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Evolution of Coastal Landforms and Sedimentary Environments of the Late Quaternary Period along Central Kerala, Southwest Coast of India

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ABSTRACT

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The central Kerala coast, southwest India, exhibits varied coastal landforms and sedimentary environments. To understand the evolution of these coastal landforms, satellite images were employed and field studies were conducted. The major coastal landforms identified in the study area are: barrier islands, beach ridges, strandlines, lagoon, palaeodelta, tidal flats/mudflats. Of the barrier islands, Vypin island is the largest barrier complex with beach ridge and swale complexes. An extension of coastal land along with the curved spit in the southern part of Vypin island is a conspicuous geomorphic feature. The formation of the new coastal land and growth of the spit have been influenced by both the natural and anthropogenic processes. A number of parallel strandlines standout as a signature of marine transgression and regression phenomena in the study area and suggest the progradation of the coastline. Palaeodelta at the Periyar river mouth signifies the point of interaction of fluvial-marine processes to far east of the present coastline. The evolution of the Vembanad lagoon and occurrence of shell and peat deposits at the subsurface levels suggest the subsidence of this part of the coastal land. The study reveals that various factors such as fluvial, marine, tectonic and climatic factors have played significant role in the evolution of landforms and sedimentary environments of the central Kerala coast.

ADDITIONAL INDEX WORDS: *Barrier islands, lagoon, strandlines.*

INTRODUCTION

Sea level and climatic changes during the Quaternary period have strongly influenced the geomorphic and sedimentation processes in the coastal regions. Much of the coastal land was carved out during the Late Quaternary period and the geomorphic evolution greatly influenced the history of mankind. Sea level changes during the Holocene have influenced the evolution of coastal environments such as estuaries/lagoons and barrier complexes and controlled the sedimentation in the coastal environments. Landform evolution along the southwest coast of India had been guided more by the tropical weathering under conditions of planation. The evolution and subsequent changes of coastal landforms were influenced by various factors viz., the coastal processes, sea level changes, tectonics etc.

The study of Quaternary deposits on continental margins provides the opportunity for explaining the relations between surfaces and deposits that originate during one cycle of relative sea-level fluctuation (POSAMENTIER *et al.*, 1988). Although the late Pleistocene paleo-topography appears as a basic factor in controlling the areal distribution of Holocene deposits, modern processes have also been influential. The other important factors that control the Holocene sedimentation are the Holocene sea level fluctuations, coastal land configuration and the sediment input from the rivers.

India has a coastline of 5600 km length, both on the west and east coasts. The west coast shows compound nature and exhibits dynamic changes, especially along the Kerala coast, in the southwestern part of India. Of the 560 km coastline of Kerala, a cumulative length of 360 km shows dynamic changes in terms of erosion and deposition patterns. Tectonic processes, bringing about uplift/subsidence altered the fluvial regime with resultant changes in the rates of erosion and deposition of sediments (SOMAN, 2002). Occurrence of Quaternary formations at various elevations along the Kerala coast speaks of recent uplift. Incidence of a chain of coast-parallel estuaries/lagoons with rivers debouching into them and separated from the sea by spits/bars along the central Kerala coast provides evidence of a progarding coastline.

In this paper, we discuss the evolution of coastal landforms along central Kerala coast extending from 9°30'-10°15' N Latitude and 76°10-76°30E Longitude and their significance in the deposition of coastal clastic sediments. These studies help for the effective management of the coastal zone.

GEOMORPHIC AND GEOLOGIC SETTING OF CENTRAL KERALA

The coastal region under study is at the foot of the Western Ghats escarpment and its pediment. The geomorphology of the coast is heterogeneous, principally marked by the presence of numerous short and parallel rivers flowing from the Ghats.

The coast of central Kerala is characterized by various landforms such as lagoons, barrier islands, beach ridges, paleo-strandlines, alluvial plains, marshy plains and flood plains. The Vembanad lagoon, a part of the study area, is the largest estuarine-lagoon (backwater) system on the west coast of India. Rivers such as Periyar, Muvattupuzha, Minachil, Pamba and Achankovil flow across the coastal plain, carry an annual runoff of $892x10^3$ metric cubic feet and drain in to the Vembanad lagoon. A series of sand dunes oriented parallel to the general direction of the coastline hinders at places the flow of the rivers, thereby trapping sediments and enlarging the alluvial plains (Figure 1). Structurally, the area is controlled by NW-SE, NNW-SSE and ENE-WSW lineaments. The evolution of coastline is guided to certain extent by NNW-SSE and NW-SE lineaments (RAO, *et al.*, 1985). The shoreline is generally straight trending NNW- SSE with minor variations and lies as a narrow and low-lying land. The lineaments are found to be neotectonically active and have culminated in the offsetting of the straight coastline at some places and sharp bends in stream courses and lagoons.

