SEDIMENTOLOGY AND GEOCHEMISTRY OF SOME SELECTED MANGROVE ECOSYSTEMS OF KERALA, SOUTHWEST COAST OF INDIA

THESIS
SUBMITTED IN PARTIAL FULFILMENT FOR THE DEGREE OF
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BY

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MARCH 1997

To my Anitha-

a fond dedication

CERTIFICATE

This is to certify that this thesis work entitled "SEDIMENTOLOGY AND GEOCHEMISTRY OF SOME SELECTED MANGROVE ECO SYSTEMS OF KERALA, SOUTHWEST COAST OF INDIA" *is an authentic record of the research work done by* A. BADARUDEEN, *under my scientific supervision and guidance, for the partial fullfillment and the requirements for the* Doctor of Philosophy *Degree of the* Cochin University of Science and Technology. *No part of it has been previously formed the basis for the award of any degree, diploma or associateship in any other university.*

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DECLARATION

I hereby declare that the thesis ***"SEDIMENTOLOGY AND GEOCHEMISTRY OF SOME SELECTED MANGROVE ECO-SYSTEMS OF KERALA, SOUTHWEST COAST OF INDIA"*** is an authentic record of research work carried out by me under the guidance of **Dr. K. Sajan**, Reader in Marine Geology, Department of Marine Geology and Geophysics, School of Marine Sciences, Cochin University of Science and Technology, and no part of it has previously formed the basis of the award of any degree, diploma, associateship, fellowship or other similar title or recognition.

KOCHI,
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PREFACE

Mangroves are intertidal wetlands, common in many tropical and subtropical countries. The total world wide mangrove area is estimated at about 17,000 sq. km. (Mangroves and salt marshes - Leaflet, 1996). In India the mangrove flora covers approximately 6740 km^2, ie, 40% of the world's mangrove estimates. Among the Indian mangroves the Sunderbans mangroves of West Bengal alone share more than 60% and the remaining are found to spread as patches in Maharashtra, Gujarat, Orissa, Goa, Andhra Pradesh, Tamil Nadu, Kerala and the Andaman and Nicobar Islands.

Mangrove ecosystem is unique in several respects, and mostly it is very fragile owing to the peculiar conditions of their hydrodynamics and sedimentation. This inter-tidal forested ecosystem supports many genetically diverse communities of terrestrial and aquatic organisms of direct and indirect socio-economic value. Scientific researches indicate that mangroves not only play a pivotal role in the stabilisation of coastal land masses from erosion and but acts as a buffer between transitional, nearshore lagoonal or estuarine environments. It is interesting to note that these amphibious flora can recover quickly if they are damaged by natural disasters. Recent studies on the geochemical characteristics of the mangrove environments indicated that the sediments in this zone hold substantially high quantities of pollutants, particularly heavy metals without much damage to the vegetation.

Mangroves have many enemies and man is not the only one. Large areas of mangrove forests are regularly wiped out due to the problems compounded with various man-made impacts. These wet coastal formation with luxuriant vegetative cover are ruthlessly being seized, reclaimed and eventually being turned into fallow landscapes. The slow decline of the mangrove forests in tropical tidal zones may persist for many years but it doesn't register in the public consciousness until it is directly accompanied by dramatic events. Long term natural calamities, of course, can cause stunted growth which ultimately lead to the total demolish of this coastal greenery from the affected area. Such incidences may result from macro-climatic changes, sea level fluctuations, salt accumulation in the soil, substantial sediment deposits in the aftermath of heavy rainfall and flooding.

As a result of the issues of care and conservation and sustainable utilisation, the proper management of mangrove forests have become more pressing than ever. Much recent ecological and toxicological debate has been centered around the question of validity of making predictions about the future of mangrove ecosystem as a result of the newly evolved environmental policy. Though much information exist on the biodiversity, floristic composition and characteristics, geographical distribution and uses of mangroves, systematic documentation of the various sedimentological and geochemical phenomena in relation to the mangrove flora are scarce. Hazardous, persistent, man-made chemicals and waste produces are entering the mangrove ecosystem at from the adjacent watersheds which strengthened alarming rates the indispensible need for further researches on the environmental behaviours, fate and the effect of such products. Studies on the effect of heavy metals, pesticides and the other toxic signals through bioassay and toxicity tests on mangrove species as well as in sediments definitely will furnish ample clues to establish the actual operative mechanisms of these environments. A thorough review of literature made in this angle reveals that some attempts have already been initiated the world over the record the physico-chemical characteristics of major abiotic components such as sediments and water of many mangrove ecosystem, however, adequate information is lacking in the Indian Environmental Science scenario. The present investigation is an attempt to record the sedimentological, mineralogical and geochemical characteristics of sediments as well as the heavy metal enrichment in the various species of mangrove flora of three important mangrove ecosystems of Kerala, located at Veli (South Kerala), Kochi (Central Kerala) and Kannur (North Kerala). The results of the above investigation have been analysed statistically, discussed based on the available literature and presented in this thesis under seven chapters.

Chapter I deals with the general introduction of mangroves and their worldwide distribution with special reference to India. The locations of the study area, geology, climate and objectives of the study are also included in this chapter. The details of field work, methods of sampling, processing, preservation and analytical procedures of samples for textural, mineralogical and geochemical studies and the various computational techniques employed in data processing are dealt in Chapter II. Chapter III describes the textural characteristics of the surficial and core sediments collected from the study area. Chapter IV depicts the details about the heavy and clay mineralogical make up of Veli, Kochi and Kannur mangroves. An attempt has also been made to work out the provenance of the mangrove sediments as well. The geochemistry of organic carbon, phosphorus and various other major (Na, K, Fe) and trace elements (Mn, Pb, Cd, Co, Cu and Zn) of the sediments are presented and discussed in Chapter V. Speciation studies using sequential extraction methods were performed to know the metal distributions, in various chemical phases of the sediments. Chapter VI illustrates the heavy metal levels in various mangrove flora of the study areas. The heavy metal levels are discussed in terms of that enriched in sediments. The summary and the salient conclusions drawn there of are furnished in Chapter VII.

References cited are furnished towards the end of the thesis.

The following research papers are published on the sedimentological and geochemical aspects of mangrove environments during the period of this investigation

1. A. Badarudeen, K.T. Damodaran, K. Sajan, and D. Padmalal (1996). Texture and geochemistry of the sediments of a tropical mangrove ecosystem, southwest coast of India. Environ.Geol., Vol, 27; pp, 164-169.

2. A. Badarudeen, K. Maya and K. Sajan (1997). Sediment, organic carbon and trace metal distrubitions in the mangrove environment at Veli, Kerala. Proc. Ninth. Kerala Science Congress, Thiruvananthapuram, pp, 85-87.

CONTENTS

CHAPTER 1

GENERAL INTRODUCTION

1.1 MANGROVES

Mangroves are salt-tolerant forest ecosystems spreading in the coastal tracts of tropical and sub-tropical countries. Under favourable circumstances, mangroves develop into extensive and productive forests, sheltering the life and soil of the coastal environments from ecological disasters, natural calamities, etc. This unique ecosystem is reservoir of a plethora of plant and animal species, which are associated together over a long period of evolutionary history. But their interdependance and also their dependance to the abiotic environments which support these special stock of organisms have not so far been received much attention neither in the scientific scenario nor in the public conscience. At the same time, over-exploitation of mangroves for timber, firewood, woodchips, charcoal, tannins, bark dyes, honey etc; has been increasing exponentially in the last few decades. As a consequence many of the world's famous mangroves are now at the edge of imposed shrinkage threats (Michael Mastellar, 1996; Ralf Schwamborn and Ulrich Saint Paul, 1996).

Mangroves have many uses (Table 1). They not only stabilise the shorelines but also act as a bulwark against the encroachment of sea waters to the adjacent coastal areas. It is worth to note that, these coastal vegetations together with the algae and seaweeds play a pivotal role in regulating the physico-chemical as well as biological processes operating in the coastal and nearshore environments(Dieter Uthoff, 1996).

Table 1
Some important uses of mangroves/mangrove products

Sl.No.	Mangrove species	Products	Uses
1.	*Acanthus ilicifolius*	Fruit	Blood purifier, dressing for boils, snake bite.
		Leaves	Relieve rheumatism.
2.	*Acrostichum aureum*	Succulent fiddlehead Fronds	Eaten raw or cooked Roofing material
3.	*Avicennia marina*	Young leaves	Eaten raw or boiled Source of
		Bark	tannin and astringent
		Seeds	Eaten after leaching and cooking
		Roots	Relieving minor fish stings.
4.	*Avicennia officinalis*	Seeds	Eaten after leaching and cooking, relieving ulcers.
		Barks and roots	Aphordisiac
5.	*Bruguiera gymnorrhiza*	Barks	Seasoning for raw fish, condiment.
		Fruits	Medicine for sore eyes.
		Wood	Timber and fire wood
		Pneumatophore	Scent
		Hypocotyl	Eaten as vegetable.
6.	*Derris trifoliata*	Stem and roots	Fish poison
7.	*Excoecaria agallocha*	Sap	Fish and arrow head poison, medication for tooth ache, ulcers and fish stings
		Leaves	Epilepsy
8.	*Rhizophora mucronata*	Bark, prop roots and sap	Mosquito repellent
		Fruit	Eaten, fermented to produce light wine
		Wood	Timber, firewood
		Bark	Tannin
9.	*Sonneratia caseolaris*	Fruit	Eaten
		Sap	Cosmetics

In mangrove environments, different kinds of interrelated families get themselves adapted to grow under the influence of both saline and brackish water conditions. In some rare cases, they even adapt in the fresh water environments too. It is a nature's miracle and one would definitely be astonished when he/she really measures the remarkable capacity for salt tolerance exhibited by these plants. The leaves of many mangroves possess halophilons properties with a thick cuticle, large mucilage cells, etc. The forms of buttress, knee, stilt roots, vertical pneumatophores etc are some of the other adaptations exhibited by the mangrove plants to thrive in harmony with the intertidal zones where ocean embraces the land.

1.2. DISTRIBUTION OF MANGROVES

1.2.1. Mangroves: The World Distribution

Mangroves are well distributed in Asia, North America, Australia and NewZealand. Though their habitat in the tropical and subtropical areas are characteristically confined to the intertidal zones (littoral), mangroves are also reported from arid regions as well (eg, mangrove patches of East and West Africa). World wide natural distribution (Fig. 1) of mangrove vegetation has been broadly divided into two by Chapman (1976). The first group consists of the East African Coast, coasts of Pakistan, India, Burma, Malaysia, Thailand, Philippines, Southern Japan, Australia, Newzealand, and the Southern pacific Archipelago. The second group comprises the Atlantic coast of Africa and America including the islands of Galopagous. Some of the world's largest mangrove swamps are found along the south west coast of Florida, Pacific coast of Columbia, West coast of Malaya and also along the Northern coast of Borneo. The occurrences of great variety of species, in the Indian and Pacific ocean regions suggest that the mangroves probably originated in these regions. About 55 species are considered as being covered by the term mangrove, and of these, a total of 42 are reported from the Indian and

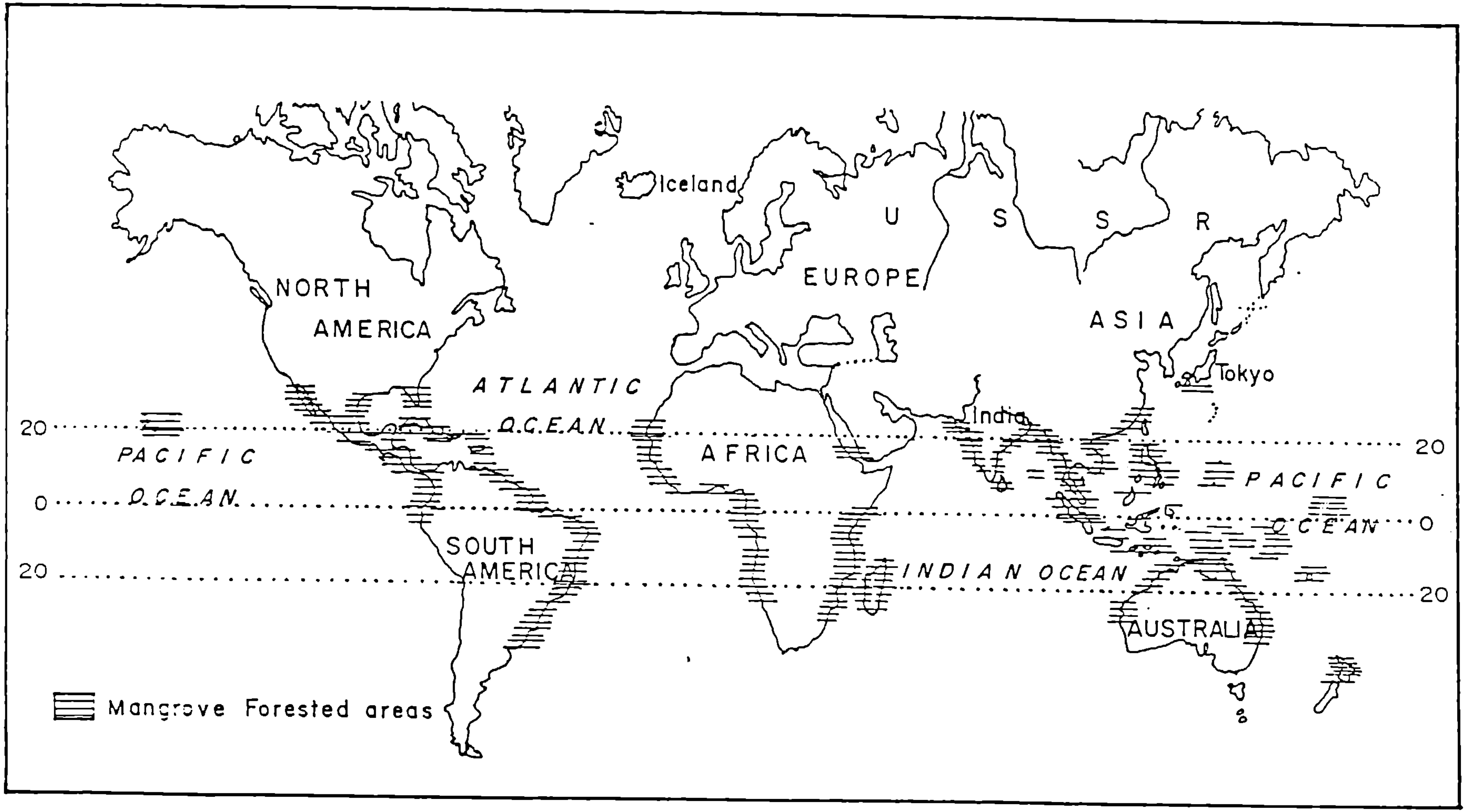


Fig 1. THE WORLD DISTRIBUTION OF MANGROVES. (Source: MEF, 1987, INDIA)

Pacific regions, (Chapman, 1976). The general distribution of mangroves through out the world indicates zonal as well as purely individual colonial patterns.

1.2.2. Mangroves: The Indian Distribution

Indian coasts host luxurient mangrove vegetation particularly on either sides of the major estuaries, marginal lagoons, creeks and shallow bays. The total area of the mangrove cover in India is estimated to about 6740 km2; ie, about 7% of the world's total mangrove spread. Among the Indian mangroves, the Sunderbans of West Bengal is the largest one (4200 Km2). It is followed by the Andaman and Nicobar Islands (1190Km2). The mangroves of the above two localities together accounts for 80% of the total Indian mangroves (MEF, 1987). The remaining mangroves are scattered in Maharashtra, Gujarat, Orissa, Goa, Andhra Pradesh, Tamil Nadu, Karnataka and Kerala (Table 2; Fig. 2).

1.2.3. Mangroves: The Kerala scene.

The mangroves of Kerala are isolated and far between at present (Fig.3) and confined to the upper reaches of estuaries, lagoons, backwaters and creeks (Mohanan, 1997). A survey conducted by the scientists of the Centre for Earth Science Studies (CESS) Trivandrum revealed that the mangroves of Kerala are impacted severely by human intervention (Ramachandran and Mohanan 1991). They reported occurances of mangroves in Veli, Kollam, Kumarakam, Kochi, Kannamali, Chetwai, Nadakavu, Edakkad, Pappinisseri, Kungimangalam, Chiteri, Palayangadi, Kotti, Kavvai, Thalassery, Vadakara, Kallai, Tirur and Edappalli.

1.3. SCOPE OF THE PRESENT STUDY

From a cursory glance on the literature pertaining to the mangrove environments (see chapter VI) reveals that although much information exists on the

Table: 2

Indian Mangroves: A General Estimate
Source : M E F (1987)

State/Union territory	Total area of mangrove forests (approx.Km^2)
1. Andaman and Nicobar islands	1190
2. West Bengal	4200
3. Orissa	150
4. Andhra Pradesh	200
5. Tamil Nadu	150
6. Karnataka	60
7. Goa	200
8. Maharastra	329
9. Gujarat	259
10. Kerala	2*
Total	6740

* Ramachandran and Mohanan (1991).

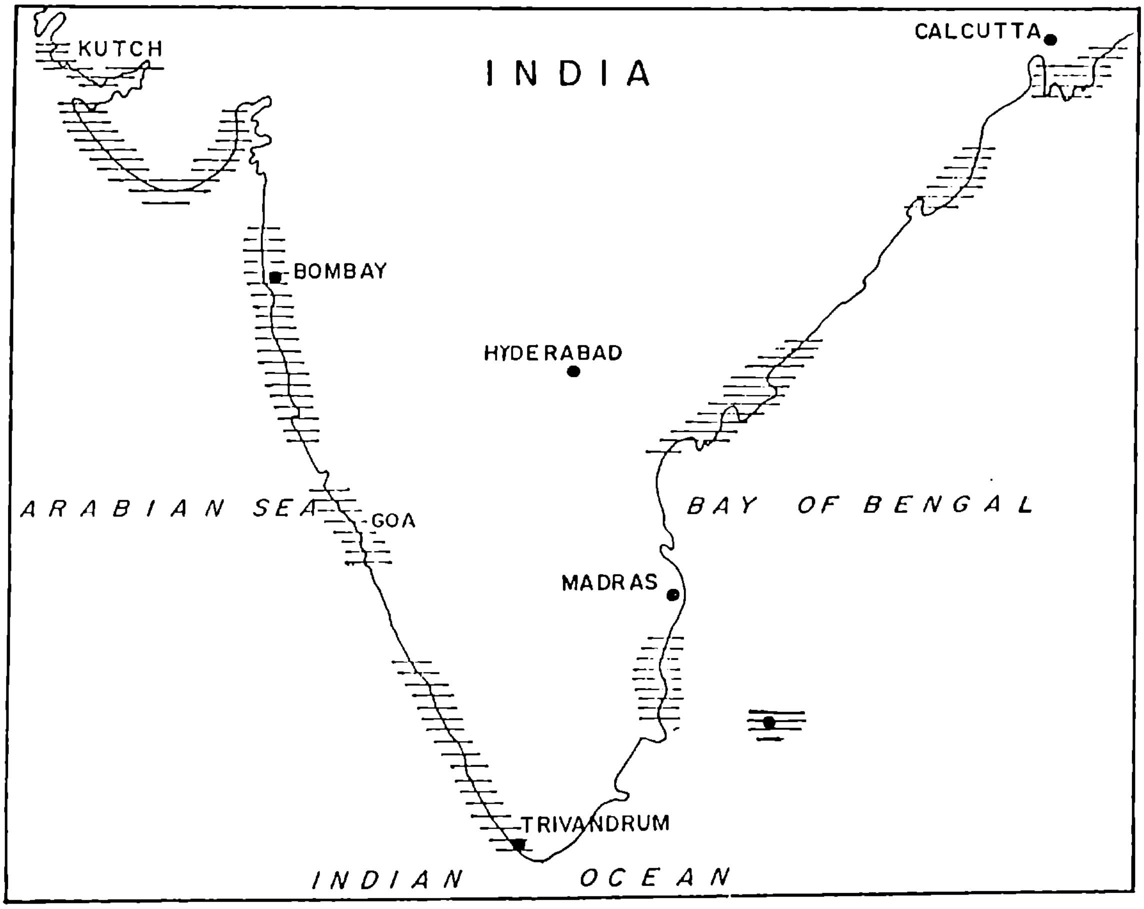


Fig 2. THE MAJOR MANGROVE FIELDS OF INDIA (Source: MEF, 1987).

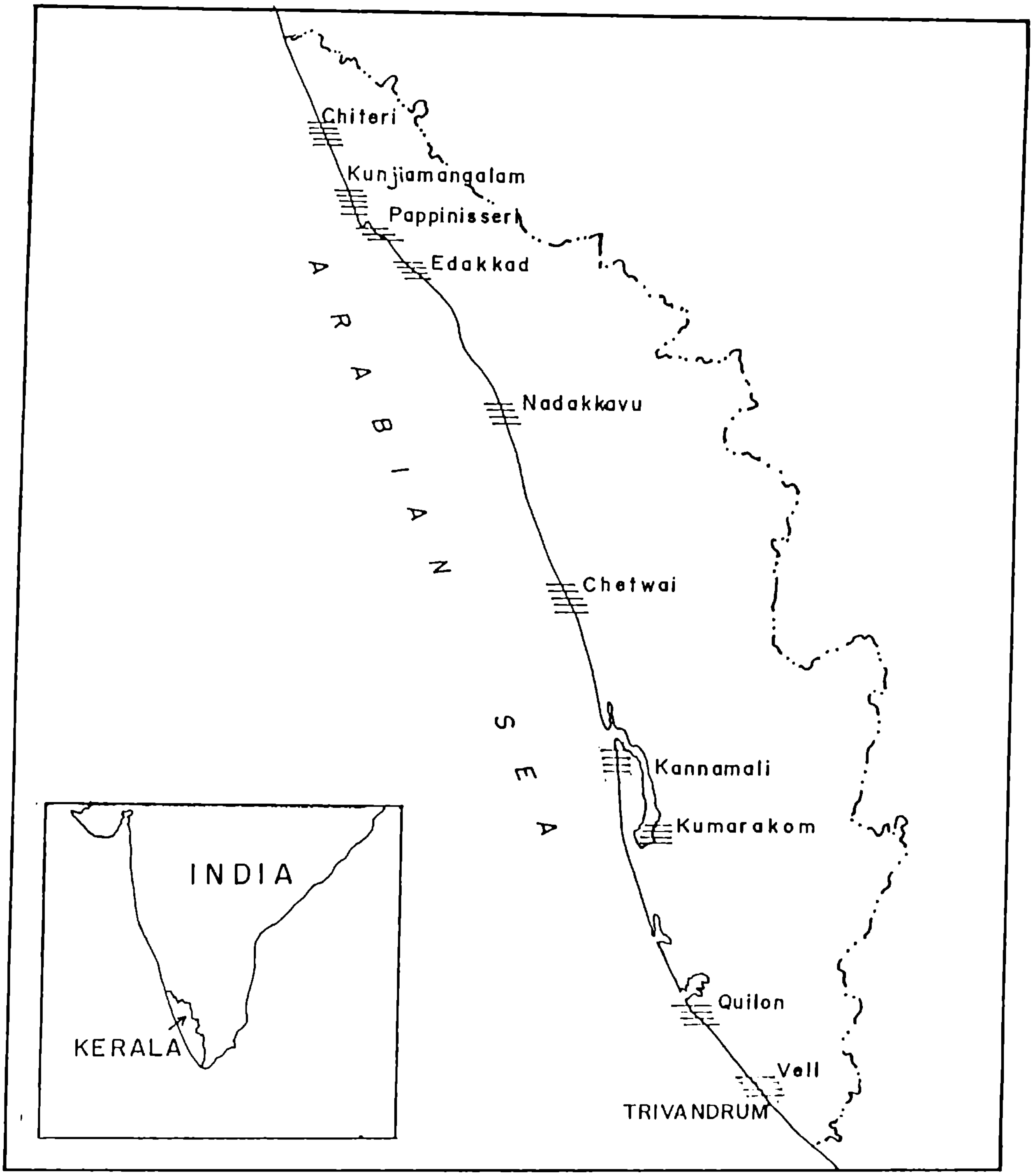


Fig 3. LOCATION OF MAJOR MANGROVE FIELDS OF KERALA (Source : Ramachandran and Mohanan, 1991).

biodiversity, floristic characteristics, geographic distribution and uses of the major mangrove ecosystems of the world, not much investigations have been carried out to explore the sedimentological and geochemical processes (ie, the abiotic processes) operating in these environments, particularly in relation to the mangrove vegetation. However, some movements have been initiated in this angle to bring-forth the role of mangrove flora in regulating the geological and geochemical processes operating in the mangrove forested coastal stretches, by Delacerd, (1983); Laffond et al, (1984) and Badarudeen et al (1996). The present investigation is too in this direction and provides a data-base on the above processes operating in three major mangrove fields of Kerala, located at Veli, Kochi and Kannur regions. The data-base can be used for formulating developmental activities in the coastal zones of the state which are forested with mangroves and mangrove associates.

1.4. STUDY AREA:

1.4.1 Location

The mangroves selected for this investigation are located at Veli (an important mangrove ecosystem of south Kerala), Kochi (central Kerala) and Kannur (north Kerala) areas. The mangrove patches of Veli are found near the mouth of the Veli Kayal and dissected by the Kulathur thodu into north-east and south-west segments (Fig.4). The mangrove is located between Lat. 8° 30' 0" N-8° 31' 30" N and Long. 76° 52' 30" E - 76° 54' 0" E. At Kochi, three mangrove patches are selected for this study which include Vypin, Malippuram and Vallarpadam (Fig.5). They fall between north latitude 9° 59' 0" - 10° 11' 30", and east longitude 76 ° 14' 0" - 76 ° 16' 00". The Veli and Kochi mangroves receive pollutants from many sources including industrial, urban and agricultural. The third mangrove location identified for this study, the Kannur mangroves, hardly receives pollutants from industrial and urban sources. This mangrove is located between Lat. 12° 3' 30" N 12° 5' 30" N, Long. 76° 13' 0" E - 76° 14'30" E (Fig.6).

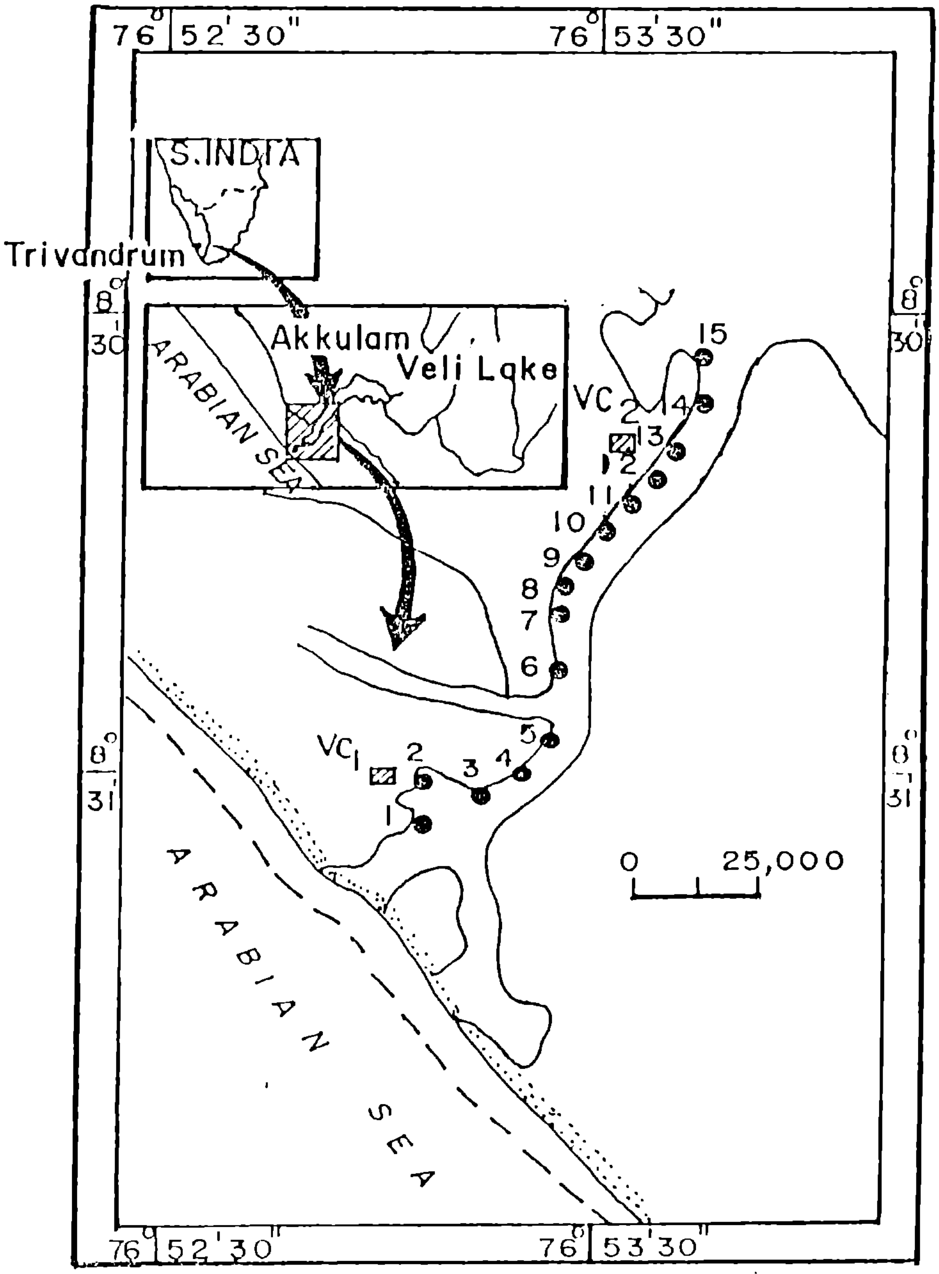


Fig 4. VELI MANGROVES : SAMPLING LOCATIONS

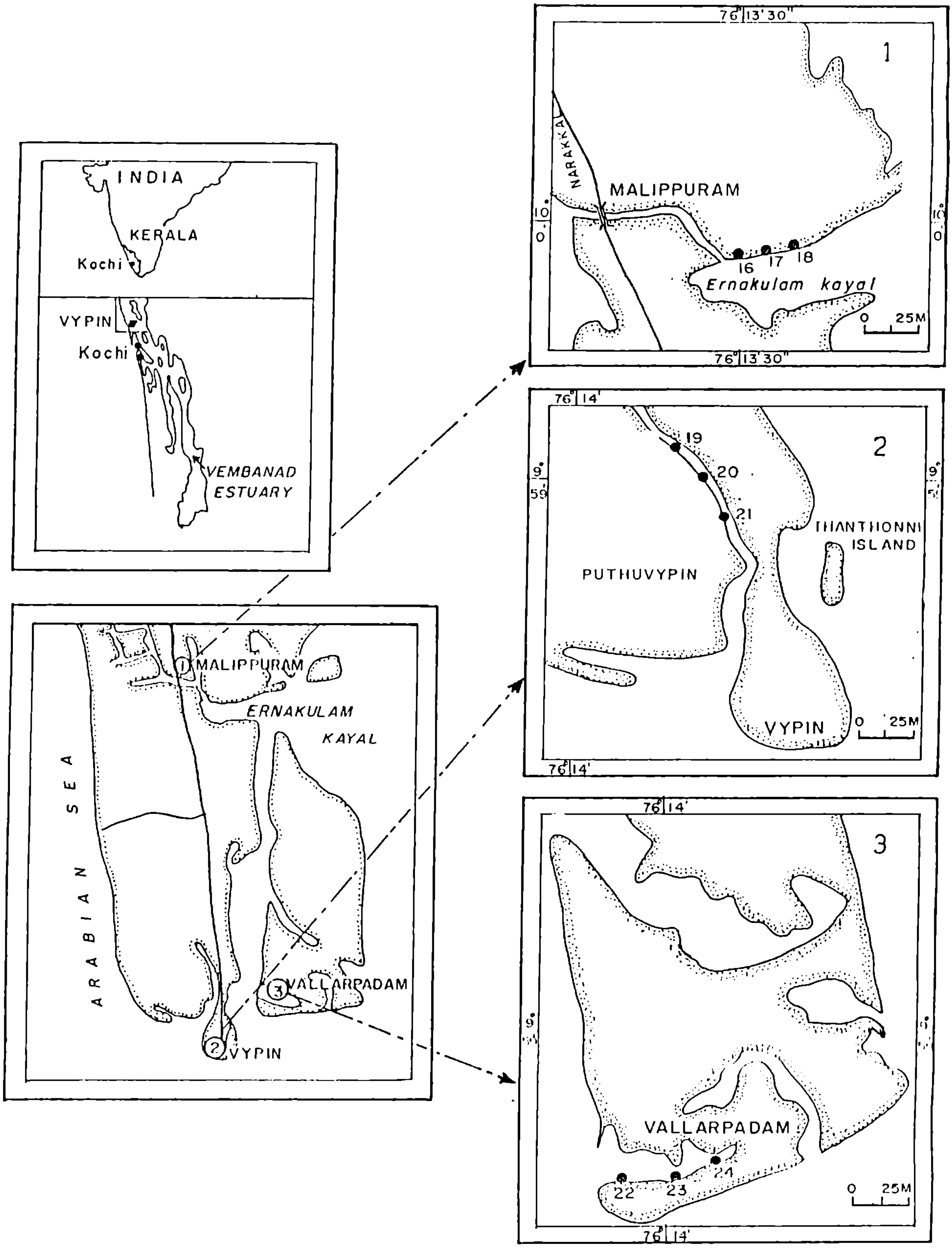


Fig 5. KOCHI MANGROVES : SAMPLING LOCATIONS

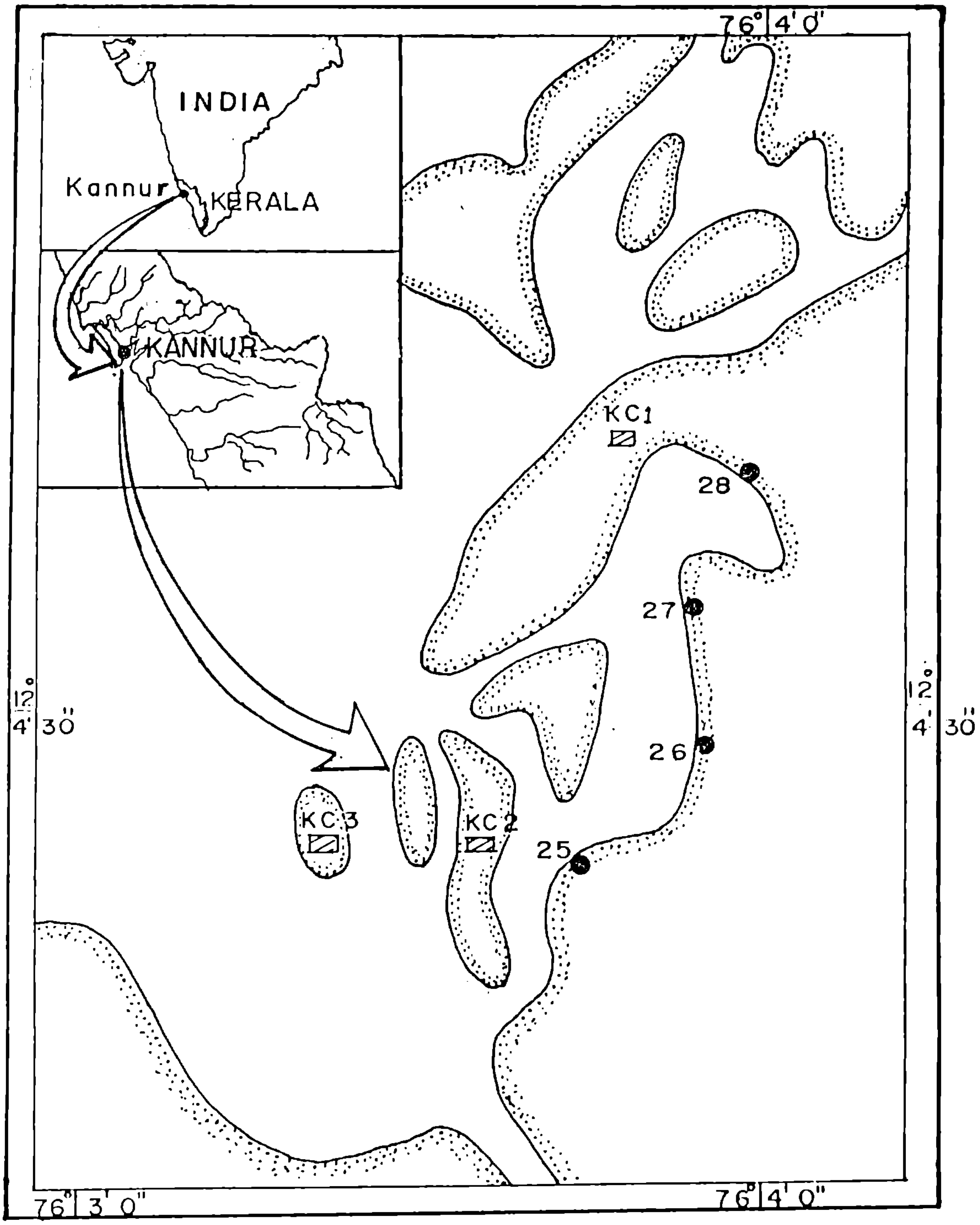


Fig 6. KANNUR MANGROVES : SAMPLING LOCATIONS

1.4.2(A). **Geology: (General)**

Geologically, Kerala state forms a part of the peninsular shield bounded on the east by the Western Ghats and west by the Arabian sea. Four major rock units are reported from the State. They are the Precambrian crystallines, Tertiary sedimentaries, Laterites (Pleistocene age) developed over Precambrian crystallines and Tertiary sedimentaries and the Recent to Sub-Recent sediments. Table 3 depicts the revised stratigraphic sequence of Kerala illustrating the major rock units.

1.4.2.1. Precambrian Crystallines

Precambrian crystallines occupy a considerable area of Kerala which include Khondalite group, Charnockite group, migmatite complex, Wyanadu group, penninsular gneissic complex, Dharwar Super Group and some basic and acidic rocks (GSI, 1995). The former three together cover more than 80% of the total area of Kerala. Khondalite group of rocks are essentially garnet sillimanite schist or gneisses and are associated with narrow bands of pyroxene granulite, quartzites, garnet gneisses and patchy charnockites. They predominante in south Kerala. The ratio of quartzo - feldspathic layers and schistose layers within the Khondalite suite vary from place to place. In certain parts of the area, lenticular bands of cordierite gneiss occur in association with khondalite group of rocks. Age determination of these rock types indicate a range of 670 to 220 Ma. (Santhosh, 1987 and Chacko et al, 1988).

Table: 3

A revised lithostratigraphic classification of sedimentary sequences of Kerala (after Raha, 1996)

Period		Formation	Lithology
Quaternary		Vembanad Formation	Beach sands, alluvium, red (teri) sands, peat beds with semicarbonised wood, calcareous claysetc.
		Unconformity (Marked by Laterite)	
Tertiary	MALABAR SUPER GROUP / WARKALLI GROUP	Ambalapuzha Formation	Sandstones, clays, lignite
		Quilon Formation	Limestone, marls, cala-careous clays and sands
		Mayyanad Formation	Sandstones, coarse gravelly sands, clays, lignites and carbonaceous clays
		Unconformity	
Late Mesozoic		Karuchal Formation	Hard, compact, ferru genous gritty sandstone conglomeratic near base with clay interbeds and arkoses in the upper part
		Unconformity (Marked by Bauxite)	
Archaean Gneisses, granulites and schists			

The charnockite group comprises mainly Quartz - Feldspar - Hypersthene granulites (charnockite), with or without gneissosity and hypersthene-diopside gneisses with minor amounts of pyroxene granulite, pyroxinite, cordierite gneiss and magnetite - quartz veins. The migmatite complex consists of garnet - biotite gneiss, hornblende gneiss, hornblende - biotite gneiss, quartz-mica (composite) gneiss, garnet - biotite gneiss, quartzo - feldspathic gneiss, leptynites and garnetiferous granite gneiss. The Wyanadu group of rocks consists of high grade meta - sedimentary, metabasic and ultramafic rocks and confined mainly to the northern part of Kerala. The Penninsular gneissic complex is marked by the presence of foliated granite, pink granite gneiss, hornblende - biotite gneiss (sheared) with bands of schists and ultramafites and biotite - hornblende gneiss. The Dharwar Super Group is represented in Kerala by Vengadu formation composed mainly of quartz - mica schists, quartzites and conglomerates.

1.4.2.2. Tertiary Sedimentaries:

The Tertiary sedimentary formation of Kerala unconformably overlies the Precambrians and extends from Cape Comorin in the south to Manjeshwar in the north. It is the southern most one among the chain of Tertiary basins along the west coast of Peninsular India. The inland part of the Tertiary basin consists of Neogene and Quaternary sediments. The Neogene sediments comprise a series of variegated sandstones and clays with lenticular seams of lignite (Warkalli beds) and more compact sands and clays with thin beds of lime stone (Quilon beds) (Poulose and Narayana swamy, 1968).

The Quilon beds consist of fossiliferous limestone, sandstone and clays (Menon, 1967). The type area of this lithounit is at Padappakara in Kollam district, where a full succession of the Quilon beds expose on the flanks of the hillocks facing the Ashtamudi estuary. These formations were earlier considered to be present in the above locality only, but later investigations have brought out similar rock units at localities like Chathannur, Nedungolam (Kumar and Pichamuthu, 1933), Edava (Damodaran, 1955) and at Kidangayara (Menon, 1967) etc. Formations similar to that of Quilon are recognised in Jaffna (Sri Lanka) as well.

The Warkalli beds are overlained by the Quilon beds or altered Precambrian crystallines and often covered by either laterites or Recent to Sub-Recent sediments. The type section is at Varkala, where the Warkalli beds are exposed well on sea cliffs facing the Arabian sea. This formation is nearly horizontal and has been traced out in almost the entire coastal areas and stretches from Cape Comorin in south to Kottayam/Ernakulam in the north. The exposed occurences of the Warkalli beds are at Chilakkoor, Vettur (Thiruvananthapuram District), Kundara (Kollam District), Thamarakulam, Puliyur (Alleppey District) in the south, and Palayangadi, Ramapuram, Nileshwar, Kalanad (Kannur District) and Cheruvathur (Kasargod District) in the north. This formation is lateritized down to a depth of 10-13m, and in places where sandstones directly overlie the gneisses, this is Kaolinised down to about 10m.

1.4.2.3.Laterites:

The laterites of Kerala have been assigned Pliestocene age by the GSI (1973). Laterites have a very extensive development and they form low hills of undulating plain and very often stands out as cliffs along the coast. Laterites are seen to cover both the sedimentaries as well as the Precambrian crystallines and form a hard duricrust which is reddish brown to brownish black in colour, irregular and also with cellular structure. They are highly limonitic, porous, pitted and the pits often contain clayey materials. In the lower part of the duricrust, it is usually reddish brown to pink in colour, soft and with a vermicular structure. The laterites overlying the gneisses are very light, reddish brown, porous and having a gravelly texture. Many of the pores have quartz infillings in them. At places where the laterites directly lying over the crystallines, it is noted that, the laterites retain some of the original foliations of the rocks from which they are evolved. The laterites form extensive flat platforms from the sea level to about 200m elevation.

1.4.2.4.Recent to Sub-Recent sediments

The Recent to Sub-Recent sediments include fringes of parallel sand bars, sandy flats, alluvial sands and lacustrine deposits. In some places the Recent to Sub-Recent sediments separate from the Tertiary sedimentary rocks by a polymict pebble bed. From economic point of view, this formation, particularly the beach sands, is the most important one owing to the attractive concentrates of valuable placer minerals like ilmenite, rutile, zircon, monazite etc.

1.4.2(B) **Geologic setting of the study areas**

Of the various geologic formations discussed earlier, those flooring the catchment areas of the three mangrove patches selected for this investigation-ie, Veli, Kochi and Kannur are depicted in Fig. 7. A very detailed scanning of the various rock units is not attempted as it is beyond the scope of this investigation and the figures given are self explanatory interms of its geologic setting.

