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Floristic composition, palynology and sedimentary facies of Hadi mangrove swamp (Maharashtra)

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ABSTRACT
The mangrove profile of Hadi has been subjected to palynological analysis and sedimentary facies study. On the basis of identifiable taxa, number of ecological complexes has been recognized. No organic recovery at 50 cm level and its conspicuous absence may be related to an ecological shift probably as a result of a natural cause. The abundance of spores of a freshwater flood plain fern (*Ceratopteris thalictroides*) at 100 cm level suggests a possible influx of freshwater. Further, the recovery of good mangrove pollen (Rhizophoraceae and Avicenniaceae) between 130 and 140 cm interval indicates luxuriance of mangrove as a result of periodic influx of freshwater. As the sustenance of mangroves is related to hydrodynamics and sedimentology, the mangrove swamps form an ideal storage site for palaeomonsoon records. There is hardly any input of environmental magnetism along with pollen analysis from the mangrove sediments of India for high-resolution palaeoclimatic study. Hence, the importance of an integrated study of mangrove sediments has been discussed using Hadi swamp profile.

INTRODUCTION

The term 'mangrove' has been defined in various ways by many, but all of them in one way or other, are related to a plant community associated with the near-shore marine habitat. In fact, the mangrove occupies a niche of itself, as it is in a transitional zone between the marine and terrestrial environments of the low-lying tropical coastlines. The tidal amplitude of sea and the fresh water input maintains an ecological balance for the sustenance of this specialized ecosystem along the coast. Although the mangrove vegetation consists mostly of taxonomically unrelated plant species (Table 1), they have similar physiognomy, physiological characteristics and structural adaptations to the habitat (Tomlinson 1986). All mangroves are adapted to high water stress, exhibit mechanisms that allow water uptake against the physiological water gradient and have xerophytic adaptations.

Mangroves are known by their specialized aerial roots and viviparous seedlings. The root architecture of mangroves is a highly specialized feature. In addition to the normal function of mechanical support and absorption of nutrient and water, these roots provide interface for gaseous exchange. Mangroves exhibit specialized roots like stilt roots or aerial roots (*Rhizophora* sp.), pneumatophores (*Avicennia* & *Sonneratia* sp.), knee roots (*Bruguiera* sp.), plank roots (*Xylocarpus* sp.). This root architecture constitutes a conspicuous element of mangroves and has tremendous influence on sediment accumulation.

In India, mangroves are unevenly distributed along the east and west coast and islands. Because of major deltas along the east coast, the mangroves are better and well developed here as compared to those of west coast. According to the report of Forest Survey of India (1999), the total area of mangrove cover is estimated to be 4,87,100 ha of which, nearly 56.7% (2,75,800 ha) occurs along the east coast while 23.5% (1,14,700 ha) is found along west coast and remaining 19.8% (96,000 ha) is present along the Andaman and Nicobar Islands. Factors such as geomorphology, climate, tidal amplitude and duration and quantity of freshwater inflow determine their distribution (Blasco 1975, 1984; Thom 1984). Extensive and diverse mangrove wetlands are found in Sunderban region of West Bengal and Andaman and Nicobar Islands. The aspect of environmental setting varies from place to place depending upon the source of freshwater, their annual discharge, total rainfall, duration of dry interval and the tidal amplitude. The mangrove wetlands of Sundarbans and Mahanadi are tide-dominated type, whereas those of Godavari, Krishna and the Cauvery are of river-dominated type. The major mangrove wetland of Gujarat falls under the category of drowned valley type, as there is no perennial river which contributes freshwater to this area. The carbonate platform on low energy coast makes up the environmental setting of the Andaman Nicobar islands mangrove wetlands (Selvam 2003).

