TEXTURE, MINERALOGY AND GEOCHEMISTRY OF SEDIMENTS FROM THE COASTAL PLAINS BETWEEN KODUNGALLUR AND CHELLANAM, CENTRAL KERALA, INDIA

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CERTIFICATE

I certify that the thesis entitled **"Texture, Mineralogy and Geochemistry of Sediments from the Coastal Plains between Kodungallur and Chellanam, Central Kerala, India"** has been prepared by Mr. R.V. Rajan under my supervision and guidance in partial fulfilment of the requirements for the degree of Doctor of Philosophy and no part thereof has been submitted for any other degree.

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Preface

Coastal regions are ever dynamic and change over space and time. These changes may range from a fewer minutes to longer centuries and from a few meters to larger area, even worldwide. Hardly, these changes are continuous and constant. Inconsistency as observed in these changes, both in space and spell, is functioned at the influence of various factors like the types of shoreline (rocky, sandy or bay), nature of oceanic or sea waves that pass by the coast, variations in tides, nature and strength of storms, changes in sea levels and finally the anthropologic activities.

Changes occurring along the coast receive prime importance in total planning and development of the present world. About sixty percent of world population lives on coastal plains, which covers only eighteen percentage of the whole land mass. This gives a huge number as far as the density of population is considered. The coastal plains yield 18.33 % of the primary production of which marine fishing contributes around 95% of the coastal economic activities.

In India, the coastline extends to about 7,500 km of which the mainland accounts for 5,400 km. Lakshadweep coast extends to 132 km and Andaman and Nicobar islands have a coastline of about 1,900 km. Nearly 250 million people live within a distance of 60 km from the coast. Since major Indian cities lie on coastal plain, it is estimated that more population in India would move into coastal plains in this century. And therefore proper understanding of the spatial and temporal behaviors of the coast forms essential in the developmental agenda of the country.

The State of Kerala enjoys a coastline of 560 kilometers long. Like any other coast it is compound in nature and exhibits dynamic changes throughout space and time. Other than the natural pressures that activate this dynamism, the coast of Kerala experiences an intensive anthropogenic pressure in the form of colonization and economic activities. The later has doomed down the coastal ecosystems.

The coastal zone of Kerala is endowed with a very wide range of ecosystems like mangroves, coral reefs, sea grasses, salt marshes, sand dunes, estuaries, lagoons, etc., which are characterized by distinct biotic and abiotic processes. Recent developmental activities in the coastal area adversely affect the natural coastal ecosystems and natural coastal dynamism.

Sedimentological studies were carried out along the western coast especially on several aspects of surface sediments, attempts on the vertical variation of the sedimentary characteristics of the beach ridges and the intervening swales are meagre. Hence a research programme has been drawn up to account the salient sedimentological mineralogical and geochemical aspects of the coastal plain sediments in respect of the beach ridges, alluvial plains, mangroves, intertidal mudflats and swales of central Kerala region, between Kodungallur in the north and Chellanam in the south. The findings are presented in six chapters formatted to address the aim of this research.

Following introduction to the problem and study area, the first Chapter highlights the objectives of the study. In addition, geology and geomorphology of the study area and the hinterland have also been presented.

The methods employed in the study, consisting of fieldwork, sampling, laboratory investigation and computation of data are presented in the second Chapter.

The third Chapter deals with the results of the granulometric analysis carried out on the sediments. The various textural attributes and grain size parameters have been presented and their variation with regard to depth has been discussed.

The fourth Chapter deals with the mineralogical aspects of the coastal plain sediments. The results of heavy mineral analysis of the beach sediments, and the lateral and down core variations in the heavy mineral content have been discussed. The variations in the XRD analysis of the samples collected from various environments along the study area have also been presented.

Geochemical analysis have been carried out on some selected coastal plain - from swales, intertidal mudflats, mangroves and alluvial environments to understand the geochemical variations with respective to depth and are discussed in the Fifth chapter.

The Sixth chapter is devoted to summary and conclusions based on the above results. The references cited are alphabetized at the end of the thesis.

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CHAPTER 1

GENERAL INTRODUCTION

1.1 Introduction

The coastline of India has been undergoing physical change throughout the geological time. Although the last tectonic phase in the Indian Peninsula has been one of general emergence, the present coastal geomorphology of India has evolved largely in the background of the post-glacial transgression over the pre-existing topography of the offshore, shore and coastal zones. The Holocene sea level fluctuated in the course of the last 6,000 years and the marked regression is indicated between 3,000 and 5,000 yrs B.P.

Kerala coast is generally described as a submergent coast though Bekal and Paiyambalam at Kasaragod, Dharmadam and Azhikode at Kannur, and Varkala at Kollam have been assigned as emergent coasts. Lateritic cliffs, rocky promontories, offshore stalks, long beaches, estuaries, lagoons, spits and bars are characteristics of Kerala coast. The sand ridges, extensive lagoons and barrier islands are indicative of a dynamic coast with transgression and regression in the recent geological past. The central Kerala coast around Kochi is of recent origin. There are about 700 land-locked islands (including barrier islands) in Kerala. Though there are 41 rivers bringing enormous quantity of sediments, deltas are not formed due to the high wave energy condition of the coast. However, Narayana et al. (2001) have identified a small palaeo-delta near the mouth of Periyar river. The Vembanad is one of the largest estuarine systems in the country.

Coastal and near shore sediments have been studied over the past few decades by several researchers on various aspects, such as sea level changes, sedimentation, neotectonics, coastal geomorphology, and paleo-environment in off-shore and on-shore areas and rivers basins .The sedimentological, micropaleontological, stable isotope, radiometric and calcium carbonate records in ocean sediments provide the best evidence of rapid climatic and sea level changes during the Late Quaternary period (Chappell, 1947; Fairbanks, 1989; Charles et al., 1996; Naidu and Malmgren, 1999; Thamban et. al., 2001).

Over the years advanced sedimentological studies using modern techniques have evolved, especially in applying it to the sedimentation aspects of beaches and river networks. Morphodynamic processes that occur in response to changes in external conditions guide the coastal evolution (Stanley et al., 1972; Wright and Thom, 1977). The Holocene lake level and the role of paleowinds in the geomorphic expression, the shoreline and beach architecture and the role of lake-level variation in the development of beach ridges along southern Michigan area have been studied by Thompson et al. (2004), Johnson et al. (2002) and Thompson (1992), respectively. Larsen (1994) emphasizes the role of isostasy in the uplift of the coastal region and the usefulness of beach ridges in monitoring the isostatic changes. The origin of the beach ridges have been studied by many workers who emphasize the action of wind and the winnowing effect of the sea wave in their formation (Fox et al., 1966; Fraser et al., 1991; Komar, 1998). The consequences of fluctuations in boundary conditions, which produce event beds that ultimately form lithofacies units (Swift et al., 1991). Exogenous inputs from the environment, which comprises climatic and geological controls, are responsible for the geographic variation among coasts (Davies, 1980). The criteria for recognizing the transgressive and post-transgressive sand ridges have been discussed for the New Jersey continental shelf area (Stubblefield et al., 1984).

In India the first major attempt to study the coastal and near shore sediments of India was made by the Andhra University, under the guidance of La Fond in 1952. The study of upper Quaternary sea level record along the east coast of India gathered momentum since 1970 (Meijerink, 1971; Prudhvi Raju and Vaidyanadhan, 1978; Sambasiva Roa and Vaidyanadhan, 1979; Bruckner, 1988, 1989; Loveson and Rajamanickam, 1987; Banerjee, 1993;

Banerjee et al. 1997; Vaz and Banerjee, 1997). Ahmad's (1972) was the first book on coastal geomorphology of India, which contains data collected from large-scale maps, and inferences on the nature of the coasts based on such data. Near shore sediments especially on the mineralogical regimes off Mangalore (Siddiquie and Mallik, 1972; Mallik, 1972) and off Ratnagiri (Rajamanickam et.al., 1986; Rajamanickam and Gujar, 1984) are available. Thamban et.al. (2001) have studied the fluctuations in hydrography along the southwestern continental margin of India. Rao et al. (1996) studied the neotectonic activity and sea level changes during Late Quaternary, along the western continental margin. Banerjee (2000) identified Late Pleistocene-Holocene sea level high stands (+4 m) in the Rameswaram –Tuticorin sector and Godavari deltaic region of east coast of India. Kale and Rajaguru (1985) and Hashimi et al. (1995) used estimated and inferred ages and constructed sea level curves for the Late Quaternary for the western continental margin of India. Available information on the Quaternary sea level changes along the Indian coasts has been summarised by Merh(1992). An account of Quaternary sea level and its impact on shoreline displacement and coastal environment can be found in Rajamanickam (1990) and Rajamanickam and Tooley (2001). The works by Wagle et.al., (1994), Subrahmanya (1996) and Pandarinath et al. (2001) provide additional information of sea level changes. The Gujarat and Sourashtra coasts, which according to Pant and Juial (1993), is an ideal location to demonstrate both eustatic and tectonic features. Coastal landforms are strongly affected by sea level changes and tectonism. Paleo-shore lines have been identified as narrow (white) bands, running parallel to the coast of Saurashtra, Gujarat by Baskaran et al. (1987).

On the west coast, Tipper (1914) carried out the first studies on the beach sands of Kerala. Viswanathan (1949) studied the beach sands for the economic importance of titanium bearing minerals. According to Mathai and Nair (1988), the present coastal landscape in Central Kerala is the combined result of sea level fluctuations and various fluvio-marine processes during the recent geological past. Sabu and Thrivikramaji (2002) emphasizes that the evolution of coastal plains and their environments of Kerala are controlled by marine transgression and regression during the Tertiary time.

The coastal plain sediments of Kerala received little attention on the variation of down core sedimentological and geochemical aspects. It is in this context present work has been undertaken in the study area, i.e., the coastal tract between Kodungallur in north and Chellanam in south (Fig1.1), with the following objectives.

1. To document the variation in texture with depth of the coastal plain sediments.
2. To study the mineralogical variation (heavy and clay minerals) of sediments.
3. To investigate the geochemical distribution of major and trace elements and organic carbon of the sediments.

1.2 Geology and Geomorphology of Central Kerala

The Kerala region is an important segment of the South Indian Precambrian terrain bounded by the Western Ghats on the east and Arabian Sea on the west. The area is mainly covered by four major rock units (Fig. 1.2). They are (i) Precambrian crystalline rocks - which include charnockites, garnet biotite gneisses, hornblende gneisses, and other unclassified gneisses, which occupy a considerable area of Kerala. (ii) Tertiary sedimentary rocks, which unconformably overlie the Precambrians, which extend as a narrow belt along the major part of Kerala coast, comprise continental (Warkalli beds) and marine (Quilon beds) facies. The continental facies is made of carbonaceous clays with lignite/ coal seams, china clays and friable sandstones and the marine facies is composed of sandstones and carbonaceous clays with thin bands of fossiliferous limestones (Poulose and Narayanaswami, 1968) (iii) Laterites, the third major litho-unit covering about 60 % of the surface of Kerala and (iv) Recent to sub recent sediments, which extends from Kasaragod in the north to Kanyakumari in the south, which

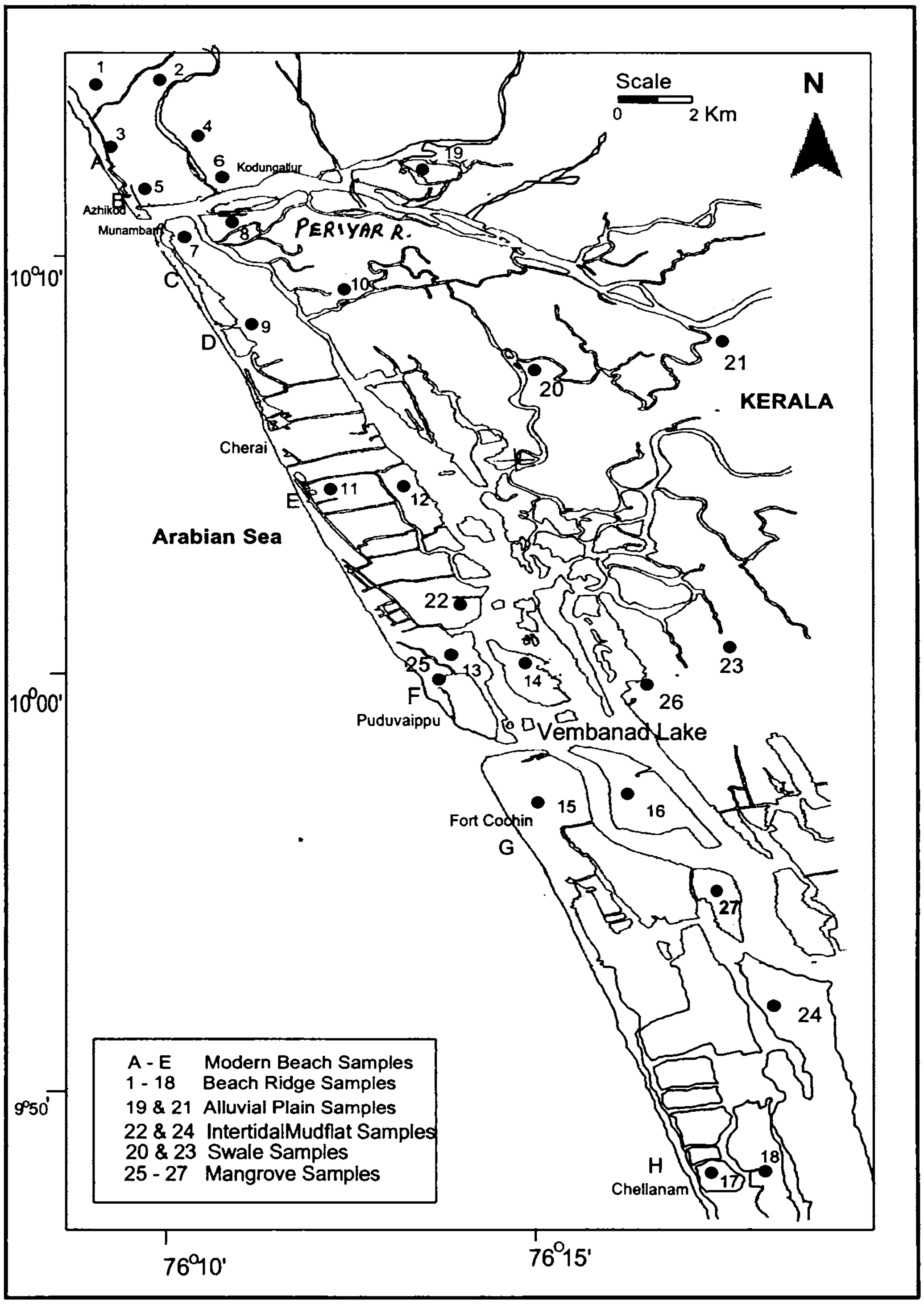

Fig 1.1 Study area and sampling locations

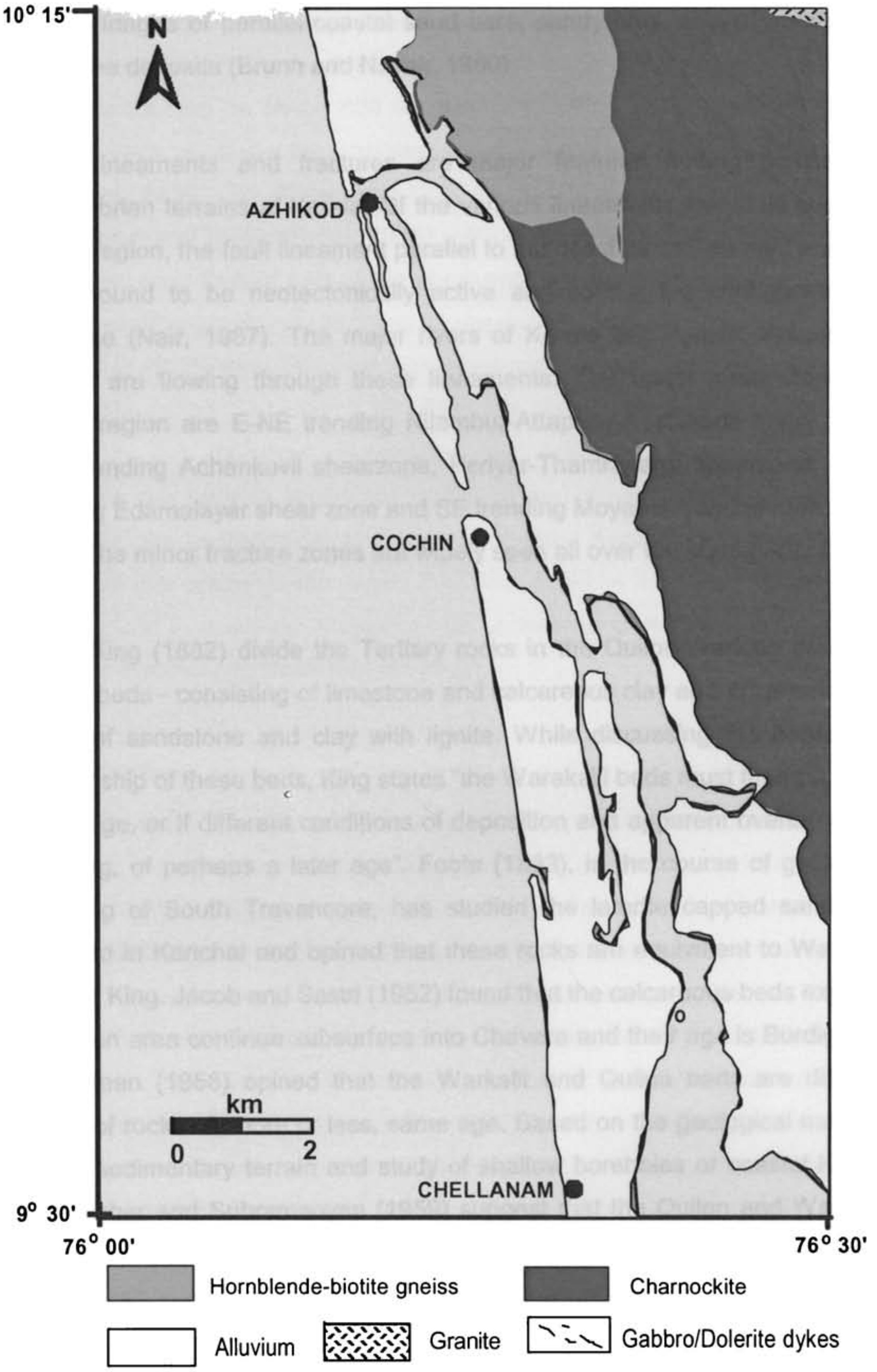

Fig 1.2. Geological map of the study area (compiled after GSI, 1995)

include fringes of parallel coastal sand bars, sandy flats, alluvial sands and lacustrine deposits (Brunn and Nayak, 1980).

Lineaments and fractures are major features cutting across the Precambrian terrains of Kerala. Of the various lineaments identified over the Kerala region, the fault lineament parallel to the coast as well as right angle to it are found to be neotectonically active and control the configuration of shoreline (Nair, 1987). The major rivers of Kerala like Periyar, Achankovil, Pamba are flowing through these lineaments. The major shear zones of Kerala region are E-NE trending Nilambur-Attapady-Kozhikode shear zone, E-W trending Achankovil shearzone, Periyar-Thamraparni shearzone, NNW trending Edamalayar shear zone and SE trending Moyar-Bavali-Mercara shear zone. The minor fracture zones are widely seen all over the state (GSI, 1995).

King (1882) divide the Tertiary rocks in the Quilon-Warkala area into Quilon beds - consisting of limestone and calcareous clay and Warakalli beds made of sandstone and clay with lignite. While discussing the homotaxial relationship of these beds, King states "the Warakalli beds must then be of the same age, or if different conditions of deposition and apparent overlap go for anything, of perhaps a later age". Foote (1883), in the course of geological mapping of South Travancore, has studied the laterite capped sandstone exposed in Karichal and opined that these rocks are equivalent to Warakalli beds of King. Jacob and Sastri (1952) found that the calcareous beds exposed in Quilon area continue subsurface into Chavara and their age is Burdigalian. Narayanan (1958) opined that the Warkalli and Quilon beds are different facies of rocks of, more or less, same age. Based on the geological mapping of the sedimentary terrain and study of shallow boreholes of coastal Kerala, Desikachar and Subramanyan (1959) suggest that the Quilon and Warakalli beds continue far into the north up to Kainakari and Ambalapuzha.

Bose et al. (1976) suggested that the deepest part of the sedimentary basin is between Chellanam and Chavara, and around Alleppey the thickness of sediments may be about 600 m. Rao and Datta (1976) opined that the Wrakalli beds could be the continental equivalents of Quilon beds, a view expressed earlier by Narayanan (1958) and doubted by King (1882). Varadarajan and Balakrishnan (1976) were of the view that the laterite along the coastal area formed part of the continental shelf and their occurrence as terraces of different elevations could be due to Neogene and Quaternary uplift. Desikachar (1976) identified four formations and these in the ascending order are (i) Mayyanad Formation, (ii) Azheekal Fromation, (iii) Ambalapuzha Formation, (iv) Kainakari Formation; the Azheekal and Ambalapuzha formations are roughly equivalent to Quilon and Warkalli beds. Desikachar highlighted the hydrocarbon prospects of offshore Kerala Basin. Murty et al. (1976) felt that greater sedimentary thickness could be expected northwest of Alleppey and Ponnani on account of the extension of the Achankovil shear zone and Palghat gap faults into the basin.

1.3 Drainage

The state of Kerala is drained by 44 rivers, of which 3 are east flowing. The streams originating from the Western Ghats are short and swift flowing, showing various stages of gradation. Cascades and waterfalls mark these streams in the upper reaches, although in the plains they show evidences of maturity of development. Some of these rivers have steep gradients (1/250 or more) in their initial reaches. In the case of Periyar and Chalakudi rivers, this extends for three-fourths of their course, while such gradients are also discernible in the upper reaches of Chaliyar, Valapattanam river, Vamanapuram Ar. and Karamana Ar, suggesting their youthful stages of development (cf. Resource Atlas of Kerala, 1984). Rejuvenation of the catchment area, closely linked with the west coast faulting and later adjustments may, in all probability, be the reason for the youthful behaviour of the rivers, while high-energy shoreline might have prevented delta formation in the river mouths.

The general drainage pattern of the rivers of central Kerala is dendritic, although in places, trellis, sub-parallel and radial patterns are also noticeable. Most river courses are straight, indicating structural control. General course of the rivers is along prominent lineaments (NW-SE and NE-SW). The five major rivers, namely Periyar, Bharathapuzha, Pamba, Chaliyar and Chalakudi together drain 40% of the geographical area of the State.

Periyar River: The river Periyar having a length of 244 km is the longest river in Kerala (Table 1.1). It has a drainage area of 5398 km^2 (cf. Water Resource of Kerala, 1974), of which 114km^2 lies in Tamil Nadu. The catchment area spreads over the districts of Idukki and Ernakulam. Formed by the confluence of a large number of streams originating from the Sivagiri hills in the Western Ghats at an elevation of 1800 m, it finds its source from the south and east of the Periyar reservoir and Periyar wild life sanctuary areas. From the exit point of the Periyar dam, the river flows almost in NNW direction with occasional meanders up to the Idukki dam area. From Idukki the river flows northwards up to the Mudrapuzha confluence. The main tributaries of the Mudrapuzha originate from the Mattupatti, Anamudi areas and flows through Munnar town, which is a junction of three arms of the river. It passes through several gorges, the important one being the Idukki gorge. Major reservoirs like Idukki, Periyar, Anairangal, Mattupetti and Setuparvatipuram are within the basin area.The Periyar river takes a straight NW course up to Bhutathankettu reservoir. The main branches, Edamala Ar and Puyamkutty Ar debouch their sediments into Bhutathamkettu reservoir. From there, the Periyar river and its distributaries join the Vembanad lake at Azhikod. The sinuosity of the river is 1.75, which is moderate and decreases towards the downstream direction. The river flows through a metamorphic terrain consisting of charnockite, khondalite, garnet-biotite and hornblende-biotite gneisses, besides migmatite and granite.

Table1.1 Details of the rivers discharging into the Vembanad Estuary (Water Resources of Kerala, 1974; Soman, 2002)

River	Length (km)	Catchment Area (km^2)	Annual Run-off (1000 MC ft.)
Karuvannur	48	1054	42.00
Chalakudi	130	1704	42.00
Periyar	244	5398	434.00
Muvattupuzha	121	1554	93.68
Meenachil	78	1272	96.27
Manimala	90	847	72.67
Pamba	176	2235	222.80
Achankovil	128	1484	76.00

Muvattupuzha River: Muvattupuzha River is one of the major perennial rivers in central Kerala. It has a length of about 121 km and a catchment area of about 1,554 km^2 (cf. Water Resource of Kerala, 1974). The river originates from the Western Ghats and drains mainly through highly lateritised crystalline rocks. It debouches into the Vembanad estuary near Vaikom. Two major tributaries namely Thodupuzha and Kaliyar join the Muvattupuzha river near Muvattupuzha town. The Thodupuzha river has two main tributaries i.e., Vazhipuzha and Kudayathoorpuzha. The streamlets flowing down from the area north of Uppukunnu hills, west of Kuilimala hills i.e., Komb Ar and Toni Ar join to form the Kaliyar river, which flows towards northwest. After flowing as a single stream up to Vettukattumukku, the river branches into two distributaries namely Ittupuzha and Murinjapuzha. The river exhibits dendrite drainage pattern. The river discharge ranges from 50m^3/sec (premonsoon) to 400m^3/sec (monsoon). Peak discharge is recorded during June to October. Considerable changes have taken place in the flow characteristics of the Muvattupuzha river after the commissioning of the Idukki hydroelectric project in 1976, across the adjoining Periyar river. The tailrace water

(19.83-$78.5 m^3$/sec) was directed into the Thodupuzha tributary from Moolamattom power station.

Pamba River : The river Pamba is the third longest river (176 km) in Kerala, and has the fourth largest catchment area (2235 km^2). It rises in the hill ranges of Pathanamthitta district and the adjoining Pirmed plateau, and is formed by the confluence of Pambiyar Ar, Kakki Ar, Arudai Ar, Kakkad Ar and Kal Ar. Pamba and Kakki are the major reservoirs in the basin. From Vadasserikkara to Chengannur, the river flows through midland terrain with minor meanderings down stream of Payipad, the Pamba river coalesces with other river distributories, which flow in the NNW direction to join the Vembanad lake. A paleochannel drainage basin is observed between Puthenkavu and Arattupuzha. Flowing through the crystalline rocks the basin displays dendritic to sub-dendritic and rarely rectangular and trellis drainage patterns.

Chalakudy River: The Chalakudy river has a length of 130 km and a drainage area of 1704 km^2. Five streams – Parambikulam, Kuriakutty, Sholayar, Karapara and Anakkayam form the Chalakudy river. Of these, Parambikulam and Sholayar rise in the Anaimalai hills at elevations above 1733 m and 1332 m, respectively. The river flows through thick forests and the channel has many waterfalls until it reaches the plains at Kanjirapally. The river debouches into the right arm of the Periyar at Puthenvelikkara. Poringalkuttu, Sholayar and Parambikulam are the major reservoirs in the basin. Charnockites and migmatitic gneisses are encountered along the river course.

Achankovil River: The river Achankovil has a length of 128 km and a catchment area of 1484 km^2. It originates from the border of Kerala and Tamil Nadu to the ESE of Achankovil. The Achankovil river has no prominent tributaries, other than small streamlets. The river has a straight northwesterly course from the Western Ghats to Konni and then it deviate to west. The Achankovil shear zone coincides with the drainage basin of the Achankovil river. This river joins with the river Pamba near Chennithala, before entering into the Vembanad estuary. The Achankovil river has again connection with Pamba river at Payipad and the main stream (local name, Puthan Ar) flows to the sea through Thottappalli spillway.

Manimala River: The major stream and its feeding streamlets originate from the mountainous regions at Uppanmala, Melethadom hills (1140 m above MSL) and areas around Endayar hills. Many small streamlets like Talungal Thodu, Kokkayar Ar joins the main stream. Two other tributaries join the main stream at Mundakkayam. Two other major tributaries join together and flow for a length of approximately 4 km before it joins the Manimala river. From there the river flows in the northwesterly direction and finally joins the Vembanad lake. Tidal action is noted up to Tirumoolapuram . This river is comparatively narrower than the Pamba and other major rivers. The Manimala river has a length of 90 km and has a catchment area of 847 km^2 out of this approximately 20 km runs through high land region, 45 km through midland and the rest (25 km) through low land areas.

Meenachil River: The Meenachil river has a length of 78 km and a catchment area of 1272 km^2. Major part (38 km) of this stream runs through midland terrain, 21 km through the highland and the rest (16 km) is seen to flow through the low land terrain. The river assumes its name after the confluence of its two important affluents at Erattupetta , one coming from Poonjar and the other from Tikkoi area. The Poonjar branch has two main tributaries and many small streamlets joining it. The other main branch has two tributaries i.e. the Kalattukadavu Ar and Tikkoi Ar. The Meenachil flows in the westerly direction from Erattupetta to Palai . Kudamuruti Thodu is a tributary of this. Before reaching the town of Kottayam, seven other tributaries join the main stream. The Meenachil river drain into Vembanad lake at Kumarakam .

Karuvannur River: The streamlets Kurumalipuzha and Manali Ar, which originate from the Western Ghats join to form the Karuvannur River. The Manali Ar collects its headwaters from the Vaniamparakunnu hills (400 m above MSL) and reaches the Peechi reservoir. From Peechi it flows in a southwesterly direction and joins the Kurumalipuzha at Pudukad area. The Chimonipuzha has three tributaries, which arise in the Payampara and Chimoni hill. Now a dam has been put here. Before joining the Vembanad Lake, one distributory goes towards north and joins the sea and the other main river channel trends south and reaches the Vembanad lake near Kodungallur. This river drains an extensive area of more than 1000 km^2 having a total length of 90 km.

1.4 Geomorphology of the coast

The width of the coastal plain in the State of Kerala varies from 35 to 120 km with an average of 65 km. Within this small width, the physiographical and topographical features change considerably. Kerala has a coastline of 560 km. Of this a cumulative 360 km length of coastline is very dynamic and fluctuates seasonally. Based on vulnerability and dynamism, the shoreline is divided into (1) permeable, gently sloping sandy shoreline (2) semi permeable, cliffed sedimentary shoreline and (3) impermeable crystalline shoreline arranged in order of intensity of erosion.

The central Kerala coast is described as a submerged coast, falling under the terrigenous coast of primary morphologic disequilibrium. Accordingly the long-term tendency of coastal evolution is to increase the linear extent of erosional coastal segments at the expense of intervening depositional areas and when the process completes a coast of equilibrium results. The coastal features include beaches, beach cliffs, stacks, islands, shore platforms, spits, bars, beach ridges, estuaries, lagoons, mud flats, tidal flats and deltaic plains (Nair, 1987; Thrivikramaji, 1987).

The characteristic features of Kerala coast are the backwaters and the estuaries. They include lakes (kayals) and sea inlets, which stretch irregularly along the coast (Joseph and Thrivikramaji, 2002). The biggest one is the Vembanad Lake, with about 230 km^2 in area, opens into the Arabian Sea at Fort Cochin. The other important backwaters are at Ashtamudi, Veli, Kadhinam-Kulam, Anjego, Edava, Nadayara, Paravur, Kayamkulam, Kodungallur and Chetuva. Coastal inlets play an important role in the exchange of water between bays/estuarys and ocean. There are about 48 inlets in Kerala, out of which 20 shows permanent nature of opening, whereas the remaining 28 open only during the monsoon season (Nair et al., 1993). Munambam inlet is a major permanent inlet just north of Cochin inlet, through which Periyar River joins the sea. Island and islets are major landforms seen along the lagoon.

The shoreline of Kerala is generally straight, trending NNW-SSE, with minor variations. Even though the straight-line configuration is apparent in a synoptic view, the shoreline is highly irregular and indented especially around promontories comprising of crystallines and sedimentaries. Stretches of shoreline between promontories are usually depositional in nature with sandy beaches and are locally straight. Long shore drift deposits straighten out the shore features over long stretches (Nair, 1987). The coastal landforms are generally elongated parallel to the coast. They are mainly made of sand and alluvium. Strandlines are seen along these elongated coastal landforms and are considered to be ancient shorelines by most geomorphologists. As an ancient shoreline strandline refers collectively to the assemblage of various features characteristic of former coastal area. Strandlines in this sense may be either above or below the actual water level. Strandline need not necessarily refers to marine features. Ancient lake shorelines are occasionally called strandlines (Smith, 1968). Coastal erosion is a major problem along the Coast of Kerala. In the central Kerala region, considerable stretches of shoreline from Fort Cochin to Manaccadum are reported to undergo severe erosion

(Murthy et al., 1980). Shore protection structures such as seawalls and groins have been constructed to check erosions of alarming proportions.

1.5 Climate and Rainfall

Kerala region experiences the tropical climate and the dominating feature is the monsoon. Subtropical type of climatic regime is seen in certain areas in the eastern part of the state due to the high variation in relief from west coast to the hilly regions of the Western Ghats in the east. Through Palghat gap and Ariankavu pass the heat waves from the plains of Tamil Nadu enters Kerala.

According to Indian Meteorological Department the seasons of Kerala can be grouped into a) the hot weather period (the pre-monoon season, during March-May), b) the south – west monsoon (June – September), c) the retreating monsoon (September-November) and d) the winter (December-February). The atmospheric temperature is maximum (37°C) during the premonsoon period and from June it gradually comes down due to heavy rainfall. Land and sea breezes influence the coastal area and here the seasonal and diurnal variations of temperature and almost of the same range (5° - 70° C). Kerala experiences two monsoons, namely the Southwest (June to September) and northeast (October – December) monsoon. The State of Kerala receives highest annual rainfall among other states of India, which is three times the average rainfall of India. The average annual rainfall varies from 100-500 cm with an average of about 300cm. The northeast monsoon is generally weak along the West Coast and the average annual rainfall is about 60 cm (Pisharody, 1992; Sampath and Vinayak, 1989).

1.6 Waves, Currents and Tides

West coast of India is under the influence of the SW monsoon between June and September, which is considered as the rough weather season from wave climate point of view. The wave activity is very strong during June and

July but the intensity reduces by August and September. The sea remains relatively calm during October to May (fair weather season). During fair weather season, long swells often mixed with the local sea winds prevail along the coast. The dominant energy along near shore is composed of gravity waves and mean currents of circulation. Far infra-gravity wave energy is about two orders of magnitude larger than that of gravity waves and evidence of edge waves in the infra-gravity band was demonstrated by Tatavarti et al. (1996). Far infra-gravity waves may be a common feature in the nearshore oceans in the presence of longshore currents (Bowen and Holman, 1989).

The wind and current systems along the coast play an important role in the dynamics of mud banks of the southwest coast if India. The important feature of the wind system in the Indian seas is the seasonal reversal of direction associated with two monsoons. Along the west coast of India, during the southwest monsoon the winds blow southwards from May to September and attain a northerly direction during the northeastern monsoon. Thus, the seasonally reversing wind pattern influences the southward littoral drift during the southwest monsoon, while a northward drift occurs during the northeastern monsoon. By the middle of May, the southwest monsoonal winds of oceanic origin are established. These winds continue to increase gradually until June when there is a 'burst' or sudden strengthening of the southwest winds. During July and August, the winds have their highest strength, and in September the wind force decreases ahead of the fall transition, which lasts through October and November (Sharma, 1978).

Estuarine hydrography plays an important role in the sedimentation and geochemical processes of this environment. The quantum, duration, transport and settlement of the particulate sediments depend directly on estuarine hydrography. The hydrography of the Vembanad estuary has been investigated by several researchers (Quasim and Reddy, 1967; Quasim et al., 1968; Sankaranarayanan et al., 1986; Anirudhan, 1988; Rasheed et al., 1995). Processes like exchange of heat with atmosphere and other localised phenomena are also likely to influence the hydrographic conditions of the system. The temperature of water in estuary varies between 25 -31 C. Low salinity values ranging from 0 to 10 x 10^3 psu at the surface and 0 to 12 x 10^3 psu at the bottom are observed during monsoons. This is brought by the combined effect of land drainage from the prevailing monsoonal rains causing high freshwater discharge from the river and intrusion of saltwater from the sea. As the season advances to post and premonsoon, higher salinity values ranging from 10 to 22x10^{-3} psu at the surface and 12 to 24x10^{-3} psu at the bottom were observed (Anirudhan, 1988). The estuarine waters considerably get diluted near the Muvattupuzha river confluence. The pH values of the surface and bottom water vary from 6.6 to 7.4 and slight increase is observed seasonally up to postmonsoon period.

1.7 Area of Study

The study area extends between latitudes 9°47" to 10°13" N and longitude 76°10" to 76°23" E, from Kodungallur in the north to Chellanam in the south for a length of 42 km. In the eastern part, the area extends beyond the swales, at times as far east as 15 km. The Arabian Sea forms the western limit. Vembanad estuary, which fringes the study area on the eastern side is the largest backwater system in the west coast of India and is the largest water body in Kerala extending parallel to the coast from Alleppey in the south to Munambam in the north (latitudes 9°28" – 10°10" N and longitudes 76°13" - 76°25" E). It has a length of about 113 km and the breadth varies from a few hundred meters to 14.5 m, covering an area of about 233 km^2. It is elongated and oriented in NW-SE direction. This estuary system has two openings with the Lakshadweep sea; one at Fort Cochin and other at Munambam (northern part of the study area). Seven major rivers (five from south of Cochin; Achankovil, Pamba, Meenachil, Manimala and Muvattupuzha and two from north; Periyar and Chalakkudi) debouch into the estuary. The area of Vembanad kayal in 1912 was 315 km^{2}and by 1983 it shrank by 43.09% to 179.25km^2 (Nair et al. 1987), essentially due to reclamation and

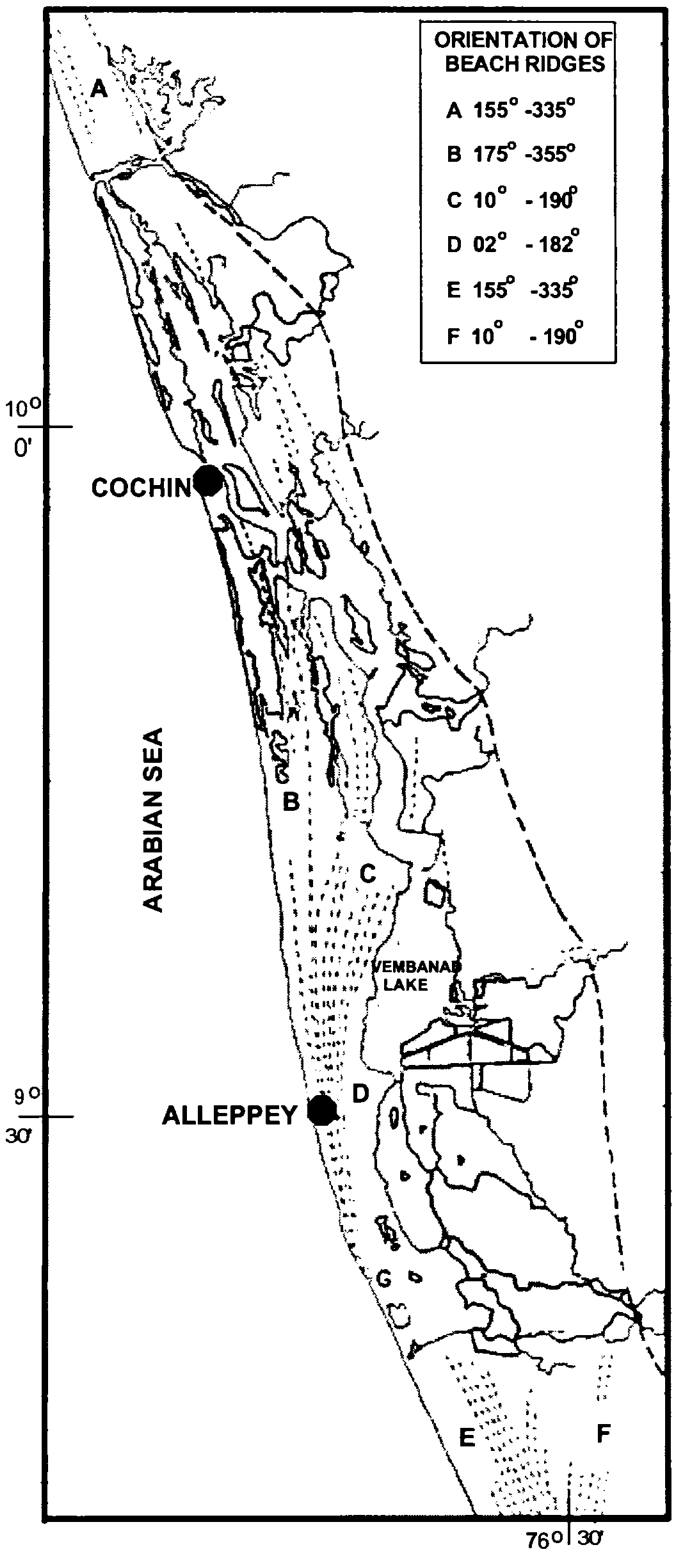

Fig. 1.3 Orientation of palaeo-beach ridges from Central Kerala (After Mallik and Suchindan, 1984)

encroachment. The available C14 dates indicate Holocene evolution of the estuary. Spatial disposition of the distributory system of rivers in the deltaic upper Kuttanad area, comprising Achankovil, Pamba and Manimala suggests existence of a single mighty river prior to the Holocene sea-level rise.

