Chapter 3

Coastal Sequences

Introduction

The Late Quaternary coastal sequences of the study area are dominantly made up of the bioclastic carbonate sediments, distinguishable only based on their textural characteristics and bounding surfaces in the form of palaeosol horizons, fluvial silty sand horizon, gravelly layers, karstified top of the underlying unit, erosional surface showing abrupt termination of the sedimentary structures, etc. The lithological units identified based on these and their petrographic properties have been discussed in the earlier chapter, and a detailed account on their field occurrences, local facies variations and other megascopic characteristics has been given in the current chapter. For the purpose, the coastal tract of about 300km between the Okha in north and Jafrabad in southeast has been divided into three major segments (Fig. 3.1) based on their geomorphic characteristics. Very distinctly the coastline between Okha and Veraval shows presence of the shore parallel beach ridges which becomes very prominent in segment-2 running between the Porbandar and Veraval, whereas the segment-3 (Veravl – Jafrabad) exhibits a characteristic presence of impressive coastal cliffs and associated features like tidal notches and shore platforms

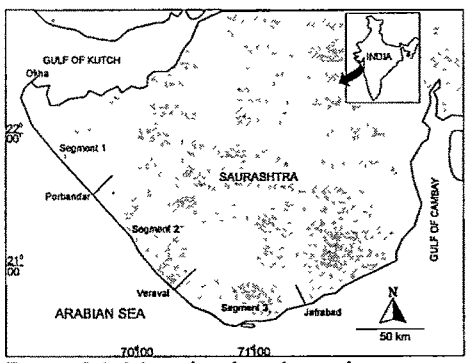

Figure 3 1 Map showing the major segments investigated in the study area.

Okha-Porbandar Segment

This NE-SW oriented segment begins from the port city Okha and extends upto Porbandar in south. The total stretch between these two ends of the segment is of about 115km. Very little drainage could develop in this segment and the geomorphic set up of the area is thus quite different from the other segments described in the forthcoming text. The segment is dotted with numerous creeks viz , Gomti, Ghughawada and Meda; Meda creek marks the southernmost boundary of this segment.

Geomorphologically, this segment is unique as linear and pocket beaches, beach ridges, embayment, foreshore dunes, tidal flats, coastal cliffs, and rocky shore platforms are present in this segment. There are several raised mud flats in this segment which are associated with the above mentioned creeks. Figure3.2 summarizes the geomorphic and physiographic set up of this part of the segment.

Okha-Dwarka stretch

Relatively narrow coastal zone of this stretch is constituted by linear coast parallel beaches, recent beach ridges, tidal flats, semi-circular embayment, foredunes, low-moderately high coastal cliffs and rocky shore platforms. Geomorphologically a unique feature 'Okha Rann' lies within this stretch which is a low lying intertidal flat of about 100sq.km facing the Gulf of Kachchh (Fig. 3.2 a). Beaches in this stretch are of low-moderate angle (3^{o}-5^{o}) and mainly longshore currents seem to be responsible for their formation. However, exceptionally high angle beach have been noticed near Dwarka at Rupen Bandar (N 21^{o} 15' 56.23" & E 68^{o} 57' 10.96") which dips at 15^{o}. The beaches are made up of white coloured biogenic carbonate sand wherein the molluscan shell fragments, coralline fragments and echinoid grains are dominating. Coarser gravels

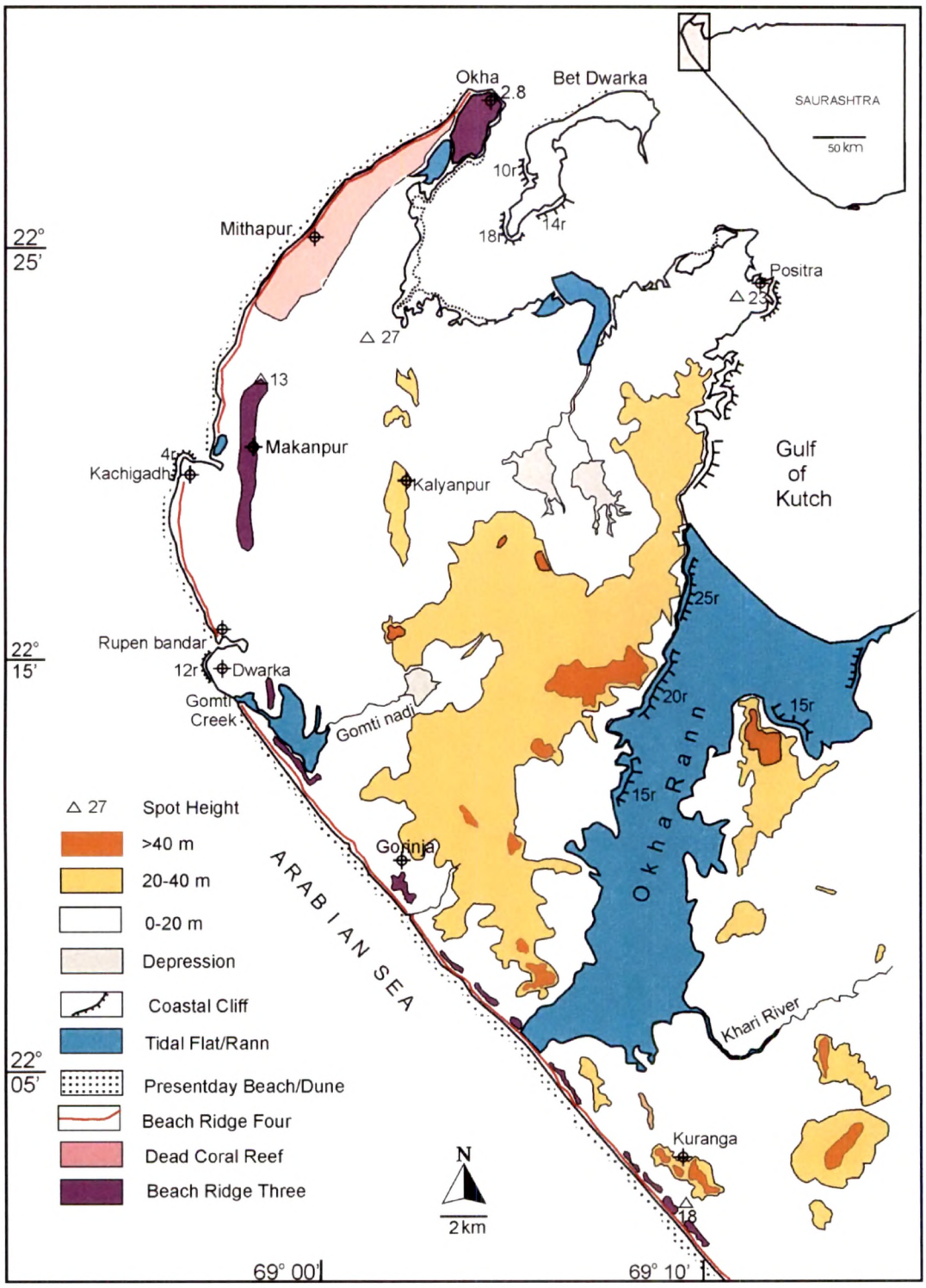

Figure 3.2 a. Physiographic and geomorphic map of the Okha-Dwarka area of segment-1.

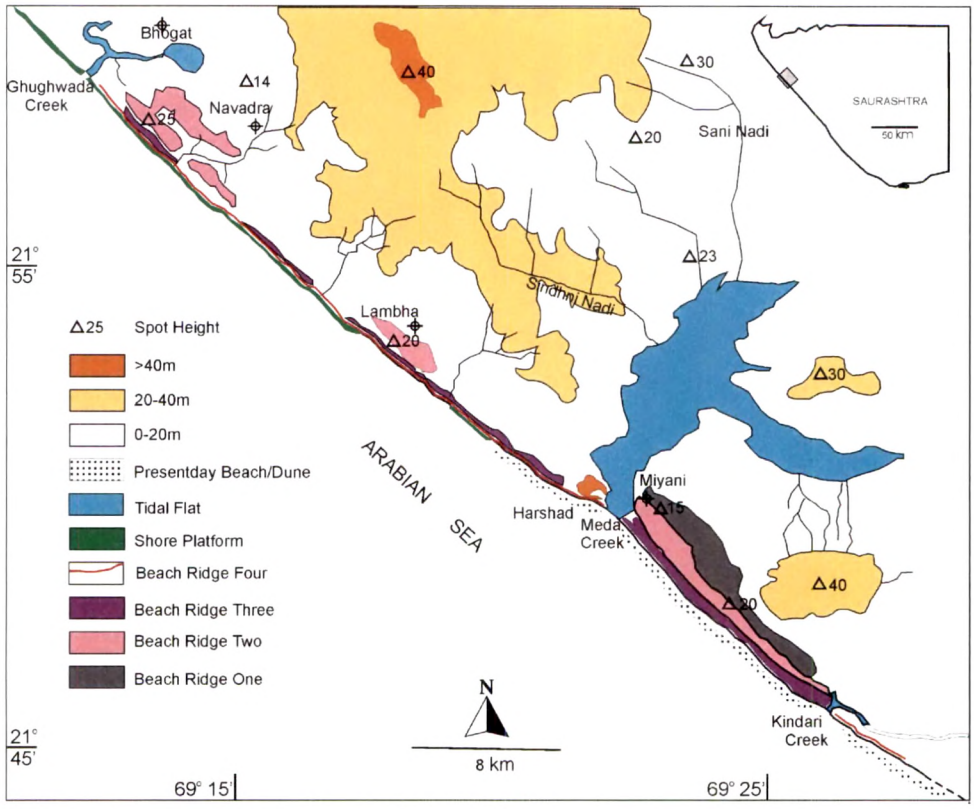

Figure 3.2 b. Physiographic and geomorphic map of Bhogat-Miyani area of segment-1.

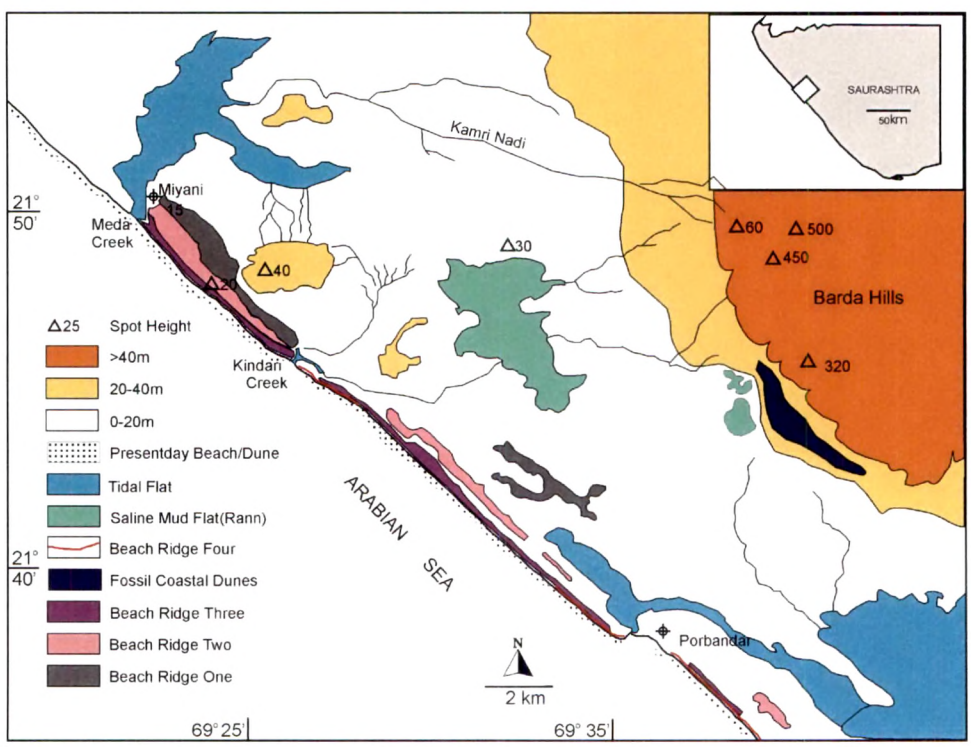

Figure 3.2 c. Physiographic and geomorphic map of Miyani-Porbandar area of segment-1.

and sands of older limestone belonging to older Dwarka Formation are also occasionally noticed. The amount of detrital content in the beach sediments along this stretch as well as in the segment is relatively less as there is no major fluvial system that can contribute to it.

The semi-circular embayments of this stretch are another interesting feature. According to Kar (1995), mainly wave action produces such semi-circular embayment which is followed by colonization of the marine life forms. Gradual silting in this embayment turns them into lagoon and tidal flats. The process is than shifted to the next place leaving behind the straightened coastline. Such embayments are distinctly visible near Mithapur, Mojap, and Rupen Bandar of this stretch (Fig. 3.3).

