

Holocene land-sea interactions and landform changes in the coastal lands of Vembanad lagoon, Kerala, SW India

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The sedimentological, palynological, geomorphological and stable isotope ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) studies of six borehole cores retrieved from the Vembanad basin together with sedimentological studies of 14 surface sediment samples collected from the barrier beach separating the lagoon from nearby sea were analysed for decoding signatures of land – sea interactions in the sedimentary archives of the area. The radiocarbon age of the subsurface sediments varied from 10620±160 yrs BP to 3990±150 yrs BP. Stable isotope studies reveal indications of the dominance of marine components in the basal portions of the borehole sediments of southern sector. Presence of higher order riparian vegetation is noticed in central and northern sectors of the basin before the region being occupied by lagoon waters of the Holocene transgressive phase. The northward drift of sediments was well represented in the mineralogical diversities of the heavy mineral residue, in addition to the northerly deflections of the distributary channels, especially in the northern part of the basin. The lagoon entrances also showed significant changes during the Holocene epoch. The prominent entrance of the lagoon till Late Holocene was at Andhakaranazhi which was indicated by the anomalous presence of pyroboles (pyroxenes + amphiboles) within the sillimanite dominant domain of the sub-surface sedimentary archive. This entrance became inactive during the latter half of the Late Holocene because of sediment build up and subsequent landform changes. Simultaneously, the entrance at Fort Kochi was developed for the exchange of water between the lagoon and the sea.

[Keywords: Holocene land-sea interactions, Landform changes, Vembanad lagoon South west coast of India]

Introduction

The coastal areas are one of the most dynamic and strategic regions of the world where sea water is in constant interaction with land¹. The area is known for outstanding natural beauty, economic prosperity and also human stress. Therefore, any significant change in the level of sea water or land will have direct effect on the life/economic security of the people in the area.

Vembanad lagoon is the largest back water system in the southwestern coast of India which receives the status of an area of outstanding natural beauty in the tourist map of the world. The lagoon and its river catchments cover about 15000 km² area of the Kerala and play a key role in the socio-economic and geo-environmental scenarios of the state. The coastal lands of the Vembanad basin are influenced by both natural processes and man-made interferences. Reports reveal that a substantial part of this wetland has been reclaimed for various developmental purposes during the period 1839-2004². As most of the developmental initiatives and economic activities of the state are centered on the banks of the Vembanad

lagoon, especially around Kochi (otherwise called the Queen of Arabian Sea), a better understanding of the millennial scale changes of land-sea interactions, coastal dynamics and landform changes will be very essential for designing sustainable development strategies in this strategic coastal strip in south western India. In addition to this, we believe that the information will be useful for chalking out strategies for the conservation and management of this unique backwater system which is declared recently as a Ramsar wetland of international importance.

Geo-environmental setting

Vembanad lagoon has a length of 113 km and water spread area of 230 km². The coastal plains of the lagoon has extremely low relief, except at certain stretches near Cherthala (southern arm) and Paravur (northern arm) where the terrain is dissected by a series of dunes with a maximum height of about 8 m. The width of the lagoon³ varies from a few hundred meters to about 4.5 km. An estuarine condition prevails in the lagoon during most part of

sediment (beach sands) and 6 borehole cores were collected from the area (Fig. 1) for detailed laboratory studies. Sub-samples were subjected to textural analysis following Lewis⁵. Organic matter rich sub-samples from selected depths were subjected to radiocarbon dating at Birbal Sahni Institute of Palaeobotany, Lucknow (India) for establishing the chronological bearing of sediment deposition. Heavy mineralogical analysis of the fine sand fractions of surface and borehole samples was carried out following Mange and Maurer⁶. A few selected sub-samples were subjected to stable isotope estimations for carbon ($\delta^{13}\text{C}_{\text{org}}$) and nitrogen ($\delta^{15}\text{N}$) at Centre for Tropical Marine Ecology (ZMT), Bremen (Germany) following standard procedures^{7,8}.

