CHAPTER 2

GEOLOGICAL AND GEOMORPHOLOGICAL STUDIES

The Nal area presently is a regional low and derives its sediment input both from the Saurashtra side and from the eastern alluvial plains. It, therefore, becomes important to know the Quaternary geological history of both the regions as they are likely to have influenced the sediment record of the Nal region. In this Chapter, the available information about the geology and tectonic history of the surrounding regions, is summarised. This provided a framework within which the results of present geologic and geomorphic investigations, also discussed in this chapter, were interpreted.

2.1 Background information

The Quaternary sediments of Gujarat show the presence of palaeo-strandlines, inland and elevated miliolites, fault controlled variable thickness of sediments, fault controlled drainage pattern and raised mud-flats indicating the active role of tectonism, both syn- and post-depositional, in the development of present day landscape. On the basis of geological history and sediment types, the Quaternary sediments of Gujarat can be sub-divided as (see Fig. 2.1):

1. Quaternary sediments of Central and North Gujarat.
2. Quaternary sediments of Saurashtra.
3. Quaternary sediments of Ranns of Kachchh.
4. Quaternary sediments of Nal depression.

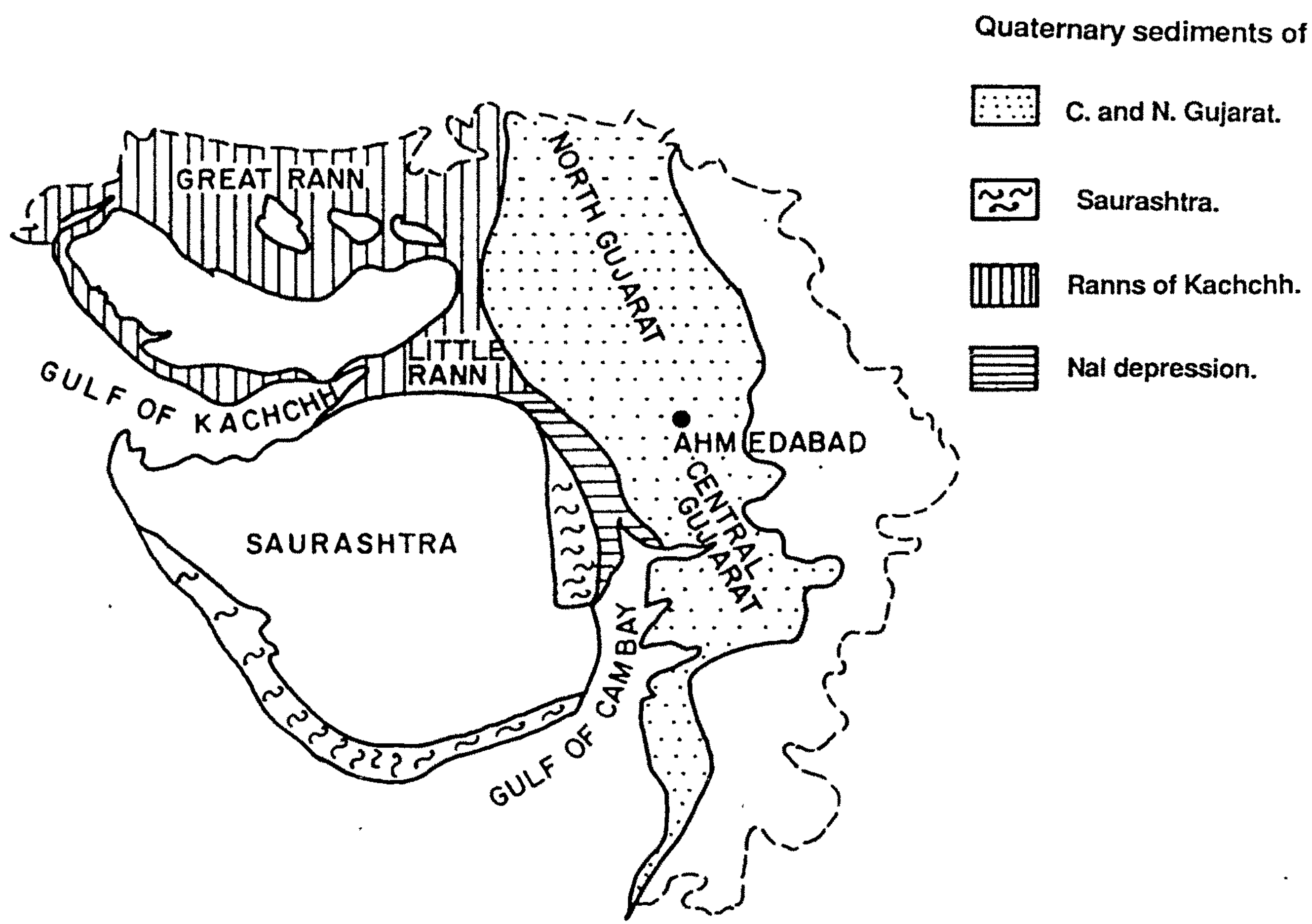


Fig. 2.1 The sub-divisions of Quaternary sediments of Gujarat.

The geographic distribution and available geological information for each of these units is discussed below.

2.1.1 Quaternary sediments of central and north Gujarat

The Quaternary sediments of Gujarat alluvial plains are bounded by the Aravalli range in the NE, by the Narmada geofracture in the south and on the northern side gradually merge with the recent aeolian deposits of the Thar Desert. To the west, these alluvial deposits gradually slope towards the Nal depression (Fig. 2.1). The major part of deposition has occurred within the Cambay and Narmada Grabens. These Quaternary sediments have been extensively studied and reported. A summary of these studies is presented below.

The Cambay basin is a graben bounded by two NS trending faults (Fig. 1.3) that developed at the close of the Cretaceous. Biswas, (1982, 1987) attributed this basin formation to the rifting of the western continental margin. During Tertiary, the sedimentation was dominantly marine. However, with the advent of the Quaternary, a change in sedimentation pattern occurred. The Lower Pleistocene deposits have been reported to comprise fluvio-marine/deltaic sediments indicating fluctuating shallow water marine and continental conditions (Chandra and Chaudhary, 1969). Later tectonic activity has exposed several sections along river courses which have been described by several workers (Foote, 1898; Sankalia, 1945; Zeuner, 1950; Sareen et al, 1992). The first major transgression during Quaternary took place only in Middle Pleistocene and is represented by the mottled clays having blue green colour in some sections. Chamyal and Merh (1992), have described the sequence in the Sabarmati basin (Fig. 2.2) in detail. The sequence comprises of Hirpura Formation of late Middle to Middle Pleistocene age, consisting of mottled basal clay, consolidated gravels, pedogenised mud and cross stratified gravels. Overlying these are red soils developed over silty sands and pedogenised laminated muds of the Vijapur Formation which have been

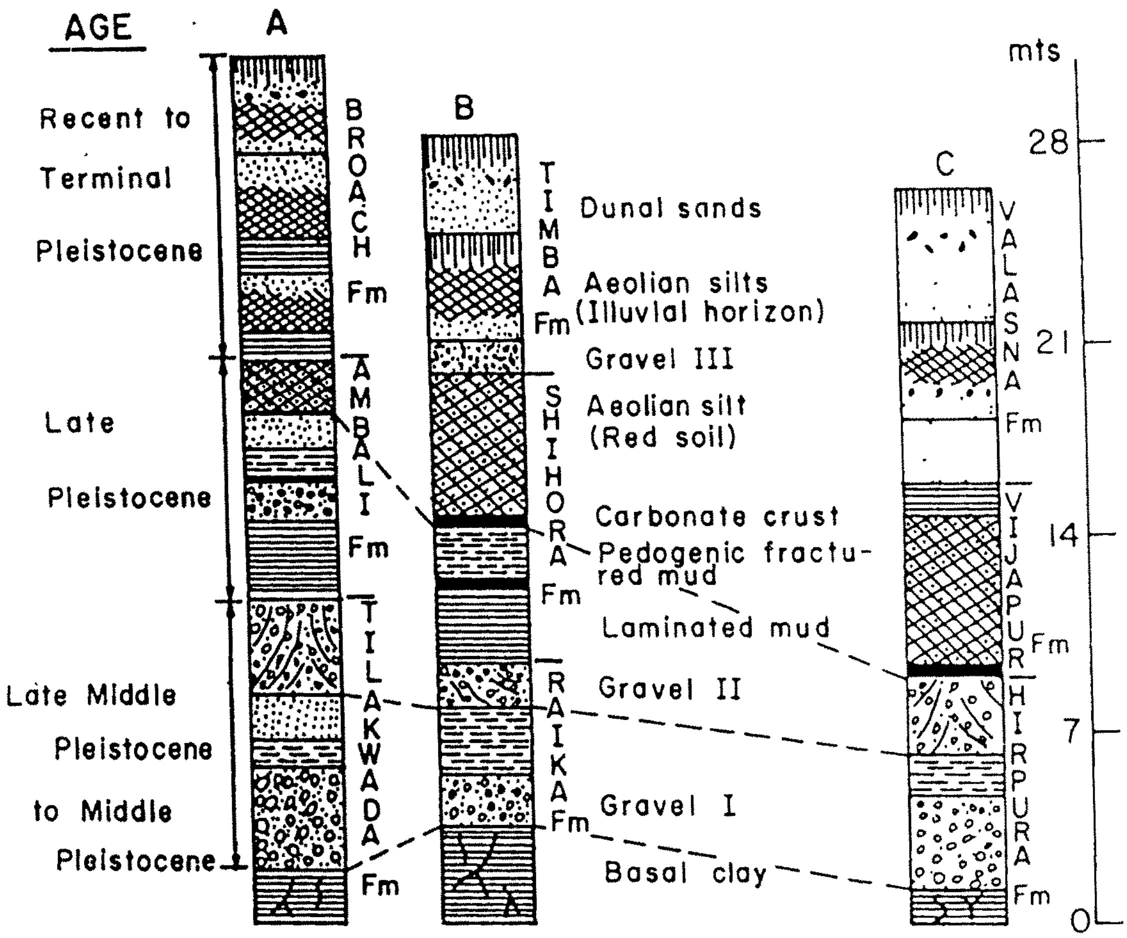


Fig. 2.2 Composite Quaternary sediment profiles of river basins of Gujarat.
(A) Narmada (B) Mahi (C) Sabarmati.
(Redrawn from Chamyal and Merh, 1992)

assigned an age of Late Pleistocene. On top is the Valasna Formation comprising sands, aeolian sand and silts of Terminal Pleistocene to Recent age. Chamyal and Merh (1992), and Merh and Chamyal (1993), have attempted to provide an integrated picture of the exposed sequences in the various N. Gujarat rivers and correlate them with those of Mahi and Narmada to the south (Fig. 2.2). South of Narmada the alluvial deposits do not exceed 100m, between Narmada and Sabarmati the maximum thickness is 200m, while in north Gujarat it reaches upto 500m (Merh and Chamyal, 1993). The varying thickness of Quaternary sediments has been attributed to their deposition within a number of sub-basins of different sizes and depth which were formed due to the reactivation of the pre-existing Tertiary faults (Maurya et al, 1995). Such a huge thickness of sediments cannot be attributed to the action of present day rivers which are erosional. Sridhar et al (1994), have visualised the existence of a stronger fluvial system to explain the vast thickness of sediments accumulated in the graben. This 'super-fluvial' system was believed to have originated in the Aravallis and to flow south-west to drain into the Gulf of Kachchh. The disruption of the super-fluvial system, during middle to late Quaternary, appears to have been caused by differential uplifts within the graben (Ghosh, 1952; Sareen et al, 1993), eustatic changes in the base level and uplift of the Aravallis (Ahmad, 1986). The evidences of tectonism can be seen in the form of entrenched rivers, cliffy banks and fault controlled river courses.

Early Holocene coastal deposits, comprising raised mud flats are found between Mahi and Narmada rivers (Merh and Chamyal, 1993).

2.1.2 Quaternary sediments of Saurashtra

The Lower Pleistocene, on the Saurashtra coast, is represented by fluvial sands and conglomerates (Merh and Chamyal, 1993). After the advent of the mid-Pleistocene, which was marked by a major marine transgression, the Quaternary record in Saurashtra is better developed. The Lower Pleistocene deposits are overlain by deposits of miliolite formation. These are the most striking Pleistocene deposits of Saurashtra. They are essentially consolidated biogenic beach sands and the constituent rocks dominantly made up of sand sized calcareous shell fragments and tests of foraminifers of family Miliolidae. The miliolites occupy the western and southern coastal fringes (Fig. 2.1) and also occur as discrete outliers in the inland areas (Barda, Alech hills, Chotila hill, foothills of Mt. Girnar). The occurrences of miliolites at different levels has resulted in a lively discussion with one side invoking a succession of high strandlines during Quaternary (see references in Merh, 1992) and the other side (Bhaskaran et al, 1989) proposing to explain the occurrence of miliolites at higher levels by invoking a tectonic upliftment of the order of 0.23 to 2.2 mm per year during the Late Quaternary. Both these theories are, however, not acceptable to most workers who point to the reported (Pascoe, 1964; Chapman, 1900; Wadia, 1953; Patel and Bhatt, 1995) abundance of typical aeolian features preserved in most of the inland occurrences. The coastal miliolites have been grouped into two distinct members - an underlying shelly limestone (unconsolidated beach rock) and overlying aeolian beach accumulations (Merh and Chamyal, 1993). The underlying member has occurrences at elevations of +25m msl and is encountered upto 15-20km inland. Beyond this the shelly limestone is absent and all miliolite occurrences comprise aeolian accumulations of miliolite resting over older rocks (Merh, 1995). On this basis, the maximum level of mid Pleistocene transgression is estimated to be about +25m msl. Uranium series dating has been used to suggest that miliolite formation over Saurashtra may have occurred in three age brackets ranging from 170± 30, 95 ±15, and 60 ±10 ka (Bhaskaran et al, 1989). These dates must however be treated with caution in view of the possibility of contamination of samples and the absence of field evidence for tectonism on the scale reported by these workers (Gupta, 1991).

