6
DISCUSSION

GENERAL

The Quaternary period spans for about 2 million years of the earth history. Rapid climate changes and fluctuating interface between the land and the sea during the Late Quaternary period have attracted a large group of scientists. Several studies from marine and terrestrial environments have yielded a number of evidence suggestive of this. The relative sea level changes along the Indian coast in general, and western India in particular, have been documented by several workers using different types of evidence; and sea level curves pertaining to the middle to late Pleistocene time have been proposed (Kale and Rajaguru 1985; Hashimi *et al* 1995). The studies of Quaternary geological records in western India are mainly attributed to the fascinating carbonate deposits occurring all along the Saurashtra coast, popularly known as the 'miliolitic limestone' for its direct relevance to the Quaternary sea level changes and climatic fluctuations (Gupta and Amin 1974, Bruckner *et al* 1987, Patel 1991b, Juyal *et al* 1995, Bhatt and Patel 1998, Mathur and Pandey 2002, Mathur 2005, Bhatt and Bhonde 2006). The occurrence of miliolite limestone sequences and erosive features developed therein from the Meda creek and adjacent coast have been interpreted and discussed here in the light of the above.

Later epoch of the Quaternary period is the Holocene epoch that marks the history of about last 10ka. Based on the climatic history, entire Holocene can be characterized as a sequence of 10 or more global-scale little ice ages, fairly irregularly spaced, each lasting a few centuries, and separated by global warming events (Bluemle 1999). The global rise in the sea level, which accompanied the melting of great ice sheets of the last glacial episode, started ca. 14 ka BP and continued with minor oscillations till the present sea level was reached. Mainly, there exists three views on the sea-level changes during the last 6 ka BP viz. (i) the sea level underwent relatively large and repeated fluctuation from 1.5 m below to 3 m above the present level (Fairbridge 1961); (ii) the sea-level has been lower than the present but, has maintained a continuous rising trend with an ever decreasing amplitude, before reaching its present level (Shepard 1964), and (iii) the sea-level rose above the present level ca. 5 ka BP and oscillated between 2 m above and the present level (Baker and Haworth 2000). Various studies in India have indicated that the sea level was much below (~ 90 m) the present level about 14.5 ka BP (Kale and Rajaguru 1985, Hashimi et al 1995, Rao *et al* 1996, Mathur 2004). It rose to around –70 m about 10 ka BP at a fast rate and then slowed down considerably till it reached the present level about 7 ka BP. The sea level reached 2–4 m higher than the present about 5–6 ka BP and continued to rise further till about 4.5 ka BP (Nigam *et al* 1990, Gupta and Amin 1974). Since then, the sea level has been falling as demonstrated by the occurrence of old tidal flats inland to the newer tidal flats. Even the shifts of the coastal dunes, younging towards the seacoast, lead to the same conclusion of the emergence of the coast in recent times (Mathur 2004).

Recent advances in palaeo-climate studies have made possible to understand the Holocene climate in the coastal and marine environments. This led to ocean base climate indices, such as the North Atlantic Oscillation (NAO) index (Cook *et al* 2002), large-scale temperature (Mann *et al* 1998) and sea level pressure (Luterbacher *et al* 2002) patterns, and hemispheric mean temperature (Mann et al 1999, Crowley and Lowery 2000, Folland *et al* 2001). Evidences of Holocene climate change have been studied by a number of workers using proxies from the ODP sediment cores. Other than isotopes, proxies like clay minerals, foraminifera, pollens, charophytes, ostracods, pteracods, etc., are easy to workout and can generate a large database that provides valuable insights into the broad patterns of climate variability and changes. Unfortunately, not a single proxy alone is adequate for reconstructing the large-scale patterns of past climate. "Multiproxy" methods exploit the complementary strengths of each of these proxies to reconstruct the same at local and regional scales that can be correlated with those of the global data bases.

In general, the study area exhibits two distinct episodes of coastal deposition; individual being punctuated by minor breaks. The older episodes pertains to the Pleistocene history and has been recognised in the form of Miliolite and Chaya Formations. Their field disposition, petrography and geomorphology have been described in the previous text. With a profound unconformity the Holocene record constitutes the sediments of the Meda creek which has been studied in the greater detail.

