1.1 General Introduction

According to the predictions the global sea level will rise between 0.2 and 0.5 m during the coming c 100 yrs as a consequence of global warming (Church et al., 2006; Bindoff et al., 2007). In order to improve the possibilities to predict future sea-level change, knowledge about both amplitudes and durations of eustatic fluctuations in the past is essential. During the last glacial maximum the eustatic sea level was between approx. 150 and 130 m lower than present (e.g. Colonna et al., 1996; Lambeck and Chappel, 2001; Ramsay and Cooper, 2002; Woodroffe and Horton, 2005). In the early Holocene, global sea levels rose rapidly as a response to increasing temperatures, glacial melting and larger volumes of water within the world’s oceans. At c 8000-6000 cal BP, the sea reached levels similar to today (e.g. Zwartz et al., 1998). At many sites worldwide, this was followed by a major transgressive trend, with a rise in sea level above modern levels that affected earlier glaciated areas where isostatic uplift had been substantial (e.g. Svendsen and Mangerud, 1987; Risberg et al., 1991; Berglund et al., 2005; Mann and Streveler, 2008).
All over the world, several Quaternary proxy data have been used to reconstruct past sea levels, mainly radiocarbon or OSL dating of exposures of marine facies or shore line indicators (e.g. Carr et al., 2010) as well as paleo-environmental indicators in lagoon or estuary sediments (e.g. Baxter and Meadows, 1999). Estuaries and deltas develop at river mouths during transgressive and regressive phases, respectively (Boyd et al., 1992). In particular, the postglacial Holocene sea-level rise has contributed importantly to the estuary-to-delta transition (Hori et al. 2004). By analyzing radiocarbon ages of the basal or near-basal sediments of the world’s deltas, Stanley and Warne (1994) showed that delta initiation occurred on a worldwide scale after about 8500–6500 years BP and concluded that the initiation was controlled principally by the declining rate of the Holocene sea-level rise.

Worldwide there were different regional sea-level changes since the last glacial maximum (LGM) (Irion et al., 2012). Along the northern Canadian coast, for example, sea level has been falling throughout the Holocene due to the glacial rebound of the crust after the last glaciation (Peltier, 1988). This is comparable to the development in Scandinavia (Steffen and Kaufmann, 2005) where sea level drops today. From about Virginia/USA to Mexico there is a constant sea-level rise similar to the Holocene sea-level development of the southern North Sea (e.g. Vink et al., 2007). From the border of Ceará/Rio Grande do Norte down to Patagonia, indicators of Holocene sea level point to a level that was up to 5 m higher than today's mean sea level (Angulo et al., 1999; Martin et al., 2003; Caldas et al., 2006a, b)

The nearshore zone is a highly energetic environment affected by surface gravity waves and mean currents. The nearshore environment is also a transition zone characterised by on-offshore sediment transport between the surf zone and the offshore zone. The exchange of sediment between the inshore and
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the offshore environment plays a major role on coastal evolution and shoreline stability (Swift, 1976). A good understanding of sediment transport processes in the nearshore zone is important for scientists and coastal zone managers. The reaction of sediments to hydrodynamics processes result in reworking and redistribution of sediments. It is of fundamental and scientific importance to understand how sediments from various internal and external sources on the shoreface are reworked and redistributed by the shoreface hydrodynamic processes (Liu and Zarillo, 1990).

The longshore current transports sediments that have been placed into motion by the waves, and being continuous along extensive stretches of the coast, can potentially move the sediment for many kilometers in the longshore direction. The longshore movement of sand on beaches manifests itself whenever this natural movement is prevented through the construction of jetties, breakwaters and groins. Such structures act as dam to the littoral drift, causing a build of the beach on its updrift side and simultaneous erosion in the downdrift direction. This often has severe consequences in the erosion of coastal property, and for this reason coastal engineers have shown a considerable interest in the quantities of littoral drift and the process responsible for littoral transport is also of interest to the geologist as a sand transporting agent and to the coastal sediment features.

The estuarine/lagoonal and nearshore sediment characteristics such as texture, geotechnical studies, clay mineralogy, organic matter, etc. throws light on various coastal and nearshore processes and these properties help to understand the sediment history during Holocene/Late Quaternary. The present study envisages understanding the sedimentary environment through physical, geotechnical, textural, and clay mineralogical studies of surface and core samples of central Kerala coast. In addition to the sedimentological and
geotechnical studies 14C dating and palynological studies were done for the onshore borehole sediments drilled to a depth of 40 m for unraveling the geochronology, depositional history, sea level variation during the Late Quaternary and sediment provenance.

