a general undulation to the topography which is found to be considerably modified in areas of extensive agriculture. The western margin is marked by the Ranns of Kachchh.

The Coastal Zone

The coastline is rather straight and is marked by the broad estuarine mouths of the Narmada, the Dhadhar, the Mahi, the Sabarmati and several creeks. The Gulf of Cambay is characterised by many sandy stretches which are influenced by marine as well as river action. The Gulf is enclosed on all sides by marshy coasts and dotted with several bars and islands locally known as 'Bets'. The coastline along Mainland Gujarat suggests present day depositional processes in the form of constructional features such as broad mudflats, braided water channels, stretches of heavy silting, swamps and alluvial islands along the coastline. The sea water enters to a

Plate 6.3 Photograph of the saline wasteland between Gulf of Cambay and the Rann of Kutch.

Plate 6.4 Photograph showing Quaternary deposits extending upto the coastline in Mahi estuary (Loc. Kavi).

considerable distance in the inland during high tide resulting in the formation of tidal mudflats within the channel.

The mouth of the Narmada is funnel shaped with a well developed mouth bar, the Aliabet island. The width of the estuary near the Gulf of Cambay is more than 18 km. The northern bank is high and precipitous. The Aliabet is uncultivable and is covered by thick swamps. This island located opposite to the mouth of Bhukhi river, reached its present size only after 1825. Before that, there were four islands which combined to give rise to the Aliabet island. The Aliabet is a mouth bar of gigantic dimensions. The westernmost part of it is around 20 kms long and is 10 kms wide. Mangrove swamps cover a large part of this island. The course of the Narmada is divided into two by this island. The main channel is the northern one whereas the southern one is gradually becoming dormant. The tidal effect is seen as far as Jhanor about 30 miles upstream of Bharuch. A small E-W stretch of alluvium occurs south of Narmada between Rajpipla and Ankleshwar. The cliffy junction of this plains with the highlands in the south marks the palaeochannel of the Narmada (Agarwal, 1986). The evidences for the palaeochannel is indicated by the presence of many cut off meanders, ox bow lakes and straight segment of the abandoned channel.

The presence of several creeks between the mouths of Narmada and Mahi, impart an irrregular aspect to an otherwise straight coastline. Apart from the mouth of Narmada the rest of the coastline is marked by extensive mudflats which are several kilometers wide. The alluvial cliffs abruptly rise above the mudflats (Plate 6.4). The alluvial cliffs in the Mahi estuary are as high as 20-25 m. Beyond the cliffs, extend the

Gujarat alluvial plains. Sandy beaches and coastal dunes are rarely encountered. A few small sandy patches rise above the mudflats forming alluvial islands known as 'Bets'. The estuarine mouths of the Mahi and Sabarmati are characterised by the presence of mudflats. The maximum width of the mouth of the Mahi is 4-5 km which is all the way conspicous by wide mudflats. Similarly the mouth of the Dhadhar river is also charactersied by the presence of these mudflats.

The coastline between Mahi and Sabarmati is marked by raised mudflats and vast salt wastelands. The mouth of Sabamati shows presence of several mouth bars. Old palaeo-channel of Sabarmati can be seen on the west of its present course on latest images (Nayak and Sahai, 1984). It is presently flowing along the course of an old stream shown in 1868-1891 topographical maps of Survey of India.

Ravines\Gullies

The ravines in and around the river valleys is a very significant feature of the landscape of the study area (Fig. 6.1). Almost all the river sides, even the insignificant streams show development of deep gullies and ravines to variable extent. The three major rivers of the study area exhibit the greatest development of these ravines (Plate 6.5). The ravines extend for many kilometeres inland in these river valleys. Interestingly, these ravines are encountered right upto the coastline in Mahi and Narmada valleys. In Sabarmati valley, the ravines terminate downstream of Ahemadabad. The ravines are conspicuous both in the pediment zone as well as the basinal part. The ravine affected areas constitute an erosional surface and is one of

Plate 6.5 Photograph of ravines in Sabarmati valley. (Loc. Sanpad).

the most significant geomorphic unit in the area. This surface is characterised by deeply cut ravines suggestive of a badland topography. In some cases the dissection in these ravinous reaches upto 15 m.