1.4.3. **Climate**

The state has tropical humid climate with an opressive summer and plentiful

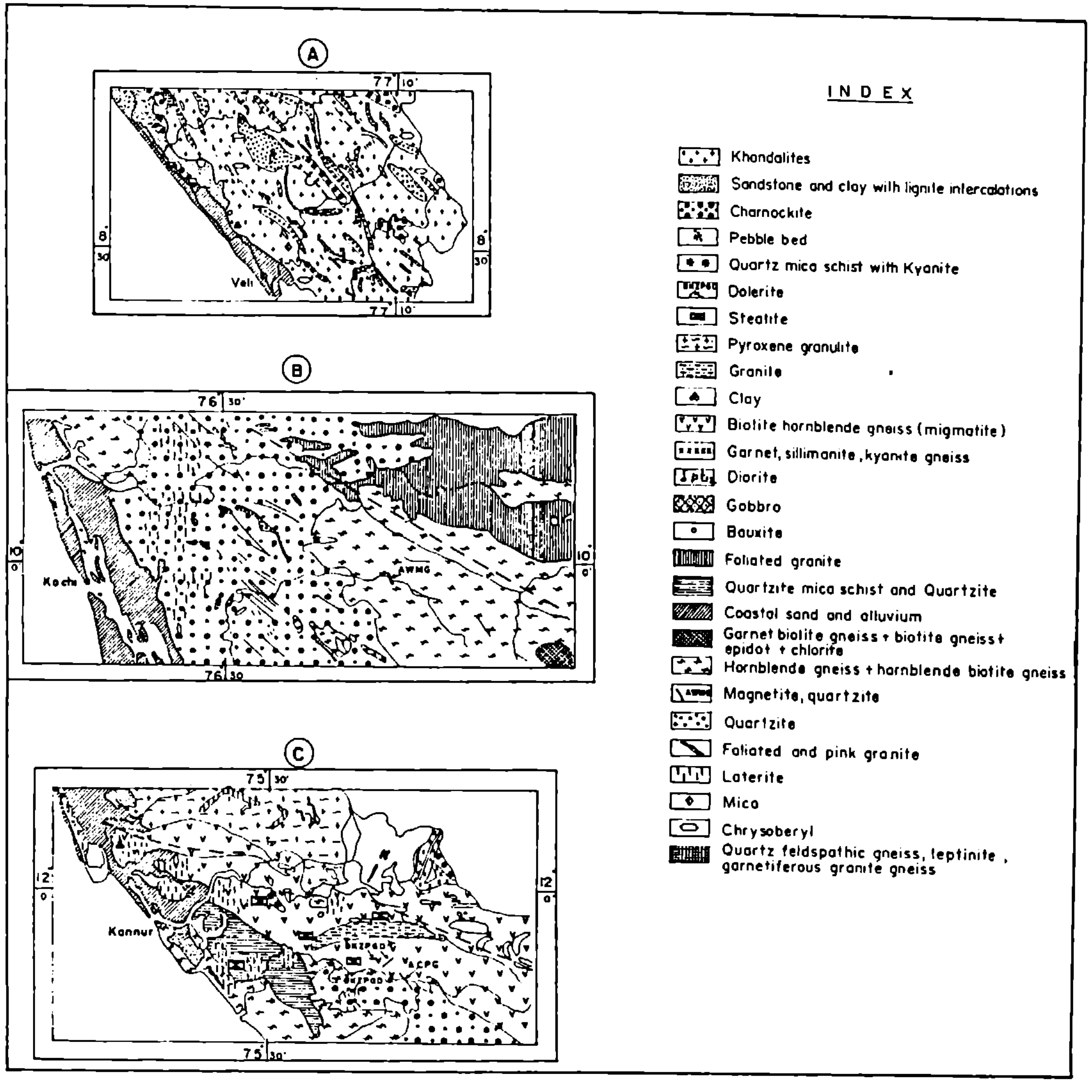


Fig 7. GEOLOGIC SETTING OF THE HINTERLAND OF VELI (A), KOCHI (B) AND KANNUR (C).

seasonal rainfall. The hot summer season from March to May is followed by South West monsoon from June to September. October and November form the post monsoon or the retreating monsoon season. The period from December to February is the North East monsoon season.

The average rainfall is of the order of 2500 to 3000mm with over 60% of rainfall is concentrated during the South West monsoon season. The average maximum temperature is from 30°C to 35°C with minimum temperature of 20°C to 25°C. The humidity ranges from 70% to 80% and is less from December to March. Winds are light to moderate during most of the year with varying wind directions depending on seasons.

1.5 OBJECTIVES OF THE PRESENT INVESTIGATION

The major objectives of this investigation are the following.

To study the granulometric composition and the spatial variation of textural attributes of Veli, Kochi and Kannur mangrove environments of the Kerala coast.

To understand the bearing of textural grades and statistical parameters on the hydrodynamic conditions of these mangrove environments.

To analyse the heavy and clay mineralogical constitutions of the study areas.

To delineate the probable provenances of the mangrove sediments.

To findout the geochemical variability of organic carbon, phosphorus and certain major (Na, K, Fe) and trace (Mn, Cu, Co, Pb, Cd and Zn) elements in the bulk sediments of the study areas.

To estimate the distribution of trace elements (Co, Pb, Cu, Cd and Zn) in the various chemical phases of the sediments using sequential extraction procedures.

To document the major mangroves and mangrove associates of Veli, Kochi and Kannur regions with their physiological and ecological features.

To evaluate the heavy metal levels in the leaves and stems of the major mangroves and mangrove associates in relation to the sediments.

CHAPTER 2

MATERIALS AND METHODS

This chapter deals with a comprehensive description of the field work carried out, in the Veli, Kochi and Kannur mangroves and the different meth ods employed in the collection, processing and analysis of samples used in this investigation.

2.1 FIELD WORK

A total of 84 surface sediment samples were collected from the mangrove environments of Veli (45), Kochi (29) and Kannur (12) regions. From each station, three samples were collected: one each from landward profile (LP), intermediate profile (IP) and shallow water profile (SWP). Two consecutive stations were seperated by a horizontal distance of 50 metres. Sediments along the landward profile and intermediate profile were obtained by penetrating a PVC pipe of 10cm diameter into the sediment sub stratum of the mangrove environments. The top 8-10 cm was taken after removing the litter (if present) at the surface. From the shallow water areas, the surface sediment samples have been obtained by using a van-veen grab sampler. All the samples were carefully transferred to pre-labelled polyethylene bags and preserved in a deep freezer till further analyses/processing. The pH of the samples were measured on the sampling site using portable pH meter. In addition to the surface sediments, a few core samples were also collected from Veli (VC_1 and VC_2), Kochi (CC_1, CC_2, CC_3 and CC_4), and Kannur (KC_1, KC_2 and KC_3) mangrove environments using a specially fabricated coring device. The details of the cores are given in Table 4A.

Besides, representative leaves (matured leaves - 5th - 8th leaves from the apex), and stems (4-6 cm long portion of stem below 5-7 cm from apex) of the major mangrove and mangrove associates have also been collected for chemical analysis. The most dominant species have been subjected to chemical analysis on dry weight basis as well as ash weight method. The following is a list (Table 4B) of man groves and mangrove associates of Veli, Kochi and Kannur mangrove environments.

2.2 LABORATORY INVESTIGATIONS

2.2.1 **Texture**

2.2.1.1 Granulometric studies

A portion of the sediment sample was washed with distilled water to remove soluble salts and then dried it in a hot air woven at 55°C ± 3°C to constant weight. Known quantities of silt and clay rich sediments were dispersed overnight in 0.025 N solution of sodium hexametaphosphate.

The coarse fraction was seperated from the dispersed sediments by wet seiving using a 230 mesh (63μ) ASTM sieve. The filtrate containing silt and clay fractions were carefully transferred to a gaduated 1 litre measuring jar and vol ume made up. The solution was then stirred thoroughly to obtain a homog enous suspension. A 20ml of the filtrate was pipetted out into pre weighed 50ml beakers at stipulated time gaps as suggested by Lewis,(1984). All the aliquots were oven dried to constant temperature of aproximately 60oC and weighed ac curately after cooling at room temperature. Dry sieving was carried out on sand fraction to complete the analysis.

Table 4A
Locations of sediment cores and their specifications

Core No	Location	Core length (cm)
VC_1	Veli-south western side	60
VC_2	Veli-north eastern side	70
CC_1	Kochi-Vypin	60
CC_2	Kochi-Malippuram	60
CC_3	Kochi-Vallarpadam	70
CC_4	Kochi-Vallarpadam	100
KC_1	Kannur-north eastern side	80
KC_2	Kannur-south western side	80
KC_3	Kannur-south western side	60

Table 4B
The various mangroves and mangrove associates documented and a whose leaves and stems are collected for chemical analysis

Sl. No	Veli mangroves	Kochi mangroves	Kannur mangroves
1.	**Acrostichum aureum*	**Avicennia officinalis*	**Avicennia marina*
2.	**Barringtonia racemosa*	**Rhizophora mucronata*	**Excoecaria agallocha*
3.	**Acanthus ilicifolius*	**Excoecaria agallocha*	**Derris trifoliata*
4.	**Avicennia officinalis*	**Acanthus ilicifolius*	**Acanthus ilicifolius*
5.	*Vitis vitigenia*	*Bruguiera gymnorrhiza*	*Rhizophora mucronata*
6	*Sonneratia caseolaris*		*Kandelia candel*
7.	*Derris trifoliata*		*Avicennia officinalis*
8.	*Cerbera odollam and*		*Acrostichum aureum and*
9.	*Premna serratifolia*		*Rhizophora apiculata*

* Most common species covering >70% of the study area

The cumulative weight percentages of the above analysis were plotted against the respective grain sizes in phi unit, on a probably chart. The cumulative frequency curve is computed and the values of 1 ϕ, 5 ϕ, 16 ϕ, 25 ϕ, 50 ϕ, 75 ϕ, 84 ϕ and 95 ϕ percetiles were recorded. For few samples (with high per centage of clay), which do not attain high percentiles, the conventional extrpolation methods suggested by Folk and Ward (1957) was adopted. A brief account of the grain size parameters such as mean size, median, standard deviation, skewness and kurtosis and their computational equations given by Folk and Ward (1957) are given below.

Mean size (Mz) of clastic sediments is the statistical average of grain size population. It is calculated from the phi value details using the equation

$$Mz\ (\text{phimean}) = \frac{\phi\,16 + \phi\,50 + \phi\,84}{3}$$

The standard deviation (sorting coefficient σ_1) is defined as the particle spread on either side of the average grain size values. Sorting values are indicative of mean energy conditions of the depositional environments. (Sherwood and Nelson, 1979). The sediment sorting is good, if the spread sizes are relatively narrow.

$$\text{Standard deviation} = \frac{\phi\,84 - \phi\,16}{4} + \frac{\phi\,95 - \phi\,5}{6.6}$$

Skewness of clastic sediments describe the symmetry of grain size distribution and is a sensitive indicator of sub population mixing. (Folk and Ward, 1957; Spencer, 1968; Mason and Folk, 1963). Friedman, (1967) and Coronan (1972) emphasised that Polymodel sediments can give variable skewness values depending upon the sub-population mixing. Well sorted unimodal sediments are symmetrical, with a skewness value of zero. In fine skewed sediment populations, the frequency curve chops at the coarser end and tails at the finer. The reverse condition is characteristic of coarse skewed sediments.

$$\text{Skewness} = \frac{\phi 16 + \phi 84 - 2 * \phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2 * \phi 50}{2(\phi 95 - \phi 5)}$$

Kurtosis measures the peakedness of grain size distribution curve.

$$\text{Kurtosis} = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}$$

In addition to the above, bivariate plots (Friedman, 1967) of statistical parameters, textural types (Folk et al, 1970) of sediments and CM - pattern (Passega, 1964) also worked out to elucidate the various physical processes (including the hydrodynamic regimes) to which the sediments are subjected.

2.2.1.2 Scanning Electron Microscopic (SEM) studies

Following the method of Krinsley and Doornkamp (1973), the samples were prepared for the surface textural analysis by SEM. Quartz grains between size 80 and 120 ASTM meshes were chosen for this study, because grains of this size are likely to record all of the well known surface features. (Krinsley and McCoy, 1977). While grains smaller than this are biased towards recording chemical effects and those larger than this are biased towards overprinting abrasions (Margolis, 1968)

Approximately 0.25gm of each sample was treated for 30 minute with con centrated hydrochloric acid at 90°C to remove the carbonate particles and washed in distilled water. These samples were then soaked overnight in hydrogen per oxide to remove organic debris and washed again in distilled water. Iron sur face coatings were removed by boiling in stannous chloride solution and washed again in distilled water. The grains were then mounted on 13mm specimen stubs. The mounted grains were sputter coated with gold and photomicrographs were taken using stereoscan Jeol.Jsm 35C scanning microscope at standard magnifications ranging from 60X to 2000X. The interpretations were made following, Krinsley, (1966) Margolis, (1968), DoornKamp, (1966) and Marshal, (1987).

2.2.2 **Mineralogy**

Different methods were adopted to study the mineralogical constitution of mangrove sediments. They are summarised below.

Heavy Minerals: The sand fraction was washed thoroughly with deionised wa ter and oven dried at 50^0 C 3°C. About 50gm of the coned and quartered sand fraction was seived for half phi interval. From fine (+80 +120 ASTM meshes) and very fine(+170 +230 ASTM meshes) sand fractions, heavy and light min erals were separated using bromoform ($CH Br_3$ - 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 min eral contents. The heavy minerals were then boiled for few minutes with dil

Hcl and a pinch of stannous chloride crystals to remove Fe/Mn coating over the detrital heavy grains. A total of 300-400 grains from each heavy residue was mounted on glass slides using Canada balsm. The individual minerals in each slide were studied under a Leitz Petrological micro scope following Krumbein, (1938).

Mineralogy of clay: Smear slides of clay fractions (<2 size) were prepared after treating the samples with 6% HCl and 30% H_2O_2 to remove $CaCO_3$ and organic carbon, respectively (Gibbs, 1968). The slides were run on a phillips X-ray diffractometer using K α radiation and Ni-filter. Machine settings of 40kv, 20ma and goniometer speed of 2^0 20min-1 were used. The identification of the clay mineral has been carried out following JCPDS (1974).

* Montmorillonite is identified by its (001) peak at 14A°.
* Illite exhibits a major peak at 10A° and a minor peak at 5A° and 3.3 A°.
* Kaolinite will give strong peaks at 7.16 A° and 3.58 A° and always exhibit a very small peak at 2.38 A°. Kaolinite and chlorite exhibit same spacing and hence their identification some times become difficult.
* Gibbsite gives distnct peaks at 4.85 A°.

2.2.3 **Geochemistry**

An amount of 0.5gm of very finely powdered sediment sample was mixed with perchloric acid and hydrofluric acid in 1:3 proportion in a clean dry teflon crucible and heated on a sand bath until no fumes come out of it. Five ml of double distilled water was added to it and filtered the solution until the digestion of the sample is completed. Made this up to a known volume (50ml) and was used for the geochemical analyses following various techniques (Table 5).

A brief description of the methods employed is given below.

Table 5
Various analytical methods and instrument Model employed in geochemcial studies.

Sl. No.	Parameters studied	Methods	Instrument/ model	Reference
1.	Sediment organic carbon	Titrimetric		El-wakeel and Riley (1957)
2.	Sediment calcium carbonate	Titrimetric		Jackson (1956)
3.	pH	Electromet rically determind		
4.	Phosphorous	Colourimetric	Shimodz 160 A	Murphy and Riley (1962)
5.	Sodium	Flame photo metric	Elico.CL- 22A	APHA 1981
6.	Potassium	Flame photo metric	Elico.CL- 22A	APHA 1981
7.	Iron, Manganese and Trace metals	Atomic Absorption spectrophoto metric	Perkin Elmer model 2380	Rantala and Loring (1975)
8.	Heavy metal speciation	Centrifuging	Remi R.23	Tessier et al, (1979)

2.2.3.1 Digestion of leaf and stem

Mature (average sized) fresh leaves and stems of the major mangrove species and their associate plants were collected and washed with deionised water to remove the adhering matter. The plant parts were then dried at 80°C for constant weight. Dried plant parts were homogenised and then ignited at 800°C for 5 hours in muffle furnace using silica crucibles. A known quantity of ash samples were digested with perchloric acid - hydrochloric acid mixture following Lithnor (1975). The filtrate was them made to 50ml with double distilled water. Blanks were run at the similar sequence of treatments. The solutions were analysed for Mn, Cu, Co, Zn, Pb and Cd, using an Atomic Absorption spectrophotometer (model PE 2380).

2.2.3.2 Organic Carbon

The bulk organic carbon in the sediment samples were determined by the oxidation method of El-wakeel and Riley (1957). The principle is that the organic matter in the sample was oxidised by a known quantity of chromic acid and the amount of chromic acid consumed was determined by titrating against ferrous ammonium sulphate. Diphenylamene was used as indicator. The average of triplicate measurements not differing 0.2% of the analyse were used in this study.

2.2.3.3 Calcium Carbonate

The principle of determination of $CaCO_3$ consist of the treatment of the sample with a known amount of dilute hydrochloric acid and the estimation of excess HCl by titrating with standard NaOH solution, using bromothymol blue as indicator (Jackson 1957). The experiment is repeated for concordant values.

2.2.3.4 Phosphorus

Phosphorus as phosphate ($P0_4$-P) form was determined based on the reac tion of the ions with an acidified molybdate reagent to yield a phospho-molyb date complex (Murphy and Riley, 1962). It was then reduced to a highly blue coloured compound. The intensity of the colour developed will be proportional to the concentration of the phosphate phosphorus in the solution. This solution exhibits maximum absorption at 880nm. The amount of phosphate phosphorus was determined by comparing with a set of standard samples.

2.2.3.5 Sodium and Potassium

Sodium and Potassium were determined using Flame Photometer, based on the procedure described by APHA (1981). In order to avoid the inter element and anionic effects, Fe and Al were removed from solution by precipitating with ammonia solution. It was then aspirated for the estimation of Na and K. Calibration curves for Na and K were drawn separately and concentration of the above metals were estimated.

2.2.3.6 Iron, Manganese and Tracemetals

Fe, Mn and tracemetals (Co, Pb, Cd, Cu and Zn) were analysed using atomic absorption spectrophotometer (Model PE 2380) following the methods of Rantala and Loring (1975).

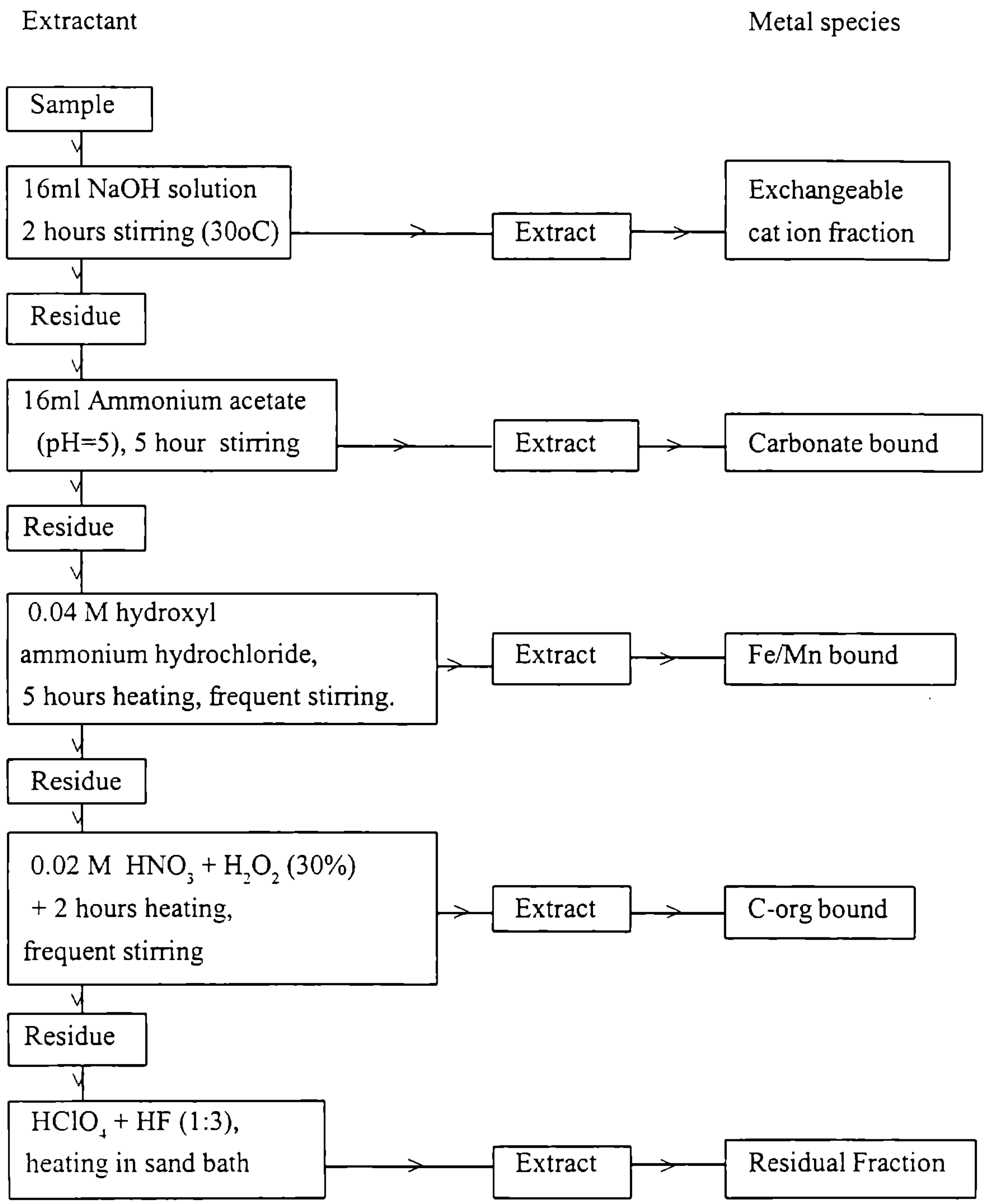
2.2.3.7 Precision and accuracy

The precision and accuracy of the heavy metal estimations were checked against the international standard samples G2 and SCO_1. All the metal values were in agreement with the published/certified values. (see Table 23 in Chapter 5).

2.2.3.8 Heavy metal speciation

The different steps involved in speciation studies are summerised in the Fig. 8.

Fig. 8 **Flowchart of sequential extraction procedures**



Detailed Procedure :

a) Easily exchangeable

16 ml of 1M sodium acetate solution was added to 2gm of the sediment sample in a test tube and kept it for 1 hour. The above mixture was stirred fre - quently and centrifuged at RPM 3000 for about 30 minutes. 10ml of the supernatent solution was taken in plastic bottle after filtering. The above residue was washed in double distilled water and discarded the supernatent solution after centrifuging.

b) Carbonate Bound

16ml of 1 M sodium acetate solution adjusted to pH-5 with acetic acid- was added to the above residue and stirred thoroughly for about 5 hours. 10 ml of the supernatent solution was collected in plastic bottles after centrifuging (at PM-3000 for 1/2 an hour) and filtering. The residue was washed using double distilled water.

c) Fe-Mn oxide bound

30ml of 0.04 M hydroxylammonium hydrochloride in 25% acetic acid was added to the above residue and heated the mixture in a water bath at 96°C for 5 hours with intermittent stirring. The solution was cooled, centrifuged and col lected after filtering. The residue was then washed with double distilled water.

d) Organic carbon bound

6ml of 0.02 M nitric acid and 10ml of 30% H_2O_2 adjusted to pH-2 with HNO_3 was added and the mixture was heated to 85°C for 2 hours with occasional agitation. It was then cooled, centrifuged and collected the supernatent solution in bottles after it was filtered. The residue was washed with double distilled water.

e) Residual Fraction

The above bulk residue was digested using perchloric acid and hydroflouric acid in the proportion 1:3. It was then made up to 50 ml using double distilled water and 5 ml of 1:1 hydrochloric acid. Blanks were also run at the same sequence of treatments for all of the above fractions. These solutions were fed into Atomic Absorption Spectrophotometer (Perkin Elmer model 2380) for analysing the tracemetals (Co, Pb, Cu and Zn).

CHAPTER 3

TEXTURE OF MANGROVE SEDIMENTS

3.1. INTRODUCTION

Texture, is a basic descriptive measure of sediments that controls all the physico-chemical characteristics of aquatic environments including the mangrove forested intertidal zones. It deals mainly with size, shape and mutual relationship between individual particles constituting the sediments. In many studies the image of grain size spectrum, its properties and the statistical parameters computed from the size populations are only used for getting insight into the transportational and depositional process/mechanisms of sediments and sedimentary rocks (Friedman, 1961; 1967; Visher, 1969; Blatt et al, 1972; Pettijohn, 1975; Sly et al, 1982; Seralathan and Padmalal, 1993; Sajan et al, 1992; etc.). Repeated statistical analyses revealed that the proper selection and combination of size parameters can be used as an effective tool to discriminate various depositional environments of ancient as well as recent origin (Folk, 1966; Friedman, 1967; and Hails and Hoyt, 1969; Roy et al, 1993; Gupta et al, 1994). There have been a fund of information on textural aspects of the major sedimentary environments in the geo-scientific literature which are summarised separately in 'Review of Literature' section below. Unfortunately, many of the researches are confined mainly to the beach, dune, riverine, estuariene and nearshore environments of the world and only very few efforts have been extended to the mangrove forested sedimentary environments. (Reghunath et al, 1995; Badarudeen et al, 1996; 1997). In view of this an attempt has been made in this chapter to explore the grain size characteristics of Veli, Kochi, and Kannur mangrove ecosystems of Kerala to have better insight into the various processes operating in the mangrove environments of these regions.

3.2. REVIEW OF LITERATURE

The existance of statistical relationships among various size parameters viz-phimean, standard deviation (sediment sorting), skewness and kurtosis have been well established. The relationship between phimean and sorting is documented by many investigators and they proved the best sorted sediments are generally those with mean size in the fine sand grade (Pettijohn, 1957; Griffiths, 1967; Allen 1970 and Hakanson and Jansson, 1983). Published literature is also in plenty dealing with how best the granulometric parameters be effective in differentiating various depositional environments. (Mason and Folk, 1958; Friedman, 1961; Griffiths, 1962; Moiola et al, 1974; Stapor and Tanner, 1975; Nordstrom, 1977; Goldberg, 1980; Sly et al, 1982; Seralathan, 1988 and Padmalal, 1992). Friedman, (1961; 1967) has studied the textural parameters of the samples of relatively fine grained sands taken from many different localities around the world representing dunes, beaches and rivers and found that the most effective distinction of sands from these three environments is shown by a scatter diagram of moment standard deviation (sorting) versus moment skewness. Quartile measures (Trask, 1932 and Krumbien, 1938) were found to be inadiquate to represent the entire grain size image of sediment population since they incorporate only 50% of the particle population. The method of Inman, (1952) is applicable for nearly normal or normal distributions and fails to reflect the mean size of bimodal or strongly skewed sediment populations. Folk and Ward, (1957) proposed graphic measures by incorporating median of the coarsest third, average size of the finest third and the middle third. Compared to that of McCommons, (1962) method which represent 96% of the population, graphic measures are found to be more popular because of its simplicity in the statistical processing and easiness in application.

Moment measure is considered as a sensitive measure for the environmental discriminations because, it can incorporate the entire size frequency range of population (Friedman, 1961 and 1967). Passega, (1957, 1964) has given a new dimension to the statistical procedures of grain size analysis and he established the relationship between texture of sediments and process of transportation rather than between texture and environment as a whole. By plotting coarsest 1 percentile grain size (C) and the median size (M) of sediment samples on a double log paper, Passega, (1957) interpreted the distinct patterns of C-M plots interms of different modes of transportations. Visher, (1969) explained the log normal sub populations within the total grain size distribution curve as representing suspension, saltation and surface creep or rolling modes of transportational mechanisms. Other noteworthy contributions in the textural attributes of clastic sediments are of (Cadigan, (1961); Fuller, (1961) Greenwood, (1969); John, (1971); Davis and Fox, (1972); Veeraya and Varadachari, (1975); Anwar et al, (1982); Khalaf et al, (1982) and Stokes et al, (1989).

In India, the textural implications of sediments from different environments have been attempted by many researchers (Sahu, 1964; Mishra, 1969; Rajamanickam and Gujar, 1985; Samsuddin, 1986; Seralathan, 1988; John, .l. 1971) and Seralathen and Padmalal (1993). Subba Rao, (1967) has made a detailed investigation on the composition and texture of shelf sediments of the east coast of India. Grain size characteristics of sediments deposited at the mouth of Hoogly river were carried out by Mallik, (1975). Rajamanickam and Gujar, (1985) have investigated the grain size distribution of the surficial sediments of west coast of India. The sediments of the continental shelf of Karnataka coast have been analysed texturally by Hashimi and Nair, (1981). Murthy and Rao, (1989) have investigated the textural characteristics of the sediments of Vishakhapatanam coast.

Like the shelves, considerable information exist on the textural aspects of beach sands as well (Kidwai, 1971; Veerayya and Varadhachari, 1975; Samsuddin, 1986; Purendra et al, 1987; Unnikrishnan, 1987; and Sasidharan and Damodaran, 1988). Granulometric attributes of the beach, strand plain and inner shelf sediments of northern Kerala coast have been investigated by Samsuddin, (1990). Studies on textural and sedimentological aspects of central Vembanad estuary were carried out by Padmalal, (1992).

Although ample literature exists on the grain size characteristics of river, dune, beach and nearshore environments, not much published accounts exist on the mangrove environments of the world (Ukpong, 1992 and Badarudeen et al, 1996). The present investigation deals with the complex relationships of various grain size parameters computed from the sediment samples of Veli, Kochi and Kannur areas over the various sedimentational processes operating there.

3.3. RESULTS AND DISCUSSION:

3.3.1. Granulometric analysis and Textural facies.

3.3.1.1 Veli Mangroves

Surface sediments: The sand, silt and clay contents of the sediment samples collected from the Veli mangroves are furnished in Table 6. The intermediate profile (IP) and the shallow water profile (SWP) account for substantially high content of sand compared to that in landward profile (LP). The averages of sand in intermediate, shallow water and landward profiles are 72.24%, 69.74%

Table - 6

Granulometric details of the surface sediments of Veli, Kochi and Kannur mangroves.

(Values are given in percentages)

Sample No.	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Mud (silt+clay)	Sand (total)	Textural type (Folk et al,1970)
Veli mangroves										
1. a	0.16	5.54	19.72	21.20	5.37	26.75	21.27	48.02	51.98	Muddy sand
b	1.02	12.21	22.41	25.72	5.07	17.52	16.04	33.56	66.44	Muddy sand
c	0.05	3.07	7.23	4.80	1.11	52.81	30.91	83.72	16.28	Sandy mud
2. a	0.26	6.25	18.33	18.89	3.32	28.39	24.56	52.95	47.08	Muddy sand
b	0.78	15.04	29.76	16.54	1.61	18.78	17.29	36.07	63.93	Muddy sand
c	1.29	15.97	28.42	17.63	1.79	22.66	12.23	34.89	65.11	Muddy sand
3. a	0.13	5.13	18.67	15.43	7.08	18.47	35.10	53.57	46.43	Sandy mud
b	0.24	5.46	21.97	16.72	8.08	23.05	24.46	47.51	52.49	Muddy sand
c	0.94	19.24	24.79	21.29	4.71	16.72	12.32	29.04	70.96	Muddy sand
4. a	3.07	8.48	19.78	19.03	5.62	19.39	26.63	46.02	53.98	Muddy sand
b	4.13	17.05	23.37	23.05	16.41	6.09	9.88	15.97	84.03	Muddy sand
5. a	5.44	2.64	19.03	19.60	6.38	23.59	23.34	46.93	53.07	Muddy sand
c.	1.05	16.08	38.64	23.03	1.21	12.89	7.09	19.98	80.02	Muddy sand
6. a	0.80	14.44	29.77	19.23	8.66	10.92	16.17	27.08	72.92	Muddy sand
b	0.49	12.90	28.35	14.78	1.16	13.98	28.4	42.38	57.62	Clayey sand
c	0.98	19.60	35.12	25.77	1.51	5.43	11.59	17.02	82.98	Clayey sand
7. a	3.19	10.59	19.45	6.98	3.28	28.43	28.08	56.51	43.49	Sandy mud
b	0.43	9.89	17.04	14.41	5.36	21.53	31.33	52.86	47.14	Sandy mud
c	0.42	15.65	43.99	26.44	2.47	7.15	3.87	11.02	88.98	Muddy sand

Sample No.	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Mud (silt+clay)	Sand (total)	Textural type (Folk et al,1970)
8. a	1.03	17.16	48.45	13.02	5.02	10.19	5.11	15.30	84.70	Muddy sand
b	0.76	11.96	43.00	27.57	2.35	10.21	4.15	14.36	85.64	Silty sand
c	2.75	9.29	41.45	23.00	0.14	19.24	4.13	23.37	76.63	Silty sand
9. a	0.02	2.97	23.55	15.88	4.53	42.64	10.39	53.03	46.97	Sandy silt
b	0.04	2.38	52.37	32.34	2.00	5.32	5.55	10.87	89.13	Muddy sand
c	0.35	5.76	50.41	20.59	2.18	14.11	6.58	20.69	79.31	Muddy sand
10.a	1.20	3.29	6.93	8.35	1.21	71.79	7.20	78.99	22.01	Sandy silt
b	7.54	34.69	29.61	8.32	1.33	13.97	4.47	18.43	81.57	Silty sand
11.a	4.76	39.45	38.25	12.83	1.11	2.07	1.51	3.60	96.94	Sand
b	2.29	16.48	26.41	18.12	4.70	18.75	13.22	31.97	68.03	Muddy sand
c	2.07	23.82	38.63	19.16	1.39	11.33	3.6	14.93	85.07	Silty sand
12.a	0.411	2.28	26.57	13.79	3.04	39.3	14.63	53.93	46.07	Sandy silt
b	1.91	3.28	34.61	14.10	2.15	11.13	4.83	15.96	84.04	Silty sand
13.a	0.08	5.12	3.53	2.05	8.83	50.7	31.00	81.76	18.24	Sandy mud
c	0.59	10.15	28.76	26.57	4.89	14.85	13.59	28.44	71.56	Muddy sand
14.a	0.44	9.04	13.58	9.89	1.39	32.76	32.9	65.66	34.34	Sandy mud
c	0.49	3.98	12.35	15.10	6.70	33.04	28.33	61.67	38.63	Sandy mud
15.a	0.59	0.70	35.64	29.82	1.71	15.64	6.9	91.26	8.74	Silty sand
b	0.74	16.91	40.83	27.17	1.16	7.25	5.92	13.17	86.83	Muddy sand
c	5.63	11.63	34.03	25.49	4.60	10.20	8.42	18.62	81.38	Muddy sand
Kochi mangroves										
16.a	1.49	7.02	11.36	38.72	9.22	25.67	6.53	32.19	67.81	Silty sand
b	0.93	11.11	7.41	25.17	10.93	41.23	3.2	44.43	55.57	Silty sand
c	0.76	4.11	12.30	18.47	8.38	40.73	15.22	55.95	44.05	Sandy silt

Sample No.	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Mud (silt+clay)	Sand (total)	Textural type (Folk et al,1970)
17.a	0.70	4.48	15.17	5.61	1.47	50.49	22.09	72.58	27.42	Sandy silt
b	1.05	5.08	18.69	8.27	3.98	55.83	17.07	72.90	27.1	Sandy silt
c	0.34	11.37	15.18	18.12	1.06	36.84	17.07	53.91	46.09	Sandy silt
18.a	0.00	5.05	14.25	9.96	5.01	38.03	27.69	65.72	34.28	Sandy mud
b	3.09	9.50	21.87	3.32	1.36	37.50	23.35	60.85	39.15	Sandy mud
c	3.10	8.99	14.64	6.22	4.74	39.00	23.29	62.29	37.71	Sandy mud
19.a	2.15	3.83	16.83	43.23	17.76	13.21	2.97	16.18	83.82	Silty sand
b	3.47	3.29	14.21	43.13	20.51	13.76	1.63	15.39	84.61	Silty sand
c	0.59	4.27	19.67	35.60	14.30	18.50	7.05	25.55	74.45	Silty sand
20.a	13.39	12.04	12.30	33.86	16.95	6.64	4.80	11.45	88.55	Muddy sand
b	2.22	5.82	22.11	36.95	13.45	13.25	6.18	19.43	80.57	Silty sand
c	5.23	8.04	17.54	44.72	7.13	9.24	8.09	17.33	82.67	Muddy sand
21.a	0.56	11.84	30.96	48.17	1.78	5.86	0.80	6.67	93.33	Silty sand
b	4.34	14.03	11.74	15.05	3.38	28.84	22.59	51.43	48.57	Sandy mud
c	6.31	16.63	15.14	29.73	6.55	17.15	8.46	25.62	74.38	Muddy sand
22.a	0.78	5.40	14.24	63.86	7.10	7.21	1.39	8.61	91.39	Silty sand
b	0.51	4.52	9.13	18.84	6.08	39.95	20.96	60.91	39.09	Sandy mud
c	2.07	7.02	12.74	53.65	14.64	7.56	2.29	9.85	90.15	Silty sand
23.a	13.94	12.04	13.6	29.51	6.34	15.67	8.89	24.56	75.44	Muddy sand
b	0.24	12.84	21.84	38.93	6.19	11.47	8.47	19.94	80.06	Muddy sand
c	7.39	18.06	18.87	18.49	2.91	19.49	14.77	34.26	65.74	Muddy sand
24.a	5.11	13.58	12.33	36.15	15.15	9.38	8.27	17.65	82.35	Muddy sand
b	5.57	12.4	13.76	22.84	12.50	20.22	12.69	32.91	67.09	Muddy sand
c	4.52	8.81	22.25	39.38	7.27	11.66	6.1	17.76	82.24	Muddy sand
Kannur mangroves										
25.a	1.07	12.61	25.72	25.67	11.89	12.37	7.66	20.03	79.97	Muddy sand
b	0.92	16.11	16.99	24.15	16.01	20.42	5.35	25.77	74.23	Silty sand
c	11.15	20.79	14.75	25.35	7.06	13.21	7.69	20.89	79.11	Muddy sand

Sample No.	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Mud (silt+clay)	Sand (total)	Textural type (Folk et al,1970)
26.a	10.39	19.15	16.05	17.65	7.35	19.05	10.35	29.40	70.6	Muddy sand
b	8.18	13.10	18.41	16.17	12.94	21.93	9.26	31.19	68.81	Silty sand
c	0.082	17.02	21.07	22.35	9.9	15.55	14.2	29.75	70.25	Muddy sand
27.a	0.38	10.68	7.15	9.2	3.04	37.29	32.33	69.51	30.49	Sandy mud
b	0.47	9.2	4.90	7.99	1.25	47.44	28.70	76.14	23.86	Sandy mud
c	4.66	3.65	6.43	8.44	1.87	50.11	24.82	74.93	25.67	Sandy mud
28.a	5.01	4.86	12.4	6.93	4.54	38.04	27.34	65.38	34.62	Sandy mud
b	0.21	5.14	5.74	19.35	1.90	36.38	31.3	37.68	32.32	Sandy mud
c	3.71	6.23	16.05	15.32	7.84	32.91	17.94	50.84	49.16	Sandy mud

a = Landward sample; b = Intermediate sample; c = Shallow water sample.

and 48.45%, respectively. The average silt and clay contents are 28.07% and 18.98% in landward profile, 13.96% and 13.8% in intermediate profile and 18.37% and 11.88% in shallow water profile. The size spectral analysis of coarser fractions indicates that the sand grains of the Veli Mangrove environment fall mainly in the coarse to fine sand grade of Wentworth size scale. The sediment facies model worked out for the samples (Fig.9 A) shows that the sediment substratum exhibits a spectrum of textural classes viz- muddy sand (mS), sandy mud (sM), sandy silt (sZ), silty sand (zS), clayey sand (cS) and sand (S). Of these, the former two textural classes together constitute 70% of the total samples analysed. Other textural classes are present only in marginal amounts (Table 6).

Based on the textural differences noticed, the Veli mangrove environment can be divided into two sectors; the south west sector positioned on the left side of the Kulathurthodu is dominated by muddy sand (60%). Sporadic cases of sandy mud and clayey sand are also observed on the margins of this segment. Contrary to this, the northeast segment, located on the right side of the Kulathurthodu exhibits highly complex textural association. The landward profile of this segment shows predominance of mud (46.85%), whereas, the intermediate and shallow water profiles are floored by sand dominated sedimentary facies. An overall evaluation of the textural characteristics of the Veli mangroves sheds enough light onto the complex interaction between the abiotic and biotic components of this unique ecosystem. The south west segment is influenced more by the tidal activity than the north east segment. The flooding and ebbing of tidal waters constantly winnows the finer particles like silts and clays back to the sea, leaving the more coarser grains rich in sand *in situ*. (in this context, it is important to note that the bar mouth of the Akkulam - Veli lake was kept opened during the time of sample collection). This mechanism might be responsible for the substantially high content of sand over silt and clay particles in the south west segment. The less dense

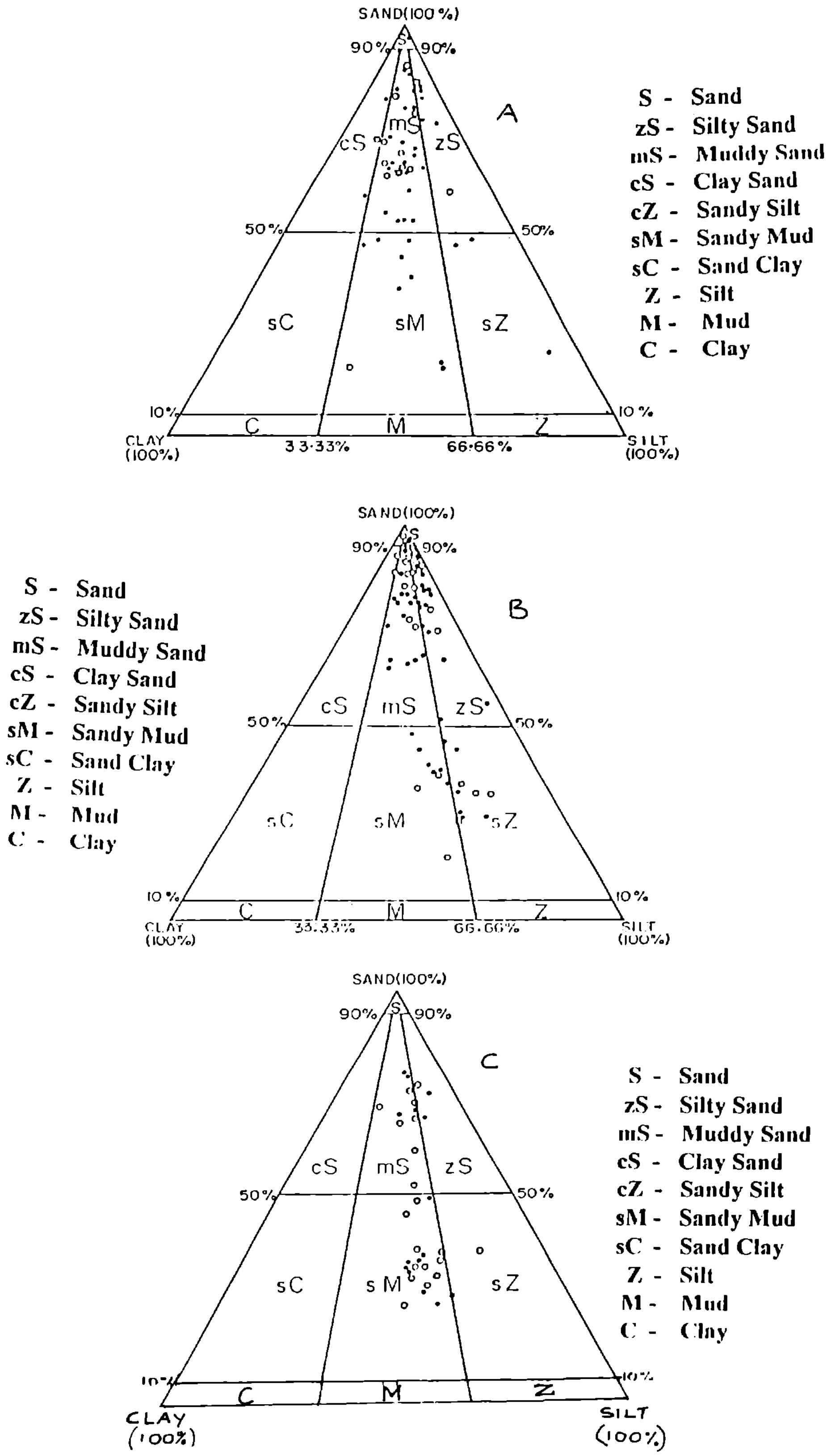


Fig 9. TERNARY DIAGRAM SHOWING TEXTURAL TYPES OF THE SURFACE(•) AND CORE (o) SEDIMENTS OF VELI (A), KOCHI (B) AND KANNUR (C) MANGROVES. (AFTER FOLK et al, 1970)

mangrove vegetation of this region is another factor promoting selective erosion of finer particulates from the sedimented population.

Contrary to the southwest segment, the northeast portion is affected by low energy tidal currents and luxurient mangrove cover. While the low energy tidal currents is insufficient in the effective winnowing of finer particles, the luxuriant mangrove forests and its root systems effectively traps the finer clastics and thereby stabilizing the mangrove forested north eastern bank from erosion threats. The substantially high content of mud over sand in the landward profile of this sector also exemplifies the ability of mangrove vegetation in trapping finer particles in the sediment substratum.

Core sediments: The lithological variation along the vertical profile of the Veli mangroves registered in the two cores (VC_1 recovered from the south western segment and VC_2- from the north eastern segment) is depicted in Fig.10. The core VC_1 is 60 cm in length and composed of muddy sand (50cm) and silty sand (10cm). The latter lithotype is found intervened within the former below 40cm from the surface. The sand, silt and clay content averages 75.33%, 11.58% and 13.04% in muddy sand and 60.1%, 30.76% and 9.14% in silty sand. On the otherhand, the core VC_2 is heterogenous in its textural assemblage (Table 7) and encompasses muddy sand, clayey sand, sandy mud and muddy sand from top to bottom. Among the various textural classes the muddy sand dominates over others. The average contents of sand, silt and clay are 69.95%, 15.61% and 14.45%, respectively in muddy sand, 73.08%, 8.6% and 18.33% in clayey sand and 16.91%, 30.78% and 52.31% in sandy mud. The observed textural complexity of VC_2 over VC_1 also pin points the difference in hydrodynamic regimes of the south western and north eastern segments of the Veli mangroves.