On the southern side of the Vembanad estuary, a barrage has been constructed near Thannermukham to prevent saltwater intrusion especially during extreme droughts (premonsoon). The backwaters are bounded by barrier islands and have numerous interconnecting canals. The bathymetry of the Vembanad estuary suggests that the depth of the water column in the estuary varies from <1m to 8.5 m. It is shallower in the northern and southern parts of the estuary as well as in the adjacent narrow channels in the central part (<1 – 2m). The central part of the estuary is deeper with the water depth generally varying from 2 – 5 m. The deepest part (8.5 m) is in its southern part, south of Thanneermukkom bund to the northeast of Varanam church. Most of the sediments in the estuary consist of different admixtures of clay, silt and sand. Based on borehole data, thickness of the sediments in the lake is found to vary from 34 to 63 m, and the sediments include mixtures of sand and clay, and occasional lignite patches. The coastal plain is marked by a number of beach ridges running parallel to the coast and lake margins (Fig1.3).

* * *

CHAPTER 2

MATERIALS AND METHODS

2.1 Introduction

This chapter deals with the various methods employed in the collection, processing and analysis of sediments samples used for this investigation. The present investigation consists of two phases, namely, field survey and laboratory investigations.

2.2 Field survey

A total of 18 pit/core sediment samples were collected along the beach ridges between Kodungallur and Chellanam (Fig.2.1). Within the coastal plain areas, five prominent sub environments such as beach ridges, swales, alluvial plains, intertidal mud flats and mangroves have been selected and representative sediment samples were collected. The sampling was carried out between March and May 2000. The time interval between sampling was minimized as much as possible to get better accuracy.

Pit samples were collected in environments where ground water table was much below. In some environments pit samples have been collected at the surficial levels above the water table and core samples at the bottom. The vertical pit samples were collected at every 10 cm interval. In case of the core samples, the 10cm diameter PVC pipe was cut and the sampling interval was maintained at 10 cm interval. Thus in beach ridges as many as 450 sub samples were made from the 18-pit/core samples for sieving. From the mangroves, sediment samples were collected by penetrating 10 cm diameter PVC pipe into the ground.

All samples were carefully transferred to neatly labeled polyethylene bags and were brought to the laboratory and kept in an inert atmosphere till further processing or analysis. Utmost care was taken not to contaminate the samples during collection and handling.

2.3 Texture

Sand samples were washed, dried and subjected to coning and quartering and a representative portion (about 150 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 ($^1/_2$ ϕ) interval. The fractions left over in each sieve were carefully transferred, weighed and cumulative weight percentages were calculated. Samples, which contains significant amount of silt and clay particularly from alluvial plains, mangroves, intertidal flats and swales were subjected to combined sieving and pipette analyses as suggested by Lewis (1984). Known quantities of silt and clay rich sediments were dispersed overnight in 0.025N solution of sodium hexametaphosphate. Using a 230 (63 µm) the coarse fraction was separated from the dispersed sediments by wet sieving. The filtrate containing the silt and clay fractions were carefully transferred to a graduated 1 litre measuring jar and volume made up. The solution was then stirred thoroughly to obtain a homogenous suspension. A 20 ml of the filtrate was pipetted out into previously weighed 50 ml beaker at fixed time intervals from depths as suggested by Lewis (1984). All the aliquots were oven dried to constant weight at 60 ± 3° C and weighed accurately after cooling at room temperature. Dry sieving was carried out on sand fraction to complete the analysis.

The cumulative weight percentages of the above analyses were plotted against the respective grain sizes (in phi units) on a probability chart. From the cumulative frequency curve the values of 1, 5, 16, 25, 50, 75, 84 and 95 percentiles were recorded. For a few samples (with high percentage of clay), which do not attain higher percentiles, the conventional extrapolation method suggested by Folk and Ward (1957) was adopted. 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 to elucidate the hydrodynamic conditions of the depositional medium. In addition to this, the percentages of sand

(2– 0.063mm) mud (< 0.063 mm) for the swale, intertidal, mud flat, alluvial plain and mangrove sediments, were also plotted on a triangular diagram of Folk et al. (1970) to determine the sediment types. CM pattern of sediments was worked out following Passega (1964).

2.4 Mineralogy

The methods adapted to study mineralogical constitution of the study are summarized below.

2.4.1 Heavy minerals

For heavy mineral separation, the already sieved samples for textural analysis were used. Before separation the respective sand fraction of each class medium sand (+45 and +60 mesh), fine sand (+80 and +120 mesh), very fine sand (+170 and +230 mesh) was thoroughly mixed and coned and quartered. Heavy minerals were separated from the lighter ones in three sand fractions using bromoform ($CHBr_3$ – specific gravity: 2.85 at 20°C changing 0.023°C) and separating funnel. The minerals thus separated were washed with acetone, dried and weighed to find out the total heavy and light mineral contents. The heavy minerals were then boiled for a few minutes with dilute HCl and a tinge of stannous chloride crystals to remove Fe/Mn coating over the detrital heavy grains. A total of 300 to 400 grains from each heavy residue was mounted on glass slides using Canada balsam. The individual minerals in each slide were studied under a Leitz petrological microscope following standard methods.

2.4.2 Mineralogy of clay fractions (XRD)

Twenty-three samples from five cores (Fig. 1.1) collected from alluvial plain, swales and mudflats. The samples were treated with H_2O_2 to eliminates the organic matter and were analysed semi quantitatively by X-ray diffraction technique at National Institute of Oceanography, Goa. Oriented smear slides as suggested by Gibbs (1968) were prepared for the clay fraction (< 2 μm) and run on Phillips X-ray diffractometer using Kα radiation and Ni filter. The slides were then glycolated and repeated the experiment. The chart drive 1cm/minute, goniometer 1°/ minute and intensity $2X10^2$ were maintained.

1) Montmorillonite is identified by its (001) peak at 14 Å, which expands to 17 Å on glycolation.
2) Kaolinite gives peaks at the same spacing as that of chlorite and hence their identification becomes difficult. However, Biscaye (1964) pointed out that kaolinite in addition to two strong peaks at 7.16 Å and 3.58 Å gives always very small peak at 2.38 Å.
3) Illite exhibits a major peak at 10 Å and minor peaks at 5 Å and 3.3 Å. The peaks remain unaffected on glycolation.
4) Gibbsite gives distinct peak at 4.85 Å.

2.4.3 Scanning Electron Microscopic (SEM) Studies

Scanning Electron Microscopy has become an essential tool in the micro morphological investigation of minerals and their alteration features. Such studies are important to delineate the environment of weathering and transportation and subsequent alteration in the environment of deposition (Krinsely and Doomkamp, 1973).

Standard procedures as suggested by Goudie and Bull (1984) were used for SEM analysis. Sub-samples containing heavy mineral grains from fine sand fraction (+80 and +120 mesh) were treated with 10% hydrochloric acid, stannous chloride and sodium hexametaphosphate to remove carbonates, iron coatings and clay particles respectively. Then the grains were washed, dried and mounted on stubs. The mounted grains were sputter coated with gold and photomicrographs were taken using Stereoscan 180 at standard magnifications ranging from 160x to 2400x. The SEM analysis was carried out at Regional Research Laboratory (RRL) Trivandrum using the instrument. The interpretations of the photomicrographs thus obtained were made following Georgieve and Stoffers (1980) and Marshall (1987).

2.5 Geochemistry

Clay sediment samples were subjected to geochemical analysis. A known amount of well-powdered clay size fraction was digested with HF-HNO_3-$HClO_4$ mixture. A total of 60 samples were used for elemental analysis with the help of AAS available at the Department of Chemical Oceanography, School of Marine Sciences (PERKIN-ELMER 2380) and with ICP AES (Thermo Electron IRIS INTREPID II XSP DUO) at Sophisticated Testing and Instrumentation Centre (STIC), Cochin University of Science and Technology as per analytical method (APHA).

2.6 Sediment organic carbon:

The sediment organic carbon was determined by wet oxidation method of ElWakeel and Riley (1957). Organic matter was oxidized by a known quantity of chromic acid and the amount of chromic acid used was then determined by back titration with standard ferrous ammonium sulphate solution. Diphenylamine was used as an indicator. The average of triplicate measurements not differing by 0.2% of the analyses was used in this study.

2.7 Precision and accuracy

The precision and accuracy of the heavy metal estimation were checked against two USGS standard rock samples G_2 and W_1 (Table 2.1). All the metal values were in agreement with the published values of Rantala and Loring (1975) and Flanagan (1976).

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Table 2.1 Heavy metal concentrations of USGS standard rocks (Fe in percentage; others in ppm)

W1	Fe	Mn	Cd	Zn	Cr	Ni	Co	Cu	Pb
Observed	7.87	134		89	121	72	44	116	31.58
	-0.02	-0.002		-1.4	-1.2	-0.82	-0.22	-0.52	-0.32
Published (1)	7.76	132		86	114	76	47	110	31.2
Published (2)	7.96	127		86	116	66	41	122	34
G2									
Observed	1.83	28	0.031	84	9	9	8	13	10
	-0.03	-0.002	-0.001	-1.25	-0.42	-0.21	-0.24	-0.63	-0.42
Published (1)	0.185	26	0.39	85	7	5	5.5	12	8
Published (2)	1.9	25		87	7	12	7	12	12

Paranthesis - Standard deviation of triplicate analyses

1. Flanagan (1976)
2. Rantala and Loring (1975)

CHAPTER 3

TEXTURE

3.1 Introduction

The mechanism of transportation and deposition of unconsolidated sediments can be deciphered from the granulometric studies. Hence exhaustive research has been carried out on grain size characteristics for the past six to seven decades. Extensive works by various researchers from different parts of the globe have revealed that there has been significant correlation between size frequency distribution and depositional processes. Proper selection and combination of statistical parameters can excellently be used to discriminate various environments of deposition of ancient as well as recent sediments (Folk, 1966; Friedman, 1967; and Hails and Hoyt, 1969). Apart from environmental implications, the particle size distribution is related to the source materials, processes of weathering, abrasion and corrosion of the grains and sorting processes during transport and deposition (Mishra, 1969; Patro et al., 1989; Williams et al., 1978; Forstner and Wittmann, 1983; Seralathan, 1979, 1988; Samsuddin, 1990; Padmalal and Seralathan, 1991; Padmalal, 1992; Joseph et al., 1997; Majumdar and Ganapathi, 1999; Rajamanickam and Gujar, 1984, 1985, 1997; Rajaguru et al., 1995). Hence, an attempt has been made to understand the particle size distribution of the coastal plain sediments of the Kodungallur – Chellanam area so as to have a proper insight of its influence on the mineralogy and geochemistry.

The characteristics of grain size distribution of sediments are related to the source materials, process of weathering, abrasion and corrosion of the grains and sorting processes during transportation and deposition. The size distributions of clastic sediments have revealed the existence of a strong statistical relationship between the different size parameters such as mean size, sorting (standard deviation), skewness and kurtosis. The relation between mean size and sorting is particularly well established and many studies have shown that the best-sorted sediments are generally those with mean size in the fine sand grade (Pettijohn, 1957; Griffiths, 1967; and Allen, 1970). Several attempts have been made to differentiate various environments from size spectral analysis, as particle distribution is highly sensitive to the environment of deposition (Mason and Folk, 1958; Friedman, 1961, 1967; Griffiths, 1962; Moiola et al., 1974; Stapor and Tanner, 1975; Nordstrom, 1977; Goldberg, 1980; Sly et al., 1982; and Seralathan, 1988). Friedman (1961, 1967) has analysed the fine-grained sands collected from many different localities around the world from dunes, beaches and rivers. A scatter diagram of moment standard deviation (sorting) versus moment skewness shows the most effective distinction of sands from these three environments. Visher (1969), based on the log normal distribution of grain size has identified three types of populations such as rolling, saltation and suspension, which indicate distinct modes of transportational and depositional processes. Passega (1957, 1964) has established a relationship between texture of sediments and process of deposition rather than between texture and environment as a whole. The study indicates that the finest fractions are transported independently and the coarser particles exhibit a logarithmic relation between the first percentile (C) and median (M) of clastic sediments.

Several researchers (Sahu, 1964; Mishra, 1969; Veerayya and Varadachari, 1975; Rajamanickam and Gujar, 1985; Samsuddin, 1986; Seralathan, 1988; and Jahan et al., 1990) have attempted textural attributes of sediments from different environments. Subba Rao (1967) has made a detailed investigation on the composition and texture of the shelf sediments of the east coast of India. Grain size characteristics of sediments off Hoogly river has been carried out by Mallik (1975). Rajamanickam (1983) and Rajamanickam and Gujar (1985) have investigated the grain size distribution of the surficial sediments of the shelf sediments of the west coast of India. Hashmi and Nair (1981) carried out the sediment characteristics of the continental shelf off Karnataka coast. Murty and Rao (1989) have investigated the textural characteristics of the sediments of Visakhapatnam coast. Textural aspects of the beach sands along the west coast of India have been studied by many workers (Kidwai, 1971; Veerayya and Varadachari, 1975; Samsuddin, 1986; Purandara et al., 1987; Unnikrishnan, 1987; and Sasidharan and Damodaran, 1988). Naidu (1968), Seetharamaswamy (1970) and Satyanarayana (1973) have studied the sediment texture of Godavary, Krishna and Mahanadi drainage systems respectively. Dora (1978) has investigated the textural characteristics of Vasishta-Godavari drainage system. A detailed granulometric investigation of the sediments of the major and sub environments of the modern deltaic sediments of Cauvery river has been studied by Seralathan (1979). Mohan (1990) has studied the grain size parameters of the Vellar River and estuary. The grain size characteristic of Vembanad Lake has been studied by many workers (Josanto, 1971b; Murty and Veerayya, 1972a; and Purandara et al. 1987). Sundaresan Pillai (1989), Seralathan et.al (1993), Seralathan and Padmalal (1994), and Padmalal et. al (1998) studied the sediment characteristics of the Muvathupuzha and Vembanad estuary.

3.2 Results

3.2.1 Beach ridges

The grain size variation of the beach ridge sands are presented in Table 3.1 and presented in Fig. 3.1a-r.

Pit 1: In this pit, the phi mean size ranges from 0.92 to 2.05∅ (coarse to fine sand). The sediments are moderately well sorted to moderately sorted (SD = 0.77 - 0.49∅), skewed in a wide range - fine skewed to coarse skewed (0.30 to -0.32) and the kurtosis values range between 0.78 and 1.43, i.e., platykurtic to leptokurtic. A general upward fining sequence is noticed in the sediments at a depth of 250 to 140 cm and an upward coarsening pattern from 140 to 110 cm in the upper part of the core, from 110cm to the surface the

Table 3.1 Grain size parameters of beach ridge sediments, Central Kerala

Western Ridge Pit 1					Eastern Ridge Pit 2				
Depth (cm)	Mean (Mz)	Standard Deviation (σ_I)	Skewness (Sk_I)	Kurtosis (K_G)	Depth (cm)	Mean (Mz)	Standard Deviation (σ_I)	Skewness (Sk_I)	Kurtosis (K_G)
10	1.28	0.84	0.00	0.91	10	1.20	0.79	0.22	0.85
20	1.13	0.66	0.28	1.36	20	0.97	0.77	0.26	0.97
30	1.20	0.68	0.27	1.08	30	1.22	0.64	0.14	1.06
40	0.92	0.75	0.30	1.31	40	1.10	0.80	0.19	1.03
50	1.18	0.73	0.26	1.43	50	1.07	0.74	0.19	0.95
60	1.17	0.69	0.12	1.16	60	1.41	0.66	0.14	0.82
70	1.29	0.74	0.10	0.87	70	1.34	0.53	-0.06	0.97
80	1.34	0.77	0.12	0.86	80	1.42	0.69	0.19	0.95
90	2.05	0.68	-0.32	1.15	90	1.84	0.70	-0.15	0.97
100	1.74	0.73	-0.05	0.82	100	2.12	0.63	-0.37	1.67
110	1.43	0.61	0.08	0.78	110	1.84	0.69	-0.11	1.38
120	1.48	0.70	0.29	1.38	120	2.13	0.55	-0.22	1.10
130	1.38	0.68	0.23	1.03	130	1.81	0.64	-0.13	1.08
140	1.70	0.61	-0.06	0.95	140	1.76	0.68	-0.25	1.00
150	1.89	0.66	-0.17	0.92	150	1.72	0.61	-0.25	1.02
160	1.66	0.59	-0.20	0.90	160	1.22	0.70	0.15	0.91
170	1.82	0.68	-0.09	1.03	170	1.37	0.70	0.18	1.17
180	1.58	0.61	-0.16	0.95	180	1.16	0.64	0.21	0.93
190	1.27	0.64	0.11	1.00	190	1.21	0.70	0.10	0.91
200	1.19	0.68	-0.02	1.20	200	1.34	0.61	0.04	0.90
210	1.61	0.54	0.03	0.85	210	1.43	0.50	0.07	0.97
220	1.44	0.49	-0.10	0.89	220	1.35	0.62	-0.11	0.85
230	1.58	0.59	0.02	1.11	230	1.50	0.54	-0.05	0.89
240	1.32	0.52	0.16	1.06	240	1.45	0.61	0.13	1.03
250	1.42	0.58	0.19	1.00	250	1.51	0.56	-0.07	0.93

Table 3.1 continued

Western Ridge Pit 3						Eastern Ridge Pit 4				
Depth (cm)	Mean (Mz)	Standard Deviation (σ_i)	Skewness (Sk_i)	Kurtosis (K_G)		Depth (cm)	Mean (Mz)	Standard Deviation (σ_i)	Skewness (Sk_i)	Kurtosis (K_G)
10	1.22	0.82	0.02	0.91		10	1.05	0.80	0.22	0.96
20	1.12	0.67	0.26	1.19		20	1.15	0.77	0.22	0.95
30	1.24	0.71	0.30	0.88		30	1.34	0.64	0.16	1.16
40	0.96	0.75	0.18	1.17		40	1.22	0.68	0.22	1.46
50	1.18	0.69	0.18	1.10		50	1.29	0.65	-0.01	0.74
60	1.20	0.66	0.16	0.97		60	1.44	0.56	-0.02	1.09
70	1.29	0.64	0.08	0.91		70	1.20	0.79	0.23	0.84
80	1.27	0.68	0.02	0.93		80	1.22	0.70	0.15	0.91
90	1.33	0.68	0.23	1.03		90	1.10	0.80	0.21	1.03
100	1.14	0.69	0.28	1.28		100	1.90	0.66	-0.10	1.30
110	1.20	0.61	0.20	0.84		110	2.12	0.60	-0.19	1.18
120	1.77	0.72	-0.01	0.86		120	1.99	0.66	-0.16	1.38
130	2.08	0.66	-0.29	1.21		130	2.11	0.58	-0.29	1.10
140	1.70	0.68	-0.06	0.95		140	1.88	0.60	-0.19	1.22
150	1.92	0.67	-0.17	1.06		150	1.82	0.70	-0.32	1.00
160	1.86	0.63	-0.16	1.00		160	1.74	0.63	-0.22	1.00
170	1.82	0.64	-0.18	0.97		170	1.58	0.62	-0.08	0.81
180	1.59	0.61	-0.17	0.95		180	1.65	0.70	0.25	1.06
190	1.38	0.70	-0.01	1.21		190	1.72	0.75	0.02	0.80
200	1.27	0.58	0.12	0.87		200	1.40	0.59	-0.04	0.87
210	1.35	0.50	-0.05	0.85		210	1.56	0.42	-0.09	1.48
220	1.43	0.62	-0.37	1.04		220	1.52	0.65	-0.13	0.77
230	1.41	0.58	0.18	1.11		230	1.69	0.47	-0.23	1.70
240	1.49	0.49	0.02	0.98		240	1.53	0.54	-0.04	1.54
250	1.42	0.55	0.19	1.00		250	1.84	0.51	-0.32	1.19

Table 3.1 continued

Western Ridge Pit 5						Eastern Ridge Pit 6				
Depth (cm)	Mean (Mz)	Standard Deviation (σ_i)	Skewness (Sk_i)	Kurtosis (K_G)		Depth (cm)	Mean (Mz)	Standard Deviation (σ_i)	Skewness (Sk_i)	Kurtosis (K_G)
10	1.08	0.80	0.22	0.81		10	1.20	0.72	0.19	0.84
20	1.23	0.77	0.18	0.80		20	1.12	0.69	0.12	0.85
30	1.13	0.66	0.08	0.89		30	1.31	0.69	0.19	0.83
40	1.09	0.81	0.22	0.78		40	1.21	0.66	0.17	0.88
50	1.24	0.59	0.17	0.85		50	1.34	0.55	0.01	0.79
60	1.38	0.51	0.05	0.86		60	2.05	0.41	-0.17	0.93
70	1.78	0.72	-0.20	0.85		70	2.10	0.50	-0.04	1.31
80	2.07	0.35	0.07	1.02		80	2.12	0.42	0.03	1.03
90	2.03	0.40	0.19	1.03		90	2.27	0.40	-0.09	1.01
100	2.28	0.38	0.03	0.96		100	2.25	0.42	0.04	1.05
110	2.01	0.44	0.11	0.98		110	1.91	0.50	-0.07	0.89
120	1.96	0.53	0.14	1.24		120	2.32	0.41	0.08	1.16
130	1.87	0.43	0.26	1.18		130	2.21	0.56	-0.29	1.35
140	1.97	0.34	0.17	1.15		140	1.77	0.72	-0.19	0.88
150	2.10	0.43	0.07	1.01		150	2.03	0.59	-0.09	0.98
160	1.86	0.76	-0.23	1.10		160	1.83	0.62	-0.13	1.05
170	1.76	0.68	-0.23	0.95		170	1.80	0.63	-0.17	1.11
180	1.53	0.55	-0.06	0.95		180	1.75	0.62	-0.06	0.98
190	1.18	0.70	0.10	0.85		190	1.41	0.69	0.12	0.90
200	1.40	0.59	-0.04	0.87		200	1.37	0.61	-0.02	0.85
210	1.33	0.58	0.01	0.83		210	1.40	0.58	0.01	0.83
220	1.36	0.62	-0.17	0.85		220	1.33	0.64	-0.17	0.84
230	1.58	0.51	0.12	1.21		230	1.44	0.65	-0.13	0.77
240	1.50	0.55	-0.05	0.95		240	1.46	0.56	-0.03	0.99
250	1.48	0.55	-0.01	0.97		250	1.66	0.58	0.12	0.95

Table 3.1 continued

Western Ridge Pit 7						Eastern Ridge Pit 8				
Depth (cm)	Mean (Mz)	Standard Deviation (σ_i)	Skewness (Sk_i)	Kurtosis (K_G)		Depth (cm)	Mean (Mz)	Standard Deviation (σ_i)	Skewness (Sk_i)	Kurtosis (K_G)
10	1.09	0.89	0.22	0.78		10	0.99	0.76	0.24	1.10
20	1.20	0.76	0.24	0.80		20	1.16	0.79	0.28	0.94
30	1.21	0.66	0.17	0.89		30	1.31	0.66	0.14	0.89
40	1.11	0.81	0.22	0.78		40	1.19	0.83	0.25	0.85
50	1.14	0.61	0.20	0.84		50	1.01	0.63	0.26	0.82
60	1.28	0.55	0.10	0.78		60	1.42	0.50	0.02	0.82
70	1.38	0.72	0.18	0.92		70	1.16	0.65	-0.27	0.92
80	1.20	0.62	0.05	0.88		80	1.26	0.69	0.17	0.88
90	1.28	0.67	0.17	0.86		90	1.39	0.67	0.10	0.94
100	1.20	0.67	0.19	0.88		100	1.56	0.61	-0.12	0.95
110	1.69	0.55	0.03	1.01		110	1.92	0.56	-0.29	0.99
120	1.81	0.68	-0.13	0.86		120	1.87	0.72	-0.11	0.94
130	2.21	0.56	-0.29	1.31		130	1.83	0.58	-0.01	0.92
140	1.87	0.69	-0.23	0.86		140	1.67	0.70	-0.22	0.93
150	2.01	0.57	-0.22	1.03		150	1.53	0.61	-0.11	1.04
160	1.91	0.59	-0.07	1.11		160	1.47	0.56	0.17	0.98
170	1.80	0.63	-0.17	1.04		170	1.17	0.67	0.18	0.91
180	1.53	0.55	-0.06	1.01		180	1.38	0.63	-0.06	1.02
190	1.46	0.69	0.12	0.86		190	1.20	0.69	0.12	0.86
200	1.37	0.61	-0.02	0.85		200	1.29	0.51	-0.02	0.85
210	1.33	0.51	0.01	0.83		210	1.39	0.61	-0.01	0.78
220	1.35	0.62	-0.17	0.87		220	1.31	0.69	0.17	0.83
230	1.38	0.54	-0.10	0.89		230	1.67	0.72	-0.12	0.87
240	1.50	0.55	-0.05	0.95		240	1.80	0.65	-0.19	0.99
250	1.48	0.53	-0.01	0.97		250	1.84	0.61	-0.01	1.08

Table 3.1 continued

Western Ridge Pit 9						Eastern Ridge Pit 10				
Depth (cm)	Mean (Mz)	Standard Deviation (σ_i)	Skewness (Sk_i)	Kurtosis (K_G)		Depth (cm)	Mean (Mz)	Standard Deviation (σ_i)	Skewness (Sk_i)	Kurtosis (K_G)
10	1.18	0.75	0.09	0.94		10	1.26	0.84	0.21	0.88
20	1.31	0.67	0.05	0.97		20	1.22	0.76	0.07	0.92
30	1.42	0.72	0.03	0.75		30	1.36	0.68	0.03	0.77
40	1.03	0.81	0.15	1.23		40	1.10	0.84	0.16	1.03
50	1.25	0.79	0.32	0.90		50	1.38	0.74	0.24	0.96
60	1.26	0.67	0.06	0.99		60	1.61	0.71	0.17	0.83
70	1.37	0.81	0.17	0.91		70	1.83	0.78	-0.25	0.89
80	1.27	0.68	0.03	0.92		80	2.14	0.63	-0.29	1.22
90	1.38	0.78	0.26	1.01		90	1.87	0.70	-0.19	0.97
100	1.25	0.66	0.05	0.89		100	2.05	0.62	-0.35	1.21
110	1.34	0.55	-0.01	0.88		110	1.59	0.59	-0.13	1.28
120	1.91	0.66	-0.09	1.02		120	1.89	0.60	-0.10	1.11
130	2.20	0.58	-0.17	1.22		130	1.62	0.62	0.01	0.89
140	1.75	0.66	0.01	1.13		140	1.24	0.67	0.09	0.90
150	1.89	0.69	-0.20	1.01		150	1.35	0.81	0.17	0.90
160	1.63	0.62	-0.19	1.01		160	1.28	0.68	0.11	0.85
170	1.78	0.64	-0.17	0.96		170	1.31	0.71	0.22	1.01
180	1.51	0.58	-0.10	1.12		180	1.21	0.69	0.03	0.80
190	1.21	0.72	0.03	1.07		190	1.38	0.61	-0.03	1.08
200	1.33	0.64	0.01	0.83		200	1.28	0.69	0.14	0.83
210	1.35	0.50	-0.05	0.85		210	1.30	0.59	0.11	0.85
220	1.33	0.61	-0.05	0.90		220	1.37	0.59	-0.17	0.86
230	1.39	0.55	0.17	1.24		230	1.47	0.53	-0.03	1.05
240	1.49	0.55	0.00	0.93		240	1.53	0.57	-0.05	0.99
250	1.42	0.56	0.21	1.03		250	1.59	0.63	-0.01	0.98

Table 3.1 continued

Western Ridge Pit 11						Eastern Ridge Pit 12				
Depth (cm)	Mean (Mz)	Standard Deviation (σ_i)	Skewness (Sk_i)	Kurtosis (K_G)		Depth (cm)	Mean (Mz)	Standard Deviation (σ_i)	Skewness (Sk_i)	Kurtosis (K_G)
10	1.02	0.77	0.17	1.11		10	1.58	0.69	-0.06	0.99
20	1.21	0.77	0.29	1.02		20	1.55	0.64	-0.10	0.94
30	1.22	0.66	0.18	0.91		30	1.48	0.69	-0.17	0.90
40	1.10	0.81	0.19	0.86		40	1.35	0.73	-0.10	1.00
50	1.12	0.66	0.15	0.78		50	1.96	0.52	0.12	1.28
60	1.36	0.53	-0.15	0.89		60	2.05	0.46	0.21	1.42
70	1.41	0.61	0.09	0.99		70	1.89	0.42	0.21	1.15
80	1.21	0.71	0.14	0.94		80	1.74	0.67	-0.22	1.05
90	1.32	0.69	0.15	0.88		90	1.83	0.75	-0.27	1.13
100	1.22	0.66	0.16	0.99		100	2.06	0.51	-0.12	1.22
110	1.13	0.62	0.19	0.84		110	1.98	0.33	0.28	1.22
120	1.85	0.72	-0.25	0.88		120	1.87	0.66	-0.23	1.24
130	2.19	0.56	-0.21	1.35		130	1.76	0.69	-0.12	1.09
140	1.96	0.61	-0.11	1.19		140	1.7	0.82	-0.25	0.87
150	2.03	0.49	-0.01	1.01		150	1.89	0.75	-0.28	1.10
160	1.92	0.58	-0.01	1.08		160	1.96	0.68	-0.11	1.18
170	1.80	0.63	-0.17	1.05		170	2.07	0.63	-0.30	1.24
180	1.53	0.55	-0.06	0.95		180	1.81	0.61	-0.15	1.24
190	1.20	0.71	0.14	0.87		190	1.71	0.68	-0.06	0.95
200	1.37	0.61	-0.02	0.85		200	1.79	0.62	-0.13	1.05
210	1.35	0.50	0.04	0.83		210	1.67	0.47	-0.16	1.28
220	1.35	0.62	-0.17	0.85		220	1.53	0.55	-0.06	0.95
230	1.53	0.54	-0.23	0.95		230	1.36	0.62	-0.17	0.85
240	1.51	0.56	-0.07	0.96		240	1.53	0.58	-0.05	0.97
250	1.47	0.56	-0.02	1.01		250	1.58	0.59	-0.15	0.98

Table 3.1 continued

Western Ridge Pit 13						Eastern Ridge Pit 14				
Depth (cm)	Mean (Mz)	Standard Deviation (σ_i)	Skewness (Sk_i)	Kurtosis (K_G)		Depth (cm)	Mean (Mz)	Standard Deviation (σ_i)	Skewness (Sk_i)	Kurtosis (K_G)
10	0.99	0.77	0.24	0.99		10	1.25	0.69	0.12	1.16
20	1.19	0.85	0.19	0.90		20	1.34	0.77	0.27	0.99
30	1.23	0.74	0.15	0.98		30	1.01	0.59	0.18	1.06
40	1.10	0.81	0.21	0.87		40	1.41	0.71	0.27	0.98
50	1.17	0.61	0.07	0.89		50	0.98	0.52	0.07	0.91
60	1.33	0.53	-0.07	0.87		60	1.45	0.49	-0.29	0.79
70	1.20	0.78	0.24	0.86		70	1.01	0.69	0.11	0.88
80	1.22	0.70	0.15	0.86		80	1.38	0.81	0.18	0.99
90	1.29	0.67	0.17	0.95		90	1.45	0.59	-0.01	0.84
100	1.21	0.66	0.17	1.03		100	1.78	0.49	-0.12	0.99
110	1.25	0.64	0.20	0.94		110	1.69	0.61	0.08	0.81
120	1.85	0.71	-0.24	0.97		120	1.72	0.65	-0.11	0.87
130	2.17	0.59	-0.27	1.50		130	1.58	0.51	-0.21	1.35
140	1.98	0.59	-0.24	1.12		140	1.24	0.59	-0.11	0.93
150	1.76	0.68	-0.23	0.95		150	1.74	0.49	-0.27	1.18
160	1.83	0.59	-0.01	0.97		160	1.43	0.67	-0.19	1.23
170	1.99	0.62	-0.19	1.06		170	1.35	0.59	-0.17	1.04
180	1.71	0.61	-0.22	1.05		180	1.50	0.55	-0.06	0.95
190	1.24	0.65	0.13	0.88		190	1.39	0.62	0.19	0.94
200	1.37	0.61	-0.02	0.81		200	1.11	0.69	-0.18	0.87
210	1.31	0.55	0.10	0.87		210	1.29	0.61	0.12	0.75
220	1.18	0.62	-0.17	0.85		220	1.39	0.69	-0.01	0.92
230	1.34	0.54	-0.10	0.89		230	1.47	0.59	-0.19	0.78
240	1.51	0.56	-0.07	0.96		240	1.61	0.61	-0.12	0.84
250	1.62	0.60	-0.10	1.03		250	1.71	0.66	-0.01	0.92

Table 3.1 continued

Western Ridge Pit 15						Eastern Ridge Pit 16				
Depth (cm)	Mean (Mz)	Standard Deviation (σ_i)	Skewness (Sk_i)	Kurtosis (K_G)		Depth (cm)	Mean (Mz)	Standard Deviation (σ_i)	Skewness (Sk_i)	Kurtosis (K_G)
10	1.10	0.83	0.20	0.97		10	1.20	0.82	0.12	0.97
20	1.31	0.77	0.10	0.95		20	1.46	0.79	0.08	0.95
30	1.44	0.63	0.16	1.11		30	1.53	0.63	0.20	1.11
40	1.17	0.81	0.26	1.10		40	1.32	0.71	0.14	1.24
50	1.41	0.63	-0.05	0.76		50	1.44	0.58	0.01	1.30
60	1.48	0.54	0.06	1.76		60	1.20	0.84	0.17	1.25
70	1.19	0.84	0.21	0.96		70	1.98	0.63	-0.10	1.38
80	1.29	0.69	-0.07	1.04		80	2.12	0.63	-0.40	1.34
90	1.38	0.64	0.29	1.04		90	1.76	0.69	-0.19	1.14
100	1.31	0.67	0.09	1.34		100	2.01	0.51	-0.01	1.05
110	1.23	0.65	-0.01	1.27		110	1.92	0.57	-0.09	1.23
120	2.02	0.58	-0.09	1.60		120	1.71	0.87	-0.12	1.12
130	2.09	0.64	-0.38	1.48		130	1.67	0.69	-0.14	0.98
140	1.74	0.71	-0.21	1.16		140	1.42	0.61	-0.03	0.84
150	2.11	0.58	-0.29	1.10		150	1.33	0.72	-0.03	1.04
160	1.88	0.58	-0.18	1.18		160	1.50	0.73	0.16	1.17
170	1.82	0.70	-0.32	1.00		170	1.39	0.64	-0.05	1.25
180	1.74	0.63	-0.22	1.00		180	1.38	0.67	-0.17	1.61
190	1.33	0.75	0.02	0.80		190	1.41	0.61	-0.14	0.87
200	1.37	0.59	0.09	0.87		200	1.33	0.58	0.05	0.97
210	1.43	0.46	-0.01	1.42		210	1.58	0.59	-0.01	0.99
220	1.44	0.65	-0.13	0.77		220	1.42	0.68	-0.17	0.69
230	1.67	0.47	-0.16	1.70		230	1.70	0.49	-0.12	1.70
240	1.54	0.53	-0.04	1.54		240	1.62	0.56	-0.08	1.05
250	1.81	0.56	-0.16	1.22		250	1.76	0.54	0.08	1.16

Table 3.1 continued

Western Ridge Pit 17						Eastern Ridge Pit 18				
Depth (cm)	Mean (Mz)	Standard Deviation (σ_i)	Skewness (Sk_i)	Kurtosis (K_G)		Depth (cm)	Mean (Mz)	Standard Deviation (σ_i)	Skewness (Sk_i)	Kurtosis (K_G)
10	1.05	0.78	0.18	0.97		10	1.31	0.82	0.16	0.86
20	1.21	0.77	0.28	0.90		20	1.41	0.66	0.10	0.83
30	1.22	0.66	0.17	0.94		30	1.31	0.67	-0.08	0.85
40	1.09	0.81	0.21	0.88		40	1.12	0.80	0.12	1.08
50	1.10	0.64	0.15	0.84		50	1.23	0.66	0.11	1.00
60	1.34	0.53	-0.06	0.89		60	1.81	0.72	-0.13	0.86
70	1.41	0.75	0.19	0.82		70	2.21	0.57	-0.16	1.21
80	1.21	0.71	0.14	0.88		80	1.85	0.70	-0.15	1.01
90	1.28	0.67	0.17	0.85		90	2.01	0.62	-0.22	1.33
100	1.21	0.61	0.13	1.11		100	1.90	0.58	-0.01	1.25
110	1.14	0.65	0.20	0.84		110	1.89	0.60	-0.10	0.96
120	1.75	0.77	-0.19	0.88		120	1.48	0.58	0.01	1.13
130	2.21	0.56	-0.29	1.35		130	1.29	0.67	-0.08	0.98
140	1.87	0.69	-0.23	0.94		140	1.19	0.69	0.10	0.85
150	2.01	0.61	-0.24	1.11		150	1.15	0.60	0.23	0.96
160	1.91	0.55	-0.01	1.14		160	1.32	0.84	0.11	0.90
170	1.70	0.63	-0.17	1.04		170	1.26	0.79	0.29	0.86
180	1.53	0.55	-0.06	0.95		180	1.37	0.76	0.28	0.99
190	1.23	0.69	0.12	0.86		190	1.47	0.55	-0.04	0.89
200	1.37	0.61	-0.02	0.85		200	1.32	0.58	0.11	0.95
210	1.35	0.50	0.04	0.83		210	1.51	0.57	-0.03	1.00
220	1.33	0.62	-0.17	0.85		220	1.53	0.53	-0.05	1.01
230	1.54	0.54	-0.10	0.89		230	1.22	0.63	0.02	1.07
240	1.61	0.52	-0.01	1.01		240	1.31	0.64	0.04	0.83
250	1.48	0.55	-0.01	0.97		250	1.37	0.60	-0.17	1.00