On the eastern side of Saurashtra, a sharp contact of alluvium with the basalt is observed in the N-S direction extending from a little west of the Nal Sarovar (Fig. 1.2 and Fig. 2.1). This may represent a faulted boundary. The eastern portion is believed to have been under the sea until recent times (Sood, 1983). Further east of Saurashtra, the alluvium gradually slopes into the Nal depression. The east-west trending Bhavnagar fault extending from Bhavnagar in the east to Damnagar in the west (A'B' in Fig. 1.3) marks the boundary between an enormous thickness of alluvium in the north and Deccan traps in the south. There is no trace of Deccan traps in the north. The basalt flows, to the south of Bhavnagar fault, dip to the north at 30° suggesting that the northern side may be the downthrown side (Sood, 1983).

The Holocene sediments of Saurashtra comprise the Chaya formation consisting of semi-consolidated to consolidated shell limestone, coral reefs and oyster beds and are found to be resting over Dwarka formation or over Miliolite (Merh, 1995). The youngest Holocene sediments consist of alluvium deposited by the Bhadar and other rivers of Saurashtra.

2.1.3 Quaternary sediments of the Ranns of Kachchh

The Ranns of Kachchh are marshy salt plains, north of Saurashtra. These lie just above normal high tide and stretch for nearly 300 km from east to west and nearly 150 km north to south. These are divided by the island of Kachchh into two areas: Great Rann in the north and the Little Rann in the south. The two Ranns get flooded during monsoon season due to sea water forced up by SW monsoon and river input from the east. It was surmised (Pascoe, 1964) that in the recent past the Ranns of Kachchh were a shallow gulf or an arm of the sea that was filled up during Holocene by the silt brought in by the streams draining the surrounding areas.

Gupta (1973, 1975) reported a three layer sequence, from the Little Rann, comprising of a layer of stiff bluish and black clay overlying a layer of gritty sandy clay. This sandy layer, in turn, was underlain by a layer of yellowish clay locally called 'Murund'. He also reported that, unlike the gradual transition from bluish black clay to sandy clay, the contact between sandy clay layer and underlying yellow 'Murund' was abrupt. On the basis of sedimentation rates of 2mm/yr, calculated from radiocarbon dates, Gupta (1973, 1976) concluded that even as late as 2ka BP, the Rann was about 4m deep and remained inundated throughout the year.

2.1.4 Quaternary sediments of the Nal depression

This region is a low lying area between the alluvial plains of the central Gujarat and the alluvial deposits of the eastern Saurashtra (Fig. 2.1). There are no exposed sections in this region and hence very little is known about this area. Owing to it's low lying topography, is believed to represent a filled up sea link, that previously existed between the Little Rann in the north and the Gulf of Khambhat in the south (Sukeshwala, 1948; Allchin et al, 1978; Merh and Chamyal, 1993). The link is believed to have existed till ~2ka BP (Merh, 1992) and remnants of this sea are thought to be represented by the Nal Sarovar. Gupta (1973), raised a shallow core from Nal Sarovar and indicated an age of 7ka, on inorganic fraction, at 5m depth. Till date, no detailed study has been done in the Nal region.

2.2 Present study

The aim of present work is to understand the geologic evolution of the Nal region and to study its palaeoclimatic history. Therefore, a multi-pronged approach was used to decipher the sedimentary and geomorphic record of this region. Satellite imageries and toposheets have been used to study and map the geomorphology and drainage pattern. This, together with the existing bore hole data in the region, was synthesised with the available data on global eustatic sea level changes, to develop a hypothesis for the evolution of the Nal region. This hypothesis was subsequently tested by raising a core from Nal Sarovar, in the central part of Nal depression, and subjecting it to extensive sedimentological and chronometric investigations.

In the following, the details of the methodology adopted, results and their interpretation pertaining to the evolution of the Nal region are presented.

2.2.1 Remote sensing studies

2.2.1.1 Methodology

The objective of these studies was to construct drainage and geomorphological maps of the region and to identify palaeochannels. IRS FCC 1A imagery was used in combination with Survey of India toposheets.

The studies were carried out at the Gujarat Engineering Research Institute (GERI), Baroda; the M.S. University of Baroda; Centre for Environmental Planning and Technology (CEPT), Ahmedabad, and the Space Application Centre (SAC), Ahmedabad. A paper print of IRS FCC imagery (Row: 32 Path: 52, colour code: 2,3,4) on 1:250,000 scale obtained from National Remote sensing Agency (NRSA), Hyderabad was used. This imagery is covered in Survey of India Toposheets 46A, 46B, 41M and 41N on 1:250,000 scale. Both pre- and post- monsoon imageries were initially compared. It was found that in the pre-monsoon print the drainage pattern could be distinguished quite clearly on the basis of tonal changes and linearity of channels. This is because of diminished vegetation cover and the river courses being dry or having very little water. In the post-monsoon imagery, the drab dusty summer colours were replaced by a blaze of colours. It then became difficult to interpret the imagery. Hence, for drainage pattern analysis, pre-monsoon imagery was used. The drainage pattern was traced out from the toposheets and subsequently compared with the satellite imagery. This made possible the identification of palaeochannels. Some minor shifts in the river courses in the past 30yrs, especially in case of Sabarmati river were observed but are not of much interest to this study. The emphasis, of the present study, was on older abandoned channels which may have been responsible for bringing sediments to the Nal area and would give some clue about the tectonic evolution of the region. The same imagery was also used for the preparation of the geomorphological map of the region which showed the presence of features like stabilised dunes, raised mud flats and inland deltas. Fig. 2.3, 2.4 and 2.5

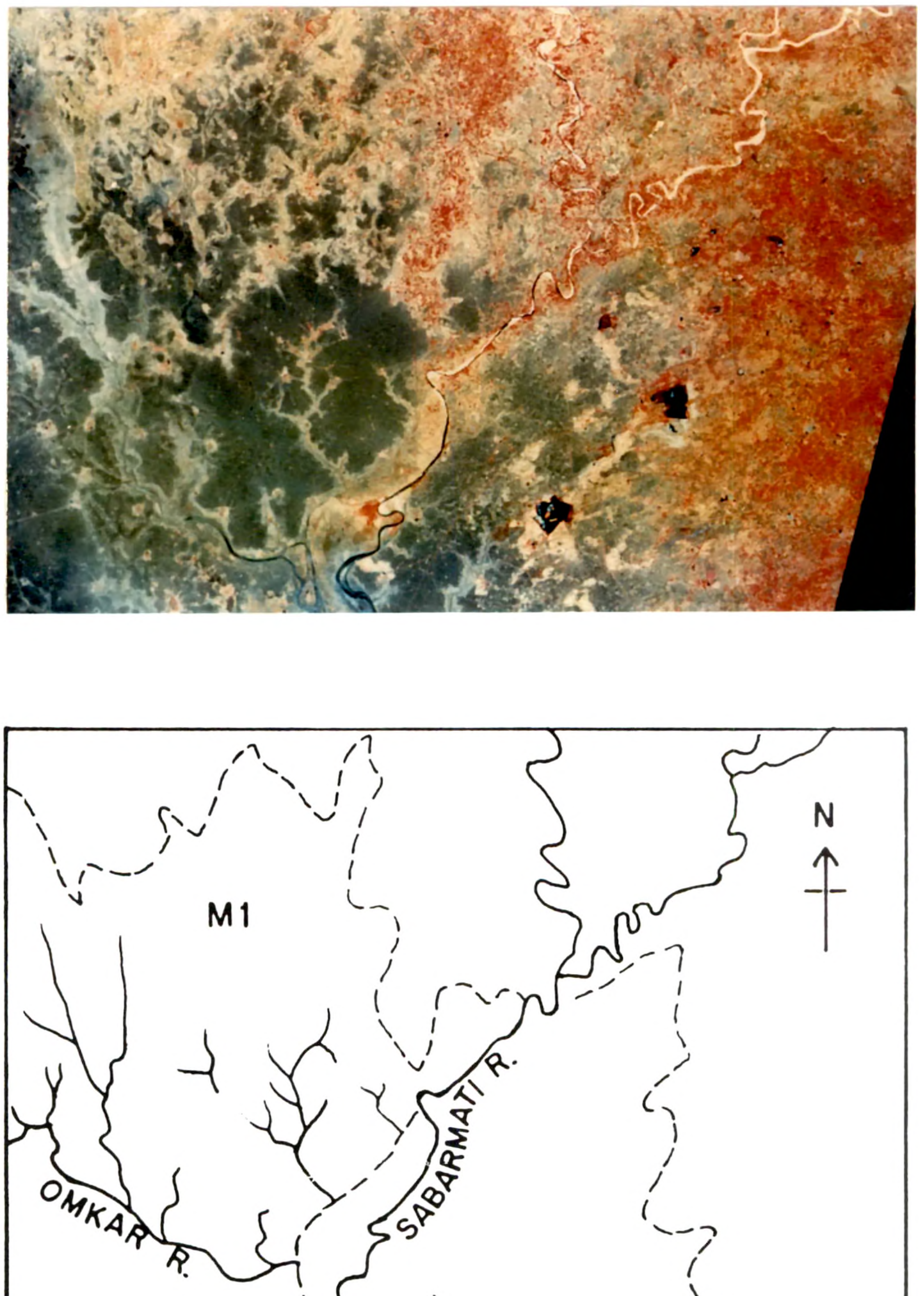


Fig. 2.3 Satellite imagery and interpretation showing deranged drainage pattern in older mud flats, south of Nal Sarovar.

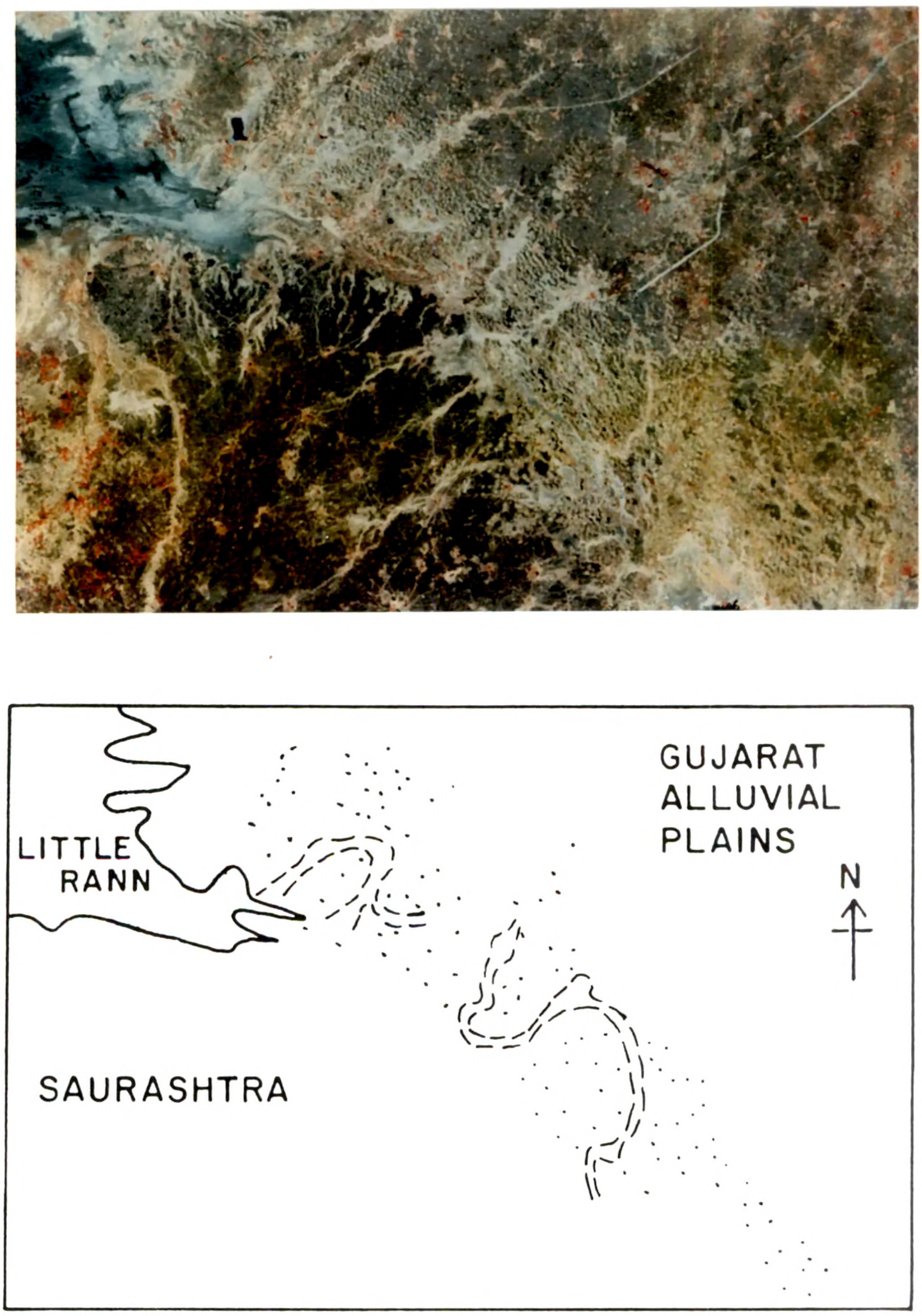


Fig. 2.4 Satellite imagery and interpretation showing the location of palaeochannels (dashed lines), dunes (dots) and alluvial plains, north of Nal Sarovar.

