Chapter - IV

G E O L O G I C A L S E T T I N G

GENERAL

The Quaternary carbonate deposits that comprise the ancient beach rocks, miliolite limestones and poorly consolidated stabilised sand dunes form the scattered exposures all along the length & breadth of the Saurashtra Peninsula. Their deposition is controlled to a great extent by the availability of organogenic carbonate sands along the beaches of ancient shoreline, fluctuating palaeoclimate, wind dynamics and pre-depositional topography.

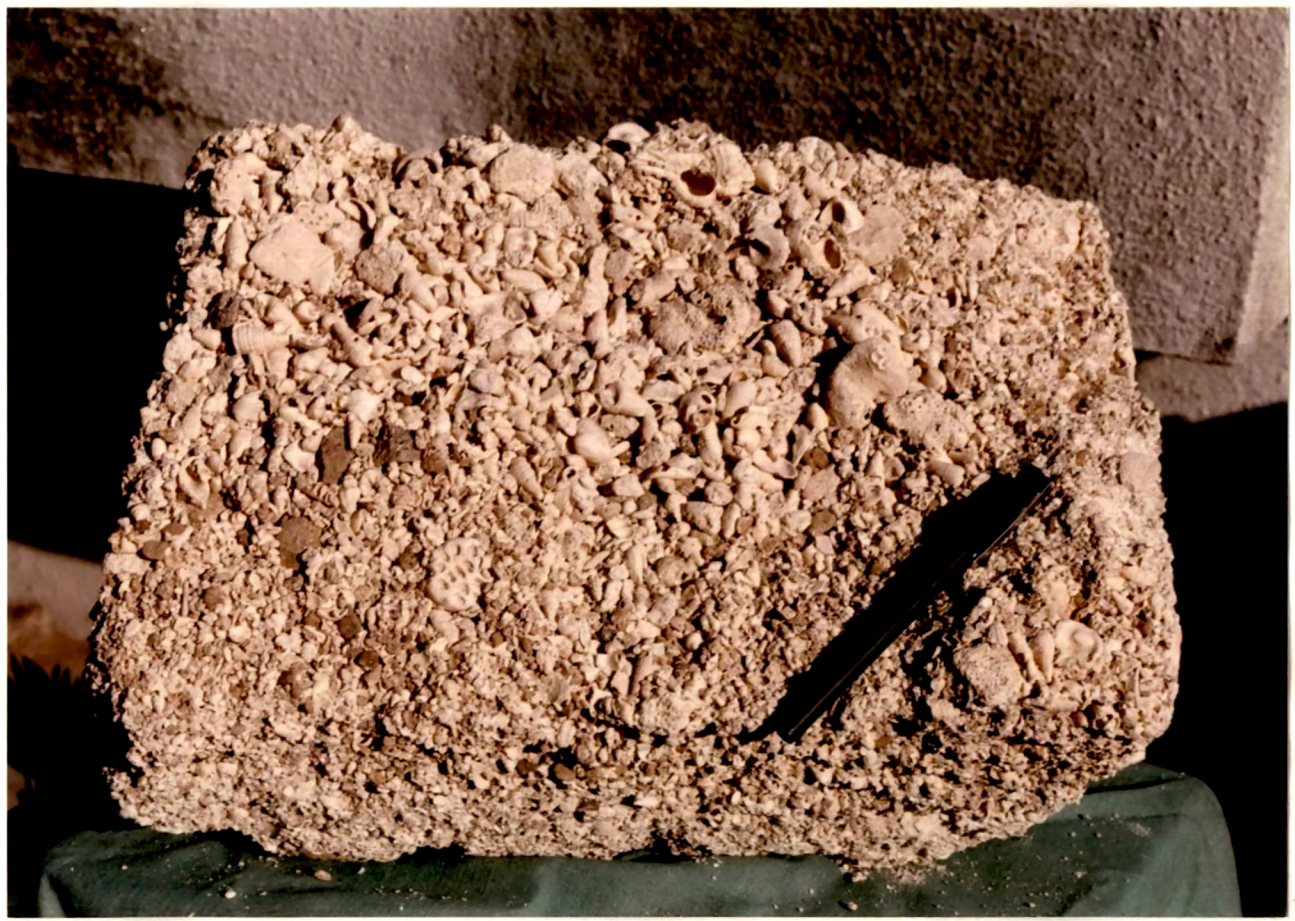
The ancient beach rocks constitute intertidal to supratidal deposits and are confined to a 350 km long and 0.5 to 3 km wide coastal strip that stretches from Dwarka in the NW upto Veraval

and beyond in SE. The miliolite limestones occur all along the South Saurashtra coast facing the present day high energy coastal segments from Okha-Dwarka in NW upto Veraval-Diu-Gopnath in SE. Tracing them in the landward areas, away from the coast, they gradually form the sporadic exposures of varying altitudes in the north as far as Jamnagar-Rajkot-Chotila and beyond. Alike beach rocks, the stabilised carbonate sand dunes are restricted only to the southern coast of Saurashtra resting either on beach rocks or on miliolites.

ANCIENT BEACH ROCKS

These white to dirty white coloured coarse grained bioclastic fragmental rocks, comprising complete and broken megashells of pelecypoda and gasteropoda alongwith the pebbles of corals and fragments of older rocks, underlie the coastal miliolite exposures all along the southwestern coast of Saurashtra. With the overlying miliolites, they show either sharp or gradational contact. The earlier workers were intrigued to delineate their stratigraphic position and have considered them younger than the miliolites. As a matter of fact the careful field observations clearly reveals them to be older than the miliolites (Patel, 1991 a). At most of the places the ancient beach rocks show facies variation in grainsize (Plate IV.1); vertical (bottom to top) as well as lateral (coast to landward). The intercalations of fine aeolian (miliolitic) material, especially in the upper portions of beach rocks suggest a typical beach-dune complex.

Plate IV.1



Closer view of a beach rock sample showing lateral variation in grain size (Loc. Baradia)

Varying in thickness, these rocks are confined to an almost continuous narrow coastal strip of 0.5 to maximum upto 3 km width and occur from littoral areas upto about 15 m AMSL. These rocks mostly form good exposures on the coastal tract near Dwarka, Baradia, Kuranga, Navadra, Harshad, Ratadi, Porbandar, Tukda, Gosa, Pata, Shil, Mangrol, Chorwad, Arena, Veraval, Kadwar etc. (Fig.IV.1). In the following paragraphs the author has attempted to present the salient features of the various exposures of these rocks.

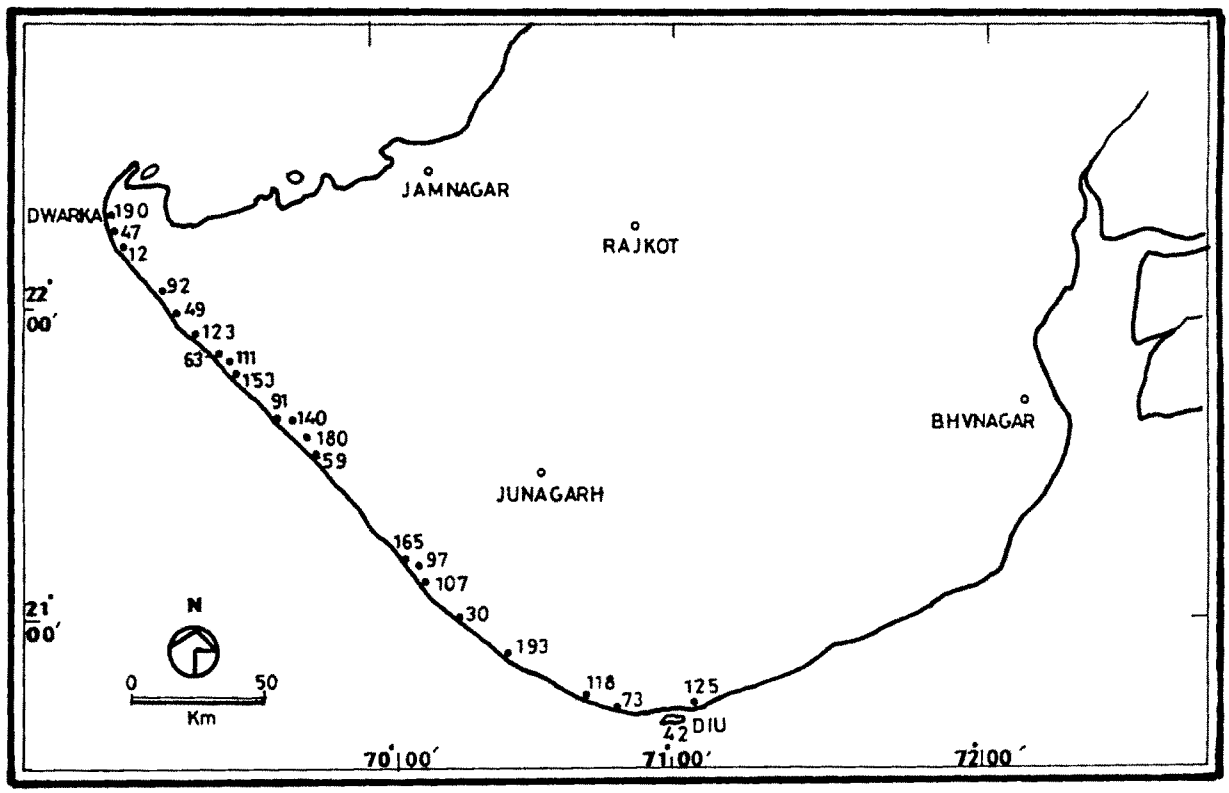


FIG IV.1 EXPOSURES OF ANCIENT BEACH ROCKS IN SAURASHTRA

(1) Dwarka - Baradia - Navadra exposures

This group of exposures occupies the narrow coastal tract from Varwala (N of Dwarka) upto Baradia and Gorinja villages (S of Dwarka) and cover an area of about 15-20 sq. km and supports good quarries for building stones. They exhibit low angled cross beddings and graded beddings in their thickest portions. These deposits vary in grain size from medium-coarse grained to very coarse-granule size and comprise the complete & broken shells of *Turritella, Cypraea, Conus, Tellina, Ostrea, Venus* etc. - all cemented by fine aragonite and calcite, thus forming typical beach deposits. They rest over the rocks of Dwarka and Gaj beds (Plate IV.2) and their base is marked by the imbricated & unsorted pebbles of older rocks, corals and larger gasteropod shells, making the contact conglomeratic. In general, the finer component is hard and compact forming a typical klinkstone while the coarser strata are very porous and friable. These deposits are capped by a meter or so thick aeolian sheet of reworked finer beach material with a weathered contact. Near high tide level (HTL) at sunset point of Dwarka, due to the surf & wave actions, these rocks show typical honey-comb & knife-edge weathering (Plate IV.3).