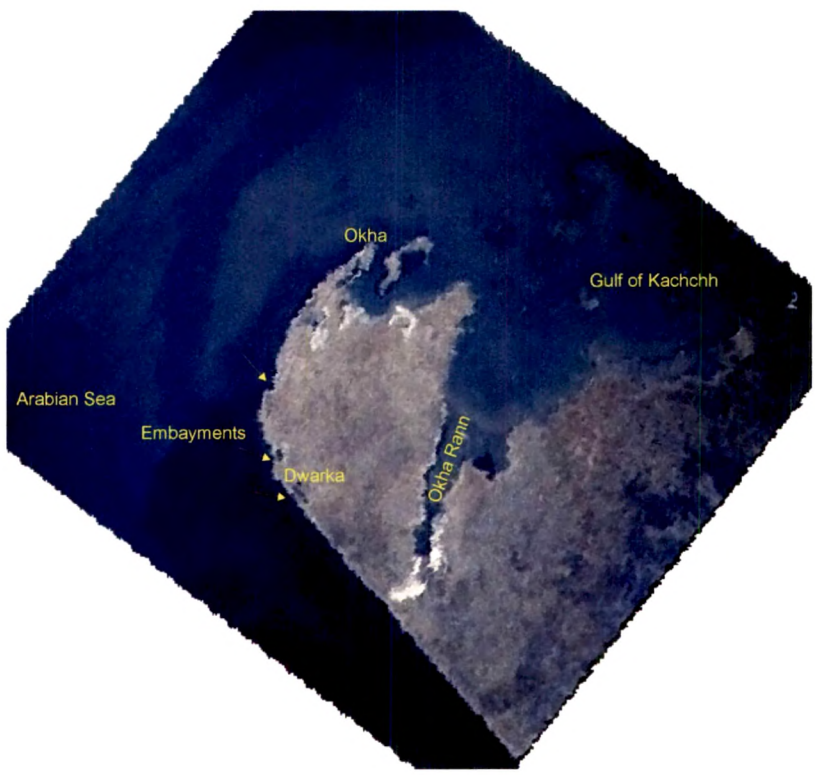

Figure 3.3 A satellite view of the northwestern Saurashtra.
(Source: http://eol.jsc.nasa.gov)

4Geologically interesting feature of this stretch is the occurrence of the dead coral reef between Okha-Mithapur. This has been assigned as Armada reef Member of the Chaya Formation (Bhatt, 2000). They are associated with the facies clearly indicative of higher sea level in this region, of the Late Pleistocene and Holocene.

The prominent beach ridge (beach ridge three) of this stretch running parallel to the present day coast is made up of the shell limestone unit associated with the aforesaid dead coral reef. This is made up of dirty white coloured medium to coarse grained shell limestone which is porous but, indurated, and is recognized as the lithological unit-4. It also contains fragments of corals, bryozoans, echinoderms and coralline algae along with those of the gastropods and pelecypods. This has been considered representing palaeo-strandline in the region. Near Makanpur, (N 22° 20' 18.91" & E 68° 57' 46.29") such a beach ridge occurs about 900m away from the present shore and hosts an active building-stone quarry. The ridge attains a maximum height of about 15m and runs for about 2km in north-south direction. Towards north, these shell limestone do not show ridge like structure but, constitute the major part of the Mithapur-Okha area forming low mounds and occur showing gently seaward dipping sheets.

Moving further south at Kachhigadh lighthouse (N 22° 19' 53 08" & E 68° 57' 05.64") and further towards Dwarka where the rocks extend right up to the coast, about 3 to 5 m high coastal cliffs and associated shore platforms shape out the coastal geomorphology. The cliffs are made up of recrystallized, cross-bedded pinkish coloured limestone of the Dwarka Formation that is mapped in the region as being Kalyanpur Limestone Member (Bhatt, 2000). The cliffs are associated with the rocky shore platform that extends seaward with a gentle angle of about 2-5°.

The pilgrimage town of Dwarka is situated on a slightly elevated mound that gently slope towards east where it is surrounded by the low lying marshy tract attached to the Gomti river mouth. Towards the sea, the Dwarka coast possesses impressive cliffs of about 12m height and associated shore platform. Near Bhadkeshwar temple (N 22° 14' 37.51" & E 68° 57' 15.15") the cliffs also show the presence of sea caves, and is made up of recrystallized limestone of the Dwarka Formation (Fig. 3.4). The rocky stack of Bhadkeshwar is, however totally made up of shell limestone that unconformably overlay the Dwarka limestones (Fig. 3.5). Towards south of this, i.e. near sun-set point, these Quaternary limestones are exposed in the shore platform forming pinnacle rocks. The Shell limestone reaches up to 5m height from the MSL and also occurs surrounding the Dwarka area on its eastern side where it attains maximum thickness of about 8-10m. On the quarry faces, the limestone exhibit graded bedding, wavy laminations with thin algal layers, shell rich pockets and low angle tabular cross-beddings (Fig. 3.6 a,b), all suggesting its deposition in a typical intertidal to supratidal marine environment.

Figure 3.4 A sea cave the coastal cliff of Dwarka. (Height of person standing 165cm)

Figure 3.5 Unconformable contact between the Dwarka limestone and the shell limestone belonging to the unit-4.

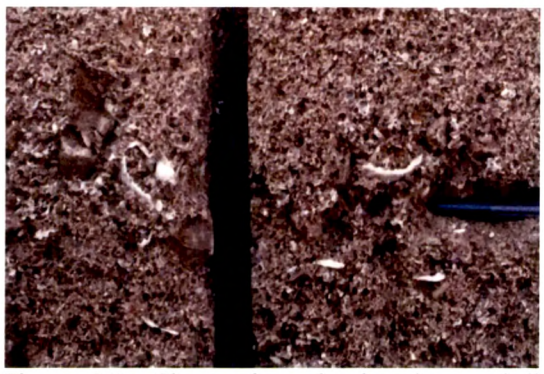

Figure 3.6a Closer view showing larger shell fragments in a quarry near Dwarka. (Length of the pen 10cm)

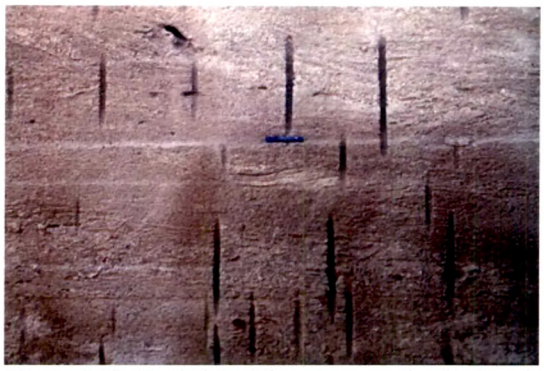

Figure 3.6b Graded bedding & wavy lamination in shell limestone. (Length of the pen 10cm)

Dwarka – Bhogat stretch

After crossing the Gomti creek near Dwarka (N 22° 13' 57.90" & E 68° 58' 45.92") a quarry situated at about 300m away from the present day shoreline is composed of medium to coarse grained shell rich limestone which goes with unit -4. This is composition wise similar to the Makanpur quarry explained earlier and represent the same beach ridge in continuation to it.

Gorinja (N 22° 08' 46.23" & E 69° 02' 47.93") is situated 12.5km south of the Dwarka town. Here, two distinct shore parallel beach ridges have been encountered. The inner one is situated about 300m away from the present shore. A quarry examined in this ridge shows the presence of medium to coarse grained shell limestone with gentle seaward dips. However, the top of the sequence is karstified. Towards the coast the facies becomes coarser and it merges with the coarse grained shell limestone belonging to the Okha Shell Limestone Member. This gently seaward dipping sheets form a relatively lower (~3-4m high) beach ridge still about 100m away from the shore. About 3m high beach ridge four merging with the present day beach and foreshore dunes separates the beach ridge three from the shoreline. It is interesting to note the occurrence of dead corals (*Favia*, a massive coral usually develop in the sub-tidal range), in the

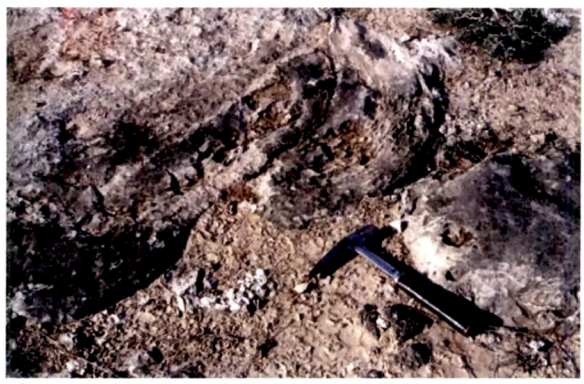

Figure 3.7 Dead coral (*Favia*) in shell limestone unit at Gorinja. (Length of hammer 30cm)

basal part of the beach ridge three that is made up of the shell limestone (Fig. 3.7). Another interesting geomorphic feature seen here is a palaeo-cliff of 1.5m height that occurs about 250m away from the present day coastline. Typical tidal notch has been developed at the base of the cliff. Gently about 2^{o} to 3^{o} sea ward dipping shore platform lies in front of this cliff wherein several joints trending in E-W direction are observed. The joint are parallel to each other with not much separation and abuts after running few meters.

Figure 3.8 High angle dip in the limestone unit of Dwarka Formation at Kuranga.

Near Kuranga, (N 22^{o} 02' 26" & E 69^{o} 08' 40") south of the Okha Rann, about 400 meters away from the shoreline a mound of 18m height exposes highly recrystallized limestones of the upper most part of Dwarka Formation with the bedding plane attitude 130^{o}/ 46^{o} due NE (Fig. 3.8). Such a steep dips normally does not represent the depositional dips. Hence, it could be attributed to the tectonic origin under the influence of the Okha Rann fault which trends in the NNE-SSW direction. However, no other evidences like any deformation could be traced out here. As we move towards the coast from this mound, the topography gradually falls and then again rises to form a beach ridge three of about 7m that is made up of the litho unit-4. The present day beach

has and angle of about 5° and is consisting of medium to coarse grained bioclastic sand. Near the low water line, however, the rocks of the beach ridge three get exposed to form a shore platform of limited width. Thus, here also two successive beach ridges, one behind another, can be traced out like the previous location. The inner ridge is again backed by vast depression wherein patchy outcrops of fine grained white coloured limestone showing a thin algal type coating over them have been encountered. Towards land, this depression abuts against a NW-SE trending ridge of about 20m that is made up of the differentially weathered rocks of the Dwarka Formation. The stretch ends Near Ghughwada creek.

Bhogat-Mivani stretch

Unlike earlier stretch which was characterized by linear beaches and coast parallel ridges, this stretch is characterized by raised and present day mud flats associated with the creeks and rocky shore platforms. The raised mud flats reach up to 8-10 km landwards. At Navadra, (N 21° 56' 10.73" & E 69° 14' 33.26") the buff to pink coloured a bit recrystallized cross-bedded limestone forms the beach ridge two of about 4-5 m height. Near the shore the limestone forms low cliffs of about 1-2 m, and abrasion platforms with limited beach and dune sand accumulations on it. The shell limestone deposits forms only a thin veneer in this stretch unlike the earlier where they were forming a distinct beach ridge. The steeper physiography of this coastal stretch is also evident by the steep offshore slope, as seen on the bathymetric charts. It appears that this coastal segment is evolved under the influence of local tectonics. A quarry was examined near the coast of Lamba, (N 21° 52' 23.61" & E 69° 18' 37.51") about 20 km south of Navadra. The quarry is about 150 m away from the present day coastline and is situated

in the beach ridge three. About 3 m high beach ridge four lies on its west towards the sea. The beach ridge three consists of off- white coloured coarse grained shell rich limestone wherein, several molluscan shells and shell fragments can be easily seen. This ridge is the only occurrence that can be correlated with the earlier segment that has a prominent beach ridge three of earlier sea level behind the present day wave built beach ridge and the Holocene wind built beach ridge (beach ridge four) near Makanpur and Gorinja. This beach ridge also is aligned in NW-SE direction like those of the previous segment, but occurs relatively nearer to the present day shore. A generalized cross section of this stretch is shown in (Fig. 3.9).

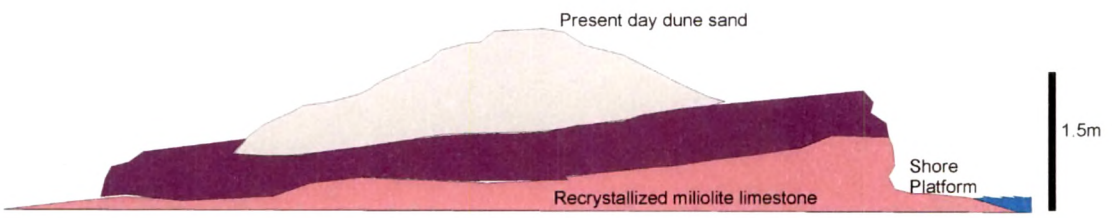

Figure 3.9 Generalized Geological section along Navadra – Lamba segment.

Two major but, seasonal streams Sindhni nadi and Sani nadi drains fresh water in to the Meda creek. A prominent physiographic feature that attains a height of about 65 m occurs right on the coast near Gandhvi (Harshad). This is made up of volcanic rocks belonging to the Deccan Trap Formation. The hill is surrounded by a thick accumulation of the miliolite limestone and also shell limestone (unit- 3 & 4). Towards its west, the carbonate accumulation forms about 500m wide platform that gradually slopes towards the sea. On its eastern side, the medium to coarse grained carbonate deposits which are also exhibiting planar cross-stratification possess numerous biogenic structures, and rest on the slope of the hill. The miliolite limestone deposits occurs also forming low mounds on the banks of the raised mud flats associated to the Meda creek. It is worth mentioning

here that about 7m of tectonic uplift in this area has been calculated using radiometric dates of some oyster shells from the carbonate deposits at Harshad (Pant & Juyal, 1995).

