2

PREVIOUS STUDIES

CHAPTER 2

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GENERAL

The Quaternary deposits of Mainland Gujarat have received meager attention by the geologists in the past. Although, these are made-up of huge thickness of non-marine sediments, preserving within them an interesting record of successive geological events, yet they remained uninvestigated till a couple of decades back. As already stated the late Quaternary continental record is characterized by layered continental sequences of fluvial and aeolian deposition and has preserved within them striking evidence of tectonism and climatic changes. Studies were carried out essentially by pre-historians and archeologists in the first half of this century. They did provide some stratigraphic and lithologic details. Scattered geological information is also available in the published and unpublished reports pertaining to groundwater investigations. It was only when the ONGC started oil exploration and exploitation activities that the importance of Quaternary sediments regarding their lithology, stratigraphy and thickness of sequences was realized. Of course the ONGC data has always been brief and vague.

It was only in the course of last 3 decades that the geologists got interested in carrying out systematic studies of these deposits commonly referred to as alluvial plains of Gujarat. Systematic studies were initiated in the various river basins of Gujarat , viz. Luni, Sabarmati, Mahi and Narmada. Augmented by data furnished by ONGC and the State Government Irrigation Department, it has been possible for

a number of workers in recent years to generate vital information of different aspects of the evolutionary history of these plains. As such not much worthwhile information has been generated on Mahi river basin, but considering the fact that the factors responsible for the geological evolution were more or less comparable in North and Central Gujarat, previous studies in areas outside the Mahi basin are equally relevant and provide a good background information. The present author has summarized below details of the various studies carried out by the previous workers. For the purpose of convenience of description and maintaining continuity of evolutionary thought, the subject matter presented below has been categorized under five heads;

1) Archaeological aspects,

2) Stratigraphy and lithology,

3) Geomorphology including drainage,

4) Tectonic aspects,

5) Palaeoclimatic aspects.

ARCHAEOLOGICAL ASPECTS

The archaeological information on Mahi sequence was given by Sankalia (1946), who worked on the major river systems of Gujarat. He reported microlithic and Paleolithic artifacts from the lower Mahi at Vasad, Rayka and Dabka. Later on, Zeuner (1950), for the first time studied these Pleistocene deposits of Gujarat from the geochronological angle. In his study, he mainly concentrated on the fossil

soils, exposed in the succession at Rayka, Vasad and Dabka. He observed that the exposed sequence showed a series of alternate layers of mottled clay and gravel at the base, and the gravel phases were followed upward by the usual deposition of fluviatile silts rich in calcium carbonate. A conspicuous feature that he observed was the ubiquitous occurrence of a red soil horizon. This horizon according to Zeuner (1950), divides the succession into an overlying aeolian and underlying fluvial deposits. He found a close similarity between the Mahi sequence and that of the artifacts bearing sediment of Sabarmati. Although Zeuner did not come out across any Paleolithic tools, as he did in the stratigraphically comparable sediment succession from Sabarmati and Narmada, but he more or less agreed with archaeological postulations of Foote (1898) and Sankalia (1946).

In the years to follow, the emphasis shifted to the overlying aeolian dunal horizon; and all over Gujarat, archaeologists came across Mesolithic sites in association with the stabilized dunes. Foote (1898) had for the first time reported such an association from North Gujarat. Subsequently, Subbarao (1952), on the basis of over 800 specimens collected on the surface of about 30 sites, reported Mesolithic sites from the lower Mahi valley. He described Mesolithic sites at Amrapur, Vasad and Kambholaj from lower Mahi valley. He has reported occurrence of two soil horizons from lower Mahi valley, dark brown soil and yellowish brown soil. According to him at Kambholaj, Vasad and Amrapur, the brown soil of about 2 m developed over the dunal sand containing microliths over

the surface. The artifacts were predominantly made from the river pebbles of quartz, chert, and chalcedony.

