Trans. Inst. Indian Geographers

Late Holocene Geomorphology of Konkan Coast of Maharashtra

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Abstract

There are many conflicting field evidences of Holocene sea level changes along entire Konkan coast of Maharashtra. It was apparent in the field that the reported field evidences for Holocene sea level changes are unequivocal and that detailed topographic and stratigraphic studies of the coastal area would be required to elucidate the Holocene coastal evolution. These sea level changes were mainly recorded as configurational changes. The identification and mapping of coastal features along the coast reveal that during the late Holocene this coast was characterized by barrier spits, open inlets and estuaries. Wide dune systems comprising of fore and back dunes, mangrove swamps, abandoned and realigned spit bars and littoral terraces found almost everywhere on this coast suggest some degree of reorientation and configurational change in the late Holocene.

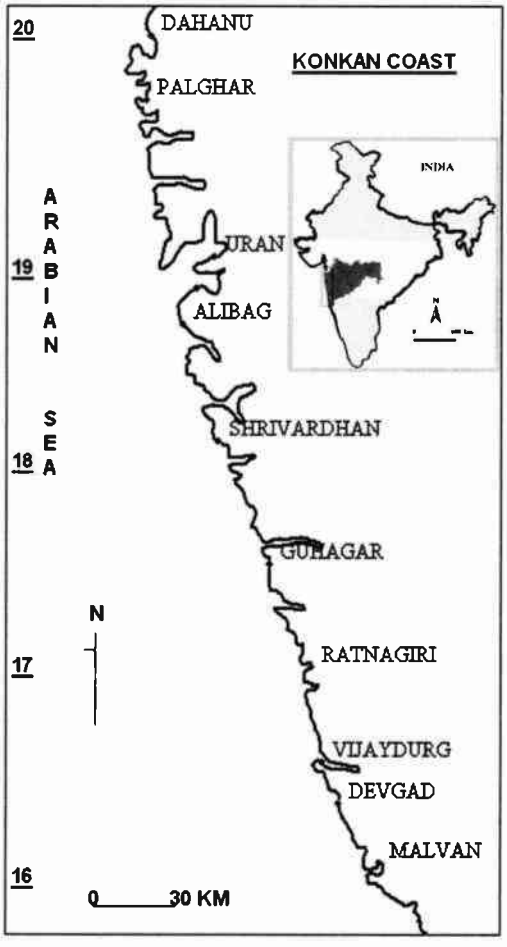
The estuarine systems on this coast matured during the late Holocene, with progressive sedimentation and seasonal inlet closure, leading to the dominance of mangrove swamps in the past 1000 years. Coastal configuration and features are interpreted to represent a mid to late Holocene high stand along this coast.

Introduction:

Significant reorientation of the coastline and coastal features including extensive coastal plains, barrier spits and beaches, estuaries and swamps, has occurred throughout the late Holocene (<4000 YBP) along the entire coastline of Maharashtra. This is in response to changes in sediment supply brought about by variations in sediment availability and/ or coastal hydrodynamics, together with sea level changes. Sediment availability has largely been furnished by the fluvial material delivered to the coastal zone and with a lesser proportion contributed by the erosion of nearby headlands. This has enriched the littoral sediment reservoir with clastics and in places realigned the coast and altered the hydrodynamic processes within the near shore littoral zone. In the late Holocene extensive coastal plain development occurred along the coast possibly in response to slight lowering of sea level.

The Holocene involves a considerable interplay between natural and anthropogenic factors and is a very complex geological period (Deo et al 2010). The timeframe of the Holocene in India is not yet well established. Belcher and Belcher (2000) propose a chronology wherein the period of Early Holocene is considered as 10 ka to 7 ka BP. Mid Holocene is considered to be a period from 7 ka to 3 ka BP and the Late Holocene is a period of last 3000 years BP. The present paper uses the period of last 4000 years as a Late Holocene on the basis of geomorphic features and available ^{14}C dates.

The changes on Konkan coast in late Holocene were mainly recorded as



configurational changes. Changes in the balance of erosion and accretion result in the horizontal displacements which are known as configurational changes (Chappell 1982). Coastal landforms such as beaches, old spits, dune ridges, tidal flats, mangrove swamps and raised terraces are produced due to such changes.