The surface is well developed all along the three major river valleys. This erosional surface is delimited by the flat alluvial plain on one side and the river channel on the other. Along the river channel it is marked by steep cliffs of 15 to 45m. The sediments comprising this surface are described by earlier workers and are of fluvio-marine, fluvial and aeolian origin. The lithostratigraphy of the sediments of this surface has been established (Chamyal and Merh, 1992; 1995, Merh and Chamyal, 1997). This sequence which dates from Middle Pleistocene to Terminal Pleistocene reveals several phases of climatic changes. This suggests that this erosional phase took place during Holocene.

Valley fill Terraces

These terraces are developed within the channel of the various rivers (Fig. 6.1). The three major rivers viz. the Sabarmati, the Mahi and the Narmada show good developement of these terraces (Plate 6.6, 6.7, 6.8). They form a series of discontinuous elevated surfaces which are confined by the present day channel on one side and terminate abruptly against the older (Pleistocene) ravine affected sequence on the other side. Morphologically, these flat topped elevated surfaces typically correspond to the morphology of a fluvial terrace and is preserved on the insides of the present day meander bends Interestingly, these terraces are found in

Plate 6.6 Photomosaic showing Holocene terraces abutting against the ravine affected Pleistocene sediments at the confluence of Sabarmati and Hathmati river. The cliffy edge of the ravinal surface marks the palaeobank (Loc. Sanpad).

Plate 6.7 Photomosaic showing Holocene terraces abutting against the ravine affected Pleistocene sediments in lower Mahi valley. The cliffy edge of the ravinal surface marks the palaeobank (Loc. Sultanpura).

Plate 6.8 Photomosaic showing Holocene terraces abutting against the ravine affected Pleistocene sediments in lower Narmada valley. The cliffy edge of the ravinal surface marks the palaeobank (Loc. Sinor).

the river channel right from within the the pediment zone to the estuarine mouths. Within the smaller rivers, these terraces occur as isolated and unmappable units.

In case of the Sabarmati river, the valley fill terraces are not found downstream of Ahemadabad. The downstream part of the Sabarmati the area is a low flat depression which is geomorphologically correlatable to the terraces within the channel. In case of the Narmada and Mahi valleys these terraces are encountered right upto the coast. The following salient features have great significance with respect to their genesis and interpretation.

1. These terraces occur in all the three major river valleys of the study area.
2. They are encountered all along the river channel right upto the pediment zone to the estuarine river mouths.
3. The terraces are unpaired.
4. The sediments comprising the terrace vary from tidal in the river mouths to fluvial in the upper reaches.
5. The width of these terraces vary from a few tens of meters to as much as 3 km in the broad estuarine river mouths.

The fact that these terraces occupy the incised valleys and terminate against the ravine affected sequence (Plate 6.6, 6.7, 6.8) suggest that these terraces post dates the ravinal erosion and fluvial incision in the river valleys. Circumstantial evidences recorded in the field and the geomorphic setting indicate that these terraces were deposited during the Middle Holocene high sea indicating two separate erosional phases. There is no evidence which suggests that the phase of ravine

erosion and terrace formation is coeval. These two are the result of two different erosional phases seperated in time. The rise of sea level during the Middle Holocene led to the choking of the river channel resulting in the deposition of these terraces. This deposition never extended beyond the river channel as the channel itself was confined by steep incised cliffs. This is due to the fact that the Mid Holocene rise was of the order of a few meters only.

THE FLUVIAL SYSTEM

River morphology and channel behaviour have long been the domain of geomorphologists who attempt to explain river morphology by studying river deposits. Little attention has been paid to active tectonic movement as a factor of influencing river morphology and channel behaviour. Tectonic movement comtemporaneous with the formation of the modern river morphology is referred as "active tectonic movement". The main reason why tectonic movement has largely been ignored as a factor of inlfuencing river morphology and channel behaviour is its slowness (Ouchi, 1985).

