CHAPTER - II

PREVIOUS WORK

The Quaternary continental deposits of N. Gujarat and SW Rajasthan have attracted attention of geologists, pedologists and archaeologists for almost a century. The very early studies in the later part of 19th century were carried out by the officers of the Geological Survey of India. Subsequently in the course of last four decades, these Quaternary deposits have been studied by archaeologists and geomorphologists, mostly from the point of view of climatic changes during late Quaternary, paleo-drainage and evolution of Thar Desert. It should however be emphasized that although considerable information has been generated by the previous workers, a coherent picture of the various Quaternary events detailing the evolution of this part of western India has remained fragmentary and somewhat sketchy.

As compared to N. Gujarat, S. Rajasthan has been better investigated and considering the continuity of the terrain features of S. Rajasthan into N. Gujarat, the author found the data generated by various earlier workers on Rajasthan quite useful in understanding the complexities of the N. Gujarat plains falling within the limits of the study area. With a view to provide an appropriate background to his own investigations and conclusions, the author has taken a rather broader view of the various previous studies such that the details obtained from those studies could be appropriately utilised to supplement his own observations.

The subject matter of this chapter has been categorised to include (i) very early studies belonging to the later part of the 19th century (ii) studies carried out in the early part of this century and (iii) studies carried out by geomorphologists and archaeologists in the later part of this century. Most of the studies pertain to Rajasthan, but some important ones also give details of the Gujarat Quaternaries.

EARLY STUDIES

Oldham C.F. (1874 and 1893), an officer of the Geological Survey of India gave an exhaustive account of the various rivers flowing across NW India and discussed their past behaviour as well. According to him, the river Saraswati mentioned in the Vedas, which has since almost disappeared was once a mighty river rivalling the Indus and the Ganges and was perhaps a feeder river for the various other channels flowing through the region. He also identified the courses of four major tributaries of the erstwhile Saraswati which according to him were receiving waters of the Himalayan river Yamuna. He further demarcated the extent of the Thar Desert and the changes in the river regimes that occurred even during the vedic times, approximately 3000 years B.P.

Oldham R.D. (1886 B) also of the Geological Survey of India was the first worker to state that the river Yamuna flowed originally into NW India and was the feeder river for most of the other ancient rivers including the `Lost' Saraswati. He further observed that most of the earlier courses of the rivers at present were covered by younger sediments, dominantly the desert sands.

The only work on N. Gujarat is that of Foote (1898). He extensively surveyed the various areas falling within the former Gaekwad's state of Baroda and in this connection, described the various alluvial and sub-aerial formations of some of the major rivers of N. Gujarat. His is the first ever detailed description of the alluvial horizons exposed in the cliff sections of the Sabarmati and Mahi rivers. He emphasized on the Sabarmati cliff sections. Significantly, he at that time itself opined that the rivers Sabarmati and Mahi at present are more destructive than constructive and the extent of deposition is negligible. Observations made by Foote are noteworthy, as he identified many traces of an older drainage system around the Sabarmati river, now forming a series of lagoons along its eastern flanks. Also judging by the depths of the channels of Meshwo and Khari the two tributaries of the Sabarmati, he concluded that they had been at work for a much shorter time than the Sabarmati and were relatively younger in age.

STUDIES CARRIED OUT DURING EARLY PART OF THE 2OTH CENTURY

The geologists of the Geological Survey of India, during the earlier half of this century, viz, Heron, Auden, Krishnan and Ghosh have highlighted the factor of tectonism in the drainage discruption of NW India. Interestingly, these workers have not taken into account the factor of climate in drainage disruption.

Heron (1917, 1936 and 1938) gave importance to the role played by epeirogenic activities in the disruption of the drainage. He divided the epeirogeny (neotectonism) into three episodes, first in Mesozoic, the second in Tertiary and the third in Quaternary. According to him, the Chambal- Yamuna ravines provide a good example of the last epeirogeny as they represent an actively upwarping tract in which the agents of erosion and denudation are presently active. Heron (1938) postulated that Rajasthan during early Tertiary formed a peneplain which during the Middle Tertiary was uplifted by 1,000 m and attained the present altitude during the Holocene. The uplift was presumably along an NW-SE axis corresponding to the incipient Himalayan Trend and that it was roughly dome-shaped leading to the reversal of the then existing drainage system. As of today the rivers of this region are not deepening their channels and instead meander and cut sideways.

