Chapter 6

Evolution

Quaternary Sea Level Changes

The Quaternary period is characterized by rapid and large scale sea level changes that have left behind traces in the form of a variety of coastal landforms. Morphostratigraphic studies of such landforms unravel episodic evolution of the landscape that is a net result of regional and local geological processes remained operative on varying timescale Sea level change is prime geological process that always had a profound effect on the geomorphic evolution of any coastline, including the coastal fluvial system, especially during the Quaternary time. The study of changes in the relative position of the sea with reference to the land during this time also provides sounder basis for the prediction of the future sea level changes and their consequences (Pirazzoli et al., 1989). A wide spectrum of the reasons behind sea level fluctuation includes melting and locking of ice sheets in the form of glaciers, alternation of oceanic currents and ocean volume, long term meteorological processes taking place due to the orbital position of the earth in space and also the crustal movements (Williams et al., 1993).

Being attached with the sea, the coast can not remain passive to the change in the sea level and so, the natural morphodynamics of coasts, especially low-lying areas, have been commonly investigated to study the sea level changes (Bird, 1993). The Quaternary sea level changes and neotectonic activities have been studied globe over as a causative mechanism of the evolution of many coastal areas of the world; the coastal landforms

and lithosomes, its sedimentological characteristics, stratigraphic correlations, studies of the coastal river basins, palaeoecological changes, etc. have remained popular tools for this purpose (Lajoie, 1986; Fairbanks, 1989; Trainhail, 1989; Pirazzoli & Salvat, 1992; Carter & Woodroffe, 1994). Unlike the continental records, the ocean-floor sediments provide undisturbed records of the changes in palaeoenvironment. For such purpose, the oxygen isotope measurements from the calcareous shells of foraminifera have been used as a proxy to temperature changes in the oceans. During the glacial period oceans become more enriched in the heavier oxygen isotope (^{18}O) as the lighter one (^{16}O) gets locked into the ice sheets. The formaminiferal tests are capable of preserving the record of this. Although, the sea level curves obtained by oxygen isotope measurements vary from region to region and have certain limitations, they provide the best approximation for the sea level changes (Firth, 2000). There are some standard and most referred oxygen isotope curves available indicating the prominent glacial and interglacial climate stages during the Quaternary Period (Fig. 6.1).

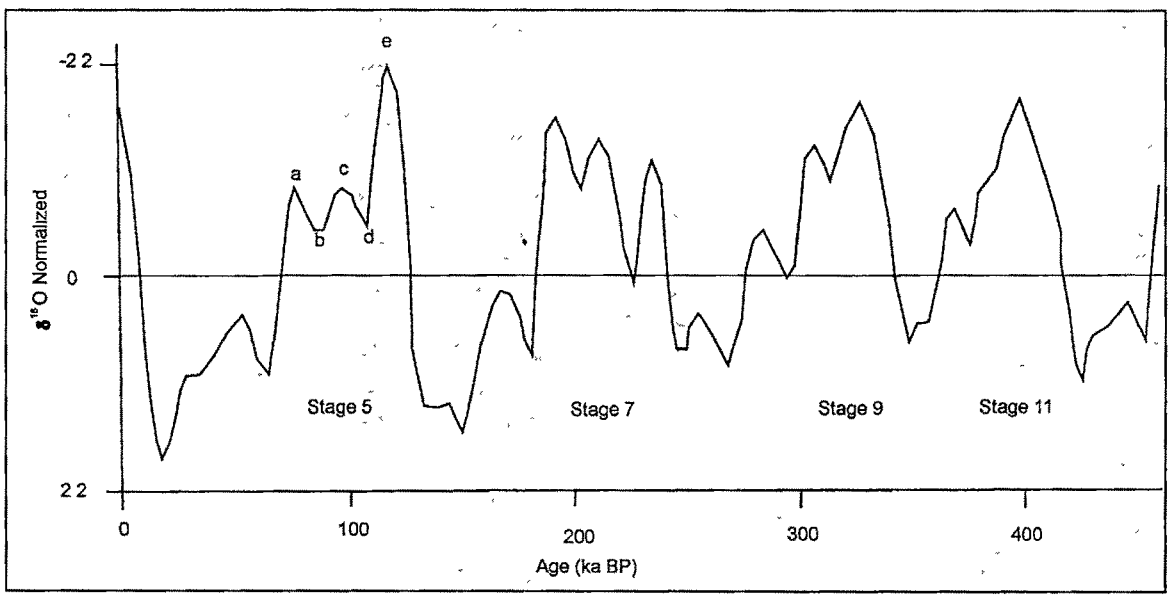


Figure 6.1 Marine oxygen isotope curve after Imbrie et al., (1984) showing various isotope stages, A proxy record of sea level high and low stands.

