2

GEOLOGICAL SETUP

REGIONAL GEOLOGY

The Saurashtra peninsula (N20°30'to 22°30' and E69°00' to 72°30') is surrounded by the sea water from the three sides, (1) Gulf of Kachchh in the north, (2) Gulf of Khambhat in the east and (3)Arabian sea in SW and SE. The NE portion, which connects the peninsula with the mainland of Gujarat, is also a natural depression, once covered with a shallow sea connecting both the Gulfs (Prasad *et al* 1997). The region has experienced a distinct geological history that has evolved this peninsula quite differently from the neighboring regions of Kachchh and Mainland Gujarat.

Tectonic setup

Regional physiographic setting of Saurashtra peninsula is a reflection of its tectonic framework. Saurashtra massif is a horst (Biswas 1982) bounded by Kachchh rift in the North and Cambay rift in the East. Extension of Narmada rift and West Coast Fault are accounted for straight nature of the western and southern coastline of the Saurashtra (Figure 2.1). Interactive movements of Indian Plate during Cretaceous after breakup from the Gondwanaland are the major factors responsible for tectonic setup of the Saurashtra (Biswas 1982). A prominent feature observed offshore Dwarka is the occurrence of Saurashtra Arch trending in NE-SW that separates Saurashtra offshore basin from the Kachchh rift. Almost perpendicular to this, a major fault zone trending NNW-SSE off Porbandar coast defines Saurashtra platform and separates it from the deeper zone due west (Zutshi *et al* 1989).

Four major structural trends have been identified from the lineament study of the Saurashtra viz., NE-SW, ENE-WSW to E-W, NW-SE and NNE-SSW to N-S trend. The gravity trends ın Saurashtra indicated highs of 40-60 mGal near Junagadh, Barda and Alech hills (Mishra *et al* 2001). The gravıty anomaly is circular at Junagadh representing the volcanic plug whereas, at Barda and Alech ındıvidually are cırcular, but together they form an E-W trend indicating fracture zone occupied by these volcanic plugs. Prominent low gravity of about - 40 mGal has been observed over Jasdan plateau that ıs attributed to the isostatic compensation or to some deep seated source, probably the upper mantle.

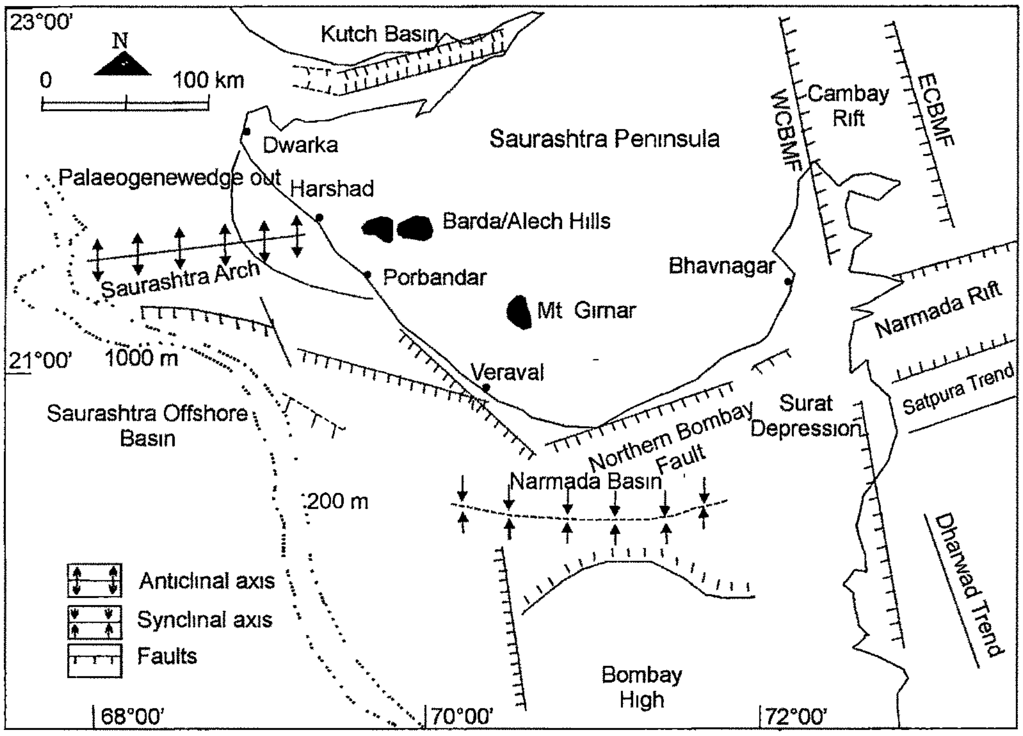

Fıgure 2 1 Structural setup of the Saurashtra Penınsula and ıts offshore (After Chauhan *et al* 1993)

Stratigraphic Setup

Saurashtra region contains a geological record belonging to the Mesozoic and Cenozoic era (Table 2.1).

Table 2 1 Stratigraphic setup of Saurashtra region (After Merh 1995)

Age	Formation	Depositional Environment
Holocene	Recent Deposits	Coastal dunes, tidal flats, beaches, alluvium etc.,
	---------------------------- Unconformity ----------------------	
	Chaya Formation	
Lower Pleistocene to Upper Pleistocene	Miliolite Limestone	Littoral, costal dune and aeolian
	---------------------------- Unconformity ----------------------	
Lower Miocene	Dwarka Formations /Piram beds	Littoral to shallow continental shelf /Fluvio-littoral
	---------------------------- Unconformity ----------------------	
	Gaj Formations	Upper part continental shelf
	---------------------------- Unconformity ----------------------	
Paleocene	Laterite	Sub aerial weathering under tropical and subtropical conditions
Upper Cretaceous to Lower Eocene	Deccan Trap Formation	extensive volcanic activities giving rise to basaltic lava flows and intrusive bodies
	---------------------------- Unconformity ----------------------	
Upper Jurassic to Lower Cretaceous	Wadhwan Formation	Inner shelf marine environment
	Dhrangadhra Formation	Coastal swamp and deltaic deposits
	---------------------------- Basement rocks not exposed ----------------------------	

Stratigraphically the sequence begins with Dhrangadhra Formations followed upward by Wadhwan Formation, Deccan Traps, Gaj Formation, Dwarka Formation and finally Miliolite and Chaya Formations and Recent Deposits (Figure 2.2).

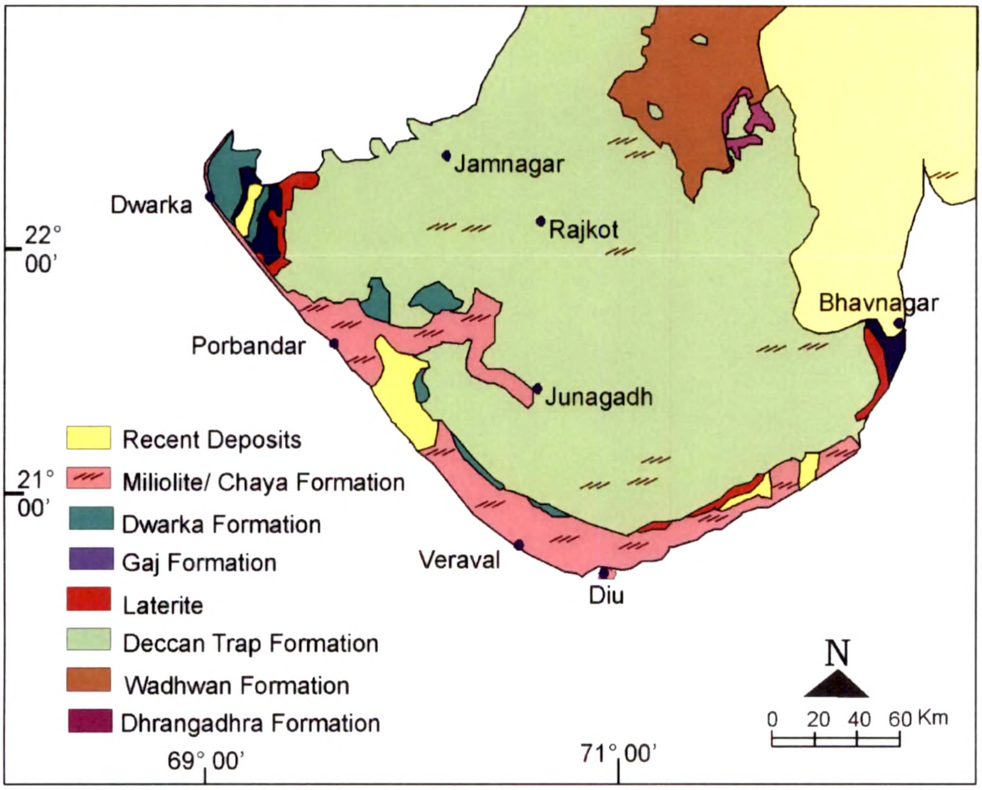

Figure 2.2 Geological map of Saurashtra Peninsula (Modified from Merh 1995)

