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Use of magnetic susceptibility for identification of mangrove deposits in vibracores from deltaic environments

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ABSTRACT
The most commonly used technique for retrieving sediments from modern mangroves is through the use of vibracoring equipment. The retrieved cores are small in diameter; hence conventional methods of fewer analyses are limited by sample availability. Due to the suitability of mangrove sediments for palaeomonsoon reconstruction, it becomes necessary to discriminate mangrove sediments from others. This is achieved by examining the magnetic susceptibility, χ of the cores, which show characteristically low, and invariant χ values. This criterion reliably discriminates mangrove sediments in the east coast deltaic environments of the Godavari, Krishna and Cauvery deltas highlighting the role of χ as a rapid tracer to distinguish between depositional and nondepositional environments.

INTRODUCTION

The major peninsular rivers of Godavari, Krishna and Cauvery built large deltas on the east coast of India, over a total extent of about 19,187 km^2. The initiation of the modern deltas is believed to have begun around 8500-6500 yrs BP due to 'deceleration of sea level rise' (Stanley & Warne, 1994). These rivers bring in a total sediment load of 28x10^9 tonnes annually into the Bay of Bengal (Milliman & Syvitski 1992). The Godavari delta progrades in a northeast direction while Krishna and Cauvery built their deltas in a southwestern direction, mainly due to nearshore wave and current patterns. The shape of the deltaic coast is arcuate in the case of Godavari and Krishna while that of Cauvery is straight. All these three deltas are characterized by the presence of extensive mangrove swamps along their seaward margins. With its characteristic root system, the mangrove vegetation traps the sediments (Kumaran et al., this volume) and promotes deposition especially in the lower delta plain. Coastal studies carried out in recent years have revealed a vast amount of diverse information that contributes to the understanding of processes in the coastal region along the Indian coasts (Vaz & Banerjee 1997; Banerjee 2000). Hence, mangrove swamps are considered as the repositories of sediment record, which lend clues to the palaeoenvironmental conditions in the region. An attempt is made to recognize the palaeo-mangrove sediments in the vibracores by the study of magnetic susceptibility.

The basic premise for palaeoclimatic reconstruction employing environmental magnetism is that fluctuations in magnetic properties are solely on account of weathering in the provenance which in turn is related to the nature of climate and a uniform sedimentation rate without any significant breaks in the sequence of sedimentation. For these conditions to be true, it is essential that the depositional environment remains consistent for the sediments studied from a palaeoclimatic perspective i.e. the autogenic component is negated. In vibracores owing to the restricted diameter of the core, depositional conditions can best be discerned using granulometry, organic carbon content and magnetic susceptibility. In deltaic regions, mangrove environments fulfill the basic criterion of uniform sedimentation rates. However, core samples collected from the modern mangrove environments sometimes contain non-mangrove sediments also in their down-core sections. As such, it is essential to properly identify the mangrove sediments for further analysis in order to understand the paleomonsoon conditions. The purpose of this study is to demonstrate the identification of mangrove environment in three vibracores from the deltas of Godavari, Krishna and

Cauvery by mineral magnetic susceptibility. Comparisons are also made with the granulometric and organic carbon content of these cores.

COASTAL SETTING

The east coast deltas are prograded by the barrier formation and lagoon filling processes. During the evolution of these deltas, a number of sedimentary environments are formed namely river channel, natural levee, abandoned channels, palaeo-beach ridges, mangrove swamps, lagoon, estuary, spit, beach, tidal channels, creeks and distributary mouth bars.

A relatively low relief intertidal zone characterizes the mangrove swamp environment, extending over 1 to 6 km inland behind the present shoreline. There is no significant climatic difference among the east coast deltas. The total annual sediment discharges by Godavari, Krishna and Cauvery rivers, respectively are 1,05,000; 67,675 and 20,950 million cumecs and total sediment loads are 16.80, 10.56 and 0.71 x 10^9 kg yr^{-1} respectively. The area has a mesotidal, semi-diurnal range, where normal tides attain a maximum of 2.0 m and spring tides have a range of 3.2 m. The prevailing climate is characterized by distinct summer, pluvial and winter seasons. The annual temperature ranges from 25° C to 42° C and the rainfall is 600-1000 mm/yr. The two distinct long shore currents, viz., the SW monsoon from June to September with northerly long shore currents and the NE monsoon from November to February with prevailing southerly currents influencing the depositional / erosional patterns along the east coast deltas of India (Murthy & Murthy 2001).

