SEA LEVEL VARIATIONS DURING THE LATE QUATERNARY AND COASTAL EVOLUTION ALONG THE NORTHERN KERALA, SOUTH WEST OF INDIA

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by

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CERTIFICATE

This is to certify that this thesis entitled "SEA LEVEL VARIATIONS DURING THE LATE QUATERNARY AND COASTAL EVOLUTION ALONG THE NORTHERN KERALA, SOUTH WEST OF INDIA", is an authentic record of the research work carried out by Mr.Haneeshkumar.V under my supervision and guidance at the Marine Science Division, Centre for Earth Science Studies, Thiruvananthapuram- 695 031 in partial fulfilment of the requirements for the Ph.D. Degree of Cochin University of Science and Technology, under the Faculty of Marine Sciences and no part thereof has been presented for the award of any degree in any University.

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PREFACE

Coastal evolution during Quaternary is mainly related to sea level changes, and have direct bearing on climatic oscillations. From IGCP 61 to IGCP 274, the concept of a single uniform world-wide sea level curve transformed into site-specific regional sea level curve. Significant contributions have been made world over to determine various episodes of marine transgression and regression and efforts are going on for achieving precision in establishing the sea level curve from a regional perspective. During the last two decades, studies to understand the nature of Holocene sea level fluctuation and chronometric transgressional and regressional history of western and eastern coasts of India were undertaken by many authors.

The Kerala coast is one of the least explored as far as reconstruction of sea level history and coastal evolution are concerned. Most of the investigation on late Quaternary sediments were based on studies on independent sequences either exposed inland or on the shelf areas. However, no effort has been made to derive a comprehensive picture of coastal evolution and climatic changes along this part of the coast by integrating the coastal and shelf sequences. In the present investigation, an attempt is made to document various episodes of transgression and regression during the late Quaternary period from the study of coastal and shelf sequences extending from the inland across the beach to the shelf domain. Shore parallel beach ridges with alternating swales and occurrence of strand line deposits on the shelf make the northern Kerala coast an ideal natural laboratory for documenting the morpho-dynamic response of the coast to the changing sea level. The present study is confined to two shore-normal east-west trending transects. viz. Punjavi and Onakkunnu in the northern Kerala coast. These coastal plain transects were extended further to the offshore up to the shelf edge.

The thesis is addressed in six chapters with further subdivision and sectionalization. In the first chapter, significance of the work is introduced. Brief review of literature includes sections on national and international endeavors on Quaternary research. climate, *drainage, geology, physiography, nature of the continental shelf and bathymetry of the study area are also presented. The study area is introduced in this chapter.*

Morphologic setup of the study area derived from the Survey of India toposheets, satellite images and air photos is dealt in the second chapter. Along the transects referred to hitherto, plane table mapping was carried out in 1:2250 and 1:5000 scale and reduced levels with respect to the Present Mean Sea Level (PMSL) of different sets of beach ridges and swales were established. An attempt is made to infer the transgressional and regressional history of the area from the perspective of origin of beach ridges.

To understand variations in sedimentary facies, twenty three core samples varying in depth between 7 and 11 metre were collected from the coastal plain. The third chapter deals with the characteristic lithologic features of the coastal plain sequences, down-core variation of the grain size and heavy mineral suite. Granulometric signatures are used to reconstruct the past depositional environment. Morpho-stratigraphic disposition of the coastal plain deposits are also inferred. Down-core variations in heavy mineral association is discussed in this chapter. In the light of their stability, dispersal and provenance, an attempt is also made to elucidate the post-depositional transformation of these deposits.

Shelf sequences are discussed in the fourth chapter. Textural attributes were used to categorize the sediments into various types. An attempt is made here to gain insight into the nature of modern/relict sedimentation. Climatic control over the sediment accumulation pattern is inferred based on distribution of organic matter, calcium carbonate and radio-carbon dates. Rate of sedimentation and the preservation potential of organic matter on the shelf sediment is also discussed.

The fifth chapter deals with correlation and chronological framework of coastal and shelf sequences. Here, an attempt is made to derive evolutionary phases of the northern Kerala coast, by collating results from coastal geomorphology, correlation of sedimentary *sequences and radio-carbon dates of the strand plain and adjoining shelf sequences. The sixth chapter summarizes the salient points and the conclusions arrived at from the present investigation.*

In connection with this thesis, following research papers/abstracts have been published in different national/international journals.

***Haneeshkumar, V.,** Ramachandran, K.K., Samsuddin, M. and Suchindan, G.K. 1999. "Heavy mineral distribution in the Holocene Coastal sediments along the Northern Kerala, India". Paper presented in the Meeting-cum-Workshop on Quaternary coastal environments: Records of Rapid changes and responses held at Bharathidasan University, Tiruchirapalli, October 1999. (Abstract vol. pp 13-15)*

***Haneeshkumar, V.,** Ramachandran, K.K., Suchindan, G.K, Samsuddin M. and Singh A.D., 1998. "Morphostratigraphic implications of Holocene coastal landforms along the northern Kerala. Paper presented in National symposium on Late Quaternary Geology and sea level changes, held at Cochin University of Science and Technology, Kochi. (Abstract vol. p 41)*

*Suchindan, G.K., Samsuddin, M., Ramachandran, K.K. and **Haneeshkumar, V.,** 1996. Holocene coastal landforms along the northern Kerala coast and their implications on sea level changes. Paper presented in International seminar on Quaternary sea level variations, shore line displacement and coastal environment. held at Tamil University Thanjavur. (Abstract vol. p 72)*

*Ramachandran, K.K., Samsuddin, M., **Haneeshkumar, V.** and Suchindan, G.K., 1996. Organic matter and $CaCO_3$ accumulation pattern in the shelf sediments off northern Kerala southwest India. (Abstract, International Seminar 'GIO' 96 held at NIO, Goa during October, 1996. p 103)*

Singh A.D., Ramachandran, K.K., Samsuddin, M., Nisha, N.R. and ***Haneesh Kumar, V.,*** *2001. Significance of Pteropods in deciphering the late Quaternary sea-level history along the south western Indian shelf. Geo-marine letters (Springer-Verlag) (in press).*

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Chapter 1

INTRODUCTION

1.1 BACKGROUND

Coastal evolution since the late Pleistocene had been dominated by repeated changes in climate, which is well-preserved world over, indicated by penecontemporaneous changes in sea level. In order to establish local and global variations in sea level during the Quaternary and to document different episodes of marine transgression and regression, great deal of work has been carried out in many parts of the world. Worldwide efforts are also being made to achieve precision in establishing regional sea level curves at site-specific framework.

1.2 INTERNATIONAL STATUS

For more than a century, earth scientists have been accumulating evidences on sea level fluctuation during the Quaternary period. The inter-governmental panel on climate change was in general agreement on a rise in global sea level in the order of 0.31 to 1.10 m between 1990 and 2100 (Houghton et al., 1990). However, a recent estimate suggested a global mean sea level rise of around 0.2 m during the last century (Pirazzoli, 1986; Gornitz and Lebedeft, 1987; Douglas and Herbrechsneier, 1989; Peltier and Tushinghom, 1989; Klige, 1990; Emery and Aubrey, 1991). Based on the sea level data from different areas, number of sea level curves has been constructed, which were found to be highly useful in reconstructing global scenarios in sea level (Kraft et al., 1987; Pirazzoli, 1991; Tushinghom and Peltier, 1993). According to "Projected model" proposed by IPCC in 2000, the global sea level rise is of the order of 0.09 to 0.88 meter.

In 1961, a highly fluctuating sea level curve for the Holocene was established by Fairbridge and was well referred by the scientific community. During the mid-Holocene, sea level in some parts of the world was indeed higher than that at present (Dominquez et al., 1987; Giresse, 1989). This was in good agreement with most comprehensive geophysical model of sea level ICE-2 (Peltier, 1988). Much earlier, along the Carolina coast, Gayes et al. (1992) have reported that a rapid mid-Holocene sea level position, which was 3 m below the PMSL at 4570-5200 YBP, fell by 1 m below its position by 4280 YBP. The sea level continued to fall again by 3 m by 3600 YBP, before reaching the present position. According to Houghton et al. (1990), most of the mid-Holocene

Years Before Present)

warming have taken place prior to 6000 (YBP) while most of the higher sea levels occurred at least 1000 years later. If the same climatic phenomena occur again, with global warming, the sea-level might register a rise in sea level of the order of few meters of eustatic sea level rise, instead of few centimeters rise (Kuhn, 1989).

Contrasting effect of tectonic, isostatic and gravitational influences associated with global variations in ice and water masses rule out the possibility of global applicability of sea level curves. It is a well-established fact that, changes in shape of the earth's geoid cause regional differences in the pattern of post-glacial sea level change. In areas such as eastern South America, West Africa and Australia, sea-level changes are largely caused by changes in water volume rather than land movement. With the discovery of geoidal deformation, it became obvious that available ocean level changes data base differ widely over the globe and can never be expressed in terms of globally valid eustatic curves as previously believed (Fairbridge, 1961; Newman et al., 1980; Bloom, 1983; Morner, 1987b; Pirazzoli, 1991).

For the sake of continuity or discontinuity of forcing functions, it is important to realize that the earth came into a new mode in Mid-Holocene time when the glacial eustatic rise and corresponding rotational deceleration is finished. The sea level changes became dominated by redistribution of water masses due to interchange of angular momentum between the solid earth and main circulation system of the ocean (Morner, 1980; 1995). With respect to the late Holocene sea-level changes in the order of decades to a century, there are small to insignificant effects from glacial eustasy due to mass distribution. Similarly, the effects on the water column are seen only to be in the order of decimeters at the most (Nakiboglu and Lambeck, 1991; Morner, 1994). The major effects are instead, the dynamic redistribution of water masses via the ocean current system. It means that even if the global sea level has changed during the last 150 years, it can only be in the order of about 1 mm rise per year (Morner, 1992; 1995). During the last of glacial maximum at about 18,000 YBP, the sea surface circulation pattern of the Indian Ocean was significantly different from the modern pattern and the SW monsoon wind prevailed weaker than today (Prell et al., 1980).

As a result of eustatic rise in sea level, wide assemblages of bivalves and univalve molluscs got accumulated in the coastal deposits of many part of the world. They are considered as well-known geo-scientific tool in deciphering former sea level stands. In general, the faster the sea level rise, the higher the possibility of its burial, drowning or destruction. The faster the fall in sea level, the more probable the preservation of depositional bodies such as beach ridges and coastal dunes. Utilising the interplay between the inland marine shells and submerged deposits, Fairbridge (1976) was able to reconstruct various episodes of transgression and regression and was successful in establishing a sea level curve for that area.

In Europe, North America, Africa and Australia, detailed geomorphological, palynological, micropaleontological and geoarchaeological studies of the Quaternary deposits have helped in the reconstruction of different paleogeomorphic environments (Schumm, 1977; Goudie, 1977; William and Faure, 1980; Butzer, 1980). However, such studies have clearly demonstrated the complexities involved in the interpretation of continental sediments and have also helped to highlight the problems encountered in establishing the cause and effect relationship due to numerous undetectable parameters involved in the reconstruction of Quaternary Paleogeography.

Seminuik (1981) and Eronen et al. (1987) utilized the stratigraphic sequences of tidal flats and swampy environments to deduce past climatic conditions and Holocene sea level fluctuations. In their pioneering work, Curray and Moore (1964) illustrated the formation of beach ridges and their importance in elucidating sea level changes. Seminuik (1983) and Tanner (1992, 1993) also emphasized the importance of beach ridge in deciphering various stages of evolution of the coastal plain.

1.3 NATIONAL STATUS

Studies on the Quaternary deposits along the Indian coasts have received special attention in the recent years from the point of view of establishing past sea level changes. On the east coast, sea level studies have mostly been based on depositional and erosional features exposed in different coastal environments. Available information, however, is more qualitative. On the contrary, west coast is better investigated by different group of workers, where, a great deal of information not only on transgressional and regressional aspects of high strand lines but also on low stands in the continental shelf is available.

In his pioneering work, Ahmed, (1972) correlated disposition of certain land features to the global inter-glacial transgression/regression. However, during the last two decades, with the generation of more data, attempts were made to correlate strand line features at different elevations or depths with that of the glacio-eustatic sea level changes that occurred during the Quaternary. Analyses of oil-well data from the northern Arabian sea (Aditya and Sinha, 1976) have found to be highly useful in understanding the sea level fluctuation during the Tertiary and early Quaternary period.

1.3.1 East Coast

On the east coast, sea level fluctuations were mostly inferred from the studies pertaining to major river deltas and various coastal landforms like islands, beach ridges, rock terraces, caves and relict sediments in the continental shelves (Niyogi, 1975; Bhaskara Rao and Vaidyanathan, 1975; Prudhvi Raju and Vaidyanathan, 1981). Studies on Holocene sea level changes off Visakhapatnam shelf indicated a late Pleistocene regression down to about 130 m below thePMSL. Prudhvi Raju et al. (1985) related the red sand exposures of the Vishakapatnam coast resting over a rock outcrop at about 7 m above MSL to a high stand of sea level.

Banerjee and Sen (1985) studied the floral and faunal assemblages and informed an opinion that tidal mangrove forests flourished further north of the present extent of

Sunderbans at about 6000 to 7000 YBP. Niyogi (1971) reported three levels of terrace at 6.1 m, 4.7 m and 3.8 m above MSL in the Subarnarekha River delta and the adjoining coast of West Bengal.

In the Godavari delta, Sambasiva Rao and Vaidyanathan (1979) grouped four strand lines under the Holocene period. Samples such as peat/wood material, shell fragments, calcrete rich mud etc. taken from the farthest beach ridge to the Krishna delta gave an age range of 6500 YBP to 2050 YBP (Krishna Rao et al., 1990). Radiocarbon dating of mollusc shells from a bar at about 25 km from the present coastline in the Nizampatnam Bay gave an age of 8200 ± 120 YBP, suggesting a Holocene sea level drop of about 17 m. Here, Srinivasa Rao et al. (1990) postulated a rapid rise in the sea level at around 8000 YBP, thereby drowning the barrier island. Evidences of low sea stands at -49 m and -56 m near the Pulicat Lake in the form of pebble horizons have been identified by Nageswara Rao (1979).

Meijerink (1971) inferred a low strand line at 70 m, at the close of the Wurm glacial stage. The sea level rose rapidly to the present level in the course of post-glacial transgression, thereby inundating 11000-12000 years old Pleistocene fluvial deposits of the Cauvery region. A series of beach ridges in Cauvery delta, each rising 7.2 m, 6.9 m and 5.5 m above the PMSL are related to three strand lines at their respective positions (Sambasiva Rao, 1982).

Vaidyanadhan (1981) related coral reefs and few terraces lying close to Rameswaram Island between Tamilnadu and Sri Lanka to the emergence of the coast. Morphological analysis of coastal landform indicated emergence of the Rameswaram coast at about 4000 YBP (Rao, 1990). Along the Tamilnadu coast, during the late Quaternary (Upper Pleistocene) transgression, the sea level rose to +2 m and +8 m during the last inter-glacial stage. The Holocene transgression reached its maximum height during 6240 YBP to 2740 YBP, the level hardly rising 0.5 m to 1m above the PMSL (Bruckner, 1989). The terraces around Mandapam and Rameswaram coast ranging in height from 0.20 m to 0.62

m above MSL, gave ages varying from 5440 ± 60 to 140 ± 45 YBP (Victor Rajamanickam and Lovesan, 1990).

1.3.2 West Coast

In order to establish the tentative Holocene transgression-regression history of the west coast in chronometric terms, absolute dates of beach rocks, shelf surface sediments, corals, oolitic limestone etc. from shore and coastal zone have been used by many workers. Kale and Rajaguru (1983; 1985) inferred a lowering of sea level in the west coast of India to the tune of 1.5 m to 2.5 m at about 6500 YBP and have also obtained a sea level curve from the closing phase of Pleistocene to late Holocene. Based on their work on the Neogene and Quaternary transgressional and regressional history of the west coast of India, the fluctuation of sea level through time has been attributed to global eustatic changes in sea level and also to the tectonic movements. From the carbonate content and the faunal composition of the coastal Arabian Sea sediments, Borole et al. (1982) provided clear-cut evidences for a major environmental change around 13,000 YBP in the surface ocean waters along the Saurashtra coast.

Based on radiocarbon dates, Agarwal et al. (1973) and Kale et al. (1984) provided important information on series of transgression and regression phenomenon along the Maharashtra coast. According to them, before 30,000 to 35,000 YBP, the sea level was considered to be very much lower than at present, but started rising from 30,000 YBP. This was followed by a regression, was coupled with a rise in sea level around 15,000 YBP. The sea level attained its maximum level during the mid-Holocene. It was also observed that at about 6000 YBP the sea level was almost the same as that at present, but in subsequent periods, i.e. between 6,000 and 2,000 YBP, a further rise of 1 m to 6 m was indicated. Similarly, Sukhthankar and Pandian (1990) identified various geomorphic features related to marine regression during Holocene in the Maharashtra coast and highlighted the significance of neotectonism in shaping the shoreline. Along the Goa coast, Wagle (1982) inferred presence of drowned river valleys at a depth of 27 m to 35 m below the PMSL. Based on oxygen isotope and sedimentological records of a sediment core from the southwestern continental margin of India, fluctuations in sea surface hydrography during the last deglaciation have been studied by Thampan et al. (2001). The large glacial-interglacial amplitude in oxygen isotope records and high-amplitude oscillations within the Holocene suggested influence of deglacial warming and regional variation in precipitation on the hydrography of the region. Although significant sea surface warming occurred during the early deglacial period (around 15 ka BP), major increase in precipitation was only after ~9-8 ka BP. The Holocene was also characterised by large changes in salinity variations and appears to be synchronous with the monsoonal precipitation events on land.

Extensive studies on the milliolitic rocks of Saurashtra coast resulted in the accumulation of a wealth of information on high strand line positions during Quaternary (Lele, 1973; Marathe et al., 1977; Banerjee and Sen, 1987; Verma and Mathur, 1988; Purnachandra Rao and Veerayya, 1996). Synthesizing the observations of different workers, Merh (1980) illustrated five stages of transgressive and regressive episodes along the Saurashtra coast. Merh (1992) had also put the highest middle Pleistocene strand line position of the Saurashtra coast at about 25 m. Thus, it is likely that even 2000 years ago the Rann was below 4 m of water depth. Studies in the Little Rann also proved to the effect that the sea level fluctuated even within the Holocene (Gupta, 1975). The existence of an earlier fluvial network, the role of neo-tectonism and sea level changes are considered to be the main factors for overall evolution of this part of Western India (Chamayal et al., 1994). Studies on the deep sea Arabian Sea cores provide valuable information about the Quaternary climatic and oceanographic history of this region (Gupta and Srinivasan, 1990a, 1990b; Srinivasan and Singh, 1991, 1992; Singh and Srinivasan, 1993). Bathymetric and shallow seismic data from the continental slope of Saurashtra-Bombay indicated presence of wide submarine terraces at 130 m, 145 m and 170 m and reef structures at 320 m to 360 m water depths.

1.3.2.1 Kerala scenario

In the Kerala coast many studies have been carried out on various aspects of sea level changes from the point of view of stratigraphic, lithological, geochronological and paleontological framework. (Jacob and Sastri, 1952; Paulose and Narayanaswamy, 1968; Ramanujam, 1987; Aditya and Sinha, 1976; Raha et al., 1983, 1987). From the study of beach rocks along the south west coast of India, Thrivikramji and Ramasarma (1981) inferred a 4 to 5 m fall in sea level during the Holocene period. Sawarkar (1969) has located auriferous alluvial gravels farther inland in the Nilambur valley at an elevation of 150 m above mean sea level. Guzder (1980) attributed the alluvial gravels in Nilambur valley to sea level changes during the early late Pleistocene period. The peat beds that form prominent Quaternary units in Kerala were considered to be developed from the submergence of coastal forests, thereby representing series of transgression and regression (Power et al., 1983, Rajendran et al., 1989). The radio carbon dating of decayed wood from carbonaceous clay from Ponnani gave an age of 8230-10240 YBP indicating transgression of the sea during Early Holocene period (Rajan et al., 1992), which ultimately resulted in destruction of the coastal mangroves.

From the point of view of late Quaternary sea level changes, the continental shelf of Kerala was explored by many workers. The submerged terraces found at -92 m, -85 m, -75 m and -55 m in the continental shelf of west coast represent four still stands of sea levels of the Holocene age (9,000-11,000 YBP), the period during which the sea was in a transgressive phase (Nair, 1974, 1975). Nair and Hashmi (1980) ascribed the formation of oolitic limestone in the Kerala shelf to warmer conditions and low terrestrial run off during the Holocene period (9000-11000 YBP). Agarwal (1990) considered the west coast of India to be an emergent type and identified a rise in sea level to the order of 0.3 m during the past 57 years.

Occurrences of typical morphological features along different parts of the Kerala coast do indicate that there were repeated episodes of transgression and regression (Samsuddin et al., 1992; Suchindan et al., 1996; Haneeshkumar et al., 1998). Samsuddin et al. (1992) considered the strand plain deposits along the northern Kerala coast to be the morphological manifestations of marine transgression/regressions. The striking parallelism of Vembanad Lake with that of the series of strand lines in the Central Kerala coast is also an example of the transgressive-regressive episodes (Mallik and Suchindan, 1984). A linear sand body at a depth of 20 m to 30 m offshore with typical textural characteristics of the beach deposits, running almost parallel to this coastline, is also considered as another example of low stand of sea level (Prithviraj and Prakash, 1991; Ramachandran, 1992). Relict terrigeneous sediments in the outer shelf between Mangalore and Cochin imply that the Holocene sedimentation to the outer shelf is minimal and has been unable to cover the Late Pleistocene sediments. This is confirmed by the exposure of terrestrial carbonates such as calcretes and paleosols of Pleistocene age at 50 m to 60 m water depth (Rao and Thamban, 1997).

Most of the investigations on the late Quaternary sediments along the Kerala coast were based either on sequences exposed inland or from the shelf areas. Little attempt has been made to establish a complete scenario of coastal evolution and climatic changes, which necessitates a comprehensive study along well-defined E-W transects extending from the inland across the beach to shelf domain.

1.4 OBJECTIVES OF THE STUDY

The northern Kerala coast characterised by series of beach ridges alternating with swales in the hinterland and occurrence of series of strandline deposits on the shelf offers an excellent opportunity for attempting a systematic study of coastal evolution and sea level changes.

In the present investigation, a study was initiated to understand the late Quaternary fluctuation in sea level and corresponding effect on the shoreline therein with the following objectives:

1. Litho-stratigraphic reconstruction of environments of deposition from the coastal plain and shelf sequences;
2. Documentation of episodes of transgression and regression by studying different coastal plain sequences and shelf deposits and

3. Evolve a comprehensive picture of late Quaternary coastal evolution and sea level changes along the northern Kerala coast by collating morphological, lithological and geochronological evidences from the coastal plain and shelf sequences.

1.5 PHYSIOGRAPHY

Physiographically, the State can be classified into five zones (Resource Atlas of Kerala, 1984). The mountains and peaks that rise above 1800 m within the Western Ghats constitute only 0.64% of the total area. The highlands at an altitude of >75 m occupy 20.35% of the area.

The undulating western fringe of the highlands and lateritised rocky spurs projecting westward form the midlands within altitude of 8 m to 75 m cover nearly 8.44% of the total area. The areas falling below the altitudinal range of <8 m, and which consists of dissected peneplains constitute the lowlands. Numerous flood plains, terraces, valley hills, colluvium and sedimentary formation are parts of these landforms. In the northern and southern parts of the State this unit merges with the coastal plain.

Coastal plains, with lagoons and vast low-lying areas fringing the coast, is not only an important physiographic unit of Kerala, but also important in terms of economic activity and demographic distribution. In this physiographic zone, most of the areas show relief between 4 m to about 6 m above MSL. Beach dunes, ancient beach ridges, barrier flats, coastal alluvial plains, flood plains, river terraces, marshes and lagoons constitute this unit. A characteristic feature of this unit is the series of beach ridges and swales roughly aligned parallel to the coast.

1.6 GEOLOGY OF KERALA

Four major lithologic units are reported from the northern Kerala coast (Fig 1.1). viz., Precambrian Crystallines, Tertiary Sedimentaries, Laterite cappings over Precambrian Crystallines, and the Recent to Sub-Recent sediments.

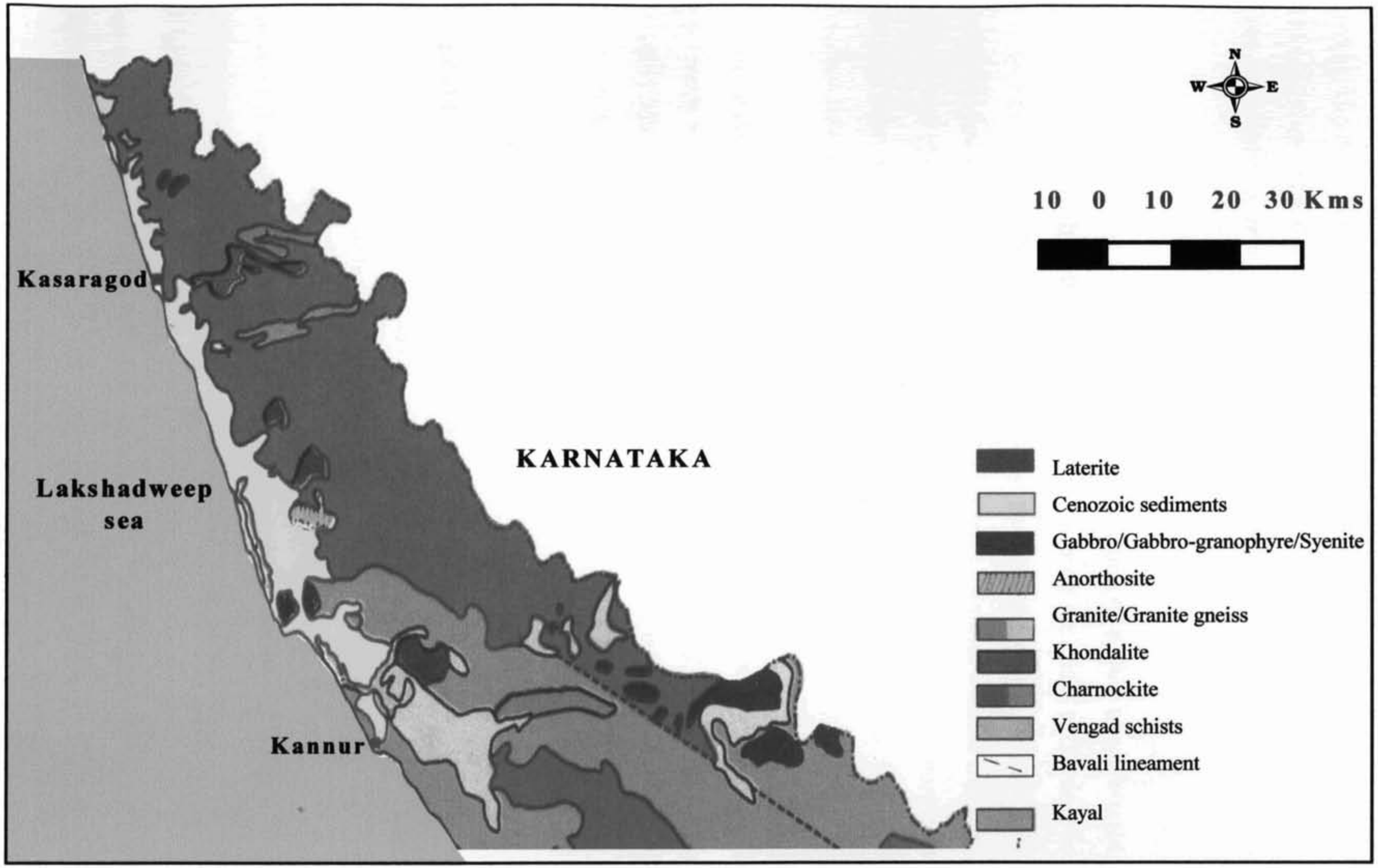


Fig. 1.1 **Geological map of the Northern Kerala** ***(Modified after Geological Map of Kerala, GSI, 1973 & 1995)***

Precambrian Crystallines: The Precambrian crystallines, which include Charnockite group, Migmatite complex, Khondalite group, Wyanad group, Peninsular gneissic complex, Dharwar super group and some basic and acidic rocks (GSI, 1995), occupy considerable portions of northern Kerala. The former three cover more than 80% of the total area of Kerala.

Tertiary Sedimentaries: The Tertiary sedimentary formation of Kerala unconformably lie over the Precambrians. It is the southern-most one among the chain of Tertiary basins along the west coast of Peninsular India. Inland part of the Tertiary basin consists of Neogene and Quaternary sediments. Neogene sediments comprise a series of variegated sandstones and clays with lenticular seams of lignite (Warkalli beds) and more compact sands and clays with thin beds of limestone named as Quilon beds (Paulose and Narayanaswamy, 1968).

Quaternary Sediments: The Quaternary sediments include parallel sand ridges, sand flats, alluvial sands and lacustrine deposits. The coastal plain, generally do not rise more than 15 m above MSL. The coastal sands at places are rich in heavy minerals such as ilmenite, monazite, zircon, rutile etc.

1.7 CONTINENTAL SHELF AND BATHYMETRY

The continental shelf bordering the west coast of India is remarkably straight, which is considered to be formed due to faulting during the Pleistocene (Krishnan, 1968). The shelf along this part is broader and flatter when compared to world averages. Width of the shelf increases from 40 km off Trivandrum in the south to 320 km off the Gulf of Cambay in the north (Ramaraju, 1973). Based on the surface roughness of the continental shelf, Siddique and Rajamanickam (1974) ascribed the shelf break between 120 m and 145 m and the average shelf break occurring at a water depth of 100 m. Topographic studies on the outer shelf of the western continental shelf indicated small scale irregularities of the order of 1-8 m in height at depth between 35 m and 145 m. (Nair, 1975; Wagle et al., 1994; Subbaraju and Wagle, 1996). Generally the shelf has a gentler slope near the sh and the gradient increasing further seawards.

1.8 CLIMATE

Kerala State has a tropical humid climate with an oppressive summer and plentiful seasonal rainfall. The hot summer season from March to May is followed by SW monsoon from June to September. October and November months form the post monsoon or the retreating monsoon season. The period from October to December is the N-E monsoon season (Resource Atlas of Kerala). It is because of the seasonal reversal of wind circulation in the Arabian Sea, the monsoonal climate is generated along the SW coast of India. The climate of Kerala is broadly grouped under the following season (Ananthakrishna et al., 1979): viz., winter month (January-February), hot weather period (March-May), SW monsoon (June-September) and NE monsoon (October-November).

1.9 WAVE CLIMATE

Though there are seasonal variations in the occurrence of wave activity, generally maximum wave activity is observed during the monsoon months. During the fair season, the wave height is less than 1m. Increase in wave activity is evident in the monsoon months. Wave height during the rough season is more or less normally distributed. The maximum breaker height generally shows a peak during June-July, while it is low from October through March. The increase in breaker height commences in May and continues till September. The distribution of mean monthly breaker period generally shows that waves break at higher frequency during the S-W monsoon. The longshore currents also vary considerably in time and space. The currents are towards south during the monsoon period. During the non-monsoon months, it shifts towards north. However, there are exceptions to these general trends. During the monsoon months there are both alongshore and onshore-offshore component of current. Under the influence of the longshore and onshore-offshore currents, the beaches erode to a great extent during the monsoon. Non-monsoon months are characterised by constructive wave action, thus accelerating building up of beach to a great extent.

1.10 FLUVIAL INPUTS

Out of the 44 rivers that drain the State of Kerala, 3 are east flowing. Absence of delta formation is the characteristic feature of the Kerala Rivers. Most of the river courses are straight, indicating a structural control. Major rivers that drain the study area are: Karingote, Nileswaram, and Valapatnam. Drainage basins of these rivers are occupied by charnockite, khondalite, different type of gneisses, sediments of Tertiary age, laterite cappings on crystallines and sediments of Sub-Recent to Recent age. The characteristic features of the rivers are given in Table 1.1

Table 1.1 Length of rivers (km), their catchment area (km^2) and total run off (1000Mc ft).

Sl. no	River	Length	Catchment area	Run-off
1	Karingote river	64	561	50.36
2	Nileswaram river	46	190	16.5
3	Valapattanam river	110	867	97.7

1.11 STUDY AREA

The region of investigation lies in the coastal plain of the northern Kerala coast in the Kasaragod district. To understand the coastal evolution with all the aspects of sea level changes during the Pleistocene to Holocene period, a systematic study along two shore-normal East-West transects originating from the strand plain and cutting across the beach to the shelf domain is attempted. The study was carried out along Punjavi-Muthappankavu (Latitude 12^0 17′ 30″ and Longitude 75^0 5′ to 75^0 7′ 30″) and Padanna-Onakkunnu (Latitude 12^0 10′ and Longitude 75^0 7′ 30″ to 75^0 10′) regions of the northern Kerala coast. Location map of the study area is illustrated in Figure 1.2. The coastal plain sequence of Punjavi transect, with a landward extension of about 2.4 km is further extended to 78 km towards the continental shelf. The Onakkunnu transect that has about 6.4 km landward length is extended to about 74 km into the continental shelf. Detailed location map of the study area showing core locations are given in the corresponding Chapters.

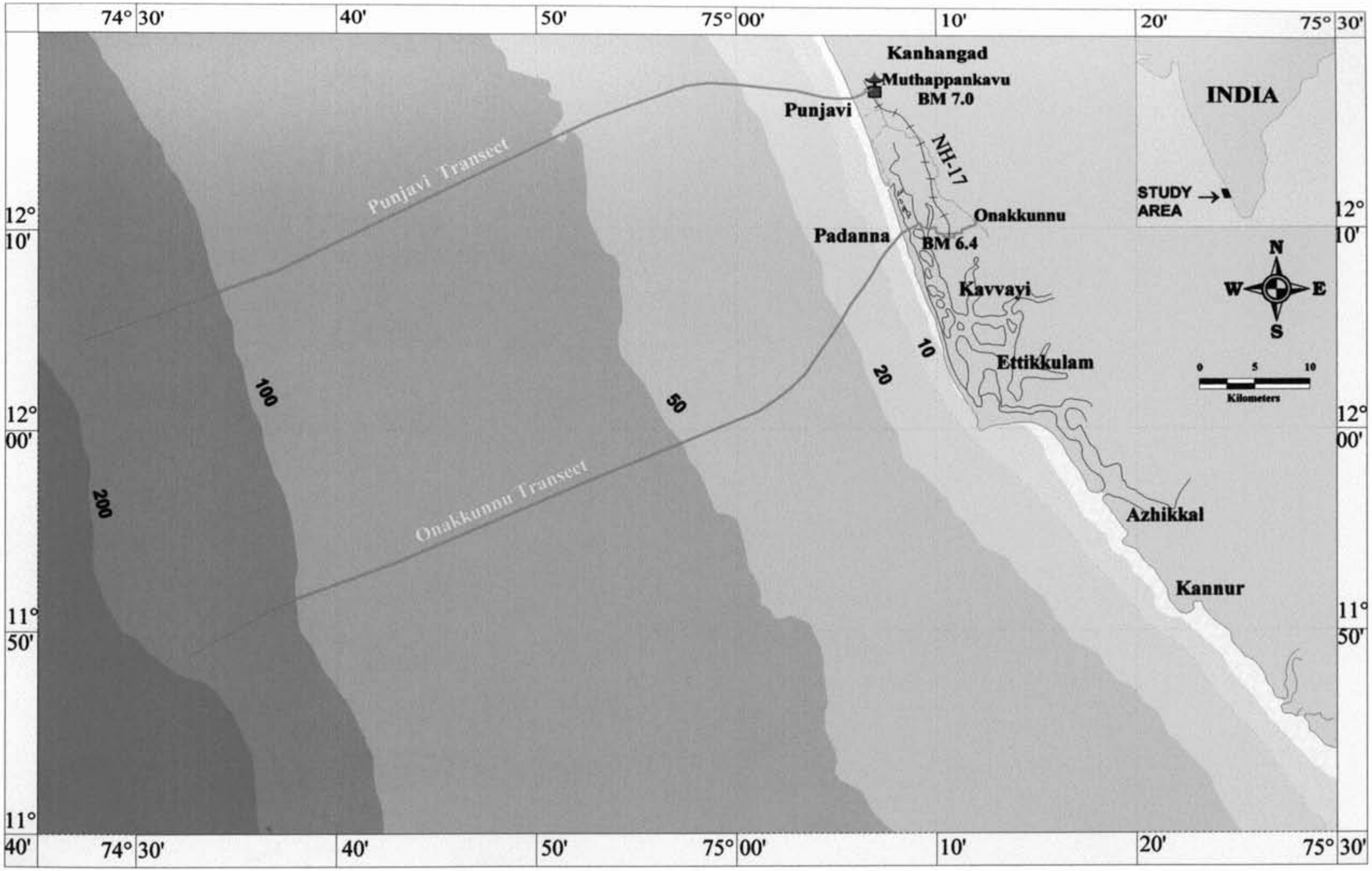


Fig. 1.2 Map of the study area showing locations of Punjavi and Onakunnu Transects

Chapter 2

COASTAL GEOMORPHOLOGY

2.1 BACKGROUND

The coastline of India extending over 7000 km is quite variable both in form and nature. The eastern coastline is generally deltaic, gently indented and extensively developed. On the contrary, the western coastline is highly irregular, steep-cliffed and wave eroded (Ahmed, 1968). The Kerala coast in the southwest part of this complex coastline is very dynamic in nature and is subjected to seasonal changes in beach configuration brought about by high waves and currents. The shoreline of Kerala can be grouped mainly into erosional or retrograding coastal segments and depositional or prograding coastal segments. However, there are also stretches, which are more or less free from any changes. The erosional coastal segments are characterised by sea cliffs, stacks and shore platforms. Features like wide beaches, bars, tombolo and beach ridge/dune complexes and lagoons characterise the depositional sectors.

2.2 NATURE OF THE KERALA COAST

According to Nair (1987) the shoreline of Kerala, which is generally straight and trending NNW-SSE, is highly irregular and indented especially around the promontories. Stretches of shoreline between promontories are usually depositional in nature. Based on the vulnerability and dynamism of shorelines, Nair (1987) characterised the Kerala coast into permeable, gently sloping, sandy, semi-permeable, cliffed-sedimentary, impermeable and crystalline shorelines. Thrivikramji (1979) proposed a classification, in which, the Kerala coast was divided into a few typical coastal environments viz. strand plain shoreline/permeable shoreline, cliffed shoreline with a seasonal beach and a compound coast.

Estuaries and lagoons show a general N-S to NNW-SSE or E-W to WSW-ENE trend with wide variation in width. The estuaries are generally the submerged river mouths popularly known as *kayals*. Estuaries and lagoons are thus considered as the product of submergent and emergent aspects of the coast (Nair, 1987). Faulting, uplifting and downwarping are recorded in a number of places in the western coast and offshore. The geometrical linearity of the coastline and the straight trend of some of the rivers clearly reflect a tectonic control in their formation, which were also evident from satellite imageries. Most of the rivers are flowing to the west and debauch in the sea. Due to the interaction of the fluvio-marine interface, offshore bars start building up and gradually obstruct the stream mouths and water bodies. With the formation of sand bars in the offshore, large spits are formed, ultimately cutting the geometry of the coast to a great extent.

Thus, it is evident that the Kerala coast was subjected to various degree of tectonic activity and different stages of transgression and regression. The landforms are considered as the resultant response of a variety of interacting processes that have operated with varying magnitude and frequency during the late Quaternary period. Late Quaternary coastal evolution and sea level changes can be well understood only when a detailed account of geomorphological set up of the area is made available. Here, an attempt is made to precisely map the late Quaternary landforms along the two transects with respect to the PMSL and to analyse its possible influence on the transgression and regression phenomenon of the northern Kerala coast.

2.3 METHODOLOGY

Detailed physiography of the region of investigation is represented diagrammatically in the Figures 2.1 & 2.2 prepared from a study of Survey of India toposheets (1:50,000 and 1:25,000), air photos (1:15,000 scale) and satellite imageries (1: 50,000), supplemented by fieldwork. In the base map, topographic features, major road network, rivers, railway line etc. were transferred from the Survey of India toposheets. The roads, water bodies and geomorphic features were updated using the air photos. The elements of photographic interpretations viz. shape, size, tone, shadow, pattern, texture, site and resolution were taken into account for the identification of landforms. Along the Punjavi (Transect I) and Onakkunnu (Transect II), plane table mapping and theodolite survey of the geomorphic units were carried out in 1:2250 and 1:5000 scales respectively.

2.4 TRANSECT ELEVATION SECTIONS:

The region consists of isolated hills of laterite protruding through the late Quaternary

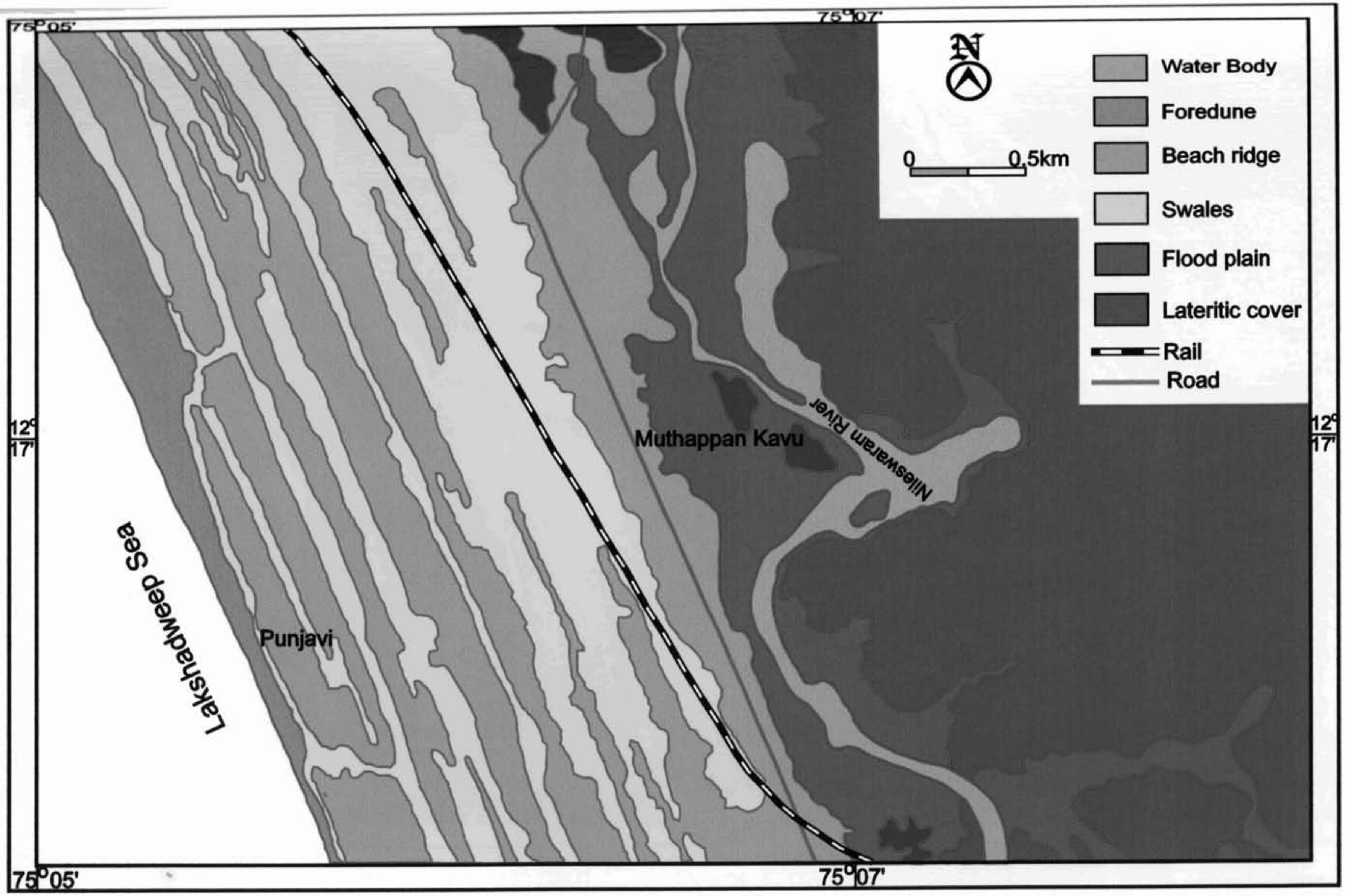


Fig. 2.1: Geomorphic map of Punjavi transect

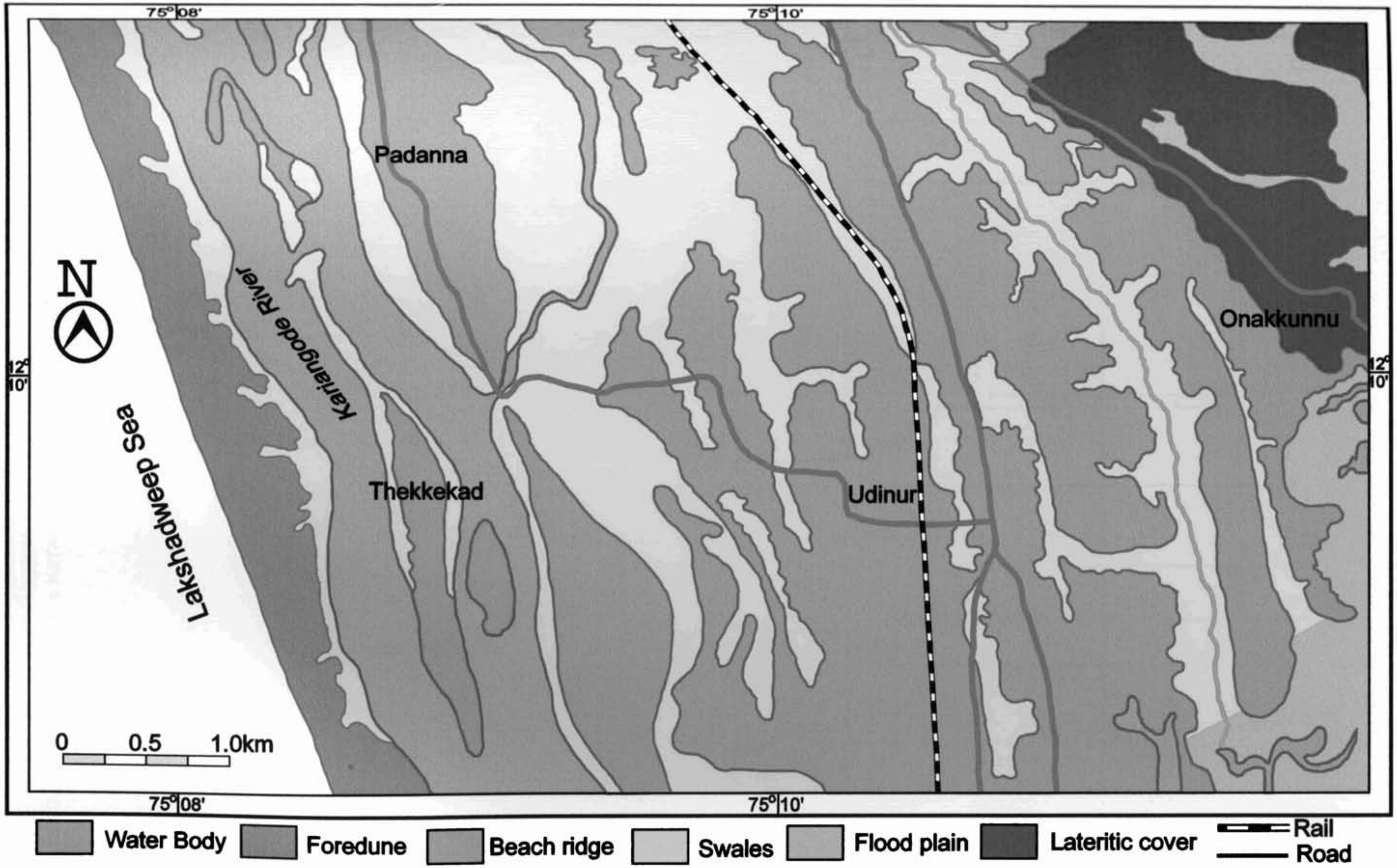


Fig. 2.2: Geomorphic map of Onakkunnu transect

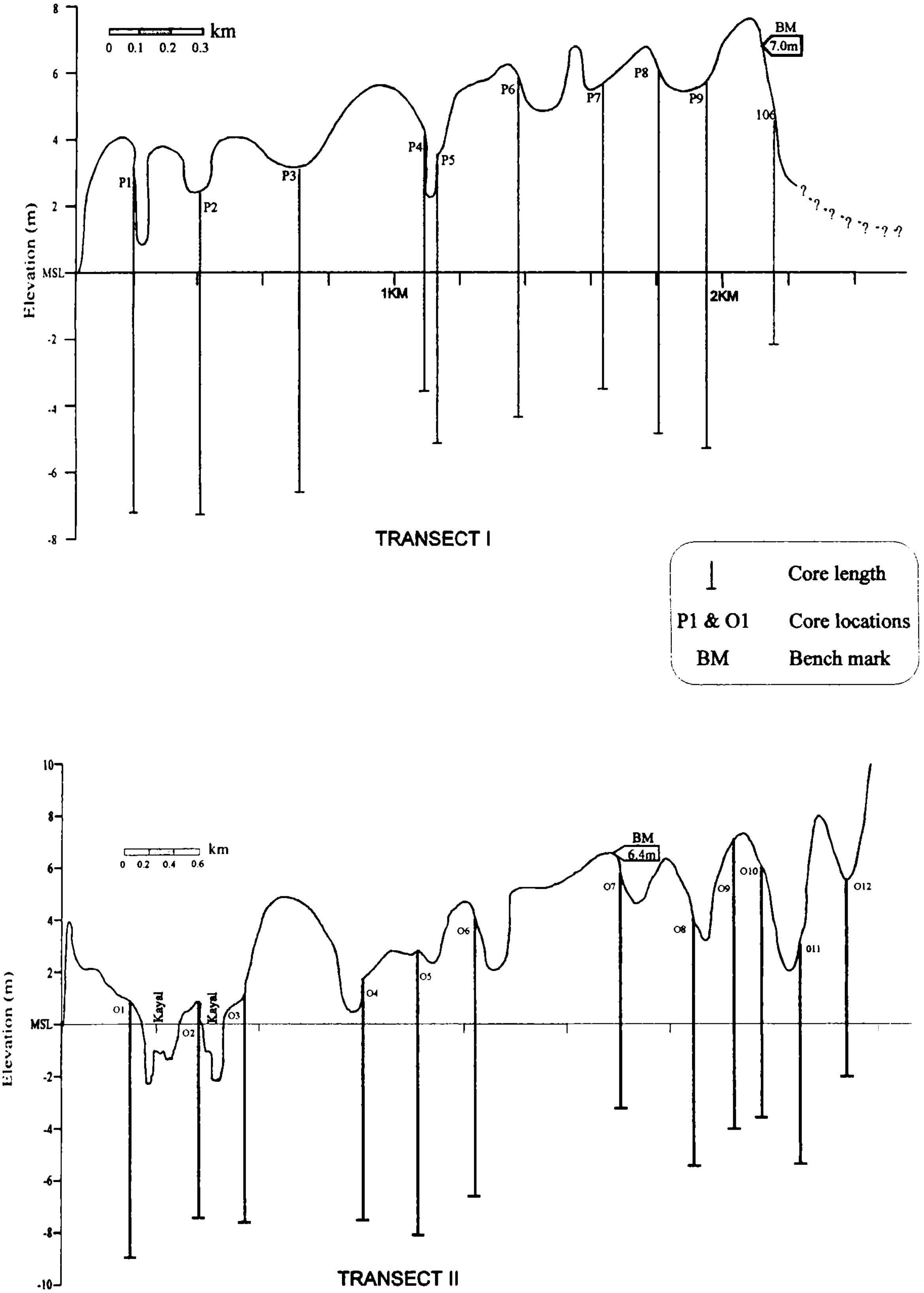


Fig. 2.3 Transect elevation section of Punjavi (Transect 1) and Onakkunnu (Transect 2) showing the location and length of cores

sediments of the coastal plain (Plate I). The late Quaternary sediments consist of flood plain deposits (Plate II), estuaries (Plate III), a wide strand plain of sub-parallel elongate beach ridges (Plate IV) and swales (Plate V). It is also apparent that the trends of these ridges parallel the present coast. Extensive anthropogenic activities are prevalent in this area (Plate VI), due to which most of the ridges are obliterated. The characteristic features of the two transects are illustrated below:

Based on the plane table mapping and theodolite survey, configurations of different geomorphic units were worked out. Reduced levels at each of the swale and ridge positions were determined with reference to PMSL by precise leveling (Fig 2.3). Based on the reduced levels, cross-sections of elevations of transects with respect to PMSL were prepared. Location of cores and their corresponding depths are also shown in the Figure.

2.4.1 Punjavi Transect

This transect extends over a length of 2.4 km, the eastern boundary of which is bounded by the flood plain deposits of Nileswaram River in the east and the beach in the west (Fig 2.1). The width, area and elevations of ridges and swales vary from one another. Swale width varies between 50 m to 300 m, whereas the ridge width varies 120 m to 380 m. The average height of the ridge (swale bottom to ridge crest) is 3.2 m. Along this transect, ridges and swales maintain a striking parallelism with the coastline. Dimensional variation of these ridges and swales are shown in Table 2.1. The ridges support mainly cashew plantations and other mixed trees. The swales are either reclaimed or used for paddy cultivation sparingly.

2.4.2 Onakkunnu Transect

Extending from Padanna beach to Onakkunnu in the east, this transect which is 6.4 km in length, is also offset by lateritic outcrops (Fig 2.2). The dimension of the ridges and swales vary from one another. Swale width varies from 500 m to 1100 m, whereas the ridge width varies from 450 m to 1100 m. Average height of the ridge is 3.9 m. Unlike the northern transect, the inner most ridges are curvilinear in nature. The ridges lying close to the shoreline are almost parallel to the present-day coast. Towards the fore dune side, the barrier ridges are backed by the Ettikulam estuary. In Ettikulam estuary there are three elongated discontinuous sand dunes, which are vegetated and stable.

Table: 2.1. Distance (km from beach), elevation (above PMSL) and the width (km) of strandlines of Punjavi transect.

BEACH RIDGE			SWALE		
Distance	Elevation	Width	Distance	Elevation	Width
0.15	3.71	0.17	0.30	1.00	0.05
0.17	4.01	0.12	0.41	2.32	0.09
0.51	5.52	0.13	0.68	3.13	0.18
0.96	6.30	0.33	1.13	2.30	0.07
1.30	6. 18	0.21	1.45	4.72	0.14
1.50	6.90	0.05	1.59	5.45	0.12
1.80	7.73	0.11	1.86	5.38	0.18

Table: 2.2 Distance (km from beach), elevation (above PMSL) and the width (km) of strandlines of Onakkunnu transect.

BEACH RIDGE			SWALE		
Distance	Elevation	Width	Distance	Elevation	Width
0.07	3.86	0.72	0.72	-3.08	0.29
1.11	1.00	0.18	1.25	-3.91	0.19
1.81	4.70	0.93	2.39	0.53	0.34
3.21	4.52	0.75	3.41	2.00	0.25
4.31	6.38	1.14	4.55	4.50	0.22
4.77	6.10	0.31	5.09	3.04	0.23
5.37	7.10	0.30	5.71	2.00	0.32
5.95	7.71	0.19	6.12	5.30	0.19

2.5 MORPHOLOGICAL FEATURES

Eight sets of beach ridges and swales were identified in Onakkunnu transect and seven sets in Punjavi transect. In general, the ridges and swales are aligned roughly parallel to the present-day shoreline. The flood plain deposits of Nileswaram River obliterate the eastern most beach ridge/swale in Punjavi transect. The two transect locations are distinct in their geomorphological set up. In Punjavi transect, the strand lines are aligned parallel to the coast. Whereas, in Onakkunnu transect the inner most ridges are curvilinear in nature (*refer Fig 2.2*), but towards the fore dune side, the ridges retain parallelism to the coast. The curvilinear nature of the innermost ridges indirectly points to the nature of the then embayment of coast, which could have been curvilinear during the Holocene period.

In both transects, innermost ridge top lies slightly above 7.5 m and the fore dune is at 4 m. By joining the successive ridge tops and swale bottom, general seaward slope is evident from the inner most ridge/swale to the sea.

2.5.1 Coastal Landforms

The coastal landforms are considered to be the products of variety of interacting processes with varying magnitude and frequency that have operated during the late Quaternary period. The landforms in the study area are primarily the result of mixed action of fluvial, estuarine and marine activities.

2.5.1.1 Fluvial and estuarine landforms

The depositional processes of Nileswaram River and Karingote River have lead to the development of fluvial landforms in the form of river valleys and flood plain deposits. Large areas of silty clay surface of the flood plain have been extensively cultivated for paddy, coconut, plantain, tapioca and other types of crops. The flood plains abutting against the lateritic outcrops are considered as the landward limit of the wave activity during the Holocene.

2.5.1.2 Marine landforms

The strand plains, which are considered as marine landforms, are constituted by beach ridges and swales. Beach ridges are sub parallel ridges of sand, shell or pebble, varying in amplitude from a few inches to many feet. Swales are the depression between the beach ridges. Spacings between the ridges are quite variable.

In the Onakkunnu transect, the Ettikulam lagoon is composed of 10 islets among which, six are showing typical augen shape. On verification of the Survey of India toposheet of 1914, this lagoon was connected to the sea by two inlets. However, at present, it is connected to the sea through the Karingote River mouth. Thrivikramji (1987), considered these islets of Ettikulam lagoon (including the boomerang islets of northern part) as remnants of an ancient barrier island. The linear segment of three stable islands in Ettikulam lagoon are fully cultivated and densely settled suggesting its stability.

2.6 ORIGIN OF BEACH RIDGES

The strand lines of Kerala coast have been subjected to extensive studies in recent years (Samsuddin et al., 1992; Suchindan et al., 1996; Haneesh Kumar et al., 1998). Samsuddin et al. (1992) inferred that in the initial stages of its deposition, the strand plain sediments were associated with a wave-dominated environment. With the emergence of the coast, the strand plain sediments remain detached from the aqueous environment, thus exposing to the sub-aerial action of weathering processes. From the morphostratigraphic study of strandlines, the innermost ridges are the morphological manifestation of sea level maxima during mid-Holocene (Suchindan et al. (1996). Based on the study of satellite images, Mallik and Suchindan (1984) illustrated that beach ridges are formed due to repeated regression and transgression of the shore and their orientation controlled by changes in direction of approach of the wave front.