Quaternary sea level changes have been studied from tectonically stable regions like Bahamas & Bermuda which are also considered as 'tide gauges of the world' to differentiate the role of neotectonics in reading the palaeo-sea levels (Vacher & Hearty, 1989). Similarly, studies also exist from unstable regions like Barbados, New Guiana, Greece, Mediterranean regions and Italy where tectonically uplifted records of sea levels have been used to derive the past sea levels (Pirazzoli, 1996). Recently, Zazo (1999) has reviewed the occurrences of the interglacial high sea levels from the areas like Bermudas, Bahamas, Italy, Chile, Peru and Spain that are located in different geodynamic settings. Accordingly, during the marine oxygen isotope stages 1, 9, 11 and 5 the sea level remained higher, but so similar that its topographical height can not be confidently concluded. However, the isotopic substage 5e has been widely accepted to reach up to +6m to +7m above the present mean sea level at 125ka BP (Chapell & Shackleton, 1986; Bard et al., 1990 & 1993)

Pleistocene records for sea level changes have been presented from Bermuda since long back (Sayles, 1931). These records are in the form of complex mosaic of carbonate aeolianites, marine limestone, protosols and palaeosols (Vacher & Hearty, 1989). Based on a better chronostratigraphic control utilizing the radiocarbon, uranium-series and amino-acid recimization methods, a comprehensive model of the the morphostratigraphic evolution of the Bahama islands has been proposed (Hearty & Kindler, 1994; Kindler & Hearty, 1995) Accordingly, the oldest event that is dominated by the aeolianites formation has been assigned the age range of 300 to 400 ka which represents the oxygen isotope stage 9/11. The younger carbonate deposition event which falls in the age range of 100 to 85 ka corresponds to the oxygen isotope stage 5 (substages 5c & 5a). A well studied record on the Bahama pertains to the substage 5e

(140 to 120 ka) that suggests the occurrence of +6m high sea level. This has been supported with the ages of corals from shallowing upward sequences of oolitic-peloidal deposits from the northern Bahamas (Neumann & Moore, 1975).

The occurrence of +4m high oxygen isotope substage 5e sea level in the form of coral and oyster reefs, typical beach and lagoonal lithofacies as well as the geomorphic features like marine terraces has been reported along the Indian coast in general, and the Saurashtra, in particular (Brückner et al., 1987; Bruckner 1989).

The geomorphic, geologic and tectonic characteristics of the Late Quaternary deposits from the Saurashtra coast have been investigated under the present study to unravel the spatial changes in the land-sea interface in the region. For the purpose linkage between the sea level changes and the coastal as well as fluvial geological records has been established and the same has been interpreted in light of the available geochronological data on the carbonate deposits of the study area.

Links of the Coastal Records to Sea Level Changes

The coastal tract of southwestern Saurashtra consists of chiefly the organogenic carbonate deposits much popular as the miliolites A closer field investigation of these carbonate sequences have shown more than one episode of their formation (Patel & Bhatt, 1995). In general, there occur three distinct and separable carbonate sequences, each being separated by a prominent stratigraphic break. The oldest sequence is characterized by its recrystallized nature and relatively reddish brown colour (5YR 6/4 to 5/6). This sequence rests unconformably over the fossiliferous clays and marlstone of the Gaj Formation and the recrystallized dark brown coloured (5YR 3/2 to 3/4) pecten and oyster shells bearing limestone of the Dwarka Formation. This unconformity forms a

major geomorphic surface in the region that separates the Neogene landscape from the Quaternary succession with locally occurring palaeosols. The first coastal carbonate sequence has a coarse grained cross bedded and recrystallized shell limestone unit that has been referred to the unit-1 in the previous chapters. Based on its lithological similarities with the limestone of the Dwarka cliff, earlier workers have considered them to be the Dwarka Formation. However, in absence of the discovery of any typical Miocene fossil so described from the type area, Bhatt (2004) considered this sequence to be representing the oldest Quaternary transgression, signature of which occurs up to 40m amsl in the Porbandar – Veraval area. A prominent geomorphic surface developed over this oldest Quaternary carbonate sequence is characterized by a wide spread occurrence of red coloured palaeosol (*Terra Rossa*) formed due to the chemical weathering of this limestone unit under the meteoric environment The palaeosol unit exhibits varying thickness, maximum up to 2m, being better exposed at the base of the majority of the coastal cliffs on the southern coast of Saurashtra. In the Diu – Veraval area, however, this palaeosol unit crops out in the coastal plain but occurs at much deeper levels in the coastal miliolite quarries. The middle sequence which is composed of the unit-2 and unit-3 is comparatively better sorted medium to fine grained and diagenetically less altered. This has been widely referred to as the Miliolite Formation, *sensu stricto*. Although, the unit-2 occurs as patchy inliers having limited thickness, the unit-3 occurs spanning over a wide area along the coastal tract and reaches to about 35m of thickness in the study area. The sequence starts with a relatively coarse grained shell limestone (unit-2) at the base that has been encountered at deeper levels in the coastal quarries. The sequence is also found consisting of minor breaks in the deposition as shown by a thin erosional surface, protosol layers and/or abrupt termination of the cross-stratifications