Almost identical occurrences were reported by Allchin and Goudie (1971) and Allchin, *et al.*, (1978). These workers identified major Mesolithic sites from the Pavagarh dune and on the top of the SW to NE aligned dunes on either sides of Mahi river. Lower Paleolithic artifacts were also reported from the lower indurated gravel in Mahi river at Itari (Allchin *et al.*, 1978).

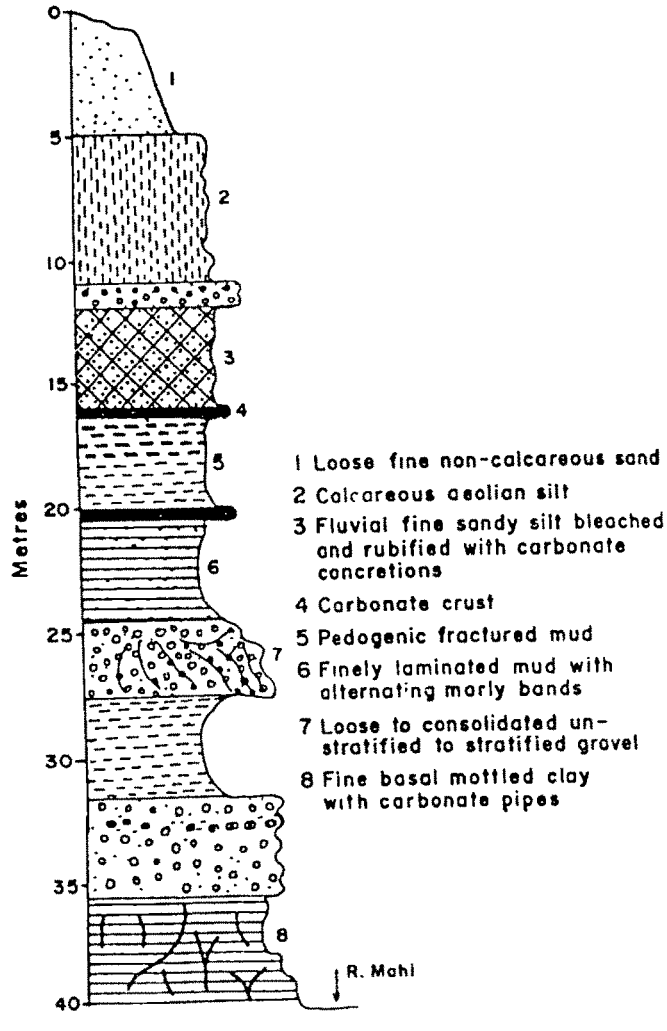
STRATIGRAPHY AND LITHOLOGY

Stratigraphic and chronologic details were emphasized by Zeuner (1950, 1963). He was the first worker to provide lithological details, stratigraphic sequence and chronology of the Pleistocene deposits of Gujarat plains. He provided the following chronological sequence for Mahi river, identifying nine major units.

Z	Surface soil
W	Wind blown sand, showing dunal topography.
V	Brown soil representing land surface of the plateau.
U	Yellowish-brown sandy silts alongwith kunkars (calcrete), appears to be aeolian in origin (35 ft).
T	Red soil resting over yellowish-brown silts (29 ft).
S	Brown silts with layers of kunkar (8 ft).
R	Fine gravel and coarse sand cemented alongwith pebbles of kunkars (12 ft).
Q	Mottled clay impregnated with lime (15 ft) at water level occurs another gravel bed.

