(Summary of the Thesis Entitled)

High Resolution Studies of the Late Quaternary Sequences of Meda Creek and adjoining areas of Coastal Saurashtra, Western India: A Geo-ecological perspective

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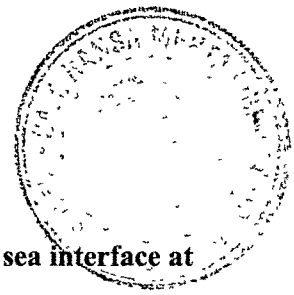


BACKGROUND

Coastal zones are the repositories of evidence of changing land sea interface at various temporal scales; million to decadal and even annual. A number of studies are available from various parts of the world, dealing with the palaeoclimate and sea level changes during Holocene. Estuaries are one such natural sink, where low energy conditions support deposition with minimum or nil erosion that leads to undisturbed and continuous sequence of sediments, provide very good proxies of past environment. The present study has been therefore, carried out to explore such type of high resolution record from the bottom of the Meda creek which is famous for the Harshad Mata temple on its right bank.

The region is located on the margin of arid and semi arid climatic domains of the State. The study area forms a part of western Saurashtra which is marked by a large Deccan Trap plateau in the centre, fringed by a narrow strip of coastal plain, highly crenulated coastline in the north and relatively straight coast in the south.

The study area can be divided into three distinct units; (1) Barda hill (2) highly dissected undulating mounds forming upper catchment and (3) coastal low lying area, with coast parallel linear ridges that reach upto 10 m AMSL.

Vartu is the major river, originating from the Barda Hills and Gop dungar flows in west direction to meet Meda creek near Rawal. Second river, Sani nadi occupies a catchment with gently slopping terrain mainly consisting of buried pediments and alluvial plain.

The study area consists of a variety of geomorphic units starting from hills to

costal plains, beaches and intertidal areas. Barda hill igneous complex is a semicircular hill in the eastern side of the study area that attains about 600 m height in the study area. The pediment zone is partly covered by the aeolianites of Middle Pleistocene age that constitutes the miliolite deposits. Pediment zone is followed by gentle sea ward slopping plain marked by alluvium with narrow well dissected valleys and mounds.

The soils of the study area are fine and clayey in nature, with montmorillonite is the major clay mineral. Almost all soil units are calcareous in nature, pointing towards dry climate. Upper catchment is marked by very shallow to shallow well drained soil units, whereas costal soils are deep, poorly drained and are saline. Soils of pediment zone and rock mounds are lithic and paralithic nature.

Study area is has a variety of natural ecosystems like forests of Barda hill, grassland, scrublands, estuary, coastal dune and intertidal areas. The forests of Barda hills are rich in biodiversity. Agricultural land has occupied large terrestrial area with rain fed agriculture dominates with minimum irrigation.

GEOLOGY OF THE STUDY AREA

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. 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 in

Saurashtra indicated highs of 40-60 mGal near Junagadh, Barda and Alech hills.

Saurashtra region contains a geological record belonging to the Mesozoic and Cenozoic era.

Age	Formation	Member
Holocene	Mahuva Formation	-
	Katpar Formation and	-
---------- Unconformity ----------		
Lower Pleistocene to Upper Pleistocene	Chaya Formation	Porbandar Calcarenite Member
		Aramda Reef Member
		Okha Shell Limestone Member
	Miliolite Limestone	Adityana Member
		Dhobalia Talav Member
----------	Unconformity	----------
Lower Miocene	Dwarka Formations	Kalyanpur Limestone Member
		Shankhodar Sand Clay Member
		Poshitra Limestone Member
---------- Unconformity ----------		
	Gaj Formations	Ranjitpur Limestone Member
		Ashapura Clay Member
---------- Unconformity ----------		
Paleocene	Laterite	-
Upper Cretaceous to Lower Eocene	Deccan Trap Formation	-
---------- Unconformity ----------		
Upper Jurassic to Lower Cretaceous	Wadhwan Formation	Ranjitpur Limestone Member
		Ashapura Clay Member
		Ranjitpur Limestone Member
	Dhrangadhra Formation	-
---------- Basement rocks not exposed----------		

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 Barda hill massif is made up of mainly felsite (granophyre) and quartz felsite

rocks. In the coastal area the Harshad hill also represents the Deccan Trap Formation.