Dhrangadhra Formation

The rocks belong to this formation were first described by Fedden (1884) and Oldham (1893). Shrivastava (1963) assigned them a formal litho-stratigraphic status as the Dhrangadhra Formation. The rocks constituting the Dhrangadhra Formation are feldspathic sandstone, argillaceous sandstone, sandy shale and clay with occasional coal bands. Sandstone is the dominant rock type of the Formation. The thickness of this formation has been estimated up to 550 m based on a borehole drilled near Dhandhuka, where it lies over granite basement. Physical continuity of Wagad and Bhuj sandstone with the Dhrangadhra Formation has been envisaged by Biswas (1987). An occurrence of carbonized plant fossils in the Dhrangadhra Formation suggests their formation in coastal swamp environment; the Formation being considered to be of typical deltaic type environment (Karami, 1990). This Formation is also correlated with Himmatnagar Sandstone of North Gujarat which is thought to be Lower Cretaceous in age. The Dhrangadhra Formation has been assigned an age of Upper Jurassic (Tithoninan) to Lower Cretaceous (Neocomian and possibly extending upto Albian). Fedden (1884) correlated plant bearing beds of this formation with the Umia Beds of Kachchh.

Wadhwan Formation

The Wadhwan Formation conformably lies over the Dhrangadhra Formation with mostly gradational contact. This is best exposed in Bhogavo river near Surendranagar. Fedden (1884) was first to map them and has named this formation after their best exposure near Wadhwan village. Shrivastava (1963) identified several gastropods, pelecypods, bryozoans, echinoderms and microfossils (*Cytheretta* and *Quinquelocullina* and some Rotalids) to suggest their shallow marine origin. The deltaic environment of the Dhrangadhra Formation become shallow marine when the sediments of the Wadhwan Formation were deposited (Merh, 1995). Chiplonkar and Borkar (1973) separated out the limestone units occurring in this formation and designated them as the Surendranagar Limestone Member, Navania Limestone Member and Badhuka Limestone Member in ascending order.

Formation	Member	Lithology
Wadhwan Formation	Badhuka Limestone Member	Fossiliferous lime stone containing fossils of pelecypods, bivalves, gastropods, echinoderm and algae
	Navania Limestone Member	Impure limestone poor in fossil
	Surendranagar Sandstone Member	Brick red, brown, yellowish soft friable sandstone with poorly preserved fossil

On the basis of faunal assemblage they correlated this with the Nimar Sandstone, the Nodular Limestone and the Coralline Limestone respectively of the Bagh Beds of Lower Narmada Valley. However, Biswas (1987) has explained them by correlating with the Bhuj Sandstone.

Deccan Trap Formation

A major part of Saurashtra peninsula is occupied by the magmatic rocks of the Deccan Trap Formation. These rocks constitute elevated table land with an uneven topography. The bulk of the formation is made up of succession of lava flows dominantly of tholeiitic basalt. Common rock type encountered is fine to medium grained grayish black basalt with its variations and amygdaloidal basalt forming marker flows. Based on the Deep Seismic Survey (DSS) profiles, Kaila *et al* (1981) estimated thickness of the Deccan Trap Formation in the west of Junagadh to be between 900 to 1300 m whereas, in the east as low as 350m.

Within the Daccan Trap country several igneous complexes occur as a result of magmatic differentiation. The Girnar, Barda, Alech, Osham and Chimardi hills are some of such examples that standout from the basalt plateau.

Numerous basalt, dolerite and lamproite dykes conspicuously occur in three major directions viz., ENE-WSW, E-W and NE-SW. They range in width from 2 to 5 m but, runs for several kilometers. These are structurally controlled and follow major fracture and lineament trends (Sant 1999). Many of the NE-SW trending dykes are now recognised as the fault controlled tilted flows manifesting the extension of the Narmada rift zone (Mishra *et al* 2001).

The inter-trappean beds also occur within the Deccan Trap Formation of Saurashtra. One such occurrence is near Bamanbore and Ninama that is as thick as

35m and contain massive, poorly bedded chalky limestone with basal conglomerate. Based on fossil remains, the age of these inter-trappean beds has been estimated to be Paleocene to lower Eocene (Merh 1995).

Laterites

Laterites form almost a continuous zone between the Deccan Trap and the Gaj Formations, and occur as discontinuous patches forming colourful ridges, right from the Jamnagar in the north up to Bhavnagar in the south. Laterite shows a good development in the area about 40 to 45 km west of the Khambhalia around the villages of Mewasa, Bhatia and Ran. Here, ferruginous duricrust has been mostly eroded exposing bauxite horizon. Some sections clearly show the derivation of laterite from the underlying basalt. In contrast to this, laterite exposures along the coastal plain of the Junagadh and Amreli district are fragmentary and highly ferruginous showing poor development of the profile. Laterite again shows a good development in Bhavnagar area where it extends for almost 50 km and forms about 1 to 5 km wide zone.

Gaj Formation

Sediments belonging to the Gaj Formation are best exposed in 30 to 40m high cliffs on the western flank of the Okha Rann. They are mostly argillaceous and partly calcareous, comprising of yellow and grey coloured clays, variegated clays with gypsum bands and calcareous silt and sandstone along with thin bands of yellow brown coloured limestones. The Gaj Formation has been divided into two members, the Ashapura Clay Member and Ranjitpur Limestone Member (Bhatt 2000).

Formation	Member	Lithology
Gaj Formation	Ranjitpur Limestone Member	Yellow to brown coloured very compact fossiliferous limestone
	Ashapura Clay Member	Laminated clays with bands of grey maroon and yellow colour.

The Ashapura Clay Member is dominantly consisting of laminated clays with bands of grey maroon and yellow colour. Topmost unit of the Member is made-up of yellow marl and siltstone which is dolomitic in nature. The Ashapura Clay Member is characterised by thin fossiliferous bands at different levels, where most of shell material is dissolved and only their moulds and casts are visible. In the eastern part of the Okha Rann, typical earthy yellow clay conformably lies over laterites with a bouldery conglomerate horizon at the base which becomes gravelly after a meter thickness towards top. This forms an unconformable contact between the Gaj Formation and Laterites. Average thickness of 90m has been estimated for this Formation.

The Ranjitpur Limestone Member is not a dominant unit like the previous one, and is having sporadic exposures. It attains a status of the Member due to its distinct calcareous nature within otherwise argillaceous Gaj Formation. The unit comprises typical yellow to brown coloured very compact fossiliferous limestone which is extensively bored and contains recrystallised shells of *Acila, Arca, Pectene* and *Ostrea*. Lower Miocene age has been suggested for the Member on the basis of *Pectunculus pecene, Pecten* sp., *Pecten bouei, Pecten faveri* and *Ostrea multicostata* and that of the larger foraminifera belonging to the *Miogypsinidae* family (Kachhara *et al* 1998).

Dwarka Formation

The Dwarka Formation has got a disconformable contact with the below lying Gaj Formation and is consisting of highly recrystallised limestone and sandy clay sequences. The Formation is chiefly composed of two distinct fossiliferous sequences along with clastic dominated non fossiliferous sequence in-between. This Formation has been divided into three members viz., Poshitra Limestone Member, Shankhodar Sand Clay Member and Kalyanpur Limestone Member (Bhatt 2000).

The Poshitra Member consists of coralline and fossiliferous limestone which have been recrystallised. At places, the brown coloured recrystallised limestone of this member exhibits trough cross beddings and ripple marks. The Member attains maximum thickness of about 2m in subsurface.

The type section for the Shankhodar Sand-Clay Member is at Bet Dwarka where the coastal cliffs expose grey and yellow clays with occasional bands of brown coloured sandy clays and grey white coloured consolidated clays. The sequence also exhibits sedimentary structures like low angle cross-bedding, ripple drift laminations and ripple marks. The top of this member is marked by 0.5 -1 m thick conglomerate horizon. The total thickness of this unit is estimated to be about 50-60 m.