that is common in the coastal aeolianites. It is therefore, more likely that the formation of this second coastal ridge that has yet been linked to the higher sea levels could be better linked to an oscillatory regressive sea and/or stand still having its beaches near to the present shore or even offshore wards. This is further supported by a dominantly aeolian nature of the sequences and occurrences of partly submerged aeolianites made up of this limestone unit. The youngest consolidated carbonate sequence is typically consisting of the poorly sorted, coarse grained shell limestone (unit-4) that unconformably lies over the middle sequence, and is lithostratigraphically designated as the Chaya Formation. Prominent occurrences of the erosional coastal geomorphic features like raised shore platforms, cliffs and tidal notches developed in the older miliolite sequence providing the substrate to this shell limestone sequence link its formation to a higher sea level that has reached up to 4 to 5 m elevation almost all along the Saurashtra coast. At places like Mithapur, Madhavpur and Mangrol, the sequence also consists of dead coral reef assemblage (unit-5) having characteristic massive corals like *Favia* sp. In the Dwarka-Okha area these lithological variants are mapped in detail and are designated as the Okha Shell limestone Member and the Aramda Reef Member by Bhatt (2000). The characteristic low angle planar and trough cross-stratifications, asymmetric ripple marks, algal mats associated with the sediments, biogenic structures and textural as well as compositional nature of this carbonate sequence confirms its inter- tidal to supra-tidal deposition. In light of the available radiometric and ESR dates, the occurrences of this typical marine unit at higher elevation than the present shore have been linked to the last interglacial (Bhatt & Patel, 1998). The typical mound like occurrences of white coloured miliolites showing curved dune beddings and resting over the carbonate units 1 to 5, represent aeolian deposition of the sand derived from this high sea shore. This has been

described as the unit-6 in the previous chapters Along the south Saurashtra coast, the occurrence of unit-4 & 5 are not common. This high sea is better recorded in the form of tidal notches, shore platforms and marine benches mainly developed in unit-3 (Fig. 6.2).

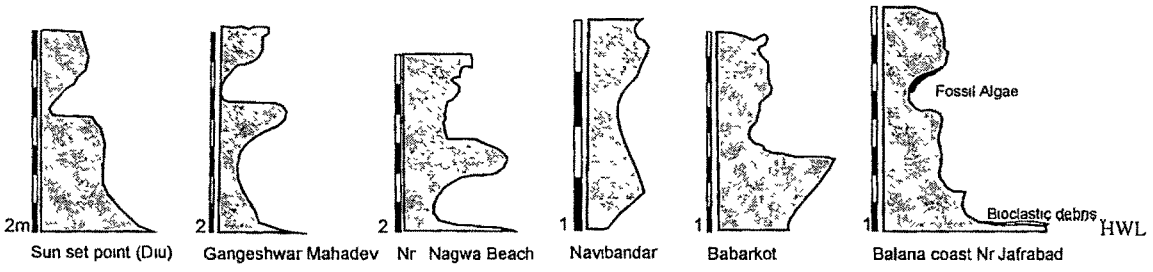


Figure 6.2 Profiles of various cliffs and associated tidal notches exhibiting former sea levels along south Saurashtra coast

The semi-consolidated bioturbated beach sand (unit-7), vast palaeo-tidal flats (unit-8) and stabilized coastal dunes (unit-9) form the top most sequence in the study area that occurs about 2 to 3 m amsl, representing the Late Holocene marine flooding. The available radiometric dates (Table VI.1) of oysters occurring up to +2m amsl support this A prominent geomorphic surface over the older Quaternary units forms an unconformity below this Holocene event The carbonate sequences have been attempted for radiometric dating by the scientists of the Physical Research Laboratory, Ahemedabad. Some dates are also made available by the other workers. Table VI.1 summarizes the available geochronological data. Some of these dates have remained controversial due to the diagenetic alterations in these deposits, and also the dating being done mainly of the bulk rock instead of a single shell extracted out of it (Brückner et al., 1987; Gupta, 1991). However, considering these dates being considerably underestimate, it is possible to make use of it at least in establishing the order of events.