Miyani-Porbandar stretch

This stretch clearly shows presence of three distinct beach ridges one behind the other indicative of the oscillations in sea level. The road to Porbandar runs on the top of the beach ridge one which is highly denudated and so, does not exhibit typical appearance of a ridge.

Figure 3.10 A protosol layer separating two successive beach ridge of miliolite limestone near Miyani. (Depth of quarry 5m)

However, this extends shoreward reaching to a thickness of about 5-6 meters underlying the younger ridge (beach ridge two) with a prominent karstified contact characterized by about half a meter thick protosol unit (Fig. 3. 10). Near Miyani, (N 21° 49' 47.38" & E 69° 22' 51.98") towards eastern side of the road the top most part of this oldest Quaternary ridge exposes slightly recrystallized limestone unit that unconformably lies over the sandy, grayish yellow coloured fossiliferous sequence of the Gaj Formation that can be seen in about 12 m deep trench cut under the Meda-Kindari link canal project. The limestone shows bedding plane attitude 140°/13° due NE that is suggestive of the landward side of this ridge. Towards the coast, this unit is overlain by the beach ridge two made up of relatively porous lighter coloured cross-bedded limestone ridge that attains maximum height of about 12m and host a number of quarries all along its length. About 4m high cliff with a prominent tidal notch has been seen on seaward side of this ridge (Fig. 3. 11). A few patches consisting fragments of barnacles, corals and molluscan

shells attached to the bio-bored rocks of the shore platform at the base of this cliff have also been encountered (Fig. 3.12).

Figure 3.11 A palaeocliff in the miliolite limestone near Miyani. (Length of hammer 30cm)

Figure 3.12 Biological borings & a layer of shell limestone at the base of palaeocliff at Miyani. (Diameter of lens cap 5cm)

However, this cliff is about 200m away from the present day coast that is having a sandy beach and associated ridge (Fig. 3.13) forming the seasonal spit and mouth bar across the Meda creek. Thus, the occurrence of this palaeo-cliff and associated shore platform represent an ancient higher sea level during which the energy condition and coastal configuration in this part of the area was distinctly different than today.

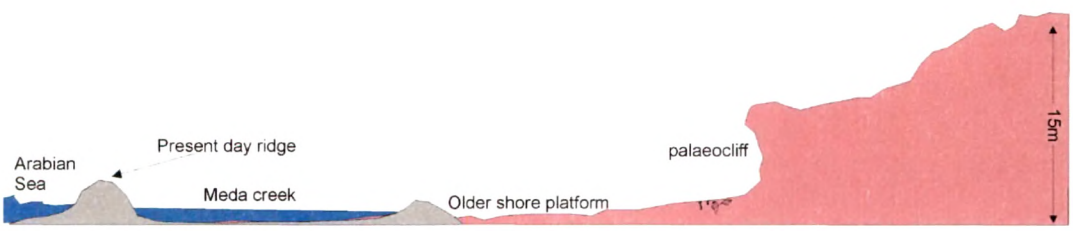

Figure 3.13 A profile across the coast near Miyani showing the occurrence of abandoned cliff.

Towards south of Miyani, near Visavda and beyond, the belt comprising of three distinct beach ridges attains a width of more than two kilometers. The ridges are separated by prominent linear geomorphic depressions, called swales. The first beach ridge forms an elevated ground that is stretching linearly having its maximum height of about of about 10m. It is characterized by its typical reddish pink colour and

recrystallized top. Partly, the rocks are covered by a thin veneer of loamy soil. The rocks consist of recrystallized megashells of gastropods and pelecypods, dominantly being oysters. In general coast parallel running this ridge becomes relatively broader and goes away from the present shore between Kantela and Bokira. In this part of the area, the tidal flats and associated salt pans of about 1km width lie on its western side differentiating it from the second ridge. The second ridge towards west of the road is situated about half a kilometer away from the road forming relatively higher physiographic expression (about 15m) that runs parallel to the coast. Few villages like Ratadi, Kantela, Kunchdi etc are situated near this ridge, and are famous for the limestone quarries. The quarries in this ridge exposes buff coloured relatively better sorted, cross-bedded limestone which are mainly Calcarenite (litho unit-3) typically representing the miliolite limestones. The thickness of limestone of this ridge reaches to more than 20m resting with a sharp erosional contact with the older relatively recrystallized pinkish coloured limestones. The contact is characterized by a thin conglomeratic horizon consisting of sub-rounded to well rounded gravels and pebbles of older rocks The beach ridge three that occurs near to the present shore has attained a maximum height of 16-20m in this segment. Between Miyani and Visavda up to the Kindari creek, this ridge occurs about 500-600m away from the present shore, separated by a shore parallel running beach ridge four that consists of the stabilized dune sand described earlier as the litho unit-9 (Fig. 3.2c). However, south of Kindari creek this ridge goes closer to the present shore and forms typical rocky highland that is covered on the shoreward side by the present day beach and coastal dune sand. The upper part of this beach ridge three is composed of relatively coarse grained, porous and shell rich limestones which are considered belonging to the unit-4. The thickness of this shell

limestone unit reaches maximum up to 10m. The lower part of the ridge is made up of cross-stratified miliolite limestone belonging to the beach ridge two. Pebbles and cobbles of this older limestone characterize the conglomeratic base of the overlying shell limestone unit At places, the unit-3 gets exposed during low tide along the present day sandy coast. The present day shoreline has gentler to steeper sandy beaches backed by the beach ridge four that reaches to the height of 4-5m.

Porbandar-Veraval Segment

This is the longest segment of the study area which runs for about 110km between Porbandar and Veraval. This segment has a unique geomorphic set up in comparison with the previously described Okha-Porbandar segment as its coastline is characterized by successive coast parallel beach ridges and a vast depression behind these ridges that shows characteristic dark tone on the satellite images (Fig. 2.6). This depression is locally known as 'Ghed' that gets flooded during the monsoon time. In general it possesses black coloured sandy clays, however, in the dug wells the below lying pink coloured recrystallized limestones can be easily seen. The clay unit possesses local lenses of gravels and sand, and attains thickness of about 6-8m. The beach ridge one that commonly occurs from the Miyani up to the Porbandar doesn't appear south of the Porbandar, although it reappears between Navibandar and Madhavpur as discontinuous, but prominent linear feature showing physiographic high on SOI topographic sheet (Fig 3.14) In the Navibandar - Madhavpur area the beach ridge one (litho unit-1) is partially covered under the alluvium, but NW-SE oriented outcrops can be seen at Kadachh and Mander about 3-4 km inland wards from the present shoreline.

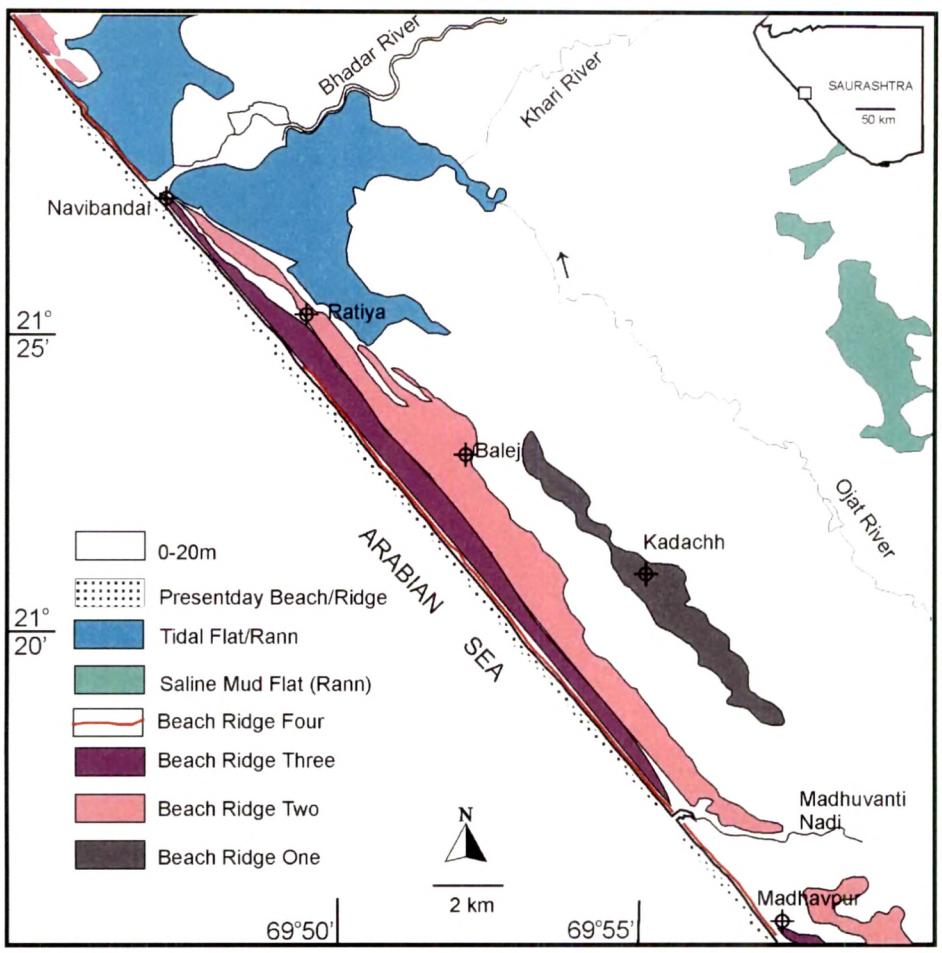

Figure 3.14 Geomorphic set up of the Porbandar (Goasa) – Madhavpur area.

Porbandar – Madhavpur stretch

The coastal tract between Porbandar and Navibandar shows presence of two distinct ridges that runs parallel to the present shore. The inner one is composed of the typical buff coloured, cross-stratified miliolite limestone while, the shoreward one is made up of shell limestone. The city of Porbandar is situated on the miliolites belonging to the beach ridge two that are exposed in the form of a low (about 3m) cliff on the coast. The miliolite limestone of this ridge attains maximum thickness of about 6m, and rests with a disconformity on brown coloured recrystallized Dwarka limestones. The beach ridge three shows a prominent physiography reaching up to 20m height and occurs south of Porbandar (N 21° 36' 13.13" & E 69° 38' 29.58"), about a kilometer away from the

present day shoreline. The rocks are characteristically medium to coarse grained, shell rich, porous Calcirudite belonging to the litho unit-4. The whole thickness of about 8 to 10m is exposed in a number of abandoned quarries wherein, the base is characterized by the occurrence of several molluscan mega shells like *Ostrea, Tellina, Cerithium* etc while the top is relatively finer. more sorted and devoid of mega shells The Porbandar-Veraval road runs on seaward side of this ridge facing a flat shallow depression that separates the beach ridge four and present shore from the beach ridge three. The beach ridge four reaches up to 5m height forming the core of the backshore dunes associated with the present day sandy beaches.

At Gosabara, about 16km south of Porbandar, an inlet of sea extends about 3km inlandward where it is backed by a huge flat low lying area having highly irregular boundary, that remains flooded during the rainy season. On the satellite imagery this geomorphic unit appears with a distinct grayish to white tone and fine texture. The grey and white tones reflect muddy salt encrusted characters of the deposits in this depression South of this the beach ridge three occurs nearer to the present shore in comparison to its occurrence up till now. At Tukda and Gosa, (south of Porbandar) on either side of the road the shell limestones of beach ridge three get exposed in the shallow quarries. The occurrence of oysters, clam shells, murex, barnacles, drifted coral fragments etc. in these deposits is conspicuous At Narvai, on right bank of Bhadar river mouth, the oyster bed along with coral and shell fragments occurs unconformably resting on the slightly recrystallized abraded surface of the miliolite limestone. A linear sandy ridge runs parallel to the present day shore that is backed here by the tidal flat associated with the Bhadar river mouth.

On southern side of the Bhadar river mouth between Navibandar and Madhavpur the road runs on the beach ridge two. The coastal belt is characterized by two distinct coast parallel ridges separated by a shallow depression that is partially covered by the dune sand On either side of the road near Raitya (N 21° 23' 58.02" & E 69° 50' 14.23"), Balej, Mocha, Pata etc. villages several shallow quarries expose medium to coarse grained, poorly sorted shell limestone; a characteristic of the beach ridge three. At Navibandar right on the coast, the shell limestone occurs forming a prominent coast parallel ridge of about 4-5m height. In a dug well the poorly sorted conglomeratic base of this unit occurs at about 3m depth having approximately thickness of 2.5m. This unit possesses dominant composition of well rounded to sub-rounded clasts of trap derived material that is cemented by the carbonate. The upper part has relatively less dominance of such detrital material, but is coarse grained, porous and shell rich in nature On the eastern side of Navibandar, a shallow depression that is covered by black coloured sandy alluvium separates another prominent ridge on which the road to Veraval runs. In shallow wells dug in this depression cross-stratified pinkish coloured miliolite limestone has been encountered at a depth of 1-2m. The miliolite limestone that constitutes the second ridge are white to dirty white coloured, moderately sorted, cross-bedded having slightly duricrusted recrystallized exposed surface. On the eastern side of the road near Bhadar river bridge at Navibandar mud cracks have been encountered in one of the exposure of these rocks (Fig. 3.15). Here the rocks also show presence of thin layers of trap sand and occasionally biogenic structures like trails and burrows. As the base of this unit is not exposed anywhere in this area, the thickness has not been estimated. Near Balej, south of Navibandar, in a road side quarry a conspicuous thickness of shell limestone is exposed The rocks are moderately sorted and in general coarse to very

coarse grained in nature, typically of the litho unit-4. They show gentle sea ward dips, but on eastern side the dips are inlandwards. The thickness reaches to about 5m and the base has sharp contact with the below lying miliolite limestone. The thickness reduces towards the eastern side where these deposits abut against a prominent ridge of miliolite limestone–beach ridge two that reaches the elevation of about 30m. Scattered, unsorted, tabular and irregular blocks of this limestone (unit-3) have been encountered floating into the younger shell limestone unit (Fig. 3.16). Such occurrences suggest erosion of the older ridge by higher sea that has deposited this younger shell limestone unit. It is interesting even to note that the unit-4 that constitute this ridge contains relatively more amount of detritals (insoluble residues) of about 30% in contrast to its other occurrences which show up to 8%. The same unit extends southward and encountered at several places like Mocha, Singaria and Pata on the road side. Near Pata the road turns closer to the present shore and runs over the sandy, semi-consolidated ridge that connects to Madhavpur. More than one parallel to semi-parallel ridge occurs between Balej and Pata, which are made up of miliolite limestone. However, in absence of prominent depression characterized by different facies of deposits and bounding surface to differentiate litho-units, such occurrences in a very narrow belt of 500m width are considered representative of a common sea level.