Formation	Member	Lithology
Dwarka Formation	Kalyanpur Limestone Member	Pink to brown recrystallised fossiliferous limestone
	Shankhodar Sand Clay Member	Grey and yellow clays with bands of brown sandy clays and grey white consolidated clays.
	Poshitra Limestone Member	Recrystallised coralline and fossiliferous limestone

The Kalyanpur Limestone Member is characterized by pinkish to brown coloured highly recrystallised fossiliferous limestone that has a sharp contact with below lying non-calcareous clastic dominated sequences. The rocks show planar and tough cross beddings. This member characterizes topmost part of the Dwarka Formation and occurs at many places in western Saurashtra. As the Member has a distinct unconformable contact with the general sand-clay sequences of the other part of the Dwarka Formation, a possibility of its being younger and different litho unit can not be ruled out (Bhatt 2000).

Miliolite Formation

The Quaternary carbonate deposits designated as the Miliolite Formation are spread all along the western and southwestern coastline of Saurashtra. The Formation is composed of medium to fine grained, well sorted, rounded to sub rounded allochems like foraminiferal tests, peloids, molluscan shell fragments, coral, coralline algae, bryozoans, echinoderm, etc., chiefly cemented by the low magnesium non-ferron sparry calcite cement (Bhatt and Patel 1996). It shows varied thickness depending upon the pre-miliolite topography (Patel 1991a). In the coastal areas the Formation attains a thickness of about 25 m whereas, in the inland areas it range between 2 to 25m. The high angle tabular and wedge type planar cross stratification and mound like body geometry have been considered indicative of aeolian deposition. The dominantly bioclastic composition has been used to advocate its marine deposition. Recent views accept the occurrence of both, aeolian and marine origin. The details on this Formation have been reviewed by Merh (1980) and Bhatt (2003). This Formation has been divided into two members viz., Dhobalia Talav Member consisting of alternating pelletoid limestone and micrite, and Adityana Member consisting of white coloured pelletoid limestone 'calcarenite'.

Formation	Member	Lithology
Miliolite Formation	Adityana Member	White pelletoid limestone 'calcarenite'
	Dhobalia Talav Member	Pelletoid limestone with micrite

Age range of the Formation based on geochronology and palaeontological criteria has been decided as early Middle Pleistocene to Late Pleistocene. It is understood based on their radiometric age data (Baskaran *et al* 1989) that the Miliolite are deposited in three different episodes: M-I (50-70 ka), M-II (75-150 ka) and M-III (140 -210 ka).

Chaya Formation

Mathur and Mehra (1975) separated out the coarse grained bioclastic limestone deposits occurring associated with the Miliolite Limestone in the coastal area of the western Saurashtra as a formal litho-stratigraphic unit to define the Chaya Formation. The Formation consists of buff coloured coarse grained gently seaward dipping rocks containing mega fossils that can be termed as the 'Calcirudite'. The rocks have been described in the literature as coastal fringing rocks (Fedden 1884) and ancient beach rocks (Patel 1991). The significance of these bioclastic shore deposits in the study of Late Quaternary sea level changes in the region has been discussed by Bhatt and Patel (1998). The Chaya Formation is divisible into two members viz., Okha Shell Limestone Member which is off white coloured shell rich limestone and conglomerate of approximately 10 m thickness and Aramda Reef Member made up of coralline limestone well exposed near village Aramda, of approximately 4m thickness (Bhatt 2000).

Formation	Member	Lithology
Chaya Formation	Porbandar Calcarenite Member	Calcarenite
	Aramda Reef Member	Coralline limestone
	Okha Shell Limestone Member	Off white shell limestone and conglomerate

Recently Pandey *et al* (2007) have added Calcarenite Member in this Formation and named it as Porbandar Calcarenite Member.

Rocks belonging to the Chaya Formation are encountered along the coastal belt at an elevation range of 4-10m. The Formation has been assigned Middle to Late Pleistocene age (Bhatt 2003).

Holocene Deposits

The Holocene record of Saurashtra has not been investigated yet with much details. It is characterized by stabilized coastal dunes, raised mudflats, shell beds, dead coral reefs, etc., that can be prominently used to construct the Holocene history of the region. Apart from these, the present day fluvial deposits, pediment debris, beach and tidal clay deposits etc., are considered under the Holocene deposits. De (1989) has classified the Holocene deposits from the south Saurashtra into Katpar Formation and Mahuva Formation. The ancient pedogenised tidal flats and clays have been designated as Katpar Formation of Middle Holocene age whereas alluvium, coastal beach, dune and rann clays of Late Holocene age are named as the Mahuva Formation.

GEOLOGY OF THE STUDY AREA

Rivers like Vartu, Sani, Sorti and Kaman are draining into the Meda Creek passes mainly through the exposures of the Daccan Trap Formation and in laterites in upper reaches, whereas in the coastal area the local streams drain through the Miliolite Formation of the Quaternary age. The disposition of these lithological constituents is described hereunder.

Daccan Trap Formation

Catchment of the, Meda creek is dominated by the Daccan Trap Formation, mainly represented by the basalt and its derivatives. Prophyritic basalt with numerous joints is the most common rock type encountered in large part of the study area but, amygdaloidal basalt flows are also outcropped locally. The Daccan Trap is exposed in the form of NNW- SSE trending dykes around Movan, Ramgadh and Sidhpur in north and northeast of the Meda creek. Length of these dykes varies from few meters to 2-3 km, whereas width remains around 10 to 30 meters. The Barda hill that forms a prominent hill massif rises abruptly above the contour of 100 AMSL, and is made up of mainly felsite (granophyre) and quartz felsite rocks. An acute body of granophyre and rhyolite plug of 10 km diameter with sub vertical inward dipping flow structure indicate a volcanic vent.

On the way to Bhanvad near Ghumli village an outcrop of a mesocratic basalt flow having vesicles at the top, has been seen, which also has a numerous joints (Figure 2.3). A presence of white coloured phenocrysts of feldspars can be easily seen in the hand specimen. The joints measured in these rocks are (J1) N- S/ 84° due W; (J2) N 300°/ 40° due N and (J3) N 75°/ 55° due NW. In the coastal area the Harshad hill of about 65 m forms a prominent physiographic feature that represents the Deccan Trap Formation.

Figure 2.3 Three sets of joints in the Deccan Trap basalt near Ghumli. (length of hammer handle 40 cm)

Laterites

Laterites are exposed on the extreme western part of the study area. Here, they are exposed as continuous N-S trending bands. The width of the band varies from 1 to 3 km. Laterites exhibit a variety of textures and colours that ranges from purple, red, yellow, brown to grey mottled. Major localities are Panel Talav, Satpar and Methla. Laterites form a number of mounds rising few meters above the ground level at Gungari (Virpur), Methla and Satpar. Good exposures of laterites were encountered in the Sindhni nadi, where they form 3 to 7 meter high cliffs. Laterite exposures were also encountered in the quarries in north of Shikotar mata temple near Harshad.

Gaj and Dwarka Formations

The rocks belonging to the Gaj Formation of Miocene age, are not exposed in the study area. However, they can be observed in some of the well sections around Degam. Lithology of the Ashapura Clay Member has been manifested by the subdued low lying flat topography between Miyani and Bhanvad.

Recrystallised brown coloured arenaceous limestone unit of the Dwarka Formation that has been designated as the Kalyanpur Limestone Member in the type area (Bhatt 2000) has been encountered in the shallow dug wells, mostly south of the Meda Creek between Tukda and Degam towards the Porbandar. Few exposures, of the Dwarka Formation were examined in the Meda-Kindari Link Canal. Here the limestone is of pinkish to white coloured, sandy and cross bedded in nature and attains maximum up to 10 meter thickness in the subsurface.

Miliolite and Chaya Formations

The study pertains to the details of the Quaternary sequences of the Meda Creek area and hence, outcrops of the same have been recorded with more details. As stated earlier, the Quaternary sequences consists of the Miliolite and Chaya Formations which are textural verities of bioclastic limestones having graded contacts between the time coeval deposits and erosional contacts between the older limestone sequences of the same formations.