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.

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.

Late Quaternary Sequences

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. 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.

In the preset study an attempt has been made to describe the occurrences Quaternary carbonate deposits with its megascopic as well as microscopic details.

MF1 (foraminifera rich bioclastic grainstone) is very coarse grained with bioclasts of foraminifers and shell fragments. 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.

MF2 (coralline grainstone with shell fragments) contains algal remains, molluscan shells, echinoderms, corals with lithoclasts of recrystallised arenaceous limestone. The presence of embedded coral and algal remains indicates lower intertidal to subtidal source sediments. The cement is mainly doogtoothspar rim.

MF3 (molluca rich grainstone) contains remnants of algal remains and ichnofossils and a remarkable amount of shell fragments, indicating middle to lower intertidal environments shell fragments. Cement is micrite and microsparite.

MF4 (lithoclast containing peloidal limestone) is rich in ooides and sub rounded lithoclasts of the older limestone units dominate the allochems. The bioclasts are mainly molluscan shell fragments.

MF5 (oolitic grainstone with lithoclasts) contains ooides, lithoclasts, shell fragments and foraminifera. The cement is mainly low Mg microsparite. Presences of ooides indicate a shallow agitated nearshore marine environment.

MF6 (foraminifera grainstone with shell fragments) is a well sorted fine to very fine bioclasts like foraminifera, fragments of bivalves and echinoderm etc. along with pellets and detrital grains are seen cemented in the microsparitic cements. This unit forms a typical example of climbing dune deposit on the slope.

MF7 (bioclastic grainstone containing ooides) shows presence of medium to coarse grain shell fragments foraminifers cemented with equant micro sparitic cement. It is exposed as lensoid bodies resting over typical erosive

surface on the older miliolitic units.

MF8 (peloidal grainstone with foraminifers) contains sorted, rounded to subrounded, fine to very fine grained peloids and Foraminifera tests cemented with the blocky rim cement of low Mg sparite. It represents a typical obstacle deposits of miliolite.

The foresaid microfacies have been studied depositing with varied relations and their stratigraphic relations as outcropped and characteristics were recorded as under.

On southeastern side of Harshad Hill facing the Meda creek 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. Four distinct units were observed in this section, representing MF 6, MF7 and MF8.

On the southern slope of the Harshad hill miliolites are exposed as sheet deposits practically stacked one over 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, displaying swash marks on the vertical face and cellular erosion on the top. At the lower levels surface of the benches is seen coated with the globular or stromatolitic thin layers of could be due to an algal mat. The exposure is represented by MF3, MF4, MF5 and MF6. On the west of Harshad village at this location contact between the Quaternary sequence and the Deccan Trap formation is pebbly conglomerate. The conglomerates are overlain by coarse grained pink coloured limestone (MF2)

upwardly followed by yellow colored limestone (MF2) having coral fragments (*Favia* sp.) embedded into it.

On the lee side of the Harsad hill, the miliolite limestone forms a huge triangular lobe like body typically showing falling dune geometry. This section is a classic example of a falling dunes (having MF6, MF7 and MF8) formed due to aeolian activities, where shallow depression between two peaks of a hill acted as a corridor for the transportation and deposition of carbonate sand on the leeward side of a prominent coastal obstacle.

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 studied indicate a detached this cliff from the active sea.