Sedimentation in mangroves is determined by interaction between the mangrove root systems and sediment laden tidal waters. Due to the high rates of accretion, mangrove sediments may turn out to be very useful for palaeomonsoon studies. In any palaeoclimatic reconstruction study it is imperative to understand the sedimentation process and resultant facies in a given depositional environment. This is very important in order to gauge whether basic premises such as continuous sedimentation rates are met or not. The purpose of this paper is to describe the floristic and palynological comparison from Hadi, Maharashtra. Details on sedimentation process are discussed to explain the cause of facies variation in the profile.

METHODS

A field site was identified near the back mangrove area of Hadi (Fig. 1a), which has been converted in to a seasonal paddy field. Retrieving of the subsurface profile was carried out by making a rectangular trench of (2m x 1m x 2m). Exact geographical position of a trench was recorded ($16^{0}08'38''$ N & $73^{0}28'36''$ E) using a Magellan 315 Geographic Positioning System. 20 samples at an interval of 10 cm were collected and analyzed for their palaeobiological content. Standard procedure for separation of organic matter from the sediment using a combined hydrofluoric acid (HF) and mild alkali treatment was used followed by wet sieving (Traverse 1988). Bartington MS-2B duel frequency susceptometer is used for magnetic susceptibility measurements.

HADI MANGROVE SWAMP

Village Hadi is located on the Malvan – Achra road, 7 Km North to Malvan (Fig. 1a). It is situated along the east bank of Kalvali creek about 7 Km away from the mouth where Gad river meets the creek. It is situated on the upland area (10-40 m) between the creek and the creek arm, which is extended southwards to Kandalgaon (Fig. 1a). The minimum and maximum atmospheric temperature recorded at Malvan ranges from 18^{o}C (December) to 35^{o}C (May) and relative humidity ranges from 50 to 90 %. This region experiences 2000-3000 mm average rainfall during the months of June to September. The tidal amplitude in this region is around 2 m.

Along the west bank of Kalvali creek, a striking beach feature of beach rock is observed. It has about 4 km long expanse of sandy beach facing the Arabian Sea. The tidal currents are strong along the west bank of Kalvali creek, which do not allow the growth, and development of biota. On the eastern bank of Kalvali creek, along the creeklets and small bays with low tidal force, swampy habitats are developed. The substratum is of sandy to silty clay type where the mean salinity ranges from 5 – 30%. These estuarine swamps harbor supratidal mangrove formation. The fringing areas are dominated by *Rhizophora mucronata* and *Avicennia officinalis*. In addition, mangroves like *Rhizophora apiculata*, *Avicennia marina*, *Sonneratia alba* and *Excoecaria agallocha* occur frequently. A rare population of *Kandelia candal* has also been encountered from this region. In the oligohaline zone (salinity less than 5%) *Aegiceras corniculata* grows in abundance.

In general, the growth of mangroves is moderate and of sheltered zone type. Average height of mangrove vegetation is about 4 m. There is no specific zonation observed from estuary towards terrestrial end. Regarding the rooting pattern stilt roots of *Rhizophora* and pneumatophores of *Avicennia* are dominant and densely distributed in the swamp (Fig. 2). Stilt roots attain the average height of about 5 feet while the pneumatophores are of 1 foot.

These mangroves are subjected to various threats. A recent trend of construction of salt bund (locally known as *Khar Bandhara*) is very significant in this context. Salt bunds are constructed to prevent the intrusion brackish water in the swamps, which leads to conversion of the mangrove habitats into paddy fields. In addition, species of *Avicennia* and *Sonneratia* are under destruction for the fuel wood.

In a trench, the upper 1-meter interval is made up of alluvial soil cover, laterite, limonitic sediments and sands, while the lower part represents clay sediments. There are carbonaceous plastic clays rich in organic matter, which is continuous through out the profile (Fig. 1b).