Fig 3.1 Grain size variation of the beach ridge sands

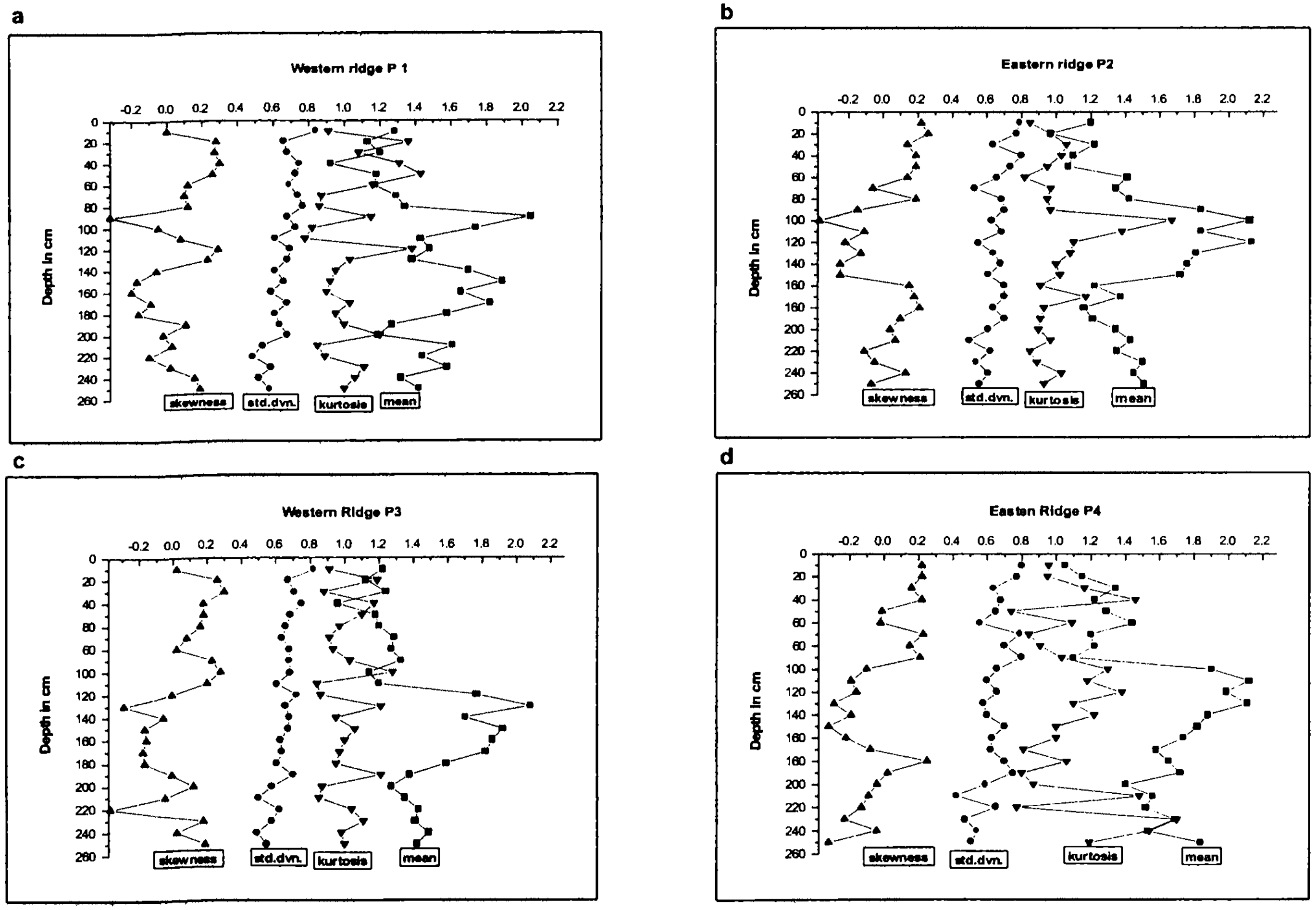


Fig 3.1 continue

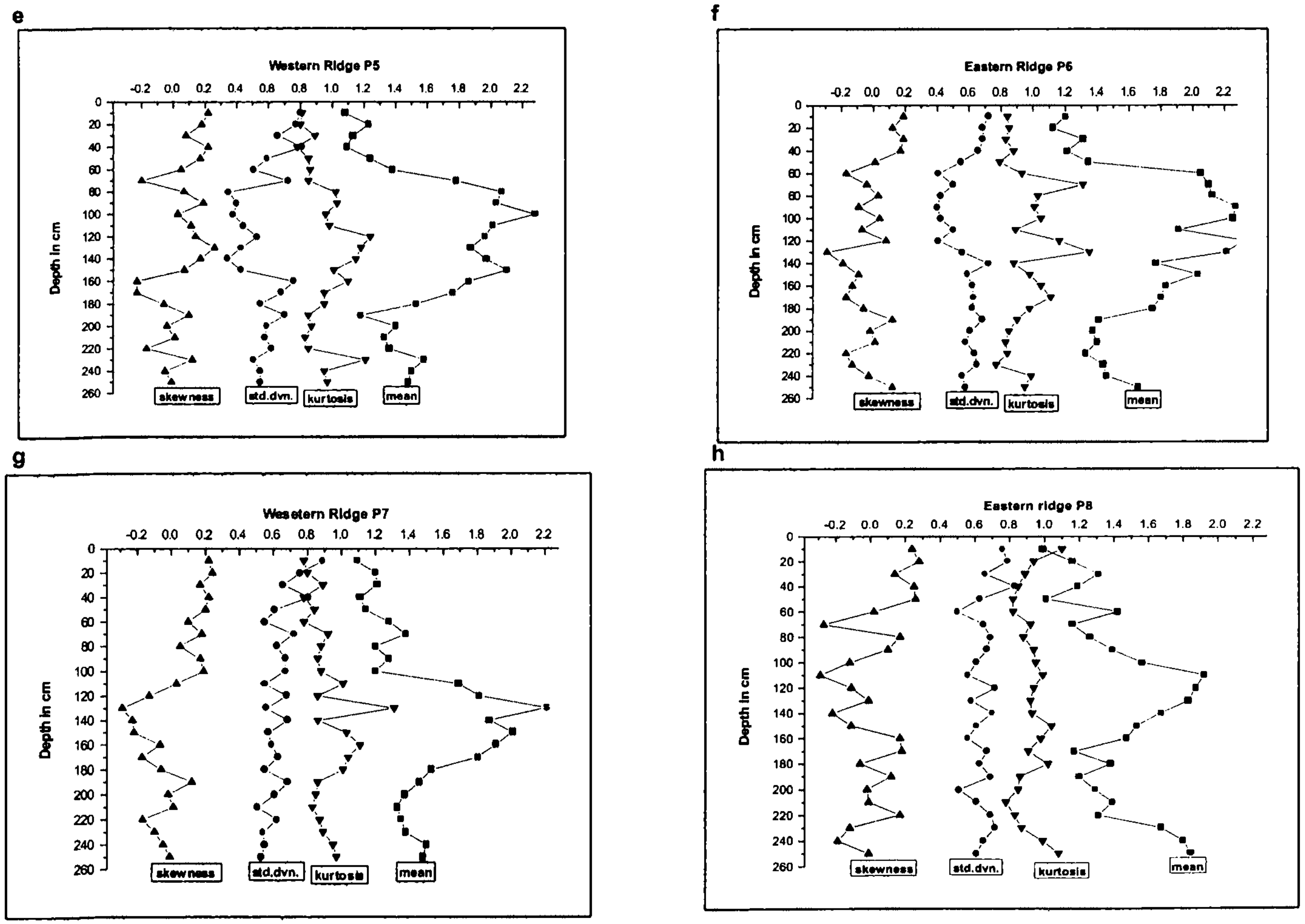


Fig 3.1 continue

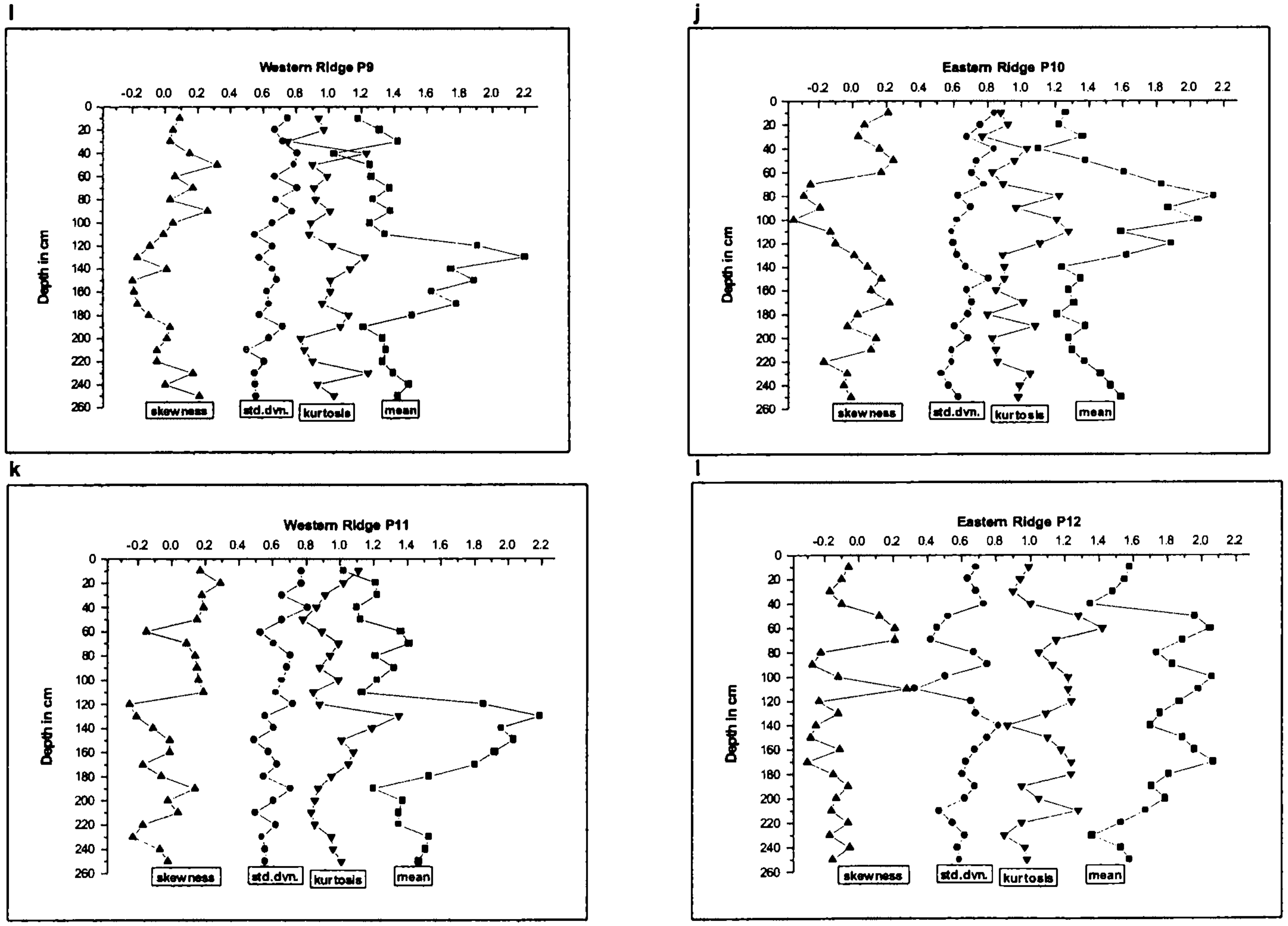


Fig 3.1 continue

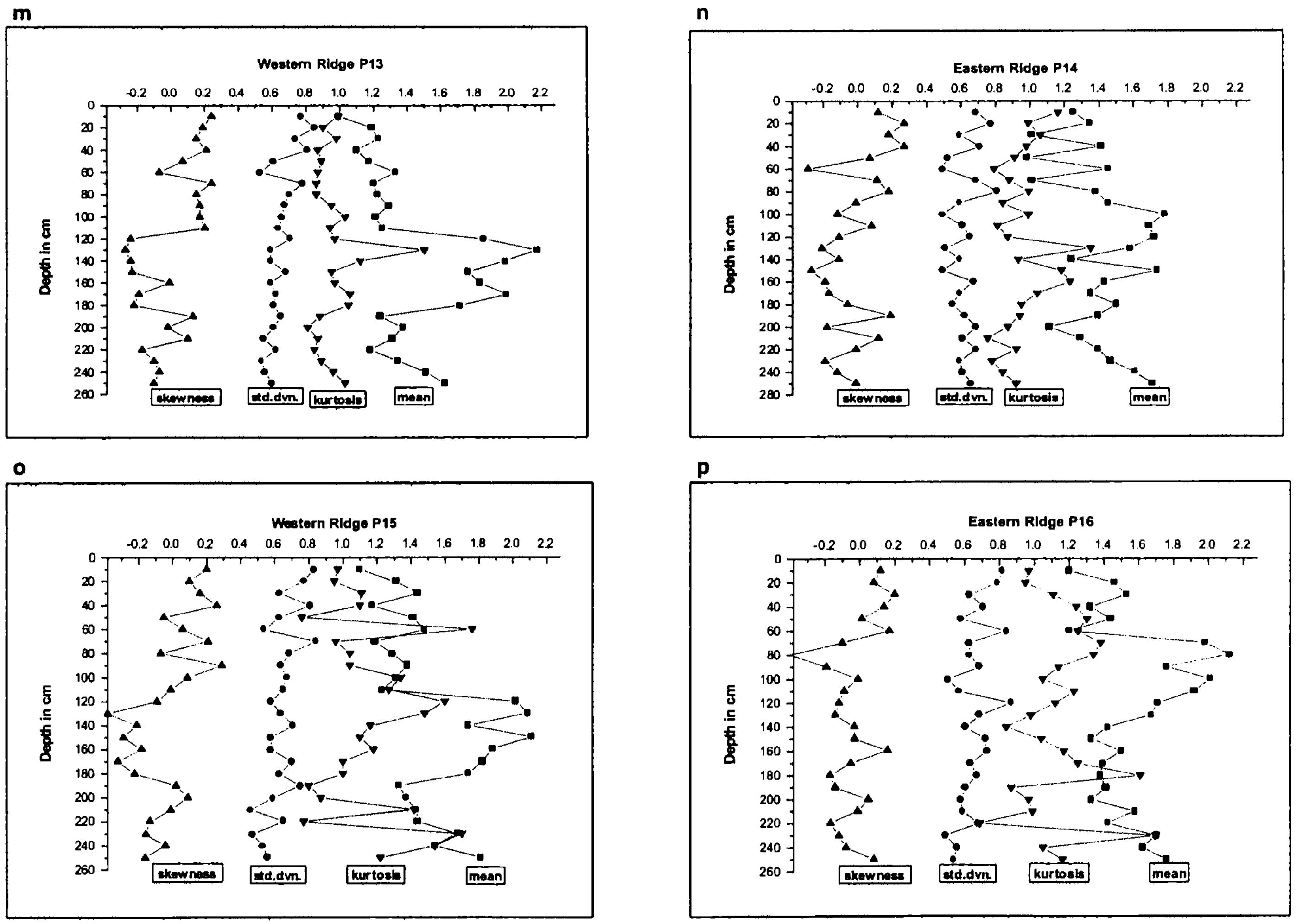
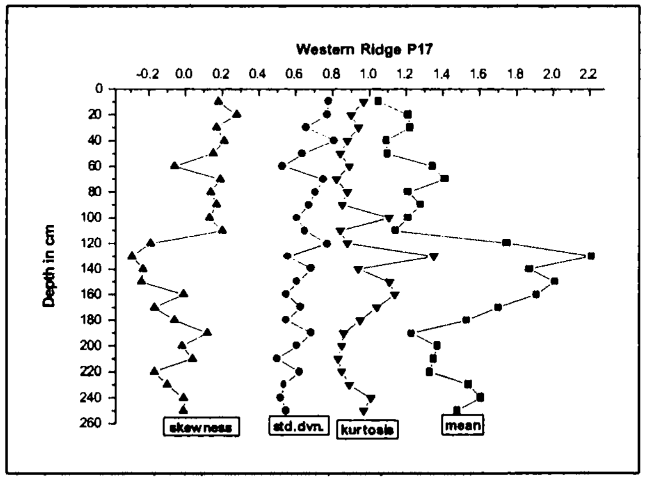
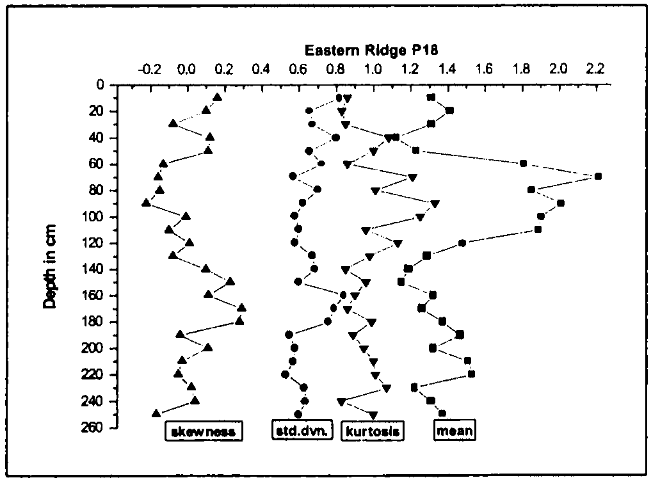


Fig 3.1 continue

q



r



fining nature is again repeated. Another striking feature noticed is that three distinct sets of upward fining sequences are noticed within the lower part of the pit (Fig. 3.1a)

Pit 2: The sediments in this pit are generally coarse sand to fine sand (phi mean values = 0.97-2.13∅). The standard deviation shows a range between 0.50 and 0.80∅, which is almost same as the Pit 1 (moderately well sorted to moderately sorted) and very fine skewed to coarse skewed (0.26- -0.37). The kurtosis values falls between 0.82 and 1.67, which is platykurtic to very leptokurtic. In this pit the sediments show alternative sequences of coarsening and fining at different depths (Fig. 3.1b). The well-noticed pattern is a general coarsening upward from 250 to 160 cm and a fining upward nature from 160 to 100 cm and again a reversal from 100 cm to the ground surface.

Pit 3: The phi value has recorded a range of 0.96 to 2.08∅ (coarse to fine sand). Well sorted to moderately well sorted nature is the characteristics of these sediments (SD = 0.49 to 0.75∅) with a wide range in the skewness from very fine skewed to coarsely skewed (0.30 and -0.37). Kurtosis shows a range from 0.84 to 1.28 (platykurtic to leptokurtic). In the lower part of the pit a general coarsening upward is observed from 250 cm to 200 cm, which is followed by another a fining sequence till 120 cm. From 120 cm onwards, the sediments show a coarsening trend upward but then the phi values become almost steady later (Fig. 3.1c).

Pit 4: This pit is having coarse to medium sand (phi mean = 1.10-2.12∅) and the other statistical parameters like standard deviation, skewness and kurtosis show variations with a range of 0.42 to 0.80∅, for standard deviation (moderately sorted to well sorted), 0.25 to -0.32 for skewness (fine skewed to coarse skewed), 0.74 to 1.70 and for kurtosis (platykurtic to very leptokurtic). In this pit between depths of 250 to 200 cm, a general upward coarsening sequence has been recorded, from 200 cm to 100 cm a gradual fining upward is observed. The fining upward trend reverses to a coarsening upward trend from 100 to 60 cm and finally a coarsening upward trend from 60 cm to the surface level (Fig. 3.1d)

Pit 5: Medium to fine sand with phi mean values ranging from 1.09 and 2.28∅ are observed in this pit. They are well sorted to moderately sorted (0.34-0.81∅) sediments with very fine skewed to coarse skewed (0.26 - -0.23) and platykurtic to leptokurtic (0.78- 1.24). A general coarsening of sediments upward has been observed from 250 to 190 cm, From 190 cm to 100 cm a fining upward nature is recorded. From 100 cm onwards a coarsening upward nature has been observed (Fig. 3.1e).

Pit 6: Similar to the other samples this pit also contain coarse to medium sand (1.12-2.32∅). The range values observed for standard deviation, skewness and kurtosis are 0.40 to 0.72, 0.19 to -0.29 and 0.77 to1.35 respectively, are, and for this pit. These values give an explanation that the sediments are well sorted to moderately sorted, very fine skewed to coarse skewed and platykurtic to leptokurtic. The bottom 30 cm layer records a coarsening upward sequence followed by a fining upward sequence from 220 cm to 120 cm. In the upper layers from 120 cm onwards there is coarsening upward sequence. (Fig. 3.1f)

Pit 7: This pit record 1.11 and 2.21∅ as the range of phi mean (medium to fine sand). This pit is characterized by moderately well sorted to moderately sorted (0.51-0.81∅), very fine skewed to coarse skewed (0.24 to -0.29) and platykurtic to leptokurtic (0.78 -1.31) sediments. An upward coarsening from 250 cm to 210 cm has been observed followed by a general fining from 210 cm to 130 cm, There after an upward coarsening has been documented from 130 cm to surface level (Fig. 3.1g).

Pit 8: The variations in phi mean size in this pit are from 1.11 to 2.21 (medium to fine sand) been observed in this pit. The standard deviation range from 0.51

to 0.81∅ (moderately well sorted to moderately sorted), while skewness and kurtosis show a range from 0.24 -0.29 and 0.78 to 1.31 respectively. i.e., the sediments are very fine skewed to coarse skewed and platykurtic to leptokurtic. A general coarsening of sediments upward has been observed for about 80 cm i.e., 250 and 170 cm; from 170 cm to 110 cm a fining upward trend has been recorded. From 110 cm onward an upward coarsening trend has been observed (Fig. 3.1h).

Pit 9: The phi mean size in this pit ranges between 1.03 -2.20, i.e., they are medium to fine sand. Standard deviation, skewness and kurtosis show a range of 0.32 to 0.81∅,(moderately well sorted to moderately sorted), from 0.50 to -0.20 (fine skewed to coarse skewed) and 0.75 to 1.24 (platykurtic to leptokurtic) respectively. From 250 cm depth to 220 cm, a general coarsening upward nature has been observed. From 220 cm to 130 cm depth, i.e., for the next 90 cm thickness, the sediments show a gradual fining upward sequence. This fining upward trend reverses to a coarsening upward trend from 130 cm to the surface level (Fig. 3.1i)

Pit 10: The sediments from this pit contain medium to fine sand category (1.10 to 2.14∅), as similar to most of the other pits the sediments are moderately well sorted to moderately sorted (0.50-0.84∅), very fine skewed to coarse skewed (0.24 to -0.20) and platykurtic to leptokurtic (0.75-1.28). A general coarsening upward of sediment has been observed for thickness 110 cm in the bottom most layer which followed by a fining upward sequence for a thickness of 60 cm from 140 cm to 80 cm depth. In the upper layers 80 cm onwards a gradual decrease in the phi mean values indicating a general coarsening upward has been recorded (Fig. 3.1j)

Pit 11: Medium to fine sand with phi mean values ranging from 1.10 to 2.19 has been observed in this pit. The standard deviation shows a range of 0.49 to 0.81∅ defining the sediments being well sorted to moderately sorted, while skewness and kurtosis show a range 0.29 to -0.25 and from 0.78 to 1.37.

These values indicate that the samples are very fine skewed to coarse skewed and platykurtic to leptokurtic. A general coarsening of sediments has been observed for 60 cm thickness in this core, from 250 to 190 cm. From 190 cm to 130 cm, for 60 cm thickness, a fining upward trend has been recorded. From 130 cm to the surface a coarsening trend has been observed (Fig. 3.1k).

Pit 12: The recorded ranges of phi mean values are 1.35 and 2.07∅ respectively, which represent the medium to fine sand grade. On contrary to many of the other samples, this pit is characterized with very well sorted to moderately sorted sediments (SD = 0.33 -0.82∅). The sample is very fine to coarse skewed (0.26 to -0.30) and platykurtic to leptokurtic (0.85-1.42). A general coarsening upward sediments has been observed for a thickness of 20 cm in the bottom most layers, from 250 to 230 cm. From 230 cm to 60 cm a fining upward nature is recorded. Here the fining upward trend is in three distinct episodes rather than a single event, from 60 cm a coarsening upward nature has been observed (Fig. 3.1l).

Pit 13: Variations in phi mean values from 1.10 to 2.10∅ have been observed in this pit. The standard deviation ranges 0.53 to 0.85∅, while skewness and kurtosis show a range from 0.24 to -0.27 and 0.80 to 1.50 respectively. From the above values it can be inferred that the sediments are medium to fine sand with moderately well sorted to moderately sorted in nature. They are very finely to coarsely skewed and platykurtic to leptokurtic. A general coarsening upwards of sediments has been observed for a thickness of 30 cm in the bottom of this pit, i.e., from 250 to 220 cm. From 220 cm to 130 cm, for a thickness of 90 cm, a fining upward trend has been recorded. From 130 cm to the surface level an upward coarsening is documented (Fig. 3.1m).

Pit 14: The samples are coarse to medium sand (phi mean values = 0.98 to 1.78∅). The standard deviation shows it is moderately well sorted to moderately sorted (SD = 0.49-0.81∅). Skewness and kurtosis falls in very fine skewed to coarse skewed (0.27 to -0.29) and platykurtic to leptokurtic (0.75-1.35) respectively. A general coarsening upward of sediments have been observed for a thickness of 50 cm in the bottom most layers, from 250 to 200 cm, from 200 cm to 100 cm a fining upward nature is recorded in the 100 cm thick pile of sediments. Here the fining upward trend is in three distinct episodes rather than a single event. From 100 cm onwards, a coarsening upward nature has been observed till the surface (Fig. 3.1n).

Pit 15: The phi mean value ranging from 1.17 to 2.11Ø i.e., it belongs to medium to fine sand. Standard deviation, skewness and kurtosis show a range of 0.46 to 0.84Ø (well sorted to moderately sorted), 0.29 to -0.38 (very fine skewed to very coarse skewed) and 0.76 to 1.76 platykurtic to leptokurtic respectively. The bottom layers from 250 cm to 190 cm for a thickness of 60 cm record a coarsening upward sequence followed by a fining upward sequence for a thickness of 60 cm from 190 cm to 130 cm depth. The upper layers from 130 cm onwards exhibit a more or less coarsening upward character (Fig. 3.1o).

Pit 16: This pit is having medium to fine sand (phi mean values =1.20 to 2.12Ø). The standard deviation ranges from 0.49 to 0.87Ø (well sorted to moderately sorted). The sediment from this pit shows very fine skewed to very coarse skewed (0.20 to -0.40). The samples are very platykurtic to leptokurtic (0.69-1.70). A general coarsening upward of sediments has been observed from 250 to 150 cm, from 150 cm to 80 cm a fining upward trend has been recorded for 70 cm thickness. From 80 cm onwards a coarsening upward trend has been observed (Fig. 3.1p)

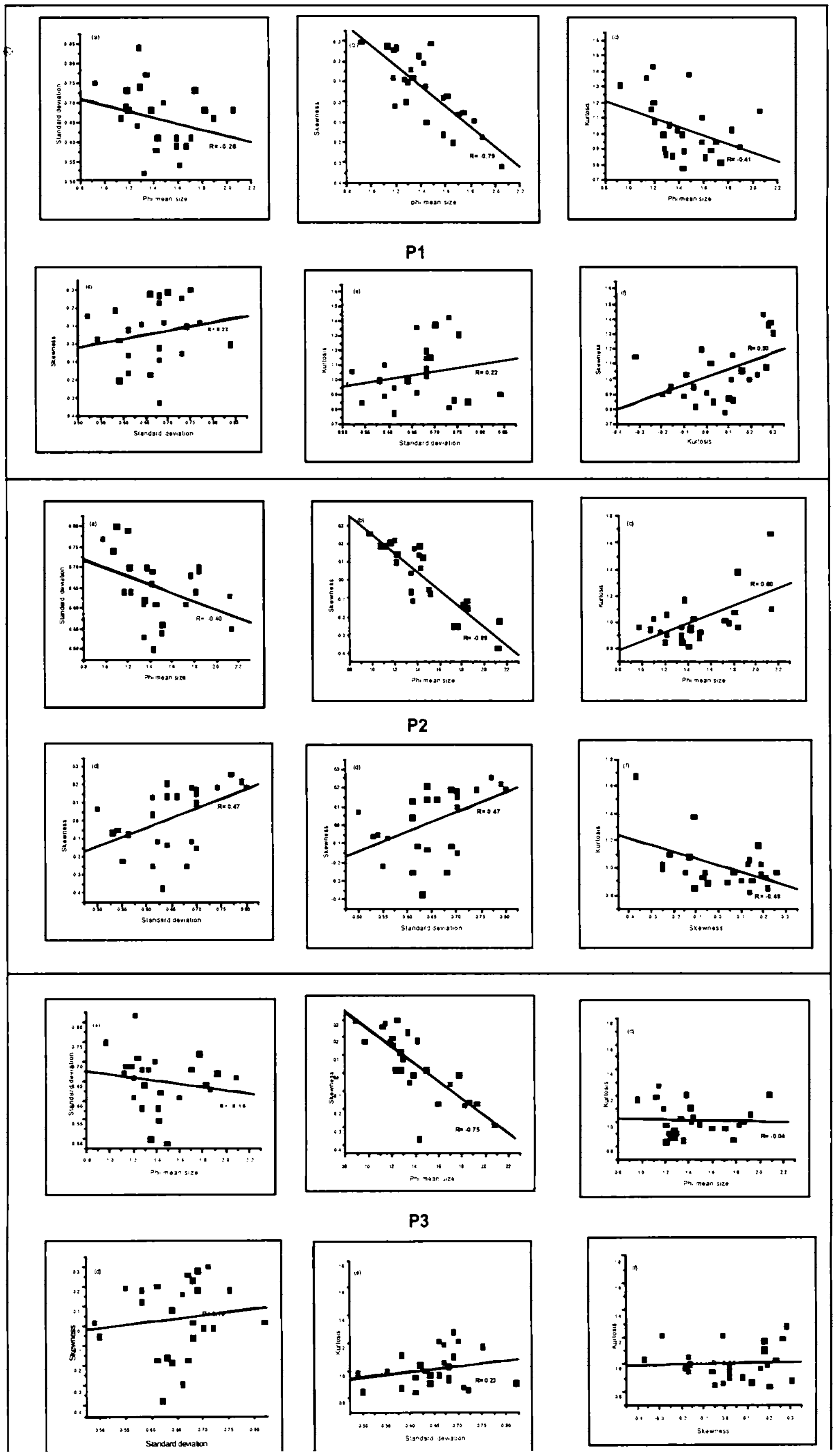
Pit 17: The recorded range of phi mean values are1.09 to 2.21Ø respectively (medium to fine sand). The standard deviation shows that sediments are moderately well sorted to moderately sorted (0.50-0.81Ø). Sediments from this pit are very fine to very coarse skewed (0.28 to -0.29). The kurtosis values are in a range of 0.82 to 1.35, which defines that the samples are platykurtic to leptokurtic. A general coarsening upward of sediments has been observed for a thickness of 60 cm in the bottom most layers, from 250 to 190 cm. From 190 cm to 130 cm a fining upward nature is recorded in the 60 cm thick pile of sediments. A more or less coarsening trend has been observed for the top most sediment layers from 130 to the surface (Fig. 3.1q).

Pit 18: This pit is generally contains medium to fine sand (phi mean values = 1.12 to 2.21∅) with well moderately to moderately sorting (SD = 0.53-0.84∅), very fine to very coarse skewed (0.29 to -0.22) and platykurtic to leptokurtic (0.83-1.33). A general coarsening upward of sediments has been observed from 250 to 150 cm depth. Here the coarsening, instead of being recorded as a single event, has been recorded as two events. From 150 cm to 70 cm, for a thickness of 80 cm, a fining upward trend has been observed. From 70 cm to the surface level an upward coarsening is documented (Fig. 3.1r).

3.2.2 Scatter diagrams

The various statistical parameters such as mean size, standard deviation, skewness and kurtosis have been plotted against each other (Fig. 3.2). Several investigators (Folk and Ward, 1957; Sahu, 1964; Friedman, 1967 and Abed, 1982) have observed significant trends. The mean size of clastic sediments is the statistical average of grain size. Standard deviation or sorting value indicates the particle spread on either side of the average (Folk and Ward, 1957; McKinney and Friedman, 1970). The sediment sorting is good if the spread sizes are relatively narrow. Skewness of sediments in a measure of symmetry of grain size population and reflects environment of deposition (Folk and Ward, 1957; Folk, 1968). In textural analysis skewness is considered as an important parameter because of its extreme sensitivity in subpopulation mixing. Well-sorted unimodal sediments are usually symmetrical with zero skewness. In a fine skewed sediment population, the distribution of grains will be from coarser to finer and the frequency curve

Fig 3.2 Bivariate plots of statistical parameters of beach ridges



chops at the coarser end and tails at the finer. The reverse condition is characteristic of coarse skewed sediments.

The phi mean versus standard deviation shows an almost linear relation (Fig. 3.2). The sorting worsens as the phi mean size decreases. The medium and fine sands ($1\phi - 3\phi$) show moderate to moderately well sorted nature. It is difficult to demarcate the paleoridge sediments from the recent ridge sediments possibly due to the presence of coarse as well as fine sediments in both the ridges. Most of the ridge sediments of the study area with moderately well sorted to moderately sorted nature is symmetrical with respect to skewness even though there is a significant variation in phi mean size of sediments. It is significant to note that if the standard deviation is function of phi mean size, sorting and skewness will bear a mathematical relationship to each other (Folk and Ward, 1957). Symmetrical curve can be obtained either in a unimodal sediments with good sorting or equal mixtures of two modes which have the poorest mode of sorting. With one mode dominant and other subordinate, the sediments exhibit moderate sorting but give extreme values of skewness (Folk and Ward, 1957; McKinney and Friedman, 1970) as observed in most of the sediment samples of both the paleo and the recent beach ridges (Table 3.2).

Perfectly sorted, unimodal sediments have a skewness value zero and very slight deviation on sorting results in near symmetrical skewness. Most of the ridge sediment is fine skewed to coarse skewed (Table 3.1, Fig 3.2). Fine skewness is due to the relative increase of coarse sediments over the fines. Friedman (1967) and Cronan (1972) have indicated that the polymodal sediment can show variable skewness values depending on the specific proportion of subpopulation abundance. The sub samples of the pit sediments of the ridge environment are mostly platykurtic to leptokurtic although very leptokurtic nature is also exhibited. As the sediments are mostly moderately well sorted to poorly sorted, the predominance of fine population makes the sediments mesokurtic to leptokurtic.

3.3 Discussion

Beach ridges are the dominant coastal accumulation of sands (Anthony, 1995). The development and evolution of beach ridges reflects the interplay of several interactive factors. The most important of these factors is the uninterrupted sediment supply, relative sea level and wave characteristics (Anthony, 1995). In places where the sediment supply is rather slow or moderate, the development of beach ridge takes a long time.

In the Central Kerala region, the beach ridge plains are developed in a broad bay. The beach ridge plain in the vicinity of Azhikode has a width of about 2 km and in the Munambam – Puthuvaippu area about 1 to 1.5 km. South of Fort Cochin the width of beach ridge plain varies from a few hundred metres to 1.5 km. The study area can be considered in terms of Davis (1980) model as a cyclone and storm free, but wave dominated coast. Therefore, the wave force is the major mechanism behind the beach ridges formation. Tanner (1987) and Tanner and Demirpokt (1988) distinguished four major well defined sand beach ridges of which swash built ridges and settling lag ridges or the combination of these two types are very common world over than the storm surge and dune ridges.

The vertical pits made in the study area reveal that the beach ridges have formed in many places primarily by swash built type and in other places by settling lag sediments. The swash-built ridges are low angle fair weather beach type with cross bedding (Plate 1). The granulometry of ridges resemble the adjacent fair-weather beach (Tanner, 1995). In this study also the beach ridge sediment and the modern beach sediments (Table 3.2) resemble closely. On the other hand settling-lag ridges have the bedding in horizontal, discontinuous and with out any well defined cross bedding of any kind (Plate 2), and there was no significant wave work in their construction and hence they were made largely by the settling-lag mechanism (Tanner and Demirpolat, 1988). Therefore the coarsening upward sequence indicates that the beach ridges have developed during a progradation period or a small level fall in sea level. The beach ridges in the study area would have been constructed from near shore sand supplies by infilling the shallow sea that served as an important trap for the river borne sediments supplied from the adjoining rivers such as Bharatapuzha, Periyar, Meenachil and Pamba. Alongshore drift has also a major role in building the sand ridges as the major drift in the locality during southwest monsoon is towards south.

Table 3.2. Grain size parameters of the modern beach sands

Location	Phi mean	Standard Deviation	Skewness	Kurtosis
A	1.60	0.70	-0.01	1.00
B	2.01	0.57	-0.08	1.07
C	2.25	0.58	-0.01	1.31
D	2.37	0.79	-0.04	0.93
E	0.92	0.89	0.08	1.01
F	2.31	0.41	0.07	1.39
G	1.46	1.27	-0.20	0.64
H	1.31	0.59	0.10	0.94

Sand supplies from the nearshore zone for beach ridge construction have widely been reported in the literature where adequate sand supply from rivers or deltas is not available (Tanner, 1987). Curray et al., (1969), Tanner (1988), Stapor et al., (1991), Thom et al.,(1981), Short et al., (1991) all have advocated that nearshore source of sand for beach ridge growth. A falling sea level, which leads to lowering of wave base, is commonly recognized as an important factor in the building of successive beach ridges (Carter, 1988; Anthony, 1991). Onshore supply of sand may have been enhanced by sea level fall (Anthony, 1995). In regressive beach ridges the general concept is that depositional surfaces dip downwards parallel to the present beach and shore face (Kraft and John, 1979). In accordance with the above concept the vertical pit made at Puthuvaippu- a prograding type of coast- shows a clear seaward dipping sequence, attesting that a progradation of the beach ridges is accompanied by a coarsening upward sequence (Fig. 3.1a-r). The beach ridge sands in coarsening upward sequence are uniformly fine to medium sand and moderately well sorted with subtle changes in sorting. In contrast, the fining upward sequence would have formed in a small scale sea-level rise and therefore, the sediments range from fine to very fine category.

3.4 Textural classification of sediments

3.4.1 Alluvial plain: Table 3.3 indicates the weight percentage of sand, silt and clay in various environments such as alluvial plains, intertidal mudflats and swales. From Fig. 3.3a it is evident that the alluvial plain sediments are of two types namely clay and sandy mud. The sand percentage varies from 7.9 to 28.3%. A variation from 9.4 to 49.28% for silt and clay respectively has been recorded. A 10 cm layer rich in clay has been observed at depth 100-110 cm in P21. Sandy clay is the predominant type of sediment in P21 while sandy mud and sandy clay have been recorded in P19.

3.4.2 Swales: As far as the sediment composition is concerned, sandy clay is the most prominent type observed in both in P20 and P23 (Fig.3.3b). Sandy mud is also recorded at 30-40cm depth in the pit samples and at a depth of 120-150cm in P20. In P23 sandy mud has been observed at 80-110 cm depth and again in 140-150cm depth (Table.3.3).