Near Navadra, about 65 km SE of Dwarka, a 2-3 km long transverse ridge of miliolite limestone grades downward into the coarse beach rocks which inturn is underlain by recrystallised brownish foraminiferal limestone. The beach rocks of this area are relatively recrystallised and poor in large megafossils than those of Dwarka area.

Plate IV.2

Beach rocks resting on yellow marls of Dwarka Beds near ACC cement factory at Dwarka

Plate IV.3

Knife-edge weathering in beach rocks near sun-set point at Dwarka

(2) Harshad - Ratadi - Kunchhdi exposures

At Harshad, at the base of 56 m high trappean hill, shelly beach concrete underlies the miliolites with sharp contact (Plate IV.4). Further south near Ratadi in a coastal quarry they are again encountered at 6 to 8 m depth grading upward into miliolite rocks. These rocks comprise mostly broken recrystallised molluscan shell fragments and rest over Gaj beds with half a meter thick sandy soil layer in between. The exposures of these rocks near Kunchhdi (5 km NW of Porbandar) comprise lots of oyster shells embedded with some molluscan shells forming 2-3 m thick subhorizontal sheets. The bioclasts of these exposures are very much recrystallised and hence difficult to identify.

(3) Porbandar - Gosa - Mangrol exposures

The beach rock exposures occurring around Porbandar form the base of the coast parallel 5 to 6 km long miliolite ridges. The country between Porbandar and Ratanpur near Bhadar creek is occupied by almost continuous coastal ridges of varying heights (5 to 25 m) which are extensively quarried for the building stones. Here the beach rocks grade upward into an aeolian top (miliolites) which is very much cavernous due to the typical honey-comb weathering by percolating meteoric waters. Near Tukda (15 km south) in about 20 m thick profile, beach rocks grade into the fine, shelly miliolite rocks upward, resting over the Tertiary rocks. They comprise some chalkified marine megafossils of genera *Cerithium, Arca, Ostraea, Tellina, Conus* etc. suggestive of shallow marine to lagoonal environment. Again around Gosa -

Plate IV.4

Beach rocks showing sharp contact with the overlying miliolites (Loc. Harshad)

Navagam quarry, the oyster beds are encountered at the depth of about 10 to 12 m where they are embedded in the fine miliolitic material(Plate IV.5). These exposures are extended southward upto Shil, Mangrol, Veraval and Kadwar. At Mangrol, the beach rocks are encountered at the base of miliolite quarries between Mangrol Port and Maktupur village. Here the bioclasts of these rocks are mostly in chalkified stage.

(4) Arena - Veraval - Kadwar exposures

About 5 km beyond Mangrol towards Chorwad, near Arena village, on a road side good surface exposures of 5 to 6 m thick, coarse & shelly, recrystallised and partly weathered beach rocks are encountered around 16 m AMSL. Above this altitude no exposure of beach rocks are traced suggesting the limit of ancient sea (Middle Pleistocene transgression) in Saurashtra. These beach rocks are overlain by the patchy exposures of longitudinal miliolite dunes; their contact with beach rocks being sharp (Plate IV.5A).

Right on the Veraval coast, these ancient beach rocks unconformably overlie the cross laminated, brown coloured, highly recrystallised, compact, foraminiferal limestones (? Dwarkas) with an erosional contact (Plate IV.6) that resemble to the miliolites in thin sections. As a matter of fact these recrystallised limestones are supposed to be older than Middle Pleistocene. This forms a southern most exposure identical to those of the Dwarka sunset point in north. The beach rocks of Veraval comprise some pebbles of corals (*Favia sp., Saptastrea sp.*) and megashells of mollusca (*Cypraea sp., Natica sp., Ostraea sp.* etc.) embedded

Plate IV.5

Closer view of a sample of oyster bed collected from Gosa-Navagam

Plate IV.5A

Sharp contact between beach rocks and miliolites at Arena

Plate IV.6

Beach rocks overlying the recrystallised foraminiferal limestone near Veraval light-house

together with coarse (1 to 5 mm) shell fragments, clayey matrix and micrite cements, typically suggesting their deposition in intertidal to supratidal areas.

On Kadwar coast, 3.5 km west of the Gujarat Heavy Chemicals Ltd. (GHCL), the beach rocks form a wave-cut platform and coastal ridges. The quarry sections of these shelly, crystallised, dirty white coloured rocks rest over the sandy palaeosol. The top of this deposit grades into finer aeolian deposit with numerous solution channels & vugs lined by red sediments. In the intertidal zone, the beach rocks show development of hard duricrust on account of their cellular weathering (Plate IV.7). Similar coarse grained bioclastic limestones are also encountered in milioite quarry sections at Malada and Masania in Diu island. The rocks identical to these are also met at different depths in some of the well sections in coastal tract between Diu and Gopnath.

MILIOLITE LIMESTONES

The miliolite limestones are widely spread over the Saurashtra Peninsula occupying the area between Okha-Dwarka-Harshad in west, Chotila-Sihor-Gopnath in east, Khambhaliya-Jamnagar-Chotila in north and Porbandar-Veraval-Diu-Gopnath in south. Their occurrences are sporadic & patchy - restricted only at the sheltered sites with varied modes of deposition; mostly as dune and sheet deposits, exhibiting typical aeolian sedimentary structures. The author has recorded about 150 miliolite exposures scattered all over the peninsula and collected the first-hand

Plate IV.7

Beach rocks showing cellular weathering at Kadwar coast

information regarding their field characters. In the forthcoming paragraphs, the broad description of major mililolite exposures and their association with the surrounding rocks, as visualised in the field, have been discussed. For the purpose of convenience the various miliolite exposures are grouped into nine (I to IX) sectors and have been described from SW to NE - the prominent palaeowind direction being responsible for their present disposition (Fig. IV.2).

I. Dwarka - Makanpur - Aniyali Exposures

The miliolite occurrences have been recorded for the first time from Dwarka Peninsula. About 0.75 km ESE of Dwarka, the area is occupied by ancient beach rocks with over running 0.5 to 1 m thick coarse grained, cross-bedded miliolite sheets. Again about 3.5 km north of Dwarka, near Varwala a longitudinal miliolite dune having 250m X 60m dimension has been encountered. This dune comprises shelly, recrystallised and porous miliolites overlying the ancient beach rocks and encircled by the tidal flats. Similar 4-5 m thick exposures are encountered near Makanpur, 8 km north of Dwarka, where a disused miliolite quarry is situated in a 300 to 400 m long transverse dune (Plate IV.8). These deposits are medium to coarse grained, shelly and friable in nature, and are separated from the present day beach & coastal dune by a shallow depression, occasionaly filled by high-tide waters. About 12 km east of Dwarka, near Aniyali yet another small exposure of buff coloured, medium grained, thinly laminated, oolitic miliolites is encountered in a depressed area.