Auden (1952) investigated the salt lake deposits of Rajasthan and came up with some very pertinent questions regarding the salinity of the lakes and groundwater of Rajasthan. He has also invoked an uplift of the regions in recent times and according to him, the salt deposits would not occur at their present heights (Sambhar 360 m, Didwana 338 m, Jamsar 212 m) unless there had been a reversal of gradient and drainage disruption due to uplift. On the other hand Krishnan (1952) has considered the salt lakes to be remnants of the Tertiary sea. He also invoked a post-Tertiary uplift of the Aravalli range. The large lakes and lagoons according to him thus have a marine origin. He has stated that the Rann of Kachchh was a shallow arm of the sea persisting right through the Tertiary probably until the Pleistocene, an emptying outlet for a number of major rivers and streams such as the Saraswati, Indus and Luni.

He visualised a drainage system which had an ultimate connection with the Himalaya and believed that the Saraswati derived its waters from the Sutlej and also the Yamuna was a feeder river to other streams flowing in the region. Disruption of this drainage was attributed to the uplift of Aravalli range as a horst only very recently.

Ghosh. P.K. (1952) has added some more information on the nature of this uplift of the Aravalli and in his opinion the uplift was more in the central part of Aravalli as compared to the two flanks in the Delhi area or the Gujarat extremity where he estimated that the uplift was of the order of 300 m.

STUDIES CARRIED OUT DURING LAST FOUR DECADES BY ARCHAEOLOGISTS AND GEOMORPHOLOGISTS

In the course of last four decades, new thrusts were given to the studies on Rajasthan and Gujarat, emphasizing on archaeological aspects. Studies were carried out by a number of workers who dealt with paleoclimates, drainage disruption and depositional aspects of Quaternary sediments.

Zeuner (1950, 1963) was the first worker to provide details of the Pleistocene chronology of Gujarat. He investigated the deposits as revealed in all the major rivers of Gujarat, though he paid greater attention to the Sabarmati river. According to him N. Gujarat formed a tectonic graben or basin, an area of recent tectonic subsidence. He postulated that the tectonic basin must have formed or started to form after the early Tertiary and in this depression the Sabarmati drainage system developed. He has also suggested the likelihood of Sabarmati having shifted its course slowly to the east. He envisaged climatic changes during the deposition of the entire continental sequence, comprising repeated oscillations between dry and wet conditions. Based on the sediment record examined by him, he reconstructed a succession of deposits and related climatic phases (Table 2.1).

Ghose B. (1965, 1971) worked on the Luni river basin of S. Rajasthan and with the help of aerial photographs observed relicts of numerous prior channels; by reconstructing the courses of dead stream channels, he suggested that a few thousand years ago, the region was marked by an extensive drainage system which according to him, had a history longer than the Himalayan rivers and was responsible for the removal of the initial surface of the sedimentary rocks and formation of the vast alluvial plains. This drainage system was active for a very long period of time and attained maturity before finally becoming defunct. He attributed the onset of aridity and subsequent fluctuation of this drainage system. Climatic events in the Luni basin were reconstructed by Singh and Ghose (1977) by using fluvial and aeolian landforms as indicators of late Quaternary climates. Geomorphological studies comprising identification of various landforms viz. extensive channels and relict old valleys, buried pediments, rocky pediments and plateaus, high stabilised dunes, inland sandy basins, saline depressions, unconsolidated active dunes and sand sheets enabled them to reconstruct previous drainage system of the region vis-a-vis climatic fluctuations in the region.

On the basis of sedimentological studies, Singh and Ghose(1977) inferred that the successive horizons of finer and coarser sediments in the Luni basin were laid layer by layer by fluvial activities and precipitations which varied considerably in their intensity. It has been argued by these workers that the prolonged humid phase of Pleistocene period was followed by a major arid phase in the pre-Holocene time. A significant contribution of these workers was the dating of