Fig. 2 shows the lithological characteristics of the borehole cores collected from the coastal lands of the Vembanad basin. The granulometric data and statistical parameters worked out for the beach samples are given in Table 1. Table 2 gives the heavy mineral contents in the surface sediments samples collected from the barrier beach separating the lagoon from the sea together with that of the borehole cores. The beach sands are generally dominated by fine and medium sands which together cover about 70% of the size population. Except the two samples at Mararikulam (Sample Number 9) and Kanjiramchira (Sample Number 10), which are dominated by medium sand, the rest of the samples are dominated by fine sand. The sands are moderately well to moderately sorted (0.55ϕ to 0.91ϕ), coarse to

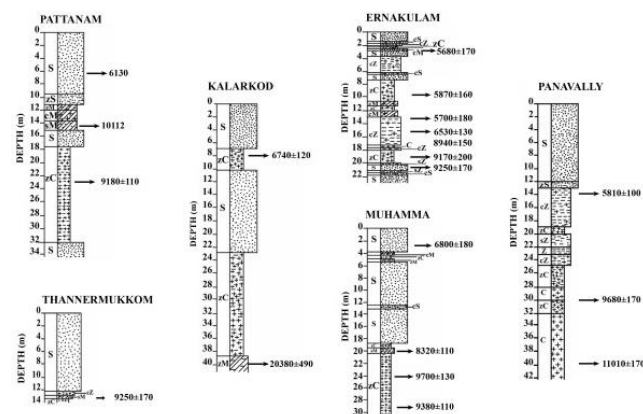


Fig. 2—Litholog of Pattanam, Thannermukkam, Kalarkod, Ernakulam, Muhamma and Panavally borehole cores. S Sand, zS Silty sand, cS Clayey sand, sM Sandy mud, cZ Clayey silt, zM Silty mud, cM Clayey mud, sC Sandy clay, zC Silty clay, C Clay

Table 1—Statistical parameters of beach sands collected from the study area

Sample Number	Statistical parameters			
	Mean (ϕ)	Sorting (ϕ)	Skewness	Kurtosis
1	2.03	0.91	-0.27	0.98
2	1.97	0.69	-0.05	0.79
3	2.18	0.63	-0.24	0.85
4	2.22	0.60	-0.24	0.92
5	2.04	0.64	-0.05	0.74
6	2.66	0.75	0.02	1.24
7	2.75	0.66	0.12	1.04
8	2.41	0.73	-0.05	1.23
9	1.86	0.63	0.19	0.79
10	1.73	0.65	0.15	1.12
11	2.20	0.67	-0.12	0.91
12	2.31	0.65	-0.12	1.22
13	2.49	0.55	-0.01	1.35
14	2.16	0.63	-0.20	0.80

Phi mean 1 to 2 (Medium sand), 2 to 3 (Fine sand); Sorting: 0.50 to 0.71 (Moderately well sorted), 0.71 to 1.00 (Moderately sorted); Skewness: 0.30 to 0.10 (Finely skewed), 0.10 to -0.10 (Nearly Symmetrical), -0.10 to -0.30 (Coarse skewed); Kurtosis: 0.67 to 0.90 (Platykurtic), 0.90 to 1.11 (Mesokurtic), 1.11 to 1.50 (Leptokurtic).

The lithological characteristics of the borehole core

(Fig. 2) reveal that except the Ernakulam borehole core, all the other cores are characterised by a sand apron which is often intervened by silt/clay dominated sediments whose age varies from 5390±140 yrs BP (Pattanam) to 6800±180 yrs BP (Muhamma). The Panavally (5810±100 yrs BP), Ernakulam (5680±170 yrs BP) and Pattanam (5390±140 yrs BP) borehole cores recorded almost similar age at the base of the sand apron. This clearly indicates that the upper part of the sand unit at Muhamma and Kalarkod in the southern sector as well as the entire sand unit of Panavally, Ernakulam and Pattanam have been deposited during Middle Holocene when the sea level reached its maximum land-ward limit. At the same time, the lower part of the sand unit in the southern part of the lagoon might have been deposited during Early Holocene.