MATERIALS AND METHODS

Three vibracores each of 63 mm diameter were collected down to about 2 m depth one each in the deltas of Godavari, Krishna and Cauvery during 1995-1997 (Fig.1). A detailed description of vibracoring procedure is given in Gandhi et al. (2000). Position fixing of vibracore locations was done using a handheld GPS instrument. The vibracores were vertically split in the

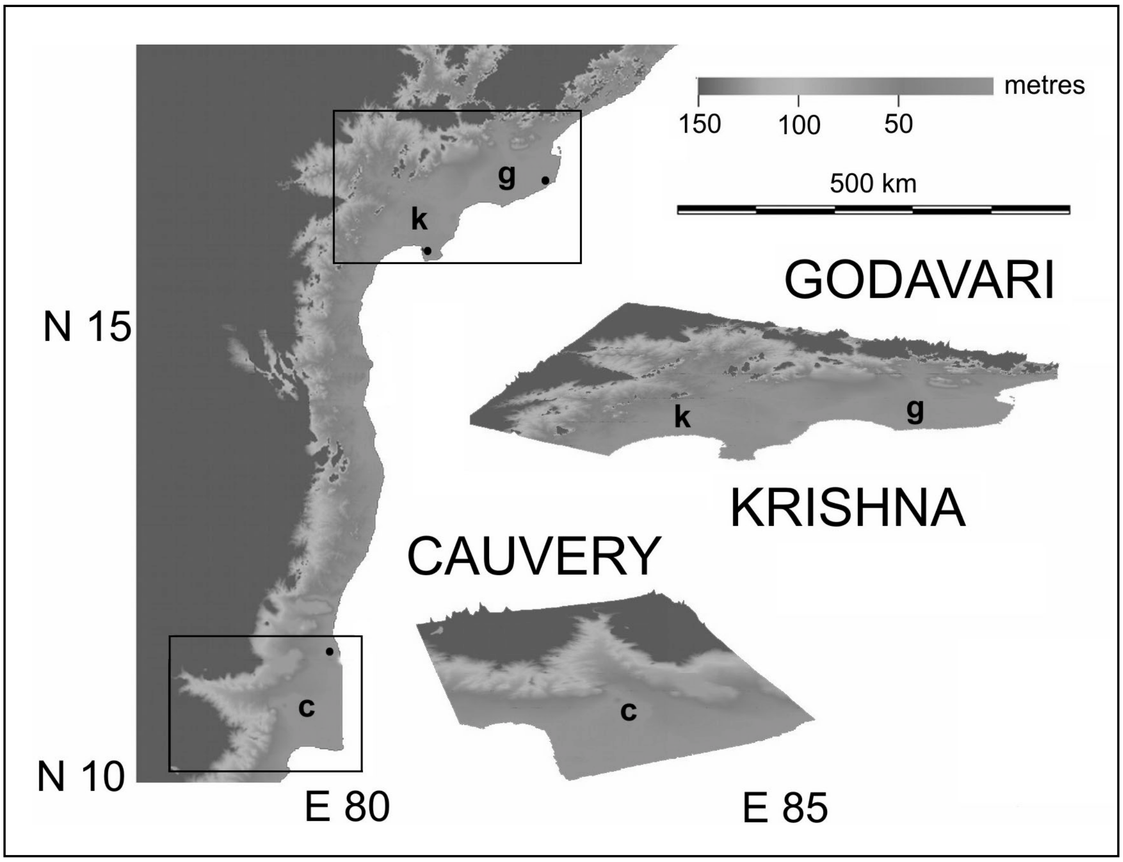

Figure 1. Digital elevation model showing the locations of the vibracore sites in the Godavari, Krishna and Cauvery mangrove swamp zones.