The rivers of Gujarat alluvial plains show several evidences which indicate overwhelming influence of the subsurface structural features. Remarkable correlatability is observed between the fluvial characterstics and subsurface structural elements (Fig.6.2). The courses of some of the rivers mark the various subsurface faults. The drainage basins, subbasins and the drainage divides are tectonically controlled. The three major rivers draining the Gujarat plains, viz. the Sabarmati, the

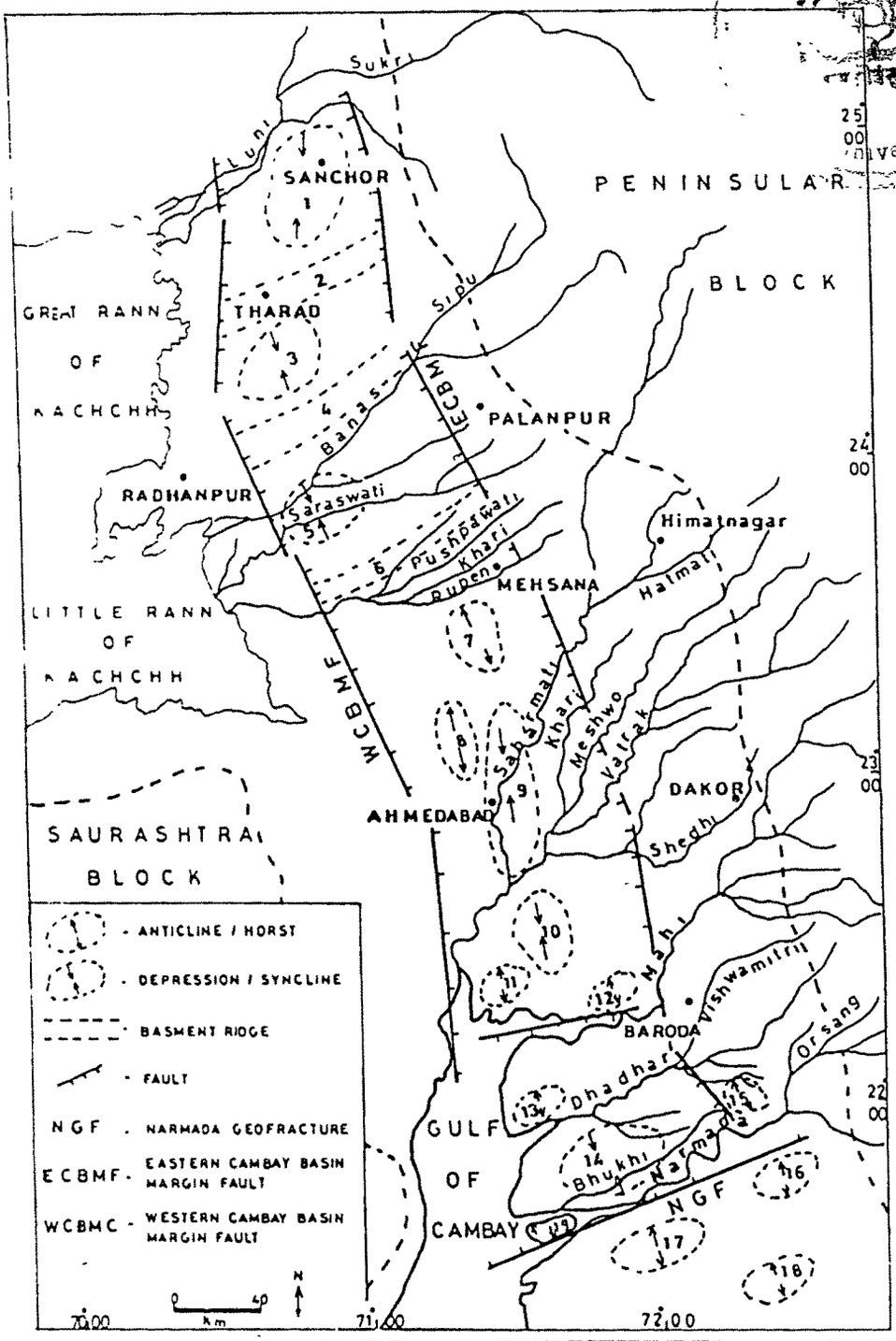


Fig. 6.2 Subsurface structural features superimposed over the drainage map of the study area. (1. Sanchor depression 2. Tharad ridge 3. Paiyak depression 4. Diyodar ridge 5. Patan depression 6. Unhawa ridge 7. Mehsana horst 8. Kalol high 9. Gandhinagar basin 10. Tarapur depression 11. Cambay high 12. Kathana anticline 13. Dhadhar anticline 14. Broach syncline 15. Atali anticline 16. Jhagadia anticline 17. Ankleshwar anticline 18. Talodra anticline 19. Aliabet anticline.

Mahi and the Narmada are characterised by similar geomorphic features which suggest an identical evolutionary history of these basins during Late Quaternary.

The Narmada river rises in the hills of Amarkantak M.P. Throughout its course the Narmada is characterised by its narrow valley with Vindhyans on the right bank and the Satpuras on the left bank. The breadth of the river is slightly less than a kilometer as it enters Gujarat which widens to 1.5 km near Broach. Below Broach it widens to a very broad estuary. The northern bank is high and cliffy. Within the river channel braidation in the lower reaches has given rise to islands, viz. Kabirwad and Aliabet. The Bhukhi river froms a deep incised channel and as the high tides encroach the channel it appears like an inlet of the sea. The Orsang flows E-W in its upper and middle reaches, but in the lower part its suddenly swings to NNE-SSW and meets the Narmada at Chandod. This course of Orsang does not follow the general SW slope of the area suggesting a strong tectonic control. This change on the course of Orsang appears to have captured the E-W course of Heran river.