The total heavy mineral content gives markedly higher values in the borehole core at Pattanam and minimum at Thannirmukkam (Table 2). The major heavy mineral species identified in the

Table 2—Heavy mineral contents of the fine sand fraction in the beach sands and borehole cores of the study area

Sample location	THM (Wt %)	Heavy mineral species (number %)					
		Opagues	Sillimanite	Zircon	Pyriboles	Garnet	Biotite
Beach sands							
Sector 1	5.4 - 14.9 (9.2)	4.3 - 6.0 (5.0)	0.9 - 4.1 (2.5)	1.2 - 1.7 (1.5)	84.3 - 89.7 (87.0)	0.8 - 3.4 (1.8)	-
Sector 2	3.5 - 7.7 (5.7)	7.6 - 11.8 (9.7)	4.4 - 7.19 (5.82)	1.3 - 2.6 (2.0)	74.5 - 82.7 (78.6)	1.3 - 1.8 (1.6)	-
Sector 3	0.5 - 14.9 (7.2)	7.7 - 22.9 (16.1)	22.7 - 74.6 (56.2)	0.9 - 2.6 (1.6)	12.4 - 64.1 (38.3)	0.8 - 1.1 (0.9)	Traces
Sector 4	64.8 - 96.5 (83.2)	58.3 - 87.6 (75.0)	5.8 - 39.0 (20.2)	0.9 - 5.5 (2.9)		0.4 - 1.0 (0.7)	-
Subsurface sediments (Holocene)							
I	0.7 – 12.3 (3.2)	9.1 – 64.4 (43.1)	25.3 – 54.6 (40.5)	0 – 3.0 (1.5)	-	-	-
II	0.8 – 3.4 (1.7)	8.6 – 42.9 (28.5)	47.1 – 77.4 (61.8)	2.3 – 5.7 (3.8)	Trace	Trace	Trace
III	0.1 – 1.4 (0.6)	4.5 – 20.5 (11.2)	40 – 86.9 (66.2)	1.2 – 5.4 (2.9)	1.9 – 27.3 (8.5)	Trace	0 – 3.4 (1.4)
IV	1.2 – 5.6 (3.4)	17.0 – 41.4 (29.8)	55 – 74.1 (63.3)	0.9 – 4.6 (2.7)	-	Trace	Trace
V	0.3 – 7.1 (2.9)	4.6 – 16.3 (7.8)	2.9 – 6.3 (4.7)	1.5 – 3.8 (2.6)	63.8 – 82.4 (74.7)	1.1 – 6.9 (3.7)	1.3 – 5.4 (3.2)
VI	4.2 – 17.6 (11.2)	2.1 – 20.4 (6.8)	0.7 – 3.8 (1.9)	0.9 – 7.1 (3.4)	62.2 – 89.8 (80.5)	0.9 – 4.5 (2.1)	Trace

Sector 1: Munamabam to Njarakkal; Sector 2: Fort Kochi to Chellanam; Sector 3: Andakaranazhi to Kanjiramchira; Sector 4: Ambalapuzha to Pudukulangara

fine skewed and platy to leptokurtic (Table 2).

borehole cores are opaques (represented by ilmenite and magnetite) and sillimanite in the borehole core sands of the southern sector (south of Panavally) with an anomalous increase of pyribole contents (pyroxenes and amphiboles) in the Thannirmukkam borehole core. The borehole cores north of the Panavally is characterised by marked depletion of sillimanite with a concomitant increase in the content of pyriboles.

In an earlier study, Padmalal *et al.*⁹ revealed that the long shore drift of sediments, originally derived from the garnet-sillimanite gneissic (khondalite suite of rocks) provenance, was detected up to 6-7 km north of Panavally station. Nabila¹⁰ also detected sillimanite rich surface sands in a location ~7 km north of Panavally. The sea level rise coupled with the northward drift of littoral currents Early-Middle Holocene was responsible for the progradation and development of sand barriers separating the lagoon from the sea. Abundant supply of sediments in the Early Holocene was responsible for the build up of barrier system while short supply caused its breaching into barrier islands^{11,12}.

Although the sillimanite/pyribole boundary is located 7 km north of Panavally (Fig. 3), the corresponding line in the present beach is noticed about 10 km south west of Panavally, near Andhakaranazhi (Fig. 4). This together with the anomalous occurrence of pyriboles in the Thannirmukkam borehole core as well as the observed geomorphic expressions points to the existence of an outlet system in this sector linking the lagoon with the nearby sea.