Figure 3.15 Mud cracks in the miliolite limestone of ancient beach ridge near Navibandar.

Figure 3.16 Drifted blocks of limestone from the older beach ridge as seen in a shell limestone quarry near Balej.

Although, a prominent coast parallel linear ridge (beach ridge one) runs about 3-4km inlandwards where upon the Kadachh and Mander villages are situated As mentioned earlier this ridge is partially covered under the alluvium, but the exposures of its constituent miliolite limestone have been encountered in the dug wells The rocks are pinkish coloured, cross-bedded and duricrusted. This ridge abuts about a kilometer south of Mander against a low lying flat alluvial plain north of Madhavpur. Near Madhavpur a distinct truncation in the thus occurring coast parallel ridges can be seen in a form of flat, low lying, triangular area that is under the dense agricultural practice separated from the sea by about 200m wide present day beach ridge over which the road is passing. The triangular low lying area can be distinctly seen on the satellite scene (Fig. 2.6). This part is drained by a small seasonal stream called Madhuvanti Nadi. The stream is highly irregular in shape and controlled by the topography that is formed by the so described beach ridges. At the mouth of Madhuvanti Nadi (N 21° 16' 56.16" & E 69° 55' 54.34") on either side abrasion platform has been formed in the shell limestone unit that gets exposed during low tide. At Madhavpur (N 21° 15' 09.59" & E 69° 58' 08.30") a number of abandoned quarries have exposed about 10-12m thick grayish white coloured, porous, coarse to very coarse grained limestone unit which contains scattered complete as well as broken molluscan shells and coral fragments in the lower part. The upper part of sequence is relatively sorted and exhibits planar cross-stratifications, and appears to be of aeolian deposition of these marine sediments.

Madhavpur - Chorwad stretch

The Madhavpur – Mangrol area exhibits more prominently the occurrences of successive beach ridges in a relatively wider coastal strip (Fig. 3.17). Apart from the beach ridges,

the coastal cliffs of moderate height (2-3m) start appearing. Towards south of Madhavpur the porous limestone bearing beach ridge three occurs nearer to the present day shore up to the coast of Antroli and then after it looses its peculiar ridge form. It occurs in patches forming 0.5-1.0m thick sheets that unconformably rest over the abraded and slightly recrystallized top of the miliolite limestone.

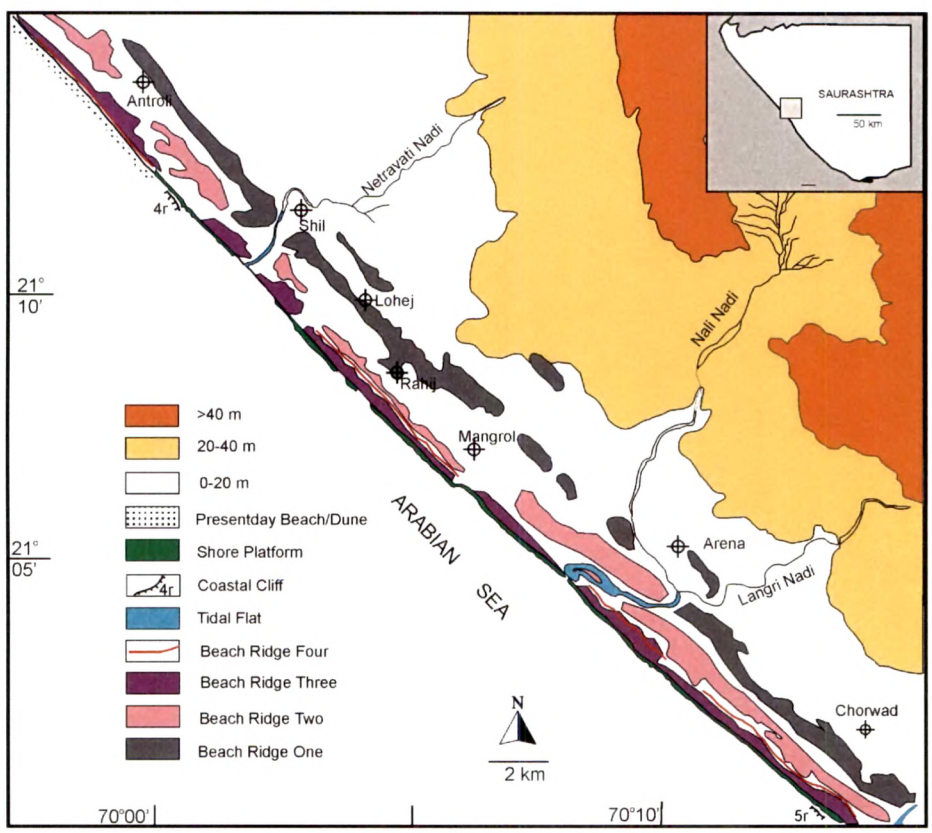

Figure 3.17 Physiographic and geomorphic set up of the Madhavpur-Chorwad area of segment-2

Figure 3.18 Coastal cliffs and shore platform in the ancient miliolite ridge on the coast of Aantroli-Lohej.

Between Antroli and Lohej the coast is rocky exposing moderate cliffs of about 4-6m formed in the miliolite limestones of beach ridge two (Fig. 3.18). Whereas, the coast between Mangrol and Chorwad is again marked by a prominent beach ridge reaching up to 15m height, and is composed of the shell limestone. The intertidal zone however, exposes the miliolite rocks of beach ridge two to form abrasion platform. The road between Madhavpur and Veraval runs on the top of the beach ridge one that is characterized by comparatively recrystallized very coarse grained to gravelly, cross-bedded shell limestone of the litho unit-2. The attitude of bedding plane in this unit distinctly shows two opposite dip directions i.e. SW (seaward) and NE as well as SE (landward). This substantiates its wave built beach ridge morphology as well. Near Shil (N 21° 15' 56.23" & E 68° 57' 10.96") towards the coast an abandoned quarry in the first ridge exposes about 7m thickness of this limestone unit. The rocks exhibit tabular cross-stratifications having upto 25° general dips towards the sea (Fig. 3. 19). At Shil Bandar the rock outcrops are mostly covered under the dune and beach sands. Here Netravati Nadi meets to the Arabian Sea but, the mouth remains closed by a sand bar during major part of the year except monsoon. A few patchy outcrops of shell limestone

Figure 3.19 The shell limestone of the second ancient beach ridge exposing tabular cross-stratifications with seaward dips near Shil. (Height of the person 175cm)

belonging to the beach ridge three can be seen as inliers in the recent sand. However, at Mangrol coast this unit appears as a conspicuous ridge hosting several quarries of shell limestone Here, it attains height of about 10-12m running parallel to the coast just above the High Water Line (HWL) In few abandoned quarries, maximum thickness of this unit has been estimated to be about 5-6m. The rocks are typical Calcirudites dominantly composed of broken and complete molluscan shells, coral fragments and gravels of older miliolites.

At the depth of about 1.5m in a quarry situated near Mangrol Bandar (21° 06' 54.56" & E 70° 05' 30.86"), a conspicuous occurrence of dead coral reef has been encountered. It exposes mainly massive coral belonging to the genus *Favia* along with other biogenic remains characterizing a reef assemblage (Fig. 3.20). This unit unconformably rest on abraded surface of the older miliolite limestone that constitute the beach ridge two behind it towards the land. In this quarry the shell limestone unit is of about 3m thickness and exhibits low angle planar cross-stratifications showing sea ward dips (N 135°/ 5° due WSW). This ridge is overlain by about 2-3m thick stabilized carbonate dune sand (Fig. 3 21). At a slightly lower level than this quarry towards sea a massive sand unit, that is semi-consolidated and devoid of any appreciable stratification, is overlain by about 1m thick porous, partly consolidated and stratified, very coarse, carbonate sand unit occurring about 3m amsl (Fig. 3.22). This unit is distinctly bio-turbated and shows numerous feeding burrows characterizing its intertidal deposition (Fig. 3.23). Perhaps, this unit represents the Holocene high sea in the region. The beach ridge two of miliolite limestone that underlain the shell limestone also get exposed forming abrasion platforms on present day shoreline. The typical ridge form of this miliolite limestone is obliterated due to extensive quarrying at Mangrol Bandar (Fig

3 24). However, 10-15m high ridge at about 600m away from the present shore can be seen northward from this place. This ridge is the beach ridge two made up of aeolianites (miliolite limestone) that rest on typical beach facies, described so far. The Mangrol town is situated on southward extension of the beach ridge one on which the Porbandar – Veraval road runs. A distinct depression of about 1km width separates this ridge from the beach ridge two that is situated nearer to the sea. This depression is characterized by reddish coloured kankary and loamy soil that supports agricultural fields and orchards. In few dug wells the unit-1 limestone can be seen at a depth of 2-3m underlying the soil. This limestone unit is a bit recrystallized and cavernous.

The area east of the Mangrol is interesting due to the occurrence of carbonate shore deposits at elevation of about 40m amsl and 7km away from the present shore. The signature of such occurrences can be easily appreciated from the satellite data in a form of white linear feature that extends from south of Sabli Nadi in the north upto Saraswati Nadi in the south. The deposits here do not form a prominent ridge like geomorphic feature, but occurs as patches of 1-2m thick sheets showing westward dips. The lower part of the unit characteristically shows conglomeratic nature due to well rounded to sub-rounded gravels and pebbles of mostly limestones and sandstones of Gaj Formation, and subordinately those of geodes derived from the weathering of amygadaloidal basalt of Deccan Trap Formation. Similar outcrops have been encountered at south of Bhat Simroli on Mangrol – Keshod road, Lambodra on south bank of Noli river, Bhanduri, Gadu on Veraval – Keshod road, Moraj on Veraval – Talala road etc.

South of Mangrol, the beach ridge one shed out its prominent ridge form and inliers of recrystallized shell rich limestones of this unit occurs on either side of the road towards Chorwad. A distinct bend in the Noli river is seen near Sheriyaj and south of

Figure 3.20. A dead coral reef as exposed on a quarry base near Mangrol Bandar. (Diameter of lens cap- 5cm)

Figure 3.21 Stabilized dune sand resting over the ancient beach ridge made up of shell limestone at Mangrol Bandar. (Height of quarry face 1.5m)

Figure 3.22 Cross-stratified and bio-turbated beach sand deposits at 3m amsl on Mangrol coast. (Length of hammer 30cm)

Figure 3.23Skolithos ichnofacies in semi-consolidated beach sand occurring at 3m amsl on the Mangrol coast. (Length of pen 10cm)

Figure 3.24 Abandoned quarry in the ancient beach ridge two of miliolite near Mangrol Bandar.

Arena as the stream is controlled by the relict occurrences of this ridge. About 8 km from the Mangrol, at Arena gently seaward dipping, very coarse to gravelly, shell rich limestone occur with a recrystallized top (Fig. 3.25). In a shallow quarry the porous nature of rocks can be seen where the inter-granular porosity in the recrystallized bio-clasts is lined by deep red colour matrix. The planar tabular cross-beddings can also be appreciated on quarry face. Similar outcrops have been encountered at Kukaswada, Budhecha, Husenabad etc. areas nearby. These outcrops are dotted with mound like occurrences of white coloured, well sorted, and fine grained typical miliolite limestone characterizing the litho unit-6 that forms the fossil coastal dunes related to the beach ridge three. The curved dunal beddings and geometry of the mounds suggest its aeolian nature. At Sepa, about 3.5km from Arean, prominent NE-SW oriented mounds of such white coloured miliolite limestones have been encountered resting unconformably over the recrystallized shell limestone. The miliolite shows planar, wedge type cross-stratification with curved beddings varying dips from 18° to 32° due SW and SE. Here, ball like concretions in miliolites have also been seen that ranges in diameter from 5-10cm (Fig. 3.26).

Figure 3.25 Seaward dipping shell rich limestone with recrystallized top at Arean.