PLEISTOCENE HISTORY

The Pleistocene history of the study area has been recorded in the form of the Miliolite and Chaya Formations, covering an age span from 200 to 80 ka BP (Baskaran *et al* 1989, Juyal *et al* 1995). The deposits occur in the form of costal cliffs and benches, shore platforms, coastal dune ridges and obstacle dunes. These deposits appear as monotonous bioclastic limestone sequence. However, 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 of corals and molluscan shells along with the foraminifera and pelloids cemented with dogtoothspar cement, indicate shallow marine to beach facies. Units exposed on the slope of the Harshad hill facing the Arabian Sea and Meda creek represents aeolianites deposited on the trappean obstacles. On the northern slope of Harshad hill this can be readily seen in the form of the falling dunes.

Several microfacies described earlier indicate the deposition of miliolite in near shore intertidal to backshore environments.

The deposits of the study area exhibit many erosive features like sea notches, benches with swash marks and cellular weathering. Sea notches above the present day sea level are exposed at two places in the north-western side of Meda creek; one at Shikotar mata temple and another on Miyani side, at the level of 2-3 m above the present day sea level. On the coast of Shikotar mata an occurrence of dead coral reefs in the supratidal region also confirms relatively much higher sea level in the past.

Another set of evidence is in the form of a number of benches with swash mark and cellular weathering much above the present day sea level. Presence of coral reef, ichnofossils, algal remains and embedded shell fragments on these benches depicts an oscillatory nature of the late Pleistocene sea in this part of the region.

A schematic section prepared by combining the exposures along the south and south west slope of the Harshad hill indicates five benches (B2 to B6) at higher levels from 4 m to 21 m AMSL(Figure 6.1). Juyal *et al* (1995) have reported $^{230}Th/^{234}U$ age of 126.5 + 8.5-8.1 ka BP for an oyster at 13 m level from one of these benches. This confirms the age of the miliolite being older than 126 ka and formation of the benches by the MIS-5 sea.

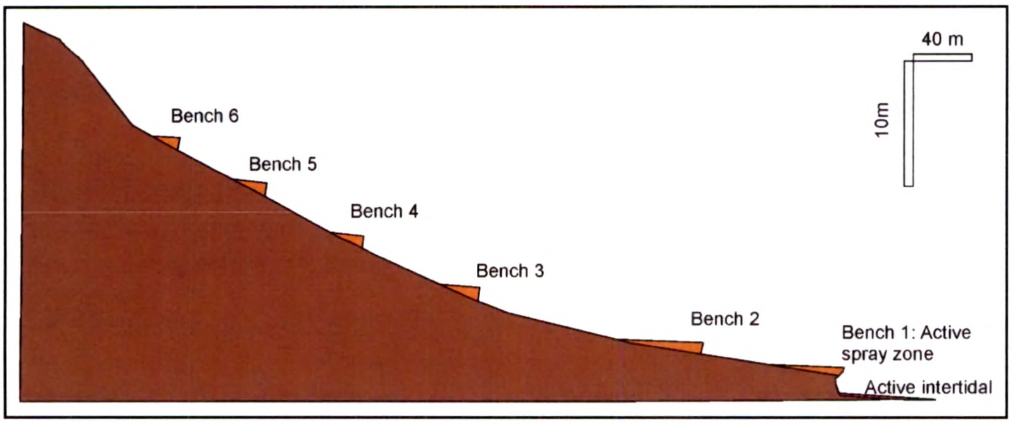

Figure 6.1 A physiographic profile showing raised marine benches on Harshad hill slope.

The benches making older miliolite also occur as shore parallel beach ridges on the south western side of the Meda creek, between Miyani and Porbandar. They may be correlated with the MIS-9 or 11 higher sea, as the higher occurrences of the deposits linking with the MIS-11 have been reported from the other places in the world (Hearty 2007). The beach ridges occurring at higher elevations than that of the MIS-5 level have been correlated with MIS-9 and MIS-11 in the SW Saurashtra along the Mangrol-Chorwad coast (Bhonde 2004).