The identification and mapping of coastal features along the coast reveal that during the late Holocene this coast was characterized by barrier spits, open inlets and estuaries. Wide dune systems comprising of fore and back dunes at Diveagar (18.17/72.99), Mochemad (15.8/73.66) , Tambaldeg (16.29/73.41), mangrove swamps of Thane (19.24 / 72.97), Revas (18.79/72.93), Bankot (17.97/ 73.05), abandoned and realigned spit bars at Revdanda (18.55 / 72.93), Kalbadevi (17.04 /73.28), Ubhadanda (15.03/73.63) and littoral terraces found almost everywhere on this coast suggest some degree of reorientation and configurational change in the late Holocene.

Modern spits and beaches show seaward extension. New beaches have also formed in last 100 years. Redistribution of sediments and shallowing of river mouths is also seen. The area in the vicinity of Vaghotan (16.55 /73.34), Achara (16.19/73.44) and Gad creek (16.1/73.46) best preserves many features of late Holocene sea levels on this coast. Here, as elsewhere, landward margin of terraces are irregular and give an idea of configuration of earlier coastline. The prior estuaries probably maintained their configuration at least until 3800 YBP as suggested by ^{14}C dates from the defunct tidal basins (Deswandikar 2000).

The estuarine systems on this coast matured during the late Holocene, with progressive sedimentation and seasonal inlet closure, leading to the dominance of mangrove swamps in the past 1000 years. Kumaran et al (2005) have argued that optimum development of mangrove swamps has occurred during a period of better rainfall in early and mid Holocene. Late Holocene was relatively a dry but dynamic period (Shankar 2006).

Contemporaneous with the transition of open estuaries to mangrove swamps was the aggradation and progradation of coastal plains. The coastal progradation in late Holocene took place following the late Holocene sea-level high stand 2300 to 3800

yr BP. A slight relative sea-level lowering may have also contributed to the positive sediment budget. Recent erosion has exhumed portions of former shore platforms covered by thick mangrove peat which was dated to 680 years BP.

The beach rock ridge is a conspicuous feature that parallels the shoreline for over 3 km at number of places (Guzder 1980, Bruckner 1987, Ghate 2007, Karlekar et al 1998, Karlekar 2000, 2007, Rajaguru et al 2005). Lithified, seaward dipping beach dune ridges contain mineral sands and shell fragments most likely transported from terrestrial environment to the shore by nearby streams in late Holocene. Such fossil beach ridges could be seen along Dighi (18.27/72.97) Shrivardhan (18.05/73.0) coast of Raigad district. The beach rocks on the entire coast were lithified from beach sands deposited within the tidal range of sea level in late Holocene.

Study Area

Konkan ,the western littoral of Maharashtra, stretches from 15° 45'N to 20° N latitudes and 72° 44'E to 73° 41'E longitudes (Fig.1). It is a 60-km to 90-km wide coastal strip especially to the north of Mumbai. To the south of Mumbai it is a narrow coastal region of forest-covered hills, coastal plains and tidal creeks, fringed with swamps and river plains. The south Konkan has a thick and extensive cover of laterites. It is a shoreline broken by drowned river valleys, and small river mouth creeks and beaches. (Dikshit 1976, Karlekar 2009) It is separated from upland Maharashtra by a west-facing escarpment of Sahyadrian Mountains.

On the basis of, lithology, geomorphic configuration, nature of hinterland and climate, Konkan region of Maharashtra can be divided in to North Konkan, Middle Konkan and South Konkan

The climate of the area shows a regular variation on account of the alternating southwest and northeast monsoon. The weather on the coast is therefore more seasonal in nature. June to September is the season of southwest monsoon. Winds on the sea, in this period, are southwesterly and westerly. The winds on the coast, however, are mainly westerly. It is a season of general rains. October and November are marked by light winds. Occasional tropical cyclones may occur on the Arabian Sea in this period. The period from the end of southwest monsoon to its re commencement is usually identified as a fair weather season.