Figure 3.26 Ball like concretions in the miliolite limestone at Sepa. (Diameter of lens cap 5cm)

Towards the shore, the occurrences of recrystallized shell limestone between Arean and Kukaswada are covered under the alluvium. Between Korada and Chorwad Bandar again a prominent NW-SE trending ridge occurs about a kilometer away from the present shore. This ridge is constituted by slightly pinkish coloured, medium to coarse grained, moderately sorted and cross-bedded miliolite limestones. This represents a beach ridge two that has been traced out in the previous segments also. The rocks are slightly recrystallized, less porous and have slightly duricrusted cavernous top. The beds show gentle (9° to 10°) southwestward dips. In a dug well between Kukaswada and Khambhaliya, about 1.5m thick unit of this limestone is underlain by 0.5m thick kankary red brown coloured palaeosol. The soil is further underlain by recrystallized shell limestones, thickness of which could not be estimated. In the low lying area between this beach ridge two and the Arena – Kukaswada road perhaps this palaeosol layer gets exposed showing its typical reddish colour and kankary nature in the fields. At Kukaswada, the recrystallized shell limestone outcrops show bedding plane attitudes N 110°/ 20° due SW. A prominent ridge of 10-15m height runs parallel to the present day shore between Khambhaliya and Chorwad Bandar, just behind the HWL. This is the beach ridge three that is composed of shell limestones belonging to the type Chaya Formation. This ridge is separated from the previous ridge by about 500m wide low lying area that is covered under the aeolian sand that is reworked and stabilized by the meteoric action. At

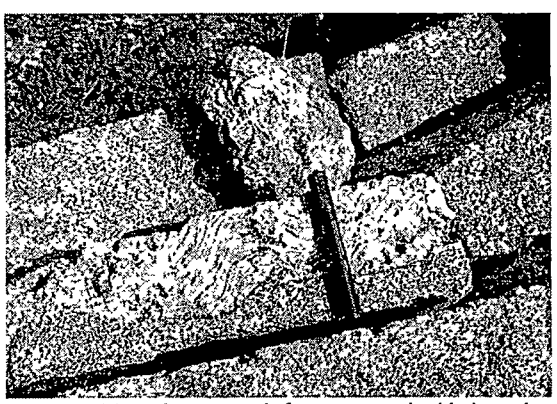

Figure 3.27 A large coral fragment embedded in the shell limestone at Chorwad Holiday Camp (Length of pen 10cm)

Chorwad Bandar, about 5-8m deep stone quarry exposes very coarse to gravelly, poorly sorted, porous shell limestones showing gentler seaward dips of planar and locally trough cross-bedded sequence. There also occurs a scattered large fragment of gastropod and pelecypod shells and corals (Fig. 3. 27). On the coast of Chorwad Bandar behind the holiday camp, this shell limestone unit occurs as 0.5-1m thick patches of sheets resting unconformably over the pinkish coloured miliolite limestone of the older ridge. The miliolite limestone also forms low cliffs of about 1-2m and extends seawards in the form of the abrasion platform.

The Mangrol and its adjacent coastal strip of the study area hosts outcrops of the all lithological variants of the Quaternary carbonate sequences that compose the coastal geomorphic scenario. Moreover, the variations in the geomorphic features are also encountered in this part of the area more profoundly. Therefore, a detailed geological mapping of this window has been carried out aided by the examination of well logs, and a composite subsurface geological section has also been prepared to appreciate the stratigraphic relationships between so described lithological units (Fig. 3.28 & 3.29).

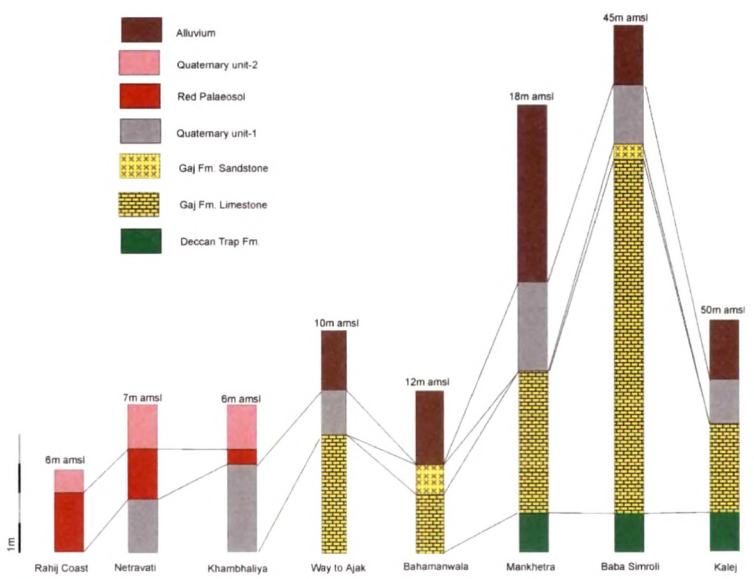

Figure 3.28 A stratigraphic correlation of various lithounits encountered in the dug well section of Mangroal – Shil area.

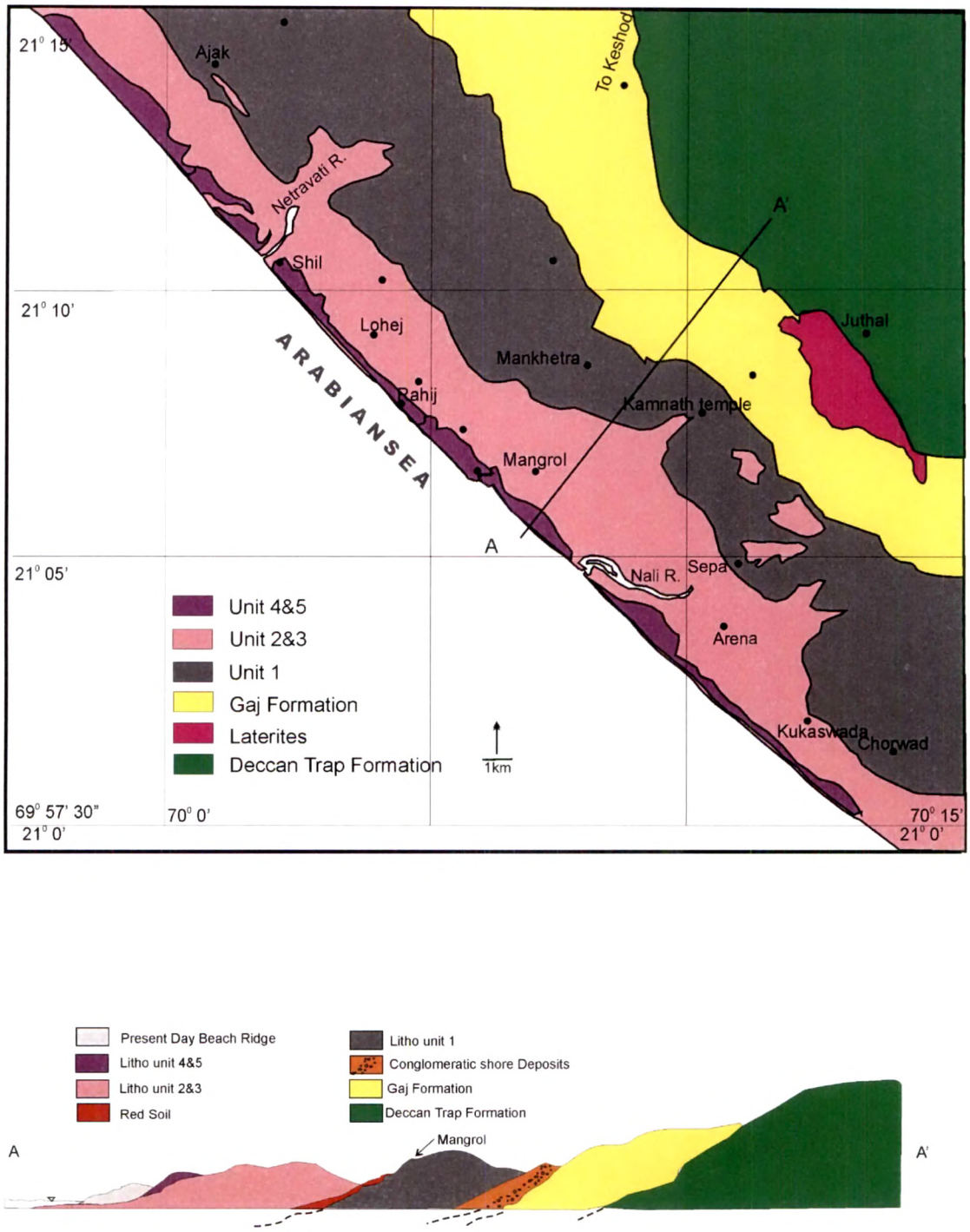

Figure 3.29 Geological map of the Mangrol-Shil area and a schematic geological section along A-A' depicting the stratigraphic relationship between various lithounits.

Chorwad – Chhara stretch

South of this at Vadodara the beach ridge two and beach ridge three occurs together and it is difficult to differentiate their morphology on account of their irregular, but elongated form attaining its maximum height of about 10m Figure. 3.30 demonstrate the details of physiographic and geomorphic set up of this part of the area. The outcrops of the miliolite limestone that constitutes the beach ridge two shows bedding plane attitudes N 130°/ 15° due SW, and forms 3-5m high cliffs and an abrasion platform on the present day shore. The upper part of a 5m high cliff on the Vadodara coast exhibits polygonal cracks in the miliolite limestone that could be a result of drying out of water saturated sediments indicating the deposition of this miliolite under aqueous conditions (Fig 3 31). About 2km south of Vadodara on the coast of Adri a raised shore platform can be appreciated as its top shows seaward oriented furrows that must have been formed by the receding water during low tides (Fig. 3 32). This ancient shore platform is partially covered by about 0.5-1m thick porous and very coarse grained shell limestone sheets (unit-4) that substantiate the inference. The present height of this platform is about 3m amsl It is also interesting to note the occurrence of a sea cave about 400m away from the present shore (Fig. 3.33) On shoreward side of this cave the dunes and beach sand has covered all rock outcrops. The Nagnath Mahadev temple is presently situated in this cave. These erosional features are related to a high sea level that must have deposited the younger shell limestones that occur unconformably resting over this miliolite limestone unit. In a sheltered depression behind the miliolite cliffs, about 0.8m thick white coloured, very fine grained, thinly laminated chalky deposits have been encountered. This perhaps represents a lagoonal deposit related to the aforesaid sea level Two prominent sets of joints have been encountered significantly developed in the unit-2

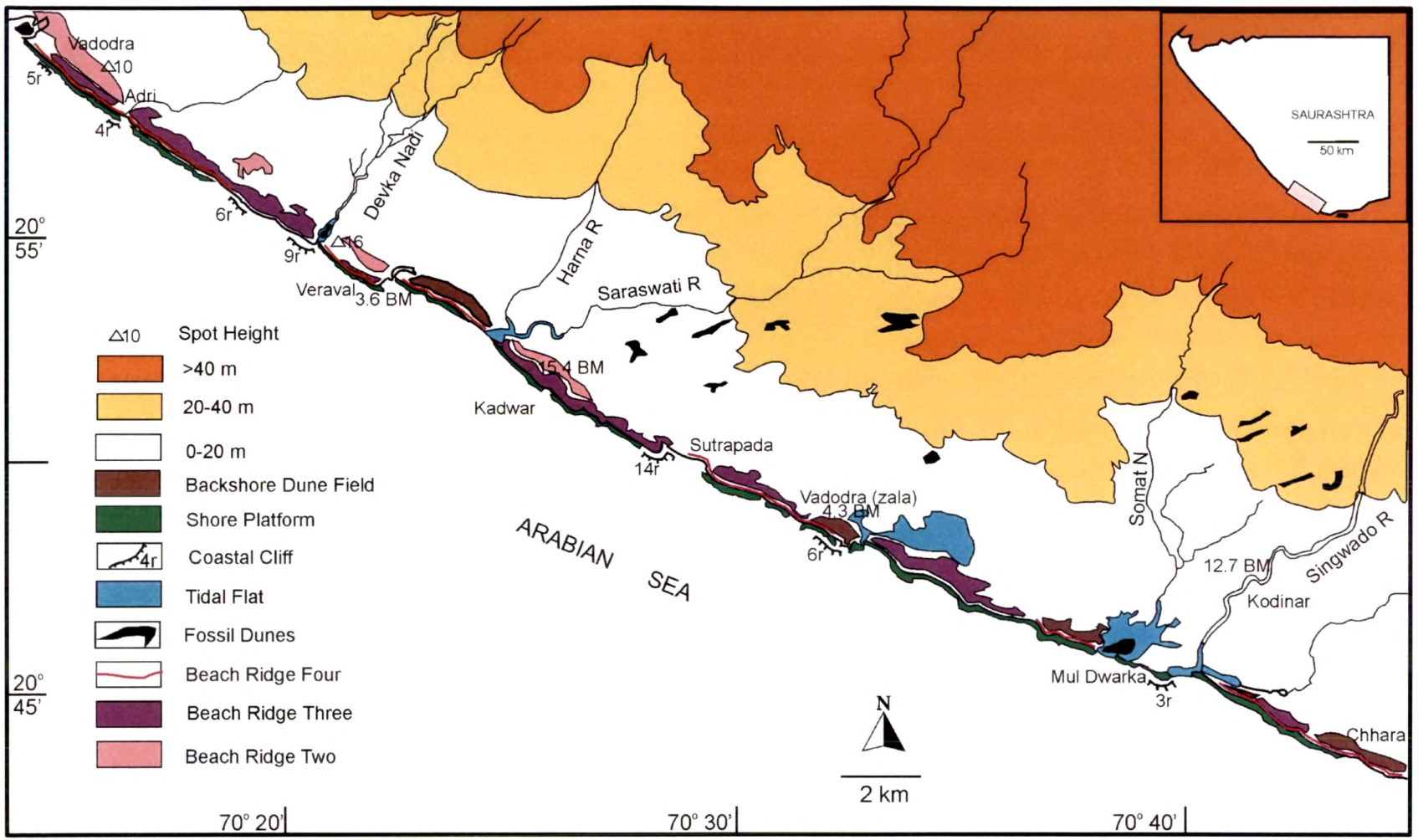

Figure 3.30 Physiographic and geomorphic set up of the area between Chorwad-Chharaa of segment-2.