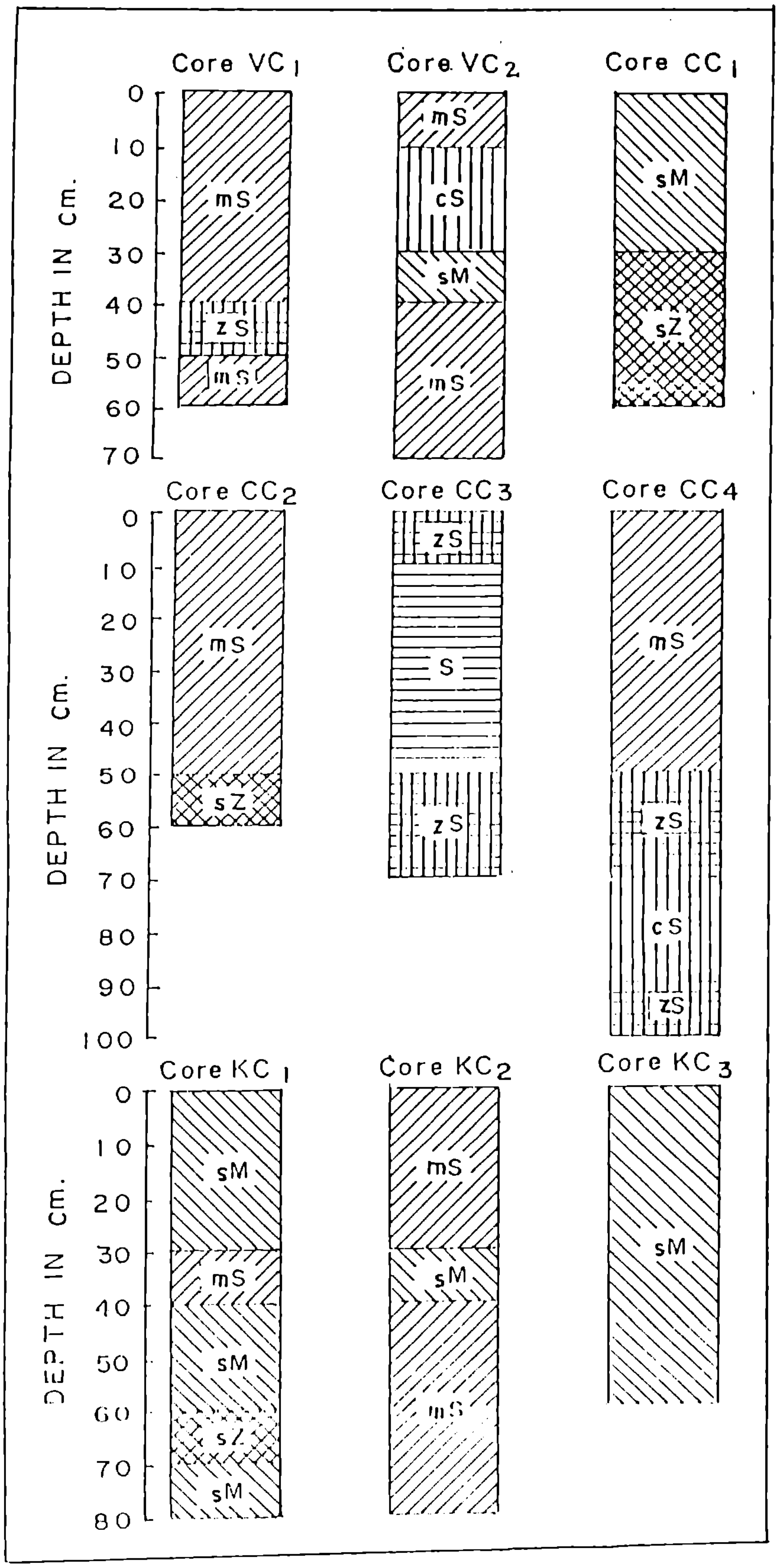


Fig. 10. TEXTURAL FACIES ALONG THE VERTICAL PROFILE OF SEDIMENT CORES FROM VELI (VC_1 AND VC_2), KOCHI (CC_1, CC_2, CC_3 AND CC_4) AND KANNUR (KC_1, KC_2 AND KC_3) MANGROVES. (ref. Fig. 9 for textural facies details

Analysis of sand fractions of the core smaples reveals predominance (~ 90%) of coarse to fine sands in VC_1 and medium to fine sands (~ 70%) in VC_2. This again suppliments the prevalence of comparatively high energy depositional regime in the region neighbourhood of the core VC_1, while slightly low energy (often fluctuating) depositional regime around the core site VC_2. Further probing of sand fractions of these two cores manifests that the very fine sands in core VC_2 show more than two times the enrichment than VC_1. The content of silt in both the cores is almost the same (av; 14.18% in VC_1 and 15.77% in VC_2) and whose specific size ranges from coarse to fine in the Wentworth size scale.

3.3.1.2 Kochi mangroves

Vembanad Lake, the largest lake in the south west coast of India, hosts profusely developed mangrove patches on its various islands and banks. However, in the present investigation three major mangrove patches spread at Vypin, Malippuram and Vallarpadam areas have been selected. The textural characteristics of these mangrove patches registered in both surface and core sediments are given below.

Surface Sediments: The sediments of Vypin register highest amount of sand (43.17%) and clay (18.77%) along landward profile (LP) while the intermediate profile (IP) accounts for the highest content of silt (44.85%, Table 6). Size spectral analyses of coarser fractions of this environment unveil overbearing of medium and fine sand against the other entities of sand grade. The facies model worked for this ecosystems (Fig. 9B) evinces three textural types: sandy silt (sZ), sandy mud (sM) and silty sand (zS). Of these, the former two together comprise over 75% of the total samples. The sandy mud textural class dominates in the north western part of the Vypin area whereas sandy silt dominates from the central zones towards southern part - indicating comparatively stronger tidal activities towards the southern tip of this mangrove patch. Size spectral analysis of coarse fractions reveals that >65% of the sand fraction of this environment belong to the medium to fine grained size class. The southern most sector is marked by the appearance of silty sand textural facies. The overbearing of mud dominated textural facies at Vypin region could be due to the prevalence of a low energy hydrodynamic regime which in turn catalyzed by the luxurient mangrove vegetation along the narrow extension of the estuary. Contrary to the Vypin mangroves, the surficial sediments of the Malippuram region is composed solely of sand dominant (mS) textural facies leaving no room for any other textural types. The sand, silt and clay fractions are almost uniformly distributed along the three profiles (LP, IP and SWP) studied. Size spectral analysis of sand fraction reveals that the grains fall mainly in the coarse to fine sand grade. Occurrence of full spectrum of sand dominant textural units floored in the mangrove substratum of Malippuram region reflects the intensity of tidal activities to which the sediments are subjected. The ebbing winnows the finer particles like silt and clay back to the Arabian Sea leaving sand particles *in situ*. Further, the lack of dense mangrove vegetation in this region aggravates the removal of finer particulate matters from the sediment population.

Like the Malippuram mangroves, the sediments at Vallarpadam also exhibit overbearing of sand dominated textural classes. The landward profile accounts for the highest content of sand (89.27%), whereas the intermediate profile exhibits higher silt (23.95%) and clay (7.24%) values. Size spectral analysis shows that over 80% of the grains in the sand population fall in the medium to very fine category. The sediments of Vallarpadam mangroves show three main textural types viz - silty sand (zS), muddy sand (mS), and sandy mud (sM). Among these, silty sand and muddy sand together comprise nearly 85% of the total samples analysed. Spatial distribution of sediments reveal mixed assemblages of various textural associates (zS, mS and sM) are scattered along the west, central and north eastern segments of the study area.

Core sediments: The various textural types recorded in the core CC_1 of Vypin is depicted in Fig. 10. The core is 60cm in length and composed of only two textural classes, the sandy mud (sM) and sandy silt (sZ). Thirty centimeter thick sandy mud layer is found underlined by sandy silt of same thickness. The sand, silt and clay contents of the core averages about 26.29%, 47.39% and 26.31% in sandy mud layer, and 33.57%, 50.74% and 15.69% in the sandy silt layer. Coarse to fine sands cover ~80% of the sand population. The core CC_2 is sand dominant and is texturally not so complicated in its sedimentary record, except a 10 cm thick sandy silt (sZ) intervened at about 50cm depth of the muddy sand (mS) sediment column. The sand, silt and clay contents of the core CC_2 varies between 25.74% and 92.92% (av: 75.72%), 5.99% and 50.91% (av: 15.91%) and 1.09% and 23.35% (av; 8.36%), respectively. Size analysis of sand and silt fractions of this core reveals that 90% of sands belongs to coarse - fine sand grade and nearly 70% of the silt falls in the coarse - fine silt class. The average sand content of the core CC_2 shows more than 2 fold enrichment to that of CC_1. Comparison of silt and clay contents of the two cores CC_1 and CC_2 unveils that the latter has 3 fold enrichment of silt and 2 fold enrichment of clay compared to the former(CC_1)

The cores CC_3 and CC_4 of Vallarpadam exhibit different textural classes along vertical profiles. The 70cm core CC_3 is composed of sand and silty sand. But the sand layer is found intervened at 10 cm and 60 cm from the surface by silty sands. The sand, silt and clay contents averages about 95.38%, 2.63% and

1.98% in sand layer and 90.42%, 8.02% and 1.55% in silty sand layer. The overall average of sand, silt and clay fractions of the core CC_3 is 93.25%, 4.94% and 1.79%, respectively. Size fractionation studies display that over 90% of sand belongs to coarse - fine class, whereas about 70% of silt falls in the coarse to silt class of Wentworth scale. The core CC_4 is sand dominant and pocesses the highest degree of diversity in textural assemblages (Fig. 10). This 1 m core is composed mainly of muddy sand (50cm), silty sand (20cm), clayey sand (20cm) and silty sand (10cm) in the order mentioned from surface to the bottom. Of these, the clayey sand layer is found to be intervened within the silty sand layer at a distance of 80cm from below the surface. The muddy sand layer forms the thickest lithounit extending down to a depth of 50cm from the surface. The overall averages of sand, silt and clay contents of this core are 87.79%, 7.83% and 4.36%, respectively. Species wise estimation indicates that the sand, silt and clay content averages 90.97%, 5.07% and 3.99% in muddy sand, 81%, 15.21% and 2.50% in silty sand and 89.02%, 3.69% and 2.76% in clayey sand layers, respectively. Size analysis of sand reveals, more than 85% of this size grade falls in the medium to very fine sand class.

3.3.1.3 Kannur mangroves

Surface Sediments: Compared to Veli and Kochi mangroves (except the Vypin mangrove patch of Kochi), the surface sediments of Kannur mangroves register substantially high content of mud. The content of sand remains almost constant in all the three profiles studied (Table 6). Size spectral analysis of sand fraction shows that the grains fall in the coarse to fine grade of Wentworth size scale. Three main types of textural facies are encountered in this mangrove area (Fig. 9c). They are sandy mud (sM), muddy sand (mS) and silty sand (zS). Among these, sM and mS facies together comprise >80% of the total samples analysed. The spatial distribution of sediments reveals that sandy mud (sM) dominates in the northern part of the study area whereas muddy sand and silty sand predominates in the southern part located closer to the tidal inlet. The thick mangrove vegetative cover and the decreased tidal effect in the northern part of the study area are some of the factors favouring siltation and subsequent accumulation of muddy sediments. The southern part accommodates sand dominant textural facies like muddy sand (68%) and silty sand (32%), which distinctly indicates the prevalence of a comparatively high energy hydrodynamic regime prevailing in this zone. Tidal water reaches this region mainly through two inlets. The flooding and ebbing of tidal waters accelerate wash off of finer particulates, particularly the silts and clays, leaving the coarser sands *in situ*. Further, the less dense mangrove vegetation also promotes the pace of the above-said winnowing process. These are some of the major reasons which attribute the sand dominant sediment characteristics in the southern sector contrary to the mud dominent northern counterparts.

Core sediments: Three cores (KC_1, KC_2 and KC_3) were analysed for finding the vertical variations in the sedimentary record of the Kannur mangroves. The core KC_1 exhibits a complex association of textural attributes vertical (Table 7, Fig. 10). Sandy mud (sM) is the major textural facies of this core; however, the core is intervened at 40cm and 70cm by muddy sand (10cm thick) and sandy silt (10cm thick) layers. The sand, silt and clay contents of KC_1 varies between 33.76% and 51.7% (av; 37.99%), 28.13% and 50.48% (av; 38.37%) and 12.75% and 30.24% (av: 23.52%), respectively. Size analysis of sands and silts reveal that the coarse and medium sands amounting nearly 40% of the total sands while the silts are generally in very coarse to fine grade.

Table - 7

Granulometric details of the core sediments of Veli, Kochi and Kannur mangroves.

(Values are given in percentages)

Sub sample intervals in cm.	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Mud (silt+clay)	Sand (total)	Textural type (Folk et al,1970)
Veli mangroves										
Core VC1										
0-10	0.63	10.67	28.68	21.24	2.93	14.99	20.85	35.84	64.16	Muddy sand
10-20	0.51	12.61	29.99	21.77	2.71	12.72	19.70	32.42	67.5	Muddy sand
20-30	3.97	12.74	31.08	16.66	1.90	16.66	16.97	33.63	66.3	Muddy sand
30-40	10.92	17.03	30.80	22.38	21.72	4.61	4.06	8.67	91.3	Muddy sand
40-50	5.91	11.76	22.07	15.73	4.62	30.76	9.16	39.9	60.1	Silty sand
50-60	2.73	24.29	41.80	17.37	1.22	8.92	3.65	12.57	87.4	Muddy sand
Core VC2										
0-10	5.19	5.91	23.09	12.96	12.54	22.28	18.00	40.28	59.72	Muddy sand
10-20	6.01	3.06	24.81	34.18	4.70	8.42	18.82	27.24	72.8	Clayey Sand
20-30	0.079	0.53	22.49	45.65	4.61	8.78	17.85	26.63	73.37	Clayey sand
30-40	0.80	1.30	4.03	7.70	3.06	30.78	52.31	83.09	16.91	Sandy mud
40-50	7.62	29.52	22.30	20.12	4.45	6.41	9.56	15.97	84.08	Muddy sand
50-60	5.79	12.63	26.70	21.32	4.10	14.51	14.94	29.45	70.55	Muddy sand
60-70	1.12	3.88	23.91	31.99	4.58	19.22	15.29	34.51	65.49	Muddy sand
Kochi mangroves										
Core CC1										
0-10	0.56	4.20	3.12	15.08	1.25	48.95	26.84	75.79	24.21	Sandy mud
10-20	0.36	3.09	2.48	10.40	0.47	53.55	29.63	83.18	16.82	Sandy mud
20-30	6.49	10.82	1.44	16.85	2.23	39.67	22.47	62.14	37.86	Sandy mud
30-40	4.22	9.5	3.12	13.67	2.19	54.46	12.84	67.29	32.71	Sandy silt
40-50	0.86	8.02	8.31	11.04	4.71	50.72	16.30	67.02	32.98	Sandy silt
50-60	1.08	6.27	10.73	11.91	5.00	47.06	17.93	64.98	35.02	Sandy silt

Sub sample intervals in cm.	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Mud (silt+clay)	Sand (total)	Textural type (Folk et al,1970)
Core CC2										
0-10	6.71	17.36	34.53	29.62	4.67	5.99	1.09	7.08	92.92	Silty sand
10-20	8.97	19.32	27.14	25.12	7.78	7.97	3.67	11.64	88.36	Muddy sand
20-30	8.11	14.16	33.42	28.09	1.98	9.62	4.60	14.22	85.78	Muddy sand
30-40	3.34	18.48	34.31	26.53	2.04	7.83	7.48	15.31	84.69	Muddy sand
40-50	2.16	16.21	25.75	26.15	6.58	13.17	9.98	23.15	76.85	Muddy sand
50-60	1.07	6.27	9.41	8.13	0.84	50.91	23.35	74.26	25.74	Sandy silt
Core CC3										
0-10	0.47	0.74	31.15	45.38	5.18	9.08	1.98	11.06	88.94	Silty sand
10-20	0.19	6.13	31.29	51.82	4.97	4.11	1.47	5.58	94.42	Sand
20-30	2.68	15.05	34.12	28.49	14.91	1.97	2.76	4.72	95.28	Sand
30-40	0.54	11.94	37.31	44.06	3.17	1.34	1.65	2.99	97.01	Sand
40-50	5.00	9.97	36.33	40.34	3.17	3.11	2.06	5.17	94.83	Sand
50-60	0.98	21.39	38.12	30.08	3.58	5.21	0.62	5.83	94.17	Silty sand
60-70	0.44	9.51	33.77	43.22	1.18	9.78	2.05	11.85	88.15	Silty sand
Core CC4										
0-10	0.74	22.03	9.17	34.6	21.23	7.31	4.89	12.20	87.80	Muddy sand
10-20	5.32	7.15	18.71	46.27	14.67	3.85	4.00	7.85	92.15	Muddy sand
20-30	0.078	7.73	19.41	43.45	20.45	4.87	3.90	8.77	91.23	Muddy sand
30-40	3.4	13.49	16.29	41.57	17.57	4.86	2.80	7.66	92.34	Muddy sand
40-50	1.27	3.79	21.89	44.67	19.68	4.5	4.17	8.67	91.33	Muddy sand
50-60	1.12	8.13	14.94	32.00	17.83	20.56	5.40	25.96	74.04	Silty sand
60-70	2.94	3.73	15.84	41.01	15.63	17.13	3.70	20.83	79.17	Silty sand
70-80	0.82	8.44	18.42	46.07	14.48	4.07	7.67	11.75	88.25	Clayey sand
80-90	0.76	10.20	25.37	43.99	11.51	3.31	4.85	48.16	91.84	Clayey sand
90-100	1.26	3.44	20.59	49.23	15.24	7.93	2.27	10.21	89.79	Silty sand

Sub sample intervals in cm.	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Mud (silt+clay)	Sand (total)	Textural type (Folk et al, 1970)
Kannur mangroves										
Core KC1										
0-10	0.34	10.14	14.38	4.94	1.52	38.45	30.24	68.66	31.34	Sandy mud
10-20	0.46	16.57	9.75	6.02	1.19	37.99	27.99	65.99	34.01	Sandy mud
20-30	5.10	17.88	15.34	5.17	2.21	29.46	24.83	54.31	45.61	Sandy mud
30-40	4.65	12.67	16.01	12.03	6.31	28.13	20.17	48.30	51.7	Muddy sand
40-50	6.23	10.99	17.53	0.515	1.08	35.66	27.10	63.65	36.35	Sandy mud
50-60	0.14	10.54	20.92	1.33	0.97	43.17	22.87	66.04	33.76	Sandy mud
60-70	0.62	16.75	15.24	2.15	20.01	50.40	12.75	63.23	36.78	Sandy silt
70-80	0.051	8.55	11.36	13.00	2.01	42.8	22.22	65.02	34.98	Sandy mud
Core CC2										
0-10	0.89	1.91	27.81	20.53	9.56	24.34	14.94	39.28	60.72	Muddy sand
10-20	3.68	13.02	31.75	19.15	6.08	17.78	8.55	26.32	73.68	Muddy sand
20-30	6.40	14.22	25.6	19.4	6.29	11.07	17.02	28.09	71.91	Muddy sand
30-40	1.13	13.68	19.24	11.6	2.72	30.66	20.97	51.63	48.37	Sandy mud
40-50	4.83	15.19	24.6	24.3	7.7	14.55	8.80	23.35	76.65	Muddy sand
50-60	5.65	20.20	26.11	16.95	0.85	19.48	10.77	30.25	69.75	Muddy sand
60-70	3.34	13.55	27.51	18.06	6.00	16.56	14.97	31.52	68.48	Muddy sand
70-80	7.00	17.33	27.2	22.8	2.73	15.66	7.28	22.94	77.06	Silty sand
Core KC3										
0-10	9.01	5.29	10.58	2.85	2.35	43.97	25.95	69.92	30.08	Sandy mud
10-20	4.68	6.04	12.75	1.72	1.31	43.38	30.12	73.49	26.51	Sandy mud
20-30	3.41	5.92	9.10	6.49	1.29	43.28	30.51	73.79	26.21	Sandy mud
30-40	0.068	3.53	15.15	10.92	0.32	38.26	31.75	70.01	29.99	Sandy mud
40-50	0.26	5.25	15.95	5.8	4.03	40.27	28.42	68.70	31.30	Sandy mud
50-60	0.97	9.42	5.32	5.37	1.67	40.21	37.03	77.23	22.77	Sandy mud

The core KC_2 is sand dominant and is sedimentologically not so complicated compared to KC_1. However, an intercalation of 10cm thick sandy mud is recorded at about 30cm below the surface (Fig.10). The average sand, silt and clay contents are 63.33% (48.37% to 79.97%), 18.76% (11.07% to 30.66%) and 12.91% (7.28% to 20.97%), respectively. The content of sand in this core shows 2 fold enrichment (on an average level) compared to that in KC_1, indicating a high energy hydrodynamic set up existing at the core site KC_2 for the last several years. The sands of this core fall generally in the coarse to fine class of Wentworth.

The core KC_3 does not show any variation in its textural facies pattern. It is composed entirely of sandy mud with average sand content of 27.81% (22.77% to 31.3%). The silt and clay content averages about 41.56% (38.26% to 43.97%) and 30.63% (25.95% to 37.03%), respectively. The homogenity in the textural facies of the core as well as the dominance of mud over other size grades indicate the prevalence of a regular (uniform) hydroperiod with rapid siltation in the core site.

3.3.2. **Statistical parameters of Mangrove sediments**

The various statistical parameters such as phimean, standard deviation (sediment sorting), skewness and kurtosis computed for the surface and core sediments of the three mangrove localities studied in this investigation (Viz. Veli, Kochi and Kannur) are furnished in Tables 8 and 9. Figs. 11-13 present, the variations of these parameters along the cores recovered from the above said localities.

3.3.2.1. Veli Mangroves:

Surface sediments: The sediment substratum of this mangrove environment

Table - 8

Textural parameters for the surface sediments of Veli, Kochi and Kannur mangroves.

Sample No.		Mean (ϕ)	Standard Deviation (ϕ)	Skewness	Kurtosis
Veli mangroves					
1.	a	4.33	2.74	0.35	0.68
	b	3.60	2.72	0.52	0.93
	c	3.70	2.43	0.02	1.06
2	a	4.50	2.89	0.34	0.68
	b	3.43	2.79	0.62	0.87
	c	3.13	2.56	0.55	1.06
3	a	5.20	3.13	0.11	0.51
	b	4.50	2.94	0.28	0.66
	c	3.10	1.38	0.53	0.97
4	a	4.23	3.11	0.45	0.64
	b	2.43	2.17	0.37	1.59
5	a	4.57	3.19	0.27	0.75
	c	2.43	2.07	0.59	1.95
6	a	3.57	2.93	0.62	1.12
	b	4.10	3.14	0.60	0.53
	c	2.46	2.20	0.62	2.27
7	a	4.83	3.17	-0.06	0.61
	b	4.77	3.07	0.10	0.57
	c	1.93	1.31	0.32	1.84
8	a	2.17	1.82	0.56	1.93
	b	2.23	1.62	0.49	1.75
	c	2.60	1.85	0.52	1.70
9	a	3.97	2.12	-0.05	0.80
	b	2.06	1.29	0.60	2.29
	c	2.77	2.04	0.72	2.11
10	a	4.57	1.90	0.27	1.53
	b	2.10	2.51	0.61	2.00
11	a	1.20	0.88	0.22	1.02
	b	3.30	2.69	0.51	0.86
	c	3.00	1.94	-0.28	1.72
12.	a	4.23	2.49	0.09	0.72
	b	1.50	1.87	0.58	1.67

Sample No.		Mean (ϕ)	Standard Deviation (ϕ)	Skewness	Kurtosis
13	a	6.07	2.59	0.07	1.02
	c	3.10	2.04	0.38	0.90
14	a	5.10	3.04	-0.08	0.66
	c	3.07	2.84	0.10	0.70
15	a	2.67	1.96	0.45	1.33
	b	1.97	1.52	031	2.29
	c	2.57	2.26	0.50	1.72
Kochi mangroves					
16	a	2.53	2.11	0.44	1.02
	b	3.46	1.82	-0.04	1.04
	c	4.41	2.44	0.11	0.99
17	a	4.70	2.69	0.03	0.86
	b	4.86	2.41	0.67	1.09
	c	4.30	2.67	0.02	0.77
18	a	5.03	2.67	-0.13	0.69
	b	4.61	2.95	-0.09	0.68
	c	4.43	2.93	0.07	0.07
19	a	2.76	1.34	0.27	1.49
	b	2.80	2.29	0.16	1.37
	c	3.13	1.84	0.29	1.48
20	a	2.16	2.10	-0.03	1.51
	b	2.82	1.91	0.37	1.92
	c	2.73	2.16	0.36	2.98
21	a	3.13	2.51	0.37	1.12
	b	4.26	3.05	0.08	0.74
	c	2.96	2.51	0.27	0.27
22	a	2.40	0.91	0.12	2.34
	b	4.93	2.63	0.09	1.73
	c	2.56	1.28	0.15	2.04
23	a	2.53	2.72	0.04	1.31
	b	3.20	2.36	0.47	1.61
	c	3.30	2.99	0.46	0.75
24	a	2.76	2.54	0.45	1.72
	b	3.37	2.72	0.29	1.20
	c	2.71	2.00	0.35	1.99

Sample No.		Mean (ϕ)	Standard Deviation (ϕ)	Skewness	Kurtosis
Kannur mangroves					
25	a	1.83	2.11	0.46	1.40
	b	2.87	2.14	0.32	1.22
	c	2.41	2.44	0.30	1.27
26	a	2.90	2.75	0.35	1.01
	b	3.23	2.64	0.25	0.91
	c	3.46	2.79	0.49	0.51
27	a	5.10	2.85	-0.17	0.74
	b	5.40	2.77	-0.14	1.18
	c	5.30	2.78	-0.13	1.03
28	a	5.56	3.26	-0.14	0.71
	b	5.53	2.78	-0.20	0.81
	c	4.31	2.73	0.15	0.77

a = Landward sample; b = Intermediate sample; c = Shallow water sample

Table - 9

Textural parameters for the core sediments of Veli, Kochi and Kannur mangroves .

Sub Sample intervals in cm.	Mean (ϕ)	Standard Deviation (ϕ)	Skewness	Kurtosis
Veli mangroves				
Core VC1				
0-10	3.72	2.82	0.57	0.71
10-20	3.83	2.98	0.57	1.09
20-30	3.60	2.71	0.56	0.78
30-40	1.56	1.70	0.17	1.94
40-50	3.21	2.71	0.29	0.87
50-60	1.87	1.52	0.43	1.44
Core VC2				
0-10	4.00	2.87	0.30	0.91
10-20	3.57	2.62	0.56	1.18
20-30	3.97	2.59	0.54	1.37
30-40	3.72	2.41	0.06	0.83
40-50	2.01	2.14	0.44	1.45
50-60	3.36	2.92	0.67	1.17
60-70	3.77	2.56	0.49	0.99
Kochi mangroves				
Core CC1				
0-10	5.60	2.96	-0.04	0.89
10-20	6.13	2.52	0.06	0.79
20-30	4.60	3.03	-0.03	0.87
30-40	4.30	2.39	-0.07	1.18
40-50	4.63	2.68	0.00	0.87
50-60	4.60	2.67	0.08	0.86
Core CC2				
0-10	1.83	1.15	0.29	1.09
10-20	1.96	1.78	0.20	1.47
20-30	2.03	1.87	0.25	2.05
30-40	2.23	2.00	0.51	1.84
40-50	3.10	2.53	0.53	1.33
50-60	5.00	2.75	0.00	1.03
Core CC3				
0-10	2.26	1.08	0.19	1.56
10-20	2.16	0.83	0.21	2.54
20-30	2.10	1.25	0.22	1.18
30-40	1.93	0.81	-0.04	1.00
40-50	1.93	1.11	-0.01	1.50
50-60	1.77	1.01	0.11	1.22
60-70	2.21	1.13	0.23	1.36

Sub Sample intervals in cm.	Mean (ϕ)	Standard Deviation (ϕ)	Skewness	Kurtosis
Core CC4				
0-10	2.40	1.71	0.46	1.33
10-20	2.41	1.46	0.07	2.62
20-30	2.50	1.37	0.22	1.77
30-40	2.31	1.53	0.09	1.75
40-50	2.52	1.45	0.27	2.22
50-60	3.76	1.63	0.51	2.00
60-70	2.90	1.52	0.23	1.48
70-80	3.03	2.01	0.25	1.94
80-90	2.30	1.41	0.31	1.83
90-100	2.46	1.31	0.23	2.31
Kannur mangroves				
Core KC1				
0-10	5.03	2.85	-0.30	0.65
10-20	4.83	3.06	-0.18	0.66
20-30	4.26	3.10	-0.04	0.65
30-40	3.93	2.90	0.29	0.60
40-50	4.50	3.09	-0.14	0.73
50-60	4.90	2.82	-0.22	0.65
60-70	4.16	2.67	-0.15	0.67
70-80	5.00	2.73	-0.13	0.72
Core KC2				
0-10	4.23	2.36	0.48	0.68
10-20	2.73	2.22	0.49	1.15
20-30	3.51	2.91	0.58	1.13
30-40	4.40	3.03	0.40	0.72
40-50	3.06	2.63	0.47	1.37
50-60	2.87	2.56	0.49	0.53
60-70	3.47	2.94	0.54	1.18
70-80	2.30	2.39	0.40	1.50
Core KC3				
0-10	4.66	3.02	-0.19	0.79
10-20	5.16	3.08	-0.17	0.72
20-30	5.13	2.82	-0.17	0.93
30-40	4.97	2.74	0.05	0.65
40-50	5.40	3.05	-0.05	0.67
50-60	5.60	3.08	-0.17	0.95

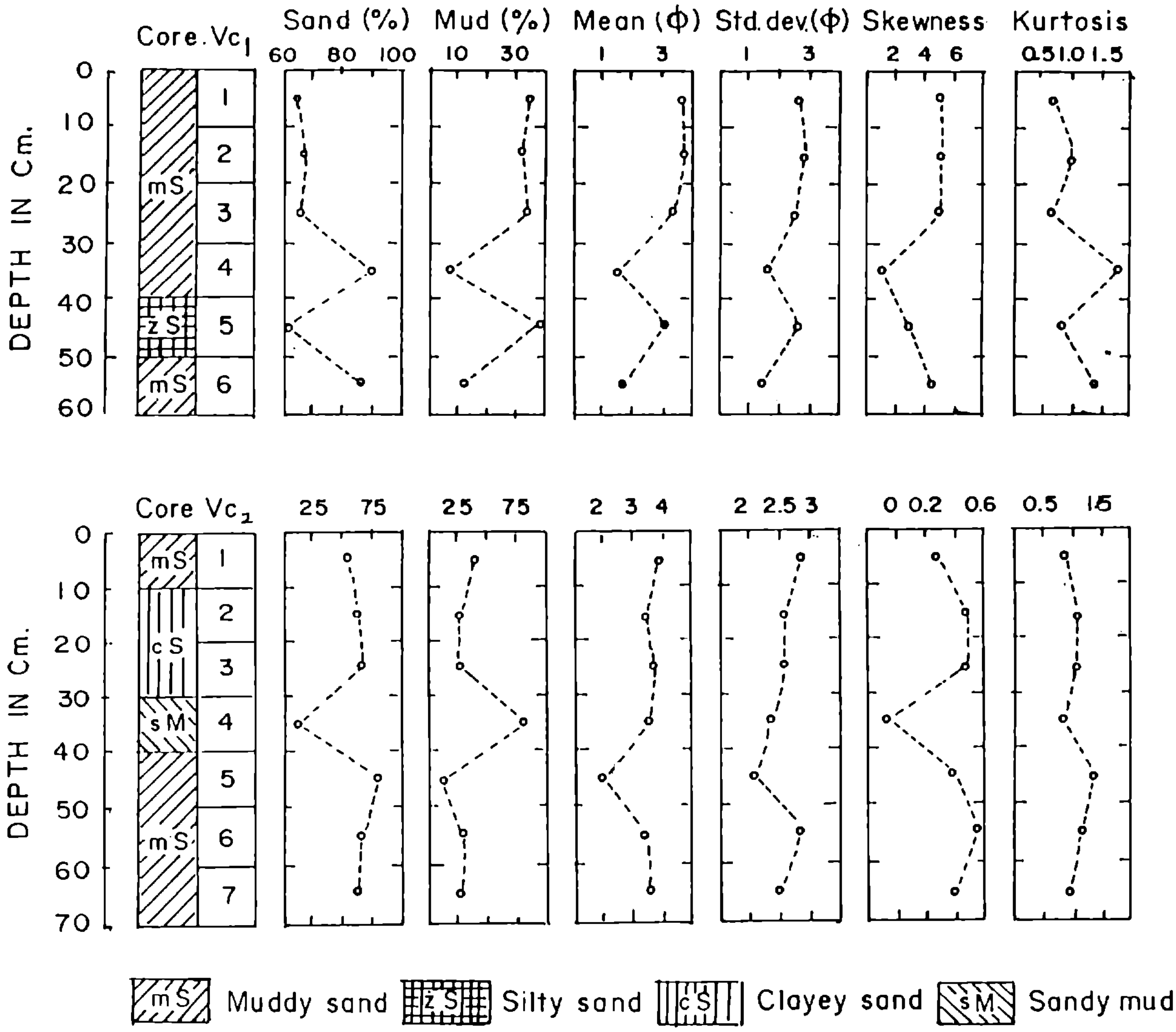


Fig. 11. VARIATION OF STATISTICAL PARAMETERS ALONG THE PROFILE OF SEDIMENT CORES OF VELI MANGROVES.

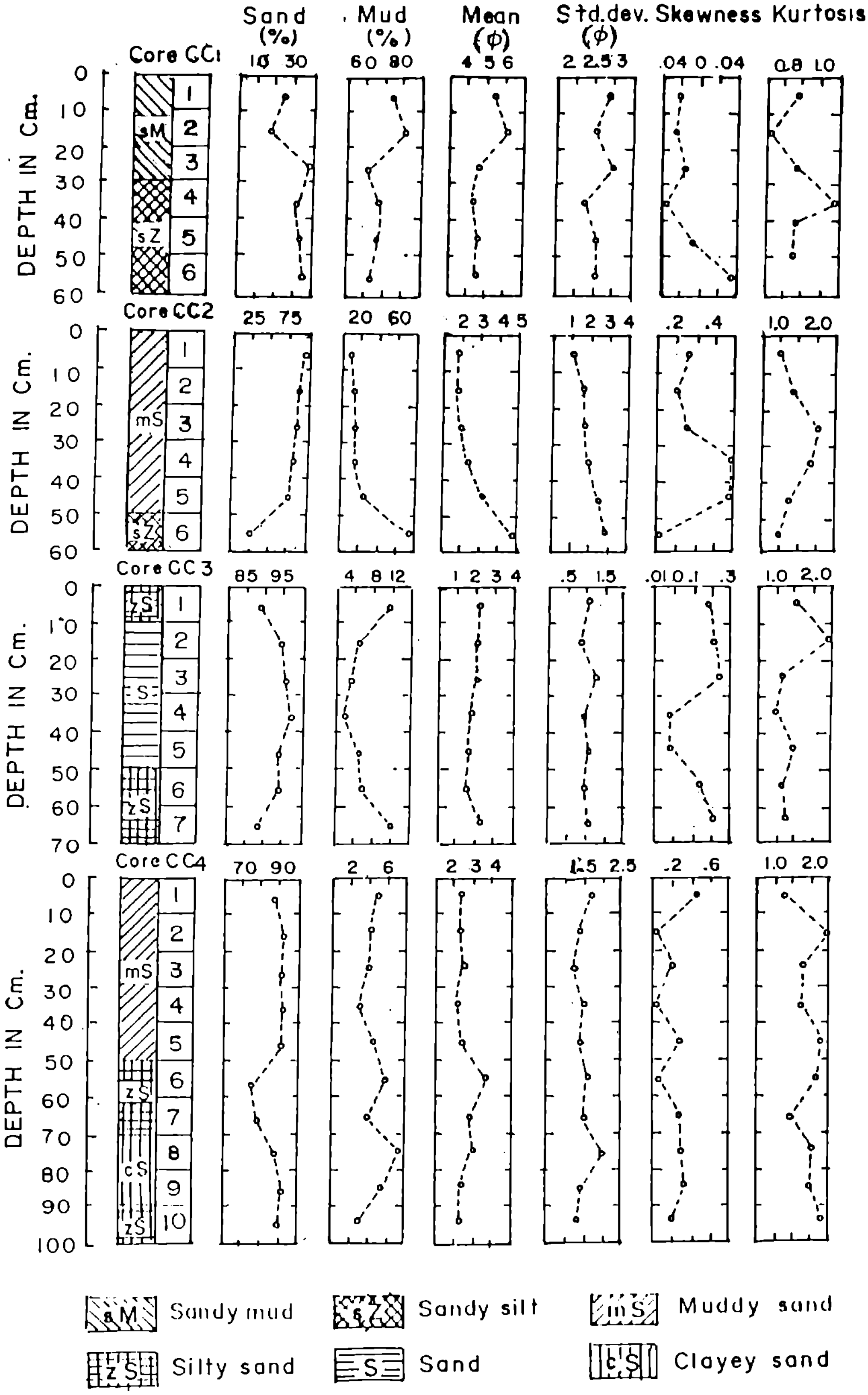


Fig. 12. VARIATION OF STATISTICAL PARAMETERS, SAND AND MUD ALONG THE PROFILE OF SEDIMENT CORES OF KOCHI MANGROVES

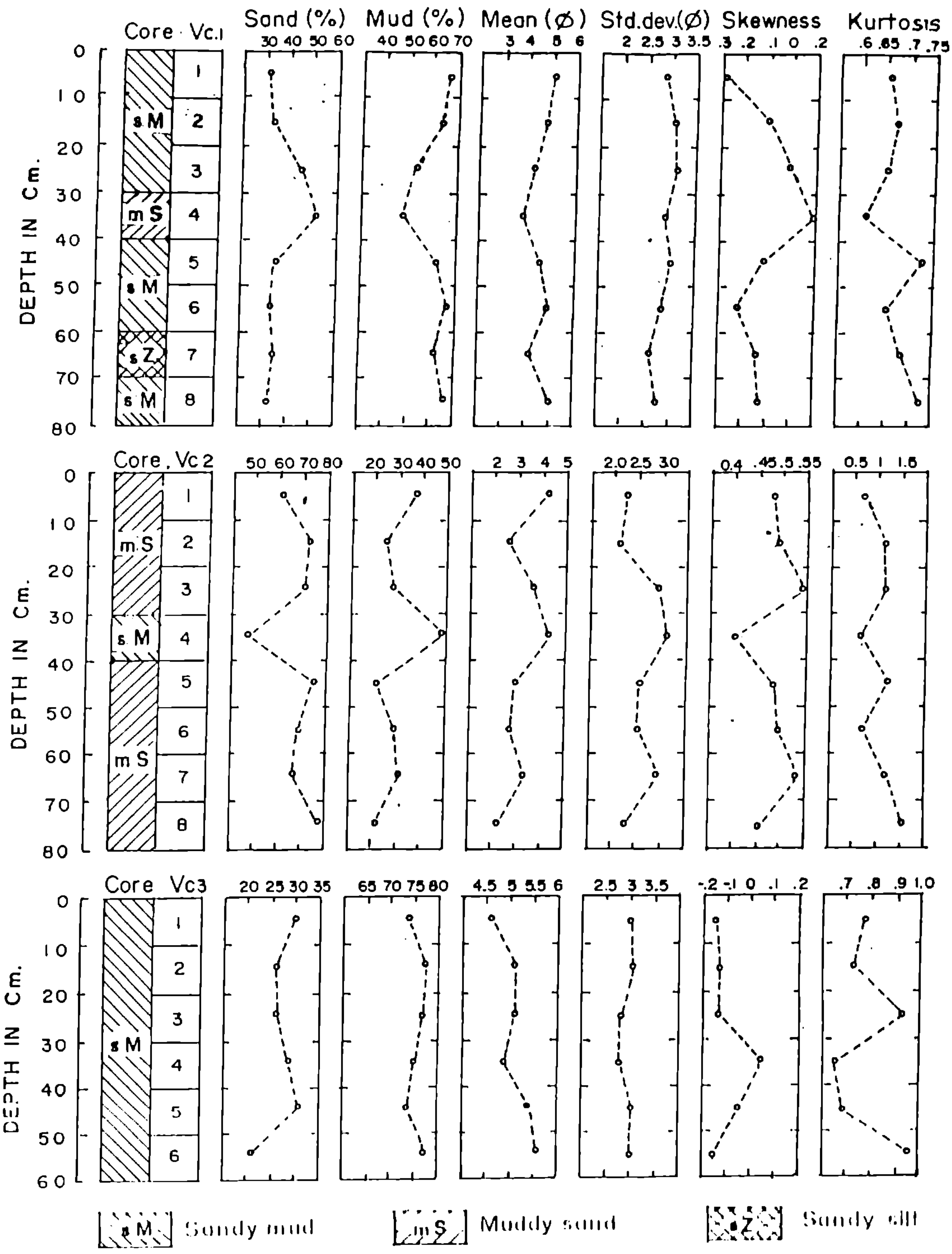


Fig. 13. VARIATION OF STATISTICAL PARAMETERS, SAND, MUD ALONG THE PROFILE OF SEDIMENT CORES OF KANNUR MANGROVES

records phi mean values between 1.1 to 5.6 (Medium sand to medium silt). It is computed that, about 70% of surface area of the landward profile of this ecosystem accomodates particles of phimean values between 3 and 5, whereas the intermediate and shallow water profiles are covered mainly by particles with mean values between 2 and 3. This observed gradational decrease in the phimean towards the shallow water profile of the Veli mangroves also reiterates the selective removal processes of finer particles as explained earlier. By taking account of the verbal limits of Folk and Ward (1957), the sediments of Veli mangroves are, ingeneral, fall in the moderatley sorted to very poorly sorted category. The standard deviation values varies between 0.88ϕ and 3.19ϕ , with an average of 2.34ϕ . The landward profile of this environment accounts for nearly 75% of very poorly sorted sediments and the remaining exhibits moderately to poorly sorted particle dispersal pattern. The intermediate profile and shallow water profile exhibit marginal improvement in its sorting coefficients when one evaluates the statistics of the samples analysed in each category. The intermediate and shallow water profiles altogether constitute only 65% of very poorly sorted sediments, whereas 75% of the samples are very poorly sorted in the landward profile. This also support the aforesaid physical mechanisms operating in the mangrove forested areas of Veli region. The skewness of sands collected from the landward, intermediate and shallow water profiles of Veli mangroves varies from 0.08 to 0.72 (very fine to near symmetrically skewed) with average of 0.35. The landward profile samples are, ingeneral, fine skewed (av; 0.24) while the intermediate and shallow water profiles are very finely skewed (av; 0.42). Sediments of Veli mangroves exhibit kurtosis values between 0.51 and 2.29 (very platy kurtic to very leptokurtic). On an average, the landward profile samples are mesokurtic (av: 0.93) whereby the intermediate and shallow water profile samples are leptokurtic (intermediate profile; 1.33, shallow water profile 1.5). While considering the three profiles together, it is obvious that 57% of sediment samples exhibit very platy to mesokurtic grain size dispersal pattern. The remaining samples fall in the very lepto (35%) and lepto kurtic categories.

Core sediments: The different statistical attributes of the core sediments of Veli mangroves show average phimean value of 2.96 for VC_1 and 3.48 for VC_2. The former core depicts variation of phi mean values from 2 to 4 (medium to very fine sand) while the latter core ranges from 3 to 4 (fine to very fine sand). The sub-samples of VC_1 are poorly to very poorly sorted in nature, whereas that of VC_2 are entirely of poorly sorted in nature. The skewness values of VC_1 varies between 0.17 and 0.43 (fine skewed to very fine skewed) and VC_2 between -0.06 and 0.77 (nearly symmetrical to very fine skewed). An overall evaluation of the skewness of the two cores reveals that very fine skewed sediments account for a considerable portion (VC_1: 66.6%; VC_2: 88.77%) of the sediment substratum. The kurtosis values of the core VC_1 varies from 0.71 to 1.94 (platy kurtic to very leptokurtic) and that of $VC_2$from 0.83 to 1.45 (mesokurtic to leptokurtic). Approximately 50% sediments of core VC_1 is platy kurtic and the rest of fractions are compounded by meso, lepto and very lepto kurtic sediments. However, in core VC_2 the lionshare (> 86%) is of lepto and mesokurtic and the remaining falls in the platykurtic category.

3.3.2.2. Kochi Mangroves

Surface sediments: Phi mean value of the mangrove sediments of Kochi varies between 2.16 and 5.03 (fine sand to medium silt). Of the three mangrove patches examined in Kochi (Viz. Vypin, Malippuram, and Vallarpadam) area, the sediment population of Vallarpadam evinces comparatively coarser size grade (2.53ϕ to 3.37ϕ), than Malippuram (2.16ϕ to 4.93ϕ) and Vypin (2.53ϕ to 5.03ϕ). The surface sediment population of Kochi mangroves shows wide range of standard deviation values from 0.91ϕ to 3.05ϕ ie, moderately sorted to very poorly sorted. Among which the very poorly sorted ones predominate over the other samples (88.87% at Vypin, 58.33% at Vallarpadam and 100% at Malippuram). The Vallarpadam and Vypin area together share approximately 45% of poorly sorted sediments and the former station contains very little amount of moderately sorted sediments. The ranges and averages of standard deviations at Vypin, Vallarpadam and Malippuram mangroves are 1.82ϕ to 2.95ϕ (av; 2.52ϕ), 0.91ϕ to 3.05ϕ (av: 2.04ϕ) and 2ϕ to 2.99ϕ (av: 2.56ϕ), respectively. Skewness values of sediments of Kochi mangroves exhibit variation from 0.026 to 0.67 (nearly symmetrical to very fine skewed) with average value of 0.21. More than 85% of the substratum of this mangrove area is occupied by fine skewed sediments indicating that the selective removal of finer particulates is progressing in most of the regions (eg. Malippuram and Vallarpadam) and the remaining area is floored by coarse skewed sediments indicating intense silt deposits (eg. Vypin). It is observed that, on an average scale the samples from Vypin and Vallarpadam regions cover fine skewed sediments, whereby Malippuram region is marked by the dominance of very fine skewed sediments. The skewness variation for the individual mangrove patches are -0.047 to 0.67 (av; 0.12) for Vypin -0.032 to 0.37 (av; 0.20) for Vallarpadam and 0.042 to 0.47 (av; 0.34) for Malippuram areas. Kurtosis values range from 0.68 to 2.98 (Platy kurtic to very lepto kurtic). The sand fraction of Vypin reveals that 45% of the sediments are mesokurtic in nature and the remaining are platy kurtic. However, at Vallarpadam, the sediments are characterised by very leptokurtic (50%), leptokurtic (40%) and platy kurtic (10%) categories. The representative shares of very leptokurtic, lepto kurtic and mesokurtic sediments along the Malippuram are 50%, 33% and 17%, respectively. Kurtosis values for mangroves of Kochi region are 0.68 to 1.09 for Vypin. 0.74 to 2.98 for Vallarpadam and 0.75 to 1.99 for Malippuram.