Recent Deposits

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"). A core of 90 cm was raised from the base of the profile, giving a total sample of 2.9 meter. The core log indicates domination of clay, with some shell fragments at the base. The lowermost unit of about 60 cm is composed of water saturated clay. From 60 -100 cm the grayish clay unit with sparse occurrence of gastropod shells was seen. This is overlain by layers of clays and sand between 100 and140 cm. A cross laminated sand unit from 140 to 170 cm merges upward (170 to 190 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 topmost layer is a heterogeneous mixture of sand-slit and clay

with rootlets of grass and other aquatic vegetation.

Habitat characterization :

To understand geological control over ecology, benthic macro-fauna in the intertidal area, creek water quality and micro-fauna in the creek area were studied.

Open sea rocky intertidal forms a linear narrow zone, having a width of about 50 m, extending westwards from the high water line. The intertidal exhibits two distinct physiographic domains because of two distinct types of rocks exposed i.e, Deccan Trap and Miliolite limestone. A survey was carried out during the low tide, to study the control of this substrate morphology differences on the distribution and diversity of the intertidal benthic community along two shore-normal transects T1 along basalt and T2 along limestone. The density and diversity of benthic community was determined by line transect intersect method. Diversity of benthic fauna along T-2 is 1.25, which is higher than that of T-1 (0.97). Species richness along T-2 is 0.624, which is also higher than that of T-1 (0.606).

The substrate along T-1 is of basalt forms a typical spheroidal weathering style results in to a positive relief with convex upward nature. Therefore, the region gets quickly exposed with low tides, which makes difficult for many organisms to survive in water stress conditions. This is reflected in the comparatively less faunal density and diversity along T-1. Barnacle (***Balanus amphitrite***) is a dominating because of their sealable test, are more tolerant to adverse conditions. The miliolite limestone substrate along T-2 is a porous rock that retains water for longer period, reducing desiccation stress. Due to

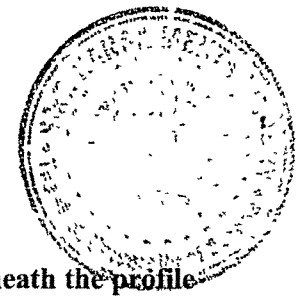
erosion by the wave action and solution action of water, the limestone forms a typical cellular intertidal containing several pit-holes and solution rills of different shapes and dimension. Coral species reported in T-2, mainly attributed to the solution rills and pits carved in the miliolite limestone.

To evaluate the primary habitat conditions in the Meda creek, several proxies pertains to the creek water and creek bottom sediments were studied. In the year 2003 water sampling was carried out for the three seasons viz., pre-monsoon (April), monsoon (June) and post monsoon (September), at five locations. The water samples were analyzed for its pH, salinity, nutrients and DO properties indicate a sea water dominated creek with high salinity. The upstream barrage limiting the inflow of fresh water from small seasonal river into the active part of creek making it a sea dominated creek. However, low TSS values due to mouthbar act as a berrier to wave energy. Grains size analysis of the bottom sediments also indicate domination of clays followed by silt also indicates low energy environment, with mouth bar absorbing maximum wave energy, the creek almost behaves as sheltered basin even from the landward side due to the barrage.

XRD analysis indicates presence of clay minerals like, montmorillonite, illite and kaolinite. Montmorillonite clay is a weathering product of basaltic rocks, found in the catchments of the Meda creek and large part of the Saurashtra, whereas illite and kaolinite are reported in the sea, could be contributed by weathering of alkaline rocks in the catchments of Indus river or rivers of mainland Gujarat where they are exposed in abundance.

The sand size particles were taken from active creek, trench and core sample to study biological proxies like foraminifera, ostracods, pteropods and charophytes.

