Evaluation of the Holocene environmental changes of the southwest coast, India: A palaeopalynological approach

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The climatic variability and the influence of temperature and sea level fluctuations on the earth's surface configuration during the Holocene are being discussed all over the world. The present study evaluates the palaeo-environmental conditions of western coast of India during this epoch through the analysis of pollen grains embedded in a carbonaceous clay formation ($\cong 0.4\text{--}0.6$ m) found sandwiched within the palaeodeposit of sand of Meenachil River basin. The carbon dating revealed that the clay formation has an age of 5786 ± 94 ^{14}C yr BP, while the embedded wood samples have the age varying in between 2888 ± 78 and 5780 ± 95 ^{14}C yr BP. The overall analysis suggests that the southwestern margin of India had experienced high intensity rainfall during the earlier part of the Atlantic chronozone due to then strengthened Asiatic monsoon, while water stagnation and hydrological modifications were observed during the later part. The dominance of weeds and lesser number of tree elements suggested a drier climate during the end of the Atlantic period. Besides, the morphometric rearrangement of the Meenachil River contemporaneous to the geomorphological modifications of the southwestern coast of India shall be classified into three categories: (1) Pre-Vembanad Lake formation, (2) Contemporaneous to lake formation and (3) Post-Lake formation.

1. Introduction

Vegetational changes reflected in fossil pollen spectra are a primary source of information on climatic fluctuation during the past and it along with radiocarbon dates are used for the reconstruction of late Pleistocene and Holocene dynamics of vegetation and climate (Andreev *et al.* 2001). Holocene climatic changes were reconstructed from pollen by different mathematical (transfer functions) methods

(Webb and Bryston 1972; Bryston and Kutzbach 1974; Sachs *et al.* 1977; Klimanov 1984; Heusser *et al.* 1985; Guiot *et al.* 1993; Andreev and Klimanov 2000; Tomescu 2000). The palynological studies not only analysed the changes in vegetation due to climatic variations and sea level fluctuations occurred in the Quaternary period, but gave fruitful information about changes in base level of erosion also (Nair 1966; Birks and Birks 1980; Williams *et al.* 1998; Newby *et al.* 2000).

Keywords. Meenachil River; ^{14}C dating; pollens; palaeoenvironment, Asiatic monsoon; Vembanad Lake.

Wille *et al.* (2000) reconstructed the vegetation and climate history Popayan area of southern Colombia for the periods from 27,000–9200 yr BP and 2100 yr BP to sub-Recent by using the pollen grains. It was with the help of sedimentary pollen records that many scientists arrived on a contention that the late Quaternary evolution of several coastal and deltaic systems in the Mediterranean area were controlled mostly by relative sea level changes (Oomkens 1970; Coutellier and Stanley 1987; Tesson *et al.* 1990, 1993; Gensous and Tesson 1996, 1998; Somoza *et al.* 1998; Amorosi and Milli 2001). Palynological studies used for analysing the changes in the land area covered by mangroves during the late Quaternary are abundantly documented as consequences of sea level and climate changes (Ellison 1989, 1996; Woodroffe and Grindrod 1991; Lezine 1997). The climate and relative lake level fluctuations can be attributed to the changes in vegetation types in a catchment area and its pollen record can help to reconstruct the vegetation profile and types (Vincens *et al.* 2003). From the palynological study of surface marine sediments, the distribution patterns of pollen and spores and their relationships with source areas and transport systems can be established (Caratini *et al.* 1980; Hooghiemstra *et al.* 1986; Lezine and Hooghiemstra 1990; Dupont and Agwu 1991; Frederiksen *et al.* 1994). Such studies are essential to interpret marine pollen records in sediment cores, which document vegetational changes associated with the major environmental fluctuations that occurred in the past (Van Campo and Bengo 2004).