Core Sediments: Analysis of phi mean reveals that, the core CC_1 (Vypin) exhibits variation from 4.3 to 6.13 (coarse to fine silt), whereas in core CC_2 (Malippuram) the phimean varies between 1.83 and 5 (medium sand to coarse silt). The mangrove substratum of Vallarpadam region (CC_3 and CC_4) shows mean size variation from 1.77ϕ to 3.76ϕ. The vertical variation of textural attributes of core CC_1 and CC_2 divulge that, in the former, coarse and medium silt together constitute more than 82% of the total samples, and in the latter nearly 66% of the coarser clastics belong to medium to fine sand category. Further, in CC_3 and CC_4, 88% of the sediments are fine (70.58%) and medium (17.04%) sand grade and remaining are composed of very fine sand.

The average standard deviation values of Vypin, Vallarpadam and Malippuram mangroves are 2.52ϕ (2.39ϕ to 3.03ϕ), 1.39ϕ (0.81ϕ to 2.63ϕ) and 2.01ϕ (1.15ϕ to 2.98ϕ), respectively. The Vypin region demonstrates cent percent very poorly sorted sediments and its counterparts in Vallarpadam and Malippuram exhibit comparatively low percentage values (Vallarpadam 11.76%; Malippuram 50%). In Vallarpadam region over 75% of samples are poorly sorted while that of Malippuram is only about 50%. Skewness values for the cores recovered from Vypin, Malippuram and Vallarpadam are 0 to 0.089, 0.2 to 0.51 and 0.04 to 0.76. Majority of the sub-samples of core CC_1 maintains nearly symmetrical skewness. More than 82% of Vallarpadam mangrove sub samples are near symmetrical and fine skewed in nature. The values of Kurtosis varies from 0.79 to 1.18 (platy Kurtic to leptokurtic) at Vypin, 1.03 to 2.05 (mesokurtic to very lepto kurtic) at Malippuram and 1 to 2.62 (mesokurtic to very leptokurtic) at Vallarpadam.

3.3.2.3 Kannur Mangroves

Surface sediments: The phimean values of the sediments of Kannur, in general, varies between 1.83 and 5.56 (av; 3.79) (medium sand to medium silt). The southern sector of the Kannur mangroves is dominated by an admixture of different size classes of sands exhibiting phimean values between 1 and 4 , whereas its northern counterpart is covered by particles of phimean between 4 and 6 (coarse and medium silts). Regarding the standard deviation, the Kannur mangrove is floored entirely of poorly sorted sediments with standard deviation values between 2.11ϕ and 3.26ϕ (av; 2.67ϕ). But the processes which contributed the poorly sorted particle dispersal pattern in the north and south sectors of the Kannur mangroves are entirely different. In the northern part, intense siltation and lack of post depositional reworking attributed poor sorting, also reflected in the higher phimean values, whereas in the southern part selective removal of particles from the already deposited sediments attributed poor sorting. Similar mechanisms are reported by Thomas et al, (1974) in the lake banks and profundal zones of the lake Ontario. Skewness varies widely from -0.13 to 0.49 from the very coarse to very fine class of Folk and Ward, (1957). Out of the total samples, nearly 40% are coarse skewed and the rest are fine and very fine skewed in nature. The mixture of coarse skewed and fine skewed sediments, according to Daune, (1964), is indicative of faster deposition of sediments. This inturn supports the views deduced from standard deviation values. Kurtosis ranges from 0.51 to 1.40 (very platy to lepto kurtic). The northern sector of Kannur mangroves is dominated by mesokurtic sediments, whereas in the south east sector, the sediment distribution is mainly leptokurtic. Nominal amounts of platy kurtic sediments are marked at the centre of the sampling location. In general this ecosystem accomodates 59% of platy kurtic and meso kurtic sediments and the rest of fractions fall in the leptokurtic category.

Core sediments: The range of phimean in the core KC_1, KC_2 and KC_3 are 3.93 to 5.03 (very fine sand to medium silt), 4.66 to 5.6 (coarse silt to medium silt) and 2.3 to 4.4 (fine sand to coarse silt), respectively. The average and range of standard deviation values are 2.9ϕ (2.67ϕ to 3.1ϕ) for KC_1, 2.63ϕ (2.22ϕ to 3.03ϕ) for KC_2 and 2.97ϕ (2.74ϕ to 3.08ϕ) for KC_3. Like surface sediments, the cores are also composed of very poorly sorted sediments. The range of skewness values for the sub-samples of the three cores are from 0.04 to 0.29 (symmetrically skewed to finely skewed), from -0.05 to 0.05 (near symmetrically skewed) and from 0.4 to 0.58 (very fine skewed), respectively. The average and range of kurtosis values are 0.67 and 0.60 - 0.73 (very lepto kurtic to platy kurtic) for KC_1, 0.79 and 0.65 - 0.95 (very lepto kurtic to mesokurtic) for KC_2 and 1.03 and 0.53 1.5 (very platy kurtic to lepto kurtic) for KC_3.

3.3.3 Bivariate plots

To bring forth the geological significance of the textural parameters, sedimentologists usually depend on the scatter diagrams or cross plots of various statistical prameters. (Folk and Ward, 1957; Sahu, 1964; Friedman, 1967; Abed, 1982; Khan, 1984; Sajan, 1988; Padmalal, 1992 and Sundaresan, 1993). In this investigation also an attempt has been made to unfold the informations concealed within these cross-plots. The cross-plots between various statistical parameters for the surface and core sediments of Veli, Kochi and Kannur mangroves are depicted in Figs 14-16.

The plots of phi mean and standard deviation show positive correlation in all the three mangrove environments. Majority of the samples of these man-

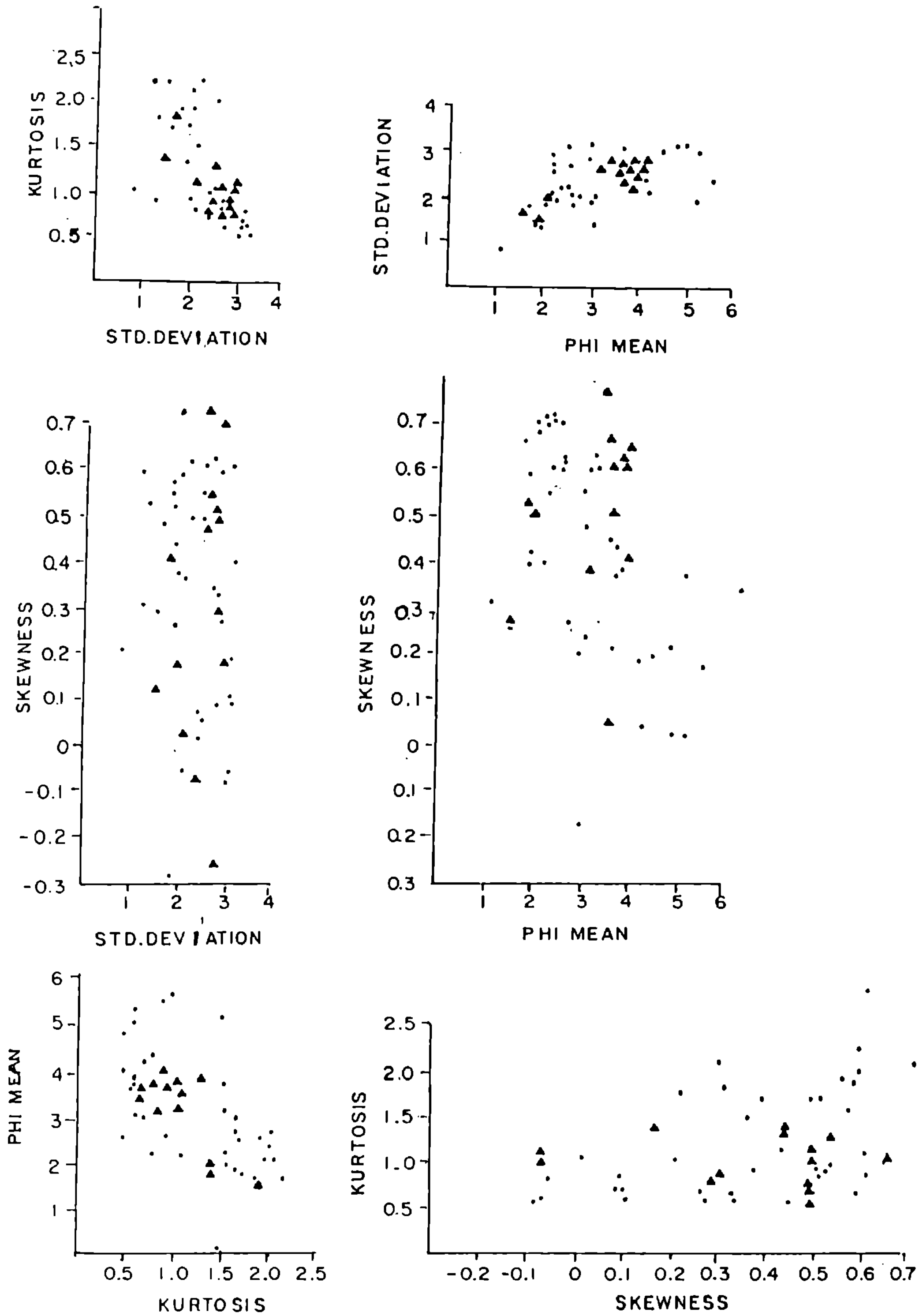


Fig. 14. CROSS PLOTS BETWEEN VARIOUS STATISTICAL PARAMETERS [SURFACE (•) AND CORE (▲)] OF VELI MANGROVES

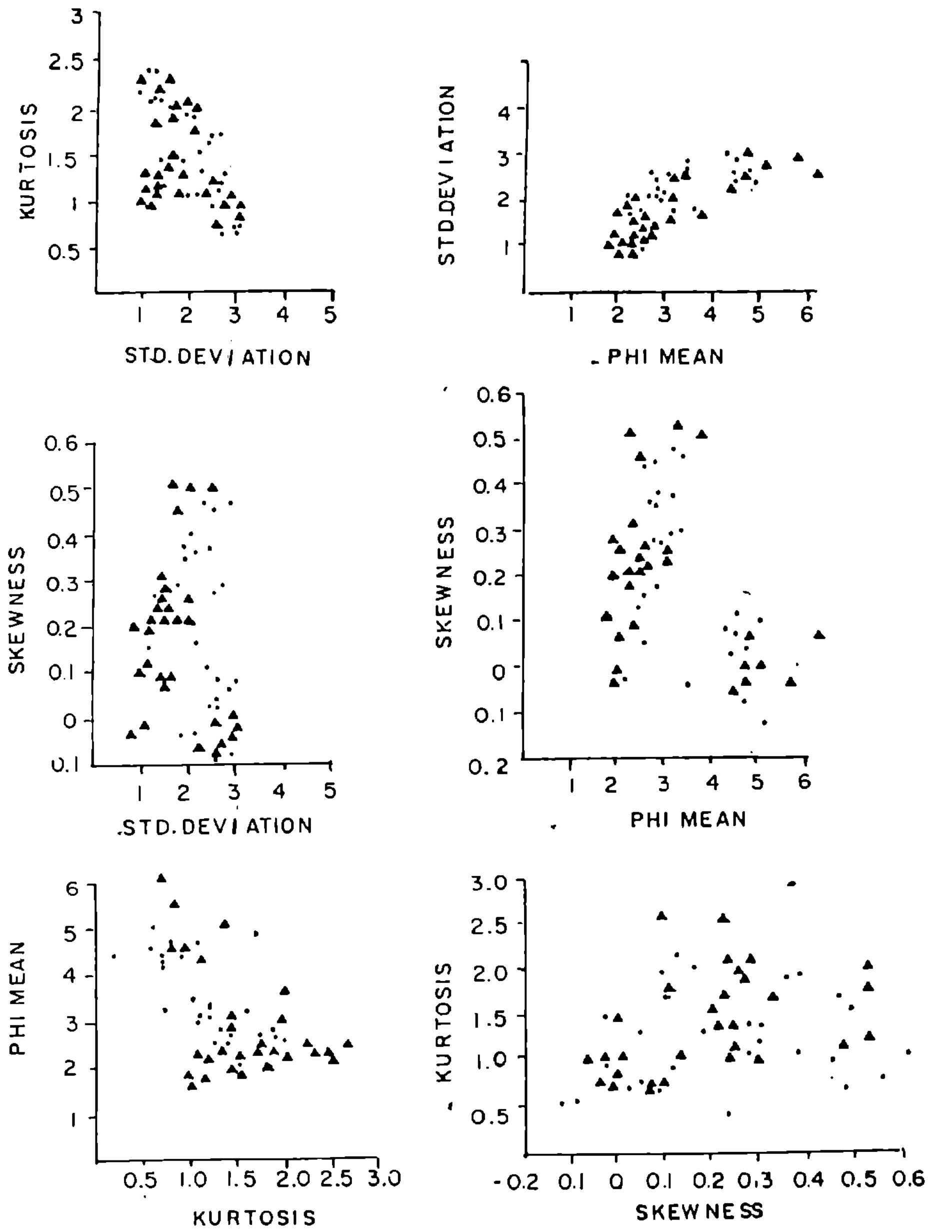


Fig. 15. CROSS PLOTS BETWEEN VARIOUS STATISTICAL PARAMETERS [SURFACE (•) AND CORE (▲)] SEDIMENTS OF KOCHI MANGROVES.

groves fall in fine sand to medium silt category with standard deviation values between 1.2ϕ and 3.2ϕ Figs. 14-16 reveal that, as the phi mean increases (ie., size in mm scale decreases) the sorting capacity of the samples also increases (ie, sediment improve sorting), a feature also reported earlier by many investigators (Folk and Ward, 1957; Friedman, 1967; Seralathan, 1979 and Roy et al, 1993). Thus the mangrove environments are also following the theoretical considerations of sediment sorting although the environment is intervened by highly complicated physico - chemical and biological factors.

The bivariate plots between phimean and skewness are depicted in Fig 15, which shows no clustering due to the drastic differences in the phimean values of Vypin, Malippuram and Vallarappadam mangroves. The mud dominated Vypin mangroves with higher phimean values form an isolate cluster or crossplots whereas the sand dominated Malippuram - Vallarpadam mangroves form separate cross plots of elongate fashion owing to their wide range in skewness values.

The cross plots between phimean and kurtosis of Veli mangroves give very platy kurtic to very lepto kurtic variation with values ranging between 0.5 and 2.5. The mangrove sediments of Kochi, with substantially high amount of very fine - coarse sands also exhibit very platy to very lepto kurtosis. The Kannur mangroves on the other hand, divulge particle size from fine to medium silt with platy to leptokurtic sediments, with an average phimean of 0.96.

The cross-plots of standard deviation vs skewness depict a linear relationship (Fig 14-16). Sediments of Veli and Kochi regions are, in general, poorly to very poorly sorted and near symmetrical to very finely skewed in nature. However, the clastic fractions of Kannur demonstrate two distinct clustering, showing coarse and fine - very fine skewness. Formation of fine skewed sediments in the

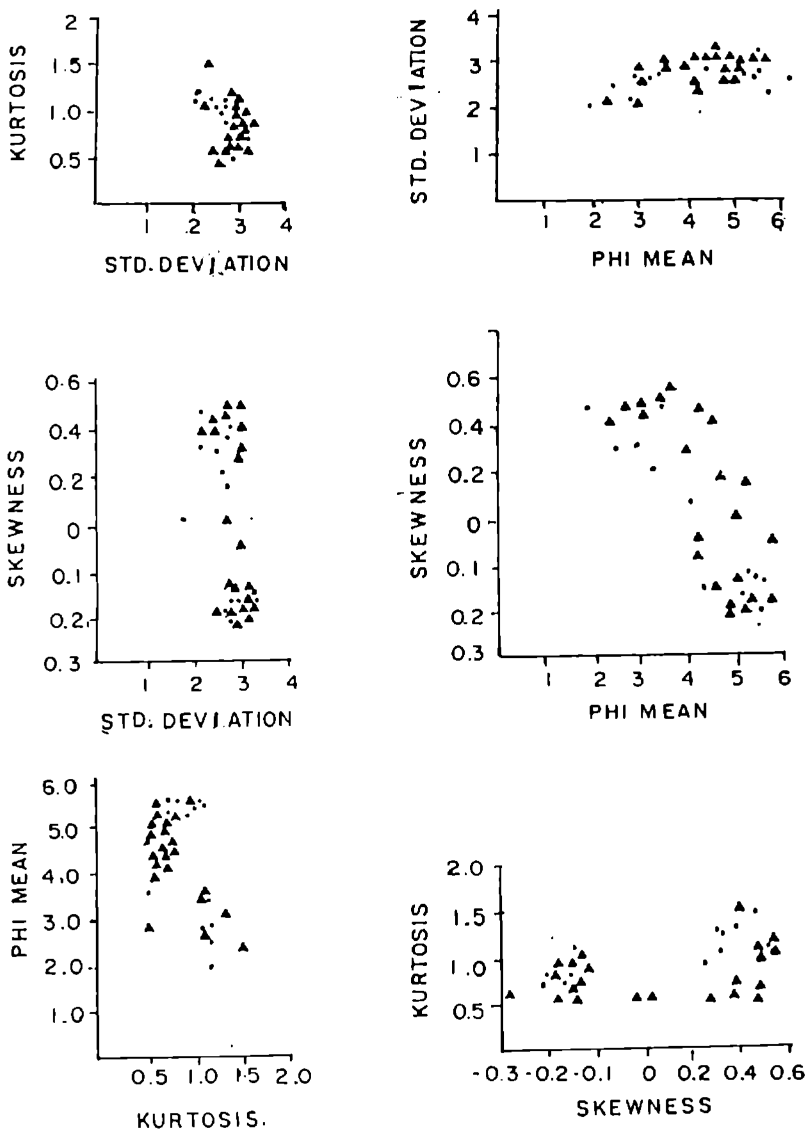


Fig. 16. CROSS PLOTS BETWEEN VARIOUS STATISTICAL PARAMETERS [SURFACE (•) AND CORE (▲)] SEDIMENTS OF KANNUR MANGROVES.

northeastern part of the Kannur mangroves has been resulted from excessive siltation and subsequent deposition of mud. This process is catalysed by the thick mangrove canopy there. Skewed sediments particularly of the southern sector has been resulted from the predominance of sand modes, indicative of high energy conditions, where fine sediments are removed by winnowing action and coarse sediments are added by tidal influx as well as the input of terrestrial waters.

The sorting co-efficients against kurtosis of the sediments of Veli and Kochi mangroves exhibit similarity as the kurtosis increases. However, the Kannur sediments do not reveal such a trend in the bivariate plots. Scatter plots between skewness and kurtosis show vide variation in Veli and Kochi and do not give any significant trend. But at Kannur the sediment distribution unveils distinct clus tering on either side of the graph based on hydrodynamic conditions as men tioned earlier.

3.3.4 C M - Model

The C M-model of Passega, (1957) worked out for the mangrove sedi ments is depicted in Fig. 17 and the values of first percentile 'C' and median 'M' in microns are given in Table 10. The plots of C vs M do not exhibit any specific segregation pattern like that of the classic model of Passega, (1964). Instead, they scatter within I, II, III, IV, V and VII sectors irrespective of the variations in geographic settings. A similar trend in C-M pattern has also been reported earlier by Seralathan, (1988) for the mangrove sediments of Cauvery delta and he explained that the observed scattering is imparted due to the drastic differences in the hydrodynamic regime prevailing in the mangrove forested in tertidal zones characterised by ebbing, flooding and also the floristic over the interferances physical mechanisms.

Table - 10
One Percentile (C) and median (M) values for the surface sediments of Veli, Kochi and Kannur Mangroves

Sample. Nos	C (in microns)	M (in microns)
VELI SEDIMENTS		
Veli mangroves		
1.a	820	82
b	1800	155
c	620	25
2.a	765	78
b	0.00	220
c	1080	220
3.a	770	36
b	770	78
c	0.00	205
4 .a	2000	125
b	1420	220
5.a	4000	78
c	0.00	290
6.a	1620	220
b	0.00	180
c	820	290
7.a	1620	32
b	880	44
c	880	290
8.a	0.00	310
b	940	270
c	1420	250
9.a	660	51
b	660	270
c	765	270
10.a	1220	28
b	1620	410
11.a	1320	51
b	1220	205
c	0.00	145
12.a	710	55
b	1320	350
13.a	710	21
c	820	190
14.a	880	26
c	770	36
15.a	880	205
b	1320	270
c	1080	250
Kochi mangroves		
16.a	2650	210
b	0.00	82
c	800	51
17.a	880	39
b	2000	39
c	820	48
18.a	660	26
b	1620	35
c	1620	51
19.a	1620	165
b	4000	15
c	820	125
20.a	6500	190
b	1880	180
c	2850	190
21.a	2000	180
b	1620	58
c	2500	205
22.a	940	190
b	880	39
c	1420	180
23.a	5700	205
b	820	180
c	2150	205
24.a	1080	205
b	2300	135
c	2000	190
Kannur mangroves		
25.a	2000	380
b	0.00	155
c	2850	245
26.a	2500	205
b	1880	145
c	940	180
27.a	820	22
b	880	20
c	1420	22
28.a	0.00	16
b	710	16
c	132	63

Sample. Nos.	C (in microns)	M (in microns)
CORE SEDIMENTS		
veli mangroves		
Core VC1		
0-10	940	180
10-20	880	180
20-30	880	180
30-40	3300	330
40-50	2500	155
50-60	1350	350
Core VC2		
0-10	4000	120
10-20	1320	180
20-30	465	165
30-40	880	8.0
40-50	1750	330
50-60	2500	220
60-70	1080	155
Kochi mangroves		
Core CC1		
0-10	840	22
10-20	710	18
20-30	2300	28
30-40	2000	44
40-50	0.00	39
50-60	0.00	44
Core CC2		
0-10	910	310
10-20	2150	270
20-30	3300	270
30-40	1420	290
40-50	940	205
50-60	0.00	32
Core CC3		
0-10	880	220
10-20	765	245
20-30	1320	250
30-40	940	250
40-50	2650	250
50-60	500	290
60-70	4000	245

Sample. Nos.	C (in microns)	M (in microns)
Core CC4		
0-10	940	180
10-20	2150	180
20-30	710	180
30-40	1420	190
40-50	940	180
50-60	710	145
60-70	1750	145
70-80	1750	125
80-90	940	220
90-100	500	190
Kannur mangroves		
Core KC1		
0-10	940	21
10-20	880	24
20-30	1620	44
30-40	0.00	120
40-50	2650	35
50-60	765	22
60-70	940	9
70-80	820	22
Core KC2		
0-10	880	125
10-20	1520	245
20-30	1520	220
30-40	0.00	58
40-50	1880	205
50-60	1420	250
60-70	1420	190
70-80	2150	250
Core KC3		
0-10	1320	30
10-20	1320	22
20-30	1750	22
.30-40	660	35
40-50	765	22
50-60	0.00	21

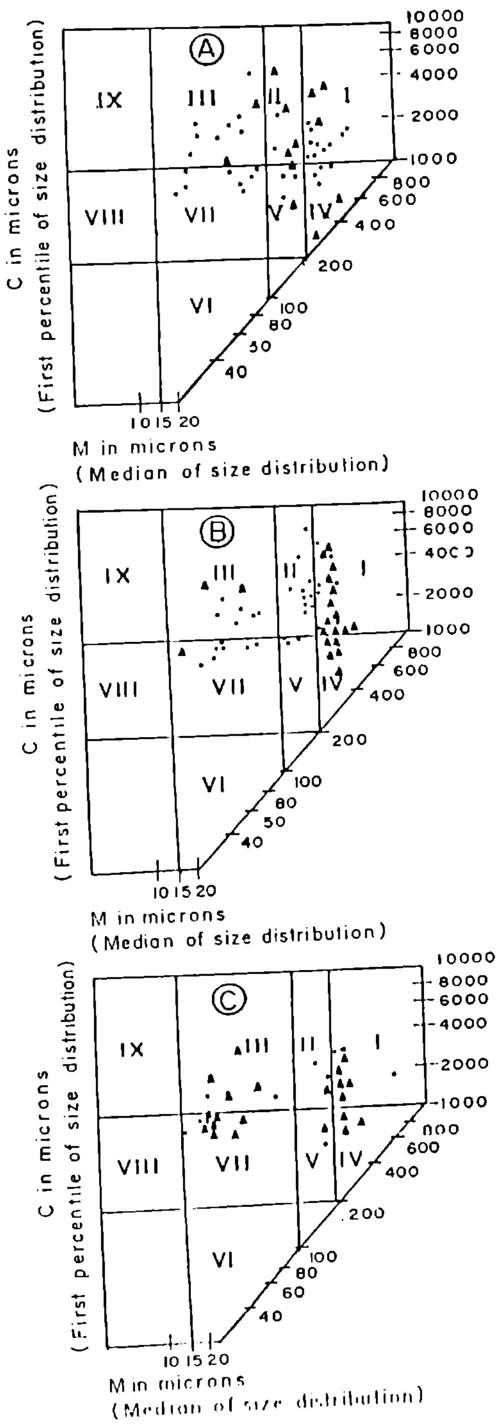


Fig. 17. C M PATTERNS OF THE SURFACE (•) AND CORE (▲) SEDIMENTS OF THE MANGROVE ENVIRONMENTS OF VELI (A), KOCHI (B) AND KANNUR (C) REGIONS.

Out of the total samples analysed, 57% samples of Veli, 53% of Kochi and 63% of Kannur have first percentile values greater than 1000 microns and they fall within the segments I -III of Passega, (1964). The rest of samples are distributed in the segments IV, V and VII and have first percentile values less than 1000 microns. The former group reflects suspension and rolling modes of transportational history, whilst the latter indicate graded suspension and uniform suspension. The sediment population representing the above diverse categories of transportational machanisms indicate the complexity in the hydrodynamic processes operating in the mangrove forested environments as suggested by Seralathan, (1988) elsewhere. The tidal activities are definitely intervened by the biological factor (ie, canopy cover) at various levels depending on the type of species, growth characteristics and geographic setting.

3.3.5 Surface Textures

Introduction : The study of surface textural features of quartz grains using Scanning Electron Microscopic (SEM) techniques has been developed as a major tool, in recent years, to discriminate the various sedimentary environments of recent and sub-recent sediments (Krinsley and Doonkamp, 1973). Surface textures of clastic particles have been extensively used to determine.

a) the depositional sedimentary environment of recent sediments
b) the source and provenance of sediments
c) the different stages of diagenesis, nature and origin of silica overgrowths on quartz grains etc.

Each environment is not only characterized by unique porocesses and energy levels peculier of that environment but also give birth to specific features/ textures characteristic of that enviroment. A quartz grain taken from beach bears characteristic textural signature on its surface which strongly reflects wave action. This signature is quite distinct from those produced by the action of rivers, wind or glaciers. Surface textures are mainly of two types; of which the first deals with the dullness or polish of the fragment and the other concerns the markings on the surface. Many researchers advocated that, a systematic study of the above two classes provides an insight into the history of transportation and deposition of clastic sediments (Krinsley, Doornkamp, 1973; Baker, 1976 and Marshal, 1987). Waugh, (1965, 1970) used the surface textural studies to extrapolate the extent of diagenesis in ancient deposits. The development of quasi-quantified diagnesis to SEM analysis (Margolis, 1968); Margolis and Kellner, 1969; Carter, 1984) has clearly shown that no single surface texture or feature can be used to identify the post environmental history of a deposit, but it is the combination of the features that enable the determination.

In view of the above, an attempt has been made in this investigation to study the surface textural patterns of quartz grains (+60 and +80 mesh) collected form the mangrove ecosystems of Veli, Kochi and Kannur areas. Surface morphometry of quartz grain collected from each of the above stations are discussed below.

3.3.5.1 Veli

The quartz grains scanned from the mangrove environment of Veli are subangular to sub-rounded (plate I) in nature. A few grains exhibit subhedral outline with broken and partially smooth edges (Plate II). The grain in plate III exhibits a

PLATE I - SCANNING ELECTRON PHOTOMICROGRAPH OF SUB-ANGULAR TO SUB-ROUNDED QUARTZ GRAINS OF VELI MANGROVES

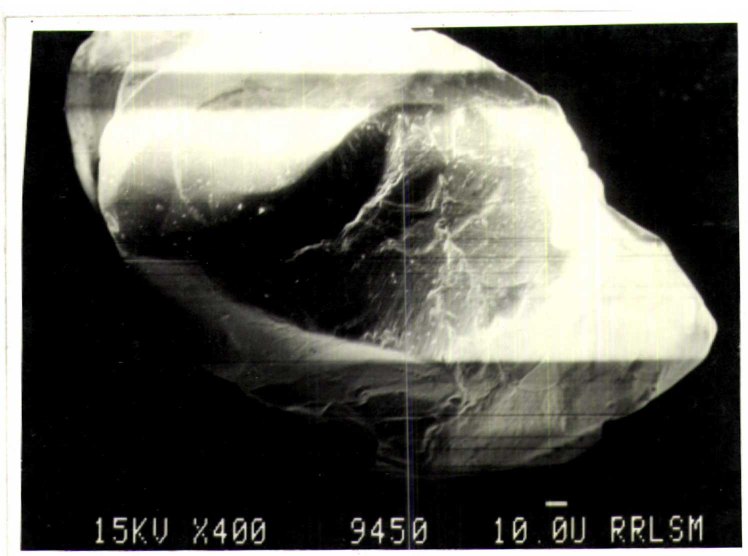


PLATE II - S E M PHOTOMICROGAPH OF A QUARTZ GRAIN SHOWING BROKEN SURFACES

network of irregularly branched arcuate cracks indicating the extent of physical weathering to whch the grains are subjected (Krinsley, Greeley and Polack, 1979). This grain is conspicously weatherd and possesses stepped or layered structures. Quartz grains in Plate III and IV depict the superimposition of surface signatures of different genetic episodes, including both physical and chemical ones. Mechanically produced V-shaped pits, linear and curved grooves (Plates IV and V), stacked primary cleavage plains and secondary amorphous quartz overgrowths (Plate IV), chemically etched triangular pits, and bulbous edges (Plates III, IV & V) are other notable microrelief features encountered on the quartz grains of Veli mangroves.

The angularity of grains indicates moderate distance of transportation and the subhedral nature might have resulted due to the action of comparitively high energy sublittoral environment. The coarse clastics of Veli mangrove environment do not show thick bearing of V-patterns and hence it is apparent to infer that these grains might have experienced higher intensities of agitation but of shorter duration. Linde and Mycielska Dowgiallo, (1980) opined that the size and abudndace of V's are tend to increase with longer periods and higher intensities of subacquous action. Linear and curved grooves are presumed to be derived during energetic subaquous collisions (Margolis and Krinsley, 1974) and are invariably showing fluvial environment (Higgs, 1979). A set of stacked primary cleavages plains and secondary amorphous quartz overgrowths (Plate IV) could have developed due to the pressure solution and chemical etching rather than weathering. The outgrowths formation had been related to the crystal structure (Karpovich, 1971) at different stages of diagenetic history of the sediment (Marzolf, 1976, Pristone, 1977).

Observations and analysis of various morphological overprints depicted on quartz grains of Veli mangroves reveal a complex pattern of transportational his-

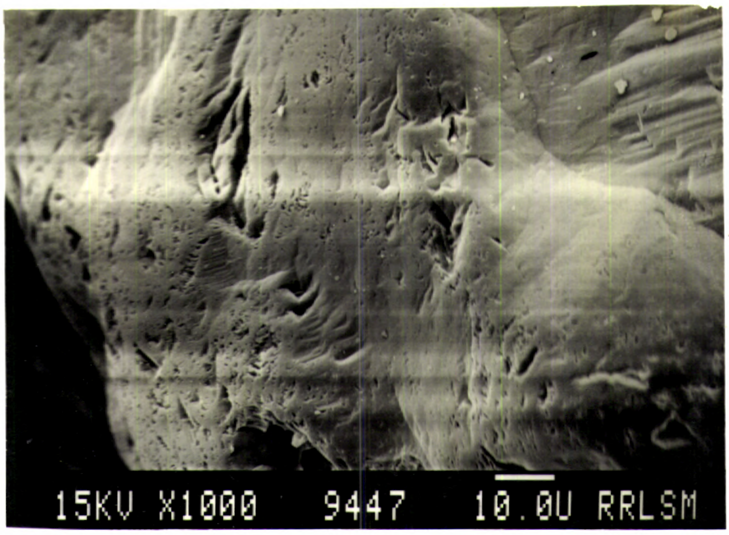


PLATE III - QUARTZ GRAIN PICKED UP FROM THE VELI MANGROVE SHOWING BULBOUS PROJECTIONS, ARCUATE GROOVES, V-SHAPED PITS AND STEPPED STRUCTURES.

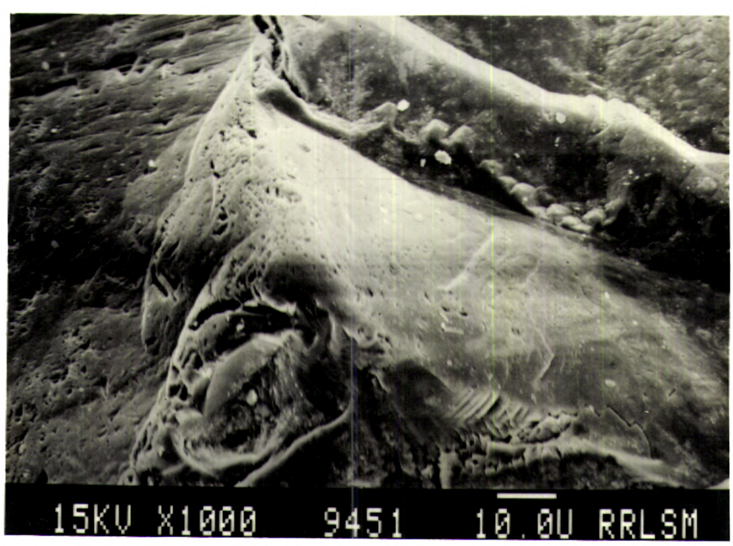


PLATE IV - PHOTOMICROGRAPH OF A GRAIN SHOWING SURFACE TEXTURAL FEATURES OF CHEMICAL ORIGIN (SOLUTION PITS AND GROOVES) AS WELL AS STACKED CLEEVAGE PLAINS

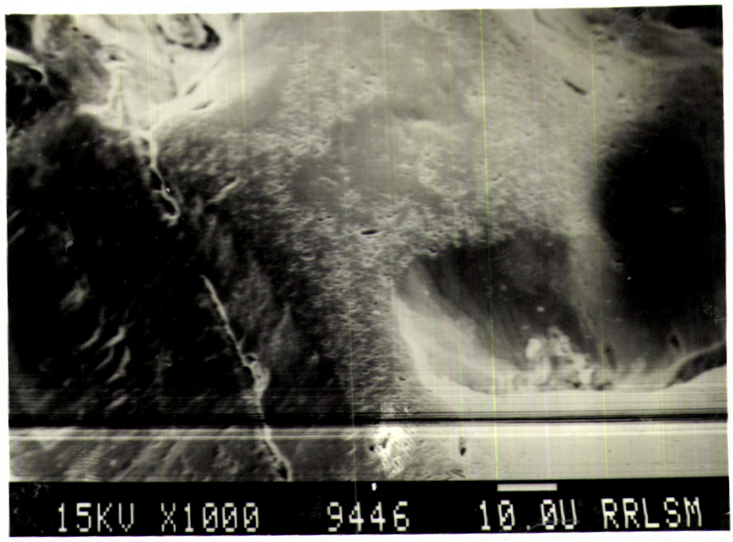


PLATE V - S E M PHOTOGRAPH SHOWING BULBOUS SURFACES, LINEAR GROOVES, IMPACT (?) PITS AND SOME SOLUTION FEATURES OF A QUARTZ GRAIN OF VELI MANGROVES.

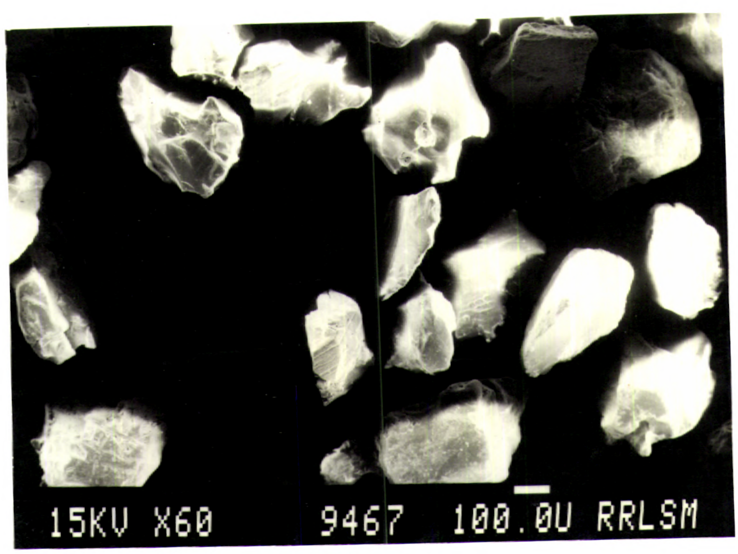


PLATE VI - A OVERALL VIEW OF QUARTZ SANDS OF KOCHI MANGROVES SHOWING SUB-ANGULAR TO SUB-ROUNDED GRAIN BOUNDARIES tory. These grains originally brought by fluvitile action and deposited in the beach or sublittoral environment from where they form the part of mangrove sediments.

3.3.5.2 Kochi

Examination of the surface textures of quartz sand grains picked up from the different mangrove patches of Kochi divulges that the majority of the grains are subangular to subrounded (Plate VIII) which on closer inspection reveal that it is of primary origin upon which an arc stepped secondary linear furrow found cross cuting the primary cleavage plain. Morphological overprints of upturned plates, impact dishes and irregular fractures are also observed in some of the grains (Plate VIII).

Subangular to subrounded nature of the grains explain the immaturity of sediments. The arc stepped furrows, resulted from grain collision indicating the influence of fluvial environment. These grains experience a succession of high energy collisions (Pascoe, 1961) causing cleavage scarps observed as upturned plates. These post-depositional microstructures indicate that, originally these grains might have resided in the fore dune of beach environments from where the first hand characteristics of aeolian action (Margolis, 1968; Krinsley and Doornkamp, 1973) occurred. From these micro textural imprints, it is concluded that, the quartz grains of Kochi mangroves originally belong to the nearly beaches experiencing sublittoral environments. The dissolution features observed in Plate IX might have resulted due to the diagenesis perhaps in the estuarine conditions.

3.3.5.3 Kannur

Study of grain size images of quartz seperated from the sediments of Kannur reaveals, an outline of subrounded to rounded nature (Plate X). Other surface

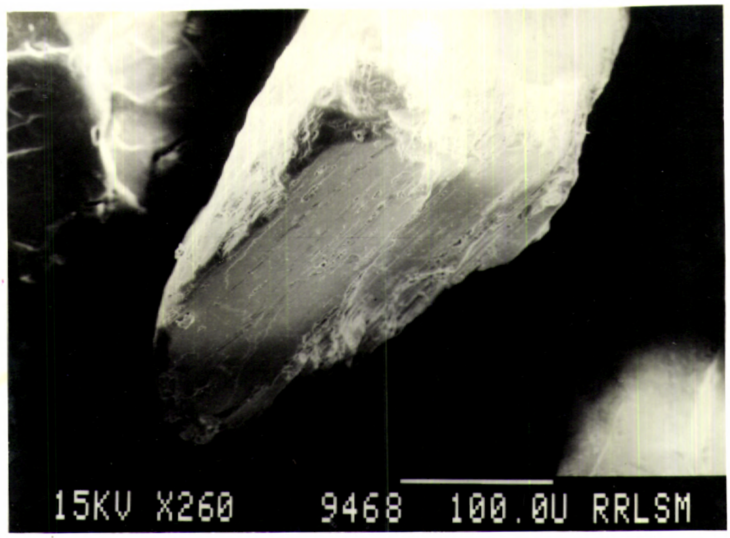


PLATE VII - A CLOSE UP OF AN ELONGATED GRAIN SHOWING FRESHLY DERIVED, SMOOTH SURFACES.

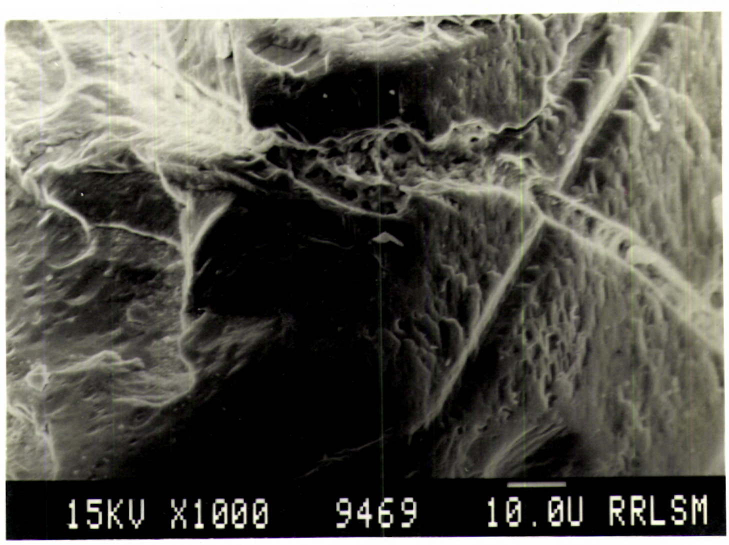


PLATE VIII - PHOTOMICROGRAPH OF A QUARTZ GRAIN EXHBITING INTERPLAY OF MICRO RELIEF FEATURES OF DIFFERENT GENETIC EPISODES.

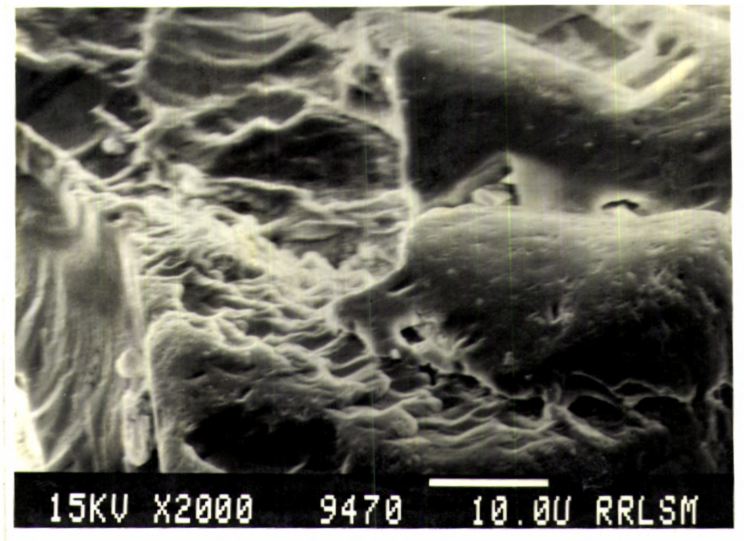


PLATE IX - GRAIN SURFACE SHOWING HIGHLY COMPLEX SOLUTION STRUCTURES

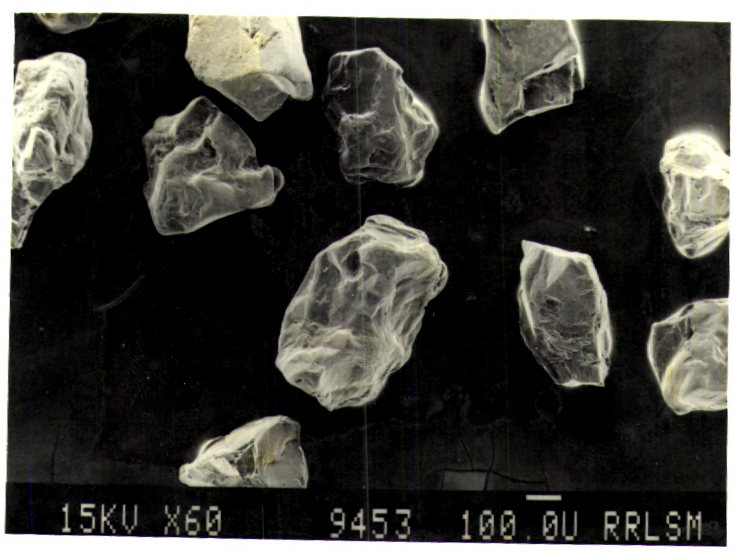


PLATE X - AN OVERALL VIEW OF QUARTZ SANDS OF KANNUR MANGROVES SHOWING SUB-ROUNDED TO ROUNDED GRAIN MARGINS.

textural imprints depicted on the said grains of Kannur area include bulbous edges, solution structures and minor impact pits (Plate XI and XII), V-shaped pattern, conchoidal fractures (Plate X) and linear and curved grooves (Plate XI). The roundedness of the grains explain that, sediments of this environment are highly matured (Gravenor, 1985). The buloous edges (Plae X) are characteristics of sub-acquous conditions to which the grains have been subjected. 'V' shaped pits found overprinted on the bulbous edges (Plate X) indicate the first stage of mechanical action. Conchoidal fractures and small impact pits (Plate X) are indicative of high energy surface conditions. Linear and curved grooves are also produced due to subacueous abrason (Marshell, 1987). Grains of very clean surface with no evidence of chemical precipitation were also encountered, however, dissolution pits are observed (Plates X and XI) indicating chemical action.

From the overall evalution of the various microrelief features of quartz grains of the Kannur mangrove environment, it is inferred that the sediment grains of this region are highly matured and bear textural signatures of physical origin. No chemical features are encountered except the diagenetic dissolution structures. The clastic grains of this region might have come from the nearby beach environments.