Palynological analysis of the mangrove sediments of Hadi has yielded a fairly rich and diversified microfossil assemblage. It has been possible to recognize marine, estuarine (brackish water), fresh water aquatics, sandy beach, and terrestrial or hinterland ecological complexes from the microfossil contents (Fig. 3). Besides, fern and fungal complexes have also been identified. The common forms found in all samples, viz., *Ceratopteris*, dinoflagellates, fungal spores, algal cysts, fungal fruiting bodies, foraminiferal linings, mangrove pollen and marine planktons are used for fixing the ecological preferences. Overall, the palynoflora is well preserved with its normal size, shape and ornamentations. It is well identifiable at 300-400 X magnification with the

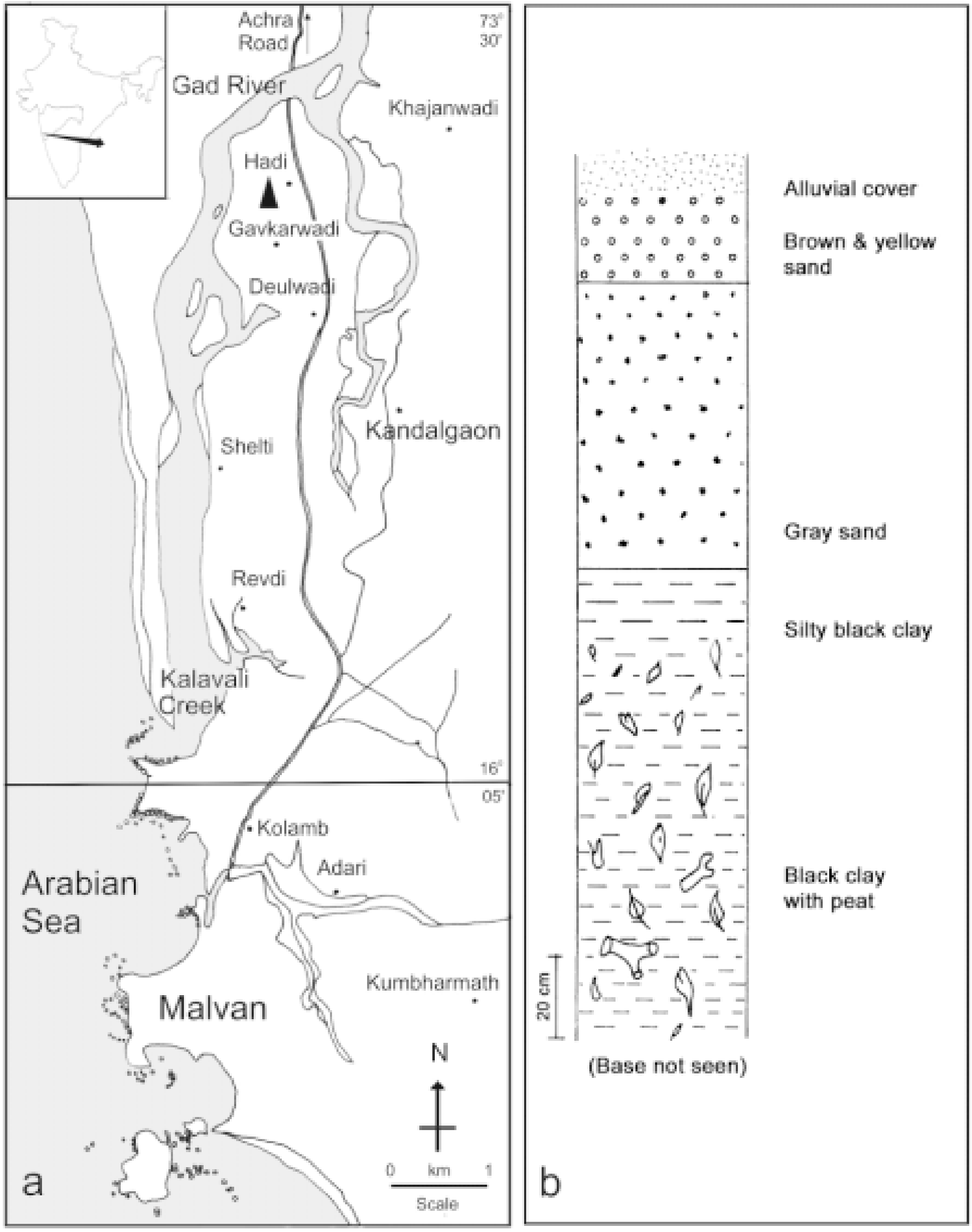

Figure 1. (a) Location map of Hadi section near Malvan and (b) its lithological details.