Table 1. Sedimentological parameters of the surface sediments in different deltaic environments (after Swamy et al. 1990)

Environment	Godavari					Krishna					Cauvery				
	Sand	Silt	Clay	Mz	OM	Sand	Silt	Clay	Mz	OM	Sand	Silt	Clay	Mz	OM
River Channel	95	3	2	2.92	1.0	95	5	—	2.68	0.65	98	2	—	—	2.00
Natural Levee	13	62	25	4.03	1.1	7	58	36	4.00	2.00	—	—	—	—	—
Flood Plain	8	45	47	5.07	0.4	17	48	36	6.00	1.35	—	—	—	—	—
Estuary	65	30	5	3.98	1.5	69	23	8	3.51	1.22	68	27	5	3.42	2.7
Mangrove Swamp	2	57	41	6.46	1.6	1	42	57	6.71	1.48	22	49	29	6.02	3.1
Tidal Channel	12	36	52	6.72	1.7	26	46	28	6.98	2.22	38	32	30	7.24	3.5
Tidal Flat	30	38	32	5.61	1.6	35	41	24	5.32	1.97	—	—	—	—	—
Lagoon	70	25	5	4.02	2.3	45	32	23	7.00	2.50	—	—	—	—	—
Beach	98	2	—	2.67	—	98	2	—	2.44	—	98	2	—	2.32	—

laboratory and were visually logged. One half of each core was subsampled for granulometric studies following standard procedures and textural parameters calculated following Folk & Ward (1957). Organic carbon was measured using the procedure defined in El Wakeel & Riley (1961). Magnetic susceptibility measurements (χ) were carried out on bulk samples collected at 2 cm interval from all the cores at Tuebingen University, Germany. A KLY-2 kappabridge (Agico) was used to determine low-field magnetic susceptibility χ, which is expressed on a mass specific basis with units of m^3kg^{-1}. In the present paper, all χ values are given in terms of $10^{-8}m^3kg^{-1}$. ^{14}C dating of the organic matter content was carried out in the Birbal Sahni Institute of Palaeobotany, Lucknow from the bulk clay dominated samples. (BSIP Nos: Godavari – BS 2011; Krishna – BS 2037 and Cauvery – BS 2006).

RESULTS

The characteristics of the sediments recovered from the three-vibracore samples are analysed and the results are shown in Fig. 2. For comparison, surface sediment characteristics of different deltaic environments are also given in Table 1.

The vibracore sample from the mangrove swamp in the Godavari delta was collected south of the Nilarevu river mouth adjacent to the chenier plains at an elevation of +0.10 m above msl (Fig. 1). Six distinct sediment layers are noticed in this 2.2 m long core (Fig. 2a). The basal layer shows a mean size of 6 ϕ, with 2.15 to 2.3% of organic carbon. Its magnetic susceptibility (χ) ranges from 160 to 260 ($x10^{-8}m^3kg^{-1}$) and is highly variable (Fig. 3a). This layer is overlain by a 50 cm thick fine sand with 2.9 to 3.15 ϕ mean size and 0.3 to 0.45% of organic carbon. The χ values fluctuate from 60 to 290 ($x10^{-8}m^3kg^{-1}$) in this zone. This layer is in turn overlain by thin alternating layers of sandy mud, sand and muddy sand which continue till the 100 cm level in the core. Here too variable χ, mean size and organic matter values are observed (Fig. 2a). From 100 cm to the top of the core, χ shows a different characteristic altogether and is markedly invariant with the χ values having concentrated around 130. In this region, mean size too is around 6 ϕ with the largest amount of organic content of around 2%. The radiocarbon dating of organic matter in this layer from a depth of 83 cm below the surface indicates an age of 2145 to 1741 cal yr BP. Towards top, the sediments become coarser having a mean size of 3ϕ, accompanied by a reduction in organic carbon to ~0.4 %.

