STUDIES ON
LATE QUATERNARY SEDIMENTS AND SEA LEVEL CHANGES OF THE CENTRAL KERALA COAST, INDIA

THESIS SUBMITTED TO THE

COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY

IN PARTIAL FULFILMENT OF
THE REQUIREMENT FOR THE DEGREE OF

Doctor of Philosophy
in
Marine Geology

UNDER THE FACULTY OF MARINE SCIENCES

BY

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DECEMBER 1998

CERTIFICATE

This is to certify that this thesis entitled, "STUDIES ON LATE QUATERNARY SEDIMENTS AND SEA LEVEL CHANGES OF THE CENTRAL KERALA COAST,INDIA"is an authentic record of the research work carried out by Sri SHAJAN.K.P, under My supervision and guidance at the Department of Marine Geology and Geophysics,School of Marine science,Cochin University of Science and Technology, 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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CONTENTS

CHAPTER 1

1. INTRODUCTION:

1.1 Introduction: The study of Quaternary geology is so vital in understanding the past geological and climatic events which in turn help to understand properly the present day climatic patterns, changes in land forms and land-sea relationship so as to forecast the future changes. The present awareness about the adverse effects of global climatic changes, due to the rapid industrialization and population growth, further demands in-depth studies on recent geological and climatic changes all over the world. Eventhough the effect of global warming and related climatic changes would affect badly the developing countries like India, very little work has been done so far in India in this regard.

In the history of geology, the Quaternary branch has been neglected mainly because of the little economic wealth it offers. In the begining it was considered only as a branch of prehistoric archaeology. The scenario has now considerably improved. The recent concerns about the present and future climatic changes dramatically transformed this discipline to one of the most important branches within the earth science discipline. Now geomorphologists, geologists, archaeologists, oceanographers, climatologists and a host of other scientists from many other disciplines show their interests in this new up coming branch of geology. Now several institutions and organizations all over the world are engaged in the research related to Quaternary geology, climatic and sealevel changes.

1.1. a Quaternary sediments

In the geological time scale, the Quaternary period represents the past two million years. Major climatic events like glaciations and interglaciations along with major changes in sea level have occurred during this short span of geological time. The Quaternary is also marked by the appearance of human race and the evolution of various cultures, particularly during the late Pleistocene and Holocene times. Marine transgression and regression are common during this time which has resulted in the shifting of the coast lines world over. The rise and fall in sea level have left their signatures in the sedimentaries of the coastal plains and inland areas. Further the oscillations have resulted in geomorphological changes like the development of back waters, estuaries, formation of marine terraces, spits, barriers, beach ridges and shifting of river courses. Archaeological changes like abandoning or submergence of ancient port cities and formation of prehistorical and historical settlements are also very common in coastal areas due to oscillations of sea level.

Occurrence of relict beaches of late Quaternary and Holocene ages well below the present mean sealevel (Shepard, 1963; Fairbridge, 1968; Bloom, 1983) strongly supports the belief that as the ice sheets retreated following the last glacial maximum, the coast line shifted its position towards land due to increase in the volume of the oceans. However, not all submerged beaches of the same age lie at the same elevation, indicating that the ocean did not rise uniformly at all places relative to the land. It has often been suggested that, because the earth is not rigid, this non uniform rise of relative sealevel would be expected even at large distances from the melting ice (Bloom, 1977; Chappell, 1982). Walcott et al., (1972) have studied the global distribution of relative sea level during the last 20000 years. He argued that the reduced ice load has caused gravitational (isostatic) disequilibrium and therefore, that those land once occupied by ice should rise relative to the sea surface. Peripheral to the glacial region, submergence is expected because of material flow into the uplifting region. Walcott et al.,(1972) have calculated the post glacial sealevel rise for different regions of the globe and assigned a rise of 88 m since 18000 yrs B.P. for the south west coast of India which lies in the zone IV of their 6 fold zonal classification.

Clark et al., (1978) have assumed that there was no ice melts after 5000 yrs B.P. and in their model curve eustatic sealevel is never higher than the present. Both the total rise in global sealevel since the last glacial maximum and the form of sealevel curve during the past 7000 yrs B.P. are in dispute (Fairbridge, 1968; Shepard, 1963). Fairbridge (1976) has believed that eustatic sealevel was at a higher level at about 5000 yrs B.P. than it is today, whereas Bloom (1970) has supported the idea that sea level has continued to rise since that time (Clark et al., 1978).

There are no stable regions where eustatic sea level can be measured accurately, because deglaciation and the addition of water to the ocean basins deform the earth and change the observers point of reference (Clark et al.,1978). Rather, by considering the relative sealevel changes at individual locations through out the world and comparing these observations to the predictions of a self-consistent model, it will ultimately be possible to infer a eustatic sealevel rise (Clark et al., 1978).

Systematic studies on the Quaternary climatic oscillations during the past few decades brought out clearly that the present day sealevel has fluctuated in response to the advance and retreat of the continental glaciers. A number of sea level curves have been reconstructed based on isotope studies by many authors for late Quaternary period. Important among them are Curray (1960), Emery and Garrison (1967), Milliman and Emery (1968), Fairbridge (1968), Guilcher (1969) and Bloom (1970). There is a general agreement among various authors that during the last major interglacial at about 125000 yrs B.P. sea level was at an elevation close to that of present level. Many authors have studied various aspects of Quaternary paleoclimate and sea level changes. Emiliani (1966) has studied the oxygen isotopic record of the foraminiferal tests of the Caribbean during the late Quaternary period. Shackleton (1967) has concluded based on the analysis of the oxygen isotopic record of benthic foraminifera that the oxygen isotopic records register an increase during glacial periods. Study of core sediments from equatorial Pacific ocean has enabled Shackleton and Opdyke (1973) to infer various oxygen isotopic stages and paleomagnetic record for the last 1.6 my. Five stages are recognised in the isotopic record of the last 130000 yrs B.P. in which stage 1 and 5 e corresponds to the Holocene interglacial and last interglacial periods. Bradley (1985) has given a detailed account of various methods of palaeoclimatic reconstruction for Quaternary period. Tooley (1980) has also given a detailed account of various methods of palaeo-environmental reconstruction in an archaeological context.

1.1. b Quaternary Sea level Changes

In the study of Quaternary coastal landscape and coastal evolution, eustatic change of sea level is the most important and dominant factor. The eustatic change in sea level is brought as a result of glaciation and deglaciations happened on a global scale. There are 4 major ice ages that occurred during Quaternary, namely Gunz, Mindel, Riss and Wurm. For each ice ages, sealevel lowered considerably to the tune of around 100 m and in succeeding inter glacial phase, it again rose either to the previous level or above/below it. The last glacial maxima has occurred around 18000 to 12000 yrs B.P. as a result of Wurm ice age. The maximum lowering of sea level is believed to have occurred during this phase and estimates vary from 80 to 140 m. During the most rapid deglaciation phase which followed the last ice age, from about 10000-7000 yrs B.P., sea level may have risen at a rate of 10 m/yr (Bloom 1970). Nair (1974) has made the pioneering attempt to study Holocene sea level fluctuations in the western Indian shelf. Quaternary climatic and sea level changes on the west coast of India have been studied by various authors like Gupta (1972), Nair and Hashimi (1980), Van Compo (1982), Borole et al., (1982), Kale and Rajaguru (1985), Baskaran et al., (1989), Caratini et al., (1990), Somayajula (1990), Shankar and Karbassi (1992), Hashimi et al., (1995), Pandarinath et al., (1998) and Subramanya (1998). Kale and Rajaguru (1985) have given a detailed account of Neogene and Quaternary transgressional and regressional history of the west coast of India. Agrawal (1989) has suggested marine regressional phase before 35000 yrs B.P. and trangression around 30000 yrs B.P. followed by regression upto 10000 yrs B.P. and thereafter, the sea started rising after 15000 yrs B.P. and reached a height of 3 m above the present level around 5000 yrs. B.P. Indian evidences show that the maximum lowering of sea level to the tune of about 100 m below the present level occurred around 14500 yrs B.P. following a small rise of about 20 m (ie 100-80 m)at about 12500 yrs B.P. with a net rate of 10 m/1000 yrs. This was followed by a still stand of sea level for about 2500 yrs B.P. Again from 10000 yrs B.P. to 7000 yrs B.P. sea level rose at a faster rate (20 m/1000 years). After 7000 yrs B.P. it fluctuated more or less at the present level. (Hashimi et al., 1995). On a global scale, the sea level was within a few meters to its present level around 6000 yrs B.P.and there after the local climatic and tectonic events have resulted in minor fluctuations in sea level. It is now generally agreed that specific areas should have their own sea level curves for the Holocene period rather than a generalized curve generated for other regions.

1.2 Causes of sea level changes

The causes of sea level changes are briefly given below:-

i) **Neotectonism** :- The present day south west coast of India has resulted from the block faulting in early Tertiary and in this block faulted basin, the Neogene and Quaternary sediments are accumulated. This fault was active throughout Neogene as evidenced by the uplifted and subsided nature of sedimentaries on the coastal fringes of Kerala. The evidences for the neotectonic activities along the west coast of India are summarized below.

a) The extensive occurrence of late Quaternary beach rocks, or littoral concrete as it may be variously called in the Konkan area, is well above the present sea level. The Konkan coastal plain is believed to have uplifted in recent times.

b) Occurrence of miliolite lime stone beds to several km inland to the present day coast on Saurashtra indicate upliftment. c) The friable grity calcareous sandstone of marine origin above the present sealevel near Cape Comorin, points to emergence of land.

ii) **Isostatic changes** :- Isostatic changes are resulted from the changes in surface load. These are regional in nature, but are also of different types. Glacio-eustacy refers to changes in surface load due to the formation of ice sheets. This kind of change has not affected the study area, as Kerala has never experienced any ice cap throughout the Quaternary or the Teritary times. Hydro-isostacy is resulted by the changes in the earth's crust in response to water load and its maximum effect can be seen in the equatorial region.

iii) **Climatic Changes** :- Rajaguru et al., (1993), in their detailed work on late Quaternary climatic changes in Western India have ascribed a semi-arid to arid climatic condition in the whole of western India during late Pleistocene which corresponds with the Last Glacial Maxima (LGM). The beginning of Holocene is marked by a humid climate with monsoonal activity similar to the present day. They also concluded that the whole of Holocene epoch experienced almost similar climatic condition as that of the present day. Compared to other parts of western coast of India, the south west monsoon is more intense on Kerala coast. According to Pisharody (1983) monsoonal activities began during the Miocenc period. Palaeoclimatic studies for western India were carried out by Agrawal and Roy (1975), Van campo (1980), Rajaguru(1983), Somayajulu et al., (1988), and Hashimi et al., (1995) and a generalized picture has been emerged now. But on Kerala coast, very little work has been done in this regard.

iv) Glacio-eustacy :- The most important single factor which has contributed to the world wide sea level changes in Quaternary period is undoubtedly the glacio-eustacy. The glacial - interglacial phases as a result of cooling and warming of global climate led to the oscillations of global sea level to the order of 100 m or more. Eventhough Kerala coast never experienced any glacial phases during Quaternary, the effect of a rising sea level after LGM has left the evidences in the form of submerged marine terraces at various oceanic depths, shell deposits and marine sediments and strand plains far inland and finally the most prominent geomorphological feature namely the backwaters in the coastal belts. These fluctuations in sea level resulted in extensive sedimentation and geomorphological changes in the coastal areas.

v) Coastal Configurational Changes:- Changes in the balance of depositional and erosional processes result in horizontal displacements known as configurational changes (Chappell, 1982).

Configurational changes are controlled and modified by climate, vegetation, wave processes, human interference and they produce a variety of coastal land forms such as tidal flats, beaches, marshy lands, swamps etc. However, there is no evidences on Kerala coast for major configurational changes either in the historical or pre-historical period by human interference. Now, like other coasts of the world, Kerala coast is also experiencing changes in its configuration due to the activities of modern man and the resulting natural processes.

1.3 Palaeoclimatic studies on Kerala coast

On the basis of the planktonic foraminiferal frequency changes four intervals of major climatic cooling have been recognised by Singh (1993) in Indian ocean region, one in late Pliocene (2-3 my B.P.), and 3 in the Pleistocene; i.e at 1.6 my (immediately above the Pliocene-Pleistocene foundary), at 0.6 my and during the late Pleistocene. Singh (1998), based on the temporal variation in the composition of faunal assemblages has suggested a detailed oceanographic and climatic changes during late Quaternary period from inner shelf sediments off Kerala coast. He could identify a weak upwelling in association with a weak monsoon between 23000 and 18000 yrs B.P. However, the intensity of upwelling and monsoonal strength had increased gradually around 18000-15000 yrs B.P. followed by a brief interval of weak monsoon. A strong monsoon from 12000 to 10000 yrs B.P. have also been predicted. The south west monsoon was weaker around 5000 yrs B.P. with minor fluctuations in its strength.

Based on pollen analysis of core samples from sediments off Cochin, Van compo (1980) has observed lesser mangrove pollen from 22000 to 18000 yrs B.P. suggesting dry climatic condition. However, good frequency of mangrove taxa have been recorded around 11000 yrs B.P. suggesting humid climatic conditions. The decline of mangrove vegetation after 6000 yrs B.P. is largely attributed to biotic influence. Based on carbon isotopic record of tropical peats of Nilgiris, Sukumar et al.,(1993) have pointed out that the predominance of C4 plants were due to a very arid phase and weak monsoons during LGM ie 20000-16000 yrs B.P. From about 16000 to 10000 yrs B.P. a swing towards C3 plants indicates strong south west monsoons, peak around 11000 yrs B.P. The early Holocene (10000-6000 yrs. B.P). is again marked by a shift towards C4 vegetation, indicating a progressively more arid climate.

Evethough many workers have attempted geology and geomorphology of Kerala from the time of Buchanan onwards, studies on Quaternary sediments, climatic and sea level changes are very few in Keral a perspective. Nair (1996) has carried out extensive studies on the geomorphology and Quaternary geology of the coastal areas of Kerala. Other workers include Pawar et al., (1983), , Erattupuzha and George (1979), Mathai and Nair (1988),Rajendran et al., (1989) and Kunte (1995) and Narayana (1996). Recent shore line changes on Kerala coast were discussed by Erattu puzha and George (1979). Quaternary geology of Kerala was studied with the help of ^{14}C dates by Rajendran et al., (1989). Mathai and Nair (1988) have given a detailed picture of the various land form evolution in Kodungallor coast.

1.4 Geology of the region

The stratigraphic succession of Kerala can be grouped mainly into three divisions namely a) Precambrian b) Tertiaries and c) Recent and Subrecent.

Precambrian crystallines :

The Precambrian cystallines consist of charnockite suites, pyroxene granulites, pyroxenites, charnockitic gneisses, calc granulites, khondalites, garnet sillimanite gneiss, graphite biotite gneiss, quartzites, garnet biotite gneiss, cordierite gneiss, biotite hornblende gneiss, granites, pegmatitic veins and gabbro or dolerite dykes (Unnikrishnan ,1987). Majority of the rocks of Kerala, particularly the granulites and associated gneisses, belong to Precambrian. Sporadically late Precambrian-early Palaezoic granites and associated pegmatites, and Mesozoic-Cenozoic dykes intrude these rocks. The oldest rocks in Kerala are the massive charnockites which has been dated to 2930±50 my. Charnockites and associated gneisses occupy most part of the Western Ghats and midland areas of Kerala. The khondalite group of rocks are dated to 2100-2830 my and cordirite gneiss samples are of still younger age (Soman 1997).

The important Precambrian crystalline rocks of Kerala area are described below.

Charnockites : The charnockite group of rocks are commonly seen in the central and northern part of Kerala and less predominently in southern Kerala. The rocks are intensively deformed and sheared. Foliation is not prominent in these rocks. Composition of charnockite group of rocks varies from silicic to ultra basic. The various types of rocks observed in charnockite suite are charnockites, pyroxene granulite, pyroxenite, gneissic charnockites, calc granulite etc.

Khondalite suite : They are generally light coloured, fine to coarse grained and show granulitic texture with foliation. This suite is abundantly distributed in the southern part of Kerala. The various rock types are garnet sillimanite gneiss, quartz - feldspathic gneiss, quartzites, graphite bearing gneisses etc. Age determination of these rock types indicates a range of 670 to 2200 Ma (Santhosh, 1987, Chacko et al., 1988).

Garnet - biotite gneiss : This rock is found associated with cordirite gneiss, charnockites and garnet - sillimanite gneiss. The essential minerals present are quartz, feldspars, garnet and biotite with accessories like hornblende, zircon and opaques.

Corderite gneiss :- It is generally associated with granulites and charnockites. The constituent minerals are corderite, perthite, plagioclase, feldspars, garnets, biotite, sillimanite, orthopyroxene, quartz and spinel.

Biotite - hornblende gneiss :- This type of rocks are found extensively in central Kerala. The essential minerals of this rock types are quartz, feldspars, biotite and hornblende with zircon and opaques as accessories.

Acid intrusives : Granites, pegmatites and quartz veins are the common acid intrusives observed in Kerala. Apart from this, patches of syenitic intrusions are also reported from Kerala. The granite bodies generally occur as fault/lineament controlled plutons emplaced between 500 to 700 Ma ago. (Santhosh and Drury, 1988). The Precambrian crystallines are traversed by simple and complex pegmatites and quartz veins at several places.

Basic intrusives : Gabbros and dolerites constitute the most common basic intrusives emplaced within the Precambrian crystallines. Two distinctive systems of basic dykes are recognized. They are:

1) NNW - SSE trending leucogabbros which are exposed intermittently for over a length of 100 km.
2) The NW-SE trending dolerite dykes.

The Archaean formations of Ernakulam and Thrissur districts comprise of charnockites and pyroxene granulites of charnockite suite and hornblende - biolite gneiss and garnet - biolite gneiss of the migmatite suite. Charnockites are by far the most abundant rock type in the whole of Thrissur and Ernakulam districts. Here charnockite suite of rocks consists of charnockites and pyroxene granulites . They are mostly massive, occassionally showing foliation with rock cleavage trending in a NNW-SSE to NW-SE direction. The hornblende-biotite gneisses, biotite gneisses and garnet sillimanite gneisses are found mainly in the eastern part of the districts. The intrusives into the above rocks include granite, pegmatite, gabbro, dolerite and quartz veins.

Tertiaries: The Tertiary sedimentary formations of Kerala basin unconformably overlie the Precambrians. These sedimentaries spread over a part of the south western continental margin of the Peninsular India. Occurrence of marine and nonmarine rocks over the onland part was known since King (1882). Exposures are seen at many localities: Karichal, Varkala, Thonnakal, Kundara, Padappakkara, Edavu, Paravur and Kottayam in the southern Kerala, while Palaymgadi, Cheruvattur and Nileswar in the northern Kerala; and are essentially Neogene and Quaternary sediments. Paulose and Narayanswami (1968) recognized two major basins of deposition (i) between Trivandrum and Ponnani in the south and central Kerala with a maximum width of 16 km between Quilon and Kundara and (ii) between Cannanore and Kasargod in north Kerala with a maximum width of 10 km at Cheruvattur.

King (1882) divided the Tertiary rocks in the Quilon - Varkala area into Quilon beds (consisting of lime stone and calcareous clays) and the Warkalli beds (comprising sand stone and clays with lignite). Bruce Foote (1883) Jacob and Sastri (1952), Narayanan (1958) Desikachar and Subramaniyan (1959), Paulose and Narayanaswami (1968) Raghava Rao (1976) Nair and Rao (1980) and Raha et al., (1983) are some of the poineering workers in the field of Tertiary geology of Kerala.

Raha et al., (1983) designated the entire Cenozoic sequences of coastal Kerala as Malabar Super Group, comprising Karichal formation, Warkalli group and Vembanad formation. The Central Ground Water Board (CGWB) report No.33 (1993) mentions yet another formation namely Alleppey formation underlained by the Quilon beds. Nair and Rao (1980) caried out a facies analysis of the basin between Warkala and Cochin using bore hole data and classified these sedimentaries into five lithological units. However, studies on the lithology of these sediments by the workers of the CGWB, through exploratory bore hole data indicate that the upper Tertiary sediments in Kerala consists of three distinct formations namely the Warkalli, the Quilon and the Vaikom (Rao, 1976).

The lower most unit of the Tertiaries ie Vaikom beds is exposed near Vaikom in Kottayam district. The clastic unit contains sand stones, clays, gravels, coarse sands, sandy calcareous clays and thin lignite seams and this formation is typically a continental facies. Whereas the Quilon formation is of calcareous marine facies the Warkalli is of terrigerous facies. The type area for Quilon formation is Padappakkara near Quilon. Quilon formation consists of fossiliferous lime stone, laterites, sandy clays, clayey sands, carbonaceous clays, marls and calcareous sand stones. It is of early Miocene (Burdigalion) age.

The Warkalli formation consists of variegated sand stone and clays. White grey carbonaceous clays, lignite and Marcasite are also noticed. Warkallis are of Miocene age and overlie the Quilon formation. Poorly sorted sands are common and the maximum thickness is 60 m and the total aerial extent is approximately 2000 sq. km (Subramanian, 1964). According to Raha and Rajendran (1983), Warkalli sand stone consists of fractured and fragmented angular grains of quartz due to weathering and laterization. They have also reported heavy minerals like biotite, magnetite, ilmenite with minor amounts of zircon, garnets, sillimanite and pyroxenes. In Ernakulam and Thrissur districts, the Teritiary sedimentaries are seen rarely as surface exposures, but it occur all along the coastal belt underlying the Quaternary alluvium.

The Tertiaries are found overlying the crystalline massifs at a few places in central Kerala. They are composed of loosely consolidated or unconsolidated sand intercalated with variegated clay, carbonaceous clay and thin streaks of lignite. The out crops of Tertiary formations only occupy about 30 sq. km area near Kodungallur in Thrissur Dt., and are also found at places like Manjummal and Manjaly in Ernakulam Dt. These rocks are extensively lateritized which have masked their original characteristics. The out crop pattern of Tertiary formations of Thrissur Dt. conforms to outliers towards the east with a larger part underlying the surficial alluvial sediments in the west. According to CGWB report (1993), this Tertiary formations are classified as Vaikom beds (Figs. 1 & 2).

1.5 Quaternary sediments of Kerala : The coastal plains are generally covered by the Quaternary sediments comprising sands, clays, laterite, peat beds, petrified and semi petrified woods, older red teri sands, beach and dune sand deposits, sand bars, lime shell deposits, alluvium and soil; and underlain by bedded strata of Tertiaries. The formations exhibit a complex pattern of marine, estuarine and fluviatile origin. Marine and estuarine sediments are even found farther inland, and so also riverine sediments in coastal areas. Generally marine and estuarine deposits concentrate around the backwaters and lowlying areas, and alluvium along river valleys. Majority of beach ridge sediments, shell deposits and valley fills of river basins are considered to be Holocene in age. The marine, lagoonal and estuarine sediments comprising of black clays and sands and their admixtures with occasional shell layers are noticed in the low lands adjoining backwaters along the coast. The kole lands and river valleys in the coastal plains are covered by alluvium consisting of gravel, sands and clays. Nair and Rao (1980) are

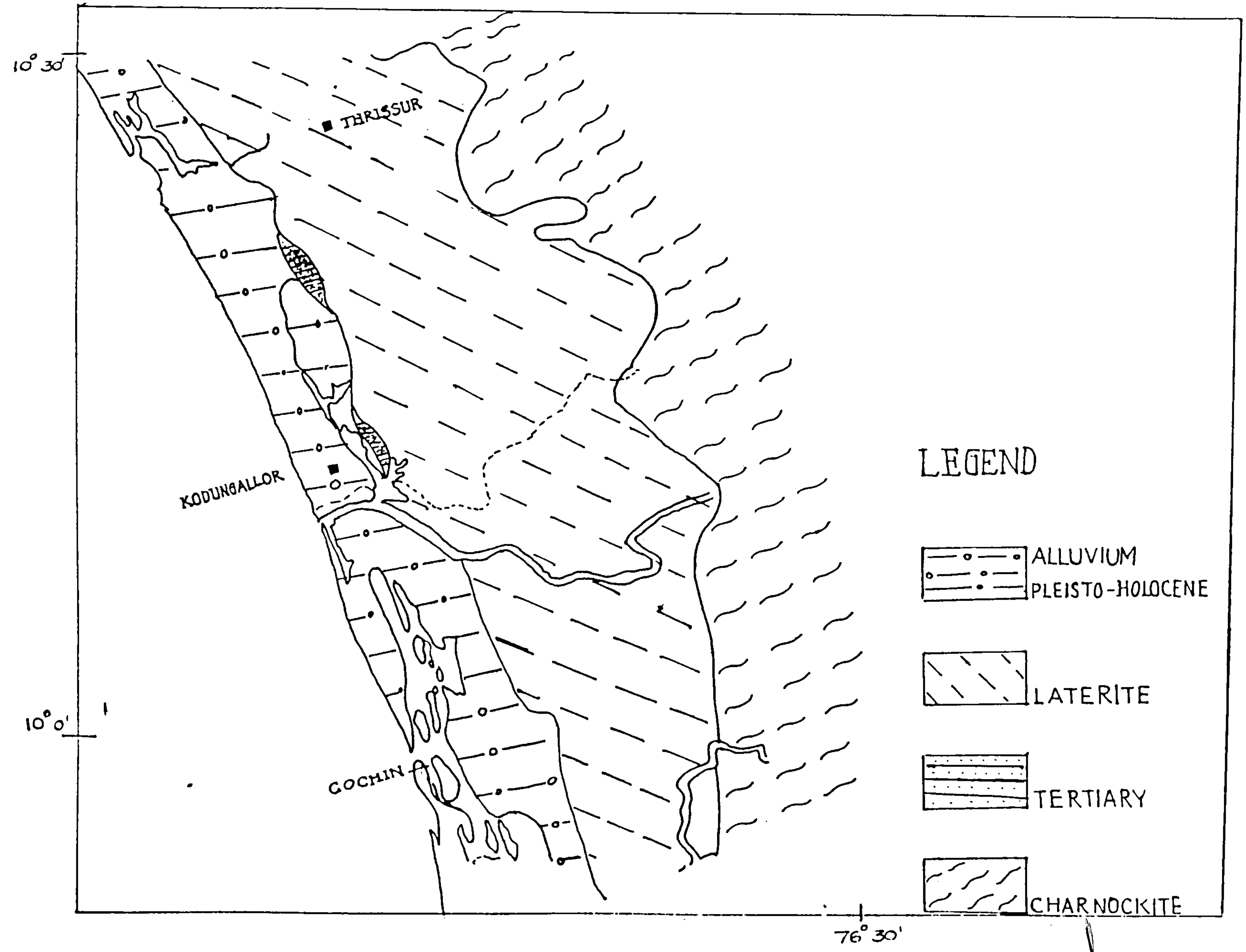


Fig.1 GEOLOGY OF STUDY AREA

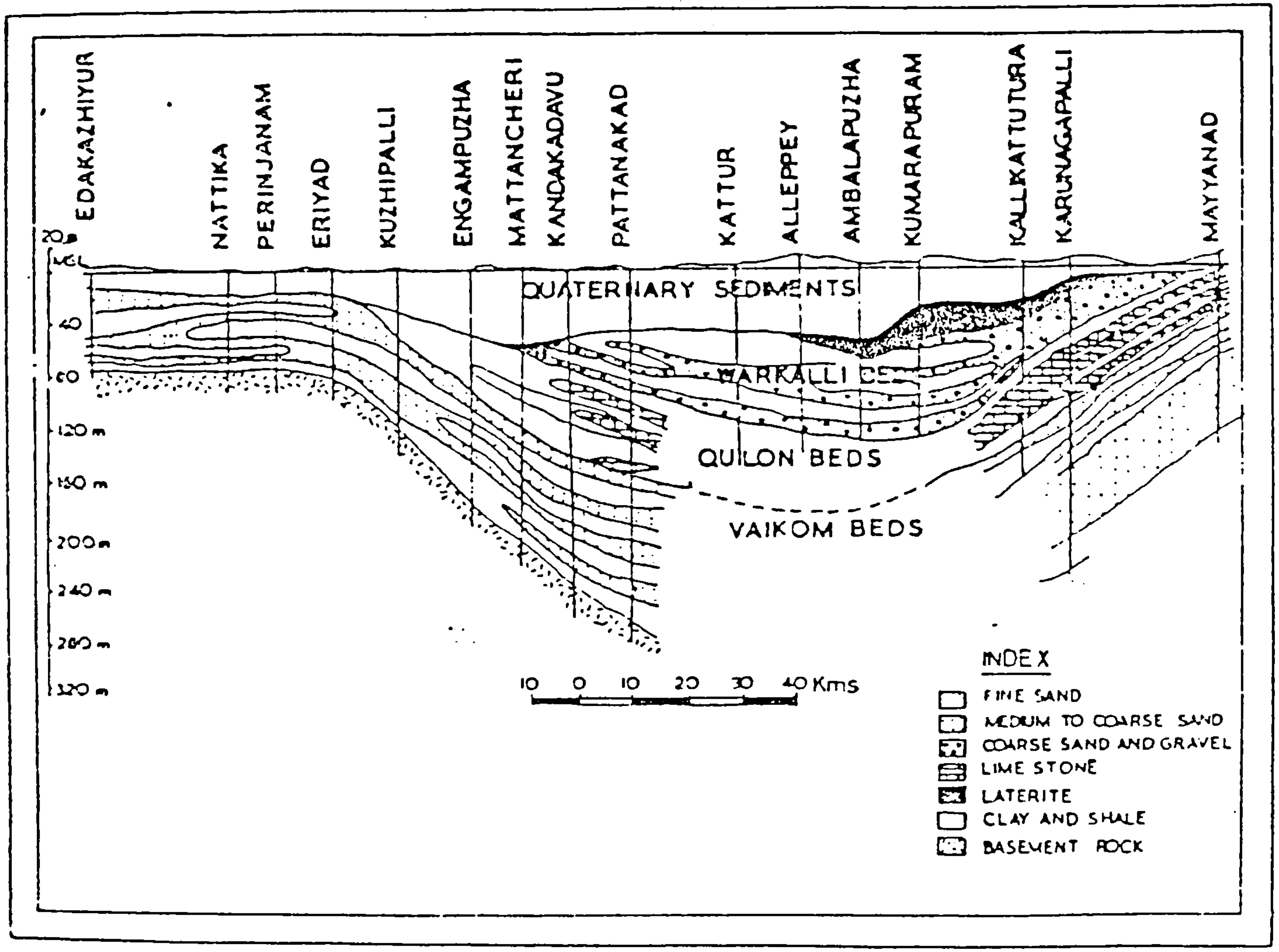


Fig. 2 Subsurface geological section along the coastal belt of Kerala based on borehole data (*after* Raghava Rao, 1976)

of the opinion that lithological unit - IV, the youngest in their classification consists of black clays, shell beds and beach sands and the major part of it is of Quaternary age. This Quaternary unit (approx. 80 m thick) is distinguishable from Tertiary unit III by the presence of a ferrugen ous laterite horizon in the subsurface sedimentary column.