	DEPOSIT	CLIMATIC INTERPRETATIONS	CULTURE
Z	Modern surface with Agriculture	Sufficient precipitation to maintain soil under natural conditions	Modern agriculture
Y	-	? Dry phase, or increased human activity destroying natural vegetation	Iron Age and Chalcolithic
X	Soil forms on Dunes	Damper than previous phase	Microliths
W	Dune formation	Drier	?
V	Flat surface developed no soil in Sabarmati area	Damper	?
U	River agrading - alluvial silt and aeolian sand	Major dry phase	?
T	Red soil formed on S	Climate humid but not as much as so as P	Lower - Paleolithic artefacts
S	Silts and sands	Climate drier	Lower - Paleolithic artefacts
R	Cemented gravel	Precipitation heavier than today, floods	Lower - Paleolithic artefacts
Q	Mottled clay deposited in basin	Climate drier than previously	Lower - Paleolithic artefacts
P	Allitic weathering, formation of laterite crusts, hilly land surface	Humid climate	?

TABLE 2.1 : Sequence of alluvial deposits and associated cultural remains on the Sabarmati River, North Gujarat, summarised from Zeuner (1950).

calcrete (Kankar nodules) in the Central Luni basin (showing an age of 28,000 - 30,000 years B.P.) over which the main alluvium was deposited.

Ghose, B. *et al.* (1980) in a subsequent work suggested that none of the present day rivers in S. Rajasthan played any significant role in the formation of the alluvial plains of the region; they visualised existence of a Himalayan river in the alluviation process in the Luni basin. According to these workers the valley segment from Pachpadra to the Great Rann could not have formed by the discharge from Luni river and it was some other major river (Saraswati) which has been subsequently obliterated. Such a river definitely did not originate in the Aravalli and was most likely to have its source in the Himalaya.

These authors also tried to identify the shifting channel courses of the `Lost' Saraswati. It is relevant to mention the work of Pandey (1986) in this connection who during his paleogeographic reconstruction of the west coast Cenozoic stratigraphy has opined that the high sediment influx during Mio-Pliocene indicated a very long distance sediment transport and for this, he has postulated that the drainage might have connected from the rapidly rising provenance of the Himalaya. There is a clear implication in his observations that in the post-Pliocene times also, most rivers originated in the Himalayas. Sutlej had an independent mouth and the Mahi was connected with the Himalaya.

The work of Allchin *et al.* (1978) which deals with the entire Thar desert of Rajasthan and the arid plains of N. Gujarat provides an excellent perspective of the Quaternary evolution of Western India in terms of aeolian and fluvial processes in relation to pre-history. Their work provides a good insight into the diversity of environment during which the early man lived in this part of the subcontinent. The observations made by these workers in Luni basin and Sabarmati river provided some valuable background information towards the present study.

Wasson *et al.* (1983) who mapped the Thar dune fields have made some very interesting and important observations. These workers have opined that the various streams of the desertic terrain comprise an important element of the southern desertic landscape revealing a very poorly organised dunes. They found that the dunes overlap sandy alluvial deposits and the entire sequence below 6 m of dunes (at Langhnaj in N. Gujarat) is fluviatile. The random distribution and lack of directional pattern of the dunes suggest that they are the result of the aeolian reworking of spreads of alluvium deposited by the ancestors of the modern rivers of the northern Gujarat plains.

Misra and his associates (1961, 1962, 1968, 1980, 1982 a, 1982 b, 1984 a, 1984 b, 1986 a, 1986 b and 1988) in the course of the last three decades have worked extensively in the desertic areas of S. Rajasthan. Although they have emphasized on the archaeological aspects, their observations in respect of palaeoclimatic changes are of considerable significance and have got important bearing on the N. Gujarat Quaternary geology.

They have concluded :

(i) Climate fluctuated between arid and semi-arid several times.throughout the late Middle Pleistocene to late Upper Pleistocene (i.e. 1,70,000 - 26,000 years B.P.)

(ii) an arid climate prevailed during late Pleistocene

(iii) The hydrological changes of the Thar were due to westward shifting of the Himalayan drainage as a result of neotectonic movements during the late Quaternary

(iv) The dried up beds of Ghaggar and several wide channels around Jaisalmer were remnants of active rivers of the past.

Studies carried out by Singh (1972, 1974) on the salt playas of Rajasthan and Bryson and Swain (1981), Swain *et al.* (1983) on the Holocene fluctuations of monsoon also have indirect bearing on the scope of the present study. But as the details provided by them have palaeoclimatic significance their findings have been appropriately evaluated while discussing the palaeoclimatic aspects of the study area in chapter VII.