Southwest coast of India was under the influence of local marine environments to a minor extent and the region has recorded a five-stage transgressive and regressive episodes (Nair 2005). Palaeopalynological analysis showed humid climate with maximum representation of mangrove vegetation (around 10,000 yr BP) in the Arabian Sea area

(Van Campo 1986). According to Rajendran *et al.* (1989) and Prakash *et al.* (2001) the formation of the backwater system found along the Indian southwest coast was linked to a series of transgression (8000–6000 yr BP) and regression (5000–3000 yr BP) events. Several studies had shown that neotectonic/eustatic event in the southern coastal stretches of peninsular India caused the modification of the coast during the Quaternary period (Narayana *et al.* 2002; Soman 2002) and the river systems also followed these changes (Narayana *et al.* 2001). Vaidhyanadhan (1971) reported that the southwest coast of India has records on filling up of a series of bays with mud during the Holocene and later covered by sand and the radiocarbon dating of one such emerged areas has given a date of 6460 yr BP. Along with other river systems of the coast, Meenachil River also had adjusted its morphology according to the coastal changes. These geomorphological modifications along with channel shifts might have caused the unique and extensive distribution of palaeo-deposit of sand, identified recently from the watershed area of Meenachil River (Mohan *et al.* 2005). The present study aims to throw light into the palaeoenvironmental conditions of southwestern coast of India during the Holocene through the analysis of pollens embedded in the palaeo-deposits present in Meenachil River basin.

2. Materials and methods

2.1 Study area

Meenachil River watershed extends from 9°25'–9°55'N latitudes and 76°20'–76°55'E longitudes. The area is a part of the south Indian Precambrian terrain characterised by the presence of granulites and associated gneiss. Later, it witnessed the intrusion of dolerite and gabbro (trending NNW–SSE

Table 1. *Sampling locations and geographical positions.*

Region	Sample no.	Geographical position		Distance from the existing water course (m)
		Latitude (N)	Longitude (E)	
R-1	1	9°38.63'	76°34.92'	55
	2	9°38.83'	76°34.92'	96
	3	9°38.83'	76°34.99'	230
R-2	4	9°37.09'	76°33.51'	160
	5	9°37.16'	76°33.60'	95
	6	9°37.30'	76°34.0'	65
R-3	7	9°36.47'	76°33.62'	80
R-4	8	9°39.63'	76°35.56'	200
	9	9°39.89'	76°35.81'	100
	10	9°39.39'	76°35.66'	100

Figure 1. Study area showing sampling locations.

Figure 2. Geomorphology of the study area.

and NW–SE respectively, which differ one another in trend, mineralogical composition and age, and therefore do not relate to a single swarm), contemporaneous tectonic deformation and metamorphism and later upliftment of the region, which all had occurred even before the last glacial maxima.

The geographical position and characteristics of palaeodeposit of sand were shown in table 1 and

figures 1–3. The sampling regions of the R-1, R-3 and R-4 are located at the southern side of the Meenachil River, while the sampling locations of the R-2 are at the northern side of the river. The R-3 has a unique character of having the geographical position in between Meenachil River and Meenadom stream (a tributary of the former), where both the rivers flow closest to each other.

Figure 3. Presence of carbonaceous clay as sandwiched between the sand column.

2.2 Sampling

The locations of palaeodeposits of sand were identified, georeferenced with the help of GPS and plotted on the base map. Eight stations were identified from four palaeo-depositional regions (R-1, R-2, R-3 and R-4) of lower reaches of Meenachil watershed (figure 1). All the regions are presently located about 15 km inland from the present Vembanad Lake – a Ramsar site and one of the largest lake systems along the western coast of India and about 28 km inland from the present coastal line. The study area possesses three distinct geomorphological units – flood plain, lower plateau lateritic valley and lower plateau lateritic (figure 2). Even though the sampling sites are located within the flood plain region, the flood plain does not possess palaeodeposit throughout its entire stretch.