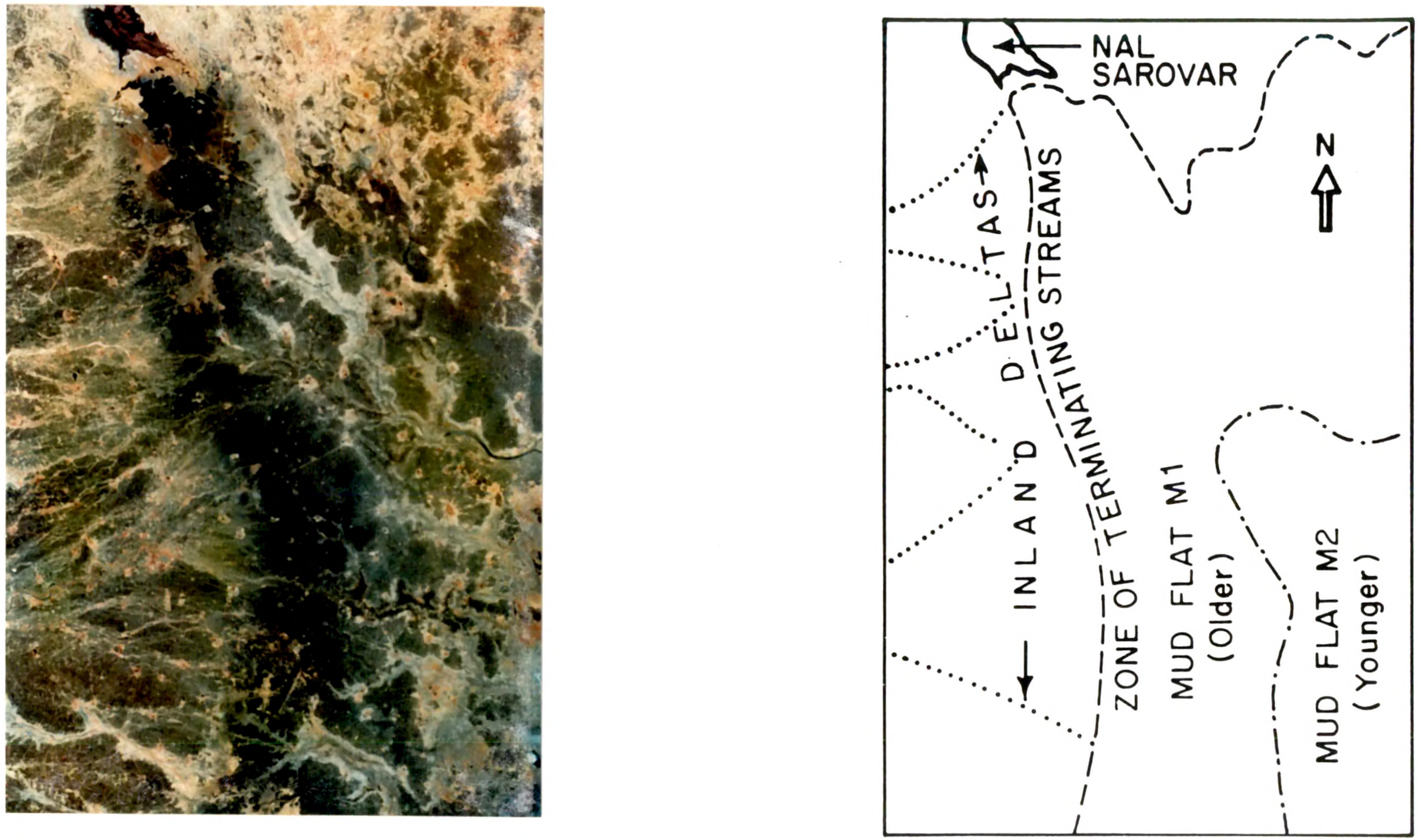


Fig. 2.5 Satellite imagery and interpretation showing inland deltas, zone of terminating streams and older mud flats, south of Nal Sarovar.

show some typical features observed in the satellite imagery. The presence of palaeochannels and other geomorphological features were confirmed by selected field checks during the Jan '96 field season.

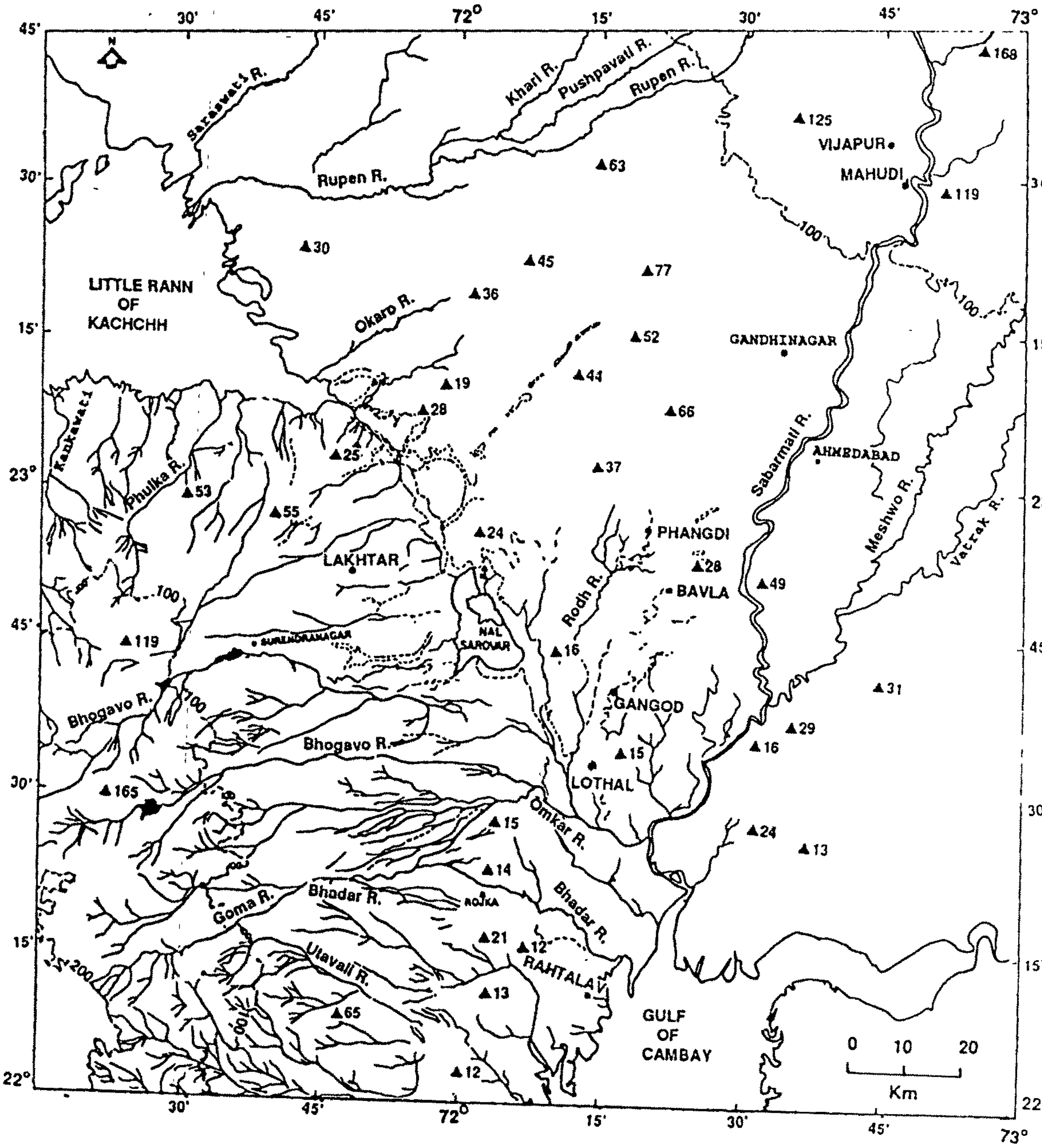
In the 1:250,000 scale drainage map, several unusual features of drainage pattern on the Saurashtra side were observed, e.g. thinning down of the major rivers, abrupt termination of streams about 35-40 km inland, changes in stream direction etc. Hence, a more detailed study was justified and carried out in the region (71°30' to 72°30') in the immediate vicinity of Nal Sarovar. For this, Survey of India toposheets 46A/4, 46A/8, 46B/1, 46B/2, 46B/3, 46B/4, 46B/5, 46B/6, 46B/7, 46B/8, 41N/9, 41N/10, 41N/11, 41N/12, 41N/13, 41N/14, 41N/15, 41N/16, 41M/12, 41M/16, (on 1:50,000 scale), were used and a drainage map on larger scale was prepared.

2.2.1.2 Results

Drainage pattern studies

On the eastern side, the major rivers of the region, Banas, Saraswati, Rupen flow into the Little Rann/Gulf of Kachchh along the SW slope of the region, with the exception of Sabarmati which cuts across the general slope and flows into the Gulf of Khambhat in the southern direction (Fig. 2.6). All these rivers show the presence of wide beds and large valleys which appear to be incompatible with the present seasonal flow. Towards the lower course of Sabarmati, near the Gulf of Khambhat, streams show a disorganised drainage pattern.

There are presently no major rivers flowing into the Nal region. However, satellite imageries indicate the presence of several abandoned meandering palaeo-channels in this region (Fig. 2.6). Upstream of the Rodh river, and in the region between the Rodh river and present day Sabarmati river, several abandoned channels were seen which may represent former courses of Sabarmati. Some of the mapped palaeochannels were also checked out in the field where a variety of related features were observed. At Phangdi, the pre-existing channels exist in patches as small seasonal streams (Plate 1) that



Palaeochannels
Spot Heights in m.
Contours in m.
Present day rivers

Fig. 2.6 A composite map showing the present day drainage pattern and location of palaeochannels in and around Nal region.

terminate abruptly. Near Bavla, it was observed that the shallow wells in the vicinity of the palaeochannels had relatively fresher water as compared to the surrounding regions. On the other hand, at Gangod, it was found that the ponds along the former river courses lost the accumulated water soon after the monsoon season due to percolation through coarse sand bed. A trench in one such pond revealed the presence of fluvial sand at 1.5m depth. Thus, it appears that the presently barren area to the east of Nal had several channels flowing through it which may have been responsible for bringing sediments into this region.

On the western, Saurashtra side, the major rivers are Bhadar and Bhogava. These flow from the Saurashtra highlands eastwards to the south of Nal Sarovar. A significant feature observed is the presence of large valleys which have been identified on the basis of their tonal changes. In this region of Saurashtra, on the IRS FCC imagery, the channels exhibit a light photo tone. Also, below the 20m contour and to the south of Nal, a zone of abruptly terminating streams was observed (Fig. 2.5 and Fig. 2.7). Only the major rivers have managed to cut across this zone and continued their flow towards the sea. Further eastwards of this zone, towards the Gulf of Khambhat, several smaller streams showing deranged drainage pattern are observed (Fig. 2.3).

On the western, Saurashtra side, very few abandoned channels have been found. The older channels still exist even though the flow through them is now largely seasonal.

Geomorphological Studies

On the Saurashtra side, both continental and marine evidences of sea level changes were found. The continental evidence includes inland deltas which have been identified on the basis of distinctive fan shape, tonal changes and associated drainage pattern (Fig. 2.5). Sood (1983), had also identified these patterns as deltas and attributed them to recent marine transgression. On the IRS FCC imagery they exhibit a light photo tone, show distributary and radiating river channels. During field checks, in a section upstream of Bhogava river, east of Limbdi, occurrence of basalt dominated coarse sand, showing cross-bedding was observed (Plate 2).

Plate 1 Photograph of a small stream formed by silting of older channels

Plate 2 Photograph of cross bedding observed in inland delta region.