The global sea level studies suggest MIS-5 high sea level of about +5 m. Occurrences of benches at 21 m can not be explained therefore, only by increasing sea level. There are occurrences of tidal notches corresponding to the MIS-5 as high as 15 m AMSL, which have been explained by a combined effects of higher the sea level and low magnitude tectonic uplift along the south Saurashtra coast (Bhatt and Bhonde 2006). However, the occurrences of benches at different levels in the study area may be related with the stand stills of the regressive MIS- 5 sea. From the study of local geomorphology, it can be deduced that the carbonate beach ridges of the middle Pleistocene high sea were eroded during the late Pleistocene regression (LGM) between 20-14 ka BP by the offshoreward migrated fluvial processes. The following transgression must have filled up this narrow channel by the tidal sediments and provided an avenue for the landward extension of the Arabian Sea.

HOLOCENE HISTORY

Analysis of the Holocene record of the Meda creek has been attempted with the help of a multiproxy study of the subsurface samples, as described before. Due to physical constrains much longer core could not be raised, but 2.9 m depth was studied mainly for texture, clay mineralogy and micropalaeontology. A sample from depth of 2.00 m has been subjected to ^{14}C radiometric dating at Birbal Sahni Institute of Palaeobotany, Lucknow that has yielded 5130 ± 160 year BP age (Personal communication with Dr. Vandana Prasad). A distinct change in the energy conditions in terms appearance of the current structures and an increased amount of sand along with drop in foraminifera against an increased amount of charophytes and pteropods at 30 cm depth, has been attributed to the construction of Barrage in 1974 A.D.

Looking towards the overall uniform style of deposition, with only very minor physical changes like thin sand/clay alteration between 70 and 100 cm depth, the age modelling become possible and some events have been identified with possible approximate age breaking. However, a detailed chronology should be attempted to obtain a fine picture.

Total ten parameters have been worked out to decipher the changes in the energy and habitat conditions along the depth. These are relative 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 forams. Figures 6.2 and 6.3 depict variation of different proxies with the depth and their status in the present day active creek area.

On comparison with the observations made in the down stream of the barrage in the Meda creek, several samples from the profile indicate conditions similar to the present day environment. However, the present day samples show a very low montmorillonite, high percent of angular forms and of *Quinqueloculina*; this could be due to comparatively lower fresh water inflow in to the creek after the construction of barrage.

The study suggests a record of six major events between the sampled depths of 7000 to 30 years BP, which are described below.

Event E1 (7.2 to 5 ka BP)

The bottom most sample marks the first important event depicting sea dominated nature of the creek area. Followings are the signature of various proxies:

1) Clay dominates the sediment with more then 60 % contribution
2) Illite dominates (about 40%) over the montmorillonite (30%).
3) Charophytes are absent indicating very little fresh water inflow.
4) Foraminifera ratio to the other bio proxies is 6, contributed by a diverse population and large number of reworked forms.