Rajaguru and his associates (1980, 1982 a, 1982 b, 1983, 1984, 1986 a, 1986 b) have studied in detail the problem of late Pleistocene aridity. The detailed study on the geo-archaeological aspects have helped in building a tentative succession for the Thar desert. Their studies around Didwana in Nagaur district of Rajasthan has established the existence of a well organised drainage system during the early Quaternary which was subsequently disorganised due to palaeohydrological and climatic factors. The flood plains developed by the early drainage system were exposed to strong aeolian activity. With the onset of aridity, dunes developed over the defunct flood playas in abandoned meander lakes. It was observed by them that the existence of paleosol horizons and calcrete layers interstratified within the fossil dune facies indicated that the dune activity was not continuous but was marked by climatic fluctuations.

Studies carried out by Dhir on Thar desert (1977, 1982, 1992 and 1994) have provided some information on the palaeoclimatic aspects of the desertic terrain. He has emphasized on the pedogenetic evidences to work out the sequence of humid and arid phases. According to him paleosols, calcretes and diagnostic landforms point to a history of climatic changes. The preservation of a conspicuous calcareousness in the sediments of the river Luni, both surfacial and underlying led Dhir (1977, 1982) to believe that environmental conditions during the Quaternary should have fluctuated within the semi-arid and arid regimes only. Thermoluminescence dates from different parts of the region have suggested that the Thar witnessed a major aeolian activity which peaked during 11-13 Ka (Dhir *et al.*, 1994). Dhir *et al.* (1992) have also described the various forms of calcrete, their chemical composition and microscopic features.

Whereas the various previous workers mentioned above have invoked the factor of climate- late Pleistocene humidity followed by pre-Holocene (Terminal Pleistocene) aridity to explain the phenomenon of drainage disruption and evolution of the present day landscape, Ahmad (1986) has added a new dimension to this problem by invoking the dominant role played by Holocene tectonism. He contended that the rivers change their courses in response to epeirogenic conditions and the deposition of the alluvial fans, their shapes and rates of deposition depended solely upon epeirogeny. He has stated that the Rajasthan desert was until recently well watered. The region was very fertile and fed by the rivers Drishdavati, Saraswati and the Luni. A rapid Holocene uplift in the Delhi area rejuvenated an insignificant stream into the present day Yamuna. Earlier he postulated that the Yamuna flowed westward as a major river following possibly along the present courses occupied by the Chambal and Mahi rivers. The later Holocene uplift forced the Yamuna to change its course and flow eastward and join Ganga. This uplift rapidly destroyed the drainage of Saraswati and other rivers, deprived of which the region turned into a desert.

Bakliwal and Grover (1988) who have synthesized the opinions of their numerous associates (Bakliwal and Sharma, 1980; Bakliwal and Ramaswamy, 1987 and Grover and Bakliwal, 1984) studied LANDSAT images of the Great Indian Desert and recognised numerous signatures of palaeochannels. These workers also invoked tectonic disturbances as one of major causes for the drainage disruption. They invoked movements along the Hardwar-Delhi ridge, Luni-Sukri lineament, Cambay Graben and Kutch Fault to explain the tectonic disturbances. Obviously, they have given considerable importance to the factor of tectonism in river shifting phenomenon.

Amal Kar and his associates (1984 a, 1984 b, 1984 c, 1987, 1988 a, 1988 b. 1988 c and 1993) in the last one decade have carried out indepth studies on the geomorphological processes in the Thar desert during the late Quaternary and have critically evaluated the phenomena of drainage disruption vis-a-vis climate related fluvial processes and role of neotectonism. He has emphasized the tectonic control in the evolution of ancient drainage and its subsequent modification. With the help of satellite imagery studies, he has concluded that the present day disorganized state of many of the streams could be attributed to neotectonism (movements along numerous lineaments) coupled with a shift to an arid climate. He has envisaged neotectonic movements along two major lineaments trending NE and SE and E-W, the morphological evidences indicating atleast two episodes of tectonic movements in the Luni-Jawai plains during the Quaternary period. In one of his papers Kar (1988 b) has extended his concept of tectonism as revealed in S. Rajasthan to the Ranns of Kachchh, thereby implying that the major lineaments of the two regions were more or less identical. This aspect of the Rajasthan neotectonism extending into Gujarat has been highlighted by Biswas (1982, 1983 and 1987) in his various papers on the rifting of the western continental margin vis-a-vis Cambay Basin tectonics.