Table – VI 1 Summary of the available radiometric dates of the coastal carbonate deposits of Saurashtra (All are $^{230}Th/^{234}U$ ages unless otherwise specified)

Reference	Location (Height in m)	Material	Age in ka BP
Gupta & Amin (1974)	Dwarka (2) Okha (2 9) Armada (7) Bhim Rann (7)	Coral Coral Coral Coral	6±0 2 113±4 34±2 123±9
Somayajulu et al. (1985)	Armada/Dwarka (2 – 4) Bhim Rann (2 – 6)	Coral Coral	6 – 7 118 – 176
Brückener et al. (1987)	Chorwad(4) Mangrol (5) Porbandar(4) Porbandar(4) Chorwad(5)	Shell Ostrea sp. Tellina sp. Shell Tellina sp. Shell	82.1 86.0 37.3 105+10% E 94.9 S 115 R
Baskaran et al. (1987)	Between (6) Veraval and (20) Madhavpur (26) (40) (55)	Miliolites	52+3 2-3.1 168+22-18 65.4+5.5-5.2 235+36-27 177+19-17
Baskaran et al. (1989)	Various parts of Saurashtra(1-300)	Miliolites	56-70(MI) 75-115(MII) 140-200(MIII)
Juyal et al. (1995)	Harshad (13) Patan(12) Porbandar(1) Porbandar(2) Rupen River(2) Chikhali(4) Diu (2) Jafrabad(3)	Oyster Oyster Clam Shell Clam Shell Oyster Oyster Oyster Oyster Oyster Oyster	126 5+8 5-8.0 119.5+9.7-9.0 129.3+10.7-9.7 132.7+11.0-10.0 2.5 ±0.2 3.3 ±0.2 87.2+9.7-9.0 71.1+6.2-5.9 6.4 ±0.7 8.6 ± 0 6
Mathur & Pandey (2002)	Mithapur (2.73 – 4.2)	Gastropod (Turbo) Coral (Favia)	18.3 ±0.085 41.2 ±0.50 (AMS ages)
Bhatt (2004)	Sarkeshwar (4) Sarkeshwar (2.7) Khada (1) Zala Vadodra (3)	Algae Oyster Oyster Horn	13.92 ± 0.18 26.54 ± 0.31 3.47 ± 0.11 2.28± 0.10 (Radiocarbon)

Accordingly, majority of the molluscan shell dates indicate signature of the high sea pertaining to the oxygen isotope stage 5. These shells were mainly extracted from the litho unit-4 that constitute the beach ridge three and hence, the beach ridge one and two have to be predated to the stage 5. On comparison with the standard sea level curve of Shackleton (1987) and that of Kindler & Hearty (1995), the geochronological data available and various geomorphic and geological units of the study area suggest their links with the interglacial higher sea levels of stage 9/11, 7, 5 and 1 (Fig. 6.3 and 6.4).

In absence of high resolution chronological data, however, it is not possible at present to differentiate the substages from the coastal records; a possibility of such attempt still remains open.