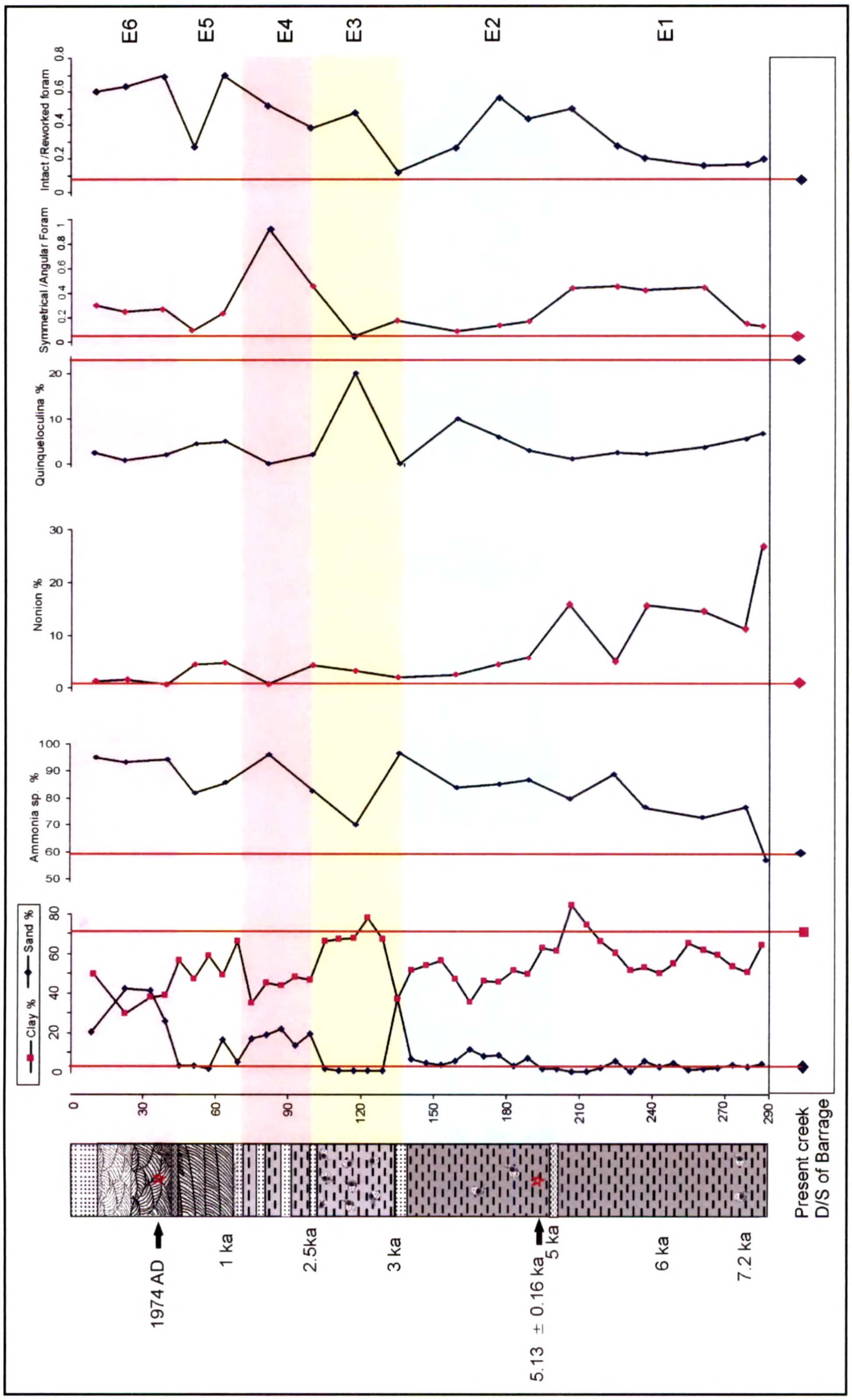

Figure 6.2 Variation diagram of sediment texture and foraminifers along with comparison of its morpho-groups. Various events are identified based on these relationships.