The Quaternary sediments of the study area include black clayey, silty and muddy sediments intercalated with sands, peat beds and shells. These sediments are found throughout the coastal areas in all subsurface columns. Lateritic clays are also seen in the subsurface coastal sedimentary column of the study area. The Quaternary sediments exposed on the surface in the study area are white beach sands, brown beach sands, shell deposits, black clays and older alluvium. The older alluvium and brown sands are found lateritized in some areas.

The Quaternary is the most important stratigraphic division with regard to the mineral wealth of Kerala. The important mineral deposits of the Quaternary sediments are beach placers, silica sands, shell and clay deposits. The beach placer deposits are the main source of ilmenite, monazite, zircon, garnet and sillimanite. The silica sands are widely used in the manufacture of glass and glass products. Shell deposits are used for making cement and lime. The clay deposits of inland river basin and kole lands are the main raw material for tile and brick manufacturing.

Laterites : The word laterite is derived from the latin word "later" for bricks. It was first noticed by Buchanan (1807) from Angadippuram in North Kerala.

The residual formation of laterite occur as a cover over the crystalline rock and sedimentaries in 60% of Kerala's surface area except the high land areas. They are considered to be residual deposits formed under special climatic conditions which are ideal for active weathering. It is mainly composed of hydrated oxides of Fe and Al together with minor amount of Mn, Ti, V and Zn. The minerals present are kaolin, quartz, goethite, haematite, tremolite and gibbsite. These rocks are considered to be the primary source of black minerals in the beach sands of Kerala. The thickness of laterite capping in Kerala varies from a few cm to approximately 30 m.

1.6 Physiography

Kerala is a narrow strip of land on the south western part of Peninsular India, with width varying from 30 km in the north and south and to about 130 km in the central region. Though the total geographic area of the state is just 38,854.97 km^2, ($\simeq$ 1% of India's total area), the physical features exhibit wide ranging variation. Topography of the state covers altitudes ranging from below mean sealevel to about 3000 m above mean sealevel. The western ghats form an almost continuous mountain chain on the eastern border of the state, and occasionally broken by a few passes. The Anamalai (2695 m) is the highest peak in Peninsular India. The mountain ranges and the high intensity of rainfall during the two monsoons, namely SW and NE , gave birth to a number of perennial rivers which resulted in the formation of varied land forms.

Kerala has a coastline of about 560 km. Kerala has a total of 7 lagoons and 27 estuaries, of which the Vembanad lake is the largest with an area of 205 km^2. Kerala is traversed by 44 rivers of which 41 have their course towards the Arabian Sea . They take their origin from the Western Ghats and flow towards the west until they drain into either the backwaters or the Arabian Sea. The rivers are mainly monsoon fed and most of them are perennial in character. During the monsoon season, rivers flow with turbulence and the larger rivers frequently rise 3 to 4 m above their danger level causing extensive flooding in midland and coastal areas . The total run-off of Kerala rivers is about 2,50,000 million cubic feet ie about 5% of Indias total water potential.

Physiographically, Kerala can be divided into three well defined natural divisions viz. low lands, midlands and high lands. These physiographic zones are very important in determining the drainage systems, vegetational pattern and resources in the area. Kerala has more or less identical physiographic situation as that of the coastal Karnataka and Maharashtra respectively. The lowlands, which are below 8 m elevation, is a lowlying plain of varying width with successive stretches of sand bars, beach ridges, spits, barriers, estuaries, backwaters and various fluvio-marine land forms. The backwaters which generally run parallel to the coast are occasionally connected to the sea by permanent or seasonal creeks. The coast of Kerala is comparatively straight and is similar to Konkan coast in this respect. The faulting of the west coast of India has resulted the straight features of Kerala coast. The mid lands, which ranges in elevation from 8 to 75 m, are intersected by a number of rivers and streams. The laterite plateau stretches from the hilly terrain to the low land in a succession of gentle slopes and near to the coast, it merges with coastal plains and lagoons. A series of plantation surfaces have been noticed in this area. The high land division comprises the western tracts of the Western Ghats, which flanks on the eastern side. It is composed of a succession of ridges and peaks and presents a general irregular outline. Further the high lands have a precipitous descent towards the west and are connected with a succession of low hills diminishing in attitude towards the coast.

1.7 Climate and Rainfall

Central Kerala falls in the region of tropical monsoon climate. On the basis of hydro-meteorological conditions, four seasons are identified namely, premonsoon or hot weather period (March-May), southwest monsoon (June-September), northeast monsoon (October-December) and winter (January-February). The southwest monsoon constitutes the principal and primary rainy season which gives 75% of the annual rainfall while northeast monsoon provides a secondary rainy season. The winter months are characterised by minimum clouds and rainfall, and the premonsoon is a period of increasing thunderstorm activity. The total annual rainfall of the state varies from about 4500 mm in the northern Kerala to about 2000 mm in the south (average 3010mm). Ernakulam (3210 mm) and Thrissur Districts (3160 mm) receive rainfall a little above the state average. The atmospheric temperature is maximum (>32 ^{o}C) during premonsoon period and from June onwards it gradually decreases due to heavy rainfall. An increasing trend of temperature is noticed again during October- November, followed by lower temperature (< 27 °C) during December and January.

1.8 Population pattern About 80% of the world's population are concentrated mainly on the coastal zone which is one of the most dynamically active environments on earth. In this context the coastal zone of central Kerala is not an exception as majority of the population are concentrated on this fragile zone of the ecosystem. Based on the 1991 census, Ernakulam and Thrissur Districts record a population of 28.17 lakhs and 27.37 lakhs respectively. World wide expanding population has a distinguishing impact on coastal zone development. Knox and Miyabara (1984) has authenticated that the population migration is probably the most fundamental and pervasive of all planning factors which intensify conflicts and coastal management issues. This aspect has placed a more emphasis on the human settlements and the impact of sea level variations on the coastal zone of central Kerala, which is discussed in the text in proper.

1.9 Objectives

The late Quaternary sediments and sea level changes of the central Kerala region have not been studied in detail. Only limited informations are available based on bore hole samples and this is the first attempt based on geomorphological evidences, lithological characteristics, geochronology, palynology, palaeontology, geochemistry and geoarchaeology. The main objective of this investigation are

(i) to evaluate the coastal land forms of the study area, with special emphasis on the Kodungallur area

(ii) to analyse the textural variations of the strand plain and deep borehole sediments from Ernakulam, Kodungallur and Koleland area

(iii) to understand sea level variations in relation to ^{14}C chronology

(iv) to derive information on sea level changes with the help of geochemical, palynological and palaeontological data and

(v) to assess the late Holocene regressive phase in the study area based on archaeological remains

CHAPTER 2

2. MATERIALS AND METHODS

2.1. Introduction

This chapter deals with the various methods employed in the collection of data pertaining to the Quaternary sediments and sea level changes of central Kerala Coast. The present investigation is scheduled into two phases namely i) field survey/sample collection and ii) laboratory methods

2.2 Field Survey

Collection of sediment samples was done in a systematic manner. All the sampling sites are shown in Fig.3. Mainly two types of sediment samples were collected from the study area: a) sand samples from shallow pits, sand quarries and vertical sections exposed in the strand plains of Kodungallur region and b) samples from boreholes. Sand samples were collected across the coast in the Kodungallur region, where maximum number of beach ridges are noticed. Ten sampling stations were fixed roughly at 0.75 km interval from the present beach towards interior. A total of 100 samples ie 10 each from each one station at 20 cm vertical interval were collected. In addition, 3 subsurface peat samples were collected from three places namely Karuvannur (2m depth), Vellangallur (5m depth) and Valloor (5m depth) in Trichur district.

In the northern region ten samples were collected from a 20 m deep bore hole at Elavathur named as(core VI) in the Kole land area. In the Kodungallur region, another 20 samples from two bore holes in a place called Poovathumkadavu were collected. These bore holes are struck respectively in the eastern bank and the

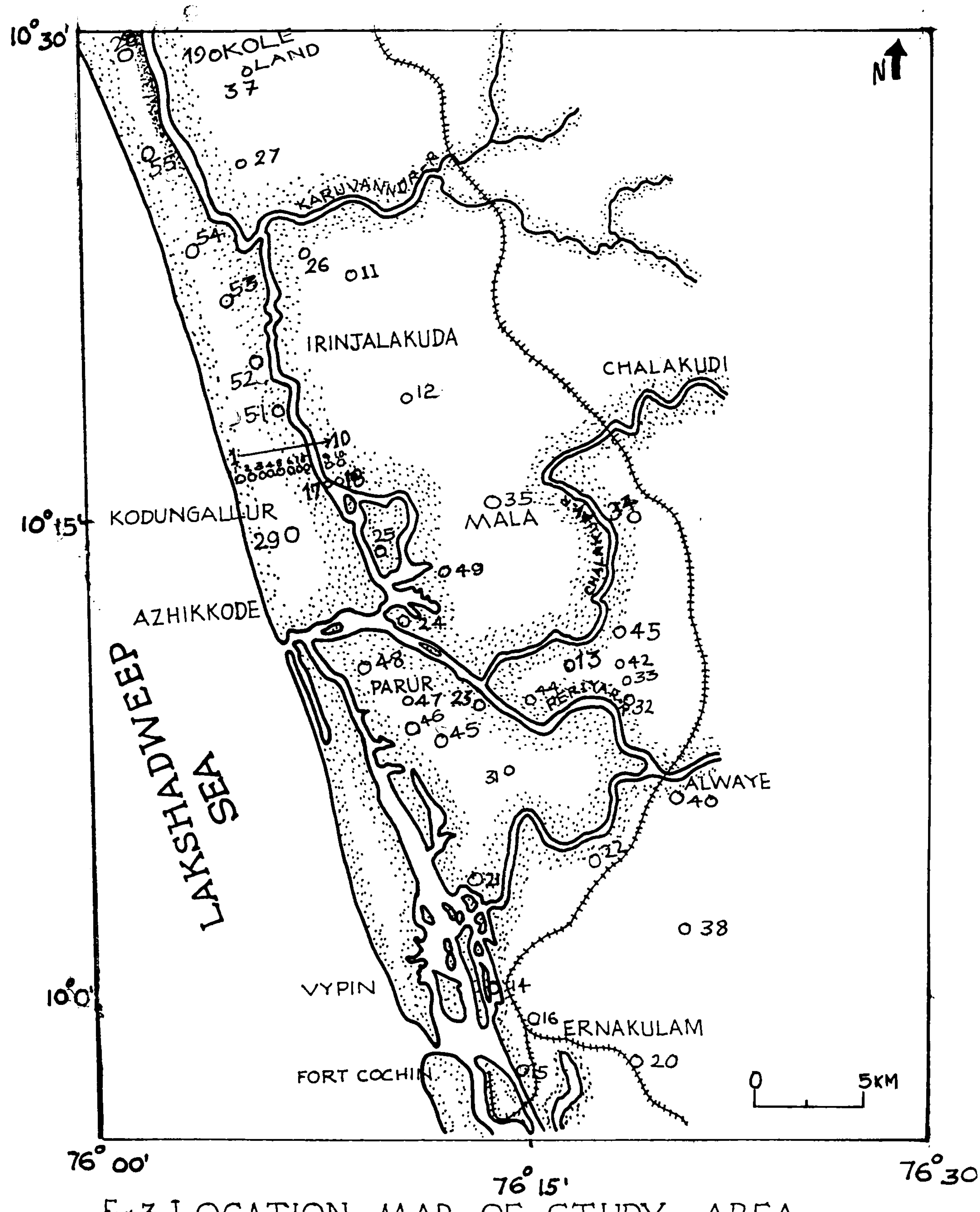


Fig.3 LOCATION MAP OF STUDY AREA

sites mentioned in location map

Strand sites Station No. 1 to 10

Flood plain sediments

11. Karuvannur
12. Vellangallur
13. Valloor

Core sediment sites

14. Cochin Backwater (Core No. 1)
15. Ernakulam South (Core No.2)
16. Kaloor (Core No.3)
17. Poovathumkadavu (Core No. 4)
18. Poovathumkadavu (Core No. 5)
19. Elavathur (Core No. 6)

Geomorphological Locations

20. Thripunuthura
21. Manjummal
22. Kalamassery
23. Manjaly
24. Krishnankotta
25. Pullut
26. Karalam
27. Kanjani
28. Mullassery
29. Kodungallur
30. Poovathumkadavu
31. Alangad
32. Aduvassery
33. Chengamanadu
34. Vallur
35. Mala
36. Karuvannur
37. Koleland

Archeological sites

38. Thevakkal
39. Kalamassery
40. Alwaye
41. Chengamanadu
42. Kurumassery
43. Aduvassery
44. Kunnukara
45. Valluvally
46. Kottovally
47. Paravoor
48. Pattanam
49. Puthenchira
50. Pullut
51. Perinjanam
52. Acheswaram
53. Chendrappinni
54. Thriprayar
55. Engandiyur

middle of Pullut channel (core V and VI). In the Ernakulam area a total of 57 sediment samples were collected at 1-3 m interval from 3 bore holes namely at Cochin back water(core I), Ernakulam south(core II) and Kaloor(core III). All bore holes were drilled by Rotary core drilling method. All samples were collected with a steel scapula and carefully transferred to neatly labelled Polyethelene bags. Care was taken while collection and handling of samples to avoid contamination. All the samples were brought to the laboratory and kept in an inert atmosphere till further processing and analysis. Sediments logs were obtained from central ground water board office, Trivandrum.

2.3. Laboratory Methods

2.3.1 Texture

Sand samples were washed, dried and subjected to con-ing and quartering and a representative portion (about 100 gm) was subjected to dry sieving. Each sample was sieved for 15 minutes on a mechanical Ro-Tap sieve shaker using a standard set of ASTM Endecott sieves at half phi (1/2Ø) interval. The fractions left over in each sieves were carefully transferred, weighed and cumulative weight percentages were calculated. Samples which contain significant amount of silt and clay fractions were analysed by combined sieving and pipette analysis as suggested by Lewis (1984).

For pipette analysis, known quantities of silt and clay rich sediments were dispersed overnight in 0.025 N solution of sodium hexametaphosphate. The coarse fraction was separated from the dispersed sediments and pipette analysis was carried out following Lewis (1984). All the aliquots were oven dried to constant weight at 60 ^{o}C and weighed accurately after cooling at room temperature. Dry sieving was carried out on sand fraction to complete the analysis.

From the cumulative weight percentages of the above analyses the grain size parameters such as mean size, standard deviation, skewness and kurtosis were calculated following Folk and Ward (1957).

The interrelationships existing between these parameters have also been worked out for the sediments of the Kodungallur region to elucidate the hydrodynamic conditions of the deposition medium. The percentages of sand, silt and clay for bore hole sediments were plotted on a triangular diagram of Folk et al. (1970) to determine the sediment types.

2.3.2. Geochemistry

Sediment samples were washed gently (for desalting) with deionised double distilled water. A 0.5 gm of the well powdered, homogenised sediment was digested with $HF\text{-}HNO_3\text{-}HclO_4$ acid mixture. All the digested samples were used for elemental (Fe, Mn, Cd, Cr and Ni) analysis by Atomic absorption spectrophotometric method in a Perkin Elmer Model 2380 Atomic absorption spectrophotometer (Rantala and Loring 1975).

2.3.3 Sediment Organic Carbon :

The sediment organic carbon was determined by wet oxidation method of Elwakeal and Riley (1957). The organic carbon was oxidized by a known quantity of chromic acid and the amount of chromic acid consumed was then determined by titrating against ferrous ammonium sulphate solution. Diphenyl amine was used as an indicator. The average of triplicate measurements not

2.3.4. Calcium Carbonate :

The percentage of $CaCO_3$ in sediment samples was determined following the method of Hutchinson and Mcheman (1947). The principle is that, treating the sample with known amount of HCl acid and estimating the excess of HCl by back titration with standard NaOH using bromothymol blue as indicator. The average of triplicate measurements not differing .2% of the analysis was used in the study.

2.3.5. Palynology :

A total of eight peat samples were processed and studied at the Birbal Sahni Institute of Palaeobotany, Lucknow. The method involves the following steps. About 5 gm of peat sample was boiled in 10% KOH for 5-10 minutes and the material was filtered through 200 mesh sieve. The filtrate is then centrifuged, washed with distilled water for 3-4 times and treated with 35-40% hydrofluric acid for 4-5 days to eliminate mineral fractions and then a few drops of con. HCl is added. After washing with glacial acetic acid and centrifuging, the residue is acetolysed with a mixture of acetic anhydride and conc. sulphuric acid in 9:1 ratio for the removal of cellulose. The residue is washed again with glacial acetic acid and centrifuged. The acetolysed material after washing for 3-4 times with water, is stored in a vial tube containing 50% glycerine and a few drops of phenol is added to avoid fungus action. Pollen slides are prepared by putting a few drops of glycerine soaked material on a glass slide and covering it with cover glass and then identified.

2.3.6. Palaeontology:

About 15 gm of the core samples were disaggregated and boiled in 15% hydrogen peroxide solution; wet sieved, the shell fragments were hand picked from the sieved fraction and later it was subjected to microscopical examination. About 200 microfossil specimens were picked with the help of a pointed brush and kept in a slide. Identification and counting have been carried out using a binocular microscope.

2.3.7 Radio carbon dating:

The carbonaceous sediment samples were dated at the Radio carbon laboratory of the Physical Research Laboratory, Ahmedabad, following Agrawal et al (1971). The sediment samples were powdered and washed in distilled water. It was then treated with dilute HCl to remove carbonate fraction. The carbon in the organic matter of the sediment was converted into benzene. Radio carbon activity of the benzene was measured by liquid scintillating counter "QUANTULUS". The dates presented here are based on the radio carbon half life value of 5730 yrs.

2.4 Archaeology

Archaeological survey has been carried out in order to find past cultural remains in the study area. Archaeological objects and pottery of various cultures were collected from a number of sites in the coastal areas of Thrissur and Ernakulam district (Fig.3). Even though no systematic archaeological excavation was conducted in this regard, exploration and trial trenching have been carried out to recover archaeological objects. The collected materials are now kept in the archaeological museum, Center for Cultural and Ecological studies, Union Christian college, Alwaye.

CHAPTER 3

3.1 GEOMORPHOLOGY OF THE AREA

3.1.1 Introduction:

The present study area covers the entire stretch of coastal low land and part of the western midland area of central Kerala, comprising depositional and denudational land forms and having an average width of about 15 km and length 60 km. The coastal geomorphology of Kerala has been strongly influenced by a number of factors such as lithostratigraphy, structure, neotectonics and climatic conditions. Geomorphological study in the area has resulted in the identification of six morphostratigraphic surfaces /units. They are the equivalents of landforms identified by Nair (1996) such as the Kunnamkulam surface (post Pliocene), the Guruvayur surface (late Pleistocene to early Holocene),the Ponnani surface (early Holocene) and the Periyar, the Viyyam and the Kadappuram surfaces (late Holocene).

3.1.2 Results and Discussion: The western part of the mid land area, a plateau like landform lying immediately to the east of the coastal plain, is having an elevation ranging from 20 to 60 m above MSL. It is covered by a thick blanket of laterites, about 20 m in thickness (Plate 1), overlying the crystalline basement of charnockite or charnockitic gneiss. Occasionally, it is found overlain by the Tertiary sediments. The surface is intensely dissected, resulting in the development of irregular and elongated valleys which were subsequently covered by alluvium. These extensive valley fills are the present day paddy fields of the midland region of central Kerala. This plateau like landform of the study area corresponds to the Kunnamkulam surface identified by Nair (1996) and is essentially a surface of

Plate 1 Primary laterite section at Manjaly south east of Paravoor

Plate 2 Ridge and swale topography, Kodungallur area

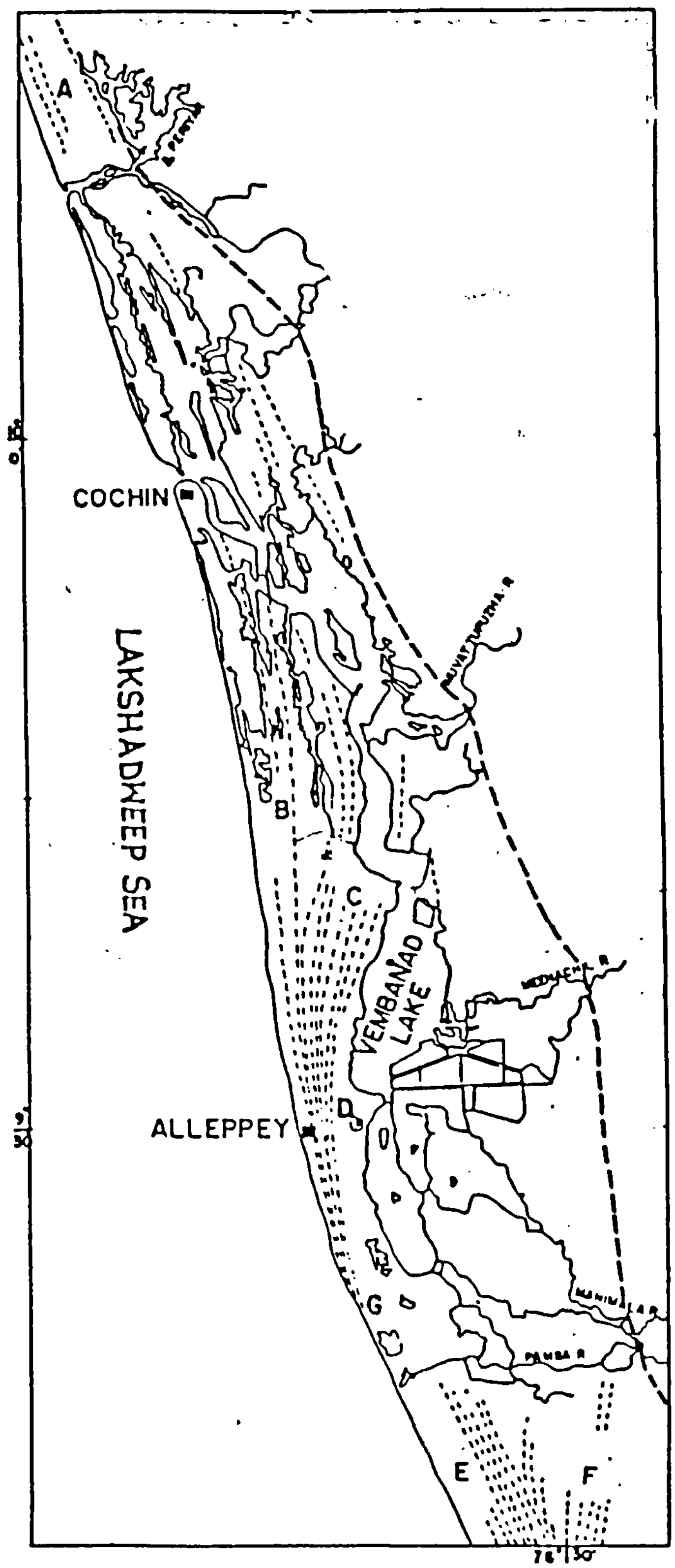


Fig.4 Orientation of palaeo-beach ridges (Source: Mallik and Suchindan, 1984)

Plate 3 Brown coloured beach ridge sand, Kodungallur area

Plate 4 Vegetated dune sediments, south east of Paravoor

directions and are essentially parallel to the present day coast. In addition, some irregularly aligned beach ridges are seen near the innermost palaeocoastline and are mostly composed of fine grained white sands (Plate 4). This surface, which is currently undergoing dissection and is tectonically active, can be of late Pleistocene to early Holocene origin, and was named as Guruvayur surface (Nair, 1996). In a transect about 5 km north of Kodungallur, eight prominent palaeobeach ridges have been identified. Further north i.e. in the Engandiyur - Mullassery transect, only six ridges have been identified whereas in Njarakkal area only 3 prominent ridges have been found. A few sand dunes are also noticed to the east of Pullut channel, ie. NE of Kodungallur area. The height of the ridges varies from 2 to 6 m above MSL and the ridges exhibit a sloping pattern towards the present coast.

According to Mathai and Nair (1988), the strand lines and linear sand dunes of the Kodungallur area are evidences for a periodic cyclicity in the regression of the sea, indicating dominance of marine forces in the evolution of various land forms. Although, they attribute that the alignment of Pullut river and the Varapuzha river marks the earliest palaeocoastline but in the transect north of Kodungallur, atleast two more beach ridges have been found to the east of Pullut channel. The orientation of these ridges as well as the colour and texture of sediments differ much from the present day beach ridges indicating that these eastern most ridges are the result of earlier transgressive - regressive phases of late Pleistocene time whereas the ridges to the west of Pullut channel are the result of Holocene transgression and the subsequent regression.

The major land forms of fluvial origin are the extensive terraces shaped mainly by Karuvannur and Periyar river systems. All these river terraces are found at different elevations and have been named as the Ponnani surface (Nair, 1996). Prominent terraces at different elevations are found at Kalamassery, Alangad, Aduvassery - Chengamanad, Valloor, Mala, Karuvannur and in the Koleland areas. River terraces are the result of upgrading or down cutting of the channels due to changes in baselevel. In this connection, they can be linked to sea level variation. The vast remnant flood plains / river terraces range in elevation from 1 to 5 m than the present flood plains might have resulted from the upgradation of river channels during the high stand of sea level around mid Holocene time.

The fluvial land forms corresponding to that of Periyar surface (Nair, 1996) are the present day flood plains, valley plains, channel bars, point bars and active channels. A number of channel bars are noticed along the course of the river Periyar in the coastal areas. Braided drainage pattern with channel bars and point bars in between is particularly noticed to the south of Periyar estuary. A few channel bars are also noticed in the Karuvannur and Chalakudy rivers in the midland region. According to Mathai and Nair (1988), the successive growth of the channel bars in the area gave rise to a braided drainage pattern, preserved even at present, because of the constant change in river course due to blockage of the river mouth through sediment deposition. The river channels in the midland and coastal areas are found incised into the existing fluvial deposits and hence indicative of a baselevel recession probably caused by the regression of the sea in late Holocene time.

Close to the present coast line, the prominent land forms identified are tidal flats, mud flats, coastal lagoons etc. These are essentially fluvio-marine in origin and are the equivalent of Viyyam surface of Nair's (1996) nomenclature. Marshy low lands are noticed at many places immediately behind the shore lines. The lagoons occupy a considerable surface area in central Kerala's coastal plains. The Cochin backwater system forms part of the Vembanad lake and encompasses a number of small islands in Ernakulam area. The northward extension of this system is known as Thottappilly backwaters (25 km long, 1 km wide), and runs almost parallel to the present coast separating Vypin barrier island (Plate 5) from the main land. North of Periyar estuary, a narrow water body known as Pullut channel (40 km long) runs parallel to the coast from Pullut to Chavakkad. At places, it is also known as Canoli canal after a Britisher, Canoli who was instrumental in joining this linear water body with Periyar for transportation purpose. This channel attains its maximum width in Kandassamkadavu area in Trichur district. The landforms predominantly of marine origin are the present day beaches, spits and barrier beaches. Nair (1996) has named these landforms as Kadappuram surface. The shore line in the study area is geometrically straight with out any cliffs. A prominent spit is noticed at the northern end of Periyar river mouth. The shore line north of Periyar is simple whereas it is a compound coast in the southern part, showing emergent and submergent nature (Senthiappan and Rangamannar, 1978). Kunte (1995) has identified the Vypin - Cochin barrier island systems as the most extensive among the three barrier island systems of the Kerala coast. On either end of the Vypin barrier island (26.5 km long

Plate 5 Thottappilly backwater and barrier island, south west of Paravoor

and 1 to 2.5 km wide) two narrow and elongated spits are identified. Except the beaches at Cherai (south of Periyar) and Koorikuzhi, others are narrow. During the southwest monsoon season, the entire beach is subjected to severe wave erosion resulting in the uprootment of shore line vegetation and disturbance to human settlements.

3.1.3. Coastal Evolution

The coastal evolution along the central Kerala region is related to the process of marine transgression and regression and in association with coastal process such as waves, tides and longshore currents existed during the late Quaternary period. The presence of several sand barriers along the present day coast and also in the recent past as exhibited by the inland barriers it is suggested that the physical processes during mid and late Holocene were also similar in nature. Since there are no major delta system along this section of the coast, it is imperative that the coast since early-mid-late Holocene has been subjected to severe physical processes where by the fluvial inputs have been constantly reworked (Davis and Hayes, 1984).

Barriers formed during marine transgression: In a low gradient coast whether laterally unbounded or embayed, that are subjected to wave action at times of rising sea level are characterised by transgressive barriers (Roy et al., 1994). The resulting barriers are essentially transitory in nature that maintain themselves in dynamic equilibrium with rising sea level by the landward transfer of sand eroded from the shoreface, to back barrier settings. In this study the beach ridges lying east of Pullut channel resembles the one mentioned above. In certain cross sections particularly east of pullut channel the barriers are only 3 to 4m thick and are lying right on the lateritic surfaces. The barriers, once formed, would have shifted landward when the sea level was rising relatively rapidly. Further when the sea level was rising rapidly, eolian processes have also acted simultaneously on the barriers which resulted in the transportation of fine sands eastward over the laterite masses. When the sea attained its maximum transgression and stable conditions established, several small foredune complexes occurred. Therefore from the above, it is clear that the east bank of Pullut channel as well as beach ridges east of it and the thin veneer of sand over the laterites have all formed during the transgressive episode in the early Holocene period. During the processes of landward movement of barriers either by roll over or sand drift by wind it encloses the back swamp deposit. Thus in this region extensive peat deposits are found below the sand horizon.