The deposits of Miliolite Formation occur in the form of costal cliffs, shore platforms, coastal dune ridges and obstacle dunes. They contain allochems and lithoclasts cemented in micrite and fine grained sparite cements. These can be termed as calcarenite (Grabau 1904) and stratigrphically can be classified as the Adityana Member of the Miliolite Formation. The coastal occurrences, mainly exposed as cliffs and benches, are rich in large bioclasts like bivalves, gastropods, corals, algae and also fragments of older miliolite units. These are described as calcirudite (Grabau 1904) that characterize the Chaya Formation (Bhatt & Patel 1998). Near Shikotarmata temple, a large outcrop of dead coral reef has been encountered (Figure 2.4) just above the present intertidal area. The moderate to deep quarry sections and natural cuttings indicate more then one episodes of miliolite deposition with minor periods of quiescence.

In the following paragraphs an attempt has been made to describe the occurrences with its megascopic as well as microscopic details. For the purpose, the following

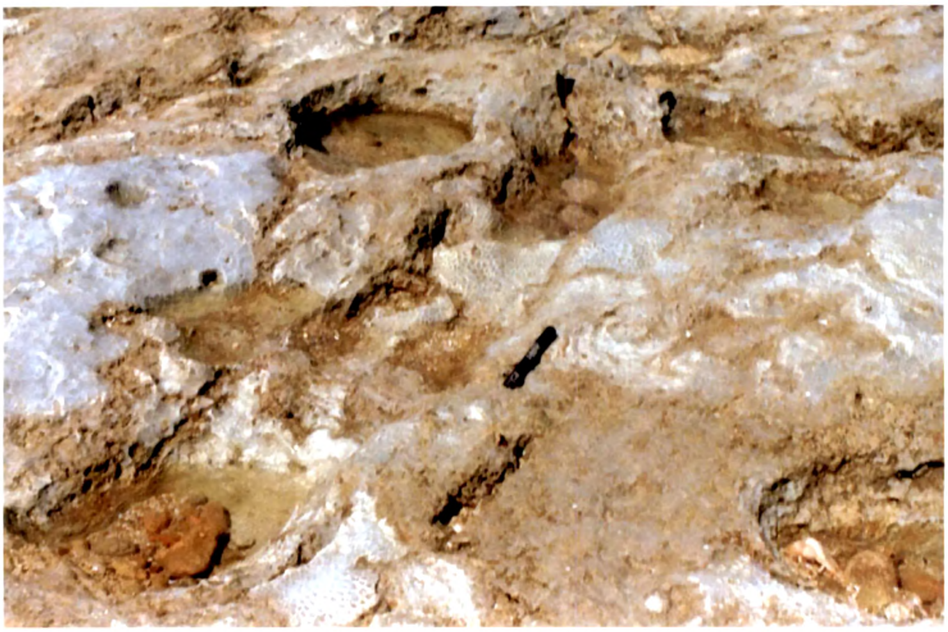

Figure 2.4 Dead coral reef exposed in the supratidal region of Shikotar mata coast (length of marker pen 10 cm).

micro-facies have been identified within the limestone sequences that represent a variety of energy conditions in a shallow intertidal to supratidal area. The micro-facies (MF) are described here as per their stratigraphic order of occurrence i.e. from the older to younger age, and their standard designation as per Flugel (1972) has been referred to as Standard Micro Facies (SMF).

CARBONATE MICRO-FACIES

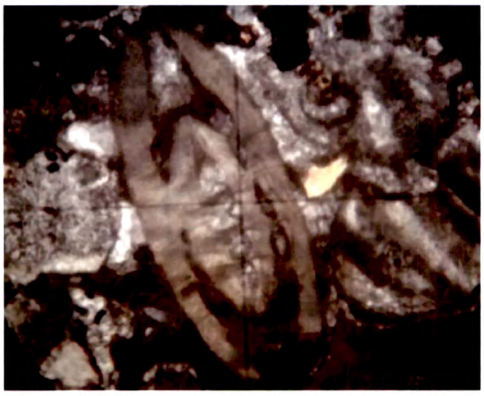

Figure 2.5 Photomicrograph showing a typical nature of MF1 (length of the photo 1.5 mm)

MF1 (SMF 18)

This facie is exposed at the base of a cliff facing the Arabian Sea, resting over the Deccan Trap basalt substrate. It is coarse to very coarse grained having the bioclasts mainly like foraminifers and shell fragments (Figure 2.5). The cement is sparite showing dogtooth- spar texture made up of high

Mg calcite that indicates a beach environment and cementation under shallow marine conditions. Dissolution of allochems and replacement by sparry calcite can also be seen.

The facie can be described as foraminifera rich bioclastic grainstone and as per Folk (1962) it can be classified as a biosparite.

MF2 (SMF 5)

This facie is exposed as a small bench at 4 m AMSL. The unit contains embedded coral fragments. Thin section shows a presence of algal remains, molluscan shells, echinoderms, corals and lithoclasts of recrystallised arenaceous limestone (could be derived from the lower conglomeratic unit). The presence of embedded coral and algal remains indicates lower intertidal to subtidal source sediments (Figure 2.6). The cement is mainly doogtoothspar rim. This can be described coralline grainstone with shell fragments. This can be classified as biosparite (Folk 1962).

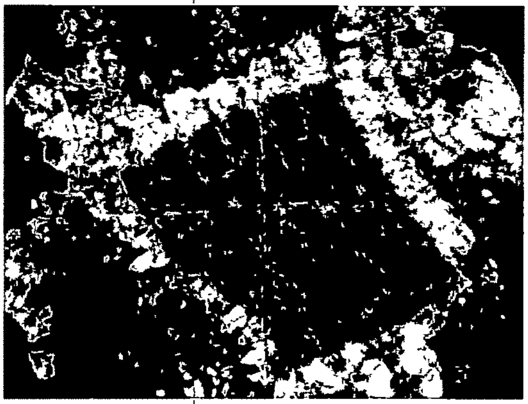

Figure 2 6 Photomicrograph showing fragment of coralline algae with a rim of sparry calcite cement characterizing the MF2 (length of the photo 1 mm)

MF3 (SMF 11)

The facie is exposed at 10 m AMSL. The unit contains algal remains and ichnofossils and a remarkable amount of shell fragments, indicating middle to lower intertidal environments (Figure 2.7). Under the microscope it exhibits presence of shell fragments (Figure 2.8), foraminifer tests and quartz cemented in micritic and microsparitic cement.

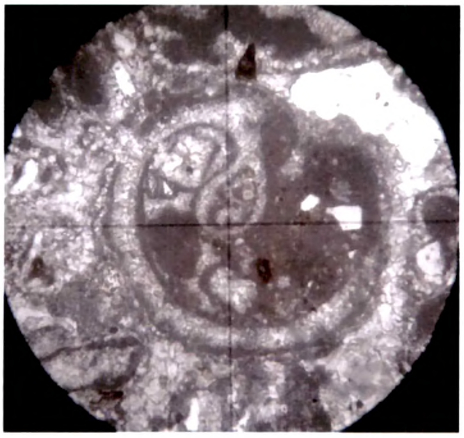

Figure 2.7 Photomicrograph of MF 3 showing a cross section of gastropod shell which is in filled by the finer detrital grains (length of the photo 2 mm)

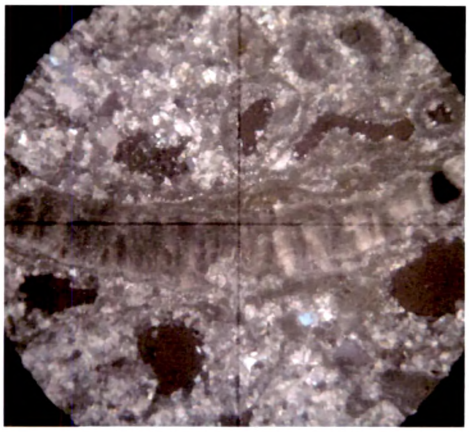

Figure 2.8 Photomicrograph of the same facies with a molluscan shell fragment and microspar cement (length of the photo 2 mm)

The facies can be described as the molluca rich grainstone. Some gastropods typically show infilling of the micritic and quartz grains. In general it is represented by biomicrite (Folk, 1962).