Bedi and Vaidyanadhan (1982) who investigated the geomorphology of the area around lower Narmada Valley have also highlighted the role of neotectonism. They have stated that the area consists of landforms of a polygenetic landscape formed due to an interaction of endogenic and exogenic processes during the Quaternary. They have visualised that the morphogenesis of the present landscape started somewhere in the late Quaternary period, paleohydrological changes and neotectonic activity having played important roles in the morphogenesis of the landscape.

WORKS ON THE STUDY AREA

Geological details on the area falling within the limits of the study area broadly comprising the terrain between the Luni and Sabarmati river basins have not fully emerged in the works of the earlier investigators. As such not much attention has been paid in the past on the various aspects of the evolution of the area during Quaternary period. In the later part of the 19^{th} century Foote (1898) studied the Sabarmati sediments and gave the stratigraphic sequence. His description has already been included earlier.

Another work on Sabarmati is due to Sankalia (1946) who studied Sabarmati from the archaeological point of view, reported lower Paleolithic tools from the basal gravels. Sankalia however concentrated more on the stabilised aeolian dunes and excavated a number of sites. The dune at Langhnaj received particular attention. The dune is fixed by vegetation and the excavations showed a soil profile approximately 1.5 m in depth . Cultural remains of Mesolithic period are found to a depth of just over 1 m. Another site similar to Langhnaj excavated by Sankalia is in close proximity to the Sabarmati on a dune near Hirpura. The excavation here did not add significantly to the information provided by Langhnaj, but the Hirpura locality is of interest on account of its cutting by the Sabarmati river. Interestingly the Hirpura dune with the Mesolithic site upon it completes the stratigraphic sequence near the bottom of which are the indurated lower most gravels containing lower Paleolithic artefacts.

Zeuner (1950, 1963) as alluded earlier described the major rivers of the Gujarat alluvial plains and stated that the Sabarmati river showed the best exposed sequence of Quaternary deposits. Information on the sediments of the study area is also available in the work of Allchin *et al.* (1978) who have carried out an in depth evaluation of the palaeogeographic and prehistoric aspects. They have carried out investigations in various parts of S. Rajasthan and all over Gujarat and have synthesized the results of the previous studies. These workers found that the Sabarmati river course is characterised by two terraces, calling them as Madhavghat and Kamrod terraces respectively after the names of the villages where they show good development. According to them, the Sabarmati river like most other rivers shows a major episode of aggradation which in the Sabarmati is represented by cliffs and gullies cut into the Madhavghat terrace material and was again followed by a second phase of aggradation that gave rise to the lower Kamrod terrace. A reddish fossil soil well exposed at Hirpura and Madhavghat was interpreted by these workers to point to a period of still-stand (non-deposition) within the major aggradational phase.

Below Madhavghat the terrace system is not seen fully developed on the right bank but continues at its full height on the left bank for several kilometers, breaking down and finally disappearing as a single feature near Walad, somewhat to the north of Ahmedabad. At Nawapura-Dholka, below Ahmedabad, the lower Kamrod terrace is only 4 m above the winter water level, but some remnant hillocks of the Madhavghat terrace rise as high as 27 m. Another major contribution of these workers was in respect of the many fossil dunes in N. Gujarat and S. Rajasthan; some of which are associated with rocky hills as in Rajasthan while quite a few rest over the alluvium in a fairly close proximity to the Sabarmati river.