Figure 3.31 Polygonal cracks as seen in the miliolite limestone on the top of a cliff near Vadodra coast. (Length of hammer 30cm)

Figure 3.32 Abrasion furrows in the miliolite limestone on the top of a cliff at Adri coast. (Height of person 165cm)

Figure 3.33 A biogenic encrustation on the roof of a palaeo sea cave at Adri coast. Length of scale 5cm

Figure 3.34 Prominent cross cutting joints in the litho unit-2 as seen on the Adri coast. (Height of person 165cm)

that constitute the beach ridge two, and forms 3-4m high coastal cliff and raised shore platform (Fig. 3.34). The joints are oriented in NE-SW and E-W directions. The miliolite ridge occurs now onwards more closer to the present shoreline and forms at places cliffs of 4-6m height. A generalized geological section (Fig. 3. 35) exhibits the stratigraphic relationship and mode of occurrence of unit-2 and unit-3 on the Adri coast.

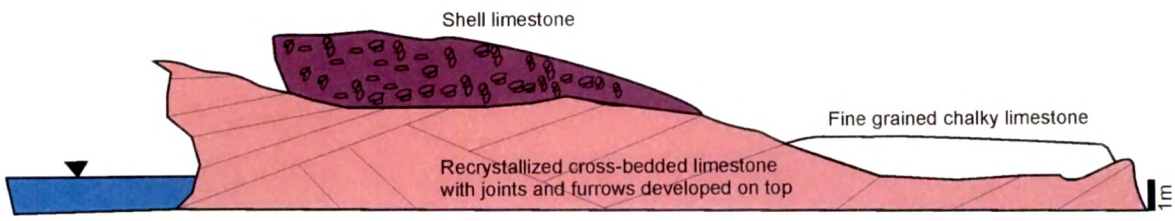

Figure 3.35 A generalized geological cross section of the Adri coast

At Veraval near light house the yellowish coloured, medium to fine grained, cross-bedded miliolite limestones form 3-4m high coastal mounds that gradually extends seawards as shore platform. Here, about one meter thick sheet of shell limestone has been encountered that possesses scattered fragments of molluscan shells and corals. The rocks are traversed by two prominent sets of joints showing NW-SE and NE-SW trends (Fig. 3. 36). These joints have been discussed elaborately in the forthcoming chapter on

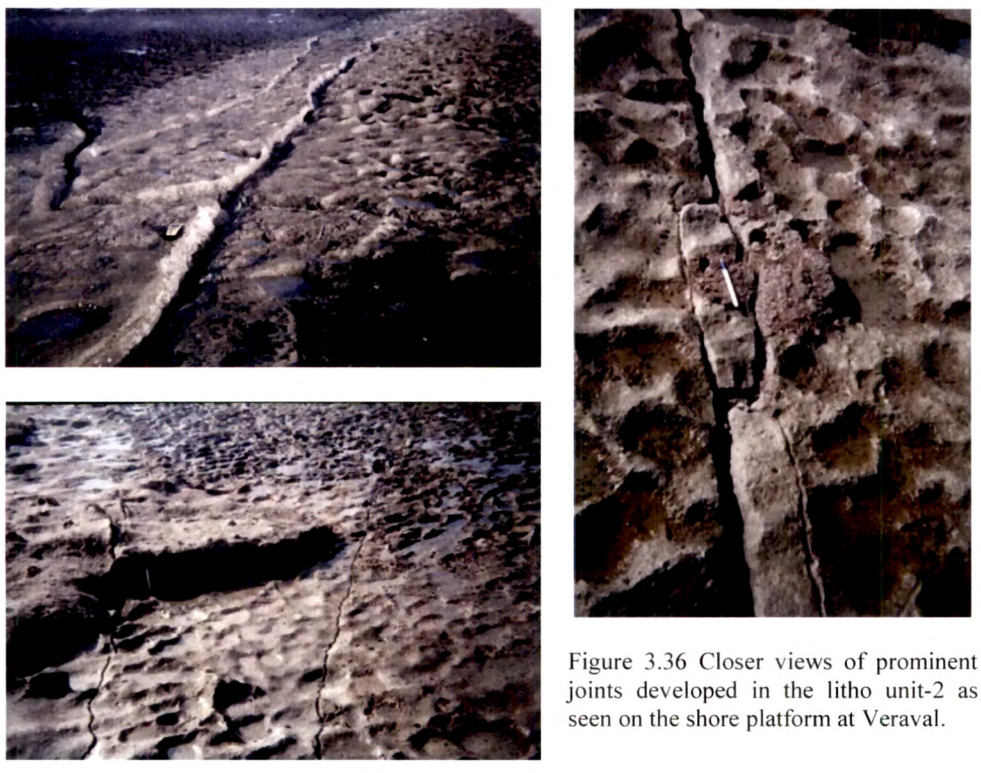

Figure 3.36 Closer views of prominent joints developed in the litho unit-2 as seen on the shore platform at Veraval.

imprints of Neotectonics. Nearby this place behind Indian Rayon factory, the coastal miliolite unit occurs underlain by a prominent red coloured palaeosol layer. In the area around Veraval and Somnath this palaeosol unit is exposed on the surface in the fields and also in road side trenches. The recrystallized older shell limestones have been seen exposed in the near shore areas unlike the earlier described part of the study area.

However, on Veraval – Talala road near Govindpura, patches of these rocks can be seen on road side and in upper part of the sequence exposed in dug wells. At Somnath, the miliolite limestones occurs forming shore parallel ridge over which the town of Prabhas Patan is situated. In the abandoned quarries this limestone unit exhibits moderate to steeply inclined planar cross-stratifications suggesting its distinct aeolianites form The rocks are medium to very coarse grained and moderately sorted with significant porosity.

Veraval-Jafrabad Segment

Like the Porbandar – Veraval segment, the Veraval – Jafrabad segment of the study area also has a considerable length and stretches for about 110km along east-west The coastline of this segment shows distinct change in the coastal geomorphology in comparison to that of all the previously described segments. Veraval onwards the prominent occurrences of impressive coastal cliffs, shore platforms and sea stacks have replaced linear sandy beaches which were commonly occurring up till now. The coastline is cut by numerous coastal streams viz., Hiran, Saraswati, Singwado, Somat, Sangwadi, Rupen, Machhundri, Rawal, Raidi and Dhantrvadi rivers which are originating from the Gir highlands. These are ephemeral streams and usually bring water and sediments in the monsoon season. The composition of present day beach and associated dune sediments also shows marked change due to the detritus influx contributed by these rivers. The width of the coastal plain has also relatively reduced in this segment as the prominent physiographic break occurs nearer to the shore in the form of the Gir hills. Instead of transverse shore parallel ridges of various generations, the miliolite limestones and shell limestone occur in this segment stacked above one another

as can be seen in the coastal cliffs and a narrow coastal zone. However, the coastal plain between Veraval and Una is dotted by a number of fossil dunes composed of white coloured, well sorted, medium grained miliolite limestones prominently showing curved and high angle dune beddings. The geometry and orientation of these miliolite mounds suggest majority of them being parabolic and longitudinal dunes along with some barchans too Figure 3 37 presents the overall physiography and geomorphic set up of this coastal segment of the study area.

Veraval – Diu stretch

As can be seen on the Landsat Image (Fig 3.38), the coastline between Diu and Gopnath is straight and jagged by a number of NE-SW oriented creeks and associated tidal flats and dune fields with a very sharp texture of the coast characterized by rocky cliffs and islands This ENE-WSW oriented sharp linear coastline is accounted to the westward extension of the Son-Narmada-Tapti (SONATA) structural trend. The distinct cliffy nature of the coastline becomes prominent Diu onwards where up to 30m high cliffs have been encountered. Between Veraval and Diu, however, the moderate (up to 5m) height cliffs starts appearing as can be seen at Kadwar, Vadodra (Zala), Dhamlej, Mul-Dwarka etc Here, the shell limestone unit occurs forming a 3-4m high patchy mounds right on the coast, and moderately high linear ridges (beach ridge three) near to the coast. At Kadwar a number of abandoned quarries in this unit have exposed the abraded and karstified top of the lower miliolite limestone unit. The younger sequence is porous, poorly sorted and very coarse grained wherein relict fragments of older limestone and drifted corals can also be seen (Fig 3.39) Here, in about 5m high cliff a typical marine facie has been encountered unconformably lying over the ancient abrasion platform

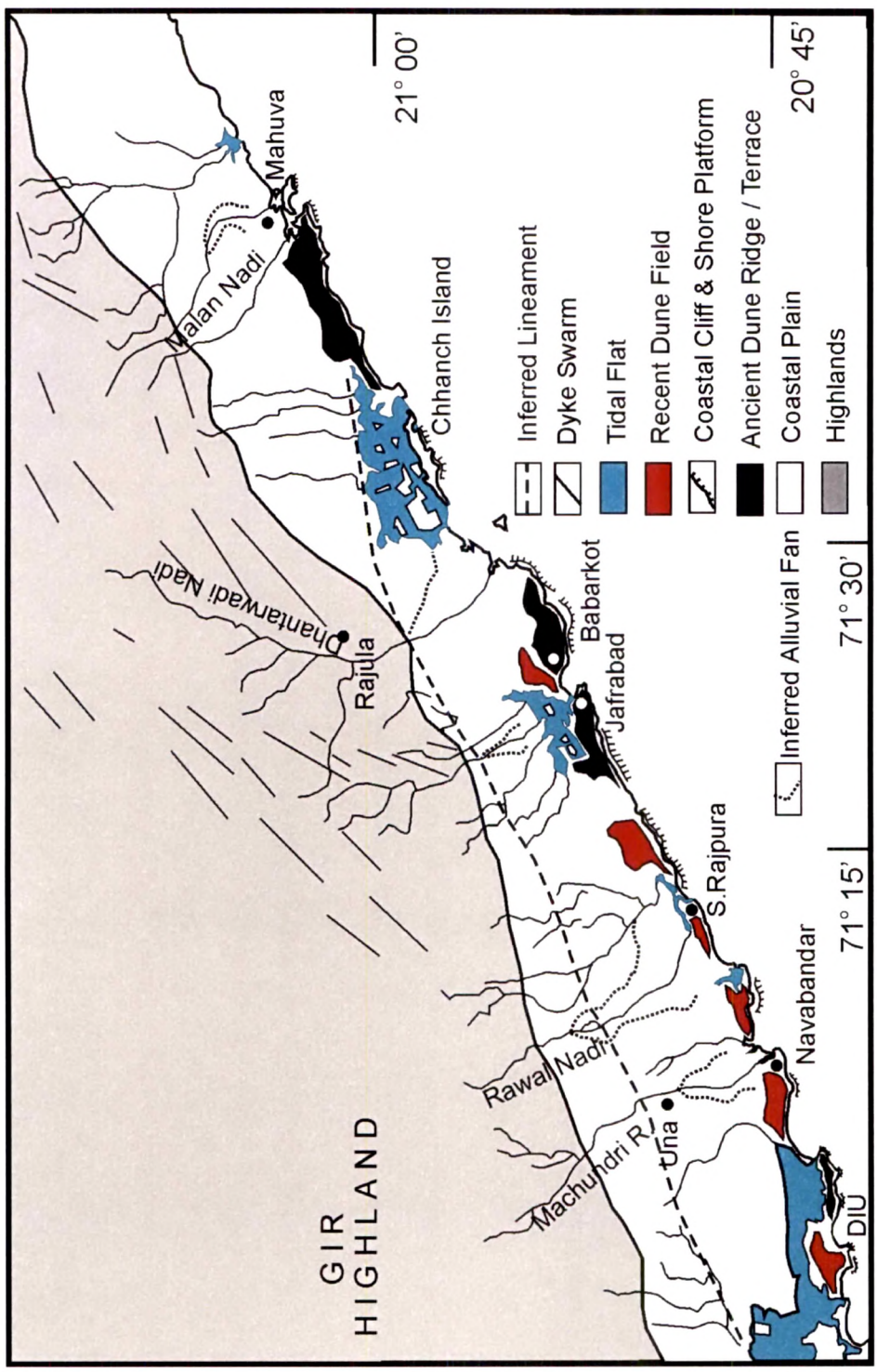

Figure 3.37 Geomorphic set up of the Diu-Jafrabad stretch of segment-3.