MF4 (SMF 14)

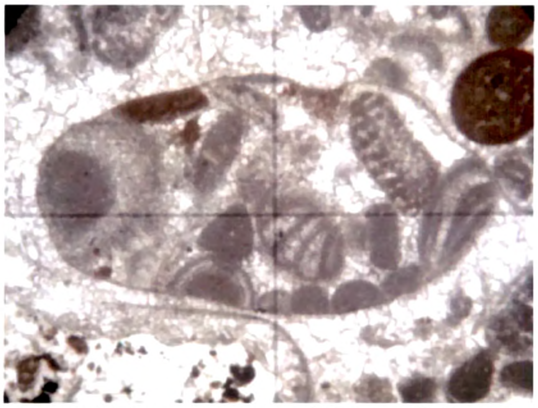

Figure 2.9 Photomicrograph of MF 4 exhibiting a well rounded lithoclast derived from the older miliolite sequence, and cemented with low mg sparry calcite (length of the photo 1.5 mm)

The facie is exposed as a platform at 13 m AMSL, in the lower parts of southern side of the Harshad hill. Ooides and sub rounded lithoclasts of the older limestone units dominate the allochems (Figure 2.9). The bioclasts are mainly molluscan shell fragments. The peloids and pellets exhibit overall floating texture in a blocky sparitic groundmass characterisis a typical pel-biosparite (Folk 1962). The facie typically represents lithoclast containing peloidal limestone.

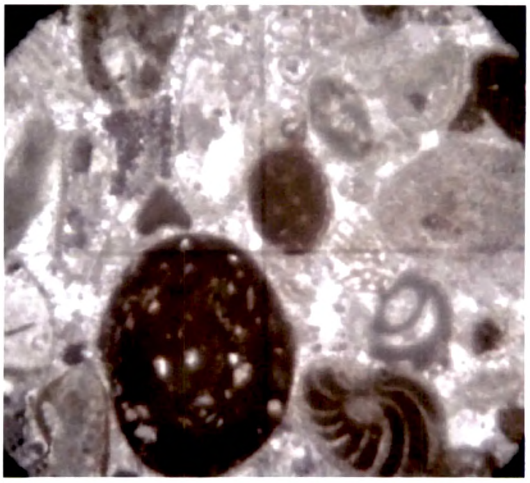

Figure 2.10 Photomicrograph of MF5 showing its general texture and composition (length of the photo 2 mm)

MF5 (SMF 17)

This facie is exposed at about 17 to 21 m AMSL in the southern side of the Harshad hill, as sheet deposits. Thin section shows ooides, lithoclasts, shell fragments and foraminifera (Figure 2.10).

The cement is mainly low Mg microsparite. The lithoclatsts of older rocks like the Dwarka and Miliolite Formations were also found. The ooides consists of nucleus of older rock fragments, mineral grains and even foraminiferal grains. The Shell fragments contain coating of micrite followed by sparite. The presences of ooides indicate a shallow agitated nearshore marine environment for the sediments which may be then deposited in intertidal to supratidal area. As per Folk (1962) it can be classified as oobiosparite and can be designated as oolitic grainstone with lithoclasts.

MF6 (SMF 18)

This unit forms a typical example of climbing dune deposit on the slope of Harshad hill. A distinct loose packing and floating texture (Figure 2.11) supports its aeolian deposition. Well sorted fine to very fine bioclasts like

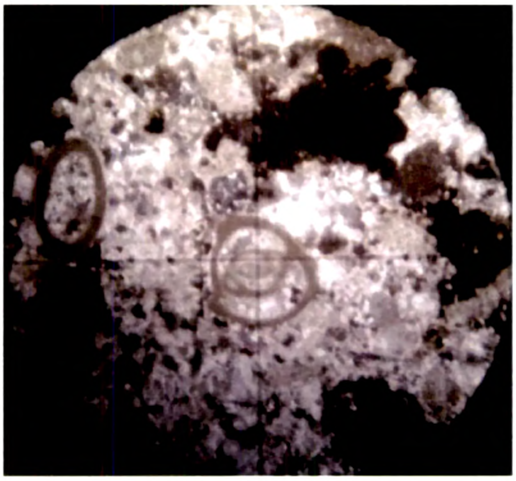

Figure 2.11 Photomicrograph of the MF6 showing dominant allochem being foraminifera in microsparitic cement (length of the photo 2 mm).

foraminifera, fragments of bivalves and echinoderm etc. along with pellets and detrital grains are seen cemented in the microsparitic cements. This can be designated as pelbiosparite (Folk 1962) and identified as foraminiferal grainstone with shell fragments.

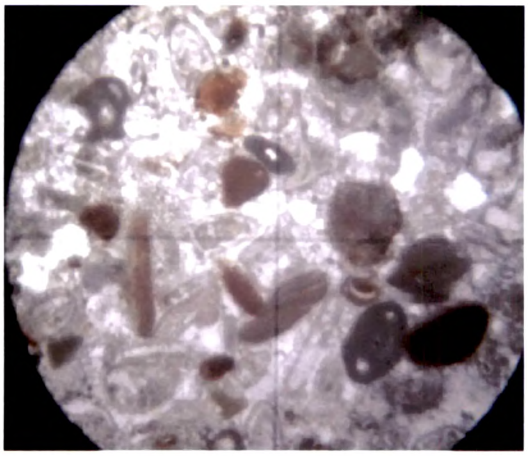

Figure 2.12 Photomicrograph of MF7 showing foraminiferal grains and shell fragments cemented in microsparite (length of the photo 2 mm).

MF7 (SMF 15)

The unit occurring as lensoid bodies resting over typical erosive surface on the older miliolitic units shows a presence of medium to coarse grain shell fragments foraminifers cemented with equant micro sparitic cement (Figure 2.12).

Scarce presence of ooides and limestone lithoclasts has also been encountered. The unit shows better compaction in comparison with the previous one. Drusy mosaic cement indicates cementation under meteoric vadose conditions. This biosparite characterise a facies called bioclastic grainstone containing ooides.

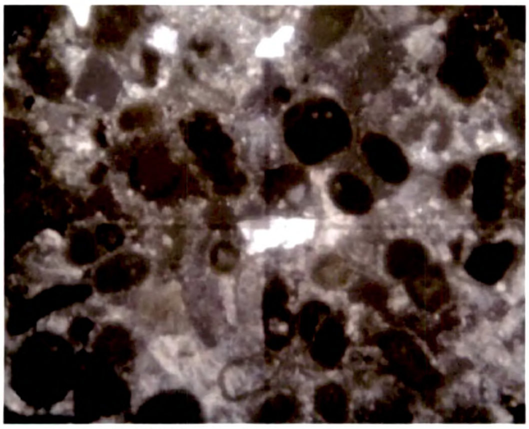

Figure 2.13 Photomicrograph showing a typical texture of MF 8 (length of photo 1.5 mm)

MF8 (SMF 15)

The typical obstacle deposits of miliolite are characterised by this facies. It contains much sorted, rounded to subrounded, fine to very fine grained peloids and foraminifera tests cemented with the blocky rim cement of low Mg sparite and thus can be called as pelsparite and bioplesparite as per Folk (1962). The facies can be designated as peloidal grainstone with foraminifers (Figure 2.13).