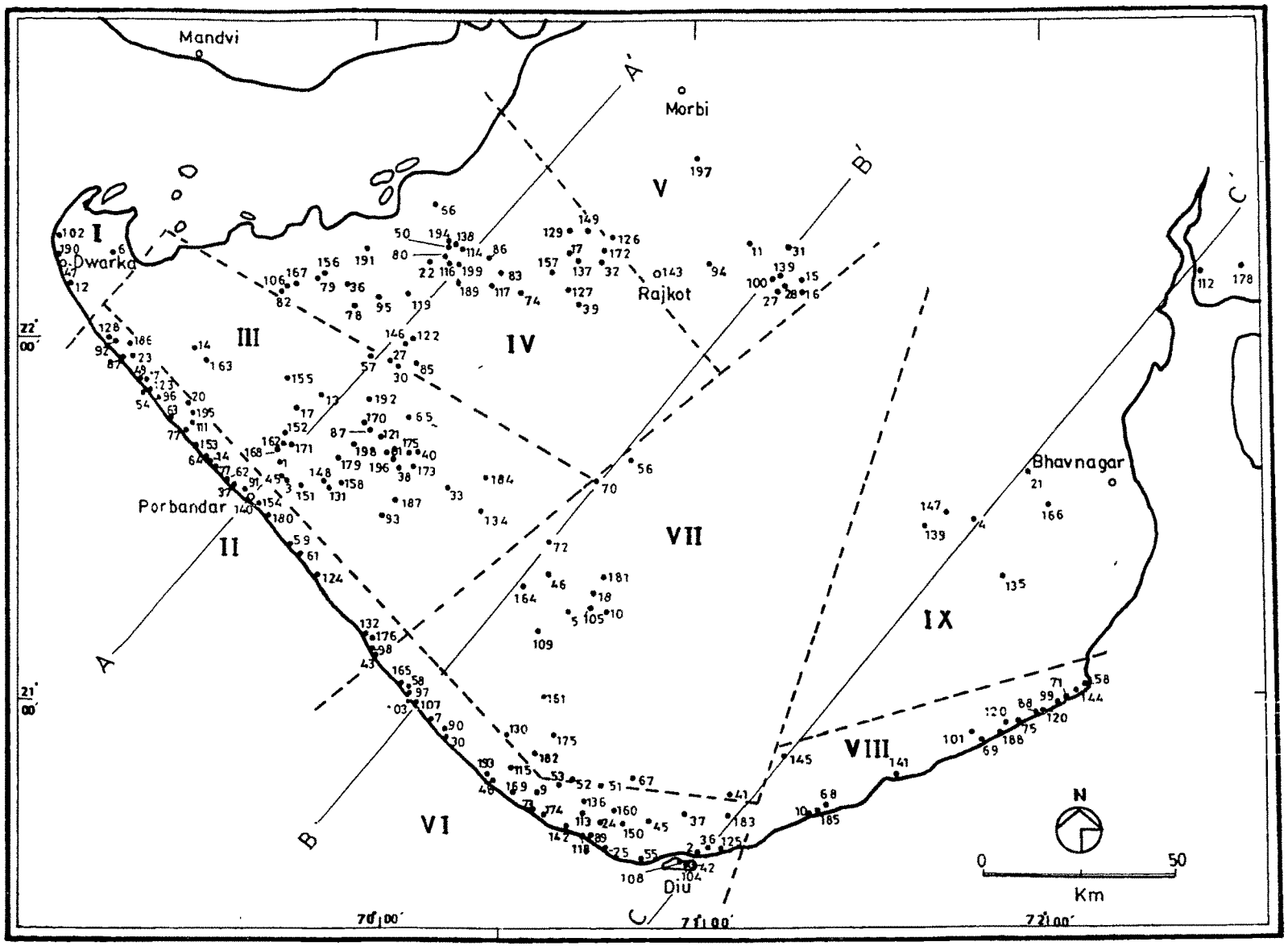


FIG. IV.2 DISTRIBUTION OF MILIOLITES IN SAURASHTRA

Plate IV.8

Abandond miliolite quarry near Makanpur

II. Okhamadhi - Harshad - Porbandar - Madhavpur Exposures

From Okhamadhi upto Madhavpur, there occurs almost continuous coast parallel transverse coarser miliolite ridges that rest directly either on beach rocks with sharp or gradational contacts or on the older rocks like Dwarkas, Gaj and Deccan Traps.

At southern fringe of Okha Rann, near Gopalji temple at Okhamadhi, 0.5 to 0.75 m thick sheet miliolites, that show gentle seaward dips, rest on the older brown coloured highly recrystallised foraminiferal limestones (Plate IV.9) identical to those of sunset point at Dwarka, which inturn are underlain by fossiliferous Gaj marls & limestones. About 3 to 4 km south near Kharakhetar lake, a patch of white coloured, very friable miliolite rocks (100 sq. m) occupy the depression in gasteropoda cast bearing yellow coloured Gaj limestone country.

About 15 km south of Okhamadhi near Gaji Nes, on the right bank of Ghughadwa creek, white coloured, compact miliolites, hardly exceeding 50 sq. m in extent, occupy the notches of 18 m high hill of Gaj limestones. Near Navadra, 8 to 10 km south of Bhogat, the miliolites form transverse dunes - 2 to 3 km in length, 0.5 km in width and 7 to 8 m in height. These are shelly in nature and finer than those of Makanpur, Varwala & Baradia exposures. They rest in typical reddish brown, recrystallised, foraminiferal limestones identical to that of Varvala, Chorwad, Okhamadhi and Dwarka area.

At Harshad the miliolite sand drifts have given rise to the typical climbing and falling dune deposits on southern and

Plate IV.9

Coastal miliolite sheets resting on Dwarka Beds near Okhamadhi

northern sides of a 56 m high coast parallel trappean hill. The seaward facing climbing dune possess maximum thickness of about 4 m and rest unconformably on ancient beach rocks and trappean rocks. The falling dune occurrences of Harshad are conspicuous. These are restricted to the depressions on the leeward side of the trappean ridge, forming 4 to 5 m thick triangular deposits with 20^{o} to 30^{o} dips following the shape of the depression (Plate IV.10). The miliolite exposures are also encountered in inlandward areas upto Vadi Dhar, Chachlana, Virpur, Chandarwada etc. where undulatory trappean terrain has provided number of sites for the deposition of wind borne milioitic sands. On the left bank of Meda creek, at and around Miyani, 1 to 2 m thick miliolite sheets, that rest on the ancient coastal plains, show 3^{o} to 5^{o} seaward dips. These sheets are hard and compact as compared to those occurring at the base of obstacle deposits or in intramontane depressions. Beyond Miyani towards Porbandar, transverse coastal miliolite dunes are encountered in the vicinity of Bhavpara, Ratadi, Kantela, Kunchhdi etc. At Ratadi, white coloured fine shelly miliolite deposits grade downward into a coarser fragmental beach deposits. They lack in distinct internal sedimentary structures and show precipitation of secondary calcites in their pores; due to their softness they are being extensively quarried (Plate IV.11). Similar deposits are extended upto Porbandar, Tukda, Gosa, Talasa and Madhavpur. Near Porbandar the top of these deposits is hard, recrystallised and cavernous on account of their direct exposure to the meteoric waters while, those lying below are soft and loosely consolidated providing good

Plate IV.10

Miliolites forming falling dune deposits at Harshad

Plate IV.11

Quarry section in a transverse coastal miliolite dune at Ratadi

subsurface miliolite quarries (Plate IV.12). Beach rocks are encountered at the base of these milioite quarries.

Beyond Porbandar further south, between Tukda, Gosa and Navagam villages thick miliolite deposits form transverse dunes conformably resting over the ancient beach rocks. Here the medium grained, dirty white and highly porous miliolites show maximum thickness of about 15 m. They show cross stratifications and normal grading near their base with 15^{o} to 20^{o} foreset dips due east and northeast. Near Talasa, 5 km south of Navibandar, coast parallel ridges of miliolites are encountered which possess approximate dimension of 3 to 4 km (l) X 300 m (w) X 6 to 8 m (h).

Near Madhavpur, the modified transverse dunes are thrown into wave like form with alternate convex and concave downwind sectors which show moderate to steep dips on curved bedding planes. In the Sabli river mouth at Madhavpur, the miliolite sheets of varying thickness are extended seaward with gentle 5^{o}-10^{o} dips. These sheets are intercalated with sandy clay layers suggesting their deposition in alternating conditions (Plate IV.13). The miliolites of this area, occurring either as sheet or transverse dune deposits, are little impure and fine grained as compared to those of Dwarka - Harshad - Porbandar coastal tract. At Diwasa, 2 km south of Madhavpur, 15 to 20 cm thick cavernous miliolite layers are encountered alternating with red kankary soil layers. In a nearby well, such sequence forms atleast a 5-6 m thick section comprising miliolite layers of varying thickness with a shelly coquinoid base. The satellite imageries of the

Plate IV.12

Abandond coastal miliolite quarry showing recrystallised and cavernous top (Loc. Porbandar)

Plate IV.13

Seaward extending miliolite sheets in Sabli river mouth near Madhavpur

coastal area between Porbandar and Veraval reveal the existence of atleast three coast parallel transverse ridges of miliolites. Their association with ancient beach rocks at their base represents typical ancient beach - dune complexes and provide a vital clue in interpreting the origin of miliolite rocks in Saurashtra Peninsula.

III. Barda - Alech - Gop hills Exposures

These group of exposures are restricted to southwestern and northeastern fringes of the trappean hills of Barda, Alech and Gop, forming either windward or leeward obstacle deposits which gradually merge into the sheet deposits. The huge deposits of Adityana and Ranawao, 18 km NE of Porbandar, represent typical obstacle deposits lying on southern and southwestern fringes of the Barda hills. These occupy approximately 25 to 30 sq.km area between Adityana - Ranawao and Porbandar forming gentle seaward dipping sheets, suggestive of their transportation from the ancient beaches of Porbandar area. The sporadic miliolite sheets of varying thickness (1 to 3 m) are also encountered in the small valleys and stream cuttings in this area which often show cross laminations. Around Dobaliya Talav and Amardad, number of chalk quarries are observed, one of which shows a profile consisting of 1 to 1.5 m thick impure miliolite sheet underlain by 4-5 m thick chalk bed resting on brown coloured recrystallised limestones. These chalks (micrites) seem to have been derived from the wash product of the carbonate sands from higher elevations and deposited in shallow depressed areas and also over the miliolite sheets of early cycle (Plate IV.14).

Plate IV.14

Chalk quarries of Amardad, west of Ranawao

Between Adityana and Ranawao, the miliolites form typical echo dune deposits. These deposits are about 1 km in width and 30 to 50 m in thickness. They show several sets of wedge type planar cross stratifications with 20^{o} to 25^{o} forsets dips due upwind and/or downwind directions forming typical herringbone cross stratifications. The climbing dune deposits of miliolites also occur resting on the southern slopes of 140 m high hill, about 8 km ENE of Ranawao. The country inbetween is dotted with few crescentic parabolic or longitudinal miliolite dunes of varying dimensions. Thin sub-horizontal miliolite sheets also occur in the intramontane depressions, river cuttings and at the base of obstacle deposits around Satvirda, Ramgarh, Pansara, Dhangva Nadi, Bileshwari Nadi etc. About 3 km NE of Ranpur, a shadow dune deposit of white coloured, fine grained, pure miliolite rocks is encountered at 110 m above MSL which show 6 to 8 m thickness and northwesterly dipping low to moderate angle planar cross stratifications. Similar shadow dunes are also seen near Sijar Nes, Kanmera Dungar, Supiya Nes etc.