1.2 Objectives of the present study

The study area is the domain of natural sedimentary processes and different depositional environments. The proposed study is taken up to envisage the following aspects:

1. To understand the relationship between organic matter, textural, physical and geotechnical properties.
2. To understand the relationship between the clay minerals and geotechnical properties of sediments
3. To delineate the depositional environments in the coastal and marine settings.
4. To decipher the paleo-environmental conditions along the central Kerala coast.

1.3 Study Area

The study area comprises a part of Vembanad estuary/lagoon and nearshore region of Cochin and the study area is confined between latitudes 9°45’ - 10°15’N and longitudes 76° -76°30’E (Fig 1.1). The lagoon is connected to the Arabian Sea through a permanent opening, the Cochin bar mouth, which, is about 450m wide and 8-13 m deep. Here, the depth is maintained by dredging as this opening is used for navigational activities. The bar mouth is also responsible for the tidal flux of the Cochin backwater system. Tides are semidiurnal type, showing substantial range and time. The average tidal range
near the mouth of the estuary is ~ 0.9m. Periyar river which is a part of the Vembanad lagoon has an outlet to the Arabian Sea at Munambam.

Six rivers, Periyar, Muvattupuzha, Chitrapuzha, Pamba and Achankovil debouch into the Vembanad Lake. Of these Periyar is the largest river, Hence Vembanad receives large amount of fresh water and sediments. Cochin backwaters and nearshore areas are separated by the barrier islands such as Vypin. There are a number of islands in the landward side of backwaters and these are Willington Island, Bolghatty etc.
Nearshore region off Cochin receives large flux of both water and sediment during the monsoon. The intense wave activity and longshore current play dominant role in the dispersal and distribution patterns of sediments that are brought from the land through the Vembanad estuary. A number of shoals are observed along the mouth of Cochin inlet.

Geomorphologic studies along the coastal tract between Thrissur in the north and Kollam Quilon) in the south, reveals several morphometric units that have a bearing on the Neogene evolution of this region. Of particular interest is the existence of a palaeodelta in the coastal zone near Munambam, extending from the present shoreline for about 11 km into the inland region along the course of the Periyar River (Narayana et al., 2001a). A borehole drilled to a depth of 40 m from this paleo-delta is also used for the present study.

1.4 Previous Studies

Nair and Sankar (1995) has classified and evaluated the coastal wetlands of Kerala using IRS-1A LISS II data. Nair and Nalinakumar (1997) has discussed about the sediment deposition on a microtidal environment using remote sensing data. Hashimi (1981) has done a comparative study of the moment and graphic size parameters of the sediments of the western continental shelf of India. The studies reveal that the mean size and standard deviation may be calculated either by the moment method or by graphic methods without any significant differences, as the methods is highly correlated. The distribution and textural variation of sediments off West Coast of India have been investigated by various workers (Stewart et al., 1965; Kolla and Kidd, 1982; Hashimi et al., 1978; Nair et al., 1978). Topography and nature of sediments of western continental shelf of India were studied by Nair et al., (1978) and Hashimi et al., (1978). Hashimi and Nair (1981) carried out study on surfacial
sediments of Karnataka coast. Studies on sediment transport on the continental shelf of Mangalore by Narayana and Pandarinath (1991) revealed that the transport direction is towards onshore where fluvial influence is absent and the direction is towards both onshore and offshore where the fluvial influence is prevalent.

Veerayya and Murty (1974) have studied the textural characteristics and distribution of bottom sediments of Vembanad Lake from Cochin to Alleppey with a view to understand the depositional processes operating in different parts of the lake. These studies have revealed that (1) In the southern half of the lake, coarser fractions are confined to the western margin of the lake and finer fractions occupy the rest of the area while in the northern half, finer fractions are restricted to the estuarine region and coarser fraction occupy the rest of the area including the rivers, (2) well sorted and negatively skewed sediments are present in the Muvattupuzha and Ittupuzha rivers and in neighborhood of these river mouths and some of the subsidiary channels while poorly sorted and positively skewed sediments are present in the rest of the lake. Seralathan et al (1993) have studied the distribution of sediment and organic carbon in the Cochin harbour area. The study reveals that the mud and the sandy mud are spread over most part of the area with patches of muddy sand and silty sand.

Nair et al (1993) has studied the distribution of sediment characteristics of Cochin estuary in relation to changing hydrography. They have observed a seasonal special grading of particles as sand, silt and clay in the estuary. The contents of organic carbon, phosphorous and iron in sediments were closely studied in relation to hydrographical changes and attempts were made to describe the textural distribution on the above basis. Northern and southern arms of the upper estuary were mainly composed of sand particles. The lower estuarine regions indicated seasonal abundance of sand during monsoons.