Waves, tides and modern coastal processes

Variation in sea waves and tidal waves, their intensity and frequency, their approach, height and persistence, are the main factors that influence the modern coastal processes along the Konkan coast. There is a remarkable north-south and seasonal variation in these attributes all along the coast. The variations are found to be site specific within the major regions.

Wind direction and wind speed also show definite trends from north to south. It is found that the waves are westerly in pre monsoon period on middle and south Konkan coast and north westerly on northern coast with a speed varying between 3 and 8 knots. The south Konkan experiences winds of 5 to 11 knots in this period. Monsoon is a period of westerly to southwesterly waves with a speed exceeding 10 knots along major part of Konkan coast. The wave approaches

and the wind speeds can change locally due to considerable refraction as the waves approach the indented shoreline. Waves become steeper near the shore especially during monsoon.

On the basis of wave heights two distinct seasons can be identified, namely, monsoon (June to September) and fair weather (October to may). Wave heights do not normally exceed 2 m in fair weather. In monsoon waves exceeding 5 m height are seen, especially along south Konkan coast. Long period waves, with a wave period of 10 to 12 seconds, dominate fair weather season. In monsoon wave period decreases to 3 to 6 seconds. Towards the end of monsoon wave period increases to 10 seconds indicating the arrival of swells.

The Nearshore Zone

The breaker zone near the shore is about 200 m wide from June to September and very high breakers are produced in this period. Wave breakers in monsoon are of spilling and plunging type. In fair weather breakers are characterized by low, surging or collapsing waves. The surf zone produced in monsoon is more than 200 m wide and considerably reduces to less than 25 m in fair weather.

The long shore currents measured at a few places show that these currents are significant especially south of 18 degrees north parallel. The currents are southeastwards in monsoon and move with an average velocity of 30 to 40 cm / s. In fair weather they are north northwestwards and have a velocity of 8 to 20 cm / s. The direction and the velocity of the long shore currents changes locally and they are mainly influenced by the local coastal configuration. North to NNW, currents are strongest in October and SE currents are powerful in July. In monsoon the nearshore area is also dominated by rip currents.

The Konkan coast experiences semi diurnal tides with a tidal range that varies from less than 2 m to more than 3.5 m. The tidal range gradually increases from south to north i.e. from 1.5 m at Redi to 5.4 m at Valsad. Tidal currents are very weak along the south Konkan coast. Here their velocity rarely exceeds 10 cm /s. Strong tidal currents with a velocity of 70 to 90 cm per second are recorded along the north Konkan coast.

Sandy beaches predominate the shoreline, but there are few mud beaches such as at Rewas and shingle beaches like that at Shekhadi. The sediment characteristics and the morphodynamics of these beaches are controlled mainly by specific wave and tide environment related to seasons and tidal range. Wide beaches with a well-developed berm and beach face are characteristic of fair weather period. The beaches are transformed to narrow beaches with steep to very steep beach faces in monsoon with varying degree of steepness and beach cutting.

Swash aligned beaches (Davies, 1977) on this coast are found along indented and irregular stretches. In some cases they are transformed to drift aligned beaches in monsoon.Sand dunes This is a well-marked and distinct feature of this coast. On the backside of many beaches primary dunes with characteristic wind ripples and parallel ridges of secondary dunes can be easily recognized. The embryo dunes, foredunes and backdunes are relatively more conspicuous at Diveagar, Kelshi, Tambaldeg, Mochemad and Velaghar. There is a great variability as regards their

morphology, orientation and the degree of preservation (Deswandikar et al., 1996).

Impressive sea cliffs, sea caves and shore platforms characterize the rocky coast of Konkan. These features are usually found along joints, cracks and other weaker sections of the rocky headlands.

The estuaries and creeks on this coast are distinct especially due to their tidal and fresh water regime. They also exhibit a complex pattern of sediment input. The tidal inlets to the south of 18 degrees north parallel are wave dominated. Northern estuaries have a strong tidal control. Most of the estuaries on Konkan coast are NW – SE oriented and suggest a structural control in the tidal sectors of the streams. In north Konkan, creeks and estuaries are found to be bar built and coastal plain estuaries. Lengthening of ebb conditions is an important aspect and is reflected in the tidal delay period (residence time) of about 1 to 2.5 hours (Karlekar, 1996). Imbalance between the length of the estuary and the contemporary tidal range is seen in the ponding of tidal water in mid portion of some estuaries like Kelshi and Anjarle.