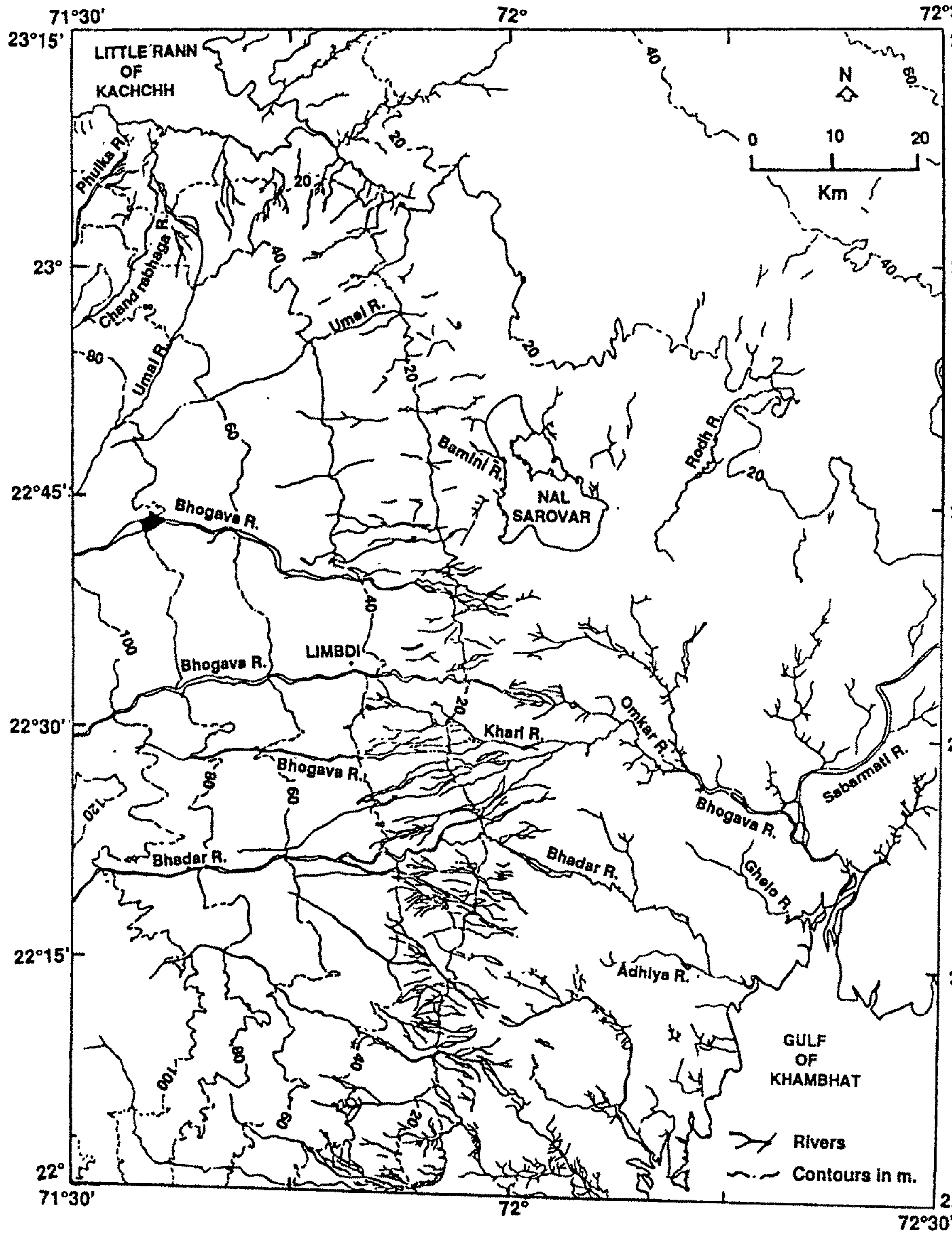


Fig. 2.7 A composite map showing deranged drainage pattern and zone of terminating streams below 20m contour in the Nal region. Above 40m contour only the major rivers are shown.

At a lower elevation, to the east of inland deltas and south of Nal, on the basis of tonal and colour changes, two sets of older mud flats were identified (Fig. 2.5 and Fig. 2.8). The older one (M1), with a darker tone is at ~+14m msl and was mapped on both the eastern and western side of the Gulf of Khambhat. The younger (M2), at a slightly lower elevation, had a lighter tone and is noticeable only on the western side. The region of mud flats showed the presence of deranged drainage pattern (Fig. 2.3 and Fig. 2.7). Present day mud flats were also mapped from the satellite imageries.

On the eastern side, however, no such evidence of sea level changes was observed and the entire region is covered by the alluvium. To the N-NE of Nal Sarovar, however, stabilised dunes which are indicative of past aridity in this region could be seen (Fig. 2.4 and Fig. 2.8).

2.2.1.3 Discussion

Summarising, the features mapped in the Nal region represent three distinct depositional environments: marine, aeolian and fluvial. On the basis of satellite imagery and field studies, the area could be sub-divided into the following geomorphologic units (Fig. 2.8):

1. Inland deltas.

2. Older mud flats.

3. Alluvium.

4. Stabilised dunes.

In the following, significance of each of these features to the evolution of the Nal region is discussed.

1. Inland deltas: These are presently 30km inland at an elevation >15m and the palaeo-strandline located at ~+15m msl (Fig. 2.8). In this region several small streams are seen which terminate abruptly at the palaeo-strandline. According to Thornbury (1985), two conditions are necessary for the formation of deltas - the availability of sediments and sheltered conditions at the site of deposition. Deltas may not form at the mouths of streams which enter the sea where their mouths are so exposed to wave and current action that the

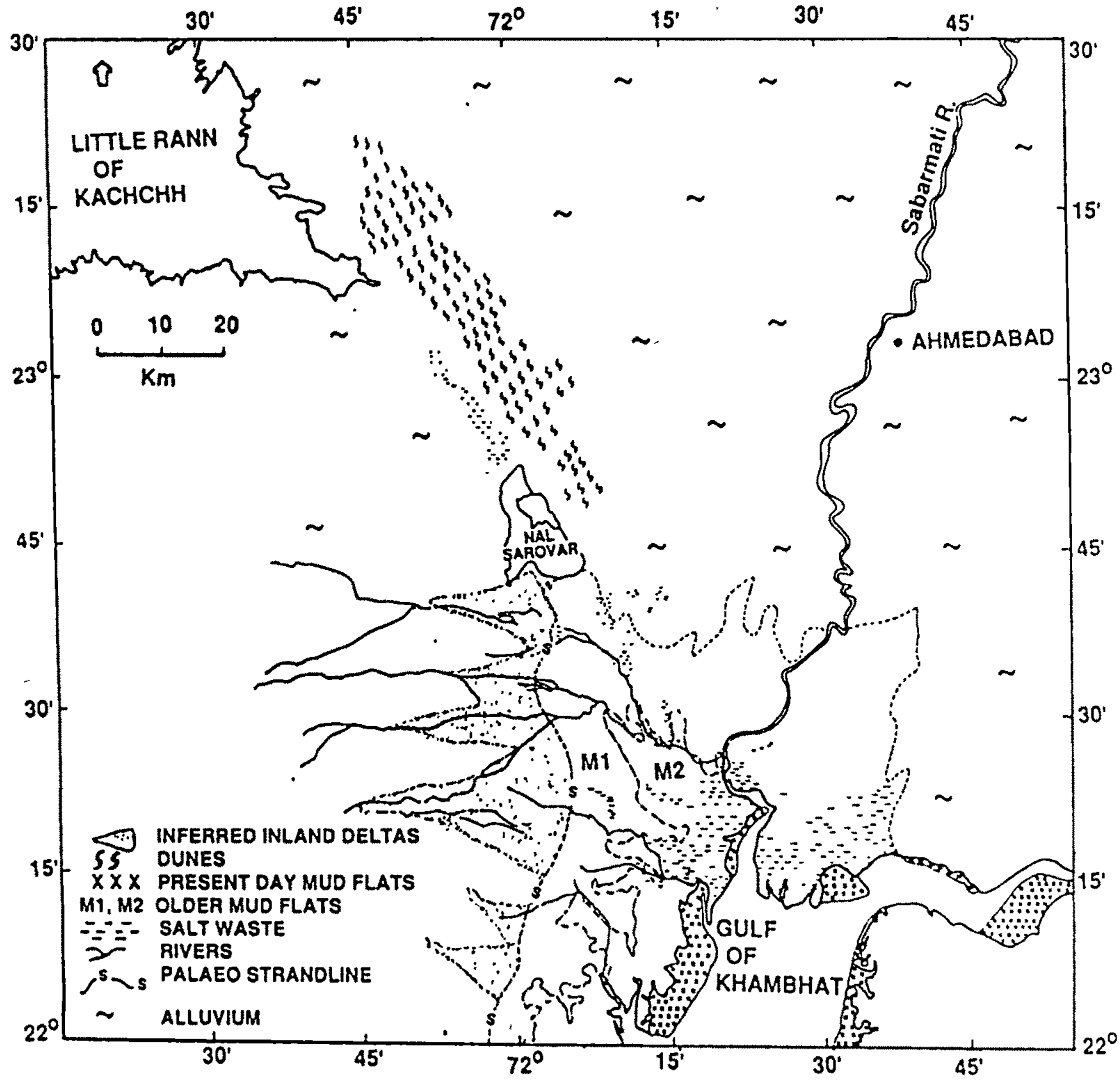


Fig. 2.8 Geomorphological map of Nal region.

sediments are removed as soon as they are deposited. The rivers to the west of the palaeo-strandline have large valleys which are incompatible with their present seasonal flow. It is likely that these were formed during a substantially wetter period in the past, when the rivers had higher erosional potential and larger load carrying capacity.

Field studies indicated limited river entrenchment of about 4m in the palaeo-delta region indicating that there has not been a significant uplift in this region subsequent to their formation. The two observations, namely, larger valleys and the absence of significant entrenchment suggest a higher stillstand of sea, at some time in the past, being responsible for the formation of these inland deltas.

2. Older mud flats: At a lower elevation to the east of inland deltas and south of Nal Sarovar, towards the Gulf of Khambhat, two sets of inland mud-flats (M1 and M2) have been identified between ~+14m and ~+10m msl. No significant entrenchment (maximum observed 2m) of rivers is observed in mud flats indicating that, since their formation, there has not been any major uplift in this region. The region of mud flats also showed the presence of deranged drainage pattern. This drainage pattern is indicative of the recent development of drainage in a region (Thornbury, 1985). The present elevation of these older mud flats may not be taken as an indication of the extent of sea level rise since the region close to Gulf of Khambhat is subjected to tidal surges as high as 12m. In this region, present day mud flats are being formed at elevations upto +8m. So a sea level rise of even a few meters accompanied by tidal surges would be enough to form both the older mud flats.

3. Dunes: Stabilised dunes are present N-NE of Nal Sarovar. However, no exposed sections were found in the northern part. Patel and Desai (1988), have attributed the formation of these dunes to periods of stronger aeolian activity during periods of regression following the Flandrian sea level rise.

4. Alluvium: This is found to the east and north of Nal Sarovar. No surficial expression of Pleistocene sea level change was found. Rather, these sediments show the influence of tectonism in the form of abandoned river channels, entrenched streams and fault controlled river courses. The general slope of the region is towards SW.

It is possible to explain the formation of these geomorphic features keeping in view the eustatic sea level changes (Fig. 2.9) and possible role of tectonism during the Late Quaternary. Presence of inland deltas and older mud flats was interpreted to indicate the evidence of at least two episodes of transgression in the Nal region. The evidence of topographical position and deranged drainage pattern pointed to the mud flats (M1 and M2) having been formed during the most recent, Holocene, transgression with M2 probably representing one of the stillstands of the sea during regression. This would imply that the inland deltas were formed during an earlier transgression of the sea. Available record of eustatic sea level changes indicated a high sea level of +7m during the last major interglacial transgression (isotope stage 5e, ~125ka) (Ku et al, 1974; Cronin et al, 1981; Chappel and Shackleton, 1985; Pant and Juyal, 1993) and for Holocene, a range of 2-6m, (Gupta, 1976); or ~3m (Pant and Juyal, 1993; Hashimi et al, 1995) has been suggested. Since the palaeo-strandline is presently at +15m msl, assigning an age of isotope stage 5e (~125ka) to the inland deltas, would require only a small tectonic uplift subsequent to their formation. These would be consistent with the evidences of only two transgressions of the sea, in the Nal region, and field observations of limited river entrenchment, on the Saurashtra side, in the inland delta region. This is contrary to the view held by Bhaskaran et al (1989), who have indicated an uplift of >50m for the Saurashtra peninsula, in this region, during Late Quaternary on the basis of miliolite ages. In any case, at the time of formation of these palaeo-deltas, the entire Nal region would have been covered by a shallow sea.

According to Patel and Desai (1988), the sand dunes to the north and north-east of Nal Sarovar were formed during periods of stronger aeolian activity during regression, following the Flandrian sea level rise. However, TL data of Langhnaj, north of Ahmedabad, would suggest the dune building activity to have begun as early as ~20 ka (Wasson et al, 1983) with intervening periods of stabilisation.

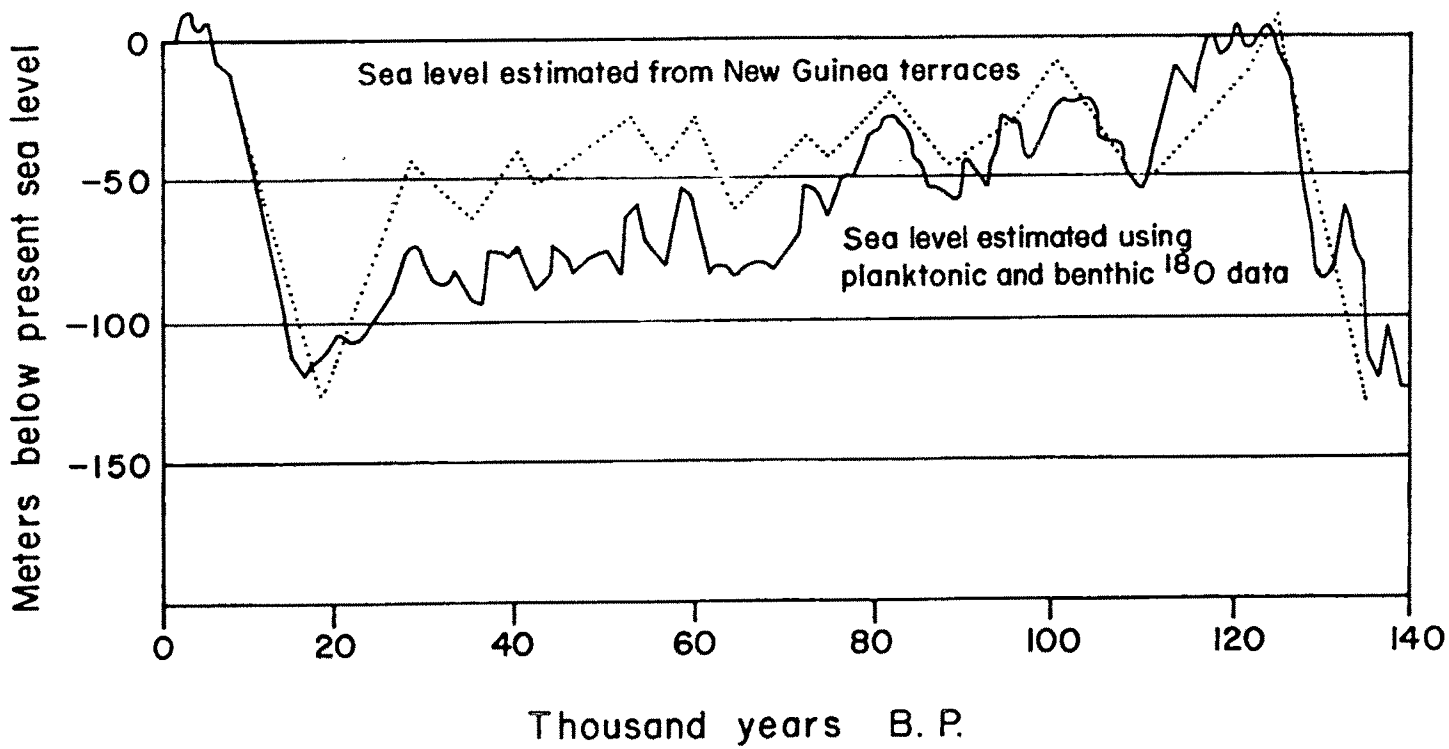


Fig. 2.9 Plots of eustatic sea level change (Redrawn from Gillespie and Molnar, 1995).