The sedimentary framework and the distribution of organic carbon have been studied in the rivers and estuaries of Kerala by many workers. Murthy and Veerayya (1972 a, b and 1981) made a preliminary study of organic carbon in the sediments of the Vembanad Lake. Their studies on the sediments of Vembanad lagoon revealed that the distribution of organic matter is strictly following the hydrographic features of the lake. The organic carbon content was found to vary between 0.06-3.48 percent. They also reported that silty-clays and clayey silts had higher organic matter content than sand and silty sands. Several attempts were made to study the organic carbon distribution in the various deltas, estuaries and lakes in India. The distribution of organic matter in the Ashtamudi lake sediment was studied by Sajan and Damodran, 1981. Studies on the hydrodynamic sorting and transport of terrestrially derived organic carbon in sediments of the Mississippi and Atchafalaya rivers were done by Bianchi et al (2007). Goni et al (1997) have assessed the sources and importance of land derived organic matter in the surface sediments from the Gulf of Mexico. Eadie et al (1994) studied about the nutrient enhanced coastal productivity in sediments from the Louisiana continental shelf. The terrestrial sources and the export of particulate organic carbon in the Waipaoa
Sedimentary System, New Zealand have been assessed by Blair et al (2010). The transfer of erosion related organic carbon from land to ocean in the Waipaoa Sedimentary System, New Zealand was analysed by Brackley (2006).

Becker et al (2004) studied the geotechnical characteristics of post-glacial organic sediments in Lake Bergsee, southern Black Forest, Germany. Samples of marine deposits retrieved at an onshore old reclamation site on the north coast of Taipa, Macau were analysed for the geotechnical characterization by Yan and Ma (2010). Soil classification based on the expansivity of different clay minerals has been studied by Sridharan and Prakash (2000). Marine geotechnical properties in the head of Zakynthos canyon, Greece were analysed with the application of computational intelligence tools by Ferentinou et al (2012). These studies provide background information for the assessment of submarine slope stability and also shed light on the sedimentary processes that take place on the seafloor. The changes in late Pleistocene–Holocene sedimentary facies of the Mekong River Delta and the influence of sedimentary environment on geotechnical engineering properties were studied by Truong et al (2011). They discusses the influences of sedimentary environment and conditions on geotechnical properties of the sedimentary facies. Correlation between clay mineralogy and Atterberg limits was done by Schmitz et al (2004). They stated that if a correlation between the Atterberg tests and the clay mineralogy would be available to engineers working in soil mechanics, an estimate of the changes in mechanical properties could be given when the changes in clay mineralogy are known. Depositional and geotechnical properties of marine clays collected from boreholes along onshore sites were studied by Liu et al (2011). Geotechnical properties of the Cassino Beach mud were analysed by Dias and Alves (2009). Hajjaji et al
(2010) have analysed the mineralogy and plasticity in clay sediments from north-east Tunisia.

All fine-grained materials with large surface area are capable of accumulating heavy metal ions at the solid-liquid interface as a result of intermolecular forces (adsorption). The pH values may dominate the adsorption processes of heavy metal cations. The heavy metals are completely released under extremely acidic conditions (Forstner and Whittmann, 1981). Organic carbon plays an important role in the dispersal pattern of many major and trace elements. Mineralogy and geochemistry of sediments of Muvattupuzha and central Vembanad estuary were studied by Padmalal (1992). Sediment characteristics in relation to changing hydrography of Cochin estuary were investigated by Nair et al (1993). Metal concentration in recently deposited sediments in Cochin backwaters were analysed by Nair et al. (1990) and Priju and Narayana (2004). Resmi (2004) has carried out trace element assessment from three aquatic environments such as mangroves, river and estuary of the central Kerala coast. Sarika (2005) has studied the trace element concentrations in the mangroves along the Kerala coast. Geochemical index of trace metals in the surficial sediments from the western continental shelf of India were assessed by Laluraj and Nair (2006). The spatial analysis of trace element contamination in the sediments of Tamiraparani estuary, southeast coast of India was done by Magesh et al (2011). The enhanced preservation of organic matter in fine-grained sediments can lead to trace metal enrichment in their authigenic phase either through complexation reactions or by increasing sorptive capacity of the sediments (Alberic et al., 2000). The heavy metals of the surface sediments of the Portuguese continental shelf were assessed by Mil-Homens et al (2006). The distribution and enrichment of trace metals in marine sediments of Bay of Bengal, off Ennore, south-east coast of India was analysed by Raj and

Physical sorting of river-transported material is a well-known process documented in sediments at the fluvial/marine interface (Mitchell and West, 2002; Hori and Saito, 2007). These processes also occur in clay-mineral suspensions, as the coarse-grained illite and kaolinite particles are preferentially deposited at or near to the fluvial/marine interface, in contrast to the smaller grains of smectite, which may pass into the sea (Meunier, 2005). The composition and origin of clay minerals in Holocene sediments from the south-eastern North Sea was studied by Zuther et al (2000). The varied pathways of river-borne clay minerals in the near-shore region of south-eastern North Sea was analysed by Pache et al (2008). Provenance and distribution of clay minerals in the sediments of the western continental shelf and slope of India was studied by Rao and Rao (1995). The reconstruction of late Quaternary monsoon oscillations based on clay mineral proxies using sediment cores from the western margin of India was done by Thamban et al (2002). The pathways of clay mineral transport in the coastal zone of the Brazilian continental shelf were studied by De Morais et al (2006). The preferential settling of smectite on the Amazon continental shelf was analysed by Patchineelam and De Figueiredo (2000).