The major sedimentary environments of Konkan creeks and estuaries are marsh and swamp edge, high and low tide flats, sand lenses, sand banks and islands and scoured channels (Karlekar et al., 1993). Mangroves are thickly vegetated intertidal estuarine wetlands, confined to silty bog formations on Konkan coast. They are restricted mainly to the sheltered shoreline zones regulated by tidal flooding.

Methodology

Topographic survey of near shore areas was conducted and sediment samples from terraces, beaches dunes and estuaries were analyzed. A few samples submitted for radiometric dating included beach rock sediments and mangrove peat. The dates already reported and available were also used for interpretation. The changes in terrain configuration were confirmed from Google and satellite.images.

This paper is primarily based on field observations supported by topographic interpretations. Due to lack of high resolution stratigraphic data, interpretations of littoral features are subjective and in some cases not precise.

Discussion

The coastal dune fields : The coastal dune fields at Diveagar (18.17 / 72.99), Mochemad (15.8 / 73.66), Tambaldeg (16.29 / 73.41), which are now stabilized, and occur in a high energy wind regime are found 200 to 700 m inland. Along the coast a narrow belt of 4 to 6 m high dune ridges is observed. These are gradually replaced inland by 10 to 15 m high irregular dune forms. Behind the dunes lies a large area of intertidal mud flats with fringing mangrove swamps.

There are no traces of fossil beach dune deposits covered under modern sand at these places. The sand in such dune fields originated from beach deposits. A large but pulsating supply of sand was available to beaches. The composition of such dune field deposits indicates that the periods of dune field growth alternated with dune field stabilization in late Holocene. The final phase of dune field growth took place in a period of relative low sea level and resulted in an increased availability of sand in the shore zone and high influx of sand in dune

field. These dune systems developed from an extensive sand stretch which existed in late Holocene.

Today the blown sand from the beach extends for only a km inland and settles at varying distances mainly producing embryo and fore dunes. A period of stability of ancient dunes appears to have occurred 3000 YBP.

The 10 to 15 m high dunes found beyond interdunal areas are essentially mid to late Holocene events on this coast. They are found where coastal configuration is conducive for their preservation, on a wide littoral plain (Plate 1 & 2 : see page 31).

Fossil beach dune ridge: The fossilized aeolian deposits overlie a late Holocene beach / spit deposits at sites such as Diveagar (18.17 / 72.99),Kolthare (17.65 / 73.13), Guhagar (17.48 / 73.19), Nandgaon (18.38 / 72.93) and Valavati (17.21 / 73.25) 200 to 500 m inland which form shore parallel ridges along the coast (Karlekar 2009). Their height varies from 3 to 6 m ASL. At some places like Varavade (18.85 / 72.95) these aeolian fossil deposits are even covered by modern aeolian sand.

The total ridge system thus can be divided in 3 units. Lowermost unit is a late Holocene spit or beach deposit found at a depth of more than 1.5 m. The average thickness of this unit is 150 cm. It is covered by a late Holocene deposit of dune origin and is 250 cm thick (Plate 3 : see page 32). This two unit system is a common, late Holocene, beach dune fossil deposit found frequently on this coast. The third and the uppermost unit of modern sand is not very common.

The boundary between lowermost beach unit and the middle dune unit is very distinct. The beach / spit deposits in the lowermost unit have been dated to 2400 to 2600 YBP. The fossil dune unit overlying the lower unit has been dated to 2200 to 2300 YBP. From the historical records and local information it appears that the modern dune sand, wherever it occurs on the top of lower two unit system, formed in last 30 to 35 decades. At Tambaldeg (16.29 /73.41), Mochemad (15.8 / 73.66) and Munage(16.23 / 73.42) in a micro tidal wave dominated environment, where 15 to 20 m high aeolian sand dunes are found 500 to 700 m inland, 3 unit column described above is not seen.