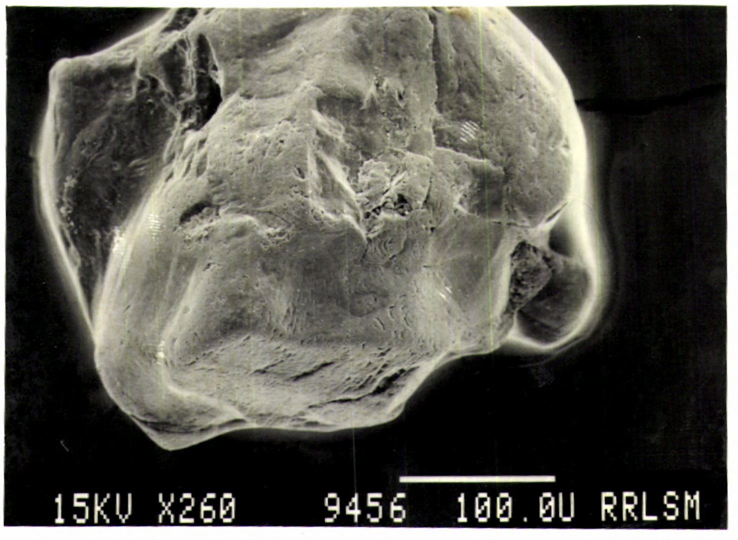


PLATE XI - A CLOSE-UP OF A QUARTZ SAND SHOWING WELL DEVELOPED BULBOUS EDGES OVERPRINTED WITH MINOR IMPACT PITS.

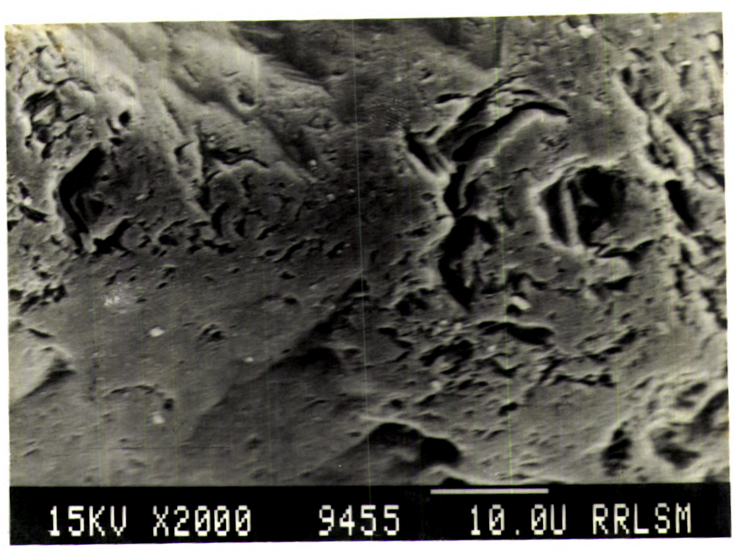


PLATE XII - A HIGHER MAGNIFICATION (2000X) PHOTO MICROPGRAPH SHOWING PROFUSELY DEVELOPED SOLUTION PITS.

CHAPTER 4

MINERALOGY OF HEAVIES AND CLAYS

4.1. INTRODUCTION

The term 'heavies', often used in sedimentary petrology to refer the heavy mineral (minerals whose specific gravity is greater than 2.89) residue of sediments and sedimentary rocks. The study of heavy minerals, heavy mineralogy - is the oldest endeavour in sedimentology; however, this branch of science has received wide attention only after the investigations of Rubey, (1933) and Rittenhouse, (1943). The investigation of heavy minerals in sediments has many applications not only in the academic exercises, but also in the economic scenario. Heavies are effective tools to decode the hidden information regarding provenance and transportational history of sediments and sedimentary rocks.

The term 'clay' is used as a rock term and also as a particle size term in the mechanical analysis of both sediments and soils. In general, the term 'clay' implies a natural, earthy, fine grained material which develops plasticity when mixed with a limited amount of water. Chemical analysis of clays show that, they are composed essentially of silica, alumina and water and also frequently with appreciable quantities of alkali and alkaline earth metals. This term has no genetic significance; instead, it is used for materials that are derived from weathering and/or hydrothermal activity of most pre-existing rocks. Clay mineralogy, the science dealing with the mineralogical constitution of sediments (< 2 micron size), has now been widely applied in aquatic environments as it has a considerable bearing on the various physico-chemical processes operating between sediments and water.

4.2. REVIEW OF LITERATURE

The era of mordern heavy mineralogy begins with the classic work of Rubey, (1933). He was the first to explain precisely about the size distribution of heavy minerals in sedimentary deposits. The complex interrelationship between the source rock characteristics and the transportational processes was stressed by Rittenhouse, (1943). Ever since the introduction of hydraulic equivalent concept by Rubey, (1933), it has been widely recognised that the hydraulic behaviour of heavy minerals are jointly influenced by their physical properties (size, shape and density), availability of minerals and the dynamics of transporting medium. Blatt and Sutherland, (1969) have shown that, the rate of chemical alteration is greater in coarse grained sediments than in less permeable fine grained ones due to the free movement of intrastratal solution through the former than the latter. Bradley, (1952); Van Andel and Poole, (1960); Lowright et al, (1972); Stapor, (1973); Stingerland (1977); Flores and Shideler, (1978); Morton, (1986) and Statteger, (1987) have used the heavy mineral assembles in unravelling the transportational and depositional histories of sediments. Pettijohn, (1941) suggested that the diversities in heavy mineral assemblages are more in the youngest sediments than ancient ones, and further, the number of heavy mineral species decreases in the latter due to the prolonged action of intrastratal solution. Contrary to this, Krynine, (1942) stressed provenance as a key factor for the aforesaid mineralogical diversity. Briggs et al, (1962) have pointed out that both density and shape of minerals are important in imparting the sorting of minerals. The role of progressive sorting based on size and specific gravity differences has also been studied by researchers like Allen, (1970); Carver, (1971); Blatt et al, (1972); Komar and Wang, (1984) and Komar et al, (1989); Sajan, (1988) and Rao et al, (1995).

Jacob, (1956) made a detailed study on the heavy mineral concentrates of the beach sands of Thirunelveli and Tanjore districts of Tamil Nadu. Heavy mineral suites of Visakhapatanam area have been investigated by Roy, (1958). Tipper, (1914) and Brown and Dey, (1955) have studied the heavy mineral deposits between Quilon and Cape Comorin on the south west coast of India. Heavy mineral suites of the beach sands of Kerala have been investigated by Prabhakara Rao,(1968);Purandra et al, (1987); Mallik et al, (1986); Unnikrishnan, (1987) and Sasidharan and Damodaran, (1988). Heavy mineral concentrates in the shelf regions of the west coast of India have been evaluated by Siddique and Rajamanickam, (1979). Sajan (1988; 1992) has carried out detailed analysis on the heavy minerals in the modern sediments of Ashtamudy lake. Heavy mineral assemblages of the beach, strand plain and innershelf sediments of the northern Kerala coast have been worked out by Samsuddin(1990). Padmalal (1992) discussed mineralogical make up of Muvattupuzha river and central Vembanad estuarine sediments.

4.3. HEAVY MINERALS

4.3.1. Total Heavy Minerals (THM)

4.3.1.1 Surface Sediments

Tables 11 furnishes the weight percentages of total heavies present in the fine (80 + 120) and very fine.(170 + 230 ASTM meshes) sand fractions of surface and core sediments of the three mangrove (Veli, Kochi and Kannur) ecosystems. Fig. 18 illustrates the relative proportions of heavy and light minerals present in these fractions. The fine sands of the Veli region exhibit a wide range in the total heavy minerals which vary between 1.95% and 7.6% with average of 4.83%. From table 11 it is evident that the landward profile (LP) shows gradual decrease

Table - 11

Heavy mineral distribution in the surface and core sediments of Veli, Kochi and Kannur mangrove ecosystems.

Sample No	THM	TLM	Opaques	N-op	N-op(%)									Al/oth
	(100%)		(100%)		Hb	Hy	Bi	Si	Zi	Ga	Mo	Ky	Ru	
A. FINE SAND														
Surface Sediments														
Veli mangroves														
3. a	7.61	16.5	55.43	44.56	0.27	--	0.27	36.76	2.22	--	3.62	--	--	1.39
b	6.33	21.49	70.17	29.84	1.84	1.03	--	17.53	5.53	--	2.76	--	--	0.92
c	2.86	13.73	65.88	34.11	--	--	--	30.88	0.88	--	2.35	--	--	--
8. b	6.22	10.77	63.82	36.17	--	--	--	21.98	11.35	--	2.83	--	--	--
c	1.95	4.17	77.96	22.03	0.56	--	--	16.10	2.54	--	2.54	--	0.28	0.56
13.b	5.34	15.42	72.32	27.68	0.23	--	0.23	22.79	2.09	--	1.16	--	0.23	0.93
Kochi mangroves														
16 a	1.44	49.02	24.24	75.75	48.48	16.36	--	4.24	6.66	--	--	--	--	--
18.b	1.63	33.81	35.08	64.91	38.59	13.88	17.54	7.01						
c	1.94	8.22	33.86	66.13	29.06	21.33	2.13	1.33	3.46	--	0.8	--	0.53	1.75
20 c	2.01	47.45	44.44	55.56	33.33	15.68	--	--	6.53	--	--	--	--	1.06
21 c	2.69	8.68	58.50	41.49	26.87	9.52	--	--	2.38	0.68	0.68	--	--	--
22 a	3.15	26.39	44.73	55.26	14.13	10.28	--	2.08	26.73	0.25	--	2.0	--	1.36
b	0.88	21.32	55.56	44.44	23.80	9.52	--	8.73	2.3	--	--	--	--	1.28
c	3.48	30.29	44.14	55.85	29.76	17.05	--	2.67	3.34	1.00	--	--	1.00	1.00
24 a	2.80	40.12	17.16	82.38	33.80	32.95	1.42	2.27	6.25	0.852	0.28	0.85	0.85	2.84
b	2.61	34.81	32.34	67.65	27.29	20.17	8.30	0.89	2.37	0.29	0.29	0.59	--	0.59
c	5.18	3.92	40.62	59.37	33.07	17.44	--	0.78	2.86	0.78	1.30	0.78	--	--

Sample No	THM (100%)	TLM (100%)	Opaques (100%)	N-op (100%)	N-op(%) Hb	Hy	Bi	Si	Zi	Ga	Mo	Ky	Ru	Al/oth
Kannur mangroves														
25 a	1.27	50.19	52.00	48.00	22.19	2.52	1.95	16.42	0.52	2.15	--	--	1.02	1.23
25 b	2.15	48.59	55.05	44.95	18.42	3.16	2.15	15.48	1.01	3.19	1.11	0.43	--	--
25 c	2.76	51.67	45.16	54.84	26.38	5.18	3.25	18.91	--	0.55	--	--	0.63	--
26 a	1.63	45.02	64.13	35.87	7.7	3.26	1.63	19.49	--	1.08	--	--	--	2.71
26 b	4.07	38.18	62.78	37.22	5.62	4.92	3.15	10.85	2.01	2.82	1.62	3.15	2.12	0.96
26 c	4.89	43.63	48.08	51.92	24.85	6.45	2.74	9.92	1.92	2.18	0.63	2.42	--	0.81
28 a	2.19	44.12	53.2	46.8	21.34	4.53	1.25	16.24	1.2	--	--	1.51	--	0.73
28 b	2.35	49.38	42.16	57.84	27.13	7.25	0.56	14.39	--	1.12	2.10	2.52	1.53	1.24
28 c	5.12	54.69	38.43	61.57	30.42	10.16	--	16.39	0.95	1.18	1.29	--	1.18	--
Core Sediments														
Veli mangroves														
Core VC1 50-60cm.	0.91	19.97	80	20	--	--	--	10	1.17	--	3.52	2.35	1.17	1.76
Core VC2 10-20cm.	27.17	21.37	81.04	18.95	--	--	--	9.15	1.30	--	4.57	1.30	--	2.61
50-60cm.	3.92	26.67	38.58	61.41	1.24	--	--	55.60	1.24	--	1.65	--	--	1.65
Kochi mangroves														
Core CC1 20-30cm.	12.76	82.67	54.47	45.52	26.49	14.17	--	--	2.61	0.37	0.74	--	--	1.11
Core CC2 30-40cm.	13.59	17.80	67.56	32.43	16.21	9.90	--	--	3.60	--	--	--	0.45	2.25
Core CC3 40-50cm.	4.94	36.07	50.59	49.40	25.60	13.09	2.97	4.76	--	--	0.59	--	--	2.38
Core CC4 30-40cm.	1.67	70.0	44.44	55.56	35.97	11.64	0.53	--	3.70	1.05	1.05	--	--	1.58
Kannur mangroves														
Core KC2 10-20cm.	6.21	42.15	60.18	39.82	7.85	4.21	0.85	20.45	1.85	1.12	--	2.11	0.85	0.53
50-60cm.	7.81	49.16	53.89	46.11	6.52	5.74	1.52	26.83	2.53	0.99	1.05	--	--	0.93
Core KC3 10-20cm.	3.64	33.72	62.17	37.85	5.18	1.55	--	24.87	2.59	--	1.03	--	--	2.59
50-60cm.	5.55	14.83	64.10	35.89	5.12	3.41	--	24.78	--	--	--	2.56	--	--

Sample No		THM	TLM	Opaques	N-op	N-op(%)									Al/oth
		(100%)		(100%)		Hb	Hy	Bi	Si	Zi	Ga	Mo	Ky	Ru	
B. VERY FINE SAND															
Surface Sediments															
Veli mangroves															
3.	b	16.17	56.05	77.40	22.59	--	--	--	16.82	1.44	--	1.44	--	--	2.88
	c	35.25	48.51	71.96	28.03	--	--	1.69	17.79	9.32	--	0.84	--	--	0.92
8	a	28.03	60.47	71.96	28.03	--	--	--	22.42	2.33	--	2.33	--	--	0.93
	b	31.22	51.82	87.14	12.85	--	--	--	12.85	--	--	--	--	--	--
	c	19.83	74.04	72.65	27.34	--	--	--	20.81	1.22	0.81	3.67	0.81	--	--
13	a	11.26	69.81	55.12	44.87	--	--	--	39.10	1.92	0.64	3.20	--	--	--
Kochi mangroves															
16	a	1.39	48.14	18.40	81.59	33.83	38.30	3.98	0.49	1.49	1.49	--	--	1.99	--
18	a	1.18	22.79	35	65	32.5	12.5	--	55.66	--	--	0.5	--	--	1.5
	b	4.02	60.61	28.33	71.66	30.55	21.11	3.33	2.2	7.78	3.89	--	--	--	2.78
	c	2.15	49.11	19.60	80.39	45.09	9.80	--	--	5.88	--	--	--	--	--
20	c	1.96	48.57	29.29	70.70	29.29	25	2.34	2.34	7.03	2.73	--	--	1.17	0.78
21	c	4.77	83.75	37.68	62.31	21.60	16.58	6.03	3.01	10.55	0.50	1.50	0.50	1.00	1.00
22	a	2.01	68.39	42.72	57.27	18.63	25.45	--	2.72	7.72	2.27	0.90	--	--	--
	b	1.67	76.28	23.69	76.30	32.94	16.76	2.31	17.91	2.31	--	--	--	1.73	2.31
	c	1.76	64.64	31.13	68.86	33.96	11.32	2.83	2.83	13.20	--	--	--	--	4.71
24.	a	1.74	55.33	27.63	72.36	47.36	15.78	--	--	3.94	--	1.31	--	--	1.81
	b	3.40	59.15	37.61	62.38	36.69	13.76	3.66	2.75	0.91	--	--	--	1.83	2.75
	c	4.62	86.23	41.37	58.62	19.31	19.31	6.20	6.89	4.13	0.68	--	--	--	2.06

Sample No		THM	TLM	Opaques	N-op	N-op(%)									Al/oth
		(100%)		(100%)		Hb	Hy	Bi	Si	Zi	Ga	Mo	Ky	Ru	
Kannur mangroves															
25	a	44.00	56.00	24.18	3.52	0.89	19.20	1.12	2.15	1.05		2.11--	1.78		
	b	2.96	46.3	47.00	53.00	26.33	4.22	1.32	16.21	2.15	1.45	--	1.08	0.24	--
	c	3.15	42.44	49.28	50.72	25.84	6.58	--	10.31	3.94	--	--	2.85	0.64	0.56
26.	a	2.62	50.73	58.16	41.84	18.12	2.89	1.25	12.33	4.58	--	--	1.00	--	1.67
	b	5.16	52.59	53.78	46.22	10.79	7.85	1.23	18.92	2.12	1.52	--	2.11	--	1.68
	c	5.82	45.66	39.82	60.18	32.15	8.92	2.15	12.38	2.63	--	--	--	0.82	1.13
28.	a	2.85	50.84	38.12	61.88	27.43	8.28	3.52	14.33	2.67	1.18	2.05	1.89	0.72	0.53
	b	1.99	46.28	44.42	55.58	24.37	5.46	1.58	15.41	3.56	1.10	--	2.52	--	0.86
	c	2.53	37.66	50.16	49.84	22.45	3.76	--	17.32	2.89	--	--	1.58	--	1.84
Core Sediments Veli mangroves															
Core VC1															
10-20cm.		31.09	49.42	81.36	18.63	--	--	--	11.18	0.62	--	3.10	--	--	3.72
50-60cm.		24.95	54.67	87.97	12.20	--	--	--	8.45	--	--	1.88	0.94	0.47	0.47
Core VC2															
10-20cm.		9.52	41.94	58.33	41.66	--	--	--	26.38	2.77	--	4.16	1.38	--	6.94
50-60cm.		11.75	57.65	72.54	27.45	--	--	--	15.68	3.92	--	3.92	--	--	3.92
Kochi mangroves															
Core CC1															
20-30cm.		1.44	3.11	48.38	51.67	37.09	8.06	--	--	3.22	--	--	--	--	3.22
Core CC2															
30-40cm.		3.86	64.75	41.32	58.68	33.88	9.91	--	2.47	7.43	--	--	--	1.65	3.30
Core CC3															
40-50cm.		2.80	56.18	33.33	66.67	41.40	12.61	--	9.90	--	--	--	0.90	1.00	--
Core CC4															
30-40cm.		3.12	25.21	23.52	76.47	42.64	13.23	--	--	10.29	2.94	--	--	--	7.35

Sample No	THM	TLM	Opaques	N-op	N-op(%)									Al/oth
	(100%)		(100%)		Hb	Hy	Bi	Si	Zi	Ga	Mo	Ky	Ru	
Kannur mangroves														
Core KC2														
10-20cm.	8.23	38.33	50.15	49.85	18.55	3.76	--	16.84	2.20	1.01	1.82	3.51	1.51	0.65
50-60cm.	7.55	40.19	45.23	54.78	22.15	4.05	1.82	21.23	3.84	0.99	--	--	--	0.70
Core KC3														
10-20cm.	2.89	59.88	35.46	64.53	4.43	--	1.47	--	1.47	--	1.47	--	--	--
50-60cm.	1.60	70.93	34.56	65.43	4.93	3.70	--	55.56	--	--	--	1.23	--	--

a = Landward sample b = Intermediate sample c = Shallow water sample

THM = Total Heavy Minerals
TLM = Total Light Minerals
N-op = Non - opaques
Hb = Hornblende
Al/oth = Altered/others
Hy = Hypersthene
Bi = Biotite
Si = Sillimanite
Zi = Zircon
Ga = Garnet
Mo = Monazite
Ky = Kyanite
Ru = Rutile

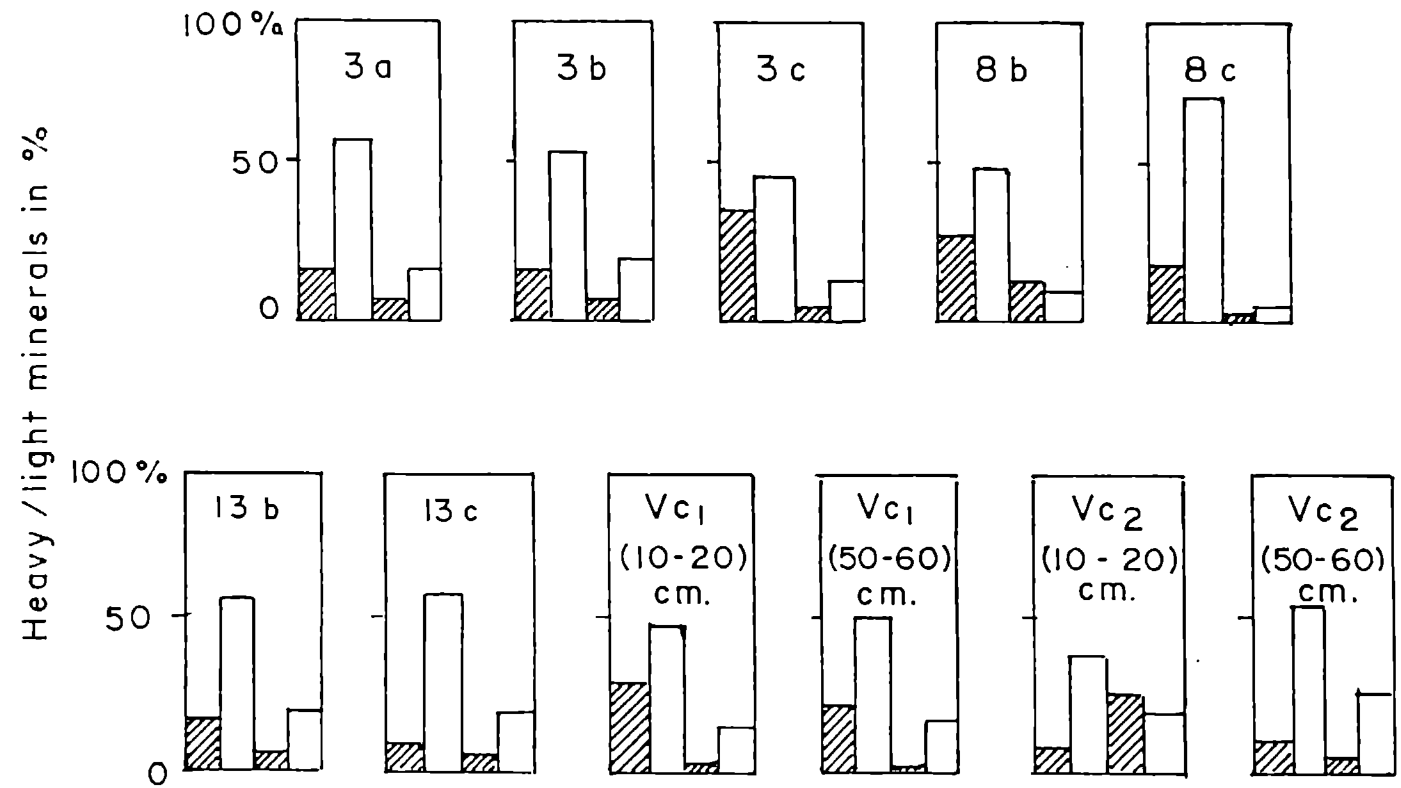


Fig. 18 A. VELI MANGROVES
DISTRIBUTION OF TOTAL HEAVY MINERALS(▨) AND LIGHT MINERALS (□) IN THE FINE SAND (FS) AND VERY FINE SAND (VFS) FRACTIONS OF THE SURFACE AND CORE SEDIMENTS OF VELI (A), KOCHI (B) AND KANNUR (C) REGIONS.

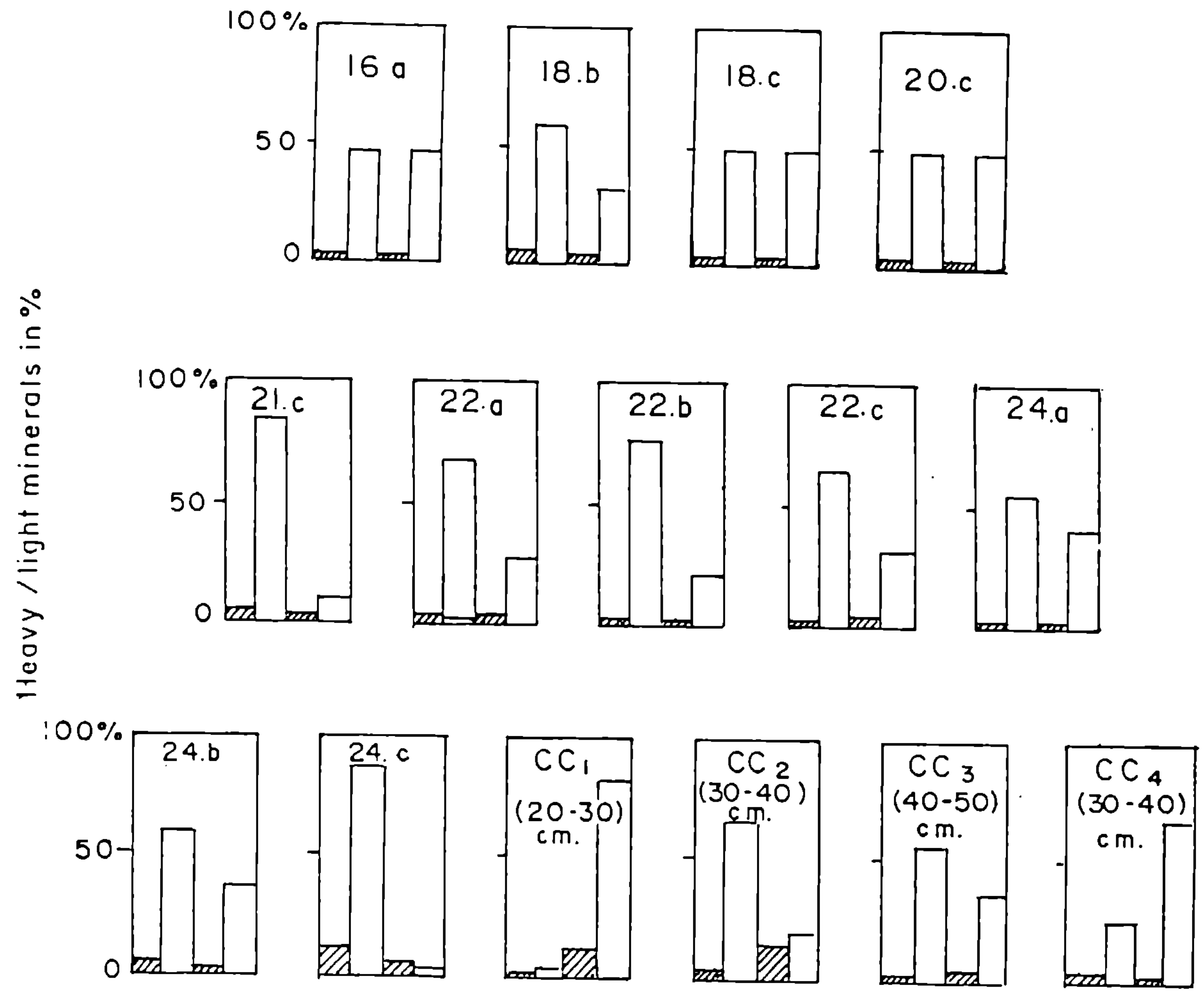


Fig. 18 B. KOCHI MANGROVES.

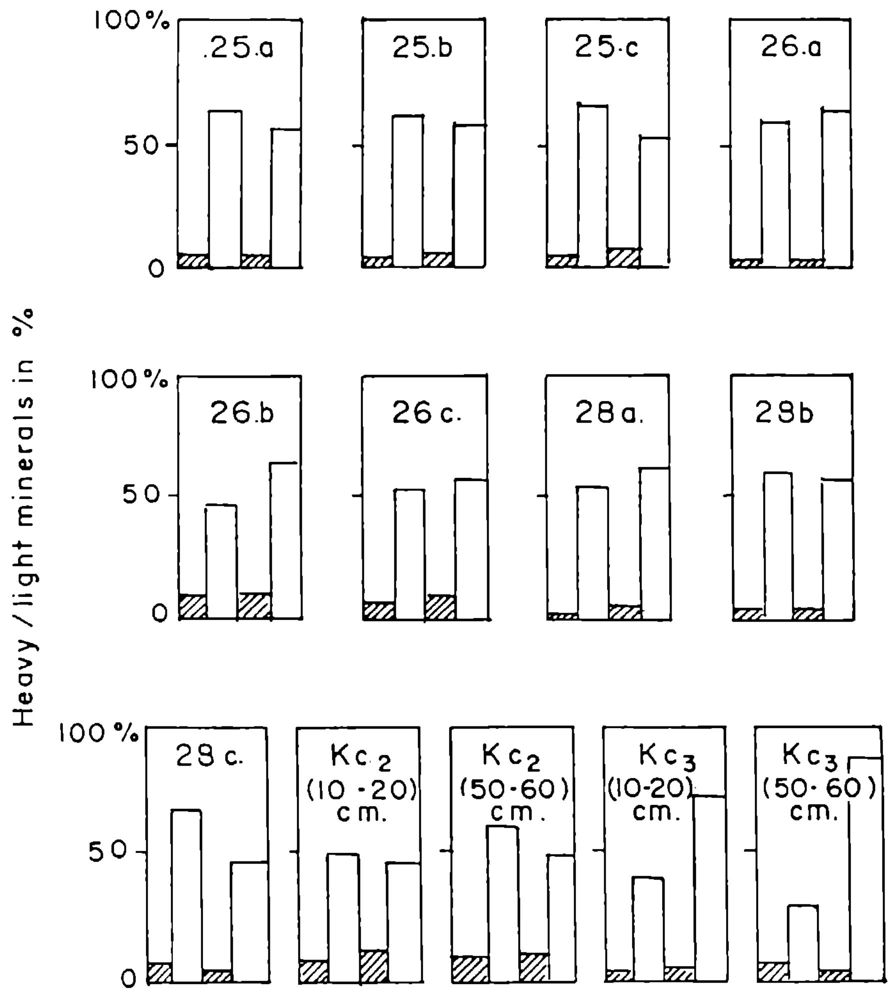


Fig. 18 C. KANNUR MANGROVES.

in total heavy minerals from south west to north east direction. The intermediate profile (IP) demonstrates more or less uniform distribution pattern (average 5.96%). Contrary to the above two cases, the shallow water profile (SWP) exhibits marked fluctuations in the content of total heavy minerals (Table 11) from north to south.

The total heavy minerals in the veryfine sand fraction varies from 9.46% to 35.25% showing an average of 20.53%. A comparative evaluation of the total heavy mineral contents of fine and very fine sand fractions of Veli mangroves reveals that the latter fractions are composed of substantially higher amounts of total heavies than the former. In contrast to the distribution of fine sands, the total heavy minerals in the very fine sands are haphazardly distributed in all the three profiles. Both highest (35.25%) and lowest (9.46%) total heavy mineral contents are recorded from the shallow water profile, located in the southwest and northeast segments, respectively. The landward profile shows an average THM of 18.89%, whereby the intermediate and shallow water profiles show 21.18% and 21.51% of THM, respectively. It clearly shows that the heavy minerals are enriched successively but marginally towards the shallow water profile indicating the role of tidal water in enriching the heavy mineral residue at the Veli mangrove environment.

The heavy mineral contents in the fine sands of Kochi sediments range from 0.88% to 5.18% (av; 2.55%). Contrary to Veli, the Kochi mangroves exhibit little uniformity in the dispersal pattern of heavy minerals. The intermediate profile record the lowest amount of heavies (av; 1.7%), while the shallow water profile registers the highest (av;5%). The average heavy mineral content of the landward profile is computed as 2.55%. Compared to the Veli mangroves, the Kochi mangroves exhibit nearly 2 fold increase in the content of the total heavy minerals.

The total heavy minerals in the very fine sands of Kochi show a minimum of 1.18% and a maximum of 4.62% (av; 4.15%). The landward profile shows the lowest amount (1.58%) of heavies, whereas the intermediate profile (av; 3.03%) and shallow water profile (av; 3.05%) contain more or less equal amounts. On an average, the very fine sand fractions show approximately 2 fold enhancement of total heavies than the fine sand fractions. The shallow water profile concentrates higher contents of heavy minerals in the case of fine as well as very fine sands. The order of abundance of THM are shallow water profile > intermediate profile > landward profile in the fine and shallow water profile > landward profile > intermediate profile in the very fine sands.

The mangrove environment of Kannur exhibits variation of heavy minerals from 1.27% to 5.12% (av; 2.93%) in the fine sand. The shallow water profile accounts for the highest content of heavies (av; 4.25%), followed by intermediate profile (av; 2.85%) and landward profile (av; 1.69%). Gradual increase of heavy mineral contents are noticed from the southwest to northeast, along the landward as well as shallow water profiles. However, no such gradational variation has been noticed along the intermediate profile.

Heavy minerals present in the very fine sand fraction ranges between 1.99% and 8.23% with an average of 3.24%. Similar to the distribution of heavies in fine sand fraction, here too, the shallow water profile demonstrates elevated amounts (av; 3.83%) of THM compared to the landward (av; 2.54%) as well as intermediate (av; 3.37%) profiles. A close insight into the distribution patterns of heavy minerals in the very fine sand fractions divulges that heavy minerals are increasing gradually from north east to south west direction along the landward profile. By comparing the THM contents in the fine and very fine sand fractions, it is vivid that in all the above localities the latter fraction contains higher amount than the former. In general, the relative abundances of total heavy minerals in both fine and very fine sands are of the order shallow water profile > intermediate profile > landward profile.

4.3.1.2 Core Sediments

The sediment cores collected from the Veli mangroves VC_1 and VC_2 show that the heavy mineral contents decrease considerably with increase of depth in fine sand fractions. Of the two cores, VC_2 demonstrates the highest (27.17%) heavy mineral content at a depth of 10-20 cms and VC_1 accomodates the lowest (0.91%) amount at about 50-60 cms from below the surface. In general, the heavy minerals of core VC_2 show more than 7 fold enrichment of heavies than the core VC_1. The contents of total heavy minerals in very fine sand fractions vary from 24.95% to 31.09% in core VC_1 and that in core VC_2 ranges between 9.52% and 11.75%. This sand fraction in VC_1 also shows depletion of heavies with depth, whereas the core VC_2 exemplifies a reverse pattern; in that higher depths contain higher amounts of heavies. On an average scale, the heavies in the very fine sand fractions of core VC_1 demonstrates nearly 2 fold enhancement than core VC_2.

The fine sand fractions of sediment cores of Vypin (CC_1) shows an average of 12.76% of heavy minerals and that of Malippuram (CC_2) region contains 13.59%. Heavy mineral contents of Vallarpadam (CC_3= 4.94% and CC_4= 1.67%) area, on an average scale, exhibits more than 4 fold decrease in the content of heavies compared to Vypin and Malippuram. In general, the average heavy mineral content varies from 1.67% to 13.59% with average content of 8.24%. But, regarding the total heavy minerals in very fine sand fraction, it is clear that, the cores CC_1 (av; 1.44%), CC_2 (av; 3.86%) and CC_3 (av; 2.8%) records substantially lower amounts of heavies compared to that in the fine sands. The core CC_4 encompasses an average of 3.12% of total heavies. Generally speaking, the heavy minerals in this sand fraction ranges between 1.44% and 3.86% (av; 2.81%). This average value of heavies in very fine sand is approximately 3 times less than that of fine sands. The comparative availability of heavy minerals in fine and very fine sands are $CC_2 > CC_1 > CC_3 > CC_4$ and $CC_2 > CC_4 > CC_3 > CC_1$, respectively.

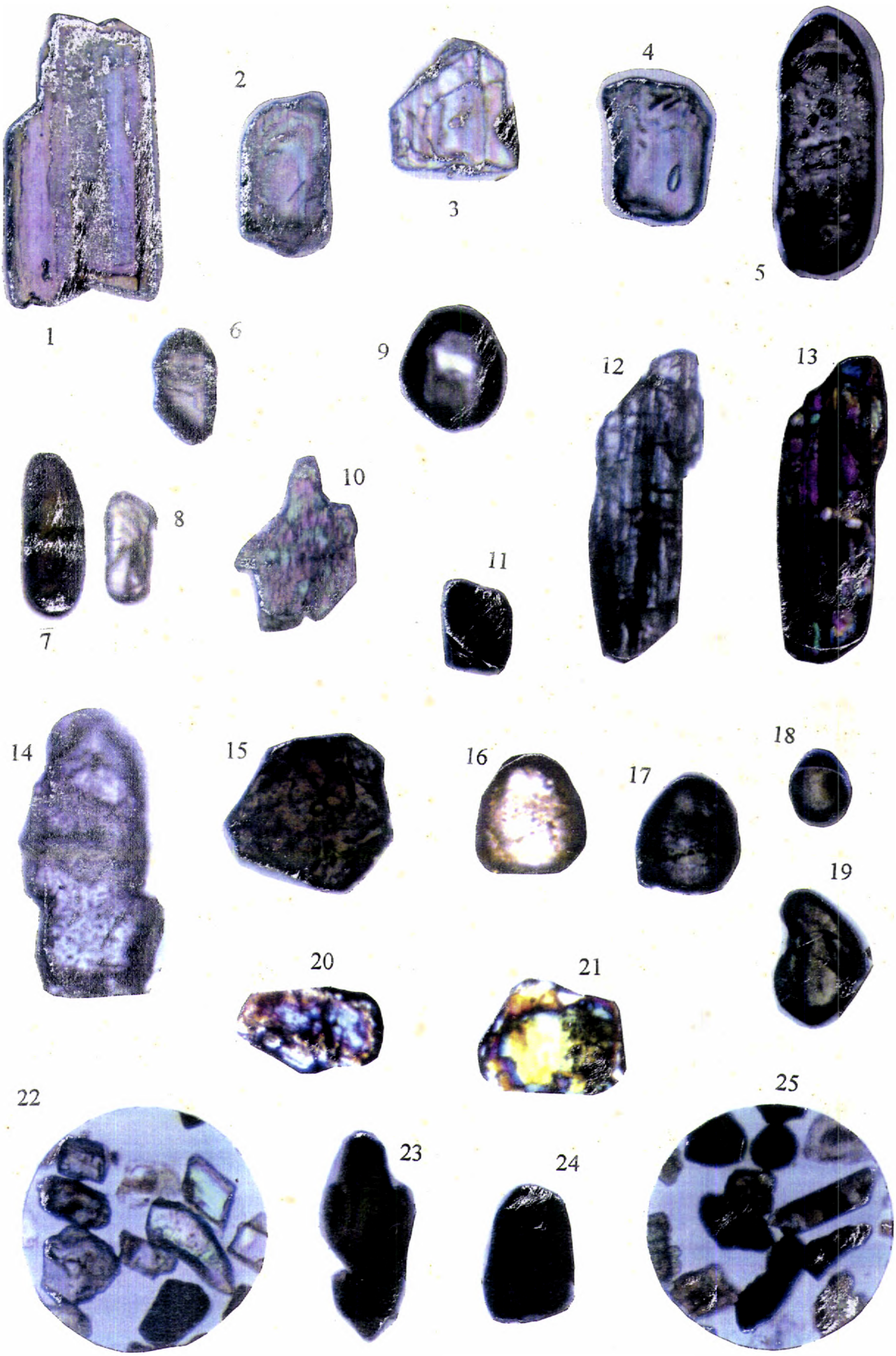
The heavy mineral contents in the fine sands of the sediment cores KC_2 and KC_3 varies widely and in general, they range from 3.64% to 7.81% with average total heavy content of 5.8%. The core KC_2 records higher amount of heavies than KC_3. The former core concentrates 6.21% of heavy minerals at about 10-20 cm depth whereas the latter core accomodates only 3.64% at the same depth. However, in the core KC_2, the fine sands exhibit 7.81% of heavy minerals at about 50-60 cm from below the surface, whereby the core KC_3 shows only 5.5% for the same depth. Similarly, the very fine sand fraction of the above core, ranges from 1.6% to 8.23% exhibiting an average total heavy mineral content of 8.97%. Here, the very fine sand accomodates enhanced accumulation of heavies than the fine counterparts. The very fine sand fractions of core KC_2 unveil approximately 3-7 fold increase of heavies than core KC_3.

4.3.2. **Heavy mineral assemblage**

Heavy mineralogical constitution of the sediments of the three mangrove ecosystems encompasses a spectrum of minerals which includes hornblende, hypersthene, zircon and sillimanite as major minerals, and biotite, garnet, monazite, kyanite and rutile as minor minerals (plate XIII). Table 11 furnish the abundances of heavy minerals in the fine and very fine sand fractions of surface as well as core

MINERALS IN PLATE XIII

1	- Sphene
2,3,8	- Sillimanite
4	- Sillimanite with fluid inclusion
5	- Cloudy Zircon with Pyramidal termination
6	- Zircon
7	- Zircon (Metamict variety)
9	- Cloudy Zircon
10	- Hypersthene (Crossed nicols)
11	- Rutile
12,13	- Kyanite (Plane polarised and Crossed micols)
14,15	- Garnet
16,17	- Monazite (Crossed nicols and plane polarised light)
17,18,19	Monazite (with honey yellow colour)
20,21	- Altered Minerals.
22	- Sillimanite, Opaque and Garnet
23	- Hornblende
24	- Opaque (Sub-rounded)
25	- Opaque, Hornblende and hypersthene.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sediments. The minerals identified together with the characteristic optical features are given below.

4.3.2.1 Opaques

Opaques are abundant in the fine and very fine sands of all the three mangrove sediments. They range between 55.43% and 77.96% (av; 67.59%) in fine and 55.12% and 87.14% (av; 72.70%) in the veryfine sand grades of the Veli mangroves. In the core sediments, opaques vary from 38.58% to 81.04% in fine and 58.33% to 87.97% in very fine sands. Unlike Veli, the Kochi mangroves show comparatively lower values of opaque minerals (fine sand, av. 39.15 and very fine sand, av. 31.03%). The opaques of the above fractions in the core sediments reveal that, the fine fractions of sand is occupied by an average of 54.26% whereas the very fine fraction accounts for an opaque content of 36.64%. Examination of selected opaque samples of mangrove sediments under ore microscope shows that, majority of the opaque minerals are subrounded to well rounded. A few grains are scanned under reflected light which indicated that ilmanite constitutes a major part of the opaque population although, a minor part of ilmanites are altered to leucoxene. From ore microscopic studies of some selected samples, it is revealed that apart from ilmanite a minor amount of magnetite and haematite are also present in total opaque population. The value of opaques in the fine sand fractions of Kannur ranges from 38.43% to 64.13% (av; 51.2%) and that of very fine sand fraction varies from 38.12% to 58.16% (av; 47.79%). The above fraction in core sediments show a mean opaque content of 60.08% (in fine sands) and 41.34% (in very fine sands). It is generally observed that, core sediments of Kannur record substantially a high amount of opaques at lower depths than the deeper parts of both the fine and very fine sand categories. A comparison of the opaque contents of three mangroves indicate that the sediments at Veli possess higher opaque concentrates which is followed by Kannur and finally Kochi.

4.3.2.2 Amphiboles

Amphiboles are common rock forming minerals of many igneous and metamorphic rocks and are widespread in detrital sediments. Amphiboles constitute extremely complex group and show considerable variation in physical and chemical properties. Hornblende is the dominant amphibole member identified in the heavy residues of all the three areas. This mineral exhibits a wide variation in colour, brown, green or bluish green. They show perfect prismatic cleavage and in the coarser grades appears to be opaque and transluscent at the edges. Morphology of this grain varies from slender prisms and sometimes irregular or even rectangular in shape. Inclusions of accessory minerals and opaque particles are also observed.

The heavy mineral residues in the fine sands of Veli accounts for an average hornblende content of 0.73% (0.23% to 1.84%). In very fine sands, it is totally absent both in surface and core sediments. The concentration in the fine sands of the core sediments averages about 1.24%. However, in Kochi the average amount of hornblends in fine and very fine sand is almost equal in both surface and core sediments they range from 14.3% to 38.59% in the former and 1.24% to 35.97% in the latter. The value of hornblende range between 18.63% and 47.36% in very fine sands and its core counter parts show variation from 4.43% to 22.15%. Similarly, the fine sand fraction of Kannur shows an average of 17.66% (7.7% to 30.42%) and the core sediments demonstrate a mean hornblende value of 4.41% (5.12% to 7.85%). Likewise, the very fine sand fractions illustrate hornblende variations from 10.79% to 32.15% (av; 23.52%) and in core sediments the value fluctuates between 4.43% to 22.15% (av; 12.52%). Considering the contents of hornblende in the surface and core sediments of the three mangrove environments together, it is vivid that the Kochi area shows the highest percentage followed by Kannur and Veli.

4.3.2.3 Pyroxenes

Hypersthene is the principal pyroxene mineral identified from the study areas. It occurs as irregular fragments of larger crystals, cleavage pieces or short stubby prisms. It exhibits shades of pink, pale, reddish brown and green colours. The most diagnostic feature of hypersthene in the study area is the distinct pleochroism with varying intensities and parallel extinction.

The fine and very fine sand fractions of both the surface and the core sediments of Veli reveal the absence of hypersthene. The fine and very fine sand fractions of Kochi area amounts an average of 16.74% (9.52% to 32.95%) and 18.79% (9.80% to 38.3%). The surface sediments of Kannur show 2.52% to 10.16% (av; 5.3%) of hypersthene in fine and 2.89% to 8.92% (av; 5.72%) in very fine sands. But its average content in the above sand fractions of the core sediments are more or less equal and range from 1.5% to 5.74% (av; 3.72%) and 3.70% to 4.05% (av; 3.83%).

4.3.2.4 Biotite

It occurs commonly as flaky form, appears brownish under plane polarised light and also shows strong pleochroism. The content of biotite is totally absent or negligible in the sediments of Veli. The content of biotite ranges from 0.56% to 3.25% (av; 1.85%) in the fine sands and 0.89% to 3.52% (av; 1.7%) in the very fine sands.

4.3.2.5 Zircon

The Zircon grains are characterised by high relief and surrounded by a black halo. In the study area the morphology of zircons varies from sharp euhedral crystals to prismatic fragments. Some of them show perfect zoning, and parallel extinction. Metamict or Malacon Zircon (see plate XIII) a product of radiation damage resulting from the radioactive thorium and uranium in zircon is also observed from the sediments of Kochi and Veli environments. Radiation converts crystalline zircon into an optically amorphous structure and they are dusty, dark brown or black and are isotropic.