However, the factors that are responsible for growth of ridges are not very well understood. There are diversified views among different authors. According to Johnson (1919), multiple ridges arise through continued shallowing of the offshore profile, usually because of abundant sediment supply. Another school of thought (Bird, 1960) is that, continued growth of new fore dune, which gradually cuts off sand supply to its predecessors, becomes relatively stable. If the shoreline progradation continues, alternating episodes of cut and fill will lead to the formation of a series of parallel ridges separated by swales.

Curray (1959) and Curray and Moore (1964a) attributed successive accretion of new beach ridges to the coast by up building and emergence of longshore bars. It was postulated that after sufficient influx of sand into the nearshore zone, a submerged longshore bar is built upward, until it emerges above sea level during conditions of low wave action. With continued low wave action, this bar is enlarged, until it captures the wave action and becomes a new beach ridge. Former beach is thereby isolated, leaving an elongate depression between the new and old ridges. If conditions of high wave action continue, the newly created beach ridge is destroyed and the sand either pushed up on to the face of the old ridge or else removed to deeper water. With continuance of low waves, more sand is piled on the seaward face and on top of the newly emerged beach ridge, eventually becoming a permanent beach ridge with dune capping.

Based on the mode of origin and morphology, four reasonably well-defined sandy beach ridge types have been identified by Tanner (1987, 1995) and Tanner and Damirpolat (1988). *Swash-built* and *settling lag ridges* are geometrically regular, only a few tens of meters above the adjacent soils and commonly occur in ridge sets and systems. But the *eolian* and *storm surge* ridges do not show these characteristics. Swash-built beach ridges have diagnostic map spacing, accretion rate, periodicity, cross bedding and granulometry. The cross bedding and granulometry of this beach ridges indicate fair weather waves on a sandy beach in contrast with settling lag ridges, which have the same external geometry, but, deposited without important wave work. Each swash type sandy beach ridge was made by a sea level rise-and-fall couplet, position of swale marking the lower position. The mechanism reflects the fact that transverse profile from beach to sea is gently concave upward, with maximum curvature close to shore. Gently curved, essentially parallel, beach-type cross bedding of the beach ridges in the study area shows that they are swash-built type (Plate VII). Moreover, the textural composition of the present day beach and beach ridges are almost similar, hence inferred almost similar condition to the origin of present day beach and that of beach ridges (*This aspect is dealt with in detail in the Chapter III*).

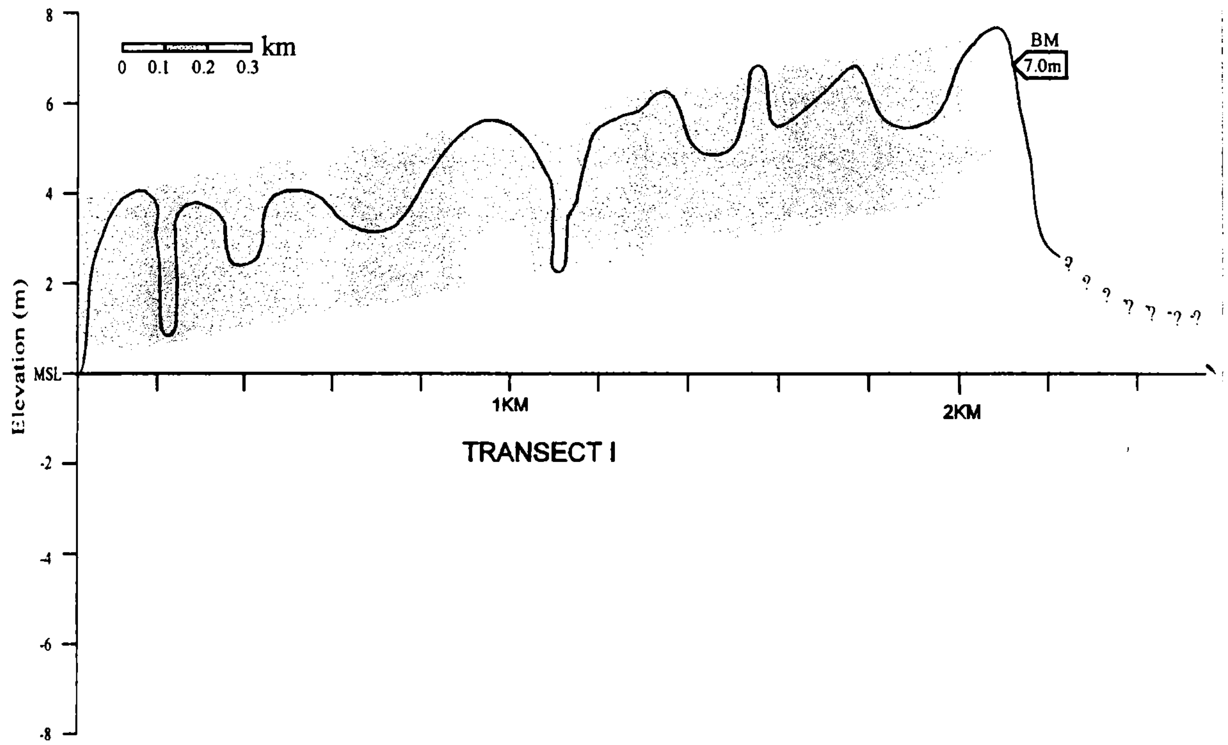
In explaining evolution of the barrier islands of Kerala, Kunte (1995) illustrated different stages of its formation with respect to beach ridges viz., (a) initial emergence of land during which paleo-beach ridges were formed (*regressional phase*), (b) subsequent submergence of the land, which is characterised by the engulfment of beach ridges (*transgressional phase*) and (c) emergence of the coast during which, the breaching (*regressional phase*) of ridges and barrier island formation took place.

The innermost beach ridges of the study area have been modified to varying degree since they were first formed. Stream activity, slope degradation and eolian reworking of sand are responsible for the modification of the ridges. In the Punjavi transect the characteristic of the innermost ridge is obliterated to a great extent by the flood plain deposits of Nileswaram River. Two types of slope degradation have influenced the morphology of beach ridges. The first involves removal of sand from ridge crests and swales. Rain impact, anthropogenic activities and surface run-off appear to be primarily responsible for degradation of the ridge morphology.

2.7 MORPHLOLOGICAL EVIDENCES ON SEA LEVEL CHANGES

The northern Kerala coast consisting of well preserved raised strand plain sequences with sand/clay deposits, spits, stacks, submerged offshore terraces, a continuous offshore sand bar etc., are considered as evidences of sea level change during the late Quaternary. Apart from the morphological evidences, stratigraphic sequences are well preserved in the cores collected from the coastal plains of northern Kerala. This has ultimately resulted in the inference of complex sequences of marine, estuarine and freshwater deposits. Records of these high stands of sea level could be deciphered from a series of paleo-shoreline deposits ranging in elevation from +7.73 m to –3.91 m (Fig 2.3).

The two transects, namely Punjavi and Onakkunnu are distinct in their geomorphological set up, where, seven and eight sets of beach ridges and swales were identified respectively. Along the Onakunnu transect, the Thekkekad, Vadakekad and Kokal islands, which are situated in the Ettikkulam estuary show striking parallelism to the trend of



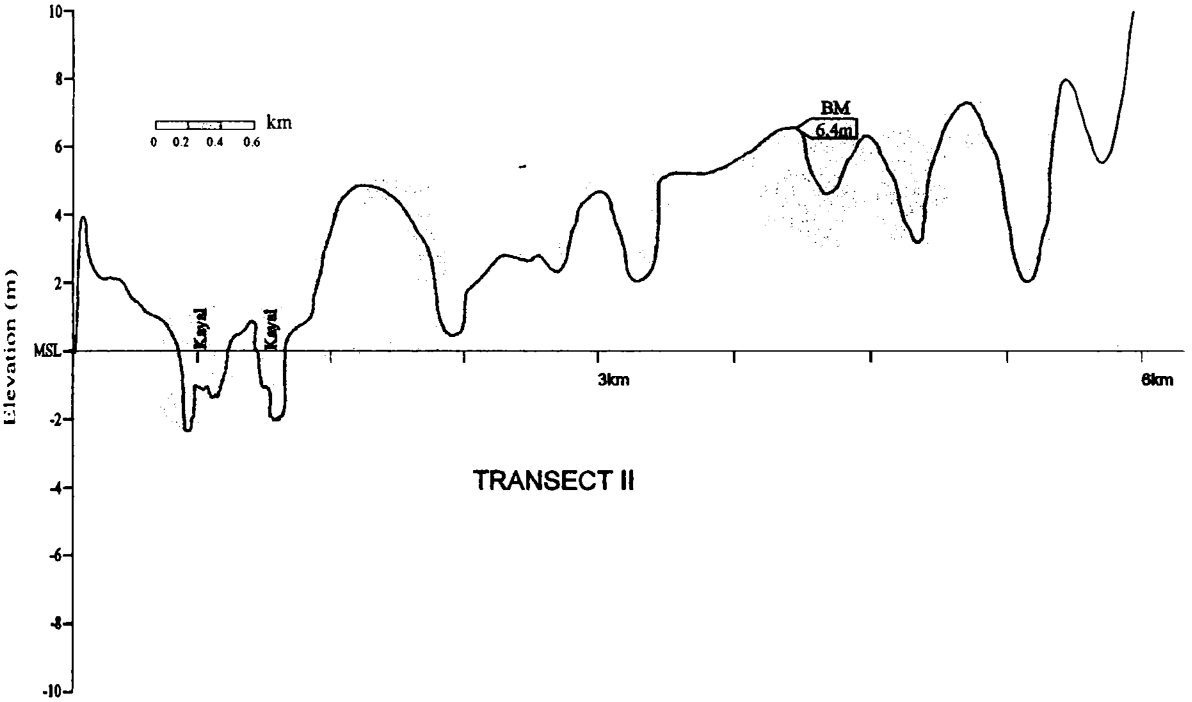


Fig. 2.4 Cross section of Transects I & II showing approximate seaward gradients

strand line. This is considered as a surface manifestation of regressive episode. Along the central Kerala coast, the coast-parallel beach ridges are reported to be the product of regressive and transgressive episodes during the Holocene (Mallik and Suchindan, 1984). Radiocarbon dating of shell samples collected from the Thekkekad island from a core-depth of 6.3 m below PMSL gave an age of 2830 ± 30 YBP. This shows that the deposition of shell associated with regressive phase took place around 3000 YBP. The subsequent regressive phase must have helped the growth of sand bars into islets, which later got separated from the sea, resulting in the formation of Ettikulam estuary with the linear islet series trending parallel to the coast. An earlier report on the origin of sand bar along this coast also attributed to the regression of the sea during 5000-3000 YBP (Rajendran et al., 1989).

Spot heights with respect to PMSL of ridge-top and swale-bottom were used to draw an east-west profile (Fig 2.3) to understand the disposition of the successive ridges and swales. In both the transects, the inner most ridge-top is situated at an elevation of about 8 m and the fore dune at about 4 m above PMSL. A general seaward slope is evident from both the profiles (Fig 2.4). The seaward dipping alternating bands of heavy/light minerals observed from pits further confirm this observation (Plate VII). Approximate seaward gradients of the strand plain sequence is estimated to be around 1:530 and 1:150 for Punjavi and Onakkunnu respectively. The seaward slope of the ridge top and swale bottom indicate that the coastal strand plain is the result of marine regression during different periods.

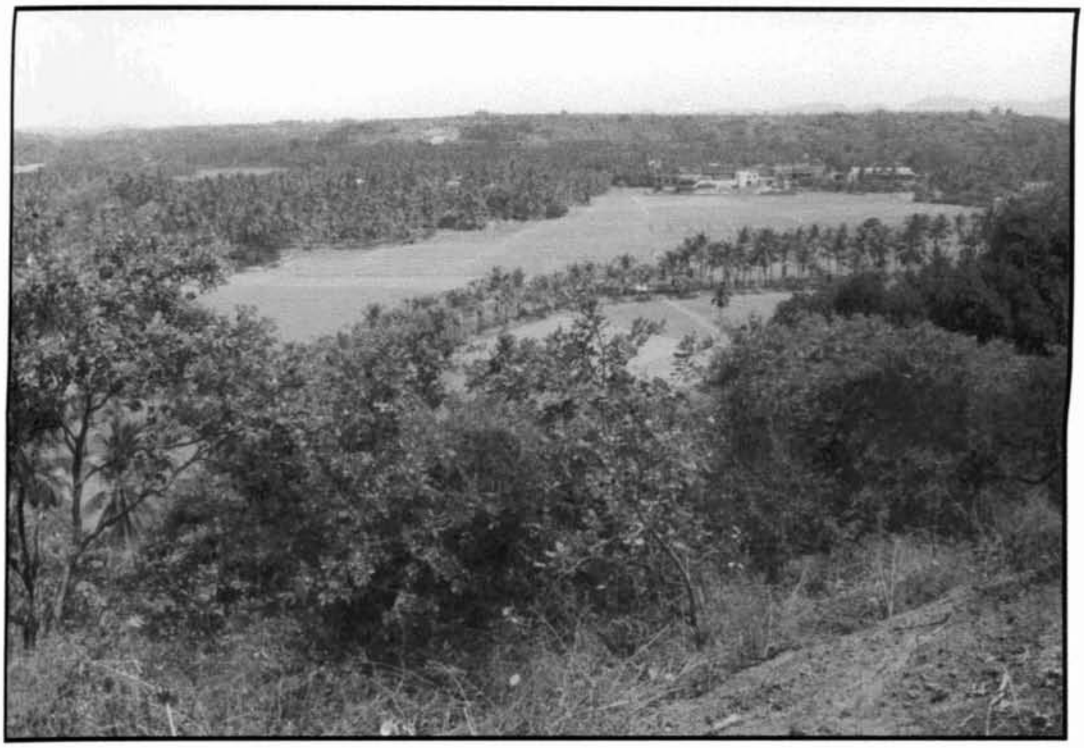


Plate I Panoramic view of the coastal plain area

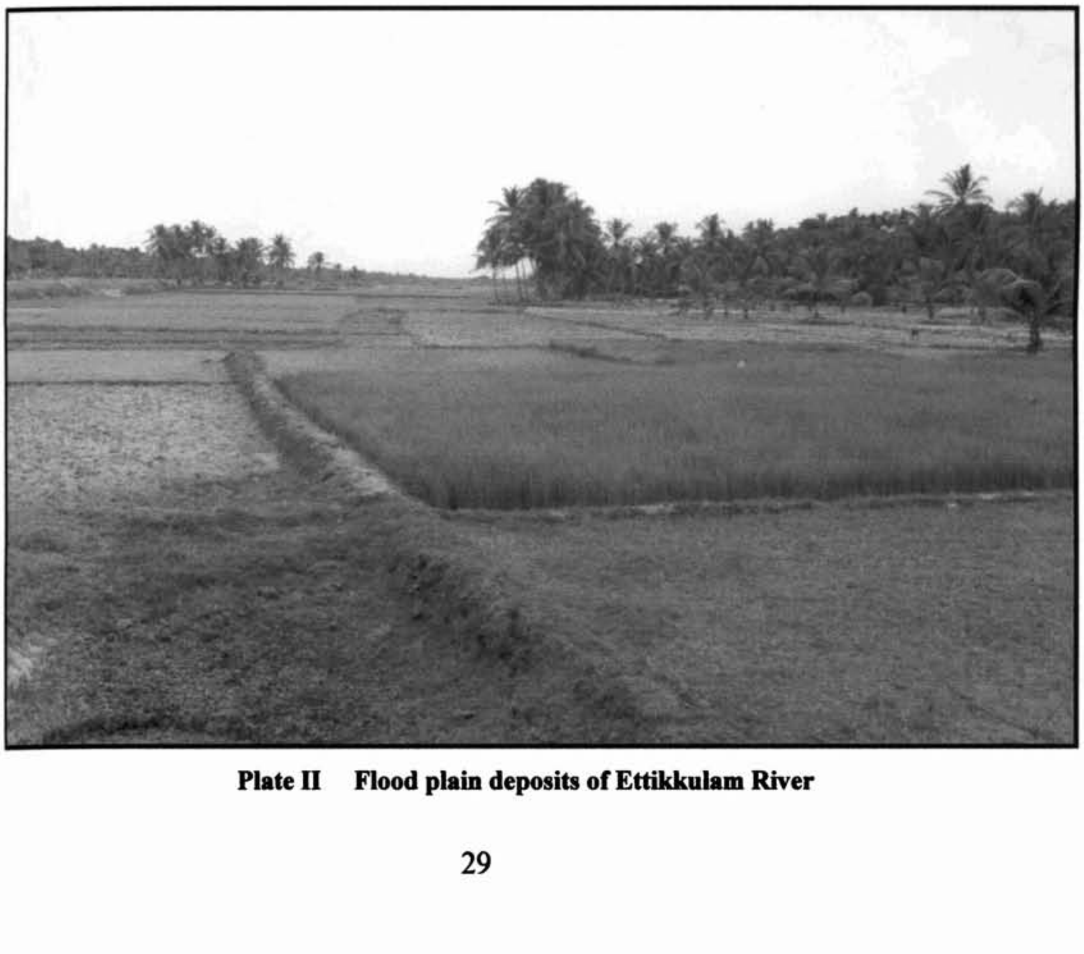


Plate II Flood plain deposits of Ettikkulam River

Plate III View of the Ettikkulam Estuary

Plate IV Beach ridge and swale system

Plate V Closer view of the swale

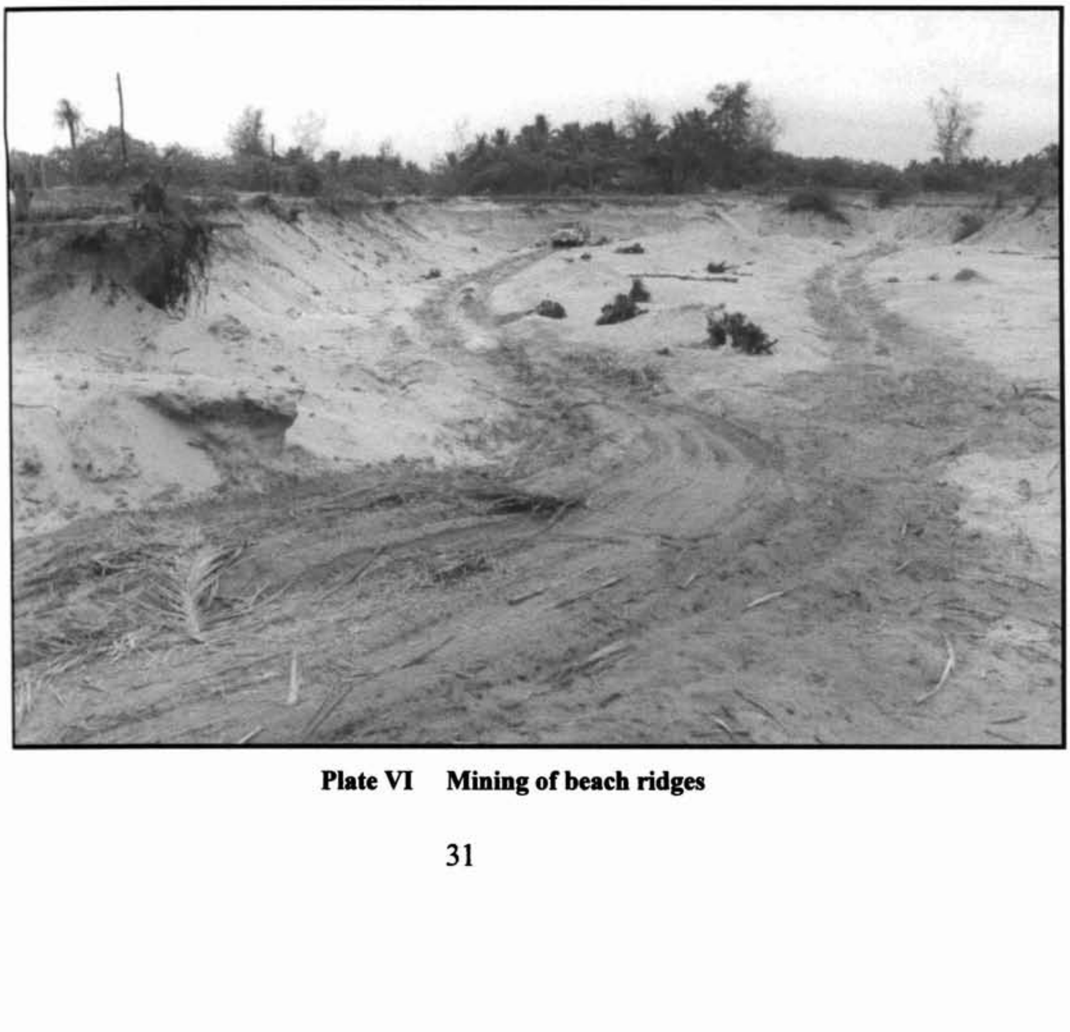


Plate VI Mining of beach ridges

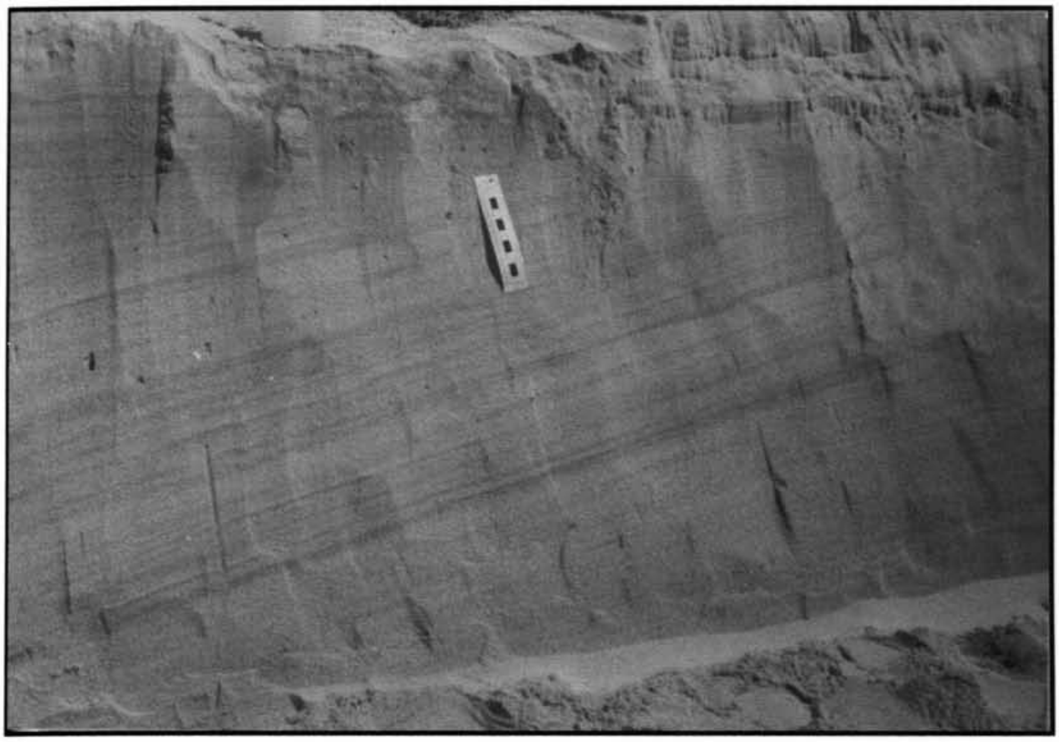


Plate VII **Alternating bands of heavy and light minerals showing seaward slope**

Chapter 3

COASTAL PLAIN SEQUENCES

3.1 BACKGROUND

Coastal plain deposits are the prominent geomorphologic features where significant quantities of sediments are accumulated. These landforms are characterised by definite sets of beach ridges and swales, traversed by fluvial and estuarine deposits. The sediment therein are the product of transgression/regression and depend upon many factors such as rate of sedimentation, nature of sediment supply, intensity of oceanographic parameters, subaerial exposures etc. Most of the existing coastal features were considered to be evolved during the past 6000 years when the sea has remained at or close to its present level of much of the world's coastal line (Bloom, 1977).

Sediment textures bear a close relationship to the depositional conditions, topography, wave and current pattern and associated criteria (Rao and Thamban ~~et al.~~, 1997; Singh et al., 1998; Mohan et al., 1998; Ramkumar et al., 2000; Mohan et al., 2000). Grain size parameters were related mainly to the formative processes of the clastic sediments and thus represent specific environments of its deposition. Various statistical measures were proposed to understand the mode of transportation and the environments of deposition of the sediments (Folk and Ward, 1957, Friedman, 1961, 1967 and 1979).

Duane (1964) and Cronan (1972) effectively discriminated different depositional environments and have noted that in combination with other criteria, skewness can be used as a valuable tool in paleo-envrionmental interpretations. Significant contributions were made to distinguish the statistical variations of grain size in dune, beach and nearshore sediments (Cadigan, 1961; Fuller, 1961; Giles & Pilkey, 1965; Greenwood, 1969; Davis and Fox, 1972; Shideler, 1978; Anwar et al., 1979; Khalaf et al., 1982; El-Ella and Coleman, 1985; Dubois 1972, 1989; Stokes et al., 1989). Nordstorm (1977) has successfully utilised the grain size statistics to distinguish high and moderate energy environments and attributed the differences to wave energy and beach mobility. Based on the moment summation method, Chappel (1967) identified fossil strand lines in the Quaternary deposits. Hodgson and Scott (1970) were able to identify ancient beach sediments by the combination of size analysis and quartz grain surface textures.

In the Indian continent, grain size characteristics were mainly utilised to distinguish major depositional environments (Veerayya, 1972; Rao and Rao, 1974; Veerayya and Varadachari, 1975; Chaudhiri et al., 1981; Prakash et al., 1984; Ramamoorthy et al., 1986; Rao et al., 1997; Singh et al., 1998; Mohan ~~et al~~ and Rajamanickam, 1998; Ramkumar et al., 2000; Mohan ~~et al.~~ and Rajamanickam., 2000). However, little attempts were made to understand significant variation in sediments within an environment viz. the foreshore (Bascom, 1951; Miller and Zeighler, 1958; Fox et al., 1966; Friedman and Sanders, 1978; Chaudhiri et al., 1981; Samsuddin, 1986; Ramkumar et al., 2000). In the present investigation, granulometric, mineralogical and geochronological aspects of the strand plain sediments were studied in order to understand the transportational/ depositional history and post-depositional transformation of these deposits.

3.2 METHODOLOGY

The database for the present study is sediment cores collected along the two E-W transects viz. Punjavi (Transect I) and Onakkunnu (Transect II) running perpendicular to the coastline, covering the strand plain, beach and offshore. Twenty two cores varying in length from 6.55 to 11.1 m were collected from the beach and strand plain domains. Sediments and uncontaminated shell/ peat samples were taken from the beach ridges and swales for the analysis of lithology, mineralogy and radiocarbon dating. Location of samples taken from the coastal plain is illustrated in Figs 3.1 & 3.2.

After washing, drying, coning and quartering, approximately 100 g of the sample was sieved at half ϕ interval using ASTM standard test sieves in a Ro-Tap Sieve Shaker for 20 minutes. The results of sieve analysis are expressed in weight percentage and are used for calculating statistical parameters viz. mean, median, standard deviation, skewness and kurtosis following the procedure of Folk and Ward (1957) using a FORTRAN computer program. Using the individual weight percentages of each sieve fraction, the frequency curves were drawn using the computer program, for the representative samples of each environment. Visher's (1969) log probability curves were also drawn for selected samples to delineate different mechanisms of deposition.

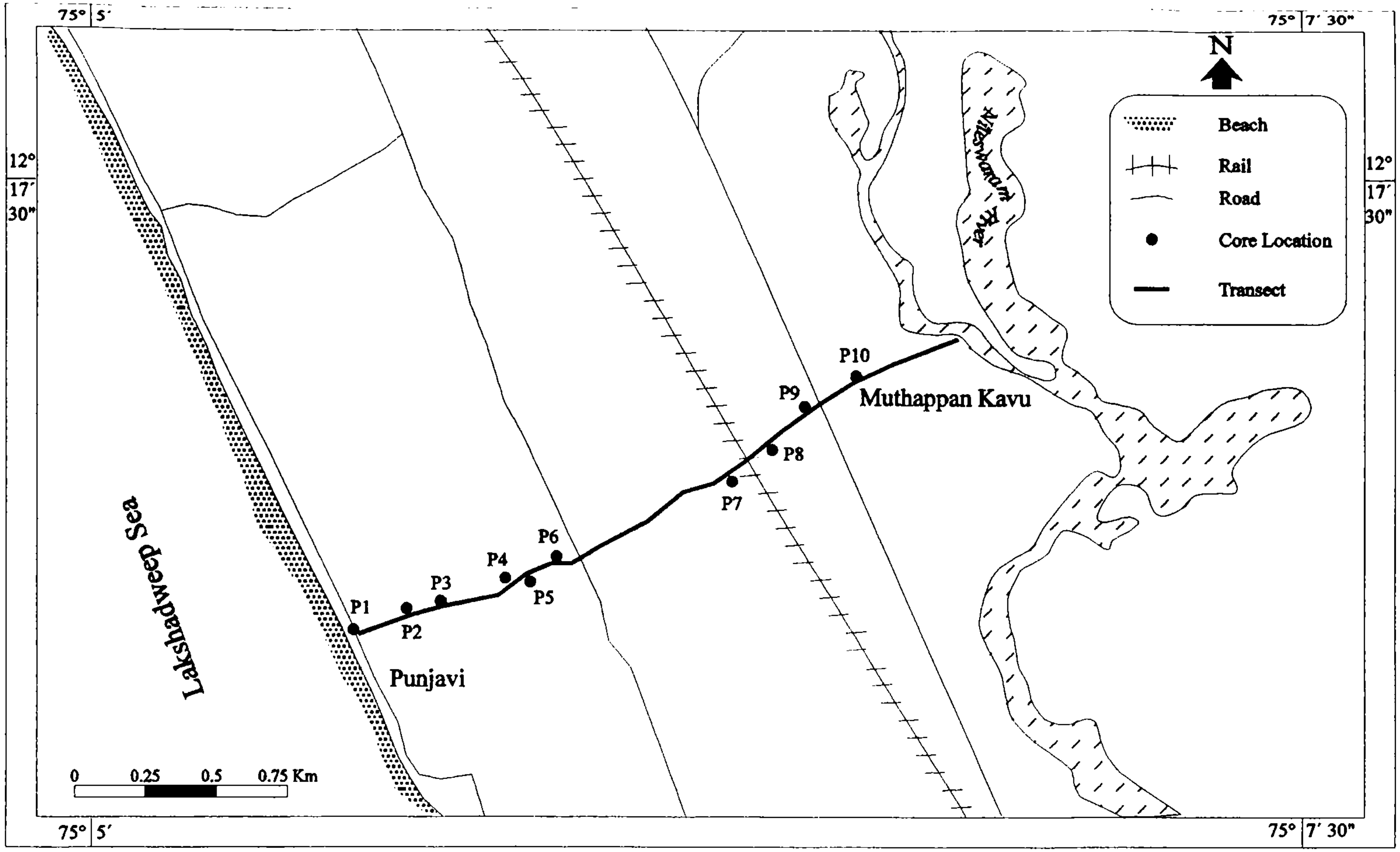


Fig. 3.1 Map showing the core locations in the coastal plain area of Punjavi transect

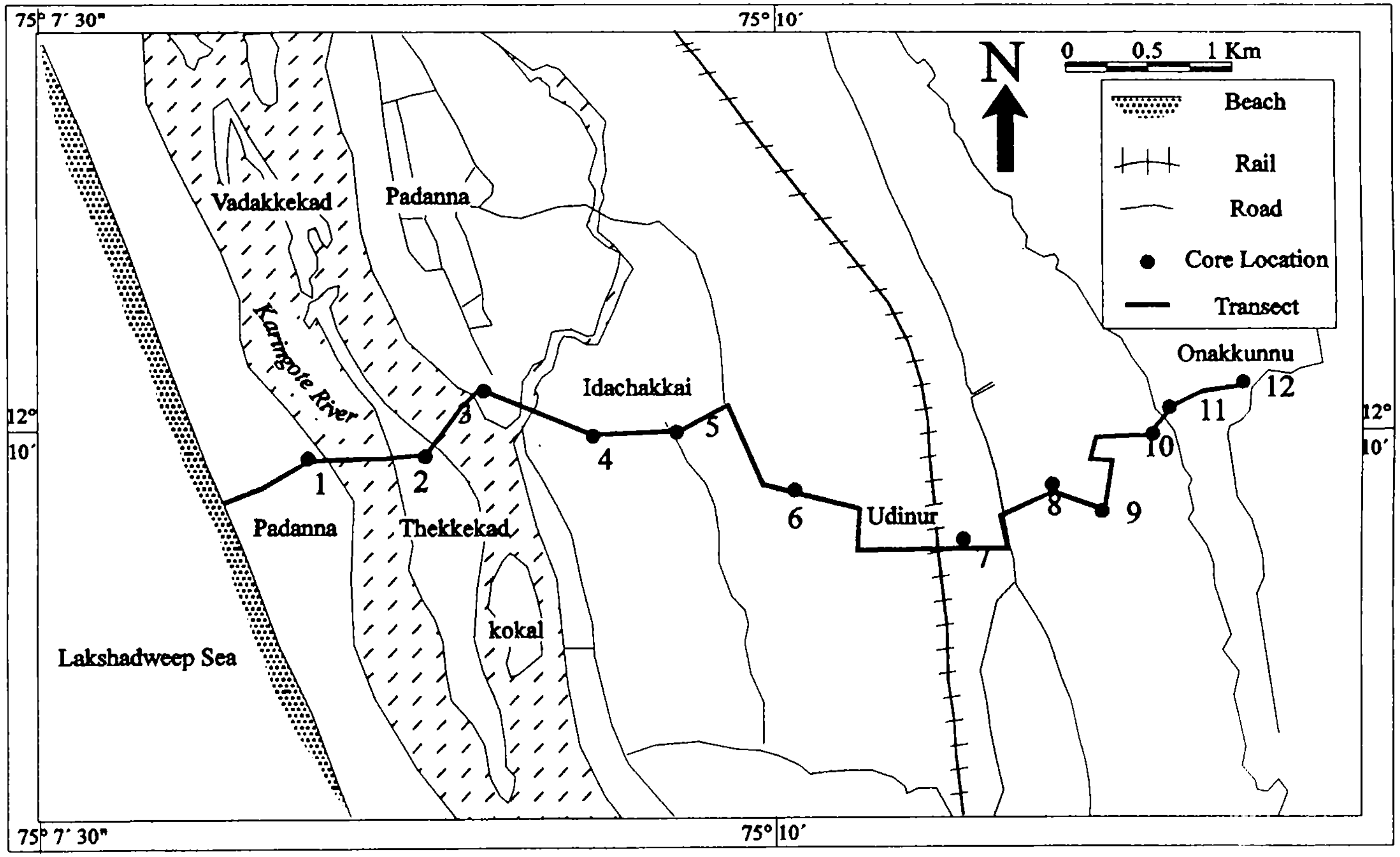


Fig. 3.2 Map showing the core locations in the coastal plain area of Onakkunnu transect

Less than 120 mesh fractions of selected samples that represent different depositional regimes were selected for heavy mineral analysis. Heavy minerals were separated using bromoform (sp.gr 2.89 at 20^0 C) and mounted on glass slides with canada balsam. Approximately 200-300 grains were counted in a petrologic microscope attached with a mechanical stage and percentage count of the mineral grains were calculated (Carver, 1971). Peat and shell samples were collected for C^{14} dating. Spot heights and length of the core taken in the study area are given in the Table 3.1.

Table. 3.1: Spot height (m), core length (m), distance from the beach (km)-Punjavi and Onakkunnu Transect.

Core name	Core length	Spot height	Distance from beach
P-1	10.50	3.09	0.19
P-2	09.80	2.50	0.41
P-3	09.80	3.25	0.71
P-4	07.80	4.15	1.09
P-5	08.70	3.62	1.13
P-6	10.40	6.03	1.38
P-7	09.10	5.81	1.63
P-8	11.00	6.41	1.80
P-9	11.05	5.88	1.95
P-10	06.55	5.05	2.16
O-1	09.80	1.00	0.58
O-2	08.35	0.95	1.12
O-3	08.70	1.20	1.53
O-4	09.20	1.75	2.39
O-5	11.00	2.72	2.83
O-6	10.60	4.13	3.08
O-7	08.90	5.81	4.41
O-8	09.50	4.15	4.48
O-9	11.10	7.06	5.29
O-10	09.50	6.09	5.49
O-11	08.60	3.20	5.79
O-12	07.50	5.47	6.13

3.3 SEDIMENTARY FACIES

Recognition of shallow water sedimentary environments and their stratigraphic features have a vital contribution in the reconstruction of sedimentary processes and stratigraphic sequences (Coleman et al., 1983; Wright, 1985; Komar, 1983). Partial modifications of the sedimentary facies particularly in the faunal and organic contents after its burial are possible. Inference on the sedimentary facies in the core samples is chiefly attempted here based on the colour, texture, mineralogy and organic remains in the sediments. Obviously, the details on depositional structures are unworkable based on the bailer-based core sampling procedure. However, pitting carried out at selected locations has clearly indicated a seaward dipping regressive disposition (*refer PlateVII*). The sequential geometry of the sedimentary facies can be worked out once the facies are identified along the core length and extend the same laterally to the adjacent cores. This can be done fairly well in the present study since the coring is carried out along an east west transect. Here, primarily, textural and mineralogical data are made use of to identify the sedimentary facies along the length of the cores.

Depth-dependent sedimentary facies have been identified from the analysis of 302 samples by comparing lithology and mineralogy of the strand plain sediments of two transects. The techniques used in the identification of sedimentary facies are by inferring their depositional environment based on the textural attributes of the sediments. Since most of the sediments are sandy, facies are qualified in the present study by an environmental term, which expresses some distinctive attribute of the unit such as near shore fine sand. Graphically computed mean size and standard deviation values of the sediments collected from various modern environments in the study area are used here to develop a simple bivariate graphical model of environs of depositions. Sample points of the core sediment plotted on to this model readily identifies the respective environment, though in some cases subjective interpretation is required to resolve the discrimination. Five closely knitted depositional environments are distinguishable from the bivariate graphical model (Fig 3.3 & 3.4).

The graphical model so developed based on the grain size properties of the sediments from modern environment is found to be fairly good in assisting in the environmental interpretation of subsurface deposits recovered through coring from the area. Probably

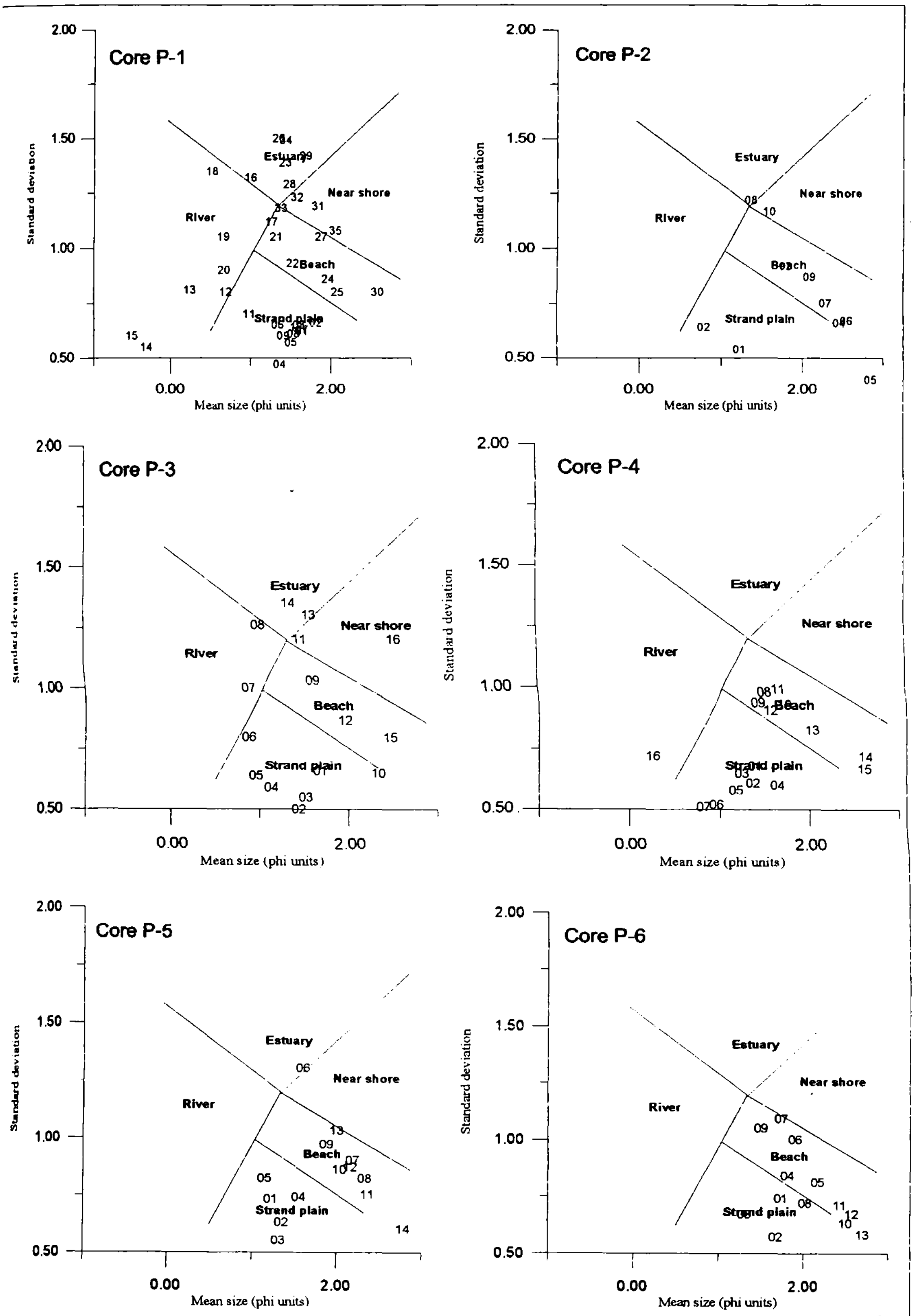


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Fig. 3.3 Environmental discrimination of sediment samples collected from the coastal plain area of Punjavi transect

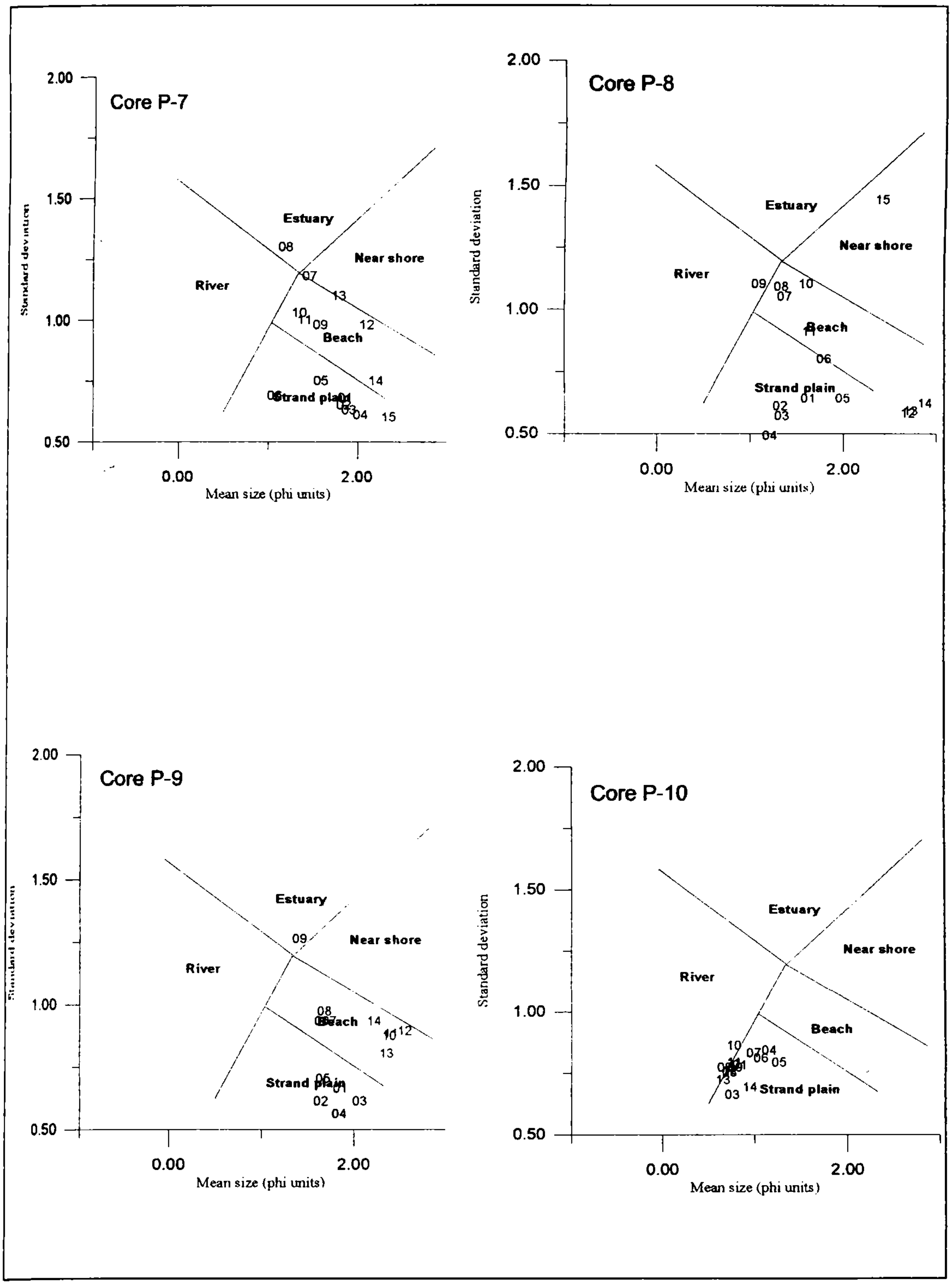

Fig. 3.3 Environmental discrimination of sediment samples collected from the coastal plain area of Punjavi transect.

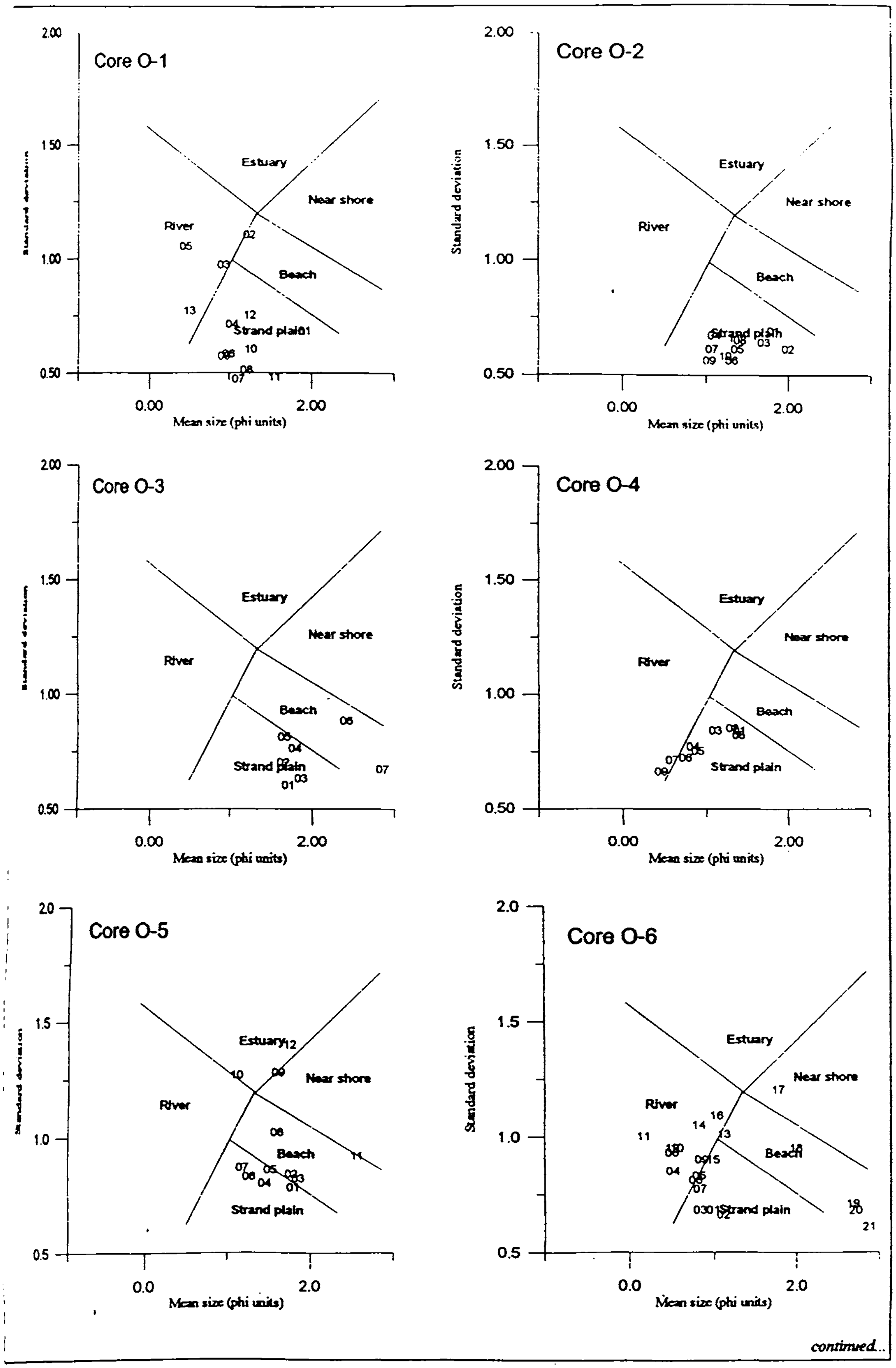

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Fig. 3.4 Environmental discrimination of sediment samples collected from the coastal plain area of Onakkunnu transect

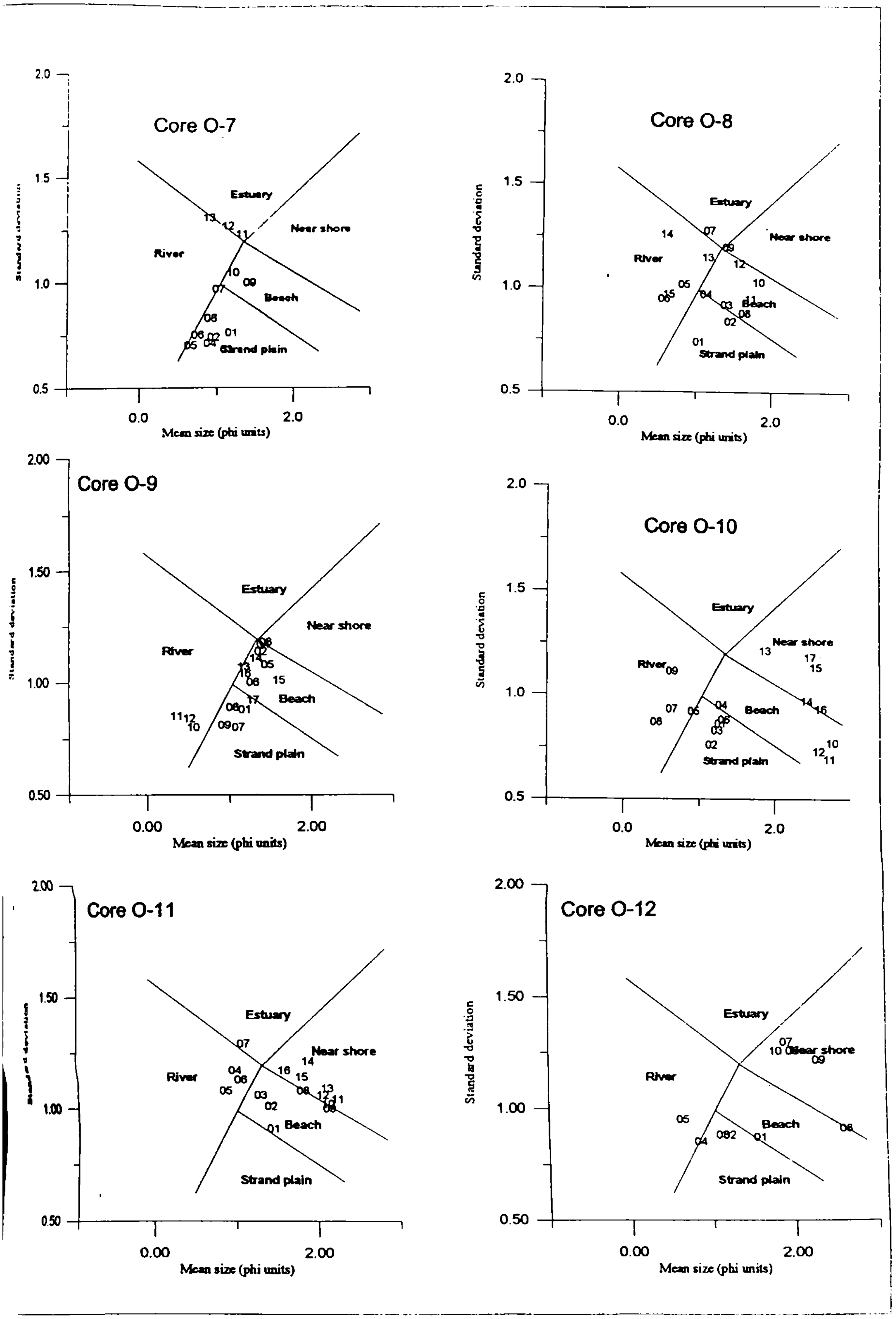

Fig. 3.4 Environmental discrimination of sediment samples collected from the coastal plain area of Onakkunnu transect

this would apply only to this area, as the environmental framework resulting in the facies deposition is area specific and may not apply to even on a regional scale. Facies determinations have been made from the samples by the comparison of lithology and faunas. Based on the graphical model, the following facies have been distinguished and associated with their respective environment of deposition.

The ***near shore marine sand facies*** are quite varied in grain size. Mean size ranges anywhere below 1.25 ϕ, which is essentially anything finer than medium sand size and extends even up to clay size. The varied nature of size is an expression of the reworking that takes place seaward of the beach zone strongly influenced by the oscillatory motion induced by shoaling waves, passage of broken waves and longshore currents. Consequently, standard deviation also display considerable variation from well sorted to very poorly sorted nature.

The ***estuarine-coastal lagoon*** environment of deposition is a typical transition zone that incorporates areas, which are relatively protected from the influence of ocean waves, but influenced by various degrees of tidal forcing. The influence of both fluvial and marine regimes render wide variation in mean size as the tidally derived fine detritus mixes with fluvial sand resulting in a muddy sand lithofacies ranging in mean size from 0.0 ϕ to 4.0 ϕ and even beyond that. Sorting is obviously poor as the processes are often not well defined.

Size grading of ***fluvial sediments*** is markedly coarse and is coarser than 1.25 ϕ. Unlike the other two sediments mentioned hitherto, the river sediments are invariably sub-rounded to sub-angular and contain notable amounts of lithic and feldspathic grains apart from the generally quartzose nature. Fluvial sands generally show moderately sorted to poorly sorted nature depending on the differential transport regime.

Beach sand phi mean in this area corresponds to medium sand. There can be some variations as per the well-established relationship between mean grain size of sediment and beach gradient spatially. Chiefly quartzose in nature, they display very limited variation in standard deviation values. Sorting is anything better than moderately sorted sands. The description of litho logs noted while coring and the texture based tracing of environment is found to be most satisfying in the case of identification of beach sediments.

Strand plain sediments show textural continuity with that of the beach sediments in the area but are relatively a bit coarser and better sorted. Clear distinction is possible based on the colour if undergone intrastratal dissolution of minerals. They are distinctly free from any carbonate shell remains. The wind winnowing has saltated the fines probably rendering a coarser than beach texture to the strand plain sediments.

3.3.1 Sedimentary Facies-Punjavi Transect

Ten cores, ranging in length from 6.55 and 11.05 m were taken from this transect. By comparing lithology and mineralogy, facies determination have been made from the analysis of 162 samples. Table 3.2 shows the details of grain-size parameters of the core samples collected from the transect-I. Lithological characteristics of these cores are described below. Figs 3.5 to 3.14 give the depth-dependent variation of size parameters, lithology and frequency curves.