Barriers/ridges formed during marine regression: All barriers/ sand ridges west of Pullut channel are formed by wave and wind deposition under conditions of falling relative sea level after 6500 yrs B.P. Since all the sand ridges west of Pullut channel slope westward it is an indication thay have formed during regressive phase. In some southeast Australian coast, barrier progradation was triggered through offshore influx of sand when the sea level stabilised around 6500 yrs B.P. (Thom et al., 1981, Thom and Roy, 1985). Therefore each strand plain starting from the west bank of Pullut channel with its height ranging from 3-6m indicate that these strand plains would have formed under a stable sea condition followed by a fall in sea level. The sandy materials are distributed from source area by longshore drift.

Formation of Pullut/Varappuzha estuary: These represent the remnant estuaries formed during falling sea level or stable sea conditions through deflection of existing river courses or formation of longshore bars which later developed into barriers. Roy et al. (1980) have reported that the many estuaries behind the wave built sand deposits along the southeast coast of Australia have their origin during stable sea levels. As said earlier in each stable condition a strand plain formed with a swale behind which would have been a remnant estuary.

3.2. TEXTURE

3.2.1 Introduction

Sediments are the by-product of weathering. Each environment leaves its imprint on the sediment and therefore the various sediment characteristics can reflect their respective environment of deposition. Grain size study is the most important field of research in the whole spectrum of sedimentology because: (a) the grain size is a basic descriptive measure of sediments; (b) the grain size distributions may be characteristic of sediments deposited in certain environments; (c) the grain size distributions may yield information about the physical mechanisms acted on the sediments during deposition and (d) the grain size may be related to other properties such as mineralogy,geochemistry etc. Hence, the various transportational and depositional processes are best reflected in textural parameters of sediments.

In the past 4-5 decades, there have been numerous attempts to differentiate environments of deposition using grain size parameters. Steadily the sedimentological parameters have emerged as an important tool in differentiating various palaeo environmental conditions existed through out the geological time and also in discriminating depositional environments of recent origin. Further, the particle size distribution of an ancient and modern sediments have an effect on the mineralogy and chemistry of sediments (Forstner and Wittman, 1983).

Hence, over the years, workers are able to differentiate a number of depositional environments from size spectral analysis as particle distribution is highly influenced by the environment of deposition. (Folk and Ward, 1957 ; Mason and Folk, 1958; Sahu, 1964; Friedman 1961, 1967; Hails and Hoyt, 1969; Nordstom, 1977; Goldberg 1980; Seralathan, 1979, 1986, 1988; Jahan et al., 1990; Padmalal, 1992 and Ngusaru, 1995).

Friedman (1961, 1967) with the help of scatter diagrams of mean versus standard deviation and sorting versus skewness of sandy sediments has shown that statistical parameters can be effectively used to differentiate dune, beach and river environments. Visher (1969) has studied the log normal distribution of grain size and was able to identify three types of sediment populations such as rolling, saltation and suspension; each indicative of a distinct mode of transportational and depositional process.

Chamely et al., (1977) has used grain size pattern as one of the parameters to study palaeoclimatic variations in the North West African coast. Tooley (1980) has emphasized the use of stratigraphy in palaeoenvironmental reconstruction. Yeo and Risk (1981) have shown that the grain size analysis can be used to study marine transgressive and regressive stratigraphy. The Quaternary sea level history of Swartklip area in South Africa has been studied by Barwis and Tankard (1983) based on sediment facies analysis. Semeniuk and Searle (1985) have studied the relation of past climate to different depositional facies of calcrete sediment formation. Thom and Roy (1985) have linked the Holocene sea level history to patterns of sedimentation in South East Australia. Reconstruction of palaeogeography and palaeoenvironment of Holocene dune sediments has been carried out by Filion (1987). The Quaternary transgressive and regressive episodes based on borehole sediment data in the Gulf of Argos, Greece have been studied by Van Andel et al. (1990). Martin and Suguio (1992) have inferred the relative sealevel changes along the central Brazilian coast based on palaeobeach ridge sediments. With the help of sediment size analysis and thermoluminescenes (TL) dating, Lees et al. (1993) have interpreted various phases of marine transgression and dune initiation in the early Holocene and mid Holocene periods. The late Quaternary sealevel fluctuations in Washington area have been inferred from the study of lake sediments by Andersen et al. (1994).

In India textural analysis of sediments from different environments have been studied by many researchers. Most of the studies have been focused on surficial sediments of riverine, estuarine, beach, mangrove-swamps and continental shelf region. Shelf sediments have been studied by many researchers (Subba Rao, 1967; Mallik, 1975; Rajamanickam and Gujar, 1985; Hashimi and Nair, 1981, 1986; Murthy and Rao, 1989 ; Ramachandran 1992 and Purnachandra Rao et al.,1997). Hashimi and Nair (1976) have studied the shelf sediments of west coast of India in order to infer palaeoclimates and past sealevel changes in the region.

By studying the shelf sediments off Gopalpur, Orissa, east coast of India (Rao and Rajamanickam,1980) could be able to bring out information on low sealevel stand during Holocene. Considerable work has been carried out on modern riverine, estuarine and shelf sediments of the east and west coast of India. (Kidwai, 1971; Seetaramaswamy, 1970; Satyanarayana, 1973; Veeryya and Varadachari, 1975; Seralathan 1979; Samsuddin, 1986; Chavady and Nayak 1987; Purandara et al., 1987; Unnikrishnan, 1987; Sasidharan and Damodaran, 1988; Padmalal, 1992). Seetaramaswamy (1970) has studied the sediment texture of the drainage system of the river Krishna on the east coast of India. Seralathan (1979) has studied the modern deltaic sediments of the Cauvery river and could be able to differentiate the various depositional environments on the basis of textural analysis. Sedimentological aspects of bottom sediments of Vembanad lake have been carried out by Mallik and Suchindran (1984). Padmalal (1992) has carried out a detailed granulometric analysis of riverine and esturine sediments of central Kerala and inferred the modern and ancient depositional regimes existed in the area.

However, no such study has been carried out exclusively on the Quaternary sediments on the Kerala coast. In Gujarat coast, the Quaternary sediments have been studied by a number of workers like Rajaguru and Marathe (1975), Gupta (1975). Quaternary beach rocks and sediments of Maharashtra and Konkan coast have been studied by Ghate (1985) and Wagle (1990). Gardner (1986) has carried out detailed study of Quaternary coastal sediments of southern Tamil Nadu coast. Hence, an attempt has been made in this chapter to understand the particle size distribution of certain selected subsurface and strand sediments of the coastal area of central Kerala so as to have proper insight into their origin and environments of deposition.

3.2.2. Results and Discussion

a) Strand plains sediments:

Table 1 lists the grain size parameters of 100 sediment samples collected from the strand plains of Kodungallur area. Table 2 gives the average values of the statistical parameters.

Mean size:- The mean size of clastic sediments is the statistical average of grain size population expressed in phi (Ø) units. Out of the 100 samples analyzed, 70 samples fall in the medium sand range grade, 27 fine grained sand and 3 coarse grained sand. Fig. 5 show the vertical variation of the phi mean size from 0 to 2 m depth in all the ten sampling stations of the Kodungallur area. At station 1, the sediments are coarser at 1 to 1.2 m level and finer at 2 m depth. Except the bottom most sample a coarsening downward trend is observed At station 2, finer sediments are found at the top and coarser at the bottom. In stations 3,4,5,6,7,8 and 9 a coarsening downward trend is observed upto a depth range 1.4 m to 1.6 m and thereafter the sediments become finer again. A general fining downward trend is noticed at station 10.

Standard deviation : - Standard deviation or sediment sorting is the particle spread on either side of the average. The sediment sorting is good if the spread sizes are relatively narrow. Out of the 100 sand samples, 73 are moderately well sorted, 24 moderately sorted and only 3 samples are well sorted. In general as grain size decreases sorting improves (Fig.9). At station 10, all ten samples are found to be only moderately

Table 1 Grain size parameters of strand sediments from Kodungallur

Station 1

Depth (m)	Phi mean	S.D	Skewness	Kurtosis
0.20	1.65	0.70	-0.02	1.01
0.40	1.68	0.80	0.10	0.72
0.60	1.78	0.60	0.24	0.95
0.80	1.71	0.69	0.02	1.10
1.00	1.37	0.71	-0.03	1.04
1.20	1.39	0.52	0.06	1.43
1.40	1.64	0.52	0.16	1.25
1.60	1.44	0.62	0.04	1.23
1.80	1.38	0.62	0.01	1.19
2.00	1.91	0.67	-0.01	1.15

Station 2

Depth (m)	Phi mean	S.D	Skewness	Kurtosis
0.20	2.25	0.02	-0.03	1.07
0.40	2.07	0.59	-0.16	0.86
0.60	1.82	0.63	0.07	1.05
0.80	1.95	0.51	0.18	0.79
1.00	1.90	0.65	0.05	0.84
1.20	2.10	0.52	0.07	0.72
1.40	2.01	0.55	0.07	0.78
1.60	1.86	0.59	0.14	0.83
1.80	2.08	0.67	0.19	0.82
2.00	1.73	0.67	0.05	1.08

Station 3

Depth (m)	Phi mean	S.D	Skewness	Kurtosis
0.20	1.81	0.59	-0.06	0.82
0.40	1.75	0.69	0.22	1.06
0.60	1.42	0.46	0.09	1.54
0.80	1.52	0.70	0.07	1.15
1.00	1.20	0.71	0.11	1.08
1.20	1.09	0.83	-0.04	1.23
1.40	1.17	0.71	0.11	1.09
1.60	1.35	0.54	0.50	0.11
1.80	1.55	0.82	-0.06	1.12
2.00	2.37	0.70	-0.44	1.12

Station 4

Depth (m)	Phi mean	S.D	Skewness	Kurtosis
0.20	1.92	0.66	0.08	0.72
0.40	1.89	0.61	-0.01	1.06
0.60	1.82	0.62	0.04	1.04
0.80	1.67	0.60	0.16	1.20
1.00	1.75	0.61	-0.03	0.94
1.20	1.13	0.50	0.06	1.37
1.40	1.18	0.88	-0.28	1.07
1.60	1.07	0.63	0.01	1.30
1.80	1.37	0.66	0.09	1.22
2.00	1.74	0.75	-0.02	0.77

Station 5

Depth (m)	Phi mean	S.D	Skewness	Kurtosis
0.20	2.09	0.63	-0.11	1.12
0.40	2.29	0.51	-0.11	1.25
0.60	2.07	0.64	-0.11	0.91
0.80	1.52	0.67	-0.01	0.91
1.00	1.59	0.66	0.02	0.98
1.20	1.71	0.55	0.03	0.89
1.40	1.65	0.49	-0.01	0.89
1.60	1.35	0.73	-0.04	0.98
1.80	1.74	0.54	0.11	0.87
2.00	1.70	0.60	0.05	0.87

Station 6

Depth (m)	Phi mean	S.D	Skewness	Kurtosis
0.20	1.76	0.69	0.26	1.07
0.40	1.85	0.64	0.26	0.81
0.60	1.80	0.74	0.16	1.07
0.80	1.52	0.53	0.09	1.29
1.00	1.46	0.61	0.08	1.25
1.20	1.65	0.59	0.11	1.26
1.40	1.56	0.69	-0.04	1.29
1.60	1.55	0.53	0.07	1.40
1.80	1.90	0.61	0.19	0.77
2.00	1.99	0.57	0.19	0.70

(Con't ....2)

Grain size parameters of strand sediments from Kodungallur

Station 7

Depth (m)	Phi mean	S.D	Skewness	Kurtosis
0.20	1.85	0.56	-0.11	0.96
0.40	1.99	0.57	0.05	0.71
0.60	1.42	0.61	0.08	0.81
0.80	1.83	0.59	-0.03	0.88
1.00	1.73	0.58	-0.04	0.87
1.20	1.70	0.58	0.04	0.92
1.40	1.59	0.63	0.03	0.97
1.60	1.58	0.68	0.24	0.82
1.80	1.95	0.73	0.18	0.88
2.00	2.32	0.63	-0.30	1.29

Station 9

Depth (m)	Phi mean	S.D	Skewness	Kurtosis
0.20	1.90	0.53	-0.19	0.87
0.40	2.17	0.46	-0.07	1.06
0.60	2.31	0.49	-0.36	1.44
0.80	2.04	0.55	-0.10	0.77
1.00	2.06	0.63	-0.11	0.92
1.20	1.94	0.69	-0.26	0.80
1.40	1.93	0.61	-0.03	0.75
1.60	2.09	0.63	-0.11	1.12
1.80	2.11	0.68	-0.34	1.06
2.00	2.37	0.55	-0.23	1.16

Station 8

Depth (m)	Phi mean	S.D	Skewness	Kurtosis
0.20	1.38	0.81	0.05	0.91
0.40	1.42	0.59	0.11	0.79
0.60	1.32	0.70	-0.05	0.98
0.80	1.08	0.63	0.03	1.30
1.00	0.70	0.93	0.03	0.93
1.20	0.61	0.84	0.05	0.92
1.40	0.96	0.77	0.03	1.03
1.60	1.44	0.59	0.08	1.12
1.80	1.11	0.80	0.22	0.93
2.00	1.57	0.70	-0.04	1.36

Station 10

Depth (m)	Phi mean	S.D	Skewness	Kurtosis
0.20	2.08	0.88	-0.15	1.01
0.40	2.14	0.83	-0.21	1.03
0.60	2.18	0.87	-0.21	1.07
0.80	2.13	0.84	-0.19	0.99
1.00	2.07	0.81	-0.15	0.90
1.20	2.17	0.81	-0.19	0.93
1.40	2.15	0.82	-0.21	0.85
1.60	2.25	0.89	-0.11	1.09
1.80	2.48	0.72	-0.25	1.22
2.00	2.40	0.75	-0.22	1.20

Table 2

Average values of Mean size, Standard deviation, Skewness and Kurtosis

Mean	Standard Deviation	Skewness	Kurtosis
1.60	0.65	0.06	1.11
1.90	0.59	0.06	0.88
1.52	0.68	0.05	1.13
1.55	0.66	0.01	1.07
1.77	0.60	-0.02	0.97
1.70	0.62	0.14	1.09
1.80	0.56	0.01	0.91
1.15	0.73	0.05	1.03
2.09	0.52	-0.18	1.00
2.21	0.82	-0.19	1.03

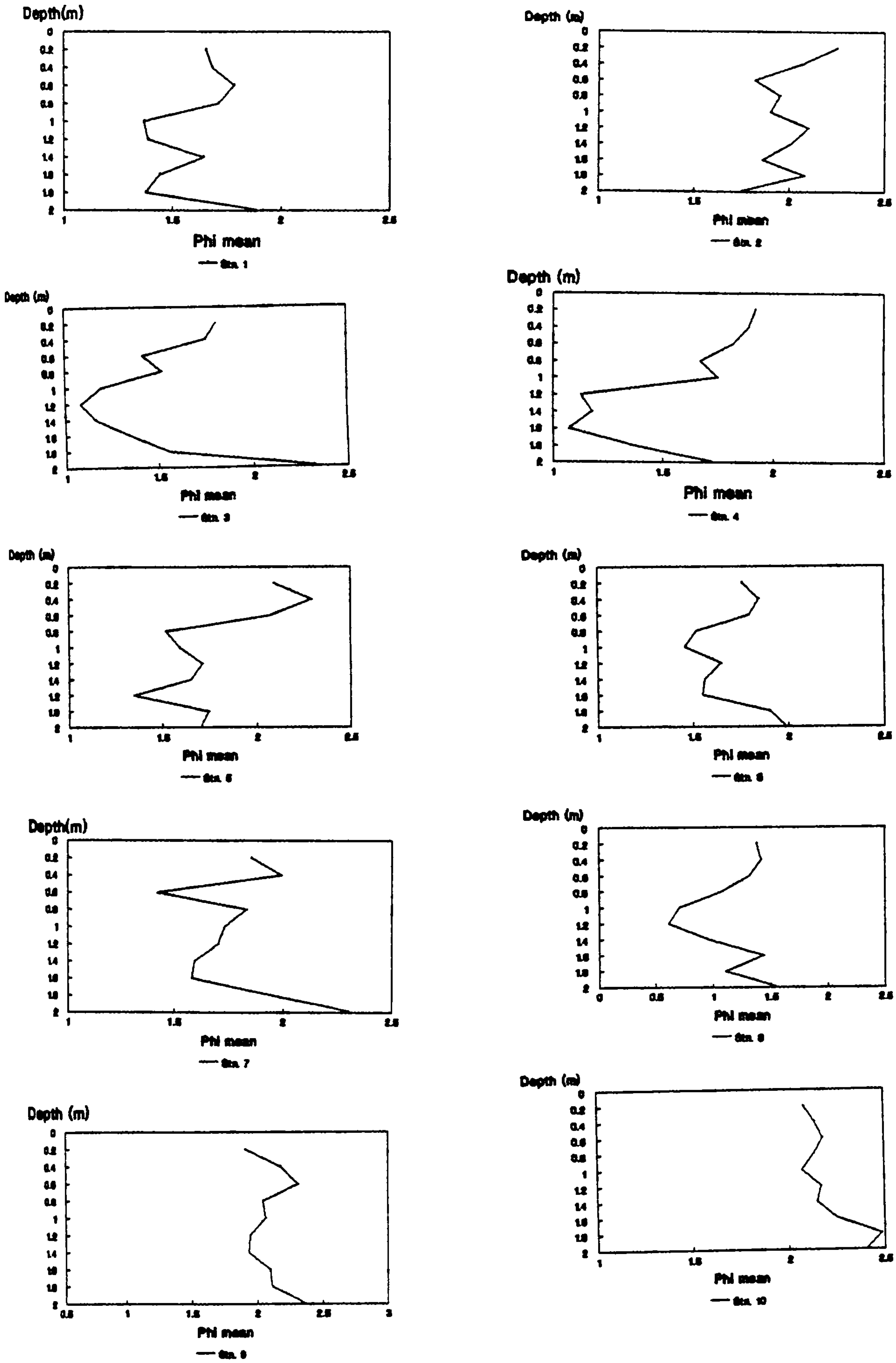


Fig.5 Variation of phi mean with depth

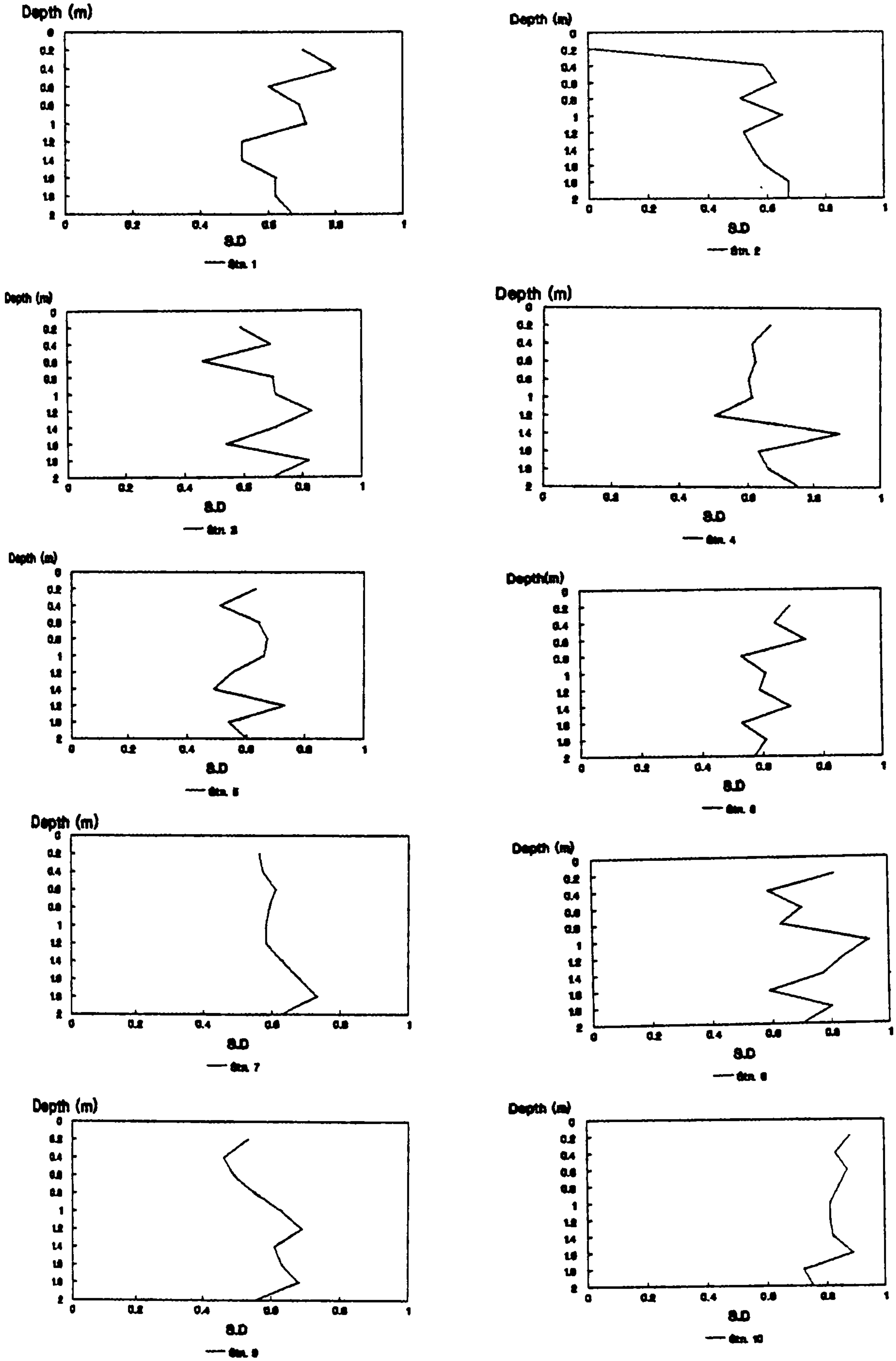


Fig.6 Variation of standard deviation with depth

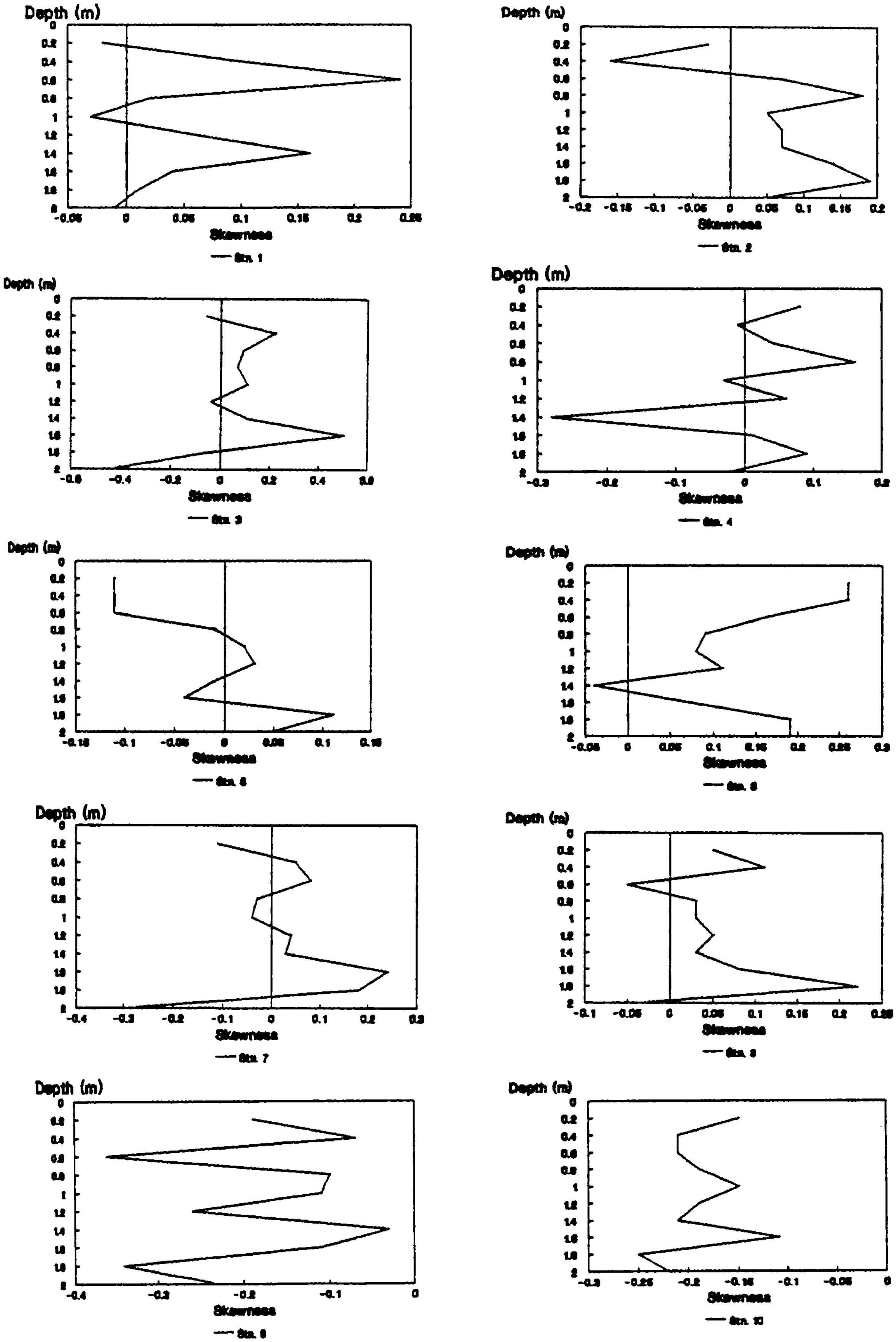


Fig.7 Variation of skewness with depth

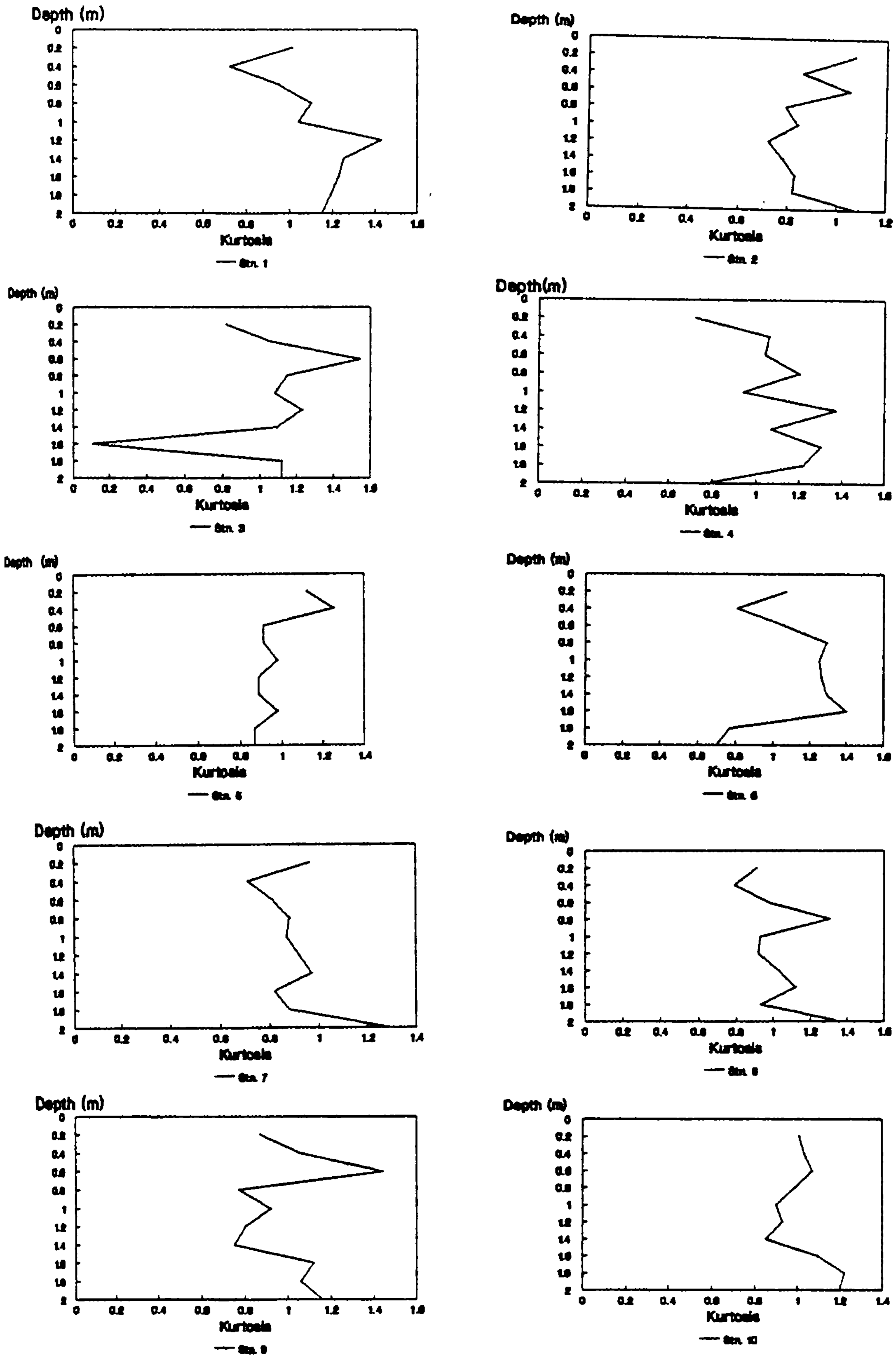


Fig.8 Variation of kurtosis with depth

sorted. Sorting does not show any clear vertical trend at stations 1,2,3,4,5 and 8 (Fig 6). In stations 7 and 9 sorting worsens with depth whereas it improves with depth in station 6 and 10.

Skewness:- Skewness of the sediments is a measure of the asymmetry of grain size population and reflects the environment of deposition. In textural analysis skewness is considered as an important parameter because of its extreme sensitivity in sub population mixing. Majority of the analysed samples show near symmetrical skewness whereas 25 samples are coarsely skewed and only 18 samples are finely skewed. In stations 9 and 10 coarse skewed samples predominate. In a fine skewed sediment population, the distribution of grains will be from coarse to finer end and the frequency curve chops at the coarser end and tails at the finer. Martins (1965) has suggested that the coarse skewness in sediments could be due to two possible reasons namely

(1) addition of materials to the coarser terminal or

(2) selective removal of fine particles from a normal population by winnowing action.