2.2.2 Subsurface lithological correlation

In the absence of surface exposures, preliminary investigations into the geological evolution of Nal region was attempted through the study of lithologs of bore holes (depth of sections 60-200m) drilled for ground water exploitation by the Central and State govt. agencies CGWB, GWRDC, GWSSB.

2.2.2.1 Methodology

As a standard practice, the litholog is prepared in the field itself by the geologists present with the team. The appearance and texture of the sediment form the basis for preparation of the litholog. As such, no detailed description of sand size such as coarse, medium or fine were available for the present study. Instead only broad divisions like top mud (comprising dominantly silt), sand and clay/silty clay have been made for the purpose of lithological correlation. Location of bore holes analysed for this study are shown in Fig. 2.10. On the basis of well log data, three transects, two in NE-SW direction and one in N-S direction, (Fig. 2.11) were constructed. The lithologs of other bore wells, not included in transects are shown in Figures 2.12 and 2.13.

2.2.2.2 Results and Discussion

The NE-SW transect (Fig. 2.11) indicated that, in the eastern side of Nal, the lithology is dominated by sand with intercalations of clay/silty clay. In the vicinity of Nal and in the N-S direction, extending from near the Little Rann in the north to Dholera in south, near the Gulf of Khambhat, a change in lithology to a layer of sand underlain by a thick (40-55m) sequence of clay/silty clay is seen (Fig. 2.11). This feature is also seen in the lithologs of Vekria (Fig. 2.12), Ranagadh and Phulwadi (Fig. 2.13) which also lie in the Nal region. This indicates a similarity in depositional environment in the entire low lying region, extending from near the Gulf of Khambhat to Little Rann, in a narrow corridor about ~25 km wide as shown in Fig. 2.10. In the following, the expression Nal

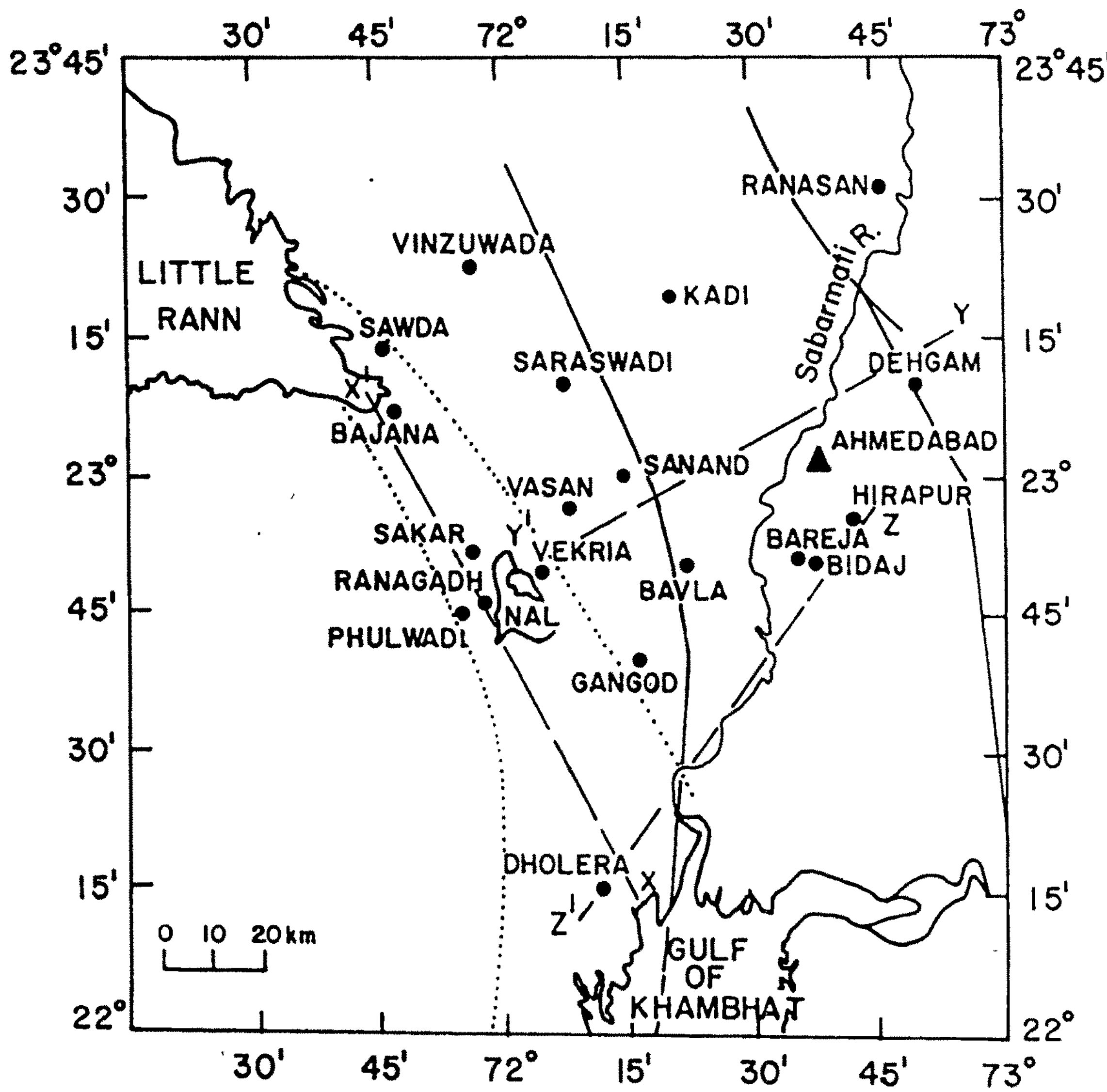


Fig. 2.10 Map showing the location of bore hole sites and transects taken. Also shown are eastern and western margins of Cambay Graben. The approximate boundaries of the Nal region are shown by dotted lines.

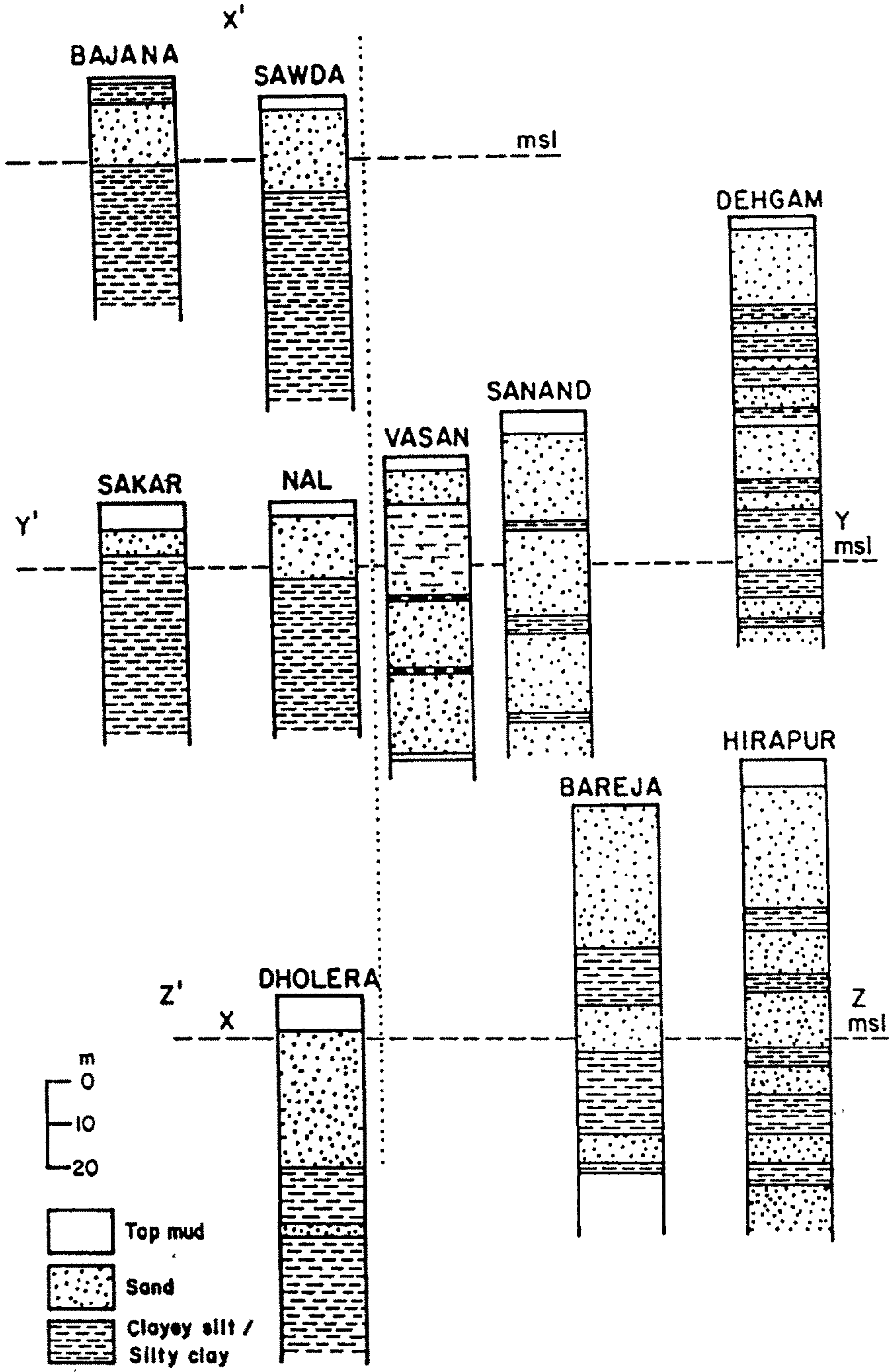


Fig. 2.11 Lithological variation along the transects shown in Fig. 2.10.

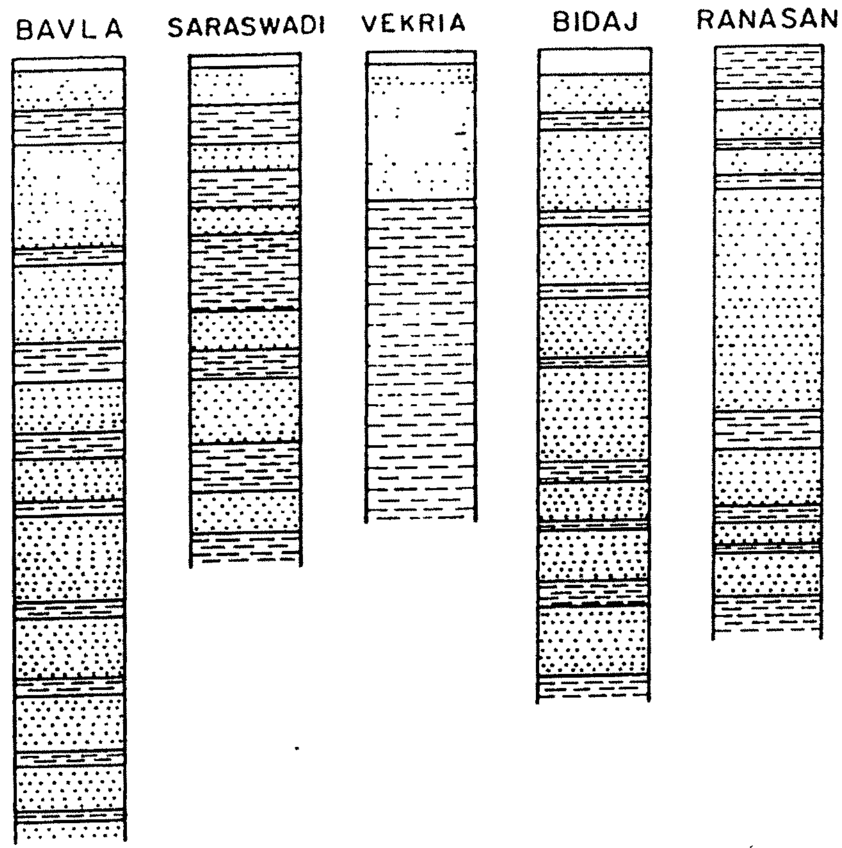


Fig. 2.12 Additional bore hole lithologs for sites shown in Fig. 2.10.