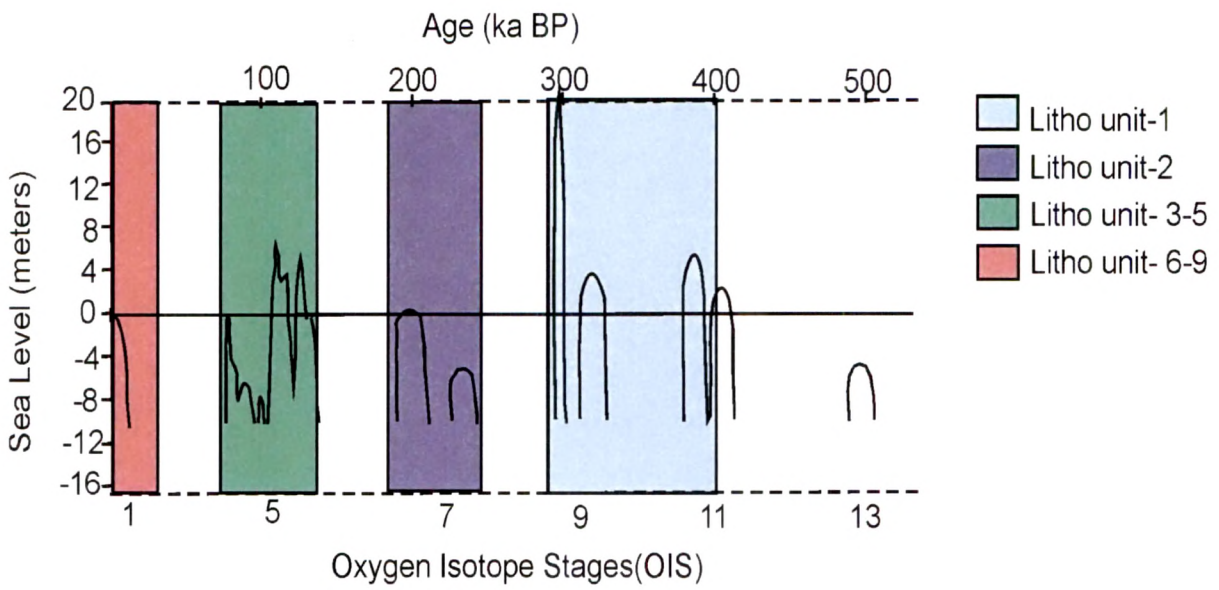


Figure 6.3 Plots of litho units encountered in the coastal carbonate sequences of the study area on the sea level curve of Kindler & Hearty (1995), on the basis of available chronological data and associated bias.