3.4.3 Intertidal mudflats: A variation in sand content from 9.87 to 27.09% has been recorded in the intertidal mudflat sediments (Table.3.3). A similar variation between 10.4 and 48.84% for silt and 26.51 to 78.54% for clay

Table 3.3. Distribution of sand, silt and clay in sediments with their nomenclature in different environments

P 19 Alluvial plain

Depth (cm)	Sand %	Silt %	Clay %	Nomenclature
0-10	11.02	31.51	57.47	sandy clay
10-20	11.56	29.76	58.68	sandy clay
20-30	10.29	33.9	55.81	sandy clay
30-40	15.42	32.72	51.86	sandy clay
40-50	28.15	42.01	29.84	sandy mud
50-60	15.64	29.12	55.24	sandy clay
60-70	10.19	33.89	55.92	sandy clay
70-80	11.52	30.9	57.58	sandy clay
80-90	11.87	29.31	58.82	sandy clay
90-100	11.01	29.31	59.68	sandy clay
100-110	22.45	47.12	30.43	sandy mud
110-120	18.27	29.32	52.41	sandy clay
120-130	32.3	34.85	32.85	sandy clay
130-140	20.6	49.28	30.12	sandy mud
140-150	27.12	46.24	26.64	sandy mud
150-160	32.5	36.65	30.85	sandy mud
160-170	22.52	28.31	49.17	sandy clay
170-180	14.58	28.82	56.6	sandy clay
180-190	21.86	47.12	31.02	sandy mud
190-200	28.31	25.64	46.05	sandy clay

P 21 Alluvial plain

Depth (cm)	Sand %	Silt %	Clay %	Nomenclature
0-10	10.58	31.95	57.47	sandy clay
10-20	11.52	31.58	56.9	sandy clay
20-30	13.6	21.1	65.3	sandy clay
30-40	13.4	30.32	56.28	sandy clay
40-50	12.84	29.6	57.56	sandy clay
50-60	11.95	28.2	59.85	sandy clay
60-70	14.15	33.9	51.95	sandy mud
70-80	22.68	47.2	30.12	sandy clay
80-90	10.3	34.7	55	sandy clay
90-100	10.6	9.4	80	sandy clay
100-110	7.9	33.2	58.9	mud
110-120	11.12	25.1	63.78	sandy clay
120-130	10.2	32.7	57.1	sandy clay

Table 3.3 continued

P 24 Intertidal mudflat

Depth (cm)	Sand %	Silt %	Clay %	Nomenclature
0-10	10.82	24.1	65.08	sandy clay
10-20	11.54	27.32	61.14	sandy clay
20-30	11.9	26.58	61.52	sandy clay
30-40	10.7	25.12	64.18	sandy clay
40-50	10.2	31.7	58.1	sandy clay
50-60	10.5	10.4	79.1	sandy clay
60-70	9.87	11.59	78.54	sandy clay
70-80	10.4	25.58	64.02	sandy clay
80-90	11.7	23.7	64.6	sandy clay
90-100	9.77	12.13	78.1	sandy clay
100-110	10.3	10.9	78.8	sandy clay
110-120	11.01	26.1	62.89	sandy clay
120-130	11.12	25.79	63.09	sandy clay
130-140	11.45	23.32	65.23	sandy clay
140-150	10.3	27.7	62	sandy clay

P 22 Intertidal mudflat

Depth (cm)	Sand %	Silt %	Clay %	Nomenclature
0-10	13.24	29.21	57.55	sandy clay
10-20	12.81	28.54	58.65	sandy clay
20-30	21.45	46.12	32.43	sandy mud
30-40	17.22	27.52	55.26	sandy clay
40-50	30.57	34.51	33.92	sandy clay
50-60	21.04	48.84	30.12	sandy mud
60-70	25.55	47.94	26.51	sandy mud
70-80	31.25	37.91	30.84	sandy mud
80-90	27.09	24.28	48.63	sandy clay

Table 3.3 continued

P 20 Swale

Depth (cm)	Sand %	Silt %	Clay %	Nomenclature
0-10	11.01	30.31	58.68	sandy clay
10-20	16.45	27.3	56.25	sandy clay
20-30	10.3	34.7	55	sandy clay
30-40	22.58	46.58	30.84	sandy mud
40-50	14.56	28.32	57.12	sandy clay
50-60	11.19	32.89	55.92	sandy clay
60-70	14.52	30.9	54.58	sandy clay
70-80	10.01	31.31	58.68	sandy clay
80-90	11.34	29.31	59.35	sandy clay
90-100	20.93	49.27	29.8	sandy mud
100-110	13.4	29.32	57.28	sandy clay
110-120	31.8	33.84	34.36	sandy clay
120-130	26.76	44.57	28.67	sandy mud
130-140	28.85	45.6	25.55	sandy mud
140-150	31	38.15	30.85	sandy mud
150-160	22.79	31.54	45.67	sandy clay
160-170	14.45	30.92	54.63	sandy clay

P 23 Swale

Depth (cm)	Sand %	Silt %	Clay %	Nomenclature
0-10	11.85	31.52	56.63	sandy clay
10-20	14.87	33.85	51.28	sandy clay
20-30	10.3	34.7	55	sandy clay
30-40	22.68	47.2	30.12	sandy mud
40-50	13.33	31.44	55.23	sandy clay
50-60	10.78	33.73	55.49	sandy clay
60-70	11.85	30.9	57.25	sandy clay
70-80	19.56	26.35	54.09	sandy clay
80-90	31.45	36.12	32.43	sandy mud
90-100	25.51	45.12	29.37	sandy mud
100-110	24.48	48.79	26.73	sandy mud
110-120	31.68	34.78	33.54	sandy clay
120-130	21.67	31.47	46.86	sandy clay
130-140	15.53	30.15	54.32	sandy clay
140-150	22.68	47.12	30.2	sandy mud
150-160	25.19	28.32	46.49	sandy clay
160-170	33.3	27	39.7	sandy clay
170-180	11.95	28.4	59.65	sandy clay

Table 3.3 continued

P 25 Mangrove

Depth (cm)	Sand %	Silt %	Clay %	Nomenclature
0-10	15.62	54.75	29.63	sandy mud
10-20	22.42	51.72	25.86	sandy mud
20-30	15.82	54.55	29.63	sandy mud
30-40	23.21	49.45	27.34	sandy mud
40-50	19.82	52.55	27.63	sandy mud
50-60	13.81	56.27	29.92	sandy mud
60-70	37.36	40.17	22.47	sandy mud
70-80	34.99	47.23	17.78	sandy mud
80-90	31.92	51.87	16.21	sandy mud
90-100	32.39	53.44	14.17	sandy mud
100-110	26.84	49.82	23.34	sandy mud
110-120	25.71	50.89	23.4	sandy mud
120-130	24.21	50.16	25.63	sandy mud
130-140	25.74	50.91	23.35	sandy mud
140-150	33.91	49.01	17.08	sandy mud

P 26 Mangrove

Depth (cm)	Sand %	Silt %	Clay %	Nomenclature
10-20	92.15	3.84	4.01	clayey sand
20-30	88.36	7.97	3.67	sand
30-40	87.72	7.92	4.36	clayey sand
40-50	91.33	4.61	4.06	clayey sand
50-60	87.43	8.92	3.65	clayey sand
60-70	84.03	6.41	9.56	clayey sand
70-80	59.72	22.28	18	clayey sand
80-90	65.49	19.22	15.29	clayey sand
90-100	66.37	16.66	16.97	clayey sand
100-110	67.58	12.72	19.7	clayey sand
110-120	72.76	8.42	18.82	clayey sand
120-130	73.37	8.78	17.85	clayey sand
130-140	70.55	14.51	14.94	clayey sand
140-150	64.16	14.99	20.85	clayey sand

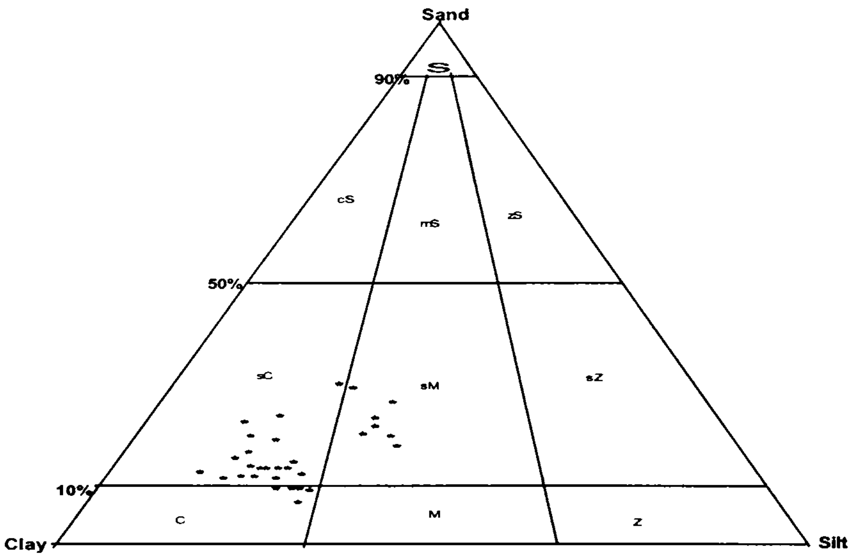


Fig 3.3 a Ternary diagram illustrating the nature of sediments in alluvial plain

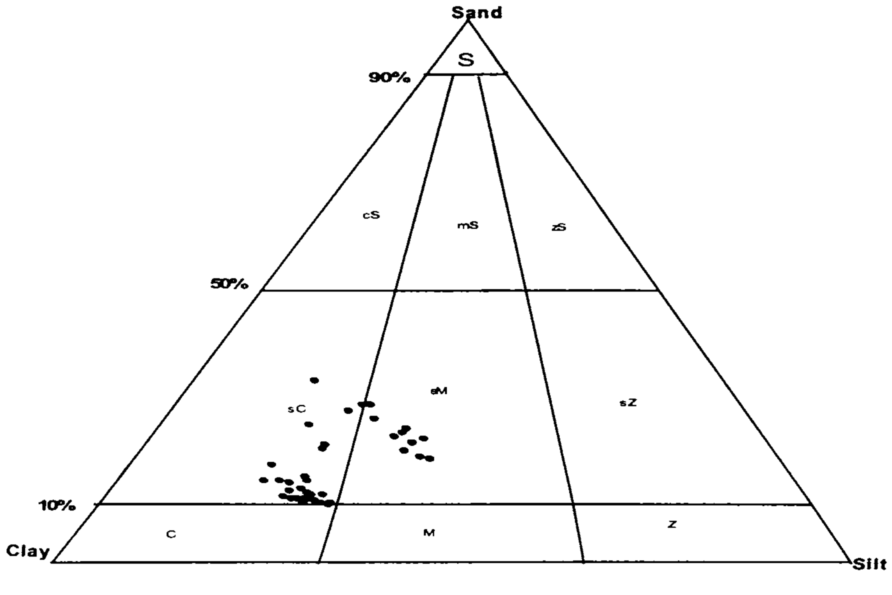


Fig 3.3 b Ternary diagram illustrating the nature of sediments in swale

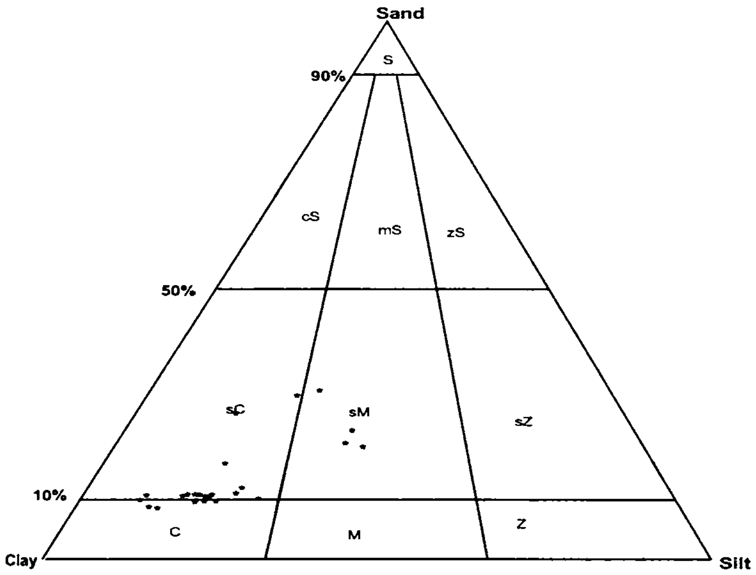


Fig 3.3 c Ternary diagram illustrating the nature of sediments in the intertidal mudflat

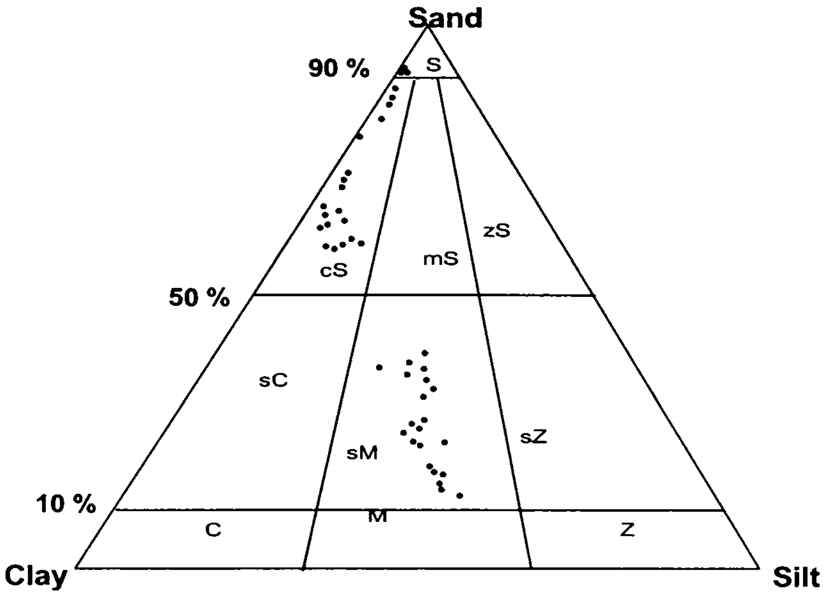


Fig 3.3 d Ternary diagram illustrating the nature of sediments in the mangrove

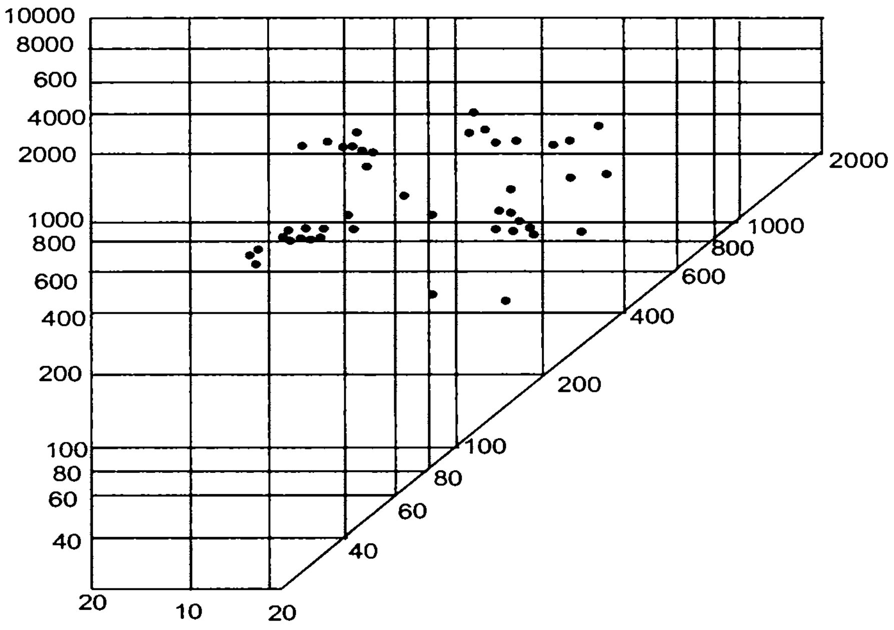


Fig 3.4 CM Pattern of Sediments of Mangroves

fractions has been exhibited. Sandy clay is the only type of sediment recorded in P24 while sandy clay and sandy mud are observed in P22 (Fig.3.3c).

3.4.4 Mangrove sediments: The three sampling sites P25, P26 and P27 show considerable variation in textural parameters as well as sand silt clay ratio of mangrove sediments (Table 3.3) (Fig. 3.4) .In P25 mangrove the minimum sand percentage is 15.62 and in P27 mangrove the minimum is 16.82 P26 is showing a uniformly higher % of sand. In P26 the lower sand percentage is 64.16. The upper sand limit is 34.99% in P25, 67.81% in P27 and 92.15% in P26. Both in P25 and P27 a gradual increase in sand content with depth is noticed. The bottom most samples collected at 150 cm depth show sand content of 33.91% in P25, 64.16% in P26 and 65.76% in P27. Unlike P25 and P27 the mangroves at P26 shows a decreasing sand content with depth. (Fig. 3.3d)

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CHAPTER 4

MINERALOGY

4.1 Introduction

Minerals are integral part of rocks and sediments. Assemblage of heavy and light minerals in sedimentary deposits has been used for many years to unravel the sources and transportation history of sediments. Worldwide, the mineralogical make up of sediments is used for the evaluation of various physico-chemical processes involved during weathering, transportation and deposition. The knowledge of relative abundance of heavy fractions renders valuable information on the nature of contribution, longshore transport direction and energy conditions of the depositing medium.

Studies on mineralogical composition of sediments should always accompany the study on textural characteristics, as the texture has a direct bearing on the mineralogical constitution of sediments. In many published literatures heavy minerals are examined in several fractions of sediments to represent the entire heavy mineralogical assemblage of sediments. This is so because heavy minerals are deposited according to the difference in size, shape and density and hence a single size fraction seldom represents the entire mineralogical composition of the sediments (Rubey, 1933; Rittenhouse, 1943; Friedman, 1961; Mishra, 1969; Blatt et al., 1972 and Patro et al., 1989). Moreover, knowledge of size frequency distribution of individual minerals is essential to understand the interaction between physical properties of minerals and the physical processes operated at the time of transportation and deposition. Further, heavy minerals serve as a source of information about the nature of initial size distribution resulting from the mechanical disintegration at the source, the effect of dynamic processes on the original size distribution and assertion in nature of the phenomenon of hydraulic equivalence of sizes.

4.2. Review of Literature

The era of modern heavy mineralogy begins with the classic work of Rubey (1933), who explained precisely about the size distribution of heavy minerals in sedimentary deposits using settling velocity equation. Subsequently Rittenhouse (1943) stressed the complex interrelationship between source rock characteristics and transport processes that determine the heavy mineral distribution in fluvial setup. Ever since the introduction of hydraulic equivalent concept by Rubey (1933), it has been widely recognized that the hydraulic behaviour of heavy minerals is jointly influenced by their physical properties (size, shape and density), availability of the minerals and dynamics of the transporting medium. Since then the studies on detrital heavy minerals received wide attention due to their strong bearing on the provenance of the sediments as well as their wide use as a correlation tool in solving various sedimentological problems. Briggs (1965) investigated the interrelationships between various heavy minerals and the influence of size, shape and density on hydraulic sorting. Blatt and Sutherland (1969) have shown that the rate of chemical alteration is greater in coarse-grained sediments than in less permeable fine-grained sediments due to the availability of enough intrastratal solution in the former. Bradley (1957), Van Andel and Pooley (1960), Lowright et al. (1972), Stapor (1973), Stingerland (1977), Flores and Shideler (1978), Morton (1986) and Statteger (1987) have used the heavy mineral assemblages in unravelling the transportational and depositional history of sediments.

The effects of physical and chemical weathering on minerals are often difficult to distinguish (Edelman and Doeglas, 1933; Dryden and Dryden, 1946; and Raeside, 1959). Pettijohn (1941) advocated that the diversities in heavy mineral assemblages are more in the younger sediments than ancient ones, and further, the number of heavy mineral species may gradually decrease as the age of the sediment increases. Such a decrease in the heavy mineral species could be primarily due to the action of intrastratal solution (Pettijohn, 1941). In contrast, Krynine (1942) stressed that provenance as the key factor for the above said mineralogical diversities. Allen (1970), Carver (1971), Blatt et al. (1972), Komar and

Wang (1984) and Komar et al. (1989) have studied the role of progressive sorting based on size and specific gravity differences. Coastal placers of Florida coast have been carried out by Elsner (1982). Hamilton and Collins (1998) have made a detailed analysis on the placer formation processes on the south western coast of Australia.

In India, detailed studies on heavy mineral assemblages of the beach sands, teri sands, beach ridges and dunes have been carried out since 1950. Jacob (1956) made a detailed study on the heavy minerals of the beach sands of Thirunelveli, Ramanadhapuram and Thanjavur districts of Tamil Nadu. The heavy mineral assemblages of Tamil Nadu beach and coastal plain region have been investigated by several workers (Chandrasekar, 1992; Angusamy, 1995; Mohan 1995; Chandrasekar and Rajamanickam, 1997; Angusamy and Rajamanickam 2000 a and b; Chandrasekar and Rajamanickam, 2001; Chandrasekar et al. 2003). Rao (1989), Sengupta et al. (1990), Acharya and Panigrahy (1998) have studied the coastal placers of Orissa coast. Roy (1958), Ramohana Rao et al. (1983) investigated the heavy mineral suites of Visakhapatnam-Bhimunipatnam areas. Mahadevan and Rao (1960) discussed the heavy mineral concentrates of Visakhapatnam beach. Tipper (1914) and Brown and Dey (1955) have studied the heavy mineral deposits between Quilon and Kanyakumari on the southwest coast of India. Investigators like Aswathanarayana (1964), Prabhakara Rao (1968), Mallik (1986), Unnikrishnan (1987), Purandara et al. (1987), Sasidharan and Damodaran (1988), Purandara (1990) and Krishnan et al. (2001) have studied the heavy mineral suite of the beach sands of Kerala. Rajendran et al. (1996) have investigated the heavy mineral composition of lower Bharathapuzha river sediments and their influence on the geochemical constituents of bed sediments. Babu and Seralathan (2005) have made a detailed study on the buried placer deposits of the central Kerala coast between Periyar and Bharathapuzha rivers. Padmalal et al., (1998) made a detailed account of mineral suites of Muvattupuzha river and Vembanad estuary. The heavy mineral deposits of the shelf region of the west coast of India have also been studied by several investigators (Mallik, 1974; Siddique et al., 1979; Siddique and Rajamanickam, 1979; and Rajamanickam, 1983). Mallik

(1981) made a detailed study on the distribution pattern of heavy minerals of the continental shelf of Kakinada. Kidwai et al. (1981) have investigated the distribution of heavy minerals in the outer continental shelf sediments between Vengurla and Mangalore. They have suggested that heavy mineral assemblages of sediments indicate mixed igneous and metamorphic provenance. Detailed geological and geophysical surveys conducted along the Konkan coast by Gujar et al. (1989) revealed the occurrences of several promising isolated placer deposits.

4.3 Results

The total heavy mineral content from beach ridge in different size classes at four depth ranges namely 0-50cm, 50-100cm, 100-150cm and 150-200cm levels are given in Tables 4.1-4.3.The individual mineral species identified in the three sectors at different depth under different size classes are present in Tables 4.1-4.3 and their distributions are present in Figs. 4.1.1.1-4.3.2.4. The heavy minerals have been studied by diving the area into three sectors namely the northern (north of Periyar river), central (between Periyar river and Vembanad inlet) and the southern (south of Vembanad inlet).

4.3.1 Total Heavy Minerals

A distinct variation in the total heavy mineral percentage is observed (Table 4.1) in the representative pits (P1,5,7,11,13,15, and 17) between sectors.

Northern sector: Total heavy mineral content in medium sand fractions of P1 varies in 0-50cm, 50-100cm, 100-150cm and 150-200cm depth zones, which has been recorded as 4.28%, 14.59%, 21.05% and 26.01% respectively. In the fine sand fractions 12.52%, 27.56%, 32.89% and 54.55% are the concentrations from the four depth zones mentioned above. Down pit variation in the total heavy mineral content has been observed in the very fine fractions of sand from 0-50cm, 50-100cm, 100-150cm and 150-200cm depth zones with the corresponding values of 14.19%, 41.34%, 54.47% and 71.93%. In the medium sand fraction of the

Table 4.1 Variation of heavy mineral from different pits from different depths (count %) – (Northern Sector)

P 1

Total HM (%)	4.28	12.52	14.19	14.59	27.56	41.34	21.05	32.89	54.47	26.01	54.55	71.93
Mineral	Depth 0- 50 cm			Depth 50- 100 cm			Depth 100- 150 cm			Depth 150 -200 cm		
	MS	FS	VFS	MS	FS	VFS	MS	FS	VFS	MS	FS	VFS
Actinolite	0.00	1.00	6.00	0.67	3.00	1.00	0.67	4.00	2.67	0.67	3.00	1.00
Tremolite	0.00	5.33	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hornblende	0.00	4.67	0.33	1.67	1.33	0.67	2.33	1.67	0.67	1.67	0.00	1.33
Glaucophane	18.67	17.00	10.67	20.33	4.00	1.00	19.67	4.00	1.00	15.67	0.67	20.00
Hypersthene	6.00	9.67	19.67	8.67	12.67	2.33	6.67	12.00	2.33	6.67	2.33	6.67
Biotite	5.00	7.00	10.00	1.67	10.67	5.67	1.67	10.33	5.67	1.67	0.00	1.67
Chlorite	49.00	26.67	9.67	29.00	27.00	2.67	31.00	26.33	3.00	33.33	5.33	26.67
Epidote	6.67	2.67	1.00	3.33	0.67	0.00	3.67	0.67	0.00	3.33	0.00	0.00
Garnets	8.67	17.00	27.67	6.67	29.33	3.67	3.67	29.67	3.67	3.33	8.33	7.00
Monazite	0.00	0.00	0.00	0.00	0.00	3.00	0.00	0.00	2.33	0.00	0.00	6.67
Rutile	0.00	0.00	0.00	0.00	0.00	3.33	0.00	0.00	3.67	0.00	0.00	1.67
Sillimanite	0.00	3.00	2.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Topaz	0.00	0.00	1.00	1.67	2.67	0.00	1.67	2.00	0.00	1.67	1.33	1.33
Tourmaline	5.33	3.67	0.67	1.67	4.00	0.00	2.33	4.00	0.00	1.67	5.33	1.33
Zircon	0.00	1.00	3.00	0.00	3.33	9.67	0.00	3.67	9.33	0.00	8.00	0.00
Opaques	0.67	1.33	3.67	24.67	1.33	67.00	26.67	1.67	65.67	30.33	65.67	24.67

Table 4.1 continued

P 5

Total HM (%)	8.23	15.84	21.52	12.24	30.14	55.59	32.87	56.85	78.91	37.52	68.84	87.52
Mineral	**pth 0- 50 cm**			**Depth 50- 100 cm**			**Depth 100- 150 cm**			**Depth 150 -200 cm**		
	MS	**FS**	**VFS**	**MS**	**FS**	**VFS**	**MS**	**FS**	**VFS**	**MS**	**FS**	**VFS**
Actinolite	0.33	1.00	5.00	0.67	2.33	1.67	0.67	3.67	2.67	0.67	2.67	0.67
Tremolite	0.67	5.33	4.00	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hornblende	0.33	5.00	0.33	1.67	1.67	1.00	2.00	1.33	0.67	1.67	0.00	1.33
Glaucophane	17.33	19.00	10.67	21.00	5.00	2.00	19.67	4.00	1.33	15.33	1.00	20.33
Hypersthene	9.67	10.00	20.00	7.33	13.67	2.67	6.67	12.33	2.33	6.67	2.33	7.00
Biotite	6.33	7.00	9.00	2.00	10.00	4.67	1.00	11.33	5.67	2.00	0.00	2.67
Chlorite	45.33	26.33	8.67	26.33	26.00	2.33	30.33	25.33	3.00	35.33	5.33	24.33
Epidote	5.33	2.33	0.67	3.33	0.33	0.33	3.33	0.67	0.00	2.33	0.00	0.00
Garnets	8.33	15.67	29.33	6.33	29.00	3.67	3.00	31.33	3.33	3.33	8.67	6.67
Monazite	0.00	0.33	0.00	0.00	0.00	2.00	0.00	0.00	2.67	0.00	0.00	6.00
Rutile	0.00	0.00	0.00	0.00	0.00	4.33	0.00	0.00	3.33	0.00	0.00	1.67
Sillimanite	0.00	2.67	2.00	0.00	0.33	0.00	0.00	0.33	0.00	0.00	0.00	0.00
Topaz	0.00	0.00	0.67	1.33	2.00	0.33	1.33	2.00	0.00	1.00	1.33	1.67
Tourmaline	5.00	3.33	1.00	2.00	4.00	0.33	2.00	3.00	0.00	1.00	5.00	1.67
Zircon	0.00	0.33	3.00	0.00	3.00	8.67	0.00	3.33	8.67	0.00	7.67	0.00
Opaques	1.33	1.67	5.67	27.67	2.33	66.00	30.00	1.33	66.33	30.67	66.00	26.00

Table 4.2 Variation of heavy mineral from different pits from different depths (count %) – (Central Sector)

P 7

Total HM (%)	10.25	22.64	45.58	18.89	42.2	59	69.72	51.02	81.24	68.45	51.92	79.52
Mineral	**Depth 0- 50 cm**			**Depth 50- 100 cm**			**Depth 100- 150 cm**			**Depth 150 -200 cm**		
	MS	**FS**	**VFS**	**MS**	**FS**	**VFS**	**MS**	**FS**	**VFS**	**MS**	**FS**	**VFS**
Actinolite	4.00	4.67	6.33	8.00	6.67	1.33	8.67	4.00	2.67	7.33	2.67	1.00
Enstatite	2.67	11.33	7.33	1.00	1.67	0.33	0.33	0.67	0.33	0.33	0.67	0.33
Hornblende	3.33	13.00	4.00	5.33	8.33	6.33	6.67	4.00	3.33	4.00	2.67	6.00
Augite/ Diopsic	17.00	18.33	20.67	20.00	8.67	4.00	6.00	4.00	2.67	3.33	1.33	22.67
Hypersthene	11.67	10.00	10.67	6.67	14.67	6.67	6.00	16.67	6.00	5.33	10.33	15.67
Biotite	6.67	7.00	8.67	1.33	9.67	4.67	1.00	2.33	6.00	2.33	0.33	3.00
Chlorite	32.00	20.67	13.00	24.00	25.00	21.67	27.67	28.00	23.00	31.00	12.33	21.00
Epidote	6.67	2.00	1.67	3.33	1.33	0.33	4.67	2.67	0.33	1.00	3.33	1.00
Garnets	11.33	5.00	10.33	6.67	7.67	4.00	3.67	9.67	5.00	5.67	7.33	4.00
Monazite	0.00	0.00	0.00	0.33	0.67	1.33	0.33	0.67	2.00	0.33	0.67	0.00
Rutile	0.00	0.67	0.00	0.00	0.67	1.33	0.00	0.67	1.33	0.00	0.33	0.33
Sillimanite	0.00	2.33	2.67	0.67	1.33	0.67	0.00	1.67	0.67	0.67	2.67	0.33
Kyanite	0.00	0.33	0.67	0.67	2.00	0.33	0.00	1.33	0.00	0.33	0.67	0.00
Staurolite	3.67	1.00	1.00	1.33	2.33	0.00	1.00	1.00	0.33	0.33	6.00	0.33
Zircon	0.00	3.00	0.67	0.33	4.67	6.67	3.33	5.33	6.67	5.33	15.67	4.00
Opaques	1.00	0.67	12.33	20.33	4.67	40.33	30.67	17.33	39.67	32.67	33.00	20.33

Table 4.2 continued

P 11

Total HM (%)	4.56	15.89	47.35	6..89	17.73	21.25	11.56	18.63	23.69	14.89	18.85	26.6
Mineral	**Depth 0- 50 cm**			**Depth 50- 100 cm**			**Depth 100- 150 cm**			**Depth 150 -200 cm**		
	MS	**FS**	**VFS**	**MS**	**FS**	**VFS**	**MS**	**FS**	**VFS**	**MS**	**FS**	**VFS**
Actinolite	2.33	0.67	0.00	2.00	0.67	0.00	1.33	1.00	0.00	0.33	0.00	0.00
Tremolite	0.33	5.00	0.00	0.67	5.67	0.33	1.00	4.67	0.67	0.33	0.00	0.33
Hornblende	10.00	10.33	11.00	10.67	11.67	12.33	11.67	12.00	12.67	12.67	13.00	13.00
Glaucophane	15.00	16.67	18.33	13.33	15.00	15.67	2.00	1.33	1.00	0.67	0.67	2.33
Hypersthene	9.33	10.00	11.33	11.00	12.67	12.33	12.67	16.67	13.67	12.67	13.67	15.00
Biotite	6.67	7.00	7.33	4.67	1.33	2.67	6.00	2.33	3.67	3.00	4.00	3.00
Chlorite	30.00	30.33	30.00	27.67	29.67	29.33	28.33	28.00	30.33	30.00	29.00	28.33
Epidote	7.00	2.00	1.67	1.67	0.00	0.00	1.00	0.67	1.00	1.67	1.33	1.00
Garnets	11.00	11.00	11.33	8.33	6.67	7.00	7.67	6.67	8.33	9.00	9.67	10.00
Monazite	0.67	0.33	0.00	0.33	0.33	0.00	0.33	0.33	0.33	0.00	0.67	0.00
Rutile	0.00	0.67	0.00	0.00	0.33	0.33	0.00	0.00	0.67	0.33	0.33	0.33
Sillimanite	1.00	2.00	2.67	0.67	0.67	0.67	0.00	0.67	1.67	1.00	2.67	0.67
Topaz	3.33	2.00	0.00	0.00	0.33	0.00	0.00	0.33	0.00	0.33	0.67	0.00
Apatite	2.00	1.33	0.00	0.00	0.33	0.00	1.33	0.00	0.67	0.33	0.33	0.33
Zircon	0.33	0.33	1.00	2.33	1.33	1.33	0.00	2.00	2.33	1.33	1.67	4.00
Opaques	1.00	0.33	5.33	16.67	13.33	18.00	26.67	23.33	23.00	26.33	22.33	21.67

Table 4.2 continued

P 13

Total HM (%)	6.54	12.58	16.5	12.03	19.35	31.52	21.89	81.38	93.85	17.07	69.47	87.63
Mineral	**Depth 0- 50 cm**			**Depth 50- 100 cm**			**Depth 100- 150 cm**			**Depth 150 -200 cm**		
	MS	**FS**	**VFS**	**MS**	**FS**	**VFS**	**MS**	**FS**	**VFS**	**MS**	**FS**	**VFS**
Actinolite	0.00	0.67	0.00	0.33	0.00	0.00	0.33	0.00	0.00	0.33	0.00	0.00
Tremolite	0.33	5.00	0.00	0.00	1.00	0.33	0.33	0.67	0.00	0.33	0.00	0.33
Hornblende	15.00	15.67	16.67	16.00	16.33	18.33	16.67	17.33	17.67	17.00	17.67	18.67
Glaucophane	18.67	16.67	18.33	13.33	2.00	1.00	2.00	1.33	1.00	0.67	0.67	1.67
Hypersthene	6.67	10.00	11.33	6.67	13.67	14.00	12.67	16.67	13.67	12.67	13.67	14.00
Biotite	5.00	7.00	7.33	5.00	2.33	4.00	6.00	2.33	3.67	3.00	4.00	3.00
Chlorite	35.00	32.00	30.00	27.67	29.67	25.33	28.33	28.00	30.33	32.33	30.00	32.00
Epidote	7.00	2.00	1.67	3.33	1.00	0.33	1.00	0.67	1.00	1.67	1.33	1.00
Garnets	8.67	5.00	4.33	4.00	3.67	4.00	4.33	4.00	5.00	4.00	4.33	4.00
Monazite	0.00	0.00	0.00	0.33	0.33	0.00	0.33	0.33	0.33	0.00	0.67	0.00
Rutile	0.00	0.67	0.00	0.00	0.33	0.33	0.00	0.00	1.33	0.33	0.33	0.33
Sillimanite	1.00	1.33	2.67	0.67	0.67	0.67	0.00	1.67	2.33	1.00	2.67	0.33
Topaz	0.00	0.33	0.00	0.00	0.33	0.00	0.00	0.33	0.00	0.33	0.67	0.00
Apatite	1.33	0.00	0.00	0.00	0.33	0.00	1.33	0.00	0.67	0.33	0.00	0.33
Zircon	0.33	3.00	2.67	2.67	3.33	6.67	0.00	2.67	3.33	1.33	1.67	4.00
Opaques	1.00	0.67	5.00	20.00	25.00	25.00	26.67	24.00	19.67	24.67	22.33	20.33

Table 4.3 Variation of heavy mineral from different pits from different depths (count %) – (Southern Sector)

P 15

Total HM (%)	12.85	17.52	38.49	15.42	25.64	32.89	18.32	48.96	61.25	32.52	52.96	72.55
Mineral	**Depth 0- 50 cm**			**Depth 50- 100 cm**			**Depth 100- 150 cm**			**Depth 150 -200 cm**		
	MS	**FS**	**VFS**	**MS**	**FS**	**VFS**	**MS**	**FS**	**VFS**	**MS**	**FS**	**VFS**
Actinolite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Enstatite	1.33	2.33	0.67	2.67	1.67	2.00	1.33	1.00	2.67	2.00	0.33	1.33
Hornblende	33.33	34.33	38.67	31.33	33.00	31.67	31.67	36.33	34.00	31.00	38.00	40.67
Augite/ Diopside	1.33	1.00	1.00	1.00	2.00	0.67	1.00	1.33	1.00	0.67	0.67	1.67
Hypersthene	13.00	13.33	13.67	13.00	13.67	14.00	12.67	13.33	13.67	12.67	13.67	14.00
Biotite	3.67	5.00	4.33	3.00	3.33	6.33	5.33	4.33	5.67	6.00	4.67	3.33
Chlorite	2.33	3.00	2.00	3.00	2.33	3.33	2.00	2.33	2.33	3.00	4.00	1.67
Epidote	1.33	1.00	1.67	0.67	1.00	1.00	1.33	0.67	1.00	1.67	1.33	2.00
Garnets	4.00	3.67	4.33	3.33	3.67	4.00	4.33	4.00	5.00	4.00	4.33	4.67
Monazite	1.00	1.33	0.67	1.00	1.67	0.67	1.67	1.33	1.00	1.33	0.33	0.33
Rutile	1.67	1.00	2.00	1.33	2.33	1.67	1.00	1.33	2.00	1.33	0.67	2.00
Sillimanite	4.00	3.00	3.33	3.00	3.67	5.00	4.67	3.67	5.00	4.33	3.33	3.00
Glaucophane	0.00	0.33	0.33	0.00	0.33	0.00	0.00	0.33	0.00	0.33	0.67	0.33
Staurolite	0.00	0.00	0.33	0.00	0.33	0.33	0.67	0.00	0.67	0.00	0.00	0.00
Zircon	6.67	6.33	6.00	5.67	6.00	6.67	6.00	6.00	6.33	6.67	6.00	6.33
Opaques	26.33	24.33	21.00	31.00	25.00	22.67	26.33	24.00	19.67	25.00	22.00	18.67

Table 4.3 continued

P 17

Total HM (%)	11.98	27.56	51.69	14.03	37.52	56.89	10.58	39.15	56.14	18.69	46.78	72.30
Mineral	**Depth 0- 50 cm**			**Depth 50- 100 cm**			**Depth 100- 150 cm**			**Depth 150 -200 cm**		
	MS	**FS**	**VFS**	**MS**	**FS**	**VFS**	**MS**	**FS**	**VFS**	**MS**	**FS**	**VFS**
Actinolite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Enstatite	0.67	0.33	0.00	1.33	1.00	0.33	1.33	0.67	0.00	0.00	0.00	1.00
Hornblende	43.33	45.00	46.67	41.67	45.00	43.33	45.00	46.67	47.33	46.67	47.33	48.33
Augite/ Diopside	1.67	1.00	1.33	1.67	2.67	1.67	1.33	1.67	1.33	1.00	1.33	2.00
Hypersthene	12.33	12.67	13.33	12.67	13.00	13.67	11.67	12.67	13.00	12.00	12.33	12.67
Biotite	3.00	2.67	1.67	2.33	2.33	4.00	2.67	2.33	3.33	2.67	3.00	2.33
Chlorite	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.33	0.00
Epidote	0.33	0.00	0.00	0.67	0.00	0.00	0.33	0.00	0.33	0.00	0.00	0.00
Garnets	5.00	5.67	5.33	6.33	6.00	6.00	6.00	5.67	6.00	5.00	5.33	5.67
Monazite	0.33	0.00	0.00	0.33	0.33	0.00	0.67	0.33	0.33	1.00	0.67	0.33
Rutile	1.33	1.67	0.67	1.33	1.33	1.00	0.67	1.67	1.33	0.67	0.33	0.33
Sillimanite	2.67	2.33	2.67	2.33	2.67	4.00	3.33	3.00	3.33	2.67	2.67	2.33
Kyanite	0.33	0.67	1.00	0.33	0.33	0.67	0.33	0.67	1.00	0.33	0.67	1.00
Staurolite	0.33	0.67	0.33	0.67	0.33	0.33	0.67	0.33	0.67	0.00	0.00	0.00
Zircon	6.00	5.33	3.67	6.67	5.00	4.00	6.00	3.67	3.33	6.67	4.33	3.33
Opaques	22.67	22.00	23.33	21.67	20.00	20.67	20.00	20.67	18.67	21.33	21.67	20.67

beach ridge sediments from P5, the observed values show a distinct variation with depth. From the four depth zones such as 0-50cm, 50-100cm, 100-150cm and 150-200cm the recorded values are 8.23%, 12.24%, 32.87% and 37.52% respectively. The fine fraction of beach ridge sediments have yielded 15.84%, 30.14%, 56.85% and 68.84% of heavies from the four depth zones discussed earlier. Considerably higher values i.e. 21.52%, 55.59%, 78.91% and 87.52% of heavy mineral concentrates have been separated from the four depth zones in the very fine fraction of sand.

Central sector: Characteristic variation in P7 has been observed in the total heavy mineral percentages, which in the medium sand fractions is 10.25%, 18.89%, 69.72% and 51.92% respectively in 0-50cm, 50-100cm, 100-150cm and 150-200cm depth zones. In the fine sand fractions the recorded values are 22.64%, 42.2%, 51.02% and 68.45% in the respective depth zones of 0-50cm, 50-100cm, 100-150cm and 150-200cm. Significant enrichment amounting to 45.58%, 59%, 81.24%, and 79.52% are the total heavy mineral content in very fine fraction in the four depth zones. Total heavy mineral content in the medium sand fractions of P11 varies in the four depth zones, which has been recorded as 4.56%, 6.89%, 11.56% and 14.89% respectively. In the fine sand fractions 15.89%, 17.73%, 18.63% and 18.85% are the concentrations from the four depth zones. The observed down pit variation in the total heavy mineral content for the very fine fractions of sand in different depth zones are 47.35%, 21.25%, 23.69% and 26.36% respectively. The total heavy mineral content of medium sand fraction in P13 shows 6.54%, 12.03%, 21.89% and 17.07% respectively in 0-50cm, 50-100cm, 100-150cm and 150-200cm depth zones. The fine sands have yielded 12.58%, 19.35%, 81.38% and 69.47% of heavies and the heavy mineral values for the very fine sand fraction being 16.5%, 31.52%, 93.85% and 87.63% in the four depth zones respectively. It is important to note that this pit has yielded the highest percentage of heavies in the fine and very fine sand fractions at depths 100-200 cm.

Southern sector: In the medium sand fraction of the beach ridge sediments from P15, the observed values show a variation with depth.

From the four depth zones such as 0-50cm, 50-100cm, 100-150cm and 150-200cm the recorded values are 12.85%, 15.42%, 18.32% and 32.52% respectively. The fine fraction of beach ridge sediments have yielded 17.52%, 25.64%, 48.96% and 52.96% of heavies from the four depth zones discussed earlier. Higher values i.e. 38.49%, 32.89%, 61.25% and 72.55% of heavy mineral concentrates have been separated from the four depth zones in the very fine fraction of sand. The medium sand fraction in P17 has recorded total heavy mineral content of 11.98%, 14.03%, 10.58% and 18.69% respectively in 0-50cm, 50-100cm, 100-150cm and 150-200cm depth zones. The fine sands have yielded 27.56%, 37.52%, 39.15% and 46.78% of heavies and the heavy mineral values for the very fine sand fraction being 51.69%, 56.89%, 56.14% and 72.30% respectively.