The Men river meets the river at Tilakwada. Significantly, the Bhukhi, the Orsang and the Men meet the Narmada almost at right angles. The Dhadhar has an almost E-W course of about 120 km. The Vishwamitri joins it from the north before it meets the sea. It has a highly meandering course with low cliffy banks and a narrow channel but an unusually large estuarine mouth. The Sabarmati rises in Rajasthan and follows a slope deviatory course in the alluvial plains. Below Ahmedabad the bed of Sabarmati widens considerably. The lower course of the Sabarmati is narrow and

appears to be younger than its course in the middle and upper reaches. The Hathmati also rises from the Mewad hills of Rajasthan and meets the Sabarmati near Prantij.

The Vatrak and Meshwo rise from the Dungarpur hills of Rajasthan. These two exhibit a very conspicous meandering course and broad shallow channels with low cliffy banks. These along with other tributaries of Sabarmati river appear to be misfit streams. The Shedhi which meets the Vatrak, in contrast has an extremely narrow channel and seems to be much younger river. The rivers present in the north of Sabarmati arise from the Aravallis. These rivers are entirely dependent on the monsoon. The Banas and the Saraswati flow into the Little Rann while the others flow into the Great Rann. All these rivers have broad shallow channels.

There is a remarkable similarity of the geomorphic features in all the major river valleys indicating an identical evolutionary history (Fig. 6.3). The ravines in and around the river valleys is a striking aspect of the landscape of the study area. The drainage system of Gujarat alluvial plains exhibits certain peculiar characterstics which suggest an obvious influence of tectonism. These are as follows:

1. Presence of high steep vertical cliffs (30-50 m) along the banks of all the rivers.
2. Preferential devolopment of cliffs and ravines on one bank only.
3. Presence of tributaries on one bank only.
4. Peculiar meandering pattern (which varies in different segments of the river) in all the rivers. It should be mentioned that each river shows a different meandering pattern.