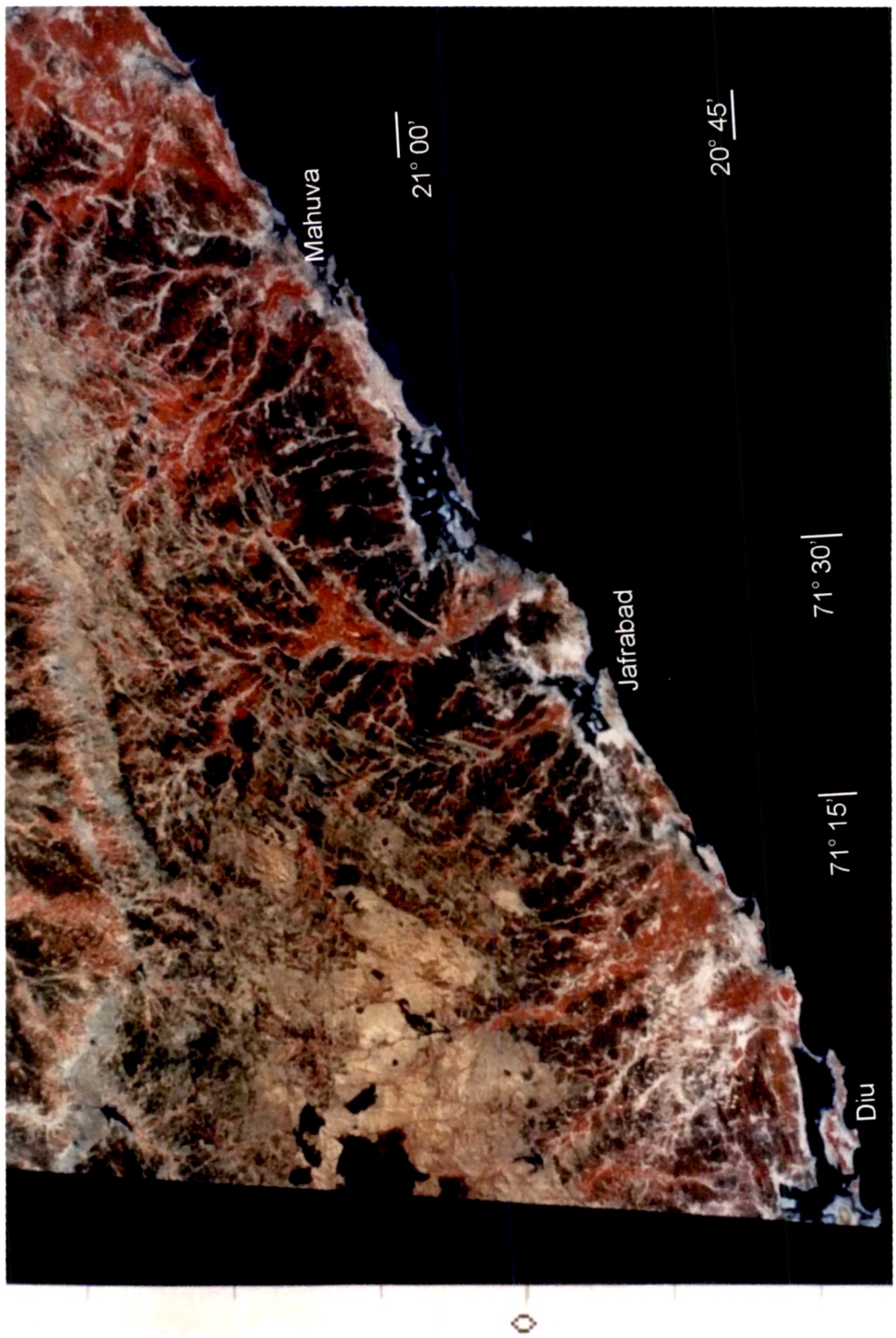

Figure 3.38 Landsat scene of the area between Diu and Mahuva of south Saurashtra coast.

of the older miliolite sequence (Fig. 3.40). About one meter thick very fine to fine grained white coloured limestone unit rests with a sharp contact, on the lower unit. This unit also shows herringbone cross-stratification and is overlain by about 0.25m thick highly bioturbated sandy unit. The topmost part of the cliff is constituted by a very coarse grained to pebbly shell rich limestone unit which is porous and does not show any prominent stratification. On the coast of Sutrapada - Vadoara (Zala) about 3km eastward form Kadwar, this shell limestone ridge occurs a bit prominently, partially covered under the present day beach and dune sand. At Vadodara, about 5m high cliff exhibits pink coloured, slightly recrystallized, cross-bedded miliolite limestone that forms the beach ridge two in the other parts of the study area is overlain by a 1 to 1-5m thick

Figure 3.39 A drift coral fragment embedded in the shell limestone of Kadwar coast. (Length of hammer 30cm)

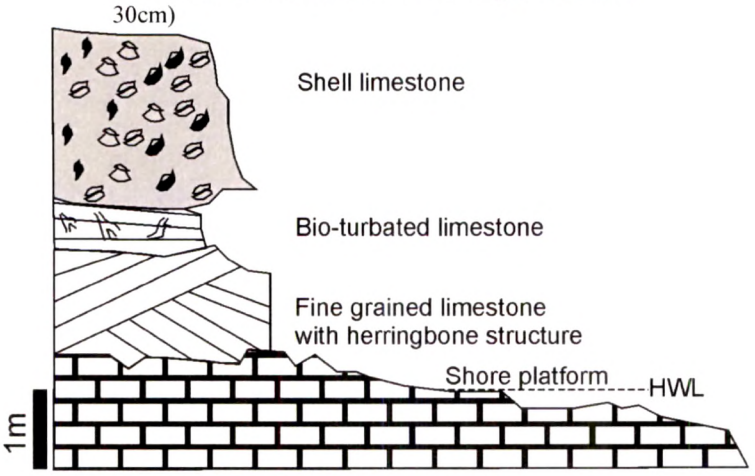

Figure 3.40 A litholog exhibiting various facies as seen at the Kadwar coast

shell limestone unit that can be seen at the lower heights resting on the ancient shore platform made up of miliolite limestone of unit two. The beach ridge four composed of stabilized, but still unlithified dune sand occurs resting on the abraded top of the unit-2 and unit-3 limestones. Slightly northward from this location (N 20° 49' 03.80" & E 70° 31' 04.13") about 200m away form the present day shore, in a sand quarry dug into the beach ridge four, a number of bone and shell fragments along with those of red-black pottery have been encountered. There also occurs a distinct ash layer having maximum about 1.0m thickness with varying geometry resting on an irregular palaeo-surface (Fig. 3 41). The examination of quarry face has shown a 3.65m thick sequence dominantly made up of very coarse carbonate sand with scattered mega shell fragments that is punctuated by two distinct sandy clay units and a thin gravelly unit. The upper clayey sand layer that is overlying the ash layer consists of numerous large shell fragments and conspicuous medium to very large sized bone fragments along with red and black pottery fragments (Fig.3.42). A piece of deer horn from this horizon has been dated by ^{14}C method with the help of the Radiocarbon laboratory of BSIP, Lucknow, and that has yielded 2350-2150 yrs BP calibrated age (Sample No. SPA-05, BS No. 2131) This sequence is capped by about 1.25m thick sheet of dune sand, the top of which is stabilized by the shrubby vegetation. Interesting ancient anthropogenic structures have been encountered in this sand quarry. These are perhaps wells dug into the lower sequence and are buried under the upper stabilized sand unit; they are crudely lined using the blocks of older limestones (Fig. 3.43). This site thus, demands an in-depth archaeological investigation bearing a potential to study human occupation of the coastal areas almost immediately after the Mid-Holocene regression.

Figure 3.41 A sand quarry face near Vadodra-Zala exposing ancient beach sand, gravel and ash layer overlain by the stabilized aeolian sand. (Height of person 165cm)

Figure3.42 A closer view of the clayey sand unit consisting of shells, bones and pottery fragments. (Length of pen 12cm)

Figure 3.43 An ancient anthropogenic structure in the sand quarry of Vadodra-Zala. The continuation of ash layer can also be seen. (Height of person 165cm)

The area between Sutrapada and Mul-Dwarka is similarly characterized by the presence of scattered coastal cliffs of low to moderate height and sandy beaches with 2-3m high backshore dunes. The pinkish coloured slightly recrystallized miliolite limestone that forms the cliffs are also exposed as sheet rocks forming shore platform. The area south of Prachi shows a characteristic physiographic drop towards the present day shore. A prominent tidal flat that does not have a significant freshwater inlet like the other creeks along this coast is noticeable. It appears that this part of the area must have experienced a conspicuous flooding by the Holocene high sea. After crossing the mouth of Singwado river, south of Kodinar, the coastline has gentle to high angle (3-10^{o}) beaches that are backed by aeolian sand covered ridge of porous, very coarse grained and darker coloured younger limestone with a distinct shell limestone base. At Madhwad the height of coastal cliffs rises to more than 20m having a raised shore platform at 17m height which is conspicuously bearing a biological erosional mark in the form of *lithophaga* borings that suggest a palaeo biological mean sea level (Fig. 3. 44 a, b). The coastline between Chhara and Madhwad exposes scattered occurrences of 4-5m high cliffs which are partially covered by the stabilized but, unconsolidated dunes. Raised mudflats behind these coastal aeolianites are also an added interesting geomorphic feature of this segment of the study area.

Figure 3.44a Raised shore platform at Madhvad light house. (Height of person 160cm)

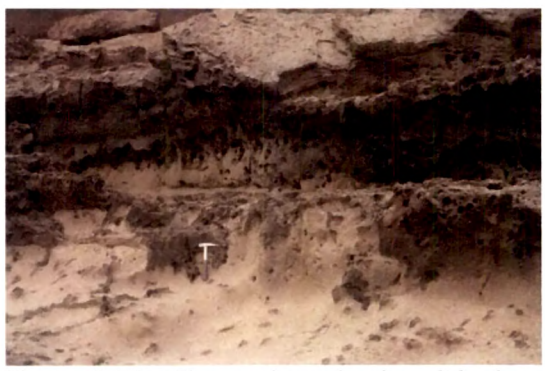

Figure 3.44b Closer view showing *lithophaga* borings at same location. (Scale 30cm)

About 6.5km long cusp shape sandy coastline runs between the Madhwad and Nagwa (Diu) that is interrupted by a tidal channel known as "Madhwad ni Khadi" through which tides enter into a prominent tidal flat region that separates the island of Diu from the Saurashtra mainland. A triangular coastal patch between Madhwad and Kotda is constituted by the stabilized sand dunes behind a gentle sandy beach. In the higher reaches of the mud flats scattered small mounds could be seen supporting the shrubby vegetation within otherwise barren saline tract. These mounds could be relict alluvial islands that are now surrounded by the present day intertidal zone.

Diu-Jafrabad stretch

The Diu Island is prominent geomorphic feature of this segment. It is the largest island among the other small rocky islands like Chhanch, Sial, Panikota, Bhensla etc. Figure 3.45 shows the geological and the geomorphic set up of the Diu Island. Between Banakwara and Nagwa, the coast has gentle sandy beach with a prominent berm ridge.

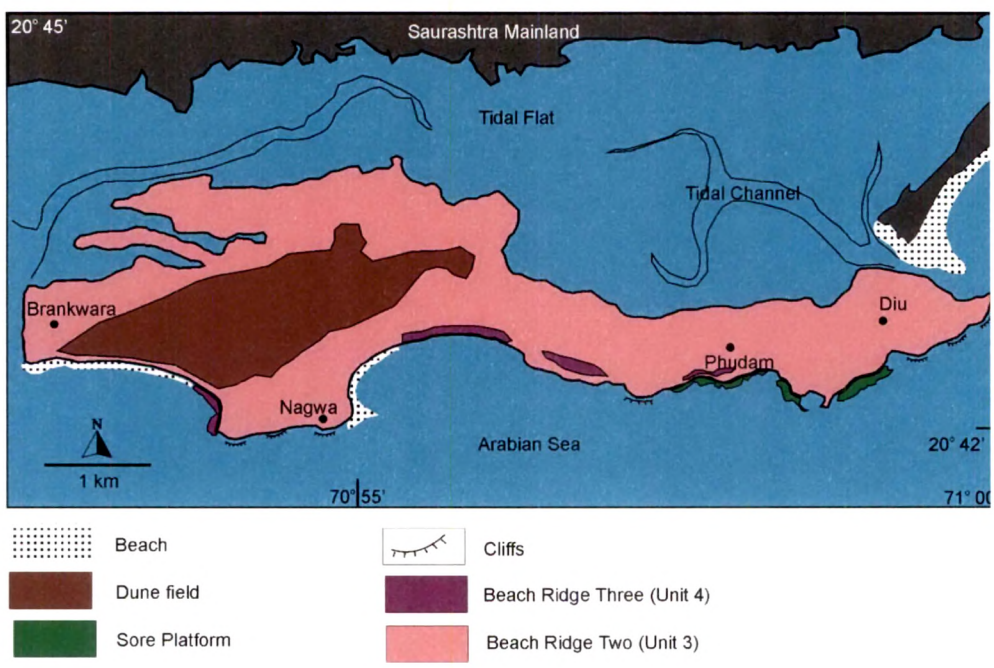

Figure 3.45 Geological and geomorphic set up of the Diu Island.