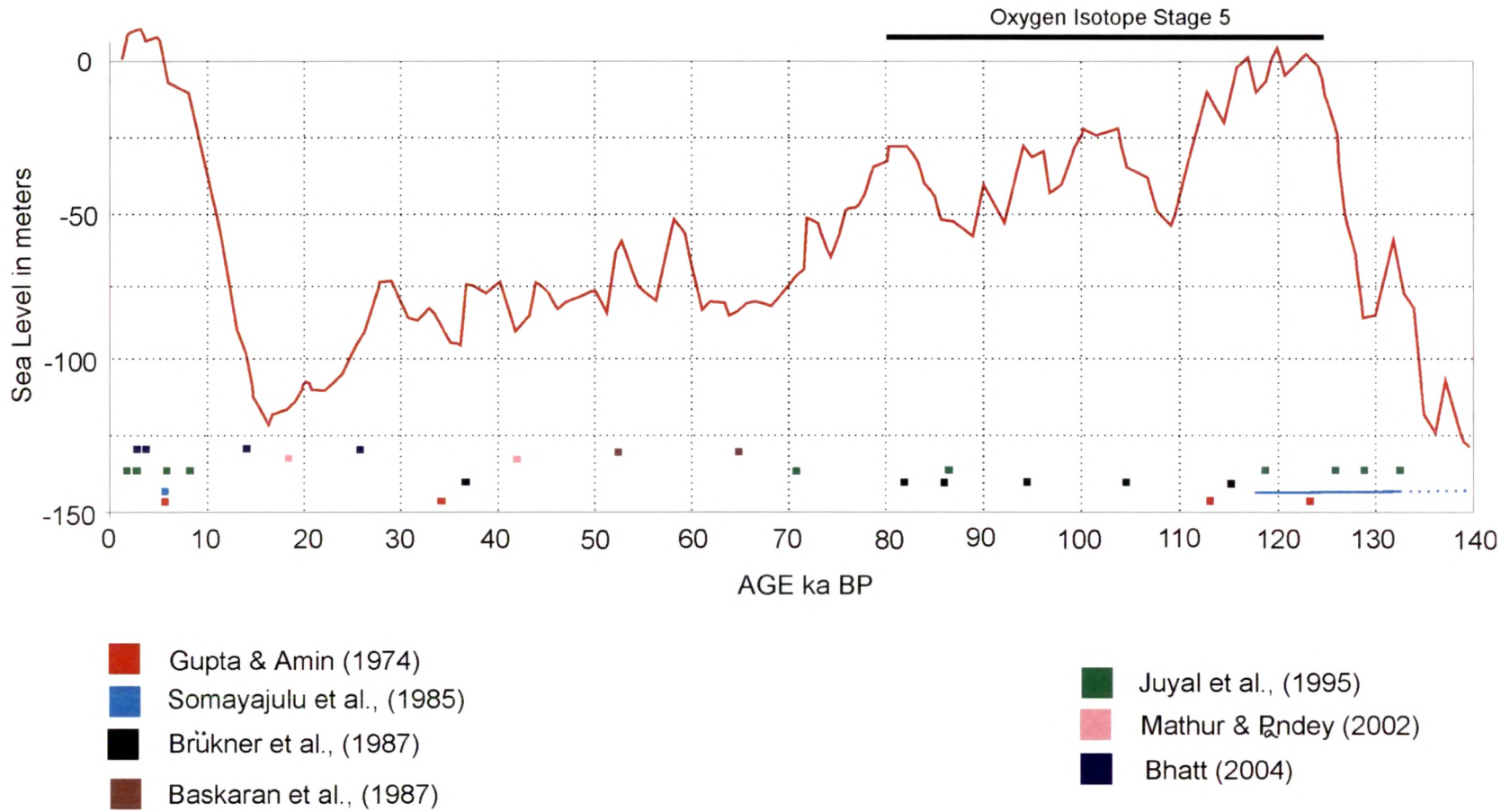


Figure 6.4 The available geochronological data shown in Table VI.1 are plotted on the sea level curve after Shackleton (1987).

Links of Fluvial Records to Sea Level Change

Late Quaternary fluvial sequences of south Saurashtra are composed of gravelly and sandy units which have been classified in to Gt, Gh, Sp, Sm, St and Sh facies Table VI 2 summarizes the facies identified in the fluvial sequences of southwestern Saurashtra and also its probable time range In general, the fluvial sequences of the study area suggest two distinct aggradational phases separated by a profound break. The Gt facies has manifested this, and so it is subdivided in to Gt1 and Gt2 facies on stratigraphic consideration The Quaternary record begins with the P1 facies exhibiting typical vertisolic characters, over the pre-Quaternary substrate suggesting a stable landscape that allowed a fair degree of pedogenesis of the Late Cretaceous volcanic rocks and the Neogene sediments. The Gt1, sharply overlying this palaeosol unit, is related to the first phase of fluvial aggradation during Quaternary time. In absence of any geochronological data from the equivalent unit in the region, it is difficult to ascertain the age difference between the pedogenesis and deposition of these gravels. This facies is associated with the Sp facies that does not contain bioclastic carbonate sand. Together, Gt1 and Sp facies constitute a sequence typically of ephemeral stream that could deposit the gravels as channel-fills and sand as overbank deposits (Miall, 1996). P2 facies suggests termination of this; however, its limited extent and less prominent soil peds with absence of any pedo-horizon perhaps suggest a lesser degree of pedogenesis and/or drier climate. This palaeosol unit in the coastal area is capped by a prominent marine flooding event recorded in the form of bioclastic carbonate dominated sand (Sm facies), biogenic structures, tidal clays, coarse grained bioclastic limestone, etc. The Sm facies that occurs for a considerable distance and elevation (~50 km & 80m amsl) upstreamwards, but their physical characteristics and higher detrital content indicate a fluvial reworking of the

carbonate sand. A palaeosol unit, equivalent to P2 facies in the rivers studied, has been reported occurring at the base of coastal miliolite sequence of south Saurashtra; the Late Acheulian tools occurring over this soil unit were considered to be of late Middle Pleistocene age (Marathe et al., 1998; Patel and Bhatt, 1995) The gravelly unit (Gh facies) at the base of Hiran river sequence has yielded Early Acheulian tools that has been dated older than 196 ka (Baskaran et al., 1986). This unit is correlated with the Gt1 of Bhadar river. The U-series ages of the carbonate sands – miliolite limestone (M-II 75 to 115 ka) lying above the Gt1/Sp and P2 facies suggest linkage to higher sea level of the oxygen isotope stage 5. This has been followed by another phase of fluvial aggradation recorded in the form of Gt2 facies that shows local variation in to Gh and Sp facies of limited extent. The sequence is covered by Fl facies, commonly occurring in the rivers of study area that can be linked to the late Holocene fluvial aggradation.

Table – VI 2 Summary of the lithofacies of fluvial sequences of south Saurashtra

Lithofacies	Description	Remarks
Fl	Mainly consists of silty sand facies, feebly pedogenetically altered at top. Mostly structure less semi-consolidated in nature.	Related to the youngest fluvial aggradation. (Holocene to Recent)
Gt2	Relatively thicker unit dominated by basalt clasts, and few chalcedony and limestone clasts. Grades locally into Sp facies.	Has yielded Middle Palaeolithic tools at Jetpur older than 56.8 ka.
Gh	Mainly basaltic and limestone clasts.	Locally developed facies.
Sm	Medium to coarse sand, dominated by allochems. Biogenic structures are present. It is similar to the miliolite limestone.	Equivalent miliolites have U-series age range 75-115 ka.
P2	Pedogenetically altered top of the Sp facies shows presence of rhizocretions. Lighter in colour and also occurs above Gt1 facies.	Lower Palaeolithic tools are reported from this unit from south Saurashtra coast.
Sp/Ss	Medium to fine sand locally occurs as scour fill gravelly sand.	Associated with Gt1 facies.
Gt1	Comprising mainly of basaltic clasts.	Early Acheulian tools recovered in Hiran river are dated >196 ka.
P1	Mainly vertisol developed over the Deccan Trap basalt, and in places, over Gaj limestone.	Oldest palaeosol found on pre-Quaternary substrate.