The coarse skewness may be due to selective removal of fine population particularly in the inland region. Skewness does not show any vertical trend with the depth in most of the stations (Fig.7) Only in station 2 and 5 the skewness changes from negative to positive with depth and this may be due to addition of fine population to the existing **medium** in the prevailing environmental condition.

Kurtosis:- Kurtosis (the peakedness of the frequency curve) is a measure of the contrast between sorting at the central part of the size distribution curve and that of tails. About 30 out of

100 samples are platykurtic, 37 meso kurtic and 33 samples are lepto kurtic. The kurtosis does not show any vertical trend with depth in most stations (Fig.8). In stations 1 kurtosis increases with depth whereas it decreases in station 5 (Fig.8).

The mean size shows a decreasing trend from present beach to inland except at stations 3, 4 and 8. The inner most beach ridge samples are fine grained whereas sample from the present day beach and stations 4,5 and 8 are medium grained. The fining tendency towards inland can be very well explained as the result of eolian activity. The coarseness of the sediments at stations 4, 5 and 8 may be due to selective winnowing of fine sands and or riverine input. Admixture of river sediment is very much possible particular to station 8 as the station is situated close to the Karuvannur river mouth even at present. Sorting has also decreased significantly towards interior. The inner most samples are only moderately sorted, whereas beach and near shore samples are moderately well sorted. In general dune sediments are very well sorted (Seralathan, 1979) whereas here only moderately sorted sediments are observed. This deviation may be due to admixture of very fine sand by wind deflation to the pre existing beach ridge sediments.

While studying the depositional pattern of inter tidal sediments in Minas basin near Novascotia, Yeo and Risk (1981) opined that grain size distribution can be effectively used to differentiate various Holocene depositional facies. Lees et al., (1993) shown that average mean size decreases from the sea coast to flat topped, partly vegetated fore dune from 1.52 to 2.07 phi and again it increases in beach ridge areas. Dune emplacement during the mid Holocene is the direct result of sealevel stabilization as per the Cooper-Thom hypothesis (Cooper, 1958). A coarsening downward trend was observed by Ngusaru (1995) at Kunduchi and Jangwani benches of Tanzania.

Within prograded (beach ridge) barriers the basic arrangement of facies type consisted of a burried transgressive sand sheets underlying a regressive sequence. In many areas, the transgressive sand sheet grades landwards into relict backbarrier / washover sands (Thom and Roy, 1985). Near symmetrical skewness is seen from the present day beach samples to interior areas upto 6 km inland, whereas coarse skewness is seen in the inner most stations at 9 and 10. The average values of skewness show finely skewed only at station 6. The coarse skewness at the interior stations can be explained as the removal of material through eolian transportation from the already existing palaeobeach ridge sediments. Leptokurtic samples predominate in station closer to the present day beach whereas mesokurtic sediments are predominant in the innermost and intermediate stations.

Scatter Diagrams: The scatter plot of phi mean size versus standard deviation (Fig.9) clearly indicate that as the phi mean size increases the sorting of the sedimnts improves. In general the sediments of strand sediments show narrow range in phi mean size. But the wide scattering of points ie wide variation in phi mean size at stations 7 and 8 may be due to admixture of coarse sand to the fine populations and so that the sediments are only moderately sorted. Since fluvial(on a limited scale), beach, storm and aeolian processes have acted at various levels in the past, there are some variations in phi mean size from one station to another. This is also reflected in the down core variation of

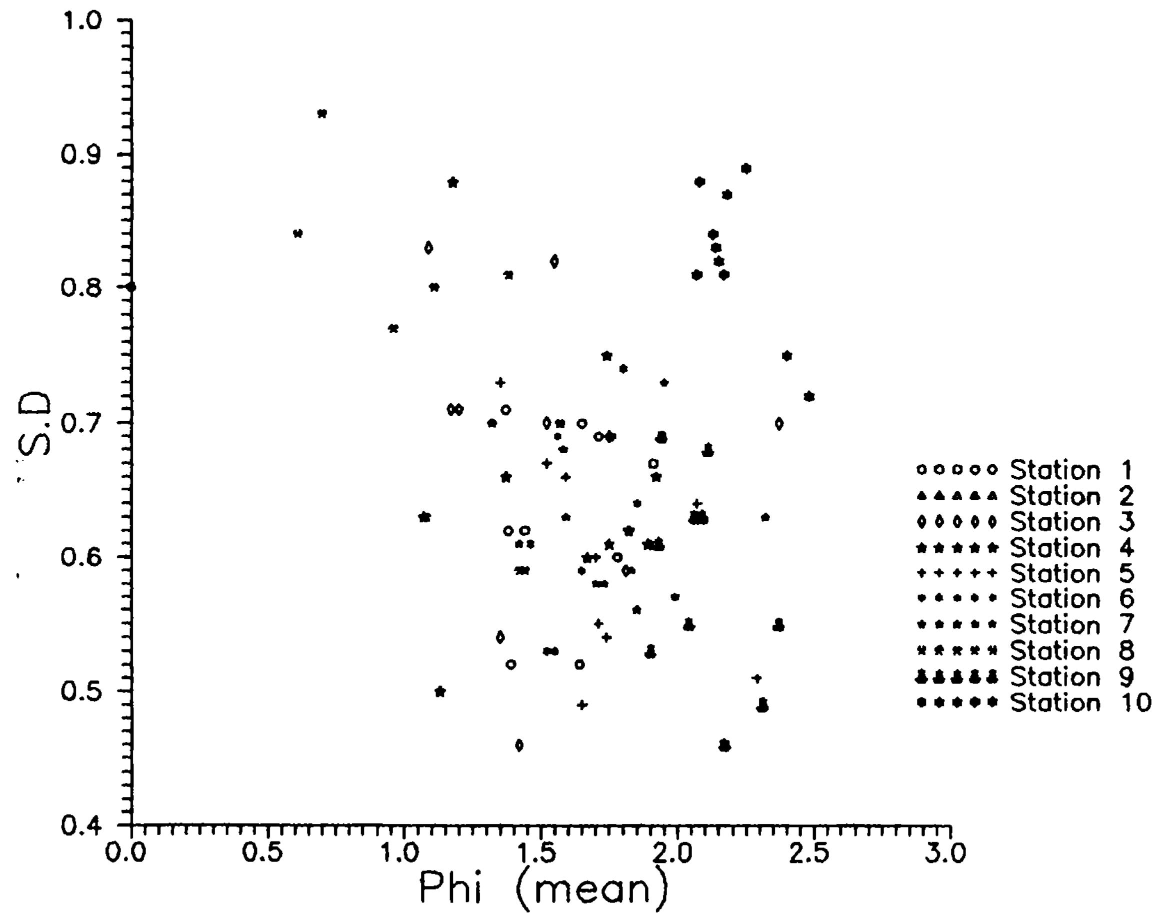


Fig.9 Scatter plot of phi mean size vs standard deviation

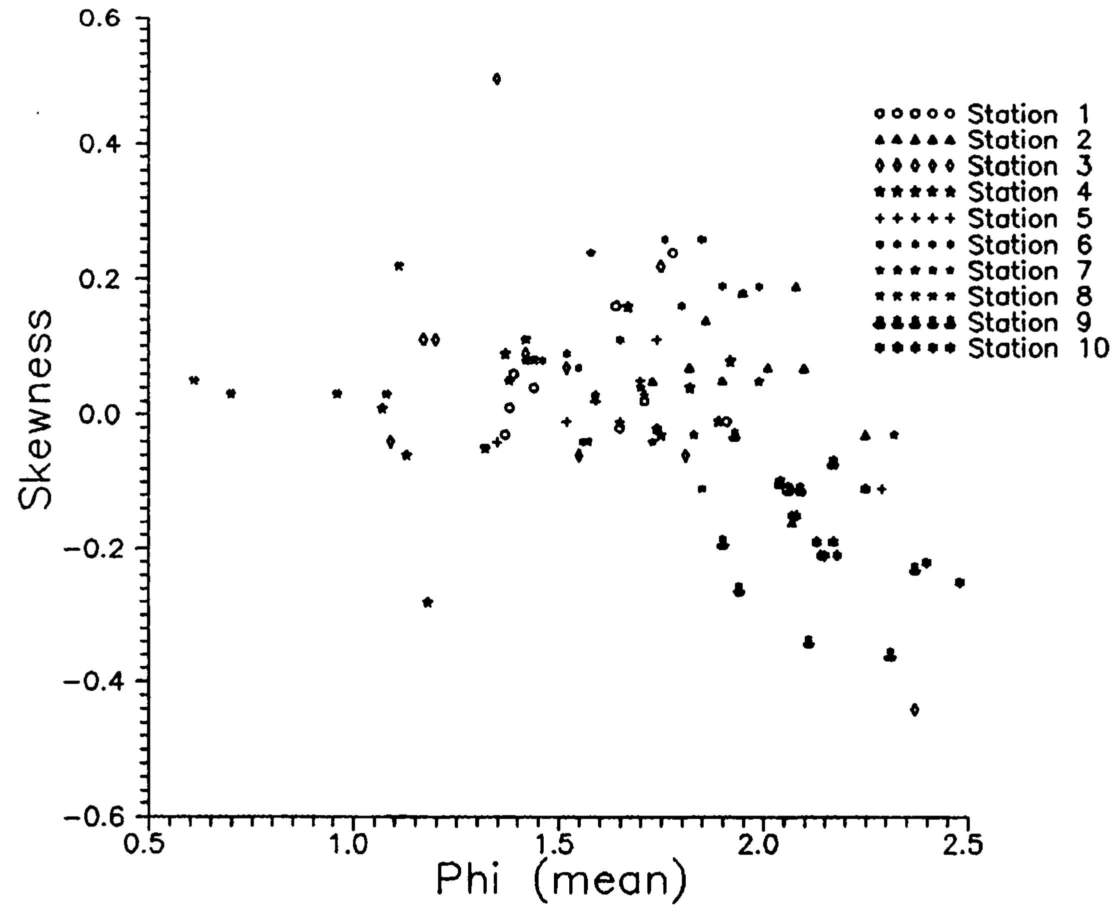


Fig.10 Scatter plot of phi mean size vs skewness

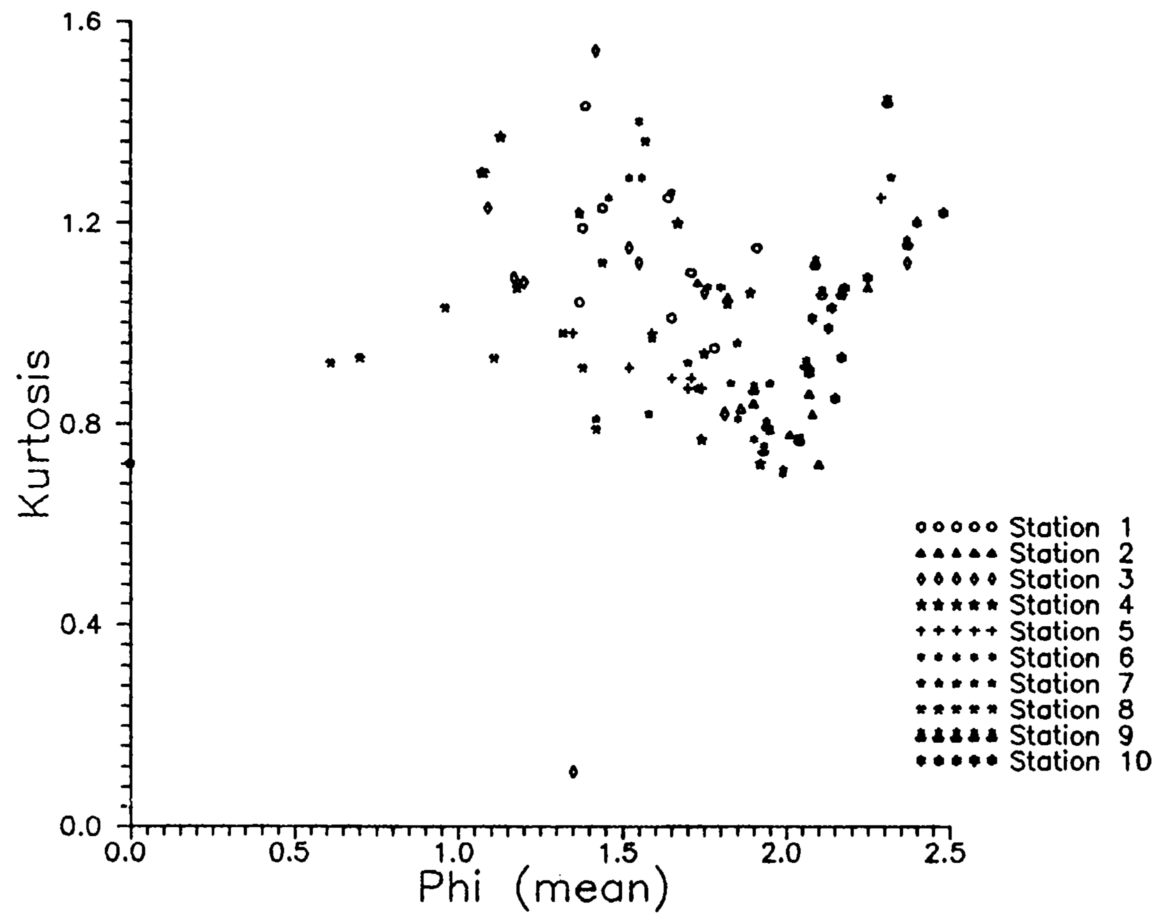


Fig.11 Scatter plot of phi mean size vs kurtosis

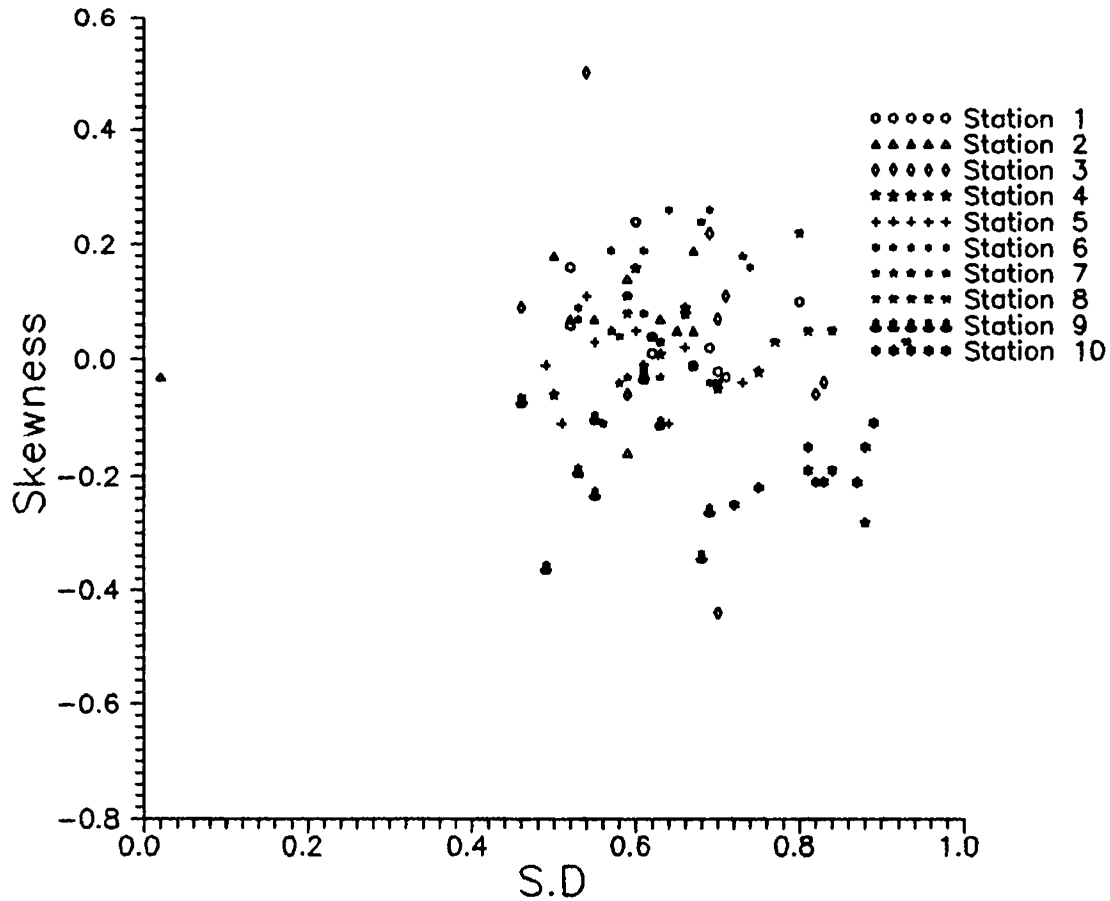


Fig.12 Bivariate plot of standard deviation vs skewness

mean size and standard deviation values. That is to say at certain level sediment characteristics of a particular environment are masked by the other forces and so the slight difference in statistical variation. But in general the phi mean size and standard deviation reflect a beach/dune environment.

The phi mean size versus skewness plot (Fig.10) shows that majority of the sediments are near symmmetrically skewed followed by positive and negative skewness. Only stations 9 and 10 show negative skewness and it may be that the eolian process have winnowed the extreme fine population. It is also evidenced from the fact that unlike in other stations the sediments show a narrow range of phi mean size mainly from 2 to 2.5 phi. The mean size versus kurtosis plot (Fig.11) indicates that as phi mean size increases the kurtosis changes from lepto to meso and then to platy kurtosis. However, beyond 2 phi, the kurtosis once again becomes leptokutric due to the addition of fine population to the existing coarse mode. The bivariant plots of standard deviation versus skewness (Fig.12) do not show any specific trend in spite of limited scattering of points. In general it can be said that a good number of strand plain sediments, with well to moderately well sorting, are symmetricl with regard to skewness. Folk and Ward (1957) has stated that symmetrical curve may be obtained either in a unimodal sample with good sorting or the equal mixtures of two modes which have the poorest possible sorting for a suite of samples. When one mode dominates the other subordinate, the sample shows moderate sorting but gives negative skewness as in the case of samples from stations 9 and 10.

The plots of standard deviation with kurtosis as well as skewness and kurtosis (Figs 13 and 14) do not show any trend.

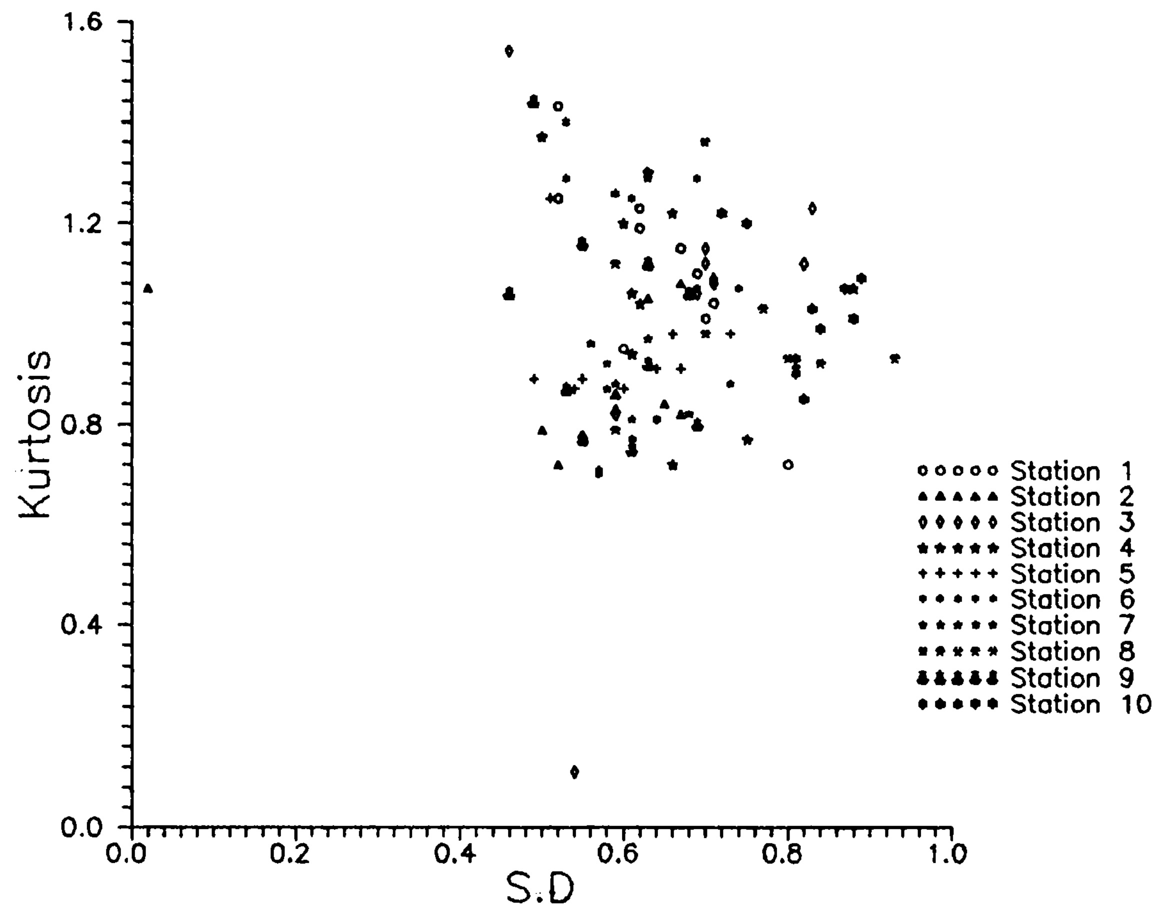


Fig.13 Bivariate plot of standard deviation vs kurtosis

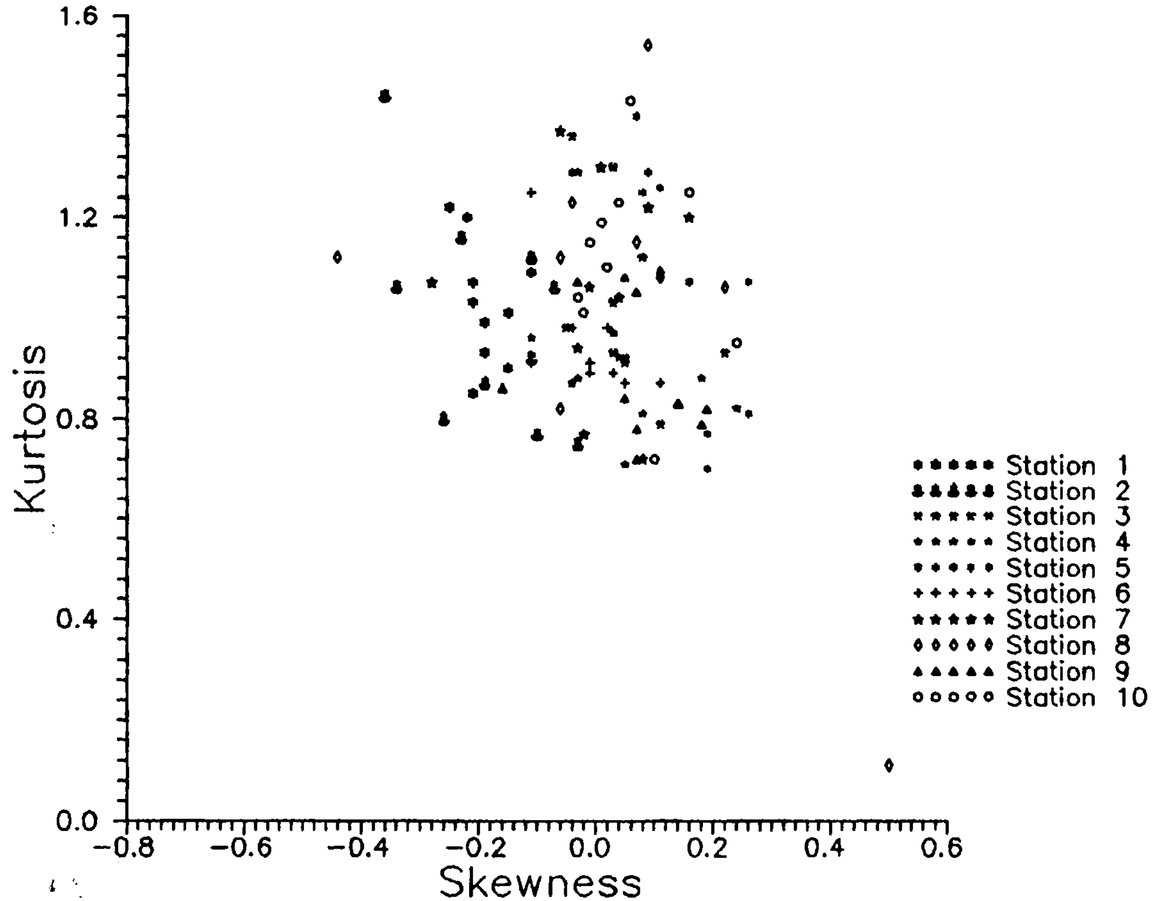


Fig.14 Bivariate plot of skewness vs kurtosis

This may be due to the fact that most of the sediments are normally distributed with regard to both skewness and kurtosis.

3.2.2.b. Core Sediments

Table 3 presents the grain size parameters of 87 sediment samples collected at 1 to 3 m interval from 6 deep bore holes of the study area. Table 4 gives the sand-silt-clay percentages and the nomenclature of the bore hole samples.The down core variation in grain size parameters are presented in Figs.15-18.

Mean size :- Fig.15 shows the variation of phi mean size with depth in all the six cores. In core I, the phi mean size exhibits a very wide range of values from 0.50 to 8.97 phi (coarse sand to coarse clay). Coarsest sediments are found at 51 m depth and the finest at 27 m. The phi mean size is < 5 phi upto 6 m, > 5 phi from 6 to 33 m , between 3 to 5 phi from 33 to 39 m and < 3 phi from 39 to 70 m. In core II, the bottom most sample (45 m) shows lower phi mean size (1.77 phi) and the highest (9.30 phi) at 27 m depth. In this core, the phi mean size is < 2 phi upto 3 m, 5 to 10 phi from 6 to 33 m and again lower values at the bottom of the core. In core III lower phi values (2.64 phi) are found at 2 m depth and higher (8.77 phi) is seen at 27 m. From 3 to 33 m the phi mean size ranges between 5 and 9 phi whereas lower values are found in the bottom sediments. Weathered basement rock ie laterite lithomorge is seen below 45 m depth.