On the southern and southwestern side of the Barda hills, the area between Ranawao, Kutiyana and Jam Jodhpur, facing the Alech hills in NE, is traversed by several streams feeding the Minsar river. This undulatory trappean terrain comprises moderate sized miliolite deposits forming climbing dune, falling dune, shadow dune as well as thin sheets around Naliyadhar, Khirsara, Sakhpur, Devda, Khagesri, Walotra etc. About 250 m high basic intrusive hill of Alech complex has provided obstructions to the

miliolitic sand drifts to give rise to the thick miliolite deposits on windward as well as on leeward sides. At Patan (about 20-25 km south of Jam Jodhpur), fine to medium grained, 4 to 5 m thick miliolites form a typical climbing dune on SW and falling dune on NE side of a 238 m high trappean hill (Plate IV.15). These deposits at their base merge into 2 to 0.5 m thick sheets covered by shrubby vegetation and a thin soil layer. At the western end of the Alech hill complex, in the vicinity of Dhank and Tapkeshwar, mostly leeward or falling dune deposits are encountered which comprise well sorted, thinly laminated miliolites ranging in grain size between 0.16 to 0.21 mm. They occupy the base of a 134 m high hill forming a falling dune. In these 10-15 m thick miliolite deposits, ancient caves with Jain architecture are also observed (Plate IV.16). Little interior to this, in a valley known as 'Khodiyar Dhar' near Tapkeshwar, miliolites show a thickness of about 20 m (Plate IV.17). At Tapkeshwar, on the northeastern slope of a 298 m high hill, these deposits typically form a 'perched dune' where the aeolian material has been accumulated in the depression several meter above the ground level without any lateral extension (Plate IV.18).

Further 20 to 25 km north of Barda and Alech hills, miliolites form climbing dunes in the depressions on an arcuate shaped southwestern slope of Gop hill (362 m) which gradually merges towards low ground to form 2 to 3 m thick sheets of miliolites. These deposits occurring between 120 & 200 m contour exhibit typical dunal cross stratifications with 10° to as much as

Plate IV.15

Tabular cross beddings in a falling dune miliolite deposit at Patan (Alech hills)

Plate IV.16

Ancient caves in the falling dune deposits near Dhank (Alech hills)

Plate IV.17

Valley fill deposit of miliolites near Tapakeshwar (Alech hills)

Plate IV.18

Miliolites forming a 'perched dune' on leeward side of trappean hill at Tapakeshwar (Alech hills)

30^{0} southwesterly dips. However, the major bedding planes follow the shape of depression (Plate IV.19). In the quarry face section the blankets of locally derived trappean fragments (scree material) embedded in miliolites have been also observed. On an average, at this locality the miliolites have occupied about 10-12 sq. km area. At Bhanvad and Retal-Kalawad impure gravelly miliolitic sheets (1-1.5 m thick) are encountered in the streams of Vartu and Sorti rivers representing washed out miliolitic material from higher altitudes and deposited by fluvial processes (Plate IV.20). Sporadic veneers of miliolites are also encountered in the plains between Barda and Gop hills.

IV. Khambhaliya - Rakka - Khatiya - Jamnagar Exposures

In the north Saurashtra region, impure miliolite sheet deposits are encountered in Ghi river near Khambhaliya, Sihan river near Mandha, Fuljar river near Modpur, Sasoi river near Pipalia & Vasai, Dhandar river near Lalpur, Nagmati & Rangmati rivers near Jamnagar, Dondi river near Paddhari, Aji & Lalpuri rivers near Rajkot etc. Around Khad Khambhaliya, Carana and Moti Bhalsan, miliolite sheets form cliffy banks in Nagmati and Nani Fuljar rivers. At Vijrakhi dam site, 20 km north of Kalavad, miliolite sheets of about 1 to 1.5 m thickness are seen resting on the southwestern slopes of the trappean hills of about 60 to 70 m heights. In the individual rivers, these deposits are traceable for considerable distances from their higher reaches upto the north Saurashtra coastal plains forming discontinuous valleyfill exposures, thus showing their occurrences at varying altitudes from 140 m to about 20 m or so. According to Patel (1991 b), their

Plate IV.19

Miliolite deposits showing a typical windward obstacle dune at Gop (Jam)

Plate IV.20

Impure gravelly miliolite sheets in Sorti river near Retal-Kalavad

occurrences at different altitudes are no way connected to the neotectonism as visualised by Ganpathi et al. (1985) but, are due to the pre-miliolite topography. Considering the Saurashtra Peninsula as a whole, these exposures form leeward deposits with gentle northward dips. However, in the low lying undulatory terrain like near Rakka, Khatiya and Vijrakhi, they occur on southern and/or northern slopes of the hills forming obstacle dunes. Lying away from the South Saurashtra coasts, these deposits are fine to very fine grained as compared to those of the coastal areas. Their sorting, both in size & shape of the sediments is very much controlled by the site of deposition. Their allochems are very much rolled and polished being unidentifiable; the detritals being higher in amount only form the constituents coarser than 0.25 mm.

About 14 to 16 km south of Jamnagar, near Piparda and Gala, miliolites occur at an elevation of about 100 m above MSL forming isolated sheets in the depressions and slowly climbing over the hill slopes. Near Nava Dhuniya, 20 km south of Jamnagar, on the SE slope of a 187 m high trappean hill, fine to very fine grained, compact and rather pure miliolites form a typical shadow dune deposit with 20^{o}–30^{o} southeastward dipping foresets of wedge type cross laminations. About 2 km further south at Rakka, miliolitic sands have crossed a 150 m high trappean ridge through the saddles and have given rise to the falling dune deposits of considerable thickness (Plate IV.21). In a quarry section, thin layers of slope-wash debris comprising angular trap fragments amidst the miliolite deposits are seen (Plate IV.22), and indicate a small

Plate IV.21

A miliolite quarry in a falling dune deposit showing tabular planar cross-beddings (Loc. Rakka)

Plate IV.22

Blankets of slope-wash debris (scree) in miliolites (Loc. Rakka)

scale break during the miliolite deposition. The author at this juncture wishes to point out that such layers, so often encountered in the obstacle miliolite deposits, may yield some important Stone Age tools if thoroughly investigated. A kilometer eastward, near Khatiya village, miliolites have occupied about 20 m deep valley between two N-S trending 200 m high trappean ridges. Here the white coloured, fine grained, thinly laminated huge miliolite deposits have provided numerous stone quarries (Plate IV.23). Besides the low to moderate angled planar cross stratifications and alternate fine & coarse sand laminations in a quarry section, these deposits show asymmetrical aeolian ripple marks and curled clay layers amidst the miliolites (Plate IV.24), again suggesting their deposition in instalments under terrestrial conditions (Reineck & Singh, 1980). Isolated miliolite exposures in the intramontane areas are also encountered south of Khatiya around Chorbedi, Chhatar, Muchharda, Kalavad etc. villages.

V. Rajkot - Bamanbor - Chotila - Wankaner Exposures

The farthest occurrences of miliolites facing the sectors II, III and IV are encountered around Rajkot and Chotila. About 1 to 2 m thick, valley fill sheets of impure miliolites occur in Lalpuri and Aji rivers near Rajkot; their lateral extent being very restricted. Just out of the Rajkot city, near Navagam octroi, 1 to 1.5 m thick, yellow coloured, very hard & compact miliolite sheets occur on the cliffy banks of Lalpuri river. These miliolites rest on about 2 m thick gravelly alluviam deposited above the Deccan Trap, and are covered by fine sandy fluvial silt. About 15 km east of Rajkot, near Kuwadava village,

Plate IV.23

Huge miliolite deposition in an intramontane valley at Khatiya

Plate IV.24

Curled clay layers in a quarry face of miliolites at Khatiya

about 1 to 2 m thick compact, sub-horizontal miliolite sheets are encountered on either banks of river Machchhu (Plate IV.25).

Again between Kuwadava and Bamanbor, in a low lying trappean terrain, patchy exposures of thin miliolite veneers are encountered occupying the intramontane depressions. In the tributaries & streamlets of Machchhu and Beti rivers, these miliolites form sheet deposits merging gradually with climbing and falling dune deposits on the hill slopes (Plate IV.26). This is ideally seen at Bamanbor (200 m AMSL), 18 km from Chotila towards Rajkot, Where they rest on low trappean ridges with gentle downward dips merging into the valleys which meet from each side to give rise to a palm like disposition (Plate IV.27). Fine to very fine grained miliolites of Bamanbor show planar tabular cross stratifications and comprise more than one layers of slope-wash debris revealing their deposition not in one stage but in instalments (Plate IV.28). The presence of numerous hollow tube like biogenic structures, occasionally infilled with the similar miliolitic material forming rods, is very significant. These tubes/rods vary in length (0.5 to 2 m) and diameter (15 to 50 mm); some of them are expanding downward possibly on account of the burrowing activity of terrestrial animals prior to their consolidation. Some of them are tapering downward and show radial branching into smaller diameter (Plate IV.29) perhaps representing the root-casts that are substantiated by the presence of altered stem-casts in these deposits. The hollow tubes show composite lining of thin algal material, while the infilled tubes consist of

Plate IV.25

A thin valley fill sheet deposit of miliolite in Machchhu river near Kuwadava

Plate IV.26

Falling dune merging into sheet deposit of miliolite at Bamanbor

Plate IV.27

Valley fill deposits of miliolite at Bamanbor

Plate IV.28

Slope-wash debris in miliolites at Bamanbor

Plate IV.29

Branching stem-cast and a rod like biogenic structure, separated from miliolite deposits of Bamanbor

small angular trap fragments lifted by burrowing animals, thus again indicating their formation in terrestrial environment. These deposits are completely devoid of any marine macroshell. About a kilometer towards Chotila in a stream cutting half a meter thick impure miliolite sheet rests disconformably over a pebbly/gravelly horizon which contains few fossil wood fragments suggesting their deposition by fluvio-aeolian processes (Plate IV.30).