(Legend is given on next page)

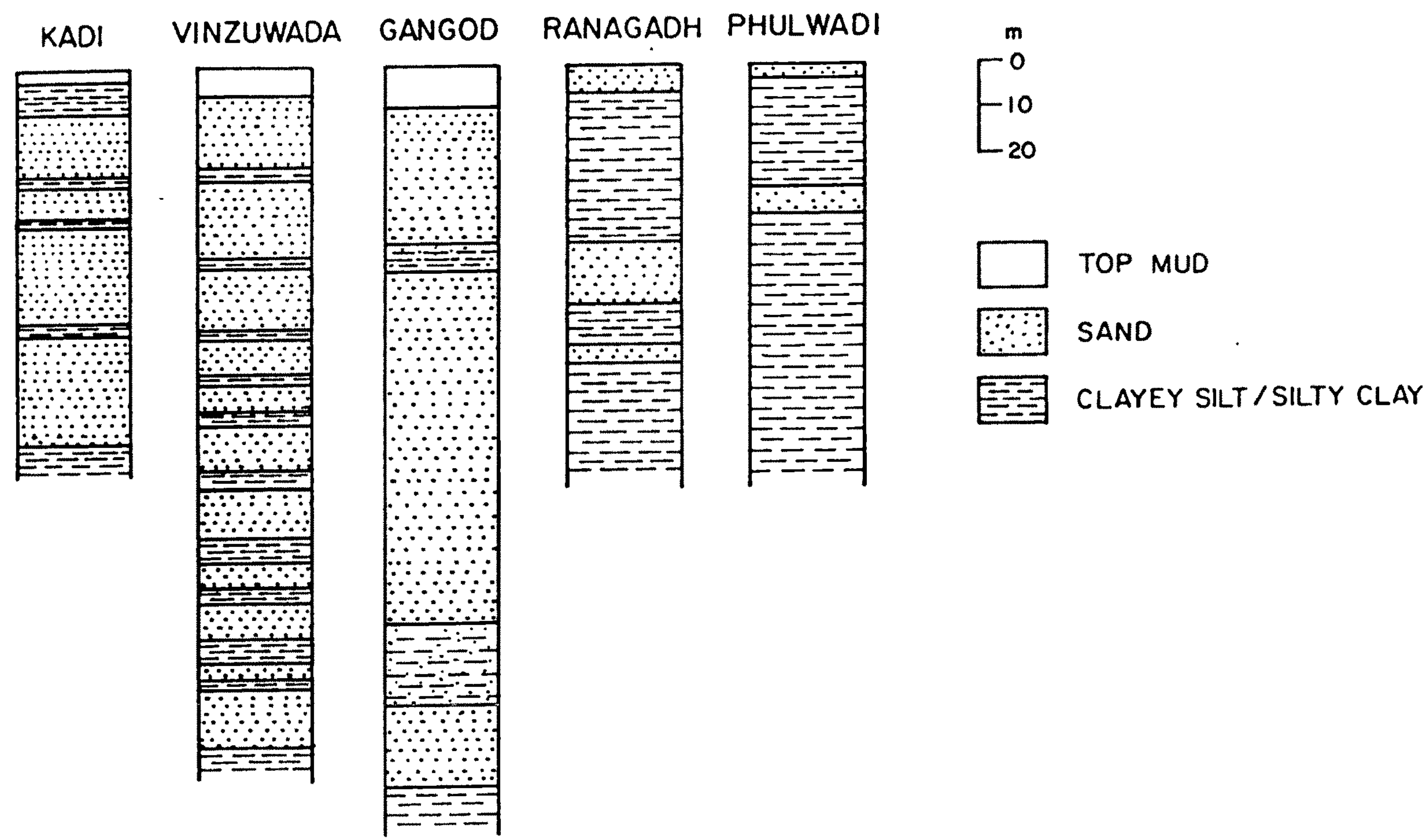


Fig. 2.13 Additional bore hole lithologs for other sites shown in Fig. 2.10.

region has been interchangeably used with Nal corridor because, as discussed subsequently, the region approximately bounded by the two dashed lines in Fig. 2.10 has had a similar geological evolution, distinct from both the eastern and western flanks.

2.2.3 Studies on Nal Sarovar core

Based on the results of remote sensing and sub-surface lithological correlation studies, which indicated evidence of sea level changes and lithological similarity in a narrow corridor extending from Little Rann to near the Gulf of Khambhat, a core was raised from the Nal Sarovar (Fig. 2.14) which lies almost in the centre of the narrow corridor. The sampling procedures are discussed in Appendix A.

2.2.3.1 Lithological description

On the basis of field observations and laboratory studies (discussed in next section) the core raised from the Nal Sarovar bed was divided into three horizons (Fig. 2.15).

1. **Horizon-3** (54-18m): This layer comprised of sticky, silty clay/clayey silt with occasional thin layers of fine sand. Occasional occurrences of coarse basalt fragments were seen. This layer also showed the presence of calcium carbonate nodules at various depths. Some of the carbonate nodules had a black coating in the hand specimen and were mistaken with basalt fragments, as subsequently indicated by acid treatment. The amount of organic matter is very low (<0.01%) and no fossils were observed in >63μ size fraction. The dominant clay mineral was identified as smectite. The contact between this horizon and overlying Horizon-2 was abrupt. The base of this layer was not reached in the core.

2. **Horizon-2**: (18-3m): This horizon is dominantly sandy and poorly cemented by secondary calcareous deposition. It also indicated a change in depositional environment. Sorting is moderate to poor and grain size is medium to coarse. Sand is dominated by quartz, heavy minerals are opaques, epidote, staurolite and garnet. Occasionally silty layers are present but since the focus here was on obtaining a regional picture, the dominant grain size (>50%) was

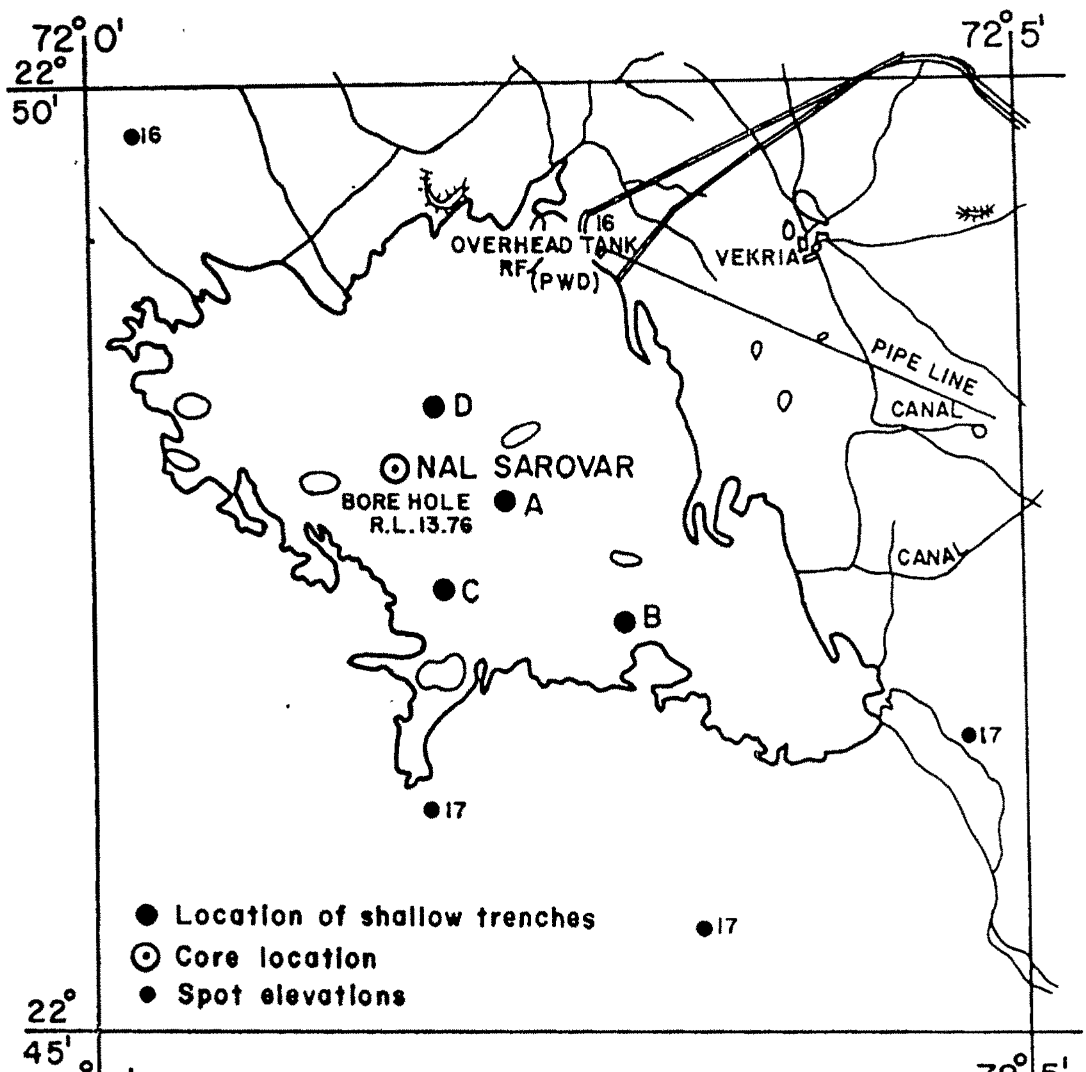


Fig. 2.14 Map showing the location of 54m long core and shallow trenches in Nal Sarovar.

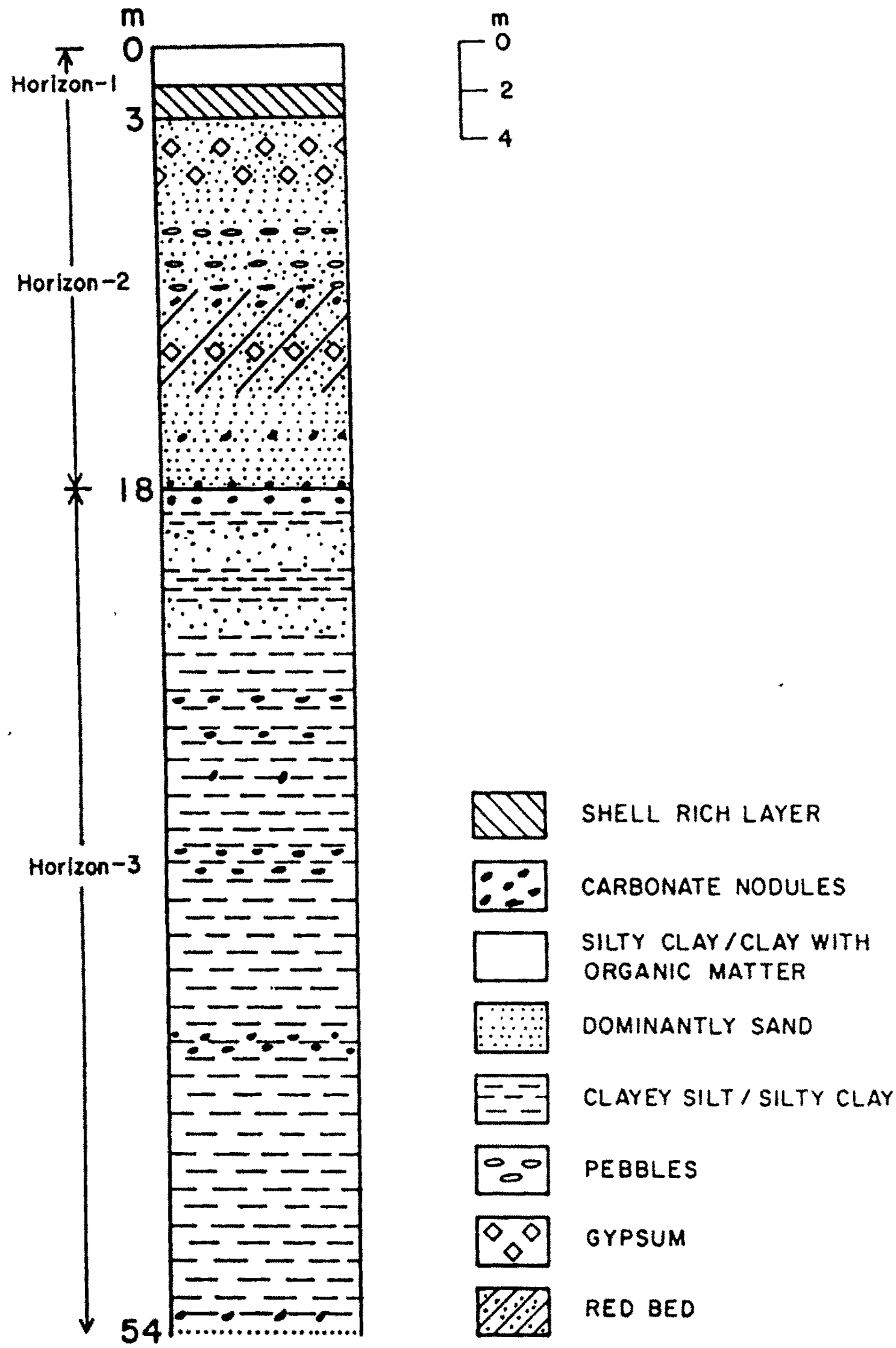


Fig. 2.15 Lithology of the Nal Sarovar core.

used for lithological correlation.

This horizon showed the presence of fine to coarse crystals of gypsum at 4m, 5m and 7m depth. The sand had a red coloration between 10-14m. Occasional basalt fragments were also found. No fossils were observed in the >63μ size range. The amount of organic matter was low (<0.01%). The contact between this layer and the overlying Horizon-1 was gradational.

