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Holocene environmental changes as recorded in sediments of a paleodelta, southwest coast of India

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A B S T R A C T

Sedimentary record of a 40 m deep borehole drilled in a paleodelta region of southwest coast of India has been studied for sedimentary proxies - texture, clay minerals, geotechnical parameters, and pollens. The sedimentary record, spanning from 12 ka to Recent in age, exhibits two different sedimentary environments of deposition. Sediments record high values of moisture content, organic carbon and plasticity index. Sediment texture and geotechnical properties indicate a distinct change in depositional environment from marine to fluvial during the sea level fall i.e., after ~7 ka. It also suggests that major rise of sea level from ~11 to ~7 ka and regression from ~7 ka to ~5 ka contributed to the changes in the environment of deposition. The downcore increase of illite and decrease of kaolinite at 12 m depth (~6 ka), and an upward increase of smectite and kaolinite, and decrease of illite concentration support the major fall in sea level in the region that accounted for the change of depositional environment. The pollen records reveal the abundant occurrence of semi-evergreen type of mangroves during early-to mid-Holocene. Thus, the multi proxy record provides an evidence of change in the environment of deposition from marine to fluvial, which might have been influenced by neotectonics, sea level variations, and monsoonal intensity in the region.

1. Introduction

Sedimentary archives from ocean and land have been studied extensively to infer paleo monsoonal intensity, climate change and environment of deposition during the Quaternary period (Singh, 1998; Govil et al., 2011; Das et al., 2013; Gupta et al., 2013; Narayana et al., 2014; Tiwari et al., 2015). Sedimentary records of coastal areas are used to infer past changes in sea levels and environment of deposition (Compton, 2001; Singh et al., 2001; Caldas et al., 2006; Carr et al., 2010; Wang et al., 2010). Sediment texture, physical and geotechnical properties, clay minerals, and pollen records were used as independent proxies in understanding the environment of deposition and sedimentation history of coastal environments and climate variations (Francus et al., 2002; Boulay et al., 2003; Kumaran et al., 2008; Dixit and Bera, 2013). However, most of these studies are based on short sediment cores and limited to a single sediment proxy. In the present study, we use multi proxy approach to understand the past monsoonal intensity and environment of deposition in the coastal region of southwest India.

Sediment texture and the geotechnical properties help to infer the hydro-dynamics of sediment deposition. Similarly, clay minerals are useful indicators of paleoclimate as they provide record of overall climatic signals (Singer, 1984; Thamban et al., 2002; Das et al., 2013). Pollens, transported by fluvial and aeolian action, accumulated in the sediments become a part of the stratigraphic record (Traverse, 1994), and are considered a sound proxy to reconstruct the vegetation history i.e. paleoenvironmental conditions of the region (Bradley, 1999; Kumaran et al., 2008; Nautiyal and Chauhan, 2009; Padmalal et al., 2011; Dixit and Bera, 2013).

Based on short sediment cores, paleoclimatic conditions of southwest coastal region of India are investigated by various researchers (e.g. Rajendran et al., 1989; Narayana, 2007; Kumaran et al., 2008; Narayana et al., 2009). However, such studies on thick sedimentary sequences from onshore regions, covering the entire Holocene, are scanty. Here, we present a unique onshore

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record of texture, geotechnical, clay minerals and pollens in a thick sedimentary sequence of a borehole drilled in the paleodelta of southwest coast of India. Sedimentary record of a paleodelta can be effectively used for climate change on high resolution scale as it is a repository of thick sediment sequences. In this paper, we discuss the sedimentary environment of deposition and the role of monsoon in depositional processes during the Holocene based on the multi proxy sedimentary record.

2. Study area

The southwest coast of India, ~560 km long and varying width from 5 to 30 km, is remarkably straight because of faulting during the late Pliocene. The central part of the coast is marked by landforms such as barrier islands, paleo strandlines, beach ridges, alluvial plains, sand dunes, flood plains and marshy lands (Narayana and Priju, 2006). Paleodelta, an important landform encompassing an area of ~50 km^2, lay landward of the modern Periyar River mouth (Narayana et al., 2001), which suggests that the River Periyar was once a major river system carrying large volume of sediments. The northern limb of the Periyar River exhibits remnant deltaic morphology and suggests the past position of the shore line (Fig. 1). Subsequent recession of the sea or uplift of the coastal tract initiated the change in shoreline position and depositional sequences. Several factors viz., tectonic, eustatic, climate and rainfall variations have contributed to the evolution of the paleodelta (Narayana et al., 2001).