Near the town of Palanpur, exists some of the most extensive fossil sand dunes which were studied by them, have yielded Mesolithic artefacts. These dunes though somewhat far from Sabarmati, but are of interest as they provide a link between Mesolithic sites associated with dunes in Rajasthan and other parts of Gujarat. The dune at Langhnaj also received greater attention from Allchin *et al.* (1978), Agreeing with Sankalia (1946), these workers also stated that the crest of the dune comprised a site of occupation since Mesolithic age. Today the dune is fixed by vegetation and their excavations showed a soil profile approximately 1.5 m in depth - about 1 m of dark brown sandy soil below which the deposit was increasingly lighter in colour, more porous and containing kankar. Cultural remains down to a depth of just over 1 m and the concentration of the mircoliths, hand made pottery and animal bones is at the bottom. There is no discernable stratigraphy and there appears to be considerable disturbance and intermixture belonging to Mesolithic and Iron age. These workers have also referred to the dune near Hirpura in close proximity to the Sabarmati river and they have to add nothing to the information provided by Langhnaj. Sankalia (1946) had already stated earlier that this dune with the Mesolithic site upon it completes the stratigraphic sequence near the bottom of which are the gravels containing lower Paleolithic artefacts.

An important observation made by these workers is that the dunes are such that when the microlith makers utilised them as living sites, the process of dissection of the upper terrace was complete or nearly so (Where the Sabarmati river enters the Gulf of Cambay, there are some lines of dunes approximately parallel to the estuary. These occur as rounded mounds rising above the frequently flooded lower alluvium. Once such dune at Mitli was found to be Mesolithic site discovered by Subbarao).

In the Luni valley, Allchin *et al.* (1978) invoked incision of the river bed and choking of the same by sands and gravels from less arid regions further east. Many of the tributaries of the Luni were blocked by aeolian activity and various evidences like the relict courses of the tributaries, presence of large cobbles in the river course, terraces,suggest that in the past, the discharge of the Luni could have been considerably bigger than at present. Many of its tributaries, the Sukri, Bandi and Jawai have become disorganized since the advent of dry climate (aeolian activity), while some viz.the Mitli have become completely disorganized and later obliterated. The gravels occurring near the mouth of the Luni river have not been described by these workers but these comprise the upper gravel in the higher reaches of this river which have been reported to contain Middle Paleolithic artefacts (Allchin *et al.*, 1978 and Misra, 1968).

Subsequent studies mostly by geologists and physicists have aimed at precise dating of the various formations and also to understand the depositional processes and environments. Studies by Singhvi *et al.* (1982) mainly pertain to the application of Thermoluminescence methods in dating the various aeolian phases to understand the chronology of paleoclimatic changes.

Singhvi *et al.* (1982) on the basis of TL data have given age estimates for the dune samples from Langhnaj and the ages given by them reveal that the sample collected at a depth of 240 cm gave an age of 20,280 years whereas the one collected from a depth of 80 cm dates back 5,180 years. Obviously the TL age data fits in well with the broad paleoclimatic picture which envisages onset of aridity at the close of Pleistocene and its continuation during the early Holocene.

Based on his results in combination with geological and archaeological studies by workers of Deccan college, CAZRI and GSI, Singhvi has suggested the following chronology of climatic events.

(1) The aeolian activity in the Thar dates back to ~ 200 ka

(2) The peak of aeolian accumulation post dates the glacial maximum and occurred at ~14 Ka,

(3) The aeolian accumulation occurred in sharp intense pulses spanning ~1-2 Ka lasting for 10 to 20 % of time since the LGM (Last Glacial Maximum).

It appears that the earliest aeolian activity in Thar desert dating back to around 200 Ka as visualised by them is based on the works of Misra and Rajaguru. Subsequent dates on the last major aridity and the following events get some support from the TL dates. According to Singhvi *et al.* (1994) the entire aeolian accumulation occurred around 15 Ka and 25 Ka and was prior to Last Glacial Maximum.

The Gujarat Quaternaries in recent years have received significant attention by Chamyal and his collaborators (Pant and Chamyal, 1990; Chamyal and Merh, 1992; Merh and Chamyal, 1993 and Chamyal *et al.*, 1994). Studies carried out by these workers mainly pertain to the depositional sequences, gross lithologies and paleoclimatic evidences as revealed in the various cliff sections of major river sections of Gujarat viz, Narmada, Mahi and Sabarmati. Pant and Chamyal (1990) gave an overview of the pattern and sequence of Quaternary sedimentation and the processes responsible for the evolution of the Mahi landscape. According to these workers the river course is controlled by a series of criss-crossing N-S and NE-SW trending faults; the N-S trending step faults have developed more or less parallel to the Eastern Cambay Basin Margin Fault. The drainage of Mahi river follows this pattern. The sedimentation has also been a result of the same structural configuration and these workers have recorded two distinct phases of erosion.