Core P-1: The upper layer is a heavy-rich gray to yellow coloured moderately well sorted medium sand intercalated with iron encrustations. These sediments are also fine to very fine skewed in nature. This layer is underlined by a light gray coloured coarse to medium sand embedded with gravels and shell hash layers and are moderate to poorly sorted and very fine skewed to near symmetrical population. The unit in between 6.9 to 7.7 m is composed of an organic-rich light gray-coloured medium to coarse sand consisting of heavies, and whole shells like bivalves, gastropods and echinoids etc. These sediments are moderate to poorly sorted and very fine to coarse skewed in nature. This unit is underlined by organic-rich clayey, fine to medium sand intercalated with heavies and faunas of the former layer. These are moderate to poorly sorted and near symmetrical to

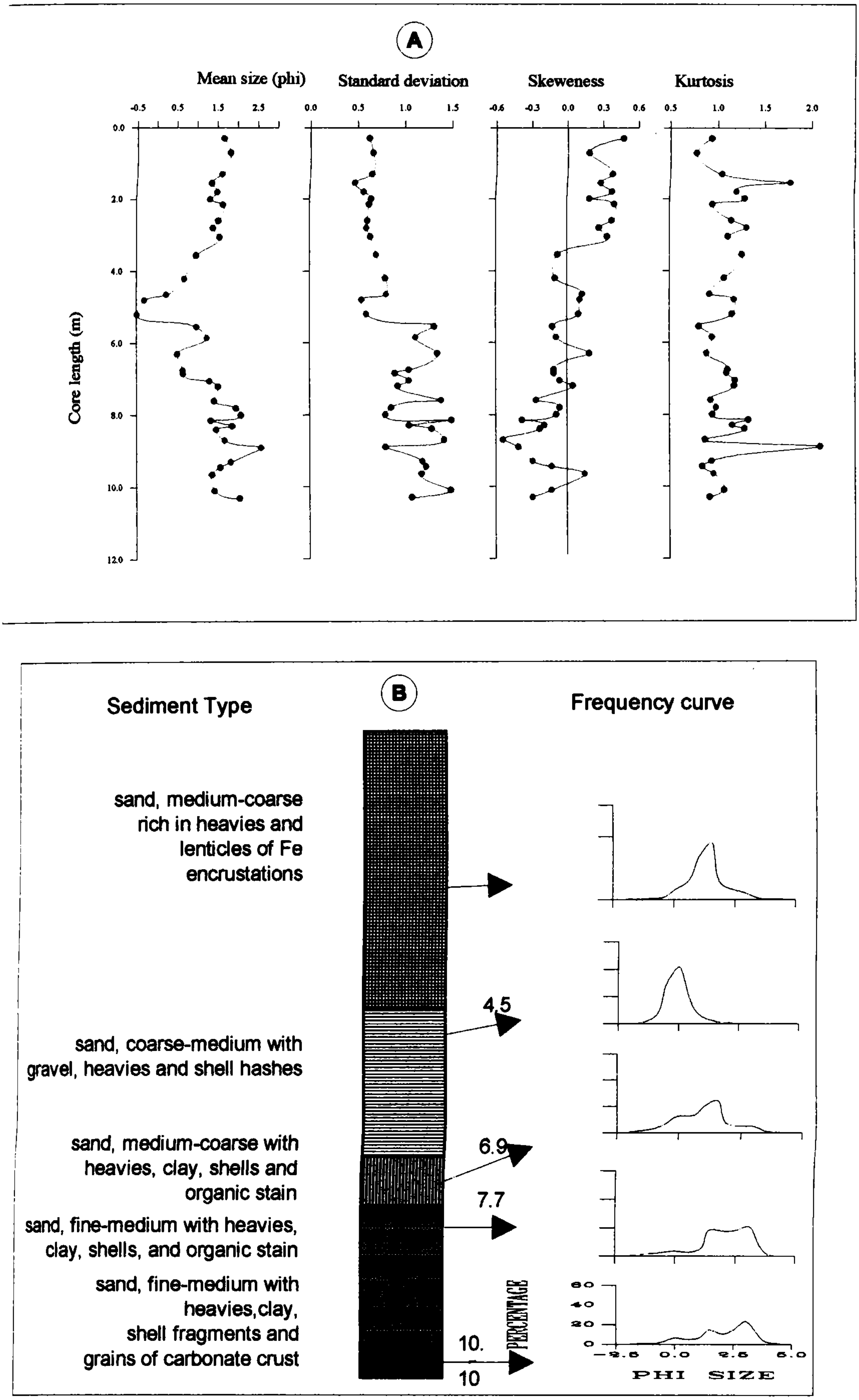

Fig. 3.5 Log of core P1 showing (A) vertical distribution of size parameters and (B) lithology and size frequency distribution

coarse skewed in nature. The bottom-most unit is composed of olive gray coloured heavy rich clayey sediments associated with shell fragments and grains of carbonate crust are poorly sorted and coarse skewed in nature (Fig 3.5). The C^{14} dating of shell sample from this unit from a depth of 9.1 m give an age of 1780 ± 80 YBP.

Core P-2: Upto a depth of 3.9 m, yellow coloured moderately well sorted to moderately sorted medium sand with gravel are exposed, which are in near symmetrical population. The unit in between 3.9 to 7.7 m is composed of a heavy rich fine to very fine sand and is well sorted to moderately well sorted with nearly symmetrical to coarse skewed population. The lower-most unit consists of black and gray coloured fine to medium sand with gravel, clay lenses and shell fragments. These sediments are moderately sorted to poorly sorted with near symmetrical to coarse skewed in nature (Fig 3.6).

Core P-3: The upper layer is composed of grayish-yellow coloured humate-impregnated medium sand. These sediments are moderately well sorted to moderately sorted with finely skewed in nature. The zone between 3.8 to 5.3 m consists of light gray coloured coarse to medium sand with gravel, which are sub-rounded to well rounded nature. These sediments are poorly sorted with coarse skewed population. The zone found in between 5.3 to 6.1 m is composed of a yellow coloured moderately well sorted, very coarse skewed heavy-rich fine sand with shell hashes are seen. The region between 6.1 to 9.5 m consists of gray coloured argillaceous medium to fine sand with shell. The shell hashes are seen at a depth of 6.4 m, below that whole shells like bivalves, gastropods and echinoids are seen. The C^{14} dating of shell samples from a depth of 6.75 m indicate an age of 1610 ± 90 YBP. These are moderately sorted to poorly sorted with coarse skewed population. The bottom most unit is composed of olive gray coloured clay bearing fine to very fine sand with whole shells and are moderately sorted to poorly sorted with very coarse skewed in nature (Fig 3.7).

Core P-4: The upper zone with a depth of 3.8 m consists of a yellow/gray coloured garnet-rich medium sand intercalated with coarse sand and kaolinite. These sediments are

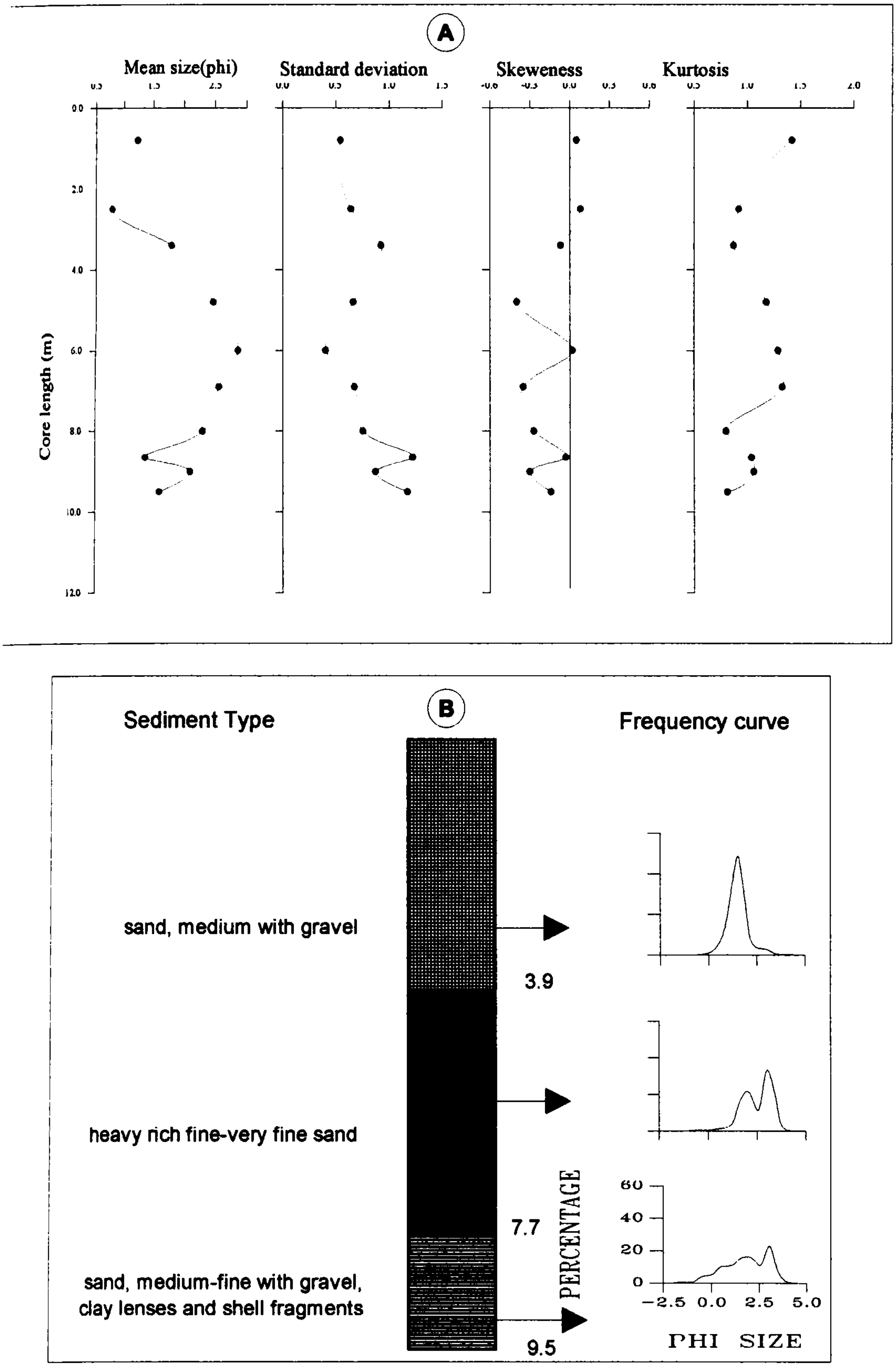

Fig. 3.6 Log of core P2 showing (A) vertical distribution of size parameters and (B) lithology and size frequency distribution

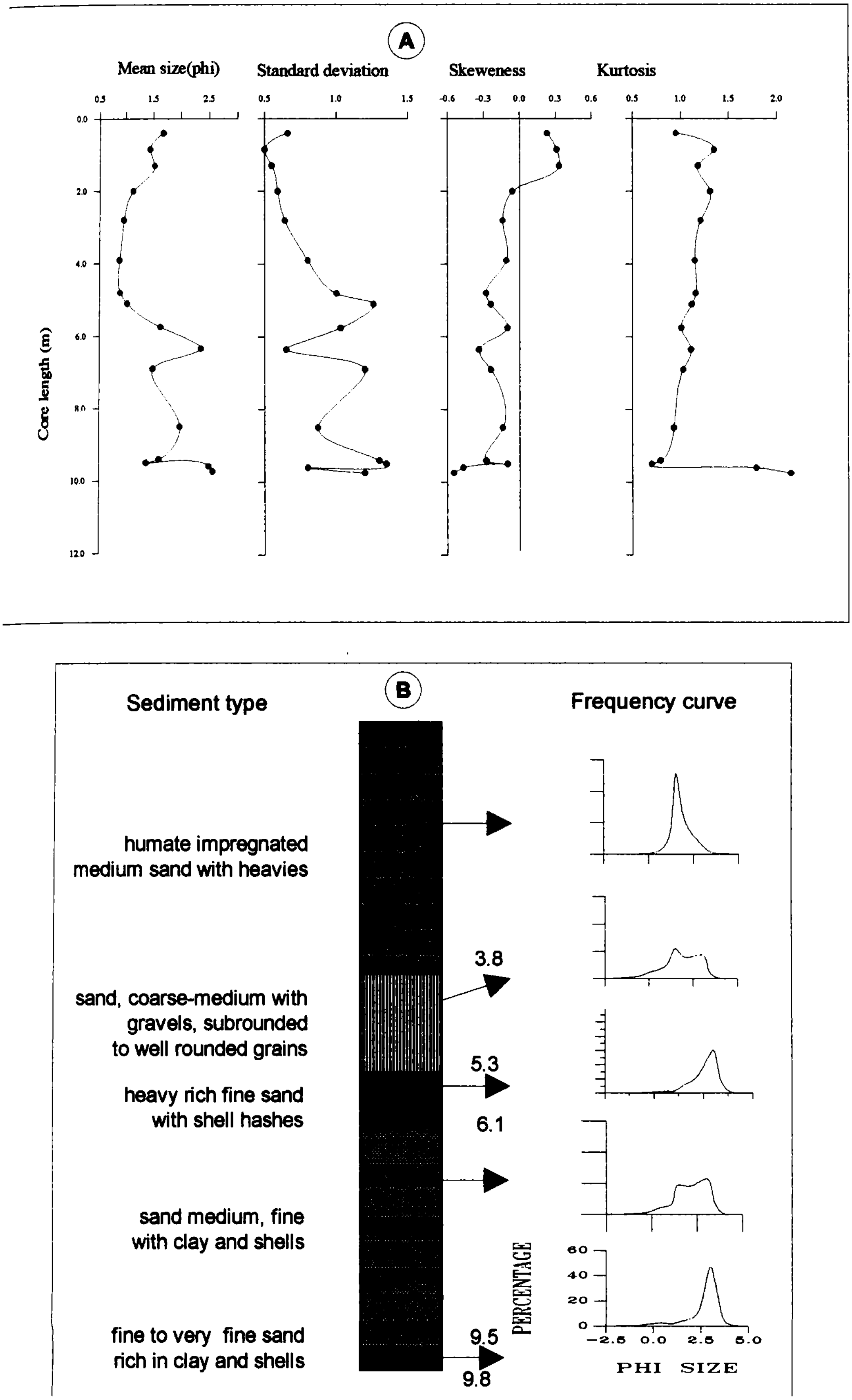

Fig. 3.7 Log of core P3 showing (A) vertical distribution of size parameters and (B) lithology and size frequency distributon

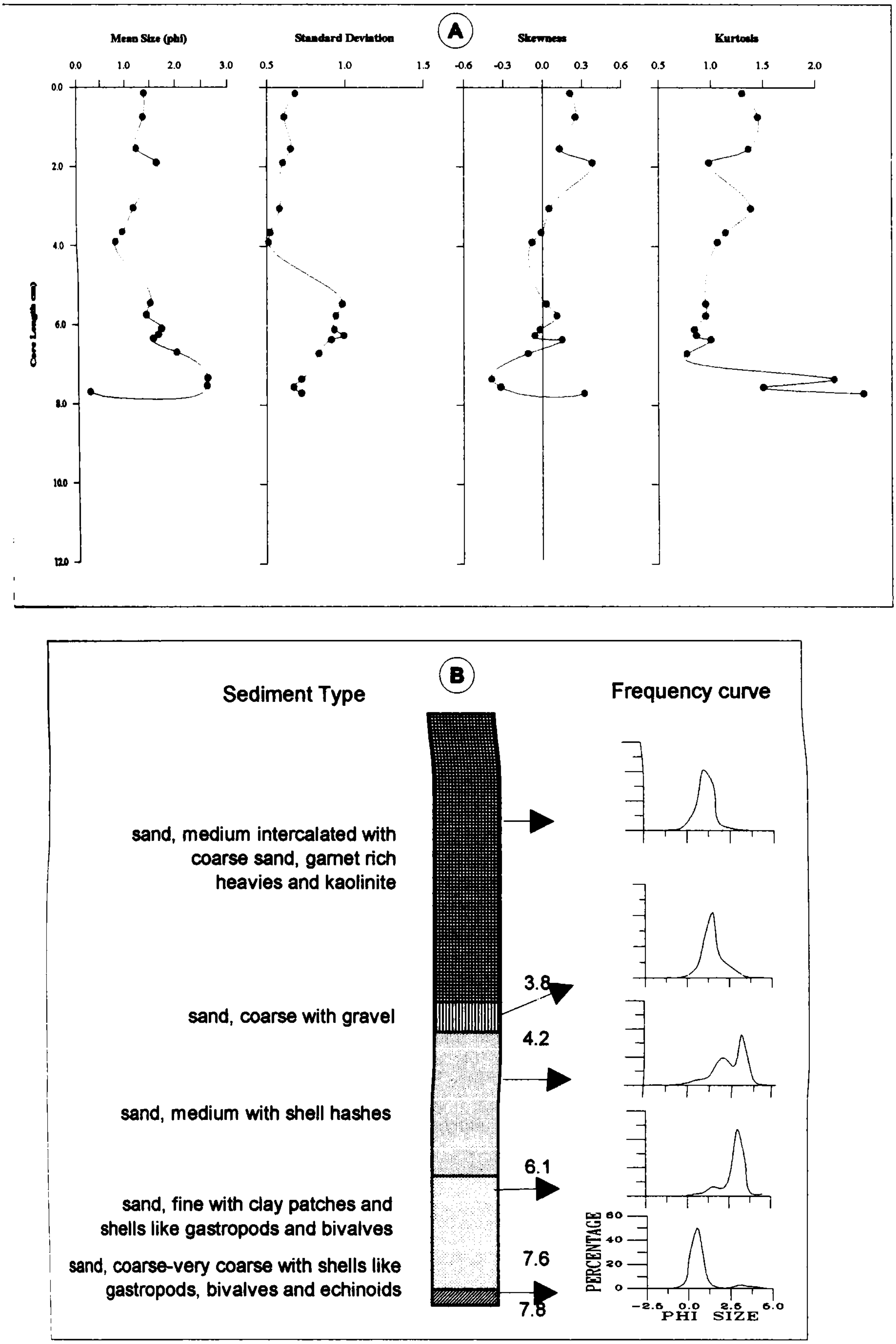

Fig. 3.8 Log of core P4 showing (A) vertical distribution of size parameters and (B) lithology and size frequency distribution

moderately well sorted with finely skewed to nearly symmetrical in nature. Below this unit is a narrow, gray-coloured zone of 0.4 m thickness with coarse sand, mixed with gravels having a moderately sorted with near symmetrical population. This layer is underlined by well sorted to moderately sorted and coarse skewed, gray-coloured medium sand abound with shell hashes. Fine sand with grayish black to olive gray coloured clay zones with whole shells like gastropods and bivalves are found in between 6.1 to 7.6 m. These sediments are moderately well sorted to moderately sorted with coarse skewed population. The bottom-most unit is composed of gray coloured coarse to very coarse sand with shells like echinoids, bivalves, and gastropods. These are moderately sorted and very fine skewed in nature (Fig 3.8).

Core P-5: The upper layer is composed of organic-rich medium to coarse sand with heavies, which are moderately well sorted to poorly sorted and fine skewed to coarse skewed in nature. The unit in between 5.3 to 6.2 m consists of black coloured fine to medium sand with clay lenses and shells like, bivalves. The shells are start appearing at a depth of 5.3 m and are moderately sorted with near symmetrical to very coarse skewed population. The bottom-most unit is a gray coloured fine to very fine sand enriched in mud and shells like bivalves, pteropods and are moderately sorted to poorly sorted with near symmetrical to very coarse skewed in nature (Fig 3.9). The C^{14} dating of shell samples from a depth of 6.45 m indicate an age of 2950 ± 50 YBP.

Core P-6: The upper zone upto a depth of 3.85 m is composed of brown and yellow coloured humate-impregnated medium to coarse sand, which are moderately well sorted to moderately sorted and are very fine skewed to nearly symmetrical in distribution. Below this unit is a gray to olive gray coloured zone having heavy-rich moderately sorted to poorly sorted, which are coarse skewed, medium to fine sand. The unit in between 7.8 to 8.5 m is composed of gray to olive gray coloured fine to very fine sand with clay and shells like gastropods, bivalves and echinoids. These are poorly sorted with nearly symmetrical in nature. The bottom most unit is a olive gray coloured moderately well sorted and coarse skewed very fine sand zone with intercalation of clay and shells like

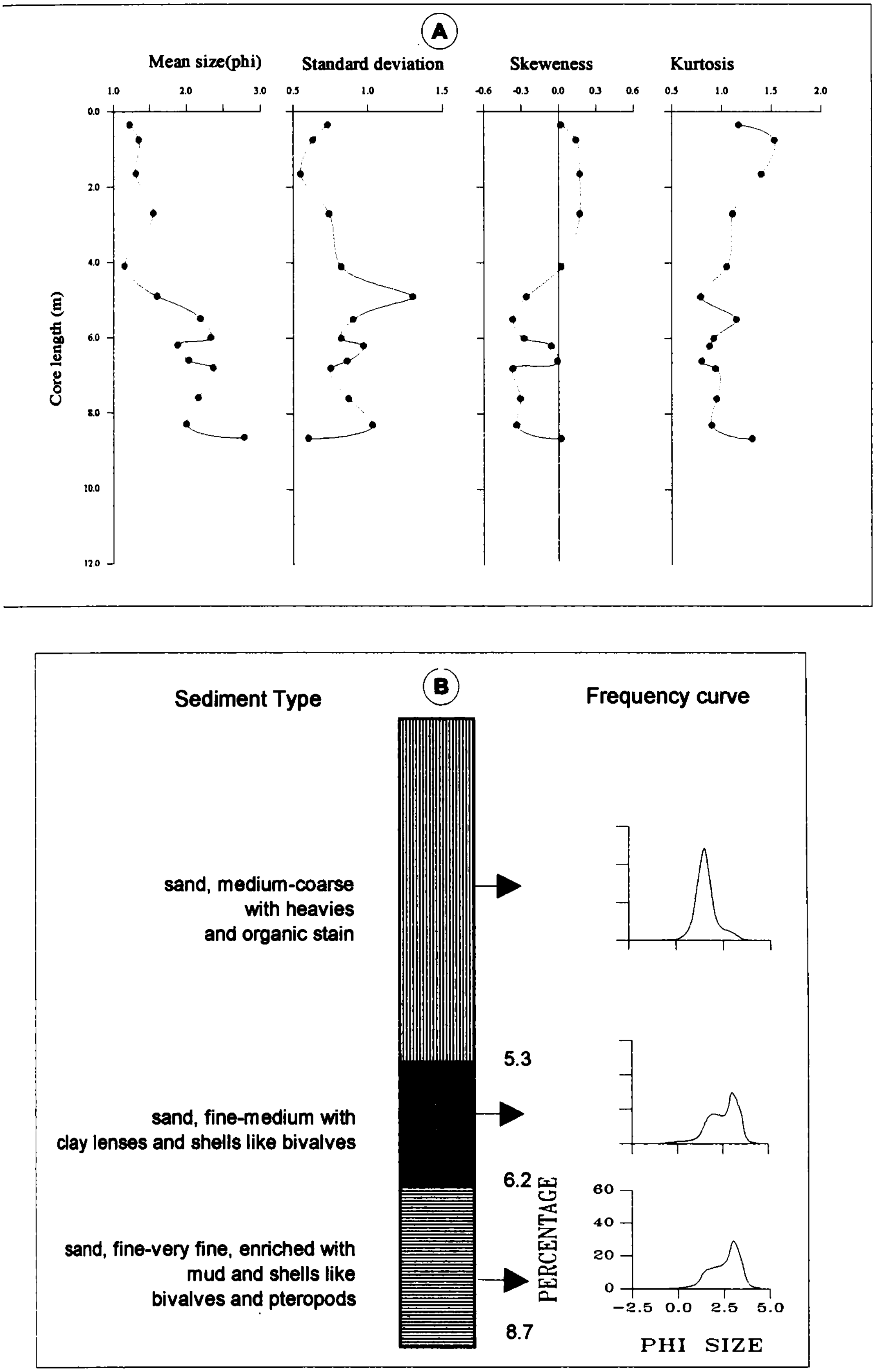

Fig. 3.9 Log of core P5 showing (A) vertical distribution of size parameters and (B) lithology and size frequency distribution

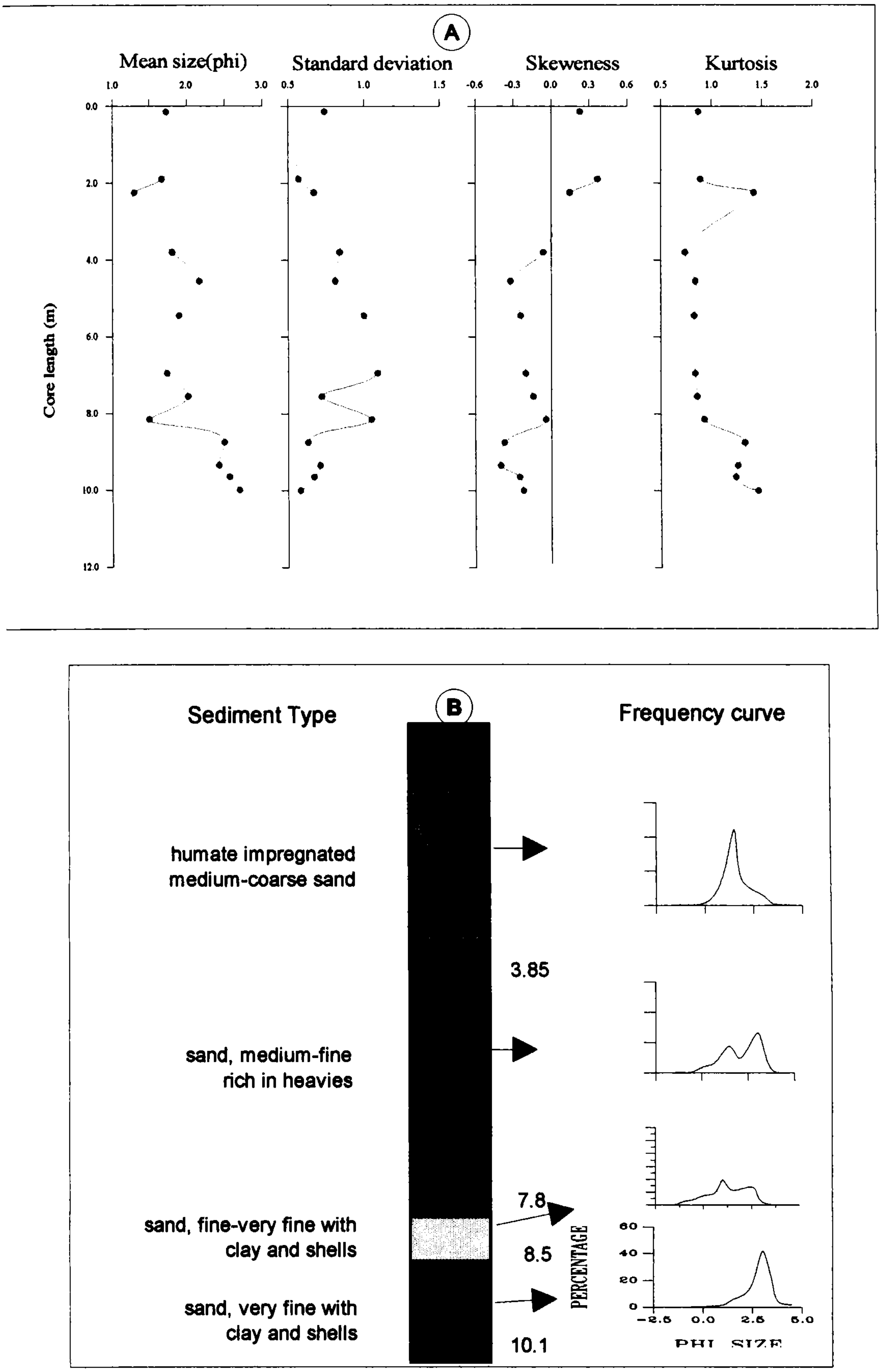

Fig. 3.10 Log of core P6 showing (A) vertical distribution of size parameters and (B) lithology and size frequency distribution

gastropods, bivalves and echinoids (Fig 3.10). The C^{14} dating of shells from a depth of 8 m indicate an age of 2630 ± 100 YBP.

Core P-7: The upper layer, which is a brown to yellow coloured humate-impregnated heavy rich medium sand is moderately well sorted with fine skewed distribution. This unit is underlined by gray-coloured fine to medium sand rich in black sand and rounded gravel. These are moderately well sorted to moderately sorted and are having a near symmetrical nature. This unit is underlined by yellow to gray coloured medium to coarse sand associated with rounded gravel and shells like gastropods and bivalves at a depth of 6.8 m. These sediments, which are moderately sorted to poorly sorted and near symmetrical to coarse skewed in distribution. The bottom most unit is composed of brownish gray to olive gray coloured fine sand intercalated with clay, shell fragments and whole shells like bivalves and gastropods. This unit, which is poorly sorted and coarse skewed in nature, also indicating a beach facies, later influenced by a nearshore regime (Fig 3.11).

Core P-8: The upper-unit is composed of gray and light yellow coloured well sorted to moderately well sorted medium sand with heavies in insignificant quantity is finely skewed to nearly symmetrical in nature. This unit is underlined by light gray with yellow bands of black sand rich fine to medium sand. These sediments are moderately well sorted with near symmetrical in nature. The unit from 4.5 to 9.5 m is composed of gray with brownish bands of coarse to medium sand with clay lenses and shell fragments like gastropods, bivalves and echinoids. These are moderately well sorted to poorly sorted with nearly symmetrical to coarse skewed population. The C^{14} dating of shell samples from a depth of 8.6 m indicate an age of 4160 ± 55 YBP. The lower-most unit is composed of olive-gray coloured clay-rich, fine to very fine sand with shell fragments and organic matter. These are moderately well sorted to poorly sorted and near symmetrical to very coarse skewed in nature (Fig 3.12).

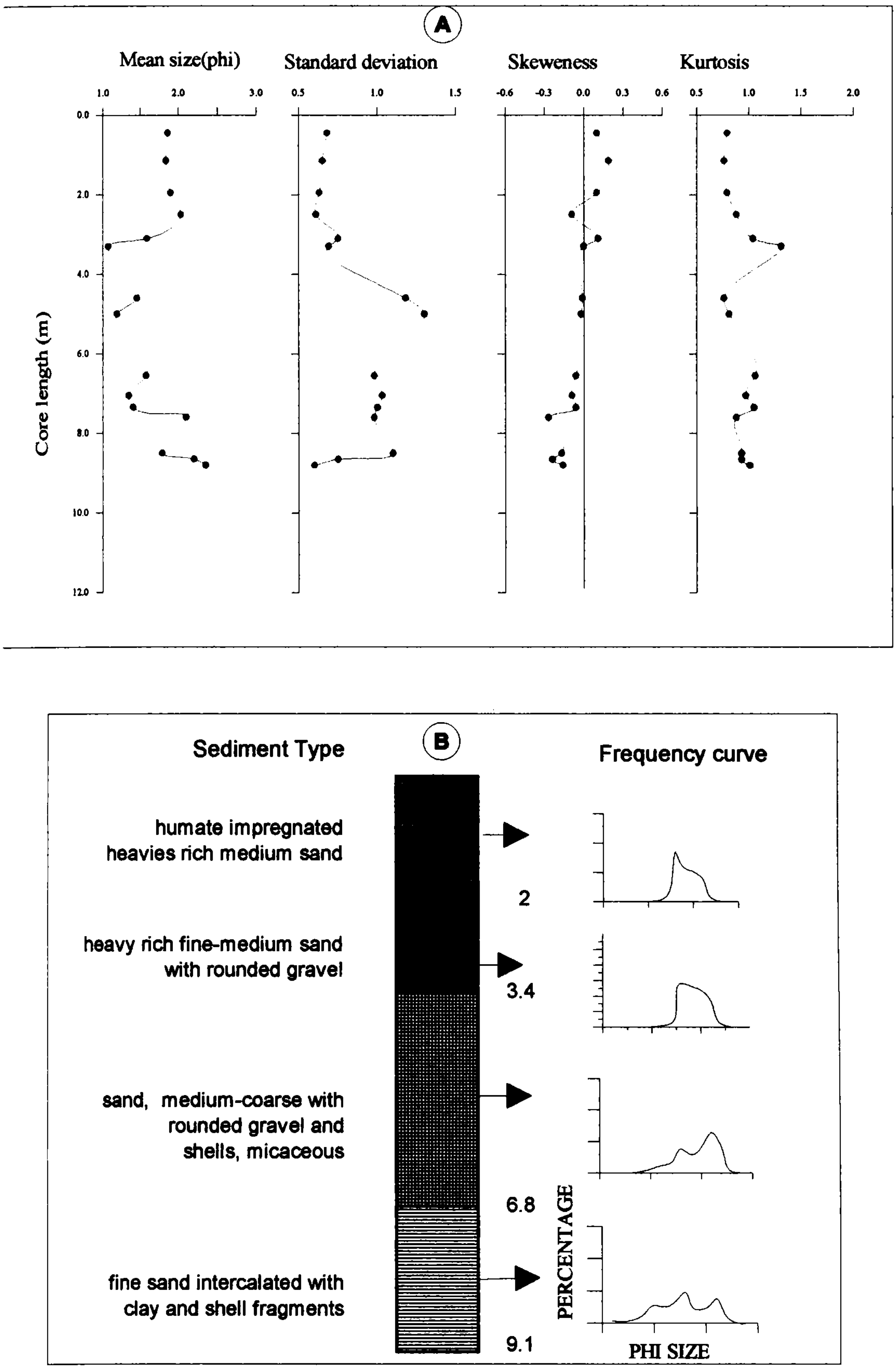

Fig. 3.11 Log of core P7 showing (A) vertical distribution of size parameters and (B) lithology and size frequency distribution

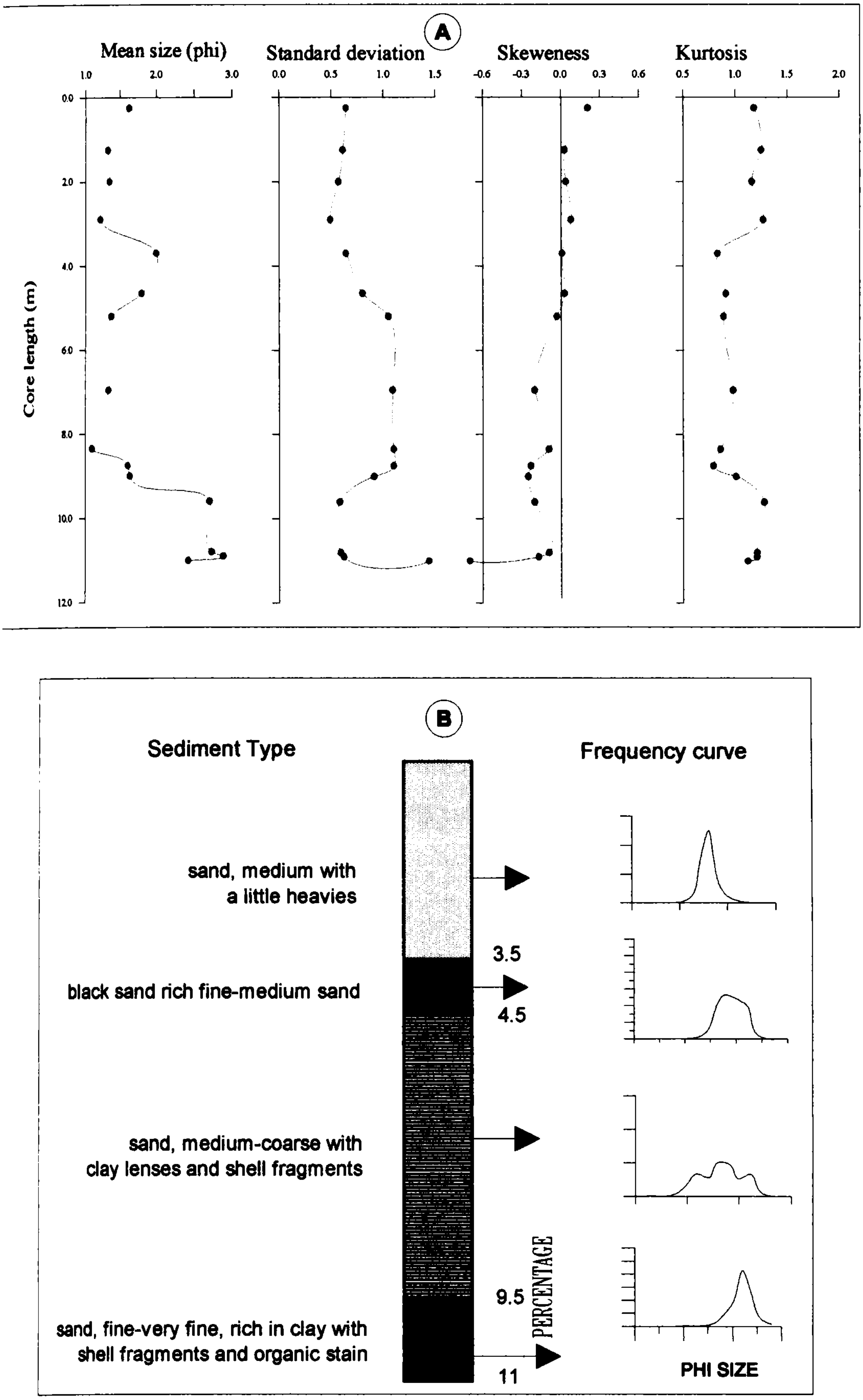

Fig. 3.12 Log of core P8 showing (A) vertical distribution of size parameters and (B) lithology and size frequency distribution

Core P-9: The upper layer which is a yellow coloured medium sand intercalated with heavies and kaolinitic patches (micaceous) are moderately well sorted and finely skewed in nature. The unit in between 1.5 to 2.5 m is composed of light gray coloured black sand rich fine sand with patches of yellow layers and are moderately well sorted with nearly symmetrical distribution. The zone between 2.5 to 6.7 m is composed of micaceous rich fine to medium sand interbedded with gravel. These sediments are moderately sorted with fine skewed to near symmetrical in nature. A narrow region in between 6.7 to 8.1 m is composed of upper yellow to lower gray coloured micaceous medium sand with shell hashes and are moderately sorted and coarse skewed in nature. The C^{14} dating of shell samples from a depth of 7.5 m indicate an age of 3740 ± 100 YBP. The lower most unit is composed of olive gray coloured clay-rich fine to medium sand with gravel and shells like echinoids, gastropods and bivalves. These sediments are moderately sorted with coarse skewed to very coarse skewed population. (Fig 3.13).

Core P-10: The top layer upto 1.2 m, is composed of moderately sorted and nearly symmetrical black-sand rich gravel bearing coarse to medium sand. This unit is underlain by a grayish yellow to grayish black coloured medium to coarse sand, which is moderately well sorted and finely skewed to near symmetrical in nature. The bottom-most unit consists of variegated coloured grayish black (2.8 to 4.9 m), olive gray (4.9 to 5.4 m), grayish brown (5.4 to 6.5 m) and yellow coloured (6.5 to 6.65 m) coarse to medium sand associated with gravel and lateritic rock fragments. These sediments are moderately sorted with near symmetrical in distribution (Fig 3.14). The bivariate plots of mean size and standard deviation clearly distinguishes different environments of deposition in the Punjavi transect (*refer Fig 3.3*)

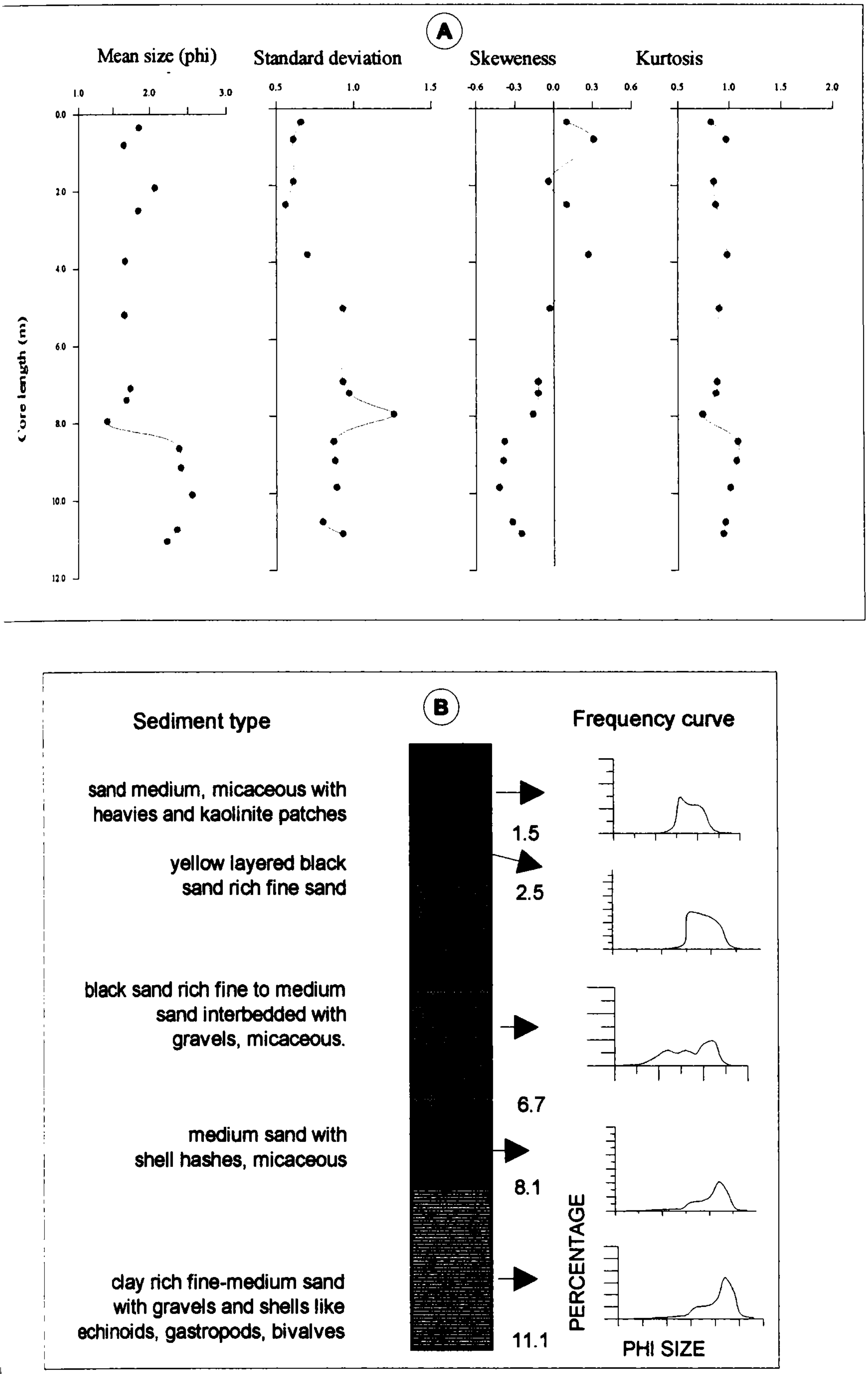

Fig. 3.13 Log of core P9 showing (A) vertical distribution of size parameters and (B) lithology and size frequency distribution

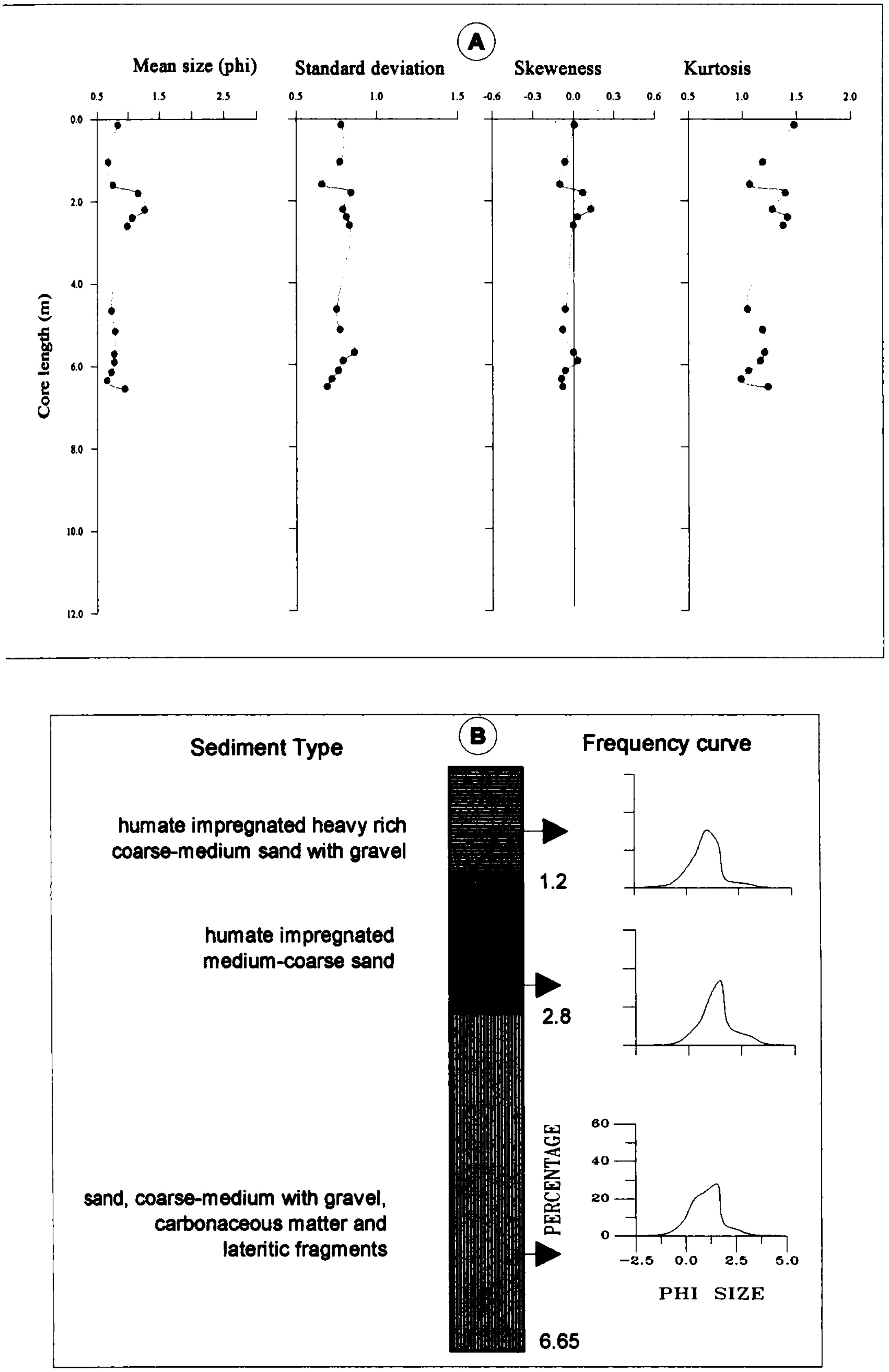

Fig. 3.14 Log of core P10 showing (A) vertical distribution of size parameters and (B) lithology and size frequency distribution

Table. 3.2: Grain size parameters of sediment samples collected from the coastal plain area of Punjavi Transect.

Sl. No	Sample	1%	5%	16%	25%	50%	75%	84%	95%	Mz	SD	Sk	KG
1	P-1/1	0.37	0.89	1.1	1.19	1.44	2.06	2.4	2.86	1.65	0.62	0.47	0.93
2	P-1/2	0.48	0.93	1.15	1.28	1.74	2.34	2.57	2.92	1.82	0.66	0.18	0.77
3	P-1/3	0.18	0.68	1.06	1.15	1.42	2.01	2.35	2.86	1.61	0.65	0.38	1.04
4	P-1/4	0.24	0.62	1.01	1.08	1.29	1.49	1.81	2.41	1.37	0.47	0.28	1.77
5	P-1/5	0.31	0.7	1.05	1.13	1.36	1.81	2.13	2.7	1.51	0.57	0.38	1.2
6	P-1/6	-0.09	0.38	0.74	0.96	1.26	1.66	2.01	2.59	1.34	0.65	0.19	1.29
7	P-1/7	0.52	0.84	1.1	1.2	1.47	2.09	2.39	2.89	1.65	0.63	0.4	0.95
8	P-1/8	0.44	0.68	1.04	1.13	1.38	1.88	2.2	2.78	1.54	0.61	0.38	1.15
9	P-1/9	0.05	0.56	0.91	1.06	1.32	1.73	2.02	2.69	1.41	0.6	0.27	1.31
10	P-1/10	0.07	0.61	1.04	1.13	1.41	1.95	2.27	2.81	1.57	0.64	0.34	1.11
11	P-1/11	-0.69	-0.23	0.32	0.59	1.05	1.4	1.6	2.29	0.99	0.7	-0.08	1.26
12	P-1/12	-1.3	-0.66	-0.1	0.2	0.78	1.25	1.42	2.1	0.7	0.8	-0.1	1.07
13	P-1/13	-1.88	-0.98	-0.54	-0.35	0.17	0.82	1.11	1.64	0.25	0.81	0.13	0.92
14	P-1/14	-1.5	-1.09	-0.82	-0.67	-0.31	-0.01	0.24	0.79	-0.3	0.55	0.11	1.18
15	P-1/15	-2	-1.52	-1.01	-0.88	-0.53	-0.12	0.08	0.63	-0.49	0.6	0.1	1.16
16	P-1/16	-2.08	-1.23	-0.45	-0.07	1.09	1.98	2.35	2.84	1	1.32	-0.12	0.81
17	P-1/17	-1.88	-0.72	0.09	0.56	1.29	2.09	2.39	2.85	1.26	1.12	-0.09	0.95
18	P-1/18	-1.99	-1.43	-0.81	-0.49	0.32	1.43	2.05	2.76	0.52	1.35	0. 19	0.89
19	P-1/19	-1.9	-1.09	-0.39	-0.03	0.79	1.33	1.57	2.59	0.66	1.05	-0.11	1.11
20	P-1/20	-1.57	-0.81	-0.22	0.1	0.78	1.28	1.45	2.35	0.67	0.9	-0.11	1.1
21	P-1/21	-1.87	-0.72	0.31	0.75	1.31	1.98	2.34	2.87	1.32	1.05	-0.06	1.19
22	P-1/22	-1.35	-0.26	0.69	1.03	1.44	2.14	2.47	2.91	1.53	0.93	0.05	1.18
23	P-1/23	-1.97	-1.13	-0.15	0.65	1.66	2.56	2.79	3.21	1.43	1.39	-0.26	0.93
24	P-1/24	-0.92	0.21	1.16	1.37	1.94	2.6	2.8	3.16	1.97	0.86	-0.06	0.99
25	P-1/25	-0.93	0.61	1.28	1.54	2.12	2.68	2.87	3.26	2.09	0.8	-0.09	0.95
26	P-1/26	-2.31	-1.75	-0.35	0.93	1.71	2.43	2.7	3.11	1.35	1.5	-0.38	1.33
27	P-1/27	-1.65	-0.66	0.93	1.22	1.91	2.59	2.81	3.2	1.88	1.05	-0.19	1.16
28	P-1/28	-2.06	-1.28	0.18	1.01	1.59	2.39	2.68	3.08	1.48	1.29	-0.23	1.29

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Sl. No	Sample	1%	5%	16%	25%	50%	75%	84%	95%	Mz	SD	Sk	KG
29	P-1/29	-1.76	-0.92	-0.15	0.79	2.29	2.8	2.95	3.33	1.69	1.42	-0.54	0.87
30	P-1/30	-1.49	-0.06	2	2.26	2.68	2.94	3.09	3.4	2.59	0.8	-0.41	1.09
31	P-1/31	-1.29	-0.44	0.51	1.08	2.07	2.76	2.95	3.4	1.84	1.19	-0.29	0.94
32	P-1/32	-1.1	-0.47	0.2	0.77	1.69	2.61	2.85	3.3	1.58	1.23	-0.13	0.84
33	P-1/33	-1.54	-0.49	0.25	0.6	1.22	2.2	2.68	3.28	1.38	1.18	-0.15	0.96
34	P-1/34	-2.38	-1.89	0.05	0.56	1.44	2.57	2.84	3.33	1.44	1.49	-0.13	1.07
35	P-1/35	-2.23	-0.19	0.9	1.24	2.23	2.85	3.05	3.42	2.06	1.08	-0.29	0.92
36	P-2/1	0	0.38	0.73	0.94	1.23	1.49	1.73	2.27	1.23	0.54	0.05	1.42
37	P-2/2	-0.46	-0.15	0.16	0.32	0.77	1.26	1.44	1.95	0.79	0.64	0.08	0.92
38	P-2/3	-0.41	0.14	0.83	1.15	1.8	2.53	2.75	3.07	1.79	0.92	-0.07	0.87
39	P-2/4	0.01	1.07	1.75	2.1	2.64	2.9	3	3.37	2.46	0.66	-0.4	1.18
40	P-2/5	1.17	1.97	2.52	2.59	2.81	3.06	3.23	3.44	2.85	0.4	0.02	1.29
41	P-2/6	-0.08	1.07	1.85	2.24	2.69	2.95	3.12	3.41	2.55	0.67	-0.35	1.33
42	P-2/7	-0.23	1	1.42	1.66	2.45	2.86	2.99	3.36	2.29	0.75	-0.27	0.8
43	P-2/8	-1.94	-0.83	0.13	0.59	1.32	2.13	2.61	3.11	1.36	1.22	-0.03	1.04
44	P-2/9	-0.82	0.15	1.2	1.57	2.22	2.73	2.86	3.16	2.09	0.87	-0.3	1.06
45	P-2/10	-0.99	-0.49	0.31	0.75	1.67	2.59	2.8	3.16	1.59	1.17	-0.14	0.81
46	P-3/1	0.13	0.68	1.09	1.21	1.57	2.14	2.4	2.85	1.68	0.66	0.23	0.95
47	P-3/2	0.29	0.68	1.04	1.12	1.33	1.67	1.94	2.49	1.44	0.5	0.31	1.35
48	P-3/3	0.21	0.71	1.07	1.15	1.4	1.83	2.08	2.66	1.52	0.55	0.33	1.18
49	P-3/4	-0.37	0.09	0.57	0.78	1.17	1.44	1.64	2.21	1.13	0.59	-0.06	1.31
50	P-3/5	-0.48	-0.18	0.34	0.59	1.04	1.38	1.5	2.13	0.96	0.64	-0.14	1.21
51	P-3/6	-1.26	-0.48	0.08	0.4	0.96	1.38	1.59	2.28	0.88	0.8	-0.11	1.15
52	P-3/7	-2.19	-0.99	-0.2	0.29	1.09	1.47	1.77	2.35	0.89	1	-0.28	1.16
53	P-3/8	-2.1	-1.43	-0.32	0.31	1.21	1.83	2.18	2.74	1.02	1.26	-0.25	1.12
54	P-3/9	-1.53	-0.41	0.59	1.02	1.61	2.39	2.65	2.97	1.62	1.03	-0.1	1.01
55	P-3/10	-0.2	1.01	1.63	1.98	2.49	2.79	2.9	3.21	2.34	0.65	-0.34	1.11
56	P-3/11	-1.8	-0.84	0.17	0.87	1.63	2.39	2.66	2.97	1.48	1.2	-0.24	1.03
57	P-3/12	-0.56	0.21	1.08	1.31	2	2.6	2.8	3.14	1.96	0.87	-0.14	0.93
58	P-3/13	-1.49	-0.71	0.06	0.6	1.84	2.66	2.87	3.26	1.59	1.3	-0.28	0.79
59	P-3/14	-1.54	-0.79	-0.16	0.21	1.44	2.55	2.79	3.22	1.36	1.35	-0.1	0.7

continued....

Sl. No	Sample	1%	5%	16%	25%	50%	75%	84%	95%	Mz	SD	Sk	KG
60	P-3/15	-0.91	0.19	1.77	2.17	2.64	2.91	3.01	3.39	2.47	0.8	-0.47	1.79
61	P-3/16	-1.57	-0.73	1.34	2.41	2.88	3.26	3.4	3.78	2.54	1.2	-0.55	2.15
62	P-4/1	-0.23	0.37	0.79	1.02	1.31	1.76	2.09	2.73	1.39	0.68	0.21	1.3
63	P-4/2	-0.12	0.53	0.84	1.03	1.29	1.64	1.97	2.68	1.37	0.61	0.25	1.45
64	P-4/3	-0.25	0.26	0.67	0.85	1.21	1.53	1.88	2.52	1.25	0.65	0.13	1.36
65	P-4/4	0.53	0.88	1.11	1.21	1.48	2.02	2.32	2.82	1.64	0.6	0.38	0.98
66	P-4/5	-0.24	0.24	0.65	0.83	1.18	1.45	1.7	2.34	1.18	0.58	0.05	1.38
67	P-4/6	-0.44	0.03	0.48	0.62	0.97	1.3	1.42	1.94	0.96	0.52	-0.01	1.14
68	P-4/7	-0.49	-0.11	0.3	0.53	0.84	1.19	1.33	1.58	0.82	0.51	-0.08	1.06
69	P-4/8	-0.83	-0.22	0.54	0.89	1.44	2.24	2.56	2.93	1.51	0.98	0.03	0.95
70	P-4/9	-0.63	-0.09	0.51	0.79	1.33	2.09	2.44	2.92	1.43	0.94	0.11	0.95
71	P-4/10	-0.5	0.09	0.78	1.08	1.7	2.5	2.72	2.99	1.73	0.93	-0.02	0.84
72	P-4/11	-0.63	-0.08	0.63	1.02	1.66	2.48	2.72	3	1.67	0.99	-0.06	0.86
73	P-4/12	-0.45	0.07	0.69	1.02	1.42	2.21	2.58	2.97	1.57	0.91	0.15	1
74	P-4/13	0.07	0.65	1.13	1.33	2.1	2.7	2.87	3.25	2.03	0.83	-0.11	0.77
75	P-4/14	-0.64	0.42	2.05	2.4	2.72	2.96	3.12	3.41	1.63	0.72	-0.39	2.18
76	P-4/15	0.2	1.03	1.96	2.32	2.72	2.98	3.18	3.44	2.62	0.67	-0.32	1.5
77	P-4/16	-0.77	-0.44	-0.21	-0.03	0.24	0.49	0.77	2.67	0.26	0.72	0.32	2.46
78	P-5/1	-0.39	0.05	0.52	0.77	1.24	1.66	1.89	2.62	1.22	0.73	0.02	1.17
79	P-5/2	-0.23	0.31	0.83	1.05	1.31	1.68	1.91	2.67	1.35	0.63	0.14	1.53
80	P-5/3	0.07	0.53	0.81	1.01	1.27	1.58	1.84	2.46	1.31	0.55	0.17	1.4
81	P-5/4	-0.2	0.38	0.86	1.08	1.45	1.99	2.33	2.84	1.55	0.74	0.17	1.11
82	P-5/5	-0.5	-0.02	0.32	0.6	1.19	1.66	1.94	2.71	1.15	0.82	0.02	1.05
83	P-5/6	-0.98	-0.64	0.07	0.63	1.83	2.68	2.88	3.28	1.6	1.3	-0.26	0.79
84	P-5/7	-0.81	0.02	1.29	1.64	2.35	2.79	2.92	3.27	2.19	0.9	-0.37	1.15
85	P-5/8	-0.42	0.72	1.42	1.71	2.47	2.9	3.09	3.4	2.33	0.82	-0.28	0.92
86	P-5/9	-0.46	0.11	0.9	1.21	1.87	2.67	2.86	3.25	1.88	0.97	-0.06	0.88
87	P-5/10	0.14	0.61	1.13	1.35	2.02	2.74	2.92	3.34	2.03	0.86	-0.01	0.8
88	P-5/11	0.18	0.98	1.49	1.84	2.57	2.89	3.02	3.39	2.36	0.75	-0.37	0.94
89	P-5/12	-0.35	0.4	1.22	1.55	2.32	2.8	2.93	3.29	2.16	0.87	-0.31	0.95
90	P-5/13	-0.69	0.01	0.82	1.28	2.23	2.79	2.93	3.31	2	1.03	-0.34	0.9

continued....