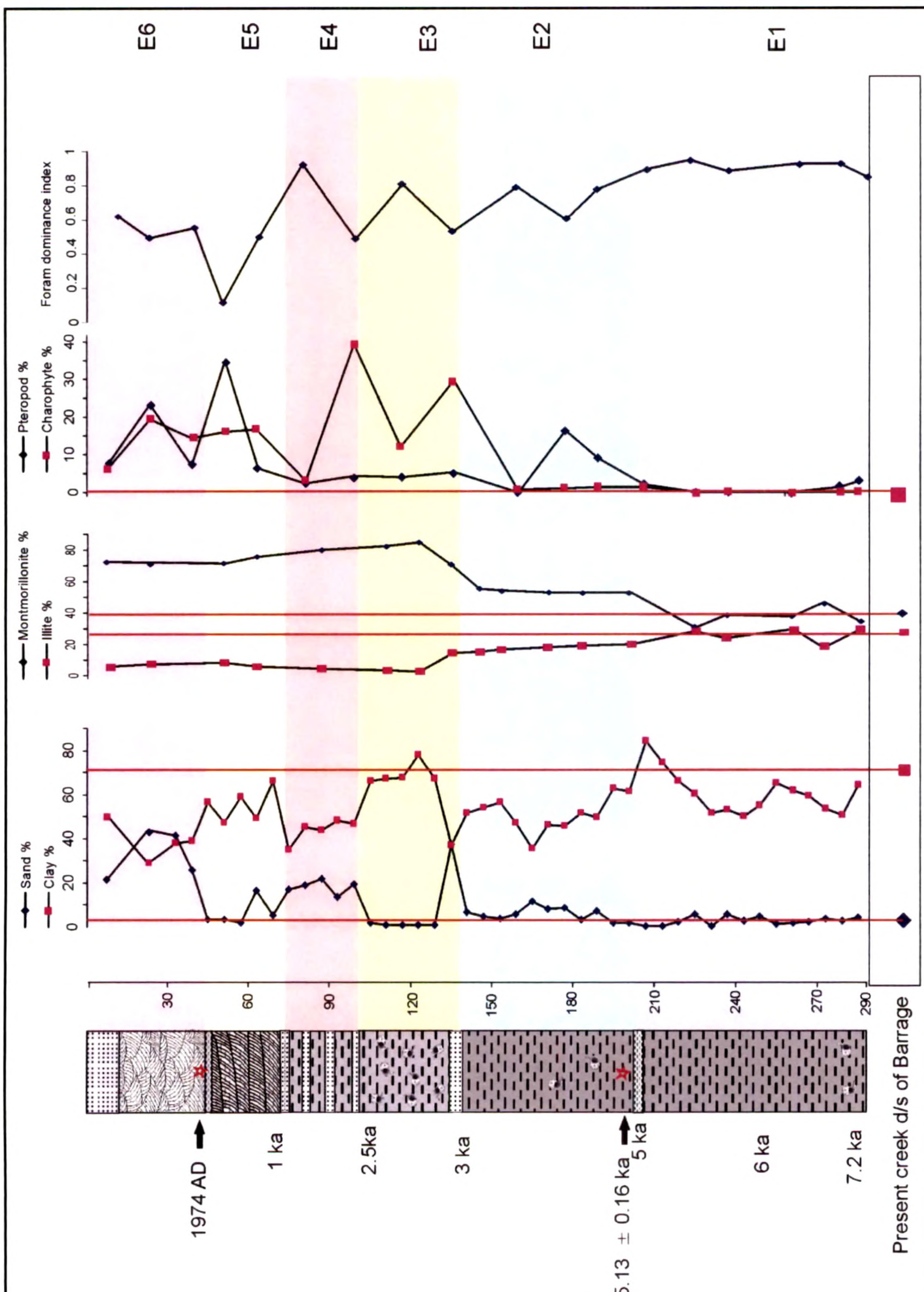

Figure 6.3 Variation diagram of sediment texture, clay minerals, ptreropods, charophytes and foraminifera dominant index manifesting various events along the profile.

Collectively, these 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.

Event E2 (5 to 3 ka BP)

The first signature of reduced salinity and mixing of fresh water can be seen at the depth of 210cm. Although, the energy level did not increase to change the dominant sediment texture. Followings are the major observations.

1) Clay percent sharply increases to almost about 90%, that indicate the pre dominance of suspension load with relatively more bathymetric depth.
2) Increased clay is accompanied by the increase in percent of montmorillonite which indicate fresh water income, as it is largely contributed by the weathering of the basaltic rock in the upstream region.
3) First appearance of the charophytes indicates input of fresh water and reduction in saline conditions.
4) A dip in the relative amount of *Ammonia* sp is found compensated by that of the *Nonion* sp.
5) Relative increase in the intact and asymmetrical morpho-groups also points towards the inflow of the fresh water.

Event E2 marks the 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 within low energy estuarine environment.

Event E3 (3 to 2.5 ka BP)

At 140 cm depth, a sudden change can be seen in the water regime with reduced influence of the sea indicated by the following nature of the proxies.