In core IV, samples upto 6 m show phi mean size values < 3 phi whereas from 6 m to the bottom of the core the mean size ranges between 7 and 9 phi except at 15 m depth where it is only 4.45 phi. Hard rock is found at 30 m depth. In core 5 , coarser sediments (< 2.1 phi) are found upto 4 m and the finer at

Table 3 . Grain size parameters of sediments in Core I (Cochin backwaters)

Sample No.	Depth (m)	Phi mean	S.D.	Skewness	Kurtosis
1	1	2.82	1.76	0.22	1.65
2	3	4.87	1.62	0.53	1.21
3	6	4.92	1.68	0.58	1.75
4	9	6.13	3.19	-0.14	1.21
5	12	7.20	1.73	-0.06	1.24
6	15	6.02	2.75	-0.02	0.76
7	18	6.62	2.42	-0.09	1.07
8	21	6.70	1.98	0.11	0.84
9	24	6.40	1.41	0.13	2.73
10	27	8.97	2.24	-0.78	0.82
11	30	5.80	1.70	-0.14	1.48
12	33	6.30	3.02	0.11	0.92
13	36	4.62	2.29	0.51	1.09
14	39	3.02	2.20	0.68	1.78
15	42	2.40	1.39	0.29	2.22
16	45	2.06	1.18	0.12	2.05
17	48	2.02	1.43	0.12	1.70
18	51	0.50	1.66	0.32	1.29
19	54	2.70	2.16	0.37	1.64
20	57	1.13	2.35	0.36	1.41
21	60	1.73	2.45	0.49	1.64
22	63	1.70	2.49	0.40	1.21
23	66	1.53	1.78	0.69	1.42
24	70	1.53	2.15	0.20	1.56

Table 3. Grain size parameters of sediments in Core II (Ernakulam)

Sample No.	Depth (m)	Phi mean	S.D.	Skewness	Kurtosis
25	1	1.78	0.76	0.23	0.78
26	3	1.77	0.67	0.14	0.84
27	6	6.67	2.07	-0.11	1.01
28	9	7.43	2.53	0.04	0.69
29	12	7.40	1.96	0.10	0.85
30	15	7.25	1.95	0.05	0.89
31	18	7.90	2.21	-0.01	0.68
32	21	7.45	2.07	0.33	0.81
33	24	8.47	1.76	-0.73	1.09
34	27	9.30	1.58	-0.62	0.93
35	30	9.67	1.62	-0.70	1.70
36	33	9.17	2.11	-0.76	1.49
37	36	3.60	4.65	0.53	0.71
38	39	8.20	2.23	-0.58	1.33
39	42	5.27	3.44	0.50	0.64
40	45	1.77	2.13	0.61	2.90

Table 3. Grain size parameters of sediments in Core III (Kaloor)

Sample No.	Depth (m)	Phi mean	S.D.	Skewness	Kurtosis
41	1	5.93	1.42	-0.13	3.28
42	2	2.64	0.61	-0.15	1.46
43	3	6.92	1.44	-0.26	1.70
44	6	5.72	1.65	-0.15	1.51
45	9	7.60	2.29	-0.03	0.67
46	12	8.23	2.21	-0.26	0.67
47	15	7.82	2.27	0.02	0.66
48	18	5.37	3.06	0.43	0.76
49	21	7.02	3.45	-0.34	0.62
50	24	5.87	2.87	0.28	0.73
51	27	8.77	2.42	-0.75	0.98
52	30	5.47	2.70	0.49	1.04
53	33	5.64	1.87	0.01	2.30
54	36	3.00	3.04	0.67	1.41
55	39	5.76	2.64	0.32	0.82
56	42	3.40	2.54	0.69	1.97
57	.45	5.12	3.68	0.51	0.54

Table 3 **Grain size parameters of sediments in Core IV(Poovathumkadavu)**

Sample No.	Depth (m)	Phi mean	S.D.	Skewness	Kurtosis
58	1	1.40	0.75	-0.06	0.95
59	2	0.66	0.84	0.07	0.97
60	3	2.86	2.45	0.20	1.41
61	6	3.00	3.28	0.56	1.36
62	9	7.53	2.12	0.20	1.02
63	12	7.45	2.70	-0.08	2.27
64	15	4.45	4.62	0.11	0.53
65	18	7.40	2.33	0.17	0.66
66	21	7.60	2.72	-0.18	1.06
67	24	8.05	2.30	-0.14	0.71
68	27	8.00	1.51	0.06	0.96
69	30	Hard rock (Charnockite)			

Table 3. **Grain size parameters of core sediments-Core –V (Poovathumkadavu)**

Sample No.	Depth (m)	Phi mean	S.D.	Skewness	Kurtosis
70	1	1.85	0.67	-0.08	0.83
71	2	2.16	0.61	-0.12	0.75
72	3	1.36	0.79	0.03	0.93
73	4	0.86	0.77	0.03	1.01
74	6	5.90	2.32	0.06	1.64
75	9	5.35	5.12	0.57	0.45
76	12	Weathered rock (laterite)			
77	15	Hard rock (Charnockite)			

Table 3 **Grain size parameters of core sediments-Core-VI-(Elavathur)**

Sample No.	Depth	Phi mean	S.D.	Skewness	Kurtosis
78	2	9.35	1.59	-0.61	3.16
79	4	9.27	1.58	-0.58	3.48
80	6	5.70	2.18	0.36	0.89
81	8	7.07	3.27	-0.75	0.64
82	10	7.82	2.68	-0.72	1.47
83	12	4.97	2.04	0.30	1.10
84	14	-0.06	1.03	0.23	2.03
85	16	0.67	1.31	0.02	1.03
86	18	1.04	1.50	0.04	1.60
87	20	Hard rock (Charnockite)			

Table 4 **Sand-silt- clay percentages and Nomenclature of Core I (Cochin backwaters)**

Sample No.	Depth (m)	Sand (%)	Silt (%)	Clay (%)	Nomenclature
1	1	76.6	6.4	17.0	Clayey sand
2	3	38.9	53.0	9.1	Sandy sil.t
3	6	37.2	53.9	3.9	Sandy sil.t
4	9	20.1	55.1	24.8	Sandy sil.t
5	12	3.1	57.6	39.3	Mud
6	15	25.4	57.7	16.9	Sandy sil.t
7	18	15.5	54.6	29.9	Sandy mud
8	21	5.6	21.0	73.4	Clay (lateritic)
9	24	4.0	82.8	13.2	Silt
10	27	5.8	60.6	33.6	Mud
11	30	12.0	78.0	10.0	Sandy sil.t
12	33	18.1	54.8	27.1	Sandy sil.t
13	36	53.3	37.2	9.5	Silty sand
14	39	74.2	17.8	8.0	Silty sand
15	42	88.2	7.8	4.0	Muddy sand
16	45	91.7	5.5	2.8	Sand
17	48	89.1	8.0	2.9	Silty sand
18	51	93.5	4.5	2.0	Sand
19	54	80.0	14.9	5.1	Silty sand
20	57	87.1	8.6	4.3	Silty sand
21	60	83.8	10.4	5.8	Muddy sand
22	63	82.4	13.0	4.6	Silty sand
23	66	89.5	7.0	3.5	Silty sand
24	70	87.0	8.8	4.2	Silty sand

Table 4 .Sand-silt- clay percentages and Nomenclature of Core II (Ernakulam)

Sample No.	Depth (m)	Sand (%)	Silt (%)	Clay (%)	Nomenclature
25	1	97.0	2.1	0.9	Sand
26	3	9.8	1.0	1.0	Sand
27	6	3.3	48.9	47.8	Mud
28	9	9.5	51.1	39.4	Mud
29	12	3.0	56.2	40.8	Mud
30	15	2.6	61.0	36.1	Mud
31	18	8.8	43.7	47.5	Mud
32	21	2.7	61.6	35.7	Mud
33	24	0.6	22.0	75.4	Clay
34	27	0.8	23.9	75.3	Clay(laterite)
35	30	0.9	17.0	82.1	Clay
36	33	0.3	19.0	80.2	Clay
37	36	66.0	12.0	22.0	Muddy sand
38	39	5.0	18.0	77.0	Clay
39	42	55.0	9.0	36.0	Clayey sand
40	45	87.6	3.0	9.0	Clayey sand

Table 4 Sand-silt- clay percentages and Nomenclature of Core III (Kaloor)

Sample No.	Depth (m)	Sand (%)	Silt (%)	Clay (%)	Nomenclature
41	1	1.0	88.0	11.0	Silt
42	2	95.0	3.0	2.0	Sand
43	3	3.4	86.7	9.1	Silt
44	6	13.0	76.5	10.5	Sandy silt
45	9	4.3	49.4	50.3	Mud
46	12	3.3	41.1	55.6	Mud
47	15	4.5	49.1	46.4	Mud (lateritic)
48	18	43.6	30.8	25.6	Sandy mud
49	21	26.3	22.8	50.9	Sandy clay
50	24	37.1	36.7	26:2	Muddy sand
51	27	10.3	21.8	67.9	Sandy clay
52	30	32.3	47.6	20.1	Sandy silt
53	33	18.0	70.0	12.0	Sandy silt
54	36	74.5	12.8	12.7	Muddy sand
55	39	34.8	38.6	26.6	Sandy mud
56	42	75.4	12.3	13.3	Muddy sand
57	45	57.6	6.0	36.4	Clayey sand (lateritic)

Table 4 **Sand-silt- clay percentages and Nomenclature of Core IV (Poovathumkadavu)**

Sample No.	Depth (m)	Sand (%)	Silt (%)	Clay (%)	Nomenclature
58	1	97.0	2.0	1.0	Sand
59	2	98.0	1.0	1.0	Sand
60	3	85.2	10.8	4.0	Muddy sand
61	6	74.5	4.5	21.0	Clayey sand
62	9	6.3	61.6	32.0	Mud
63	1	11.0	64.0	25.0	Sand silt
64	1	49.4	15.9	34.7	Clayey sand
65	1	4.6	58.3	37.1	Mud
66	2	10.9	51.3	37.8	Sandy mud
67	2	3.2	45.7	51.1	Mud
68	2	2.2	51.6	46.2	Mud
69	3	Hard rock (Charnockite)			

Table 4 **Sand-silt- clay percentages and Nomenclature of Core V (Poovathumkadavu)**

Sample No.	Depth (m)	Sand (%)	Silt (%)	Clay (%)	Nomenclature
70	1	96.0	2.0	2.0	Sand
71	2	95.0	3.0	2.0	Sand
72	3	97.0	2.0	1.0	Sand
73	4	98.0	1.0	1.0	Sand
74	6	16.7	66.7	16.6	Sandy silt
75	9	33.2	18.6	48.2	sandy clay (lateritic)
76	12	Weathered rock (laterite)			
77	15	Hard rock (Charnockite)			

Table 4 **Lithology of core sediments -Core-VI(Elavathur)**

Sample No.	Depth	Sand (%)	Silt (%)	Clay (%)	Nomenclature
78	2	7.20	6.40	86.20	Clay
79	4	6.10	9.20	84.70	Clay
80	6	23.80	57.66	18.60	Sandy silt
81	8	26.90	15.60	57.50	Sandy clay
82	10	14.60	20.30	65.10	Sandy clay
83	12	37.30	46.00	16.70	Sandy silt
84	14	94.00	2.00	4.00	Sand
85	16	95.00	2.00	3.00	Sand
86	18	96.00	2.00	2.00	Sand
87	20	Hard rock (Charnockite)			

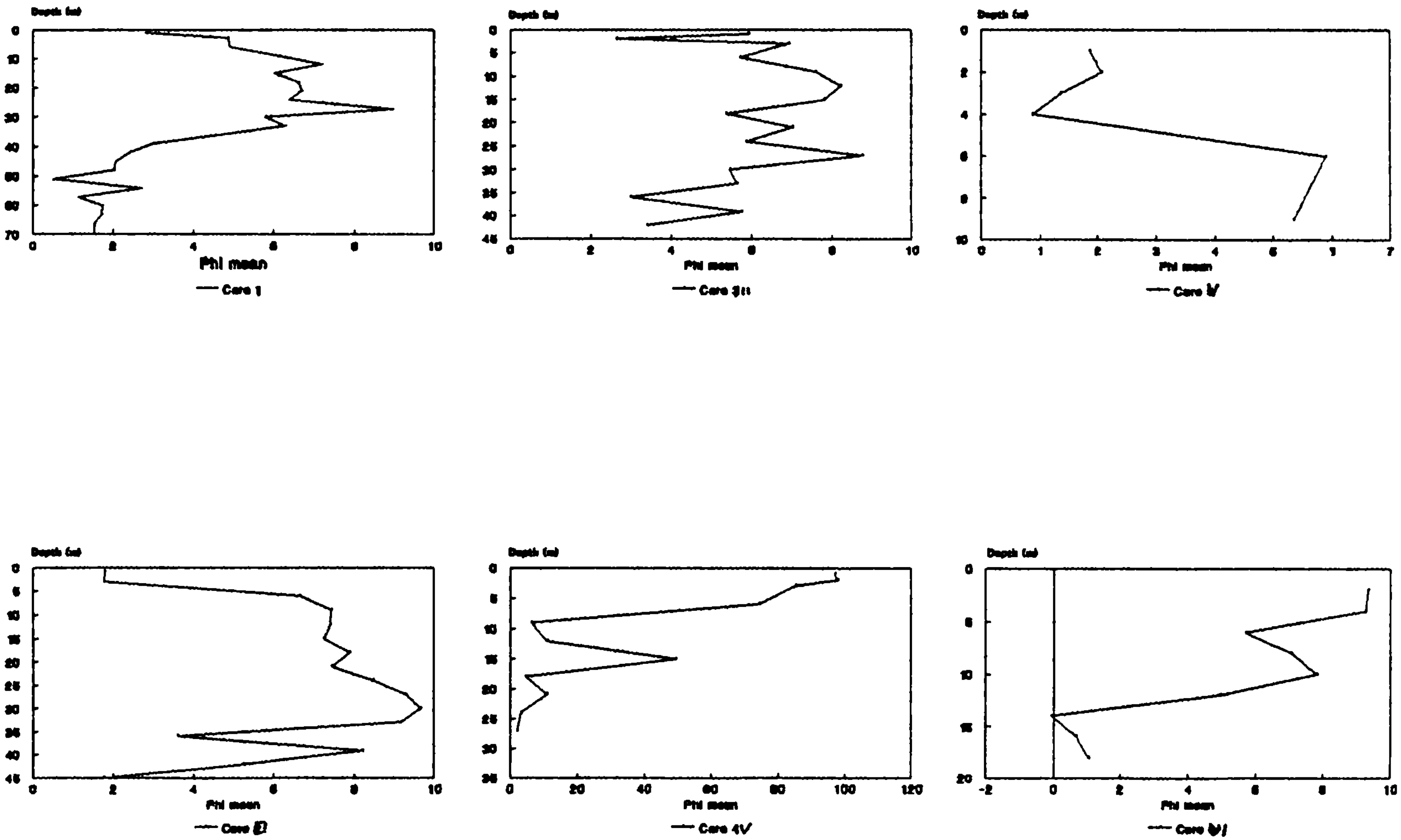


Fig.15 Down core variation of mean grain size

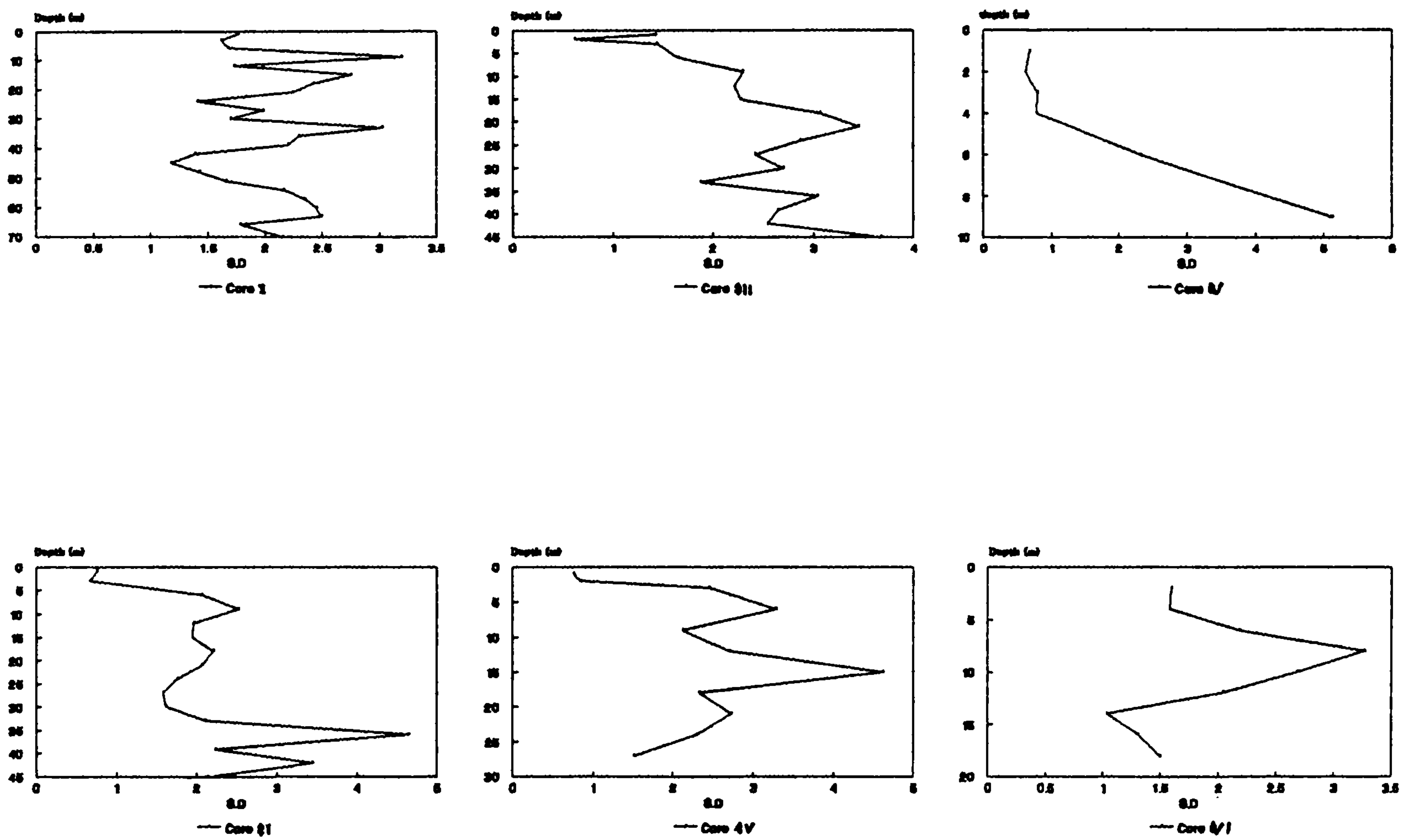


Fig.16 Down core variation of standard deviation

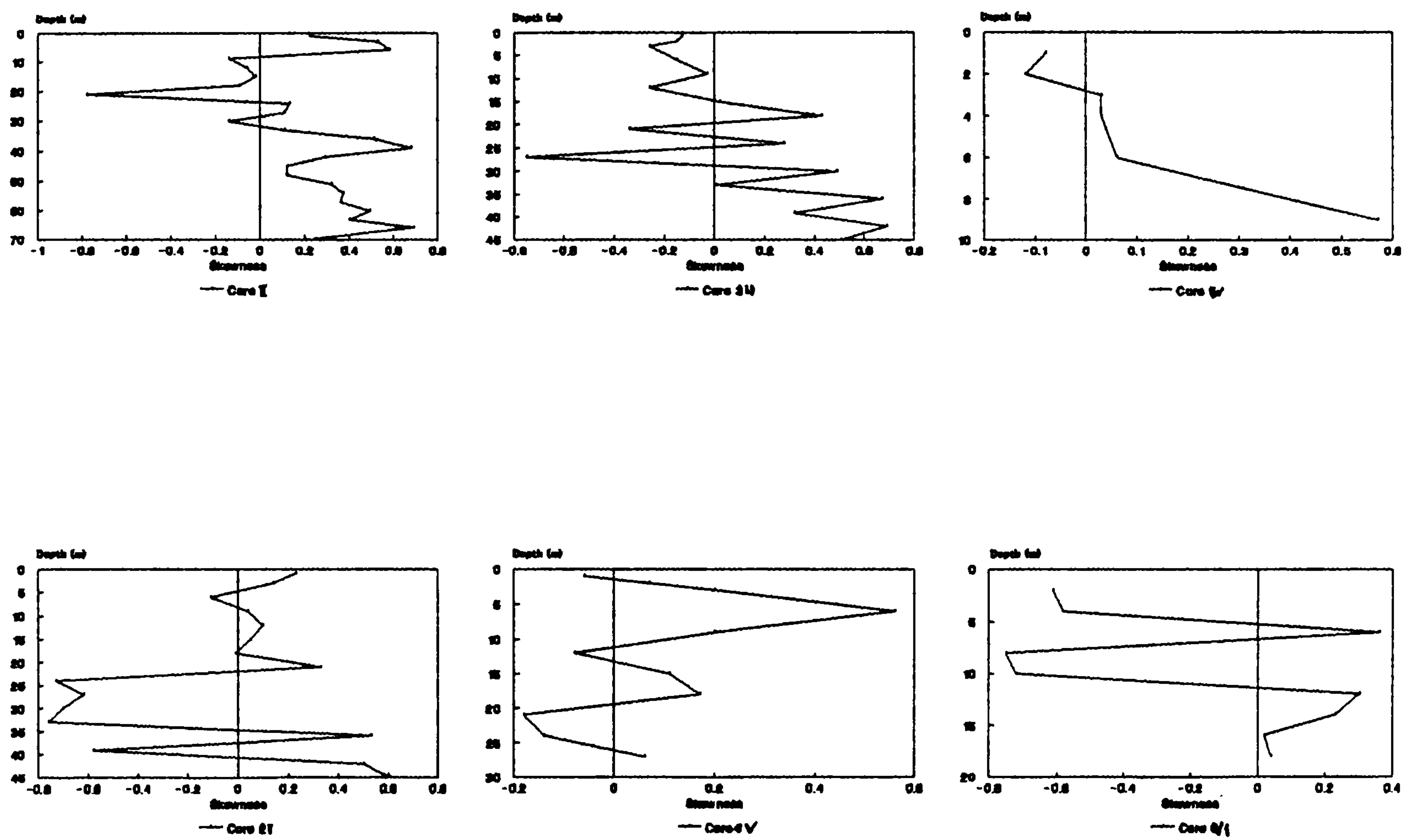


Fig.17 Down core variation of skewness

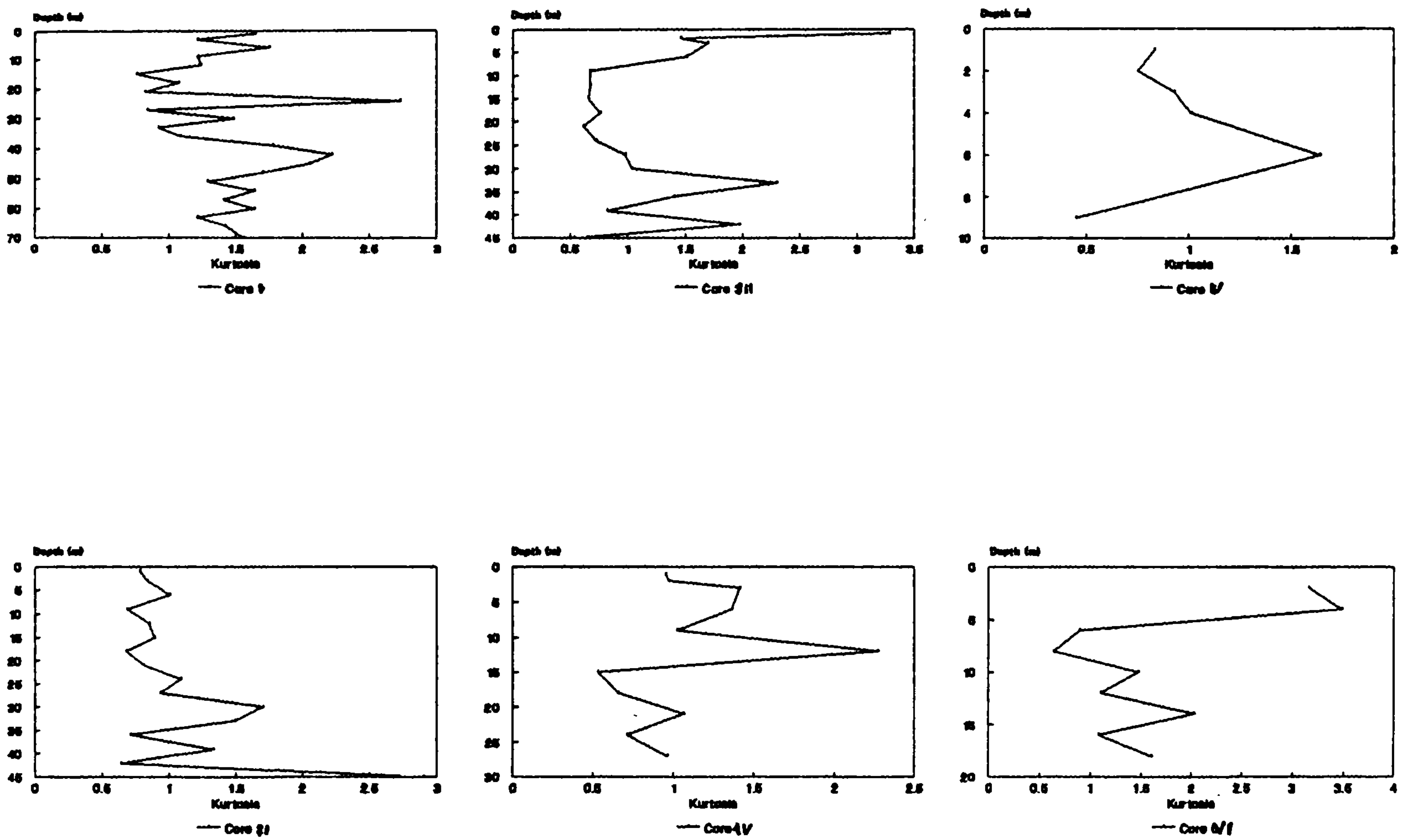


Fig.18 Down core variation of kurtosis

the bottom; hard rock charnockite is met at 15 m depth. In core VI, the finer sediments are encountered at the top 2m level whereas coarser sediments are recorded at 14 m depth. The mean size show little variation (9 to 10 phi) upto 10 m depth except at 6 m depth where the value is 5.6 phi. So also at 12 m depth mean size is 4.97 phi. The bottom samples are extremely coarse grained, < 1 phi and hard rock chrnockite is met at 20 m depth.

Standard deviation : Nearly 86 % of the core sediments are of poorly to very poorly sorted and about 10% are moderately well to moderately sorted(Fig.16).Sorting values ranges from 0.53 to 5.12 phi. Generally in the core sediments sorting improves as the size grade become either coarser or extremely finer. Out of the 30 sand sized sediments, 27% are moderately well to moderately sorted whereas about 47% are poorly sorted. Only one sample is well sorted whereas the remaining 23% of the samples are very poorly sorted. All the 12 clay size sediments show sorting values ranging from 1.5 to 2.5 phi whereas majority of the silt sized sediments are of very poorly sorted in nature. As coarser sediments are found either at the top or bottom portion of the cores, relatively good sorting values are found in those sections of the core. The abundance of finer particles impart broad particle dispersion which in turn causes very poor sorting of sediments (Allen 1970). This explains well the poorly to very poorly sorted nature of most of the core sediments. Mallik and Suchindin (1984) have observed a similar trend, reported about the poorly sorted nature of Vembanad lake bed sediments.

Skewness:- Skewness value ranges from -0.78 to +0.69 (Fig.17). Majority of core sediments are finely skewed, 30% are coarsely skewed and about 21% are near symmetrically skewed. In cores I, II and III, most samples below 33 m are finely skewed whereas the top samples upto 6 m in core 1 , and 3 m in core II exhibit the same character. Core sediments of IV, V and VI are not showing any general trend of skewness with depth.

Kurtosis :- The Kurtosis values of core sediments (Fig.18) range from very platy to extremely leptokurtic (0.45 to 3.48) Out of the 83 core samples, 46 % are lepto kurtic, 34 % platy kurtic and the rest(20 %). are meso kurtic. In core I, III and VI, the top and bottom sediments show lepto kurtic nature. In the remaining cores, kurtosis does not show any trend with depth. In core II, samples below a depth of 27 m are mostly lepto kurtic.

Late Quaternary Stratigraphy: Textural studies of different deep core sediments (Fig.19,19a)reveal the presence of a number of litho stratigraphic units at different levels in the study area. The general stratigraphy of the Ernakulam area reveal four distinct lithological units namely sandy strata at the top 3 m level, silt/muddy sediments ranging from 3 to 40 m interbedded with secondary lateritic sediments at depths ranging from 12 to 27 m and sandy sediments starting from 33-40 m onwards. The stratigraphy of inland strand plain area of Kodungallur region can be given as sandy sediments upto 6 m and clayey or muddy sediments from 6 m to the hard rock basement (i.e., 27 m from the surface). Stratigraphy of the northern part of the study area i.e., kole land region reveals three distinct units. Clayey sediments are found from 0 to 6 m depth, muddy or silty sediments from 6 to 12 m and sand from 12 m upto the basement at 18 m. Subsurface occurrence of primary laterite is observed in the inland area of Ernakulam in core 3 and Kodungallur region in core