According to Zeuner (1950) this succession was comparable to that of the Sabarmati, seen ideally at Hirpura. In Mahi, he studied the well exposed Mahi sections at Rayka, Vasad and Dabka; the Dabka section showing a better developed red soil horizon. Mahi sediments remained more or less uninvestigated for almost four decades. Recently, the river has attracted much attention. Pant and Chamyal (1990) have provided vital information in respect of the lithology of sediments and suggested a composite stratigraphy of the Quaternary deposits of Mahi river (Fig. 2.1). Pant and Chamyal (1990) considered the red soil horizon a marker horizon for stratigraphical correlations for the entire Gujarat alluvial deposits. According to these workers the total exposed thickness of the Quaternary deposits is about 30 m. The exposed succession was divided by Chamyal and Merh (1992) into three formations; Rayka, Shihora and Timba. According to them, the mottled bluish grey clays of the Rayka formation were marine in origin, and marked high strandline of Middle Pleistocene high sea level (Merh, 1992). The lowermost gravel (gravel-I) rests over the basal clays which is overlain by pedogenised structureless fractured mud. This fractured mud separates overlying cross-stratified gravel (gravel-II) from gravel-I. The Shihora formation is made up of fluvial and aeolian sediments; the lowermost member is a horizontally laminated mud with marly bands containing fresh water molluscs and which in turn is overlain by a thick pedogenised fractured mud. The upper member of this formation is made up of aeolian silts over which the red soil (rubified) horizon was developed. Over Shihora formation rests the Timba formation, the lowermost deposit of this formation is a matrix supported gravel

Fig. 2.1: Composite lithostratigraphy of lower Mahi Basin
(After Pant and Chamyal, 1990)



(gravel-III, confined to a small area near Rayka village) or a thick sand deposit. These sands are cross-stratified and are overlain by a thick silt deposit. This silt is relatively coarse grained and contains a considerable amount of fine sand. A brown soil has developed over the loess-like material. Low dunes characterize the present-day topography. These dunes are stabilized as is evident by the soil formation over them. The soils are typical aridisols. Pant and Chamyal (1990) have assigned an age > 200 ky on the basis of the occurrence of lower Paleolithic tools for the gravel-I, and according to them the underlying clays could be as old as 350 ky. The red soil horizon representing the more humid climatic condition was correlated with Stage 5e of the deep sea oxygen isotope record which dates back to around 125 ky.

GEOMORPHOLOGY INCLUDING DRAINAGE

Although geomorphologically the area is interesting, it has received less attention in the past. No exclusive study on the geomorphology of the Mahi Basin has been carried out, though some good information has been furnished by Allchin and Hegde (1969), Allchin and Goudie (1971), Goudie (1973) and Allchin *et al.*, (1978), as background for their archaeological and prehistoric studies. These workers have recognized a terrace configuration for the channels of Narmada, Mahi and Sabarmati and according to them, there were two main terraces in all the rivers of Gujarat. In Mahi, they have recognized two terraces - the upper Od terrace and the lower Galteshwar terrace. They have further observed that, the Galteshwar terrace looses lot of height downstream and merges into tidal mud flats 16 km

before the coast, while the Od terrace continues right upto the coast where it terminates in the form of a cliff. Mesolithic sites were found from the upper terrace at Od and Itari (Allchin *et al.*, 1978). On the basis of the terraces and associated sediment assemblages, they suggested that, the major phase of aggradation was represented by the surface of upper terrace, phase of downcutting was represented by cliffs and gullies in the terrace. While the second phase of aggradation was represented by the lower terrace. They have concluded that Mahi terraces show a record identical to those of Narmada and Sabarmati.

Bedi (1978) suggested that the Post-Mesozoic tectonic disposition and palaeoclimatic oscillations during Pleistocene played important role in the formation of the multicyclic polygenetic landscape of Mahi basin. He recognized three major geomorphic domains and identified related landforms :

1) Denudational domain, confined to the hilly uplands.

2) Fluvial domain, confined within the channel and the flood plains of Mahi river.

3) Aeolian domain, covering the area west of Mahi river.