The fine and very fine sand categories of the surface sediments of Veli show an average of 4.10% (0.88% to 11.3%) and 3.25% (1.22% to 9.32%), respectively. However, in core sediments, the above sand fraction ranges between 1.17% and 1.30% (av; 1.23%) for the former and 0.62% and 3.92% (av; 2.43%) for the latter sand categories. Sediments with sizes of 120 ASTM demonstrates mean zircon value of 6.28% (2.3% to 26.73%) in surface and 3.3% (2.6% to 3.7%) in the core sediments of Kochi. But in very fine sands the amounts of zircon varies from 0.91% to 13.20% (av; 5.9%) in the surface and an average of 6.98% (3.22% to 10.29%) in the core sediments. Mangrove regions of Kannur unveil an average of 1.35% (0.52% to 2.01%) of zircon in the fine sands and 2.85% (1.12% to 4.58%) in very fine sands. The content of zircon in the core sediments averages to 2.50% and 2.32% in the fine and veryfine sand fractions, respectively.

4.3.2.6 Sillimanite

In the study area sillimanite is frequently occuring as long slender prisms, short-stout prismatic fragments, equant grains or irregularly shaped fragments of larger crystals. Prismatic grains are usually colourless. Brilliant interferance colours are fairly distinctive in zircons.

The surface sediments of Veli and Kochi areas show ranges of 16.10% to 36.76% (av; 24.34%) and 0.78% to 8.73% (av; 3.33%) of sillimanite in the fine sand and 12.85% to 39.1% (av; 21.63%) and 0.49% to 55.66% (av; 9.71%) in very fine grades. The content of sillimanite in the core VC_2 is higher (av; 55.6%) than that of VC_1 (av; 10%). However, the sillimanite concentration in the very fine sands of surface and core sediments of Veli and Kochi mangroves fluctuates between 12.85% and 39.10% (av; 21.63%) as well as 0.49% and 55.66% (av; 9.68%). The cores CC_2 and CC_3 of Kochi exhibit minor amounts of sillimanite (Table 11). The sand sizes of the fine and the veryfine sediments of Kannur exhibit averages of 15.34% (9.92% to 19.49%) and 15.16% (10.31% to 19.20%), respectively. Similar to the core VC_2 of Veli, the Kannur mangroves too demonstrate enhanced accumulation of sillimanite in core sediments (av; 24.23%) in fine sand and an average of 31.21% in very fine sands.

4.3.2.7 Monazite

The mineral monazite posseses high relief, resinuous lusture and dark rim surrounding the outline. Grains are dominantly well rounded, egg shaped or spherical. It shows varying colours from pale yellow, to almost colourless or even pale amber. Rounded morphology, high relief, honey yellow colour under plain and cross polarised light are the diagnostic features of this mineral.

The fine and very fine sand fractions of Veli (av; 3.24% for fine and 3.27% for very fine) exhibit higher concentrations of monazite than the corresponding surface sediments (av; 2.54% for fine and 2.29% for very fine sands). However, the Kochi mangroves reveal very little accumulation of monazite in the fine and the very fine sands of both surface and core sediments which in general, exhibit average concentration usually less than 1% (Table 11). But the average content of monazite in the sand fractions of surface and core sediments of Kannur mangroves gives values between 1% to 2%.

4.3.2.8 Garnet, Rutile and Kyanite

Detrital garnets occur as euhedral crystals, sharp irregular fragments and subrounded to rounded grains. High relief and isotropic character enables easy diagnosis. Detrital rutile is generally small and because of extremely high refractive indices, this mineral shows a thick black halo sorrounding the grain. Rutile grains identified from the study sites are either euhedral with well developed terminations or slender prisms. It possesses shades of red, especially deep blood red colour and very high relief. Kyanite grains of these mangrove environments are quite large and are more frequent in coarser grades. The grains are mostly angular, bladed or prismatic. Kyanite is often colourless and rarely blue. Large extinction angle and good interference figure provide easy diagnosis of this mineral.

Garnet is totally absent in the Veli mangroves, whereby the very fine sands of Kochi record higher amount of garnets (av; 1.92%) than the fine sands (av; 0.64%). But in Kannur, the reverse pattern is observed in that the fine sand demonstrates higher amount (av; 1.78%) of garnets than the very fine (av; 1.48%). Mangrove sediments of Veli is totally devoid of kyanite and the presence of rutile is nominal. In general, 1% to 3% of kyanite and rutile are present in the fine and very fine sediments of Kochi and Kannur regions.

4.3.2.9 Altered minerals

This category includes minerals which could not be confirmed because of their highly altered nature. Majority of these minerals appear to be hypersthene, hornblende or biotite based on their shapes and colours.

4.3.3 **Correlation matrix of heavy minerals**

Correlation matrix of total heavy minerals (THM), light minerals and the heavy mineral assemblage in the fine and very fine sand fractions of the study areas has been worked out to unravel the relationship existing among these parameters (Table 12 and 13). The total heavy minerals, yield a significant positive bearing on opaques (r = 0.35 for fine and 0.57 for very fine) and monazite (r = 0.47 and 0.41 for fine and very fine sands), whereby the amphiboles and pyroxenes exhibit negative relationship with the total heavies (amphiboles r = – 0.27 and -- 0.71 for fine and very fine; pyroxenes: r =–0.20 for fine and–0.54 for very fine sands). The increase in the content of denser heavy minerals like opaques and monazite with increase in total heavies of sediments illustrates a high energy regime recquired for the selective sorting of these minerals. The comparative depletion of amphiboles and pyroxenes with increase of total heavies manifest that, the lighter heavies are generally transported along with lighter mineral fractions of sediments (mainly quartz). This is further supported by negative correlation of opaques with amphiboles (r = – 0.30 for fine and – 0.44 for

Table - 12

Interrelationship between heavy minerals in the fine sand fractions of the study areas.

	THM	TLM	OP	N-op	Hb	Hy	Bi	Si	Zi	Ga	Mo	Ky	Ru	Al/oth
THM	1.00													
TLM	-0.10	1.00												
OP	0.35	-0.05	1.00											
N-op	-0.27	0.44	-0.08	1.00										
Hb	-0.27	0.49	-0.30	0.78	1.00									
Hy	-0.20	0.26	-0.34	0.74	0.81	1.00								
Bi	-0.12	0.14	-0.14	0.32	0.33	0.27	1.00							
Si	0.05	-0.29	0.33	0.06	-0.55	-0.44	-0.15	1.00						
Zi	-0.17	0.36	0.05	0.28	0.18	0.023	-0.03	-0.31	1.00					
Ga	-0.15	0.45	0.05	0.20	0.19	0.044	0.08	-0.30	0.50	1.00				
Mo	0.47	-0.25	0.52	0.22	-0.46	-0.40	-0.22	0.43	-0.11	-0.10	1.00			
Ky	0.32	0.028	0.21	0.01	-0.10	-0.06	-0.08	-0.08	0.17	0.34	0.12	1.00		
Ru	0.23	0.19	0.09	0.13	0.07	0.09	-0.01	-0.21	0.30	0.17	0.09	0.46	1.00	
Al/oth	0.29	0.09	0.46	-0.08	-0.19	-0.16	-0.13	0.11	0.02	-0.03	0.28	0.047	0.03	1.00

r values	Level of significance	r values	Level of significance
0.27 to 0.33	0.1 to 0.05	0.41 to 0.52	0.01 to 0.001
0.33 to 0.38	0.05 to 0.02	>0.52	< 0.001
0.38 to 0.41	0.02 to 0.01		

THM = Total Heavy Minerals
TLM = Total Light Minerals
N-op = Non - opaques
Hb = Hornblende
Al/oth = Altered / others
Hy = Hypersthene
Bi = Biotite
Si = Sillimanite
Zi = Zircon
Ga = Garnet
Mo = Monazite
Ky = Kyanite
Ru = Rutile

Table - 13

Interrelationship between heavy minerals in the very fine sand fractions of the study areas.

	THM	TLM	OP	N-op	Hb	Hy	Bi	Si	Zi	Ga	Mo	Ky	Ru	Al/oth
THM	1.00													
TLM	0.09	1.00												
OP	0.57	-0.47	1.00											
N-op	-0.75	-0.06	-0.31	1.00										
Hb	-0.71	-0.28	-0.44	0.81	1.00									
Hy	-0.54	0.10	-0.42	0.69	0.65	1.00								
Bi	-0.29	0.41	-0.20	0.43	0.31	0.59	1.00							
Si	-0.17	0.04	0.28	-0.03	-0.31	-0.24	-0.27	1.00						
Zi	-0.34	-0.16	0.01	0.29	0.28	0.08	0.22	-0.39	1.00					
Ga	-0.29	-0.06	-0.17	0.37	0.26	0.49	0.23	-0.24	0.39	1.00				
Mo	0.41	0.15	0.53	-0.30	-0.52	-0.39	-0.24	0.33	-0.21	-0.13	1.00			
Ky	-0.21	-0.16	0.15	0.06	0.03	-0.19	-0.09	-0.01	0.42	0.08	0.04	1.00		
Ru	-0.25	0.15	-0.17	0.33	0.39	0.44	0.40	-0.13	-0.17	-0.02	-0.24	0.17	1.00	
Al/oth	-0.64	-0.27	0.12	0.13	0.12	0.02	-0.00	-0.02	0.13	0.11	0.21	-0.16	-0.18	1.00

r values	Level of significance	r values	Level of significance
0.27 to 0.33	0.1 to 0.05	0.41 to 0.52	0.01 to 0.001
0.33 to 0.38	0.05 to 0.02	> 0.52	< 0.001
0.38 to 0.41	0.02 to 0.01		

THM = Total Heavy Minerals
TLM = Total Light Minerals
N-op = Non - opaques
Hb = Hornblende
Al/oth = Altered / others

Hy = Hypersthene
Bi = Biotite
Si = Sillimanite
Zi = Zircon

Ga = Garnet
Mo = Monazite
Ky = Kyanite
Ru = Rutile

very fine sands) and pyroxenes (r = – 0.34 for fine and – 0.42 for very fine sand fractions) and positive affinity with sillimanite (r = 0.33 and 0.28 for fine and very fine sands) and monazite (r = 0.53 for fine and very fine sands). The strong positive correlation of amphibole with pyroxene (r = 0.81 and 0.65 for fine and very fine) and negative correlation with sillimanite (r = -0.56 for fine and -0.31 for very fine sands) and monazite (r = -0.47 and -0.52 for the above fractions) reaffirm the above view. Garnet exhibits strong positive relation with rutile (r = 0.47) in fine sands and negative relation in very fine sands. Since these minerals are sparsely distributed in heavy mineral crop of the study areas, the significance of these minerals in the correlation matrix has not worked out in detail.

The clustering pattern of minerals (Fig. 19) for the above sand fractions show closely knitted group of minerals such as opaques, monazite with THM which indicates a high energy denser group. Moreover, hornblende and hypersthene exhibit strong bonding as they represent the lighter heavies and low energy regime. The degree of bonding of heavy minerals which are present in traces has not been taken seriously here for detailed analysis.

4.3.4. **Provenance**

The study areas encompass distinct suits of heavy minerals (Fig 20) reflecting differences in the source rock contribution of sediments to the respective areas. The heavy mineral assemblage of the Veli area (Fig 20) consist of opaques and sillimanites (in decreasing order) as the major (>10%) minerals and zircon, monazite, hornblende, hypersthene, biotite, garnet, kyanite and rutile as minor/trace minerals (Table 11). Of the major heavies, opaques constitute bulk of the heavy mineral population, and consist mainly of ilmanite and accessory amounts of magnetite. From the geologic setting of the Veli mangroves (Fig. 7), it is evident that the

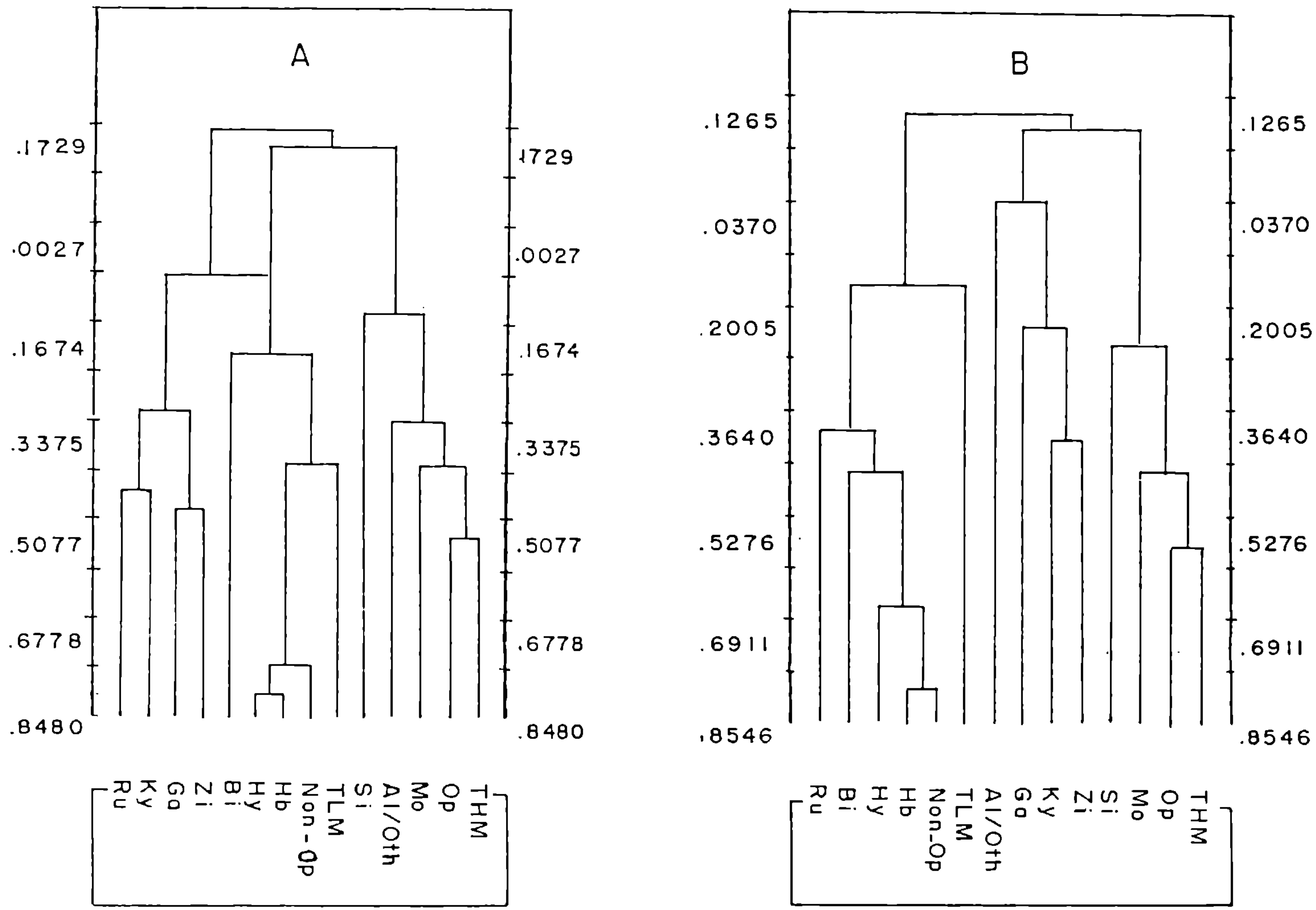

Fig. 19. DENDROGRAMS SHOWING THE INTERRELATIONSHIPS AMONG VARIOUS HEAVY MINERALS, THM AND TLM IN FINE (A) AND VERY FINE (B) SANDS.

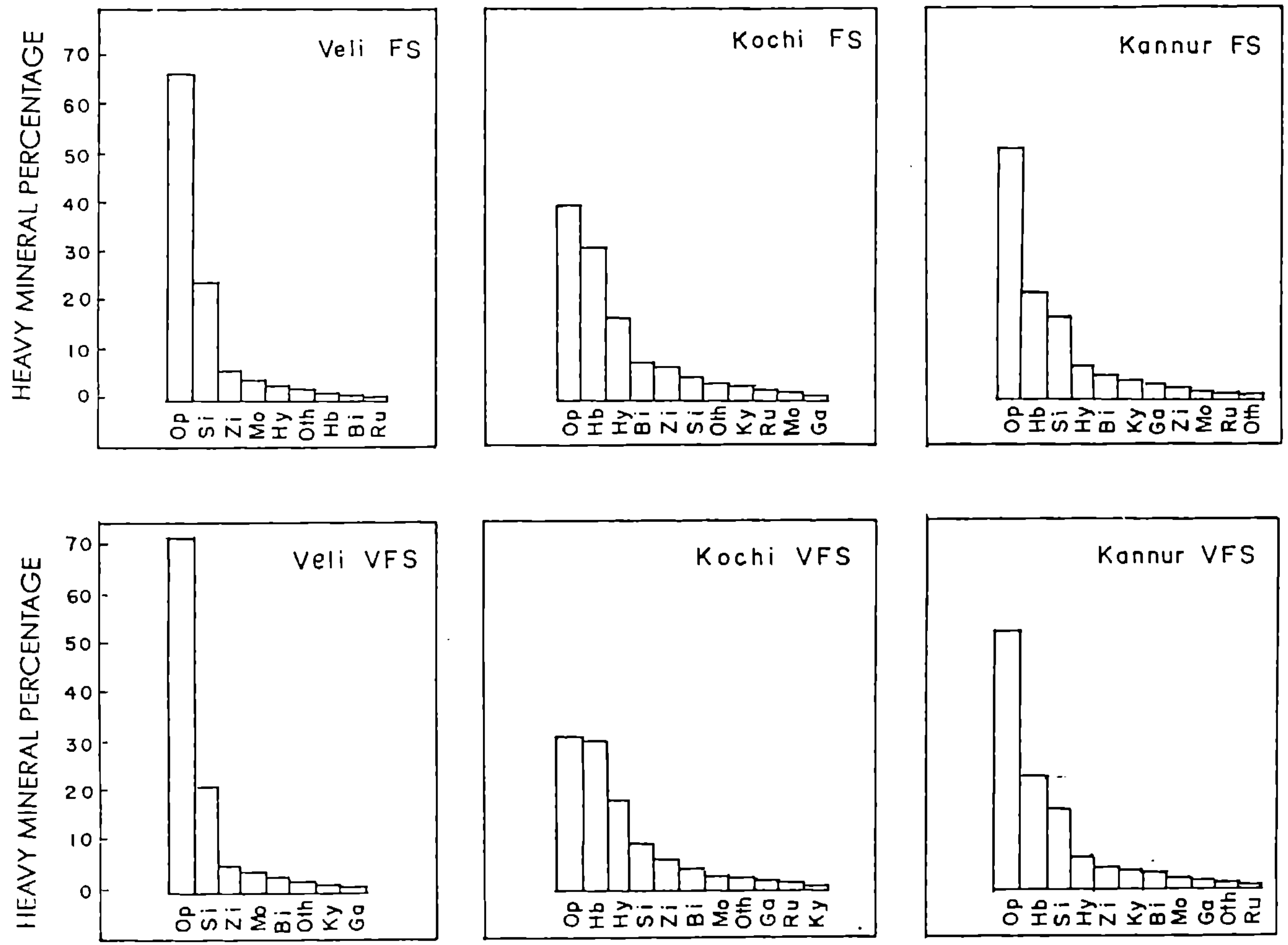

Fig. 20. AVERAGE HEAVY MINERAL CONCENTRATES IN THE FINE SAND (F S) AND VERY FINE SAND (VFS) FRACTIONS OF VELI, KOCHI AND KANNUR MANGROVES.

region is influenced by sediment inputs from the barrier beaches as well as the Kannammoola Thodu (minor drainage channel). The major drainages which brings sediments from the Western Ghats to the beach segment adjacent to Veli mangroves are the Karamana, Neyyar and the Vamanapuram rivers. These rivers bring substantial quantities of weathered detritus (sediments) from the so-called petrographic province of south Kerala - the Kerala khondalite belt. These sediments reach the mangrove area due to littoral drift. The mineral, sillimanite is indicative of khondalitic province. However, the low amount of garnet, (another heavy mineral abound in khondalite), recorded in the heavy mineral suite of Veli might be attributed to the alteration of this mineral due to its comparatively lower stability index (Dryden et al, 1946). Monazite is presumed to be liberated from sialic rocks like granites, pegmatites, etc., intruded within the rocks of Kerala khondlite belt. Hornblende and hypersthene indicate the role of hornblende-biotite gneisses and charnockites in contributing sediments to this area. The geological map (Fig. 7 A) of the area also supports the probable provenance sources to this region.

The heavy mineral suite of the mangrove patches of Kochi area is characterized by the predominance (>10%) of opaques, hornblende and hypersthene. In addition to this, zircon, sillimanite and biotite are also present in substantial quantities. Monazite, garnet, kyanite and rutile are present only in small amounts (Fig 19). Earlier, Padmalal, (1992) has also reported a similar trend in the contents of heavy mineral species in the sand fraction of the Vembanad estuarine sediments adjacent to the various mangroves patches of Kochi. The Kochi area is influenced by sediment load from seven major rivers such as Periyar and Chalakkudy, (debouching north of Kochi) Achankovil, Pamba, Meenachal, Manimala and Muvattupuzha (debouching south of Kochi). Majority of these rivers drain through the Archean crystallines composed mainly of charnockites and hornblende - biotite gneisses (Fig.7). The substantially high ionosilicates in the medium and fine sand heavy mineral fractions indicate influence of former two rock types in contributing sediments to this area. Sillimanite as recorded in Kochi mangroves is presumed to be derived from the khondalitic sources. Besides the Western Ghats major speedy disintegration of charnockites and hornblende biotite blocks used for the construction of sea walls and groyins can also contribute hornblende and hypersthene to the mangrove environments which are very close to the sea shores. The cloudy zircons with pyramidal and rounded terminations also indicative of charnokitic province. Monazite according to Padmalal, (1994) is derived mainly from the acidic intrusive rocks of the precambrian age. Contrary to the above two (Veli and Kochi) mangroves, the Kannur mangroves depict a unique association of opaques, hornblende and sillimanite as the major (>10%) category (Fig.19). However, the content of opaques exhibit approximately two fold enrichment compared to hornblende and sillimanite. Of the other heavy minerals, hypersthene is the predominant one. This unique mineralogical suite of Kannur mangroves perfectly reflects the diversities in the catchment regions of the major rivers (Aralampuzha river, Valapattanam river and Kuppam river) of Kannur area to this mangroves. From the geological setting (Fig 7) it is very evident that the heavy mineral assemblages of the area is regulated by the crystalline rock complexes of charnockites, hornblende gneisses, pyroxenes granulites and quartz mica schists.

An overall evaluation of the major heavy mineral suites of three mangrove environments studied reveals unique mineralogical association, which in turn reflecting the diversities in provenance characteristics. The Veli mangrove is exhibited by opaque-sillimanite association (wherein the opaque content is 2-3fold higher than sillimanite). Kochi by opaque - hornblende - hypersthene (wherein the opaque content is 2 fold lower compared to the cumulative contents of the remaining two) and Kannur by opaque - hornblende - sillimanite associations (wherein the opaque is substantially higher than hornblende but approximately equal compared to the cumulative amounts of the remaining two).

4.4. CLAY MINERALS

The percentages of various clay minerals (kaolinite, montmorilonite, illite and Gibbsite) recorded from the mangrove forested regions of Veli, Kochi and Kannur areas are furnished in Table 14. The kaolinite content in the intertidal zones of the Veli ecosystem varies between 68.02% and 87.85% (av; 77.94%). However, its average content at Kochi and Kannur mangrove areas are 42.57% (38.64% to 46.50%) and 49.67% (48.65% to 50.69%), respectively. Next to kaolinite, montmorillonite occupy the second position among the clay mineral suite. Sediments of Kochi exhibits comparatively high content of montmorillonite (29.9% to 39.17%, av; 34.54%) and reveal more than 3 fold enhancement than Veli (av; 9.53%). However, the clay fraction of Kannur is characterised by moderate amount of montmorillonite (av; 26.75%). Of the three mangroves, the sediments of Kochi exhibit relatively higher percentage of illite (24.27%) compared to the other two stations and show that, the Kannur sediments encompasses nearly half the amount of illite than Kochi region (Table 14). The concentration of gibbsite is nominal (Veli, 6.85%, Kochi 10.76% and Kannur 17.40%) compared to the other clay mineral constituents.

The observed high concentration of kaolinite in the three mangrove environments reflects greater intensity of laterite denudation processes operating in the drainage basins of these mangroves. Biscaye, (1964) and Fairbridge, (1967) have observed that kaolinite is one of the stable products of lateritization. The exceptionally high percentage of kaolinite recorded from Veli (av: 77.94%) mangroves could be attributed to the addition of clays from the English Indian clay

Table - 14
Mineralogical constitution of clay fractions of Veli, Kochi and Kannur mangroves.
(Values are expressed in percentage)

Sampling locations	Sample No.	Kaolinite	Illite	Montmorillonite	Gibbsite
Veli	4.b	68.02	18.24	13.73	--
	8.b	87.85	--	5.32	6.85
Kochi	17.b	38.64	24.27	29.90	7.19
	23.b	46.50	--	39.17	14.3
Kannur	25.b	50.69	--	25.35	23.96
	28.b	48.65	12.35	28.15	10.85

factory located near Veli estuary. The occurrences of high amount of kaolinite along with laterite were reported by Soman and Machado, (1986); Sajan, (1986-1988). Ghosh, (1986) reported the presence of small amount of gibbsite and montmorillonite along with kaolinite deposits. Weaver, (1967) consider that the clay mineral content in the estuaries and marine deposits is largely by detrital origin, reflecting characters of source material. Whitehouse et al, (1960) provided data to support some aspects of this argument propagated by the detrital school of thought. The advocates of diagenetic school of thought claim that, once clay minerals enter into saline water, they are no longer be in equilibrium with sea water and will undergo partial or complete chemical transformations to take up more stable phase. Grim, (1968) and Nelson, (1959) explained that, environmental diagenesis is the reason for clay mineral variation. Rao et al, (1988) proved that montmorillonite is the most dominating clay mineral along the Kerala coast. He further stated that variation in the clay mineral distribution is attributed to the differences in the energy of various environments and size segregation of minerals. The higher proportions of montmorillonite with little amount of illite and gibbsite in the mangroves studied can be explained as due to the transportation of sediments from the offshore to the estuaries by tidal currents (Rao, 1992). This supports the role of physical sorting and size segregation process for the observed diversities in the content of clay minerals of the three mangroves. Hence, it is evident that the above clay minerals are source controlled and their variation are due to physical sorting.

CHAPTER 5

GEOCHEMISTRY

5.1 INTRODUCTION

Geochemical studies of aquatic sediments have increasingly being carried out in the last few decades, owing to the need for an understanding of geochemical pathways of toxic contaminants that causes disastrous effect to our environments. These studies were also helpful in assessing the degree of pollution of the regions surrounding the aquatic regimes. It is well known that sediments are both carriers and potential sources of natural geochemical constituents derived principally from rock weathering. However, over the 200 years following the beginning of industrialization, huge changes in global budget of chemical signals, particularly of toxic contaminants have occurred challenging regulatory systems which took millions of years to evolve. In the early 1970's following the catastrophic events of cadmium and mercury poisoning, sediment associated trace metal contaminants, their carrier phases and natural regulating mechanisms have received wide public attention. Since then, exhaustive research has been carried out in the world's major estuarine regimes to monitor the trace metal discharges and its behaviour under different geochemical set ups. Gibbs, (1977) proved that the heaviest enrichment of metal occurs in the finer grades, the particulate ranging in diameter from 0.21 micro meter to 20 micro meter.

The variations of major and trace elements in the sediments are the reflections of the various factors which govern their distribution. These elements are introduced in the aquatic environment either in solid/colliodal or in soluble forms by water and wind. Elements which have their source in solid materials include those located within the lattice structure of lithogenous minerals and those incorporated into surfaces by adsorption and ion exchange processes. Solids introduced into the marginal seas especially the nearshore and mangrove environments are mainly the weathered products of the continents transported to the depositional sites by rivers and streams. Recent decade bestowed considerable attention on the elemental distribution of estuarine environments. Many of the elements in estuarine sediments can have more than one source and often are associated with more than one host mineral. The present chapter discusses the geochemical aspects of organic carbon, P, Na, K and heavy metals (Fe, Mn, Co, Pb, Cd, Cu and Zn) in the surface and core sediments of the mangrove environments of Veli, Kochi and Kannur regions and thereby to evaluate the interrelationship existing among them.

5.2 REVIEW OF LITERATURE

Recent years have witnessed a remarkable breakthrough in the study of heavy metal geochemistry, leading to the prompt knowledge of the estuarine geochemical processes. A number of geological agents are actively involved in the transfer of heavy metals from the terrestrial environment to the ocean realm. Rivers and estuaries are the major path ways in tropical and sub tropical region (Gibbs, 1977; Lal, 1977). Subramanian et al, (1985) computed that about 20% of the global supply of sediments to ocean is from the Indian subcontinent. Many researchers (Gibbs, 1967; Seetharamaswamy, 1970; Satyanarayanan, 1973; Seralathan, 1979; Stallard and Edmond, 1983; and Subramanian et al, 1985) authentically established the geochemical processes of different fluvial environments. Present decade have also achieved a great spurt of renewed activity to identify the source and sink of heavy metals in estuaries and mangrove environments. The fate of heavy metals in these environments is of extreme importance due to their impact on ecosystem (Vale, 1986; Mance, 1987; Klomp, 1990; and Windom, 1990). Recent interest in anthropogenic contamination of the mangroves by heavy metals, has magnified the urgency in elucidating the cyclicity of toxic metals in estuaries and mangrove environments. Some serious efforts were exercised by Wakushima et al, (1994) inorder to study the soil characteristics of the mangrove forests of Thailand. Rao, (1992) made an attempt to evaluate the sedimentary characteristics of Godavari estuary. Studies on the organic matter, nitrogen and phosphorus in the Portnovo mangrove sediment was conducted by Shanmughappa, (1987). The effect of oil pollution on mangrove sediments and species were reported by Jagatap and Untawale, (1980). A systematic attempt has been made by Badarudeen et al, (1996) to evaluate the trace metal geochemistry of Fe, Mn, Cu, Co, Zn and Pb contents of the mangrove sediments of Kumarakom, along the south west coast of India as well.

5.3 RESULTS AND DISCUSSION

5.3.1 Hydrogen ion concentration (pH)

The pH designates negative reciprocal of the logarithm of hydrogen ion concentration and is expressed as $-\log_{10} [H^+]$, where H^+ is the concentration of Hydrogen ions. pH affords a measure of the acidity or alkalinity. A pH value of '7' denotes neutral environmental setup or in otherwords, the existence of balance between dissociated hydrogen and hydroxyl ions. Excess of hydrogen ions impart acidity to the environment and hence the pH value in that case will be less than '7'. Conversely, an excess of hydroxyl ion imparts basicity and pH value will be greater than 7.

In the mangrove environments of Veli, Kochi and Kannur there is a marked difference in pH between the surface sediments and the deeper layers. In between them are numerous localised intermediate zones of varying pH resulted due to the imperfections in mixing or diffusion and from varying biological activities. Systematic examination of the pH values of Veli shows variation from 5.08 to 7.75 in surface sediments whereas in cores the sediments are slightly acidic to slightly alkaline (6.84 - 7.65). However, the sediments of Kochi exhibits slightly elevated values of pH compared to Veli in surface (6.2 - 8.2) as well as in core sediments (5.96 - 8.95). The mangrove sediments of Kannur also show slightly acidic to alkaline nature and exhibits values of 6.5 to 7.81 in surficial sediments and 5.9 to 7.41 in core sediments.

5.3.2 **Organic carbon (C-org)**

Organic carbon content in recently deposited sediments has received much attention in environmental monitoring and management programmes because of their bearing on the physical, chemical and biological process to which the sediments have been subjected. Recent researches are giving utmost importance to the estimation of C-org as it forms the source material for hydrocarbons and also playing a vital role in the dispersal pattern of many major and trace elements. In addition to this, knowledge of C-org helps to ascertain the nature of depositional environments and also the palaeogeographic conditions of the ancient sediments. The sedimentation followed by diagenetic decomposition of C-org can alter the Eh-pH of aquatic environments. Further, the C-org often provides the main energy source for the heterotrophic organisms as well. Since mangrove environments are one of the highly productive nearshore aquatic ecosystems, an understanding of the distribution of C-org and its bearing on other physico-chemical and biological parameters is a prerequisite for assessing and determining the extend of nutrient input and the biogeochemical transformations of major and minor/trace elements of the system. The present study describes the distribution and geochemical behaviour of organic carbon in the surface and core sediments of the three mangrove patches located at Veli, Kochi and Kannur regions.

5.3.2.1 Surface sediments

Table 15 furnishes the percentage distribution of C-org in the above environments and Table 16 and 17 summarises its averages and ranges along profiles (landward, intermediate and shallow water profiles), and in different textural units, respectively. The interrelationships between C-org and mud content for the surface sediments are depicted in Figs 21 (Veli), 22 (Kochi) and 23 (Kannur).

The C-org distribution in Veli mangrove sediments is controlled mainly by the textural attributes of sediments and in general, varies between 0.32% (sand) to 7.29% (sandy silt) (av; 3.71%). As mentioned in chapter 3, this mangrove region shows highly complex textural diversities. In sandy silt layer, the C-org ranges from 4.98% to 7.21% (av; 5.87%) whereas in sandy mud the C-org varies from 4.98% to 7.20% with a mean of 5.87%. However, its concentration in the muddy sand textural unit varies from 0.76% to 3.9% (av: 2.13%) and the clayey sand and silty sand textural parameters demonstrate an average content of 1.4% (0.95% to 1.85%) and 1.03% (0.85% to 1.5%), respectively. The average distribution of C-org in various textural classes reveals their relative order of abundance as sandy silt > sandy mud > muddy sand > clayey sand > silty sand > sand. Its distribution along profiles divulges that, the landward profile accounts for both the highest (7.29%) and lowest (0.32%) amounts (av; 4.25%) and along Intermediate and shallow water profile it varies from 0. 76% to 6.52% (av; 2.67%) and 0.84% to 6.45% (av; 2.05%), respectively. The C-org content shows strong positive covariance with mud content and is depicted in Fig. 21.

Table - 15

Chemical parameters estimated in the surface sediments of Veli, Kochi and Kannur mangroves.

Sample No.		pH	C-org	$CaCO_3$	Fe	Na	K	P	Mn	Co.	Pb	Cd.	Cu.	Zn
			(%)						(ppm)					
Veli mangroves														
1.	a	5.22	3.90	6	1.25	1.4	0.6	0.99	39	53	79	<1	61	58
	b	5.60	3.10	13	0.67	1.2	0.4	0.13	142	31	40	1	41	68
	c	5.75	6.45	6	0.83	2.6	0.8	1.94	64	13	55	1	41	39
2	a	5.38	5.02	5	1.00	1.0	0.3	0.99	33	46	32	<1	48	72
	b	6.04	3.12	15	0.72	1.4	0.3	0.36	124	26	56	<1	38	64
	c	6.70	3.08	12	0.74	4.2	1.8	0.30	180	29	40	<1	20	53
3	a	6.32	5.00	8	1.01	1.8	1.0	0.15	29	42	55	1	41	80
	b	6.57	3.89	5	0.56	1.8	1.2	0.14	157	31	56	2	46	68
	c	6.20	2.60	8	1.19	3.2	1.3	0.19	217	31	63	1	23	68
4	a	6.32	2.76	11	1.08	2.4	0.9	0.91	27	40	71	1	43	22
	b	6.51	1.01	7	0.95	2.8	0.7	0.05	202	22	87	<1	51	60
	c	6.40	1.50	5	1.04	2.8	1.1	0.13	303	20	63	2	25	84
5	a	6.30	2.64	7	1.24	3.4	1.2	0.78	97	49	71	1	51	58
	b	6.61	2.22	8	0.92	3.2	0.8	0.09	241	31	103	<1	51	75
	c	6.77	1.15	8	0.70	2.4	1.0	0.10	388	15	71	1	23	90
6	a	6.27	1.95	5	1.34	4.2	1.6	0.24	82	42	48	1	53	54
	b	6.04	1.85	4	1.05	1.4	0.9	0.71	120	40	79	<1	81	62
	c	5.92	0.95	6	0.98	4.2	1.2	0.13	303	19	63	<1	30	62

Sample No.		pH	C-org	$CaCO_3$	Fe	Na	K	P	Mn	Co.	Pb	Cd.	Cu.	Zn
			(%)						(ppm)					
7	a	6.55	4.92	11	1.08	3.4	1.3	0.73	111	55	55	2	61	61
	b	6.78	5.13	10	0.85	1.6	0.8	0.61	95	26	63	<1	44	121
	c	6.37	0.84	10	1.29	4.0	1.8	0.17	237	20	40	1	40	45
8	a	5.05	0.90	4	1.18	2.6	0.6	0.10	173	26	24	3	33	53
	b	6.37	0.85	11	0.83	4.0	0.9	0.27	87	35	72	1	23	107
	c	7.75	0.96	12	0.90	6.2	2.1	0.18	124	13	32	1	38	40
9	a	6.77	4.98	5	0.83	1.6	0.9	1.2	194	22	16	2	35	57
	b	6.69	0.76	5	1.03	8.0	0.2	0.12	60	30	16	2	40	44
	c	5.95	1.16	10	1.05	5.2	2.2	0.30	138	11	25	1	30	28
10	a	4.72	6.20	5	1.08	1.8	0.8	1.7	221	20	18	BDL	36	60
	b	6.82	1.00	6	0.98	1.4	0.5	0.12	217	27	24	2	59	53
	c	6.52	1.15	7	1.23	0.8	1.2	0.13	173	15	24	<1	38	37
11	a	5.70	0.32	6	1.11	0.8	0.2	0.09	237	19	20	<1	33	62
	b	6.15	2.99	11	0.63	1.0	1.2	0.14	165	20	32	3	25	63
	c	6.87	0.98	10	0.98	1.4	0.8	0.11	212	17	55	<1	41	40
12	a	5.89	5.02	3	0.87	1.6	0.9	1.3	128	40	71	1	36	74
	b	5.64	0.95	12	0.81	2.8	1.3	0.18	97	46	40	2	38	72
	c	6.91	0.89	10	1.02	2.4	1.0	0.10	130	15	40	1	35	35
13	a	5.04	7.05	4	1.95	1.2	0.5	1.5	54	51	79	<1	51	77
	b	5.45	6.52	10	0.70	3.2	2.1	1.4	60	35	24	<1	64	86
	c	6.82	2.57	4	1.24	3.2	1.3	0.16	171	29	16	2	65	43
14	a	6.23	5.94	5	1.09	1.6	0.9	1.5	157	37	87	1	23	78
	b	5.08	5.64	6	0.83	1.8	0.7	1.6	192	20	48	2	46	71
	c	5.05	5.49	8	1.27	4.2	1.8	1.3	238	26	48	2	35	48
15	a	6.50	7.29	3	0.89	4.2	1.3	1.8	320	15	32	2	28	77
	b	6.07	0.98	7	0.92	4.0	0.4	0.03	262	20	63	1	43	75
	c	6.19	1.10	10	1.68	3.6	1.4	0.14	287	18	32	2	30	64

Sample No.		pH	C-org	$CaCO_3$	Fe	Na	K	P	Mn	Co.	Pb	Cd.	Cu.	Zn
			(%)						(ppm)					
Kochi mangroves														
16	a	7.5	3.43	19	3.57	1.6	1.0	5.69	86	44	30	1	69	59
	b	7.6	3.62	15	6.10	1.6	1.0	4.15	104	55	31	1	71	61
	c	7.0	4.89	20	6.05	3.4	2.7	5.04	168	86	18	1	58	91
17	a	6.8	4.65	18	6.78	1.8	0.7	5.64	80	114	20	1	21	83
	b	7.8	4.63	16	5.52	4.2	2.2	5.64	104	120	26	3	59	32
	c	8.2	4.30	14	6.97	2.8	1.7	6.35	138	141	21	2	50	36
18	a	79	4.85	10	6.67	1.2	0.6	7.03	171	10.7	29	2	40	41
	b	7.3	4.25	12	6.91	2.2	1.5	6.17	100	58	27	3	60	34
	c	7.6	4.32	16	6.47	1.2	0.7	6.12	86	12	39	1	15	31
19	a	7.2	1.13	11	1.56	4.2	2.2	1.71	94	122	46	<1	63	15
	b	7.1	1.00	5	2.09	3.4	2.2	1.78	69	78	51	1	30	17
	c	7.5	1.27	10	1.92	1.4	0.7	2.34	103	118	28	3	44	27
20	a	7.4	0.98	9	3.40	1.7	1.2	2.19	60	98	24	2	56	29
	b	8.1	1.34	10	2.06	3.1	2.2	2.09	48	110	11	3	54	30
	c	8.0	1.22	10	2.65	3.4	2.5	2.26	40	47	27	1	16	23
21	a	6.2	0.52	5	4.21	2.5	1.7	2.11	122	65	38	2	12	21
	b	7.1	4.12	12	7.00	1.9	1.7	4.86	90	73	42	1	14	48
	c	7.7	1.30	7	2.90	4.08	0.6	3.27	94	84	27	1	17	37
22	a	7.3	0.62	15	2.14	2.2	1.5	2.39	111	94	49	2	35	36
	b	7.5	4.75	16	5.90	1.7	1.5	3.93	99	89	56	2	50	29
	c	7.9	0.64	14	2.65	1.9	1.5	2.97	112	103	25	1	42	32
23	a	7.3	1.58	14	4.32	2.8	1.7	3.68	104	116	36	2	69	28
	b	7.6	1.22	10	2.81	3.4	2.2	3.10	63	128	48	1	49	30
	c	7.4	3.35	21	3.87	2.8	2.5	4.26	75	114	26	2	21	40
24	a	8.1	1.92	13	3.87	2.8	3.2	3.78	122	114	30	2	30	46
	b	7.4	3.41	9	4.35	1.2	0.9	4.51	105	128	17	3	52	51
	c	7.4	1.24	14	2.56	1.6	1.0	3.85	96	115	24	2	15	40

Sample No.		pH	C-org (%)	$CaCO_3$ (%)	Fe (%)	Na (%)	K (%)	P (%)	Mn (ppm)	Co. (ppm)	Pb (ppm)	Cd. (ppm)	Cu. (ppm)	Zn (ppm)
Kannur mangroves														
25	a	7.33	2.10	4	2.90	2.5	4.2	1.92	275	30	22	<1	19	58
	b	7.48	2.20	11	3.10	1.0	8.5	0.83	282	20	28	<1	25	48
	c	7.81	1.99	13	2.31	1.9	4.2	1.59	262	35	17	<1	24	48
26	a	7.50	2.3	7	2.90	3.3	4.2	2.12	303	35	22	<1	35	63
	b	7.24	2.72	12	3.4	3.6	6.0	1.70	275	40	22	2	28	64
	c	7.43	2.31	8	3.1	1.3	10.1	2.20	288	65	28	2	31	69
27	a	6.50	5.90	12	5.4	3.6	5.4	2.66	334	58	39	<1	75	75
	b	6.58	6.02	12	5.4	1.7	9.7	2.69	314	70	39	4	73	78
	c	6.95	6.01	18	3.3	3.4	5.4	3.08	298	62	28	2	77	87
28	a	7.15	5.89	11	4.2	1.9	10.1	2.30	303	70	28	3	61	73
	b	7.05	5.84	13	4.9	3.5	5.4	3.2	305	70	32	4	63	69
	c	7.34	4.94	13	3.4	1.5	9.3	2.5	298	70	31	6	52	63

a = Landward sample b = Intermediate sample c = Shallow water sample

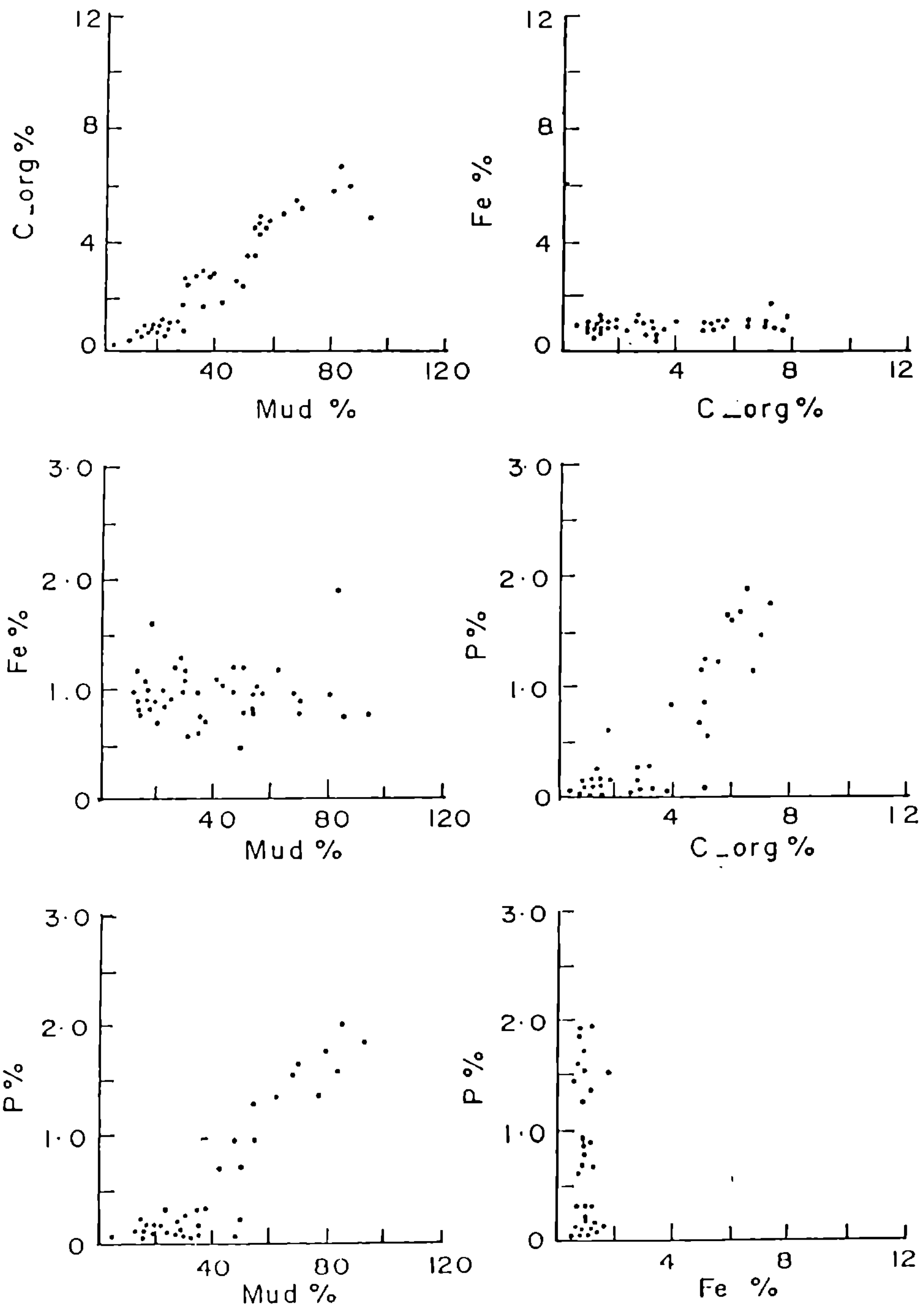

Fig. 21. THE INTERRELATIONSHIP EXISTING AMONG C- org, PHOSPHORUS, IRON AND MUD CONTENTS IN THE SURFACE SEDIMENTS OF VELI MANGROVES.