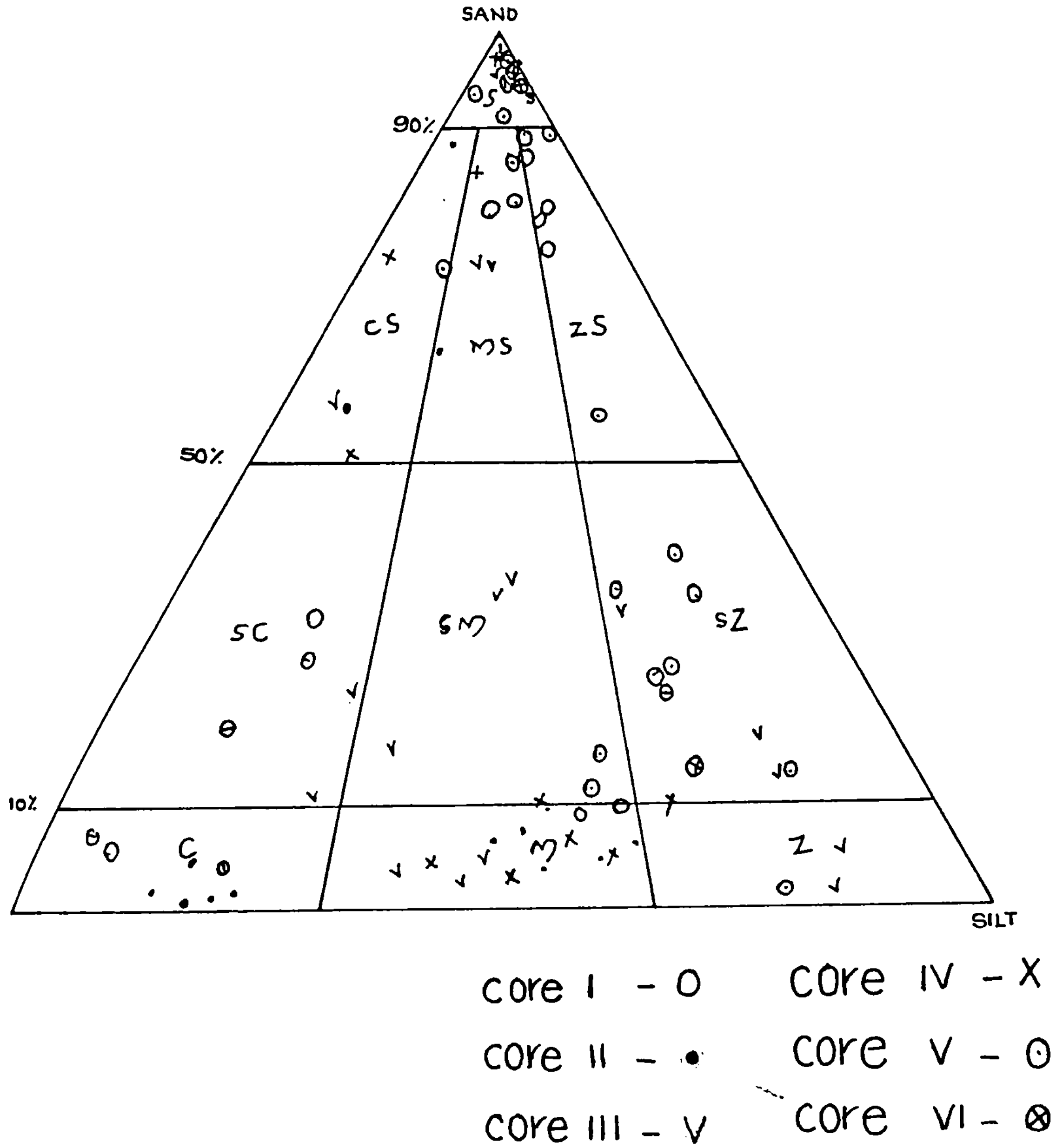


Fig.19 Ternary diagram illustrating the nature of sedimemnts in core No.1 to 6

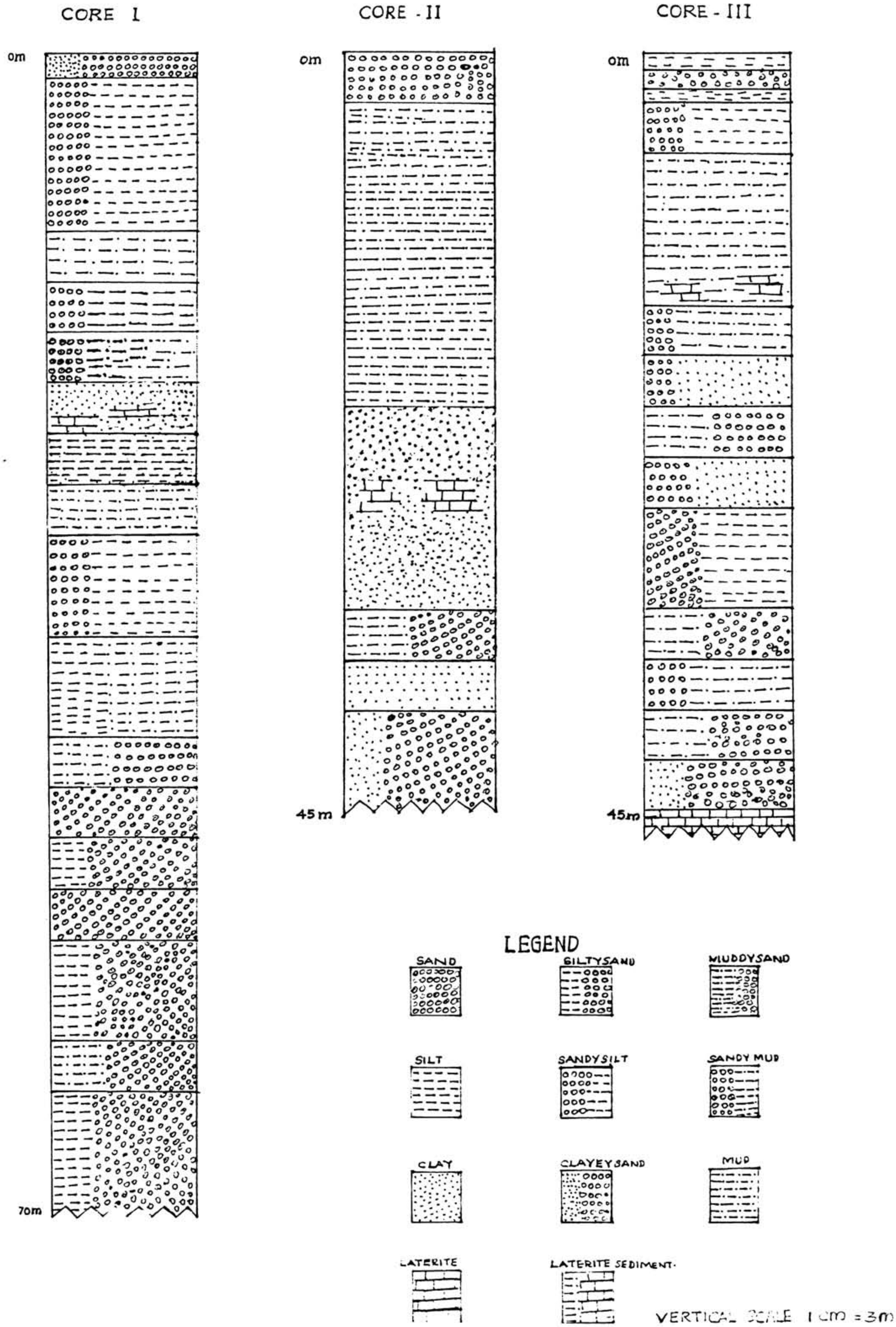
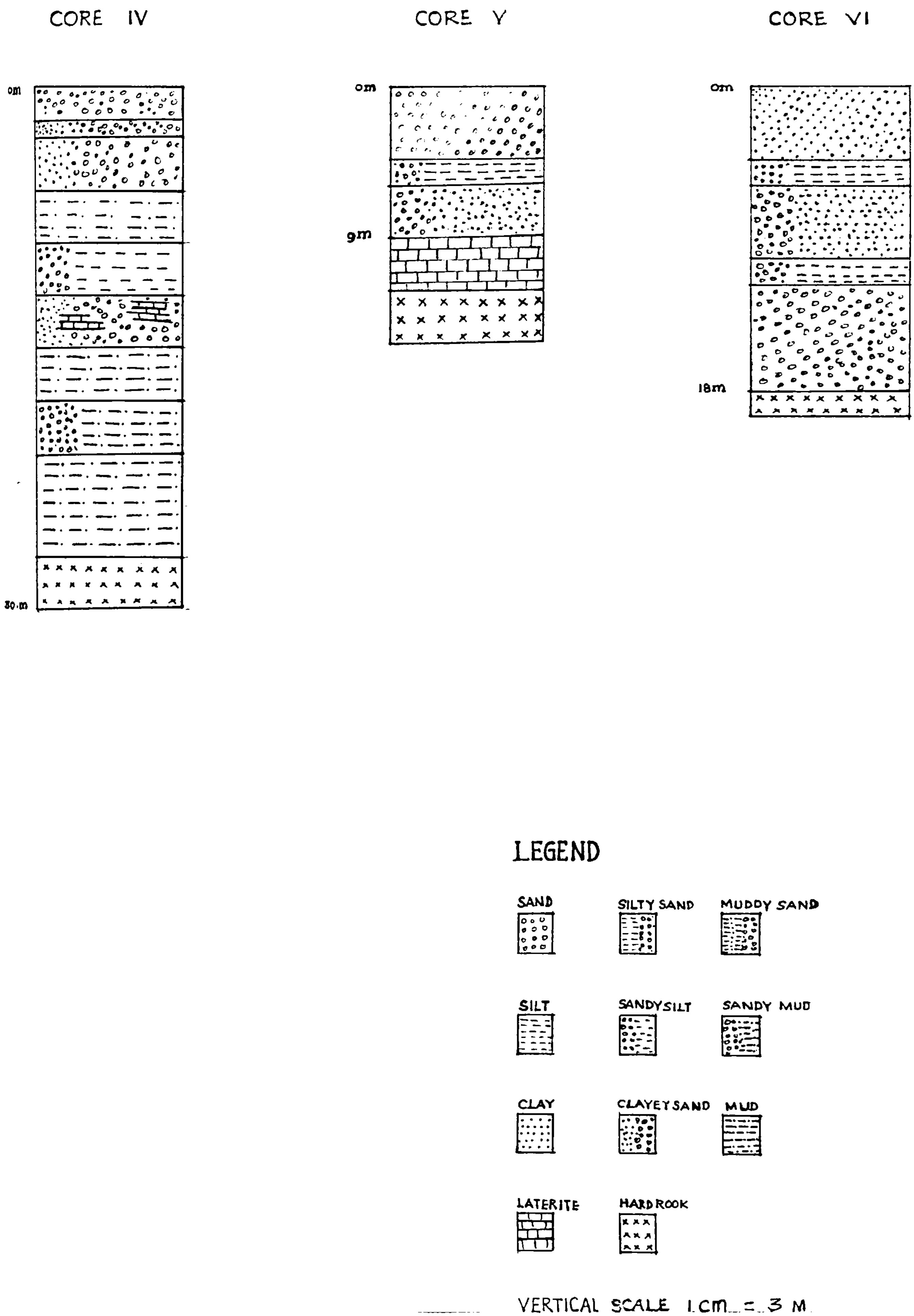


Fig.19a Lithostratigraphy of core No.1 to 6

cont'd


CORE IV
CORE Y
CORE VI
om
30.m
om
9m
om
18m
LEGEND
SAND
SILTY SAND
MUDDY SAND
SILT
SANDY SILT
SANDY MUD
CLAY
CLAYEY SAND
MUD
LATERITE
HARD ROOK
VERTICAL SCALE 1 cm = 3 M

5 at a depth of 45 and 9 m respectively whereas it is not found in kole land region.

A distinct change in the sediment character is noticed below depth range of about 33 - 40 m in different cores of Ernakulam area. The sediments below these depths are predominantly sandy nature. Radio carbon dating of organic rich sediment samples at depths of 36 and 39 m reveals that the sediments are more than 40000 years old. Further, the sediments show the typical characteristics of Warkalli formation with the presence of pebbles, gravels, feldspathic sands and peat layers (Nair and Rao, 1980). Therefore, the bottom sandy unit might be part of the Warkalli formation datable to Mio-Pliocene age and therefore the Tertiary-Quaternary boundary in Ernakulam region might be situated at about 33 - 40 m depth. The presence of pebble bed further suggests that the Warkalli sediments in this area would have deposited in a riverine environment. Nair and Rao (1980) has observed that the Warkallis were deposited in a marginal marine paralic or riverine environments.

Rajendran (1987) has opined that the coastal Quaternary sediments of Kerala comprise of alluvium, beach, dune, lime shell deposits, red sands, peat beds, calcarious clays with shells and all of them are underlained by laterites. According to Nair and Rao (1980), the laterites also mark the unconformity between Quaternary and Mio-Pliocene sediments. Apart from the extensive surface exposures of primary laterites over the crystallines, its subsurface occurrence in the inland coastal plains as secondary lateritic materials are encountered at different depths south of Periyar river (Fig.2). However, the present study reveals the occurrence of secondary lateritic material at depths ranging from 12 to 27 m (12 to 15 m in core III, 24 to 27 m in core II and 18 to 21 m (core I) in the inland part of Ernakulam region whereas the CGWB report (1993) mentions the presence of secondary laterites at two levels. The first is encountered at a depth of around 30 m whereas the second one is around 70 m in Ernakulam region. The two ^{14}C dates just below the secondary laterite horizon at a depth of 18 and 24 m have yielded ages respectively around 26000 and 30000 yrs B.P. (Table 5) whereas another sample at a depth of 16.75 m at Willingdon Island yielded an age of 8315 $\pm$ 125 yrs B.P. (Table 6). Therefore, the top most secondary lateritic sediment layer in the study area can be assigned to have formed in a period between 20000 to 12000 yrs B.P. Therefore, the secondary lateritisation event can be correlated with the last glacial maxima (LGM).

The sediments strata overlying the secondary lateritic unit might have deposited during Holocene period. The carbon dating results (Table 5) indicate that the whole sediment sequences in the Kodungallur area belong to Holocene period. The lower muddy or clayey horizon was deposited during early Holocene whereas the upper sandy horizon might have formed during the regressive phase of the sea from the area. The whole sequences in kole land area might belong to late Quaternary period. The coarse nature of sand at the bottom levels indicate a riverine environment during the last glacial maxima and the overlying clayey or silty strata were deposited during the Holocene transgression.

CHAPTER 4

4.1 GEOCHRONOLOGY AND SEA LEVEL CHANGES

4.1.1 Introduction:

In contrast to the east coast of India the Quaternary geochronology of the west of India is better understood with the help of large number of dates following U-Th, thermoluminescence and radio carbon methods. The dated sediments of Saurashtra coast are from raised beaches, inland coral reefs and miliolite limestone deposits. Over 50 miliolite samples were dated from Saurashtra region following the 230 Th/234 U method and the ages range from about 30 to 300 kyr B.P (Baskaran et al., 1989). The ages of Kutch miliolites fall into a period between late middle Pleistocene (170 kyr B.P) and early late Pleistocene (45 kyr B.P). Various coral and shell samples dated from inland coastal area of Saurashtra (Gupta, 1972) fall into two general categories namely (1) with ages of about 5500 $\pm$ 1000 yrs B.P and the samples are from the region between 1 and 3 m above MSL and (2) with ages of around 25000 $\pm$ 1000 yrs B.P. and the samples are from 3.5 to 6 m above MSL. The beach rocks or Karal from Konkan coast range in age from late Pleistocene to Holocene. The ^{14}C date of drift wood from the fossil tidal clay indicates an age of around 6000 yrs B.P (Ghate, 1985). Palaeomangroves of Kanara coast, Karnataka was dated by ^{14}C method to older than 40000 yrs B.P (Caratini, 1990). A number of authors have reported several ^{14}C dates for the coastal region of Kerala (Table 6).

Table 5. List of ^{14}C dates analysed from PRL from the present study area.

Sl.No	Lab.No	Location	Depth(m)	Material dated	Age yrs B.P
1.	PRL 1852	Poovathum Kadavu, Thrissur Dt.	6.5	Peat	6720±70
2.	PRL 1857	"	24	"	7450±120
3.	PRL 1633	Valloor, Thrissur Dt.	2	"	3390±110
4.	PRL 1632	"	.5	"	5520±160
5.	PRL 1896	Kaloor, Ernakulam Dt.	18	"	25610±840
6.	PRL 1898	"	36	"	> 40000
7.	PRL 1989	Ernakulam	24	"	29930±630
8.	PRL 1883	"	39	"	> 40000

Table 6. Published ^{14}C dates from Coastal Sediments of Kerala

Sl. No.	Lab No.	Location	Material	Age	Reference
1.	BS 673	Payyannur, Kannur Dt	Peat	4490±907	Rajendran et al., (1989)
2.	BS 674	"	"	4370±1007	"
3.	BS 711	Tellicherry Kannur Dt.	"	7230±120	"
4.		"	"	6948±130	"
5.	PRL 1883	Off Ponnani	"	8230±210	
6.	PRL 1884	"	"	10240±340	
7.	PRL 1885	"	"	8360±210	
8.	PRL 1886	"	"	8690±180	
9.	PRL 1887	"	"	9530±240	
10.	BS 689	Tannisseri, Trichur Dt.	"	6420±120	Rajendran et al., (1989)
11.	965	Wellington Island, Ernakulam Dt.	"	8080±120	Agrawal et al., (1971)
12.		Wellington Island, Ernakulam Dt.	"	8315±125	Agrawal et al., (1971)
13.		Cochin Harbour, Ernakulam Dt.	"	8795±115	Agrawal et al., (1975,1979)
14.	PRL 60	Vembanad Lake	"	8785±135	Agrawal et al., (1975-79)
15.	BS 701	Vechur, Kottayam Dt.	Shell	3710±90	Rajendran et al., (1989)
16.		Iranimangalam, Alapuzha Dt.	Peat	7050±130	Powar et al., (1983)

(contd.....)

Table 6 continue

Sl. No.	Lab. No.	Location	Material dated	Age yrs B.P	Reference
17.	BS 717	Muhamma Alapuzha Dt.	Shell	3130±100	Rajendran et al., (1989)
18.		Kurichi Alapuzha Dt.		30340±1860	Powar et al., (1983)
19.	TF 1147	Cochin Harbour	Peat	8795±115	Agrawal & Sheela Kusumgar, (1973)
20.	TF 1091	Vembanad Lake		3945±140	"
21.	TF 1090	"		3625±95	"

4.1.2 Results and Discussion

The results of ^{14}C dating analysed from the study area are given in Table 5 and the published dates for the Kerala coast are presented in Table 6. Peat and shell deposits are widely distributed along the coastal belt of Kerala. Most of the peat formations (except the one in Warkallis of Tertiary age) and shell deposits of Kerala belong to Quaternary period and their evolution is directly linked to the climatic and sealevel changes. Of the 8 dates (Table 5), 4 fall in Holocene and the rest fall in late Pleistocene. On the other hand out of the 21 dates reported by earlier workers from coastal Kerala (Table 6) 19 fall in the Holocene epoch and two in late Pleistocene. From the above (Table 6), it is clear that the maximum concentration (13 No.) of ^{14}C dates range between 10000 to 6000 yrs B.P and only 6 dates range from 5000 to 3000 yrs B.P. Overall 3 dates range from 25000 to 30000 yrs B.P. and 2 dates cross the ^{14}C limit of 40000 yrs B.P. (Table 5 & 6). The offshore samples which range in age from 10000 to 8000 yrs B.P have been reported from a shallow depth of 1 to 2 m. The subsurface peat samples from the coastal areas which range in age from 8000 to 6000 yrs B.P are reported from a wide ranging depth of 6 to 20m.

The subsurface peat and shell deposits of inland basins are recovered from a shallow depth of 1 to 4 m from the surface. The peat samples, which show greater ages ie from 25000 to 30000 yrs B.P are collected from deeper layers at 18 and 24 m respectively from the surface. The samples which show ages > 40000 yrs B.P. are collected from still greater depths of 36 and 39 m from the surface.

Radio carbon dating of Holocene deposits offers an excellent tool which could be used to unravel the sealevel changes (Donner et al., 1977). The onland subsurface peat layers at a depth of 36 and 39 m in the Ernakulam area shows ^{14}C ages greater than 40000 yrs B.P. (Table 5). The sediments at these depths show the presence of characteristic feldspathic sandy sediments with pebbles and granules along with peat layers indicating that the Warkalli formation reported elsewhere from different coastal segments of Kerala has extended upto Ernakulam region (Nair and Rao 1980). Menon (1966), while working on the Tertiary formation at Karichal and Padappakkara, has inferred that the Warkalli beds were deposited over a wider extent overlapping the Quilon beds. He also suggested an unconformity between the two formations. Prabhakar Rao (1968) after estimating the age of the lower most lignite bed exposed at Varkala by ^{14}C method, gave an age of more than 40000 yrs B.P for the Warkalli bed and stated that the Warkalli formation was deposited during the third interglacial period of around 100000 yrs B.P. Even in the absence of any faunal evidence and precise dating, most of the workers attribute that Warkalli sediments are of Mio-Pliocene period. (Murthy 1979; Nair and Rao,1980). As the dated peat samples show an age more than 40000 yrs B.P. it is obvious that the Warkalli formation extends upto Ernakulam area, but whether these beds belonging to Mio Pliocene or to a later period cannot be inferred precisely with the available evidences.

The three dates, which range in age between 30000 to 25000 yrs B.P. (Table 5 and 6) are from Ernakulam and Alleppey area where minimum thickness of coastal sediments are reported. The first date (25610±840 yrs B.P.) is from an onland flat terrain at Kaloor which is lying 8 km inland from the shore whereas the second date (29930±630 yrs B.P.) is from the Cochin backwater area (Bolgaty island) about 4 km from the present coast (Table 5). The other ^{14}C date (30340±1860 yrs B.P.) was from Kurichi area, Alleppey (Powar et al., 1983). On the basis of the occurance of peat sequences in the sediments , Powar et al., (1983) has suggested the existence of a submerged forest in Kurichi. The peat beds, which form part of the Quaternary units of Kerala, were due to submergence of coastal forests. The above dates as well as the presence of mangrove pollen at 18 m depth (Table 10) in the Ernakulam area indicate that the growth and existence of coastal mangrove forests from 30000 to 25000 yrs B.P was obvious. There are evidences at several places that the sea level was higher than the present at about 30000 yrs B.P. Gupta (1972) also suggest a higher sealevel along the west coast of India during this period. Hence the above three dates attribute a higher sealevel for coastal Kerala around 30000 to 25000 yrs B.P. and subsidence of deposits as a result of neotectonism thereafter.

Majority of ^{14}C dates from Kerala very well correspond with the generally accepted fast eustatic rise of sealevel during the early Holocene period. During the most rapid phase of deglaciation, from about 10000 to 7000 yrs B.P., sealevel may have risen at a rate of 10 m/1000 years (Bloom 1979). The two dates (7450±120 yrs B.P. and 6720±70 yrs B.P.) from the Kodungallur area support the fast rate of sea level rise as the cores are seperated by a horizontal distance of only 100 m. Here the sealevel rose from a depth of 24 to 6.5 m within a short period of 750 years. In Ernakulam area it rose from a depth of 17 m around 8300 yrs B.P. to present level around 6000 yrs B.P. The descripancies in the sealevel picture of the two areas can be explained as a result of neotectonism or to the preexisting basin configuration. A number of dates from other regions like Alleppey, and Tellicherry (Table 6) also correspond to the above said fast sealevel rise during the early part of Holocene epoch. High percentage of mangrove pollen from these peat deposits at these levels attribute mangrove existance at these levels. Therefore, it is suggested here that the flooding as a result of transgression during 8000 - 6000 yrs B.P. had destroyed the mangrove vegetation giving rise to extensive peat deposits.

A number of ^{14}C dates (Table 5 & 6) range in age from 5000 to 3000 yrs B.P. This phase corresponds with regression from mid Holocene to late Holocene time. During high stand of sealevel shell and peat were deposited extensively in the inland regions at many places of coastal Kerala. The Valloor peat bed (Table 5), is lying 20 km inland from the present coast, and the pollen analysis indicate that about 85% of the vegitation are mangroves. Further, an inland peat sample at a distance of 10 km from the coast and obtained from 5 m depth in a well section at Vellangalloor comprise essentially of mangrove vegetation (Table 10) . The peat samples from Payyannur and shell samples from Vechur and Muhamma (Table 6) show ages between 5000 to 3000 yrs B.P. The above observations clearly indicate a higher sea level during late Holocene. So also the shell deposits of Vembanad lake area, kole lands of central Kerala and other parts of coastal areas would have formed by the accumulation of dead shell bearing organisms. Rajendran et al., (1989) suggest that the regression of the sea around 5000-3000 yrs B.P. would have resulted in the trapping of shell bearing organisms in their ecological niche and were ultimately destroyed which gave rise to the subsurface shell deposits in coastal and inland regions of Kerala. Similarly the inland mangrove vegetation would have also destroyed during regression. Van der Hammen, (1974) while working on a pollen sequence in a 30 m core from Guyana, has demonstrated the usefulness of mangrove vegetational changes in interpreting the relative positions of land and sea. The regression from 5000-3000 yrs B.P. must have helped in the growth of sand bars which separated the sea from the mainland and ultimately resulted in the development of present day coastal land scape with backwaters and estuaries or with barrier beaches, palaeobeach ridges and swales.

4.2 GEOCHEMISTRY

4.2.1 Introduction:

In the last 2-3 decades the field of geochemistry has achieved great impetus mainly because of the alarming scale of environmental pollution all over the world. The fast industrialization in the present century threw billions of tons of industrial wastes and effluents to the environment, which altered severely the balance of nature. Modern geochemical studies cover a vast spectrum of area including the distribution of various chemical elements in minerals, ores, rocks, soils, waters and atmosphere as well as the circulation of these elements in nature (Goldschimdt, 1958).

Eventhough there are a number of geochronological and isotopical studies on the coastal and shelf sediments of the west coast of India in relation to sea level and past climatic variations (Baskaran and Somayajulu, 1986; Baskaran et al., 1989; Borole et al., 1982 ; Somayajulu,1988), studies on the role of geochemistry in the interpretation of sea level variations are comparatively less. Most of the workers have been concentrating on various aspects of surficial and short core sediments such as Bombay harbour sediments by Gogate et al., (1976); Kutch sediments by Murthy et al., (1978); shelf sediments of south west coast of India by Paropkari (1990), Cauvery deltaic sediments by Seralathan (1979), and Seralathan and Seetarama swamy (1987).

As far as the study area is concerned, nutrient distribution by Sakaranarayanan and Panampunnayil (1979), distribution of organic matter, phosphorous and trace metals by Murthy and Veerayya (1972, 1981), trace metals by Paul and Pillai (1983). There is absolutely no study has been carried out on the geochemistry of inland core sediments collected from coastal areas of India.

4.2.2 Organic carbon :

The important factors which govern the organic carbon content in sediments are 1) the supply of organic matter to the environment of deposition. 2) rate of deposition of organic and inorganic constitutents 3) rate of decomposition and 4) texture of the sediments. Organic carbon constitutes an integral part of riverine, esturine and shelf sediments. The increased attention in recent years to the geochemistry of organic carbon in sediments of various environments is due to its significant role in the biological, chemical and geological processes operating in these environments (Mantoura et al., 1978; Degens and Ittekot, 1983; Romankevich, 1984 and Laanne and Ruardij 1988). The relative proportions of the supply of orgnic carbon is a function of the characteristics of the catchment area in relation to the productivity of the aquatic system (Parsons and Seki, 1970; and Hakanson and Jansson, 1983). It provides the main energy source for the heterotrophic organisms and also act as a sink as well as source for various metals under different geochemical set up (Padmalal 1992).

Several workers have studied the organic carbon content of surficial sediments of rivers and estuaries in the study area. Murthy and Veerayya (1972) have made an attempt to study the organic carbon content in the surficial sediments of Vembanad lake. Mallik and Suchindan (1984) have also studied the geochemistry of organic carbon in the lake sediments.

4.2.3 Results and discussion:

The organic carbon content in the core sediments is given in Table 7 and its variation with depth is depicted in Fig 20. The average organic carbon content of core I is 4.62%. Minimum content is noticed in the laterite clay sediment at 27 m and maximum is found at 18 m. Relatively high content of organic carbon is noticed in sediments at a depth range of 12 to 24 m, 30 to 39 m and 60 to 70 m. In core II, the average value is 2.14 % and the least content is again in the lateritic clay at 24 m depth and highest is at 21 m depth. This core reveals higher organic carbon content from 6 to 21 m depth and all the bottom samples upto 45 m depth are showing very less organic

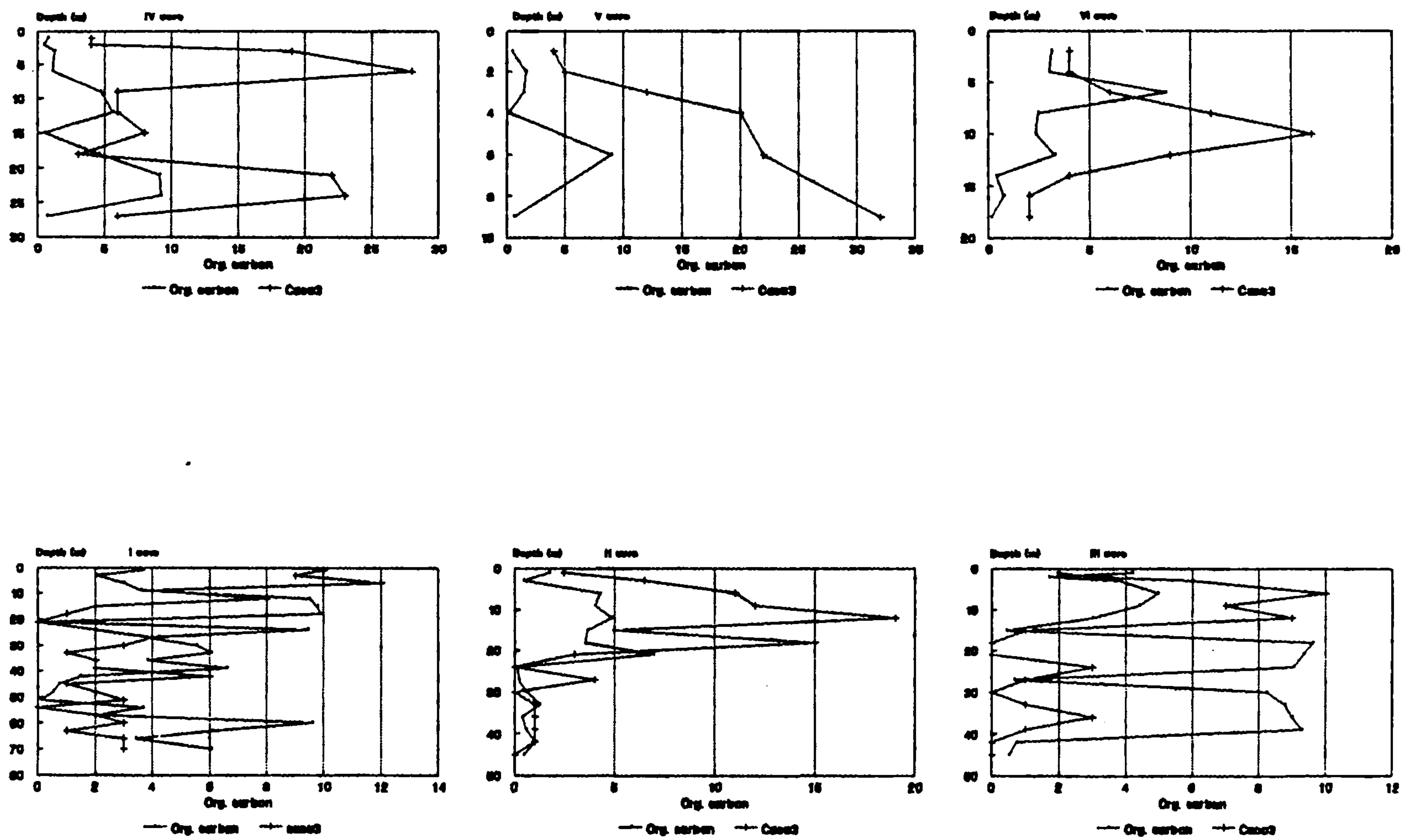


Fig.20 Down core variation of organic carbon of $CaCO_3$

carbon, mostly less than 1%. Core III shows average value of 5.16 % and the minimum and maximum are noticed at 15 m (lateritic clay) and 18 m depths respectively. Here organic carbon content is high,right from the top most sample at 1 m to 12 m, then it is very high from 18 to 39 m depth except at 27 m. The bottom sediments at 42 and 45 m are of very less organic carbon content. The average organic carbon content in the IVth core is 3.45 %, minimum at 15 m and maximum at 24 m. In this core, the concentration is higher from 9 to 12 m and again 18 to 24 m depth . The average for Core V is 2.19% and the sample at 6 m only contain significant organic carbon. In core VI, the average organic content is 2.69 % and the least value is noticed in the bottom most coarse sand and highest value at 6 m depth.

The average organic carbon content for all the six cores is 3.38%. Earlier, Murthy and Veerayya (1972) have recorded an average of 1.5% of organic carbon in the surficial sediments of Vembanad estuary, whereas Mallik and Suchindan (1984) have observed an average of 9.11%. Sajan and Damodaran (1981) have reported an average of 2.4% for the surficial sediments of Ashtamudi lake in south Kerala. Padmalal (1992) has reported an average concentration of 0.99% in the Muvathupuzha river sediments and 2.36% in the Vembanad estuarine sediments. Somayajulu (1990) has observed that element carbon is one of the indications of biological productivity.

In the study area, organic carbon content fluctuates highly with depth in all the cores except core V, in which only one concentration peak is noticed at a depth of 6m from the surface. The high concentration of organic carbon at different depth in the sediment column indicates accumulation of organic debris along with the sediments in the low lying basin near to the coast. Reineck and Singh (1980) have observed that intermittent monsoon has produced large volume of fluvial discharge containing coarse sediments and much organic debris, which were deposited in the isolated depressions.