2.3 Radiocarbon dating (Carbon-14 Method)

Carbon-14 is a rare indicative isotope that occurs naturally in the atmosphere and in living plants and animals. The half-life of 5730 years is so low that Carbon-14 has not been generally measurable in organic material older than about 40,000 years. Samples for ^{14}C dating were also taken from these four regions in a manner that the sediment sample for dating was collected from Region 1 and wood samples from other regions (R-2, R-3 and R-4). ^{14}C dating was carried out at Birbal Sahni

Institute of Palaeobotany, India using an ultra low-level Quantulus Liquid Scintillation counter employing benzene.

2.4 Pollen analysis

The representative samples for palynological analysis were collected (table 1) from the carbonaceous clay bed found sandwiched between the palaeodeposit of sand in four regions (figure 3). A schematic representation of the succession is given in figure 4. The collected sediment samples were subjected to chemical treatment and pollen grains were analysed as per the methodology suggested by Faegri and Iversen (1975). Sediment samples were gently grinded in a mortar and transferred to 100 ml graduated measuring cylinder. Later 60 ml of distilled water was added and mixed well using glass rod. The samples were kept for 30 minutes and decanted the overlying water and added Tertiary Butyl Alcohol (TBA) after stirring. The above samples were transferred into polypropylene test tubes and treated with 10% potassium hydroxide (KOH) for the removal of humic acids. The samples were then screened with the help of $150\ \mu$ mesh size sieve for removing the large particles and other fragments. Consequently treatment with 10% hydrochloric acid and 48% hydrofluoric acid was also done for the removal of carbonates and silicates from the sediment samples. Each step was repeated for several times for the

Figure 4. Succession of deposits at different regions.

Table 2. ^{14}C – Age of the palaeo-deposits.

Sl. no.	Region	Sample code	Material	Age (^{14}C yr BP)	Geographical position in relation to the Meenachil River
1	R-1	AMR VI	Sediment	5786 ± 94	South
2	R-2	AKLM I	Wood	2888 ± 78	North
3	R-3	SES I A	Wood	5570 ± 30	South
4	R-4	PRA II	Wood	5780 ± 95	South

maximum removal of sediment particles. Chemically treated pollen grains were stained using 1% aqueous safranin. The prepared slides were examined and identified under Nikon Eclipse E 400 microscope and photomicrographs were prepared.

3. Results

The results of ^{14}C dating (non-calibrated ages) are shown in table 2. The clay sample collected from Region 1 showed an age of 5786 ± 94 ^{14}C yr BP (AMR VI). The wood samples collected from Regions 3 and 4 showed 5570 ± 30 ^{14}C yr BP (SES I A) and 5780 ± 95 ^{14}C yr BP (PRA II), respectively. But the wood samples of Region 2, which is on northern side of the Meenachil River gave an age of 2888 ± 78 ^{14}C yr BP (AKLM I).

The palynological analysis showed that the floral elements composed of angiosperms (monocots and dicots), and pteridophytes. Of the 46 families identified, 32 are trees. Total number of species found at various palaeodeposit regions are presented in figure 5 and the photomicrographs of some

important pollen grains are given in figure 6. The carbonaceous clay formation of R-1 contained a total of 49 species of pollen grains, of which 43 species were identified (table 3). These pollens belong to 15 angiosperm families. The presence of Cyperaceae, Compositae, and Amaranthaceae, Amarylladiaceae, Liliaceae and Papilionaceae indicated the herbaceous weedy habitat of the region. The presence of *Casuarina equisetifolia* (P14/figure 6),

Figure 5. Total number of species found at various regions of palaeodeposit.