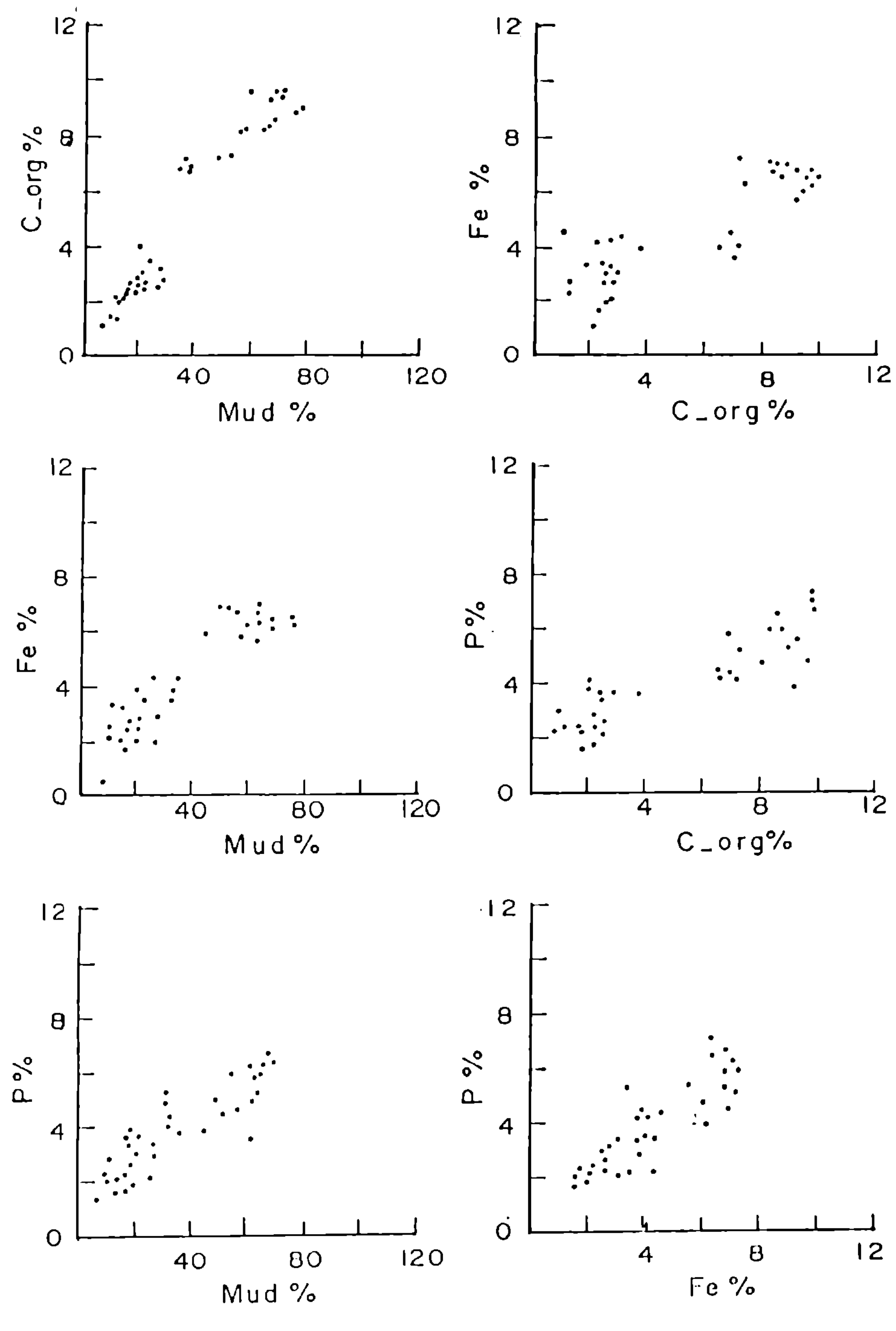

Fig. 22. THE INTERRELATIONSHIP EXISTING AMONG C- org, PHOSPHORUS, IRON AND MUD CONTENTS IN THE SURFACE SEDIMENTS OF KOCHI MANGROVES.

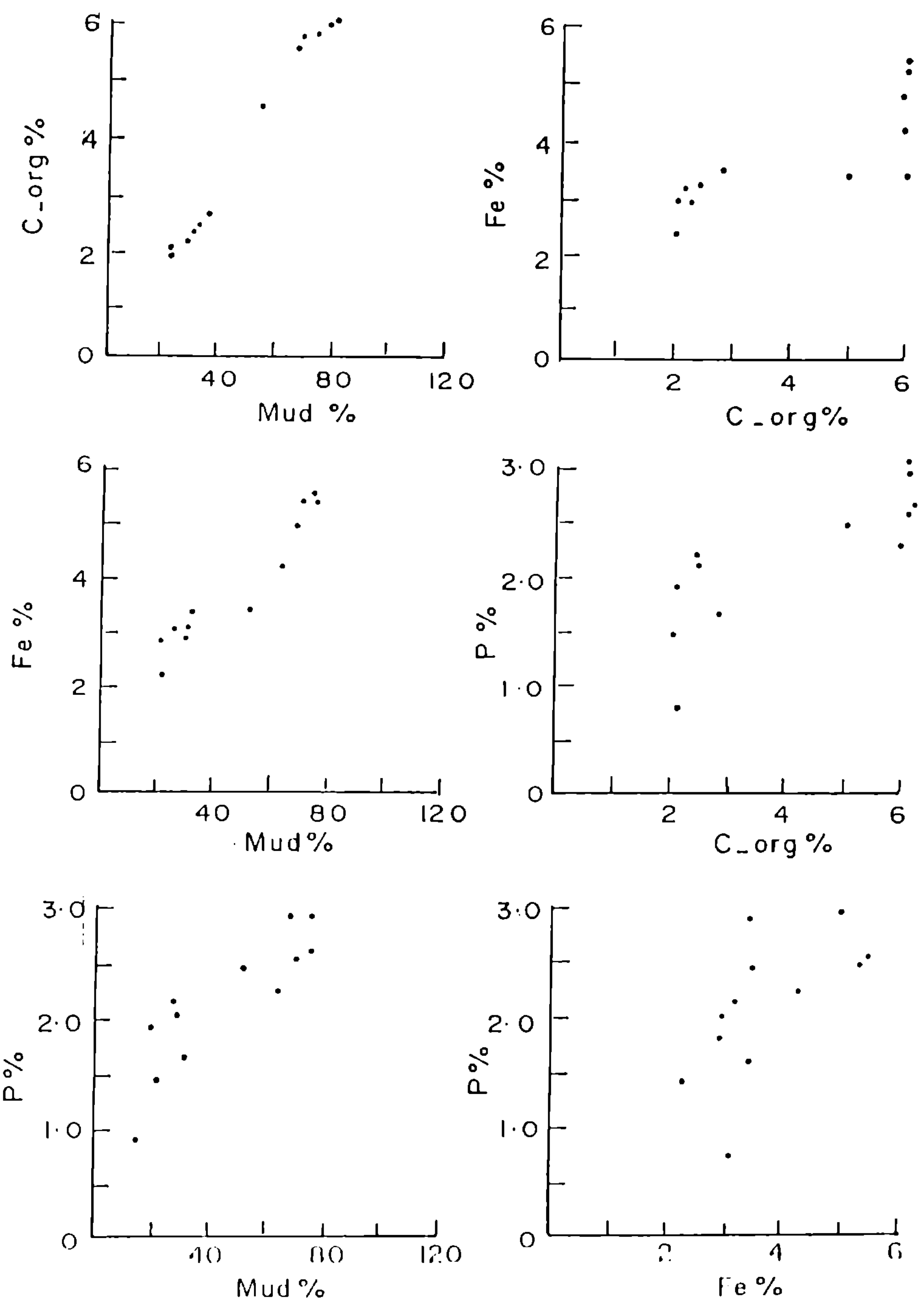

Fig. 23. THE INTERRELATIONSHIP EXISTING AMONG C- org, PHOSPHORUS, IRON AND MUD CONTENTS IN THE SURFACE SEDIMENTS OF KANNUR MANGROVES.

Out of the total samples analysed, the C-org of Kochi, varies between 0.52% to 4.89% with an average of 2.62%. More than 66% sediments of this region are of fine to very fine sand and the rest belong to mud dominant class. The C-org yields more or less similar values in all profiles except along the intermediate profile. Estimation of C-org along profiles unveil its predominance along landward profile, av; 4.25% (0.32% to 7.29%) followed by intermediate profile, av; 2.67% (0.76% to 6.52%) and shallow water profile, av; 2.50% (0.64% to 4.89%). Fig.22 illustrates the proportionate and patent relation existing between C-org and mud content. Texturally, sediments of this ecosystem is intricate and exhibits principally four textural attributes. Of this, the sandy mud and sandy silt accomodates an average of 4.45% (4.12% to 4.85%) and 4.61% (4.3% to 4.89%) of C-org, respectively. Other textural counterparts such as muddy sand accounts for an average of 1.80% (0.98% to 3.14%) and the silty sand shows an average of 1.50% (0.52% to 3.62%) of C-org.

Overall evaluation in the content of C-org in the surface sediments of Kannur shows a variation from 1.99% to 6.03%, the average being 4.01%. Its spatial distribution divulges that, the northeast segment of the study area is marked by a higher content of C-org than the southwest segment. The sandy mud and silty sand textural classes of this environment accomodate average C-org contents of 5.78% (4.9% to 6.03%) and 2.43% (2.15% to 2.71%), respectively. However, in the muddy sand textural facies, the C-org ranges from 1.09% to 2.34% with mean of 2.15%. The relative abundance of organic carbon along the profiles is intermediate profile (av; 4.19%) > landward profile (av; 4.01%) > shallowwater profile (av; 3.82%). Fig. 23 exemplifies the positive covariance between C-org and mud content existing in this mangrove region.

Table - 16

Ranges and averages of C-org , phosphorus and major as well as trace elements in the varoius profiles of Veli, Kochi and Kannur mangroves along with the overall values.

		C-org	Fe	P	Mn	Co	Pb	Cd	Cu	Zn
		(%)			(ppm)					
Veli mangroves										
Landward profile	Max.	7.29	1.95	1.8	320	55	87	3	61	80
	Min.	0.32	0.83	0.032	60	20	16	1	23	44
	Av.	4.25	1.13	0.93	127	37	51	1	42	63
Intermediate profile	Max.	6.52	1.05	1.6	262	46	103	3	81	121
	Min.	0.76	0.56	0.032	60	20	16	1	23	44
	Av.	2.67	0.83	0.397	148	29	54	1	46	73
Shallow water profile	Max.	6.45	1.68	1.94	388	31	63	2	65	90
	Min.	0.84	0.70	0.10	64	11	16	1	20	28
	Av.	2.05	1.07	0.358	211	19	44	1	33	52
Overall	Max	7.29	1.95	1.94	388	55	103	2	81	86
	Min	0.32	0.56	0.032	27	11	16	1	20	22
	Av.	3.71	1.01	0.562	162	30	48	1	40	62
Kochi mangroves										
Landward profile	Max.	4.85	6.78	7.03	171	122	49	2	69	83
	Min.	0.52	1.56	1.71	60	44	20	<1	12	15
	Av.	2.18	4.02	3.80	102	96	38	2	44	40

		C-org	Fe	P	Mn	Co	Pb	Cd	Cu	Zn
		(%)			(ppm)					
Intermediate profile	Max.	4.75	7.00	6.17	105	128	56	3	71	61
	Min.	1.00	2.06	1.78	63	55	11	1	14	17
	Av.	3.14	4.71	4.02	87	93	34	2	49	37
Shallow water profile	Max	4.89	6.97	6.35	168	141	39	3	58	91
	Min.	0.64	1.92	2.26	75	12	18	1	15	23
	Av.	2.50	4.00	4.05	101	91	26	2	31	40
Overall	Max	4.89	7.00	7.03	171	141	56	3	71	91
	Min.	0.52	1.56	1.71	40	12	11	<1	12	15
	Av.	2.62	4.50	3.95	98	93	31	2	41	39
Kannur Mangroves										
Landward profile	Max.	5.96	5.4	2.66	334	70	39	3	77	75
	Min.	2.00	2.9	1.92	275	30	22	1	19	58
	Av.	4.02	3.85	2.25	304	48	28	1	52	67
Intermediate profile	Max.	6.02	5.49	3.2	314	70	39	4	73	78
	Min.	2.1	3.12	0.83	275	20	22	1	25	48
	Av.	4.19	4.22	2.10	294	50	30	3	47	65
Shallow water profil	Max.	6.03	3.4	3.08	298	70	31	6	77	87
	Min.	1.99	2.3	1.59	262	35	17	1	24	48
	Av.	3.82	3.04	2.34	287	58	26	3	41	67
Overall	Max.	6.03	5.49	3.2	334	70	39	6	77	87
	Min.	1.99	2.3	0.83	262	20	17	1	19	48
	Av.	4.01	3.71	3.23	295	52	28	2	47	66

Table - 17

Concentrations of C-org, phosphorus and major as well as trace elements in the various textural classes of the surface sediments of Veli, Kochi and Kannur mangroves.

Textural types (Folk et al,1970)		C-org	Fe	P	Mn	Co	Pb	Cd	Cu	Zn
		(%)			(ppm)					
Veli mangroves										
Muddy sand	Average	2.13	0.96	0.26	169	29	52	1	40	58
	Range	0.76-3.9	0.56-1.68	0.03-0.99	27-287	11-53	16-103	1-4	20-61	22-75
Sandy mud	Average	5.71	1.06	1.17	103	35	55	1	43	73
	Range	4.92-0.7	0.7-1.95	0.15-1.94	29-239	13-55	24-87	1-2	20-64	39-121
Silty sand	Average	1.03	0.97	0.152	168	24	44	1	37	59
	Range	0.85-1.5	0.81-1.23	0.10-0.27	87-303	13-46	24-72	1-2	23-59	35-107
Sandy silt	Average	5.87	0.91	1.5	216	25	34	2	34	66
	Range	4.98-7.29	0.83-1.08	1.2-1.8	128-320	15-40	16-71	1-2	28-36	57-74
Clayey sand	Average	1.4	1.015	0.42	212	30	71	1	56	62
	Range	0.95-1.85	0.98-1.05	0.13-0.71	120-303	40-19	63-79	1	30-81	62
Sand	Average	0.32	1.11	0.09	237	19	20	1	33	62
Kochi mangroves										
Muddy sand	Average	1.80	3.41	3.43	84	105	30	2	36	37
	Range	0.98-3.41	2.56-4.35	2.19-4.51	40-122	47-128	172-48	1-2	15-69	23-51
Sandy mud	Average	4.45	6.59	5.62	109	65	39	2	36	37
	Range	4.12-4.85	5.9-7.00	3.93-7.03	86-171	12-95	27-56	1-3	14-60	29-48
Silty sand	Average	1.50	2.94	2.80	94	88	37	2	47	33
	Range	0.52-3.62	1.56-6.10	1.71-5.69	48-122	44-122	11-51	<1-3	12-71	15-61
Sandy silt	Average	4.61	6.33	5.66	123	115	21	2	47	61
	Range	4.3-4.89	5.52-6.97	5.04-6.35	80-168	86-141	18-26	1-3	21-59	32-91
Kannur mangroves										
Muddy sand	Average	2.15	2.8	1.95	282	41	221	1	27	60
	Range	1.99-2.34	2.3-3.10	1.59-2.20	262-303	30-65	17-28	1-2	19-31	48-69
Sandy mud	Average	5.78	5.77	2.73	309	67	33	3	67	67
	Range	4.94-6.03	4.94-6.03	2.3-3.08	298-334	58-70	28-39	1-6	52-77	52-77
Silty sand	Average	2.43	3.26	1.26	279	30	25	1	27	27
	Range	2.16-2.7	3.12-3.4	0.83-1.7	275-282	20-40	22-28	1-2	25-28	25-28

5.3.2.2 Core Sediments

Table 18 gives the vertical variation of the C-org for the core sediments of Veli (VC_1 and VC_2), Kochi (CC_1, CC_2, CC_3 and CC_4), and Kannur (KC_1, KC_2, and KC_3). Interrelationship existing among C-org, phosphorus, iron and mud percentage are illustrated in Figs.24-26 for the sediment cores of Veli, Kochi and Kannur mangroves.

In general, the organic carbon content in VC_1 varies between 0.74% to 3.20% with mean value of 2.26%. It is observed that, the core exhibits alternate waxing and waning of organic carbon contents for approximately each 10cm intervals, irrespective of the textural facies. Highest value of C-org is noticed at the top, and the lowest content recorded is from 30-40cm below the surface. The muddy sand layer accomodates an average of 2.52% (0.74% to 3.20%) of C-org whereas in the silty sand layer it varies between 0.79% and 2.72% (av; 1.75%). In core VC_2, the C-org content, in general, ranges from 1.10% to 3.39% with an average of 2.94%. This core mainly contains three textural facies, in which the highest amount of C-org (7.15%) is estimated in the sandy mud layer (30-40cm below the surface) whereas the muddy sand layer encounters a mean C-org value of 2.58% (1.18% to 3.39%). In clayey sand layer, it ranges betwen 1.59% and 1.62% (av; 1.6%). Relative abundance of C-org in VC_2 is sandy mud > muddy sand > clayey sand. Comparative study of the cores VC_1 and VC_2 reveals that, in the former, C-org and mud content decreases fairly at a depth of 30-40cm, whereby in the latter, it shows considerable enhancement at the same depth, and a total reverse pattern is observed in both cores at about 40-50cm below the surface. Vertical variation of C-org and mud content also throw light into the genetic relationship existing between them (Fig. 27).

Table - 18

Chemical parameters estimated in the sub samples of sediment cores recovered from Veli, Kochi and Kannur mangroves.

Sub sample intervals in cm.	pH	C-org	$CaCO_3$	Fe	Na	K	P	Mn	Co	Pb	Cd	Cu	Zn
		(%)						(ppm)					
Veli mangroves													
Core VC1													
0-10	7.31	3.20	12	3.78	3.1	2.1	1.25	214	33	55	1	28	61
10-20	7.29	3.00	5	3.45	2.8	2.6	0.54	153	31	55	1	92	77
20-30	7.12	3.15	14	2.95	2.3	2.9	0.55	124	29	32	2	84	51
30-40	6.92	0.74	10	2.75	3.9	3.7	0.16	181	15	40	1	31	65
40-50	6.98	2.72	10	3.78	3.6	2.1	0.60	162	18	24	1	30	80
50-60	6.84	0.79	5	1.88	4.1	4.1	1.33	124	4	16	2	15	44
Core VC2													
0-10	7.06	3.39	19	2.63	4.4	4.4	0.80	120	22	56	2	33	50
10-20	7.54	1.59	11	2.87	2.8	2.4	0.92	140	22	16	1	33	70
20-30	7.65	1.62	11	4.12	3.2	4.7	1.1	250	42	48	1	59	67
30-40	7.21	7.15	7	4.09	2.7	5.0	2.1	250	29	95	2	81	71
40-50	7.00	1.10	13	2.97	3.2	3.5	1.3	150	15	48	2	28	64
50-60	7.30	2.65	5	2.39	2.3	2.5	1.2	120	31	64	2	33	48
60-70	7.48	3.11	8	3.9	2.6	2.5	0.94	280	13	24	3	28	68.
Kochi mangroves													
Core CC1													
0-10	6.99	7.68	10	12.1	2.7	1.5	7.39	68	89	47	1	49	45
10-20	6.85	7.94	6	10.4	3.4	1.3	8.34	72	83	37	1	48	39
20-30	7.85	6.40	14	9.2	2.7	1.9	5.29	62	62	28	<1	54	11
30-40	7.75	6.72	14	9.6	3.3	1.8	4.23	34	47	49	1	35	24
40-50	7.55	6.70	19	9.9	4.5	2.3	4.94	28	31	32	1	13	18
50-60	7.99	6.45	20	10.0	1.4	1.0	4.76	24	42	27	1	24	26

Sub sample intervals in cm.	pH	C-org	$CaCO_3$	Fe	Na	K	P	Mn	Co	Pb	Cd	Cu	Zn
		(%)						(ppm)					
Core CC2													
0-10	6.10	1.75	13	2.65	1.4	1.2	1.10	69	30	19	<1	34	13
10-20	5.96	1.99	11	3.6	3.9	2.6	1.69	55	85	23	2	28	22
20-30	6.05	2.36	9	3.3	1.4	1.0	1.51	27	114	41	1	10	50
30-40	6.50	2.67	3	2.3	1.5	1.2	1.15	28	163	30	1	19	18
40-50	6.80	3.46	10	5.6	1.6	1.8	1.53	26	199	43	<1	17	12
50-60	6.8	5.98	16	9.0	1.8	2.0	5.62	14	123	32	1	40	18
Core CC3													
0-10	6.50	1.98	10	3.9	2.4	1.8	1.76	144	122	16	2	10	38
10-20	6.55	1.50	40	1.67	1.0	0.7	1.21	158	143	23	2	18	29
20-30	6.70	0.93	10	1.14	0.8	1.0	1.31	164	111	33	1	27	10
30-40	6.81	0.64	5	1.47	2.4	2.2	1.01	169	124	43	1	11	13
40-50	6.60	0.78	9	1.31	2.1	2.0	1.82	153	86	48	1	20	14
50-60	6.85	1.12	10	0.41	1.8	1.5	0.71	84	58	57	1	50	11
60-70	6.72	2.01	5.0	1.72	1.0	0.7	1.36	38	12	63	2	10	29
Core CC4													
0-10	7.75	2.12	5	4.2	1.4	1.0	2.54	24	16	13	1	20	90
10-20	8.25	1.98	4	4.1	1.6	1.2	3.10	38	24	22	2	49	12
20-30	8.50	2.00	9	4.7	1.9	1.6	2.94	52	23	24	1	58	90
30-40	8.65	1.85	11	4.3	1.4	1.0	2.29	44	18	33	2	63	10
40-50	8.95	2.15	2	4.1	1.1	2.1	1.71	40	28	43	2	30	15
50-60	8.90	3.62	10	3.8	1.6	1.2	2.01	64	20	31	2	60	18
60-70	8.35	3.41	6	4.2	1.2	2.9	2.09	81	13	41	2	70	20
70-80	8.22	2.5	2	4.1	1.6	3.0	1.99	65	16	27	2	48	29
80-90	8.11	1.96	13	4.1	2.1	1.5	2.01	74	22	42	3	52	20
90-100	8.11	1.54	6	2.9	3.0	2.3	2.16	61	21	32	2	42	28

Sub sample intervals in cm.	pH	C-org	$CaCO_3$	Fe	Na	K	P	Mn	Co	Pb	Cd	Cu	Zn
		(%)						(ppm)					
Kannur mangroves													
Core KC1													
0-10	6.93	5.78	13	4.31	2.3	2.05	1.12	232	82	44	2	56	71
10-20	6.57	5.64	13	4.02	1.5	0.99	0.27	186	75	50	3	65	72
20-30	6.26	4.99	17	3.65	4.3	1.2	0.100	177	74	44	5	77	73
30-40	6.23	3.56	12	3.50	1.6	1.2	1.55	217	85	28	3	70	70
40-50	6.20	5.79	10	3.76	1.8	1.3	0.75	227	83	39	4	75	74
50-60	6.05	5.62	11	4.20	4.7	5.5	0.45	185	75	39	2	73	76
60-70	6.15	5.63	6	4.24	3.6	1.3	0.96	217	85	44	3	64	75
70-80	6.60	5.57	11	5.27	3.7	0.92	0.91	272	90	50	3	75	77
Core KC2													
0-10	6.35	2.90	6	3.98	3.4	9.2	2.81	183	85	44	<1	64	71
10-20	7.02	2.10	6	2.52	1.2	7.8	2.22	180	65	45	<1	72	68
20-30	6.81	2.30	5	3.37	2.4	3.6	2.04	175	55	22	<1	59	63
30-40	7.28	4.85	6	3.58	2.1	3.6	2.53	204	70	60	<1	72	64
40-50	7.41	1.85	14	3.96	1.8	3.1	2.11	173	65	22	1	47	60
50-60	7.26	2.64	13	4.63	2.0	3.1	2.16	212	60	39	2	57	68
60-70	7.02	2.59	8	5.50	1.9	0.3	2.68	195	80	44	2	87	78
70-80	7.11	1.86	14	3.36	1.2	5.8	1.58	143	60	50	2	64	60
Core KC3													
0-10	6.26	5.98	6	3.00	1.6	2.05	2.37	250	77	50	2	57	72
10-20	5.90	5.99	8	3.65	1.4	0.99	0.44	311	80	56	1	85	96
20-30	5.99	6.00	5	3.87	1.4	1.20	1.18	279	80	50	1	83	91
30-40	6.85	5.97	4	4.07	2.4	1.20	0.40	292	75	42	1	65	76
40-50	7.21	5.78	5	5.23	3.8	1.30	1.47	394	110	60	1	79	73
50-60	6.32	6.00	2	4.15	2.2	0.66	1.31	345	105	38	2	76	81

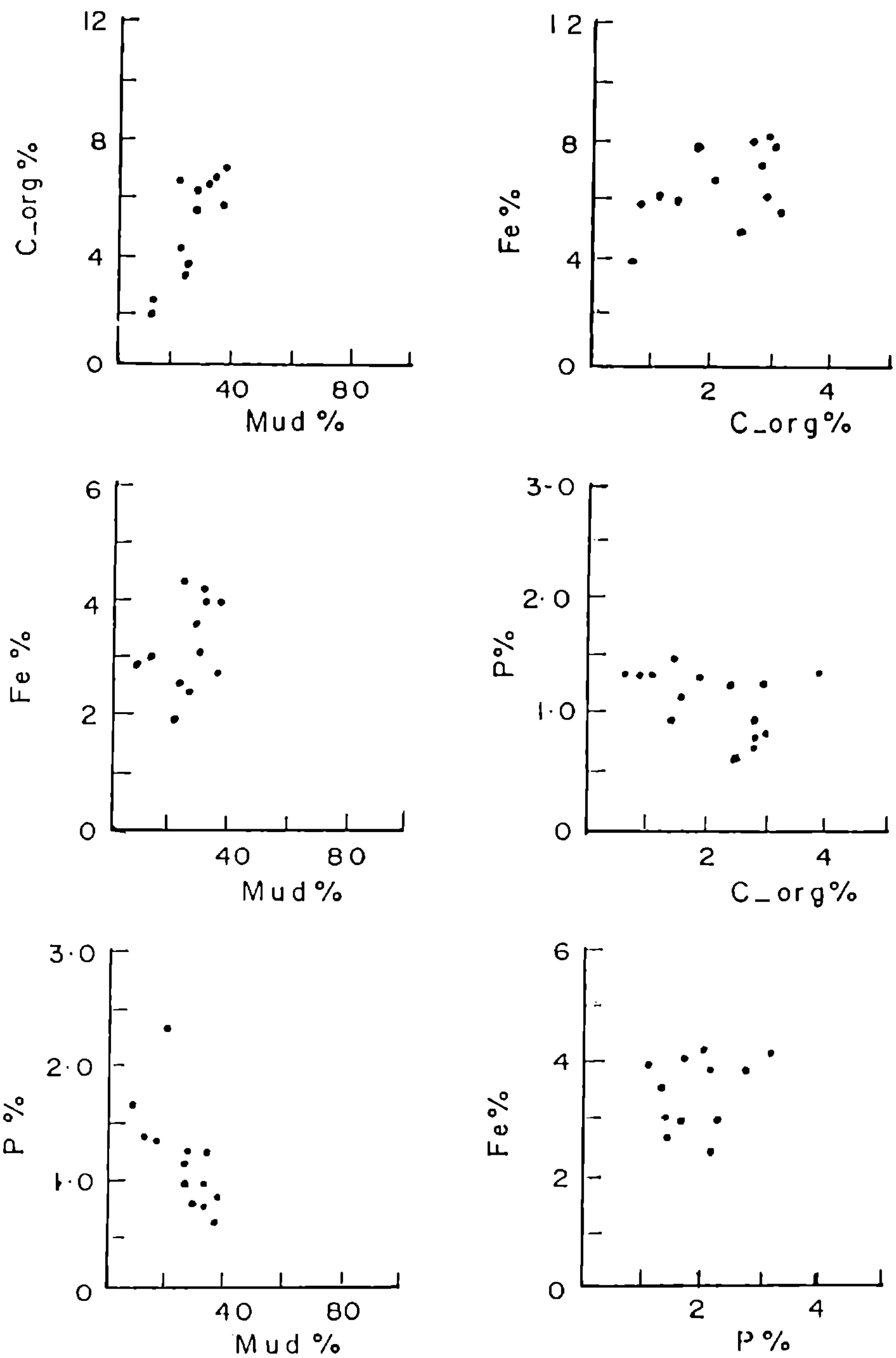

Fig. 24. THE INTERRELATIONSHIP EXISTING AMONG C- org, PHOSPHORUS, IRON AND MUD CONTENTS IN THE CORE SEDIMENTS OF VELI MANGROVES.

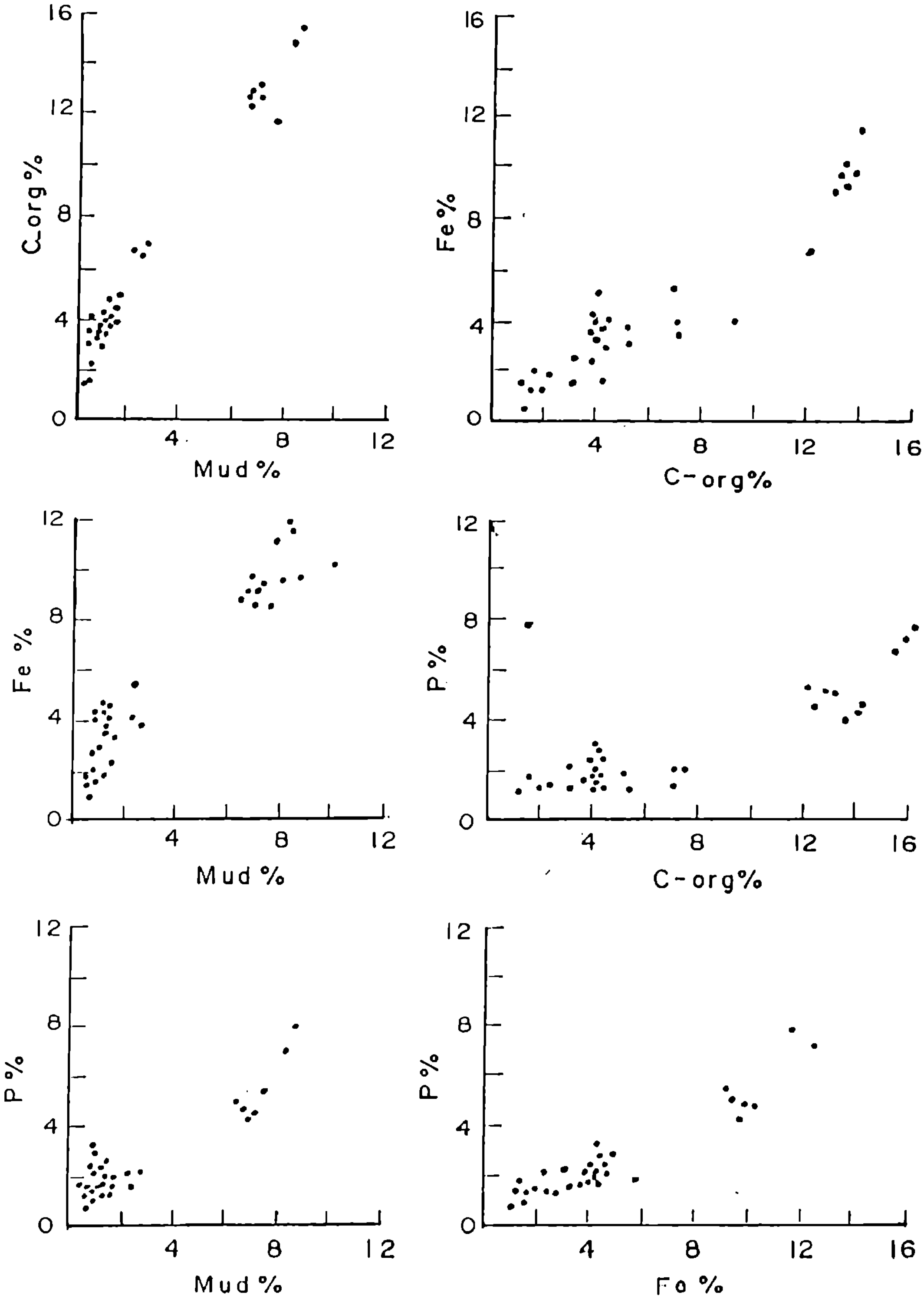

Fig. 25. THE INTERRELATIONSHIP EXISTING AMONG C- org, PHOSPHORUS, IRON AND MUD CONTENTS IN THE CORE SEDIMENTS OF KOCHI MANGROVES.

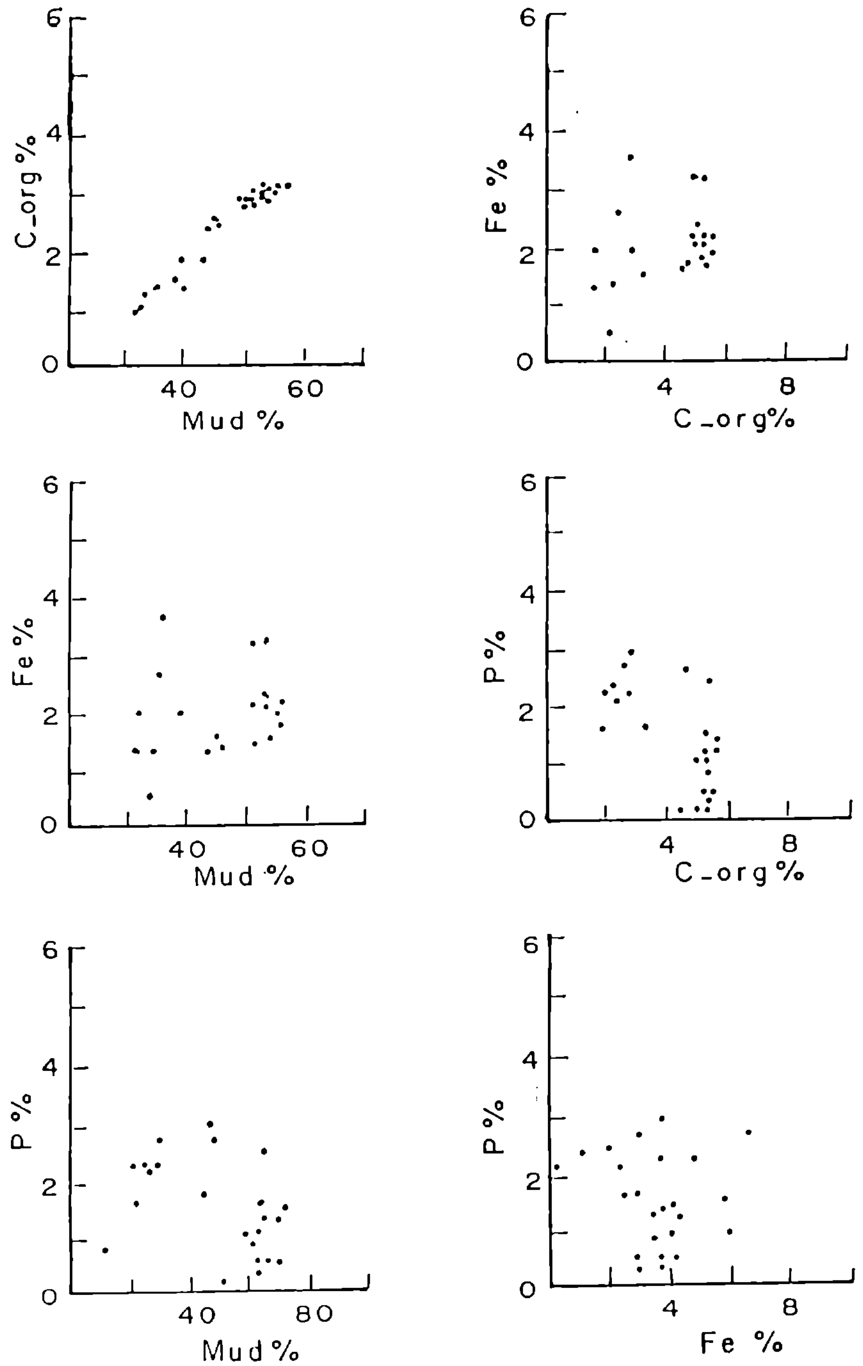

Fig. 26. THE INTERRELATIONSHIP EXISTING AMONG C- org, PHOSPHORUS, IRON AND MUD CONTENTS IN THE CORE SEDIMENTS OF KANNUR MANGROVES.

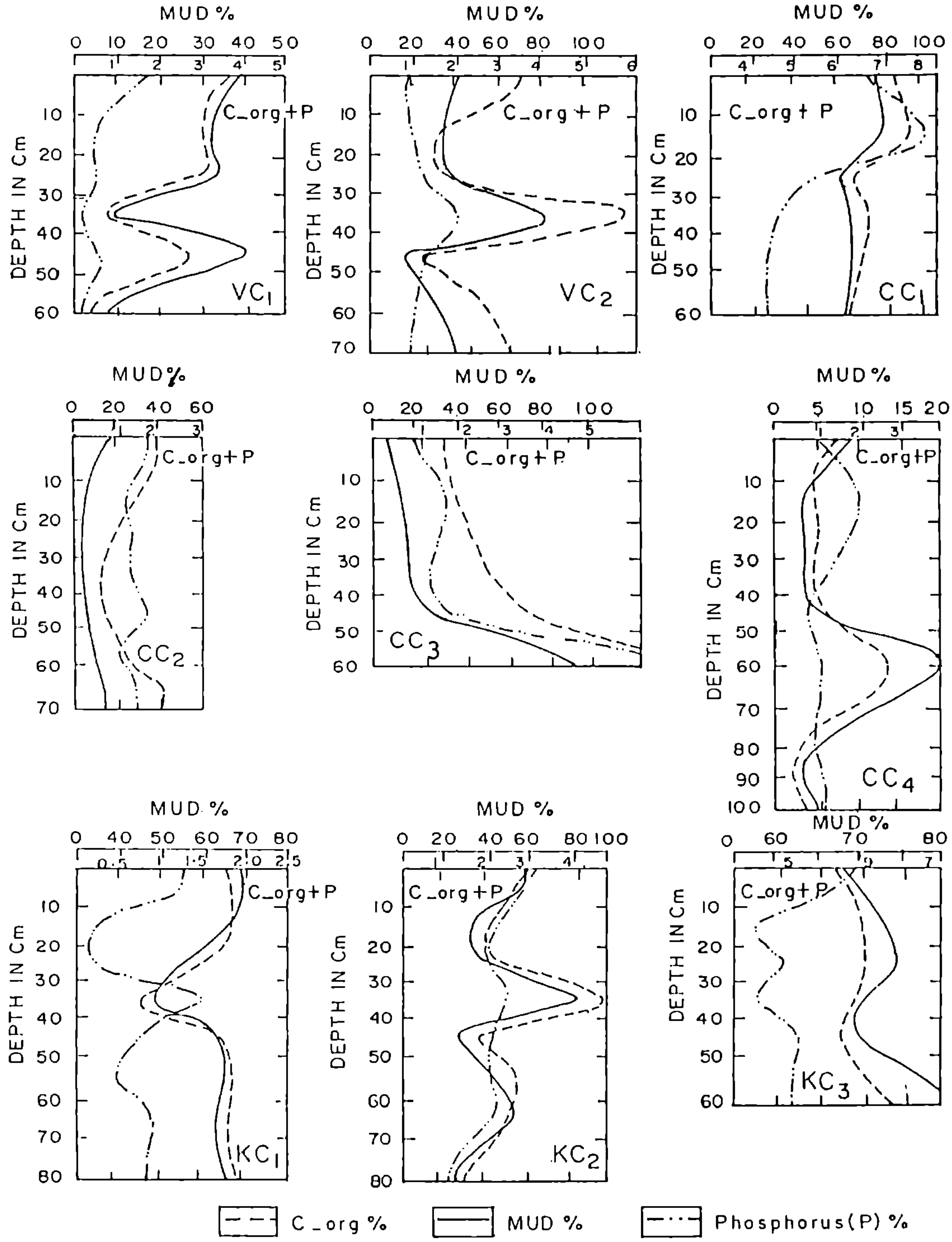

Fig. 27. VARIATION OF C-org, AND PHOSPHORUS IN RELATION TO THE MUD CONTENT AMONG THE VERTICAL PROFILE OF THE CORES COLLECTED FROM VELI (VC_1 & VC_2) KOCHI (CC_1 - CC_4) AND KANNUR (KC_1 - KC_3) MANGROVES.

Sediment cores of Vypin (CC_1) shows an average C-org content of 6.98% (6.40% to 7.94%) and that of Malippuram is 3.03% (1.75% to 5.98%). However, the cores CC_3 and CC_4 (Vallarpadam) manifest comparatively lower organic carbon values of 1.28% (0.64% to 2.01%) and 2.31% (1.54% to 3.62%), respectively. Comparatively higher concentrations of C-org at Vypin and the inadequacy of it at other stations may be due to the variability of sediments. The sandy mud textural unit of CC_1 is composed of 6.40% to 7.94% (av; 7.34%) of C-org whilst the sandy silt unit accounts for 6.45% to 6.72% (av' 6.62%). Likewise, in CC_2, an average of 2.62% of C-org is noticed in muddy sand, 1.75% in silty sand and 5.98% in sandy silt textural units. But the core CC_3 is texturally not much diverse and holds an average C-org of 0.96% (0.64 to 1.5%) in sand unit and 1.7% (1.12% to 2.01%) in silty sand textural unit. However, the mean C-org contents of 2.02%, 2.85% and 2.23% are recorded from the muddy sand, silty sand and clayey sand litho units, respectively. The strong relation between C-org and mud content are given in Fig. 25 for the above core sediments.

The overall evaluation of C-org in the sediment cores of Kannur in general, varies from 3.56% to 5.79% (av; 5.32%) in KC_1, 1.85% to 4.85% (av; 2.63%) in KC_2 and 5.78% to 6.0% (av; 5.95%) in KC_3. Among the different textural units described, the sandy mud layer accomodates highest organic carbon content in core KC_1, muddy sand lodges 2.39% in KC_2 (observed highest) and the sandy mud accomplishes 5.95% in core KC_3. Vertical variation of C-org and mud content are depicted in Fig. 27 and the variation of C-org and mud are illustrated in Fig. 26.

Discussion: In the present study, the lowest C-org content in the surface and core samples are observed in the sand dominant sediments. C-org yields higher values in the silt and clay dominated sediments in all the three mangroves studied. Increase in C-org with decreasing grain size is axiomatic. According to many investigators, the association of C-org in the finer sediments might be due to the enhanced surface area of the finer particles which inturn promotes the absorptive ability of organic colloids and also traps finer organic particles intact (Burn and Solomon, 1969; Sajan and Damodaran, 1989; Bednarz and Strzecka, 1993; Padmalal and Seralathan, 1995).

Earlier Trask, (1932) advocated that, the silt and clay enriches 2 to 4 times higher values of C-org than sands. Spatial distribution of C-org in the landward, intermediate and shallow water profile shows that the former, ingeneral, accomodates higher concentrations of C-org than the latter two (ie, the intermediate and shallow water profiles). This might be due to the wash off of organic particles/materials from the intermediate and shallow water profile by tides/waves. At the same time, the landward profile is often protected from the leaching of C-org by the thick mangrove canopy with its tightly knitted root systems, compared to the intermediate and shallow water profiles. In core sediments, the top most part exhibit, a higher concentration of C-org and does not exhibit a uniformity in its variation further downward (Sunilkumar, 1996). Sahoo et al, (1985) stated that, the C-org in the surface sediments are relatively higher in surface than in sub-surface, which could be owing to the confinement of organic residues in these layers. The waxing and waning of C-org in the sediment core of Veli could be attributed to the compaction, degradation and decomposition during diagenesis (Setty and Rao, 1972 and Fogel et al, 1989). Present study did not reveal the percolation of decayed or decomposed organic matter towards deeper layers.

In general, the variations of C-org observed along the various profiles of the three mangrove environments studied, reflect the textural control, differential hydrodynamic setup as well as the influence of various physicochemical factors such as temperatue, depth, rate of sedimentation, rate of supply of C-org, Eh and pH, etc..