MODE OF OCCURRENCE

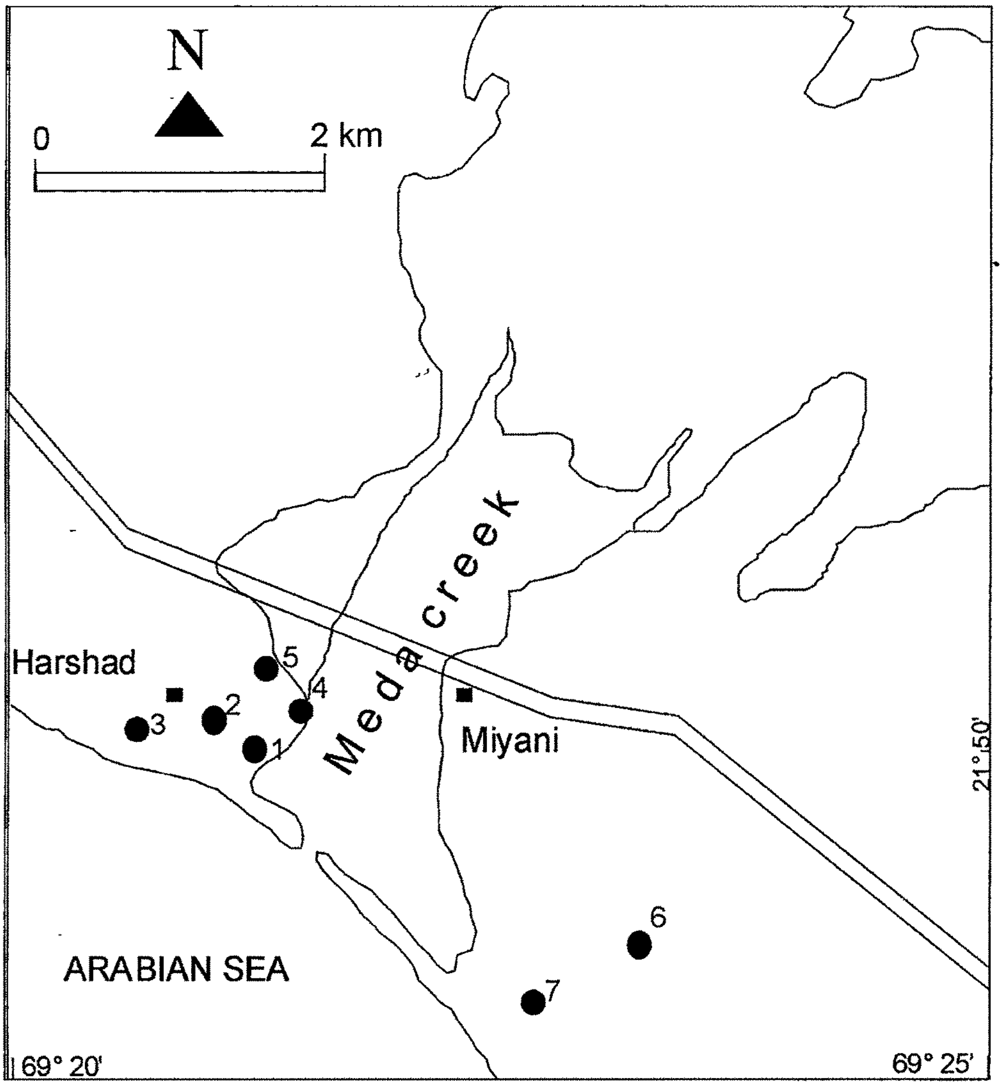

Figure 2 14 A map showing the locations of the Quaternary sections described in the following text

Location 1: (N 21°50.13', E 69°22.11')

The foresaid microfacies have been studied depositing with varied relations at various locations as shown in the Figure 2.14 and their stratigraphic relations as outcropped and characteristics were recorded as under.

On southeastern side of Harshad Hill facing the Meda creek (Figure 2.15) a mound like obstacle dune deposits of miliolite has been seen. This mainly consists of massive and laminated carbonate sequences deposited unconformably over the Deccan Trap Formation. Three distinct units were observed in this section.

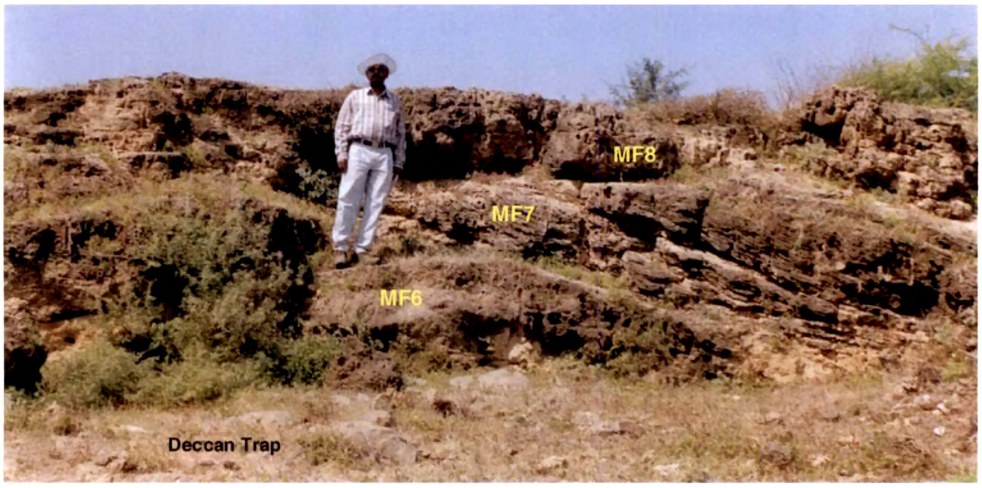

Figure 2.15 Various microfacies in the miliolite limestone as exposed on the southern fringe of the Harshad hill (height of the person 160 cm)

The lowermost unit (**MF6**) is 1.5 m thick and light yellow coloured miliolite limestone. This unit is having more massive appearance due to its diagenetic maturity. It shows a dip direction between 70°-80° with 15°-20° dip amount.

The overlying unit (**MF7**) is of two meter thick miliolite limestone deposited over an erosional surface of the lower unit. It is thinly laminated, dark brown in colour with variable dip direction from 35°to 150° showing prominent dip due ESE.

The next unit (**MF8**) is of 1 meter thick, dark coloured and cross-stratified with the dip direction varying from 110° to 140°.

In general there three distinct units are separated by sharp surfaces and they typically exhibit lensoidal body geometry.

Location 2 : (N 21°50.15', E 69°22.01' to N 21°50.20', E 69°22.08')

On the southern slope of the Harshad hill miliolites are exposed as sheet deposits practically stacked one over the other that extends seawards. Thus, the out crop does not show a typical vertical sequence. All the units rest on the Deccan Trap substrate and have gradational contact with each other. Each unit forms step like benches (Figure 2.16) displaying swash marks on the vertical face and cellular erosion on

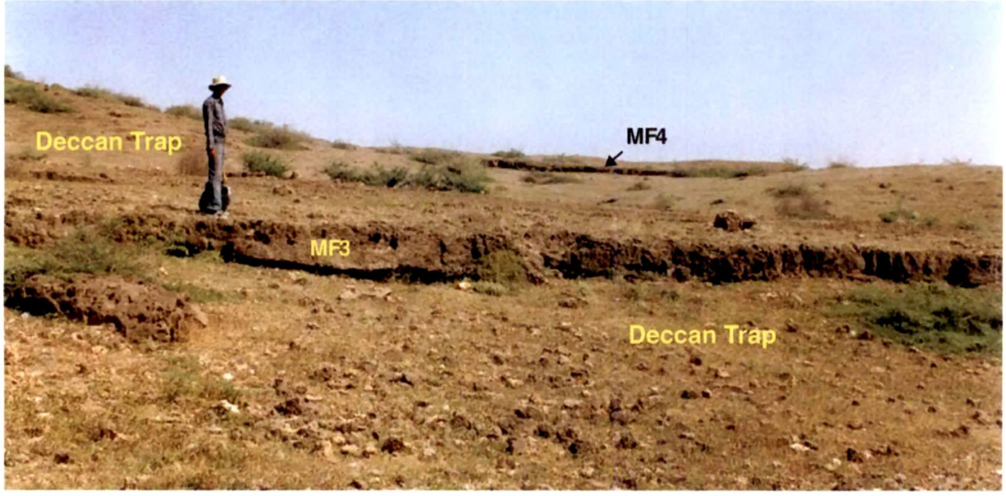

Figure 2.16 Raised marine benches developed in the miliolite sequence on the western slope of the Harshad hill. (Height of the person 170 cm)

the top. At the lower levels surface of the benches is seen coated with the ichnofossils and globular or stromatolitic thin layers of could be due to an algal mat (Figure 2.17a&b). There is distinct change in grainsize from the lower unit to upper unit. Also there is a gradation in the allochem composition starting from lithoclasts and molluscan shell rich units at the bottom to ooides and foraminifera containing top.

The lowermost unit **(MF3)** extends from the upper part of the Harshad village on the coast upto an altitude of 10 m AMSL. It consists of coarse grained highly abraded shell fragment rich rock with the thickness of 1.25 meter. The rocks are seen gently dipping towards the sea with the dip azimuths due 190°-210°.

Figure 2.17 (a) Surface of a bench in miliolite showing bulbous algal growth and (b) ichnofossil assemblage (diameter of the coin 2 cm and length of the pen 10 cm)

The above lying unit **(MF4)** attains only half a meter thickness and occurs 13 m AMSL, shows a typical honeycomb weathering and abrasion surface that typically forms due to breaking waves. The rocks are dark brown coloured, coarse grained miliolite limestone with sporadic occurrence of oyster shells. The unit is very gently dipping due SSW direction with average dip azimuths due 210°.