A mapping of the sediments exposed in the cliffs of the Mahi enabled them to build a composite stratigraphy of the sediments. It has been stated by them, that the sediment succession in the basin is intercalated with various types of soils, the most conspicuous among them comprising a red soil horizon. It was suggested by them that this red soil was a marker horizon for stratigraphical correlations for the entire alluvial plains of Gujarat. Lower Paleolithic tools found in the gravel bed at the base of the sequence enabled these workers to tentatively date the exposed sequence in the Mahi river to belong to Middle Pleistocene times. As a continuation of his studies on the Mahi river, Chamyal (Chamyal and Merh, 1992) have described the exposed sequences in all the three major rivers of Gujarat viz. Narmada, Mahi and Sabarmati and has provided a tentative sequential stratigraphy for the Central Gujarat continental deposits. He found that the sequences exposed in the cliff sections of the three rivers were more or less identical and correlatable (Table 2.2).

In a subsequent study, Merh and Chamyal (1993) have provided an overview of all the Quaternary deposits of Gujarat laid by the three major depositional environments, marine, fluvial and aeolian. It was highlighted by these workers that the Quaternary deposits of Gujarat including the continental deposits

Narmada river basin		Mahi river basin		Sabarmati river basin		Age
Formation	Lithology	Formation	Lithology	Formation	Lithology	
Broach	Vertisol, yellowish silty sand, cross-fine grained sand, laminated mud at the base	Timba	Dunal sands, aridisol, aeolian silt, brown soil, coarse sand and gravel-III	Valasna	Aridisol, dunal sands, aeolian silt, yellowish sand	Recent to Terminal Pleistocene
Ambali	Silty sand, red (rubified) soil, coarse reddish sand, gravel-III, pedogenised laminated mud	Shihora	Aeolian silt, red (rubified) soil, highly fractured and pedogenic mud, finely laminated mud with marly bands	Vijapur	Pedogenised laminated mud, thick red (rubified) soil developed over silty sands	Late Pleistocene (Wisconsin)
Tilakwada	Cross-stratified gravel-II, coarse reddish sand or pedogenised laminated mud, gravel-I, reddish brown mottled clay/bluish basal clay	Raika	Cross-bedded gravel-II, carbonate rich and pedogenically altered fractured mud gravel-I, clay laminations alternating with marly bands, mottled at places	Hirpura	Cross-stratified gravel-II, pedogenised fractured mud, consolidated gravel-I, greyish, bluish, greenish basal clay, mottled at places	Late Middle Pleistocene to Middle Pleistocene

TABLE 2.2 : Lithostratigraphy of the exposed Quaternary deposits in the semi-arid basins of Gujarat (After Chamyal and Merh, 1992).

of north and central Gujarat provide a good example of the interplay of paleoclimatic and glacio-eustatic factors in controlling the sedimentation and shaping the Quaternary landscape of Gujarat. According to these workers the sediments of the alluvial plains were deposited in structural depressions within the Cambay and Narmada grabens. A major fact that was highlighted by them was that the river sections of north and Central Gujarat viz. Narmada, Mahi, Sabarmati and Luni revealed the existence of an almost uninterrupted horizon of aeolian silts and sands resting over the fluvial sequences. They also found that sequences in all the rivers were comparable and indicative of prevalence of identical climatic variations throughout Gujarat during the Quaternary.

The tectonic factor has been highlighted by Chamyal *et al.* (1994). The role played by the Narmada and Cambay graben tectonics and the intersection of the Narmada Geo-Fracture and the EMCBF provided an appropriate depression in which the fluvial sedimentation began with a huge thickness of gravel accumulation. Almost identical conclusions have been drawn by Sridhar and Chamyal (In press) for the accumulation of gravels in the Sabarmati basin.