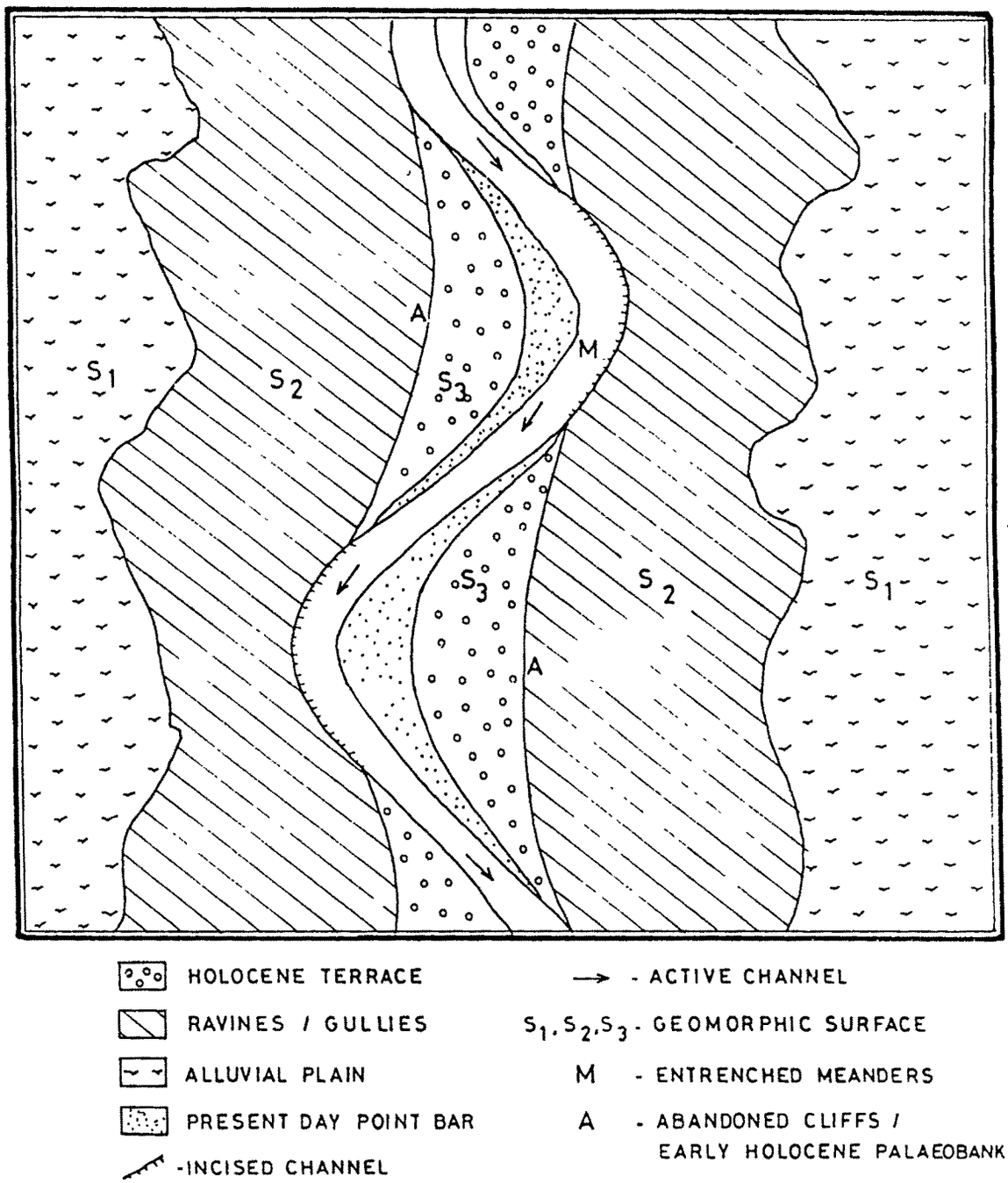


Fig. 6.3 Schematic diagram showing the general geomorphology around the rivers of Gujarat alluvial plains.