The uplands comprise mainly Aravalli metasediments, granites, Infratrappeans and Deccan Traps, which had undergone several episodes of denudation and given rise to ridges, planation surfaces and valley type topography in the area. He identified three planation surfaces, of which the highest was around Kadana (ranging between 255 m to 225 m), another around Virpur are more extensive than the first one, and the third one was around Balasinor and Vanakbori (135 m to 105 m). These surfaces, were bound by scarps, which occur in two ways;

either they bound the planation surface remnants or they are fault or fault line scarps. Along some of these fault scarps, Mahi and Panam rivers had cut prominent water gaps one near Kadana (1.6 km long and 120 m deep) and another near Lunavada (2.4 km long and 90 m deep) respectively. He also identified 2 to 3 levels of fan cut terraces typical 'Z' form, west of Kadana and also talus cones, colluvio-fluvial fans, bazada at the foot of scarps and at steep slopes. On the basis of longitudinal profile in upper (rocky) reaches, he studied gradient of either banks. The left bank shows gradient of 0.4 m/km and right bank 0.5 m/km, and suggested that, general shape of the profile was concave upward with three convexities, evidenced by the presence of nick points. Bedi (1978) identified two fluvial terraces, upper (T_2) and lower (T_1) terrace. T2 - terrace comprise older sediments like weathered to semi-consolidated, cream to yellow and reddish brown colour pedocal alongwith some sand lenses. This terrace is a paired terrace occurring on both the sides of the channel and merges with alluvial plains. In lower reaches these terraces are affected by ravine erosion. T1 - terrace comprise weathered alluvium alongwith 2 m thick grey humic silts and sand which are extensively cultivated. This terrace is unpaired and are mostly confined to the convex banks of Mahi, and merges into tidal flats near Cambay.

The aeolian domain is confined to the west of Mahi river, 3 to 7 km wide sand covered belt extending from Vasad to Janod, alongwith extensive sandy patches around Cambay and in upland areas. According to Bedi (1978), the aeolian activity had taken place in a river flood plain environment where the prevailing

wind direction was from SW to NE. On the basis of this aeolian sediment cover he deduced that, the sand migration took place simultaneously with channel entrenchment of Mahi, the available material of sand were the dry tidal flats, terrace tops and stream beds.

Pant and Chamyal (1990) reinvestigated the Mahi river basin, emphasizing on the Quaternary sedimentation. They divided the area into three major geomorphic zones (1) Uplands (2) Pediplain and (3) Alluvial, and added three additional topographic features - terraces, dunes and ravines. According to them "The upland zone is roughly east of the line joining Raniya and Thasra and consists of rocks of Aravalli Group, sandstones of Cretaceous period and Deccan Traps. It is a planation surface gently sloping towards west. Bordering the upland zone towards the SW is the gently sloping pediplain zone that is mostly composed of soil sediments derived from the uplands. The pediplain zone interfingers with the alluvial zone down Raniya, along the tributaries of Mahi and also upstream of Thasra. The alluvial zone spreads wide down the pediplain and exhibits intensive gullying and ravine formation along the Mahi and its tributaries. These features are almost absent in the lower terraces. According to them, the lower terrace between Singrot and Dabka (3 m amsl); in composition and structure, resembles tidal mudflats. The section of this terrace shows a crude lamination of mud with minor sand intercalation and bioturbation. This lower terrace from Raniya to Vasad and further downstream is represented by a degradational bench, formed due to receding nick points and deep channel entrenchment, related to base level adjustment.

Another topographical feature they identified was low hummocky dunes, confined more on the left bank than on the right. They suggested that Mahi descended the upland in a step like fashion. The tributaries of Mahi-Mesri, Goma, Kharod and Mini take abrupt U-turn before joining Mahi, and attributed this phenomenon to structural control.