Figure 6. Photomicrographs of selected pollen grains. P-1: Cyperaceae, P-2: *Cocos nucifera*, P-3: *Ilex* sp., P-4: *Amaranthus* sp., P-5: Grass, P-6: *Bombax ceiba*, P-7: *Bauhinia* sp., P-8: Chenopodiaceae, P-9: *Delonix regia*, P-10: *Nymphaeae*, P-11: *Azadirachta* sp., P-12: *Lemna* sp., P-13: *piper* sp., P-14: *Casuarina equisetifolia*, P-15: *Tribe vernoneae*, P-16: *Tribe astreae*, P-17: Grass, and P-18: *Terminalia* sp.

Table 3. Plant family and species found in the palaeodeposits of different regions.

Family	Species			
	R1	R2	R3	R4
Amaranthaceae	<i>Amaranthus</i> sp.		<i>Amaranthus</i> sp.	<i>Alternanthera</i> sp., <i>Amaranthus</i> sp.
Amaryllidaceae	U			
Caesalpiniaceae	<i>Bauhinia</i> sp.			
Casuarinaceae	<i>Casuarina equisetifolia</i>			<i>Bauhinia</i> sp.
Compositae	Tribe <i>astreae</i>			Tribe <i>astreae</i>
(Asteraceae)	Tribe <i>vernoneae</i>			Tribe <i>vernoneae</i>
Cyperaceae	U			
Poaceae	Grass sp.	<i>Oryza sativa</i>	Grass sp.	U
Ilacinaeeae	<i>Ilex</i> sp.			
Leguminosae	<i>Delonix regia</i>		U	
Liliaceae	U	U		U
Meliaceae	<i>Azadirachta indica</i>			
Myrtaceae	<i>Eugenia</i> sp.		<i>Eugenia</i> sp.	<i>Eucalyptus</i> sp.
Papilionaceae	U			U
Plantaginaceae	<i>Plantago</i> sp.			
Acanthaceae	<i>Barleria</i> sp.	<i>Barleria</i> sp.		
Asteraceae	U	U	Tribe <i>Astreae</i>	
Nymphaeaceae	<i>Nymphaea</i> sp.	<i>Nymphaea</i> sp.	<i>Nymphaea</i> sp.	<i>Nymphaea</i> sp.
Piperaceae	<i>Piper</i> sp.	<i>Piper</i> sp.		
Pteridophyte		U		U
Trapaceae		<i>Trapa natans</i>	<i>Trapa natans</i>	
Arecaceae			<i>Cocos nucifera</i>	<i>Borassus flabellifer</i> , <i>Cocos nucifera</i>
Bombacaceae			<i>Bombax ceiba</i>	
Chenopodiaceae			<i>Chenopodium</i> sp.	
Combretaceae			<i>Terminalia</i> sp.	
Mimosaceae			<i>Albizia lebbek</i>	
Plumbaginaceae			<i>Plumbago</i> sp.	
Lemnaceae				<i>Lemna</i> sp.
Lentibulariaceae				<i>Utricularia</i> sp.

U: Unidentified sp.

Azadirachta sp. and *Eugenia* sp. reveals the possibility of cultivation in this region. In R-2, 22 species of pollen grains were found, of which 16 species were identified (table 3) belonging to five angiosperm families. Two spores of pteridophytes were also found in the sample. The presence of *Nymphaea* pollen (P10/figure 6) and *Oryza sativa* pollen of Poaceae indicated the possible wetland habitat of the region. The presence of *Piper* sp. (P13/figure 6) and *Oryza sativa* pollens clearly indicated cultivation in the region. Of the total 39 species of pollens recorded from the R-3, 38 species were identified (table 3). The presence of Poaceae, Cyperaceae (P1/figure 6) and Nymphaeaceae indicated the existence of wetland system, and the dominance of grass species in this region denoted the possible water logging habitat. Besides, other weedy elements belonged to Amaranthaceae, Chenopodiaceae and Compositae were

also observed. Pollens of *Bombax ceiba* (P6/figure 6) which are characteristic to moist deciduous habitat were also recorded. The sediment samples of R-4 contain 34 species of pollen grains, out of which 28 species were identified (table 3). The collected pollens of this region belong to 14 angiosperm families. The presence of Nymphaeaceae, clearly signified a shallow aquatic habitat. Possibly it was a wetland and the absence of mangrove/mangrove associated plants indicates its freshwater nature. The presence of *Cocos nucifera* (P2/figure 6) indicated cultivation in this region.