The Krishna mangrove core of 120 cm length was collected from the western margin of Muttaiah Kaluva in the Krishna Delta at an elevation of 0.3 m above msl (Fig. 1). Four distinct units are recognized in the core (Fig. 2b). The bottom 30 cm thick gray mud shows higher mean size which ranges from 7.92 to 8.09 ϕ and higher organic carbon content between 1.78 to 1.98%. This zone has very low χ values around 250 (Fig. 3b). Again this part of the core is characteristically invariant in the magnetic susceptibility values as in the case of the Godavari core. ^{14}C dating of the sediment from a depth of about 95 cm indicates an age of 4260 to 3690 cal yr BP. Another zone beginning at 40 cm depth in the core, showing similar granulometric, organic carbon and χ characters, is separated from this layer by a 50 cm thick coarser deposit. The sediment of this horizon has a mean size ranging from 2.45 to 2.77 ϕ, low organic carbon (0.01 to 0.40%) and high χ values. Moreover, the χ is highly variable ranging from 400 to 2000. Higher χ values are observed in the upper 5 cm sediment which has a mean size of 4.1 to 4.3 ϕ and contains 1.3 to 1.5% of organic matter (Fig. 2b).

The Cauvery mangrove core is 200 cm long, collected near Pichavaram at an elevation 0.2 m above msl. The log section of the core (Fig. 2c) shows four sedimentary layers. The bottom 10 cm thick muddy sand unit has a mean size of about 2.9-3.1 ϕ, organic matter between 0.25 to 0.4% and low χ values (Fig. 3c). These sediments are overlain by 115 cm thick clayey sand deposits, which are the dominant type in the Cauvery mangrove core. The mean size of these sediments varies from 3.86 to 4.16 ϕ while the organic matter ranges from 0.28 to 0.92 % (Fig. 2c). This coarser sediment layer has χ values between 30 and 55. It should be noted that all the sediments in this core have very low susceptibility in contrast to the Godavari and Krishna core sediments. The ^{14}C dating of the 126 cm depth sediments gives an age of 2348 to 2011 cal yr BP. This clayey sand is overlain by a 40 cm thick sandy silt horizon which in turn is overlain by a sandy clay unit (thickness 30 cm) with mean size ranging from 3.60 to 5.24 ϕ, and organic content varying from 0.95 to 1.57% and very low χ values. The levels of χ are similar to that of the basal part of the core.

DISCUSSION

The sediments from the three vibracores indicate seven sedimentary units namely muddy sand, clayey sand, sandy silt, sandy clay, sandy mud, clay and mud. Muddy sands indicate high-energy depositional environment. The mangrove sediments of Godavari are predominantly sandy mud indicating low energy deposition. There is a remarkable variation in the phi mean size of the vertical sequence, in which Godavari and Krishna mangrove sequences show alternate increasing and decreasing trends from bottom to surface whereas not much variation is seen in the mean size values of the sediments in Cauvery