Sl. No	Sample	1%	5%	16%	25%	50%	75%	84%	95%	Mz	SD	Sk	KG
91	P-5/14	0.5	1.74	2.23	2.47	2.78	3.13	3.33	3.85	2.78	0.6	0.02	1.31
92	P-6/1	0.06	0.58	1.05	1.18	1.58	2.3	2.56	2.95	1.73	0.74	0.23	0.87
93	P-6/2	0.57	1.01	1.13	1.24	1.53	2.05	2.33	2.79	1.67	0.57	0.37	0.89
94	P-6/3	-0.16	0.28	0.7	0.93	1.25	1.61	1.96	2.63	1.3	0.67	0.15	1.42
95	P-6/4	-0.01	0.43	0.89	1.13	1.82	2.53	2.72	2.95	1.81	0.84	-0.06	0.74
96	P-6/5	-0.08	0.69	1.24	1.53	2.36	2.78	2.91	3.26	2.17	0.81	-0.32	0.84
97	P-6/6	-0.48	0.05	0.78	1.11	2.05	2.69	2.86	3.23	1.9	1	-0.24	0.83
98	P-6/7	-1.42	-0.29	0.55	0.94	1.86	2.64	2.82	3.17	1.74	1.09	-0.2	0.84
99	P-6/8	-0.09	0.71	1.24	1.48	2.06	2.57	2.75	2.98	2.02	0.72	-0.14	0.86
100	P-6/9	-0.9	-0.36	0.43	0.88	1.48	2.35	2.63	2.96	1.51	1.05	-0.04	0.93
101	P-6/10	0.04	1.05	1.88	2.19	2.64	2.9	3	3.36	2.5	0.63	-0.37	1.33
102	P-6/11	-0.04	0.87	1.67	2.08	2.61	2.9	3	3.38	2.43	0.71	-0.4	1.26
103	P-6/12	0.23	1.15	1.89	2.19	2.66	2.96	3.17	3.48	2.57	0.67	-0.25	1.24
104	P-6/13	0.8	1.42	2.13	2.46	2.75	3.04	3.23	3.46	2.7	0.58	-0.22	1.46
105	P-7/1	0.27	0.86	1.16	1.3	1.81	2.39	2.62	2.95	1.86	0.68	0.1	0.79
106	P-7/2	0.54	1.01	1.17	1.3	1.76	2.34	2.58	2.94	1.84	0.65	0.19	0.76
107	P-7/3	0.5	1.03	1.23	1.39	1.86	2.38	2.6	2.93	1.9	0.63	0.1	0.79
108	P-7/4	0.54	1.05	1.36	1.58	2.07	2.46	2.65	2.93	2.03	0.61	-0.09	0.88
109	P-7/5	-0.4	0.28	0.91	1.11	1.5	2.12	2.37	2.82	1.59	0.75	0.11	1.04
110	P-7/6	-0.75	-0.11	0.44	0.64	1.08	1.42	1.68	2.37	1.07	0.69	0	1.31
111	P-7/7	-1	-0.47	0.19	0.66	1.42	2.56	2.77	3.07	1.46	1.18	-0.01	0.76
112	P-7/8	-2.15	-0.93	-0.21	0.22	1.16	2.2	2.61	2.98	1.19	1.3	-0.02	0.81
113	P-7/9	-0.95	-0.3	0.61	1.03	1.56	2.27	2.56	2.92	1.58	0.98	-0.06	1.06
114	P-7/10	-1.04	-0.46	0.28	0.74	1.4	2.13	2.39	2.85	1.35	1.03	-0.09	0.97
115	P-7/11	-0.96	-0.37	0.39	0.83	1.42	2.09	2.42	2.87	1.41	1	-0.06	1.05
116	P-7/12	-0.49	0.17	1.05	1.34	2.26	2.83	3.02	3.37	2.11	0.98	-0.27	0.88
117	P-7/13	-0.97	-0.27	0.61	1.08	1.89	2.65	2.86	3.29	1.79	1.1	-0.17	0.93
118	P-7/14	-0.12	0.81	1.37	1.68	2.32	2.76	2.9	3.25	2.2	0.75	-0.24	0.93
119	P-7/15	1.01	1.28	1.72	1.99	2.42	2.78	2.91	3.26	2.35	0.6	-0.16	1.01
120	P-8/1	0.14	0.66	1.07	1.2	1.54	1.96	2.29	2.86	1.63	0.64	0.21	1.18
121	P-8/2	0.01	0.31	0.77	1.02	1.33	1.72	1.9	2.45	1.33	0.61	0.03	1.25

continued.....

Sl. No	Sample	1%	5%	16%	25%	50%	75%	84%	95%	Mz	SD	Sk	KG
122	P-8/3	0.01	0.4	0.81	1.04	1.34	1.73	1.91	2.37	1.35	0.57	0.04	1.16
123	P-8/4	0.06	0.52	0.75	0.94	1.22	1.47	1.7	2.18	1.22	0.49	0.08	1.27
124	P-8/5	0.55	1.02	1.31	1.54	1.99	2.49	2.7	2.96	2	0.64	0.01	0.83
125	P-8/6	-0.25	0.36	1.02	1.21	1.73	2.38	2.65	2.95	1.8	0.8	0.03	0.91
126	P-8/7	-0.75	-0.3	0.25	0.6	1.4	2.07	2.5	2.92	1.38	1.05	-0.04	0.89
127	P-8/8	-0.97	-0.61	0.14	0.62	1.49	2.08	2.39	2.87	1.34	1.09	-0.2	0.98
128	P-8/9	-0.97	-0.63	-0.1	0.24	1.19	1.87	2.21	2.8	1.1	1.1	-0.09	0.86
129	P-8/10	-0.86	-0.32	0.33	0.81	1.77	2.52	2.74	3	1.61	1.1	-0.23	0.79
130	P-8/11	-1.01	-0.25	0.69	1.05	1.76	2.31	2.46	2.86	1.64	0.91	-0.25	1.01
131	P-8/12	0.28	1.46	2.12	2.4	2.75	3.05	3.24	3.47	2.7	0.58	-0.2	1.28
132	P-8/13	1.01	1.63	2.14	2.4	2.75	3.09	3.29	3.64	2.73	0.59	-0.09	1.21
133	P-8/14	0.98	1.61	2.27	2.55	2.93	3.3	3.43	3.81	2.88	0.62	-0.17	1.21
134	P-8/15	-2.34	-1	0.68	1.59	3.1	3.39	3.49	3.9	2.42	1.44	-0.7	1.12
135	P-9/1	0.3	0.9	1.17	1.32	1.81	2.36	2.58	2.96	1.86	0.66	0.1	0.82
136	P-9/2	0.5	0.82	1.11	1.21	1.52	2.06	2.33	2.82	1.65	0.61	0.31	0.97
137	P-9/3	1	1.11	1.41	1.61	2.08	2.51	2.72	2.97	2.07	0.61	-0.04	0.85
138	P-9/4	1.01	1.08	1.27	1.43	1.83	2.26	2.44	2.84	1.85	0.56	0.1	0.87
139	P-9/5	0.07	0.6	1.05	1.17	1.51	2.14	2.44	2.9	1.67	0.7	0.27	0.98
140	P-9/6	-0.55	0	0.7	1.04	1.63	2.39	2.65	2.95	1.66	0.93	-0.03	0.9
141	P-9/7	-0.47	0.05	0.75	1.08	1.78	2.45	2.69	2.98	1.74	0.93	-0.12	0.88
142	P-9/8	-0.57	-0.02	0.64	1.04	1.74	2.45	2.69	2.99	1.69	0.97	-0.12	0.87
143	P-9/9	-1.66	-0.75	0.01	0.39	1.53	2.49	2.73	3.06	1.42	1.26	-0.16	0.74
144	P-9/10	-0.75	0.52	1.44	1.84	2.58	2.95	3.14	3.43	2.39	0.87	-0.38	1.08
145	P-9/11	-0.63	0.55	1.43	1.86	2.61	2.98	3.18	3.45	2.41	0.88	-0.39	1.07
146	P-9/12	-0.86	0.72	1.54	2.05	2.79	3.21	3.35	3.59	2.56	0.89	-0.42	1.01
147	P-9/13	-0.37	0.93	1.44	1.84	2.56	2.92	3.1	3.45	2.36	0.8	-0.32	0.96
148	P-9/14	-0.65	0.4	1.23	1.56	2.36	2.88	3.09	3.44	2.23	0.93	-0.25	0.94
149	P-10/1	-2.17	-0.47	0.17	0.48	0.87	1.31	1.47	2.53	0.84	0.78	0.01	1.48
150	P-10/2	-1.64	-0.69	-0.04	0.21	0.73	1.17	1.36	2.08	0.68	0.77	-0.06	1.19
151	P-10/3	-0.91	-0.4	0.1	0.35	0.81	1.21	1.36	1.86	0.76	0.66	-0.1	1.07
152	P-10/4	-0.65	-0.21	0.38	0.64	1.13	1.5	1.97	2.72	1.16	0.84	0.07	1.4

continued....

Sl. No	Sample	1%	5%	16%	25%	50%	75%	84%	95%	Mz	SD	Sk	KG
153	P-10/5	-67	0	0.55	0.76	1.2	1.64	2.05	2.75	1.27	0.79	0.13	1.28
154	P-10/6	-0.86	-0.27	0.33	0.6	1.07	1.44	1.8	2.66	1.07	0.81	0.03	1.42
155	P-10/7	-0.89	-0.35	0.21	0.53	1.02	1.41	1.72	2.62	0.99	0.83	0	1.38
156	P-10/8	-1.11	-0.47	-0.02	0.25	0.8	1.25	1.42	2.1	0.73	0.75	-0.06	1.05
157	P-10/9	-1.31	-0.52	0.05	0.34	0.86	1.29	1.45	2.26	0.79	0.77	-0.08	1.19
158	P-10/10	-1.2	-0.62	0.02	0.24	0.83	1.33	1.5	2.59	0.78	0.86	0	1.21
159	P-10/11	-0.96	-0.44	0.06	0.27	0.81	1.29	1.46	2.48	0.78	0.79	0.03	1.17
160	P-10/12	-1.25	-0.58	0	0.22	0.78	125	1.41	2.09	0.73	0.76	-0.06	1.06
161	P-10/13	-1.09	-0.62	-0.07	0.17	0.71	1.18	1.35	1.83	0.66	0.72	-0.09	0.99
162	P-10/14	-0.69	-0.19	0.28	0.54	1.03	1.38	1.53	2.34	0.95	0.69	-0.08	1.24

Mz = Mean size, SD = Standard Deviation, Sk = Skewness and KG = Kurtosis

3.3.2 Sedimentary Facies-Onakkunnu Transect

Twelve cores ranging in depth from 7.5 to 11.1 m were taken from this transect. Facies determination has been made by analysing 160 samples by comparison of lithology and mineralogy. Table 3.3 shows details of statistical parameters of Onakkunnu transect. The individual description of each core is described below. Figs 3.15 to 3.26 gives the depth-wise variation of size parameters, lithology in the cores of the transect II.

Core 0-1: The upper layer is composed of 0.3 m brown coloured reclaimed sand, below that yellow to light gray coloured shell-bearing medium sand. These sediments are moderately well sorted to moderately sorted with positively skewed to near symmetrical population. The shell fragments start appearing at a depth of 2.5 m. This unit is underlined by a coarse to medium sand with gravels and shells, like bivalves, gastropods and echinoids. These are moderately well sorted to moderately sorted with near symmetrical in nature. The unit in between 5.5 to 9.6 m is composed of light gray coloured organic rich argillaceous medium to coarse sand with above fauna and are moderately well sorted to moderately sorted with fine to coarse skewed in nature. The C^{14} dating of shell samples from a depth of 9 m gave an age of 2760 ± 100 YBP. The bottom

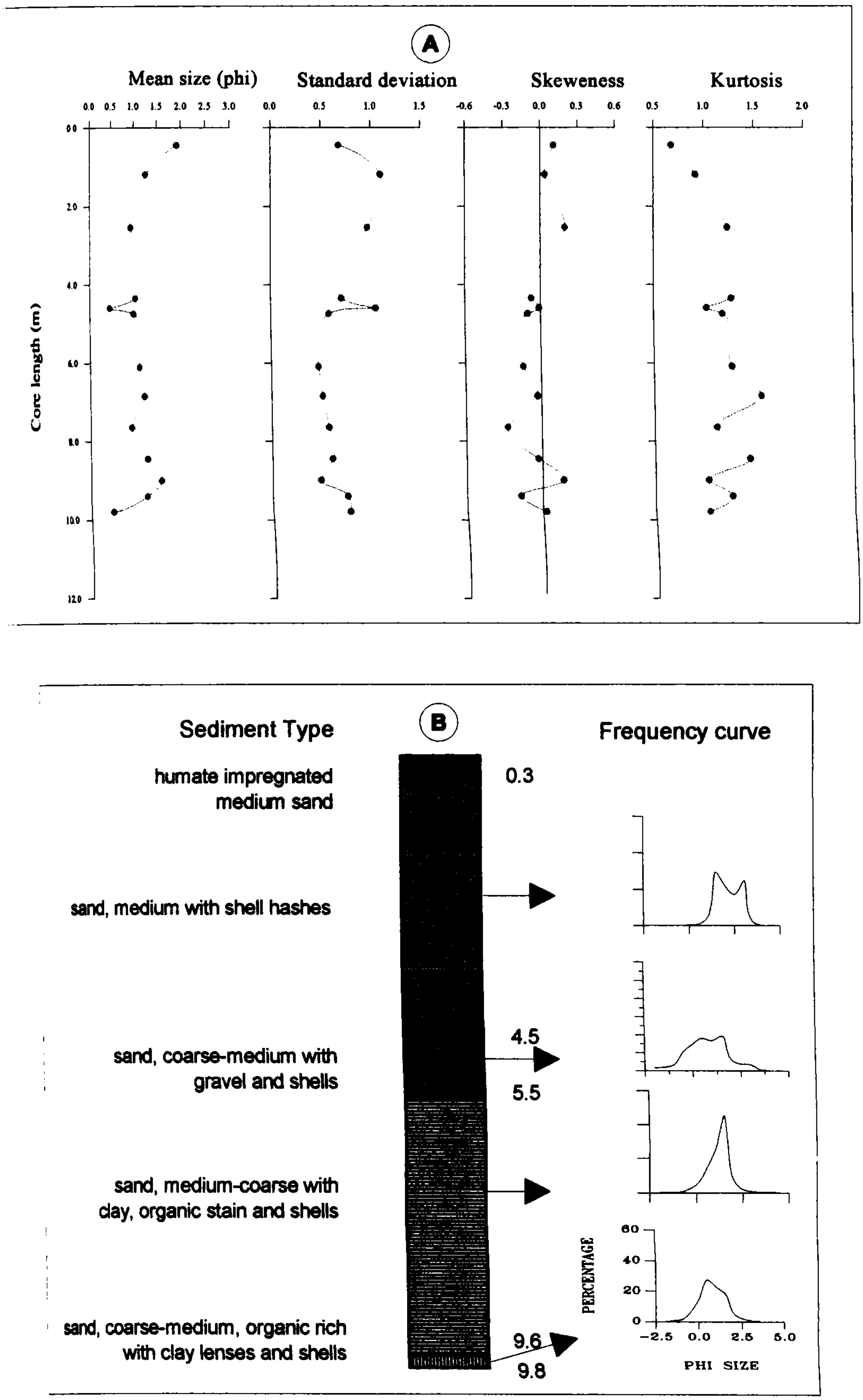


Fig. 3.15 Log of core O1 showing (A) vertical distribution of size parameters and (B) lithology and size frequency distribution

most unit is composed of organic rich light gray coloured, coarse to medium sand with clay lenses and shells are moderately well sorted and symmetrical (Fig 3. 15).

Core 0-2: This unit consists of a 6 m thick strand plain facies, the upper layer of which consists of brown coloured humate-impregnated and a gray coloured moderately well sorted, positively skewed, medium to fine sand with heavies and micaceous fractions. The unit lying between 2.1 to 6 m consists of a gray coloured medium to coarse sand with heavies are moderately well sorted and fine skewed in nature. This zone is underlain by a organic-rich medium-coarse sand, rich in clay and shells like, gastropods, echinoids, bivalves etc. The bottom-most unit is composed of olive gray coloured, very fine argillaceous sand, rich in organic matter and shells (Fig 3.16). These are moderately well sorted, near symmetrical medium sand. The C^{14} dating of shell samples from a depth of .25 m gave an age of 2830 ± 100 YBP.

Core 0-3: The upper 1 m zone is a reclaimed zone, below which is a 4.8 m moderately well sorted gray coloured, heavy-rich, medium sand is fine skewed in nature. The unit in between 4.8 to 5.8 m is composed of yellow coloured, moderately sorted medium sand with shell fragments are near symmetrical in nature. This layer is underlined by shell bearing gray coloured fine-very fine sand are moderately sorted with positively to very positively skewed nature. The C^{14} dating of shells from a depth of 6.25 m indicate an age of 3970 ± 55 YBP. The bottom-most unit is composed of grayish-green coloured very fine sand with clay and shells. The C^{14} dating of shells from a depth of 8.1 m indicate an age of 4800 ± 55 YBP. These sediments are moderately well sorted with very coarse skewed population (Fig 3.17).

Core 0-4: The upper layer composed of gray coloured medium to coarse sand, are moderately sorted with near-symmetrical in nature. The unit between 5.7 to 7.25 m is composed of gray coloured coarse to medium sand with pebbles-bearing kaolin patches. These are moderately sorted with near symmetrical to coarse skewed in nature. This unit is underlined by gray to yellow coloured very coarse to coarse sand with clay lenses and

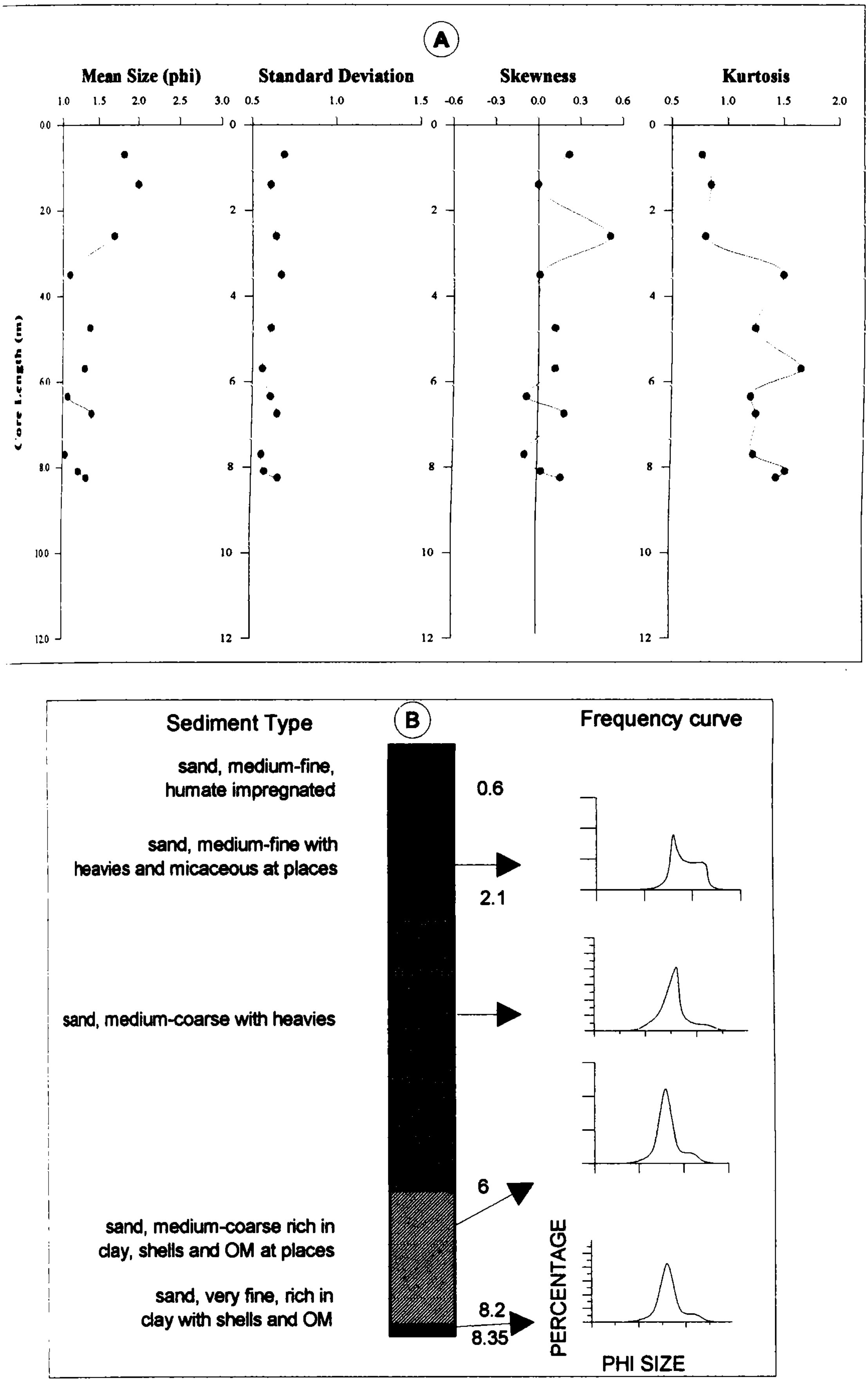


Fig. 3.16 Log of core O2 showing (A) vertical distribution of size parameters and (B) lithology and size frequency distribution

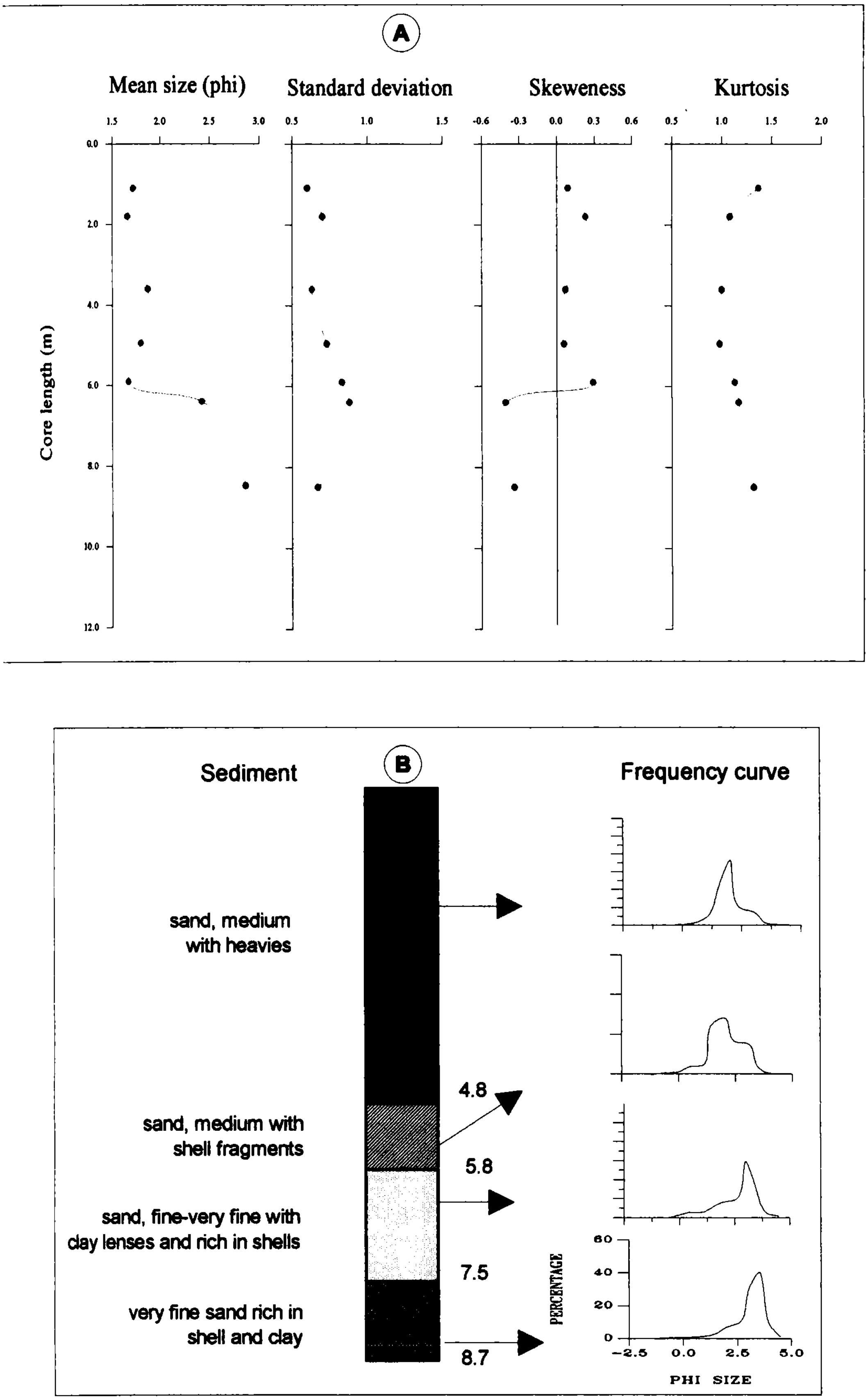


Fig. 3.17 Log of core O3 showing (A) vertical distribution of size parameters and (B) lithology and size frequency distribution

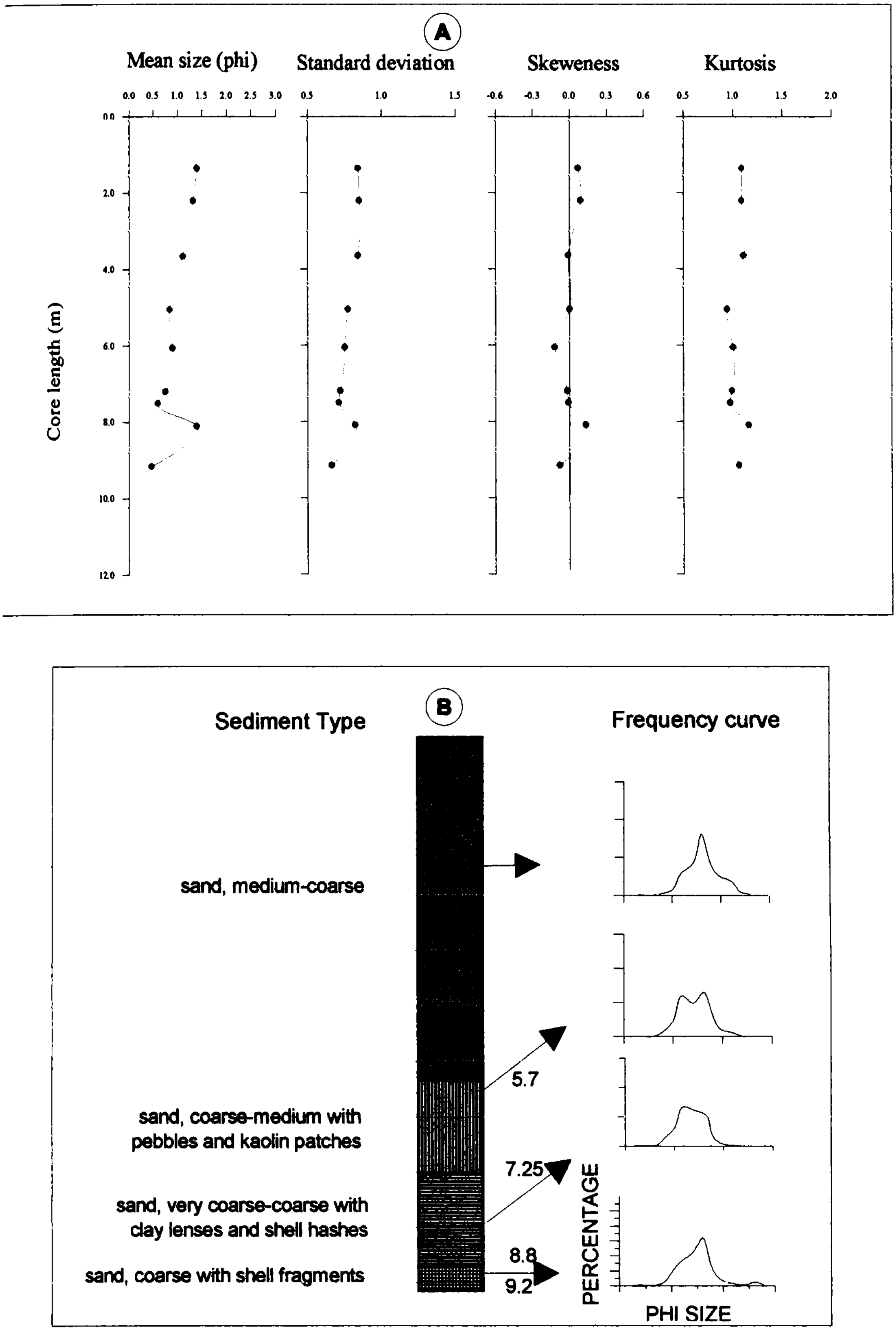


Fig. 3.18 Log of core O4 showing (A) vertical distribution of size parameters and (B) lithology and size frequency distribution

shell hashes. These sediments are moderately sorted with fine skewed to near symmetrical in nature. The bottom-most unit is a yellow coloured moderately well sorted coarse sand zone with shell fragments are near symmetrical in nature (Fig 3.18).

Core 0-5: The upper layer is characterised by medium to fine grained sand with coarse grain encrustations. This is underlined by yellow coloured, coarse-medium sand, which is moderately sorted and near-symmetrical in nature. This zone is underlined by a organic material-rich gray coloured poorly sorted, medium to fine sand with gravels and clay lenses are very coarse skewed in nature. The unit between 6.7 to 9 m is composed of upper zone, which is yellow coloured and a gray coloured zone with clay lenses bearing graveliferous medium to fine sand. These medium sands are poorly sorted with very coarse skewed in nature. The bottom-most unit is composed of dark gray coloured fine to very fine sand, rich in clay and shells of gastropods, bivalves and echinoids. These are poorly sorted sediments with near symmetrical to coarse skewed in nature (Fig 3.19). The C^{14} dating of shell samples from a depth of 10.4 m indicated an age of >30000 YBP.

Core 0-6: The upper layer which is a humate-impregnated reddish to yellow coloured, black sand rich medium sand, is moderately well sorted and near symmetrical. The bottom-unit consists of a yellow coloured horizon with intermittant bands of kaolinitic yellow (2.3 to 4.9 m), a blood red coloured zone (4.9 to 5.9 m) and light gray coloured coarse to medium sand with sub-rounded gravels and indurated pebbles. These are moderately sorted with near symmetrical to coarse skewed in nature. Below this layer is a light gray to yellow coloured black sand-rich medium to coarse sand, which is moderate to poorly sorted and are nearly symmetrical. This is underline by a yellow coloured zone consisting of poorly sorted and nearly symmetrical to coarse skewed gravel-bearing fine to medium sand with clay and calc-indurated pebbles. The bottom-most unit is composed of yellow to gray coloured organic rich clay bearing very fine to fine sand, which are moderately well sorted with positively skewed in nature (Fig 3.20).

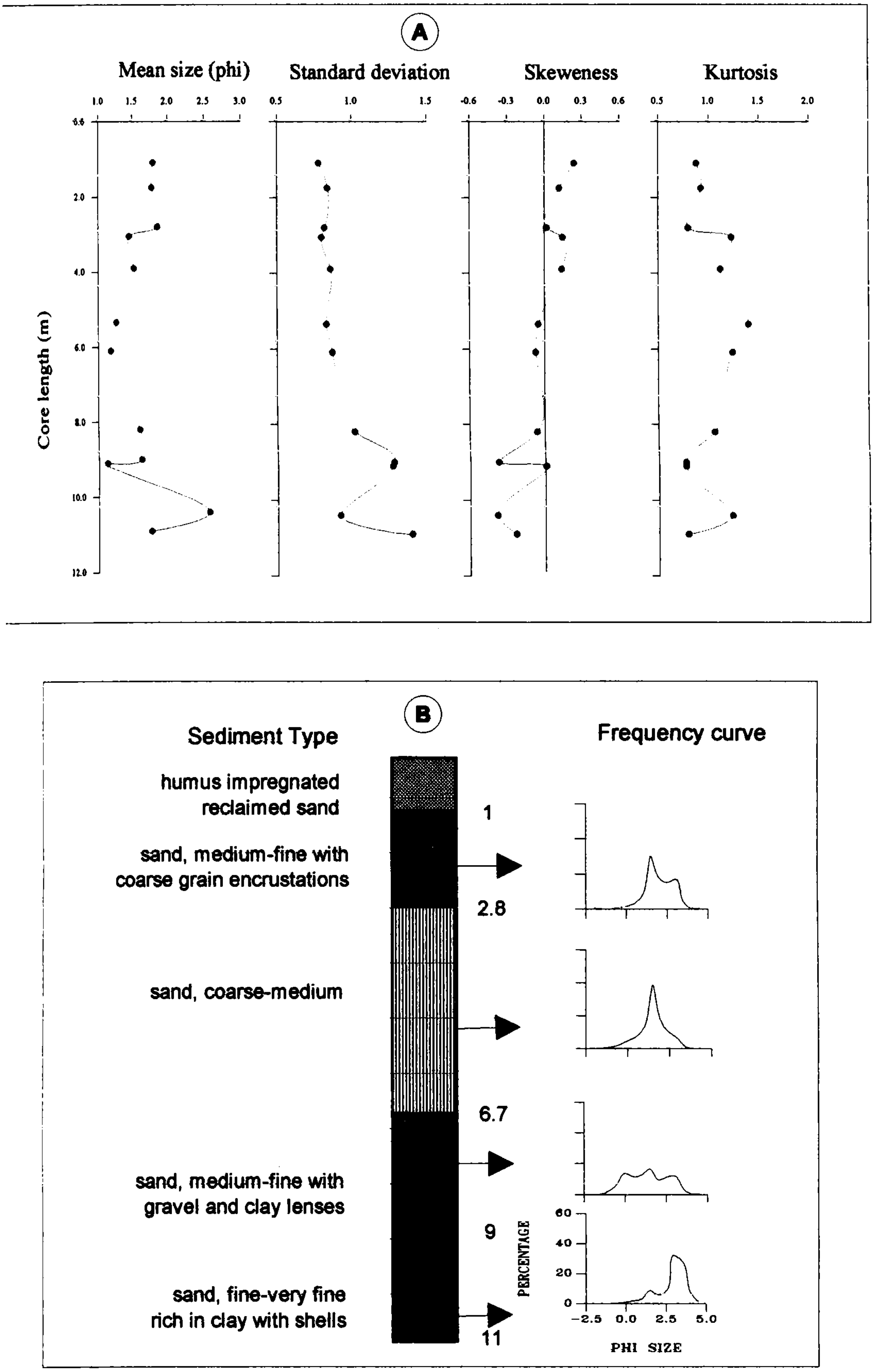


Fig. 3.19 Log of core O5 showing (A) vertical distribution of size parameters and (B) lithology and size frequency distribution

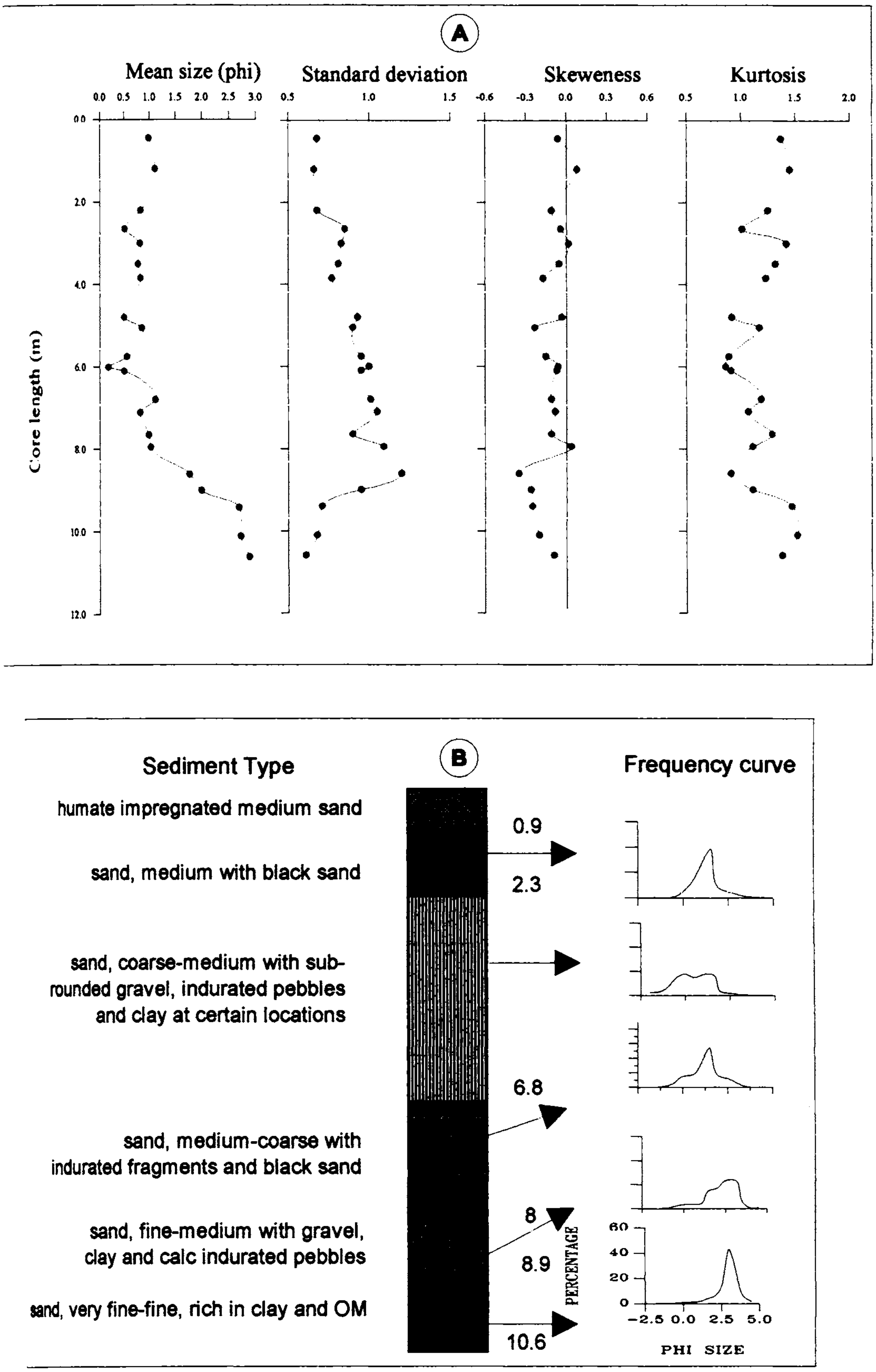


Fig. 3.20 Log of core O6 showing (A) vertical distribution of size parameters and (B) lithology and size frequency distribution

Core 0-7: The top layer, which is a moderately sorted, near symmetrical gray to yellow coloured, medium sand with indurated rock fragments. A yellow coloured zone is found to be sandwitched between the gray coloured zone. Below this layer is a yellow coloured coarse to medium sand with well-rounded gravel and micaceous clay, which are moderately sorted with near symmetrical in nature. This layer is underlined by a gray coloured, moderately sorted and nearly symmetrical coarse to medium sand with pebble-sized materials. This unit is underlined by a light gray (kaolinitic) coloured medium sand with micaceous nature. These sediments are moderately sorted with near symmetrical in nature. The bottom most unit consists of poorly sorted gray coloured coarse sand, with gravels and micaceous material (Fig 3.21).

Core 0-8: The top layer, composed of moderate to well sorted, positively skewed to near symmetrical gray-yellow coloured, medium sand with calcareous lateritic pebbles. This layer is underlined by an yellow coloured moderately sorted with near symmetrical and coarse to very coarse sand with rounded quartz pebbles and shell fragments. The zone is underlined by yellow to sandal coloured moderate to poorly sorted medium to fine sand with gravel and shell fragments, which are negatively skewed in nature. The bottom most unit is a gray to sandal coloured poorly sorted negatively to positively skewed coarse sand rich in gravel and shell fragments are seen (Fig 3.22).

Core 0-9: The upper layer is composed of a red to yellow coloured moderate to poorly sorted medium sand with fine skewed to near symmetrical population, indicating the exposure of these deposits to subaerial weathering, subsequent to deposition. This unit is underlined by light yellow coloured, pebble bearing moderately sorted coarse sand. Below this, yellow to sandal coloured medium to coarse sand with a mixture of white and black clay is seen. The sediments are moderately to poorly sorted medium sand with near symmetrical in nature, indicating thereby the influence of subaerial weathering at the same time influenced by the nearshore domain in the later stages (Fig 3.23).

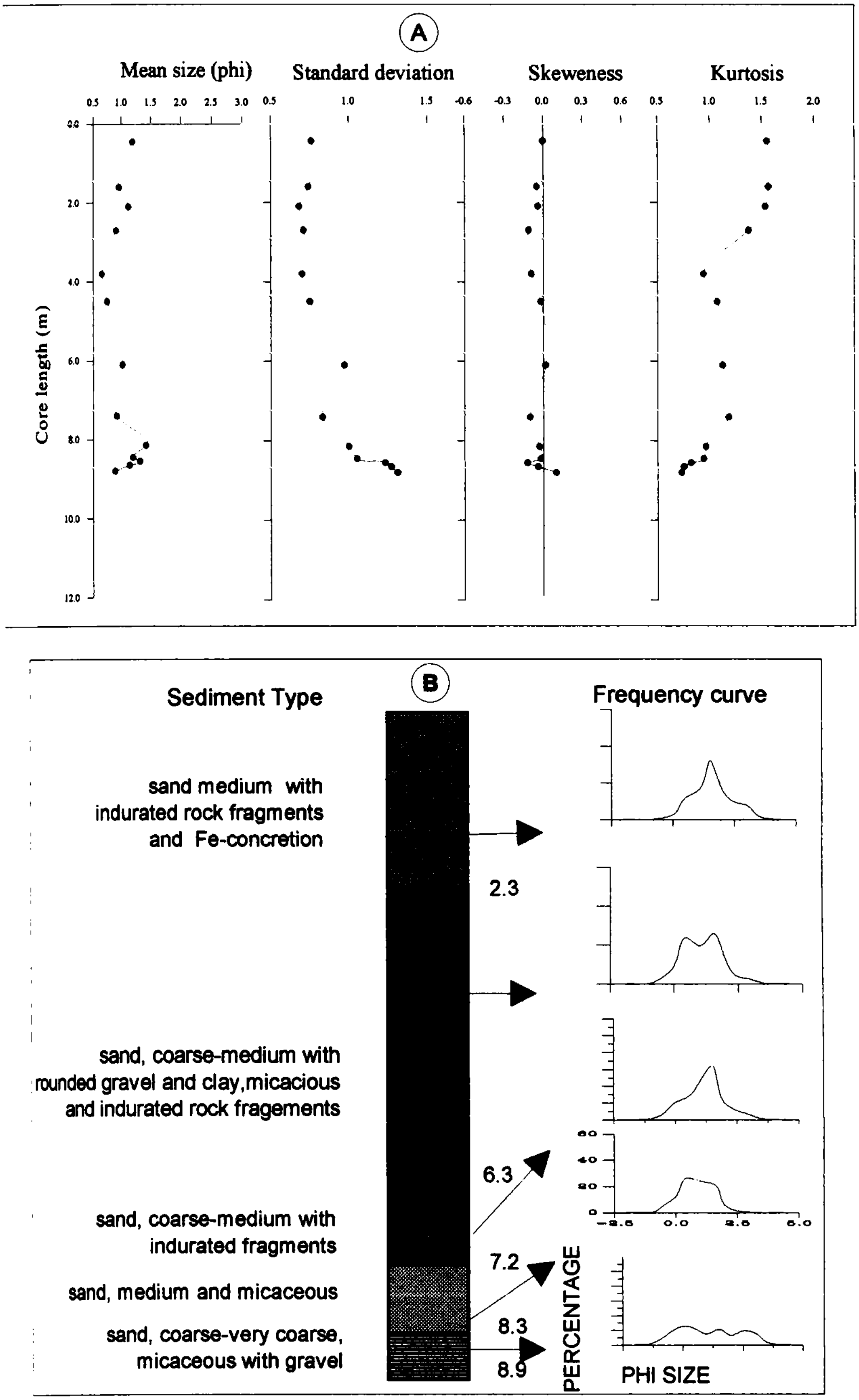


Fig. 3.21 Log of core O7 showing (A) vertical distribution of size parameters and (B) lithology and size frequency distribution

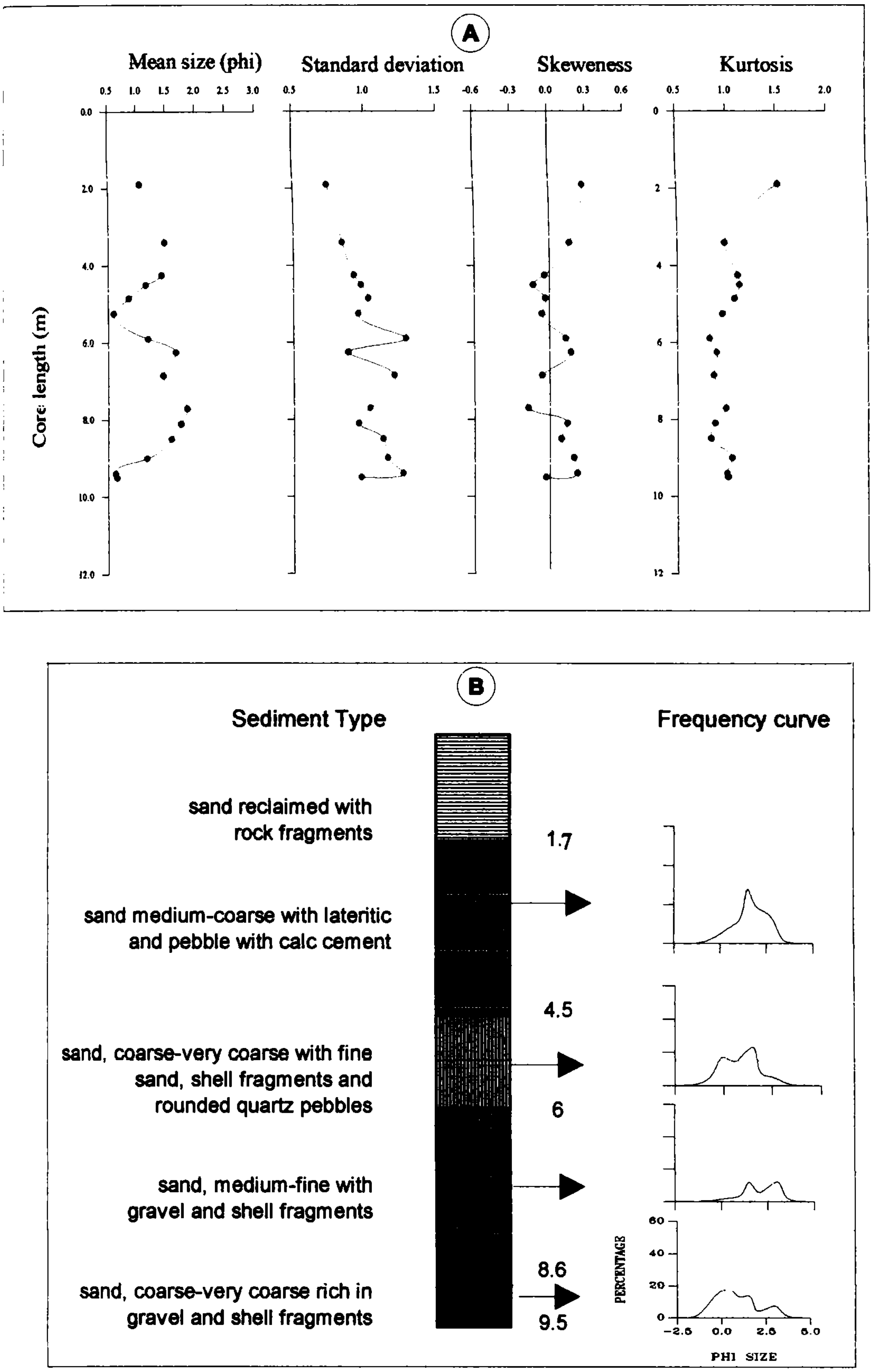


Fig. 3.22 Log of core O8 showing (A) vertical distribution of size parameters and (B) lithology and size frequency distribution

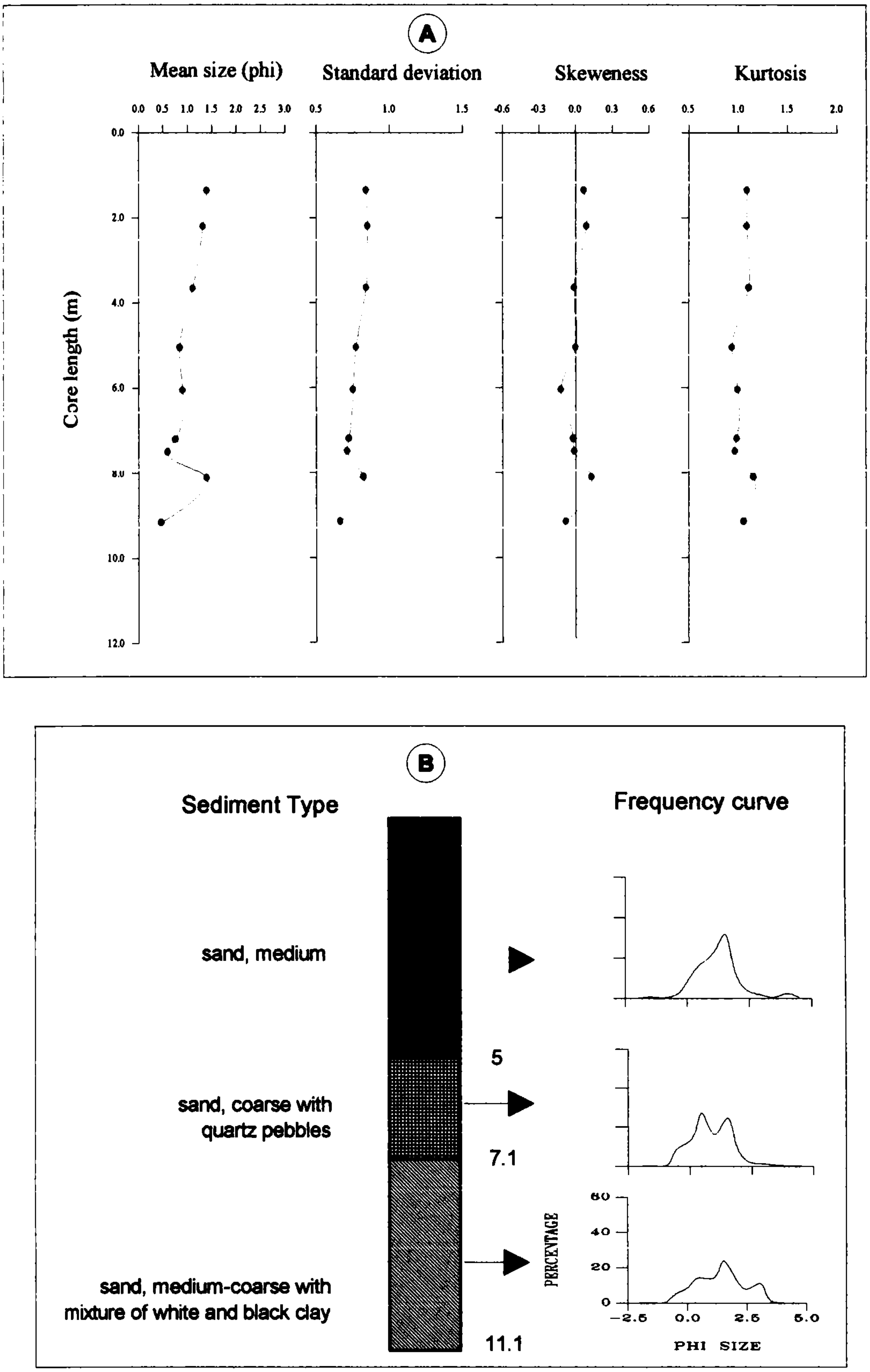


Fig. 3. 23 Log of core O9 showing (A) vertical distribution of size parameters and (B) lithology and size frequency distribution

Core 0-10: The upper layer which is a humate-impregnated, brownish yellow to light gray in colour, is a moderately sorted, positively skewed medium sand. This layer is underlined by a garnet-rich, light gray to yellow coloured coarse to medium sand intercalated with gravel, which is moderately sorted and near symmetrical in distribution. The unit between 4.5 to 5.5 m is composed of yellow coloured indurated coarse to medium sand intercalated with clay. This coarse sand is moderately sorted with fine skewed to near symmetrical in nature. A narrow, red coloured region found within the 5.5 to 6.7 m is composed of garnet rich indurated coarse to medium sand, which is moderately well sorted with near symmetrical in nature. The bottom most unit is composed of an upper yellow and lower olive gray coloured, clayey rich, fine sand with shell fragments and organic matter. Sediments are poorly sorted to negatively skewed in nature (Fig 3.24).

Core 0-11: The upper layer, which is made up of gray coloured medium to coarse sand with quartz pebbles and indurated fragments. These are moderately sorted and fine skewed in nature. Below this zone, and up to 3.2 m, is a dark gray to yellow coloured, poorly sorted, very coarse skewed and coarse to medium sand intercalated with clay and peat materials. The C^{14} dating of peat samples at a depth of 3.2 m showed an age of 5560 ± 100 YBP. This layer is underlined by fine to medium sand with sticky clays and indurated fragments. This zone illustrates different shades of yellow colour (light yellow, sandal yellow and orange yellow). The sediments are poorly sorted with nearly symmetrical to coarse skewed population. This layer is underlined by yellow to gray coloured clay-bearing fine sand. These are moderately sorted with coarse skewed in nature. The bottom-most unit is composed of a olive gray coloured, poorly sorted medium sand with abundant shells like echinoids, gastropods and bivalves probably indicating a nearshore facies (Fig 3.25). The C^{14} dating of shells samples from a depth of 8.4 m gave an age of > 40000 YBP.