The micro-palaeontological analysis of the creek bottom sediments indicate that the benthic foraminifera contribute about 98-100% to the total foramininfera number. The foraminifera recorded from the Meda creek bottom sediments are belonging to the suborders Milioliina (*Quinqueloculina, Tiloculina*), Rotaliina (*Ammonia, Cibicides, Rosalina, Astrorotalia, Rotalidium, Elphidium, Nonionella, Nonion*) and Textularina (*Loxostoma, Bolivina*). The *Ammonia* emerges as the most dominating genus contributing to 45 % of the total population. Stations 2 (TFN 216) and 3 (TFN 198) with silty clay bottom have been found most favoured by the foraminifera, followed by the Stations 1 (TFN 187) and 4 (TFN 173) having clayey silt. TFN has been recorded minimum (107) at station 5 with the sandy bottom. Though rounded symmetrical forms dominate the creek, angular asymmetrical forms have also shown their significant presence at stations 2, 3 and 4. The creek exhibits a positive correlation between clay content and angular asymmetrical forms, indicating their favour for low energy conditions. The creek being a sheltered lagoon, where fine sediments can be easily deposited in general the presence of reworked forms was more at all stations. Species diversity has been recorded lowest at station 1, and 2 and maximum at station 3 closely followed by the station 4. High TSS and low salinity were the limiting factor for low diversity of foraminifera in the creek.



PROXIES OF THE PAST

A 2 meter profile in the trench and 90 cm core sample just beneath the profile was sampled at 60 cm interval studied for sedimentological proxies. The grain size analysis has revealed the dominance of clay, with clay percent ranges from 30 to 85%, the silt ranges from 20 to 52% whereas, the sand percent measured in range of 0.5 to 42 %. In general, sand percent increases from the bottom to the top. From the bottom upto the 100 cm depth level, in almost all samples sand remains below 10 percent. The upper 40 cm unit again shows an increased amount of sand, mostly deposited by the fluvial system or an increased rainfall in the catchement areas of the Vartu and Sorti basins. The top 15 cm has a mixed nature with more or less equal amount sand, silt and clay, could be due to settling behind the barrage.

The XRD plots of the raw data indicate predominance smectite increases from bottom to top and kaolinite and illite shows reverse trend.

Relative abundances of the clay minerals were calculated from the ratios of intensities (areas) of peaks from minerals of the untreated sample. There is a sudden increase in montmorillonite peak intensity at 140 cm depth. From this level upwards, illite drops below 10%. At 54 cm depth the illite contribution increases marginally to 8.75 %. It can be deduced that the montmorillonite has mainly contributed by the land word source whereas the source of illite and kaolinites could be offshore area or some authigenic processes.

The micropaleontological study of the subsurface profile samples from the upstream of barrage has shown that. Foraminifera, Ostracods, Pterapods and Charophytes are the major groups contributing to the total microfossil in the

sediments. Foraminifera have remained as the dominating group through out the section. The dominating genus *Ammonia* is ranging from 56 to 95% among the total foraminifera with in general increasing trend towards the top. A large number of reworked specimens at lower part of the core indicate low energy conditions.

The Charophytes are green macroscopic algae that occurs in fresh and brackish water environment. In the present study only preliminary description of charophyte is attempted. Total four types have been identified while describing forms of gyrogonite an attempt has been made to indicate probable genus of the gyrogonite. Form A resembles to genus *Chara* sp., Form B to *Lamprothamnium* sp., Form C to *Lychnothamnus barbatus* and Form D to *Nitella* sp. Presence of Charophytes along with foraminifera of shallow depth nature in the samples indicates brackish water environment. Their disappearance beyond the depth of 2.3 meter indicates prevalence of much saline conditions in the past.

EVOLUTION

The study area exhibits two distinct episodes of coastal deposition; the older episodes pertains to the Pleistocene history and has been recognised in the from of Miliolite and Chaya formation, covering an age span from 200 to 80 ka.