Paleooceanic conditions along the Periyar river mouth, Late Quaternary peat deposits in the sediment records of Vembanad lagoon and evolution of central landforms and associates sedimentary environments were discussed in detail (Narayana et al., 2001b; Narayana et al., 2002; Narayana and Priju, 2004). Verma and Mathur (1979) have shown the evidences of palaeoshorelines
along west coast of India, which existed several kilometers inland from the present coastline and at much higher levels than the present sea level as evidenced by coral reefs and fossiliferous beach-rocks. The presence of the submerged shorelines was also indicated by submerged forests and occurrence of oolitic limestone at considerable depth from the present sea level. Studies on Late Quaternary sediments and sea level changes of the central Kerala, India has been done by Shajan (1998) with special emphasis on archaeological aspects. Evolution of the coastal wetland systems of SW India during the Holocene were studied by Padmalal et al (2011). Thrivikramji et al (2007) have attributed the evolution of the wetlands of Kerala coast through gradual regression of the sea after the Holocene marine transgression. The occurrence and water resource potential of fresh water lakes in south Kerala and their relation to the Quaternary geologic evolution of the Kerala coast were studied by Soman et al (2002). Joseph and Thrivikramji (2002) assessed the implications of the Kayals of Kerala coastal land to the Quaternary sea level changes.

Changes in Holocene coastal paleo-environment and sea-level variations have been recorded in estuary sediments from Macassa Bay, southern Mozambique (Norström et al., 2012). The Early Holocene history of the Baltic Sea was studied by Berglund et al (2005) from the coastal sediments of south eastern Sweden. The Holocene sea-level fluctuation was inferred from the evolution of depositional environments of the southern Langebaan Lagoon salt marsh, South Africa by Compton (2001). Late Quaternary sea-level changes in South Africa were studied by Ramsay and Cooper (2002). Angulo et al (2006) critically reviewed the mid to late Holocene sea-level fluctuations on the eastern Brazilian coastline. The Late Quaternary evolution of coastal and lowland
riverine plains of southeast Asia and northern Australia was studied by Woodroffe (1993).

Stiros et al. (2000) opined a seismic coastal uplift in a region of subsidence from their studies on the Holocene raised shorelines of Samos Island, Aegean Sea, Greece. The evidences indicate that the geomorphological evolution of Samos island and of the wider Eastern Aegean is not only due to marine transgression and regional-scale tectonics but also due to earth quakes. Beets et al. (1992) studied the Holocene evolution of the coast of Holland. The Holocene regression and the tidal radial sand ridge system formation in the Jiangsu Coastal Zone, East China was examined by Li et al. (2001). Based on the facies succession, and the tidal sand units located either in the strand plain they explain that these sand ridges were formed and developed at different time scales. Dalrymple et al. (2007) have discussed the morphologic and facies trends through the fluvial–marine transition in tide-dominated depositional systems. Yoon et al (2009) studied a deep sea core from the Drake Passage west Antarctica to reconstruct the paleo-environmental conditions over the last 150 ka.

Mangroves are one among the world's most productive ecosystem and form an important part of the coastal and estuarine environment. Living at the interface between land and sea, the mangrove plants have morphological and physiological adaptations to survive in harsh saline environment. Mangroves produce organic carbon well in excess of the ecosystem requirement and contribute significantly to global carbon cycle. Mangroves flourish on fine alluvial mud composed predominantly of silt and clay particles. Geological history and evidences show that mangroves appeared between Eocene and Oligocene period (30 - 40 million years ago). Plant remains or fossils of major mangrove genera like Rhizophora, Nypa and others from the peat sediments provide important clues in this matter (Subramanian, 2002). The World
Conservation Union's report on global status of mangroves lists 61 species (IUCN, 1983). Major mangrove species belong to less than 15 families, but the most frequent occurring mangroves belong to the *Rhizophoraceae*, *Sonneratiaceae*, and *Avicenniaceae*. The occurrence of peat deposits from various onshore locations along the Kerala coast has been reported earlier. The mangrove vegetation responses to Holocene climate change along Konkan coast of south-western India was studied by Limaye and Kumaran (2012).