The shore parallel beach dune outcrops are located 200 to 500 m inland and are composed of lithified, seaward dipping sand layers. The beach rock stratigraphy is found continuous along 3 to 5 m long outcrop at most of the places. In places it reaches 6 m height above the basal rock. The dune beach stratigraphies were cemented 3800 to 1800 YBP. Such dates are indicative of sediment supply dating from late Holocene and formation of former beach sometime afterwards.

The geographic locations of beach dune fossil outcrops are significant as regards later Holocene history of the cost. They are found on the backside of modern beaches and dunes, on the banks of modern tidal inlets and also along the seaward margin of littoral terraces (Plate 4 : see page 32).

Estuaries, Creeks and Mangroves: The studies on the coastal configuration reveal that during late Holocene this coast was characterized by barrier spits and open estuaries,

The estuarine systems probably matured during late Holocene, with progressive sedimentation. Leading to dominance of

mangrove swamps in past 1000 years or so. Aggradations and progradation of coastal plains was simultaneous with the mangrove dominance in creeks and estuaries. Wide, flat, relief less, seaward sloping terraces at 4 to 6 m height above sea level on this coast can be related to early late Holocene sea level high stand about 3800 YBP.

A slight relative sea level lowering may have contributed to positive sediment budget. The occurrence of thick mangrove swamps in Dharamatar creek (18.84 / 72.94), 2350 years old oysters shells found at the head of Dharamatar creek and a 30 cm thick and 520 to 680 years old peat in fossilized mangrove swamp at Revas(18.79 / 72.93) near the entrance of Dharamatar creek (Karlekar 1986), all confirm this sequence of events in late Holocene. This peat outcrops along 2 km of beach towards Revas and lies less than 500 m seawards of mangrove swamps in Dharamatar creek (Plate 5 : see page 33).

The estuarine systems which matured very slowly during late Holocene show no dominance of mangrove swamps in last 1000 years on this coast.

The spit bars: Late Holocene spit bars are still preserved at conducive sites and also behind the modern spits such as at Harihareshwar (17.99 / 73.03). The modern spits appear oriented parallel to the earlier spits and have a recurved end typical of wave dominated regime (Plate 6: see page 33). Small flood tide delta seen at the entrance of a few inlets bordered by spits and the recurved end of of spit indicate that the sediment is transported along the spit under wind wave driven long shore currents. The earlier spit backing the present one or the relict recurvature of the modern spits suggests that their evolution has been continuous through the late Holocene.

Mud Flats: A higher sea level by about 6 m in Late Holocene could have submerged an extensive higher mud flat area along the coast. The mouth of the tidal streams and seaward portion of small bays and estuaries were submerged and slowly filled by sediments in late Holocene period. Later regression left these deposits stranded at the levels slightly above intertidal mud flats of today.

Subsurface mud deposits of modern, supratidal mud flats were deposited in a shallow subtidal region of slightly higher sea level in late Holocene (Karlekar 2009).

Ancient tidal flats bordering the modern intertidal mud flats along creeks like, Karanja (18.85 / 72.95) and Dharamatar (18.84 / 72.94) are not submerged completely during high tides (Plate 7 : see page 34). During high tide, large part of lower, intertidal flats is submerged. The paleoenvironmental reconstruction of these higher mud flats reveals 5 to 10 m thick layer of soft marine clay which represents shallow water tidal environment.

The biota of the soft marine clay samples includes shells of gastropods, bivalves, serpulids, bryozoans, corals and the algal genus Amphora. The bryozoans and corals are known to inhabit shallow waters. Majority of these forms are littoral and suggest a shallow water tidal environment (Comments were supplied by Dr. Borkar of Maharashtra Association for Cultivation of Sciences after analyzing the shell bed sample).

Interpretations and conclusions: Reconfiguration and reorientation of the coastline and a few coastal features namely, terraces, barrier spits, beaches, estuaries and

swamps has occurred on Konkan coast of Maharashtra throughout the late Holocene.

This can be attributed to RSL change as well as variations in the availability of sediments to coastal areas. The littoral sediment traps were enriched with clastics which helped in realigning the coast in later part of Holocene. Infilling of tidal inlets, especially the estuaries, formation of spits and littoral terraces are all related to these causes.