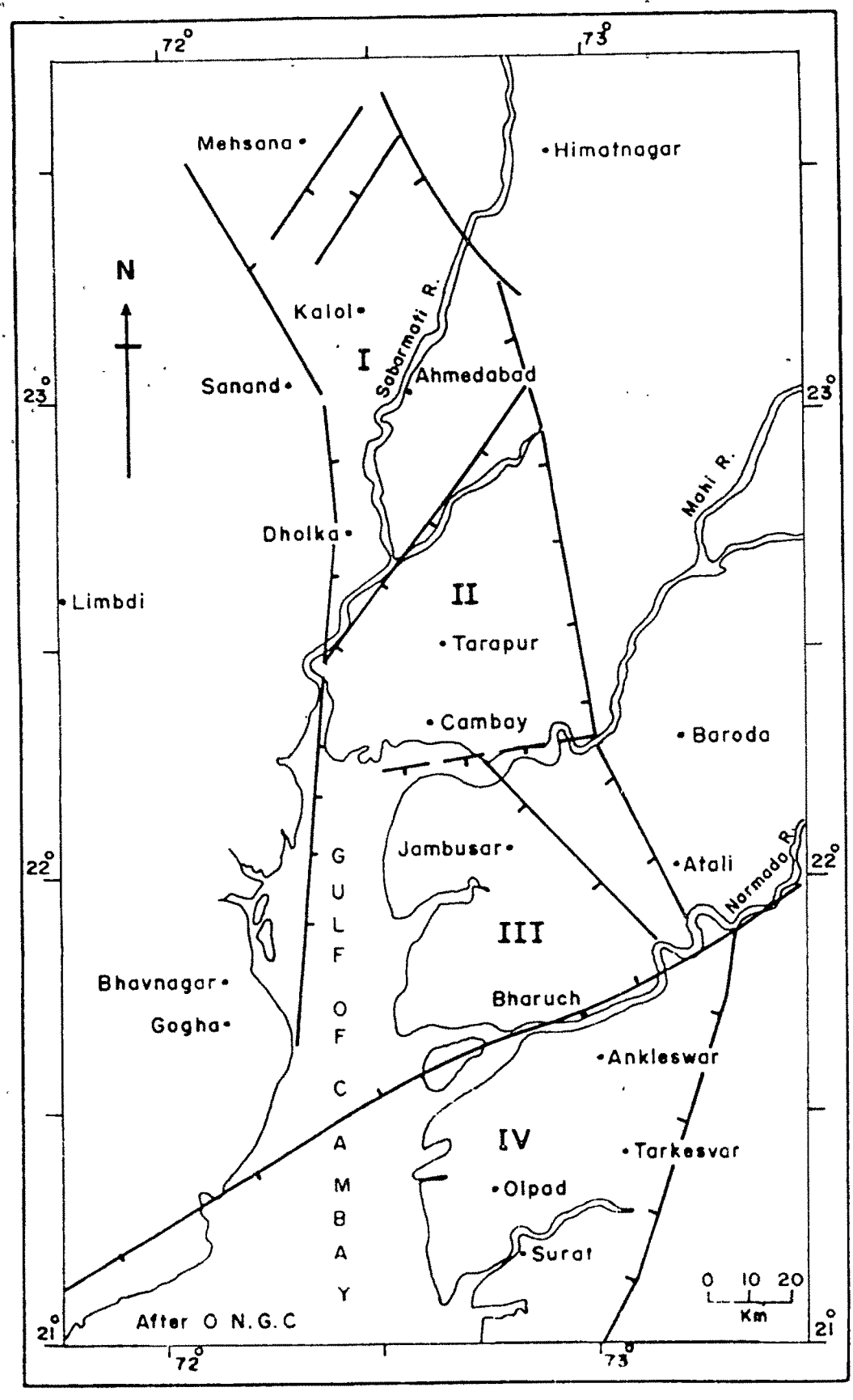
TECTONIC ASPECTS

Previous work on the tectonic aspects of the Mahi river basin is very scanty. Although the Mahi flows across the Cambay Basin, and ONGC has certainly recognized the structural importance of the river course, but no specific reference of this aspect has been made in the ONGC literature. However the Cambay Basin tectonics, is quite relevant to the channel characteristics of the river.