4.2.3 $CaCO_3$

The $CaCO_3$ content of the sediments are presented in Table 7 and presented in Fig. 20. The $CaCO_3$ content in Core I varies from 0 to 12 %,the average being 3.5 %. The sediment samples from 1 to 12 m show higher content of $CaCO_3$ and the samples at 30 m and 42 m depth have more than average concentration. The average $CaCO_3$ content of Core II is 5.13 % and the values range from 0 to 19%. The sediments from 3 to 18 m and at 27 m show significantly higher values. The average $CaCO_3$ for core III is 2.76 % and maximum value is found at 6 m depth. The sediment samples from 3 to 12 contain significant $CaCO_3$ whereas the bottom samples are mostly devoid of $Ca CO_3$. In core IV, the average $CaCO_3$ is 11.73 % and almost all samples show higher percentage of $CaCO_3$. The concentration is exceptionally higher at depths ranging from 3 to 6 m and from 21 to 24 m. The average content of $CaCO_3$ in core V is 15.83 % and all the samples show significant percentage of $CaCO_3$. It is also very high from 3 to 9 m depth. The maximum value among the sediments of the study area is recorded at 9 m in core V . The core VI also shows higher content of $CaCO_3$ and the maximum is recorded at 10 m depth. The coarse sands at bottom of the core do not contain significant quantity of $CaCO_3$

Table 7 Organic carbon and calcium carbonate contents in different core sediments

CORE I

Depth (m)	C-org (%)	$CaCO_3$ (%)
1	3.70	10
3	2.05	9
6	3.00	12
9	3.61	4
12	9.50	8
15	9.78	2
18	9.90	1
21	0.28	0
24	9.44	2
27	3.80	4
30	5.56	3
33	6.06	1
36	3.83	2
39	6.61	2
42	1.50	6
45	0.72	1
48	0.55	2
51	0.11	3
54	3.67	0
57	2.06	2
60	9.61	3
63	6.1	1
66	3.44	3
70	6.08	3

CORE II

Depth (m)	C-org (%)	$CaCO_3$ (%)
1	1.76	2.5
3	0.48	6.5
6	4.28	11
9	4.03	12
12	4.85	19
15	3.65	5
18	3.55	15
21	6.97	3
24	0.14	0
27	0.19	4
30	0.68	0
33	1.29	1
36	0.40	1
39	0.57	1
42	1.04	1
45	0.47	0

Table 7 Cont'd:...

CORE III

Depth (m)	C-org (%)	$CaCO_3$ (%)
1	4.20	2
2	1.71	3
3	3.93	6
6	4.97	10
9	4.40	7
12	3.00	9
15	0.41	1
18	9.64	0
21	9.33	0
24	9.06	3
27	0.67	1
30	8.24	0
33	8.76	1
36	9.00	3
39	9.28	1
42	0.72	0
45	0.52	0

CORE IV

Depth (m)	C-org (%)	$CaCO_3$ (%)
1	0.74	4
2	0.42	4
3	1.26	19
6	1.06	28
9	4.71	6
12	5.60	6
15	0.48	8
18	4.60	3
21	9.15	22
24	9.26	23
27	0.69	6

CORE V

Depth (m)	C-org (%)	$CaCO_3$ (%)
1	0.48	4
2	1.64	5
3	1.42	12
4	0.10	20
6	8.94	22
9	0.58	32

CORE VI

Depth (m)	C-org (%)	$CaCO_3$ (%)
2	3.12	4
4	3.01	4
6	8.78	6
8	2.43	11
10	2.32	16
12	3.28	9
14	0.37	4
16	0.74	2
18	0.16	2

$CaCO_3$ has been found to be a good indicator of glacio-interglacial stages. During late Quaternary glacial epochs, a higher proportion of terrigenous materials have accumulated in the equatorial and tropical areas than in the interglacial periods. This has been measured indirectly by estimating the proportion of $CaCO_3$ in the cores from Atlantic, off West Africa (Hays and Peruzza, 1972). According to Bradely (1985) terrestial detritus dilutes the relatively constant pelagic carbonate influx so that $CaCO_3$ influx shows an inverse relationship with terrestial material. Hence times of carbonate abundance indicate low terrestial influx. Conversely carbonate minima signify periods of higher aridity. Studies of core sediments from coastal Arabian Sea by Borole et al., (1982) indicate that higher carbonate content can be correlated with interglacial or warmer periods and lower content with glacial or cooler periods.

In Kerala, no study has so far been carried out on the $CaCO_3$ content of deep core sediments of the coastal region . In the study area, generally the upper part of the deep sea cores and most of the sediments in the shallow cores are found to be enriched in $CaCO_3$. The top 12m of the deeper cores in Ernakulam area and the whole sediment sequences in the shallow cores from the northern part of the study area show higher concentration of $CaCO_3$. The sediments at these levels fall in the Holocene epoch. Rajaguru et al., (1993) have observed that the beginning of holocene is marked by a humid climate with intense monsoonal activity and the whole Holocene epoch experienced almost similar climatic conditions as that of the present day. Somayajulu (1990) has attributed that the higher $CaCO_3$ content in the marine sediment is due to high biological productivity. Therefore, the higher $CaCO_3$ content in the

Holocene sediments in the coastal region of central Kerala could be attributed to the humid climate, fast sea level rise and high productivity in this part of the coast. Borole et al., (1982) have observed that the lower concentration of $CaCO_3$ in the coastal Arabian sea sediments as a result of cooler climate from 28000 to 13000 yrs B.P. The very poor concentration of $CaCO_3$ in the lateritic sediments encountered in different bore holes suggests that this has resulted from the major marine regression during the Last Glacial Maxima. In the west coast of India, the sediments below 40 m. are of coarse texture in nature due to fluvial input following marine regression and therefore the sediments are poor in $CaCO_3$ content.

4.2.4 Iron and Manganese

The concentrations of Fe and Mn in the three cores and strand sediments are given in Table 8 and represented in Fig. 21 Fe contents show much fluctuations in core I. The average Fe concentration is 4.10 % and the maximum concentration of 8.71 % is recorded at 21 m depth and the minimum (1.12%) is at 1.12 m depth. Fe shows a decreasing trend with depth with maximum concentration in the top 21 m of the core. The average Mn concentration is 93 ppm, its maximum (278 ppm) is recorded at 9 m and minimum (26 ppm) is at 36 m depth. Mn content in core I fluctuates very much but generally highest concentrations are found in the top 10 m of the core and low concentration in deeper core.

The average concentration of Fe in core IV is only 3.10 %

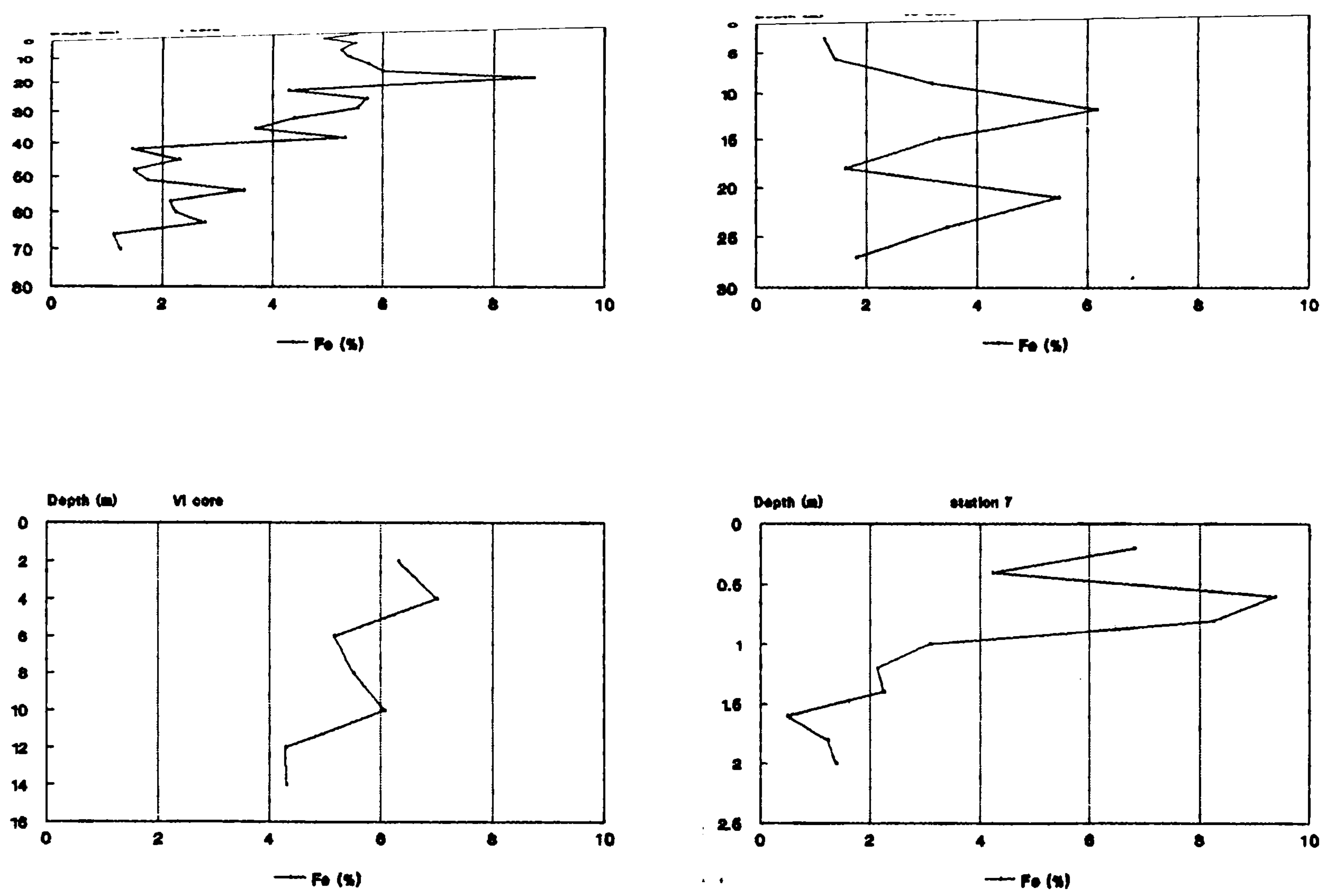


Fig.21 Vertical variation of Fe(%) at Cores I,IV,VI and stn.7

and it ranges between 1.22 % at 3 m and 6.16 % at 12 m depth. The top sediments of the core show less Fe content than the rest of the core sediments. Mn in this core ranges from 15 ppm at 15 m to 389 ppm at 21 m depth and the average is 152 ppm. In this core, deeper sediments show higher Mn content. The average concentration of iron in core VI is 5.10 % and the values do not exhibit much fluctuation. On the other hand Mn contents fluctuate highly from 137 ppm at 6 m to 905 ppm at 10 m with an average value of 403 ppm.

The strand sediments show an average of 3.92 % Fe with a range of 0.48 % at 1.60 m and 9.38 % at 0.6 m depth. Mn content also registers a similar variation 65 ppm at 1.60 m and 2349 ppm at 0.60 m; the average being 654 ppm. Fe and Mn concentrations of strand sediments are well correlated with depth. The average concentrations of Fe in the cores are comparable to the published values (Murthy and Veerayya (1981; Mallik and Suchindan (1984) for the surficial sediments of Vembanadu estuary. Ramachandran(1992) has reported an average of 7.76% Fe for the innershelf sediments of Kerala. He also found that the Fe content increases with depth of the core. In the present study, although concentration of Fe is found less than that of the innershell sediments, but a down core increase is noticed upto a depth of 21 m in core I and upto 12 m in core IV (Fig.21). The maximum concentration of 8.71% at 21 m level (core no I) is due to laterization of the sediment. As the laterites are rich in secondary oxide of Fe and Al or both the abnormal Fe at 21m depth is axiomatic. Fossil laterites are considered as good indicators of paleoclimatic condition (Rajaguru, 1989). It is said earlier (Chapter 3) that the laterization might have taken place between 20000 to 15000 yrs B.P. Therefore, the high Fe content as well as the laterization at 21 m depth suggest a more drier climate and a lower sea level during the LGM in the study area. On the other hand the high concenteration of Fe in the near surface sediments is attributed to the present day oxidation of Fe bearing minerals. Various workers (Singh, 1993, 1996, 1998) reported high intensity of monsoonal activity during early Holocene period. The high concenteration of Fe at different depths in core IV and VI may be due to minor fluctuation in the climatic conditions. The concenteration of Mn (Fig. 22) in core I is found significantly lower than the reported value for the study area. Padmalal (1992) reported 366 ppm for the surficial sediments of Vembanad estuary, Ramachandran (1992) report an average of 177 ppm Mn for the innershelf sediments whereas Pandarinath and Narayana (1998) estimated an average of 319 ppm for innershelf region off Coondapur, southern Karnataka coast. The concentration of Mn in IV and VI are more or less comparable. The sediments up to a depth of 9 m in core I show good concenteration whereas the underlying sediments are found depleted in Mn. In geneneral Mn shows more or less similar variation as that of Fe, because if its close affinity with Fe. Most of the core sediments exhibit a reverse relationship between organic carbon content and Mn concentration. Similar trend is observed by Sharma et al. (1994) in some of the shallow cores from Bombay area.

The abnormally high concentration of Fe and Mn at a depth of 0.6 -0.8 m in the strand sediments from Kodungallur are due to (Table 8) ferrecrete content. The sediments at these levels

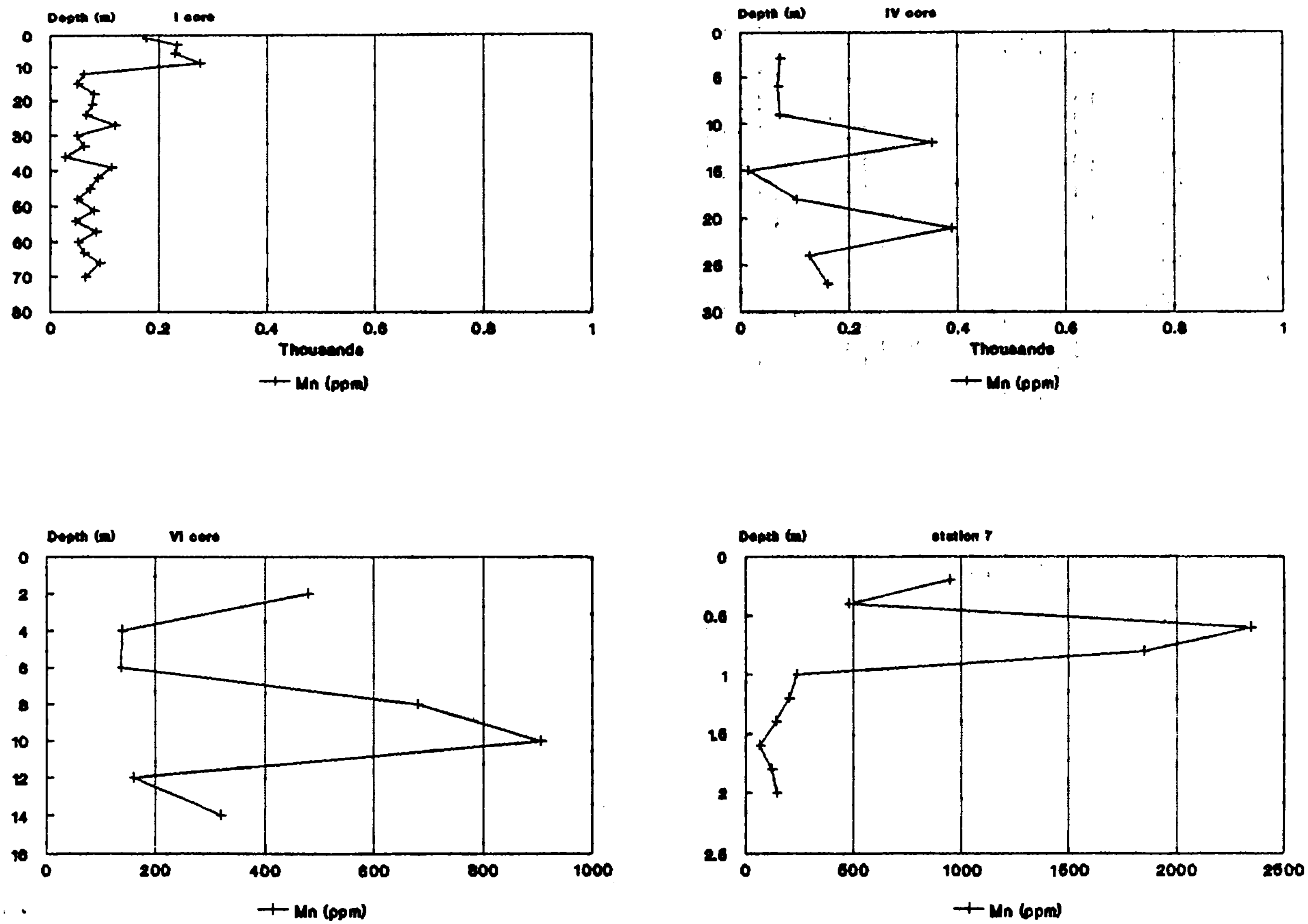


Fig.22 Vertical variation of Mn(ppm) at Cores I,IV,VI and stn.7

Plate 6 Effect of feerrecretization of paleobeach ridges north east of Kodungallur

are dark brown in colour. In the study area (Plate 6) ferrecrete concentrations are noticed mainly in the interior sand ridges area. Similarly ferrecretes are reported in the inland regions from northern and southern Tamil Nadu coast by Achyuthan (1993), Rajaguru et al. (1993) have reported a climatic aridity over western India during late Holocene and this phase of climatic aridity has revealed through the formation of ferrecrete in Kerala.

4.2.5 Trace elements

The concentration of Cd, Cr and Ni are given in Table 8 and their variations with depth in the three cores and strand plain sediemnts are presented in Fig. 23. The average concentrations of Cd, Cr and Ni are respectively 3 ppm, 128 ppm and 64 ppm in core I, 2 ppm , 110 ppm and 52 ppm in core IV, 1 ppm, 167 ppm and 93 ppm in core VI and 0.0 ppm, 139 ppm and 151 ppm in strand plain sediments. The highest Cd content is noticed at 9 m, Cr at 1 m and Ni at 15 m depth. The metal Cd does not show any concentration in the top and bottom sediments of this core whereas the least concentration of Cr and Ni are found only in the bottom most sample at 70 m depth.

In core IV, significant concentration of Cd is noticed upto 15 m depth whereas the bottom sediments are devoid of Cd. Higher concentration of Cr is noticed between 9 and 21 m depth whereas the top and bottom samples show values lesser than the average. Ni content is high in bottom sediments and low in top sediments. In core VI only traces of Cd are found upto 8 m depth, Cr and Ni show an opposite trend.

Eventhough the concentrations of Cd in the strand sediments

Table 8 **Concentration of Fe, Mn, Cd, Cr and Ni in various core sediments**

Core I (Cochin Backwaters)

Depth (m)	Fe (%)	Mn (ppm)	Cd (ppm)	Cr (ppm)	Ni (ppm)
1	5.49	178	0	172	80
3	4.92	234	0	137	63
6	5.49	230	0	161	72
9	5.23	278	20	160	75
12	5.38	62	1	145	95
15	5.73	50	0	138	111
18	6.00	81	0	155	93
21	8.71	77	6	152	54
24	4.28	66	3	148	60
27	5.70	119	12	161	88
30	5.52	49	4	145	56
33	4.38	61	1	118	52
36	3.69	26	2	103	52
39	5.29	113	3	139	67
42	1.45	87	3	121	70
45	2.3	73	1	142	57
48	1.48	49	3	144	59
51	1.72	81	2	119	46
54	3.47	45	2	69	37
57	2.14	84	1	80	52
60	2.23	51	0	117	58
63	2.77	61	0	94	55
66	1.12	91	0	100	54
70	1.24	64	0	35	28

Table (Station 7) Concentration of Fe, Mn, Cd, Cr and Ni in strand sediments

Depth (m)	Fe (%)	Mn (ppm)	Cd (ppm)	Cr (ppm)	Ni (ppm)
0.20	6.81	947	0	244	97
0.40	4.22	480	0	167	70
0.60	9.38	2349	0	224	86
0.80	8.25	1850	0	240	72
1.00	3.08	240	0	128	64
1.20	2.13	203	0	96	50
1.40	2.25	142	0	82	78
1.60	0.48	65	0	75	47
1.80	1.23	120	0	64	52
2.00	1.38	143	0	87	39

CORE IV (Poovathukadavu)

Depth (m)	Fe (%)	Mn (ppm)	Cd (ppm)	Cr (ppm)	Ni (ppm)
3	1.22	74	2	72	35
6	1.43	70	2	44	27
9	3.18	74	1	57	44
12	6.11	352	6	164	87
15			3	348	53
18	1.61	105	0	16	22
21	5.48	389	0	138	89
24	3.44	128	0	86	52
27	1.82	160	1	54	52

CORE VI (Elavathur)

Depth (m)	Fe (%)	Mn (ppm)	Cd (ppm)	Cr (ppm)	Ni (ppm)
2	6.30	480	1	156	123
4	7.00	138	4	238	129
6	5.16	137	2	153	81
8	5.50	58	1	166	87
10	6.07	905	0	172	93
12	4.29	159	0	163	57
14	4.30	320	0	132	69

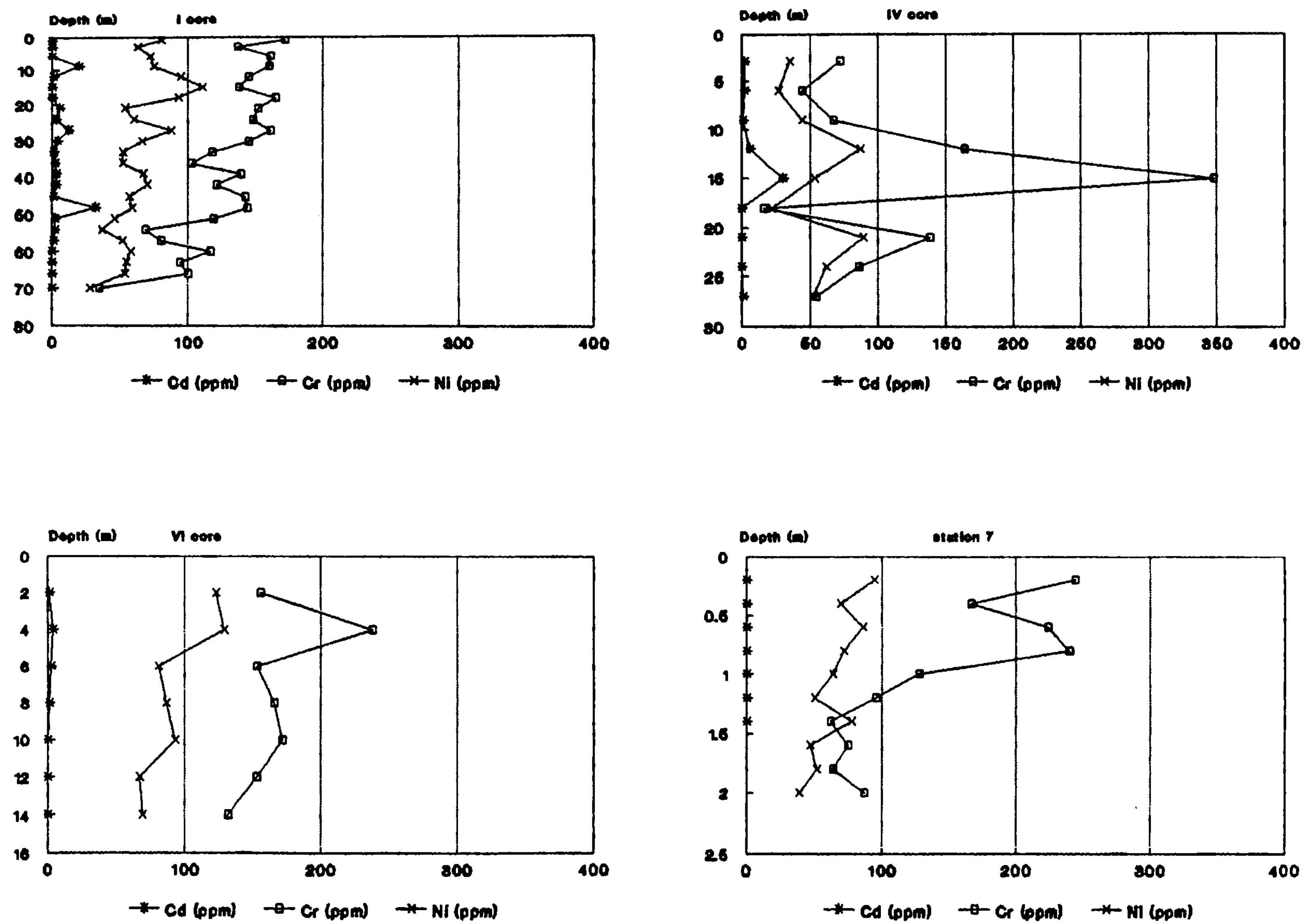


Fig.23 Vertical variation of Cd, Cr, Ni at Cores I,IV,VI and stn.7

are found to be zero, Cr and Ni show higher concentration than the core sediments. All the three elements behave similarly with depth.

The concentration of Cd, Cr and Ni are given in Table 8 and their variations with depth are presented in Fig 23. Most of the sediment samples show very low Cd concentration and about half of the samples register zero Cd content. The top sediments of core I, bottom sediments of core I, IV and VI and all the strand sediments record a zero Cd concentration. Padmalal (1992) has reported an average of 4 ppm for the surficial sediments of Vembanad estuary. Jayasree and Nair (1995) have recorded an average of 5 ppm for the Cochin estuarine sediments. Cd is one of the palaeoclimatic indicators and by measuring Cd along with other parameters like CaCo3 and organic carbon, it has been possible to infer past variations in monsoonal intensity in the Somali basin (Somayajulu, 1990). According to Boyle (1981) cd is an indicator of biological productivity. The abnormally high concentration of Cd ie. 12 and 20 ppm respectively at 27 m and 9 m depth in comparison with the sediments with the other levels in core No. I indicate that biological productivity during late Pleistocene around 30,000 yrs B.P. and mid Holocene around 6000 yrs B.P.was very high. These periods also correspond with the period of eustatic sea level rise. The zero concentration of Cd in all the analysed strand plain sediments indicate least biological productivity in the late Holocene, there by support the semi aridity theory in late holocene.

The average concentration of Cr in all the analysed sediments ie 136 ppm is similar to the values reported by earlier workers for the study area. Padmalal (1992) report an average concentration of 125 ppm in the surficial sediments of Vembanad estuary and Ramachandran (1992) observed an average of 84 ppm for the inner shelf sediments. The regional distribution of Cr in the Arabian sea sediments of Konkan coast show relative enrichment in the inner shelf compared to the outer shelf and deep sea sediments (Satyanarayana and Ramana (1994). The Cr concentration shows a decreasing trend downward in all the cores and strand sediments. Bava (1996) also reported a decreasing trend of Cr with depth in shallow cores from Cochin estuary.

The average concentration of Ni (69 ppm) is found less than the values reported by earlier workers for the surficial sediments of the area. Ramachandran (1992) has reported a high value of 147 ppm for the inner shelf sediments whereas Padmalal (1992) observed 109 ppm Ni concentration for the surficial sediments of Vembanad estuary. Satyanarayana(1994) has reported a relative enrichment of Ni in the inner shelf compared to the outer shelf sediments. In the study area all the cores and strand sediments except core 4 exhibit a definite decreasing downcore trend. However Pandarinath and Narayana (1998) reported a low concentration of Ni (66 ppm,) in the inner shelf sediments of Karnataka coast. The downcore decreasing trend in Ni content is also observed in shallow cores by Ramachandran (1992). The high concentration of Ni and Cr in core IV and VI around 15m and 4m respectively show their close affinity.

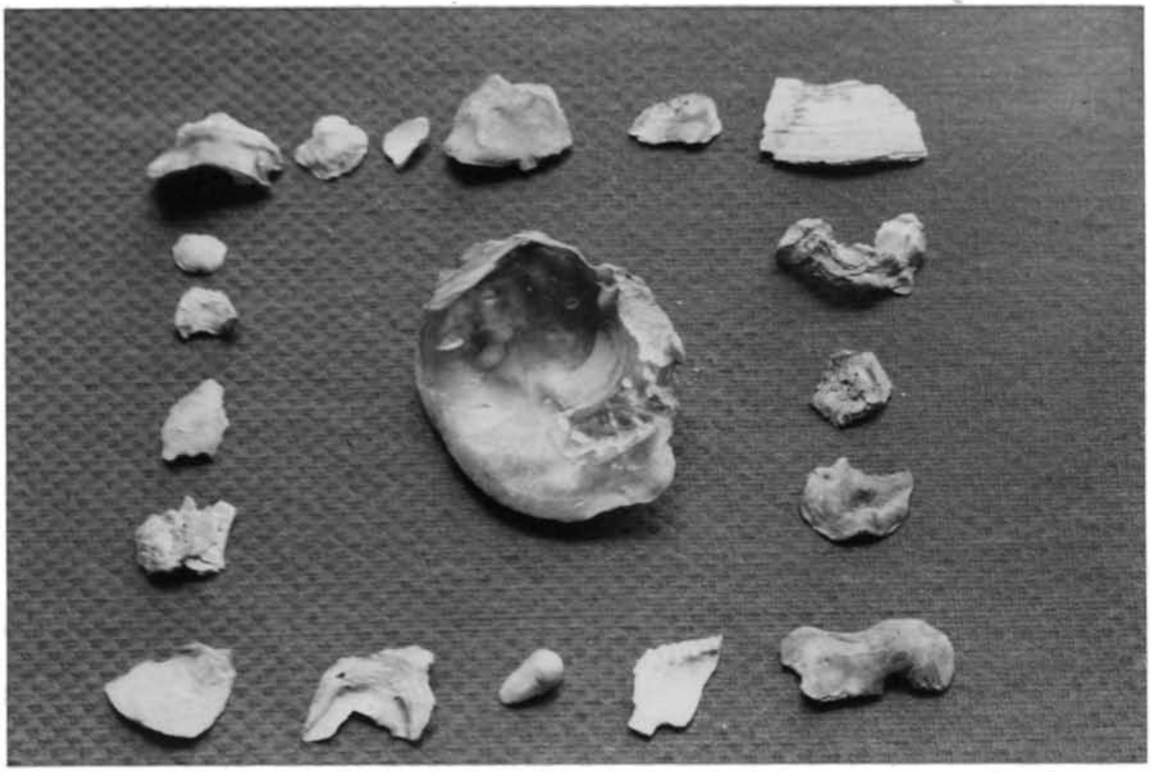


Plate 7 Fossil shells obtained from 10 m depth, Elanvathur, Koleland

4.3 PALAEONTOLOGY

4.3.1. Introduction: The systematic studies on the Quaternary climatic oscillations all over the world indicate that the world sea level has fluctuated in resonance to the advance and retreat of the continental glaciers and these fluctuations were not uniform on a global scale. A major tool used in deciphering the past climates and sealevel variations world over is undoubtedly the palaeontology, especially the micro palaeontology. Various studies such as the variations in the abundance of cold and warm water planktonic foraminifera as well as their coiling directions, variation in $CaCO_3$ content, the oxygen isotopic composition of foraminiferal tests have increased our understanding of the Quaternary climatic events on a global scale (Borole, et al., 1982 and Singh and Srinivasan, 1993).