5. Development of deeply entrenched meanders along the courses of the rivers (Plate 6.9, 6.10, 6.11).

6. Anamolous devolopment of braidation at a few places which is related to movement along subsurface faults.

The consistent presence of imposing alluvial cliffs rising upto 50 m, entrenched meanders, anamolous braids, and funnel shaped mouths are significant geomorphic evidences of tectonism encountered in all the rivers of the area. Preferential development of cliffs and ravines and presence of tributaries only on one bank has also been observed. A low elevated terrace is observed in all the river valleys. Investigations on these terraces have revealed it to be a Mid-Late Holocene terrace surface which is marine in the estuarine zones and fluvial in the upper reaches. The discovery of these terraces has been a major finding of this study which has for the first time explained the Late Pleistocene-Holocene evolution of the Gujarat plains.

The drainage asymmetery in the Gujarat alluvial plains point to a dominant control of tectonism over other geological factors. The alignment of the various river channels show excellent correlatability to the subsurface structural highs and faults (Fig. 6.2). The course of the Khari in north Gujarat, the Vatrak, lower course of Mahi river are controlled by the cross-faults which demarcate the tectonic blocks of the Cambay basin. The slope deviatory courses of the Sabarmati, the Mahi, the Vishwamitri and the Orsang follow major lineaments of the area. The presence of several areas which are devoid of drainage is quite conspicuous. These areas are-

Plate 6.9 Photograph of an entrenched meander in Sabarmati river (Loc. Mahudi).

Plate 6.10 Photograph of an entrenched meander in Mahi river (Loc. Dabka).

Plate 6.11 Photograph of an entrenched meander in Narmada river (Loc. Bhimpura).

the area to the west of the Sabarmati river, the area between the lower courses of Sabarmati and Mahi rivers, the area between the lower course of Mahi and Dhadhar river, the area to the west of the lower course of Orsang river and the area to the south of the Narmada river. These areas appear to be positive areas of uplift and correspond well with the subsurface structural highs.

The area to the west of Sabarmati is marked by several structural highs viz. Mehsana horst, Kalol high and the Sanand high. All these highs do not extend across the Sabarmati river to the east. These structural highs are responsible for the slope deviatory approach of the Sabarmati river. The rivers to the north of these highs, viz. the Khari, Rupen and Saraswati join the Ranns of Kachchh while the Sabarmati joins the Gulf of Cambay due to these subsurface highs. The area between the lower courses of the Sabarmati and the Mahi is marked by structural highs - the Cambay high and the Kathana high in the subsurface. These highs have caused the river Shedhi to join the Sabarmati river though it originates very close to the Mahi river. These highs are also responsible for the slope deviatory course of the Mahi river.

The area to the north of the lower course of Dhadhar is marked by the Dhadhar anticline while the area to the west of the lower course of Orsang river is marked by the Atali anticline. Bacause of the positive area to the north of Dhadhar, the Vishwamitri follows a NNE-SSW slope deviatory course to join the Dhadhar river. The N-S swing of the course of the lower part of Orsang is attributable to the subsurface Atali anticline. The area to the south of Narmada is marked by the Ankleshwar, Jhagadia and Kosamba anticlines. These highs are responsible for the northward

shift of the course of the Narmada river in the Gujarat alluvial plains. A significant observation made is that the N-S to NNE-SSW courses of the Sabarmati, Mahi, Vishwamitri and the Orsang appear to have captured the E-W to ENE-WSW courses of their tributaries which follow the regional slope of the plains. The Sabarmati has captured the course of Vatrak, the Mahi has captured the course of Mini, Mesri and Goma rivers, the Vishwamitiri has captured the course of its smaller E-W flowing streams and the Orsang has captured the course of the E-W flowing Heran river. The Gujarat alluvial plains therefore appear to have witnessed a phase of drainage realignment which was marked by large scale river capturing wherein the major rivers following their structurally controlled courses captured the course of the smaller streams which followed the regional slope. The reactivation of the subsurface structural features during Late Quaternary, possibly Holocene has been the major factor in the evolution of the present drainage system of the Gujarat alluvial plains.