The Mahi basin is influenced by Aravalli tectonism in its northeast and by Cambay Basin tectonic framework in its southwest. Many workers have given an outline of Cambay graben. Raju (1968) described the tectonic framework of Cambay graben. On the basis of surface and sub-surface structural elements, according to him this basin is an intra-cratonic graben bordered by Radhanpur-Barmer Arch and Kathiawar uplift on the west and Aravalli orogenic belt on the east. The statement made by him that the Cambay Basin is bounded by en echelon faults parallel to the Dharwar trend that dissects the Aravalli and Narmada trends, is of much significance. Chandra and Chowdhary (1969), who carried out further studies on Cambay graben, suggested that the Cambay graben is divisible into 4-

major structural blocks: 1) Ahmedabad-Kalol block. 2)Tarapur-Cambay block. 3)Jambusar-Bharuch block. 4) Narmada block, the Mahi river delineates the Tarapur-Cambay and Jambusar-Bharuch blocks (Fig. 2.2).

Bedi (1978) to whom goes the credit of studying the various geomorphic features and landforms related to tectonic activity in the Mahi basin envisaged that the development of Mahi river basin in Gujarat has also been influenced to a great extent by tectonic element. According to him, Mahi basin is delimited by Pre-Cambrian granites and Deccan Traps and by a vast alluvial tract covered by Cambay graben. He suggested that, the area during post-Mesozoic was more relevant, because it was during this period, that the present geographic disposition started taking shape and the formation of Cambay graben paved way for the active sedimentation later. Cambay graben is characterised by two long marginal NW-SE trending faults punctuated by cross faults trending in NNE-SSW and NE-SW (ONGC seismic data). These two long marginal faults have been reactivated time to time, from Pliocene onwards, continuing upto present time. From his observations he deduced that these Quaternary landforms in alluvial terrain indicate their evolution by a multicyclic polygenetic processes. Asymmetric shape of Mahi channel follows the junction of two faulted blocks, where the western block is upthrown and tilted westward. The nick points in the longitudinal profile of Mahi river, as well as terraces confirm the active nature of the marginal faults. The intensive gullying of old levees marked by 'V' to 'U' cross profiles are indicative of uplift. The angulate to rectangular nature of the gullies are also an indicative of



I Ahmedabad–Mehsana Block II Cambay–Tarapur Block

III Jambusar–Bharuch Block IV Narmada Block

Fig. 2.2 : Tectonic Map of Cambay Basin
(After Chandra and Chowdhary, 1969 and Raju and Srinivasan, 1983)

, reactivated fractures in the basement. The convergence nature of lower terrace indicates that river had a comparatively steeper gradient formerly, and the divergence of the upper and lower at the mouth suggests that there were phases of deep entrenchment either due to upliftment or by strand line retreat. The presence of undissected fault scarps and a hot spring near Khedapada and the displacement of left bank of Mahi along a NW-SE fault are attributed to neotectonic activity.

Biswas (1982, 1987) has discussed the causes of the Cambay Basin tectonic evolutionary history. He has very aptly explained the genesis of the Cambay Basin, its evolutionary history and related sequence of structural events were correlated to the drifting of the western continental margin and NNE drift of the Indian sub-continent.

Pant and Chamyal (1990), studied the geomorphology, drainage pattern and Quaternary sedimentation pattern with respect to structural elements and explained the processes of terrain evolution leading to present day topography. According to them, the various tectonic features, especially the fracture lineaments related to Cambay Basin, had influenced the evolution of the Mahi river. The evolution of the basin has been attributed to deep-seated faults with a N-S Dharwarian trend cutting across the major E-W Satpura and the NE-SW trending fractures. These N-S trending faults were developed parallel to the Cambay Margin Faults. The Mahi channel follows the fracture pattern of the blocks and was termed as "Trellised". The basal sediments rests over the downfaulted blocks, the outcrops of sediments on the right bank are not well exposed, being located on the downthrown side, and

entire sedimentation followed the step-faulting basement configuration. This step-faulting was confirmed by the palaeocurrent directions. The occurrence of brecciated zone and SE-NW alignment of hot spring at Tuva and Lasundra indicates deep seated faults in the region. They also identified two distinct phases of erosion. The major phases of ravine erosion was a result of peripheral uplift of Peninsular Shield against the Himalayan range (Ahmad, 1986) and by slight uplift of horst block (Pant and Chamyal, 1990) of the Cambay Basin which forms part of the alluvial plains of Gujarat.