4.3.2 Heavy mineral assemblage

The heavy mineral suite of the coastal plain sediments shows considerable variations among the three sectors. The spectrum of minerals identified with their characteristic features are described below.

Opaques: Opaques are considerably enriched in all the size grades (Table 4.1) in the northern sector. Ilmenite is the predominant mineral among the opaques while magnetite is subordinate to it. The grains of ilmenite are generally sub-rounded to well rounded and are enriched considerably in the fine and very fine sands, especially from 100-200cmdepth level. In the northern sector the opaques in medium sand in the surficial layer (0-50cm depth) constitute from 0.67-1.33%. In 50-100cm depth it constitutes 24.67-27.67%. In 100-150cm depth it forms 26.67-30% and in bottom layer it constitutes 30.33-30.67%. In fine sands the opaques form 1.33-1.67%, 1.33-2.33%, 1.33-1.67% and 65.67-66% of the heavy mineral content in 0-50cm, 50-100cm, 100-150cm and 150-200cm depths respectively. In very fine sands the opaques constitute 3.67-5.67%, 66-67%, 65.67-66.33% and 24.67-26% of the heavies in surficial layers, 50-100cm depth, 100-150cm depth and bottom layer in the northern sector. The variation of opaques in the various grades of sediments at various depths in the two pits (P_1 and P_5) is presented in Figs. 4.1.1.1-4.1.2.4.

In the central sector of the study area, the opaques are considerably enriched in all size grades and in bottom three layers i.e. except at the surface layers (Table 4.2). They are enriched considerably both in the fine sand and very fine sands at 100-150 cm and 150-200 cm depth level. The presence of opaques in the surficial layer (0-50 cm depth) amounts to 1% in medium sand, 0.33-0.67% in fine sand and 5-12.33% in very fine sand. At 50-100 cm depth, opaques ranges form 16.67–20.33% in medium sand, 4.67-25% in fine sand and 18-40.33% in very fine sand. At 100-150 cm depth opaques constitute 26.67-30.67% in medium sand, 17.33-24% in fine sand and 23.33-39.67% of very fine sand. In bottom most layer of the pits, the opaques range from 24.67-32.67% in medium sand, 22.33-33% in fine sand and 20.33-21.67% in very fine sand (Figs. 4.2.1.1-4.2.3.4).

In southern sector (Table 4.3), opaques constitute in notable amount among heavies in all the size fractions and in all the four layers. The opaques constitute 22.67-26.33% of heavies in surficial layer; 21.67-37% in 50-100cm depth; 20-26.33 % in 100-150cm and 21.33-25% in 150-200cm depth level. In fine sand fraction it constitutes 22-24.33% in 0-50cm depth level , 20-25% in 50-100cm depth , 20.67-24 % in 100-150cm depth and 21.67-22% of the heavies in the bottom layer. The very fine sand fraction contains opaques at 21-23.33% in surface layer, 20.67-22.67% in 50-100cm depth, 18.67-19.67% in 100-150cm depth and 18.67-20.67%, in the bottom layer (Figs. 4.3.1.1-4.3.2.4.).

Garnets: Garnets are found in greater proportions in all size fractions and in all the four depth zones in the northern sector (Table 4.1). Garnets occur as euhedral or broken crystal often with conchoidal fracture. Most garnets appear pink under plane polarised light, though minor amounts of colourless garnets have also been noticed. In northern sector, the garnet content in medium sand varies from 8.33-8.67% in the surficial layer (0-50cm depth), 6.33-6.67% in 50-100cm level, 3-3.67% in 100-150cm level and 3.33% in the bottom most layer. Among the fine sand fractions the garnet ranges between 15.67-17%, 29-29.33%, 29.67-31.33% and 8.33-8.67% of heavy minerals in 0-50cm, 50-100cm, 100-150cm and 150-200cm layers respectively. In very fine sand of Garnets constitute about

Fig.4.1.1.1: PI Depth 0-50cm

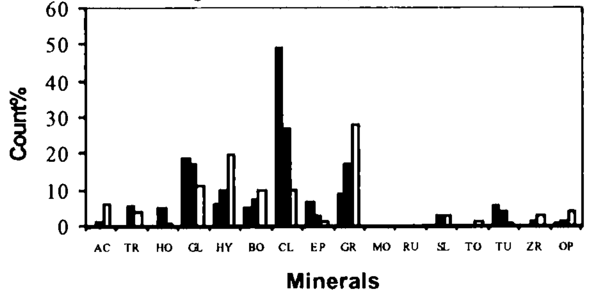


Fig.4.1.1.2:PI Depth 50-100cm

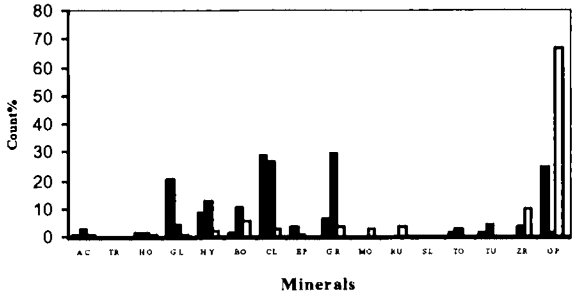


Fig. 4.1.1.3: PI Depth 100-150cm

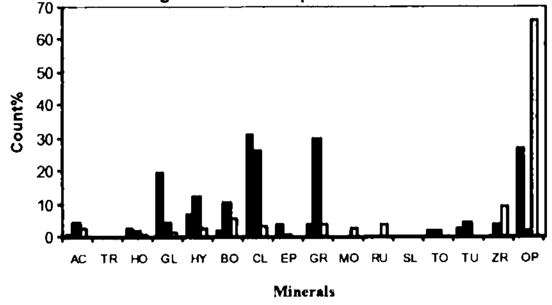
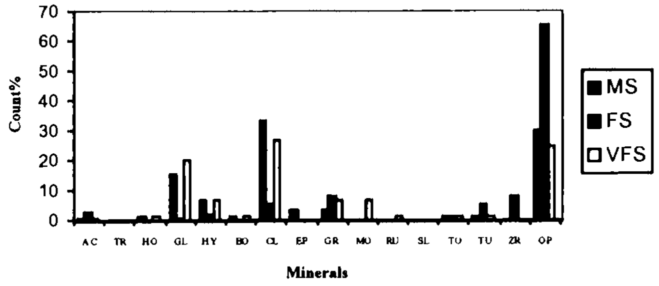
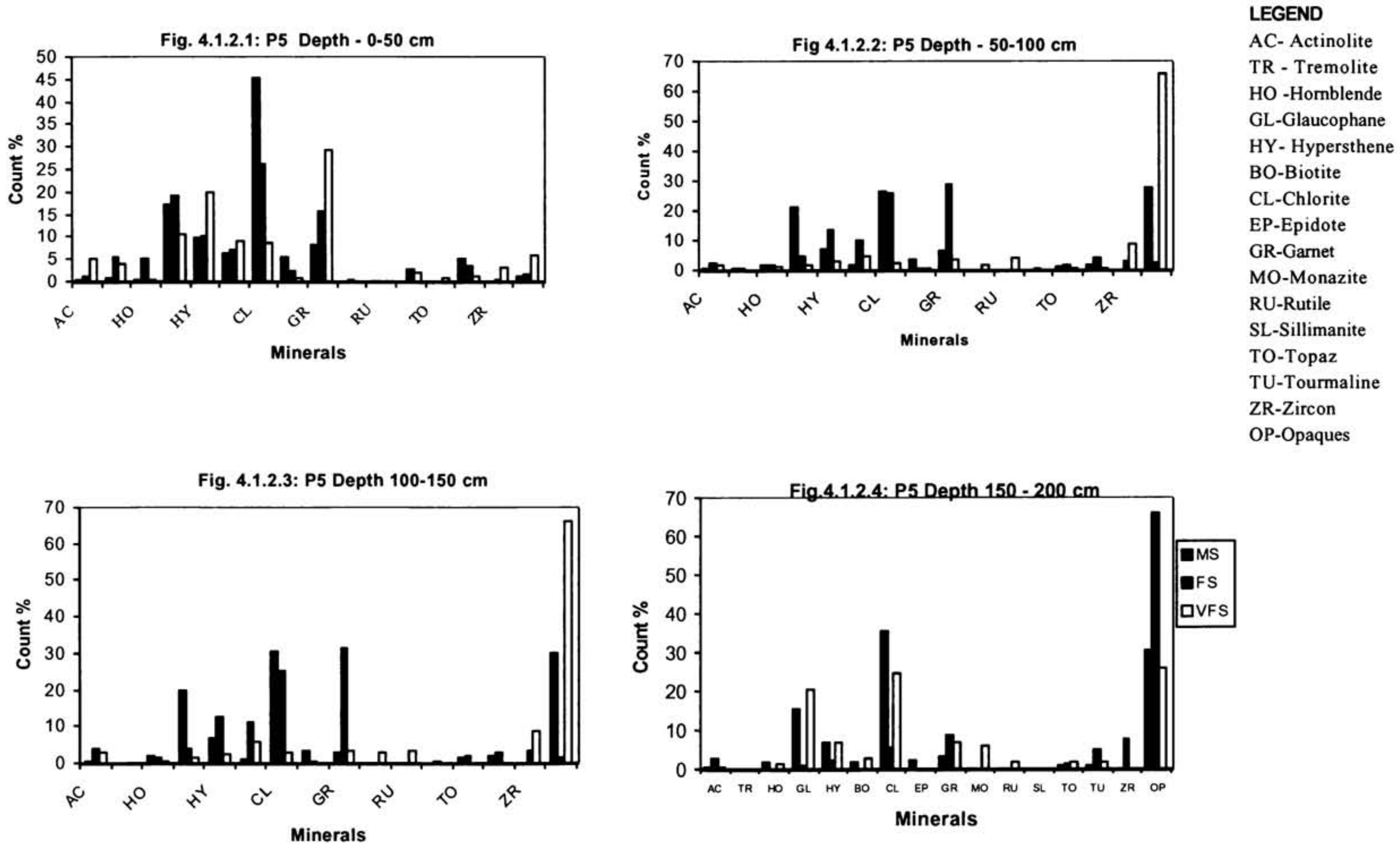


Fig.4.1.1.4 PI Depth 150-200cm



Figs.4.1.1.1 to 4.1.1.4 Distribution of heavy minerals (count%) in different depth zones and in different size grades (medium sand, fine sand and very fine sand)

LEGEND
AC- Actinolite
TR - Tremolite
HO -Hornblende
GL-Glaucophane
HY- Hypersthene
BO-Biotite
CL-Chlorite
EP-Epidote
GR-Garnet
MO-Monazite
RU-Rutile
SL-Sillimanite
TO-Topaz
TU-Tourmaline
ZR-Zircon
OP-Opaques



Figs.4.1.2.1 to 4.1.2.4 Distribution of heavy minerals (count%) in different depth zones and in different size grades (medium sand, fine sand and very fine sand)

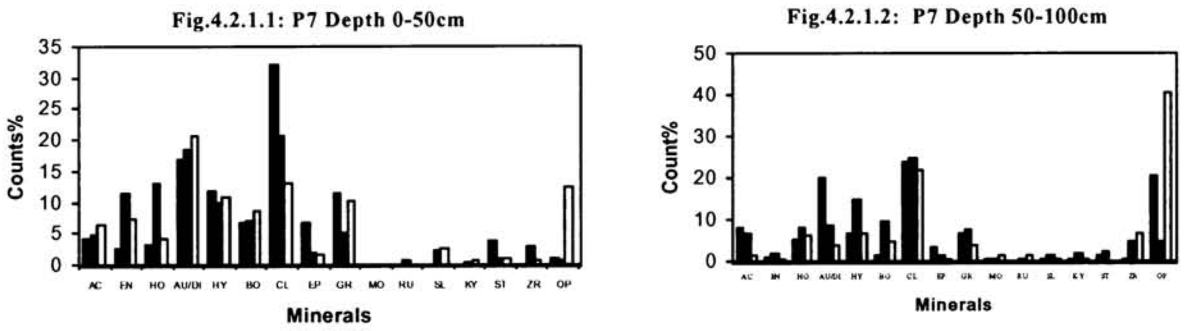


Fig.4.2.1.1: P7 Depth 0-50cm

Fig.4.2.1.2: P7 Depth 50-100cm

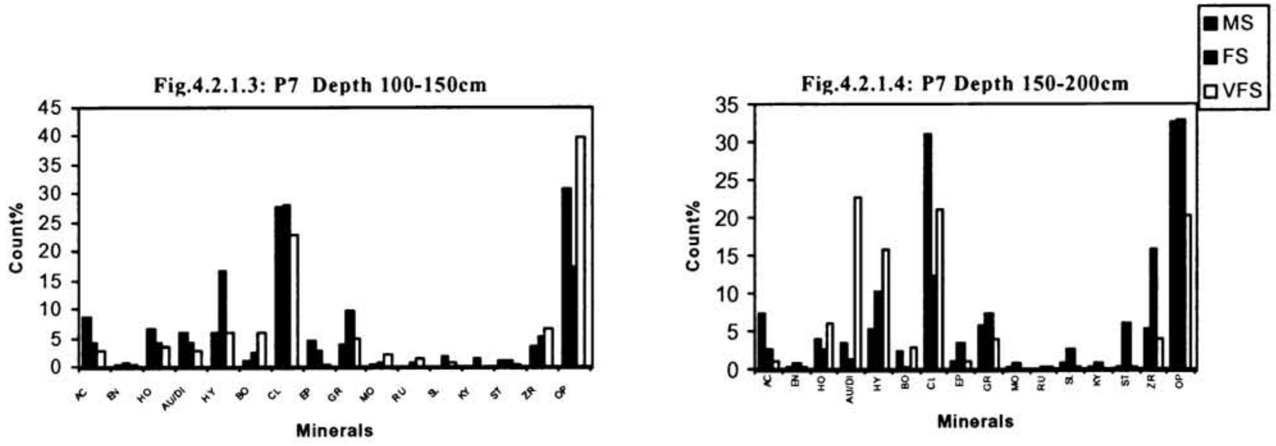


Fig.4.2.1.3: P7 Depth 100-150cm

Fig.4.2.1.4: P7 Depth 150-200cm

Figs.4.2.1.1 to 4.2.1.4 Distribution of heavy minerals (count%) in different depth zones and in different size grades (medium sand, fine sand and very fine sand)

LEGEND

AC- Actinolite
EN - Enstatite
HO -Hornblende
AU/DI-Augite/Diopside
HY- Hypersthene
BO-Biotite
CL-Chlorite
EP-Epidote
GR-Garnet
MO-Monazite
RU-Rutile
SL-Sillimanite
KY-Kyanite
ST-Staurolite
ZR-Zircon
OP-Opaques

Fig.4.2.2.1: P11 Depth 0-50cm

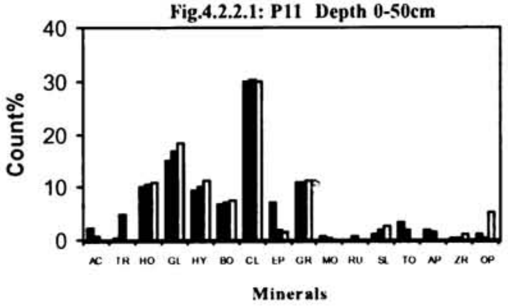


Fig.4.2.2.3: P11 Depth 50-100cm

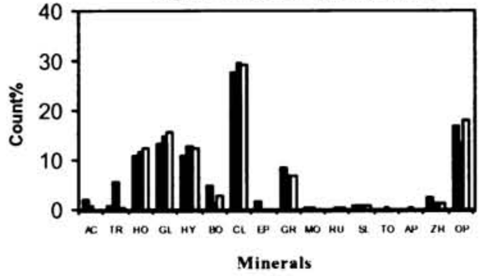


Fig.4.2.3: P11Depth 100-150cm

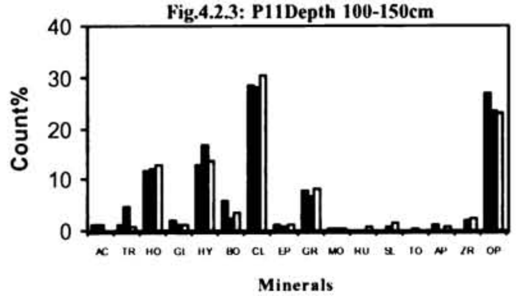
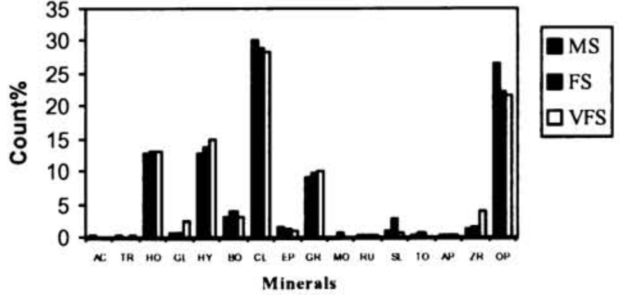


Fig.4.2.2.4: P11 Depth 150-200cm



LEGEND

AC- Actinolite
TR - Tremolite
HO -Hornblende
GL-Glaucophane
HY- Hypersthene
BO-Biotite
CL-Chlorite
EP-Epidote
GR-Garnet
MO-Monazite
RU-Rutile
SL-Sillimanite
TO-Topaz
AP-Apatite
ZR-Zircon
OP-Opaques

Figs.4.2.2.1 to 4.2.2.4 Distribution of heavy minerals (count%) in different depth zones and in different size grades (medium sand, fine sand and very fine sand)

27.67-29.33% in 0-50cm depth, about 3.67% in 50-100cm depth, about 3.33-3.67% in 100-150cm depth and about 6.67% in bottom layer under study (Figs. 4.1.1.1-4.1.2.4).

Garnets constitute a considerable proportion of heavy minerals in the central sector (Table 4.2). They are found in considerable proportions in all size fractions, in all four layers. The amount of garnet in the medium sand varies between 8.67 and 11.33% in surficial layer (0-50cm depth), between 4 and 8.33% in 50-100cm depth, between 3.67 and 6.67% in 100-150cm depth and between 4 and 9% in the bottom layer. In fine sand fraction garnet variations ranges at 5-11%, 3.67-7.67%, 4-9.67% and 4.33-9.67% in 0-50cm, 50-100cm, 100-150cm and 150-200cm layers respectively. In very fine sand garnet varies from 4.33- 11.33%, from 4-7%, from 5-8.33% and from 4-10% in 0-50cm, 50-100cm, 100-150cm and 150-200cm depths (Figs. 4.2.1.1-4.2.3.4). In the southern sector garnet content is considerably low (Figs. 4.3.1.1 to 4.3.2.4).

Chlorite: Chlorite is found in significant amount in all the four depth zones of northern sector (Table 4.1). Chlorite in the medium sand ranges from 45.33-49% in the surficial layer (0-50cm), 26.33-29% in 50-100cm depth, 30.33-31% in 100-150 cm depth and 33.33-35.33% in 150-200cm depth. In the fine sand fraction the variation of chlorite content in all four layers from top to bottom ranges are 26.33 - 26.67%, 26-27%, 25.33-26.33% and 5.33% respectively. In very fine sands are the variations are respectively from 8.67-9.67 %, 2.33-2.67%, 3%, and 24.33-26.67 % in 0-50cm, 50-100cm, 100-150cm and 150-200cm layers (Figs. 4.1.1.1-4.1.2.4).

Chlorite is found in greater proportions in all the size fractions and in all four depth zones of the central sector (Table 4.2). In the surficial layer (0-50cm) chlorite ranges from 30-35 %, 24 -27.67 % in 50-100cm depth, 27.67-28.33 % in 100-150cm and 30-32.33% in 150-200cm depth. In the fine sand fraction the variation of chlorite in the 4 layers are from 20.67-32%, 25-29.67%, 28% and 12.33-30% respectively depths. Similar variations of Chlorite content are found in the very fine sand ranging from 13-30%, 21.67-29.33%, 23-30.33% and 21-32% in 0-50cm, 50-100cm, 100-150 cm and also in the lower most 150-200cm layer (Figs. 4.2.1.1-4.2.3.4). Chlorite is absent in southern sector.

Glaucophane: In northern sector, glaucophane is found in considerable proportions in all size fractions and in all the four levels (Table 4.1). It appears fresh and occurs as angular to subangular crystals. Under microscope it is identified by its colour, cleavage and pleochroism. In northern sector of glaucophane content in the medium sand varies from 17.33-18.67% in surficial layer (0-50cm depth), in 50 -100cm depth from 20.33-21%, in the 100-150cm depth, glaucophane forms 19.67% (both pits) and in bottom most layer from 15.33-15.67%. In the fine sand fraction, the variations are 17-19%, 4-5%, 4% (both pits) and 0.67-1% of heavy minerals in 0-50cm, 50-100cm, 100-150cm and 150-200cm depth respectively. In very fine sand glaucophane constitutes 10.67% in the 0-50cm depth, 1-2% in the 50-100cm depth, 1-1.33% in 100-150cm depth and 20 – 20.33% in 150-200cm depth (Figs. 4.1.1.1- 4.1.2.4). Glaucophane is seen in considerable quantity in central sector. They are more common in the median sands of the top layer (Figs. 4.2.1.1-4.2.3.4). In southern sector glacophane is absent.

Hypersthene: In northern sector of the study area hypersthene is present in all size fractions and in all the four depth zones (Table 4.1). In the surficial layer (0-50cm depth) it varies from 6-9.67% in medium sand, 8.67-7.33% in 50-100cm depth, 6.67% in 100-150cm layer and 6.67% in the bottom most layer. In fine sand fractions the variations are 9.67-10%, 12.67-13.67%, 12 -12.33% and 2.33% of 0-50 cm, 50-100 cm, 100-150cm and 150-200cm layers respectively. The variation of hypersthene in the very fine sand is 19.67-20% in the 0-50cm depth, 2.33-2.67 % in 50-100cm depth, 2.33% in 100-150cm depth and 6.67-7% in 150-200cm bottom most layer respectively (Figs. 4.1.1.1-4.1.2.4).

In central sector of the study area hypersthene is common in all size fractions and in all four-depth zones (Table 4.2). In the medium sand it ranges from 6.67-11.67% in surficial layer (0-50cm depth); 6.67-11% in 50 -100cm depth; 6-12.67% in 100-150cm depth and 5.33-12.67% in the bottom most layer. In the fine sand fraction its presence amounts to 10%, 12.67-14.67 %, 16.67 %, 10.33-13.67 of 0-50cm, 50-100cm, 100-150cm and 150-200cm depth layers respectively. The amount of hypersthene in very fine sand is 10.67-11.33% in 0-50cm depth; 6.67-14% in 50-100 cm depth; 6-13.67% in 100-150cm depth and 14-15.67% in 150-200cm respectively (Figs. 4.2.1.1-4.2.3.4).

Hypersthene is considerably enriched in all the size grades in southern sector (Table 4.3). The hypersthene content in the surficial layer (0-50cm depth) varies from 12.33-13% in medium sand, from 12.67-13% in 50-100cm level, from 11.67-12.67 % in the 100-150cm depth and from 12-12.67% in bottom layer. In the fine sand the variation of hypersthene with the depth ranges in 12.67-13.33 %, 13 – 13.67 %, 12.67 – 13.33 % and 12.33 –13.67 % in 0-50 cm, 50-100 cm, 100-150 cm and 150-200cm respectively. The content of hypersthene vary in the very fine sand are from 13.33 -13.67% in the surficial layer, from 13.67-14% in the 50-100cm depth, from 13- -13.67% in 100-150cm depth and 12.67-14% in the bottom most layer (Figs. 4.3.1.1-4.3.2.4).

Epidote: In northern sector though epidote is present its amount is considerably low (Table 4.1). Figs. 4.1.1.1-4.1.2.4 gives size wise distribution of epidote in this part of study area. Epidote is an important heavy mineral fraction of the central sector of the study area (Table 4.2). In the surficial layer (0-50cm) the amount epidote in medium sand ranges between 6.67-7%; in 50-100cm depth it ranges between 1.67-3.33% and in 100-150cm depth it ranges between 1-4.67% and at the 150-200cm column it values vary between 1-1.67%. In fine sand fraction epidote content is 2%, 0-1.33%, 0.67-2.67% and 1.33-3.33% in the respective intervals from surface to 200cm depth. In very fine sand the contents are 1.67%, 0-0.33 %, 0.33-1% and 1% in 0-50cm, 50-100cm, 100-150cm and 150-200cm depths respectively (Figs. 4.2.1.1.1-4.2.3.4). Presence of epidote in southern sector is conspicuous as it shows depletion in fine sand (Figs. 4.3.1.1-4.3.2.4).

Biotite: Biotite is found in notable amounts in all the size fractions and in all the four depth zones (Table 4.1). In the surficial layer (0-50cm), biotite ranges between 5-6.67 %. In 50-100cm depth it varies between 1.33-5% and in 100-150cm depth the biotite content is 1-6%. At the bottom layer it varies in the range 2.33-3%. For fine sand fraction, the biotite amounts up to 7% in surficial layer, 1.33-9.67% in 50-100cm depth, 2.33% in 100-150cm and 4% in the bottom most layer. Biotite in very fine sand varies between 7.33-8.67 %, 2.67-4.67 %, 3.67-6 %, and 3 % in 0-50cm, 50-100 m, 100-150cm and 150-200 m depths respectively (Figs .4.1.1.1-4.1.2.4).

In central part of the study region biotite is distinct with its low concentration among heavies (Table 4.2). Among medium sand it amounts up to 6.67% in surficial layer, 9.67% in 50-100cm depth, 3% in 100-150cm and 2% in the bottom most layer. Biotite in fine sand varies between 5-8%, 2-3%, 0-1.5% in 0-50cm, 50-100cm depth, 100-150cm and 150- 200cm respectively. Biotite in very fine sand varies between 9.5-10%, 5-6%, 5-6% and 4% in 0-50cm, 50-100cm, 100-150cm and 150-200cm depths respectively (Figs. 4.2.1.1-4.2.3.4).

In southern sector among the medium sand, biotite ranges from 2.5-4%, 2-4.5%, 2.5%, 4% in 0-50cm, 50-100cm depth, 100-150cm and 150-200cm respectively (Table 4.3). In fine sand it varies from 2.5%, 4.4%, 2% and3% in 0-50cm, 50-100 cm, 100-150cm and 150-200cm depths respectively. In very fine sand 2%,1%, 3% and 3.5% in 0-50cm, 50-100cm, 100-150cm and 150-200cm depth respectively (Figs. 4.3.1.1-4.3.2.4).

Hornblende: Hornblende is absent in the northern sector (Table 4.1) and in the central sector (Table 4.2) it forms 2 to 6% irrespective of the depth in medium sand. In fine grain sand, it constitutes 15%, 8%, 3% and 2% in 0-50cm, 50-100cm, 100-150cm and 150-200 cm depth respectively. In very fine sand, hornblende forms 5%, 8%, 12% and 8% in 0-50cm, 50-100cm, 100-150cm and 150-200cm depth respectively (Figs. 4.2.1.1-4.2.3.4). Hornblende is found in significant amounts in all the size fractions and depth zones (Table 4.3). In the southern sector in the surficial layer (0-50cm) hornblende ranges from 33.33 to 43.33%, from 31.33-41.67% in 50-100cm depth, from 31.67- 45% in 100-150cm and from 31-46.67% in 150-200cm depth. In the fine sand fraction hornblende varies from 34.33-45% in the surficial layer, from 33-45% in the 50-100cm depth, from 36.33-

46.67% in 100-150cm depth and from 38-47.33% in the bottom most layer. Hornblende in the very fine sand fraction varies from 38.67- 46.67% in 0–50cm depth, from 31.67-43.33% in 50-100cm depth, from 34-47.33% in 100-150cm depth and from 40.67-48.33% in the bottom most layer (Figs. 4.3.1.1- 4.3.2.4).

Zircon: Zircon is found negligible in northern and central sectors (Tables4.1 and 4.2). But its concentration in fine sand is noticeable in central sector, while in northern sector very fine sized zircons are noticed (Figs. 4.1.1.1-4.1.2.4 and Figs. 4.2.1.1-4.2.3.4). Zircon is found more in the southern sector (Table 4.3). These grains are mostly colourless and sometimes with brownish tint. Zoning and inclusions are exhibited by some of these grains. Zircon is found in notable amounts in all the size fractions and in all the four depth zones. In the surficial layer of the southern sector (0-50cm) zircon ranges from 6-6.67%, 5.67-6.67% in 50-100cm depth, 6% in 100-150 cm depth and 6.67% in 150 -200cm depth. In the fine sand fraction the variations are 5.33-6.33%, 5-6%, 3.67-6% and 4.33-6% respectively with respect to the studied depth zones. In very fine sands it is about 3.67-6%, 4-6.67%, 3.33- 6.33%, and 3.33-6.33% in 0-50cm, and 50-100cm, 100-150cm and 150-200cm depths respectively (Figs. 4.3.1.1- 4.3.2.4).

4.3.3 Mechanism of heavy mineral concentration

Heavy minerals concentrates such as ilmenite, rutile, monazite, zircon and garnets from coastal placer deposits of both ancient and modern age are major economic resources in India. However, information on the sedimentological, stratigraphical, hydrodynamical and geomorphological aspects is rather limited in India to document the distributions and mechanisms of concentration of heavy minerals within a coastal plain system.

The heavy minerals in the present study area are the result of processes operating at different temporal and spatial scales. As the heavy minerals in the central Kerala form part of the late Holocene regressive coastal plain sequences and to a little extend modern environment, the sea level changes has a significant role in the heavy mineral concentration, preservation or alteration. In general the heavy mineral occurrence in the coastal plain areas is the result of processes such as segregation due to differential entrainment in the swash zone, differential transport, shear sorting and longshore and onshore sediment transport- all contribute cumulatively or singularly to the concentration of certain heavy minerals (Hamilton and Collins, 1998). The coastal plain evolution and seasonal variation in wave energy have also played a major role in the above mechanism of concentration.

Heavy minerals are particularly concentrated in the fine and very fine sands- the predominant kind of sediments available in the coastal plain areas. As much as 69.7-81.8% by weight of heavy mineral is observed in the fine sand category and 87.63- 93.85% by weight in very fine sands are observed in 100-200cm depth range. In the recently deposited coastal plains at Puthuvaippu (P13), the distribution of heavy minerals takes several forms. The coastal plain sediments consist of discrete both landward and seaward dipping planar laminae (Plates 1& 2) with high enrichment of heavy minerals at the bottom ranging from 30-50 cm thick and another (heavy mineral poor) light mineral bed at the top (Plate 3). In some other localities of the coastal plains, horizontally bedded with alternate layers of heavy and light mineral concentrations (Plates 5& 6).

The most important factors, which control the heavy mineral accumulations, are the physical processes of heavy mineral segregation. Many workers (Singerland, 1977; Sallenger, 1979; Komer and Wang, 1984) have stated that settling equivalence, differential entrainment and transport and shear sorting are the most important factors for heavy mineral occurrences in the coastal sequences.Segregation of light and heavy minerals in the near shore zones is due to preferential entrainment and transport by wave action resulting in the local enrichment (Hamilton and Collins, 1998) of heavy minerals and is largely a function of grain size and density (Singerland, 1977, 1984; Komer and Wang, 1984). As a result, fine grained denser minerals such as ilmenite, monazite, garnets, zircon etc. are preferentially concentrated in the swash zone while lighter quartz and feldspars are entrained and carried away either offshore or alongshore. These lighter minerals are once again brought back to the

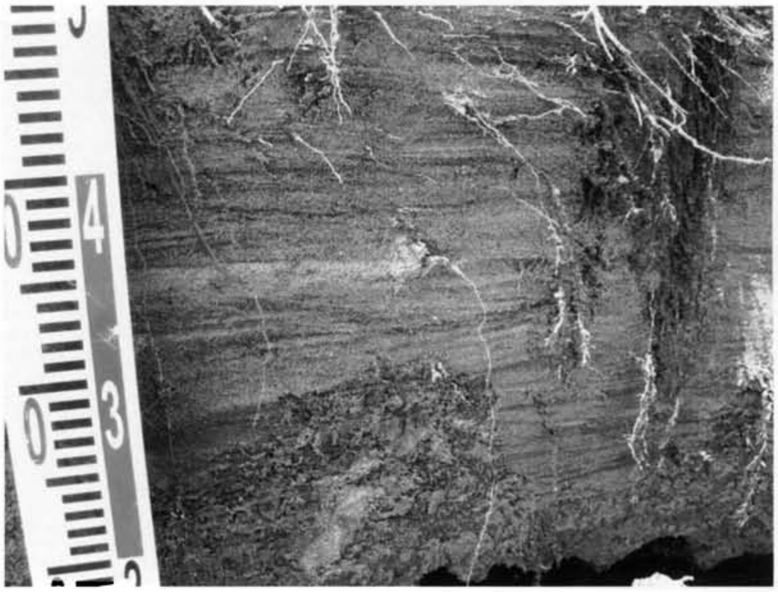


Plate 1 Well laminated heavy minerals with pockets of light minerals. The laminations show cross bedding with a dip land ward (left hand side of the pit).

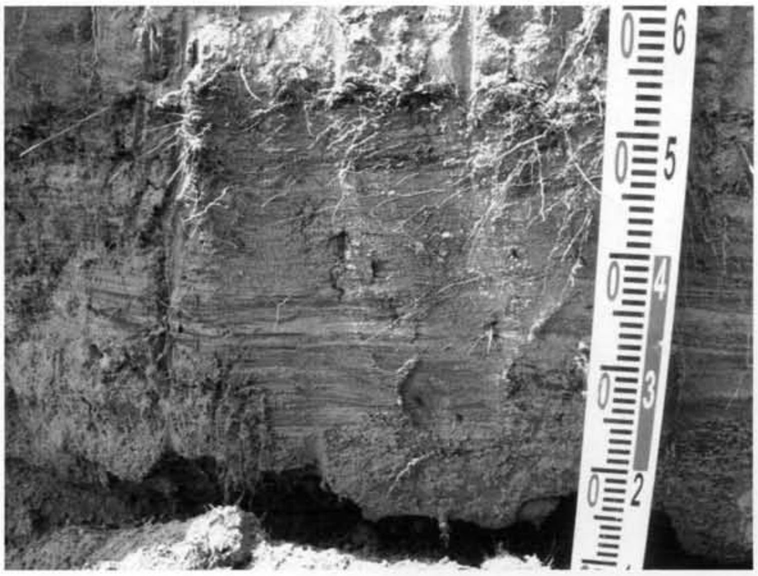


Plate 2 Intermittent layers of heavy and light minerals. Slightly dipping sea ward (right hand side of the pit). Aeolian sediments at the upper portion of the profile.

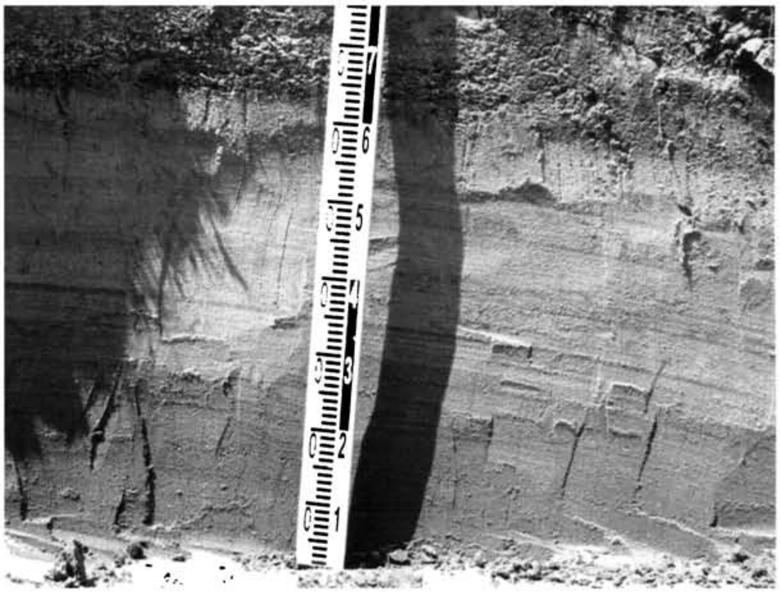


Plate 3 Contemporary coastal sediments (Pit 13) with sub-horizontal plane laminations showing very thick (30cm) heavy mineral segregation at the bottom followed by light mineral rich unit and the aeolian deposits at the top (sea on the right hand side of the pit)

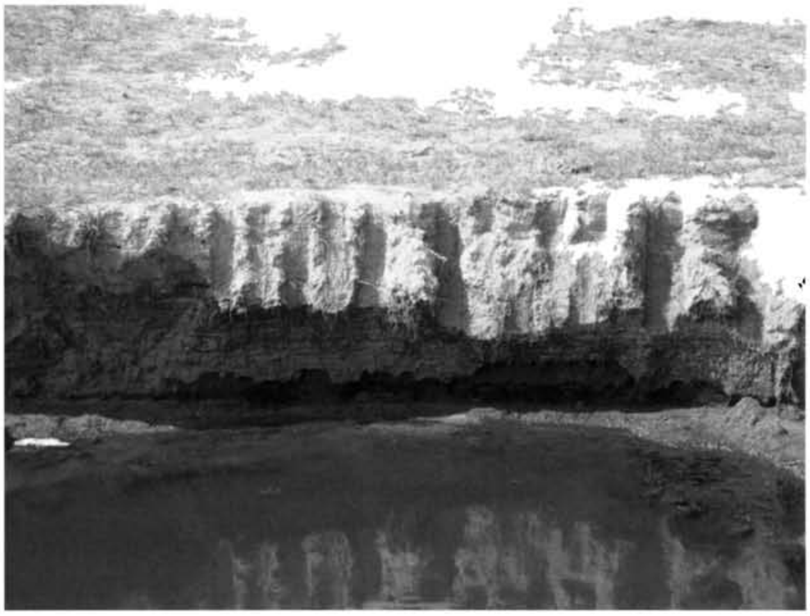


Plate 4 Laminations of heavy and light minerals in the beach, which is intercepted with the water table. This might have caused much solution activity in the minerals (evidenced in SEM)

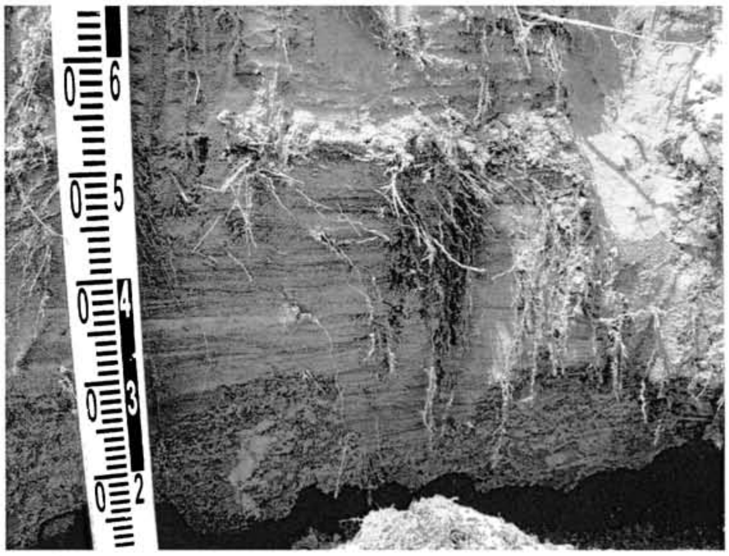


PLATE 5

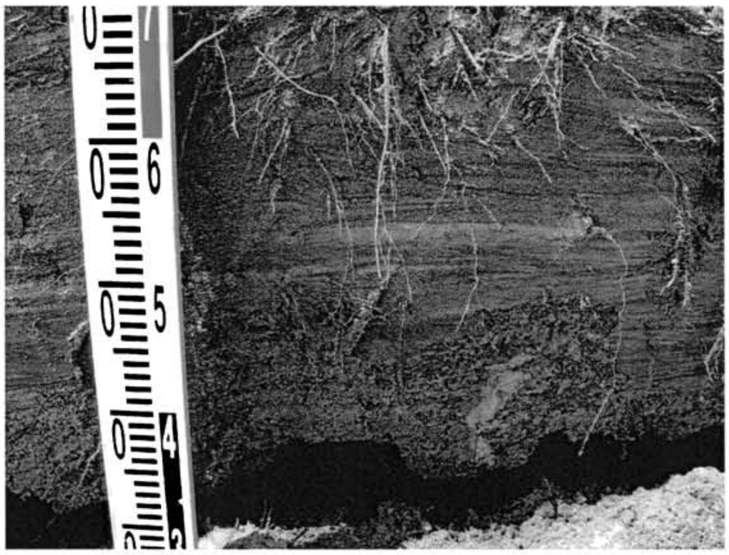


PLATE 6

Horizontally bedded alternate layers of heavy and light mineral concentrations in beach shore by waves during fair weather period and deposited over the heavy rich layer. Hence alternate layers of light and heavy minerals form in the beach zone (Plates 2, 5 &6). Collins and Hamilton (1989) have shown that in the near shore zone, the stress required to entrain minerals such as zircon and ilmenite is more than twice that required to entrain quartz grains. Hence, segregation of light and heavy minerals will occur in the swash zone when the fluid stress is above the critical level needed to move quartz, but is below the level necessary to move heavy grains such as ilmenite. The existence of similar condition in the present study area is well established by field observation (Plate 3). Under conditions of coastal progradation these heavy mineral rich beds deposits are masked and preserved from further wave action.