Core 0-12: From top to 1.9 m depth, brown and yellow to gray coloured humate-impregnated medium sands, which are moderately sorted with fine skewed to near-

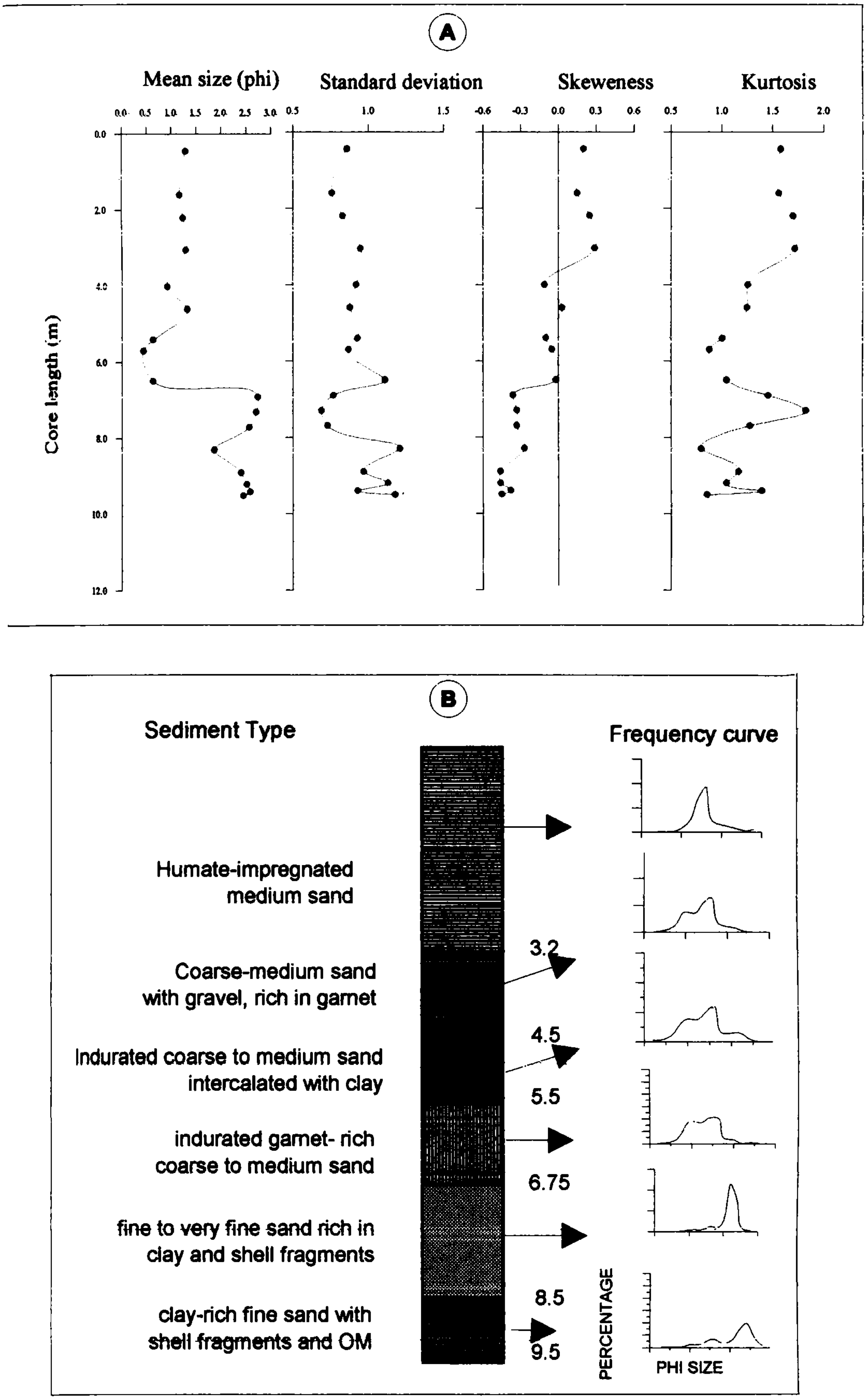


Fig. 3.24 Log of core O10 showing (A) Vertical distribution of size parameters (B) lithology and size frequency distribution

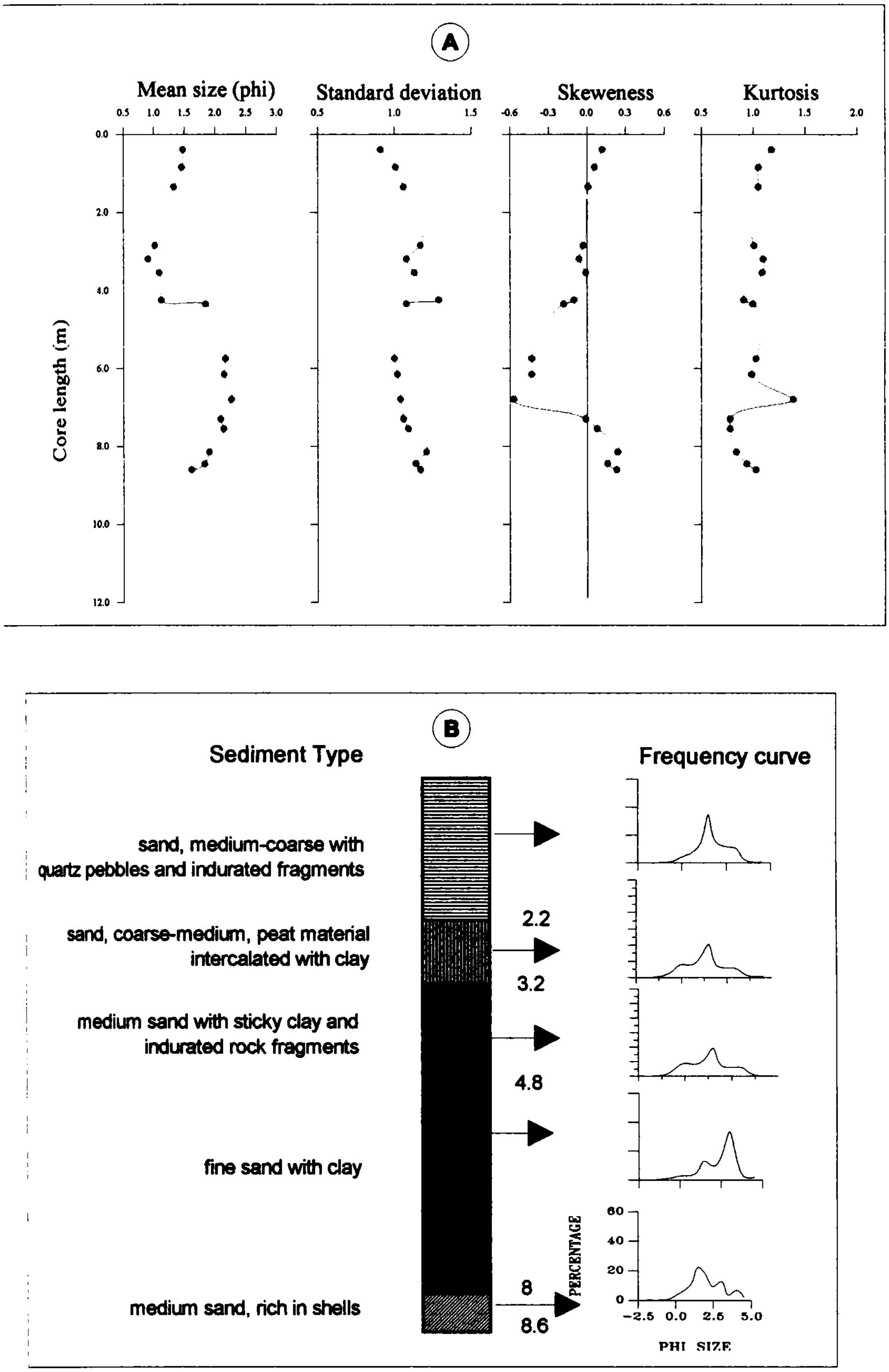


Fig. 3.25 Log of core O11 showing (A) vertical distribution of size parameters and (B) lithology and size frequency distribution

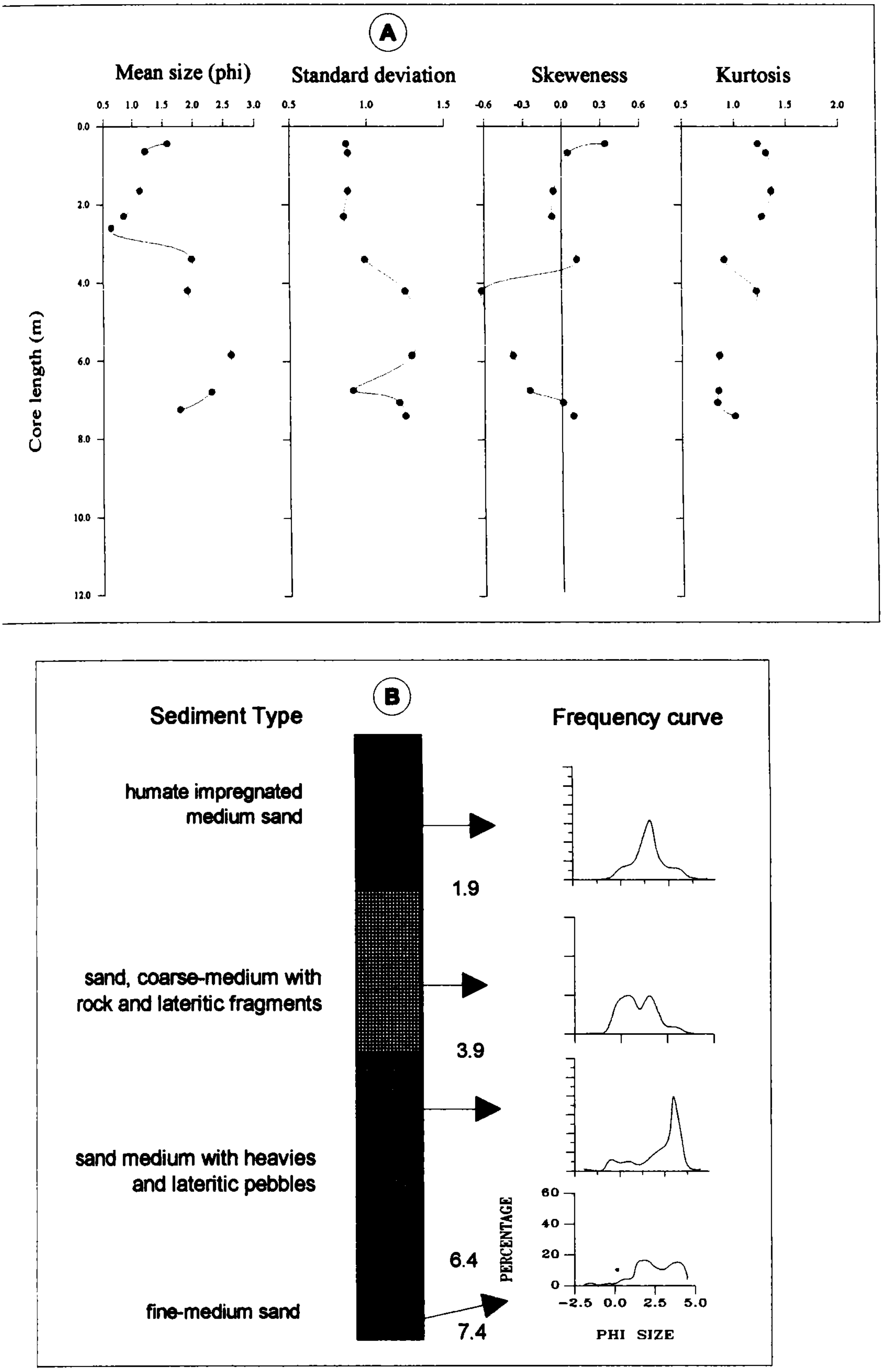


Fig. 3.26 Log of Core O12 showing (A) vertical distribution of size parameters and (B) lithology and size frequency distribution

symmetrical in nature. The unit in between 1.9 to 3.9 m consists of a gray to yellow coloured fine skewed to near symmetrical, moderately sorted coarse sand with lateritic fragments are seen. This is underlined by yellow to ochorous brown coloured medium sand, that are poorly sorted with coarse to very coarse skewed in nature. The bottom-most unit is also composed of ochorous, brown coloured poorly sorted fine to medium sand indicating probably the effect of sub-aerial weathering. The bottom-most unit intercepted the lateritic contact at a depth of 7.5 metre (Fig 3.26). The bivariate plots of mean size and standard deviation clearly distinguishes different environments of deposition in the Onakkunnu transect (*refer Fig 3.4*).

Table. 3.3: Grain size parameters of sediment samples collected from the coastal plain area of Onakkunnu Transect.

S. No	Sample	1%	5%	16%	25%	50%	75%	84%	95%	M z	SD	Sk	KG
1	0-1/1	0.51	0.97	1.18	1.34	1.86	2.54	2.72	2.94	1.92	0.68	0.11	0.68
2	0-1/2	-1.24	-0.47	0.11	0.49	1.2	1.99	2.46	2.91	1.26	1.1	0.04	0.92
3	0-1/3	-0.88	-0.4	0.07	0.29	0.85	1.4	1.91	2.95	0.94	0.97	0.2	1.24
4	0-1/4	-0.76	-0.21	0.36	0.62	1.09	1.43	1.66	2.32	1.04	0.71	-0.07	1.28
5	0-1/5	-2.19	-1.27	-0.55	-0.23	0.5	1.22	1.45	2.38	0.47	1.05	-0.01	1.03
6	0-1/6	-0.48	0.01	0.44	0.64	1.07	1.38	1.49	2.14	1	0.58	-0.1	1.19
7	0-1/7	-0.17	0.27	0.67	0.87	1.18	1.42	1.51	1.98	1.12	0.47	-0.14	1.28
8	0-1/8	-0.23	0.31	0.75	1	1.24	1.47	1.69	2.13	1.22	0.51	-0.03	1.57
9	0-1/9	-0.77	-0.18	0.35	0.6	1.05	1.33	1.43	1.83	0.94	0.57	-0.27	1.12
10	0-1/10	-0.4	0.16	0.71	1	1.27	1.6	1.82	2.28	1.27	0.6	-0.03	1.45
11	0-1/11	0.28	0.89	1.12	1.22	1.52	1.88	2.02	2.53	1.56	0.48	0.17	1.03
12	0-1/12	-2.04	-0.28	0.54	0.88	1.32	1.75	1.92	2.39	1.26	0.75	-0.17	1.27
13	0-1/13	-1.36	-0.77	0.25	0.03	0.49	1.04	1.29	1.8	0.51	0.77	0.03	1.04
14	0-2/1	0.27	0.83	1.13	1.26	1.69	2.37	2.63	2.94	1.82	0.69	0.22	0.77
15	0-2/2	0.67	1.07	1.35	1.55	2	2.45	2.66	2.93	2	0.61	0	0.85
16	0-2/3	0.11	1.01	1.12	1.21	1.47	2.18	2.51	2.91	1.7	0.64	0.51	0.8
17	0-2/4	-0.49	0	0.53	0.72	1.14	1.42	1.64	2.56	1.1	0.67	0.01	1.5
18	0-2/5	-0.15	0.36	0.83	1.05	1.32	1.75	1.09	2.49	1.38	0.61	0.12	1.25

continued....

Sl.No	Sample	1%	5%	16%	25%	50%	75%	84%	95%	M z	SD	Sk	KG
19	0-2/6	-0.23	0.38	0.83	1.04	1.27	1.54	1.83	2.4	1.31	0.56	0.12	1.66
20	0-2/7	-0.71	0	0.48	0.68	1.12	1.42	1.6	2.19	1.07	0.61	-0.08	1.21
21	0-2/8	-0.22	0.4	0.84	1.05	1.32	1.77	2.07	2.64	1.41	0.65	0.19	1.26
22	0-2/9	-0.55	0.03	0.53	0.69	1.09	1.38	1.49	2.14	1.04	0.56	-0.09	1.24
23	0-2/10	-0.26	0.25	0.7	0.93	1.23	1.48	1.76	2.34	1.23	0.58	0.03	1.53
24	0-2/11	-0.29	0.36	0.77	1.01	1.29	1.68	1.95	2.75	1.34	0.66	0.17	1.45
25	0-3/1	0.14	0.77	1.17	1.35	1.7	1.98	2.3	2.86	1.72	0.6	0.09	1.37
26	0-3/2	0.03	0.58	1.04	1.17	1.54	2.07	2.41	2.96	1.66	0.7	0.23	1.08
27	0-3/3	0.15	0.9	1.25	1.46	1.85	2.31	2.51	2.97	1.87	0.63	0.07	1
28	0-3/4	-0.28	0.46	1.08	1.26	1.73	2.31	2.6	2.96	1.8	0.76	0.06	0.98
29	0-3/5	-0.45	0.33	1	1.13	1.47	2.13	2.55	3.11	1.67	0.81	0.29	1.13
30	0-3/6	-0.24	0.43	1.47	1.89	2.63	1.96	3.16	3.47	2.42	0.88	-0.41	1.17
31	0-3/7	0.11	1.34	2.18	2.55	2.99	3.3	3.41	3.74	2.86	0.67	-0.34	1.32
32	0-4/1	-0.51	0.08	0.58	0.88	1.36	1.91	2.27	2.83	1.4	0.84	0.07	1.09
33	0-4/2	-0.73	0.03	0.49	0.78	1.28	1.83	2.19	2.83	1.32	0.85	0.09	1.09
34	0-4/3	-0.77	-0.21	0.28	0.55	1.15	1.6	1.92	2.63	1.11	0.84	-0.01	1.11
35	0-4/4	-0.85	-0.4	0.08	0.27	0.85	1.38	1.6	2.16	0.84	0.77	0	0.94
36	0-4/5	-1.19	-0.45	0.13	0.36	0.96	1.39	1.6	2.08	0.9	0.75	-0.12	1
37	0-4/6	-0.94	-0.48	0.05	0.24	0.77	1.27	1.44	2	0.75	0.72	-0.02	0.99
38	0-4/7	-0.99	-0.64	-0.12	0.11	0.59	1.11	1.31	1.72	0.59	0.71	-0.01	0.97
39	0-4/8	-0.4	0.1	0.61	0.88	1.31	1.85	2.24	2.83	1.39	0.82	0.13	1.16
40	0-4/9	-1.33	-0.76	-0.21	0.07	0.48	0.92	1.12	1.43	0.46	0.66	-0.08	1.06
41	0-5/1	-0.11	0.58	1.08	1.21	1.63	2.39	2.68	3.11	1.8	0.78	0.24	0.88
42	0-5/2	-0.99	0.23	1.02	1.17	1.65	2.41	2.68	3.03	1.78	0.84	0.12	0.93
43	0-5/4	-0.34	0.48	1.02	1.2	1.81	2.52	2.74	3.05	1.86	0.82	0.02	0.8
44	0-5/5	-0.6	0.12	0.74	1.02	1.35	1.92	2.28	2.82	1.46	0.8	0.15	1.23
45	0-5/6	-0.7	0.02	0.75	1.04	1.4	2.09	2.44	2.91	1.53	0.86	0.14	1.12
46	0-5/7	-1.2	-0.36	0.51	0.85	1.27	1.73	2.02	2.65	1.27	0.83	-0.05	1.4
47	0-5/8	-0.94	-0.37	0.33	0.71	1.23	1.7	2.01	2.62	1.19	0.87	-0.07	1.24
48	0-5/9	-1	-0.39	0.61	1.06	1.58	2.36	2.65	2.99	1.61	1.02	-0.06	1.06
49	0-5/10	-1.19	-0.62	0.05	0.62	1.99	2.66	2.84	3.24	1.63	1.28	-0.37	0.77

continued......

Sl No	Sample	1%	5%	16%	25%	50%	75%	84%	95%	M z	SD	Sk	KG
50	O-5/11	-1.29	-0.8	-0.25	0.1	1.1	2.12	2.52	2.99	1.13	1.27	0.01	0.77
51	O-5/12	-0.29	0.71	1.53	2.2	2.8	3.22	3.38	3.76	2.57	0.92	-0.38	1.23
52	O-5/13	-2.44	-0.71	0.15	0.74	1.97	2.93	3.19	3.55	1.77	1.4	-0.23	0.79
53	O-6/1	-0.72	-0.14	0.38	0.61	1.06	1.39	1.53	2.44	0.99	0.68	-0.06	1.37
54	O-6/2	-0.47	0.03	0.55	0.7	1.1	1.42	1.67	2.57	1.11	0.66	0.08	1.45
55	O-6/3	-0.89	-0.36	0.16	0.5	0.91	1.29	1.43	2.07	0.83	0.68	-0.11	1.25
56	O-6/4	-1.35	-0.85	-0.34	-0.07	0.56	1.09	1.3	2.01	0.51	0.85	-0.04	1.01
57	O-6/5	-0.97	-0.45	0.11	0.38	0.88	1.32	1.47	2.78	0.82	0.83	0.02	1.42
58	O-6/6	-1.2	-0.57	0.05	0.34	0.86	1.29	1.44	2.49	0.78	0.81	-0.05	1.32
59	O-6/7	-1.05	-0.48	0.05	0.44	0.97	1.35	1.48	2.26	0.83	0.77	-0.17	1.23
60	O-6/8	-1.67	-0.97	-0.45	-0.21	0.55	1.18	1.39	2.14	0.5	0.93	-0.03	0.92
61	O-6/9	-1.6	-0.77	-0.09	0.3	1.02	1.39	1.61	2.36	0.85	0.9	-0.23	1.17
62	O-6/10	-1.43	-0.95	-0.46	-0.16	0.71	1.27	1.44	2.16	0.56	0.95	-0.15	0.89
63	O-6/11	-2.2	-1.57	-0.87	-0.57	0.18	0.94	1.2	1.6	0.17	1	-0.06	0.86
64	O-6/12	-1.55	-1.01	-0.48	-0.21	0.59	1.21	1.41	2.13	0.5	0.95	-0.07	0.91
65	O-6/13	-1.33	-0.66	0.09	0.55	1.19	1.71	2.07	2.7	1.12	1.01	-0.11	1.19
66	O-6/14	-1.73	-0.89	0.16	0.09	0.91	1.43	1.81	2.6	0.82	1.05	-0.08	1.07
67	O-6/15	-1.25	-0.54	0.06	0.49	1.08	1.46	1.82	2.5	0.99	0.9	-0.11	1.29
68	O-6/16	-1.26	-0.65	-0.06	0.28	1.01	1.59	2.13	2.89	1.03	1.09	0.04	1.11
69	O-6/17	-1.04	-0.44	0.35	0.99	2.08	2.7	2.87	3.34	1.77	1.2	-0.35	0.91
70	O-6/18	-0.96	-0.2	1.07	1.37	2.09	2.63	2.82	3.2	1.99	0.95	-0.26	1.11
71	O-6/19	-0.28	1.12	2	2.42	2.78	3.12	3.31	3.64	2.69	0.71	-0.25	1.47
72	O-6/20	-0.25	1.14	2.09	2.42	2.76	3.1	3.3	3.66	2.72	0.68	-0.2	1.52
73	O-6/21	0.33	1.54	2.36	2.58	2.89	3.26	3.41	3.85	2.88	0.61	-0.09	1.38
74	O-7/1	-0.81	-0.18	0.51	0.76	1.2	1.5	1.86	2.61	1.19	0.76	0	1.55
75	O-7/2	-0.78	-0.29	0.34	0.6	1.04	1.38	1.5	2.66	0.96	0.74	-0.05	1.56
76	O-7/3	-0.75	-0.18	0.55	0.74	1.14	1.43	1.68	2.43	1.12	0.68	-0.04	1.53
77	O-7/4	-0.9	-0.31	0.26	0.55	1.01	1.35	1.48	2.37	0.91	0.71	-0.11	1.37
78	O-7/5	-0.95	-0.49	-0.07	0.18	0.72	1.17	1.34	1.79	0.66	0.7	-0.09	0.94
79	O-7/6	-0.92	-0.45	0.01	0.25	0.79	1.27	1.44	2.18	0.75	0.75	-0.02	1.07
80	O-7/7	-1.42	-0.49	0.03	0.39	1.02	1.55	2	2.68	1.02	0.97	0.02	1.12

continued.....

No	Sample	1%	5%	16%	25%	50%	75%	84%	95%	M z	SD	Sk	KG
	0-7/8	-0.95	-0.45	0.07	0.42	1.01	1.41	1.66	2.4	0.92	0.83	-0.1	1.18
	0-7/9	-0.96	-0.34	0.41	0.8	1.41	2.17	2.45	2.89	1.42	1	-0.03	0.96
	0-7/10	-1.1	-0.49	0.09	0.48	1.21	1.93	2.29	2.84	1.2	1.05	-0.02	0.94
	0-7/11	-1.6	-0.8	-0.03	0.41	1.39	2.31	2.61	2.98	1.32	1.23	-0.12	0.82
	0-7/12	-1.42	-0.85	-0.25	0.11	1.16	2.19	2.52	2.94	1.14	1.27	-0.04	0.75
	0-7/13	-1.48	-1	-0.49	-0.2	0.78	1.99	2.38	2.91	0.89	1.31	0.1	0.73
	0-8/1	-0.48	-0.05	0.49	0.62	0.95	1.4	1.7	2.83	1.05	0.74	0.27	1.51
	0-8/2	-0.38	0.13	0.66	0.91	1.34	2.05	2.37	2.86	1.46	0.84	0.16	0.97
	0-8/3	-0.91	-0.28	0.5	0.9	1.41	2.04	2.33	2.81	1.41	0.92	-0.04	1.1
	0-8/4	-1.24	-0.6	0.13	0.59	1.22	1.77	2.08	2.61	1.14	0.97	-0.13	1.12
	0-8/5	-1.45	-0.78	-0.19	0.13	0.9	1.43	1.84	2.6	0.85	1.02	-0.03	1.07
	0-8/6	-1.48	-0.9	-0.38	-0.11	0.68	1.28	1.48	2.32	0.59	0.95	-0.06	0.95
	0-8/7	-1.11	-0.65	-0.15	0.21	1.04	2.11	2.65	3.16	1.18	1.28	0.13	0.82
	0-8/8	-0.42	0.19	0.81	1.07	1.48	2.36	2.65	2.98	1.65	0.88	0.17	0.89
	0-8/9	-1.37	-0.7	0.16	0.68	1.42	2.45	2.71	3.03	1.43	1.2	-0.06	0.86
	0-8/10	-1.34	-0.36	0.82	1.14	1.87	2.61	2.8	3.16	1.83	1.03	-0.17	0.98
	0-8/11	-0.72	0.05	0.86	1.11	1.56	2.56	2.77	3.13	1.73	0.95	0.14	0.87
	0-8/12	-0.85	-0.3	0.47	0.82	1.44	2.56	2.8	3.23	1.57	1.12	0.09	0.83
	0-8/13	-0.92	-0.43	0.05	0.36	1.04	1.84	2.38	3.34	1.16	1.15	0.19	1.04
	0-8/14	-1.49	-1.12	-0.6	-0.3	0.42	1.34	2.02	2.87	0.62	1.26	0.22	0.99
	0-8/15	-1.5	-0.87	-0.32	-0.06	0.71	1.31	1.55	2.47	0.65	0.97	-0.03	1
	0-9/1	-0.39	0.05	0.44	0.67	1.17	1.64	1.96	3.38	1.19	0.88	0.18	1.41
	0-9/2	-0.92	0.01	0.42	0.66	1.18	1.8	2.56	4	1.39	1.14	0.36	1.43
	0-9/3	-0.47	0.02	0.4	0.66	1.2	1.83	2.74	3.92	1.45	1.18	0.35	1.37
	0-9/4	-0.53	-0.1	0.35	0.62	1.17	1.78	2.75	3.69	1.42	1.17	0.32	1.34
	0-9/5	-0.47	0.01	0.49	0.74	1.25	2.04	2.68	3.51	1.47	1.08	0.3	1.1
	0-9/6	-0.62	0	0.41	0.68	1.2	1.72	2.24	3.56	1.29	1	0.23	1.41
	0-9/7	-0.65	0.01	0.37	0.62	1.14	1.49	1.82	2.9	1.11	0.8	0.08	1.37
	0-9/8	-0.73	-0.24	0.31	0.58	1.03	1.43	1.78	3.24	1.04	0.89	0.15	1.67
	0-9/9	-0.95	-0.34	0.16	0.43	1.01	1.41	1.65	2.54	0.94	0.81	-0.05	1.2
	0-9/10	-0.96	-0.74	-0.24	0.05	0.53	1.2	1.38	1.9	0.56	0.8	0.05	0.94

continued....

Sl.No	Sample	1%	5%	16%	25%	50%	75%	84%	95%	M z	SD	Sk	KG
112	0-9/11	-1.33	-0.89	-0.53	-0.27	0.33	1.05	1.28	1.73	0.36	0.85	0.06	0.82
113	0-9/12	-1.03	-0.82	-0.37	-0.08	0.54	1.16	1.36	1.89	0.51	0.84	-0.02	0.89
114	0-9/13	-0.94	-0.54	0.07	0.39	1.17	1.84	2.28	2.84	1.18	1.07	-0.01	0.96
115	0-9/14	-0.96	-0.54	0.17	0.54	1.32	2.15	2.51	2.93	1.33	1.11	-0.03	0.88
116	0-9/15	-0.88	-0.29	0.58	1.03	1.61	2.36	2.65	2.96	1.61	1.01	-0.09	1
117	0-9/16	-0.96	-0.51	0.14	0.46	1.17	1.8	2.25	2.89	1.19	1.04	0.02	1.04
118	0-9/17	-0.69	-0.12	0.39	0.69	1.24	1.83	2.24	2.89	1.29	0.92	0.09	1.08
119	0-10/1	-2.12	0.02	0.57	0.8	1.22	1.63	2.09	3.21	1.29	0.86	0.2	1.58
120	0-10/2	-0.45	0.03	0.53	0.71	1.13	1.46	1.84	2.87	1.17	0.76	0.15	1.56
121	0-10/3	-0.4	0.08	0.57	0.74	1.15	1.49	2	3.2	1.24	0.83	0.25	1.7
122	0-10/4	-0.43	0.06	0.56	0.76	1.2	1.64	2.16	3.71	1.3	0.95	0.29	1.72
123	0-10/5	-1.44	-0.61	0.01	0.38	1.04	1.43	1.74	2.64	0.93	0.92	-0.11	1.26
124	0-10/6	-1.04	-0.32	0.54	0.82	1.28	1.84	2.19	2.77	1.33	0.88	0.03	1.25
125	0-10/7	-1.45	-0.86	-0.31	-0.01	0.76	1.29	1.46	2.36	0.64	0.93	-0.1	1.01
126	0-10/8	-1.56	-0.95	-0.47	-0.23	0.49	1.1	1.31	1.88	0.44	0.87	-0.05	0.88
127	0-10/9	-1.97	-1.06	-0.46	-0.14	0.71	1.34	1.67	2.73	0.64	1.11	-0.02	1.05
128	0-10/10	-0.25	0.94	1.95	2.48	2.88	3.25	3.38	3.69	2.74	0.77	-0.36	1.46
129	0-10/11	-0.3	0.84	2.09	2.5	2.78	3.09	3.25	3.46	2.71	0.69	-0.33	1.83
130	0-10/12	0.17	1.05	1.78	2.22	2.71	3	3.21	3.48	2.57	0.73	-0.33	1.28
131	0-10/13	-0.86	-0.3	0.46	0.93	2.1	2.85	3.06	3.42	1.87	1.21	-0.27	0.8
132	0-10/14	-0.69	0.25	1.3	1.92	2.68	3.04	3.24	3.48	2.41	0.97	-0.46	1.17
133	0-10/15	-0.8	0.2	1.2	1.89	2.88	3.33	3.47	3.9	2.52	1.13	-0.46	1.05
134	0-10/16	-0.26	0.67	1.57	2.32	2.82	3.23	3.39	3.8	2.59	0.93	-0.38	1.4
135	0-10/17	-0.53	0.09	1.05	1.5	2.81	3.31	3.47	3.89	2.45	1.18	-0.45	0.86
136	0-11/1	-0.7	-0.08	0.64	1	1.36	2.05	2.44	2.95	1.48	0.91	0.11	1.18
137	0-11/2	-0.93	-0.32	0.49	0.85	1.36	2.14	2.52	2.98	1.46	1.01	0.06	1.05
138	0-11/3	-0.94	-0.44	0.26	0.69	1.29	2.01	2.44	2.95	1.33	1.06	0.01	1.05
139	0-11/4	-1.32	-0.81	-0.22	0.17	1.07	1.69	2.22	2.91	1.02	1.17	-0.03	1.01
140	0-11/5	-1.25	-0.76	-0.22	0.13	1	1.47	1.94	2.82	0.91	1.08	-0.06	1.1
141	0-11/6	-1.23	-0.69	-0.08	0.35	1.12	1.72	2.23	2.95	1.09	1.13	-0.01	1.09
142	0-11/7	-1.58	-0.95	-0.29	0.22	1.22	2	2.48	2.98	1.13	1.29	-0.1	0.91

continued....

Sl. No	Sample	1%	5%	16%	25%	50%	75%	84%	95%	M z	SD	Sk	KG
143	0-11/8	-1.28	-0.4	0.77	1.13	1.92	2.66	2.86	3.31	1.85	1.08	-0.18	1
144	0-11/9	-0.98	-0.07	1.09	1.45	2.43	2.84	2.98	3.43	2.17	1	-0.43	1.03
145	0-11/10	-0.94	-0.08	1.05	1.39	2.43	2.85	2.99	3.43	2.15	1.02	-0.43	0.99
146	0-11/11	-1.9	-0.4	1.19	1.76	2.62	2.9	3.01	3.45	2.27	1.04	-0.57	1.39
147	0-11/12	-0.44	0.4	0.97	1.21	2.08	2.94	3.21	3.69	2.09	1.06	-0.01	0.78
148	0-11/13	-0.28	0.49	1.02	1.23	2.07	3.01	3.33	3.87	2.14	1.09	0.08	0.78
149	0-11/14	-0.44	0.15	0.75	1.05	1.67	2.89	3.32	3.91	1.91	1.21	0.24	0.84
150	0-11/15	-0.48	0.07	0.75	1.08	1.68	2.69	3.07	3.78	1.83	1.14	0.16	0.94
151	0-11/16	-0.48	-0.13	0.55	0.85	1.41	2.38	2.89	3.72	1.62	1.17	0.23	1.03
152	0-12/1	-0.32	0.35	0.87	1.07	1.39	2.08	2.5	3.38	1.59	0.87	0.34	1.23
153	0-12/2	-0.75	-0.27	0.41	0.7	1.2	1.67	2.05	2.85	1.22	0.88	0.05	1.31
154	0-12/3	-0.96	-0.39	0.27	0.65	1.19	1.58	1.94	2.69	1.13	0.88	-0.06	1.36
155	0-12/4	-0.96	-0.47	0.05	0.37	0.96	1.37	1.56	2.61	0.86	0.85	-0.07	1.27
156	0-12/5	-1.04	-0.77	-0.33	-0.09	0.58	1.37	1.67	2.46	0.64	0.99	0.12	0.91
157	0-12/6	-1.89	-0.7	0.45	1.49	2.53	2.86	2.98	3.37	1.99	1.25	-0.62	1.22
158	0-12/7	-0.93	-0.47	0.37	1.04	2.26	2.91	3.14	3.48	1.92	1.29	-0.38	0.86
159	0-12/8	0.12	1.06	1.59	1.92	2.8	3.3	3.48	3.93	2.62	0.91	-0.25	0.85
160	0-12/9	-1.68	0.09	1.1	1.38	2.21	3.27	3.59	3.95	2.3	1.21	0.01	0.84
161	0-12/10	-1.7	-0.47	0.62	1.03	1.64	2.71	3.12	3.67	1.79	1.25	0.09	1.01

Mz = Mean size, SD = Standard Deviation, Sk = Skewness and KG = Kurtosis.

3.4 MINERALOGICAL COMPOSITION

The heavy mineral placers, usually called *black sands,* are known to occur from many localities along the Indian coast. The minerals, which are commonly formed as placers, are magnetite, ilmenite, monazite, zircon, rutile, diamond, tin, gold etc. Until 1950s the heavy minerals were mainly utilised as a tool in stratigraphic correlation. Nowadays, heavy minerals are also widely used to understand source rock lithology and dispersal pattern and also for reconstruction of paleogeography of particular areas.

Folk (1954) attempted to classify heavy minerals on the basis of texture, provenance and tectonism. Van Andel (1964) studied the transport paths and depositional pattern of sands o signify various river sources, relying on the capacity of contrasting mineral ssemblages. The work carried out by Leupke (1980) showed effectiveness of heavy inerals in comparing the source and sorting effects of the sediments. Komar et al. (1984) ilised heavy minerals to understand the interrelationship of grain size and grain density o the concentration process of heavy minerals.

epke and Clifton (1985) attempted to distinguish depositional characteristic of the odern and ancient deposits. The conditions that favour placer concentration and their draulic sorting and settling processes were discussed by Slingerland and Smith ~~et al~~. (1986). The rting process and dispersal pattern of heavy minerals were studied by Komar and Wang 984), Clemens and Komar (1988) and Komar et al. (1989). Several studies have been arried out to understand the nature of heavy minerals from various environments in ifferent parts of the world (Burns, 1979; Beiersdorf et al., 1980; Meyer, 1983; Peterson al., 1985; Wickremiratne, 1986).

pper (1914) who attempted a study of monazite sands of Travancore was the pioneer as r as the study of heavy minerals in India is concerned. Origin of the heavy minerals in e beaches of southwest coast of India was dealt by Aswathanarayana (1964). Prabhakar ao (1968) studied the heavy mineral concentration in the near shore portions of south erala. Mallik (1974) gave an outline on the nature and origin of heavies in beaches and ffshore areas. He explained their origin and studied their economic potential and ploration patterns and methods. Based on the heavy mineral assemblages of the coastal eas and rivers, Mallik et al. (1987) recognised four distinct heavy mineral provinces in e Kerala coast.

avy minerals are not only used in deciphering the provenance and their dispersal ttern, but also in understanding the dissolution phenomenon and in paleogeographic construction (Gardner, 1981; Pye, 1981; Morton, 1985; ~~Pye and Gardner, 1981~~). The avy minerals that occur within a particular sedimentary sequence is governed by local hydraulic processes that operate at the time of deposition. These processes are found to vary over wide spatial and temporal framework.

Here an attempt is made to understand history of post-depositional transformations of coastal plain deposits from the detailed analysis of heavy minerals.

3.4.1 Heavy Mineral Composition

Based on the analysis of textural characteristics of the sediments of the two transects, different litho facies were identified. Samples that yielded specific textural signatures of different depositional regime viz., strand plain, riverine, near shore and beach sediments were selected for heavy mineral analysis. Tables 3.4 and 3.5 show percentage of heavy minerals in different environments. In Onakkunnu transect percentage of heavy minerals varies from 0.20% to 32.40%, with an average of 16.20%. Heavy mineral percentages of Punjavi transect ranges from 14.40% to 82.5%, with an average percentage of 45.67%. In this transect, the percentage of stable minerals like rutile, zircon, ilmenite and sillimanite account for about 52.05%, a value, which lesser than that of the Onakkunnu transect.

The beach samples such as, *P2/7, P3/15, P4/10,* and *P5/14* in Punjavi transect and samples like *O3/7* and *O6/13* in Onakkunnu transect are composed of relatively high percentage of ferromagnesium minerals. Some of the core samples, such as, *O6/1, O9/2, O10/11, P1/3, P2/1, P7/2* and *P8/4* that correspond to the strand plain sediments are orange yellow coloured or deep red coloured.

3.4.2 Heavy Mineral Provenance

The parameters that can influence the composition of heavy mineral suites in different environments are source area mineralogy, weathering and mechanical processes during their transit, hydraulic conditions during deposition and diagenesis (Morton, 1985). In the interrelated environments, where the sediments are derived mainly from fluvial-sources, the process-response of heavy mineral variability should be analysed by taking into consideration the infra-basinal hydraulic conditions during deposition and its subsequent diagenetic changes.

In the beach, heavy minerals are concentrated by waves and wave induced littoral currents. Minerals of different size, shape and density are transported onshore by suspension and bottom drag by the prevailing longshore/onshore currents. Under the strong turbulence of wave action, these minerals are transported onshore by the advancing waves. The denser heavies that cannot be transported by retreating waves are retained in the beach. The gravitational force of the retreating waves is not strong enough to carry back denser heavies. Comparatively light heavy minerals such as, hornblende and hypersthene are carried further offshore. Such selective transport of heavy minerals, ultimately result in relative enrichment of opaque and other denser heavies in the beach. Along with the denser heavies, the lighter ones that are larger in size and hydraulically equivalent to that of heavies also get deposited in the beach. Along the two transects, three perennial rivers, namely Valapatnam, Nileswaram and Karingote debauches into the sea the details of which are given in Table 1.1.

From the detailed study of heavy mineral abundances in Valapatanam, Nileswaram and Karingote rivers and also from beach and strand plain, the study area is found to contain heavy minerals in the following order of abundance: hornblende, opaque, garnet, hypersthene, monazite, rutile, epidote and clino-pyroxene, zircon, sillimanite and biotite. The hinterland consists of crystalline rocks of Archaean age, sediments of Tertiary age, laterite capping on crystallines and sediments of sub-Recent to Recent-age. The crystalline rocks include charnockite, khondalite, granite gneisses and unclassified meta-volcanics. Hornblende and biotite-gneiss occur locally and are resulted from the retrograde metamorphism and migmatisation of biotite gneiss. Laterite is the product of residual chemical weathering of both crystalline rocks and Tertiary sediments and form flat-topped hills and ridges of Recent age.

In the study area hornblende and hypersthene are derived mainly from charnockite in the hilly ranges of Western Ghats. Opaques are not only derived from charnockites but also from variety of other types mentioned hitherto. Garnet and zircon are derived from khondalites and rutile from charnockites and from the alteration of ilmenite. Monazite is derived from charnockites and khondalites. Mallik et al (1987) identified five heavy mineral provinces in the beaches of Kerala from north to south viz. mixed mineral provenance with opaque-zircon-hornblende, garnet-sillimanite-epidote, garnet-hypersthene, opaque-zircon and opaque-zircon-monazite. Of these, the study area is identified as opaque-zircon-hornblende heavy mineral provenance with garnet, sillimanite and epidote.

3.4.3 Red Sands and Environmental Significance

As explained in the preceding section, the two transects have distinctive geomorphological set up, details of which are illustrated in the previous chapters. One of the characteristic features of the Onakkunnu transect is occurrence of red sands. The red dune deposits are not only seen as surface exposures (*refer cores O-6, O-7, O-8, O-9, O-10*; Plate VIII), but as evidenced from the cores (*refer core O-5, O-11, O-12*) it occurs as sub-surface deposits also. This indicates prolonged sub-aerial exposure of the sediments to weathering during different stages of its deposition.. Yellowish coloration is manifested in ridges along the Punjavi region (Plate IX). Coloration, though considered as a general guide to the age of the tropical coastal deposits, there exists considerable variations in the factors that contribute to the intensity and age of weathering processes, which finally result in reddening of sands. Prime significance of these deposits in Quaternary studies is that it is considered as paleo environmental indicators of terrestrial sequences. Different stages of their development are also useful in paleo environmental interpretations.

On comparing the sediments of strand plain, beach, river and innershore, wide variations in different mineral constituents are discernible. Evidently, most of the strand plain sediments are dominant in stable minerals such as opaque, rutile and zircon, whereas, the beach sediments consists almost of equal proportion of opaque and hornblende. The river sediments are found to be rich in biotite and hornblende.

Reduction in the proportion of relatively less stable minerals such as hornblende, hypersthene and garnet in the Onakkunnu sediments and reddening of the sands points to the fact that, compared to Punjavi sediments, the former had undergone an effective weathering processes leading to the liberation of iron from the less stable heavy minerals. It was shown elsewhere (Pye, 1981; Gardner, 1983) that weathering of minerals such as ilmenite to a significant degree could contribute to reddening of subsurface sand. It was also shown that progressive weathering phase ultimately result in leaching. At later stage, the dark brown colouration is lost by oxidation of humate, leaving behind the grayish-white residual sand (Pye, 1981; Gardner, 1983; Haneesh Kumar et al., 1999).

Most of the studies on *insitu* weathering attribute the source of iron to easily weathered iron-bearing silicates such as amphiboles, pyroxenes and micas (Walker, 1967; Walker et al., 1978). Higher percentage of stable minerals in the Onakkunnu region further corroborates this observation. Samples of different environment which have a similar series and stability zones, owe their existence and character to selective removal of less stable minerals (Pettijohn 1957; Blatt and Sutherland, 1969). Thus relative dominance of stable minerals over the unstable minerals would probably indicate a dissolution phenomenon, where, the unstable minerals are removed by solution, thereby enriching the deposit with stable minerals.

Colour of coastal dune sediments are dependent on several variables such as availability of iron in humid and oxidising conditions, thickness of iron oxide coating, time of exposure and degree of iron oxide hydration (Soileau and Mc Cracken, 1967; Norris, 1969; Swift and Boehmer, 1972). Redness can only be a general guide to sediment age, though progressively older deposits may be distinctly redder. Norris (1969) and Setlow (1979), considered disintegration and dissolution of ferromagnesium minerals as the likely source of iron for reddening of the coastal sands.

Generally, weathering is facilitated when the dunes are no longer active, either because the sand supply has diminished or as a result of a change in climate to wet conditions. Although reddening can occur under relatively dry conditions, it requires much longer period of time than under more humid conditions. Unfortunately, the rate of both weathering and the development of a red colour are highly variable according to mineralogy and climatic regime. Gardner and Pye, (1981). Schmalz (1968) and Williams and Yaalon, (1977) attributed rate of reddening to stability of heavy minerals, amount of iron in host mineral and the micro-environmental conditions, which include sufficient moisture for hydrolysis and an oxidising environment.

Plate VIII **Surface exposure of red sand**

Plate IX **Subsurface exposure of orange yellow sand**

[illegible]	[illegible]	P1/18	[illegible]	P2/1	P2/7	[illegible]	P3/15	P4/10	P5/14	P7/2	P8/4	P9/9
Core depth	1.3 m	6.3 m	9.45m	0.8 m	8 m	1.55 m	9.6 m	3.8m	8.65 m	1.15 m	2.9 m	7.95 m
Environment	strand plain	river	near shore	strand plain	beach	strand plain	beach	beach	beach	strand plain	strand plain	estuarine
Total heavy%	43.62	28.28	16.7	62.29	13	82.6	21.41	14.73	6.89	50.18	29.15	22.55
Opaque	61.15	31.67	11.8	48.1	20	44.41	25.73	18.95	20.12	42.19	44.35	23.95
Hornblende	4.23	19	32.18	20.96	51.89	24.12	34.47	30.53	42.07	18.75	17.57	19.16
Hypersthene	1.54	8.14	10.89	0.95	1.62	2.1	4.37	5.96	1.83	4.17	2.51	2.99
Sillimanite	4.62	14.48	20.3	2.38	10.81	7.69	13.59	7.72	4.88	6.77	6.28	18.66
Garnet	13.46	9.95	6.93	14.76	4.86	9.09	9.71	14.04	10.37	15.1	15.9	12.87
Rutile	3.46	4.98	0.5	2.38	1.62	1.4	0	0	0	2.6	0.84	1.5
Zircon	5	8.14	4.46	1.9	2.16	3.85	5.34	12.63	7.93	5.73	4.18	10.18
Monazite	2.69	0.45	0.99	2.86	2.7	2.8	2.43	2.46	6.71	2.6	3.77	1.8
Epidote	0	0	0	2.38	0	1.4	0.49	0	1.22	0	0	1.2
Biotite	0.77	0	4.46	0	0	1.75	0	3.51	1.83	0	0	2.99
CPX	0.38	0.45	0.5	0	1.62	0	1.46	0	0	0	2.09	0
Others	2.69	2.71	6.93	3.33	2.7	1.4	2.43	4.21	3.05	2.08	2.51	4.49

Table 3.4 Percentage abundance of heavy minerals in the strand plain, beach, nearshore, estuarine and river sediments in the coastal plain area of Punjavi Transect

Sample name	O1/6	O2/1	O3/7	O5/5	O6/1	O6/13	O6/21	O7/6	O8/6	O9/2	O10/11	O11/3
Depth	4.75 m	0.7 m	4.95 m	3.9 m	0.45 m	6.8 m	10.6 m	4.5 m	5.25 m	0.85 m	7.3 m	1.35 m
Environment	strand plain	strand plain	beach	strand plain	strand plain	beach	near shore	river	river	beach	beach	beach
Total heavy%	22.79	20.24	19.3	15.63	9.16	26.31	10.68	20.04	29.6	32.37	12.84	25.77
Opaques	24.35	11.48	27.13	38.87	60.77	25.11	37.42	27.87	48.45	33.13	41.57	55.43
Hornblende	31.3	33.88	27.91	18.62	7.18	22.83	23.87	24.26	14.09	10.63	5.23	0
Hypersthene	1.74	1093	5.81	1.62	0.49	12.33	0.65	6.23	1.03	6.88	0.87	0
Sillimanite	9.57	20.77	10.47	9.72	4.78	12.33	9.03	17.38	12.03	13.75	16.86	19.38
Garnet	16.52	3.28	10.108	9.72	0.96	0	1.94	4.92	2.06	15.63	2.62	0.78
Rutile	0.87	1.64	1.55	1.62	3.83	3.65	0.65	10.16	1.72	4.38	3.49	1.16
Zircon	7.83	12.02	7.75	11.34	11.96	10.5	12.9	1.64	14.43	4.38	20.64	18.6
Monazite	4.35	1.09	5.81	4.05	5.26	0.91	3.23	0.98	2.06	4.38	2.33	1.55
Epidote	0	1.09	0	0	0	0.91	3.23	1.97	0.69	0	0.87	0
Biotite	0	2.73	0	0	3.35	0.91	0	0	0.34	0	0.87	0
CPX	0	0	0	0	0	3.2	0	0	0	0	0	1.16
Others	3.48	1.09	3.49	4.45	1.44	7.31	7.1	4.59	3.09	6.88	4.65	1.94
Total	100	100	100	100	100	100	100	100	100	100	100	100

Table 3.5 Percentage abundance of heavy minerals in the strand plain, beach, nearshore, estuarine and riverine sediments collected from the coastal plain area of Onakkunnu Transect

Chapter 4

CONTINENTAL SHELF SEQUENCES

4.1 BACKGROUND

The continental shelf represents a complex environment of sedimentation, where the sediments reflect general character of the materials deposited over a period of time. The terrestrial sediments along with the material produced *in situ* by organisms and those contributed by anthropogenic activities are redistributed in the shelf. Further, shelf sediments are also affected by a series of Quaternary fluctuations, thus resulting in sediments consisting of various proportions of relict, reworked and modern sediments. It is a well-known fact that all coastal areas around the world have been affected to some extent by series of sea level changes during the Quaternary. One of the driving forces for such fluctuations is the climatic variation that the earth has undergone during the geological past. Several studies were carried out to enumerate the rate of sedimentation, sea level changes and climatic records from the lithological and fossil constituents of sediments (Balsom, 1981; Beard et al., 1982; Eronen et al., 1987). Investigations of similar nature were also carried out along the southwestern shelf of India (Nair, 1974; Nair and Hashimi, 1980; Gupta and Hashimi, 1985; Nambiar and Rajagopalan, 1995; Reddy and Rao, 1992).

Topographic studies on the outer shelf of the western continental shelf indicated small scale irregularities of the order of 1-8 m in height at depths between 35 m and 140 m (Nair, 1975; Wagle et al., 1994; Subbaraju and Wagle, 1996). The most prominent ones occur between 50 m and 115 m at 50-60 m, 65-70 m, 75-80 m, 85-90 m and 110-115 m. These reefs are categorized into wave cut terraces, coral/algal reef induced terraces and paleo beach/barrier terraces and their evolution has been ascribed to reef growth progradation and wave activity during the low stands of sea level in the late Quaternary.

Nair (1974) considered the shelf as an example of a drowned coast, formed due to successive transgressive and regressive episodes. The sediment facies in the shelf embody both ancient and modern sediments presently remain inundated by reworking processes. Nair et al. (1978) and Hashimi et al. (1978) identified three distinct sedimentary facies, the first two consisting of sand and mud which are of Recent origin, while the third outer shelf relict carbonate sand facies of late Pleistocene (8,000-11,000 YBP) formed at the time of low stand of sea level. From the study of carbonate sediments and size of the quartz grains, Nair and Hashimi (1980) inferred a warmer climate and low terrestrial run off during the Holocene (about 10,000 YBP). Further, feldspar content in the sediments have also been used to infer the climatic aridity over India 11,000 years ago (Hashimi and Nair, 1986). These evidences indicate contrasting climatic changes in the deposition of the carbonate and clastic sediments on the shelf, thus suggesting rapid changes in climate from arid to humid. A review article by Rao and Wagle (1997) gives an elaborate account of the geomorphology and the surficial sediments of the continental margins of India.

Though the distribution of surficial sediments and the inferences thereon over the southwestern shelf of India has been well attempted, studies relating the past sea level changes, climatic oscillations and sedimentation rates within the shelf sequences are limited. There are a few studies reporting the sedimentation rates along the western shelf (Borole et al., 1982; Borole, 1988). Especially along the southern part of western shelf, sedimentation rates computed for cores off Taingapatnam, Ponnani, Karwar and Vengurla range from 0.11 mm/yr to 1.0 mm/yr (Nambiar et al., 1991; Manjunatha and Shankar, 1992; Nambiar and Rajagopalan, 1995). However, Rao and Wagle (1997) contested the usefulness of the peat data of Nambiar and Rajagopalan (1995) since younger age peat was located at deeper depth interval from greater water depths. Recent observations on sediment accumulation during the late Quaternary include the study on high-grade phosphorite deposits of Pleistocene origin in a core from continental slope off Goa (Rao et al., 1995) and the preservation potential of organic carbon in the sediment cores retrieved from the upper continental slope (Thampan et al., 1997). Rao et al. (1996) brought to light some of the evidences for late Quaternary neotectonic activity along the western shelf.

In the present investigation an attempt is made to study the shelf deposits, so as to have a better understanding of the late Quaternary episodes that the shelf has witnessed by collecting core samples along two shore-normal transects along the continental shelf off northern Kerala. The width of the continental shelf in Punjavi transect is 78 km whereas, in Onakkunnu transect it is about 74 km.

4.2 METHODOLOGY

The data base for this study is nine gravity cores collected during the 117th cruise of FORV Sagar Sampada at water depths ranging from 30.2 m-151 m off Pallikkare and Kavvayi and a piston core collected at approximately 40 m water depth (Figs 4.1), the details of which are summarised in the Table 4.1. Sub-sampling was done at 5 cm interval. Alternate sub-samples were taken for textural analysis. One part of the sample was subjected to textural analysis by dry sieving and pipette method (Carver, 1971). Sediments are categorized based on their textural attributes, viz., percent constituents of sand, silt and clay (Shepard, 1954). The other part was made salt-free by washing in distilled water, dried at about 60° C and pulverised to determine organic matter and $CaCO_3$ content. Organic matter was determined following the method of El wakeel and Riley (1957) and $CaCO_3$ by the method of Hutchinson and Mac- Leman (1947). Bathymetric profile of the shelf areas are depicted in Fig 4.2.

Table 4.1 Details of core sample collected from the continental shelf area, distance from the shore (in km), water depth (in m) and core length (in cm).

Transect	Core	Distance from shore	Water depth	Core length
Punjavi	S-1	78	151.0	128
	S-2	54	086.5	062
	S-3	33	061.4	136
	S-4	20	040.0	273
	S-5	11	030.2	173
Onakkunnu	S-6	18	040.0	162
	S-7	32	059.0	052
	S-8	53	079.7	049
	S-9	64	118.1	120
	S-10	74	150.5	135

4.3 SEDIMENTARY FACIES

Colour of the sediment show marginal variation from gray to olive gray. Textural attributes of the surficial sediments are presented in the Figure 4.3. Table 4.2 & 4.3 shows the percentage of sand, silt, clay, calcium carbonate and organic matter of sediment samples

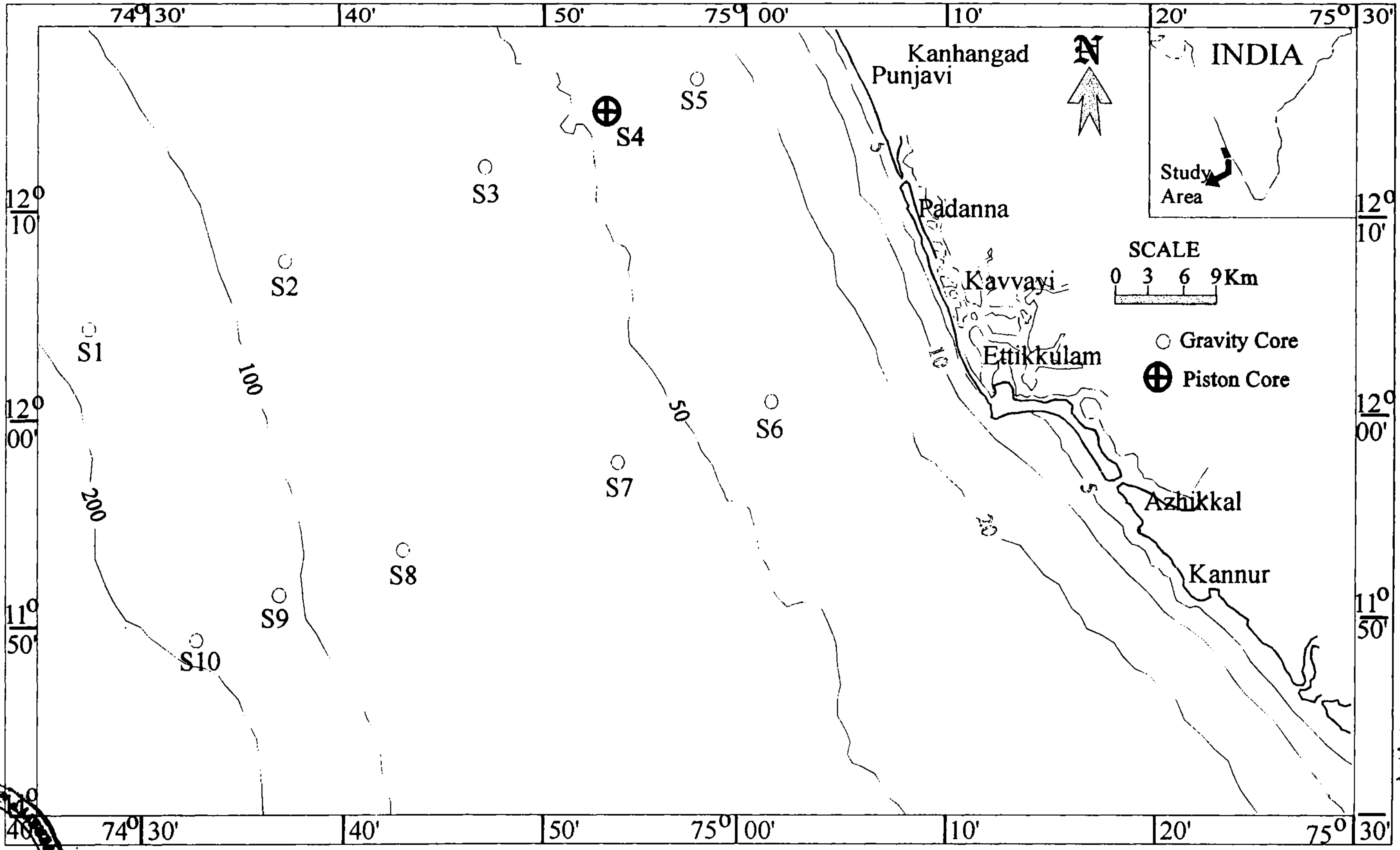


Fig. 4.1 Map showing bathymetry and sampling locations with continental shelf of the study area

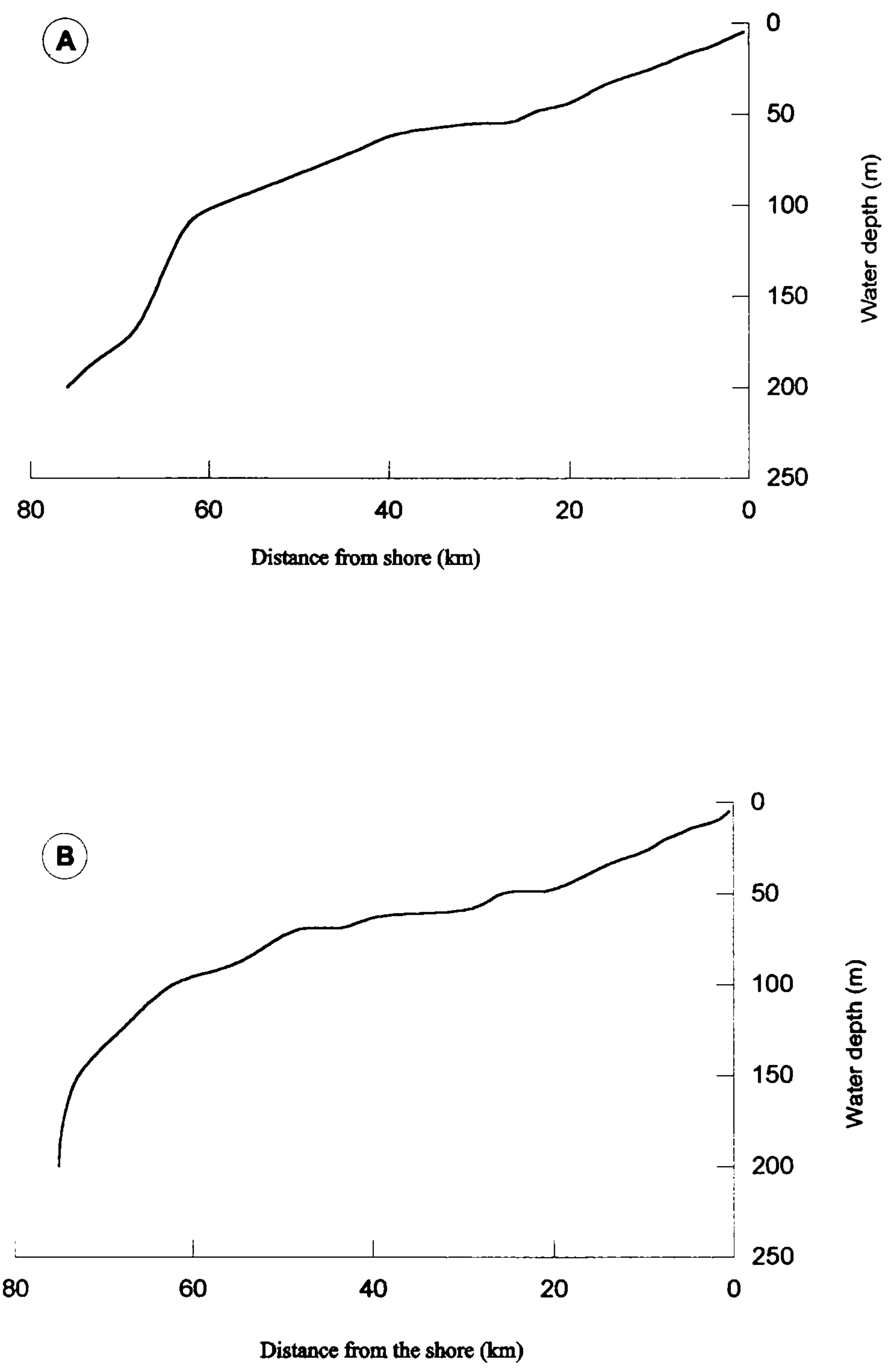


Fig.4.2 Profiles of continental shelf off (A) Punjavi and (B) Onakkunnu

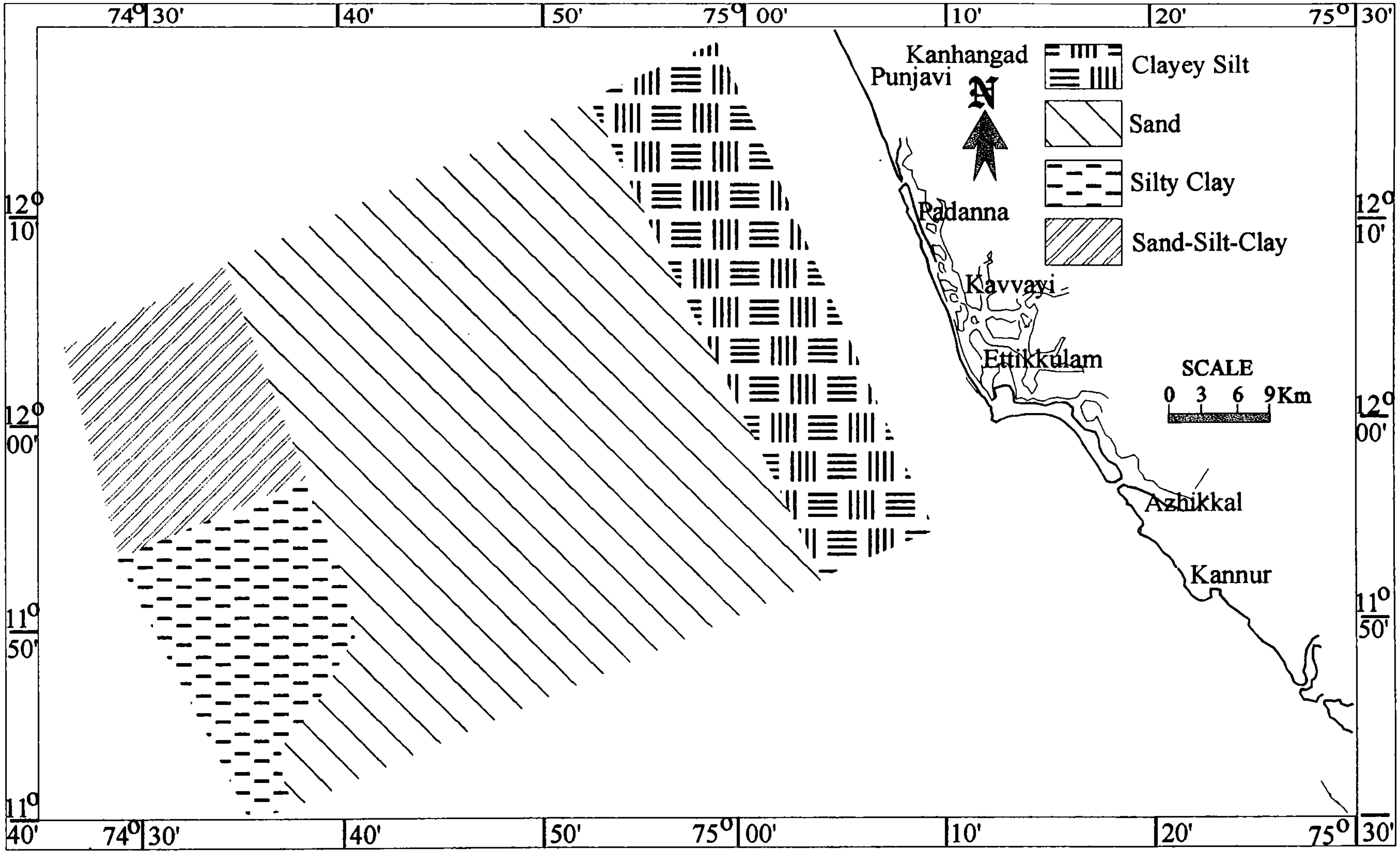


Fig. 4.3 Sediment distribution map of the continental shelf

collected from the continental shelf. Three major sedimentary units can be identified on the shelf. The innershelf region is dominated by clayey silt, which is restricted to 40 m isobath. In the mid-shelf, a wide expanse of sharply contrasting sediments rich in sand is observed. The steeper outershelf is abundant in clay with both silty clay and sand-silt-clay textural grades distributed over it. Most of the samples contain shells and shell fragments of bivalves, pteropods, echinoids, gastropods and forams, however in varying proportions in different lithological units. Compared to the innershelf, shells and microfossils are abundant in the outershelf. Traces of peaty material are reteieved from *S-3* core.