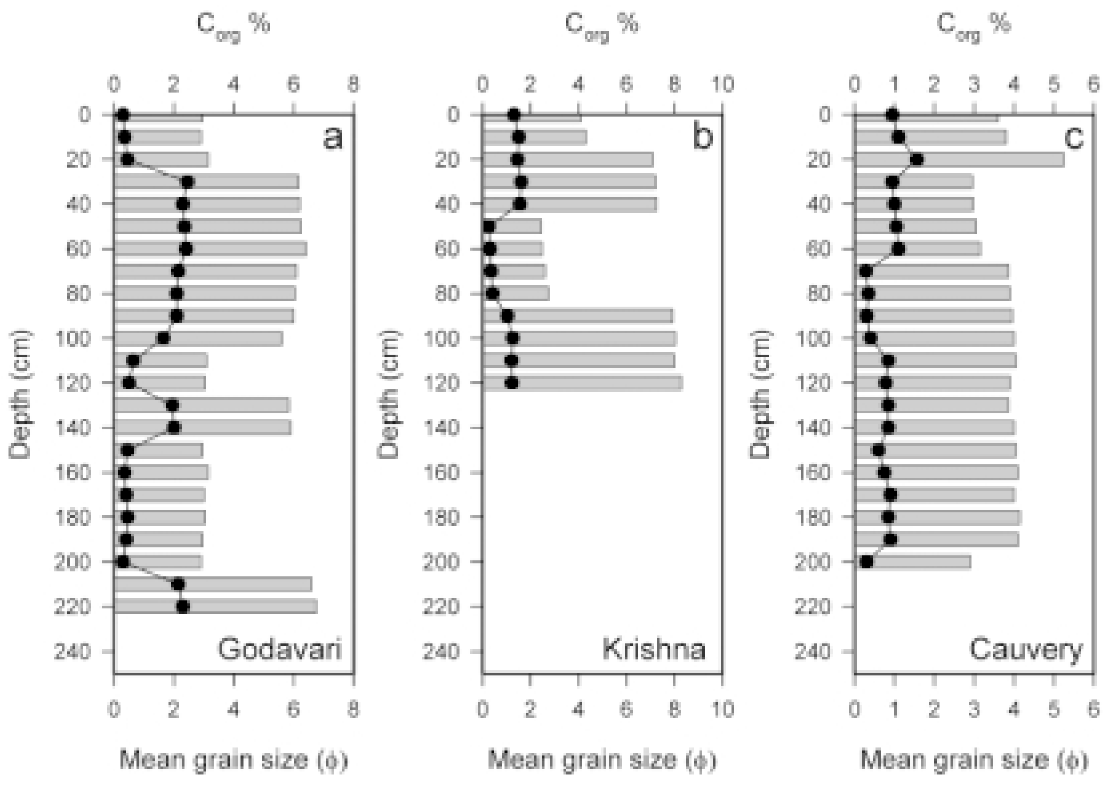

Figure 2a-c. C_{org}% and mean grain size variation in Godavari, Krishna and Cauvery mangrove sediments.