3. **Horizon-1**: (3-0m): This horizon comprised of silty clay/clay with organic matter (~0.9%). The layer became slightly sandy towards the lower part. Dominant clay mineral identified was Illite. Midway through this horizon (1.6m) was found, a gastropod (Genus *Bittium)* rich layer with a few shells of land snails, which persisted till the bottom of Horizon-1. These shells were identified by Mr. R.L. Jain, Palaeontologist, Geological Survey of India, Gujarat Circle, Gandhinagar. According to Jain (pers. comm., 1996), the habitat of these shells is very shallow fresh water to near shore tidal flat or estuarine; further the small size of these shells was suggestive of death in young age due to emergence of dry conditions.

Four other trenches, dug subsequently, in the lake bed confirmed the presence of gastropod rich layer at varying depths throughout the lake bed (Fig. 2.16). A field photograph of this shell layer, showing the gastropod shells, taken during trenching operations, is shown in Plate 3.

2.2.3.2. Sedimentological and mineralogical studies

Results and discussion

Classification of core was done on the basis of dominant grain size coupled with field observations on core samples. For the purpose of provenance identification, the mineralogy of the dominant grain size has been considered i.e. clay minerals in case of Horizon-1 and -3 and, heavy minerals in case of sandy Horizon-2. The laboratory procedures employed have been discussed in Appendix B. The results of grain size analysis and mineralogy are

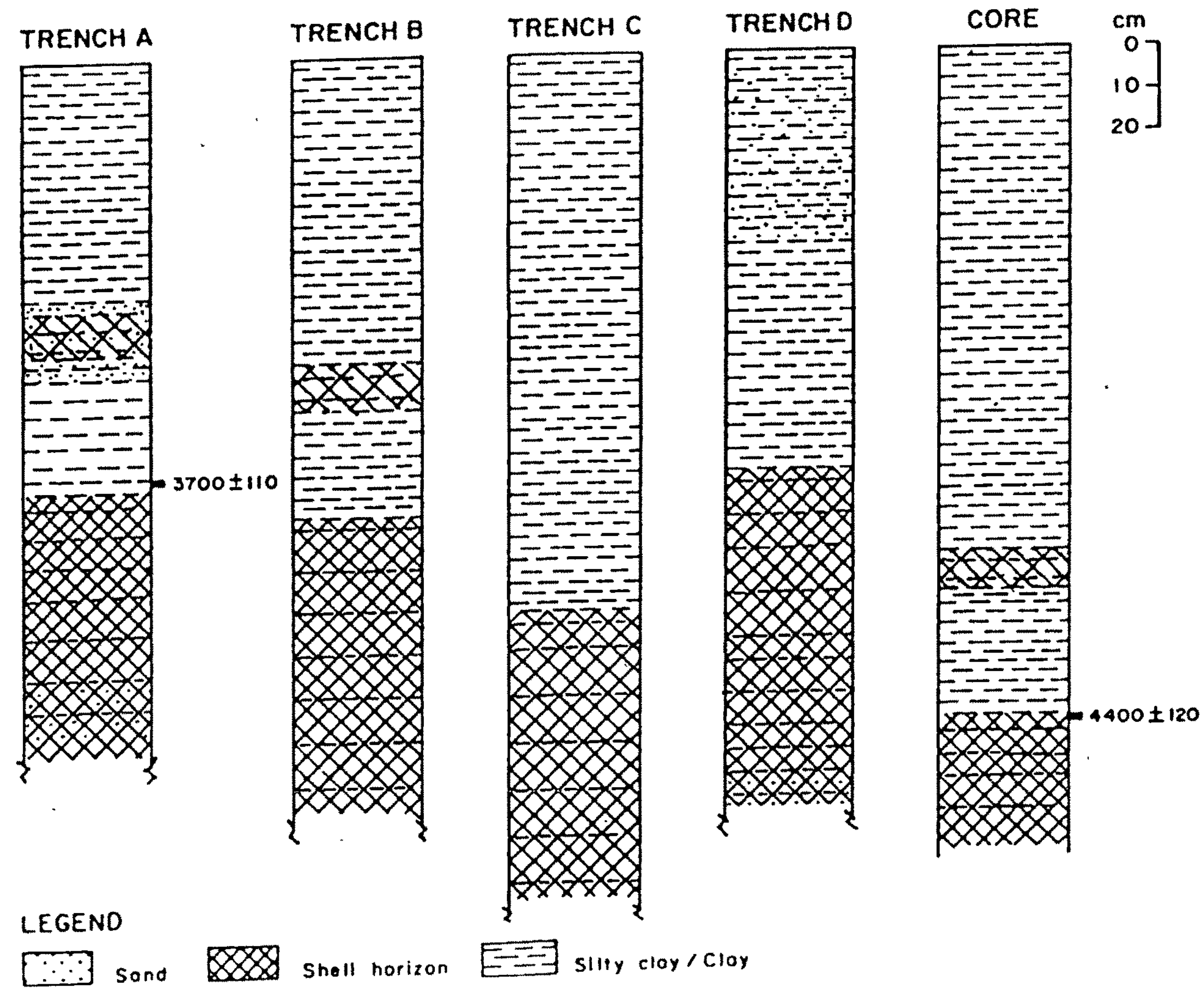


Fig. 2.16 Lithology of shallow trenches showing the presence of shell layer in Nal Sarovar.

Plate 3. Field photograph of sediments from the shell layer, Horizon-1, taken during trenching.

given in tabular form in Appendix B (Table B1 and B2) and shown graphically in Fig. 2.17 and Fig. 2.18 respectively.

Horizon-3: This comprised of silty clay/clayey silt with occasional sand layers. Core studies indicated that, mineralogically, the clay rich Horizon-3 was dominated (>70%) by smectite, indicative of its origin from the basaltic terrain. This was possibly derived from the basaltic rocks on the Saurashtra side or brought from the Gulf of Khambhat due to action of tidal currents. The latter possibility cannot be ruled out considering the RL of this horizon (-4 to -40m in the core). Mineralogically and sedimentologically, the sediments in the inner shelf near the Gulf of Khambhat are dominantly smectite and clayey/silty clay in nature (Rao, 1991; Rao and Rao, 1995), similar to the Horizon-3 of the core. Also, the clay mineral studies on sediments from near the mouths of Mahi and Narmada rivers show the dominance of smectite (Islam and Merh, 1988). There appears to be little or no contribution, to Horizon-3, from the Gulf of Kachchh side. This follows from the study of Rao and Rao (1995), which indicated that present day sediments off the Gulf of Kachchh, on the outer continental shelf, show the dominance of illite (63%) which was derived from the weathering of Himalayan rocks and transported by Indus river. They also indicated that the inner shelf sediments show an increase in smectite (22% as compared to 9% in the outer shelf). Interestingly, a yellowish, clayey layer (RL -7m) comprising about 80-90% smectite, devoid of shells and with an abrupt contact with overlying gritty sandy clay layer, has also been reported from Little Rann of Kachchh (Gupta, 1975). This layer may be correlatable with Horizon-3 of the Nal core. In terms of lithology, the Horizon-3 of the core is similar to the lower silty clay horizon found in the bore hole lithologs in the Nal region.

Considering (i) the thickness of the silty clay horizon in the borehole sections (varying between 40-55 m) in the N-S transect throughout the Nal corridor; (ii) the RL of the bottom and top of this layer (-75 to +3m respectively); (iii) mineralogy (smectite dominated); (iv) geomorphological evidence of transgressive events; (v) the global eustatic sea level curve and (vi) the possibility of some post depositional tectonic uplift of the region, an age of 73-127 ka, corresponding to the entire isotope stage 5, maybe assigned for the deposition of the silty clay, Horizon-3. For most part during this interval, the

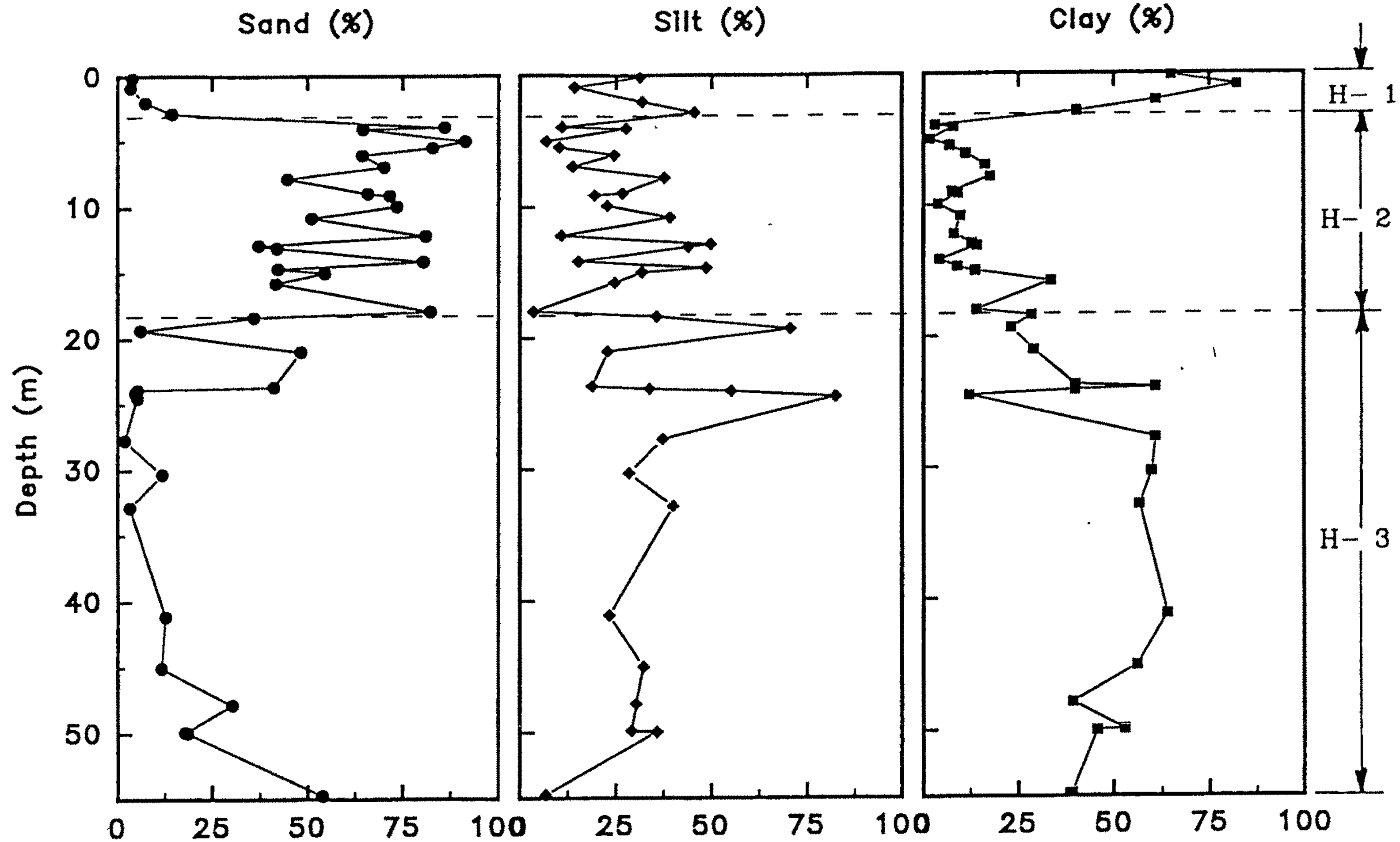


Fig. 2.17 Variation of grain size with depth, Nal Sarovar core.

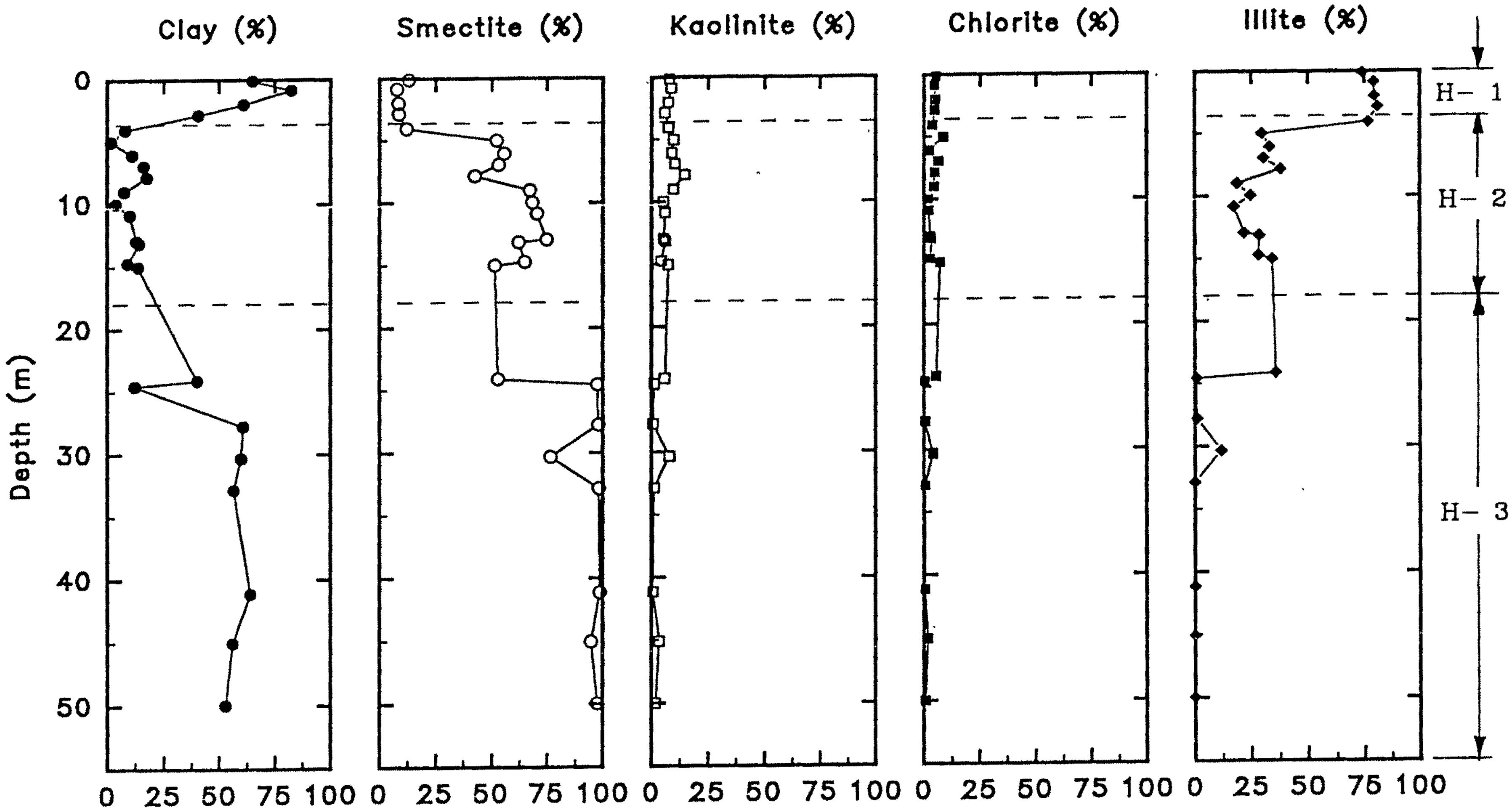


Fig. 2.18 Variation of total clay percentage and mineralogy with depth, Nal Sarovar core.