The major rock types that encompass the central Kerala are Precambrian crystallines, Tertiary sediments, Pleistocene laterites and Recent-to-Sub-Recent sediments (GSI, 1995). The Precambrian crystallines are composed of charnockites, khondalites, garnet-biotite-hornblende gneisses. The Tertiary sedimentary deposits - Quilon and Warkali formations - are composed of limestones, sandstones and clays. Laterites cover the coastal and midland regions. The coastal alluvium represents the Recent to Sub-Recent sediments.

The study area experiences a tropical climate. It falls in the micro-tidal regime (<2m). Maximum precipitation occurs during the southwest monsoon (June-September) and the average annual rainfall is about 250-300 cm. Longshore sediment transport estimation for the west coast (NAYAK and CHANDRAMOHAN, 1992) reveals that the annual gross sediment transport rate varies from 0.508 to 1.511x 106 m^3.

METHODS

The topographical maps and geocoded satellite images of IRS-1B LISS II and IRS-1D LISS III false colour composites (FCCs) generated from bands of 2, 3 and 4 on a scale of 1:50,000 are used in the present study. Satellite images are analysed for delineation of various geomorphic features and to understand the evolution of landforms. Preliminary maps of 5 x 5 grid area have been prepared and the physiographical, geomorphological, geological, and drainage data have been transferred to the base maps, and the data have been updated with the help of satellite images. The traced layers were digitized using ARC-Info software and the areal extents of different landforms were delineated and computed. Interpreted results have been substantiated with adequate ground truth/field checks.

COASTAL LANDFORMS

The coastal landforms identified in the study area are barrier islands, beach ridges, tidal flats, lagoon, strandlines, floodplains (Figure 1). A narrow stretch of sandy beach is observed all along the coastline except at Cochin inlet i.e., at southern tip of Vypin Island where wide sandy beach is seen. More than half of the study area is occupied by coastal alluvium, constituting muddy sands and shells.

Barrier Islands

A number of barrier islands are observed in the study area, of which the Vypin island is the major barrier island (Figure 1). The length of this barrier island is about 25 km. Several small islands, elongated parallel to the coast, associated with the barrier lagoon complex are seen throughout the area. These are found separated from the shore by Vembanad lagoon. Although coconut vegetation covers most of the barrier islands, mangrove vegetation is seen at a few places. A wide shore-connected barrier separating the Vembanad lagoon from the Arabian Sea is also observed in the southern part of the study area, extending from Cochin to Cherthala. This forms a major lagoon-barrier complex of the area.

Beach Ridges

A number of parallel beach ridges alternating with swales are observed in the field. The beach ridge and swale complex is seen especially at southern part of Vypin island. The width of ridges varies from 50 to 150 m and the height is about 1 m. The width of the swales varies from 50 m to 200 m. These beach ridges represent successive still-stand positions of sea of an advancing shoreline. A new coastal land and well-developed curved spit of 2 km length and 200-400 m wide is observed in the southern part of Vypin Island.

Lagoon

Vembanad lagoon occupies a major part of the study area. It extends from Munambam in the north and Alleppy in the south. The length of the Vembanad lagoon is about 80 km and the width varies from a few hundred meters to 14.5 km. The depth varies from <1 m to 14 m.

Palaeodelta

A paleodelta is identified near the mouth of Periyar river i.e., in the northern part of the study area (Figure 1). The existence of paleodelta near Munambam, extending from the present shoreline for about 11 km into the inland region along the course of the Periyar river is evidenced from the satellite imagery and field checks. The dull matground terrain devoid of any geomorphic feature is considered as a paleodelta. The paleodelta encompasses an area of about 50 km^2.

Strandlines/ Strandplain

A number of strandlines running parallel/sub-parallel to the coast for a distance of about 10-20 km occur 10-15 km inland from the present shoreline. These strandlines occur on either side of the Vembanad lagoon, and about 5 m above sea level (Figure 2). Strandlines are prominently seen in the southwestern part of the area. The successive strandlines in the area form strandplain and mostly covered with silica sands.