The concentration of heavy and light mineral layers in the coastal plain sequences, particularly in the swash zone may also result when the shear force (by swash action) is applied on a sandy bed. This pressure is greater on larger grains such as quartz and feldspars (than the heavy minerals which are usually very fine grained in nature), forcing them towards the surface of the bed. The concentrations of several heavy minerals in finer fractions are well revealed in Figs.4.1.1.2, 4.1.1.3, 4.1.2.2, 4.1.2.3, 4.2.1.2, 4.2.3.2, 4.2.1.3, and 4.3.2.1. Thus along the coastal sequences either a thin or a thick layer of inversely graded sand layer containing only heavy minerals (Plates 1 & 3) may be produced at the base (Collins and Hamilton, 1989; Hamilton and Collins, 1998).

Another important mechanism causing variations in the heavy content along the coastal plain is the longshore transport and onshore transport processes. Collins and Hamilton (1989) have stated that during longshore transport lighter grains will travel 1.5 times as fast as heavies. Therefore, the longshore transport can affect heavy mineral concentration. The predominant direction of transport in the study area is towards south during SW monsoon and northward during NE monsoon period (Kunte and Wagle, 2001). Hence on either side of river mouths of Periyar and Cochin inlet the occurrence of high concentration of heavy deposit is justifiable.

4.4 Provenance of Heavy minerals

Heavy mineral analysis is one of the most sensitive and widely used techniques in determination of provenance (Krumbein and Pettijohn, 1938; Okada, 1960; Folk, 1968; Blatt, 1985; and Morton and Hallsworth, 1999). Heavy minerals such as zircon, monazite, rutile, garnet and magnetite are used for determining the provenance of heavy mineral deposits (Rajamanickam, 1983; Chandrasekaran, 1992; Purandara, 1993; Loveson, 1994; Rajamanickam, 1997; Krishnan et al., 2001; Wong, 2002; Broadley et al., 2002). Several potential sources and pathways to the present coastal plain areas can be identified. The heavy minerals found in the buried placers along the coastal plains of the study area assessed according to different sectors to delineate their provenances.

a) Northern sector: The heavy mineral suite in the northern sector is primarily of opaques, chlorite, garnets, hypersthene, glaucophane, biotite, actinolite and tourmaline.
b) Central sector: The predominant heavy minerals of this sector are actinolite, hornblende, hypersthene, chlorite, biotite, and opaque minerals.
c) Southern sector: This sector consists of hornblende, opaques, hypersthene, zircon, garnets, sillimanite and biotite.

In southern sector, kyanite, monazite and rutile are present in minor quantities. The source for the mineral assemblage is undoubtedly the drainage basins of Muvattupuzha, Pamba and Achankovil rivers as these rivers after debouching at various places in the Vembanad lake join the sea near the Fort Cochin. The contribution of the southern distributary of Periyar namely Eloor, to the mineral assemblage might be small, as the sampling locations are located well beyond its reaches.

The drainage basins of Muvattupuzha, Meenachil, Manimala, Pamba and Achankovil rivers are mainly occupied by hornblende-biotite gneiss, unclassified gneisses, charnockites and intrusives (acidic type -granites and pegmatites; basic type- gabbro and dolerite) igneous rocks (Ravindrakumar et al., 1985, Santosh and Drury, 1988, Soman, 1998). Laterites and lateritized Miocene sedimentary rocks occupy the lower reaches of the river courses such as Muvattupuzha, Meenechil and Pamba. Denudation of rocks occupying these drainage basins could be the prime source for the high content of blue-green hornblende in the southern sector. Ilmenite is the second dominant mineral in the southern sector and thus its source lie in the metamorphic rocks of the study area. A considerable portion of the ilmenite could be derived from the sedimentary rocks and laterites, which occupy a considerable aerial extent of the drainage. Sillimanite and kyanite are undoubtedly of metamorphic origin. Colourless and pink garnets might have derived from charnockites. Mallik (1981) and Purandara (1987) have stated that the charnockites of the Western Ghats are characterized by colourless and pink garnets. Charnockites are also the prime contributors for the enrichment of hypersthene in the southern sector. The igneous suites of rocks such as granites and pegmatites contribute considerably to the enrichment of monazite and rutile.

The presence of rounded zircon in the southern sector suggests that the zircon has been subjected to reworking in the near shore environment by waves and currents before it got settled in the coastal plain environment. Occurrence of rounded zircon in the beach sediments of the central Kerala (Mallik, 1986) and in the Vembanad estuarine sediments (Padmalal, 1992, Padmalal et al., 1998) has been reported.

In central sector the predominant mineral are augite, hypersthene, biotite, chlorite, epidote, opaques and garnets. Percentage of chlorite, glaucophene indicates that the mineral belongs to Periyar provenance. Presence of considerable amount of hornblende in this sector, which is absent in north but abundant in south, indicates that the sediments of this sector has a mixed origin. Apatite is in smaller amounts more in medium sand and less in finer and very fine sand.

In northern sector the dominant heavy minerals are opaques, chlorite, garnets, hypersthene, glaucophane, biotite and actinolite. In the medium and fine fractions chlorite, glaucophane, garnets and opaques are enriched while in very fine sands opaques, hypersthene, glaucophane, biotite and actinolite predominate over others. Such concentration levels are recorded by Babu and Seralathan (2005) in the buried beach placers between Bharathapuzha and Periyar rivers. Rajendran et al. (1996) reported that the heavy minerals from the Bharathapuzha river are predominated by hornblende, pyroxene, opaques and garnets. Similarly the predominant minerals in Periyar river sediments are opaques, chlorite, garnet, hypersthene, biotite, glaucophane and tourmaline (Maya, 2005). The coastal plain sediments of northern sector being close to Periyar river mouth. One of the predominant minerals in the northern sector is chlorite, which affirms to a provenance in metamorphic terrain.

4.5 Clay Mineralogy

The study of clay minerals is an important area of research in the recent years as it throws light on weathering provenance etc. The clay minerals constitute a major part of the finer fractions of the aquatic sediments and are reactive geological materials or particulates which serves as an indicators of the over all physico-chemical environment of deposition (White house et al 1960). According to Biscaye (1965) and Grim (1968) the composition and distribution of clay minerals are good indicators of sediments dispersal in the marine environment. This is mainly because the clay mineral composition of sediments mainly depends on the climatic condition, provenance, rock types etc. of the region.

The XRD analysis of selected clay fraction helps to decipher the clay mineral assemblages in the environment of deposition. Table 4.4 shows the percentages of the various clay minerals recorded in the study area. The clay minerals present at various depths are shown as per X-Ray difractrogram in Fig (4.4.1.1-4.4.3.2)

Kaolinite is the predominant mineral of the studied environment of deposition. The other minerals present are illite, chlorite and montmorillonite .The dominant clay mineral in alluvial plain is the kaolinite (range 35.71-83.33%), while illite (0-64.29%) and chlorite (0-18.18%) constitute considerable proportion. Within the alluvial plain region, sediments collected close to the coastal region (P21) records considerable percentage of illite content than (P19) which was collected slightly upstream (Fig 4.4). A significant observation is that montmorillonite is

Table 4.4 Distribution of Chlorite, Illite, Montmorillonite and Kaolinite in sediments

P 19 Alluvial plain

Chlorite %	Illite %	Montmorillonite %	Kaolinite %
11.36	18.18	0.00	70.45
18.18	0.00	0.00	81.82
0.00	16.67	0.00	83.33
5.88	11.76	0.00	82.35
P 21 Alluvial plain			
0.00	21.28	4.26	74.47
0.00	64.29	0.00	35.71
8.33	50.00	0.00	41.67
P 22 Mudflat			
6.00	20.00	4.00	70.00
4.83	42.76	7.59	44.83
12.85	28.78	7.65	50.72
16.67	23.33	8.33	51.67
P 24 Mudflat			
0.00	32.65	8.35	59.00
7.18	53.33	14.87	24.62
0.00	23.08	20.51	56.41
10.06	6.70	7.26	75.98
P 20 Swale			
19.30	28.07	0.00	52.63
8.25	16.49	3.09	72.16
21.62	27.03	8.11	43.24
0.00	0.00	21.74	78.26
P 23 Swale			
5.71	7.62	2.86	83.81
0.00	12.65	44.93	42.42
0.00	23.08	20.51	56.41
11.36	18.18	12.85	57.60

Fig 4.4.1.1 - P 19

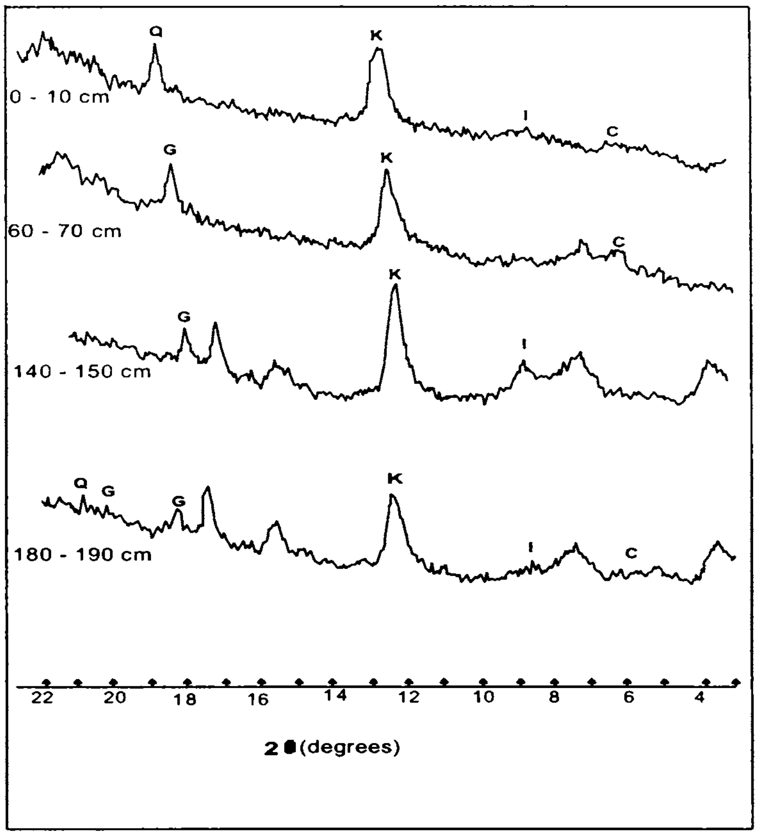


Fig 4.4.1.2 - P21

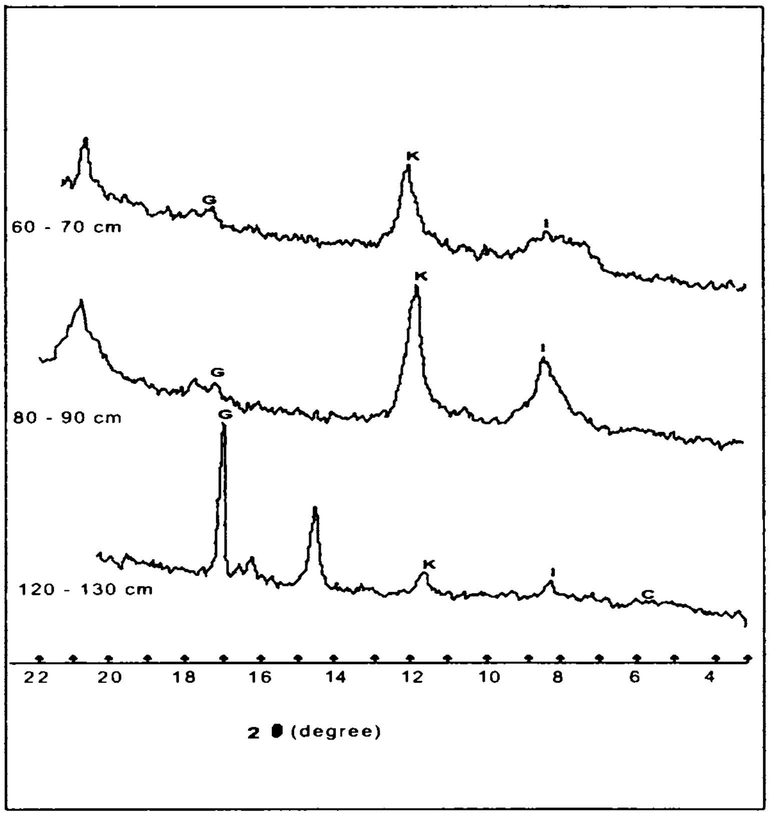


Fig 4.4.1.1 and 4.4.1.2 - X-ray diffractograms of clay fraction for Alluvial Plain

Fig 4.4.2.1 - P 22

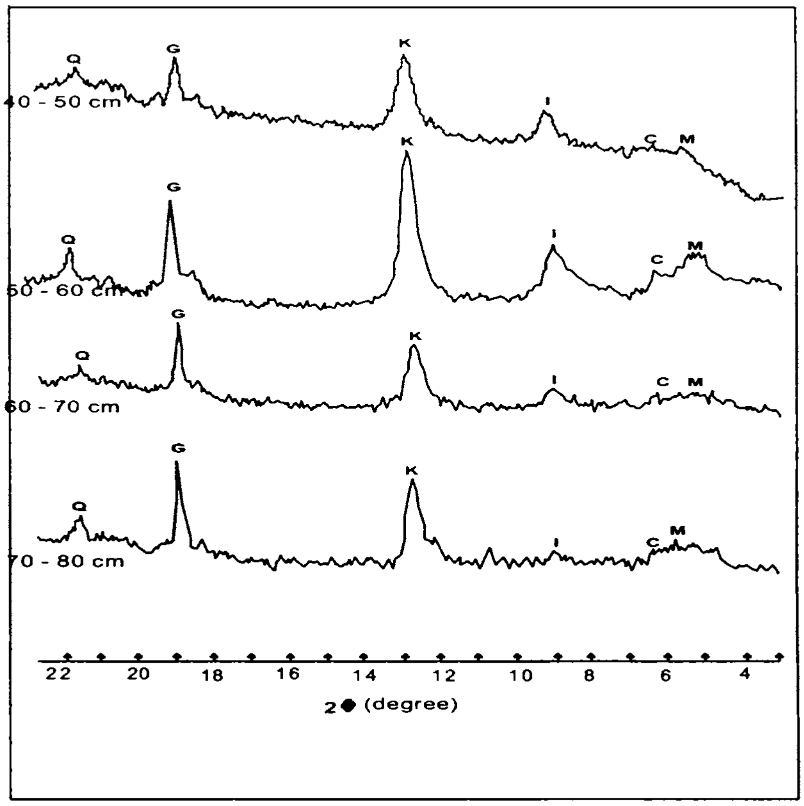


Fig 4.4.2.2 - P 24

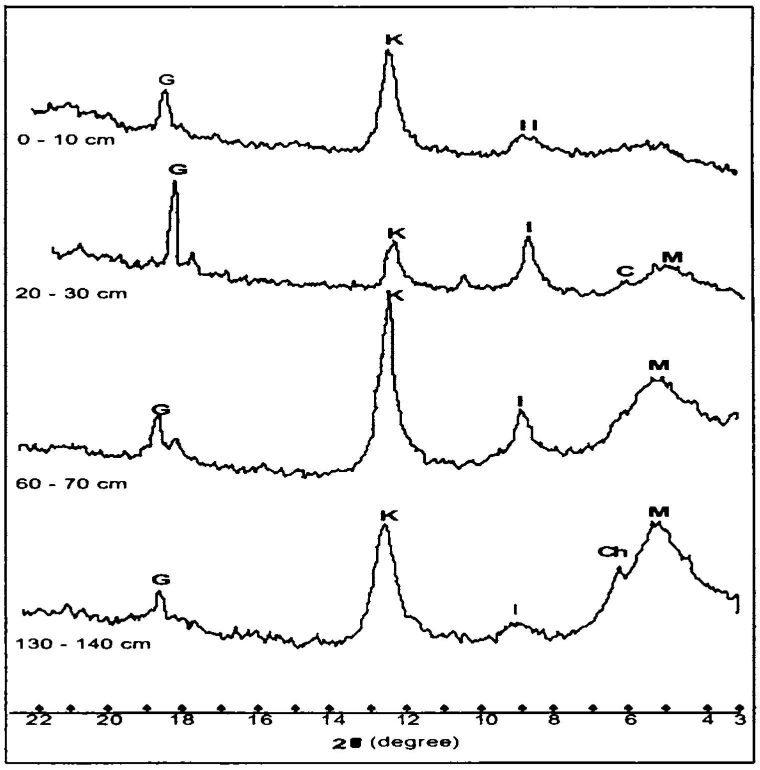


Fig 4.4.2.1 and 4.4.2.2 - X-ray diffractograms of clay fraction for Intertidal mudflat

Fig 4.4.3.1 - P 20

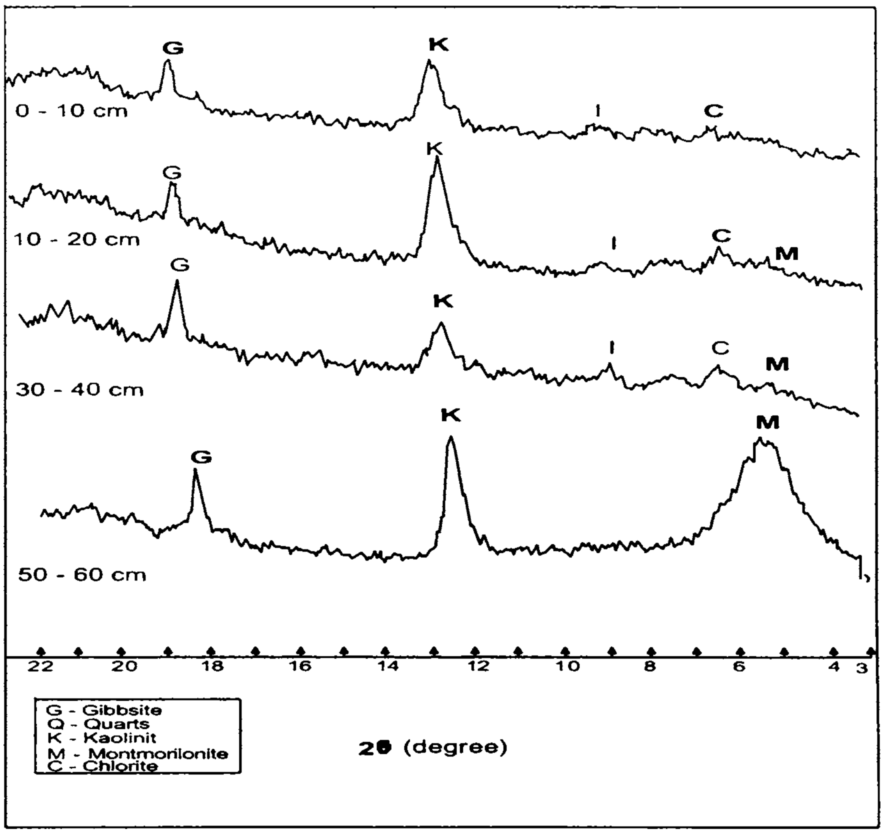


Fig 4.4.3.2 - P 23

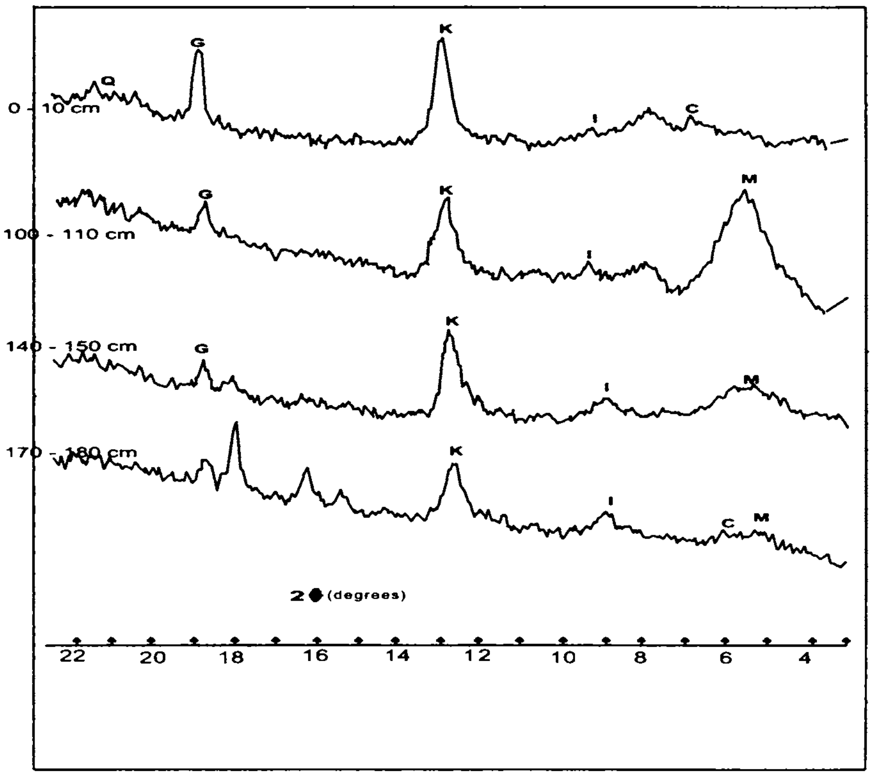


Fig 4.4.3.1 and 4.4.3.2 - X-ray diffractograms of clay fraction for swale

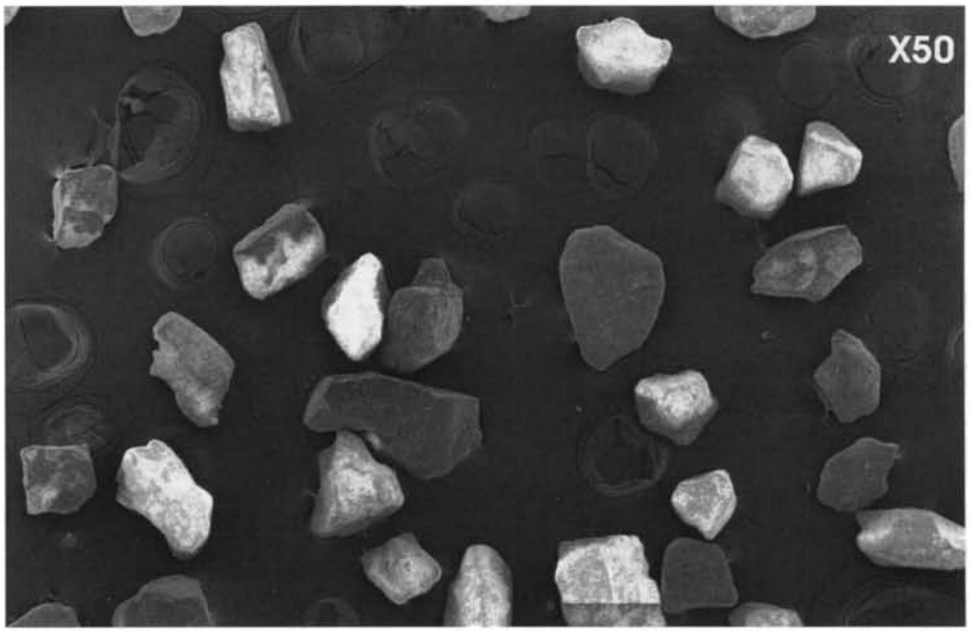


Plate 7a Scanning electron photomicrograph of some heavy minerals in the fine sands collected at a depth of 0-50 cm in Pit 18 showing rounded and anhedral grains

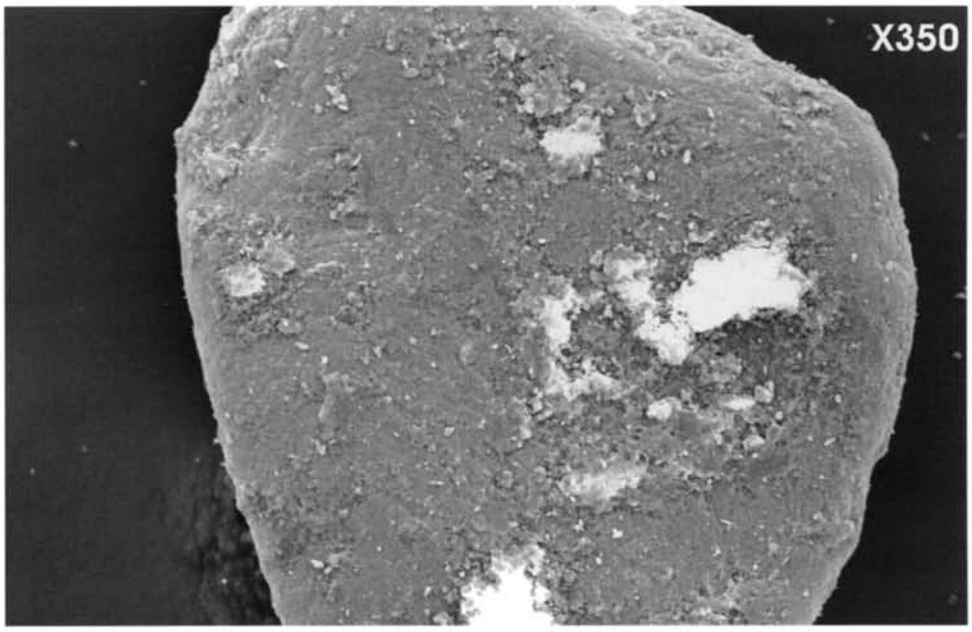


Plate 7b Scanning electron photomicrograph of ilmenite in the fine sands collected from 0-50 cm depth in Pit 18 exhibiting etch Vs and precipitation features

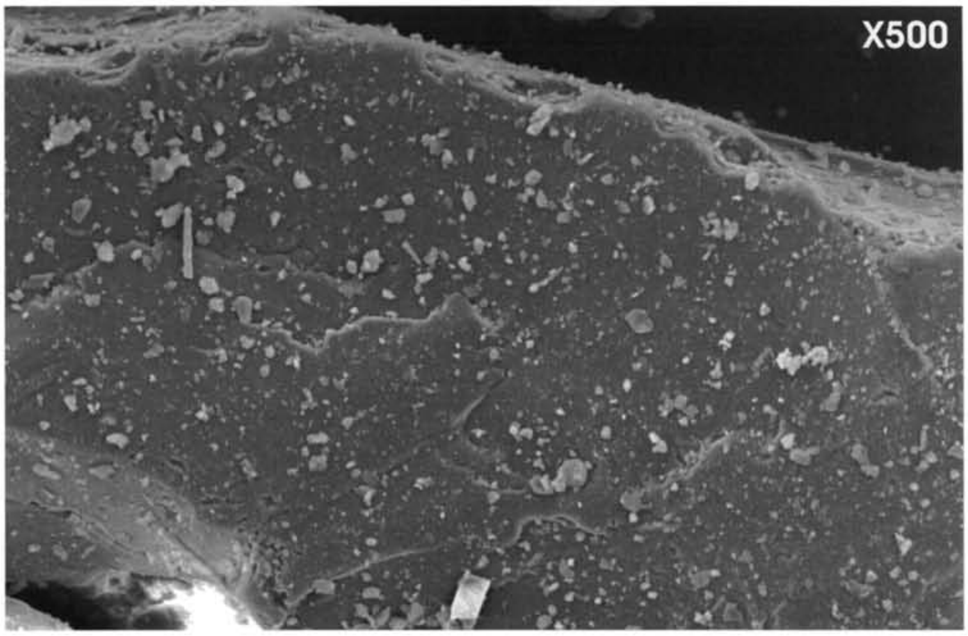


Plate 7c Scanning electron photomicrograph of ilmenite in the fine sands collected at a depth of 0-50 cm in Pit 18 exhibiting grooves, etch Vs, and solution pits

Plate 7d Scanning electron photomicrograph of some heavy minerals in the fine sands collected at a depth of 50-100 cm in Pit 18 showing angular to subhedral grains

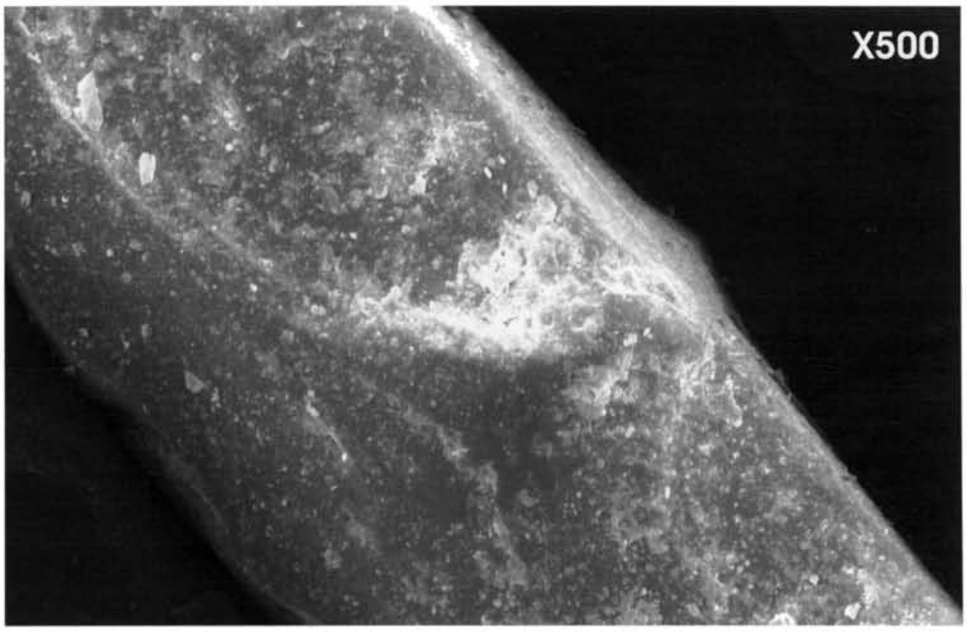


Plate 7e Scanning electron photomicrograph of **Ilmenite** in the fine sands collected at a depth of 50-100 cm in Pit 18 exhibiting breakage blocks and precipitation features

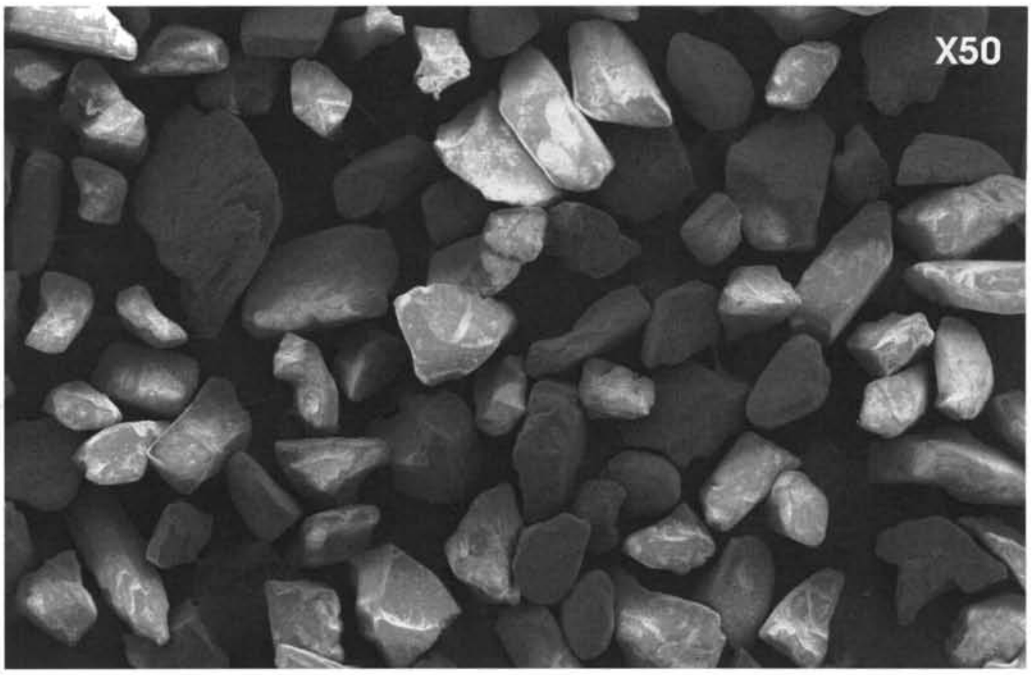


Plate 7f Scanning electron photomicrograph of some heavy minerals in the fine sands collected at a depth of 100-150 cm in Pit 18 showing anhedral to subrounded grains

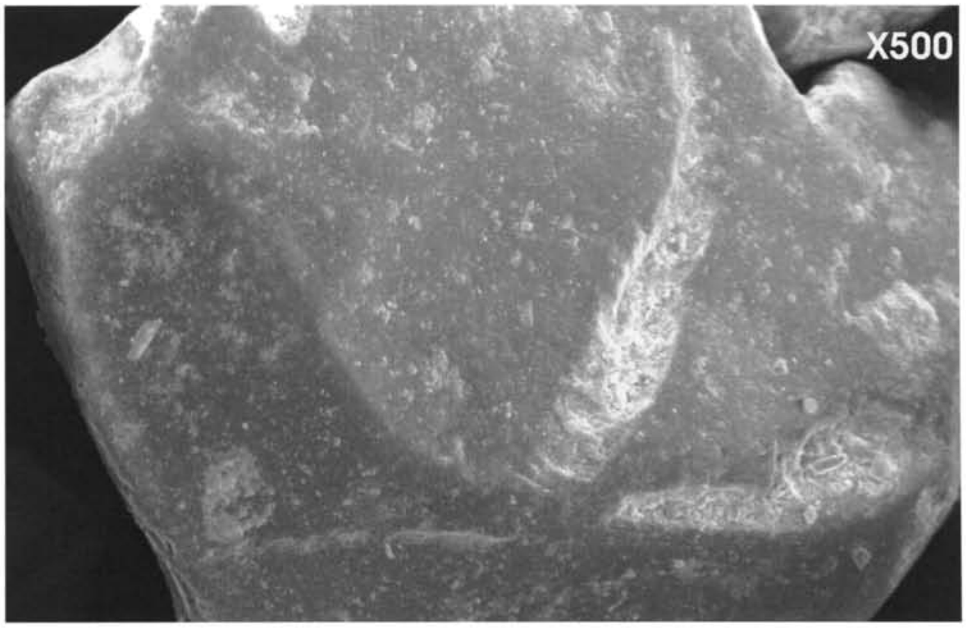


Plate 7g Scanning electron photomicrograph of ilmenite in the fine sands collected at a depth of 100-150 cm in Pit 18 revealing abrasion marks, breakage blocks, impact V marks, grooves.