4.3.1 Sedimentary Facies-Punjavi Transect

Five cores ranging in length from 0.62 to 2.73 m were taken from this transect. Down-core variations in granulometric characteristic, organic carbon and calcium carbonate percentage of Punjavi transect are given in the Table 4.2. The individual description of each core is described below.

Core S-1: The top 75 cm of the core is composed of sediments with considerable amount of sand, below which sediments are clayey in nature. The 15 sub-samples analysed for texture yield sand percent range of 0.2 to 24.85%. The silt and clay content ranges from 23.58 to 86.65% and 0.81 to 64.91% respectively. Textural classification and the down-core distribution of textural grades are depicted in Figure 4.4. Sediments show various levels of mixing, thereby exhibiting heterogeneity in the percent of constituents of different textural grades. Specifically, the top 75 cm column consists of clayey silt (except the 20-25 cm layer that consist of sand-silt-clay) and the bottom unit is predominant with silty clay. The sand content becomes insignificant in the bottom unit. Whereas silt and clay show a complimentary pattern of distribution, the silt being dominant in the top layer.

Core S-2: Being a sand dominant area, the core recovery was poor. There is hardly any variation in the lithological assemblage. The 7 sub-samples analysed for texture yield marginal variation in terms of sand (88.66 to 92.02%), silt (0.22 to 4.08%) and clay (6.83 to 10.16%) content. Figure 4.5 depicts the textural classification and the downcore distribution

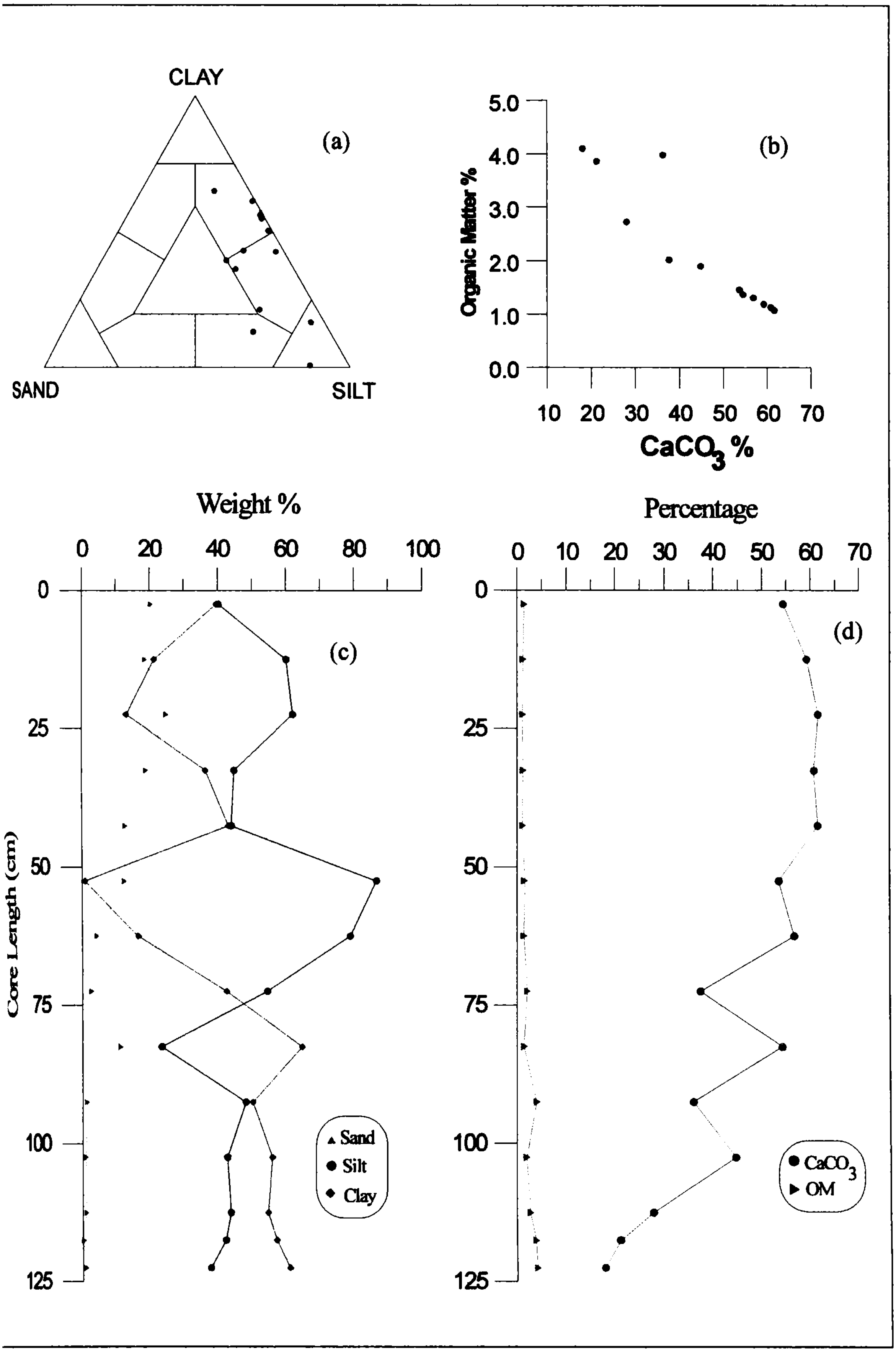


Fig.4.4 Plot of (a) textural classification, (b) organic matter Vs Calcium carbonate, downcore variation of (c) sand-silt-clay and (d) calcium carbonate and organic matter in the core S-1

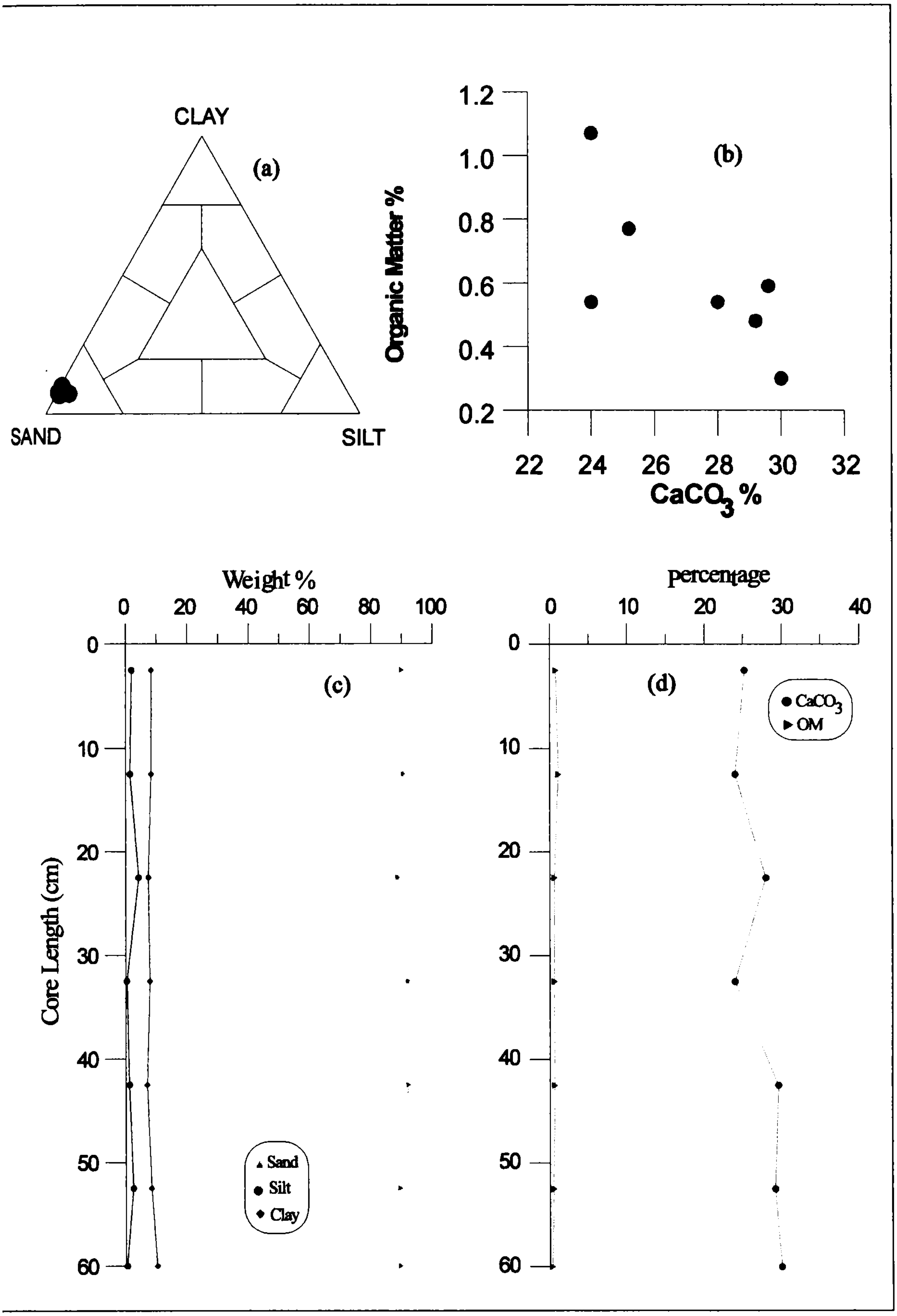


Fig.4.5 Plot of (a) textural classification, (b) organic matter Vs Calcium carbonate, downcore variation of (c) sand-silt-clay and (d) calcium carbonate and organic matter in the core S-2

of textural grades.

Core S-3: The top 90 cm of the core constitutes nearly 90% of sand, which gradually decreases to <20% in the downcore segments. The 14 sub-samples analysed for texture yield sand percent range between 16.41 and 89.29. The silt and clay content range from 2.61% to 57.46 and 5.81% to 39.26% respectively. Textural classification and the downcore distribution of textural grades are depicted in Figure 4.6. Downcore variations of silt and clay distribution demonstrate a near uniform pattern in the upper portions, whereas silt dominate over the clay in the deeper levels. Considerable level of mixing has been observed among the different textural grades. The abrupt depletion in sand percentage at about 85 cm is striking. Incidentally, the zone below this is characterised by traces of peaty material (core depth between 92.5 cm to 122.5 cm). Besides, silt content manifest higher proportion over sand and clay.

Core S-4: This piston core was obtained from Geological Survey India, Mangalore Unit. The texture of the sediments shows distinct differences between the upper and lower portions of the core (Fig. 4.7). Based on these differences, the core is divided into two contrasting units, the boundary of which is remarkable at around 170 cm of the core length. The upper unit is characterised by insignificant quantity of sand and the lower unit is remarkably rich in sand. This is quite evident from the wide range of sand content in the sediments (0.142 to 87.37%). Clay is the dominant fraction (nearly 60%) followed by the silt (<40%) in the upper unit and the sediment falls in the silty clay category. In the lower unit, silt and clay together constitute only <20%, whereas the sand content peaks to >80% and hence the sediments are categorized as sand (Fig 4.8). The range of silt and clay in the entire length of the core is 2.97-50.11% and 7.98-64.57% respectively.

Size parameters: The core S-4 being the longest, having a length of 273 cm. detailed textural analysis was performed on the 29 sub-samples to understand the environmental significance of the sediment deposition through time. Graphic parameters namely, mean size, standard deviation, skewness and kurtosis (Folk and Ward, 1957) are used here to describe the granulometric significance.

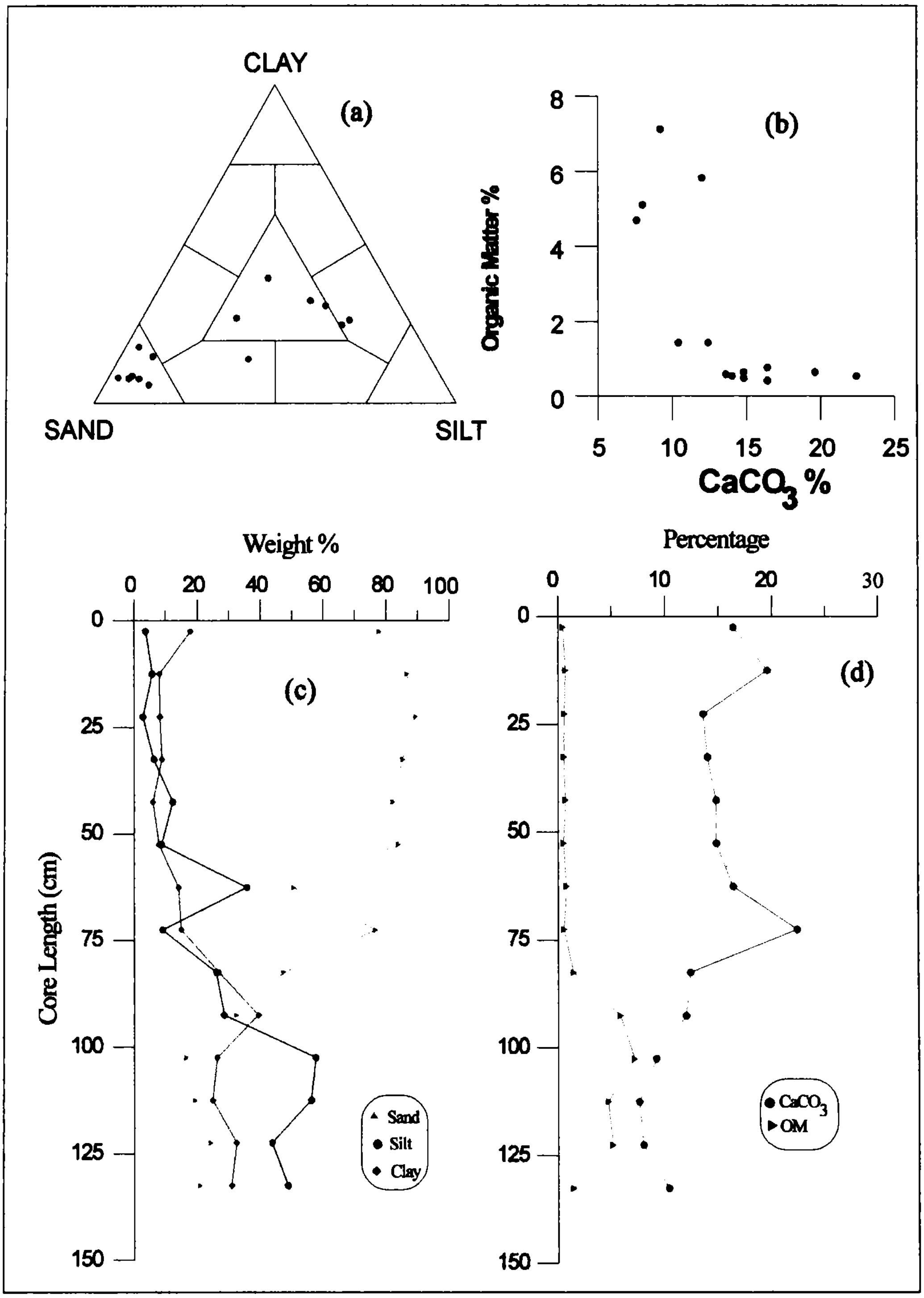


Fig.4.6 Plot of (a) textural classification, (b) organic matter Vs Calcium carbonate, downcore variation of (c) sand-silt-clay and (d) calcium carbonate and organic matter in the core S-3

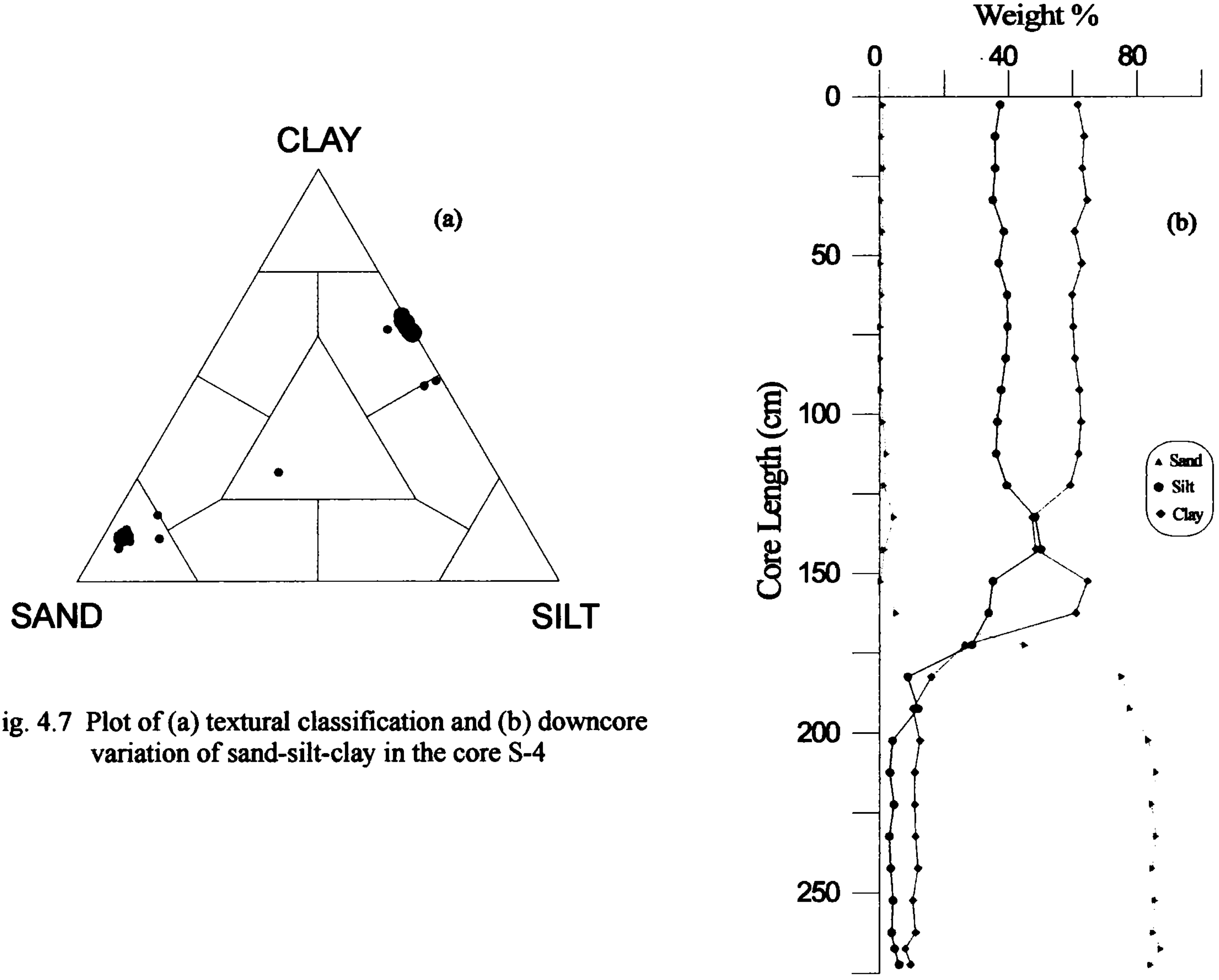


Fig. 4.7 Plot of (a) textural classification and (b) downcore variation of sand-silt-clay in the core S-4

As evident from the sediment built up described above, the size parameters of the sediments reveal separation between the top and bottom units (Fig 4.8). In the top unit the mean size fluctuates between 9.2 ϕ and 10.2 ϕ. The sediments are very poorly sorted, nearly symmetrical to positively skewed and very platykurtic to platykurtic in nature. Whereas, in the bottom unit the mean size varies between 2.63 ϕ and 4.23 ϕ. Though the sorting index of the sediments in the bottom unit is within the very poorly sorted category, they are better sorted than the overlying mud unit. This unit is characterised by very positively skewed and mesokurtic to very leptokurtic sediments.

Scatter plots: Geological significance of scatter plots of the size parameters is widely known. It gives an insight into the niche of depositional regimes. In collusion with other environmental parameters, the interpretation of such plots provides meaningful inferences on hydraulic processes. On the whole, a combined picture of the dynamics of transportation can be elucidated from the scatter plots of the graphic measures. The scatter plots are shown in the Figure 4.9.

Mean size Vs standard deviation: The trend of the scatter plot shows an inverted 'U' shape with a truncated right limb. According to Folk and Ward (1957) if the plot represents a wide range of grain sizes (gravel to clay), the scatter can form a broadened 'M" shaped curve. Since the samples plotted belong to sand and mud texture, only right-hand portion of the 'M' curve is represented. Inman (1949) and Griffiths (1951) pointed out that, sorting is rather a closely controlled 'V' shaped sinusoidal function of mean size. In this core, poorest sorting is observed for samples having a mean size of around 6 ϕ. Sorting improves towards coarser and finer ends. Samples, which fall at the lower end of the left limb having a mean size of around 2 ϕ are moderately sorted. The clay rich truncated right limb shows improvement of sorting from very poorly sorted to poorly sorted.

Mean size Vs skewness: The diagram shows an inverted 'U' shaped trend with a truncated left arm. The sediments are increasingly positively skewed in the mean size range of 2 ϕ to 6 ϕ. Folk and Ward (1957) and Cronen (1972) pointed out that skewness is very closely a

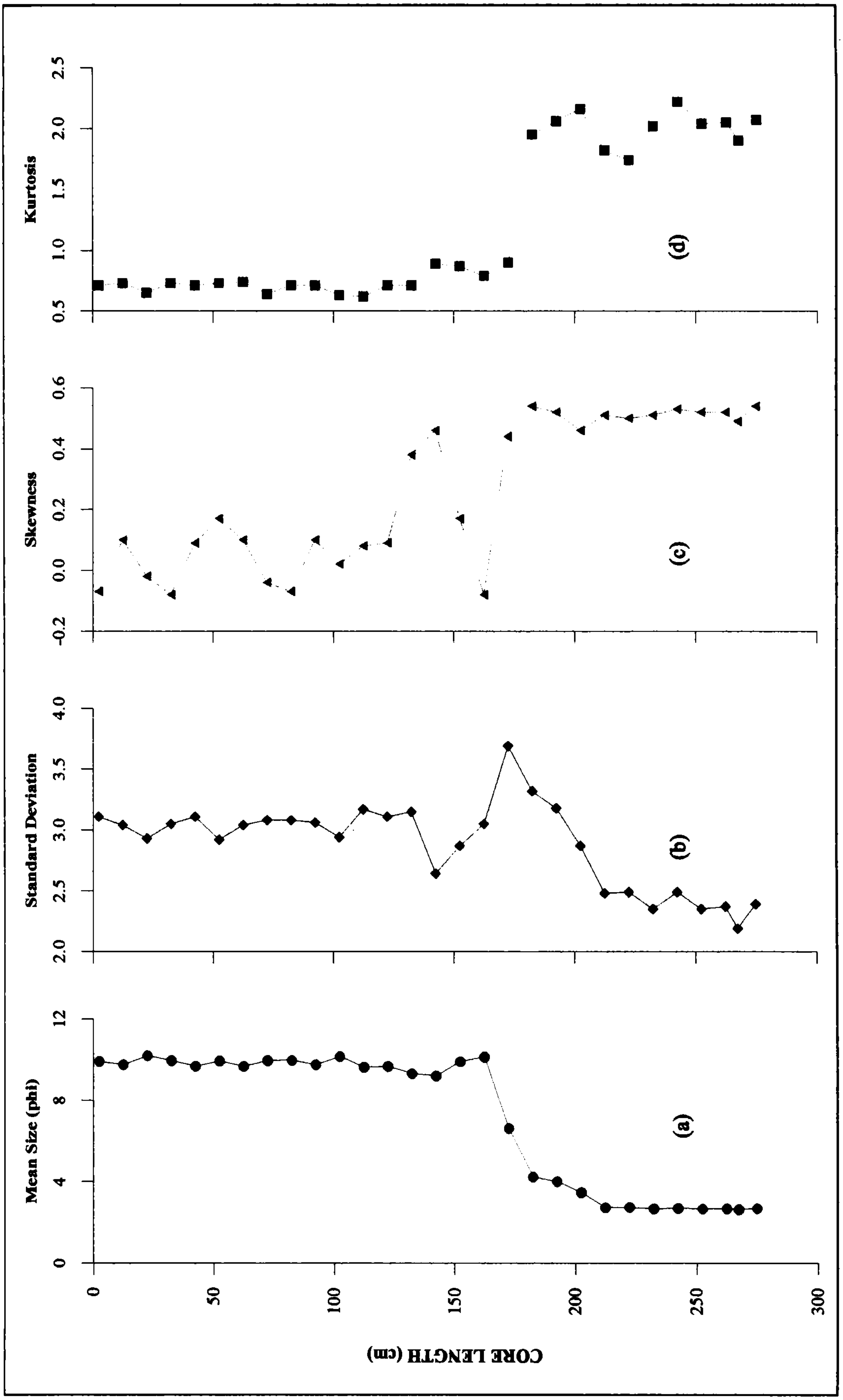


Fig.4.8 Vertical variation of (a) Mean, (b) Standard Deviation, (c) Skewness and (d) Kurtosis of Core S-4

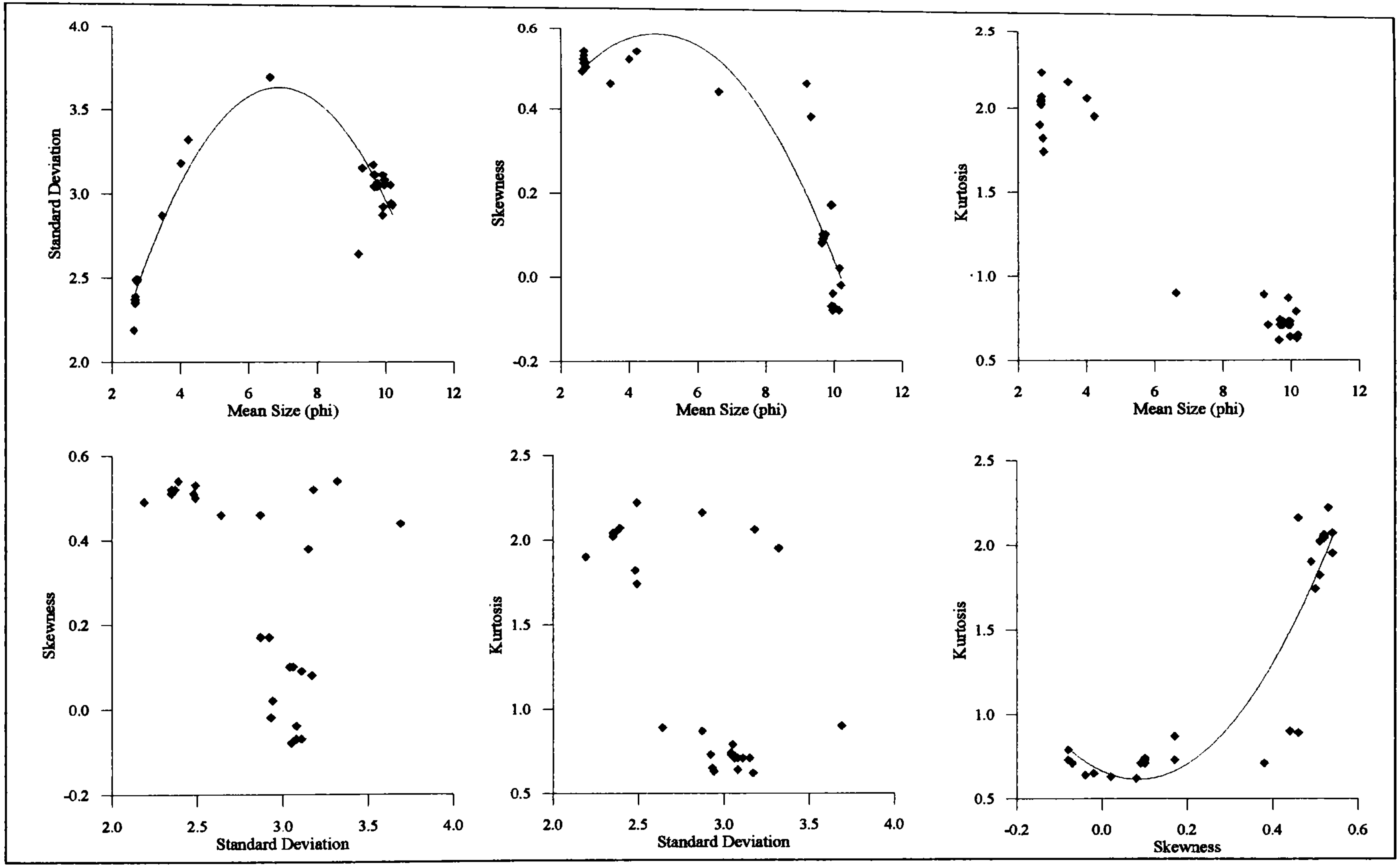


Fig. 4.9 Scatter plots of size parameters in the core S-4

function of mean size and the trend is sinusoidal in nature. It is obvious that with addition of coarser materials to the fine, the sediments become symmetrically skewed. Whereas, with subsequent addition of finer sediments, the right arm crosses over the boundary of symmetry to negatively skewed side. Hence, the asymmetry of the curve in these samples is mainly controlled by sand and clay modes. The positively skewed portion of the curve represents samples, which are predominant in sand modes with a tail of fines. The negatively skewed sediment population at the lower end of the right limb indicates an excess of clay mode with a tail of coarse.

Mean size Vs kurtosis: Definite pattern in terms of coarser and finer mean size is evident from the plot. Sediments dominant in sand are mesokurtic to very leptokurtic and that of clay are very platykurtic to platykurtic. Highest kurtosis value is in between mean size value of 2 ϕ to 4 ϕ. The sediments having mean size range between 9 ϕ to 10 ϕ are with minimum kurtosis values. The plot indicate that the frequency distribution of grain size in the sand-rich sediments are restricted to limited number of size classes, whereas, the clay-dominant sediments represent wide spectrum of textural classes.

Standard deviation Vs skewness: No definite pattern is observed in this plot. As standard deviation versus mean and mean versus skewness are showing definite relationships, theoretically, skewness should also yield some relationship with standard deviation. But the trends observed are complex. In similar situations, Folk and Ward (1957) and Mc Kinney and Friedman (1970) have reasoned that it could be due mixing of different modes of population. The scatter trend given by Folk and Ward (1957) was nearly a circular ring. The plot indicates that better sorted samples (mostly coarser sediments) show a very small fluctuation in the skewness values (very positively skewed). The symmetrical nature of the sample clusters around sorting value of 3 should not be mistaken for a perfect Gaussian distribution, instead they represent sediment regimes of mixed modal populations.

Standard deviation Vs kurtosis: The figure gives an irregular pattern similar to that of Standard deviation Vs Skewness. Interestingly the same set of clusters that has indicated

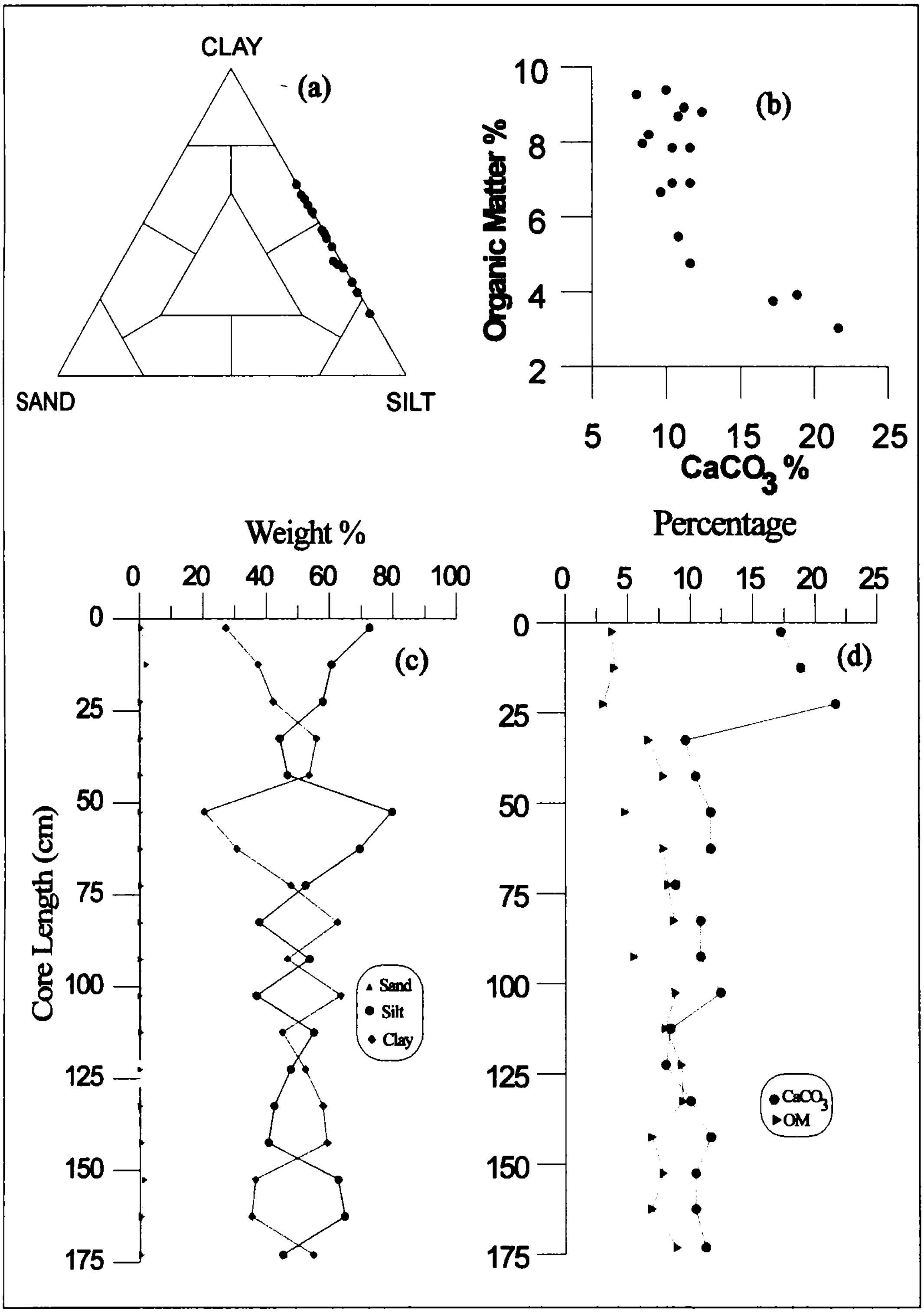


Fig.4.10 Plot of (a) textural classification, (b) organic matter Vs Calcium carbonate, downcore variation of (c) sand-silt-clay and (d) calcium carbonate and organic matter in the core S-5

symmetrical distribution are very platykurtic to platykurtic. This corroborates the above observation that these sediments, which are dominantly clayey in nature, consist of wide range of size spectrum.

Skewness Vs kurtosis: These two parameters are the indicators of the non-normality of the size distribution. The figure shows a 'U' shaped curve with a truncated left arm. Sediments, which are symmetrically skewed, are platykurtic in nature. In nutshell, a definite relationship can be established in the sediment distribution pattern, where the coarse-skewed samples are increasingly leptokurtic and vice-versa.

Core S-5: In this core the sand content is negligible. The 18 sub-samples analysed for texture has given an average sand percent of 1.15%. Figure 4.10 illustrates the textural classes and the downcore distribution of textural grades. The clay and silt percentages show various levels of intermixing, where three zones can be identified. With certain exceptions, the upper zone up to about 75 cm is dominated by silt. Below this upto 140 cm clay predominates. Further towards the base, silt prevails over the clay. The silt and clay content show an average percent value of 58.09 and 41.23 respectively. The top 75 cm column consists of clayey silt, the middle unit of silty clay and the bottom unit with clayey silt.

Table. 4.2: Percentage of Sand, Silt, Clay, $CaCO_3$ and Organic matter collected from the shelf sediments of Punjavi Transect.

Sample name	% of $CaCO_3$	% of OM	% of Sand	% of Silt	% of Clay
S-1/0-5	54.4	1.4	20.3	40.2	39.6
S-1/10-15	59.2	1.2	18.6	60.1	21.3
S-1/20-25	61.6	1.1	24.9	62	13.1
S-1/30-35	60.8	1.1	18.9	44.8	36.4
S-1/40-45	61.6	1.1	12.8	44.1	43.1
S-1/50-55	53.6	1.5	12.5	86.7	0.8
S-1/60-65	56.8	1.3	4.4	79	16.7
S-1/70-75	37.6	2.2	2.7	54.7	42.7
S-1/80-85	54.4	1.4	11.5	23.6	65
S-1/90-95	36.2	4	1.3	48.3	50.4
S-1/100-105	44.8	1.9	1	42.9	56.1
S-1/110-115	28	2.7	1.1	44	55
S-1/120-126.5	21.2	3.9	0.2	42	57.4

continued

Sample name	% of $CaCO_3$	% of OM	% of Sand	% of Silt	% of Clay
S-1/Bottom	18	4.1	1	37.9	61.2
S-2/0-5	25.2	0.8	90	1.8	8.2
S-2/10-15	24	1.1	91	1.3	8.2
S-2/20-25	28	0.5	89	4.1	7.3
S-2/30-35	24	0.5	92	0.2	7.8
S-2/40-45	29.6	0.6	92.1	1.1	6.8
S-2/50-55	29.2	0.5	89.4	2.3	8.3
S-2/Bottom	30	0.3	89.5	0.3	10.2
S-3/0-5	16.4	0.4	77.7	3.5	17.8
S-3/10-15	19.6	0.7	86.5	5.6	7.9
S-3/20-25	13.6	0.6	89.3	2.6	8.1
S-3/30-35	14	0.5	85.1	6.2	8.7
S-3/40-45	14.8	0.7	82.1	12.1	5.8
S-3/50-55	14.8	0.5	83.8	8.5	7.8
S-3/60-65	16.4	0.8	50.5	35.6	14
S-3/70-75	22.4	0.5	76.5	8.8	14.7
S-3/80-85	12.4	1.4	47.3	25.9	26.8
S-3/90-95	22	5.8	32.4	28.4	39.3
S-3/100-105	1.2	7.1	16.4	57.5	26.2
S-3/110-115	7.6	4.7	19.2	56.1	24.7
S-3/120-125	4	5.1	24.2	43.6	32.3
S-3/130-135	10.4	1.4	20.7	48.6	30.7
S-4/0-5	14.8	4.6	1.1	37.3	61.6
S-4/10-15	12	3.8	0.6	35.8	63.6
S-4/20-25	10.8	4.3	1.2	35.9	63
S-4/30-35	14.8	4.5	0.5	35.1	64.4
S-4/40-45	14.8	4.1	1	38.5	60.5
S-4/50-55	15.2	4	0.3	36.9	62.7
S-4/60-65	16	3.9	0.7	39.6	59.8
S-4/70-75	16.4	3.6	0.1	39.7	60.2
S-4/80-85	14.4	4.7	0.2	39.1	60.7
S-4/90-95	16.8	4.5	0.3	37.7	62.1
S-4/100-105	18.4	4.1	1	36.5	62.5
S-4/110-115	16	4.7	2.1	36.1	61.8
S-4/120-125	14	4.4	1.4	39.5	59.1
S-4/130-135	15.6	4.5	4	48.3	47.3
S-4/140-145	14	4.6	1	50.1	48.5
S-4/150-155	15.2	4.5	0.3	35.1	64.6
S-4/160-165	24	4.1	5.2	33.8	61
S-4/170-175	23.6	2.4	45.1	28.6	26.3
S-4/180-185	20.8	0.2	75.3	8.8	16
S-4/190-195	22.8	0.8	77.8	11.9	10.3
S-4/200-205	25.2	0.1	83.5	4	12.5
S-4/210-215	22.8	0.06	86	3.2	10.9
S-4/220-225	23.2	0.12	84.5	4	11.5

continued....

Sample name	% of $CaCO_3$	% of OM	% of Sand	% of Silt	% of Clay
S-4/230-235	29.6	0.17	85.9	3	11.2
S-4/240-245	24	0.3	84.7	3.4	11.9
S-4/250-255	22.8	0.06	85.5	4.1	10.4
S-4/260-265	23.2	0.5	85	3.8	11.3
S-4/265-270	24	0.2	87.4	4.7	8
S-4/270-273	24	0.5	84.2	6.1	9.7
S-5/0-5	11.2	3.8	0.5	72.4	27.1
S-5/10-15	18.8	3.9	2.2	60.5	37.4
S-5/20-25	21.6	3	0.3	57.7	42.1
S-5/30-35	9	6.7	0.3	44.1	55.6
S-5/40-45	10.4	7.9	0.2	46.5	53.3
S-5/50-55	11.6	4.8	0.2	79.5	20.2
S-5/60-65	11.6	7.9	0.2	69.3	30.5
S-5/70-75	8.8	8.2	0.3	52.2	47.6
S-5/80-85	10.8	8.7	0.2	37.6	62.3
S-5/90-95	10.8	5.5	0.2	53.4	46.4
S-5/100-105	12.4	8.8	0.2	36.7	63.2
S-5/110-115	8.4	8	0.3	54.8	44.8
S-5/120-125	8	9.3	0.1	47.4	52.1
S-5/130-135	10	9.4	0.2	42.2	57.6
S-5/140-145	11.6	7	0.6	40.5	59
S-5/150-155	10.4	7.9	1.4	62.3	36.2
S-5/160-165	10.4	6.9	0.4	64.4	35.1
S-5/170-173	11.2	8.9	0.5	45	54.6

4.3.2 Sedimentary Facies-Onakkunnu Transect

Five cores ranging in length from 0.49 to 1.62 m were taken from this transect. Down-core variation in granulometric characteristics, organic carbon and calcium carbonate percentage of Onakkunnu transect are given in the Table 4.3. The individual description of each core is described below.

Core S-6: Eighteen sub-samples from this shallow water core were analysed for texture. The percent range of sand varies from 0.06% to 0.52%, silt 39.05% to 91.68%, and clay 8.14% to 60.89%. The textural classes and the downcore distribution of textural grades are plotted in Figure 4.11. The sediment column have negligible amount of sand with two distinct facies. The upper segment rich in silt extend upto 75 cm and mostly fall in the category of clayey silt. The lower half consists of silty clay sediments with considerable increment of clay.

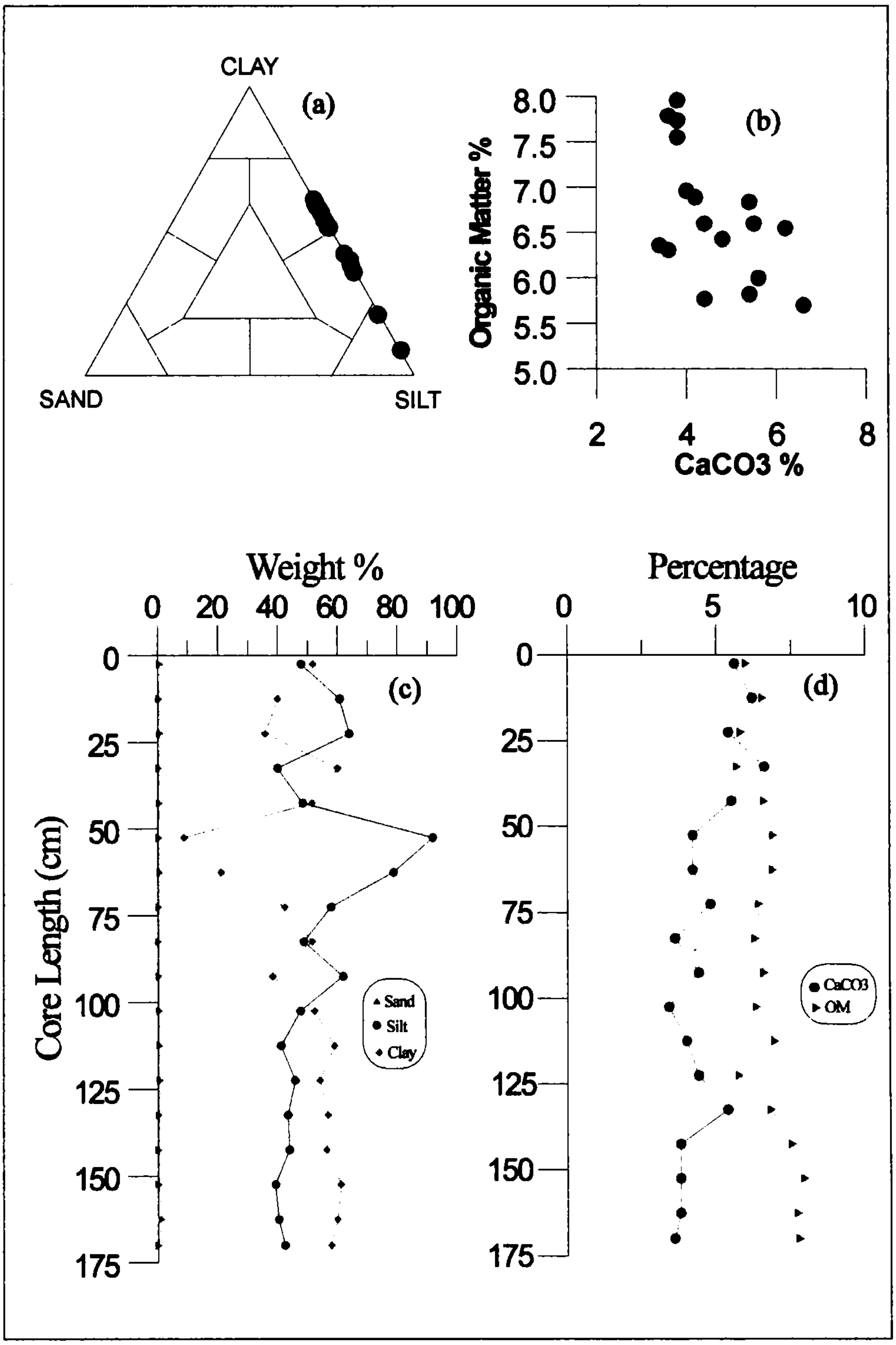


Fig.4.11 Plot of (a) textural classification, (b) organic matter Vs calcium carbonate, down core variation of (a) sand-silt-clay and (d) calcium carbonate and organic matter in the core S-6.

Core S-7: Textural classification and the downcore distribution of textural grades are depicted in Figure 4.12. Sand fraction outweighs other textural classes in the core. Six sub-samples analysed from this core gave a sand range of 85.96% to 94.53%. Silt and clay are sparse which fluctuates between 0.596% to 6.56% and 0.659 to 13.44% respectively. The downcore pattern is monotonous as the sand is uniformly distributed throughout the length. The sediments fall in the sand category. The average percentage of sand, silt and clay is 90.245%, 3.578% and 7.049% respectively.

Core S-8: Six sub-samples were analysed from this mid-shelf core. This core also demonstrates a similar trend as that of S-7 core. Figure 4.13 presents the trend of downcore variation and textural classification of sediments. Sand being the most dominant textural class range from 80.18% to 95.76%. Silt and clay are present only as minor constituents, the range of which varies from 0.4% to 9.33% and 0.424% to 10.49% respectively. The average percentage of sand, silt and clay is 87.97, 4.865 and 5.457 respectively. Close examination of the core base reveal addition of mud content at the expense of sand. This could be an obvious manifestation of change in sediment facies beneath.

Core S-9: This core presents a highly intermixed sediment facies with considerable fluctuation especially in the silt and clay content. Fourteen sub-samples were taken for textural analysis and the results are plotted in Figure 4.14. Unlike the cores dealt above, this core lacks a definite downcore trend. Except for the bottom-most sample, sand content illustrate a consistent trend, which varies from 0.093% to 22.35%. Silt and clay are highly variable as they fluctuate from 16.32% to 79.03% and 8.0% to 62.04% respectively. The average percentage of sand, silt and clay is 11.22%, 47.675% and 35.02% respectively. The texture of the sediments in the core is a mixture of silty clay and clayey silt.

Core S-10: Textural composition of the sediment core depicts three distinct units. The top 40 cm of the core is composed of sediments with 15% of sand and subequal proportions of clay and silt. The middle unit extending from 40 to 100 cm is rich in silt content (upto 80%) but show substantial decrease in clay assemblage (~20%). Below which, sediments again

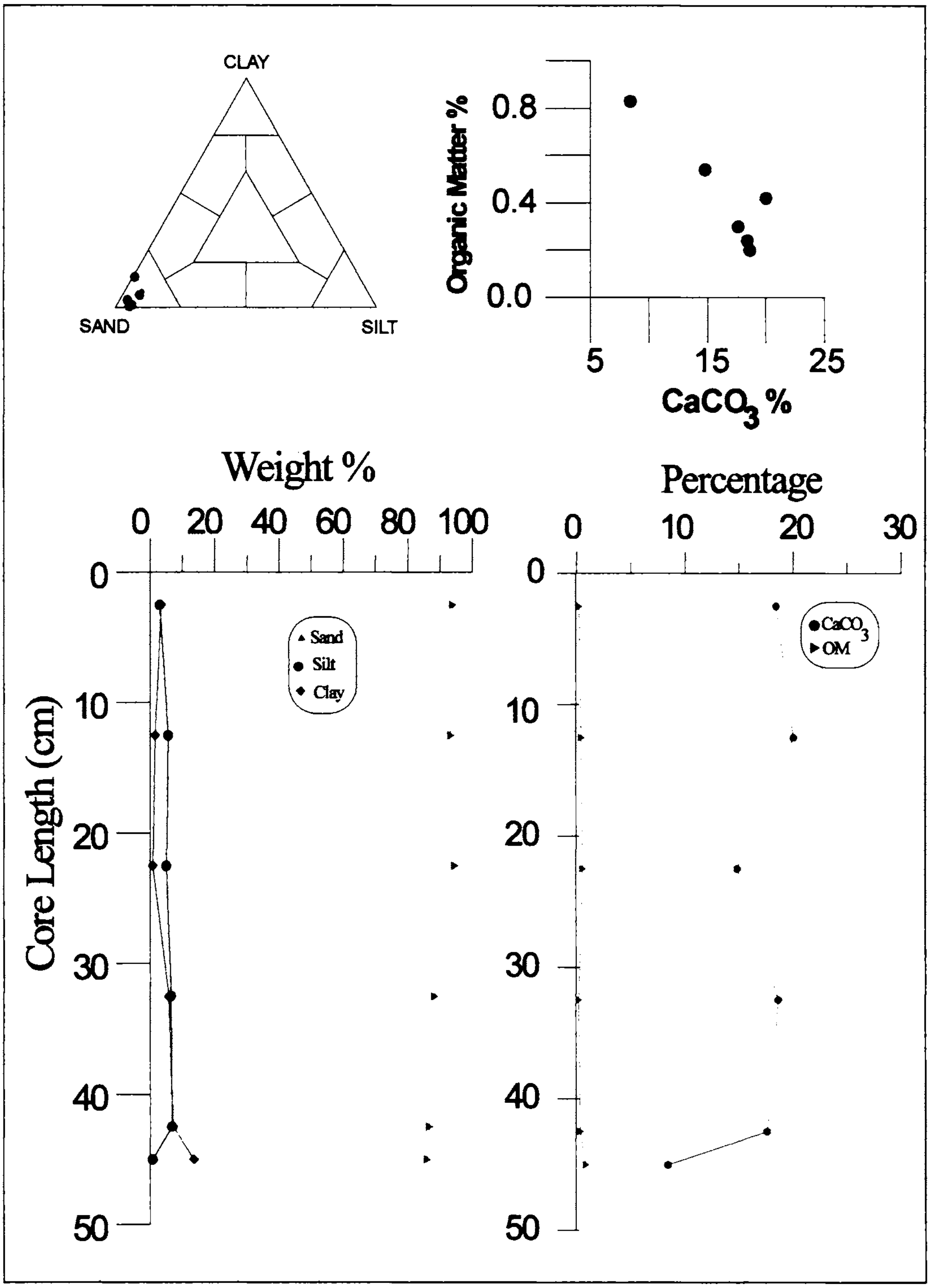


Fig.4.12 Plot of (a) textural classification, (b) organic matter Vs calcium carbonate, down core variation of (a) sand-silt-clay and (d) calcium carbonate and organic matter in the core S-7.