1) Increase in sand % points towards an increased energy level.
2) Reduced illite % indicate towards reduced influence of the clay mineral transport from the offshore region.
3) Increased amount of charophytes is pointing towards an increase fresh water inflow.
4) A rise in the dominance of hard species of *Ammonia* sp. in comparison to the other foraminifera suggests reduced salinity.
5) Low proportion of angular and reworked forms indicates higher energy condition that could flush out the same.

The event explains a 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 unit up to 100 cm depth level indicates again reduction in the sand influx. However, presence of charophytes in good number indicates a continued income of fresh water and shallow water depth to facilitate algal growth.

Event E4 (2.5 to 1 ka BP)

Between 75 and 100 cm depth, this event has been recorded in terms of thin alteration of sand and clays. This characteristically represents a tidal flat environment inturn indicating lowering of the relative sea level. The observations are as under.

1) An equal proportion of charophytes and foraminifera suggests oscillating saline and fresh water conditions.
2) Illite has remained steadily at low with increased amount of sand that suggests lower influence of the sea.
3) A higher relative index of the symmetrical forms of foraminifera also suggests the tidal flat conditions.

E5 (1 ka BP to 1974 AD)

Event E5 starts at 75 cm depth and continues up to about 40 cm depth. This is marked by a reduced sea level and also a reduced fresh water discharge supported by the followings:

1) Increased clay percent with marginal amount of sand.
2) Reduction in charophytes as well as foraminifera indicate drier phase, not favourable for either of the species.
3) Presence of cross lamination in sandy clay that indicate seasonal/short duration increase in energy with very shallow depths.

The much shallowed tidal flat/creek with lesser fresh water input suggests a relatively dry period that could not support the saline as well as fresh water fauna. The age bracket overlaps with the medieval warm period and little ice age (300-500 years BP), indicating dryness in this part of the subcontinent.

Event E6 (since 1974 AD)

The top most 40 cm of the sediments has ripple drift laminated sand that suggests the increased fluvial activities and significant absence of tidal environment. This event can be considered as a result of construction of the barrage on Meda creek in 1974. The study clearly shows;

1) Increased percent of sand with minor amount of clay.
2) Dominant presence of montmorillonite as clay mineral
3) Presence of pollens of grass and other swampy vegetation.
4) Increased amount of pteropods and charophytes against much reduced foraminifera.
5) Increase in reworked foraminifera from the older rocks

On comparison with the present day creek bottom sediments, the contrast between the upstream and downstream of barrage sub-environments becomes much distinct. The downstream barrage sediments show a record of much saline, lagoonal environment with an increased amount of clay in the top. The absence of charophytes and pteropods, and high population of foraminifera along with the relatively higher amount of illite further indicate a strong influence of the tidal creek conditions against the seasonally inundating upstream area.

Table 6.1 summarises the record of the shallow subsurface sediments from the study area and its importance in the light of the studies from the adjacent Dwarka area.

Though the present findings have more relevance to the sea level fluctuations, it also helps to understand the climatic variations during the same age span, based on the biological proxies and sand to clay ratios. Lower part of the section contains diverse foraminifera indicating high sea level which also relates to a wetter climatic condition.

Table 6 1 Summary of the Holocene history inferred out from the subsurface sediments of ancient tidal flat associated with the Meda creek

Description of Events	Age	Holocene sea level evidences by archaeological findings at Dwarka (Gaur *et al* 2007)
E6: Barrage construction lead to cross laminated sand due to fluvial activities.	1974 AD	Around medieval period (10th century AD), the sea level reached the present state
E5: Low sea level with less discharge of fresh water and shallow tidal creek/flat. Dry climate in the catchments is indicated by low floral-faunal density.	1 ka to 30 years back	
E4: Tidal flat environment with lower sea level	2.5 to 1 ka	After 2300 yrs BP, the sea level fell by 2 to 3 m along the Bet Dwarka coast.
E3: There is a sudden change in the water regimes from sea dominated environment to lower salinity tidal flat environment.	3 to 2.5 ka	Sea level continued at the high state from 3500 to 2300 yrs BP
E2: A reduced but still higher sea level with mixing of fresh water by an increased fresh water inflow.	5 to 3 ka	Sea level was higher than the present one at around 6000 yrs BP and remained there until 3500 yrs BP.
E1: High sea level with deeper nature of the creek.	7 to 5 ka	