The next units **(MF5)** has been encountered at 17 m AMSL and is exposed in the form of continuous sheet of miliolite almost 1 meter thickness. It is showing almost all characters similar to the previous units showing dark brown colour and honey comb weathering. The general dip azimuth is due 215° -220°.

The top most unit **(MF6)** found exposed at an elevation of 21 m AMSL, very close to the top of the Harshad Hill. It is a highly porous and karstified unit so, it was very difficult to appreciate beddings.

Location 3: (N 21°50.07' and E 69°21.40')

Further on the west of Harshad village at this location contact between the Quaternary sequence and the Deccan Trap Formation is pebbly conglomerate

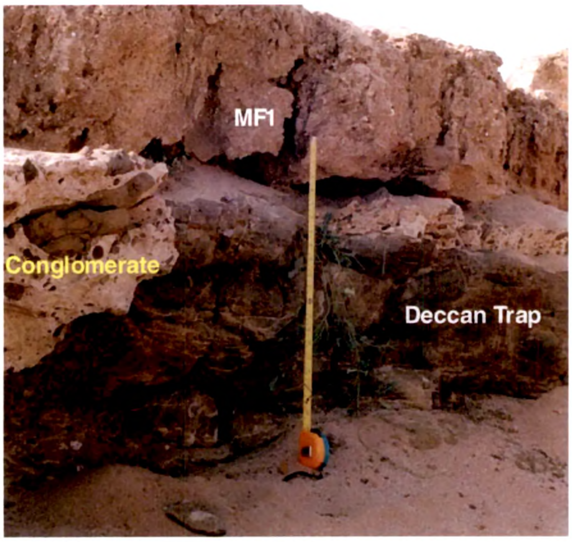

Figure 2.18 Contact between the Pleistocene carbonate sequence and the Deccan Trap Formation as seen on the coast of Harshad.

(Figure 2.18). The unit consists of sub angular to rounded fragments of basalts mostly derived from the local source. The pebble and gravels are found embedded in light yellow coloured fine grained calcareous matrix that consists of bioclatic grains and micritic to micro-sparite cement.

The micrite forms a thin rim of the primary cement around the clasts, whereas the sparite forms the second generation of cement showing typical dogtoothspar structure indicating late stage of digenesis under influence marine environment.

The conglomerates are overlain by coarse grained **(MF1)** pink coloured limestone of a half meter thickness, gently dipping due SW. This is overlain by a unit that extends upto 4 m AMSL **(MF2)**. It consists of a buff yellow colored limestone having coral fragments (*Favia* sp.) embedded into it (Figure 2.19).


Figure 2.19 Occurrence of a dead coral reef at an elevation of 4 m AMSL on the Harshad coast.

Location 4: (N 21°50.21' and E 69°22.13')

On the western bank of Meda creek near the Harshad mata temple, the road side section exhibits a lower unit (**MF6**) of dirty yellow colored cross-stratified miliolite. The rocks show 30° dip azimuth with 15° inclination. A thin layer of slope wash debris consisting of basalt fragments separates the lower unit from the upper one (**MF6**) (Figure 2.20).

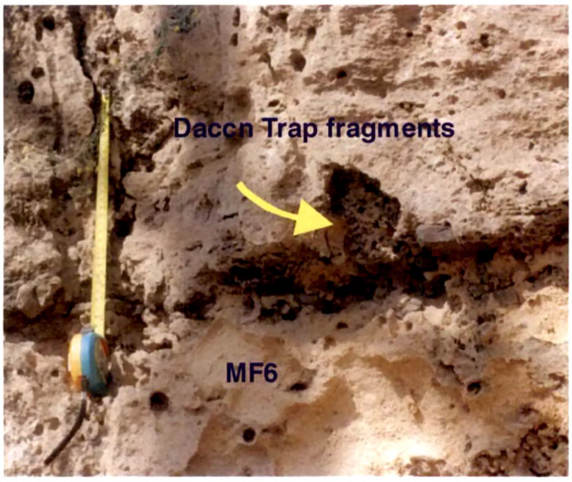

Figure 2.20 Exposure of the miliolite studded with basalt fragments derived from the hill slope.

The upper unit dips due 15° with dip amounts of about 10°-15° and is a pinkish yellow miliolite limestone that also has sparsely embedded angular fragments, derived from the Harshad hill.

Location 5: (N 21°50.39' and E 69°22.06')

On the lee side of the Harsad hill, the miliolite limestone forms a huge triangular lobe like body typically showing falling dune geometry. Towards the base, several abandoned quarries provide good section to examine the internal structures. About 10 meter thick quarry section was observed, that shows northward deeping limestone unit which forms an undulatory deposition. The lowermost unit in this section is of conglomerate, exposed at 3 meter below ground level, in a dugwell (Figure 2.21). It consists of rounded to sub-rounded fragments of gravels and pebbles of basalts in carbonate cement. The thickness of this unit is about 1 meter.

Next unit (**MF7**) exposed at the bottom of a nearby abandoned quarry consists of thinly laminated pinkish slightly re-crystallized coarse grained miliolite limestone. This 2 meter thick unit contains almost unaltered, pebble size, poorly sorted, sub angular to angular fragments of basalt, which indicate a rapid movement of the slope material under gravitational force (Figure 2.22).

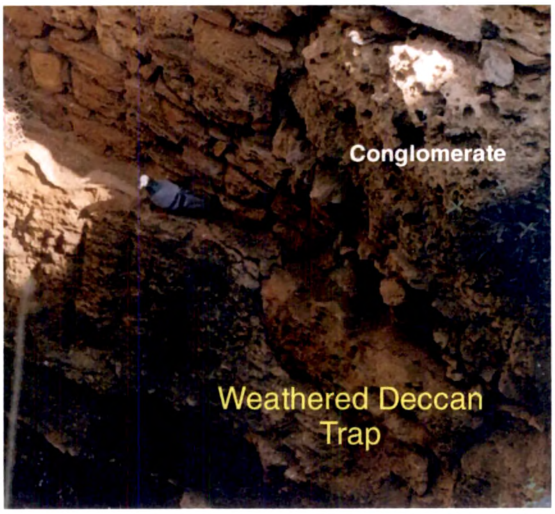

Figure 2.21 A dug well section showing conglomerate at the base of miliolite unit behind the Harshad temple.

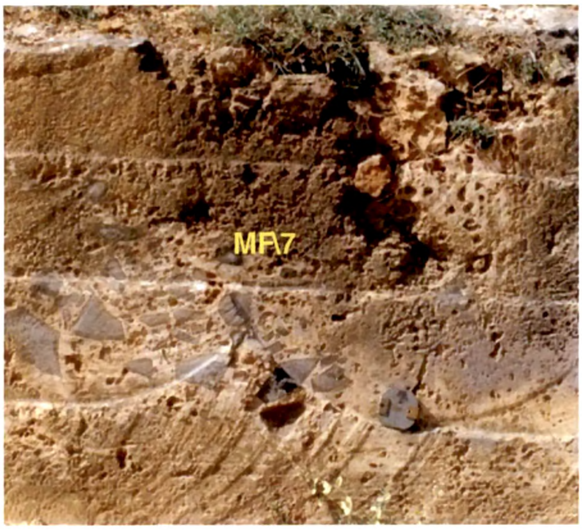

Figure 2.22 A pocket of angular fragments of basalt derived from the upslope of Harshad hill, as seen in an abandoned quarry.

Overlying unit (**MF8**) is white colored thinly laminated well crystallized limestone. This 2.5 meter thick unit deposited on an erosional surface over the lower one. General dip azimuth varies from 60° to 70° with 5° inclination. At places prominent cavernous and duricrusted surface was also observed.