4. Discussion

The non-uniform distribution pattern of the palaeodeposit of sand along the low lying regions of

the Meenachil River is suggestive of as formed by the northward and southward shifting of the main channel according to palaeoenvironmental changes including global eustatic sea level fluctuations. The absence of repeated graded bedding in the sequence of sedimentary column rules out its formation as flood plain deposit (figure 3), while graded bedding, supposed to be formed under a single realm, is seen in point bar deposits (figure 7). Besides, the occurrence of palaeodeposits of sand well above the present riverbed is clearly suggestive of elevated base level of erosion (figure 8) during the Holocene.

The fossil pollen and spores have been of special importance in gaining knowledge on the Quaternary vegetational history leading to the present day vegetation (Nair 1977). Among the herbaceous component, diversity of grass pollen as seen by their size and morphological features are suggestive of the preponderance of the group in the flora. Besides, other weedy elements belonged to *Amaranthaceae* and *Chenopodiaceae* were also present. The presence of freshwater herbs like *Lemna*, *Nymphaea*, and marshy aquatic herbs of *Cyperaceae* and *Poaceae* showed the existence of a possible wetland system in the study area. It seems that riverbed vegetation was dominated by

Figure 7. Graded bedding in point bar deposits.

Figure 8. Occurrence of palaeodeposits well above the present base level of erosion.

Figure 9. Presence of granules and current bedding suggest high velocity hydraulic regime during the early Holocene.

weeds, grasses and other ferns. There could have been pools of water formed due to the transgression of sea and such an ecological condition seems to have lead to the occurrence of aquatic species of *Nymphaea* growing along the boundaries.

The presence of pollens of *Casuarina equisetifolia*, *Azadirachta* sp. and *Eugenia* sp. from Region 1, *Piper* sp. and *Oryza sativa* from Region 2 and *Cocos nucifera* from Region 4 clearly depict the historic inference on cultivation in this area. The present findings highlight the earlier observations that the south India had indigenous agricultural developments during the Neolithic age (Fuller and Korisettar 2004; Fuller 2006).

Earlier studies suggested that around 4000 yr BP there was a very prominent neotectonic/eustatic event in the southern coastal tracts of south India (Soman 2002). Limeshell from the bottom of Vembanad Lake yielded ages of 3710 ± 90 (location: Vechoor) and 3130 ± 100 (location: Muhamma) ^{14}C yr BP (figure 1) and it was also suggested to be interpreted that foundering of the estuaries/lake systems along the southwestern coast of India was sequential and the northern estuaries/lake systems were earlier than the southern ones. In relation with this observation, it is well established that the southern palaeodeposit regions (R1, R3 and R4) of Meenachil river basins had the origin even before the formation of the Vembanad lake system along the southwestern coast.

The above results strongly suggest that the southwestern coast of India also had experienced intensified and prolonged Asiatic monsoon during the earlier part of the Atlantic chronozone (8500 to 6000 yr BP) as observed from other parts of the western coast (Borole *et al.* 1982; Ramesh 2001; Thampan *et al.* 2001; Ansari and Vink 2007; Nair *et al.* 2010) and the causative factors which triggered this mechanism were likely to be a function of mid-Holocene insolation regime (Morimoto *et al.* 2007) and shifts in the position of the Inter Tropical Convergence Zone (ITCZ) (Ansari and Vink 2007). Besides, the sedimentological analysis revealed that the mud content in the palaeodeposit of sand was very low (<2%) indicating strong winnowing action during the phase of deposition (Mohan *et al.* 2005) and the presence of granules at the bottom level of the palaeodeposit marks the high velocity hydrological regime triggered by intensified monsoonal precipitation during the earlier part of the Holocene (figure 9). The phenomenon which led to the deposition of thin layer of carbonaceous clay in between the sand layer was related to the elevated base level of erosion as recorded from other parts of the western coast of Indian peninsula during the late Holocene and its high C/N ratio is owed to the submergence of terrestrial plants (Ajaykumar *et al.* 2010).