Figure 2. (a) Mangrove habitat showing pneumatophores (b) a close view of pneumatophores of *Avicennia* sp. (c) aerial roots of mangroves (d) a close view of aerial roots of *Rhizophora* sp.

Table 1. Mangrove species & associates of Maharashtra.

AVICENNIACEAE *Avicennia officinalis* L. *Avicennia marina* (Forsk.) Vahl. *Avicennia alba* Bl.	**ACANTHACEAE** *Acanthus ilicifolius* L. *Acanthus volubilis* Wall. *Acanthus ebractiatus* Vahl.
COMBRETACEAE *Lumnitzera racemosa Willd.* *Lumnitzera littorea* (Jack.) Voigt	**FABACEAE** * *Derris trifoliate Loen.* * *Derris heterophylla* Willd.
EUPHORBIACEAE *Excoecaria agallocha L.*	**SALVADORACEAE** * *Salvadora persica L.*
MYRCINACEAE *Aegiceras corniculatum L.*	**VERBANACEAE** * *Clerodendrum inerme Gaertn.*
PLUMBAGINACEAE *Aegialitis rotundifolia* Roxb.	**MALVACEAE** * *Thespecia populnea L.*
RHIZOPHORACEAE *Rhizophora mucronata* Lamk. *Rhizophora apiculata* Bl. *Bruguiera cylindrical* (L.) Bl. *Bruguiera gymnorhiza* (L.) Lamk. *Ceriops tagal* (Perr.) Robin. *Ceriops decandra* (Griff.) Ding Hou *Kandelia candel* (L.) Druce	**SONNERATIACEAE** *Sonneratia alba* J.Sm. *Sonneratia apetala* Buch.-Ham. *Sonneratia caseolaris* (L.) Engl. **MELIACEAE** *Xylocarpous granatum* Koen.
PTERIDACEAE **Acrostichum aureum* L.	**FABACEAE** *Cynometra iripa L.*

(* Mangrove associates)

available keys. Pollen of mangroves and associates were compared with the pollen of living extant species and key provided by Thanikaimoni (1987) while fungal elements were referred to Kohlmeyer & Kohlmeyer (1979).

Among the marine micro-planktons *Operculodinium* and *Spiniferites* sp. are fairly dominant and smooth walled cysts follow. Foraminiferal linings, representing the organic tests of foraminifers and the mouthparts of certain marine annelid worm (polychaetes) are the other representatives of marine complexes.

Pollen flora of mangroves is dominated by Rhizophoraceae and minor components like *Acrostichum*. However, the pollen of *Avicennia* and *Sonneratia* are very scarce. Though the Hadi mangrove swamp presently contains species of *Kandelia,* it has not been recognized in the sediments. In mangrove associates, pollens of family Malvaceae are prominently represented by *Thespesia* sp. and *Hibiscus tiliaceus*.

Pollen of Chenopodiaceae representing the salt marsh plants were rarely found. In general, pollen of terrestrial plants were not found in abundance. Impact of fresh water environment in the microfossil assemblage is mainly dominated by the presence of spores of *Ceratopteris thalictroides*. In addition, pollen of Potamogetonaceae and Liliaceae are frequently found. The pollen can be easily recognized by their wall articulator without any complex sculpture. Apart from this, cuticles without any stomatal features, probably of aquatic plants have also been found in the palynological preparations.

Certain coastal plants viz., *Pandanus*, palms and other sandy beach taxa make up the coastal complex in the palynological assemblage. Grass pollen does come across in the microfossils. Pteridophytic complex and fungal complexes are fairly represented in the pollen assemblage. Spores, mycelia and fruiting bodies make up the fungal complex; the fruiting bodies belong to microthyriaceae families of Ascomycetes are prominent at level.