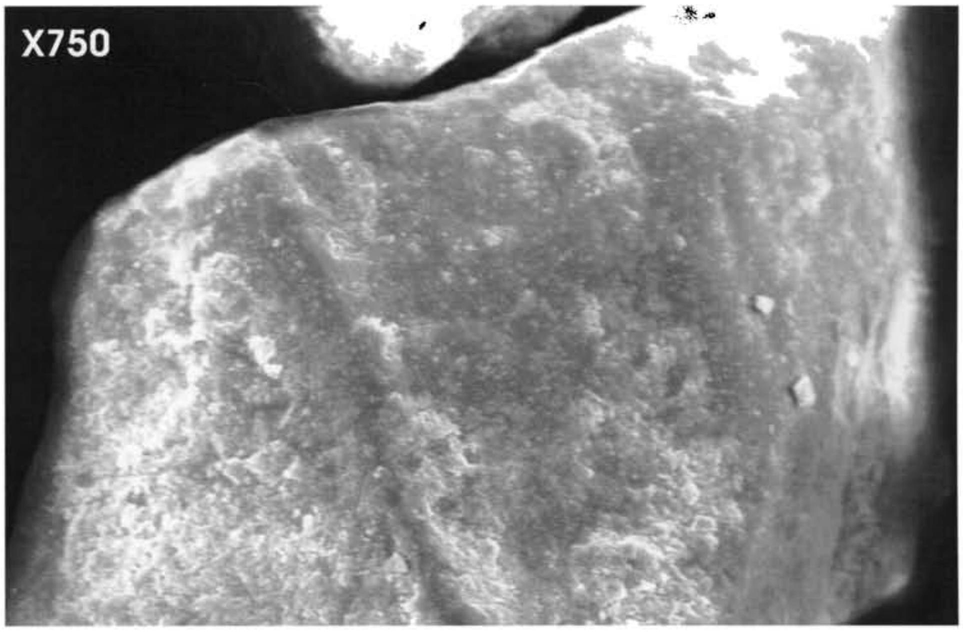


Plate 7h Scanning electron photomicrograph of ilmenite grains showing solution pits

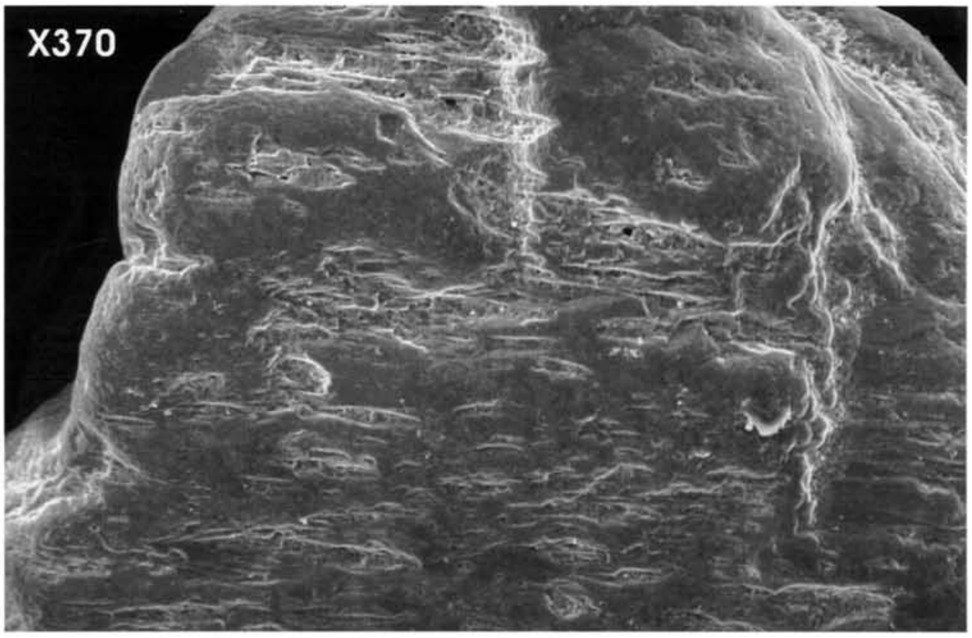


Plate 7i Scanning electron photomicrograph of sillimanite in the fine sands at a depth of 150-200 cm in Pit 14 exhibiting mechanical pits, grooves and chemical pits

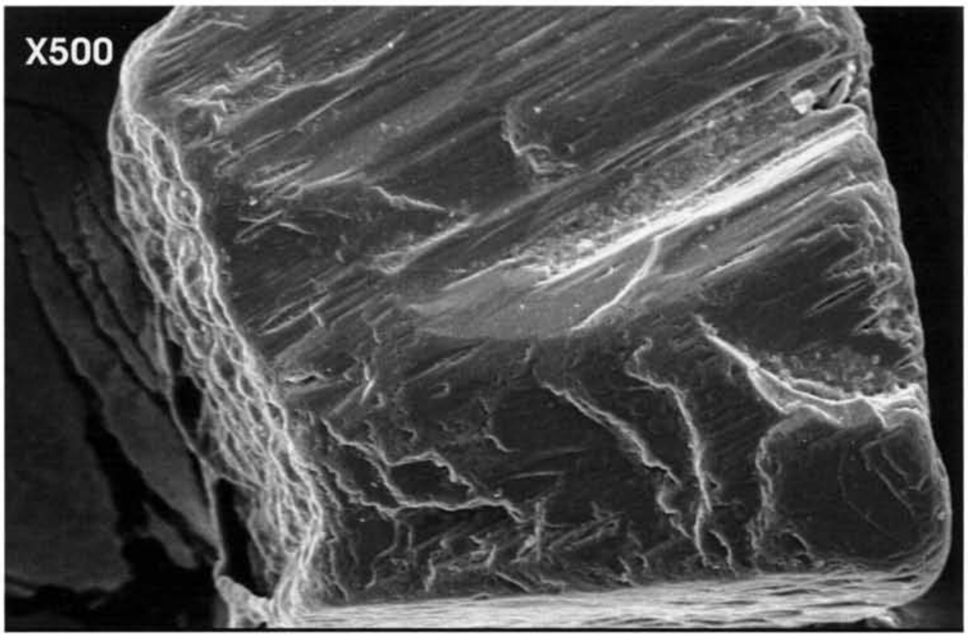


Plate 7j Scanning electron photomicrograph of ilmenite in the fine sands collected at a depth of 150-200 cm in Pit 14 exhibiting mechanical pits, grooves and chemical pits

Plate 7k Scanning electron photomicrograph of hornblende in the fine sands collected at a depth of 0-50 cm in Pit 7 exhibiting elongated to subrounded step like grooves and chemical pits

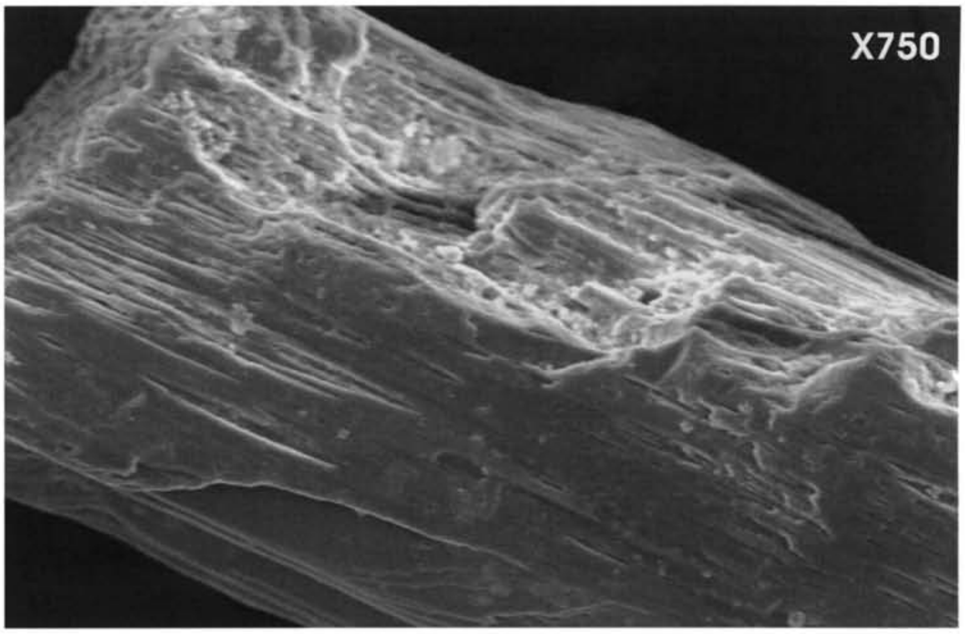


Plate 7l Scanning electron photomicrograph of hornblende in the fine sands collected at a depth of 0-50 cm in Pit 7 exhibiting step like grooves,and chemical pits

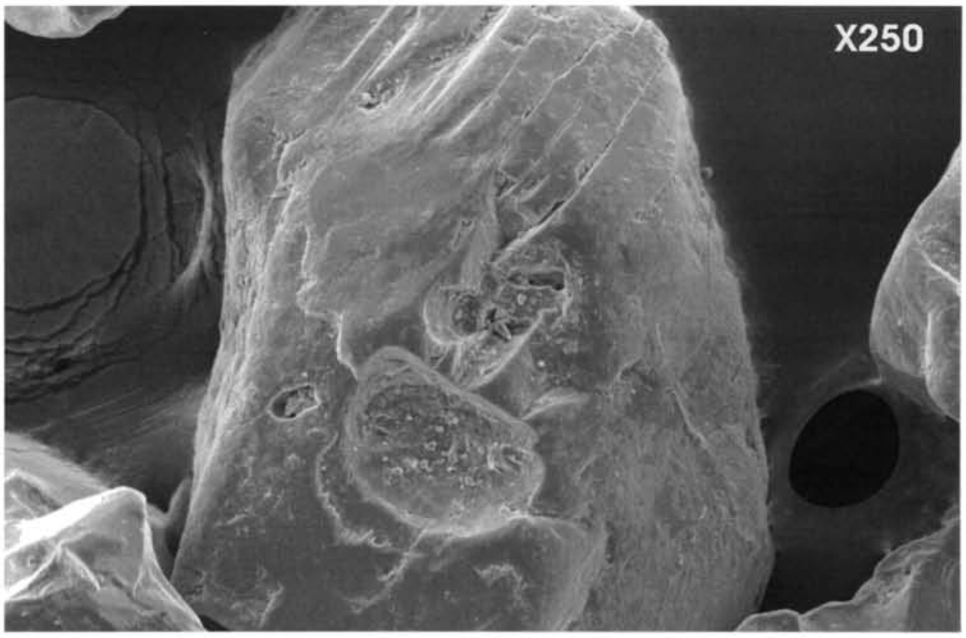


Plate 7m Scanning electron photomicrograph of garnet in the fine sands collected at a depth **50-100** cm in Pit 7 showing solution pits

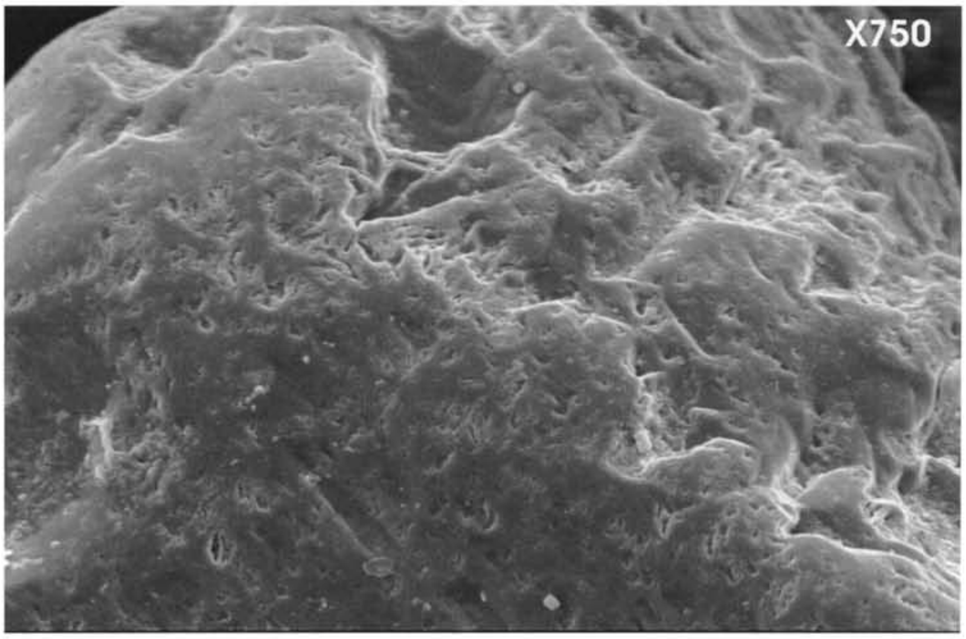


Plate 7n Scanning electron photomicrograph of ilmenite in the fine sands collected at a depth 50-100 cm in Pit 7 exhibiting solution pits

absent in all the samples of alluvial plains except one samples collected at depth 60-70cm in P21 which records 4.26%.

In the intertidal mudflats and swales, kaolinite is the predominant mineral. Its percentage is even higher than the alluvial plain sediments of P21. Next to Kaolinite, illite is the predominant mineral in the intertidal mudflats region. Chlorite content show a small range from 0-16.67%.

In swales the predominant kaolinite mineral is significantly in all the samples (Table 4.4) following which montimorillonite and illite are present in most samples. In all the surficial sediments, montmorillonite is either totally absent or present in very low quantities. With depth montmorillonite is enriched considerably.

The higher proportions of kaolinite in the alluvial plain and other environments (Table 4.4) refers the greater intensity of laterite denudation processes operating in the drainage basin of the study area. Soman and Machado (1986) have shown that kaolinite is the predominant mineral in the lateritic zone of Kerala.

Processes like saline water flocculation followed by differential settling at the site of deposition and post depositional alteration of some clay minerals can effect a concentration variation of clay minerals in the environment as well as with depth. Whitehouse et al. (1960) have shown that the river born clay minerals undergo differential settling in waters of increasing salinity and in that process illite and kaolinite flocculate at lower salinities than montmorillonite. Hence kaolinite and illite are present considerably in the entire environment. The absences of montmorillonite in the freshwater alluvial plains could be that the source rocks do not supply montmorillonite to the site of deposition. The lower proportion of kaolinite in the intertidal mudflats and swales in the bottom layers of sediments than the surface (Table 4.4) level could be possibly related to alteration as the environment is slightly alkaline. Griffin and Ingram (1955) and Grim (1968) have advocated that kaolinite is unstable in alkaline waters and would be altered either to illite or chlorite in estuarine and marine conditions.

Table 4.5 Salient features of different heavy minerals under SEM with different magnification from various depths of Pit samples

S.No.	Plate 7	Pit No.	Depth (cm)	Magnification	Mineral	Features
1	a	18	0-50	50	Group of minerals	Rounded and anhedral
2	b	18	0-50	350	Ilmenite	Etch, Vs and precipitation features
3	c	18	0-50	500	Ilmenite	Grooves, etch Vs and solution pits
4	d	18	50-100	50	Group of minerals	Angular to subhedral grains
5	e	18	50-100	500	Ilmenite	Breakage blocks and precipitation features
6	f	18	100-150	50	Group of minerals	Anhedral to sub rounded grains
7	g	18	100-150	500	Ilmenite	Abrasion marks, breakage blocks, impact V marks, grooves
8	h	18	100-150	750	Ilmenite	Solution pits
9	i	14	150-200	350	Sillimanite	Mechanical pits, grooves and chemical pits
10	j	14	150-200	500	Sillimanite	Mechanical pits, grooves and chemical pits
11	k	7	0-50	20	Hornblende	Elongated subrounded to anhedral grains, step like grooves and chemical pits
12	l	7	0-50	750	Hornblende	Subrounded to elongated, step like grooves and chemical pits
13	m	7	50-100	250	Garnet	Solution pits
14	n	7	50-100	750	Ilmenite	Solution pits

4.6 Scanning Electron Microscope (SEM) analysis

Surface textures of clastic particles often render valuable information about the physical and chemical processes acting on the particles during transportation and after deposition. Through SEM studies the signatures of strong wave action or wind/river action can be distinguished. Post depositional features mostly under water table conditions can also be distinguishable under SEM studies. Through the microfeatures, it is possible to understand the physical and chemical energy gradient, surface and sub-surface dissolution process and post depositional diagenetic modifications (Setlow and Karpovich, 1972; Baker, 1976; Marshall, 1987). Krinsley and Doornkamp (1973) have studied the surface textures of quartz grains for understanding the post depositional or diagenetic history of the sediments.

Micromorphological studies of heavy mineral grains from beach ridge sands from P7, P14 and P18 by SEM from different depths reveal the development of a number of micro features (Plate 7a-n). The salient features of SEM study are summarized in Table 4.5. Micro features of grains obtained from P18 at 0-50cm depth (Table 4.5) exhibit sub rounded to anhedral shape (Plate 7a), grooves, etch Vs, and solution pits in ilmenite grain (Plate 7c), and only etch Vs and precipitation features in another ilmenite grain (Plate 7b). Plate 7d shows the group of minerals present in P 18 which were collected at depths 50-100 cm in which elongated to anhedral grain shapes are evident. Plate 7e is an elongated illmenite grain having breakage blocks at the grain surface and is due to collision of grains under sub aqueous conditions in the high to very high littoral environment (Ambre et al., 2005). The precipitation features at the grain surface (Plate 7e) are possibly of sedimentary aluminium precipitation. Post depositional precipitation features are due to precipitation and deposition from a highly saturated solution in the low to medium energy coastal plain environment, where the water table varies from 1-1.5 m (Plate 4). Plate 7f shows group of the mineral present in the fine sands at 100-150cm depth in P18, while Plate 7g and h are the micro features of ilmenite grains under different magnifications. The prominent features identified in ilmenite are abrasion marks, breakage blocks, impact V marks and grooves (Plate 7g) while solution pits are so prominent in Plate 7h.

Sillimanite grain collected at depths 150-200cm in P14 (Table 4.5) show features of mechanical pits and grooves (Plates 7i and j) indicating mechanical activities resulting from grain to grain collision under sub aqueous environment before their burial. On the other hand the presence of chemical pits (Plates 7i and j) in the samples indicates post-depositional chemical activities.

Plate 7k and l are hornblendes having elongated to sub rounded grain shapes and is from P7, collected at depth 0-50cm. Micro features of hornblende (Plate 7l) clearly show step like grooves and chemical pits at the edges of the grain revealing both mechanical and chemical activities registered due to high energy fluvial processes as well as sub aqueous environment at the littoral zone. The garnet and ilmenite (Plate 7m and n) are collected at depth 50-100cm level in P7. The micro features found are solution pits formed by chemical activities taking place at high chemical energy level but low to medium coastal plain environment.

In general the processes responsible for the above set of features are the imprints made by mechanical action in the high energy littoral zones shortly before their burial, under sub aqueous low to moderate energy conditions and lastly by precipitation within the very low energy coastal plain environment under water table conditions. From the above results it is clear that sands from coastal plain environment have undergone mechanical and chemical weathering during transport or wave action within the littoral zone as well as after their deposition in the coastal plain environment.

CHAPTER 5

GEOCHEMISTRY

5.1 Introduction

In India a number of workers have carried out geochemical studies on sediments from various environments particularly from the coastal settings. In recent years there have been many studies to identify the sources and sinks of heavy metals in rivers, estuaries and near shore environment (Vale, 1986; Mance, 1987; Klomp, 1990; Windom, 1990). Extensive work has been done in estuaries and coastal belt by several investigators to understand the coastal environments and their evolution (Murthy and Veerayya, 1972a, b and 1981). The speciation of heavy metals in the aquatic environment has received considerable attention recently (Chen et al., 1976; Hong and Forstener, 1984; Rain, 1984). These studies throw light on their levels in the environment and their fractionation in different phases. Deep sea core sediments from northeastern Arabian sea has been studied by Rao and Setty (1967). Several studies like the Bombay harbour sediments by Gogate et al. (1976), Murty et al. (1978); geochemical studies of Cauvery river basin by Subramanian et al. (1985); Cauvery delta sediments by Seralathan (1978); Seralathan and Seetharamaswamy (1978); Cambay basin sediments by Dalal and Agarwal (1988); Gulf of Kutchch sediments by Paropkari et al. (1980, 1990) and Matkar et al. (1981); heavy metal sediments of south east coast of India by Subramanian and Mohanachandran (1990); Mahanadi river basin by Chakrapani and Subramanian (1990); geochemistry of shelf sediments of southwest coast of India by Paropkari (1990) have contributed to the understanding of the geochemical processes in varied environments. The behaviour of major and minor elements in sediments and elucidation of different factors controlling the distribution have been the objectives of a number of geochemists. The concentration and distribution of many metals in the seawater and sediments are influenced by adsorption or co precipitation with Fe and Mn oxides (Goldberg, 1954; Krauskopf, 1956; Jenne 1968; Murray and Brever, 1977). The general geochemistry of sediments including Fe, Mn and other trace metals from the deltaic regions and other coastal settings have been studied by many workers (Seralathan, 1979, 1987, 1988; Seralathan and Padmalal, 1993, 1994; Mohan, 1990, 1995, 2000; Nair and Padmalal, 2004, Sajan et al., 1992).

5.2 Results

The various geochemical elements and organic carbon are presented in Table 5.1 and their variations with depth are presented in Figs.5.1-5.3.The salient observations with regard to the distribution of various parameters are presented below.

Organic Carbon: The content of organic carbon in alluvial sediments in P21 vary from 0.22–0.62 % with an average of 0.37%. In P19 organic carbon varies from 0.31-3.57%. The average values of organic carbon for P19 are 1.03%. In alluvial plain sediments organic carbon increases with depth. Overall, the concentration of organic carbon in the swale sediments in P20 varies from 0.21-0.92% with an average of 0.50%. The organic carbon in P20 shows a steady increase with depth. In P23, organic carbon varies from 0.21-0.82%. The average value of organic carbon for P20 is 0.39%. Higher concentration of organic carbon is recorded in the lower part of the pit (Table 5.1 and Fig. 5.2).

The concentration of organic carbon in intertidal mudflat in P24 varies from 0.43-2.31% with an average of 1.07%. In general, the upper part of the pit (0-80 cm depth) shows low variation of organic carbon distribution. The highest value is recorded in the lowermost part of the pit. In P22 the organic carbon varies from 0.22-0.78%. The average value of organic carbon in P22 is 0.39%. In this pit also the highest value is recorded at the bottom most sample (Table 5.1and Fig. 5.3). The organic carbon in mangrove sediments is exceptionally very high, having a value of 7.94% in P25, while the lower

Table 5.1 Concentration of various geochemical parameters in clay fraction of Alluvial plains, Intertidal mudflats, Swales and Mangrove sediments, Central Kerala (Organic carbon, Fe, Ca, Mg, Na and K in % and others in ppm)

P19 Alluvial plain

Depth (	O.C	Fe	Ca	Mg	Na	K	Mn	Sr	Li	Cu	Co	Ni	Pb	Zn	Cd	Cr
0-10	0.31	2.16	0.33	0.12	1.11	1.55	215	189	9	10	12	128	115	27	0	64
10-20	0.34	2.65	0.37	0.19	1.55	1.25	259	201	15	11	9	159	138	39	1	80
20-30	0.36	2.81	0.48	0.21	1.14	1.78	299	246	12	0	9	196	31	30	0	78
30-40	0.49	2.16	0.60	0.15	1.36	1.60	198	358	17	10	5	124	58	67	2	151
40-50	0.58	2.61	0.72	0.15	1.67	1.84	165	545	22	11	2	130	49	32	0	98
50-60	0.49	1.99	0.61	0.10	1.49	1.49	294	301	11	8	5	189	76	35	0	127
60-70	0.82	3.29	0.59	0.14	1.19	1.28	411	260	1	9	10	218	59	54	0	100
70-80	0.61	2.10	0.50	0.16	1.30	1.20	318	227	8	8	12	254	34	37	0	92
80-90	0.74	2.84	0.40	0.21	1.59	1.39	298	198	17	9	15	227	29	36	1	80
90-100	0.58	3.93	0.32	0.29	1.27	1.18	389	147	12	10	25	292	14	83	0	115
100-11C	0.85	3.15	0.41	0.22	1.44	1.28	301	189	21	10	28	210	23	61	0	119
110-12C	0.98	2.99	0.40	0.26	1.30	1.60	278	232	14	7	20	261	29	34	0	137
120-13C	1.11	3.31	0.41	0.36	1.07	1.67	246	248	29	12	23	301	16	8	1	132
130-14C	1.85	4.79	0.10	0.25	0.59	1.16	147	115	34	12	11	181	31	21	3	135
140-15C	3.57	3.51	0.36	0.24	1.11	1.67	232	235	27	8	3	168	147	35	1	94
150-16C	1.92	3.25	0.30	0.20	0.99	1.49	201	198	31	7	2	179	157	29	0	98
160-17C	1.43	2.99	0.30	0.16	1.00	1.33	290	156	19	9	3	192	194	35	1	93
170-18C	1.37	3.07	0.36	0.12	1.22	1.79	232	203	28	7	8	219	218	30	0	84
180-19C	1.34	3.30	0.24	0.05	1.57	1.85	190	175	14	8	5	152	189	34	1	95
190-20C	0.88	2.21	0.33	0.17	1.18	1.80	214	221	10	9	8	203	250	29	0	60
Min.	0.31	1.99	0.10	0.05	0.59	1.16	147	115	1	0	2	124	14	8	0	60
Max.	3.57	4.79	0.72	0.36	1.67	1.85	411	545	34	12	28	301	250	83	3	151
Av.	1.09	3.11	0.43	0.20	1.32	1.59	272	244	18	9	11	210	98	40	1	107

Table 5. 1 continued

P21 Alluvial plain

Depth (	O.C	Fe	Ca	Mg	Na	K	Mn	Sr	Li	Cu	Co	Ni	Pb	Zn	Cd	Cr
0-10	0.26	2.25	0.27	0.13	1.00	1.75	189	148	15	15	2	227	39	28	1	86
10-20	0.27	2.54	0.31	0.15	1.54	1.36	201	152	21	7	3	203	72	35	0	89
20-30	0.31	1.99	0.29	0.17	1.05	1.16	224	175	18	11	8	167	87	43	0	112
30-40	0.22	2.68	0.34	0.21	1.49	1.85	264	201	12	7	7	196	119	37	0	124
40-50	0.30	3.03	0.41	0.26	1.25	1.46	195	198	9	10	8	257	98	49	0	117
50-60	0.24	2.94	0.50	0.28	0.99	1.40	172	232	11	17	4	198	110	42	1	142
60-70	0.22	2.17	0.50	0.30	1.00	1.58	204	218	18	12	5	219	91	37	0	139
70-80	0.33	2.99	0.40	0.30	1.27	1.69	198	198	15	15	4	228	59	30	1	136
80-90	0.38	3.53	0.22	0.20	1.18	1.88	174	172	12	10	6	259	43	32	1	127
90-100	0.41	2.82	0.18	0.12	1.53	2.51	194	154	10	6	5	283	18	29	0	127
100-11C	0.62	2.75	0.30	0.17	1.40	2.16	232	210	14	10	4	198	39	21	0	115
110-12C	0.61	2.40	0.48	0.19	1.77	2.34	247	285	7	12	3	145	65	13	1	75
120-13C	0.59	2.02	0.21	0.14	1.51	1.48	227	373	11	9	1	208	37	29	0	85
Min.	0.22	1.99	0.18	0.12	0.99	1.16	172	148	7	6	1	145	18	13	0	75
Max.	0.62	3.53	0.50	0.30	1.77	2.51	264	373	21	17	8	283	119	49	1	142
Av.	0.37	2.62	0.34	0.20	1.31	1.74	209	209	13	11	5	214	67	33	0	113

Table 5.1 continued

P24 Intertidal mudflat

Depth (	O.C	Fe	Ca	Mg	Na	K	Mn	Sr	Li	Cu	Co	Ni	Pb	Zn	Cd	Cr
0-10	0.78	1.92	0.57	0.15	0.76	0.72	312	202	1	3	1	149	45	5	2	65
10-20	0.65	1.66	0.81	0.20	0.80	0.77	266	254	8	8	1	94	6	36	0	57
20-30	0.78	1.65	0.87	0.20	0.87	0.77	257	231	3	10	5	106	38	41	0	80
30-40	0.43	1.55	0.81	0.34	0.98	1.00	131	346	15	10	3	141	29	22	1	52
40-50	0.58	2.54	1.02	0.69	0.75	0.86	159	251	21	9	5	156	37	37	0	82
50-60	0.81	1.97	0.96	0.36	0.73	1.02	132	198	32	10	2	165	40	25	2	105
60-70	0.92	2.22	0.16	0.12	0.82	1.07	110	174	44	7	3	182	35	35	0	124
70-80	0.81	2.15	0.97	0.36	0.69	0.54	153	215	121	6	3	172	29	24	0	39
80-90	1.17	3.20	1.21	0.87	0.54	0.70	195	198	102	4	2	168	53	17	0	68
90-100	1.21	4.11	1.90	0.94	0.41	0.61	249	235	137	13	2	153	67	14	0	48
100-11C	1.35	5.99	2.02	1.21	0.15	0.66	304	245	145	17	61	157	122	79	0	164
110-12C	1.20	4.44	0.38	1.06	0.51	1.15	100	390	210	29	48	201	61	81	0	251
120-13C	1.52	3.15	0.28	0.56	0.11	0.37	86	120	94	24	33	102	22	71	0	108
130-14C	1.59	3.55	2.66	0.62	0.43	0.80	131	263	72	10	8	122	118	82	1	114
140-15C	2.31	3.13	2.46	0.76	0.55	0.97	123	216	89	8	5	118	122	57	0	177
Min.	0.43	1.55	0.16	0.12	0.11	0.37	86	120	1	3	1	94	6	5	0	39
Max.	2.31	5.99	2.66	1.21	0.98	1.15	312	390	210	29	61	201	122	82	2	251
Av.	1.07	2.88	1.14	0.56	0.61	0.80	181	236	73	11	12	146	55	42	0	102

Table 5.1 continued

P22 Intertidal mudflat

Depth (	O.C	Fe	Ca	Mg	Na	K	Mn	Sr	Li	Cu	Co	Ni	Pb	Zn	Cd	Cr
0-10	0.24	1.88	0.69	0.46	0.90	0.85	341	304	2	12	9	256	87	30	1	80
10-20	0.22	3.15	0.57	0.30	0.49	0.91	418	245	8	10	18	294	51	41	0	87
20-30	0.24	2.90	0.78	0.40	0.75	0.69	534	198	4	6	16	275	42	30	0	91
30-40	0.29	2.53	0.53	0.45	0.87	0.60	298	153	11	8	12	266	41	20	0	76
40-50	0.38	2.12	1.00	0.39	0.54	0.85	586	249	18	7	18	281	31	29	0	98
50-60	0.27	3.15	1.36	0.62	1.07	1.07	625	421	89	5	5	301	23	23	0	105
60-70	0.58	2.90	0.51	0.10	0.96	0.85	643	244	91	1	12	454	10	40	1	99
70-80	0.50	3.25	1.05	0.61	0.94	0.95	836	308	142	7	18	721	31	45	0	105
80-90	0.78	2.64	0.98	0.60	0.87	0.99	183	294	104	3	13	568	42	50	0	103
Min.	0.22	1.88	0.51	0.10	0.49	0.60	183	153	2	1	5	256	10	20	0	76
Max.	0.78	3.25	1.36	0.62	1.07	1.07	836	421	142	12	18	721	87	50	1	105
Av.	0.39	2.72	0.83	0.44	0.82	0.86	496	268	52	7	13	380	40	34	0	94

Table 5.1 continue

P20 Swale

Depth (	O.C	Fe	Ca	Mg	Na	K	Mn	Sr	Li	Cu	Co	Ni	Pb	Zn	Cd	Cr
0-10	0.52	2.76	1.02	0.29	1.25	1.69	112	312	4	8	3	282	124	35	1	48
10-20	0.49	2.95	1.27	0.48	1.48	1.52	142	497	6	9	4	260	97	35	0	87
20-30	0.38	2.66	0.99	0.30	1.85	1.13	187	358	8	6	4	234	109	24	0	75
30-40	0.29	2.02	0.67	0.14	1.51	1.48	227	373	7	9	5	208	211	41	0	85
40-50	0.24	1.61	0.88	0.24	1.65	1.38	241	416	12	6	2	129	544	39	0	66
50-60	0.21	1.79	0.77	0.19	1.49	1.50	153	444	17	8	3	137	389	27	0	51
60-70	0.34	1.25	1.11	0.25	1.74	1.74	189	564	10	9	4	105	173	28	1	43
70-80	0.38	1.73	0.99	0.20	1.48	1.58	201	412	15	3	2	110	151	21	0	63
80-90	0.34	1.96	0.86	0.25	1.69	1.34	235	358	17	2	4	72	134	19	2	44
90-100	0.39	1.86	0.89	0.27	1.43	1.55	187	298	19	4	2	89	121	17	0	68
100-11C	0.42	2.10	0.80	0.20	1.70	1.86	155	378	21	12	3	98	89	33	5	90
110-12C	0.82	1.62	0.75	0.15	1.90	2.03	86	462	15	12	3	83	74	40	6	49
120-13C	0.78	2.05	0.68	0.20	1.72	1.75	140	401	11	7	4	92	39	34	1	87
130-14C	0.77	1.13	0.55	0.18	1.57	1.54	112	323	18	3	2	77	9	17	0	42
140-15C	0.92	2.35	0.65	0.20	1.49	1.39	128	298	12	6	1	75	29	16	0	52
150-16C	0.52	1.99	0.70	0.26	1.68	1.58	148	331	9	3	3	81	42	13	0	49
160-17C	0.61	1.75	0.71	0.19	1.59	1.72	161	384	12	6	3	86	29	13	0	54
Min.	0.21	1.13	0.55	0.14	1.24	1.13	86	298	4	2	1	72	9	13	0	42
Max.	0.92	2.95	1.27	0.48	1.90	2.30	241	564	21	12	5	282	544	41	6	90
Av.	0.50	1.97	0.84	0.24	1.60	1.57	165	389	13	7	3	130	139	27	1	62

Table 5.1 continue

P23 Swale

Depth (	O.C	Fe	Ca	Mg	Na	K	Mn	Sr	Li	Cu	Co	Ni	Pb	Zn	Cd	Cr
0-10	0.42	2.59	0.86	0.14	1.60	1.55	162	504	8	8	4	88	91	33	0	58
10-20	0.38	2.25	0.88	0.28	1.45	1.66	184	411	5	9	3	102	112	20	0	76
20-30	0.37	2.20	0.73	0.33	1.86	1.90	149	384	11	7	4	124	89	30	0	91
30-40	0.29	1.87	0.92	0.40	1.48	1.35	129	319	18	4	5	116	119	37	0	80
40-50	0.24	1.69	1.00	0.30	1.69	1.40	189	298	14	5	2	97	94	20	0	58
50-60	0.21	1.86	0.93	0.31	1.96	1.26	204	338	10	5	1	157	212	21	0	63
60-70	0.32	1.96	0.85	0.23	1.49	1.60	169	297	13	8	4	124	271	41	0	87
70-80	0.34	1.72	1.00	0.20	1.84	1.43	199	359	8	6	3	145	238	24	0	75
80-90	0.29	1.53	0.71	0.13	1.71	1.67	121	477	3	12	3	133	212	33	2	48
90-100	0.38	2.03	0.32	0.15	0.86	1.31	223	227	6	4	2	102	248	24	2	60
100-11C	0.34	2.43	0.66	0.11	1.11	1.56	140	367	8	7	4	120	87	48	0	55
110-12C	0.29	2.15	0.46	0.10	1.40	1.35	187	214	14	10	5	143	100	37	0	80
120-13C	0.38	1.86	0.69	0.08	1.57	1.59	154	407	10	8	3	151	124	35	1	57
130-14C	0.39	2.23	0.33	0.17	1.07	1.30	234	191	22	7	2	159	85	24	0	67
140-15C	0.42	1.99	0.49	0.13	0.98	1.02	201	254	19	12	2	145	137	30	2	81
150-16C	0.37	1.76	0.51	0.10	1.24	1.17	189	301	21	12	5	139	118	34	0	137
160-17C	0.82	2.17	0.30	0.15	1.02	1.58	221	241	17	10	2	135	194	35	1	66
170-18C	0.78	2.50	0.15	0.11	1.36	1.36	138	186	12	8	1	122	214	37	0	70
Min.	0.21	1.53	0.15	0.08	0.86	1.02	121	186	3	4	1	88	85	20	0	48
Max.	0.82	2.59	1.00	0.40	1.96	1.90	234	504	22	12	5	159	271	48	2	137
Av.	0.39	2.04	0.65	0.19	1.43	1.45	177	321	12	8	3	128	153	31	0	73

Table 5.1 continue

P25 Mangrove

Depth (	**O.C**	**Fe**	**Ca**	**Mg**	**Na**	**K**	**Mn**	**Sr**	**Li**	**Cu**	**Co**	**Ni**	**Pb**	**Zn**	**Cd**	**Cr**
0-10	7.81	5.36	0.77	1.63	0.48	0.83	302	161	188	15	44	733	6	83	0	211
110-12C	5.49	7.21	0.37	1.67	1.45	1.18	187	151	227	20	58	299	116	141	0	250
140-15C	6.12	5.06	0.75	1.64	0.38	0.82	164	138	201	15	40	243	206	93	0	220
Min.	5.49	5.06	0.37	1.63	0.38	0.82	164	138	188	15	40	243	6	83	0	211
Max.	7.81	7.21	0.77	1.67	1.45	1.18	302	161	227	20	58	733	206	141	0	250
Av.	6.47	5.88	0.63	1.65	0.77	0.94	218	150	205	17	47	425	109	106	0	227

P26 Mangrove

Depth (ı	O.C	Fe	Ca	Mg	Na	K	Mn	Sr	Li	Cu	Co	Ni	Pb	Zn	Cd	Cr
40-50	0.74	7.36	0.41	0.89	0.84	1.15	91	625	160	17	69	171	27	79	1	218
80-90	3.11	7.79	0.44	0.92	0.55	1.18	88	571	146	28	71	284	31	491	1	228
140-15C	3.10	4.58	0.28	1.02	0.52	1.28	103	55	210	14	51	343	18	67	1	252
Min.	0.74	4.58	0.28	0.89	0.52	1.15	88	55	146	14	51	171	18	67	1	218
Max.	3.11	7.79	0.44	1.02	0.84	1.28	103	625	210	28	71	343	31	491	1	252
Av.	2.32	6.58	0.38	0.94	0.64	1.20	94	417	172	20	64	266	25	212	1	233

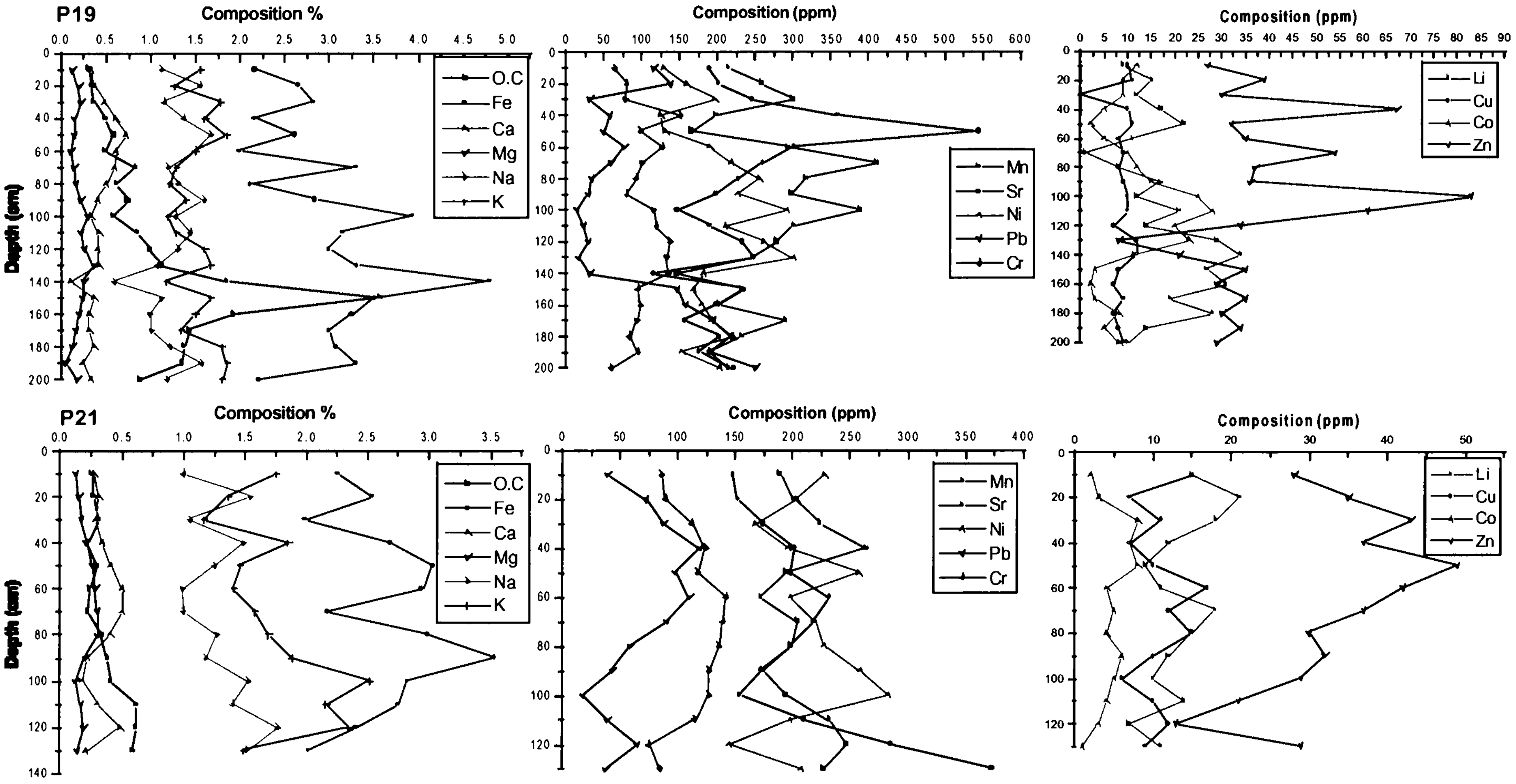


Fig 5.1 Variation of different elements and organic carbon in alluvial plains (Pits 19 &21)

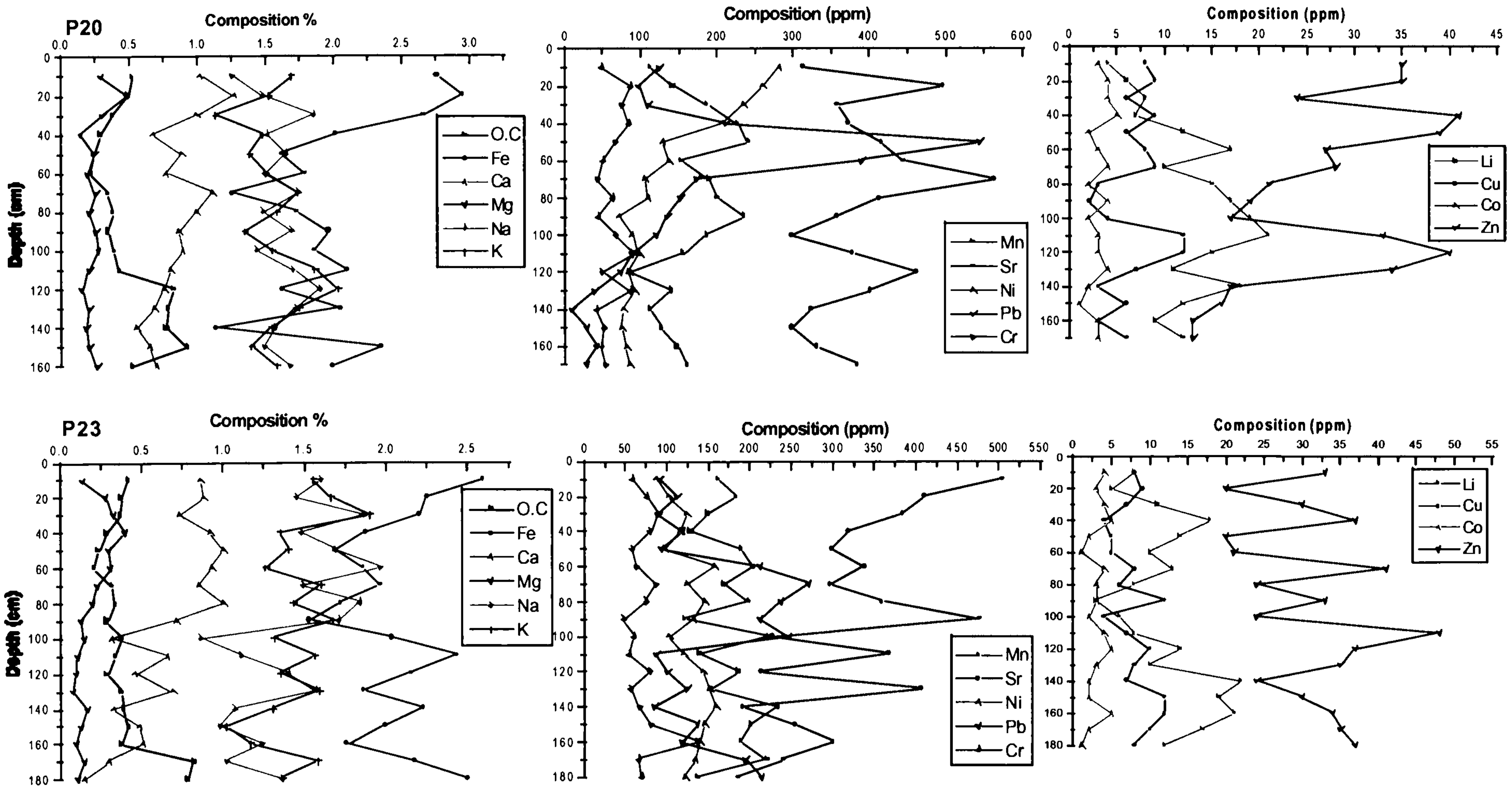


Fig 5.2 Variation of different elements and organic carbon in swales (Pits 20&23)

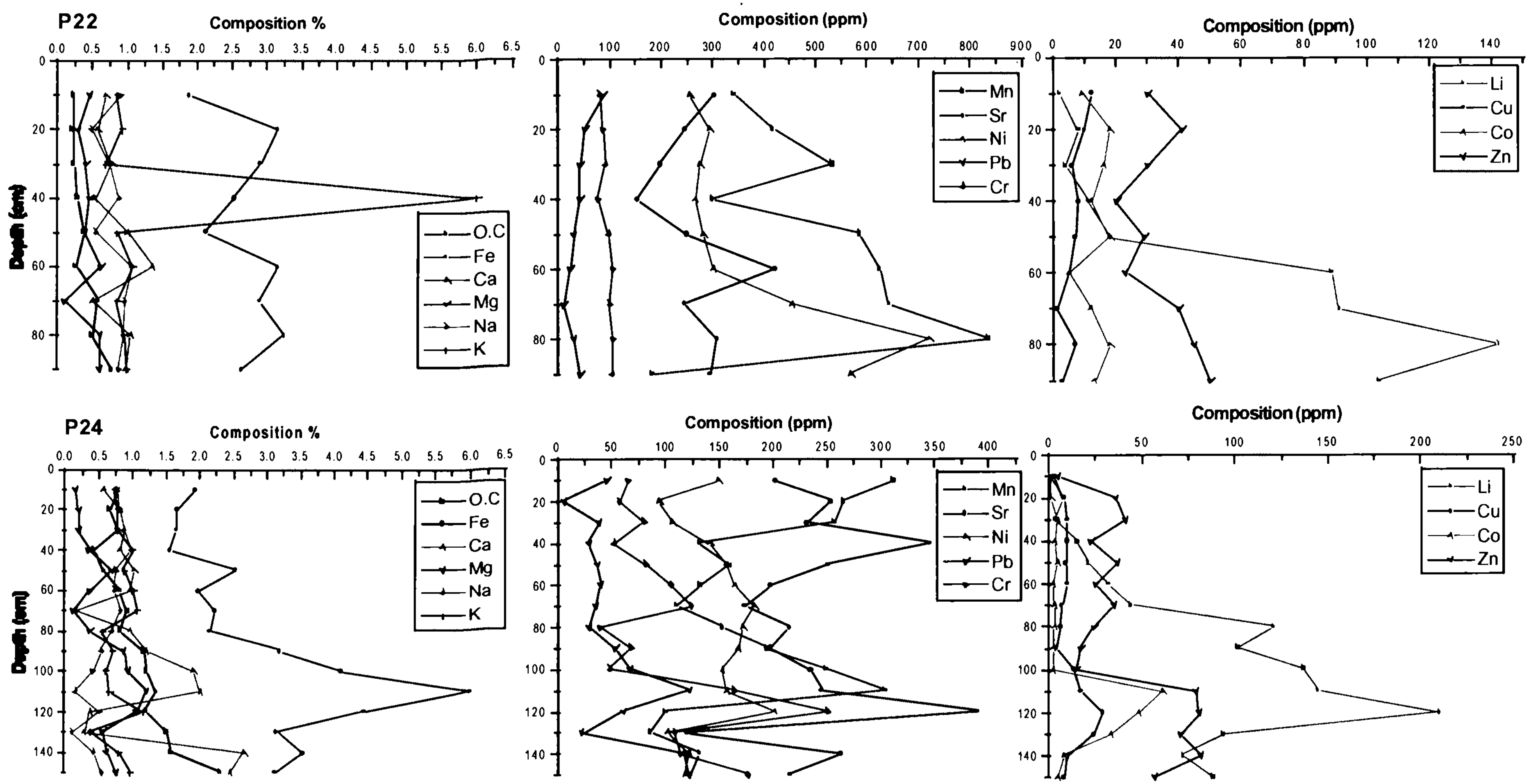


Fig 5.3 Variation of different elements and organic carbon in intertidal mud flats (Pits22&24)

concentration of 0.74% is observed in P26. The average values of organic carbon are 6.47% and 2.32% in P25 and P26 respectively.