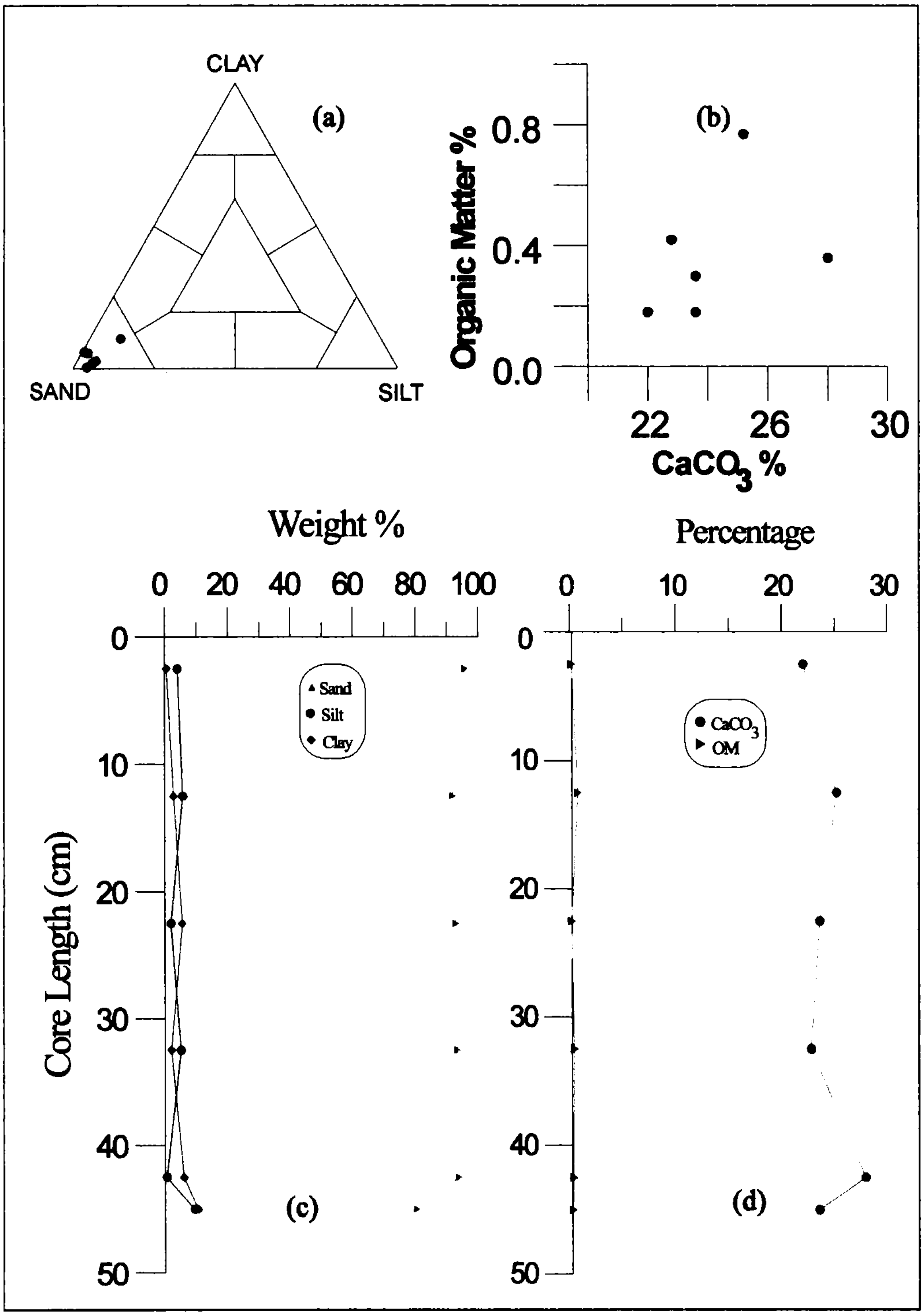


Fig.4.13 Plot of (a) textural classification, (b) organic matter Vs calcium carbonate, down core variation of (a) sand-silt-clay and (d) calcium carbonate and organic matter in the core S-8.

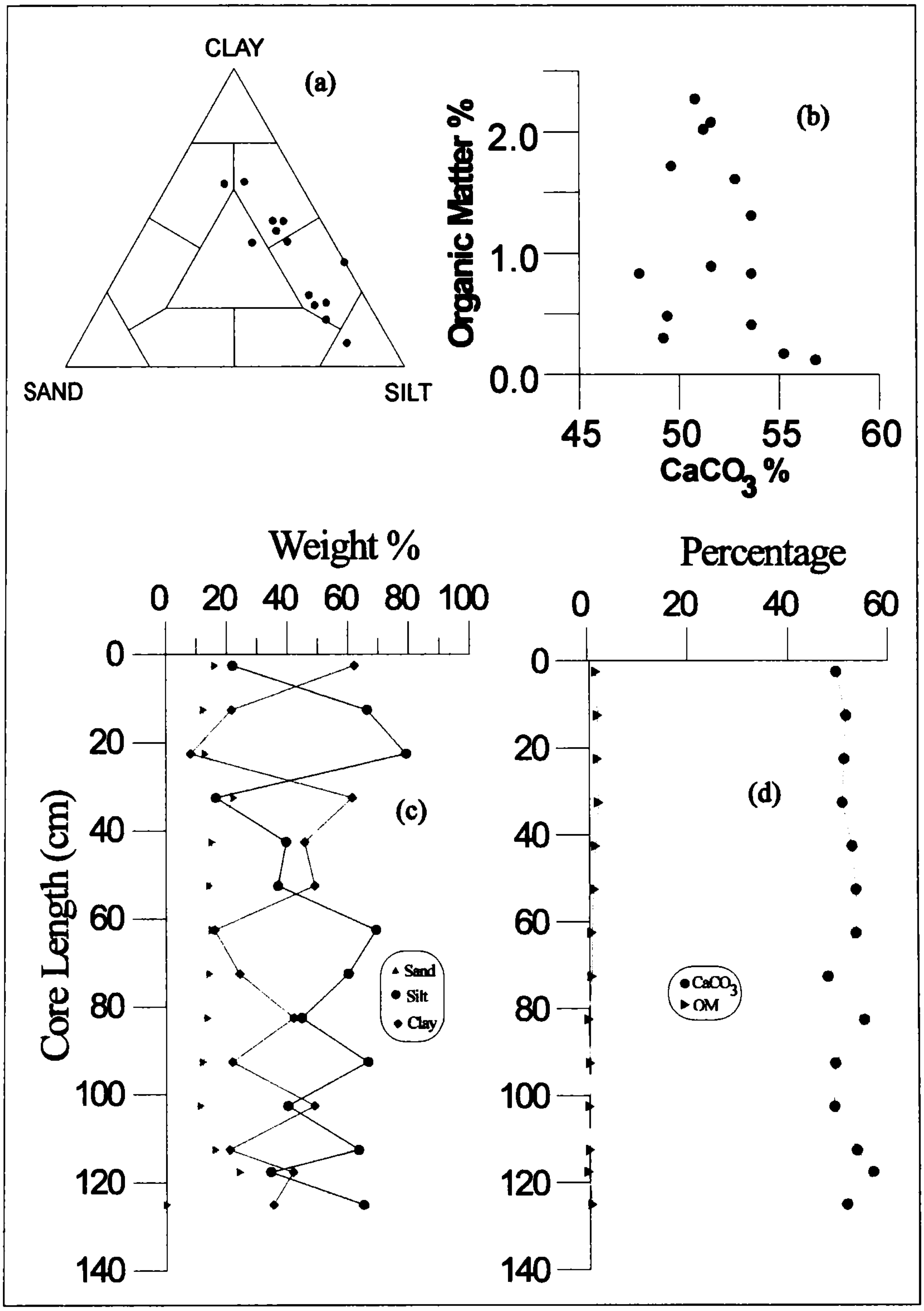


Fig.4.14 Plot of (a) textural classification, (b) organic matter Vs calcium carbonate, down core variation of (a) sand-silt-clay and (d) calcium carbonate and organic matter in the core S-9.

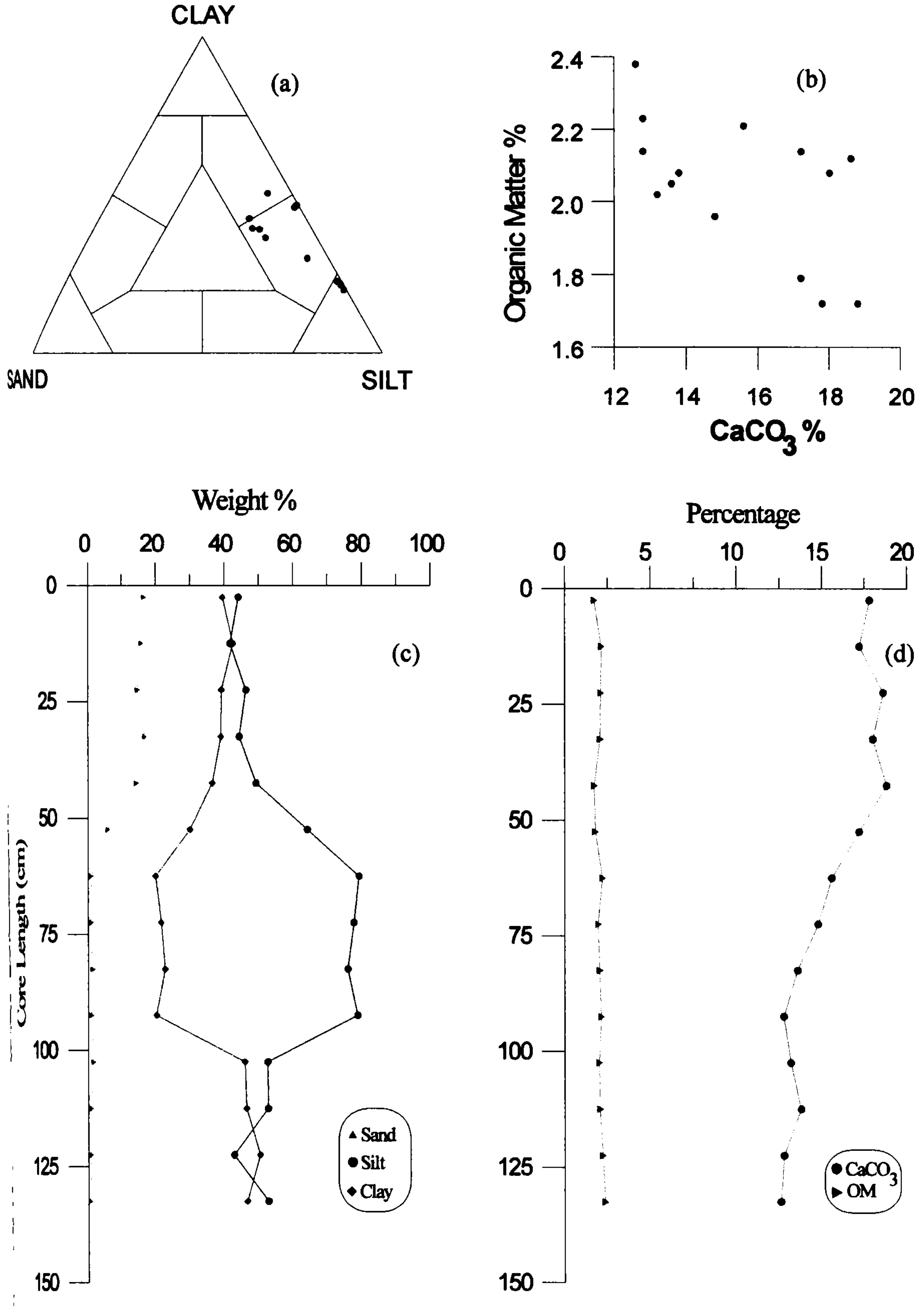


Fig. 4.15 Plot of (a) textural classification, (b) organic matter Vs calcium carbonate, down core variation of (a) sand-silt-clay and (d) calcium carbonate and organic matter in the core: S-10.

are in textural continuum with the upper unit. In the middle as well as in the bottom units, the sediments are highly impoverished in sand content. The 14 sub-samples analysed for texture yield sand percent range of 0.47 to 16.75. The silt and clay content range from 41.7% to 79.25% and 19.99% to 50.45% respectively. Textural classification and the downcore distribution of textural grades are depicted in Figure 4.15. The top 40 cm column consists chiefly of clayey silt, the middle unit predominant in silt and silty clay. The bottom-most unit consists of admixture of both silty clay and clayey silt. Silt and clay show a complimentary pattern of distribution, the silt being dominant in the middle layer.

Table. 4.3: Percentage of Sand, Silt, Clay, $CaCO_3$ and Organic matter collected from the shelf sediments of Onakkunnu Transect.

Sample name	% of $CaCO_3$	% of OM	% of Sand	% of Silt	% of Clay
S-6/0-5	5.6	6	0.5	47.8	51.7
S-6/10-15	6.2	6.5	0.2	60.6	39.9
S-6/20-25	5.4	5.8	0.5	63.8	35.8
S-6/30-35	6.6	5.7	0.2	39.9	60
S-6/40-45	7	6.6	0.3	48.3	51.4
S-6/50-55	4.2	6.9	0.2	91.7	8.1
S-6/60-65	4.2	6.9	0.5	78.5	21
S-6/70-75	4.8	6.4	0.2	57.7	42.2
S-6/80-85	3.6	6.3	0.1	48.5	51.4
S-6/90-95	4.4	6.6	0.2	61.6	38.2
S-6/100-105	3.4	6.4	0.4	47.5	52.2
S-6/110-115	4	7	0.3	40.9	58.7
S-6/120-125	4.4	5.8	0.5	45.6	53.9
S-6/130-135	5.4	6.9	0.3	43.2	56.6
S-6/140-145	3.8	7.6	0.1	43.7	56.2
S-6/150-155	3.8	8	0.1	39.1	60.9
S-6/160-165	3.8	7.7	0.1	40.2	59.7
S-6/Bottom	3.6	7.8	0.1	42.2	57.7
S-7/0-5	18.4	0.2	94	2.8	3.3
S-7/10-15	20	0.4	93.3	5.4	1.3
S-7/20-25	14.8	0.5	94.5	4.8	0.7
S-7/30-35	15.6	0.05	88.1	6.3	5.6
S-7/40-45	17.6	0.3	86.5	6.6	6.9
S-7/Bottom	18.4	0.8	86	0.6	13.4
S-8/0-5	22	0.2	96	3.8	0.4
S-8/10-15	25.2	0.8	92	5.6	2.6
S-8/20-25	23.6	0.2	93	1.8	5.4
S-8/30-35	22.8	0.4	93	4.9	1.9
S-8/40-45	28	0.4	94	0.4	5.9

continued.

Sample name	% of $CaCO_3$	% of OM	% of Sand	% of Silt	% of Clay
S-8/Bottom	23.6	0.3	80.2	9.3	10.5
S-9/0-5	49.6	2	16	21.8	62
S-9/10-15	51.6	2.1	12.3	66.2	21.5
S-9/20-25	51.2	2	13	79	8
S-9/30-35	50.8	2.3	22.4	16.3	61.3
S-9/40-45	54.8	1.6	15	39.4	45.6
S-9/50-55	53.6	1.3	14.3	36.8	48.9
S-9/60-65	53.6	0.8	15.1	69.1	15.8
S-9/70-75	48	0.8	14.4	59.9	24.1
S-9/80-85	55.2	0.2	13.5	44.5	42
S-9/90-95	49.4	0.5	12	66.4	21.6
S-9/100-105	49.2	0.3	11	39.9	48.8
S-9/110-115	53.6	0.4	16.1	63.2	20.7
S-9/115-120	56.8	0.1	24.1	34.3	41.6
S-9/Bottom	22	0.9	0.1	64.8	35.1
S-10/0-5	17.8	1.7	16.5	44.1	39.4
S-10/10-15	17.2	2.1	15.7	41.7	42.5
S-10/20-25	18.6	2.1	14.7	46.3	39.1
S-10/30-35	18	2.1	16.8	44.3	38.9
S-10/40-45	18.8	1.7	14.4	49.2	36.4
S-10/50-55	17.2	1.8	6	64.2	29.9
S-10/60-65	15.6	2.2	0.8	79.2	20
S-10/70-75	14.8	2	0.7	77.7	21.6
S-10/80-85	13.6	2.1	1.3	76	22.7
S-10/90-95	12.8	2.1	0.9	79	20.3
S-10/100-105	13.2	2	1.5	53	45.9
S-10/110-115	13.8	2.1	0.8	53	46.5
S-10/120-125	12.8	1.8	0.7	48.8	50.5
S-10/Bottom	12.6	2.4	0.5	52.8	46.7

4.4 CALCIUM CARBONATE AND ORGANIC MATTER DISTRIBUTION

The range of organic matter for all the samples analysed is from 0.059% to 9.39% by weight. Striking dissimilarity in organic matter content is evident between innershelf and outershelf samples. Average values of organic matter content in the shallow cores are 0.446 % and 6.7% respectively whereas uniform average value of 2.04% is obtained for other deeper cores. Thus, the depth dependence of the organic matter values in the sediment is evident as the organic matter content decreases towards deeper zones of the shelf.

In the S-1 core, the range of organic matter analysed is from 1.07% to 3.98% by weight. As is evident from the figure (*refer Fig 4.4*), the down-core variation of the organic matter is insignificant. However, a significant change in the depth-wise distribution is observed in the $CaCO_3$ distribution. With certain exceptions, there is a gradual and steady decrease of $CaCO_3$ percentage with depth. After being uniform up to 40 cm, it shows a sudden decrease further downward. $CaCO_3$ variation shows a sympathetic relationship with sand content. The converse holds true with clay content.

As the S-2 core is composed of nearly 90% sand, the organic matter and the $CaCO_3$ distribution are highly monotonous. Though $CaCO_3$ ranges from 24% to 30%, down core variation is inconspicuous. The organic matter ranges from 0.297% to 1.069%. The average percentage of $CaCO_3$ and organic matter in this core is 27% and 0.683 % respectively (*refer Fig 4.5*).

As the S-3 core sediment is heterogeneous in nature, the inter-relationship between the size parameters, $CaCO_3$ and organic matter is well documented. In the sand dominant zone, which extends upto 75 m, the percentage of $CaCO_3$ ranges from 15% to 25%. Sand dilution further down causes a corresponding decrease in $CaCO_3$ distribution (from 13% to 9%). However, organic matter depicts an inverse relationship with that of $CaCO_3$, which, from nearly a non-measurable quantity up to 75 m, grades to 7% in the deeper units. The average distribution of $CaCO_3$ and organic matter is 11.6% and 3.78% respectively (*refer Fig 4.6*).

There is close relationship between the texture, $CaCO_3$ and organic matter distribution in the core S-4. As in the case of textural distribution, $CaCO_3$ and organic matter also reveal two distinct units, the boundary of which falls around 170 cm of core length. The upper unit is enriched in clay and depleted in $CaCO_3$, whereas, the relationship is converse in the lower unit. The $CaCO_3$ depict sympathetic variation with sand, whereas in the case of organic matter it is with that of the mud. The percentage of $CaCO_3$ ranges from 10.8% to 29.6% and organic matter from 0.06% to 4.7%. The average percentage of $CaCO_3$ and organic matter is 20.2% and 2.3% respectively. From the down-core accumulation pattern of organic matter and $CaCO_3$, an antithetical relationship is discerned (Fig 4.16).

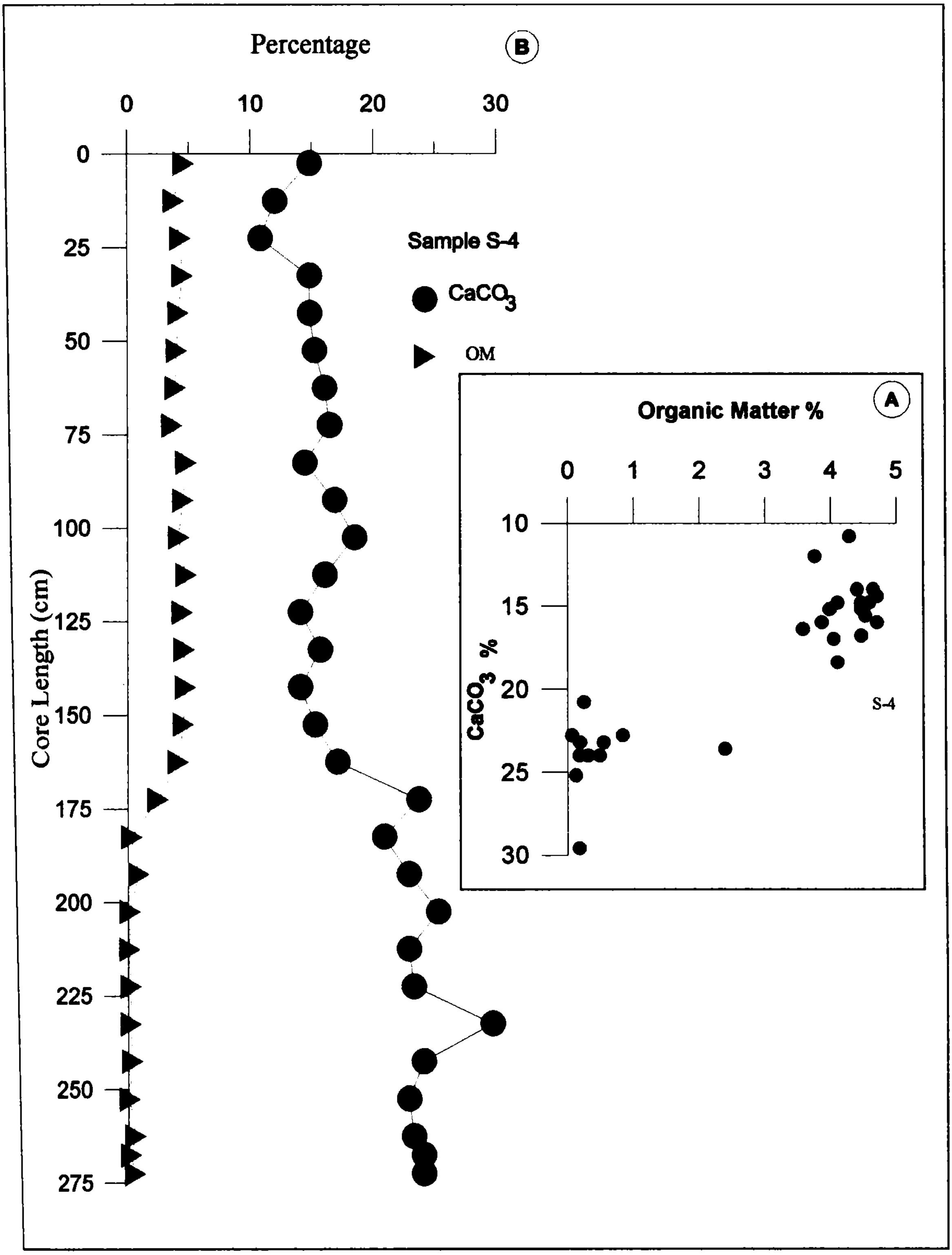


Fig. 4.16 Down core variation of Calcium carbonate and Organic matter in the core S-4

In the core S-5, which is recovered from the innershelf, the $CaCO_3$ percentage in the top units (extending up to 25 m) range from 17.5% to 22.5%. Further down, the $CaCO_3$ shows almost a uniform distribution. Converse relationship of organic matter with $CaCO_3$ is evident. which, after getting slightly diluted up to 25 m, show slight increase and grade up to 7% in the deeper units. The average percentage of $CaCO_3$ and organic matter are 14.8% and 6.21% respectively (*refer Fig 4.10*).

In the core S-6, the percentage of $CaCO_3$ and organic matter is insignificant. The $CaCO_3$ ranges from 3.4 to 7.0%, whereas the organic matter ranges from 5.7 to 7.96%. The average percentage of $CaCO_3$ and organic matter is 5.2%, 6.83%. As this core is recovered from the innershelf, the sediment constitute negligible amount of sand (*refer Fig 4.11*).

As the S-7 core is composed of nearly 90% sand, the organic matter and the $CaCO_3$ percentages show a highly monotonous trend. Though $CaCO_3$ ranges from 15% to 20%, down core variation is inconspicuous. The organic matter ranges from 0.059% to 0.832%. The average percentage of $CaCO_3$ and organic matter in this core is 17.4% and 0.446% respectively (*refer Fig 4.12*).

As the core S8 is also recovered from the sand dominant zone, no significant down-core variation is observed in the distribution of organic matter and the $CaCO_3$. Being a sand dominant zone, though the $CaCO_3$ ranges from 22% to 28%, the down-core distribution is almost uniform. The organic matter, which is present in insignificant quantity, ranges from 0.178% to 0.773%. The average percentage of $CaCO_3$ and organic matter is 25% and 0.476% respectively (*refer Fig 4.13*).

The core S-9 constitutes significant proportion of $CaCO_3$ as it is recovered from the deeper parts. Though $CaCO_3$ ranges from 48% to 56.8%, no significant trend is seen throughout the length of the core. As naturally expected, the organic matter is insignificant, which ranges from 0.118% to 2.27%. The average percentage of $CaCO_3$ and organic matter is 39.4% and 1.194% respectively (*refer Fig 4.14*).

Percentage range of $CaCO_3$ in core S-10 is from 12.6% to 18.8% and organic matter from 1.72% to 2.38%. The average percentage of $CaCO_3$ and organic matter is 15.7% and 2.05%. As is evident from the Figure (*refer Fig 4.15*), the down-core variation of the organic matter is insignificant. However, a depth-wise variation in $CaCO_3$ distribution is noticeable. There is a gradual and steady decrease of $CaCO_3$ percentage with depth. After being uniform up to 40 cm, it shows a gradual decrease further downward, conformable with sand content. The converse holds true with mud content.

The plot of organic matter versus core length, though noisy at many levels, provides a positive linear fit. Compared to S-1, spread of the points especially in the shallowest core S-5 is quite large. In the S6- S10 transect, deviation of sample points from the line fit is within the tolerable limits. In a general, there is a positive relationship between depth and Organic matter content with only minor shift in the line fit for the low and high values of organic matter.

The $CaCO_3$ yield a complementary pattern to that of organic matter distribution. Average percentage of $CaCO_3$ in the shallow cores is 5.2% and 27% respectively, whereas the deeper cores are rich in $CaCO_3$ (averages S10-7.34% and S1-39.8%) The deeper part of continental shelf shows almost a two fold relative enrichment of $CaCO_3$.

4.5 SIGNIFICANCE OF ORGANIC MATTER AND CALCIUM CARBONATE

The intimate relationships that exist between the climate and sedimentation pattern have a synergistic effect on the preservation potential of organic matter and calcium carbonate in the sediments. Carbonate and organic carbon fluctuations in the continental margins sediments are considered to be mainly governed by terrigenous input variability, and are attributed to sediment dilution effects and accompanying changes in organic preservation potential (Volat et al., 1980). These fluctuations were further found to be complicated by carbonate dissolution and organic matter decomposition and sediment redox potential (Sheu and Huang, 1989). The $CaCO_3$ record from the Arabian Sea are mostly influenced by terrigenous dilution caused by variations in the terrigenous/lithogenous flux derived from the Arabian and Somalian Peninsula during the summer monsoon season in the western Arabian Sea (Shimmield et al., 1990; Murray and Prell, 1992). Sedimentological and faunal evidences show that limestones on the outer continental shelf have been formed under shallow water conditions (Hashimi et al., 1977; Nair et al., 1979). The distribution of these sediment types over a large area of the western shelf indicates that carbonate precipitation was quantitatively large in the past compared to the present (Nair and Hashimi, 1980). The amount and type of organic matter in marine sediments reflect the supply and preservation of organic materials from terrestrial sources (Tissot et al., 1980; Summerhayes, 1981). Higher levels of organic carbon occur in the continental slope of the eastern Arabian Sea and Indian Ocean (Paropkari et al., 1987).

4.6 TEXTURAL CONTROL OVER ORGANIC MATTER VARIATION

Distribution of the organic carbon in the continental shelf is governed by a set of physico-chemical, sedimentological and hydrographic conditions. Significant textural control over the organic carbon retention of sediments was highlighted by previous researchers (Bezrukov et al., 1977). Premuzic et al. (1982) and Tissot and Welte (1978) have suggested that organic matter preservation is enhanced by the presence of clay minerals as the electrostatic forces associated with the clay particles facilitate precipitation and flocculation of organic matter. The textural pattern, organic matter and calcium carbonate distribution in the sediment cores are closely inter-related. As discussed above, the innershelf and outershelf sediments are generally rich in silt and clay fractions and the midshelf rich in sand. As perceptible changes in textural variation are seen spatially and temporally, the 'lithologic effect' of fine-grained sediments on the organic matter variation owing to differences in surface area and degree of exposure to microbial degradation can not be ruled out. Despite having similar textural characteristics, organic matter content in the inner shelf cores is almost three-fold compared to the outer shelf. Paropkari et al. (1992) also reported higher organic content invariably associated with sediments of the inner shelf of this region. This was mainly attributed to the higher terrigenous organic input. Obviously, the low content of organic matter in the outer shelf is due to the reduced supply of terrigenous discharge to the outer shelf away from the peripheral coastal region.

4.7 PRODUCTIVITY AND ORGANIC MATTER CONTENT

Increased flux of organic material is generally attributed to the increased sea surface productivity. The average annual column primary productivity in this part of the shelf was reported to be in the ranges of 0.5 and 0.75 gc/m2/day (Qasim, 1977). Only 10-20% of the primarily produced organic carbon was found to get preserved in the sediments (Muller and Suess, 1979). On the other hand, Bruyevich (1963) estimated that only 0.01% of primary produced organic carbon is preserved in slowly accumulating pelagic sediments. However, this cannot explain the general dilution of organic matter in the sediments of the outer shelf from this region, as the column productivity in the shelf is without any significant variation and the organic input to this shelf region is mainly from terrigenous source (Paropakari et al., 1987).

4.8 SEDIMENTATION RATE AND ORGANIC MATTER CONTENT

It is a well-established fact that rapid sedimentation coincides with preservation of the organic matter in the shelf sediments (Hartman et al., 1976). Ibach (1982) also established a relationship between the organic carbon and rates of sedimentation in the Pleistocene sediments on the active continental margins. Thus, higher sedimentation rate favours preservation of labile organic substances by foreshortening or bypassing the aerobic oxidation stage of microbial degradation. Heath et al. (1977) and Muller and Suess (1979) established empirical relationship between organic carbon and bulk sediment accumulation rates.

Radio carbon dating was carried out on shells from the innershelf and outershelf cores collected at 40 m and 150 m water depths. The result indicated sedimentation rates of 0.12 mm/yr for the innershelf and 0.05 mm/yr for the outershelf. However, core S-5 that was collected at a water depth of 30 m might have a higher sedimentation rate. Based on the available date information, it could be around 0.20 mm/yr. The general slow accumulation rate is chiefly attributed to the very poor discharge, low bed load transport and low concentration of suspended particulate matter by the west-flowing small rivers of this peninsula (Nambiar and Rajagopalan, 1995). Obviously the low content of organic matter in the cores of this region correspond well with the evident changes in the sedimentation rate at the inner shelf and outer shelf zones. It is thus reasonable to presume that apart from the short supply of organic rich detritus to the outer shelf, the sedimentation rate has a critical effect on the preservation potential of the accumulating organic matter on the continental shelf.

4.9 CALCIUM CARBONATE VERSUS ORGANIC MATTER DISTRIBUTION

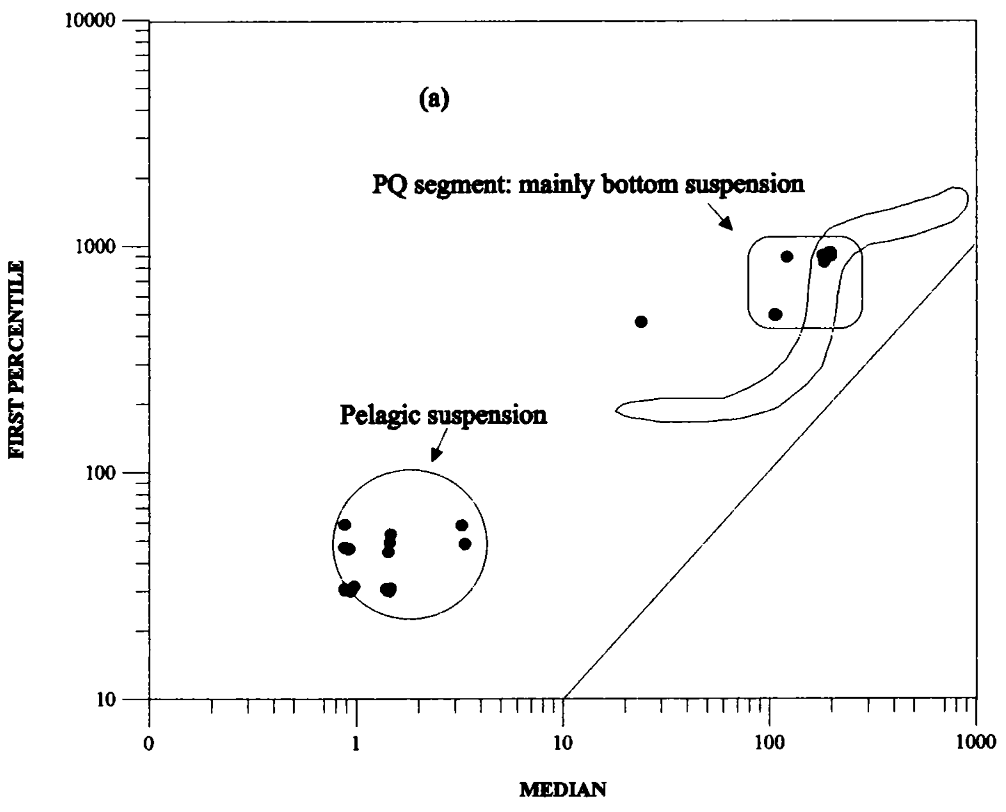
There exist a inverse relationship between the carbonate content and organic carbon of the shelf sediments. However, generalization based on data from different oceans does not always agree. Heath et al. (1977) noted a direct correlation between carbonate content and organic carbon in deep-sea sediments. However Bezrukov (1977) and Premuzic et al. (1982) noted an inverse relationship between carbonate content and the organic carbon. Our study supports the inverse relationship between $CaCO_3$ and organic matter. The antithetical relationship observed in the vertical and spatial distributions of $CaCO_3$ and organic matter needs a closer look. One of the possible reasons for the reversals in the trends of spatial accumulation pattern of $CaCO_{3\ \text{could}}$ be the clastic dilution at the proximal points of terrigeneous input. Enrichment of $CaCO_3$ depends on the availability of shell fragments and tests of organisms in the sediments. Carbonate fraction of the inner shelf sediments are abundant in shells and shell fragments of bivalves and gastropods. Whereas, the outer shelf domain is rich in pteropods, forams and echinoid spines. Assuming other factors to remain constant, the organic matter preservation is attributed to the rate of sedimentation. Apparently, in addition to the 'terrigenous dilution factor', water column containing less amount of sesten can also favour $CaCO_3$ enrichment. Higher negative relationship of organic matter with $CaCO_3$ in the outer shelf can thus be attributed to the *in situ* reduction in sedimentation rate. The shell dominance in the inner shelf could alter this relationship to some extent, which is evident from the relatively less negative correlation of organic matter with $CaCO_3$.

4.10 NATURE OF SEDIMENT ACCUMULATION PATTERN

Detailed textural distribution pattern in the shelf cores distinctly demarcates the lithofacies architecture in the innershelf, midshelf and outershelf domains (*refer Fig 5.3*). One of the major limitations faced in recreating the stratigraphy of the shelf is the poor core recovery at many locations, especially along the Onakkunnu. However, both the transects have closely similar depositional settings. The innershelf cores (*S-4, S-5 & S-6*) are dominated by mud facies with minor fluctuations in textural grades. The sand layer encountered beneath 1.7 m of core length in core S-4 lends credence to the fact that the outer-innershelf has only a thin veneer of mud. The expanse of the midshelf relict sand is wide in Punjavi compared to that of Onakkunnu both in aerial and bathyal extent. The sand layer thins out towards both the innershelf and outershelf zones. Interestingly, in this part, the shelf gradient is the least compared to innershelf and outershelf. It is in this zone that small-scale irregularities of the order of 1-8 m in height were reported by Nair (1975), Wagle et al. (1994) and Subbaraju and Wagle (1996). The most prominent ones occur between 50 m and 115 m.

The core S-4 being the longest one and has pierced the two distinct facies, the CM pattern (Passega, 1957) and probability curves (Visher, 1969; Viyard and Breyer, 1979) were utilised to have a comprehensive picture of environmental framework of deposition. The CM diagram (after Passega, 1957) of the shelf sediments depicts two distinct population clustered in the right and left side of the diagram (Fig 4.17). One set of the population indicates bed composed of sand particles deposited under the influence of rolling and graded suspension associated with maximum turbulence. Another set consists of sediments similar to the one deposited under the pelagic suspension in a relatively low energy condition. Sample points which lies in the right hand corner of the diagram is compatible with the pattern IV of Passega and Byramjee (1969) and is similar to that of the beach sediments reported by Samsuddin (1986) from the study area. The second set of samples consisting of mud with both silty-clay and sand-silt-clay grades, mainly represent, that deposited under the pelagic suspension processes. The depth-wise plot of C and M values also indicates an analogous pattern (Fig 4.17) as observed in the case of distribution of size parameters.

The cumulative probability curve of the sand domain of the shelf sediment from the core S-4 gives an insight into the nature of the deposition of the sediments (Fig 4. 18). Visher



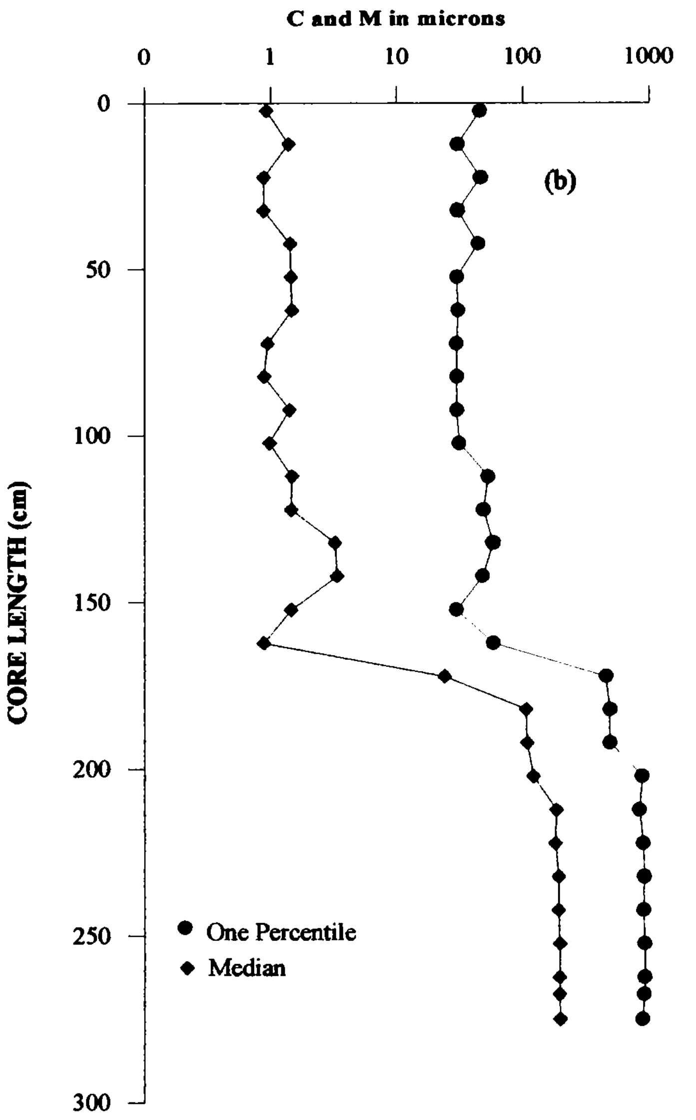


Fig. 4.17 Plot of (a) CM diagram and (b) vertical variation of C and M in the core S-4

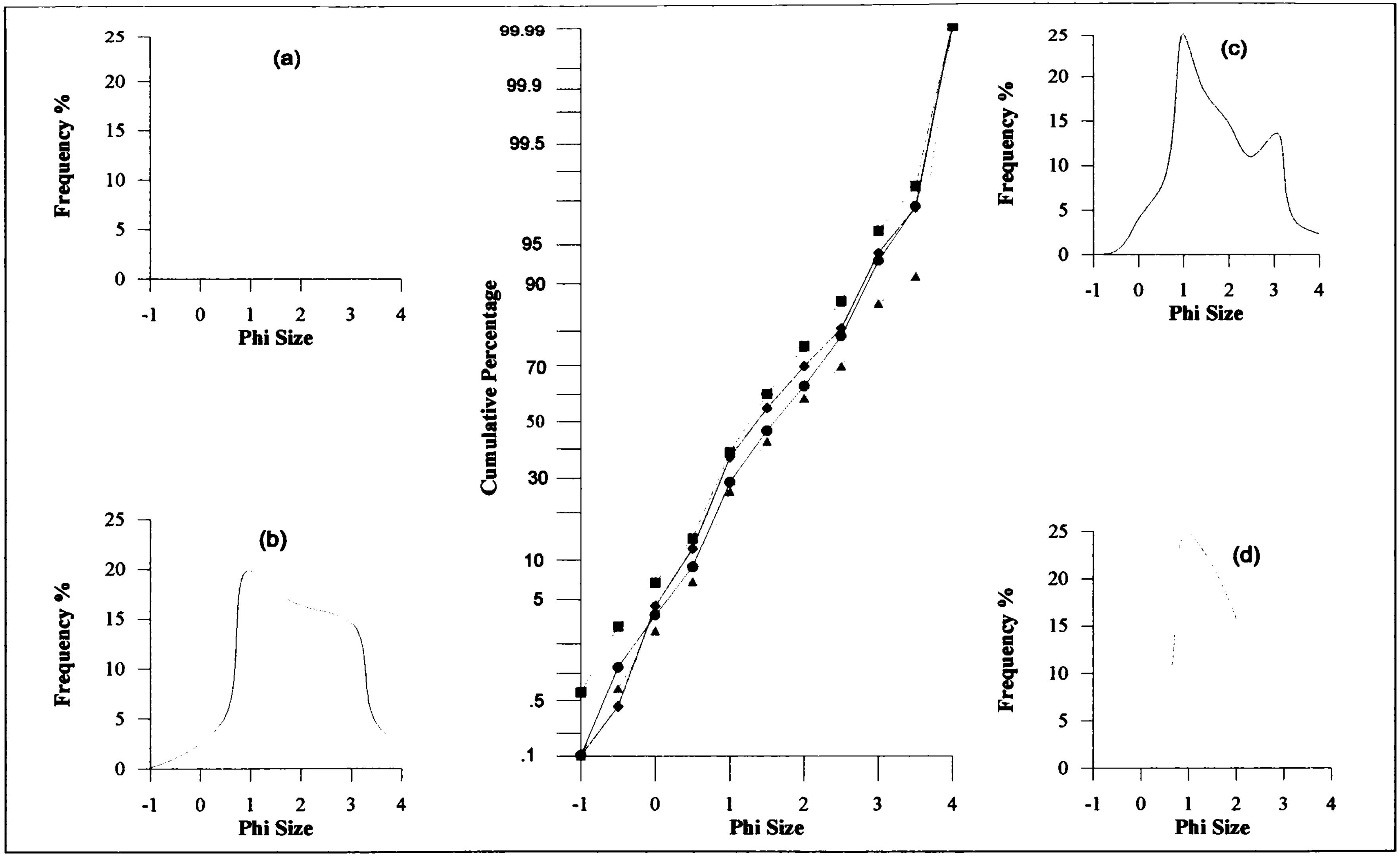


Fig. 4.18 Cumulative probability and normal size frequency curves of selected sand samples at the depths of (a) 180-185cm, (b) 200-205cm, (c) 230-235cm and (d) 260-265cm of the core sample S-4

(1969) effectively utilised the probability curves of the population to decipher the depositional history of sedimentary deposits and the hydrodynamic conditions that prevailed at the time of its deposition. The cumulative curves drawn for the relict sand consist of 4 straight-line segments, thus representing four discrete lognormal populations. In general, the truncation points of the lognormal population occur around 0, 1 and 3 phi values. According to Visher (1969) and Middleton (1976), the segments A, B & C and D represent the traction, saltation, and suspension loads respectively. The nature of the four-segmented probability curves is found to be similar to that of the beach sediments. The beach sediments normally retain two sets of saltation population, which represents the swash and backwash regimes.

The sedimentological studies amply demonstrate that a paleo-beach existed off the Kerala coast during the late Quaternary low stand of sea level, which, at present remain detached from the main land due to the subsequent transgression.

Chapter 5

CORRELATION AND CHRONOLOGY

5.1 BACKGROUND

The Quaternary period, which comprises about 2 million years of earth's geological history was characterised by strong climatic oscillations. Beginning of this period synchronised with first major glacial stage, which in the subsequent time, witnessed an alternating glacial and interglacial stages. Every glacial and interglacial period is made up of two or more sub-stages, each glacial stage interrupted by minor interglacial phases or interstadials during which, the ice front has receded. Similarly, each interglacial stage was punctuated by colder phases, during which, ice sheets were formed afresh or made notable advances in their shrunken conditions (Holmes, 1975). The Quaternary climatic history, the most important phenomenon related to climatic variations, observable all over the globe, was that of the worldwide glacio-eustatic sea level changes. A close relationship however existed between climatic stages and the eustatic sea levels, glacial, marking fall of sea levels, while interglacial, the period of high sea levels.

The ancient sediments exposed near the shoreline are manifestations of specific environments of deposition. The instantaneous position of the shoreline results from the sea level variations and rate of subsidence. The present day surface of the continental shelf and coastal plain has resulted from eustatic sea level fluctuations during the Quaternary. Position of the sea, with respect to the land can change through movement of either sea or land surface or both. Rising of sea level results in transgression or landward migration of the shoreline. Conversely, falling sea level results in seaward migration of the shoreline or regression. However, determination of different aspects of transgression and regression such as, the duration of time involved, rate of sediment supply, rate of dispersal and deposition of sediments are seldom achieved with precision. Moreover, it is difficult to assess the relative role of eustatic sea level change and tectonic movement resulting in the shoreline evolution. The indirect and speculative nature of our knowledge on the process of lateral shoreline migration makes it all the more difficult to interpret it with certainty.

There are two aspects in interpretation of transgression and regression record, namely, ordering of evidences at any one locality into a time sequence (*temporal dimension*) and relating the evidences at one locality to that at another (*spatial dimension*). The temporal dimension involves principles of stratigraphy, while the spatial dimension involves principles of correlation. Proper understanding of procedures associated with these two aspects is fundamental to conceptual interpretation of Quaternary environmental reconstruction.

Throughout the geological column, lithostratigraphic and biostratigraphic boundaries are time-parallel, and are therefore regarded as being of equivalent status to chronostratigraphic units in time-stratigraphic subdivision and subsequent correlation. This assumption cannot be used in the correlation of Quaternary successions except perhaps at the local scale. Worldwide sea level has been stable for a long period so as to allow development of pronounced shoreline features. In a broader scale, evidence of former sea levels in coastal areas, such as paleo-beaches, strandlines, buried morphological features etc. offer a valuable means of correlation between terrestrial and marine records.

The northern Kerala coast illustrates a long and detailed depositional record of geologic events, attributed to a number of factors such as, long-term tectonic stability, low to moderate wave energy, a generally concave seaward coastline, a mild and preserving climate, wide and low gradient shelf, etc. As a consequence, undisturbed major sedimentary sub-environments are preserved in the surface and subsurface deposits of this region, which include, fluvial, estuarine, moderate and low energy beach, cuspate foreland, barrier beach, lagoon, tidal inlet, tidal marsh, dune, strand plain environment, transgressive/regressive marine deposits etc.

Here, an attempt is made to understand evolutionary phases of the northern Kerala coast, by collating results on coastal geomorphology, sedimentology and chronology of strand plain and the adjoining shelf sequences.

2 SEDIMENTOLOGICAL AND MINERALOGICAL EVIDENCES

Coastal plains are the sites of significant accumulation of sediments, deposits of which thus, symbolizing prominent geomorphological features resulting from periodic transgression and regression and of the sea level fluctuations (Samsuddin et al., 1992; Suchindan et al, 1996; Haneesh kumar et al, 1998).

In order to have an in-depth knowledge on the nature of transgressive/regressive sequences, sedimentary facies in the cores collected from the strand plain were studied. Graphically computed mean size and standard deviation values of the sediments from various modern environments are used here to develop a simple bivariate graphical model and to infer different environments of deposition. Sample points of the core sediments plotted on to this model identifies the respective environment of deposition, though in some cases subjective interpretation is required to resolve the discrimination. Five closely knitted depositional environments are distinguishable from the bivariate graphical model (refer *Figs 3.3 & 3.4*). The sequential geometry of the sedimentary facies can be worked out once the facies are identified along the core length and the same could be extended laterally to the adjacent cores. This could be done fairly well in the present study, since coring at morphologically distinct locations was carried out along two east-west transects. Collating information on sedimentary facies, surface morphology, shell assemblages and radiocarbon dates, correlation of late Quaternary deposits of the study area was attempted.

Sedimentary facies are distinguishable by certain characteristic properties such as, lithology, depositional structures, fossil content, granulometry etc. Based on the granulometric and mineralogic characteristics, following sedimentary facies are identified from the core samples of coastal plain sequences: viz., the ***nearshore marine sand facies*** strongly influenced by the oscillatory motion induced by shoaling waves and longshore currents; the ***estuarine-coastal lagoon environment***, a typical transition zone that incorporates areas which are relatively protected from the influence of ocean waves, but influenced by various degrees of tidal forcing; ***fluvial sediments*** that are invariably subrounded to sub-angular; and ***beach sands*** and ***strand plain*** sediments that show textural continuity with that of the present-day beach sediments. Characteristic changes in the sediment properties supported by dated horizons have been used in defining facies boundaries. The Figures 5.1 and 5.2 show the facies architecture of Punjavi and Onakkunnu transects. The figures also show radiocarbon ages obtained for the shell/peat samples.

From the preceding discussions, it is made amply clear that, the strand plain sediments are resultant product of different stages of regression. Interestingly, though different proportions of heavy minerals account for nearly 85% of total average composition in different sedimentary environments identified hitherto, the stable minerals are found to be higher in the strand plain sediments. Change in mineral composition can be attributed to two reasons: (a) change in the provenance and (b) subsequent modification due to diagenetic changes. In the present situation, the earlier factor can be discounted since the fluvial regime drained through the same terrain. As the source area geology is characterised by charnockite, khondalite and certain unclassified crystallines and metavolcanics, there is no possibility of a change in the provenance. This lends credence to the fact that selective dissolution might have resulted in relative enrichment of more stable minerals like, opaque, rutile and zircon in the strand plain sediments. It is quite possible that the strand plain sediments, after being part of the littoral environment, could have got exposed to sub-aerial weathering during the successive phases of regression, thereby activating the intra-stratal solution processes. In this process, dissolution of iron from the ferromagnesium minerals and ferric coating on the sand grains could have lead to the reddening/yellowing of the surficial and sub-surface sediments to a great extent *refer Plate VIII & IX*).

According to Pye (1981) and Gardner and Pye (1981), rate of reddening in dune sands and other recent sediments is dependent on several factors including sand mineralogy, temperature, moisture availability, drainage conditions, degree of sediment stability and significance of airborne dust input. Colouration of sediments, though considered as a general guide to the age of tropical coastal deposits, considerable inter-locational

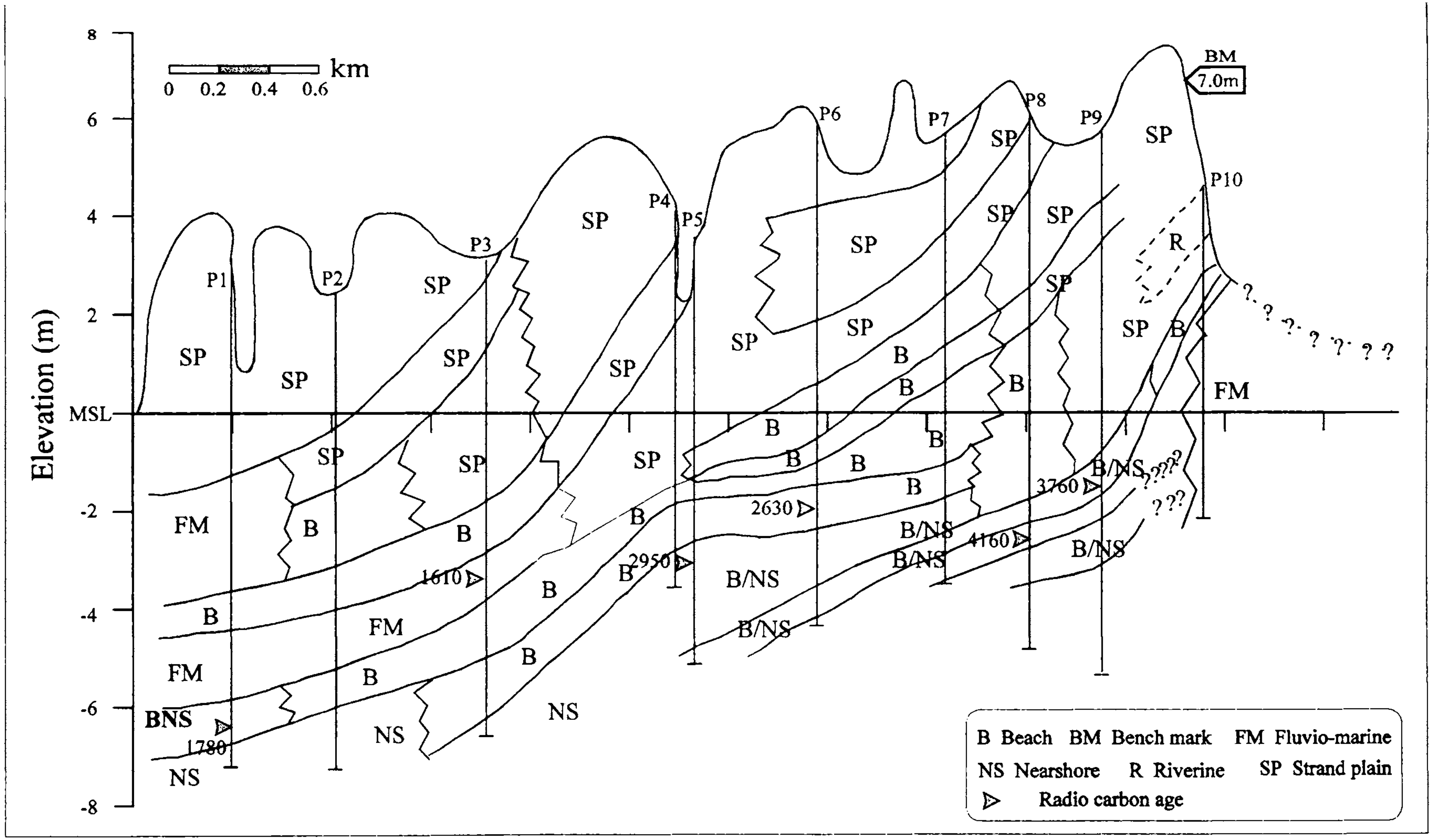


Fig. 5.1 Schematic diagram of facies architecture of coastal plain sequence along Punjavi transect

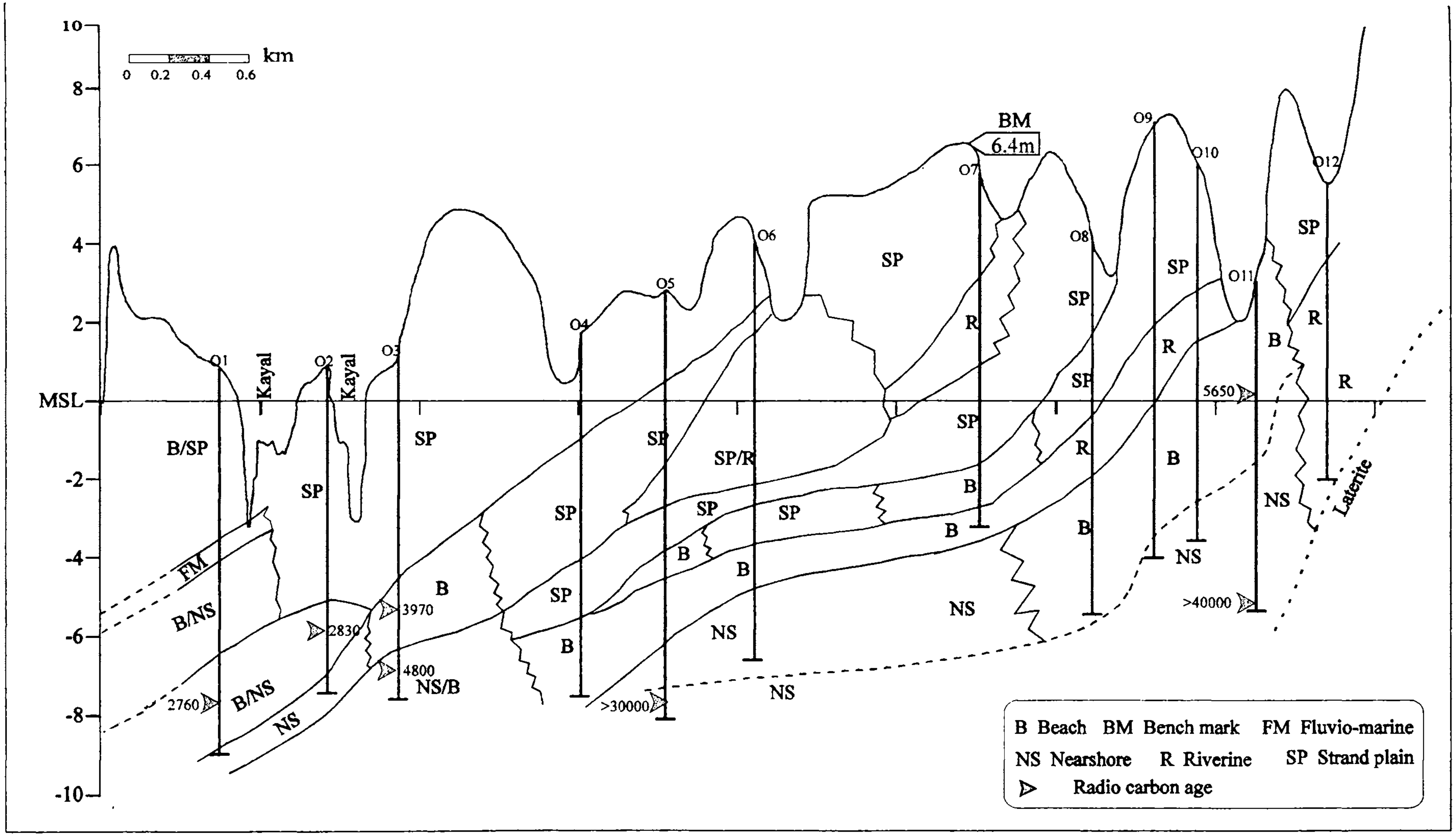


Fig. 5.2 Schematic diagram of facies architecture of coastal plain sequences along Onakkunnu transect

iations exist in the factors that contribute to intensity of post-depositional diagenetic ocesses. The reduction in the proportion of relatively less stable minerals such as mblende, hypersthene and garnet in the Onakkunnu sediments and the corresponding ddening of sands points to the fact that, compared to Punjavi sediments, the former had dergone an effective sub-aerial weathering processes resulting from the liberation of n from the less stable heavy minerals. In Onakunnu region, this may be due to specific ure of the acquifer characteristics, wherein leaching might have favoured by release of ganic acids from the acidophyllus vegetation. It was shown elsewhere (Gardner, 1983) at. weathering of ilmenite and such minerals to a significant extent could contribute to e reddening of subsurface sand. Further, progressive weathering ultimately result in aching, thereby the dark brown colouration is lost by the oxidation to leave grayish-ite residual sand.

ddening in sands as a result of mineral break down *in situ* is reported to take at least 0,000 years and estimates are of the order of one million year for the brick red colour alker, 1967; Turner, 1980). Climatic conditions undoubtedly permit reddening in both e arid and humid tropics, but, other thing being equal, the time required to attain a given gree of redness is likely to be longer in the arid tropics due to lower moisture ailability, a slower rate of mineral weathering and relatively sluggish biochemical ocesses. It is generally assumed that with the effect of humidity, the time required for e reddening get minimised. The humidity factor can accelerate the process of mineral k down. A general perception is that, in tropical climate, reddening of beach ridges d dune sands occur very rapidly (Andresse, 1970; Pye, 1981).

vious work on studies pertaining to age of the red sediments has led to the conclusion e rate of reddening of sand is though slow, might take only 10^5 to 10^6 years at certain ditions (Walker. 1967, Walker et al., 1967). However, the evidences put forward by e (1981) suggested that under humid tropical conditions bright red colours might be ned even within 10^3 to 10^4 years. The radio carbon dates obtained from the shell and samples in dark gray coloured fine and very fine sands from the Onakkunnu transect at a depth of 3.2 m and 10.4 m, gave an age of 5650 ± 110 YBP and >30000 YBP respectively. From this, it can be presumed that reddening of beach ridges might have taken place within the time specified by Pye (1981) for the tropical conditions.