Evidences of episodic high wave energy events are reflected in the form of abandoned and realigned spits on this coast. Beach dune sediments along the former coast were lithified into beach dune ridges sometime after 3800 YBP. The prior estuaries maintained configuration at least until 3000 YBP. After this progressive slow infilling of estuaries occurred. Recently after 700 YBP, a change from estuarine sedimentation to swampy sedimentation occurred, which enabled rapid mangrove colonization within estuaries. This can be linked to a slow and slight lowering of sea level in last 1000 years or so.

It is known that the sea reached its present level around 6 to 7 ka BP. Prior to that it was low (-100 to -150 m) around 11 ka to 12 ka. Then it rose rapidly up to 8 ka BP and reached present level around 6 to 7 ka BP. It then fluctuated within the amplitude of couple of meters in mid to late Holocene. There was a major transgressive phase 6 to 4 ka BP. Trangression continued till 2300 BP after which there was a regression causing slight lowering of sea level and estuarine development under fluctuating monsoonal rainfall.

Against this known stratigraphical background it appears that the coastline experienced overall change in the coastal configuration in the late Holocene tentatively after 4000 YBP, the evidences of which are scattered all along 700 km long coastline of Konkan.

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Wide dune systems comprising of fore and back dunes not related to present day shoreline are helpful in knowing late Holocene scenario.

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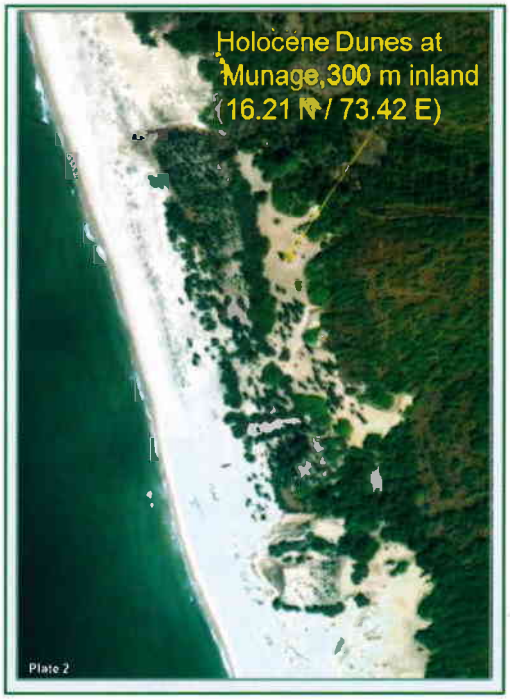

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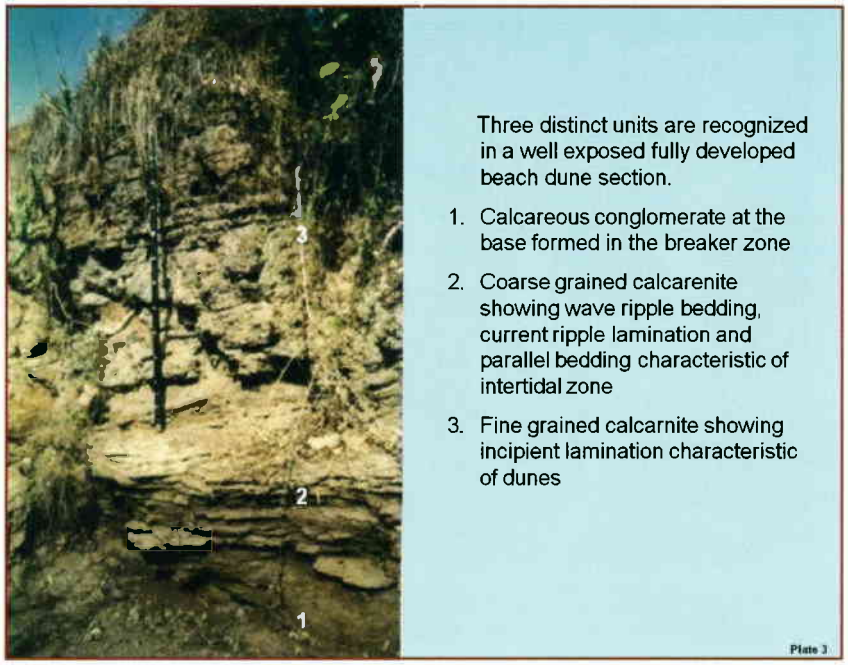