A comprehensive review made by Madella and Fuller (2006) on various palynological evidences from various water bodies in western India, has shown good monsoon during 7000 to 4000 yr BP, which continued with a lesser intensity up to 2008 yr BP, after which the region experienced a prolonged aridity, leading to arid and semiarid climatic conditions as existed in 19th century. One can visualise the signatures of the same in the present study. As mentioned earlier, the lower part that span from about 7000 to 5000 yr BP suggests a wetter climate that has followed by fluctuating energy conditions with receiving the inputs from the landward areas and shallowing of the creek. Around 2500 yr BP the Meda creek has experienced much shallowing with reduced income of freshwater from the landward side that resulted into paucity of biota both, typically marine foraminifera and brackish water algae (charophytes) till 1974 AD. Figure 6.4 depicts the comparative studies from the other parts of the world and significance of the present one in the context. Accordingly, relatively higher sea levels have been marked around 7000, 6000 and 4000 yr BP (Bitinas *et al* 2004; Gelumbauskait and Seckus 2005; Balsillie and Donoghue 2004; Blum *et al* 2001). Similarly most of the studies have reported a reduced sea level around 3000 yr BP. These are reflected in the preset study, as shown in figure 6.4.

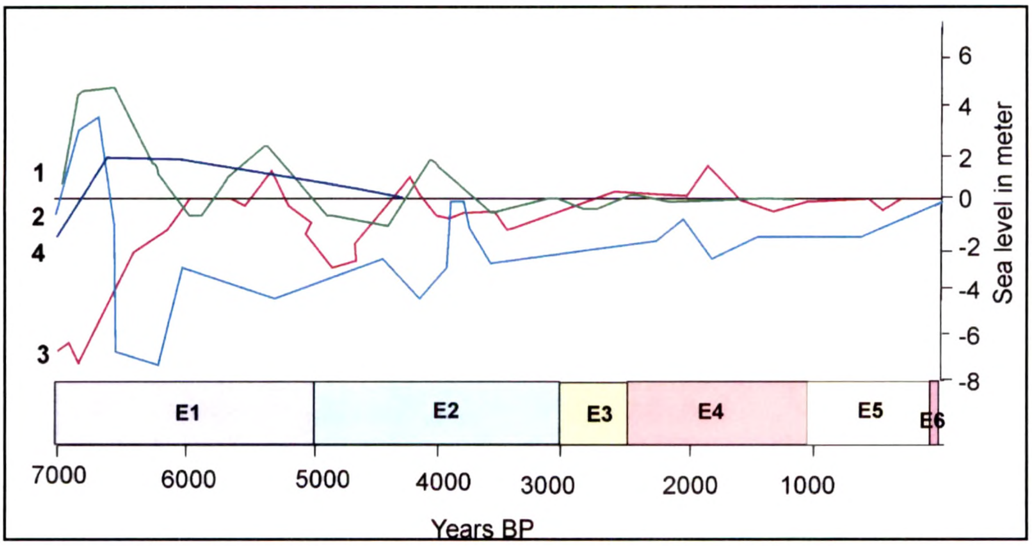

Figure 6.4 The Holocene sea level curves (1) Baqltic sea after Gelumbauskait and Seckus 2005, (2) Baltic sea after Bitinas *et al* 2004, (3) Gulf of Mexico after Balsillie and Donoghue 2004 and (4) Albama coast after Blum *et al* 2001. The events inferred from the present study are compared with these curves to appreciate the same at global context.

A minor increase in the sea level around 2000 yr BP has also been observed, particularly on the Pacific coast (Bitinas *et al* 2004; Balsillie and Donoghue 2004; Blum *et al* 2001). However, this high sea level is not reflected in the present study. The observations from the adjacent areas as well as along the west coast of India have also not recorded the same (Gaur *et al* 2007, Mathur *et al* 2004, Hashmi *et al* 1995).