5.3 RELICT SEDIMENTARY ENVIRONMENT

Sediment distribution pattern and morphological features of the present-day continental shelf along the northern Kerala coast represent composite textural fabric of relict and modern sedimentary deposits, the earlier not in equilibrium with the present day environment. Most relict sediments are related to the Holocene transgression, although some may be related to earlier Pleistocene low-stands of sea level. Continental shelf sediments cannot, therefore, be considered as the deposits solely from the present-day sedimentation processes. Different types of sediments, ranging from silty clay, sand-rich and sand-silt-clay indicate various episodes of sedimentation that the shelf has undergone during the late Quaternary period. Here, an attempt is made to gain insight into the nature of the modern/relict sedimentation pattern and their bearing on the late Quaternary coastal evolution.

Sand and mud facies constitute two basic textural entities of the shelf sediments (*refer Fig. 4.3*). The mid-shelf sand-rich sediments consist of textural grades quite similar to that of the present-day beach sediments. Ramachandran (1992) gave a detailed account of the textural characteristics of the sand-rich domains of the shelf sediments in the central Kerala, wherein, the 4-segmented probability curves are considered as typical of beach sediments. Prithviraj and Prakash (1991), Reddy and Rao (1992) and Shankar and Karbasi (1992) have also reported similar deposits of shore parallel sand-rich sediments from the southwestern continental shelf. Present day shelf dynamics could not account for such a deposit rich in sand in its present depth of occurrence. Thus, the sand-rich sediments are considered as resulted from a high-energy event during the still stand of sea level. The present depth of its occurrence is due to the sea level changes driven by the climatic oscillations during the Holocene period (*refer Fig 4.18*).

The muddy sediments over the outer shelf are considered to be deposited during early part of the Holocene prior to the deposition of sand-facies. The inner shelf domain consisting of the silty-clay sediments are deposits from the post-transgressive sedimentation processes. However, the nature and the geographic position of the surficial deposits on the shelf alone will not be sufficient to understand the scenarios of sea level changes during the late Quaternary. Therefore, to overcome this limitation, study of vertical sedimentary sequences with a chronostratigraphic perspective is imperative to derive tangible evidences of sea level history with its consequent responses. Such studies are woefully thin along the southwest coast of India, and hence, attempt is made here in the said perspectives. The down-core variation of various sedimentary units of the two transects are depicted on a simplified composite lithstratigraphic log that summarizes late Quaternary sequence in the study area. Detailed textural distribution pattern in the shelf cores distinctly demarcates the lithofacies architecture in the innershelf, midshelf and outershelf domains (Fig 5.3). One of the major limitations faced in reconstructing the stratigraphy of the shelf is the poor core recovery at many locations on the shelf, especially along the Onakkunnu transect. However, both transects have grossly similar depositional settings. The innershelf cores (*S-4, S-5 & S-6*) are dominated by mud facies with minor fluctuations in textural grades.

A shore parallel sand-rich sediment body extending along the offshore of Kerala at about 30-40 m water depth could be considered to have resulted from a high-energy event (equivalent to the present-day beach process) during a still stand of sea level (Fig 5.4). Evidences for sea level changes can also be seen in the offshore of the northern Kerala in the form of submerged terraces and drowned river valleys at depths of 110, 92, 85, 75 and 55 m, as reported by Nair (1974). The position of these landforms could be considered as representing the western-most limit of Indian shore during different stages of Quaternary sea level changes. In the outer shelf, relict carbonate sand and carbonate rocks in the form of algal and oolitic limestone of Holocene age have also been reported earlier (Hashimi and Nair, 1986). Nair et al. (1979) assigned an age of 8960 YBP to the limestone deposits occurring at a depth of 82 m along the western shelf of India. Therefore, these evidences

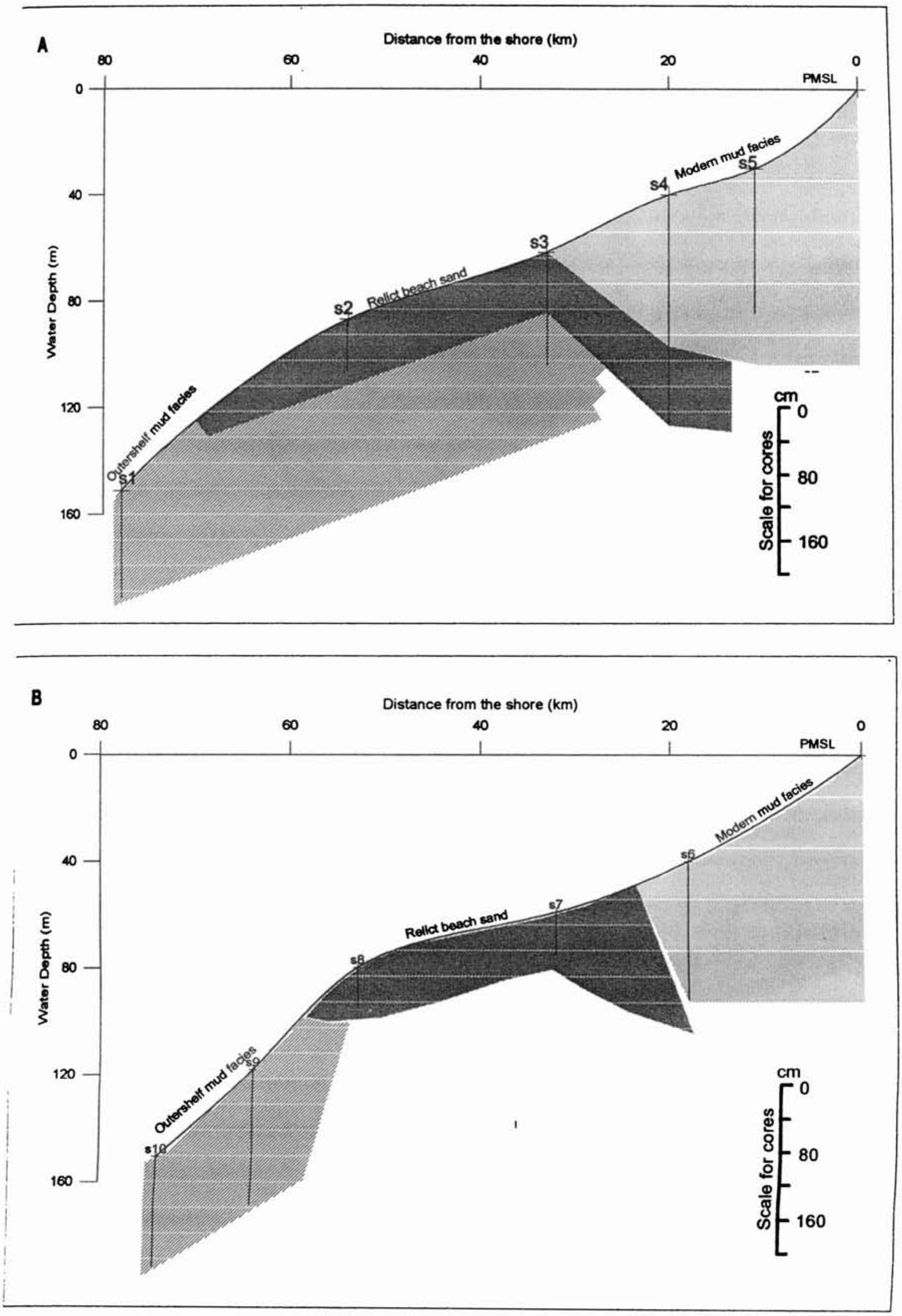


Fig. 5.3 **Schematic diagram of facies architecture of shelf sequences along (A) Punjavi and *(B) Onakkunnu transects.***

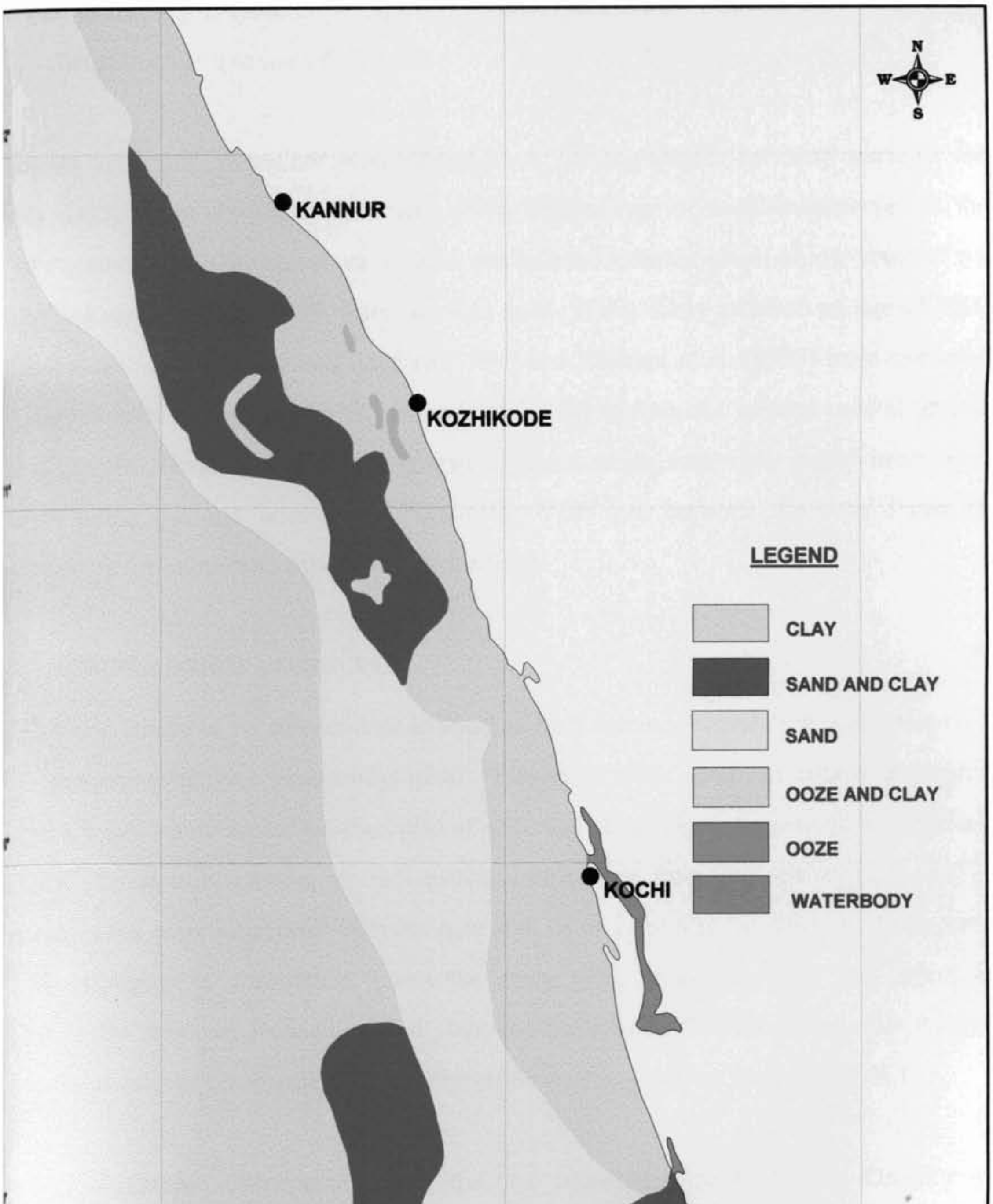


Fig. 5.4 **Generalised sediment distribution map of south west coast (Modified after GSI 1975)**

indicate contrasting climate between the carbonates and clastics on the shelf suggesting rapid change from arid to humid climate.

Holocene low stand shorelines were identified at varying depths in many parts of the continental margins elsewhere (Franzier, 1974). Similar type of deposits observed in the outer-innershelf along the east coast of India was inferred to be the result of low-stand of sea level (Mohana Rao et al., 1989; Srinivasa Rao et al., 1990). They ascribed an age of 7500 YBP to these deposits. Kale and Rajguru (1984) and Hashimi et al. (1995) have indicated that the sea level crossed the PMSL around 6500 YBP to form the present coastal (strand plain) deposits.. Hence, continuous expanse of these sandy sediments might have been formed during the age brackets of 7000-8000 YBP (i.e. between the time frame of deposition of limestone and strand plain sediments).

5.4 CHRONOLOGICAL EVIDENCES

Radiometric dating is an independent method of long distance correlation, against which the time-transgressive, lithostratigraphic, biostratigraphic and morphostratigraphic framework can be measured on the basis of observed stratigraphic sequences at different localities. As already known, no radiometric date is free from analytical errors and in some cases the error associated with the date may be so great that the date cannot be used in time-stratigraphic correlation. From the study area, seventeen shell and one peat samples were collected from the strand plain and continental shelf at different depths for radiocarbon dating. The details of the radiocarbon dating are given in the Table 5.1.

Morphostratigraphic observation along the two transects documents that Onakkunnu ridge/swale spacing as well as width is wider compared to Punjavi. Complimentary to this, the radiocarbon dating of the deposits along the two transects indicate that the sediment accumulation in any given unit is thicker in Onakkunnu transect than Punjavi. Marine deposits overlain by terrestrial peat are suggestive of a regressive phase, whereas, marine transgression can be inferred if the succession is vice-versa. The radio carbon dating of peat sample recovered from a depth of 3.2 m from core *O-11* in the coastal plain sequences of Onakkunnu transect gave an age of 5650 ± 110 yr. The reduced level computed for the peat location is more or less at the PMSL since the spot height of the core top is at 3.2 m above the PMSL. The peat materials are considered to be formed as a result of the submergence of the coastal mangroves. The peat and shell materials collected from 1 m below the PMSL from the Karnataka coastal region furnished an age of 6400 yBP (Caratini and Rajagopal, 1992). Core *O-11* is located on the seaward dip of the second set of the innermost ridge at a distance of 5.79 km from the coastline. The chrono-eustatic implication of the study is that the sea was little above the PMSL and extended up to this point to inundate the coastal mangroves. The marine deposits so located at about a distance of 5.79 km from the present-day beach is formed only after 5650 ± 110 years.

Table 5.1 Results of radiocarbon dating of the shell and peat sample collected from the Coastal plain and continental shelf

SL. No	Sample Name	Type of sample	Depth in (m)	Age in years
1	O-1	Shell	8.8 to 9.2	2760 ± 100
2	O-2	Shell	7 to 7.5	2830 ± 100
3	O-3	Shell	6.2 to 6.4	3970 ± 50
4	O-3	Shell	7.9 to 8.2	4800 ± 55
5	O-5	Shell	10.4 to 10.6	>30,000 *
6	O-11	Peat	3.2	5650 ± 110.
7	O-11	Shell	8.5	> 40,000 *
8	P-1	Shell	9.1	1780 ± 80
9	P-3	Shell	6.75	1610 ± 90
10	P-5	Shell	6.3 to 6.5	2950 ± 50
11	P-6	Shell	8.0	2630 ± 100
12	P-8	Shell	8.4 to 8.7	4160 ± 55
13	P-9	Shell	7.5	3740 ± 100
14	S-1	Shell	0.4 to 0.6	21870 ±380
15	S-1	Shell	1.2 to 1.3	36200 ± 2100
16	S-4	Shell	2.25 to 2.5	19730 ± 360
17	S-10	Shell	0.4 to 0.6	12940 ± 180
18	S-10	Shell	1.5 to 1.4	22890 ± 490

* *Cross checked in two different labs and found correct*

Thus, the present land area extending upto 6 km inland was under the sea at about 5650 ± 110 YBP. Similar kind of mid-Holocene transgressive episode is not peculiar to Indian coasts, but reported from many other tropical/sub-tropical regions. In the Persian Gulf (another tectonically stable region), similar deposits yielded ages of 6528 ± 234 YBP, 6245 ± 245 YBP, 6315 ± 479 YBP etc., for samples from 2 m and 2.7 m below PMSL (Evans et al., 1969). This is in accordance with the results obtained from the present investigation. Although, sea level changes do not show uniform global nature (Giresse, 1987), the Holocene transgressive episode is found to be a worldwide eustatic event. Despite the same general trend world over, regional factors affect the rate and nature of these episodes. The results obtained for Onakkunnu region, as well as the trend observed along the other parts of the west coast of India (Kale and Rajaguru, 1985), match well with this general trend of mid-Holocene global pattern.

Radiocarbon dating of carbonized wood samples from three sediment cores from the inner continental shelf off Taingapattanam, along the southwestern coast of India, are in the age brackets of 8400-9400 YBP. These radiometric ages correlate well with the ages of carbonized wood from inner continental shelf off Ponnani (Kerala) and Karwar (Karnataka). The occurrence of carbonized wood in the offshore areas of west coast was attributed to transgressive event, which resulted in submergence and destruction of coastal mangroves (Nambiar and Rajagopal, 1995). Similarly, peaty formation is observed in the study area in the core *S-3* at core-depth 95-125 cm, recovered from a water depth of 61.4 m, which is located about 33 km offshore from the present beach. The rate of sedimentation computed from the present study (based on the dates Vs sediment thickness) is 0.12 mm/yr, which is found to be in agreement with that reported by Nambiar and Rajagopal, (1995).

Climate leaves its own historical record in sediment accumulation pattern and has a direct influence on its composition. The late Quaternary period saw significant changes in climate, which has an impending influence on the sedimentation pattern. Nair and Hashimi (1980) and Hashimi and Nair (1986) reported that arid climatic conditions existed along the south west coast of India during the late Pleistocene and early Holocene. Carbonate content of sediments has been found to be a good indicator of glacial inter-glacial stages. Generally, high concentration of $CaCO_3$ indicates cooler periods, while, a lower content indicates warmer period (Arrhenius 1952). However, on the shelf region, this relationship is found to depend more on the terrigenous input factor rather than the climate. Increase of sedimentation rates during cold period can also increase input of terrestrial organic matter (Muller and Suess, 1979). Down-core trends, as well as the offshore distribution of organic matter and $CaCO_3$ indicate inverse relationship, with near surface and coast proximal points showing depleted $CaCO_3$ content. This amply illustrates importance of terrigenous input in controlling the accumulation pattern of organic matter and $CaCO_3$. In this context, it is important to understand the influence of sea level change, driven by the climatic oscillations on the accumulation of organic matter and $CaCO_3$.

Down core distribution of sediments in the cores *S-1* and *S-10* are characterised by clayey silt, silty clay and silt. Top units of the cores have a modest abundance of sand. The increase in sand content is compensated by a corresponding clay dilution. Silt percentages consistently increase from the upper portion to the middle part of the cores and then onwards record a declining trend. Sand content gradually decreases with core depth and become uniformly low in the deeper parts (*refer Figs 4.4 & 4.15*). This observation has a striking similarity with the down-core sand variation reported by Thampan et. al. (1997) for a core collected near to the sample locations taken for the present study.

$CaCO_3$ shows distinct similarities with that of the sand fraction as the core tops contain higher proportion compared to the lower portions (*refer Figs 4.4 & 4.15*). Here, the magnitude of fluctuation is of higher order as the range of $CaCO_3$ in the core *S-1* is at 61.8-18% and core *S-10* 63.2-30.8%, unlike the sand content. The convincing difference between the upper portion of the cores and the sediments below in terms of textural attributes and $CaCO_3$ content is most striking. Sediment built-up in the shelf regime is primarily controlled by the rate and type of sedimentation, eustasy and tectonics (Kendall and Schlager, 1981). Previous studies have shown that sea level cycles have profound impact on shallow water carbonate deposition. Biogenic sedimentation, terrigenous input and carbonate dissolution being the controlling factors at any given location, the first two factors are assumed to be of most important concerning the $CaCO_3$ distribution on the shelf. The deeper shelf at present must have become shallow-water shelf, when the sea level has fallen during the last glacial period. Thus, proximal location to terrigenous supply is unable to sustain the carbonate sedimentation, resulting in dilution of $CaCO_3$ content. Carbonates were found to dominate at the seaward margin of the shelf while clastics cover the landward margin (Kendall and Schlager, 1981).

Correlation incorporating oxygen isotope data of cores *S-10* and *S-1* has shown that the carbonate content is low during the Last Glacial Maximum (LGM), (*Figs 5.5 & 5.6; Singh et al., 2001*). Studies on paleo-productivity fluctuations in relation to monsoonal variations in the Arabian Sea indicated a weak monsoon associated with low productivity during the LGM (Duplessy, 1982; Prell and Kutzbach, 1987), which corroborates this observation.

The organic carbon in the Recent sediments are subjected to biogenic decomposition and diagenetic alteration to a limited extent. If at all the diagenetic alteration continues beneath the surface with time, then one would expect down-core reduction in organic matter content. However, in the present study, data indicate a down core increase in the organic matter content (till LGM), which is converse the general observation. This could also point to a general reduction in sedimentation rate over time to the Present. This view is supported by the converse down core trend of $CaCO_3$ distribution, as the carbonate content is normally inversely related to organic matter content (Coppedge and Balsom 1992).

5.5 LATE QUATERNARY COASTAL EVOLUTION AND SEA LEVEL CHANGES

Geological history of the area has been interpreted by collating the information acquired from various sources, such as, physiography of the coastal plain, radiocarbon dates, correlation of lithology and study of adjacent continental shelf. In this integrated

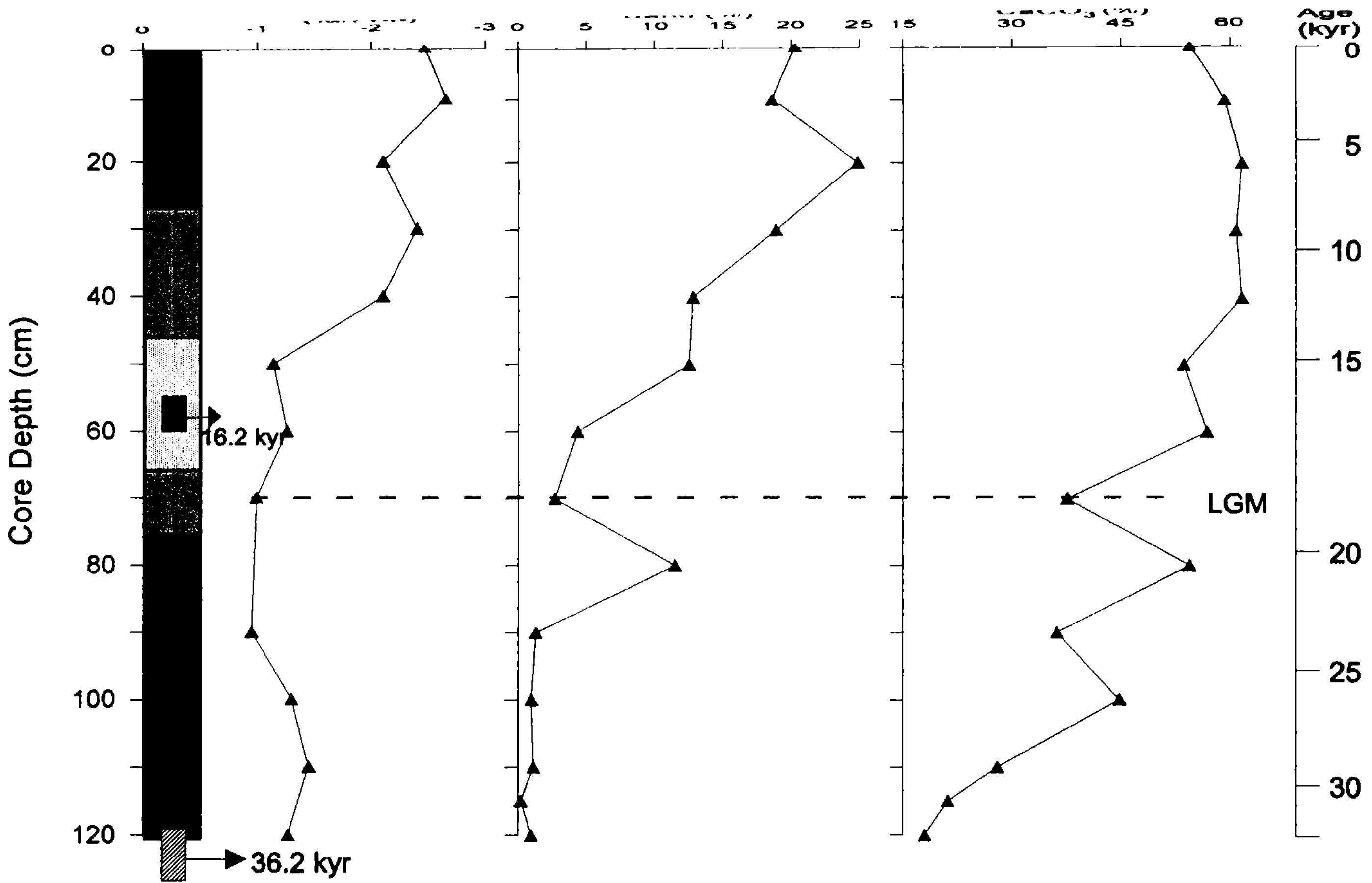


Fig. 5.5 Down core variations in lithology, Oxygen isotope record (Globigerinoides ruber), sand and $CaCO_3$ content of the core S-1. Estimated ages of the samples are given on the right side. Last Glacial Maximum (LGM) is marked at the core depth 70 cm (after Singh et al., 2001).

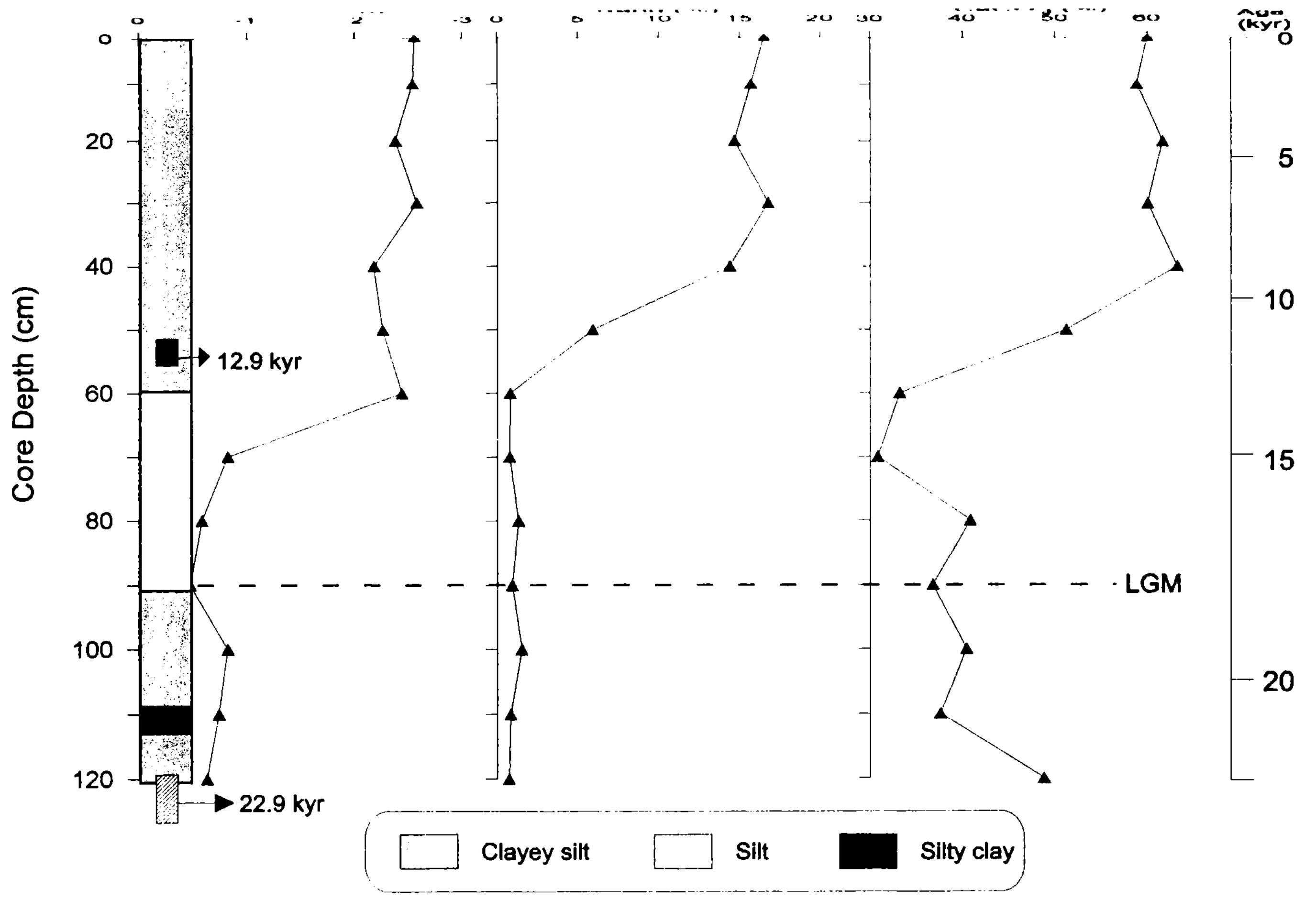


Fig. 5.6 Down core variations in lithology, Oxygen isotope record (Globigerinoides ruber), sand and $CaCO_3$ content of core S-10. Estimated ages of the samples are given on the right side. Last Glacial Maximum (LGM) is marked at the core depth 90 cm (after Singh et al., 2001)

approach, particular attention is given to the analysis of coastline shaping phenomena on different time scales. Several overlapping processes such as shore erosion, local sediment supply rate, climatic changes anthropogenic impacts and mean sea level rise (MSLR) were identified and their combined effects assessed. The eustatic sea level rise appears as a principal factor in shaping the shoreline configuration till mid Holocene. Since then, the non-eustatic factors namely, the terrigenous sediment supply rate and dynamics of barrier and estuarine system become dominant in the evolution of the near shore morphology.

5.5.1 Sea Level Variation: 36 kyr to 7 kyr

Based on the estimated sea level changes and inferred ages, Kale and Rajaguru (1985) and Hashmi et al. (1995) constructed sea level curve for this part of the coast, which differ distinctly from one another. By combining the results from geomorphological, lithological and geo-chronological frame work of the present work and from the paleobiological studies of pteropods and foraminifera (Singh et al., 2001), the evolution of the shoreline position from 36 kyr to the present is established (Fig 5.7). The bathymetric changes during last 36 kyr are inferred from the core sections by using the model on *L. inflata/creseis* abundance-depth relationship (Singh et al., 2001). The paleo-water depth estimate for each sample of the cores *S-1* and *S-10* is derived from the *L.inflata/creseis* spp. value by employing polynomial second order fit equation. About 36 kyr, sea level was 25 m below the PMSL. Lowering at a slower pace occurred between 30 and 25 kyr. Sea level at 30 kyr BP stood around 40 m below the PMSL, concurring with the observation made by Chappel and Shackleton (1986). The 30 kyr BP was a period of global regression. At 22 kyr BP sea level fell to 80 m below the PMSL. The rate of sea level lowering accelerated from 22 kyr BP, and reached its maximum lowered level of -100m during LGM (18 kyr BP). The global picture of sea level fluctuations derived from the behaviour of west Antarctic ice sheet suggests a gradual shrinkage after 18 kyr (LGM) resulting in sea level rise (Clark and Lingle 1979). Towards 14 kyr BP the sea level rose faster and stood around 50 m below the PMSL. This period marks a major transgressive episode world-over. From 14 to 11 kyr, the sea-level rise was rapid as evident from the inferred bathymetric curve. At about 11 kyr BP, the sea level was 20 m

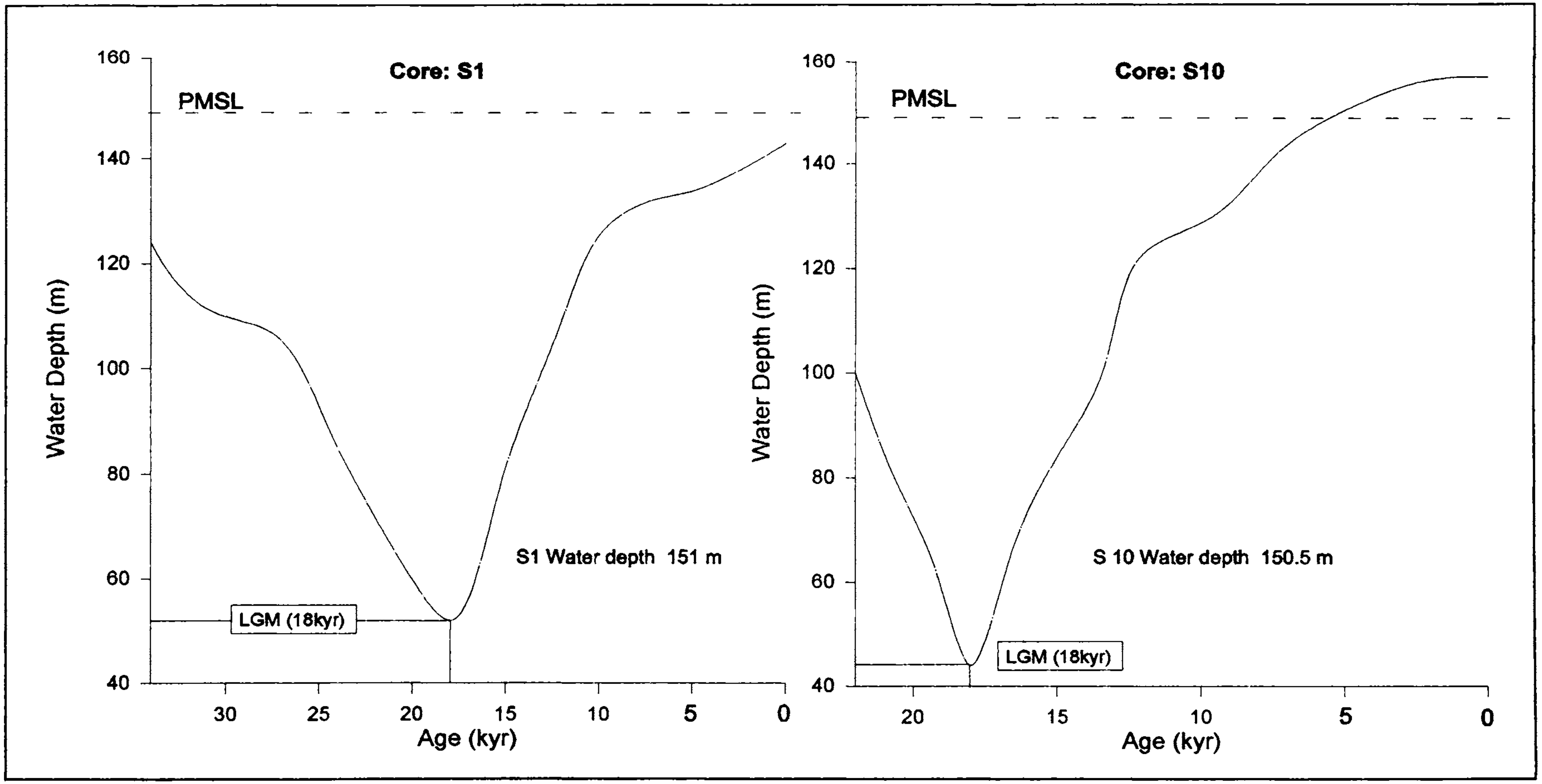


Fig. 5.7 Plot of Inferred paleo bathymetry from the cores S1 & S10 (from 36 kyr to Present, after Singh et al., 2001).

below the PMSL. The sea level continued to rise after 11 kyr BP, but at a slower rate. The sediment texture of core *S-4* collected from a water depth of 40 m show distinct difference between the upper and lower portions of the core (*refer Fig 4.17*). The upper unit is characterised by insignificant quantity of sand and the lower unit remarkably rich in sand. The sedimentological studies amply demonstrated that a paleo-beach existed off the Kerala coast during the late Quaternary low stand of sea level, which, at present, remain detached from the main land due to the subsequent transgression. Kale and Rajaguru (1984) and Hashimi et al. (1995) have indicated that the sea level crossed the PMSL around 6500 YBP to form the present coastal (strand plain) deposit. Hence, the expanse of sandy sediments on the shelf within the 40 m water depth might have been formed during the age brackets of 7000-8000 YBP. Since 7 kyr, the sea-level rise has been very sluggish. Fairbanks (1989) suggested a rapid sea-level rise between 14 and 7 kyr BP ascribing it to high glacial melt water discharge during this period. The observations made here have reasonable conformity with the Holocene sea level curve published by Hashmi et al. (1995) for the coast.

5.5.2 Regressive Episodes since 6000 YBP

Now, taking clue from the inland coastal deposits described in earlier chapter, it is deduced that around 6000 YBP, sea level was at about 5 m above the PMSL. A core sample collected from the innermost ridge shows that a marine deposit is succeeded by terrestrial peat suggesting a regressed sea. The lower muddy unit of core *O-11*, consisting of marine bivalves yielded a date of >40000 YBP. Similarly, another core bottom *O-5* having homogeneity in terms of texture and lithology with that of the *O-11*, also gave an age of >30000 YBP. Both the samples were repeated for accuracy and found to yield the same dates. Since, the radiocarbon date can give near accurate dates only upto 30000 YBP, the two samples mentioned here definitely belong to an older marine sequence. The earlier period during which the sea level crossed the PMSL was during the oxygen isotope 5e stage (Chappel and Shackleton, 1986: Fig 5.8) at about 125 kyr BP. It is quiet possible that the lower marine unit dated as >40000 and >30000 YBP belongs to the 5e stage. Detailed study is required to confirm this event. The radio carbon date of peat sample collected from core *O-11* in the coastal plain sequences of Onakkunnu transect encountered at core-depth of 3.2 m (reduced level corresponds to the PMSL) gave an age of 5650 ± 110 yr. The peat materials are formed as a result of the submergence of the coastal mangroves. This indicates that sea level was little above the PMSL about 5650 YBP. Tanner (1993) opined that the ridge top marks slightly higher-than-average sea level, and the swale bottom, slightly lower-than-average sea level. Hence the vertical difference between the elevation of two adjacent ridge and swale is considered here to infer the then position of the sea level. The ridge/swale elevation at this location indicates that the sea level stood at around 5 m above the PMSL at that time.

Radiocarbon dates of shell samples from different core-depths representing strand plain, beach and nearshore facies of coastal plain sequences show that from 6000 YBP to the Present, successive stages of marine regression have occurred along this part of the coast. Morphostratigraphy of the coastal plain sequences illustrates such eight episodes of regressive episodes corresponding to the eight sets of ridges/swales.

The age disposition of different coastal deposits shows that the inner most ridge event took place around 6000 YBP and the foredune event (adjacent to the present day beach) is a continuing phenomenon initiated since 1000 years. It is hard to infer a systematic and precise calendar for the development of each ridge event from the current data. However, excluding these constraints, it is reasonable to presume that each ridge/swale event is a minor regressive phase spanning over 500 to 700 years. The coastal plain sequences might not be essentially resulted from a continuous sea level fall, but must have been punctuated by an in between rise and pause. During the mid-Holocene, sea levels in some parts of the world were indeed higher than the present (Dominquez et al., 1987; Giresse, 1989) which conform to the most comprehensive geophysical model of sea level ICE-2 (Peltier, 1988). Gayes et al. (1992) have reported a rapid mid Holocene sea-level oscillation along the south Carolina coast where relative sea level oscillated from -3 m at 4570-5200 YBP to 1 m below its present position by 4280 YBP and then fell to -3 m by 3600 YBP before rising again to the present position. Most of the mid-Holocene warming

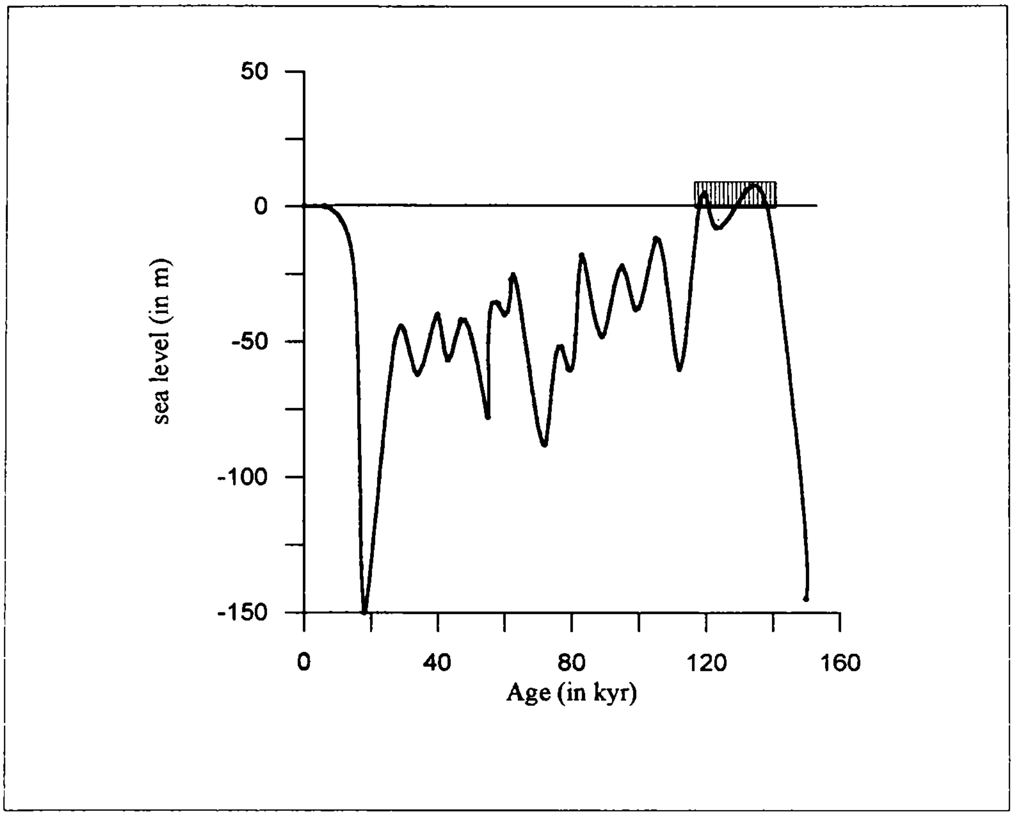


Fig. 5.8 Sea level curve after Chappel adn Shackleton (1986).

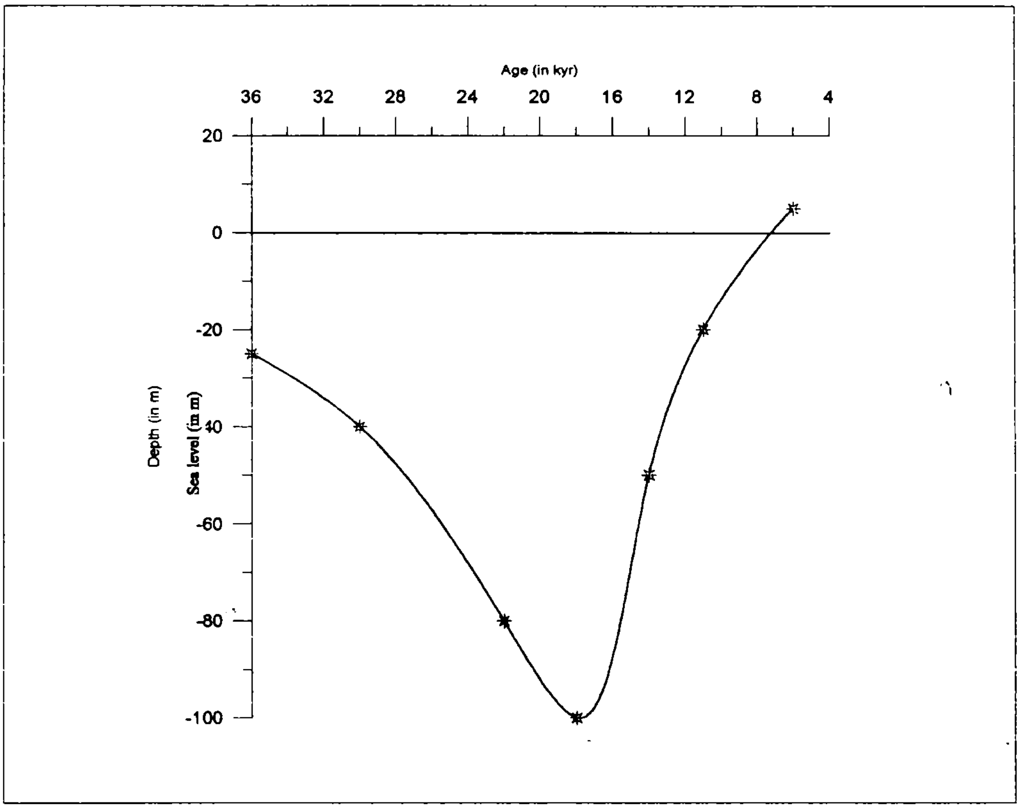


Fig. 5.9 Sea level curve from 36 kyr to present along northern Kerala.

appears to have taken place prior to 6000 YBP (Houghton et al., 1990), while most of the higher sea levels occurred at least 1000 years later. Precluding these aspects, a sea level fall of around 60 cm on the average per ridge/swale set is found to be a reasonable estimate evolved out of this study. In essence, since 6000 YBP the sea has regressed from 5m to the present MSL. But the paradox of accelerated sea level rise now being debated if true, many parts along the Kerala coast may get inundated again thrusting a transgressive episode. However, an observation by Kuhn (1989), that if the same climatic phenomena occur again, a global warming occurring in the near future might register a sea-level response that lags behind the global warming trend and reflect a few meters of eustatic sea level rise, not a few centimeters as some climate models predict, is a matter of anxiety.

5.5.3 Shoreline Positions of northern Kerala over Time (36 kyr to Present)

Compiling the oxygen isotope data (Singh et al., 2001), the results of radio carbon dating of shelf and coastal plain sequences and other evidences, a sea level fluctuation curve for the late Quaternary period was drawn for the northern Kerala coast ranging from 36 kyr to present (Fig. 5. 9)

Sea level variations since 36 kyr is comprehensively dealt here by utilising the sea level curve, the present-day bathymetric information from hydrographic charts, the contour information from the Survey of India toposheets and the physiographic map of Kerala (published by CESS) in order to reconstruct the shoreline positions over time. The Figure 5.10 is a geo-corrected illustration developed under a GIS platform that depicts the shoreline changes and the fluctuation in the total area of the segment of north Kerala. Under different scenarios of shoreline positions, its aerial extent with respect the present-day span has shown considerable variation. At 36 kyr, while the sea level situated at about 25 m below PMSL, the total area of the northern Kerala was around 11621 km^2, which is nearly 24% more than that of the present day area. During the LGM (18 kyr) when the sea level stood at its maximum of ~100m, the northern Kerala extended seaward occupying 125% more area. At about 14 kyr, the total area of the northern Kerala was around 14663 km^2, which is nearly 56% more than the present day area. During 11 kyr BP, the sea level

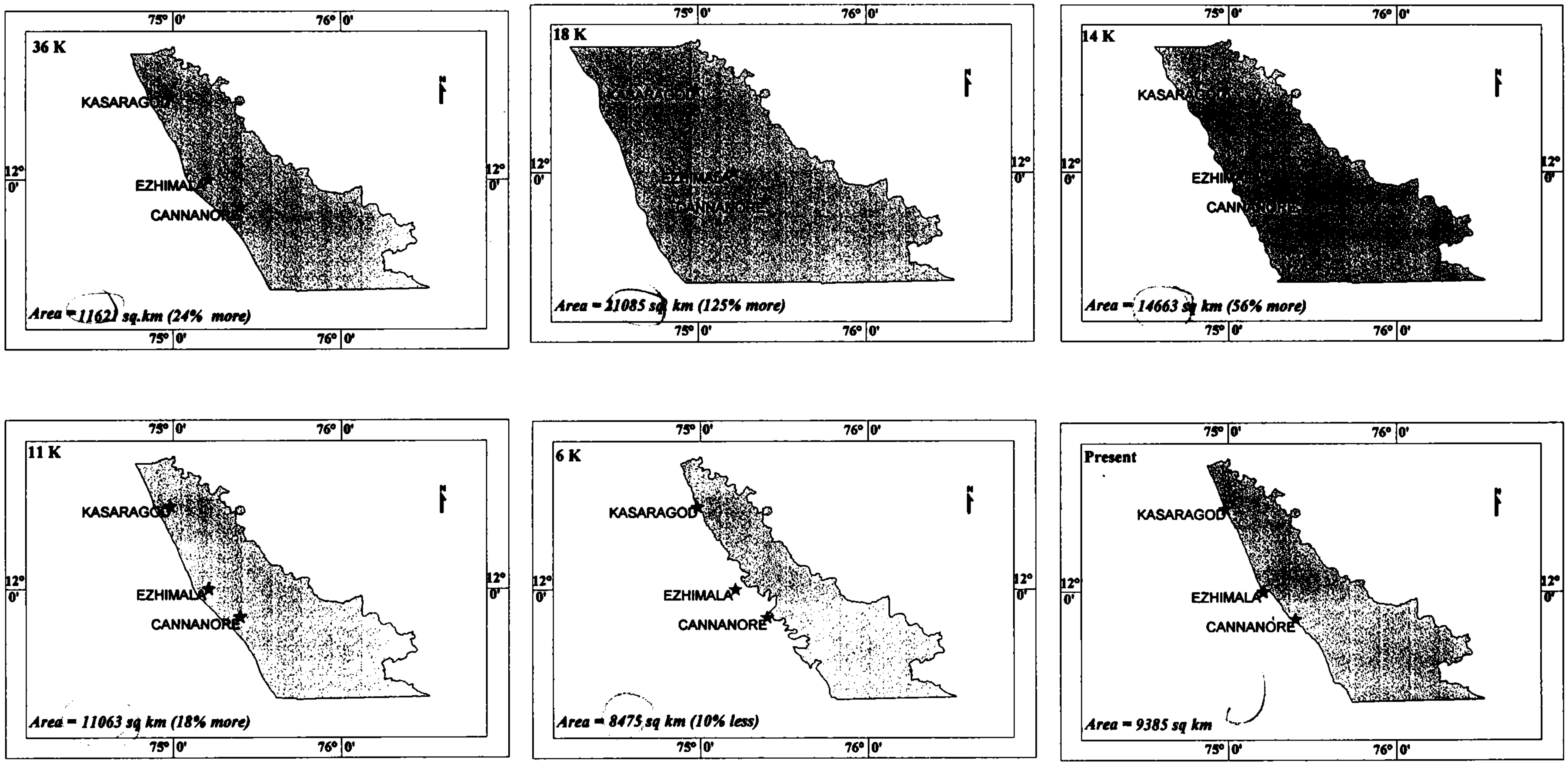


Fig. 5.10 Shoreline positions along the northern Kerala Coast from 36k to the Present

was 20 m below the PMSL, the northern Kerala extended 18% seaward and was around 11063 km^2. At about 6 kyr, the successive rise in sea level caused however 10% loss in total area and was around 8475 km^2 and ultimately got almost stabilised to its present position for the last 1000 years.

Chapter 6

SUMMARY AND CONCLUSIONS

Shore parallel beach ridges with alternating swales and occurrence of strandline deposits on the shelf make the northern Kerala coast an ideal natural laboratory for documenting morphodynamic response of the coast to changing sea levels. To understand the coastal evolution during the Pleistocene to Holocene period, a systematic study along two eastwest transects originating from the strand plain and cutting across the beach to the continental shelf domain is attempted.

Plane table mapping of geomorphic units along the two E-W transects namely Punjavi and Onakkunnu in 1:2250 and 1:5000 scale respectively were carried out. From the reduced levels, swale and ridge height were determined with reference to the PMSL. Eight sets of beach ridges and swales were identified in Onakkunnu transect and seven sets in Punjavi transect. High stand of sea level fluctuation is deciphered from a series of strandline deposits ranging in elevation from +7.73m to -3.91m. The east-west profile drawn by joining the spot heights (*with respect to PMSL*) of ridges and swales indicate a general seaward slope. The seaward slope of the ridge and swale bottom manifests successive regression during different periods.

Radiocarbon dating of shell samples collected from the Thekkekad island from a core-depth of 6.3 m below PMSL gave an age of 2830 ± 30 YBP. This shows that the deposition of shells associated with regressive phase took place at around 3000 YBP.

Based on the granulometric analysis of subsamples collected from 22 cores varying in depth from 7 to 11 m, various sedimentary facies were inferred, viz., strand plain, beach, estuarine, inner shelf and river. Morphostratigraphy and radio carbon dating of the deposits indicate that sediment accumulation is thicker in Onakkunnu than in Punjavi.

Study of heavy minerals is used to elucidate post depositional changes of the coastal plain sediments. In the Onakkunnu transect, rarity of unstable ferromagnesium minerals indicates post-depositional transformation of the deposit. Relative enrichment of stable minerals and the reddening of the sand show that the strand plain sediments, after being part of the littoral environment, could have got exposed to sub-aerial weathering during the successive phases of regression, thereby activating the intra-stratal solution processes.

In this process, dissolution of iron from the ferromagnesium minerals and ferric coating on the sand grains could have lead to the reddening of the surficial and sub-surface sediments to a great extent.

It has been established from the study that, under humid tropical conditions bright red colours might be attained even within 10^3 to 10^4 years. The radio carbon dates obtained from the shell and peat samples in dark gray coloured fine and very fine sands from the Onakkunnu transect at a depth of 3.2 m and 10.4 m gave an age of 5650 ± 110 YBP and >30000 YBP respectively.

Based on the textural analysis, calcium carbonate and organic matter contents in nine gravity cores and one piston core collected at a water depths ranging from 30.2 to 151 m, the depositional history of the shelf sediments were inferred. The four-segmented cumulative probability curve of the relict sediments at 40-m water depth is found to be quite similar to that of the beach sediments. The shelf sediments are also affected by a series of Quaternary fluctuations, thus resulting in sediments consisting of various proportions of relict, reworked and modern sediments. Intimate relationship that exist between the climate and sedimentation pattern have synergestic effect on the preservation potential of organic matter and $CaCO_3$ in the sediments. Carbonate content of sediments has been found to be a good indicator of glacial inter-glacial stages. Generally high concentration of $CaCO_3$ indicates cooler periods while a lower content indicates warmer period. Silty clay sediment in the inner shelf, sand-rich sediments in the mid shelf and silty clay/sand-silt-clay sediment in the outer shelf represent different episodes of sedimentation that the shelf has undergone during the late Quaternary period.

Sedimentological studies amply demonstrate that a paleo-beach existed off the Kerala coast during the late Quaternary low stand of sea level, which, at present, remain detached from the mainland due to the subsequent transgression. The expanse of sandy sediments at a water depth of 40 m in the mid-shelf has an age bracket of 7000-8000 YBP. Radio carbon dating on shells from the innershelf and outer shelf cores collected at 40 m and 150 m water depths, indicates a sedimentation rate of 0.12 mm/yr for the innershelf and 0.05 mm/yr for the outershelf.

By collating the result from geomorphological, lithological and geochronological studie and other published work, the evolution of shoreline position of the northern Kerala coast from 36 kyr to present is deciphered.

The radio carbon dating of marine deposits located at a distance of 5.79 km from the present beach shows that present land area extending up to 6 km inland was under the sea at about 5650 ± 110 YBP. This result matches well with the general trend of mid-Holocene *global pattern. The vertical difference between the elevation of adjacent ridges* and swales are considered for locating the then position of the sea level. The ridge/swale elevation at this location indicates that the sea level was around 5 m above PMSL around 6000 YBP.

The chrono-stratigraphy illustrates eight episodes of regressive events corresponding to eight sets of ridges and swales. The inner most ridge event took place around 6000 YBP and the fore dune adjacent to the beach is a morphologic continuum since 1000 YBP. Presuming uniformity in the conditions of depositions, formation of each ridge/swale set took around 500 to 700 years. These ridge/swale set might have been formed by the rise/fall couplet. From these, a sea level fall of around 60 cm on the average per ridge/swale set is found to be a reasonable estimate evolved out of this study.

The marine regressive episode of the coastal plain sequences encountered at deeper level shows an age of >30000 and >40000 YBP. Since, the radiocarbon date can give near accurate dates only upto 30000 YBP the two samples definitely belongs to an older marine sequences. This reveals that an earlier period during which sea level crossed the PMSL belongs to the oxygen isotope 5e stage at about 125 kyr BP. Detailed study is required to confirm this event.

The shoreline changes and the variation in the total area of the northern segment of the Kerala from 36 kyr to the present is analysed. At about 36 kyr, while the sea level situated at about 25 m below PMSL, the total area of the northern Kerala was around 11621 km^2, which is nearly 24% more than that of the present day area. During the LGM (18 kyr) *when the sea level stood at its maximum of ~100m, the northern Kerala extended seaward* occupying 125% more area and was around 21085 km^2. Since 14 kyr, with rapid rise in sea level, the coast retreated and the land dwindled continuously, which continued till 6 kyr. Since 14 kyr, with rapid rise in sea level, the coast retreated and the land dwindled continuously and ultimately got almost stabilised to its present position for the last 1000 years.

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