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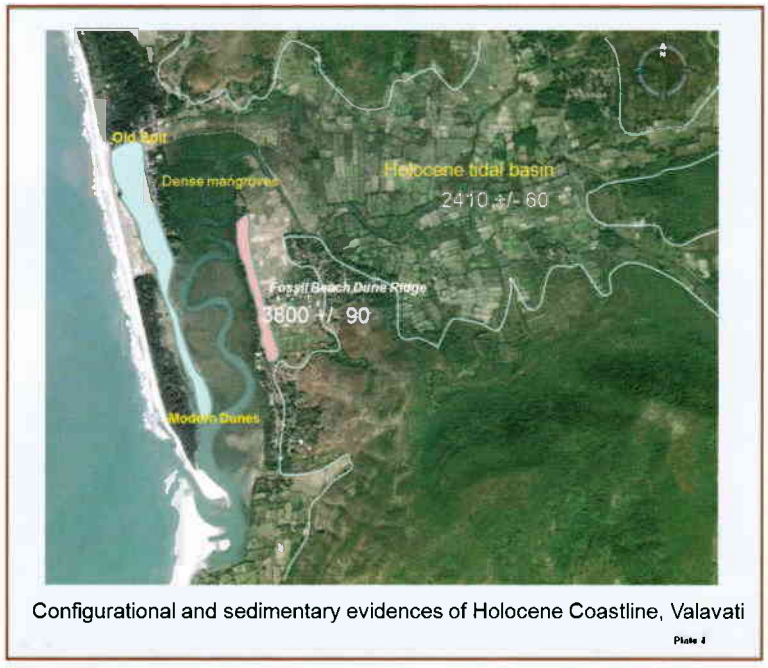

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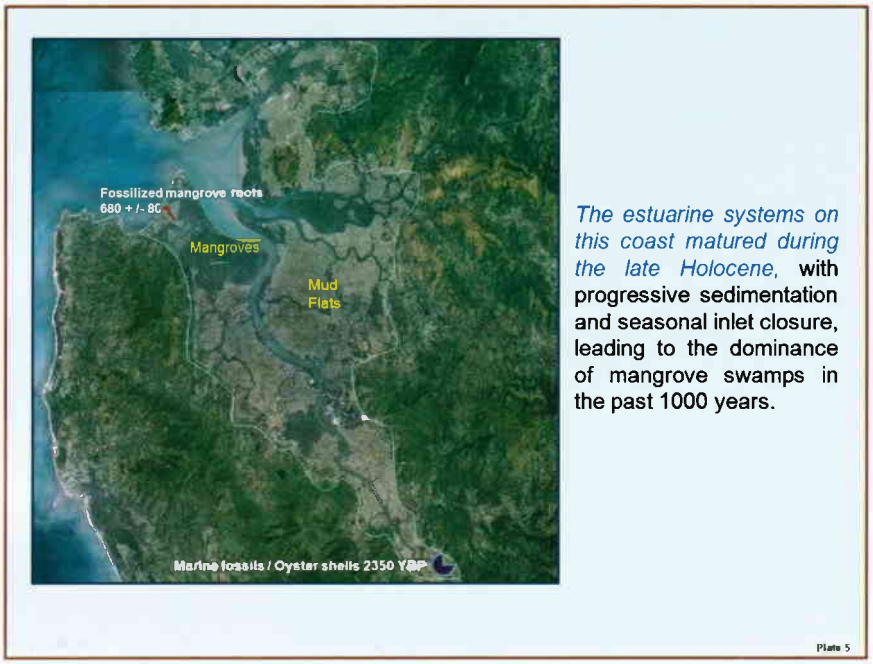

The estuarine systems on this coast matured during the late Holocene, with progressive sedimentation and seasonal inlet closure, leading to the dominance of mangrove swamps in the past 1000 years.

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During late Holocene (<4000 YBP) this coast was characterized by barrier spits, open inlets and estuaries.

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