Mudflats and Tidal Flats

Consequent on the development of wide estuarine mouths near the sea, a lot of seawater encroaches through them during high tide and submerges low-lying flat areas adjacent to the rivers forming tidal flats. Extensive tidal and mudflats are seen in the northeastern and southeastern parts of the study area.

Mangrove Swamp

Mangrove swamps are present in Vallarpadam island, southern part of Vypin island and in and around Periyar river mouth. Most of the mud/tidal flats are also covered with mangrove vegetation.

Flood Plains

A significant portion in the eastern part of the lagoon is covered with floodplain area. The flood prone areas are mostly used for paddy cultivation and aquaculture.

QUATERNARY SEDIMENTARY DEPOSITS

The coastal landforms of this region consist of Quaternary sediments overlying the Tertiary formations. The surface sediments of the lagoon are mostly a mixture of clay, silt and sand, whereas in the deeper parts peat and clay deposits are encountered. Quaternary sediments associated with the various coastal environments are explained in the Table 1.

DISCUSSION

The coastal landforms, particularly barrier islands, lagoons and tidal flats, along central Kerala have association with each other in their formation and evolution. The barrier island is the subaerial expression of an accumulation of sediment between two inlets, and between the shoreface and backbarrier lagoon. The morphology of barrier islands is the result of a variety of marine and subaerial depositional and erosional processes. Mangrove vegetation plays an important role in trapping sediment and sculpturing landscape. The major sedimentary environments of a barrier island are the beach, foredunes, dune ridges, barrier flats, salt marshes, spits and tidal flats (LEATHERMAN, 1979). Barrier spits occur at the ends of barrier islands and represent a process by which islands can migrate laterally. Spits evolve generally in shore parallel direction, however, inlet shoreline curvature may produce shore normal orientations. Shore-normal spits generally have landward trends. The migration of spits into inlets influences the efficiency of an inlet to transfer water between the sea and backbarrier lagoon, and generally requires a morphodynamic response by the inlet (OERTEL, 1985).