Based on the observations made from the sample prepared at every 10 cm interval, a number of ecological complexes are found. The relative abundance of palynoflora in the profile varies within the 2-meter sequence. Palynological assemblage of recent agricultural crops and other terrestrial vegetation is observed in upper alluvial layer. Further, the yellow brown layer exhibits diversity of marine complexes and algal cysts. At the level of 50 cm from gray sand layer there is absolute absence of organic matter. In general the organic recovery was very poor in this zone. There is a good recovery of *Ceratopteris* spores at 100 cm interval. This is followed by silty black clay, where the pollen of mangroves are fairly abundant at an interval between 130-140 cm. In fact, they are confined only at this interval and this is very significant in the profile. This clearly indicates the depositional environment. At this interval, Rhizophoraceae pollen are abundant, followed by spore of mangrove fern *Acrosticum aureum.* Influence of brackish water in this phase was evidenced by a common occurrence of flask shaped and saucer shaped forms at certain interval. Pollen of terrestrial plants are scarce in between 90-120 cm and 170-200 cm. Towards the base, a continuous layer of black plastic clay with peat is observed with significant presence of dinoflagellates indicating marine facies.

Magnetic susceptibility (χ) ranges from 18 to 80 ($x10^{-8}m^3kg^{-1}$). The lower part of the profile, which contains mangrove elements (Fig. 3) has the lowest values. These low values predominate the entire section from the base to a depth of 40 cm. The entire profile is characterized by invariability in χ values. Towards the top, χ increases significantly to up to 80 and is accompanied in the palynological record by the appearance of terrestrial and freshwater elements. This transition is governed by a change in the depositional environment, which is also explicit when compared with the trench photolog (Fig. 3).

DISCUSSION

The Hadi mangrove swamp harbour poor mangrove diversity when compared with that observed along the Konkan coast. Out of 20 species recorded in Maharashtra (Table 1) (Deshmukh 1990; Bhosale et al. 2002), 8 species are recorded in this ecosystem.

This sediment trapping mechanism results in the predominance of clays and silty clays in mangroves. In all the Indian mangroves sand, silt and clay contents range from 0-20, 0-60 and 15-80 respectively (Table 2). A mangrove depositional environment for this interval is confirmed by the presence of mangrove pollens at 130-140 cm depth.

The interwoven aerial root systems observed at Hadi are typical to the mangrove environment and are critical towards sediment trapping, which leads to the plastic clay facies very rich in organic contents. The pneumatophores control the movement of the silt and this makes the coastal landform and raises the level of the ground so that it develops a suitable substrate for the establishment of other plant species. In fact, the root system of the pioneer species holds the sediments intact and enhances the accretion process. At Hadi, *Rhizophora* species may be predicted as pioneer species in this context. Accretion process starts when organic debris is trapped by the root