The backshore dunes are extensive here stretching along NE-SW direction up to the Bhucharwada at northern end of the island and are covering an area of about 3.25 sq km The highest dune peaks reaches to about 20m This is a prominent dune field that abuts against conspicuous mounds and ridges (beach ridge two) made up of miliolite limestone on its eastern side. A few patchy inliers of seaward dipping sheets of shell limestone (unit-4) have been encountered in the upper part of the shore platform carved out of the beach ridge two between Banakwara and Nagwa (Fig. 3 46). Although, the prominent morphology of wave built beach ridge three composed of shell limestones do not occur in this place, the wind built beach ridge three of a limited length has been encountered near Nagwa and Phudam

About a kilometer before Nagwa (N 20° 42' 11.66" & E 70° 53' 55 87"), a cliff of 4m height is made up of the yellowish coloured, slightly recrystallized, planar cross-bedded miliolite limestone that shows a number of biogenic tubes having about 40-50cm length and 2-3cm diameter, the upper part of it is more compact and homogenous. The upper unit is differentiable due to a sharp surface with thin duricrust developed on the lower unit, cross-stratifications with reverse dip azimuth and lighter colour with no recrystallization (Fig 3 47). A relict beach sand deposit with a number of complete and broken molluscan shells is noticeable on the sides of the cliff at the height of about 3m This unit is of dirty colour and porous in nature. The cliffs of miliolites occur from here for about 800m length up to the Nagwa beach A prominent cliff attains a height of about 14m which is made up of compact pink coloured recrystallized miliolite limestone This cliff has a raised shore platform that has a width of about 2.3m and an abrasion notch with a distinct line of *lithophaga* borings, undoubtedly linking it to a past higher sea level (Fig 3.48), of about 8m amsl. The rocks are traversed by several parallel joints

Figure 3.46 Inliers of Shell limestone in the backshore dune sand at Banakwara. (Height of person 170cm)

Figure 3.47 Landward dipping younger miliolite unit overlying the seaward dipping older unit near Nagwa. (Height of bag 20cm)

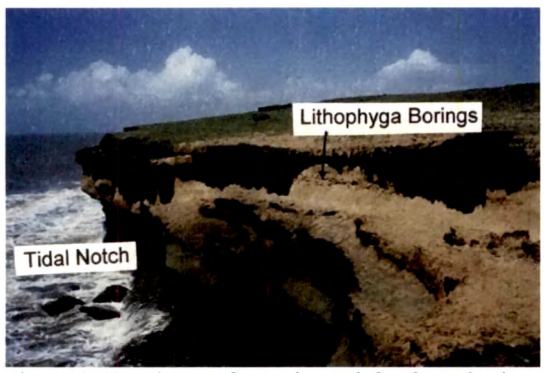

Figure 3.48 A layer of prominent *lithophaga* borings on the raised notch near Nagwa.

Figure 3.49 Sea wards dipping sheets of shell limestone at Nagwa.

showing their trends along 140°, 132°, 130°, 10° and 20°. At the base of the cliff a prominent tidal notch can be seen that extends towards the offshore forming a shore platform.

The Nagwa beach is the famous beach of the Diu Island. The beach is a gentle low angle (~3-4°) and is composed of mainly medium to coarse grained bioclastic sand. The intertidal area exposes the well stratified very coarse to gravelly shell limestone (litho unit-4). The sandy beach is backed by about 3m high beach ridge and backshore dunes. Towards eastern side, the Nagwa beach is backed by an ancient beach ridge consisting of porous seaward dipping shell limestone which is partially quarried (Fig. 3.49). This 3-4 m raised beach deposits are backed by dirty white coloured, porous,

cross-stratified aeolianites which are distinctly different from the pinkish coloured limestone that forms prominent cliffs at this place. These aeolianites represents litho unit-6 which is associated with the beach ridge three (litho unit-4). The junction between this younger miliolite unit and the older compact miliolites can be seen in a few cliff sections like Gangeshwar, Sun-set point, Phudam, Masania, etc. and also in few abandoned quarries At Gangeshwar temple, about a 15m high cliff has 3-4m thick upper unit of medium grained, thinly laminated and highly bioturbated limestone unit that rest above the older unit that is made up of compact recrystallized limestone. These two units are differentiated from each other by a meter thick red coloured palaeosol unit At the contact between two sequences, the lower unit shows a distinct erosional top that extends seaward forming a raised shore platform. The upper miliolite unit is relatively porous and exhibits convolute stratifications, similar deformed stratifications commonly occur in this unit at several other places too. At Sun-set Point of Diu Island, about 6m high cliff exposes the miliolites of the upper sequence that shows bioturbation and also convolute laminations. On the coast of Phudam, in the abandoned quarries of about 8m thick miliolites of upper sequence oppositely dipping herringbone cross-stratification can be easily seen (Fig. 3.50) that is truncated at the top by about 1.5m thick similar miliolite horizon characteristically showing wavy laminations and also convolute stratification. The episodic deposition of the carbonate sequences both, marine and associated aeolianites can be distinctly seen in addition to the quarry faces, at the base of

Figure 3 50 A quarry face in younger miliolite showing herringbone cross-stratification near Phudam (Height of person 165cm)

the Diu Fort in a trench that separates it from the Island. Interestingly, the miliolite limestone ridges or mounds could not be traced out immediately behind the tidal flats that separate the Diu Island from Saurashtra mainland. Instead, here the yellowish brown coloured, recrystallized limestones of the Dwarka Formation are exposed with a gentle abraded seaward dipping top. About 2km northward from the coastline, the mounds of white coloured miliolites occur resting over the eroded top of this Dwarka limestones. At Chikhli, located about 12km northward of the Diu island an oyster bed has been encountered in the Rupen stream at an elevation of about 2.5m amsl that can be linked to the mid-Holocene transgression (Fig. 3.51).

Figure 3.51 Oysters embedded in the algal mat in Rupen river bed near Chikhali. (Length of hammer 30cm)

On the eastern side of the Diu Island, the coastline between Ghoghla and Navabandar is characterized by low angle, sandy beaches and a huge field of backshore dunes which forms beach ridge four in the earlier coastal segment. Here it does not run parallel to coastline, but it form parabolic dunes oriented mainly in NE-SW direction. A major part of these dunes is stabilized and vegetated restricting the appreciation of its geometry. The dunes attain a height of 20-24m and cover an area of about 4 sq. km. At Navabandar, about 5km east of Diu, the compact pinkish coloured miliolite limestone re-appears forming 4-6m high coastal cliffs at the base of which a prominent shore platform extending for more than 10m can be seen.

About, 3-4m thick, porous dirty white coloured miliolite unit overlain the older compact miliolite unit with a karstified surface, where the cliff reaches to the height of

about 8m. This upper unit being porous and easily workable is quarried for the building stone and a few abandoned quarries have been encountered right on the cliff head.

Figure 3.52 A raised shore platform as seen at the Lheriya Mahadev near Khada Bandar.

Towards east of Navabandar, after crossing river Machundri again a NE-SW oriented dune field occurs associated with the raised mud flats known as Kala Rann. Here, at Khada Bandar the coastline is rocky and two prominent rocky islands viz. Panikota and Bhensla have been encountered. A cliff of about 7m at Laheriya Mahadev (Khada) shows a prominent shore platform at 3.6m height from the present day mean sea level (Fig. 3.52). Here, the cliffs expose three distinct cycles of miliolite formations which are separated by thin layers of yellowish coloured palaeosol of varying thickness, and each sequence exhibit different lithological characters as well as dip azimuth of cross-stratification. The lowermost miliolite unit shows dip azimuth in 130° while, that of overlying unit indicate 330°. The topmost unit has cross-stratifications with dip azimuths of 100°. This unit also exhibits conspicuous convolute stratifications and papery laminations (Fig. 3.53). At about 2km northward from Khada towards Simar a patch of oyster bed attached to a bit recrystallized compact miliolite rocks occurs at about 1m amsl. This oysters have yielded 3870-3590 yrs BP calibrated age range using ^{14}C dating

Figure 3.53 Convolute laminations in the younger sequence of miliolite limestone at Khada Bandar. (Length of pen 12cm)

Figure 3.54 A Coastal cliff at Dhara Bandar showing a prominent raised shore platform and notch.

method (sample no. KDA-04, BSIP record no. BS-2108). Between Simar and Jafrabad the coastline shows alternating occurrences of sandy beaches and coastal cliffs. After crossing the tidal flats associated with Rawal and Malan rivers at Dhara Bandar 8-12m coastal cliffs exhibits three sequences of planar and trough cross-bedded miliolite limestone and also a prominent raised tidal notch at about 3-4m amsl (Fig. 3.54).

At Balana, about 5km eastward from Dhara Bandar, a gentle sandy beach occurs near Sarkeshwar Mahadev temple. The beach sand does not have a significant thickness and the below lying rocky shore platform can be invariably seen in the intertidal area. The beach is backed by 3-4m high cliffs of younger and older miliolite limestone that are covered under stabilized and partially active dunes reaching to a height of about 12-15m. A raised tidal notch in relatively porous, cross-stratified miliolite limestone unit with a base of very coarse grained shell limestone, forming an abandoned cliff occurs here at 4m amsl (Fig. 3.55). In this notch fossilized remains of calcareous algae showing a typical leafy pattern have been seen; such occurrences are very rare (Fig. 3.56). In the nearby cliffs carved into the same miliolite sequence a network of dense *lithophaga* borings occurs at same elevation suggesting a distinct higher sea level (Fig. 3.57). This cliff extends eastward towards Jafrabad but, cut into the older miliolite sequences.

Figure 3.55 A raised tidal notch in the younger miliolite sequence at Sarkeshwar near Balana. In front of it the beach and dune sand can also be seen. (Height of person 165cm)

Figure 3.56 A closer view of the notch roof showing leafy pattern of biological encrustation. (Average diameter of hole 2cm)

Figure 3.57 An abandoned cliff showing a network of *lithophaga* borings. (Length of pen 12cm)

Interestingly, these cliffs showing raised tidal notches and biogenic markings are unapproachable by the waves of present sea. Towards western side of Sarkeshwar (N 20° 50' 07.41" & E 71° 17' 51.61) the cliffs become conspicuous reaching to the height of 15-18m on the Rohisa coast. These cliffs expose at places two distinct sequences of miliolites separated by a prominent erosional surface. Like at the other places, the older sequence is more compact and pinkish in colour while, the upper sequence is porous and dirty white in colour. The cliffs are associated with a conspicuous shore platform at their base. In general, the crests of aeolianites constituted by these miliolite limestones are oriented in NE-SW direction. Their ridge like occurrences becomes conspicuous between

Wadhera and Jafrabad where certain mounds reach to a height of 30-40m. The width of these miliolite occurrences is however, not beyond a kilometer where they abut against the mud flats. On the coast of Jafrabad impressive cliffs are carved out into these slightly recrystallized, cross- bedded older miliolite (litho unit-2). The cliffs reach up to 15-20m in height and exhibit a prominent raised tidal notch at 4m and also the present one at its base. The top of the cliff head is highly abraded and more or less horizontal to sub-horizontal. Pant & Juyal (1993b) have interpreted these and similar occurrences at Babarkot nearby Jafrabad as raised marine terraces. In comparison to the marine terrace at Jafrabad, that of Vadhera is inclined towards the sea at an angle of about 15°. On the Babarkot coast, in addition to the so described marine terraces raised shore platform and tidal notches at 3-4m height have been encountered (Fig. 3.58).

Figure 3.58 A raised marine terrace/tidal notch as seen on the Babarkot coast.

Similar occurrences extend eastward upto the Kovaya coast and also at the islands of Sial Bet and Chhanch. The coastline near the mouth of Dhantarvadi river is a bit sandy and is associated with a vast mud flat that cover an area of about 50 sq.km south of Victor. The famous Pipavav Port is situated here on the Motapat creek. On Sial Bet both the limestone sequences have been seen separated by a prominent undulatory surface of erosion with the development of a thin layer of protosol over the lower sequence. The attitudes of the bed are also distinctly different; the lower one being N 90° / 22° due N and the upper one N 60°/ 23° due SE. The upper unit shows planar cross-stratifications and also a considerable bioturbation, and contains mega shell rich pockets

at its base. Here also, a raised notch can be seen at about 3m height. On the sea ward side of Chhanch again prominent cliffs and a raised platform can be seen. The cliffs reach to a height of about 8m with two prominent shore platforms occurring at 2.5m and 4m height amsl. Relatively friable but, partially consolidated medium to coarse grained, bio-clastic sand accumulation has also been encountered here at an elevation of about 2m amsl that could be linked to a mid-Holocene high sea in this part of the region. Noticeably, here onwards the cliffs towards Mahuva exhibits a prominent red coloured palaeosol layer above the high water line separating two miliolite units that is sparsely seen along the coast between Diu and Chhanch. The satellite picture shows a conspicuous lineation that runs about 6-7km inlandward from the present day shore and takes east ward turn after Rajula to enter into the sea (Fig 3.38). Along this lineation shift into the river courses can also be seen, the conspicuous one being in the Dhantarvadi river. South of this lineament many rivers like Machundri, Rawal, Malan, Raidi etc. show a triangular feature with a typical red tone suggesting a significant and sudden river deposition that can support such a thick vegetation in otherwise barren tract; this has been inferred as alluvial fan deposits related with the uplift along the inferred lineament.

Some of the coastal river basins of southwestern Saurashtra were investigated in detail to understand their response to the Late Quaternary environmental changes that has in general shaped out the coastal geomorphic set up of the study area. The forthcoming chapter deals with the fluvial sequences exposed in these rivers.