On the southwestern fringe of 380 m high trappean hill of Chotila, in a small gully, the miliolites occur at ~220 m above MSL forming a small climbing dune (Plate IV.31). These miliolites are very much impure and comprise considerable amount of angular to subangular locally derived trap fragments of varying size. These 4 to 5 m thick miliolite deposits which are very porous & friable in nature show wedge type planar cross stratifications with 20^{o} to 25^{o} foreset dips due upwind direction and are very porous & friable in nature. The miliolitic material, after crossing the saddle, has been deposited on its northeastern side to form thin (1 to 1.5 m) slip face deposits which are also spreaded on the northern gentler slope of the hill at considerable height (~300 m) to form thin veneers. This has misled some of the previous workers to postulate the sea level upto this height. The detritals of these miliolites range in size from 0.5 mm to 30 cm and even more but, their allochems are of very fine sand size (< 0.25mm) and are almost unidentifiable due to their rolling.

Plate IV.30

Impure gravelly miliolite sheet in a streamlet of Beti river near Bamanbor and a fossil-wood fragment (WF) collected from gravels

Plate IV.31

A climbing dune of miliolites at Chotila hill

About 17 km south of Chotila, miliolites are also encountered as falling dune and shadow dune deposits around Chobari, Mahidad and Sanosara villages. About 3 km NNW of Chobari, in a 10 to 15 m thick quarry section, dirty white coloured miliolites show planer, tabular cross stratifications with about 20° dips due ENE. Their thickness decreases towards the base of the trappean hill. These miliolites also comprise frequent layers of slope-wash debris and very thin and compact layers of algal material which on their upper surfaces show typical globular structure. A network of root-casts is also observed in these deposits (Plate IV.32). Such floral biogenic structures are indicative of the aeolian deposition of miliolites. Similar biogenic structures are also reported associated with other aeolian deposits and termed as 'dikaka' (Glennie & Evamy, 1968). The aeolian accumulations of carbonate sands are spread to the NE of Rajkot and N of Bamanbor upto Wankaner. Between Bamanbor and Wankaner, these deposits form small patchy outcrops in the low lying undulatory terrain to form intramontane deposits. About 2 km before Wankaner, miliolites occur as thin veneers in small streams. It is also observed that, these far inland miliolites are rather more impure and comprise finer & rolled allochems as compared to those of the coastal areas.

VI. Mangrol - Veraval - Kodinar - Diu - Una exposures

The coastal strip between Mangrol and Una comprises variety of miliolite dunes representing an ancient desertic landscape. About 2 km south of Madhavpur a crescent shaped transverse dune with alternate concave & convex downwind faces comprises almost

Plate IV.32

Miliolite showing (a) thin algal coatings and (b) a network of root-casts (samples from Chobari)

with alternate concave & convex downwind faces comprises almost pure white and fine grained miliolites encrusted with dark coloured algae layers.

Around Lohej, Shil and Mangrol, miliolites form dissected transverse coastal dunes and 0.3 to 1 m thick compact sheets, resting on the ancient shelly beach rocks with sharp contact (Plate IV.33). The miliolites at Mangrol coast form atleast two to three transverse ridges containing rather coarse, friable and shelly constituents. Towards sea, these rocks are partly covered by about 3-4 m thick unconsolidated but stabilised carbonate sand dunes. In the littoral zone, the submerged miliolites form rocky platform which show cellular weathering.

Near Arena (5km north of Chorwad) on a road side, longitudinal miliolite dune that rest directly on the very coarse shelly beach rocks with sharp contact, show leeward dips with variable inclination due either sides of the dune alignment. Near Chorwad, the coastal miliolite dunes rest on similar beach rocks with gradational or sharp contact. Compact sheets of miliolites in interdunal depressions are also encountered in this area. Miliolite exposures are also met near Gadu and Veraval. Near Indian Rayon factory at Veraval, in a 5-6 m thick cliffy section, miliolites exhibit intercalations of red kankary soil horizons forming the base of section as well as separating two sub-horizontally bedded miliolite sheets which are again overlain by cross bedded miliolites with a thin karstified contact (Plate IV.34). At Somnath, medium grained and very much friable miliolites form coast parallel transverse dunes. In the Hiran-

Plate IV.33

Thin miliolite sheet resting on beach rocks with sharp contact (Loc. Shil)

Plate IV.34

Miliolites with intercalations of kankary, red coloured pedogenised layers near Indian Rayon Factory at Veraval

Saraswati confluence near Triveni, the miliolites form pinnacles with attached recent oysters.

The terrain lying between Talala, Diu, Una and Somnath is dotted with several low lying mounds of miliolites having geometry of parabolic, barchan, longitudinal and transverse dunes. These represent typically the desertic condition during their deposition. About 1.5 km off the Veraval-Prachi highway towards Kadwar, a longitudinal miliolite dune shows about 100 m length, 25 m width and 4-5 m height. Thinly laminated parabolic and barchan dunes of miliolites occur around Prachi, Ghantiya, Gangetha, Vadnagar, Kodinar etc. that show abrupt change in their dip directions. At Dolasa, 9 km east of Kodinar, a 300-400 m long and 70-80 m wide longitudinal dune rest on palaeosol and holds good (6-8 m deep) miliolite quarries. In a disused quarry, these miliolites show planar beddings dipping in either side of the dune alignment. Moreover, near Sarakhadi (6 km SE of Kodinar) buff coloured and little coarser miliolites form transverse coastal dunes as well as shore platform. Around Una, Desar, Delvada etc huge miliolite dunes are deeply quarried for building stones. These miliolites are white coloured, friable & thinly laminated with alternate coarser & finer sand laminae formed due to the minor variations in the wind velocities (Mckee, 1965). About 10 km south of Una, the Diu island forms a submerged miliolite dune complex. The cliffy coast of Diu exhibits typical dunal cross stratifications mostly with 20^{o}-30^{o} foreset dips due north and northeast. These miliolites are rather dirty white in colour, very porous and friable in nature and possess higher amount of

detritals (24%). Towards the central part of the island near Malada, in a 15-20 m deep quarry section, the base of the miliolites is comprised of megashell bearing porous beach rocks. This is overlain by medium grained, buff coloured, cross bedded miliolites which inturn are capped by red sandy soil. In this section, the presence of karstified surface indicates their deposition in instalments with small scale breaks accompanied by sub-humid climate (Plate IV.35). Diu and the surrounding areas of Ahmadpur Mandvi, Delvada, Nawa Bandar etc are characterised by the series of transverse miliolite dunes. Around Ahmadpur Mandvi and Delvada such miliolite dunes are covered by the sands of Recent and Sub-Recent carbonate dunes. On Delvada - Nawa Bandar coast, the miliolites form quite high coastal cliffs associated with wave-cut platforms. Here on account of the porous and soft nature of the rock, the cliffs are constantly being degraded by sea waves (Plate IV.36). In a 15 m deep coastal miliolite quarry at Nawa Bandar, shelly recrystallised beach rocks underlie the porous miliolites with a gradational contact; the top of these miliolites has been durycrusted due to the action of meteoric waters. Such coastal cliffs are traceable for quite a long distance upto Jafrabad and beyond.

VII. Umrethi - Badalpur - Anandpur - Junagarh - Osam exposures

This group of exposures facing NE of sector VI include the valley fill sheet deposits and obstacle dunes in the landward areas. In some of the older rivers like Hiran, Saraswati, Somat, Singwada, Machchhundri etc. and in their tributaries the valley fill sheet miliolites are encountered. They show variable

Plate IV.35

Karstified surface separating two miliolite sequences (Loc. Malad quarry, Diu)

Plate IV.36

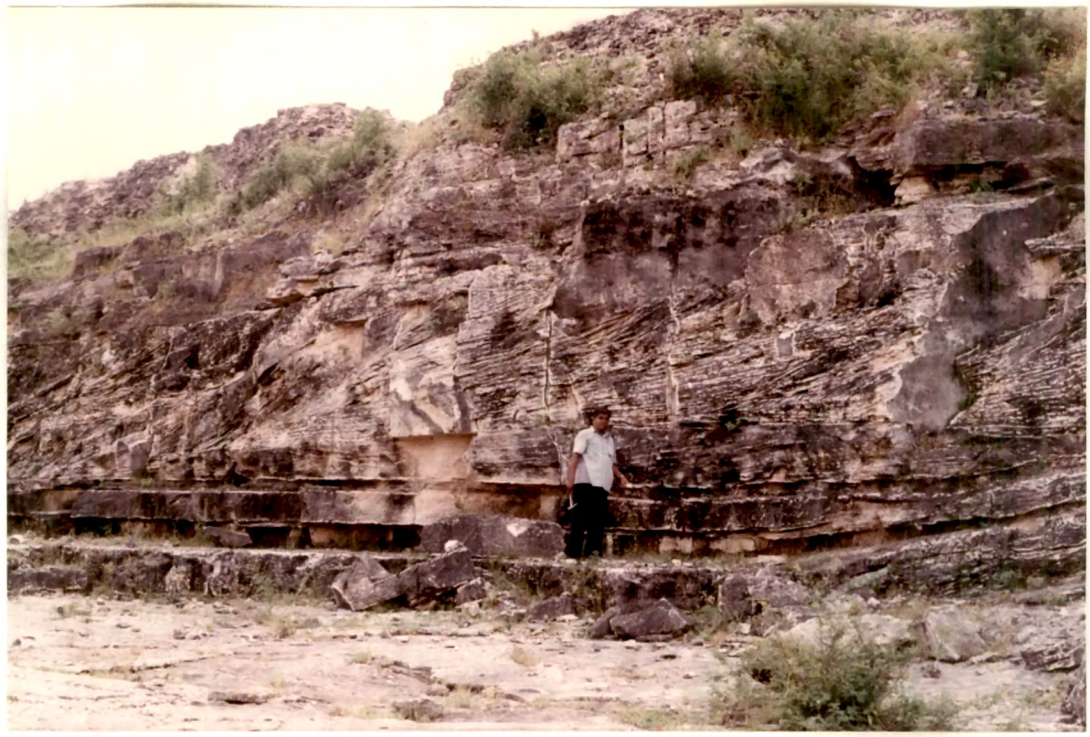
Degradation of coastal miliolite cliff (Loc. Nawa Bandar)

thickness from few cms to as thick as 6-8 m. They, in general, show gentle seaward planar beddings but on closer look, cross stratifications are cearly seen. The author has yet to see the so described oyster beds (Chayas) resting over miliolites. However, the presence of intercalations of bouldary/pebbly/sandy layers within the miliolite formation clearly suggests their deposition in instalments with small intervening phases of sub-humid nature.