This outlet that has migrated northwards and

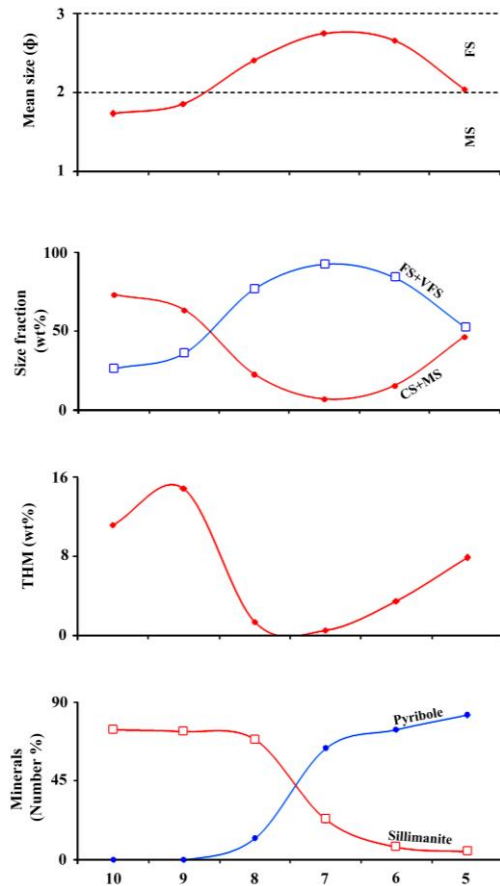


Fig. 4—Variation of phi mean, size spectral classes (FS Fine sand, VFS Very fine sand, MS Medium sand, CS coarse sand) Total Heavy Mineral (THM), Pyriboles (Pyroxene + Amphiboles) and sillimanite in the Kanjiramchira – Fort Kochi sector. See Fig. 1 for sample locations.

reached Andhakaranazhi becomes inactive during the latter half of Late Holocene. The closure/near closure

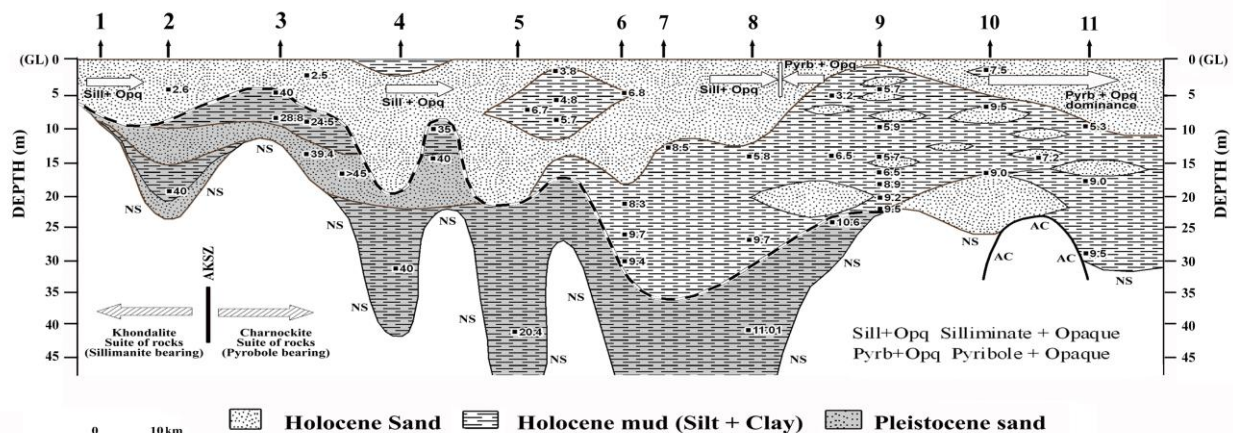


Fig. 3—Section along the coast from Ponmana to Pattanam showing the subsurface Holocene – Late Pleistocene stratigraphy. 1 Ponmana, 2 Arakkulam, 3 Panavally, 4 Thannirmukkam, 5 Pannavally, 6 Pannavally, 7 Thannirmukkam, 8 Pannavally, 9 Ernakulam, 10 Varapuzha, 11 Pattanam.

of the Andhakaranazhi outlet was followed by the development of the outlet near Fort Kochi through which the rivers empty its water and sediments into the Arabian Sea.