According to Maurya *et al.*, (1995), the Quaternary basin of the Gujarat plains was formed due to the reactivation of Tertiary basement faults, and later filled up by fluvial sediments, marking the end phase of Cambay Basin subsidence. From the variation in the thickness of Quaternary sediments in different segments, they suggested that the basin comprised a series of horst and graben structures and the Early Quaternary tectonism gave rise to a differential basement topography, whereas the tectonic activity of Late Quaternary period was responsible for carving out the present landscape.

PALAEOCLIMATIC ASPECTS

Although not much information is available on the past climatic record of Gujarat, indirect inferences can be drawn from the available works of well-known archaeologists and historians who provided valuable details on the earlier climate;

its fluctuations and changes. Their work gives a good insight into the diversity of environment during which the early man lived in this part of the sub-continent.

Zeuner (1950) envisaged climatic changes forming the deposition of the entire continental sequence comprising repeated oscillations between dry and wet phases alongwith damper phases related to soil formation. He suggested that the climatic chronology and sequence of events on the Mahi was the same as on the Sabarmati, no climatic differences were indicated, only the laterite phase (P) of Sabarmati was not represented in the Mahi. Zeuner (1950) assessed that the deposition of indurated gravels was during a major humid phase, while silt horizons were deposited during arid (dry) phases with breaks \ between them, probably an amelioration of climate towards more humid conditions. He considered that red soil was formed under humid climate.

Allchin and Goudie (1971) suggested that the Paleolithic Man was present during the deposition of the lower indurated gravel. During the red soil formation, humid climate prevailed and this was followed by a major dry phase, during which the river aggraded and deposited silts. Deposition of aeolian sand started to dominate and during this phase, the Paleolithic Man vanished. Allchin *et al.*, (1978), studying the terrace sequence suggested that the presence of aeolian component in the terraces exhibits that a phase of aggradation took place under more arid climate than that at present. The river was unable to shift its load. Radiometric dating of caliche nodules from the fossil soil indicates that this aggradation was a Late-Pleistocene phenomena and corresponds with the Last

Glacial Maxima (LGM) (Hegde and Switsur, 1974; Hegde, 1975; Switsur and West, 1975 and Allchin *et al.*, 1978). The dry phase of aridity was in progress when Upper Paleolithic man inhabited the locality, and conditions ceased before the arrival of microlithic man (Allchin and Goudie, 1971).

The Quaternary deposits of Gujarat in recent years have received significant attention by Chamyal and his collaborators (Pant and Chamyal, 1990; Chamyal and Merh, 1992; Merh and Chamyal, 1993; Chamyal *et al.*, 1994; Sridhar *et al.*, 1994; Chamyal and Merh, 1995; Chamyal *et al.*, 1995; Sridhar and Chamyal, 1995; Khadkikar *et al.*, 1996; Chamyal *et al.*, 1997; Merh and Chamyal, 1997; Sridhar *et al.*, 1997a, 1997b). Their studies mainly pertain to the depositional sequences, gross lithologies, stratigraphy, geomorphological signatures and palaeoclimatic evidences as revealed in the various rivers viz., Narmada, Mahi, Sabarmati, Rupen and Luni. They noticed that the sequences in all the rivers were broadly comparable and indicate prevalence of identical climatic variations throughout the Quaternary in Gujarat. The thick Quaternary continental deposits of fluvio-marine, fluvial and aeolian origin, show records of sea-level fluctuations and climatic variations (Merh, 1992). The base of the sequence is marked by a Middle Pleistocene marine bluish mottled clay (Merh, 1992) which is equated with the coastal Miliolites of Saurashtra. The silty sand horizon over which the red soil has developed is indicative of a humid climate around 125 ky followed by the Terminal Pleistocene - Early Holocene arid Phase which gave rise to the aeolian silts deposited over the fluvial sequence.