About 20 km inland from the coast, near Umrethi dam on the left bank of Hiran river, the miliolites show a typical 'wadi' style of deposition in the form of alternate thick aeolian sedimentation and thin sub-horizontal or lenticular fluvial deposition (Plate IV.37). Here 2 to 3 m thick cross laminated miliolites are bounded by half a meter thick horizontally bedded fine grained chalky miliolites with interbedded loose sandy/clayey layers. These miliolites rest on a meter thick horizon containing pebbles and gravels of trappean rocks cemented by miliolitic material revealing a typical flood deposits. The lateral extension of miliolites beyond the river valley does not exceed 100 m. About 5 km upstream of Umrethi, near Talala about 2-3 m thick planar cross bedded miliolites occupy both the banks as well as floor of the Hiran river (Plate IV.38). In a nearby well section, these miliolites rest on weathered Deccan Trap basalts with half a meter thick kankary soil layer. The miliolites are slightly pedogenised and also comprise thin layers of fluvial sandy silts in their upper portion.

In Saraswati river, 0.5 to 0.8 m thick miliolite sheets are traceable for about 8-10 km inlandward from its mouth. Near

Plate IV.37



Miliolites showing alternate cross-stratifed and sub-horizontal sequences in Hiran river near Umrethi dam site

Plate IV.38

Miliolite deposits occupying the Hiran river valley (Loc. Talala)

Badalpur (6.5 km inland from the coast), about 2 m thick sandy gravelly bed rest on very compact miliolite sheet. This gravel bed is again overlain by a meter thick friable miliolite sheet that contains pebbles of trap, chalcedony and other rocks, suggesting their deposition by fluvio-aeolian processes. Nowhere in this area the oyster bed is seen resting on the miliolites.

In Somat river, near Pedhwada (7 km SE of Prachi) miliolites occur as valley fill deposits occupying both the banks as well as floor of the valley with maximum thickness of about 6 m (Plate IV.39). Here, the miliolites rest sharply over the Gaj limestones and show $2^{o} - 5^{o}$ southward dips. Beyond a kilometer in the upstream direction, these deposits are not encountered. In Singwada river the sheet miliolites of varying thickness (0.25 to 5 m) are traced from Mul Dwarka village on its mouth upto 80 m contour near Jamvala village that also show distinct grainsize variation from fairly coarse (> 0.5mm) to fine & very fine grained (< 0.25mm) while tracing upstreamward. Near Jamvala, 4 to 5 m thick miliolites rest on the trappean rocks with an intervening gravelly fluvial deposits of almost same thickness. These miliolites contain lenses of chalky, compact miliolites and possess planar cross beddings.

Thin (0.2 to 0.5 m) sporadic sheets of miliolites are also encountered resting on the heterogenous fluvial gravels in Rupen and Machchhundri rivers near Kodinar, Chhachar etc. These miliolites are compact and gently seaward dipping, often exhibiting cross laminations. It is surprising that these valley

Plate IV.39

Valley fill miliolite deposits in Somat river near Pedhwada

fill deposits in various rivers, in their upstream courses thereafter abut against the hilly terrain to give rise to the huge obstacle deposits of Junagarh, Dungarpur, Jamvala etc.

The highest geomorphic expressions of Saurashtra Peninsula i.e. Girnar and its adjoining Trappean hills have provided numerous sheltered sites for the preservation of these bioclastic desert sands between Junagarh, Visavadar and Jamvala. In Sasan Gir area, sporadic veneers of miliolites occupy the depressions on western & southwestern fringes of the hills. These are hard, compact and highly recrystallised as inferred by a typical 'klink' sound while breaking.

About 14 km south of Junagarh, miliolites form thin sub-horizontal sheets on 8 to 10 m high cliffy banks of Ozat river near Anandpur. Here about 5 m thick sandy silt horizon overlie the basalts, which inturn is overlain by 2 m thick sub-horizontal miliolite sheet. This is further capped by about 2 m thick sandy alluvium. A meter thick, rather friable & impure miliolite sheet occurs at the top of this sequence. These alternate miliolite sheets and intervening sandy/silty horizons (Plate IV.40) point out their fluvio-aeolian deposition in alternating dry and wet conditions. Similar section is also observed in the same river near Shapur in downstream.

The enormous amount of coastal organogenic sands brought by southwesterly onshore winds form windward obstacle deposits at Junagarh and Dungarpur-Bilkha area. Between Junagarh and Bilkha, miliolites form huge echo dune deposits which support numerous

Plate IV.40

Miliolite sheets in Ozat river showing intercalation of fluvial sediments (Loc. Anandpur)

stone quarries. Their linear extension is about 15 km while the width does not exceed a kilometer at its maximum. Alike Adityana-Ranawao exposures, here also they exhibit herringbone type of cross stratification due to the wind echo created by huge trppean obstacle (Plate IV.41). On southern side of Dungarpur - Junagarh road, the terrain shows gently southwesterly dipping sheets of miliolites. It is these deposits that after striking to the steeper gradient of Girnar hill gave rise to the echo dune deposits of Dungarpur area.

On a gently sloping gradient of western side of Girnar hill at Junagarh, a very thick (~40 m) aeolian accumulations of carbonate sands have given rise to the windward obstacle dune of 'Uperkot' meaning higher fort. The famous historical 'Adi Chadi Vav' and 'Navghan Kuo' in uperkot have been constructed within these deposits, which are more than 35 m deep. This dune rests on about 2 m thick gravelly horizon. Almost in the middle part of the miliolite deposit of Adi Chadi Vav section, a truncated surface of non-deposition and erosion separating two distinct miliolite cycles marked by honey-comb weathering is encountered (Plate IV.42).

The Junagarh and Gir-range miliolite deposits merge into valley fill sheet deposits of Uben, Sonarakhi, Ozat, Utavali etc rivers. The sporadic veneers of miliolites are also met around Mandanpur, Virpur, Umrala, Avtadia etc. villages on southern side of Girnar hills.

Plate IV.41

Miliolite quarries in echo dune deposits near Dungarpur

Plate IV.42

Truncated surface separating the miliolites of two different cycles (Loc. Adi Chadi Vav, Junagarh)

On the western, southwestern and southern sides of 314 m high Osam hill, 25 km NE of Junagarh, the miliolites occur as typical climbing and falling dune deposits (Plate IV.43). About 7 km south of Upleta, at Patanvav (120 m AMSL) buff coloured and thinly laminated miliolite shows maximum thickness of about 6 m at the base of a 150 m high granophyre hill on its northern side. Further 1 km west of this, the miliolites form a typical 7-8 m thick climbing dune deposits that cover 2-3 sq.km area supporting a good number of stone quarries. Near Chichod, on the eastern extension of the Osam hill, small exposures of climbing dunes are encountered on a 176 m high trappean hill. Thin miliolite valley fill sheets in Bhadar and Uben rivers are extended upto Jetpur and Gondal in north & east, and upto Jam Jodhpur and beyond in west. At Jetpur, 1 to 1.5 m thick sub-horizontal compact miliolite sheets are encountered on the bank of Bhadar river, disconformably resting over a 2-3 m thick cross bedded sandy gravel bed. Sporadic and very thin patches of impure miliolites occupy the shallow depressions in undulatory trappean terrain between Jetpur and Gondal.

VIII. Jafrabad - Mahuva - Gopnath exposures

The eastward extension of coastal miliolites on South Saurashtra coast is upto Gopnath only. This segment includes the exposures of Balana, Jafrabad, Mahuva, Kotada, Jhanjhmer, Rajpura and Gopnath. In this terrain, they mostly form the coastal dunes which in their present form, on account of the various marine erosional processes, occur as wave-cut platforms and coastal cliffs; their landward extension being not more than 2 km.

Plate IV.43

Obstacle miliolite deposits abuting against trappean rocks of Osam hill (Loc. Patanvav)

Near Jafrabad light house two distinct wave-cut platforms are clearly visible, one belonging to the present shore line and the other, lying at about 6 to 8 m height, to an ancient strandline (Plate IV.44). These buff coloured, medium to slightly coarse grained, hard & compact miliolites show tabular cross stratifications and are traceable upto Nawa Bandar in west and Port Victor in east. On the coast between Balana and Vadhera, about 5 km west of Jafrabad, these rocks form upto 13 m high cliffs associated with the rocky shore platform. Here the remnant of the submerged miliolite dunes form number of small islands, half a kilometer away from the present shore. Yet another interesting cliffy section of miliolite is encountered at Jegri island near Mahuva. Here, the miliolites of the upper part of about 12 m high coastal cliff are hard and compact on account of their reach to the meteoric waters. The middle part of this dune complex is thinly laminated, loose and friable as it has remained away from the percolated meteoric waters. This part of the dune shows convolute or contorted laminations formed due to synsedimentary deformation of the laminae (Plate IV.45). Similar deformational sedimentary structures are also common in modern sand deserts (Mckee, 1980). The presence of several vertical as well as inclined hollow tube like structures which show more than 1 m length and 4 to 5 cm of almost uniform diameter in this part of dune complex is very characteristic. These tubes perhaps represent the hollow made by the burrowing animals or insects. This 5-6 m thick miliolite sequence is overlain by another 4-5 m

Plate IV.44

Wave-cut platforms related to present and an early strandlines
(Loc. Jafrabad)

Plate IV.45

Contorted laminations in miliolites of Jegri Island near Mahuva

thick compact, wedge type planar cross bedded miliolite sequence devoid of any burrow tube (Plate IV.46). This abrupt change in sedimentary and biogenic structures could be due to the break in the deposition of carbonate sands. This coast also shows two distinct wave-cut platforms (similar to that of Jafrabad), one at present sea level and another at 4 m height. On the right bank of Malan estuary near Mahuva, a series of 20 to 30 m high miliolite dunes form the coastal cliffs that exhibit cross bedded sequences. Further upstream on the river banks, thin sheets of miliolite rest on ancient gravel beds.