The stable isotope data also exhibited marked difference, especially in the basal portion of the borehole cores of the southern (Panavally: $\delta^{13}\text{C}$ - 24.33‰; $\delta^{15}\text{N}$ 8.22‰) and, central (Ernakulam: $\delta^{13}\text{C}$ - 27.17‰; $\delta^{15}\text{N}$ 5.80‰) and northern (Pattanam: $\delta^{13}\text{C}$ - 27.47‰; $\delta^{15}\text{N}$ 5.54‰) sectors of the lagoon. The stable isotope data indicates the presence of marine elements in the south (also confirmed from the abundance of non-pollen palynomorphs of marine affinity in the samples) whereas higher order, treed coastal vegetations in the central and northern sectors before the area being occupied by lagoonal waters of the Holocene transgressive phase. To conclude, the study discloses the fact that the Vembanad lagoon attained its present geomorphic configuration during Holocene epoch- the time span in the earth history known globally for marked land-sea interactions and climate changes. We believe that, information on the Holocene coastal evolution and the stratigraphic architecture deduced from the study will be useful to those who are interested in environment – friendly developments in the coastal lands of Central Kerala, including the fast developing urban – cum – industrial centre, the Kochi city.

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References

- 1 Davis, RA, *Coastal sedimentary environment*, 1978, pp. 420.
- 2 Kurup B M. Inland Fisheries Development in Kerala-Prospects and Challenges, in *Proc. Sasthrapadom National Seminar*. 2006.
- 3 Maya, K., Babu, K.N., Padmalal, D. and Sreebha, S., *Occurrence and mining of limeshell resources of Vembanad Lake, Kerala*, (Centre for Earth Science Studies: Thiruvananthapuram, India) 2007, pp. 66.
- 4 GSI., *Geological and Mineralogical Map of Kerala*, (Geological Society of India, Calcutta) 1995.
- 5 Lewis, D.W., *Practical sedimentology*, (Hutchinson Ross Publishing Company, Pennsylvania) 1984, pp.227.
- 6 Mange, M.A. and Maurer, H.F., *Heavy minerals in colour*, (Chapman and Hall, New York) 147(1992), pp. 205.
- 7 Jennerjahn, T.C., Soman, K., Ittekkot, V., Nordhaus, I., Sooraj, S., Priya, R., and Lahajnar, N., Effect of land use on the biogeochemistry of dissolved nutrients and suspended and sedimentary organic matter in the tropical Kallada River and Ashtamudi estuary, Kerala, India. *Biogeochem.*, 90(2008), 29-47.
- 8 Jennerjahn, T.C., Ittekkot, V., Arz, H.W., Behling, H., Pätzold, J., and Wefer, G., Asynchronous terrestrial and marine signals of climate change during Heinrich events, *Sci.*, 306(2004), 2236-2239.
- 9 Padmalal, D., Nair, K.M., Ruta B. Limaye., and Kumaran, K.P.N., Late Quaternary evolution of Alappuzha-Kochi coast (Kerala), SW India, in *Proc. Nat. symposium on geodynamics and evolution of Indian shield through time and space*, (Centre for Earth Science Studies, Thiruvananthapuram) 2008, 45-46.
- 10 Nabila, P.V., *Texture and mineralogy of silica sand resource of Alappuzha – Cherthala belt, Kerala, SW India*, (MES Ponnani College, Calicut University: Ponnani, Kerala) 2012.
- 11 Carter, R., Forbes, D., Jennings, S., Orford, J., Shaw, J., and Taylor, R., Barrier and lagoon coast evolution under differing relative sea-level regimes: examples from Ireland and Nova Scotia, *Mar. Geo.*, 88(1989), 221-242.
- 12 Vaz ,G.G., Mohapatra, G.P. and Hariprasad, M., Geomorphology and evolution of Barrier-Lagoon coast in a part of north Andra Pradesh. *J. Geol. Soc. India*, 49(2002), 31- 40.