To Sareen goes the credit of a reasonably detailed investigation on the geological history of Sabarmati river basin. He attempted to provide a tentative chronological sequence for the Sabarmati sediments using the dates obtained by Thermoluminescence techniques (Sareen *et al.*, 1992)). In this work four geological formations in the Sabarmati valley were recognised (Table 2.3) and it was emphasized that the older members of the Sabarmati sequence indicated deposition in a semi-arid fan environment within fluvial settings. It was suggested that the Waghpur formation dating back to 300 K. Y. comprised the oldest exposed depositional event corresponding to a high magnitude fluves of a semi-arid fan. In a subsequent publication, Sareen *et al.* (1993) while emphasizing the

FORMATION	MEMBER	TYPE SECTION	MAX. THICKNESS (m)	LITHOLOGY	MAJOR DEPOSITIONAL EVENT	AGE (ka)	REMARKS
Sabarmati	Aeolian Sand	Jantral	5	Fine Sand	Aeolian	-	-
	Fluvial Sand	Gandhinagar	3	med./fine Sand, Silt	Fluvial	3	This study*
Akhaj		Akhaj	15	Fine Sand	Aeolian	5.1	Singhvi et al. 1982
	Upper Sand	Teniwada	12	fine to med. sand	Fluvial flood plain	-	-
Mehsana	Lower Sand	Pushpawati	10	Sand, silty clay, caliche nodules	Fluvial (also pedogenetic phases)	30	This study*
	Sand	Hirpura	20	Red fine sand, silt and caliche	Fluvial semi-arid	47	This study*
Waghpur	Conglomerate	Valasana	5	Gravel, grit, coarse sand	Semi-arid fan	300	This study*

Table 2.3 : Stratigraphic succession of Sabarmati basin (After Sareen et al., 1992)*

slope and drainage characteristics, recognised the role of Quaternary tectonism as well.

The primary objective of their study was to examine the development of the Sabarmati drainage in relation to neotectonic activity on basis of demarcation of 185 lineaments in the alluvial plains surrounding the Sabarmati river, these authors concluded that two orientations dominated, one trending ENE-WSW to E-W and the other NW-SE. With the help of computerised seismic techniques they traced several NNW-SSE trending subsurface faults, east of the Sabarmati river which according to them were most probably reactivated pre-Quaternary faults. On the basis of geomorphological studies these workers envisaged reactivation of Aravalli region along Precambrian regional faults during Quaternary and the various neotectonic lineaments comprise reactivation of earlier tectonic trends. The N-S to NNE-SSW main Sabarmati drainage according to them was influenced by the Cambay graben tectonics. Further, they observed that whereas the regional slope direction is southwestward, the Sabarmati river flow shows a deviation from the regional slope and instead follows N-S to NNE-SSW trend.

This anamoly was attributed by Sareen at al. (1993) to a phenomenon of fluvial adjustment in response to neotectonic activity. It has been argued by them that the Waghpur formation tentatively dated to 300 K.Y. is dissected by the present day N-S channel and hence the neotectonic activity causing the shift should be younger and could be dated as mid- to late Quaternary. It is obvious that these workers could not satisfactorily explain the southward anamolous shift of the Sabarmati river from the regional SW slope.

The most recent work on Sabarmati river is by the present author (Sridhar *et al.*, 1994) wherein an attempt has been made to provide greater details of the total alluvial thickness of around 300 m of north Gujarat. These authors have also invoked continental (mostly fluvial) sedimentation in a huge graben bounded by Cambay Basin related faults. A critical evaluation of the exposed sequences of various north Gujarat rivers including Sabarmati, Rupen, Pushpavati, Khari, Banas and Luni and sub-surface drill-hole data has enabled them to obtain a clearer picture of the lithology of the various horizons. They have observed that the alluvium is as thick as 300 m in areas devoid of any present day drainage and have concluded that obviously the entire alluvial sequence was a product of an ancient super-fluvial system which has since been partly destroyed. This earlier drainage system which originated in the Aravalli highlands flowed southwestward and met the sea a few kilometers inlandwards from the present day boundaries of the two Ranns of Kachchh. It has been envisaged by the author that the earlier course of Sabarmati river coincided with the Rupen river flowing into the Gulf of Kachchh and development of a major N-S trending fault captured the course of the Sabarmati river causing it to swing away from its earlier course and to flow into the Gulf of Cambay. It has also been suggested that the existing rivers of north Gujarat comprised fragments of the earlier disrupted rivers, some channels having been destroyed while the others reactivated. A combination of neotectonic activity in the Cambay Basin, glacio-eustatic sea-level changes and paleoclimatic fluctuations appear to have played a major role in controlling the depositional history of the fluvial sequence and the disruption of the super-fluvial drainage system.