Stages of Geomorphic Evolution

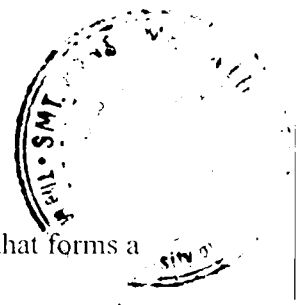
In view of the radiometric dates and the morphostratigraphic relationship between the identified coastal sequences, and also the detailed study of the fluvial sequences from the coastal rivers, the following sequential stages of evolution of the Saurashtra coast have been proposed.

Stage 1

A wide spread geomorphic surface (Geosurface – 1) has been developed over the Neogene and older rocks that represents a geological hiatus pertaining to the early Quaternary time. In the coastal areas of Saurashtra, it is characterized by the denudation and pedogenesis of the Deccan Trap and Gaj – Dwarka Formations. The palaeosol P1 facies in the fluvial sequences represents this event.

Stage 2

The first marine Quaternary deposition perhaps took place during the oxygen isotope stage 9 and/or 11 as they rest unconformably over the pre-Quaternary rocks forming a distinct beach ridge occurring at about 20m amsl which is the inner most occurrence of any coastal geomorphic feature in the study area. Its linkage to the stage 9/11 is based on the oldest radiometric dates on Quaternary carbonate deposits of the region being older than 200 ka (Baskaran et al., 1987 & 1989) These have been considered as the significantly underestimated ages as the sediments clearly show highest degree of diagenesis i.e. recrystallization and completely occluded intra and inter granular porosity. The higher sea level also suggests a better monsoon condition that could result in to a continuation of the fluvial aggradation as can be seen in the form of the Gt1 facies occurring at the same stratigraphic level in the higher reaches of the rivers. The early



Acheulian tools have been discovered from this unit in the Hiran river valley that forms a base to the overlying miliolite sequence dated to more than 196ka (Baskaran et al., 1987).

Typical marine carbonate sequence showing illustrative biogenic structures and other sedimentary structures like mud cracks comparable with the Unit-1 occurs at more than 60m amsl in Hiran, Saraswati and Singwado river. The global standard sea level curve suggests almost equal to the present day or slightly higher position (Zazo, 1999) during the oxygen isotope stage 9 & 11, whereas, the occurrences of this high sea at +20m have been reported from Bahamas by Kindler & Hearty (1995). In this regard, the occurrence of unit-1 at higher levels (20m and above) suggest a neotectonic uplift of this part of the land after its deposition.

Stage 3

The unit-1 was subjected to a wide spread event of pedogenesis that could develop a prominent red coloured kankary palaeosol occurring almost all along the southern and southwestern Saurashtra coast. The formation of palaeosol and intense karstification of the limestone sequence suggest a still wetter climate with a stabilization of the landscape that could develop the Geosurface-2. The fluvial record, therefore, indicates a continuation of the deposition of gravels and sands. The sea level must have remained lower for a considerable time that can be perhaps equated with the oxygen isotope stage 8. This is further substantiated by the discovery of the Lower Palaeolithic tools from the top of the palaeosol occurring almost at the sea level from Madhuban, near Gopnath (Marathe et al., 1998).

Stage 4

The sea level might have reached to the present level or slightly above, but with an oscillatory nature to give rise to the Unit-2 & 3 that constitute the beach ridge two in the coastal area A significant amount of carbonate sand production and its periodic exposure gave rise to a thick accumulation of aeolianites (unit-3). Minor breaks in the stacking of these aeolianites and occurrence of shore parallel beach ridges substantiate the inference. The typical marine unit (unit-2) occurring at the base of the coastal aeolianites consists of gravels of not only the Neogene limestones but also those of the Unit-1.

Stage 5

The Geosurface-3, yet another prominent geomorphic surface that occurs all over the region characterized by a significant erosion of the older carbonate sequences developed during this stage. However, unlike the Geosurface-2, this has not involved much pedogenesis. It seems that the period must have remained significantly drier to not to form any prominent depositional event. A thin protosol and/or duricrust layer has formed locally over the older limestone sequences.