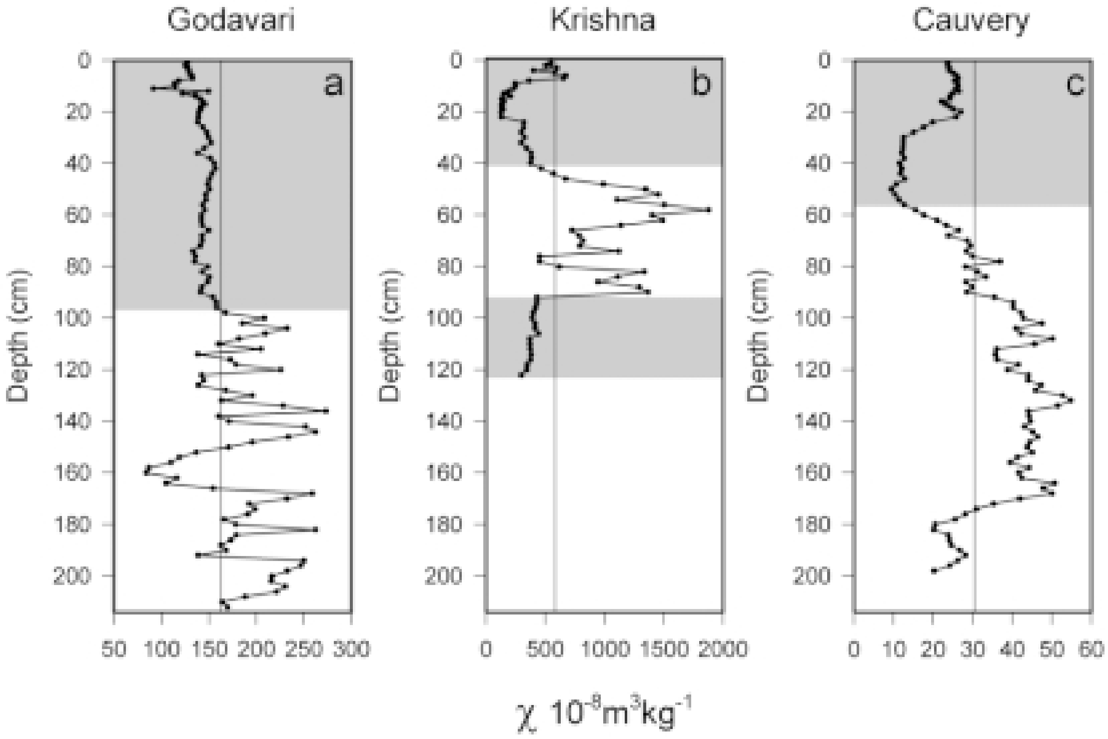

Figure 3a-c. Down-core variations in the magnetic susceptibility (χ) of the Godavari, Krishna and Cauvery mangrove sediments. Note the characteristic low χ values for the mangrove clay rich sediments (see text for details).

mangroves (Fig. 2a-c). These differences between the mangrove sediments perhaps reflect the effect of the local hydrodynamic conditions as well as variations in sediment sources in different climatic conditions from their respective river basins. Seetharamaiah et al. (2001) have also reported a decrease of phi mean size in vertical sequence from bottom to surface in Godavari mangrove area. In all these cores, sharp contacts are observed between sedimentary units, indicating rapid change in depositional conditions probably with intermittent periods of erosion. The organic matter shows an overall positive correlation with phi mean size of the sediments. The general increasing trend in the organic matter from bottom to surface reveals decreasing fluvial influence that leads to increasing productivity (Barbosa & Suguio 1999; Kolla et al. 2000) except in the top 20 cm column of the Godavari mangrove sediments.

From the foregoing discussion supported by different deltaic environments and textural characteristics given in the Table 1, it is observed that characterization and discrimination of environments with the help of sediment texture and organic matter do not properly resolve the problem of pin-pointing the environment. Since hydrodynamic characteristics of the deltaic environments are highly speculative phenomena, the prerequisites for identifying the various environments were not fulfilled sufficiently by the above factors. Hence, a better differentiation of a mangrove environment is evaluated from the study of magnetic susceptibility variations of mangrove sediments.

Generally, sediments from various environments have different magnetic susceptibility. The results of the present study indicate that even in a similar environment, ferro(i)magnetic mineral concentrations vary vertically from one delta to another. The χ values range between 10 and 2000 ($x10^{-8}m^3kg^{-1}$) with the highest ferro (i) magnetic mineral concentrations in Krishna mangrove swamp followed by Godavari and Cauvery. These magnetic mineral concentrations are equivalent to that of the Tapti salt marsh (mean χ was $12x10^{-6}$ m^3kg^{-1}) along the west coast of India as reported by Rangarajan et al. (1983). In the upper part of the cores (Fig. 3), there is a steady decrease in susceptibility percentage towards surface (left side of the vertical line). High fluctuations in susceptibility occur below 1.0 m depth in Godavari and around 0.4 m to 0.6 m depth in Krishna and Cauvery delta mangroves, revealing a change in the sequence of evolution of deltaic environments during the late Holocene. Forester et al. (1994) argued that fluctuations in Holocene magnetic susceptibility records reflect climatic change in sediment provenance areas.

In spite of the overall variability, the χ values in all these three mangrove sediments are apparently identical at least in one aspect. These χ values show a sudden decrease at about 40 to 60 cm depth in Krishna and Cauvery deltas, respectively and at about 100 cm depth in Godavari delta. Considering this possibility, the variations in χ values in these deltas is inferred to be due to a similar regional climatic and sedimentation pattern. The sudden decrease in the χ values reflects low sedimentation rates and calm energy conditions developed at a particular period, (~2000 cal yr BP here) at the depositional site. The low χ values represent the base for the development of mangrove environment. At the upper part of the Krishna and Cauvery vibracores (Fig. 3) there is a slight increase of χ values denoting increase in wave energy level, which might have led to a decrease in the rate of growth of mangroves in the recent times. In summary, χ logs across three major east coast deltaic basins add a new dimension to environmental magnetic studies in distinguishing depositional mangrove environments from non-depositional ones in a relatively more reliable and inexpensive manner.

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