The country between Mahuva, Vaghnagar and Naip is occupied by about a meter thick cross bedded and friable miliolite sheets resting on red kankary palaeosol. At Naip, coastal miliolite dunes form number of quarries. In a quarry situated about 1.5 km inland from the coast, very compact brown coloured miliolites show indistinct planar cross stratifications inclined 15^{o}-20^{o} due N and NE. These miliolites comprise recrystallised scattered shells of land snails (gasteropoda) belonging to the species of bulimus, helix, cyclothus etc., indicating the deposition of these biogenic carbonate sands in a typical terrestrial environment. At Naip, in a well section, about 3 m thick cross bedded miliolites occur below a meter thick sandy alluvium. The miliolites are further underlain by 4-6 m thick kankary palaeosol horizon resting on water bearing miliolite zone. In 10-15 m thick cliffy section at the Naip coast, the miliolite exhibits large scale dunal cross stratifications with varying foreset dips. Similar cliffs are traceable for about 8 km in the east upto Kalsar and Kotada.

Plate IV.46

Miliolites showing abrupt change in sedimentary structures in cliffy section of Jegri Island near Mahuva

Further east at Methla, miliolites form about 15 to 20 m high coastal cliffs. Such high cliffs are also extended upto Madhuvan, Jhanjhmer, Juna Rajpura and Gopnath. In this terrain they mostly form the coastal dunes which on account of various marine erosional processes occur in their present form as wave-cut platforms and coastal cliffs; their landward extension being not more than 2 km. Associated with miliolite cliffs, these wave-cut platforms clearly reveal the aeolian dunal beddings which in plan exhibit abruptly cut sets of curved beddings with moderate to high general seaward dips (Plate IV.47).

Number of thick (15 to 20 m) miliolite quarries are located at Jhanjhmer which show numerous sets of typical planar aeolian cross stratifications with 25^{o}-30^{o} dips (Plate IV.48). The rock is buff coloured and friable. The presence of eroded horizons separating the different cycles evidently suggests their deposition in instalments.

Near Juna Rajpura the miliolites form impressive coastal cliffs as well as pinnacles in the sea. About 30 m high cliff comprises atleast 3 to 4 cycles of medium to fine grained, thinly laminated, friable miliolites, each one is marked by an eroded top with change in dip direction and/or style of the depositional structures (Plate IV.49). The base of this cliffy section is marked by the presence of about 2-3 m thick red kankary soil horizon with a 0.30 m thick miliolite sheet in between. In a nearby quarry, these aeolianites show trough type cross stratifications with thin red clayey laminations that perhaps

Plate IV.47

Miliolites showing gently seaward dipping aeolian beddings exposed during low tides (Loc. Gopnath)

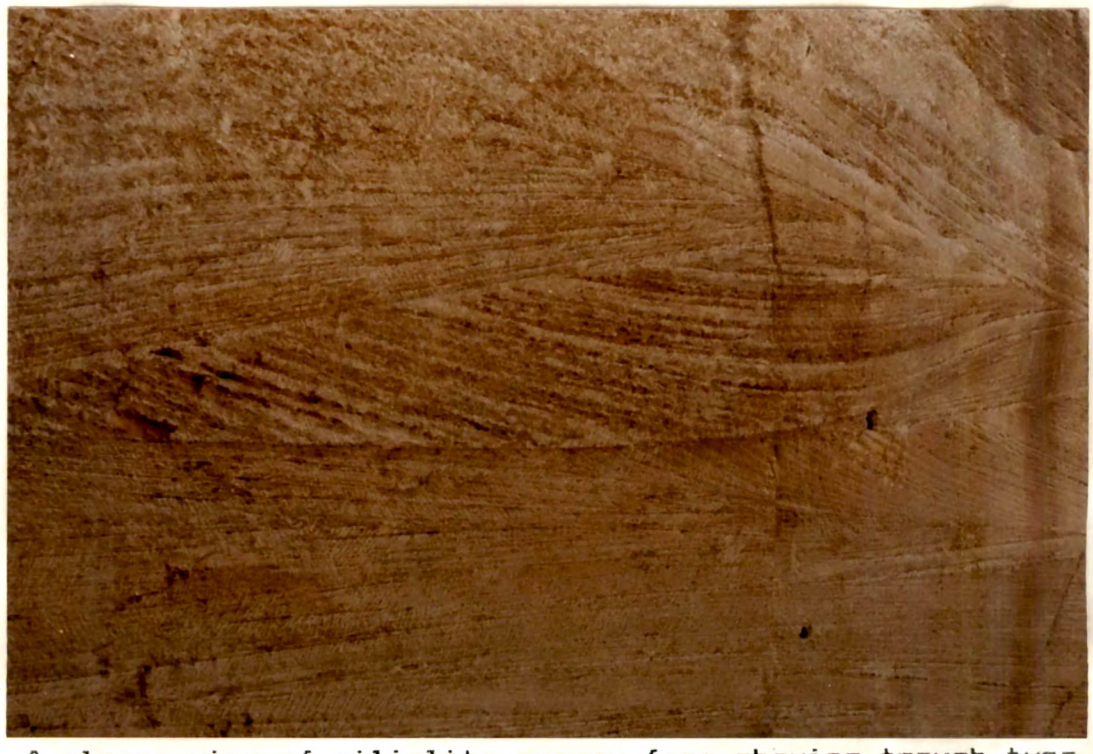
Plate IV.48

Aeolian cross-stratifications in a coastal miliolite dune quarry (Loc. Jhanjhmer)

Plate IV.49

A coastal cliff section showing different cycles of miliolite sand deposition (Loc. Juna Rajpura)

Plate IV.50



A closer view of miliolite quarry face showing trough type cross-stratifications (Loc. Juna Rajpura)

represent the fine residual product of miliolite sands (Plate IV.50). In a dug well near Nawa Rajpura, below a meter thick alluvium, about 4 m thick cross bedded miliolites with 20^{o}-25^{o} ENE foreset dips are encountered. These are again underlain by 4-5 m thick kankary palaeosol horizon below which there persists yet another 3 - 3.5 m thick miliolite sheet. These are underlain by a sub-horizontal miliolite sequence with a meter thick sandy silt layer in between.

Gopnath forms the easternmost exposure of coastal miliolite dunes. Here about 10-12 m high coastal cliff show miliolites with intercalations of red, kankary, pedogenised layers suggesting the minor breaks, concomitant with change in palaeo climate, in their deposition (Plate IV.51). The wave-cut platform here is made up of thin bedded miliolites showing typical convex southward aeolian beddings with abrupt reversal of dips. These miliolites are overlain by about 1 to 1.5 m thick red pedogenised layer as visualised on nearby cliffy section, which inturn is capped by a 2.5 m thick cross bedded miliolites with its karstified top. These are overlain by about 3 m thick cross bedded miliolite horizon with a meter thick red soil layer. About 4-5 m thick sequence of interbedded miliolites and red soil layers atop the whole lower sequence which inturn underlies the recent loam. The littoral zone is often characterised by duricrust of Oysters on miliolites (Plate IV.52). These miliolites are seen hardly extended for 1 to 1.5 km landward where they rest on Tertiary rocks.

Plate IV.51

Intercalations of kankary pedogenised layers in coastal cliff section of miliolites (Loc. Gopnath)

Plate IV.52

Oyster duricrust on miliolite platform at Gopnath coast

IX. Piparla - Ambla - Chamardi - Mitli exposures

The northeastward inland transportation of miliolitic sand drifts from the sectors VI and VII was responsible for giving rise to the Palitana, Piparla, Ambla, Ramdhari, Sihor, Chamardi etc exposures. Their occurrences are restricted to the protected areas in the undulatory trappean terrain on eastern fringes of Gir hills.

On the left bank of Kharo Nadi - a tributary of river Shetrunji near Palitana, about 1 to 1.5 m thick impure miliolite sheet is encountered. About 10 km north of Palitana and about 2 km east of village Piparla, an interesting deposit of thinly laminated, very much friable miliolites occur on northern and northeastern slopes of 157 m high trappean ridge. Here, the miliolite sands have crossed saddles in the ridge and have given rise to the typical falling dune deposits. In an abandoned quarry, miliolites show planar tabular cross stratifications with gentler northward dips (Plate IV.53). The exposed quarry faces are now coated with dark coloured dried algae layers. These deposits gradually grade into 2-3 m thick sheets at their base which further thin out to occur as thin veneers. The concentration of trappean and even miliolitic gravels is encountered at the base of thin sheets in small streams of Phalko, Sukva, Philka etc rivers implying their deposition by fluvial and/or fluvio-aeolian processes. Near Ambla, about 3 km NW of Piparla, miliolites occupy the leeward depressions of 60 to 100 m high hills, containing angular fragments of trappean country

Plate IV.53

An abandond miliolite quarry in falling dune deposit at Piparla

rocks. Root-casts, downward expanding animal burrows and mud cracks are also observed in these deposits. Similar deposits are also met in the hilly terrain south of Sanosara village. On account of the gentler windward slopes, no miliolite deposits are encountered on the southern side of these hills. At Ramdhari (3 km west of Ambla), miliolites occur as 2-4 m thick valley fill deposits forming cliffy banks in river Bhavneshri. Impure miliolite sheets also occur in Gomti Nadi west of Sihor. Part of the settlement of Sihor town is erected on the miliolites itself.

Near Chamardi, about 10 km north of Sihor towards Vallabhipur, dirty white coloured, compact and rather more detrital bearing windward miliolite deposits occupy the southern notches of about 80 to 100 m high syenite hills. They show wedge type planar cross laminations with low to moderate dips due south and maximum thickness of about 2-4 m (Plate IV.54).