Studies carried out by Guleria *et al.* (2008) on the carbonised woods embedded in the palaeodeposit of sand present in the Meenachil river basin threw light on the presence of wet climatic conditions before the deposition of the carbonaceous

clay clarifying the intensified rainfall. The presence of near shore inhabitant genera such as *Calophyllum*, *Spondias*, and *Sonneratia* indicated the proximity of sea in the area and the elevated sea level, which caused the submergence and extinction of mangroves then present along the coastal region, was also clarified. It would have been one of the reasons for not having palynological records of mangroves in the later deposited carbonaceous clay. The present study related to the totality of vegetation suggests a drier climate by virtue of the dominance of weeds and less number of tree elements was followed after the stagnancy/elevated level.

The most conspicuous geomorphological modification at the southwestern coast of India during the late Holocene was the origin and development of the Vembanad Lake system. The palaeodeposit regions R-1, R-3 and R-4 were developed even before the formation of the lake system. As stated earlier, the formation of the Vembanad Lake system was an outcome of a very prominent neotectonic/eustatic event, which caused the Meenachil River to shift from south to north than its position during the time of Pre-Vembanad lake formation. Later the region has received another episode of maximum precipitation, which led to the formation of R-2 (age is 2888 ± 78 ^{14}C yr BP) followed by an event of aridification. The results of the present work going hand in hand with the previous observations that several other parts of the western coast of India enhanced by winter monsoon during 3900 to 3000 ^{14}C yr BP followed by an onset of aridification at about 3000 yr BP (Sarkar *et al.* 2000; Luckge *et al.* 2001; Ramesh 2001). Kumaran *et al.* (2005) suggested that after about 5000 or 4000 ^{14}C yr BP, the monsoon became gradually decreased leading to drying up of many marginal mangrove ecosystem. It has also been proposed by Jayalakshmi *et al.* (2005) that there was presence of a dry climate during 2180 ± 70 ^{14}C yr BP. The absence of evergreen forest elements in pollen spectra also indicated that there was a transition of wetland and deciduous forest system. The presence of deciduous forest trees like *Terminalia* sp., *Bombax ceiba* and the occurrence of *Eugenia* species also support the observation. There seems to have been farming activities in the area with the floodplain being fed with humus rich sediments caused by flooding and the rich riverbed seems to have provided an ideal ground for growing crops.

5. Conclusions

Georeferenced locations and the nature of the terrestrial sand deposits and their proximity to the existing water courses and ^{14}C dating of sediment and carbonaceous wood samples are suggestive of

modification and shifting of stream channels of Meenachil River in relation to marine transgression/regression coupled with tectonism. The south-western coast of India had experienced intensified Asiatic monsoon during the earlier part of the Holocene and the formation of the palaeo-deposit of sand had its origin even before the formation of the Vembanad Lake system ($\cong$ 4000 yr BP). It is also suggested that the presence of clay deposit found sandwiched between the sand deposits is indicative of the decline of one fluvial condition, stagnancy and the beginning of the other. The dominance of deciduous species obtained from the palaeo-palynological studies indicated that the wet climate, which nourished the evergreen species and mangroves, had declined during the late Holocene and a drier climate was experienced later along the western coast of India. The region had experienced another episode of elevated base level of erosion around 3000 yr BP and the morphological modification of the region could be classified under: (1) Pre-Vembanad Lake formation, (2) Contemporaneous to the Lake formation and (3) Post-Lake formation.

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