Preliminary micropalaeontological studies carried out on the core sediments from Cochin area reveals periods of Marine incursions in this area. Sediments at a depth of 7 to 12 m in three cores indicate the presence of benthic feraminiferal assemblages. The assemblage is dominated by ammonia felsa beccarrifollowed by nonionfabum indicating inner shelf enviornment. The ^{14}C evidences from Cochin area (Table 5) indicate that these sediments might have been deposited during early Holocene to Mid-Holocene. All over the world this period is characterised by a high stand of sea level. Therefore the benthic feraminiferal assemblages in Cochin borehole sediments indicate a marine trangressional phase during early Holocene to mid Holocene.

The subsurface sediments collected from Kole land area at 10m depth have yielded a number of moluscan shells (Plate 7).

Percentage variation of foraminiferal tests in core sediments (Table 4.3.2)

Foraminifera Species	Core No. 1 (7 m)	Core No. 3 (9 m)	Core No.2 (12 m)
Ammonia felsabeccarii	21	46	46
Virgulina sp.	0	0	0.7
Elphidium advenum	9	0	0
Anomalina grosserugosa	13.13	13	20
Nonion fabum	36	34	32.8
Cibicides sp.	16	4	0
Ammonia beccarii	4	4	0

Megafossils present in core sediments Core No. 6 depth 10 m

Crasostrea Madrasensis
Crasostrea Cuculate
Donax species
Villorita cyprinides
Barnacle Belanum pinpinabulam
Ostrea forskali
Arca
Barnacle balanas amphitrite
Dosinia species
Martsiaa
Arca
Cardium

The dominant species are Crasostrea Madrasensis, Villorita and arca. The fossils show a changing pattern from intertidal to subtidal affinity. The intertidal forms are mostly seen in the bottom sediments around 10m whereas the top sediments show more subtidal affinity. This is indicative of a transition from trangressional phase to regressional phase as indicated by the changing pattern of megafossils studied.

A high stand of sea level roughly about 2.4 m from the present at about 4700 yrs B.P was suggested by Chen and Liu (1996) based on the study of molluscan shells and sediments in Taiwan Strait. The study of inland coral of the Saurashtra Coast helped Gupta (1972) to infer on the transgression of 30000 and 6000 yrs B.P. Various authors like Borole et al., (1982) Sing and Srinivasan (1993), Bhat (1996), Mishra et al.,(1996) and Maharana (1996) have studied the various aspects of foraminiferal evidences on west coast of India.

4.4 PALYNOLOGY

4.4.1 Introduction: The analysis of fossil pollen assemblages can give inferences on the relative ages of the sediments, vegetational history, climatic changes, sea level changes and even on the cultural development of human beings. Pollen analysis is the dominant method for the investigation of late Quaternary vegetation and climate (Tooley, 1980) and now all over the world, Palynology is an integral part of paleoclimatic studies. It involves the isolation of pollen grains at successive levels in a sediment, their identification and enumeration.

At present there are numerous works on the pollen sequences of mangroves of Holocene period. Some well established mangrove sequences are also known from Pre-Holocene. The pollen sequences from Alliance well, Surinam, described by Wijmstra (1969) provides a record of vegetation changes in response of sea level changes from late Tertiary to present. Van der Hummen (1974) has given a detailed account of relative sea level changes based on a pollen sequence in a 30 m core from Guyana. In India, detailed palynological studies have been carried out from lower Bengal basin (Mukherjee, 1971; Vishnu Mitre and Gupta,1972). Mahanadi Basin and Chilka area, Orissa (Caratini et al., 1980; Gupta and Khandelwal, 1990, Kohli, 1996), Tamil Nadu coast (Tissot, 1987; Farooqui and Sekar, 1998), Bombay (Vishnu Mitre and Guzder, 1973) and Karnataka coast (Tissot, 1990; Yadav et al, 1994).

Even though a lot of palynological work have been carried out on the coastal sedimentaries of tropical areas else where, no such work has been undertaken in Kerala. So the present study is an attempt to have an idea of the late Quaternary palynological changes in relation to sea level changes in the coastal sedimentaries of central Kerala.

4.4.2.Results and Discussion

A number of organic rich sediment layers, mostly sandy silts, are encountered at different depths in the sedimentary column of the coastal area. Two samples from core III at Kaloor (18 & 21m), and three from core I at Cochin backwaters, (39, 63 and 70m) have been analysed for pollen content. From the flood plain area one each from Vellangallur (5m depth) Valloor (5m depth) and another one from Karuvannur (2m depth) have been studied. The result of palynological analysis is given in Table 10.

The sample at 18 m depth in core (III) reveals a higher percentage of mangrove pollen (Rhizophoraceae) and significant percentages of evergreen types (Sapotaceae, Oleaceae). The arboreal pollen like Compretaceae is also present. The sample at 21 m indicates a higher percentage of evergreen pollen, where as the mangrove and arboreal types are completely absent.

The sample at 39 m in the Cochin backwater core (I) indicates higher percentage of evergreen types whereas mangrove pollens are little represented and arboreal pollen types are completely absent. The majority types at 63 m depth in the same core are evergreen but arboreal types are also present. The same feature is observed at 70 m depth also.

The flood plain peaty samples at Valloor and Vellangallur (5 m depth) show almost similar pattern of pollen content with high percentage of mangrove pollen and minor amount of herbaceous and arboreal pollen. The Karuvannur flood plain sample also (2 m depth) shows almost equal representation of herbaceous, mangrove and arboreal pollen.

The general absence of mangrove pollen in the bottom samples of Kaloor and Cochin backwater cores can be explained as a result of the regression of the sea from the area. Therefore the deeper core samples at 39, 63 and 70 m are generally devoid of mangroves but, are abundant in fresh water pollens. This, along with the coarser texture of the sediments indicates that the sediments were deposited in a fresh water environment. The available radio carbon dates (ie 30000 yrs B.P. at 24 m, 40000

Table 10
Palynological analysis of core samples

Pollen Taxa	Percentage of pollen				
Core No. and Depth (m)	Kaloor (3) 18	Kaloor(3) 21	Cochin Backwater(1) 39	Cochin Backwater(1) 63	Cochin Backwater(1) 70
Rhizophoraceae	42		8		
Ilex	8				20
Sopotaceae	12	46	48		10
Comprataceae	18			10	
Anacardiaceae		8	12		
Allophyllus	6				
Oleaceae	8			24	
Rubiaceae		12			
Myristiaceae		10			
Euphorbiaceae			10		
Poaceae				42	
Cyperaceae				8	30
Tiliaceae				6	
Meliaceae					16
unidentified	6	24	22	10	14

Palynological analysis of flood plain samples

Pollen taxa	Percentage of pollen		
Depth	Valloor 5	Vellangallur 5	Karuvannur 2
Rhizophoraceas	60	62	22
Poaceae	6	6	22
Arcaceae	6		14
Myristicaceae			8
Cyperaceae			8
Euphorbiaceae		6	6
Combretaceae		6	6
Meliaceae	6	6	
Moraceae	11		
Unidentified	11	12	12

yrs B.P. at 39m) indicate that the sediments have been deposited prior to 40000 yrs B.P. Kumaran et al. (1995) has observed that Warkalli formation have yielded mainly freshwater pollen which indicates warm humid climate with heavy rainfall during the deposition. Therefore sediments at these depths can be assinged a Mio-Pliocene age.

Eventhough mangrove vegetation is absent at 21 m depth it is abundantly present at 18 m depth in the on land Kaloor core. The sediments at 18 m depth have yielded a ^{14}C date of around 25000 yrs B.P. Kohli (1996) has stated that the period between 40000 and 21000 yrs B.P. represents reappearance of mangrove vegetation and this may be due to the frequent marine incursion. Lin et al., (1989) also identified a transgressive phase during this period. Further Gupta (1972) has reported a marine trangressive phase at about 30000 yrs B.P. for the west coast of India. So based on the above inferences and evidences, trangressive phase is suggested for central Kerala coast at about 25000 yrs B.P.

The peat samples from inland flood plain area like Valloor and Vellangallur at 5 m depth have indicated the abundance of rhizophoracea type and the sample at Valloor has been ^{14}C dated to around 5000 yrs B.P. Vellangallur lies at about 10 km whereas Vallor is located 20 km from the present coast. In both the sites, the mangrove rich peat layers are overlined either by a sand or silt bed. Tissot (1990) has reported the abundant presence of mangrove vegetation for a 4.75 m profile datable to 6000 yrs B.P at Coondapur, Karnataka which lies about 7 km inland. The presence of mangrove vegetation far inland from the present day coast at about 6000 - 5000 yrs B.P can be explained as a result of shifting of mangroves vegetation inland in consonance with the early Holocene trangression which culminated at around 6000 yrs B.P. The occurrence of herbaceous and mangrove vegetations in almost equal proportions at a depth of 2 m in Kavuvannur area, which is situated about 15 km inland from the present coast, is suggestive of the gradual decline of mangrove vegetation after 5000 yrs B.P. Van Compo (1986) assigned the decline of mangrove vegetation after 6000 yrs B.P. in offshore Cochin to the biotic influence. The higher representation of mangrove pollen in subsurface sediments of flood plains of the study area is indicative of a relatively humid climate in the early to mid Holocene times.

CHAPTER 5

5 ARCHAEOLOGICAL AND HISTORICAL STUDIES

5.1 Introduction: Geoarchaeological studies are of immense help in reconstructing the evolutionary history of an area during the late Quaternary period. In the past few decades numerous studies have been carried out on the coastal and offshore sites to ascertain the archaeology and palaeogeography of such sites (Jardine and Morrison, 1976; Chappel, 1982; and Delano 1976). Since no dating either ^{14}C or TL could be made from the Palaeo - beach ridges, the support from archaeological investigations have been taken into account to unravel the regressive phase of the sea. The study area, particularly the Kodungallur region engrave lots of archaeological information.

The first Geoarchaeological study in India was carried out by Robert Bruce Foot (1863). De Terra (1939) carried out an integrated study in the river terrains of Narmada valley and in the terraces of Kortalayar river in Madras coast. A number of workers later on carried out extensive studies on the prehistoric remains in various parts of Peninsular India. Some important work in the recent time are done by Gardner (1986) in Tamil Nadu, Pappu (1974) in Maharashtra, and Kale and Rajaguru (1983) in Konkan.

However, very few such studies have been carried in the Kerala region. The prehistoric and paleoenvironment of the region was studied by Rajendran (1984). He has carried out extensive studies on paleolithic and mesolithic industries of Kerala and was able to reconstruct the cultural sequences and paleoenvironment of paleolithic and mesolithic industries. Besides this, a number of workers have also studied on various archaeological materials mainly the megalithic remains from different parts of the state (Sathyamurthy, 1992).

5.2. Results

Extensive field works have been done in the study area in order to locate archaeological remains. Conducting archaeological exploration in the study area has been very difficult as the terrain was highly populated and cultivated. However, the exploration in the study area has resulted in the finding of mesolithic, neolithic, megalithic and early historical remains. A total number of 18 archaeological sites have been discovered out of which only one belongs to mesolithic, 2 neolithic, 13 megalithic and 2 to early historic period.

Mesolithic period: Microlithic tools are found in a place called Thevakkal, about 15 km north east of Ernakulam. Here four points,three flakes and one core are found in a lateritic soil cover. The presence of flakes along with the core shows that this was a stone age factory site. The tools are made of quartz (Plate 8) which is abundantly available in the site in the form of veins in laterite country rock. The site is situated near a water locked paddy field which would have been a palaeochannel of river Periyar.

Neolithic period: Neolithic tools are discovered from two sites in the study area. They are Aduvassery and Elavoor,respectively about 15 and 20 km north west of Alwaye. At Aduvassery, a neolithic celt (Plate 8) is found in a lateritic terrain adjoining an extensive river terrace of Periyar while at Elavoor, three celts are spotted in the present Chalakkudy river channel. All the four tools are made of granite. The location of the sites indicates that neolithic people might have used the fertile land adjoining the river beds for cultivation.

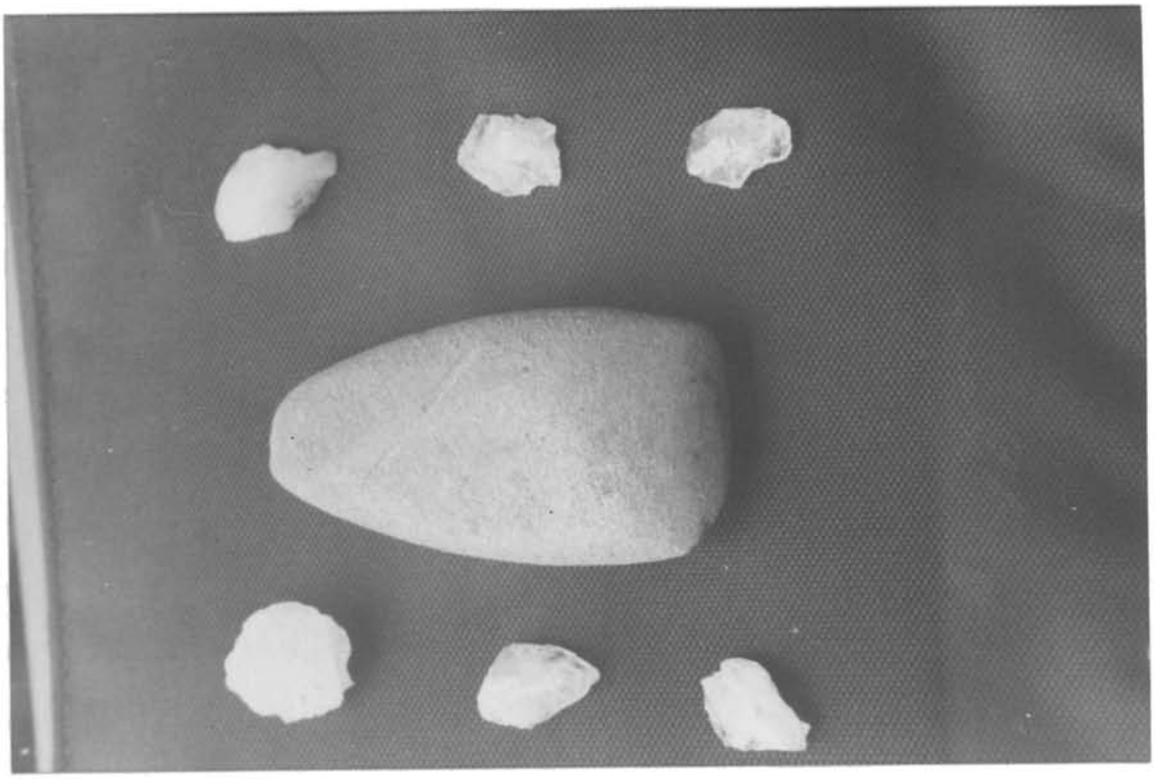


Plate 8 Mesolithic flakes and neolithic celt from Kalamassery and Elavoor respectively

Plate 9 Megalithic burial Jar, Kunnukara

Megalithic period (iron age): Hundreds of megalithic urn burials (Plate 9) are found in the study area (Fig. 3). Most of the megalithic remains are currently being destroyed by the people as most of the lands are brought under either for cultivation or used for house building. The important sites in the mid land regions are Kalamassery, Alwaye, Aduvassery, Chengamanad, Kurumassery, Kunnukara, Puthenchira and Pullut. A number of sites are also found in the coastal region between Kodungallor and Chavakkad. The prominent sites are Perinjanam, Acheswaram, Chendrappinni,Thriprayar and Engandiyur. Unlike the midland sites, coastal sites have yielded more number of urn burials. Details of few important sites and their findings are given below.

a) **Kalamassery**: Kalamassery is about 12 km north east of Ernakulam and the site is situated within the Cochin University campus (Plate 10). The site is unearthed while building operation. Archaeological remains have been found one meter below surface level in a laterite slope overlooking a water-logged paddy field. A total of twelve buried jars are found in the site. The megalithic burials here are composed of a medium sized burial jars containing associated pottery, iron implements and disintegrated bones and the jars are capped with laterite block or with a pottery lid. The jars are hand made red ware pottery, ranging in size from 50 to 80 cm in height and 40-60 cm in diameter. The associated pottery include bowls, pots, dishes, vases and cups, they are all wheel made and are essentially of black and red ware type. The burials have also yielded some disintegrated bones.

Plate 10 Megalithic site , Kalamassery

Plate 11 Megalithic bowl and rim of burial Jar, Kunnukara and Chendrappinni

b) **Chendrappinni:** Chendrappinni is 15 km north of Kodungallur. The site is situated 500 m east of NH 17, on a prominent palaeobeach ridge overlooking a swale and the Pullut channel is on the eastern side. While digging for a pipe line on the side of Chetuva-Perinjanam road the site is said to have yielded hundreds of urn burials aligned in a linear fashion . However, the author could find only ten burials either in full or broken. The megaliths in this area comprise of burial jars containing black and red ware pottery (Plate 11) and iron tools, they are covered with either laterite cap stone or pottery lid. The jars are 0.75 - 1 m in height and 0.60-1 m in diameter and conical in shape. These jars are found at a depth of 0.5 - 1.0 m below the surface. In one instance, the jar is found covered with semispherical laterite cap stone while all other jars are found covered with pottery lid. The occurrence of laterite cap stone within the beach ridges is significant as no laterite exposure is found in the area. The nearest laterite exposure is in the mid land region to the east of Pullut channel.

c) **Engandiyur:** It is situated about 25 Km north of Kodungallur. Megalithic burials are found on both the sides of Chetuva-Perinjanam road. According to the local people, hundreds of burials are found in this area. The maximum concentration of burials are noticed in a 200 m wide and 500 m long area near the Catholic Church, Engadiyur. However, the author could find only broken pieces of 10 burial jars. The jars are found 0.5 to 1 m below the ground level and covered with pottery lid. The significant feature of the site is the occurrence of russet coated painted pottery (Andra ware) which is an early historic cultural trait of Peninsular India. The russet coated painted pots have been recovered by local people and are now exhibited in the Thrissur museum.

Early historical period: Archaeological remains, supposedly of early historic period, were recovered by the author from two sites in the coastal area near Paravur . A well preserved terra-cotta ring well was found at a depth of 1 m from the surface, in Kottuvally village about 5 km SW of Paravur (Plate 12). The ring well was made up of 70 cm in diameter ,4 cm thick and 2 m deep. This site lies just 500 m west of Valluvally, the famous Roman coin hoard site. Discovery of Roman coins from Valluvally was made by some labourers while sand quarrying in the area during september 1983. The coins were found buried inside a pot and according to local public, the hoard may exceed one thousand coins. Most of the coins in this hoard were mint-fresh with legible inscriptions and it is an index to Roman gold coinage found in Kerala. The obverse side of a Roman gold coin is shown in plate 13.

Early historical objects like pot sherds and bricks are noticed on an elevated place called Pattanam, situated about 2 km NW of Paravur and 8 km SW of Kodungallur. Three glass beads and one agate bead also were recovered from this site (Plate 14). The most significant finding is a potsherd obtained from a depth of 0.70 m, which Dr.Selvakumar, Dept. of Archaeology , Deccan college post graduate Research Institute, Pune has identified as a piece of an amphorae (personal communication). The other significant feature is the presence of large sized pot sherds, probably of megalithic affinity.

Plate 12 Terracotta ring well (Early Historical Period), Kottuvally

Plate 13 Roman gold coin (Early Historical Period),Valluvally

Plate 14 Piece of amphorae ? (top left) pottery and beads (Early Historical Period), Pattanam, north west of Paravoor

5.3. **Discussion**

One of the research objectives of geoarchaeology is to reconstruct the land scape that existed around a site or group of sites at the time of occupation. The changing sea levels, during the late Quaternary have dramatically affected the distribution and preservation of sites of early coastal adapted people and the evolution of these land scapes has affected the loci of human activity. A reconstruction of the original relationship between settlements and coastal geography is often necessary starting point for any adequate interpretation of their economy and form. Geoarchaeological investigation in the study area revealed the existence of various archaeological cultures and the geographical distribution of these cultural remains can be effectively used to study the land form evolution in the past.

The earliest archaeological remains obtained from the study area are the microlithic tools obtained from a site called Thevakkal. The beginning of mesolithic culture in India has been dated to 8000 yrs B.P. and the mesolithic cultural phase in Kerala has been dated to around 5000 yrs B.P. (Rajendran, 1984) which indicate a late mesolithic habitation. The period of neolithic occupation in Kerala is uncertain, as no sites has been reported in a stratigraphical context. It has observed that neolithic cultural phase in India can be assigned a time span of around 2350 to 1200 B.C. Therefore, the mesolithic and neolithic cultural phase might have existed from 5000 to 3000 yrs B.P. in the coastal region. Eventhough, no generalization is possible on the basis of the limited number of tools recovered from the study area and also in the absence of stratigraphic context, the mesolithic and neolithic phase can be dated to the above time span in the study area. The absence of mesolithic and neolithic implements in the coastal area indicate that man inhabited only in the mid land region of the study area during this period.

The extensive occurrence of megalithic iron age cultural remains through out study area and their particular concentrations in the inner most strand plains is very significant. Megaliths in India, particularly in Peninsular India, include a variety of sepulchral and commemorative monuments which are either built of large stones or else associated with a some what homogenous group of black and red ware pottery. By and large, they are collective burials in which post exposure bones of more than one person are found buried. ^{14}C dates place the megalithic cultures of India between 1000 B.C and 1000 A.D. However, the period of their maximum popularity appears to be between 600 B.C.-100 A.D. The urn burials are the most common variety of megalithic burials found in Kerala, especially in coastal regions. In Kerala, only two ^{14}C dates are available for urn burials at Mangadu from Kollam Dt., and they show an age of 2890 ± 70 and 2850 ± 90 yrs B.P. (Sathyamurthy 1992). On the basis of typological studies of the excavated materials, the urn burials of Porkalam are dated to a period from 300 B.C. to 100 A.D. So the time span of Kerala's megalithic culture can be assigned at 900 B.C to 100 A.D.

The absence of stone age sites and the presence of vast numbers of megaliths in the interior strand plain areas are clear evidences of a migration of human settlements towards the coastal plains as the sea started receding. Mathai and Nair (1988) observed a periodic cyclicity in the emergence of landscape. The presence of early historical remains in the coastal plains where megalithism are once flourished indicate a gradual cultural development from the primitive megalithism to a settled early historical cultures.

The accounts of classical writers of Greece and Rome contain reference to Kerala. Some of these writers are Megasthenes, Pliny, and the author of the Periplus of Erythrean Sea, Ptolemy and Cosmos Indicopleustus. Most of these references give accounts of shipping routes to various ports on Malabar coast like Muziris, Tyndis, Barrace and about the export and import items. All these references indicate that Muziris was a chief port on the west coast of India and the geographical account given by these authors help us to identify that a port was situated near the Periyar river mouth in Kodungallur area. Kodungallur or Cranganore was variously called as Muziris, Muchiri, Mahodayapuram, Mahadevapattanam, Makotaipattanam, Muyirikodum Tiruvanchikulam etc. in the earlier periods. The author of the Periplus speaks in admiring terms of the chief Malabar ports of Muziris (Cranganore) and Barace (Porakkadu).

The Tamil sangam literature of early Christian centuries also give a good account of the port of Muziris. In Ahananuru, it was mentioned that the Yavanas sailed into the Muziris located at the mouth of the Periyar river, Kerala ... with gold and sailed off with pepper. Another sangam text of first century AD also mention that pepper were exchanged for gold with the visitors arrived at Muziris by ship. The Chera King Kuttuvan presented to the visitors the rare product of the sea and mountains.

The fact that cultural remains of early historical period have only found in the coastal areas around Paravur, is highly significant in the context of location of the famous ancient Port "Muziris". It was mentioned earlier that the classical accounts of the writers of ancient Greece and Rome and also the Sangam literature give vivid description of this port city. In the light of available evidences in the form of early historical archaeological remains from the sites around Paravur, it can be rightly pointed out that the location of ancient Muziris might be some where in the south east of Periyar river to present Paravur town . The absence of stone age, megalithic and early historical sites in a 3 km wide stretch in the nearshore coastal area indicate the recent emergence of the coastal land scape in central Kerala region.

CHAPTER 6

SUMMARY AND CONCLUSIONS

The study deals with Quaternary sediments and sea level changes of the central Kerala region. The geomorphological landforms of the central coastal region and grain size parameters of the kole land of northern region, strand plain sedimnets of the Kodungallur region and deep borehole samples of the Ernakulam region have been studied. The sea level variation during the late Quaternary period have been studied with the aid of 14C dates, geochemistry, palaeontology, palynology, lithologic variations and archaeological signature.

In the coastal region several land forms have been identified, which show affinity to sea level variation in the study area. The innermost palaeo-coast line is delineted based on the nature of spacial relationship between laterites and alluvium. In the northern part of the study area the coastal plain extends up to 8-10km, whereas in the Kodungallur region it ranges from 6-8km. In the Ernakulam region the coastal plain extends still interior at about 8-12km. It is observed that unlike the present coast, the paleo coastline was highly irregular. Between the paleo coast and the present day beach several linear sand ridges are found aligned parellel to the present day shore line. These ridges are intervened by swales of varying width. The beach ridges range in height from 2-6m and the ridges slope westwards indicating that they are formed during regressive phase of the sea. On the other hand, the beach ridges east of Pullut channel would have formed during transgressive phase. Maximum sea level rise to the tune of about 6m can be proposed for the study area.

The texural studies of Kodungallur region show the medium sand grade predominates followed by fine grained sands. In general, the grain size become coarser with depth in the strand plain. The standard deviation values indicate that the majority of sediments are moderately well sorted followed by moderate sorting. Sorting improves with decrease in grain size. Nearsymmetrical skewness predominates whereas coarsely skewed and finely skewed samples show a subordinate nature. The kurtosis indicates that the platykurtic,mesokurtic and leptokurtic are more or less equally distributed. The mean grain size decreases towards inland and it is due to eolian activity prevailing in the coastal region.

The deep bore hole samples in the Ernakulam region reveal four lithologic units namely, 1) a sandy unit, 2) a silty or muddy unit which is interbedded with a secondary lateritic sediments (unit 3) at different levels and a thick sandy unit at the bottom. The top three units are of late Quaternary, whereas the bottom sandy unit might be of an earlier period, possibly the Mio-Pliocene. The secondary lateritic unit can be correlated with last glacial period and would have been formed between 20000 and 12000 yrs B.P. In accordance with variation in lithology, the grain size parameters vary widely in the bore hole samples.

The sea level variations have been studied with the help of 14C dates. Four dates have been obtained in the deep borehole samples. Samples of Ernakulam region show ages from 25000 to 40000 yrs B.P. In Kodungallur region,the 14C dates indicate that the sediments are of Holocene period. The northern part of the study area also indicate that sediments are also of Holocene period. The occurence of peat beds with abundant mangrove pollen in the inland region, such as Vallor which is located 20km inland and Vellangallur (10km inland) indicate a high sea level during early Holocene. When the sea retreated the mangroves were destroyed. The geochemical study of the sediments, indicates that Fe,Mn are in a higher concentration in the lateritic horizon at a depth of 21m. The higher Fe content at this depth indicate indirectly an arid climate. The organic content at this depth is very low. The high contents of Fe,Mn and Cr in the strand plain sediments at depths of 0.6m coincide with ferricrete concentration. A late Holocene aridity is supported by the above evidence.

The abundant mangrove pollens (Rhizophoraceae) at a depth of 18m and evergreen type at a depth of 21m in core III indicate a high sea level and fresh water conditions respectively. Similarly in core I evergreen types of pollen are found at 39m, 63m and 70m depth in Cochin backwater core. Evergreen types predominates even at a depth of 70m. A general absense of mangrove pollen in the bottom samples of Kaloor and Cochin backwaters indicate that the sediments are of fresh water origin.A marine condition in the early-middle Holocene is also supported by the benthic foraminiferal assemblages. The fossil shell of the kole land region support a change from intertidal to sub-tidal regime in the early to middle Holocene.

The archeological remains, indicate a systematic variation across the coast. Microlithic tools are found in the primary lateritic region. Neolithic tools are found adjoining to the river terraces in the near coastal areas. In the strand plain sediment, evidences of megalithic cultures are found abundantly. The remains includes urn burials containing associated pottery,iron implements etc.The urns are capped with lateritic blocks or with . pottery lids. The magalithic cultures are mainly concentrated in the eastern part of strand plain region. The well preserved terracotta ring well, pottery and coins (Roman) belong to early historical period are some ofthe evidences found. Kodungallur, once a prominent port city is now situated about 5 kms inland. These clearly support that as the sea retreats, human cultures also advance towards coast. The available archaeological evidences point out that the location of ancient Muziris near to the present day Paravur.

The general sea level picture derived from the study indicate marine regression prior to 30000 yrs B.P. and 25000-15000 yrs B.P. Indications of marine transgression are noticed around 30000-25000 yrs B.P. and after 10000 yrs. Evidence for higher sea level during mid Holocene is also observed. A late Pleistocene and late Holocene climatic shift towards arid conditions is also noticed.

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