The easternmost miliolite exposure of Saurashtra Peninsula occur at Mitli near the head of the Gulf of Cambay. These are impure, very fine grained and much more friable in nature, and form scattered mounds of about 15 to 20 m heights; the core of these dunes exhibit northward dipping cross stratifications.

STABILISED SAND DUNES

The stabilised but poorly consolidated organogenic carbonate sand dunes are restricted mainly to the South Saurashtra coastal tract lying between Okha-Dwarka in NW and Gopnath in SE; their landward extension hardly exceeds 1 to 1.5 km (Fig. IV.3).

Plate IV.54

A closer view of climbing dune deposit of miliolites showing low angle aeolian cross-laminations (Loc. Chamardi)

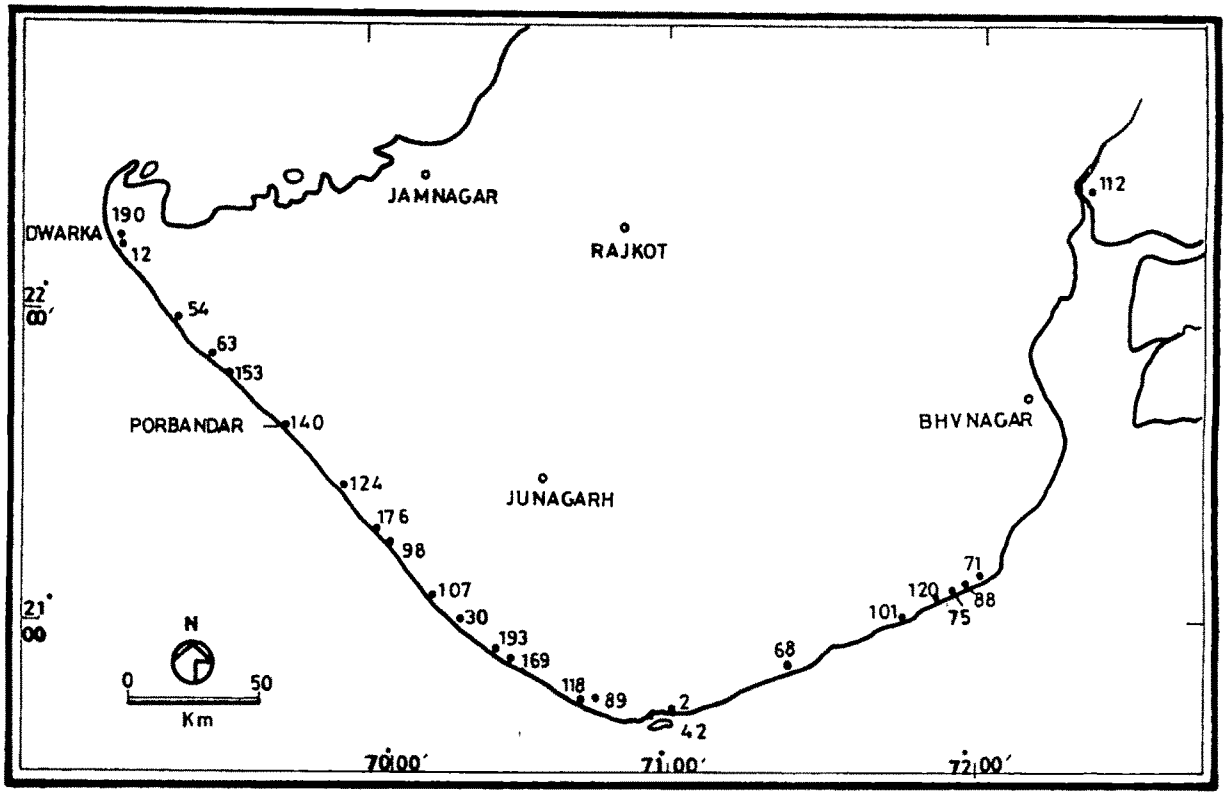


FIG. IV.3 EXPOSURES OF STABILISED SAND DUNES IN SAURASHTRA

However, similar deposits are conspicuous in the far inland areas of North Gujarat and eastern Kutch. Though, these dunes contain well sorted and identical constituents to those of miliolites, they are rich in detritals. The various allochems present in these dunes show poor abrasion as compared to those of miliolites, indicated by the presence of the robust forms of foraminifera, thus suggesting their nearness to the source. They mostly occur as transverse ridges and longitudinal mounds but on account of their diagenetic immaturity and denudation by animal and/or human activities, these dunes do not show distinct dunal morphology.

About 15 km long coastline between Okha and Dwarka is characterised by these stabilised carbonate dunes forming a kilometer long transverse ridges with varying heights between 5 & 15 m. They in general do not show any distinct internal

sedimentary structure but on a careful gleaning, after sprinkling of waters on exposures, one can see low to moderately downwindward dipping curved cross laminations. In one of the section exposed near Varwala, numerous expanding downward animal burrows are also encountered (Plate IV.55).

Just south of Dwarka town, on the left bank of Gomti river another transverse dune is encountered (Plate IV.56). This comprises medium to coarse stabilised sands of shelly nature. Further south towards Okhamadhi, their occurrences are sporadically met on the coastal tract. Between Okhamadhi and Harshad they again occur as transverse coastal ridges at several places like Kuranga, Bhogat, Hji Mastan, Navadra, Lamba etc resting either on ancient beach rocks or on miliolites or even on Tertiaries. Similar exposures are encountered between Ratadi, Kantela and Porbandar showing thickness of about 4 to 6 m. At Porbandar, these occur right on the coast resting on beach rocks and coastal miliolite ridges. South of Porbandar their occurrences are restricted due to 12-15 km long marshy saline tract of Bhadar - Ozat estuary.

The stabilised sand dunes forming transverse ridges occupy considerable areas between Navibandar and Veraval. They show variable thickness (5-7 m) with 1 to 1.5 km landward extension. They rest on ancient beach rocks and/or coastal exposures of miliolites. These dunes comprise medium to slighlty coarser (0.3 to 0.8 mm) grained bioclastic sands rich (~ 75%) in fragments of molluscan shells, bryozoan, echinoid spines, corals and tests of

Plate IV.55

Animal burrows and root protrudations in stabilised sand dune near Varwala

Plate IV.56

Stabilised sand dune on left bank of Gomti river near Dwarka

foraminifera & ostracoda; the quartz, transparent and subangular to subrounded, is chief amongst the detritals.

At Mangrol, buff coloured carbonate dunes show a thickness of about 5 m overlying chalkified shells bearing beach rocks and are devoid of any distinct sedimentary structure (Plate IV.57). The dunes are less compact and very much friable containing about 20-30% detritals. Similar exposures are traceable for about 30 to 40 km southward upto Veraval, Kadwar and Kodinar. At Mul Dwarka, 5 km SW of Kodinar, 1 to 2 m thick stabilised dune atop the miliolite sheets on either bank of Singwada river. Few meters offshore 6 to 8 m high stabilised dunes form bars (Plate IV.58). Here, the dunal sands are of dark colour on account of their higher (~ 40%) detrital content derived from the trappean rocks. Similar dunes are also met between Mul Dwarka and Chhara.

On Diu island facing the arcuate shaped sandy coastline between Brancawara and Nagwa in SW, the stabilised carbonate sand dunes form longitudinal and parabolic dunes of varying heights from 3 m to 19 m. These rest on miliolites and cover the area of about 3-4 sq. km. Similar occurrences are encountered at Dangarwadi, Bachawara, Masaniya etc. in Diu island. Between Ahmadpur Mandvi and Nawa Bandar, such calcareous sand dunes grade into barchans towards the landward areas; their morphology is considerably destroyed on account of the present day plantation. These dunal sands are fine to very fine in size and contain good amount of quartz alongwith the major bulk of the allochems.

Plate IV.57

Section of a transverse coastal stabilised sand dune resting on beach rocks (Loc. Mangrol-Maktupur)

Plate IV.58

Stabilised sand dunes forming bars in Singhwado river mouth (Loc. Mul Dwarka)

At Jafrabad, the exposures of stabilised dunes give rise to an about 20 to 25 m high cliff on the left bank of Jafrabad creek. The study of 1:50,000 toposheets and airphotos of this area clearly reveals their transverse as well as longitudinal dune morphology. The dunal material, besides detritals, comprise various allochems like foraminiferal & ostracod tests, fragments of molluscan shells, bryozoa, echinoderms, corals, sponges etc.

Exposures of similar stabilised dunes are also encountered near Mahuva just behind the Jegri island and also on Mahuva - Naip - Kalsar and Kotada coastal tract. Here their occurrences exceed 30 m height giving rise to the morphology of transverse, longitudinal, parabolic and small barchan dunes; the longitudinal dunes being predominant. The stabilised coastal carbonate dunes are further traced southeastward upto Methla, Madhuvan, Jhanjhmer and Gopnath.

It has been noticed that in these dunes, there is progressive increase in the amount of detritals from Okha-Dwarka in NW to Gopnath in SE. Again from Dwarka upto Diu, the grainsize is almost uniform between 0.3 mm and 1 mm while from Diu towards Gopnath it become considerably fine grained (0.2 mm to 0.5 mm). The occurrences of similar but rather more consolidated (but still friable) sand dunes of Tarapur, Mahiyari, Cambay, Mitli, Golana etc. are conspicuous and need merit attention (Plate IV.59). They seem to have been deposited in the same span of time as that of South Saurashtra coast but are genetically more connected with the dunes of North Gujarat and eastern Kutch reported by Patel & Desai (1988).

Plate IV.59

A low lying stabilised sand dune along road side between Mahiyari and Tarapur

From the foregoing account it is pertinent to note the various Quaternary carbonate deposits of Saurashtra assure paramount importance in conceptualising the framework of their depositional environment.