Moving up towards the hill top a 3 meter thick unit (**MF8**) is deposited on the palaeo-slope. It is a pinkish colored re-crystallized unit. The dip azimuths vary from 45°- 60° with 20° deep amount. The overlying unit (**MF6**) is 1.5 m thick and

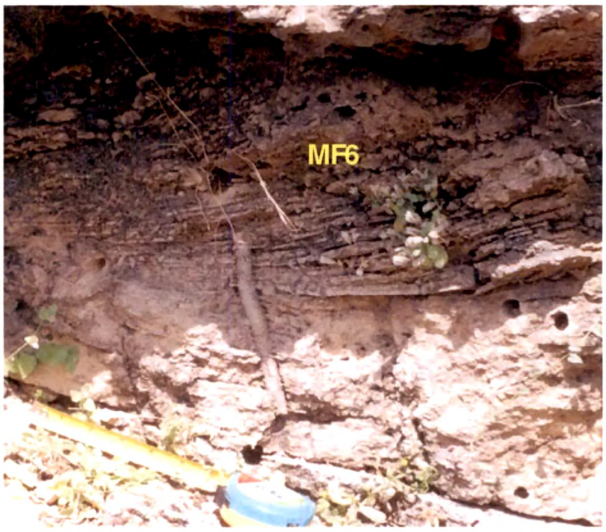

Figure 2.23 Fine stratification defining trough cross beddings in the miliolite. A few rhizomorphs can also be seen associated with it.

dark coloured with fine stratification (Figure 2.23). This section is a classic example of a falling dunes formed due to aeolian activities, where shallow depression between two peaks of a hill acted as a corridor for the trans-portation and deposition of carbonate sand on the leeward side of a prominent coastal obstacle.

Location 6: (N 21°39.37' E 69°22.58')

The Late Quaternary carbonate deposits were studied on the Miyani side of the Meda creek in coastal cliffs and in a number of quarries. A prominent coastal cliff in the miliolite with tidal notches and platform has been seen about 600 m away from the present Arabian seashore. Initially the area must be under active erosion by sea waves. A fall in sea level and formation of spit could have changed the energy conditions and detached this cliff from the active sea. At present the cliff is covered with thick thorny vegetation so and observation of the exposure did not become possible. Thin section study indicates that the unit belongs to the micro facie **MF1**.

Location 7: (N 21°49.42' E 69°23.18')

On the southern side of Miyani Village, many abandoned and active limestone quarry provide good exposures. In one of such quarry of about 6 m thick section exhibits three distinct units (Figure 2.24). All the units dip gently due southwest with varying dips. Thickness of the lower most unit **(MF6)** varies from 1 to 2 meter due to its undulatory top. It is a pinkish coloured, fine grained highly porous unit. The thin section reveals intra granular and mouldic porosity infilled with sparitic cements. The middle unit is about 2 to 3 meter thick, compact typical yellow massive unit **(MF7)**. The upper unit is a 1 to 3 meter thick unit **(MF8)** porous limestone that has a karstified and partially duricrusted top.

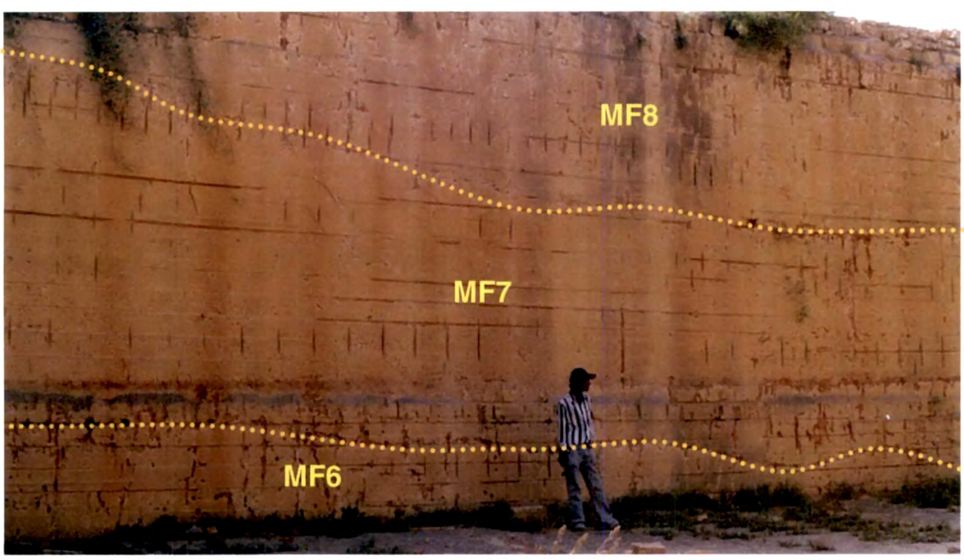

Figure 2.24 A quarry section on Miyani coast exhibiting three distinct facies in miliolite separated by thin erosive surfaces (height of the person 170 cm)

Recent Deposits

The study area possesses the sediments of Holocene age in a variety of coastal geomorphic forms like beaches, spit bars, coastal dunes, mudflats, raised mud flats and costal alluvium. The disposition of the Meda creek has facilitated the deposition of these sediments. Mouth of Meda creek is dominated by the wave formed land forms like sandy beaches, spits and mouth bar with sand shoals. The flat areas above high waterline merge with the intertidal mudflats with similar sediments. They indicate higher level of the sea during the recent past.

To study the Holocene sequences at the high resolution, a pit of 2 meter depth was dug in the middle of the palaeo-mudflat (N 21° 52' 33.20" and E 69° 24' 55.69"), also seen in figure 1.1, during the May 2005 as during this time the upstream of the barrage becomes completely dry. A core of 90 cm was raised from the base of the profile, giving a total sample of 2.9 meter (Figure 2.25).

Figure 2.25 Sampling of the shallow subsurface sediments from the dry bed of Meda creek in the upstream of barrage.

The section was properly logged (Figure 2.26) and sampled at 6 cm interval. The core log indicates domination of clay, with some shell fragments at the base. The lowermost unit of the profile is composed of dark saturated clay. Several light and dark brown bands were observed in this unit, which may be due to the organic matter present therein. From 210 -140 cm depth the grayish clay unit with sparse occurrence of gastropod shells was seen. This is overlain by layers of clays and sand between 140 and 100 cm depth. A unit with thin alternations of sand and clay occurs between 100 and 75 cm depth. A cross laminated sandy clay unit from 75 to 45 cm depth merges upward (45 to 15 cm) into a ripple drift laminated sand unit. A thin organic matter and clay rich unit separates the lower sand layer from the upper one. The unit consists of roots of swampy vegetation. The topmost layer is a heterogeneous mixture of sand-slit and clay with rootlets of grass and other aquatic vegetation.

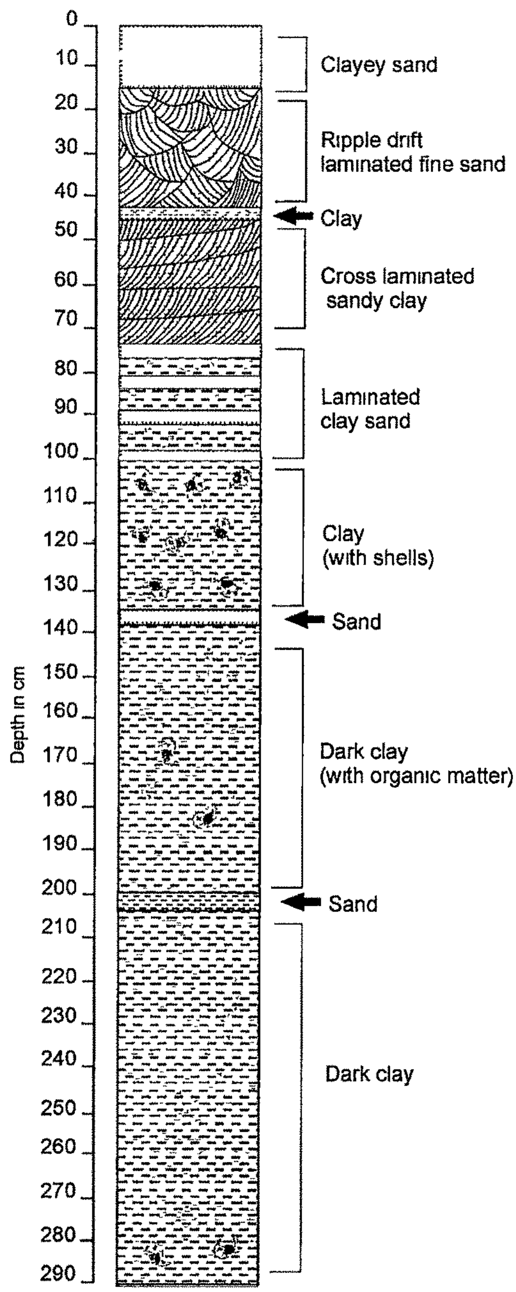

Figure 2 26 Litholog prepared from the trench section appended with the details from pipe core