Stage 6

A prominent marine flooding in the region has been recorded in the form of shell limestone (unit-4) and dead coral reefs (unit-5) occurring unconformably over the older sequences all along the western and southwestern Saurashtra coast. This occurs at an elevation of about 4-5m amsl and has been linked with the oxygen isotope stage 5. On the southern coast of Saurashtra, the event is better recorded in the form of raised shore

prominent occurrences of aeolianites (unit-6) that have dotted the coastal plain of southwestern Saurashtra were deposited during this time as the type occurrences (Una-Kodinar) fall within age range of M-I (56-70 ka) of Baskaran et al. (1989).

Stage 7

The LGM has resulted in to the formation of yet other prominent geomorphic surface that is characterized mostly by the erosion and partially by the formation of thin duricrust over the coastal sequences. The fluvial sequences show characteristic incision in the coastal plain and a possible off shore ward extension of the streams. The investigations by the NIO group (Rao et al. 1996; Chauhan et al., 1993 and references therein) have indicated at drop of about 110m in the sea level during this time. Some marine geoarchaeological investigations in the Dwarka area have shown the sea ward extension of the Gomti river (Vora et al., 1991).

Stage 8

A rapid rise in the sea level since LGM has been well demonstrated from the globe over. Along the Saurashtra coast the marine flooding pertaining to the Holocene has been recorded in the form of raised tidal flats, semi-consolidated beach sand and associated stabilized dune fields. The radiocarbon dates of oysters occurring at 2 to 3 m amsl in the coastal streams like Saraswati, Rupen and Machchhundri have indicated two different transgressions, one linked with the early Holocene (~ 10 to 12 ka) and another linked with the late Holocene (2 to 3 ka). The geomorphic features like raised tidal flats and sandy ridges along with archaeological evidence like Harappan port towns have been linked with the Holocene transgression reaching up to +6m elevation (Patel, 1991a;

Merh, 1992; Pandya, 2001). Some of the tidal notches and associated shell debris occurring along the south Saurashtra coast can also be linked with this Holocene high sea level; however, Pant & Juyal (1993b) have suggested that the remnants of Holocene high sea remained overprinted by the tectonics in this part of the study area.

Table VI.3 summarizes these sequential stages of geomorphic evolution of southwestern Saurashtra coast based on a comparative study of the coastal as well as fluvial sequences.

Table VI.3 Sequential stages of geomorphic evolution of the southwestern Saurashtra coast.

Stage	Description	Probable Age
Stage-8	Semi-consolidated bioturbated beach sand and tidal flats associated with partially lithified dune sand occurring at ~2-3m amsl represent a marine transgression. Fluvial sequences consist of Fl facies and channel gravel deposits.	Holocene (OIS 1)
Stage-7	Development of erosional surface characterized by a thin duricrust formation and mostly weathering of the older carbonate units. Incision of Gt2 facies and sea ward extension of coastal streams.	Late Pleistocene (LGM)
Stage-6	Chiefly coarse grained shell limestone and local occurrence of dead coral reefs (unit-4 &5) occurring at 4 to 5 m amsl formed commonly all along the southwestern coast. This marine flooding can also be traced in the coastal rivers. The Gt2 developed in the rivers demarcating a second aggradation phase.	Late Pleistocene (OIS 5)
Stage-5	Erosional surface characterized by recrystallization and thin duricrust formation on the top of the older coastal carbonate sequences took place. Incision of the Gt1 and Sm facies record this event in the fluvial sequences.	Late Middle Pleistocene (Beginning of OIS 5)
Stage-4	Thick accumulation of the coastal aeolianites (unit-2) took place keeping a pace with oscillatory regressive sea that could locally develop beach ridges and swale deposits (unit-3) in the vicinity of the present coast. The reworking of aeolian sand could form Sm facies in the rivers.	Late Middle Pleistocene (OIS 7)
Stage-3	Geosurface-2 characterized by wide spread red coloured palaeosol formation and intense karstification of the older limestone unit, developed. Formation of Gt1 continued with local Sp and Ss facies. Fluvial deposition extended shoreward with weakly developed P2 facies over Gt1/Sp.	Middle Pleistocene (OIS 8?)
Stage-2	The litho unit-1 comprising of reddish brown coloured recrystallized limestone with gravelly base deposited along the shore of high sea that could reach up to 20m amsl along southwestern Saurashtra coast. The Gt1 facies started depositing in the rivers because of the better monsoon conditions during this interglacial stage.	Early Middle Pleistocene (OIS 9/11?)
Stage-1	Major erosional surface (Geosurface-1) developed on the Neogene sediments and extended over the Deccan Trap basalts. The P1 faceis of fluvial record indicate a relatively stable landscape that permitted a widespread pedogenesis	Early Pleistocene