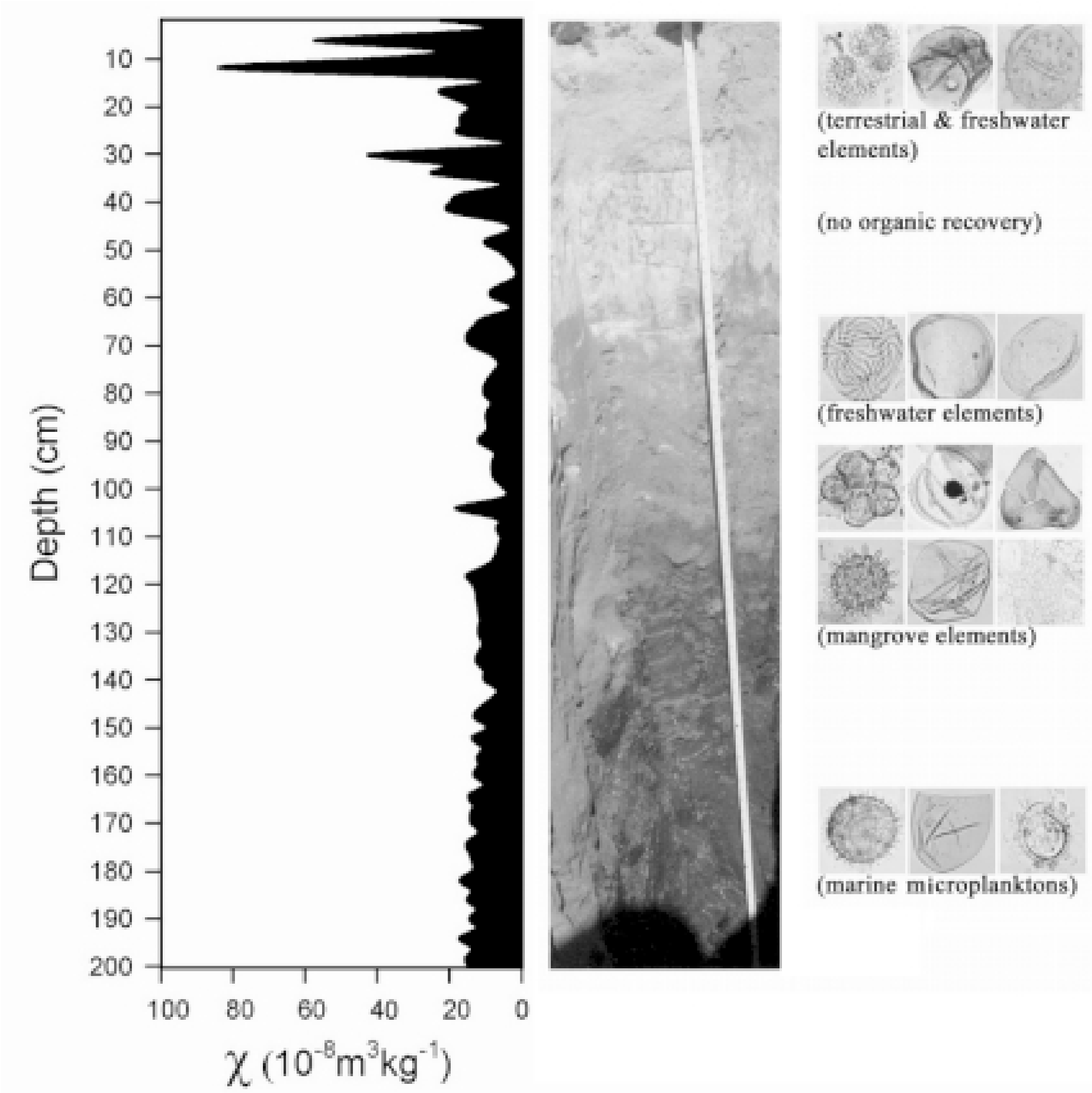

Figure 3. The Hadi mangrove trench profile with representative microfossil assemblages at different facies and corresponding susceptibility curve. Note that the low χ values correspond to the dark clays of mangrove origin.

system of mangroves. The continuous deposition of the trapped organic debris provides a suitable substrate for new seedlings to establish themselves. As more sediments are laid down, progradation of the land will ensue since the mangrove will hold them fast on a large scale. Tidal circulation, water flow, mixing, flushing and organic matter dispersion are part of the hydrodynamic processes in mangrove swamps and as such depend on the prevailing pattern of vegetative structure close to the substrate that interferes with water currents (Wolanski et al. 2001). The structure varies from simple trunks similar to vertical rods to a buttress formation, to a complex network of roots and pneumatophores. *Rhizophora* species have prop roots, with many root bunches and rootlets. *Avicennia* species have horizontal roots from which many aerial roots branch off (Fig. 2). The different root structure and architecture produce variable conditions for sedimentation process in mangrove swamps. In fact, the prop roots associated with *Rhizophora* spp. may facilitate sediment deposition to a greater degree than pneumatophores (Krauss et al. 2003).