Iron: The distribution of iron in the alluvial plain sediments varies from 1.99-4.79% in P19 and from 1.99-3.53 % in P21. The average being 2.96% and 2.62% respectively for P19 and P21. A uniform pattern of distribution of iron is recorded in the upper layers of P19 (0-60cm) depth but shows an increase in its concentration in the lower parts. In P21, the concentration of iron is substantially higher compared to P19.The iron values are comparatively high in the middle parts of the pit than the top and bottom of the pit (Fig. 5.1). The distribution of iron in the swale sediments varies from 1.13% to 2.95% in P20 and from 1.53% to 2.59% in P23. The average concentration of iron in P20 is 1.98% and in P23 it is 2.04%. Iron concentrations are considerably higher in top layers in both pits, (up to 40 cm depth) while it reduces considerably towards bottom layers, with minor fluctuations (Fig. 5.2).

Iron in the intertidal mudflat sediments varies from 1.55% to 5.99% in P24, averaging at 2.88%, and from 1.88% to 3.25% in P22, averaging at 2.73%. Though iron is considerably lower in the upper part of the P24, it steadily increases down the core. In P22, the concentration of iron shows a steady increasing trend with depth (Fig. 5.3). The distribution of iron in the mangrove sediments varies between 5.06% and 7.21% in P25, and between 4.58% and 7.79% in P26. The average content of iron in P25 is 5.88% and 6.58% in P26. Iron concentrations show a steady decreasing trend with depth in P26.

Calcium: Calcium concentrations in alluvial plains vary from 0.10-0.72% and 0.18-0.50% in P19 and P21 respectively. The average calcium concentrations are recorded at 0.41% for P19 and 0.34% for P21. Calcium shows high concentration in the middle part than top and bottom of pits (Fig. 5.1). In swales, concentrations of calcium fall between 0.55% and 1.27% (P20) and 0.15-1.00% (P23). The average concentrations are 0.84% (P20) and 0.66%

(P23). Calcium concentrations in swales show a decreasing trend with depth in both the pits (Fig. 5.2).

Concentration of calcium in intertidal mudflat ranges from 0.16-2.66% and 0.51– 1.36% in P24 and P22. The average concentrations are 1.14% and 0.83% for P24 and P22 respectively. In both pits, calcium content is relatively lower in top layers and higher concentration in the bottom layers, i.e., an increasing trend with depth (Fig. 5.3 and Table 5.1). In mangrove sediments, calcium varies from 0.37-0.77% and 0.28-0.44% in P25 and P26 respectively. The average concentration for P25 is 0.63% and for P26 is 0.38%.

Magnesium: In alluvial plains the concentration of magnesium varies from 0.05-0.36 % in P19 and 0.12-3% in P21. In P21 magnesium concentrations increase gradually up to 80cm depth and thereafter it decreases considerably (Fig. 5.1). In swales the magnesium concentrations vary from 0.14-0.48ppm in P20 and from 0.08-0.33% in P23.

Magnesium concentrations vary in intertidal mudflats from 0.12-21% in P24 and from 0.10-0.62% in P22. The concentration has a uniform increase up to 50cm depth and thereafter it fluctuates in P24 (Fig. 5.3). Magnesium in mangrove sediments varies from 1.67% (P25) to 0.89% (P26). The average value of P25 is 1.65% and that of P26 is 0.94%. In P25 there is no considerable variation in the concentration of magnesium, while in P26 it increases with depth. P25 has more magnesium content than P26.

Sodium: In alluvial sediments sodium recorded a maximum of 1.77% in P21 and a minimum of 0.59% in P19 respectively. In P19 sodium is enriched in the upper part of P19 while P21 shows an increase in sodium content with depth (Fig. 5.1). Sodium content in swale has a maximum of 1.96% and a minimum of 0.86% in P20 and P23 respectively. Sodium fluctuates considerably with depth in both pits (Fig. 5.2).

Intertidal mudflats sediments contain 1.07% of sodium as the maximum value in P22. Sodium concentration remains steady in the upper part of P24 but fluctuates in the lower part of the pits (Fig. 5.3). The mangrove sediments recorded sodium content 1.45% (maximum) and 0.38% (minimum) both in P25. The average values of sodium in P25 and P26 are 0.77% and 0.64% respectively.

Potassium: In alluvial sediments, potassium varies from 2.51–1.16%. Maximum value has been recorded in P21 (2.51%). The average value of potassium concentration is 1.51% and 1.74% in P22 and P24 respectively. Potassium concentration of swale sediment varies from 1.02-2.03%. Maximum value has been recorded in P20. The average is 1.58% and 1.45% in P20.

In the intertidal mudflats maximum concentration of potassium is 6% in P22 and minimum value is 0.37%. The average is 1.46% and 0.80% in P22 and P24 respectively. In mangrove sediments, concentration of potassium varies from 0.82-1.28%. Maximum value has been recorded in P26. The average is 0.94% and 1.20% in P25 and P26 respectively. There is a steady enrichment of potassium with depth in both pits.

Manganese: In alluvial plain sediments the maximum values of manganese are 411ppm and 264ppm and minimum values are 147ppm and 172ppm in P19 and P21 respectively. The average value of manganese is 259ppm in P19 and 209ppm in P29. In swale sediments, the maximum values of Mn are 241ppm and 234ppm and the minimum values are 86ppm and 121ppm in P20 and P23 respectively. The average manganese content is 165ppm in P20 and 177ppm in P23.

In intertidal mudflats the manganese concentration has a maximum value of 836ppm in P22 and 312ppm in P24. Its minimum values are 86ppm and 183ppm in the respective cores. In P24 the average manganese content is 181ppm and in P22 it is 496ppm. In mangrove sediments the maximum manganese concentration is 302ppm in P25 and 103ppm in P26 while the minimum values are 164ppm and 88ppm respectively. The average manganese content for P25 is 218ppm and for P26 is 94ppm.

Strontium: In alluvial sediments strontium varies between 115ppm and 545ppm. Maximum value has been recorded in P19. The average strontium content is 232ppm and 209ppm in P19 and P21 respectively. In swale sediments the concentration of strontium varies between 186 and 564ppm, with maximum content in P20. Average strontium content is 389ppm in P20 and 321ppm in P23.

Strontium content in intertidal mudflats sediment varies between 120ppm and 421ppm. The maximum value is observed in P22 with an average of 236ppm in P24 and 268ppm in P22. Strontium concentration ranges between 55-625ppm in mangrove sediments. An average of 150ppm and 417 ppm is recorded in P25 and P26 respectively.

Lithium: In alluvial sediments, lithium varies in P19 from 1ppm to 34ppm and in P21 from 7ppm to 21ppm. The average values of lithium are 18ppm and 13ppm in P19 and P22 respectively. In swale sediment, the concentration of lithium varies from 4ppm to 21ppm in P20 and 3ppm to 22ppm in P23. The average values of lithium are 13ppm and 12ppm in P20 and P23 respectively.

In intertidal mudflat sediments, lithium concentration varies between 1ppm to 210ppm in P24 and 2ppm to 142ppm in P22. The minimum values are 1ppm and 2ppm in P24 and P22 respectively. The average value in P24 is 73ppm and in P22 it is 52ppm. The concentration of lithium in mangrove sediments varies between 161ppm-188ppm in P25 and 146-625ppm in P26. The average value of lithium content is 205ppm in P25 and 172ppm in P26.

Copper: The concentrations of copper vary from 6ppm to 17ppm in alluvial plains. Maximum value of copper is recorded in P21 (17ppm), an average of 11ppm and 7ppm are recorded in P19 and P21 respectively. In swales, copper content varies from 3ppm to 12ppm (Table 5.1). Maximum and minimum values in P20 are 12ppm and 3ppm respectively. The average copper concentrations in P20 and P23 are 7ppm and 8ppm respectively. In P20 there is a steady increase of copper concentrations with depth up to 120cm and thereafter it decreases with depth. In P23 the copper content shows a steady increase with depth (Fig. 5.2).

The copper concentrations in intertidal mudflats vary from 1ppm to 29ppm. An average of 11ppm and 7ppm are recorded in P24 and P22 respectively (Table 5.1). Copper content shows a considerable increase with depth in P24 while in P22 its content decreases with depth (Fig. 5.3). In mangroves sediments copper ranges from 14 to 28ppm. Maximum value has been recorded in P26 (28ppm) and the minimum value in P22 (14ppm). The average concentrations of copper in P25 and P26 are 17ppm and 20 ppm respectively.

Cobalt: The maximum concentration of cobalt in alluvial plain is 28ppm in P19 and 8ppm in P21. The minimum values of 1ppm and 2ppm are observed in P21 and P19 respectively. The average value of cobalt in P19 and P21 are 11ppm and 5ppm respectively. In P19 higher values are recorded in the middle parts of the pit between 60 and 130cm level but in P21 the cobalt value does not show any remarkable variation (Fig. 5.1). In swales, cobalt content in both the cores is consistently low, showing a range from 1 to 5 ppm and with an average of 3ppm for both cores (Table 5.1). Cobalt does not show any specific trend with depth (Fig. 5.2).

In intertidal mudflats the maximum values observed for cobalt are 18ppm in P 22 and 61ppm in P24. The minimum values are 1ppm and 5ppm in P24 and P22 respectively. The average values are 12ppm and 13ppm in P24 and P22 respectively. This metal has recorded an increase in the lower part of P24 but an almost steady pattern is observed in P22 (Fig. 5.3). Cobalt shows the maximum value of 58ppm in P25 and 71ppm in P26 in mangrove sediments, while its minimum values are 40ppm and 51ppm in P25 and P26 respectively. The average cobalt content in P25 and P26 are 47ppm and 64ppm respectively.

Nickel: In alluvial plains, nickel varies from 124-301ppm. Maximum value has been recorded in P19. In P19 and P21 the average value is 199ppm and 214ppm respectively. There is a steady increase in nickel values with depth up to 130cm and then an uneven pattern is observed in P19. In P21, nickel does not show any specific trend with depth (Fig. 5.1). In swale, nickel concentration varies from 72ppm to 282 ppm. Maximum value has been recorded in P20. The average of nickel in P20 and P23 are 130ppm and 153ppm respectively. As the depth increases the nickel values decrease very considerably but in P23 nickel increases up to a depth of 140 cm and then decrease (Fig. 5.2).

In intertidal mudflats nickel variation is from 94 to 721ppm. Maximum value has been recorded in P22. In P24 the average nickel is 146ppm while in P22 the average is 380ppm respectively. There is no much variation in nickel concentration with depth in P24 but has shown a steady increase in P22 (Fig. 5.3). Nickel concentration in mangrove sediments is exceptionally very high showing a range from 171ppm to 733ppm. Maximum value has been recorded in P25. The average is 425ppm and 266ppm in P25 and P26 respectively. In P25 nickel increases with depth, but in the case of P26 nickel is enriched in the lower part of the pit (Table 5.1).

Lead: In alluvial plains lead records a maximum value of 250ppm in P19 and 119 ppm in P21. The observed minimum values are 14ppm and 18ppm in P19 and P21 respectively. The average values of lead in P19 and P21 are 93ppm and 67ppm respectively. Lead shows higher values in the lower parts of the P19 but the concentration shows a steady trend with depth in P21 (Fig. 5.1). The lead concentration in swale shows a maximum of 544ppm in P20 and 271ppm in P23, and a minimum of 6ppm and 10ppm are observed in P20 and P23 respectively. The average lead content in P20 and P23 are

139ppm and 153ppm respectively. Lead has recorded higher values in the upper most parts of P20 and also in the middle to lower part of P23 (Fig. 5.2).

In intertidal mudflats, lead ranges from 6ppm to 87ppm in P22 and from 10ppm to 122ppm in P24. The average concentration in these pits is 55ppm and 40ppm respectively (Table 5.1). In mangrove sediments, maximum value of lead is 206ppm in P25 and 31ppm in P26, while their minimum values are 6ppm and 18ppm respectively. An average value of 109ppm is observed in P25 while 25ppm is the average in P26.

Zinc: The concentration of zinc in alluvial sediments is found ranging from 8-83ppm (Table5.1). Average zinc content in P19 and P21 are 38ppm and 33ppm respectively. Zinc content in P19 is considerably higher than P21. In P21, zinc content show an increasing trend up to depth 100cm and then on decreasing (Fig. 5.1). In swales, zinc concentration varies from 13-48ppm. The average concentration is 27ppm in P20 and 31ppm in P23 (Table 5.1). A steady increasing pattern with depth is observed in the case of P20, but in P23 there is no much variation with depth (Fig. 5.2).

The range of zinc concentration in intertidal flat is from 5ppm to 82ppm. An average of 42ppm and 34ppm is observed in P24 and P22 respectively (Table5.1). A slight increase of zinc content with depth is recorded in P24 but P22 does not show much variation with depth (Fig. 5.3). In mangroves the concentration of zinc varies from 67- 491ppm. The average is 106ppm in P25 and 25ppm in P26 respectively. The concentration is unevenly distributed in both pits.

Cadmium: One of the least concentrated elements in the study area is cadmium and in majority of the samples cadmium is below detectable levels. The variation in the concentration of cadmium in alluvial plain is very small; maximum value of 3ppm is recorded in P19 while just 1ppm in P21. In most samples cadmium is below detectable limits (Table5.1). In swales, cadmium concentration varies from 0-6ppm in P20 and from 0-2ppm in P23. In intertidal mudflats, the concentration of cadmium values varies from 1-2ppm while in mangroves the maximum cadmium value is just 1ppm. In P25 cadmium has not been detected at all.

Chromium: Chromium in alluvial plains has shown a variation from 60ppm to 151ppm. Maximum value has been recorded in P19. An average value of 102ppm and 113ppm are recorded in P19 and P21 respectively (Table 5.1). An enrichment of chromium is observed in both pits, in the middle layer (Fig. 5.1). Chromium concentrations in swales vary from 42ppm to 137ppm (Table 5.1). Maximum value has been recorded in P20. The average is 62ppm in P20 and 73ppm in P23 respectively. There is no predictable variation of chromium content in both the pits with depth (Fig. 5.2).

In intertidal mudflats, chromium varies from 39ppm to 251ppm. An average of 102ppm and 94ppm is recorded in P24 and P22 respectively. There is a slight enrichment of chromium in the middle and lower parts in P24 while in P22 chromium increases with depth (Fig. 5.3). In mangrove sediments chromium concentration varies between 211ppm and 250ppm (Table 5.1). The maximum value has been recorded in P25. An average value of 227ppm and 233ppm is recorded in P25 and P26 respectively. There is a slight enrichment of chromium in P26 with increasing depth but in P25 no such steady pattern in the concentration of chromium is observed.

5.3 Discussion

Organic Carbon: The organic carbon in the study area shows a relatively high value in the bottom layers than the top of pits. The organic carbon contents in swales (P20 and P23), P22 of intertidal mudflats and P21 of alluvial plains are considerably lower (less than 1%) than in other pits such as P19 and P24 where the average organic carbon content is greater than 1%. The low content of organic carbon in the upper layers of sediments column indicates considerable oxidation process, which would eliminate the organic carbon in the sediments. Since the nomenclature of sediments in the study area environment is sandy mud the preservation potential of organic carbon is always low.

On the other hand the organic carbon content in mangrove sediments is exceptionally high, with an average of 6.47% in P25 and 2.32% in P26. Since mangrove environment is considered to be colonized by plants, the substratum is predominantly sandy mud (P25) and clay sand (P26) and the area is periodically inundated by tidal waves there is a greater possibility for steady supply of organic matter and greater possibility for preservation. Apart from the constant higher organic supply, the presence of anoxic condition can also lead to preservation of organic matter. Further the toxic condition existing in the mangrove environment inhibits bacterial decomposition of vegetal matters. In addition the constant moisture due to tidal action and by the tightly knit canopy and the muddy substratum inhibit oxidation of organic carbon. Seralathan and Swamy (1979) have shown that organic carbon preservation is marginally low in muddy sand than clay rich sediments like mangroves. Bava and Seralathan (1998) have observed high value of organic carbon in mangrove sediments of Cochin coast. Higher proportion of organic matter in fine grained sediments than the muddy sand is due to increased surface area of the fine particles (Elwakeel and Mahmoud, 1978).

Iron and Manganese: Iron is one of the important elements in the earth crust consequently it constitutes a common component in sedimentary deposits. It is a typical transitional element whose compound in aquatic environment has a strong bearing on the distribution pattern of other trace sediments. The most common form of iron minerals are oxides, hydroxides and sulphides. Particulate iron is deposited in sediments as iron silicate grains, inorganic oxides or oxides coatings on settling particles. Iron may also enter the sediments in association with organic debris or humic colloidal matters. Like iron, manganese is also a transitional element and is an environmentally significant element.

In the study area iron content is considerably higher in all the environments and particularly in mangroves (Table 5.1). Iron shows a steady increase with depth in alluvial plain and intertidal mudflats (Fig. 5.1 and 5.3). The significant enrichment of Fe and Mn down the pit indicates that considerable portions of these elements are bound with in the sediments other than oxide form. Through reduction processes a part of Fe and Mn can be reduced and transferred to interstitial waters. In the bottom most layer both Fe and Mn show a drastic reduction in their concentration as indicated in P19, P21 and P24. This indicates that the sediment bound Fe and Mn are released by dissolution under reduced condition. However, the released Fe and Mn are diffused to the oxic layers of sediments and get reprecitated as Mn oxides and oxihydroxides in the oxidized zone thus the concentration of Fe and Mn are slightly higher (Froelich et al, 1979; Klinkhammer, 1980; Emerson et al., 1980; Klinkhammer et al, 1982; Bender and Heggie, 1984, Heggie et al.1986; Shaw, 1988; Shaw et al 1990). In anoxic sediments enzymatic reduction (Stumm and Morgon 1981) and Mn (Froelich et al., 1979) has been postulated. The low values of Fe in swales in central part of pit could be related to reduction process. A considerable part of Fe can be fixed in sulphides, in oxygen minimum zone and as phosphate and carbonates in oxygenated environment (Santschi et al., 1990). Similarly Emerson (1976) and Matisoff et al., (1980) have stated that Mn can be fixed as $MnCO_3$ and MnS respectively. In heavy mineral rich sediment a small portion of iron and Mn can be added to clay particle by breakage of iron minerals in the high-energy zones by mechanical actions. Iron and Mn can be adsorbed as clay minerals particularly in kaolinite which is the dominant mineral (Nelson, 1959) in the study area. Organic carbon and iron show good correlation and hence iron can be fixed in organic carbon.

Sodium, Potassium, Calcium and Magnesium: Sodium and potassium mainly comes into sediments as a weathering product of minerals like orthoclase, microcline and biotite. Sodium and Potassium behaves similarly with depth indicating their close affinity. A major part of Sodium and Potassium would have tied up in clay minerals. According to Weaver (1967) and Sayles and Mangelsdorf (1977) absorption of sodium and potassium are the prime reason for enrichment of sodium and potassium in clay minerals and thereof in sediments. In alluvial plain sediments, calcium and magnesium show relatively low values and a small increase with depth in swales. Magnesium does not show any major trend with depth but calcium registers a steady increase with depth. In intertidal mudflats, calcium and magnesium show considerable increase with depth (P24). It is generally believed that calcium and magnesium increase with depth and this is possibly due to precipitation of calcium as calcium carbonate where the required carbonate may be derived from sulphide reduction process (Presley and Kaplan, 1968; Sholkovitz, 1973; Nissenbaum et al., 1972). Sholkovitz (1973) has stated that a small part of sedimentary carbonate should be of authigenic origin. Precipitation of calcium sulphate is the dominant mechanism in removing Ca from interstitial waters. Therefore, in sediments calcium would remain high at the bottom. At surficial level both Ca and phosphate can be precipitated out of solution as calcium phosphate under high redox potential.

Lead and Zinc: The average concentration of Pb on the earth surface is 16ppm (Davis, 1990). In neutral and alkaline water condition Pb ion becomes hydrolysed and gets precipitated with Fe and Mn oxides (Krauskopf, 1967) or absorbed by clay minerals as it can replace Ca and K in the clay mineral structure particularly in kaolinite. Wedepohl (1978) indicated that Pb could effectively be carried by kaolinite and montmorillonite. As kaolinite and montmorillonite contents are significantly high (See Chapter 4) in the study area (except alluvial plain) and thus its association with these two clay mineral can be justifiable. Pb also shows significant correlation with Ca and Mg indicating its association with montmorillonite clay mineral. Pb shows significant correlation with organic carbon of alluvial plain and intertidal mudflat (Table 5.2). The Pb vs organic carbon relationship has been well documented by workers like Cocker and Mathews (1983) and Glegg et al. (1988).

In nature Zn is associated with sulphides of metal such as Pb, Cu, Cd and Fe. The Zn content in the sediments mainly depends on the composition of parent rock (Sillanppa, 1972; Pendias and Pendias, 1984). Zn in the alluvial plain sediments is considerably higher in the top layers of pit and decreasing with depth. P20 of swale also show a decreasing trend with depth. On the other hand Zn in P23 (swale) and P22 and P24 (intertidal mudflats) shows an increasing trend with depth. Therefore, the high Zn content in the top layers of sediments are related to precipitation in oxide phases of Fe and Mn. So also a considerable Zn could be concentrated in organic matter particularly in the bottom layers where Zn and organic matter indicate high values. Zn concentration is considerably higher in mangrove environment showing an average of 106ppm in P25 and 212ppm and this high concentration can be due to its fixation in the form of sulphides. The presence of considerable correlation between Zn and Fe indicates their relationship (Singh and Subramanian, 1984).

Chromium: Chromium is the seventh most abundant element on the earth and an average concentration in crystal rock is 100ppm. The geochemical behaviour of Cr in sediment is controlled by its two-oxidation states Cr (III) and Cr (IV). Under oxic condition Cr (IV) is the dominant species and is more soluble and mobile where as Cr (III) which usually occur in reduced condition is not only less mobile but also rather insoluble and therefore strongly absorbed by organic matter (Cranston, 1983). Therefore, the steady increase of Cr with depth in intertidal mudflats of P24 (Fig.5.3) may be controlled by organic carbon, which also shows a steady increase with depth (Fig.5.3). The correlation matrix (Fig.5.2) between organic carbon and Cr also reveal the strong interrelationship between these parameters. In mangrove environment

Cr content is more or less twice that of other environment and the organic carbon content too is exceptionally high indicating the strong relationship between them. Therefore, Cr would been enriched in mangrove environment under reducing condition. The slight enrichment of Cr in the near surface depth in P21 of alluvial plain (30-140cm depth) could be due to its enrichment in Mn and Fe oxide phases. In this depth zone the concentration of Fe and Mn are also very high (Table 5.1& Fig. 5.1). Such a relationship has been advocated by many workers (Michard, 1971; Holdren et al., 1975; Froelich et al., 1979 and Nakayama et al., 1981). Hence a considerable portion of Cr might have been contributed by finely divided heavy mineral species

Strontium and Lithium: Strontium shows strong affinity to calcium and therefore its variation with depth resembles that of calcium. In environment where calcium precipitation takes place strontium can also be scavenged (Nissenbaum et al., 1972). Precipitation of strontium as strontium carbonate and strontium sulphate can increase the strontium content in the environment. Brooks et al., 1963 stated that strontium carbonate is less soluble than strontium sulphate. The weathering of lithium rich minerals may have led to formation of clay minerals, which in turn concentrate the high lithium. Lithium strongly resembles that of magnesium and therefore lithium is held in clay minerals like kaolinite and montmorllonite (Ashry, 1973). Likewise lithium is enriched in sediments.

Copper, Cobalt and Nickel: Cu, Co and Ni show a general decreasing trend with depth in the study area. However, at certain depths their concentrations are considerably high where the iron content is also high. In general this indicates that these elements follow the iron distribution pattern. The decrease of these element concentrations with increasing depth indicates dissolution of these elements from sediments in the anoxic bottom layers. In the near surface sediments these elements show enrichment indicating their precipitation along with iron-manganese oxide phases. Digenetic enhancement of Fe and Mn in the surface and near surface sediment column

Table 5.2 Correlation matrix of various geochemical parameters in the clay fraction of different environments

Swales

	O.C	Fe	Ca	Mg	Na	K	Mn	Sr	Li	Cu	Co	Ni	Pb	Zn	Cd	Cr
O.C	1															
Fe	0.13	1.00														
Ca	-0.37	0.00	1.00													
Mg	-0.18	0.22	0.70	1.00												
Na	-0.09	-0.28	0.57	0.35	1.00											
K	-0.09	-0.13	0.22	0.05	0.37	1.00										
Mn	-0.46	-0.08	-0.10	-0.07	-0.24	-0.52	1.00									
Sr	-0.16	-0.18	0.67	0.24	0.57	0.52	-0.26	1.00								
Li	0.09	-0.32	-0.31	-0.15	-0.19	-0.19	0.17	-0.38	1.00							
Cu	0.06	0.12	-0.19	-0.37	-0.13	0.19	-0.18	0.15	0.01	1.00						
Co	-0.32	0.11	0.25	0.10	0.13	0.13	-0.07	0.32	-0.11	0.24	1.00					
Ni	-0.23	0.53	0.24	0.27	-0.13	-0.23	0.05	-0.01	-0.36	0.26	0.21	1.00				
Pb	-0.45	-0.20	0.04	-0.06	-0.04	-0.21	0.43	0.07	-0.09	0.05	-0.14	0.16	1.00			
Zn	-0.09	0.23	-0.11	-0.23	-0.17	0.14	-0.16	0.09	-0.11	0.57	0.44	0.34	0.29	1.00		
Cd	0.21	-0.17	-0.05	-0.20	0.13	0.38	-0.22	0.18	0.19	0.43	-0.03	-0.20	-0.11	0.19	1.00	
Cr	-0.16	0.21	-0.10	0.05	-0.13	-0.23	0.19	-0.21	0.24	0.39	0.41	0.24	0.01	0.34	-0.12	1.00

Table 5.2 continued
Alluvial plains

	O.C	Fe	Ca	Mg	Na	K	Mn	Sr	Li	Cu	Co	Ni	Pb	Zn	Cd	Cr
O.C	1.00															
Fe	0.52	1.00														
Ca	-0.21	-0.35	1.00													
Mg	0.06	0.39	0.06	1.00												
Na	-0.30	-0.38	0.28	-0.37	1.00											
K	-0.06	-0.14	-0.07	-0.20	0.38	1.00										
Mn	-0.02	0.03	0.29	0.03	0.17	-0.33	1.00									
Sr	-0.08	-0.38	0.69	-0.13	0.42	0.16	-0.05	1.00								
Li	0.59	0.44	-0.23	0.26	-0.39	-0.17	-0.37	-0.09	1.00							
Cu	-0.18	0.01	0.04	0.33	-0.22	-0.15	-0.33	-0.01	0.03	1.00						
Co	-0.01	0.34	0.02	0.42	-0.06	-0.36	0.53	-0.23	0.07	-0.06	1.00					
Ni	-0.13	0.27	-0.22	0.45	-0.14	0.00	0.29	-0.37	-0.10	-0.03	0.46	1.00				
Pb	0.34	-0.08	-0.10	-0.29	-0.13	0.02	-0.18	-0.13	0.13	-0.09	-0.35	-0.38	1.00			
Zn	-0.15	0.08	0.25	0.03	0.06	-0.48	0.44	-0.02	-0.22	-0.01	0.35	0.07	-0.10	1.00		
Cd	0.18	0.36	-0.17	0.12	-0.24	-0.05	-0.38	-0.10	0.31	0.42	-0.10	-0.26	-0.08	-0.09	1.00	
Cr	-0.11	0.27	0.10	0.46	-0.22	-0.04	-0.17	-0.02	0.15	0.30	0.15	0.30	-0.40	0.25	0.28	1.00

Table 5.2 continued
Intertidal mudflats

	O.C	Fe	Ca	Mg	Na	K	Mn	Sr	Li	Cu	Co	Ni	Pb	Zn	Cd	Cr
O.C	1.00															
Fe	0.08	1.00														
Ca	0.58	0.08	1.00													
Mg	0.49	0.23	0.54	1.00												
Na	-0.63	0.02	-0.34	-0.55	1.00											
K	-0.25	-0.03	-0.17	-0.05	0.24	1.00										
Mn	-0.56	-0.11	-0.08	-0.17	0.37	0.02	1.00									
Sr	-0.25	0.17	0.13	0.26	0.38	-0.18	0.27	1.00								
Li	0.50	0.29	0.28	0.71	-0.37	-0.19	-0.04	0.30	1.00							
Cu	0.36	-0.12	-0.06	0.52	-0.60	-0.07	-0.40	0.10	0.42	1.00						
Co	0.20	0.16	-0.01	0.57	-0.57	-0.02	0.05	0.12	0.52	0.69	1.00					
Ni	-0.41	0.47	-0.17	-0.05	0.42	0.10	0.69	0.31	0.24	-0.35	0.10	1.00				
Pb	0.60	0.07	0.73	0.60	-0.50	-0.05	-0.28	0.02	0.24	0.26	0.31	-0.25	1.00			
Zn	0.54	0.23	0.28	0.45	-0.53	-0.18	-0.21	0.13	0.49	0.61	0.71	-0.01	0.48	1.00		
Cd	-0.15	-0.19	-0.09	-0.38	0.30	-0.09	-0.03	0.10	-0.34	-0.21	-0.30	-0.11	0.00	-0.32	1.00	
Cr	0.47	0.14	0.14	0.51	-0.32	-0.03	-0.12	0.27	0.54	0.57	0.67	0.03	0.45	0.74	-0.21	1.00

Table 5.2 continued

Mangroves

	Fe	Mg	Ca	Na	K	Ni	Cr	Mn	Li	Co	Cu	As	Cd
Fe	1.00												
Mg	0.25	1.00											
Ca	0.10	0.26	1.00										
Na	0.62	0.41	-0.40	1.00									
K	0.54	0.17	-0.40	0.66	1.00								
Ni	0.07	0.57	-0.04	0.15	0.17	1.00							
Cr	0.43	0.46	-0.32	0.64	0.93	0.33	1.00						
Mn	0.09	0.65	0.77	-0.09	-0.32	0.52	-0.13	1.00					
Li	0.16	0.71	-0.18	0.60	0.69	0.39	0.88	0.13	1.00				
Co	0.90	-0.08	0.16	0.43	0.60	-0.12	0.39	-0.06	0.04	1.00			
Cu	0.01	-0.47	-0.31	-0.02	0.06	-0.37	-0.04	-0.49	-0.26	0.12	1.00		
As	0.63	0.48	-0.16	0.89	0.34	0.28	0.33	0.22	0.36	0.38	-0.08	1.00	
Cd	0.44	-0.44	-0.35	0.15	0.60	-0.06	0.34	-0.54	-0.06	0.63	-0.03	-0.06	1.00

is well known (Farmer and Lovell, 1984; Spencer et al., 2003) and so Cu, Co and Ni also enriched. Other than these oxide phases Cu, Co and Ni can be controlled by organic carbon at certain depth layer where the sediment is in a state of reducing condition permanently (Spencer, 2003). This fact is well established in mangrove sediments were the concentration of Cu, Co, Ni and organic carbon are appreciably high. The interrelationship between Cu, Co and Ni with iron is shown in the Table 5.2, which shows a significant correlation, particularly for Ni in the entire environment. Concentration of these elements by organic carbon is particularly evident for Cu (Table 5.2).

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CHAPTER 6

SUMMARY AND CONCLUSIONS

The present study addresses to understand the sedimentological properties of the coast of central Kerala, to bring out the relationship between the textural, mineralogical and geochemical characters with that of the respective environment.

The grain size study of the beach ridge sediments from different pits has been investigated at close intervals, which enabled to understand the grain size variations with depth. The sediment samples from various pits of the beach ridges indicate that the sediments range primarily from medium to very fine sand, well to moderately sorted, fine to coarse skewed and leptokurtic to platykurtic. The relationship between the statistical parameters has been established. It is found that in many of the pits sediments show coarsening upward sequences in the bottom most layers. In the middle part of the pits fining upward sequences have been observed. However in the near surficial sediments coarsening upward sequences have been recorded. In certain exceptional cases only two sequences namely a fining upward sequence in the bottom layer and a coarsening upward sequence in the near surficial layers of sediments are seen.

As the study area is considered as a prograding coast, the two coarsening upward sequences are clear evidences of fall in sea levels, though changes may be of small-scale levels. However, the fining upward sequence could result by a minor fluctuation in sea level. The different laminae of the coastal plain sediments dip gently towards sea, paralleling the present beach reveal that the beach ridges of the study area represent regressive epochs.

The beach ridges have formed in many places by swash built type and in other places by settling-lag type. The swash-built ridges are low angle fair weather beach type consisting of cross bedding- both sea ward and land ward dipping, as evident from field photos. In certain places the bedding is horizontal and discontinuous without any well defined cross bedding, indicating a settling-lag origin. The grain size parameters of the beach ridges resemble that of the present beach sands, consisting of medium to very fine sand and well to moderately well sorted.

The beach ridges in the study area would have been constructed from near shore sand supplies by infilling the shallow sea that served as an important trap for the river borne sediments supplied from the rivers that drain the area. Major alongshore drifts, which prevail towards south during southwest monsoon and north during northeast monsoons, have a major role in building the sand ridges along this coast.

Textural classification of sediments has been worked out for alluvial plains, swales, intertidal mudflats and mangrove sediments. The first three environments record high proportion of sand content and the predominant sediment type is sandy clay with minor sandy mud. On the other hand mangrove sediments reveal the presence of considerable silt and clay. The predominant types of sediments are clayey sand and sandy mud.

The detailed heavy mineralogical investigations bring to light a significance variation in the beach ridges. The total heavy mineral percentage shows prominent enrichment in fine sand and very fine sands. The major minerals are opaques, chlorite, garnets, hypersthene, glaucophane, tourmaline, hornblende, zircon and biotite. The conspicuous presence/absence of some minerals leads to the identification of three provinces, namely the northern sector, central sector and the southern sector. The concentration of hornblende increases substantially from north to south, while chlorite shows an opposite trend. Inexistence of hornblende in northern sector and chlorite in southern sector of the study area is evident from respective samples. Meanwhile, both these minerals co-exist in the central sector along with minor fractions of apatite.

Detailed clay mineralogical studies reveal the proportions of major clay minerals, namely kaolinite, illite, chlorite and montmorillonite. Kaolinite constitutes a major proportion in the study area. Montmorillonite is absent in alluvial plain. Saline water flocculation followed by differential settling and post depositional alteration has affected the variation in the concentration of clay minerals in different environment with depth.

Micromorphological features of ilmenite, sillimanite, hornblende and garnet reveal the presence of breakage blocks, abrasion marks, etch Vs, grooves, precipitation features and dissolution pits. Mechanical action in high energy littoral zones is responsible for the development of breakage blocks, abrasion marks, etch Vs and grooves, while sub aqueous conditions and very low energy environment result in chemical dissolution and precipitation marks.

Distribution of major, trace elements and organic carbon show distinct vertical variations with depth. Elements such as Iron, sodium, potassium, calcium, lead, strontium and organic carbon progressively increase with depth, while cobalt, copper, lithium, zinc, chromium decrease with depth. However, the later elements exhibit enrichment at certain depths in the pits. The decreasing levels of elements with depth are related to dissolution in the anoxic to sub-oxic bottom layers. The higher concentration of trace elements in the top of the pits and at certain depths is related to fixation in iron and manganese oxide phases as well as by organic matter. Concentration of trace metals in clay minerals by adsorption is another mechanism of enrichment .This is very much evident by the higher content of trace metals and clay minerals in the study area. The relationship between trace elements with that of organic carbon, iron, manganese, calcium, sodium has been established in some environments, which fall under the study area.

The study as a whole brings light to the salient conclusions on sedimentological, mineralogical and geochemical characteristics of the coastal plain in the study area. Variations in grain size down the pit give three phases of beach building activities, ie., a coarsening upward sequence in the bottom layers, a fining upward in the middle and coarsening upward at the top. The sedimentological characteristics of the beach ridges resemble that of modern beaches attesting a likewise origin. Beach ridges are formed by swash built sediments with cross bedding and settling lag type sediments with seaward dipping/ horizontal units.

The heavy mineral investigations throws light into the fact that chlorite acts as a marker mineral in deciphering northern and central sectors of the study area from that of the southern, while hornblende demarcate the southern and central sectors from that of the northern. A mixed source for central sector is exemplified by the association of hornblende and chlorite. Through XRD, kaolinite is established as the predominant clay mineral in the study area and its source is ascribed to the laterites. The salient observation through SEM is that breakage blocks, etch Vs, grooves and abrasion marks found on ilmenite, garnet, hornblende and sillimanite are resulted by the mechanical action in high energy littoral zones, while dissolution pits and precipitation marks point to subaquous coastal conditions and low energy coastal plain environment under water table conditions.

Geochemical signatures in the study area have been brought out through the analysis of major and trace elements. Iron is significantly enriched and its control over many trace elements is evident. Copper, chromium, cobalt, lithium, lead and zinc show decreasing trend with depth, while sodium, potassium, strontium, nickel and organic carbon increases. The association of many trace elements with organic carbon has also been established. Dissolution of trace elements in anoxic environment, at depth and reprecipitation in the oxic layers, at near or subsurface, are the major mechanism that brought out the variation of certain environmentally sensitive elements.

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