entire region would have been covered by a shallow sea. The absence of marine fauna (>63μ), in few of the samples checked is puzzling. However, the environment visualised here, for the most part, was a landlocked shallow sea with influx of water and sediments from both the land and the sea. It would have been subject to considerable salinity fluctuations induced by tidal changes, fresh water flux during monsoon months and high rates of evaporation during summer months. Very few species can survive under such stressed environments of wide salinity fluctuations (Raup and Stanley, 1985). An indication of this is also found in a study of present day distribution of planktonic foraminifera in the Arabian sea. Near the Gulf of Khambhat, very low concentrations of foraminifera (<700 specimens in 1000m^3 of water) were found as compared to 7000-40,000 specimens (in 1000m^3 of water) further south. This has been attributed to arid climate around this region and resulting intense evaporation (Rao et al, 1991).

The extremely small contribution to sediments in Horizon-3, from the eastern rivers, is indicative that they were depositing their sediments in a sink farther to the east of the Nal region.

Horizon-2: This horizon comprised of sand with occasional silt rich layers. It is dominated by sand size grains of quartz, both angular and subrounded. Sorting was found to be moderate to poor and the mean grain size in the range 0.8-1.5Φ. The amount of clay was found to be very small, 3-15%. The dominant clay mineral was smectite with some amount of illite (~25%). The Sabarmati river suspended particulate matter (SPM), collected during the flood of Sept. '94 showed the distribution, smectite: illite: (chlorite+kaolinite) as 30:42:28. Similar clay mineral distribution was found in sediment samples from an 8m deep soak pit in Ahmedabad, only ~5Km from the Sabarmati river (Deshpande, unpubl. data). This, together with the clay mineral data of Horizon-2, where a dominance of smectite was found, would suggest that the clay minerals in Horizon-2 had a mixed contribution from both the western, Saurashtra, and eastern side. But since clay minerals account for only 3-15% of sediment by weight, the heavy mineral analysis of the dominant sand fraction was used to identify the provenance for Horizon-2. The heavy mineral assemblage consisted of opaques, epidote, staurolite and garnet, indicating that this material could have been derived from the igneous and/or metamorphic rocks from the east and north-east. This does not rule out redeposition of eroded sediments that had their primary source in metamorphic and/or igneous rocks of east and north-east. This is in contrast to Horizon-3 which indicated a dominant input from south and/or west.

The red beds were found in Horizon-2 (between 10-14m). Zeuner (1950), has stated that a rainfall of 20-40 inches with a long dry season would be responsible for the formation of red soils. Reddening may also take place under relatively humid conditions (Krynine, 1949; Kubeina, 1963; Folk, 1976), or it may occur under high temperature oxidising conditions with rapid decomposition of organic matter in semi-arid/arid environments. If a source of iron and oxidising conditions exist, red beds can form in both humid and arid tropics (Pye, 1983). In the present case, however, secondary calcareous accumulations suggest reddening under semi-arid regime and subaerial exposure. It is noteworthy that red beds have been reported from all over Gujarat and are used as a marker bed (Pant and Chamyal, 1990). The difference in elevation between the red beds reported in Sabarmati basin at Vijapur and the red beds in Nal core is ~100m. While the topographic component cannot be ruled out, it is interesting to note that the red beds in Gujarat alluvial plains are presently exposed in cliffy sections ~40-50m high. These beds have been dated using luminescence technique in the Vijapur section of the Sabarmati river and indicate an age of 58±5 ka (Tandon et al, 1996). Occurrence of evaporite minerals like gypsum at 4m and 7m depth, in Horizon-2, is also indicative of an arid phase.

It is believed that Sabarmati too used to flow westwards (Zeuner, 1950) into the Little Rann along the course of Rupen (Sridhar et al, 1994). Sareen et al (1993), believe the shift of Sabarmati to have occurred sometime during Late Quaternary as a result of fluvial readjustment in response to neotectonic reactivation in the region. There are several abandoned river channels to the east of Nal (mentioned earlier in Section 2.2.1.2 and Fig. 2.6) which have been identified, in this study, on the IRS FCC imagery. Possibly these represent older courses of Sabarmati river as it shifted southwards. These may have been transporting sediments to this region in the past. The rivers became inactive either due to a changeover to a drier climate and/or due to tectonism which disrupted the drainage pattern. The abandoned river courses lie in the Cambay Graben which is known to have been tectonically active during Late Quaternary (Ghosh, 1952; Sareen et al, 1993).

The presence of a thick (5-35 m) sandy horizon (RL +14m to -30m), in the bore well sections in the entire Little Rann to Gulf of Khambhat corridor, suggests that during its deposition the sea link no longer existed in this region. During this period of lowered sea level, high energy fluvial sediments were being deposited in this entire belt by the rivers which were extending their courses on the exposed Nal region. The coarser grain size, breaks in deposition as evidenced by red beds and evaporite minerals, indicate subaerial exposure and episodic deposition by a high energy agency.

The abrupt change in provenance - from south and/or west in Horizon-3 to one dominated by east and north-east in Horizon-2 is thought provoking. A regression of the sea should result in the rivers from both east and west sides extending their courses, through the Nal corridor, into the sea. This may be accompanied by advancement of depositional front into the Nal region from either side. That there is a dominance of eastern source is indicated by the heavy mineral data of Horizon-2. Sridhar et al (1994), have hypothesised the existence of a super-fluvial system which originated in east and north-east and was responsible for depositing the enormous thickness of sediments in north and central Gujarat; this super fluvial system was disrupted in Middle to Late Quaternary. If this super fluvial system existed during the deposition of Horizon-3, its depositional front then did not reach the Nal region as indicated earlier. Regression of the sea could have resulted in the westward migration of the depositional front as indicated above. Alternatively, it is possible that there was a tectonic uplift on the eastern margin of the Nal region subsequent to the deposition of Horizon-3 which resulted in the reworking and deposition of coarser sediments from the east, in the Nal region. In the absence of published subsurface data, on the thickness of Quaternary deposits from the eastern flank of the Nal corridor, it is difficult to confirm either of the two hypotheses discussed above. However, an E-W cross section constructed across Nal region (Fig. 2.19) indicates that the Cambay Graben lying to the east of Nal Sarovar was topographically the lowest elevation and had acted as a sediment sink at least until Miocene. Presently, this area has a surface elevation of +80 m to +100 m and the low elevation area has shifted to Nal Sarovar which is +13 m to +16 m msl. Evidences of Late Quaternary tectonism in the Cambay Graben have been reported (Ghosh, 1952; Sareen et al, 1993).

Horizon-1: This comprised of clay/silty clay. The dominant clay mineral was determined to be illite. Studies on clay minerals of Sabarmati river (SPM) and soak pit samples in Ahmedabad (Deshpande, unpublished data) indicate a dominance of illite. This suggests that sediments in Horizon-1 have been derived primarily from the eastern and north eastern side which comprises granitic and metamorphic rocks. Since, on the basis of textural and mineralogical characteristics, whole of Horizon-1 is similar to surface sediment, it is likely that there has not been a significant change in the provenance from today during the deposition of this horizon. At present there is no major stream draining into the Nal Sarovar. The deposits are reworked sediments derived by surface runoff draining into the Nal lake. The $\delta^{13}C$ and C/N ratios of organic fraction of this Horizon-1, reported subsequently (Chapter 3), indicate that lacustrine conditions slowly began to set in and the area became a closed basin.

Thus, as a result of the combined influence of (i) westward advance of the sedimentation front; (ii) tectonism and; (iii) the post glacial sea level rise, the elevation of the Nal Sarovar came to within few metres of its present elevation at about 7ka when it became a closed basin. The present Nal Sarovar, therefore, originated as a result of westward advance of the sedimentation front until it could no longer advance due to the presence of high land of Saurashtra. At that time either due to sedimentation process alone or aided by tectonism the west flowing rivers shifted their courses and presently only the abandoned channels remain.

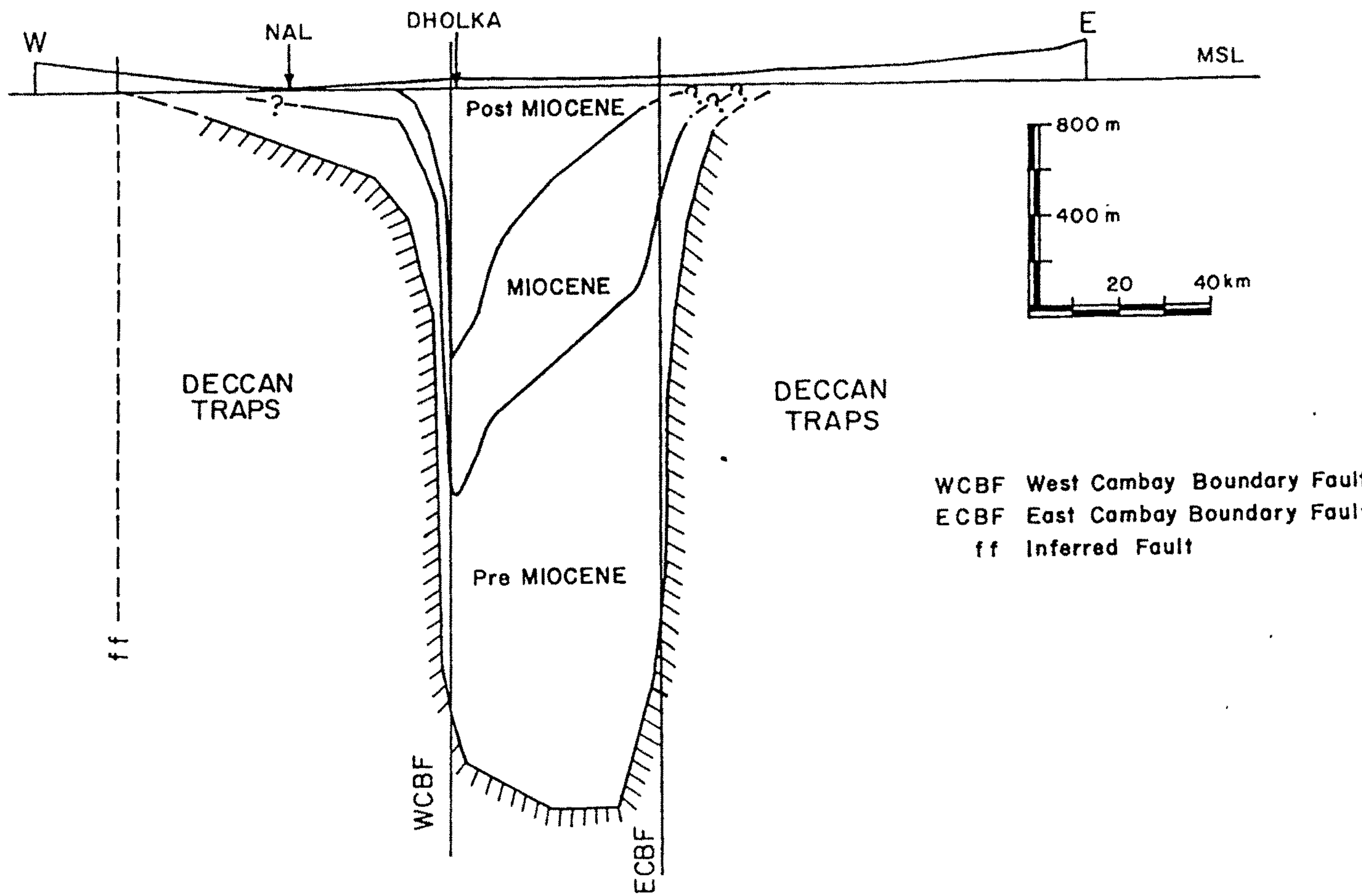


Fig. 2.19 E-W section along the Cambay Graben. (Drawn on basis of data given in Mathur et al, 1968).

Hansa Mehta Library, M. S. University of Baroda