Weak wave action, which is a characteristic feature of the ecosystem results in the formation of depositional environment with low flushing and high stagnation of water. Suspended matter, mostly fine sediment particles, churned by tidal movements vary (Wu et al. 2001). Due to the lack of vigorous water motion, the fine sediments tend to settle on the bottom, rather than get widely dispersed by flushing. The net result is an accumulation of soft sediments where poor interstitial circulation, high organic content and high microbial population, lead to anoxic condition. As a combined effect of weak circulation and high organic inputs mainly from decaying leaves and debris, there is a large amount of organic matter in the mangrove sediments. Even though mangroves could thrive in clay, silt, sand, peat and coral soils (Chapman 1976), the best-suited substrate for their growth is reportedly clay or clay silt formations.

There is a good recovery of *Ceratopteris* spores at 100 cm interval suggesting a possible influx of fresh water into the mangrove swamp. However, no organic matter is observed at the 50 cm level and its conspicuous absence may be related to an ecological shift.

The presence of the mangrove environment at lower levels suggests that their presence has been governed by a number of environmental factors. In addition to the swampy substratum, rainfall, tidal flat, ground water, fresh water input through the rivers and the mangrove swamp substrate have a significant effect on mangrove species distribution. Rainfall influences the distribution of species because it directly recharges the groundwater system and affects subsurface seepage along the hinterland edge. Freshwater flow from upland brings nutrients and silt important for the growth of mangroves. Mangroves are thus most well developed on muddy coastal plains where adequate fresh water supplies from discharges are available. Mangroves have been reported from various sedimentary environments (Khandelwal 1992). As they grow in shallow waters and inter-tidal areas, tide influenced events of desiccation and submergence are appreciably strong. The effects of environmental factors such as geomorphic, geophysical, hydrological and biotic conditions determine the extent and distribution of the mangroves.

Mangrove forests are well developed where the rainfall is high and well spread throughout the year. The rainfall conditions are more decisive for the sequence of mangrove distribution of the different zones in the tidal region (Rao 1986). The rainwater leaches down saline soil or salt particles, within the soil substratum more effectively. During the successive tidal flood the salt water inundates the land surface and the subsequent exposure of the soil substratum evaporate the water from these salt-mixed solution. These resulted in thick salt crest on the soil surface, which inhibit the regeneration and growth of the mangroves. But frequent rainwater flushing wash out the surface salt and also leach down the salt particles and turn the land suitable for the growth of mangroves (Naskar & Mandal 1999). If the rainfall is less and duration of rainy season is also very short during the year, the mangrove species may grow satisfactorily with the adequate supply of freshwater and runoff water through the drainage system. The unusual rainfall or irregular climates have adverse effect on the mangrove ecosystem.

As the climate of India is dominated by two monsoon seasons and the rate of rainfall varies from north to south along both the coasts, Holocene monsoonal changes are expected to be stored in this unique and sensitive environment located near ocean-continent interface where high rate of sediment accumulation takes place. Accordingly, the mangrove swamps develop in to good storage sites with a huge pile of fine black clays and silts ideally suited for high-resolution palaeoclimatic study. Natural events and man-made changes have significant impact on the climate, which in turn affects the vegetation, and these signatures ought to be reflected in the subsurface sediments of mangroves. Vegetation being a major component of the ecosystem, palynology (pollen spectrum) provides a picture of different constituents.

As of now, there is hardly any input of environmental magnetism along with pollen analysis from the mangrove swamp sediments of India and accordingly there is tremendous scope to utilize magnetic mineralogy while studying the evolution of mangrove vegetation and in the reconstruction of past environments. Measurements on the Hadi profile provide initial inputs on the magnetic properties of mangrove sediments from the Konkan region. Similar studies have also been carried out on east coast mangroves (Seetharamaiah et al. this issue) and the results are comparable. The importance of environmental magnetism and variation in mineral magnetic contents in response to climatic controlled processes such as vegetation succession and soil developments have already been highlighted (Thompson & Oldfield 1986). The palynological data presented in this paper, supplemented with data from sedimentology and environmental magnetism should help understand the relationship of vegetation and climatic changes through the Holocene.