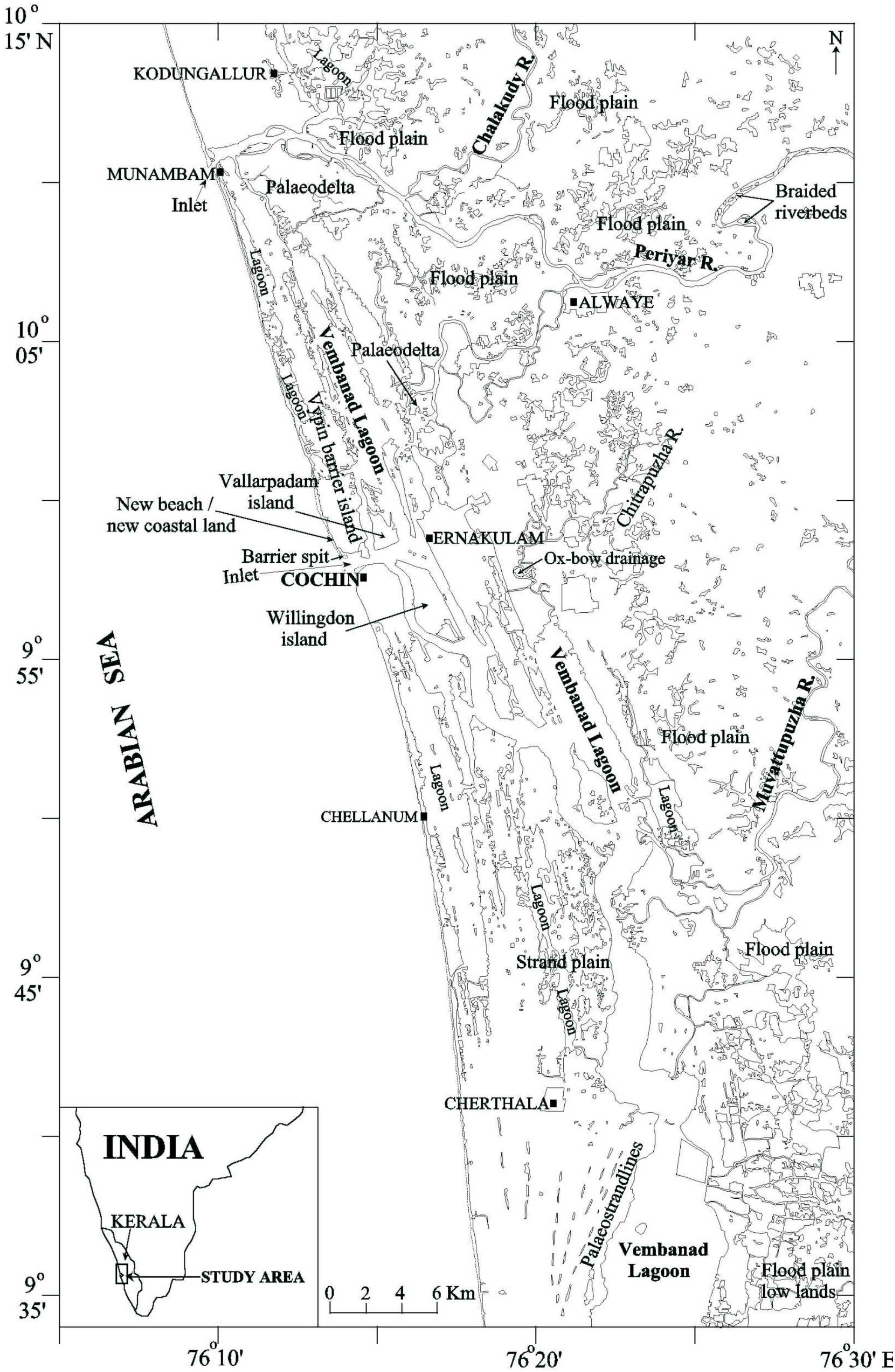

Figure 1. Landforms of the central Kerala coast interpreted from the satellite imagery (IRS 1B LISS II March 1995)

Table 1. *Coastal landforms and associated sedimentary deposits of central Kerala.*

	Coastal landforms	Sedimentary deposits
1.	Beach	Coarse sands with minor concentrations of heavy minerals. Recently accreted beach / coastal land consists of sands, clayey silts with mangrove vegetation.
2.	Barrier Islands	Silty sands with mangrove vegetation – Swamp / marshy environment.
3.	Strandlines / strandplains	Cheniers. Silica sands (95% quartz) formed by beach and eolian processes. Clay deposits at 2 m depth from the surface.
4.	Palaeodelta	Coarse sands and minor amounts of shell fragments on the surface. Fluvio-marine environment.
5.	Lagoon	Silty sands and clayey silts with intercalations of peat deposits.
6.	Flood plains	Clayey silts on the surface and peat deposits at 2 m depth from the surface

The deposition of unconsolidated sediments may occur on straight coasts when a large amount of littoral drift becomes trapped up-drift of a boundary usually an inlet or estuary mouth. With erosion of such capes, erosion may occur on the down-drift (FINKELSTEIN, 1983). To desilt the navigation channel/inlet, the dredging is being carried out periodically in the inlet area of Cochin and the dredged material is dumped in the nearshore sea, i.e., off the inlet. This increases the quantum of unconsolidated sediment available for littoral drift and in turn the growth of the barrier complex and barrier spit. The mid-late Holocene spits display marked changes in form and alignment that represent a response to changes in relative sea level, sediment supply and wave climate (FIRTH *et al.,* 1995). It is likely that the wedge of sediment being more important for the spit development.

The profound significant changes were brought in the coastal configuration and associated landforms since mid-Holocene period. The occurrence of strandlines (cheniers) suggests that the coast has undergone a series of marine transgressions and regressions during the Late Quaternary period. Chenier plains Coastal landforms, southwest India develop when: (i) substantial quantities of river-supplied mud become available for nearshore marine transport and coastal mudflat deposition; (ii) a certain balance exists between longshore sand transport, deposition and erosional sand-winnowing from the muddy coastal deposits to allow beach ridge formation (OTVOS and PRICE, 1979). Cheniers occur on shores with low-to-intermediate wave energies and small-to-large tidal ranges. Climates involved range between temperate and tropical, arid-to-humid. While the major coastal rivers cross chenier ridges with no or very little deflection, minor streams are often been deflected and channeled between semiparallel chenier ridges. Such scenario is also noticed in the present study. The presence of paleo beach ridges/cheniers suggests that there is growth of the land. This may be due to the fall in sea level or rise in the level of the land. It is possible that both the factors might have played a role in the increase of the land along central Kerala coast. The sea level was higher at 3000 yr BP than the present day along this coast. In the western coast of India, the sea level reached its maximum at 4000-6000 yrs BP (KALE and RAJAGURU, 1985; HASHIMI *et al*., 1995). According to BRUCKNER (1989), the modern sea level was attained around 2000-2800 yr BP off the Konkan coast, further north of the study area. However, there are evidences pointing to the rise of the land causing a relative fall in sea level. One such phenomenon is the uplift of the coast. At some places beach ridges become less conspicuous because of modifications brought about by human activities such as agriculture, shrimp farming etc.