The study area is covered with Precambrian crystalline rocks, Tertiary sediments, laterites and Quaternary sediments. The Tertiaries and Holocene sediments over-lay the Precambrian high grade crystalline complex of khondalites, leptynites, charnockites and gneisses. Laterites separate the Quaternary sediments from the Tertiary sediments (Soman, 2002). Coastal sediments of the region comprise alluvium, beach sands, lime shells, peat beds, and calcareous clays. Mud flats blanket some parts of the coastal region. Unconsolidated Quaternary sand deposits are the result of detritus materials supplied by the erosion of Western Ghats and distributed extensively along the coast.

The southwest coast of India experiences tropical humid climate. Summer season prevails during February to May, followed by southwest monsoon season (June to September) and post-monsoon season (October–January). Most of the rainfall occurs during the southwest monsoon season and the annual average rainfall of the study area varies from 250 to 300 cm. The temperature is maximum (35 °C) during pre-monsoon period (March to May) and it gradually comes down (24 °C) from June because of monsoon precipitation. The study area experiences dynamic climate conditions and the sea level changes that resulted in modification of the geomorphic features of the region (Hashimi et al., 1995; Narayanan and Anirudhan, 2003; Jayalakshmi et al., 2004; Narayana and Priju, 2006).

3. Samples and methods of study

A borehole was drilled to a depth of 40 m in a paleodelta region of the northern distributary of Periyar River (Fig. 1). Sediment samples were collected at different depths, sub-sampled and stored in airtight polythene bags for further analyses. Samples were analyzed for ^{14}C ages, textural and geotechnical properties, clay minerals, and pollens following the standard procedures. Bulk sediment samples of the borehole representing muddy sand at 6.0 m, silty sand at 15 m depth, mud at 23 m, inter-face of mud and silty clay at 24.50 m, and peat horizon with silty clay at 31.50 m and 39.75 m depths were chosen for radiocarbon dating and analysed for ^{14}C dating at the Birbal Sahni Institute of Paleobotany, Lucknow, India, following the procedure of Rajagopalan et al. (1978). Ages for the top section of the borehole could not be obtained as the less amount of sample was retrieved.

3.1. Textural analysis

Sand, silt and clay ratios in all the sediment samples were estimated following the standard sieve and pipette techniques (Carver, 1971; Folk, 1980). The salts from the samples were removed by repeated washing with distilled water, and subsequently organic matter and carbonates were removed by treating with H_2O_2 and glacial acetic acid. Sand and mud fractions were separated by sieving through 63 μm sieve, and the sand fraction (>63 μm) was dried and weighed. The mud fraction (<63 μm size) collected in a 1000 mL glass cylinder was subjected to pipette analysis for estimation of silt and clay fractions as per the procedure suggested by Folk (1980).

3.2. Geotechnical analysis

The physical and geotechnical parameters of sediment samples consisting of water content, wet bulk density, shear strength, and Atterberg limits were analyzed as per the procedures suggested by ASTM (2005) and Singh and Punmia (1970). The Atterberg limits include liquid limit, plastic limit, plasticity index, and liquidity index.

3.3. Clay mineral analysis

Clay minerals were analyzed employing X-Ray Diffractometer (XRD, Philips 1840 Model) at National Institute of Oceanography, Goa, as per the standard procedures (Biscay, 1964; Gibbs, 1977). Clay solutions of equal volume (1 mL) were pipetted out on glass slides from the disaggregated and deflocculated clay water suspension. The glass slides were dried at room temperature. Slides were scanned on XRD from 2 to 30° 2theta at 1° 2theta/minute using Ni filtered Cu-Kα radiation. Glycolated slides were further scanned for the confirmation of montmorillonite. The clay solution slides were scanned from 24 to 26° at 0.50 2theta/minute to differentiate the kaolinite from chlorite peaks (Biscay, 1964). Percentages of smectite, kaolinite, illite, and chlorite were semi-quantified and their relative proportions are computed.

3.4. Palynological studies

A total of forty samples were chosen for palynological studies. About 20 g of sample was boiled with 10% potassium hydroxide (KOH) for 5 min and pollens were deflocculated from the sediment and the humic acid was dissolved. Subsequently the samples were washed three times with distilled water and alkalis were removed by decantation process. Then the samples were sieved through 150 mesh sieve for separation of the coarse particles. The fine fraction samples were further treated with 10% hydrochloric acid and carbonates were removed, and after that acid content in the samples was removed by washing with distilled water. Silicates were removed from the samples by treating with 40% hydrofluoric acid (HF). The samples were again washed with distilled water to make them free from silicates and HF. The samples were further treated with glacial acetic acid (GAA) and centrifugation carried out for dehydration. Subsequently, samples were treated with acetolysing mixture (9:1 ratio of acetic anhydride and concentrated sulphuric acid), centrifuged and decanted for removal of acid, and again treated with GAA and washed with distilled water. Thereafter, 50% glycerin and a few drops of phenol were added to the residue to arrest microbial decomposition of samples. Pollen slides were

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