CONCLUSIONS

Palynological analysis of the mangrove sediments of Hadi yielded a fairly rich and diversified microfossil assemblage. It has been possible to recognize marine, estuarine, freshwater aquatics, sandy beach and terrestrial or hinterland ecological complexes. The relative abundance of palynoflora varies within the two-

Table 2. Sediment parameters of mangrove swamps of India.

Mangrove Swamp (Region)	Clay	Silt	Sand	Organic carbon
Chidiatapu (Small Andaman)	60.50-70.00	25.30-28.40	04.00-11.10	**
Bartang (Small Andaman)	63.60-66.60	30.2-32.2	02.10-06.20	**
Great Nicobar	28.60-35.00	07.50-15.70	49.30-63.90	**
Gangetic Sunderban (West Bengal)	35.00-50.00	38.00-46.00	09.00-24.00	00.23-01.08
Mahanadi (Orissa)	36.00-48.00	Tr-65.00	08.80-98.00	Tr-00.38
Godavari (Andhra Pradesh)	50.00-65.00	19.56-28.36	06.60-27.85	0.27-0.41
Krishna (Andhra Pradesh)	55.00-70.00	05.00-28.10	19.81-89.20	Low-00.42
Kokapallam	20.63-81.39	11.44-59.02	03.47-60.70	**
Nizampatnam	24.45-77.67	15.84-39.43	01.03-55.42	**
Coringa river, Kakinda (Andhra Pradesh)	54-70	30.10	5.00	02.20
Cauvery (Tamil Nadu)	20.00-30.00	2.10-24.40	22.60-94.30	00.02-00.90
Pichavaram (Tamil Nadu)	15.58	15-90.5	40-50	**
Kumarakam (Kerala)	10.00-45.00	20.00-45.00	12.00-70.00	**
Kollam (Kerala)	15.58	15.00-30.50	50.65	20.00
Devbagh creek (Kali estuary, Karnataka)	20.40	41.24	86.06	03.82
Ulhas river (Mumbai, Maharashtra)	37.45	49.36	13.19	02.88
Thane creek (Mumbai, Maharashtra)	22.77	70.89	06.74	03.33
Ghodbundar (Mumbai, Maharashtra)	16.50-32.30	10.10-16.90	32.80-51.80	**

(Data compiled from Achari et al. 2002; Goldin & Athlye 2002; Krishna Rao & Swamy 1991; Lakshminarayanan et al. 1991; Pofali et al. 1991; Mongia & Bandopadhyay 1991; Ramchandran et al. 1985; Rao 1986; Untawale 1987)

meter sequence. No organic matter was recovered at 50 cm level and it may be attributed to an ecological shift probably due to natural cause. The second ecological change is seen in the abundance of spores of *Ceratopteris*, a freshwater flood plain fern indicating possible influx of freshwater. The pollen of mangroves is fairly abundant at an interval between 130 and 140 cm and in fact, they are confined only at this level, which is very significant. This particular zone is rich in Rhizophoraceae and the mangrove fern *Acrostichum*. The abundance of mangrove elements at this level is attributed to periodic influx of freshwater as the sustenance of mangrove depends on freshwater inflow. Such ecological complexes retrieved from the profile display the temporal changes in the vegetation scenario of the palaeoenvironment.

The evolutionary process and phases and the differential rates can be addressed to by taking a look at the palaeoecology of the mangrove sediments as they form good archives for Quaternary events particularly for Holocene. Further, reaction of mangrove ecosystem to any positive or negative changes in mean sea level as a result of coastal rising or sinking could also be addressed to while studying the mangrove sediments. The magnetic properties of the clay and silt rich mangrove sediments are expected to sensitively record past changes in rainfall intensity. Hence coupled palynological and mineral magnetic studies would provide invaluable information on vegetative response to Holocene monsoon change in India.

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