The deposits occur in the form of costal cliffs and benches, shore platforms, coastal dune ridges and obstacle dunes. Variations of microfacies indicate difference of energy conditions leading to variation in texture and allochem content. Units exposed along the shore contain large unsorted fragments

corals and molluscan shells along with the foraminifera and pelloidal cemented with dogtoothspar cement, indicate shallow marine to beach facies. Five stets of benches on the southern slope of the Harshad hill indicate a higher sea level which deposited miliolite limestone with corals and algae in a shallow depth during the Pleistocene, around 120 ka. Occurrence of benches at different levels are indicative of stand still of this regression (MIS-5). A continuous drop in the sea level, first led to formation of beach facies, and later on aeolianites, indicative a prolonged dry period, represented by obstacle deposits on the slope of the Harshad hill facing the Arabian Sea and Meda creek. On the northern slope of Harshad hill this can be readily seen in the form of the falling dunes.

Analysis of the Holocene record of the Meda creek has been attempted with the help of a multiproxy study of the subsurface samples. A sample from depth of 2.00 m has been subjected to ^{14}C radiometric dating at Birbal Sahani Institute of Paleobotany, Lucknow which has yielded date of 5130 ± 160 year BP age (Personal communication with Dr. Vandana Prasad). Another control date was taken as 1974, the year of barrage construction from 30 cm depth sample with the help of sedimentological characters. Based on these two dates ages modeling was done and some events have been identified with possible approximate age breaking; with the help of elative frequencies of (1) sand, (2) clay, (3) montmorillonite, (4) illite, (3) charophytes, (4), pteropods, (5) ratio of foraminifera to pteropods, ostracods and charophytes, (6) *Ammonia*, (7) *Nonion*, (8) *Quinqueloculina*, (9) ratio of symmetrical to asymmetrical forms and (10) ratio of intact to reworked foraminifera. These events are;

1 **E1 (7.2 to 5 ka BP, depth 290-210 cm): High sea level with sea dominated nature of the creek, as collectively, proxies points towards a calm water body with 2 to 3 meter depth, well connected to the sea, moving upwards up to 210 cm depth, proxies point towards more and more influence of the sea.**

2 **E2 (5 to 3 ka BP, depth 210-140 cm): There is increase in fresh water inflow, in a still sea water dominated estuary with low energy conditions. The similar conditions prevailed up to 140 cm depth; indicate a relatively higher sea level. Biological and sedimentological proxies indicate a constant fresh water income with in low energy estuarine environment.**

3 **E3(3 to 2.5 ka BP, depth 140-100 cm): There was transition from sea dominated tidal creek environment to lower salinity tidal flat regimes with recordable influence of the continental processes that could be due to drop in the sea level. The overlying units up to 100 cm depth level indicate again less sand influx. However, but presence of charophytes in good number indicates a continued income of fresh water and shallow water depth to facilitate algal growth.**

4 **E4 (2.5 to 1 ka BP, depth 75-100 cm): This event has been recorded in terms of thin alteration of sand and clays, which characteristically represents a tidal flat environment, in turn indicating lowering of the relative sea level. An equal proportion of charophytes and foraminifera suggests oscillating saline and fresh water conditions.**

5 **E5 (1 ka BP to 1974 AD, depth 40-75 cm): This is marked by a reduced sea level and also a reduced fresh water discharge supported by low floral**

faunal density. Dry climate in the catchments is indicated by.

6 E6 (since 1974 AD, depth 0-40 cm): The ripple drift laminated sand indicating the increased fluvial activities and significant absence of tidal environment. This event can be considered as result of construction of barrage on Meda creek in 1974.

On comparison with the present day creek bottom sediment, the contrast between the upstream and downstream of barrage sub-environments becomes much distinct. The region, on back of the barrage seasonally changes its characters from a fresh water reservoir is post monsoon to brackish water pond is winter and later on a dry flats having stunted vegetation and embryonic dunes. The creek downstream of the barrage is a sheltered lagoon with high salinity conditions, represents a totally different geo-ecological setup than that of upstream environment.

The present finding are in line with findings of study carried out by Gaur et al 2007 in the Dwarka based on archeological evidences. A comparison with the various standard sea level curve obtained by in various worker was also made, which was found very much complementary with the conclusion of present study.