The general belief is that beach ridges are constructed slowly, primarily by multiple depositional events rather than in a single

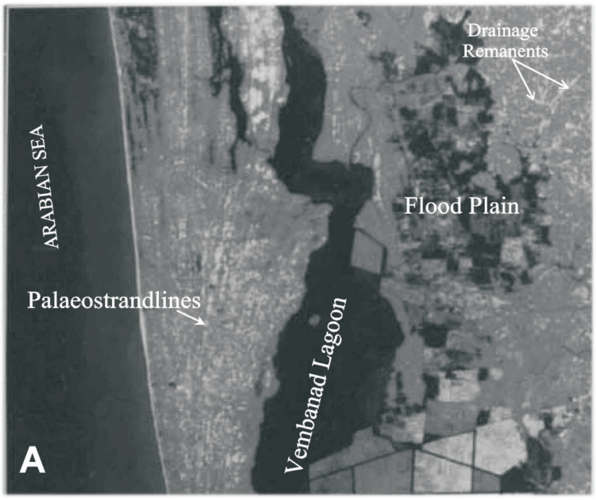

Figure 2. Showing the Strandline / strandplain deposit (A) Satellite imagery showing the different landforms in a part of the study area (B) Field photograph of the strandline / strandplain deposits.

event such as storm, and by wave run up from swell rather than storm waves. The common prerequisites for beach ridge development are onshore transport of sediment, an abundant sediment supply, and a relatively flat depositional ramp or low shoreface gradient (MORTON *et al*., 2000).

The palaeodeltaic feature at the Periyar river mouth represent the rate of deposition of sediments exceeding the rate of removal by waves and currents. However, the slow uplift of the coast might have blocked the growth of the delta (NARAYANA *et al*., 2001). The lagoons have formed in Tertiary sediments. It is believed that Vembanad lagoon was a graben. The morphology of the lagoon suggests that en-echelon faulting might have played a role in its evolution. The lagoon at many places cuts across the strandlines suggesting that it might have formed subsequent to the strandline deposits. In the recent past, the Vembanad lagoon is undergoing accelerated sedimentation and filling up with the recent sediments. Extensive tidal/mudflats are seen on the eastern side of the lagoon and most of the landform is used for aquaculture farming. As the northern part of the lagoon is shallower, the coastal alluvium to the east of this part of the lagoon is inundated during high tide period. The flood plain area further east of these tidal flats is a conspicuous feature as the rivers are unable to discharge directly into the sea because of the deflection of river courses before debouching into the lagoon.

The nature of rise in sea level during the Holocene is of great significance since it influenced the evolution of coastal environments and controlled the sedimentation in the shelf and coastal regions. In general, along the western Indian shelf the surface sediment distribution pattern reveals four main facies: (1) Modern sands of the shore zone extending to a water depth of 5-10 m (2) Recent terrigenous mud zones comprising silts and clays occupy the innershelf (3) Medium to coarse-grained relict carbonate-rich sediments containing shells and skeletal fragments of various organisms and a variety of limestones extend to the shelf edge (NAIR *et al.*, 1979; RAO and NAIR, 1992). (4) Further seaward, sand-silt-clay facies on the upper slope and silty clays and/or fine-grained laminated mud and olive-grey to dark-brown mud occur on the middle shelf to slope regions (RAO and VEERAYYA, 2000; VON STACKELBERG, 1972).

The development of coastal landforms and associated sedimentary environments are resulted from both the fluvial and marine processes. The fluvial sedimentary deposits started growing outward extension of the river mouths, while pushing the discharge points further west i.e., into the nearshore Sea. The paleo-deltaic feature in the northern part of the study area signifies this phenomenon. The peat and shell deposits of the Late Quaternary period occur at various onshore locations along the central Kerala coast. Occurrence of peat deposits at subsurface levels reveals mangrove vegetation was predominantly present along the coastal tracts in the Late Quaternary period, subsequently inundated by the higher sea level, and led to the formation of peat deposits (NARAYANA *et al.*, 2002).

The earlier studies suggest that tectonics and fluvial processes played a major role in the evolution of coastal landforms of central Kerala (see JOSEPH and THRIVIKRAMAJI, 2002). But in the authors view, several factors fluvial, marine, tectonics and climatic factors - have played significant role in the evolution of landforms and associated sedimentary environments along central Kerala coast.

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