5.3.3 **Phosphorus (P)**

Phosphorus is one of the chief nutrients which is functionally involved in the metabolic processes of living organisms (Parson, 1975; Hakanson and Jansson, 1983). It reaches the mangrove environments in allogenic and authigenic pathways. Organic productivity, inorganic precipitation from overlying waters and the influx of detrital phosphate from weathered rock massess are some of the major sources of this element. Surprisingly, the terrestrial input of phosphorus from cultivated lands, domestic and industrial sewages has been increasing recently which ultimately leads to the eutrophication problems in many aquatic environments. (Rhyther and Dunstan, 1971; Golterman, 1973; Maher and DeVris 1994). A conveyor mechanism for phoshorus is provided by aquatic organisms from the surface to the bottom, where the dissolved phosphorus is released and later incorporated into sediments. This biophile element is an unavoidable constituent of the mangrove cytoplasm, and hence biogenically it bears crucial role in the development of mangrove flora (Landergran, 1954). A review of literature reveals that, some attempts have already been done to understand the role of phosphorus in mangrove environments. Seralathan, (1988) estimated the phosphorus content and discussed the factors responsible for phosphorus fixation in mangrove environments. Phosphorus loading in the recent sediments of Kochi back waters have been investigated by Padmalal and Seralathan, (1995). Nutrients (including phosphorus) from the mangrove environments of Kochi has been studied by Sheeba et al, (1996). The present study furnishes the phosphorus distribution in the sediments of three important mangrove patches of Kerala coast located at Veli, Kochi and Kannur

5.3.3.1 Surface Sediments

Table 15 gives the percentage distribution of phosphorus for the mangrove regions of Veli, Kochi and Kannur and Table 16 and 17 summarise its ranges and average along three profiles and in different textural attributes. Scatter plots between phosphorus and mud and also organic carbon are illustrated in Fig.21.

In general, the phosphorus percentage of Veli shows a minimum of 0.032% to a maximum of 1.94% with an average of 0.56%. A close insight into the profilewise distributional pattern reveals that along landward profile the phosphorus content ranges from 0.32% to 1.8% (av; 0.93%), intermediate profile records the variation from 0.032% to 1.6% (av; 0.39%) and along shallow water profile, it fluctuates between a minimum of 0.10% to a maximum of 1.94% (av; 0.35%). Its comparative abundance along profiles are of the order landward profile > intermediate profile > shallow water profile. Among the different textural classes, the sandy silt records highest amount (1.5%) of phosphorus and the pure sandy facies is noted for its lowest content (0.09%). The relative availability of phosphorus in various textural classes are sandy silt (av: 1.5%) > sandy mud (1.17%) > clay sand (0.42%) > muddy sand (0.26%) > silty sand (av; 0.15%) > sand (0.09%). Fig. 21 illustrates the existance of positive correlation between phosphorus, mud percentage and C-org.

Overall view of phosphorus content in the Kochi mangrove sediments reveals that, it varies from 1.71% to 7.03% with average of 3.95%. The sediments of this region exhibit nearly 8 fold increase of phosphorus than Veli. Profilewise distribution unveil its relative abundance as shallow water profile > intermediate profile > landward profile. Phosphorus concentration varies between 1.71 and 7.03% (av: 4.05%) along landward profile, 1.78% and 6.17% (av: 4.02%) along intermediate profile and 2.26% and 6.35% (av: 3.8%) along shallow water profile. Among the prominent textural facies of this environment, the sandy silt accounts for an average phosphorus of 5.66% (5.04% to 6.35%) and sandy silt textural type contains mean phosphorus of 5. 62% (3.93% to 7.03%). The comparative order of phosphorus in different textural units are sandy silt > sandy mud > muddy sand > silty sand.

Kannur mangroves exhibit the phosphorus variation from 0.83% to 3.2% with mean content of 2.02%. This average value shows approximately 4 fold enrichment than Veli and nearly half the value of Kochi mangroves. Phosphorus content is highest along the shallow water profile (av: 2.34%) and lowest in the intermediate profile (av: 2.10%). However, the landward profile accomodates average phosphorus of 2.25% and ranges between 0.83% and 3.2%. The textural association of phosphorus are in the order sandy mud > muddy sand > silty sand. The muddy sand, sandy mud and silty sand textural classes show a wide variation and the average content of phosphorus as 1.59% to 2.2% (av; 1.95%), 2.23% to 3.08% (av; 2.73%) and 0.83% to 1.7% (av; 1.26%), respectively. Fig. 23 yields significant positive covariance of phosphorus Vs, C-org and mud percentage.

5.3.3.2 Core Sediements

Table 18 describes the vertical variation of phosphorus in the sediment cores of Veli, Kochi and Kannur, and Table 19 furnishes the ranges and averages with respect to various textural classes. Scatter plots between phosphorus Vs C-org and mud content are illustrated in Figs. 24-26 for the above stations. Fig. 27 demonstrates the vertical variation of phosphorus with mud and C-org for the above sediments. The core VC_1 of Veli exhibits an average phosphorus of 0.73% (0.16% to 1.33%) and that in VC_2 ranges from 0.80% to 2.1% (av; 1.19%). The chief textural classes of VC_1 are muddy sand and silty sand among which the former contains an average phosphorus of 0.62% (0.16% to 1.25%) while in the latter it is by 0.96% (0.60% to 1.33%). Similarly, the muddy sand and clayey sand textural facies of VC_2 show phosphorus variation between 0.80% and 1.3% (av; 1.06%) in the former

Table - 19

Concentration of C-org, Phosphorus and major as well as trace elements in various classes of the core sediments of Veli, Kochi and Kannur mangroves

Textural types (Folk et al,1970)	Core.No.		C-org	Fe	P	Mn	Co	Pb	Cd	Cu	Zn
			(%)			(ppm)					
Veli mangroves											
Mudy sand	VC1	Average	2.52	3.22	0.625	168	27	46	1	59	64
		Range	0.74-3.12	2.72-3.78	0.16-1.25	124-214	15-33	32-55	1-2	28-92	51-77
Silty sand	"	Average	1.75	2.83	0.965	143	11	20	1	23	62
		Range	0.79-2.72	1.88-3.78	0.60-1.33	124-162	4-18	16-24	1-2	15-31	44-80
Muddy sand	VC2	Average	2.58	2.97	1.06	195	20	48	2	31	58
		Range	1.18-3.39	2.39-3.9	0.80-1.3	120-280	13-31	24-56	2-3	28-33	48-68
Clayey sand	"	Average	1.60	3.49	1.01	195	32	32	1	46	69
		Range	1.59-1.62	2.87-4.12	0.92-1.1	140-250	22-42	16-48	1-2	33-59	67-70
Sandy mud	"		7.15	4.09	2.1	250	29	95	2	81	71
Kochi mangroves											
	CC1	Average	7.34	10.67	7.00	67	78	37	1	50	32
Sandy mud		Range	6.40-7.94	9.2-12.4	5.29-8.34	62-72	62-89	3--47	<1-1	48-54	11-45
Sandy silt	"	Average	6.62	9.83	4.64	29	40	35.81	1	24	23
		Range	6.45-6.72	9.6-10.00	4.23-4.94	24-34	31-47	27-49	<1-1	13-35	18-26
Muddy sand	CC2	Average	2.62	3.7	1.45	34	14.02	34.27	1	19	26
		Range	1.99-5.98	2.3-5.6	1.15-1.69	26-55	9-20	23-43	<1-2	10-28	12.50
Silty sand	"		1.75	2.65	1.10	69	3.	19	<1	34	13
Sandy silt	"		5.98	9.00	5.62	14	23	32	1	40	18
Sand	CC3	Average	0.96	1.39	1.33	161	116	37	1	19	17
		Range	0.64-1.50	0.41-1.47	1.01-1.82	153-169	86-143	23-49	1-2	11-27	10-29

Textural types (Folk et al.1970)	Core.No.		C-org	Fe	P	Mn	Co	Pb	Cd	Cu	Zn
			(%)			(ppm)					
Silty sand	"	Average	1.70	2.01	1.27	89	64	45	2	23	26
	"	Range	1.12-2.01	0.41-3.9	0.71-1.76	38-144	12-122	16 -63	1-2	10-50	11-38
Muddy sand	CC4	Average	2.02	4.28	2.51	40	22	27	2	44	27
		Range	1.85-2.15	4.1-4.7	1.71-3.10	24-52	16-28	13-43	1-3	20-63	10-90
Silty sand		Average	32.85	3.66	2.08	69	18	35	2	57	39
	"	Range	1.54-3.62	2.98-4.2	2.01-2.16	61-81	13-21	30-41	. 2-3	42-70	19
Clayey sand	"	Average	2.23	4.1	2.00	70	19	34	3	50	25
		Range	1.96-2.5	4.1	1.90-2.01	65-74	16-22	27-42	1-3	48-52	20-29
Kannur mangroves											
Sandy mud	KC1	Average	5.56	4.20	0.60	213	80	44	3	70	74
		Range	4.99-5.79	3.65-5.27	0.27-1.12	185-272	74-90	39-50	2-5	56-77	71-77
Muddy sand	"		3.56	3.5	1.55	217	85	28	3	70	70
Sandy silt	"		5.63	4.24	0.96	217	85	44	2	64	75
Muddy sand	KC2	Average	2.39	3.99	2.33	187	69	36	1	64	68
		Range	1.85-2.90	2.52-5.5	2.04-2.81	173-212	55-85	22-45	<1-2	48	60-78
Sandy mud			4.85	3.58	2.53	204	70	60	<1	72	64
Silty sand			1.86	3.36	1.53	143	60	50	2	64	60
Sandy mud	KC3	Average	3.99	1.19	1.19	311	88	49	1	74	82
		Range	5.78-6.04	3.0-5.23	0.4-2.37	250-394	75-110	38-60	1-3	57-85	72-96

and 0.92% to 1.1% (av; 1.01%) in the latter. Vertical variation (Fig. 27) illustrates the concomitant existence of the above paremeters.

Depthwise variation in the sediment cores of Kochi reveal that, only the core CC_1 contains higher amount of phosphorus compared to the surface sediments and shows an average phosphorus of 5.82% (4.23% to 8.34%). The content of phosphorus (with ranges and averages) of the other three cores are 1.10% to 5.62% (av; 2.1%) in CC_2, 0.7% to 1.82% (av;1.31%) in CC_3 and 1.71% to 3.1% (av; 2.28%) in CC_4. Sediments from Vypin contain 2 to 3 fold increase of phosphorus than other cores. The sandy mud textural unit has phosphorus of 5.23 % to 8.34% (av; 7.01%) while that of sandy silt is 4.23% to 4.94% (av; 4.63%). The average phosphorus accumulation in the muddy sand, silty sand and sandy silt of Malippuram (CC_2) are 1.45%, 1.10% and 5.62%, respectively. Likewise, the sand, silty sand, muddy sand and clayey sand of core CC_3 and CC_4 of Vallarpadam exhibit phosphorus variation from 1.01% to 1.82% (av; 1.33%), 0.71% to 2.16% (av; 1.67%), 1.7% to 3.10% (av; 2.51%) and 1.90% to 2.01% (av; 2.0%), respectively. The phophorus abundance in different textural facies are sandy mud > sandy silt > muddy sand > silty sand > clayey sand > sand. The positive association of phosphorus, C-org and mud are furnished in Fig. 25 and the Fig. 27 illustrate the vertical variation of the above parameters in cores CC_1, CC_2, CC_3 and CC_4.

The core KC_1 contains 0.27% to 1.55% (av; 0.76%) of phosphorus, and that in KC_2 and KC_3 varies between 1.58% to 2.81% (av; 2.26%) and 0.40% to 2.37% (av; 1.19%), respectively. Relative abundance of phosphorus in the cores are $KC_2 > KC_3 > KC_1$. Texturally KC_1 is marked by sandy mud, muddy sand and sandy silt of which the former one has an average P of 0.60% and the latter two amounts to an average of 1.55% and 0.96%, respectively. In core KC_2, the muddy sand, sandy mud and silty sand textural units mark relative phosphorus abundance as mS (av;

2.53%) > sM (av; 2.33%) > zS (av; 1.53%). The sediment type in core KC_3 is unique (sandy mud) in which, the phosphorus varies from 3.0% to 5.23% (av; 3.99%). Scatter plots (Fig. 26) gives no significant trends among phosphorus Vs mud and C-org and Fig. 27 shows the concomitant variation of the above parameters.

Discussion: An overall estimation of phosphorus in the three mangrove environments reveals that, sediments of Kochi region show the predominance of phosphorus over Veli and Kannur mangroves. Kochi sediments show nearly 6 times enrichment of phosphorus than Veli and approximately 2 fold increase than Kannur. Considering the phosphorus content in the three mangrove cores together, it is clear that, Kochi area possesses approximately 3 fold enrichment than Veli, and nearly 2 fold enhancement than Kannur. Variation of phosphorus in the three environments may be either due to high content of dissolved phosphate in the overlying water column or accumulation by organisms (which incorporates into sediments after death). Removal of phosphorus through differential hydrodynamic regime also play pivotal role in the phosphorus loading of mangroves. Differential adsorption of phosphorus by many adsorbants, its fixation by clay and organic carbon, removal of phosphorus from the overlying and interstitial waters by chemical precipitation (Chester, 1990 and Maher and Devries, 1994), contribution through sewage sludges, nutrient re-cycling by mangrove plants, increased biological production around mangrove zones, and excrements from birds typical of mangrove environments etc. are the main sources of phosphorus in these environments. In addition to the above sources, Kochi backwaters receive ample input of phosphorus through the effluent from fertilizer factory (Sheeba et al, 1996) and this might be one of the major reasons for the enhancement of phosphorus at Kochi. The sympathetic variation of phosphorus with organic matter and mud greatly substantiates that, major part of phosphorus is held up in organic matter which inturn is associated with mud content. Veli region is marked by the overbearing of coarse fractions which inhibits accumulation of C-org and hence low phosphorus values, compared to other stations. In addition, relatively low concentrations of phosphorus in core sediments of Veli and Kannur may be attributed to the compaction degradation and decomposition occured during diagenesis (Setty et al, 1972; D'silva and Bhosale, 1990).

5.3.4 **Calcium Carbonate ($CaC0_3$)**

5.3.4.1 Surface sediments

Table 15 furnishes the $CaCO_3$ content for the surface sediments of the mangrove regions of Veli, Kochi and Kannur, while Table 20 provides the ranges and averages along the profiles (landward, intermediate and shallow water) of the above mangroves.

The spatial distribution of $CaC0_3$, varies between 3% and 15% (av; 7.75%) and its profile wise variation reveals that, intermediate profile shows highest average of 8.66% (4% to 15%) followed by shallow water profile 8.4% (5% to 12%) and landward profile 5.86% (3% to 11%).

The surface sediments of Kochi, exhibit $CaC0_3$ variation between 5% and 20% (av; 12.77%). Its relative occurrence with respect to the profiles are shallow water profile > landward profile > intermediate profile in which the $CaC0_3$ content in the former zone varies between 7% and 20% (av; 14%) and the latter two profiles show variations from 5% to 19% (av; 12.66%) and 5% to 16% (av; 11.66%) respectively. The content of $CaC0_3$ in Kochi area shows 1.5 fold enrichment compared to Veli. The average $CaC0_3$ (12.77%) of Kochi mangroves shows 5 times the enrichment compared to organic carbon.

The general distribution of $CaC0_3$ along the surface sediments of Kannur reveals wide variations from 4% to 18% (av; 11.16%) and the landward, intermediate and shallow water profile accounts for its variation from 4% to 12% (av; 8.5%), 11% to 13% (av; 12%) and 8% to 18% (av; 13%), respectively.

5.3.4.2 Core Sediments

Table 18 summarises the vertical variation of $CaC0_3$ for the sediment cores of the three mangroves and Table 20 furnishes its ranges and averages for individual sediment cores.

The depthwise variation of $CaC0_3$ in the cores VC_1 and VC_2 of Veli yield averages of 9.33% (5% to 14%) and 10.57% (5% to 19%), respectively.

Vertical distribution of $CaC0_3$ recorded in the Kochi sediment cores divulges that the core CC_1 accounts for the highest $CaC0_3$ (av; 13.83%) with variations between 6% and 20% and the lowest accumulation is noted in the core CC_4 and shows variations from 2% to 13% (av; 6.8%). The $CaC0_3$ accumulation in cores CC_2 and CC_3 gives an average of 10.3% (3% to 16%) and 8.42% (5% to 10%), respectively. Its relative proportions in sediment cores are $CC_1 > CC_4 > CC_2 > CC_3$. Carbonate content of Kochi shows tallying values with that of Veli.

The $CaC0_3$ content of Kannur registers maximum values in the core KC_1 (av; 11.62%) followed subsequently by KC_2 (av; 9%) and KC_3 (av; 4.83%) whose variational limits are from 6% to 17%, 5% to 14% and 2% to 8%, respectively. From the overall evaluation of the three mangrove ecosystems, it is clear that minimum amount of $CaC0_3$ is recorded at Kannur and maximum accumulation is obtained for Kochi area.

Table - 20

Ranges and averages of Na, K and $CaCO_3$ in the surface and core sediments of Veli, Kochi and Kannur Mangroves

Surface sediments

Samples	Range/ Average	Veli Na (%)	Veli K (%)	Veli $CaCO_3$ (%)	Kochi Na (%)	Kochi K (%)	Kochi $CaCO_3$ (%)	Kannur Na (%)	Kannur K (%)	Kannur $CaCO_3$ (%)
Landward sample	Max	4.2	1.6	11	4.2	3.2	19	3.6	5.4	12
	Min	0.8	0.20	3	1.2	0.6	5	1.9	1.01	4
	Av.	2.2	0.87	5.86	2.31	1.53	12.66	2.82	3.70	8.5
Intermediate Sample	Max	5.0	2.1	15	4.2	2.2	16	3.6	9.7	13
	Min	1.0	0.2	4	1.2	0.9	5	1.0	5.4	11
	Av.	2.44	0.83	8.66	2.52	1.71	11.67	2.45	7.4	12
Shallow water Sample	Max	6.2	2.2	12	4.08	2.7	20	3.4	9.3	1.8
	Min	0.8	0.8	5	1.2	0.6	7	1.3	1.01	8
	Av.	3.42	1.38	8.41	2.50	1.54	14.00	2.02	4.97	13
Overall	Max	8	2.1	15.0	4.2	2.7	20	3.6	9.7	18
	Min	0.8	0.3	3.0	1.2	0.6	5	1.0	1.01	4
	Av.	2.75	1.02	7.75	2.14	1.48	12.77	2.43	5.36	11.16

Core sediments

Core No.	Range/ Average	Na (%)	K (%)	$CaCO_3$ (%)	Core No.	Range/ Average	Na (%)	K (%)	$CaCO_3$ (%)	Core No.	Range/ Average	Na (%)	K (%)	$CaCO_3$ (%)
VC1	Max	4.1	4.1	4.04	CC2	Max	3.9	2.6	16	KC1	Max	4.7	5.5	17
	Min	2.3	2.1	1.34		Min	1.4	1.0	3		Min	1.5	0.92	6
	Av.	3.3	2.9	2.24		Av.	1.93	1.63	10.33		Av.	2.93	1.80	11.62
VC2	Max	4.4	5.0	19		Max	2.4	2.2	10		Max	3.4	9.2	14
	Min	2.3	2.4	5	CC3	Min	0.8	0.7	5	KC2	Min	1.2	0.03	5
	Av.	3.02	3.57	10.57		Av.	1.64	1.41	8.42		Av.	2.0	4.65	9
CC1	Max	4.50	2.3	20		Max	3.0	3.0	13		Max	3.8	2.05	8
	Min	1.2	1.0	6	CC4	Min	1.1	1.0	2	KC3	Min	1.4	0.66	2
	Av.	2.93	1.65	13.83		Av.	1.69	1.78	6.8		Av.	2.13	1.23	4.83

Discussion: The $CaCO_3$ variation in the surface and core sediments reflects, the differences in the environmental conditions of deposition (Setty et al, 1972). Its content in the sediment water interface vary widely, and is attributed to the prevailing conditions of overlying water masses as well as the physico-chemical parameters. In general, the $CaCO_3$ in sediments originates from both allochthonus and autochthonus sources. Considering the three mangroves together, Veli region exhibits low $CaCO_3$ concentration compared to other stations. Mangrove zones and adjacent area are harboured by pleanty of shelled organisms like gastropods and pelecypods, which ultimately deposit their calcareous exoskeleton to the environment soon after their death. The $CaCO_3$ enrichment of Kannur (12.77%) shows 3 fold increase than C-org (av; 4.01%). This augmented value is the result of the abundance of shell fragments in sediments. Further, the shell mining activities in the estuarine bed adjoining Kannur and Kochi (southern tip of Vembanad estuary) have also contributed substantial amount of lime mud to these areas, a feature also reported earlier by Badarudeen et al, (1996). Since mangrove areas are highly productive, photosynthesis and respiration by organisms may accelerate the $CaCO_3$ precipitation (Sajan, 1983; Sebastian et al, 1990) from the overlying waters by affecting the CO_2 flux. Cloud, (1965) has stated that, any biological production which affect the amount of CO_2 in solution, disturbs the carbonate equilibria. It is proved that, low values of $CaCO_3$ represent reducing conditions, whereas high values are indicative of oxidising conditions (Krumbien and Garrels, 1952; Jonge and Villerius, 1989). No regular pattern is observed for the vertical and lateral distribution of $CaCO_3$ in all the three mangrove environments studied. The changes of $CaCO_3$ with depth reflect the environment and other factors such as in the type of fauna rate of deposition, pH, Eh, temperature, salinity, nutrients, saturation or supersaturation of other dissolved salts, organic productivity, upwelling and inflow into the region. Hulsemann (1968) suggested similar reasons for the changes noticed in the shelf sediment cores from the Florida-Hatteras region (JOIDES

Programme). The waxing and waning of $CaCO_3$ with depth are suggestive of rapid changes in the sedimentary environment resulted due to the influx of terrigenous materials.

5.3.5 **Sodium and Potassium**

5.3.5.1 Surface Sediments

Table 15 furnishes the concentration of Na and K estimated in the surface sediments of Veli, Kochi and Kannur mangroves and Table 20 presents their averages and ranges.

The sediments recovered from the Veli mangroves exhibit 0.8% to 8% of Na with an average concentration of 2.75% while K shows a substantially lower range in their concentration values (0.3 - 2.1%; av. 1.02%) compared to that of Na. Their distribution along profiles indicates that the former is enriched more in all the profiles (landward, intermediate and shallow water) than the latter. The mean concentration of Na along landward profile is 2.2% (0.8% to 4.20%). The content of this element varies between 1.0% and 5.0% (av; 2.44%) in the intermediate profile and between 0.8% and 6.2% (av; 3.42%) in the shallow water profile. Likewise, the average K concentration along landward profile, intermediate profile and shallow water profile are 0.87% (0.2% to 1.6%), 0.83% (0.2% to 2.1%) and 1.38% (0.8% to 2.2%), respectively. The relative abundance of Na and K along these profiles are of the order shallow water profile> intermediate profile> landward profile. The spatial distribution of Na and K shows no specific trend, except at certain locations where they show marginal covariance.

The concentrations of Na and K in the surface sediments of Kochi mangroves, range from 1.2% to 4.2% (av; 2.14%) and 0.6% to 2.7% (av; 1.48%), respectively. However, the average concentration of Na along the profiles does not show marked variation (landward profile, 2.3%; intermediate profile, 2.52% and shallow water profile, 2.50%). The K concentration along the profiles reveals variation between 0.6% and 3.2% (av; 7.53%) along landward profile, 0.9% to 2.2% (av; 1.71%) along intermediate profile and 0.6% to 2.7% (av; 1.54%) along shallow water profile. Comparative evaluation of these two elements in the Kochi mangroves with that of Veli unveils that the latter shows enhanced values of Na (av; 2.75%) and low concentrations of K (av; 1.02%) over the former. Their relative abundance are intermediate profile > shallow water profile > landward profile. Na and K for the sediments of Kannur mangroves varies between 1% and 3.6% (av; 2.43%) and 1.01% and 9.7% (av; 5.36%), respectively. The relative proportions of Na in the three profiles are landward profile (av; 2.82%)> intermediate profile (av; 2.45%)> shallow water profile (av; 2.02%), whereas that of K are intermediate profile (av; 7.4%) > shallow water profile (av; 4.97%) >landward profile (av; 3.7%). Comparison of K availability along profiles divulges that, intermediate profile shows 2 fold enrichment than landward profile and 1.5 times increase than the shallow water profile. Of the three mangrove sectors analysed, it is clearly exemplified that the Na values for the three mangroves do not vary much while that of K displays considerable departures (1.02% for Veli, 1.48% for Kochi and 5.36% for Kannur).

5.3.5.2 Core Sediments

Vertical variation of Na and K for the sediment cores of the three mangrove regions are given in Table 17 and its ranges and averages are provided in Table 19. The vertical variations of these two elements for the cores VC_1 and VC_2 (Veli), CC_1 CC_2, CC_3 and CC_4 (Kochi) and KC_1, KC_2 and KC_3 (Kannur) are shown in Fig. 28.

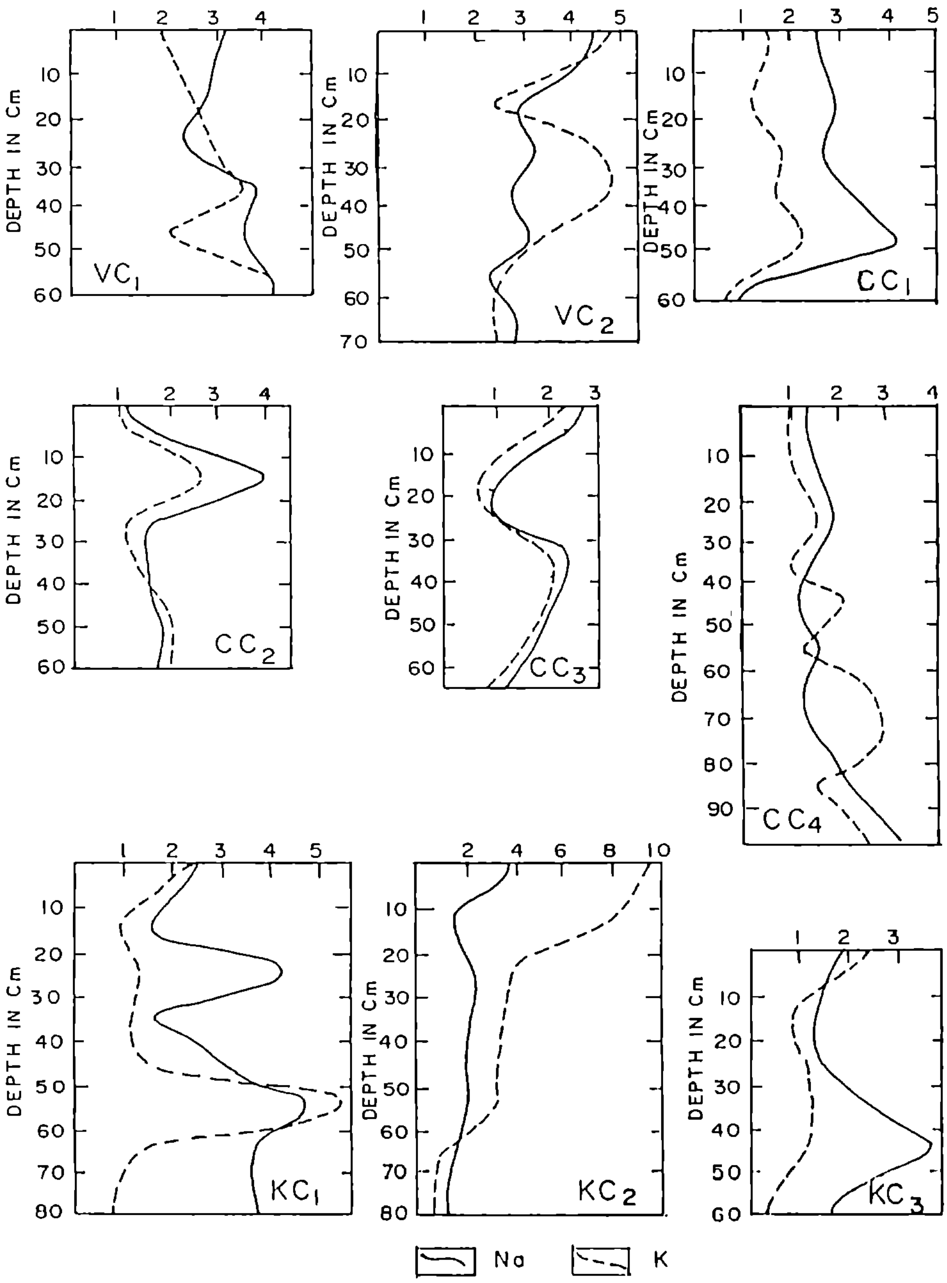

Fig. 28. VARIATION OF Na AND K ALONG VERTICAL PROFILES OF THE SEDIMENT CORES OF VELI (VC_1 & VC_2), KOCHI (CC_1 - CC_4) AND KANNUR (KC_1 - KC_3) MANGROVES.

In the core VC_1, Na varies from 2.3% to 4.1% (av; 3.3%) and that of K from 2.1% to 4.1% with mean value of 2.91%. The core VC_2 shows an average of Na content (3.02%) almost equivalent to that of core VC_1. Contrary to surface sediments, the core VC_2 evince elevated K values (av; 3.5%; range: 2.4% to 5.0%). Vertical variation of Na and K are illustrated in Fig. 28, which explains the marginal covariance existing between them.

The concentrations of Na in the sediment cores of Vypin, (CC_1) Malippuram, (CC_2) and Vallarpadam, (CC_3 and CC_4) are respectively, 1.4% to 4.5% (av; 2.93%), 1.4% to 3.9% (av; 1.93%) and 0.8% to 3% (av; 1.67%). Similarly, the distribution of K in the cores ranges from 1% to 2.3% (av; 1.63%) at Vypin, 1.1% to 2.6% (av; 1.63%) at Malippuram, 0.7% to 2.2% (av; 1.41%) and 1% to 3% (av; 1.78%) at Vallarpadam regions. Here, all the cores except the CC_4 at Vallarpadam are noticed for the higher percentage of Na content than K. In the core CC_4, the Na and K exhibits a sympathetic correlation (Fig. 28).

The variation in the content of Na and K for the core KC_1 of Kannur is 1.5% to 4.7% (av; 2.93%) and that of KC_2 is 0.9% to 5.5% (av; 1.80%). The core KC_2 demonstrates more than 2 fold enrichment of K than Na and in core KC_3, the Na and K contents average about 2.13% and 1.23%, respectively. Relative abundance of the former element in the cores are $KC_1 > KC_2 > KC_3$. Na and K vary in consonance with eachother and is illustrated in Fig. 28.

Discussion: The chemical analysis of sediments has been performed without removing salts present in the interstitial waters of sediments, because interstitial waters and its ingredients are considered as integral part of sediments. More than that the process of desaltation removes significant part of the exchangeable elements present (Welby,1958). The enhanced values of Na than K in the mangrove environments studied might be attributed to the said ion present in the aqueous solutions that fill in the pore spaces of sedimentary particles. In addition to this, a considerable part of these elements can also be fixed with the lattices of clay minerals (Sajan, 1988). As we know that, these elements are not precipitated by hydrolysis, it is presumed that, in the clay fractions of these environments the Na and K are bounded either by adsorption or cation exchange processes (Goldsmits, 1937; Heir and Adams, 1963). Rankama and Sahama, (1950) pointed out that, Na and K released during weathering remain in ionic solution, whereas Al reacts with silica to form clay minerals. The soluble products formed during weathering of plagioclase feldspars would be the primary source of Na in these mangrove environments. By taking into account the role of clay minerals in the fixation of Na it seems that, the major part of Na in mangrove environments studied is tied up in montmorillonite/ illite. Elevated values of Na over K is due to the ability of the former cation to fix with clay minerals easily. Na ions compete very effectively than K ions for the vacant exchange sites in clay minerals. At the same time, being a crucial nutrient element, the mangrove species extent remarkable affinity towards K in the carbohydrate synthesis (Rankama and Sahama, 1950) and for the development of tissues (Rose, 1983). This process also lowers the K levels in the sediments than Na. In this context, it is clear that the enhanced K content in the Kannur mangroves might be derived from the mangrove vegetative debris including the litter found abundantly in that area.

The K mainly come into sediments as a weathered product of orthoclase, microcline and biotite. Some part of K is tied up with illite, which has paculiar ability to fix K over other cations in its inter layers (Deer et al, 1962; Nelson, 1962). Considerably reduced concentration of K over Na might be owing to the removal of K by plants. Inspite of the above sources, the mangrove sediments will get addition of K through the vegetal parts of mangrove floras. The proportionate variation of Na and K, in the sediments of these mangrove environments suggest their single source of derivation.

5.3.6 **Iron and Manganese (Fe and Mn)**

Geochemical characteristics of Fe and Mn in aquatic environments have received a great deal of attention in the world's scientific scenario owing to the need for understanding the pathways of toxic contaminants which causes disastrous effects to organisms (Forstner and Wittmann, 1983). In most environments, these redox-sensitive metals transfer primarily through particulate phase. Particulate Fe and Mn form deposits in sediments as silicate grains, inorganic oxide/hydroxide forms, organo metallic complexes etc (Gibbs, 1977). Under oxidising conditions, the Fe/Mn forms co-precipitate and scavange considerable amount of trace metals dissolved in water. On the other hand, under reducing conditions, the sorbed trace metals will be desorbed back to the overlying waters or interstitial waters (Forstner and Wittmann, 1983; Mance, 1987; Klomp, 1990; Padmalal and Seralathan, 1995). Here the Fe/Mn geochemistry is highlighted to know the significance of these elements in the mangrove environments and their bearing on the dispersal patterns of these elements.

The distribution of Fe and Mn for the surface sediments of the study area is furnished in Table 15. The ranges and averages of Fe and Mn along the landward, intermediate and shallow water profiles as well as in various textural classes are furnished in Tables 16 and 17 and the cross plot Figs 21-23 and 29-31 explains the interrelationship of Fe with mud content, C-org, phosphorous and trace metals.

5.3.6.1 Iron (Fe)

The Fe content of the surface sediments of Veli mangroves ranges from 0.56% to 1.95% with an average of 1.01%. This metal records a minimum of 0.83% and a maximum of 1.95% (av; 1.13%) along landward profile, 0.56% and 1.05% (av;

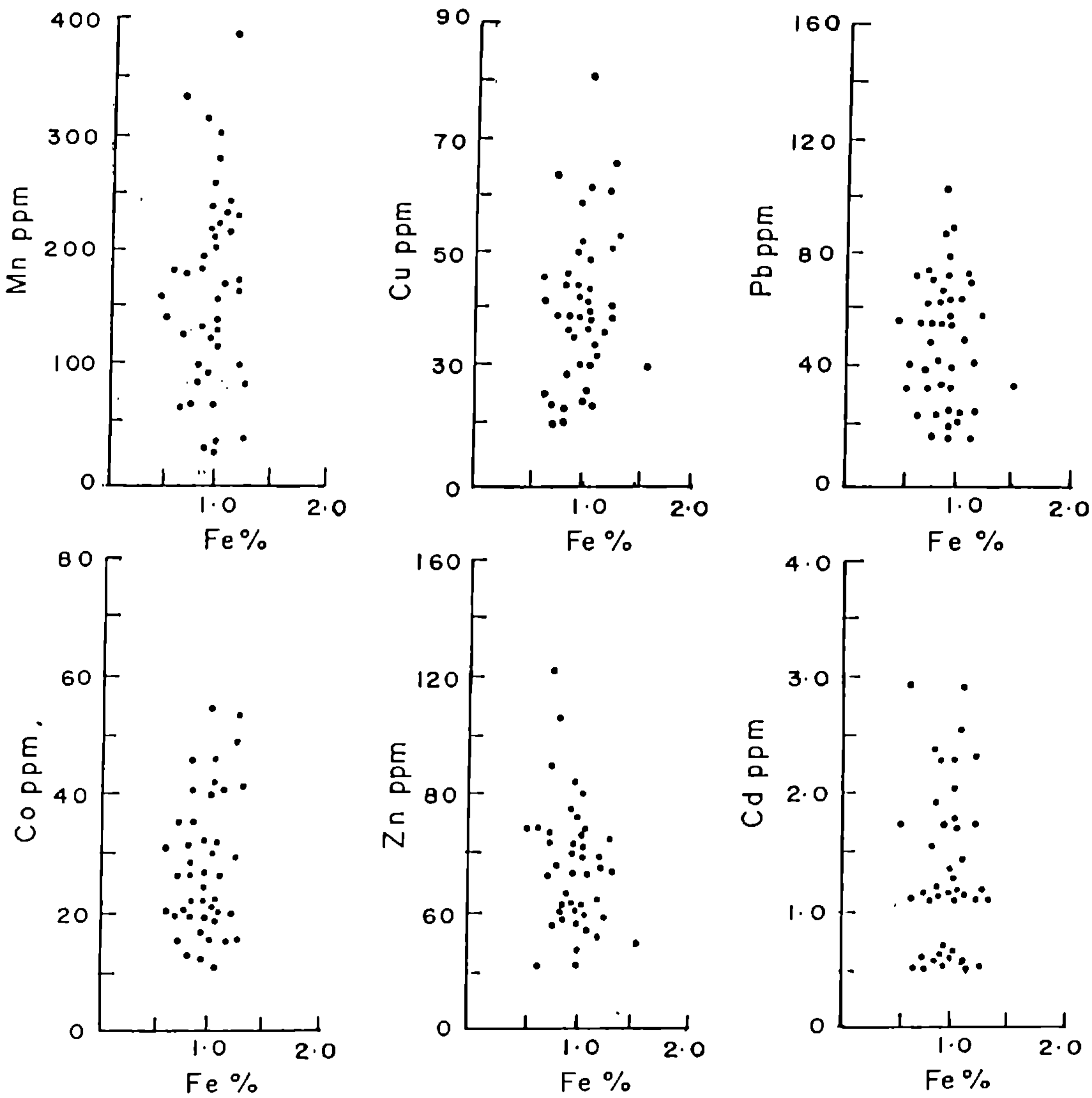

Fig. 29. RELATIONSHIP OF Fe Vs TRACE METALS FOR THE SURFACE SEDIMENTS OF VELI MANGROVES.

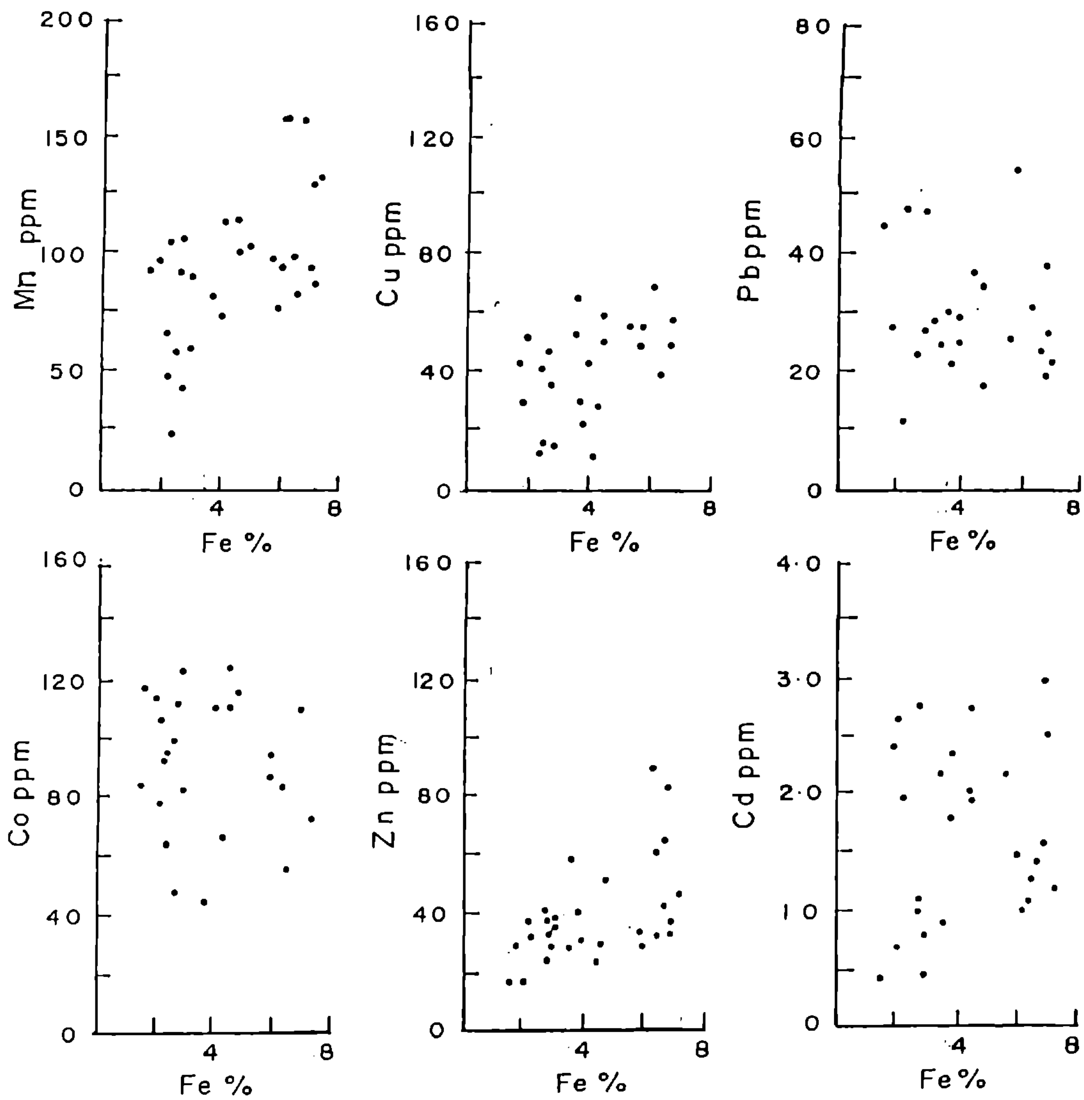

Fig. 30. RELATIONSHIP OF Fe Vs TRACE METALS FOR THE SURFACE SEDIMENTS OF KOCHI MANGROVES.

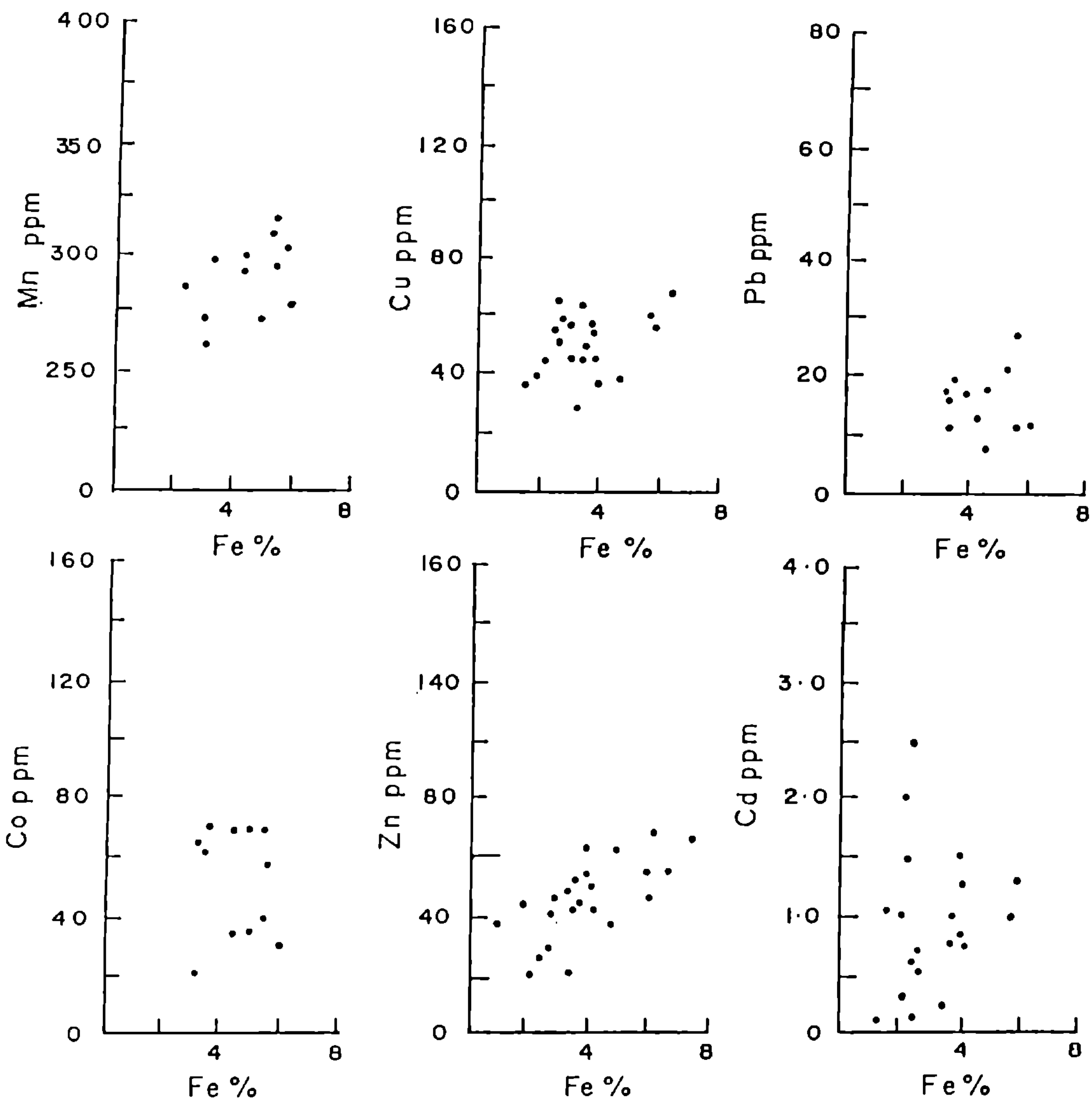

Fig. 31. RELATIONSHIP OF Fe Vs TRACE METALS FOR THE SURFACE SEDIMENTS OF KANNUR MANGROVES.

0.83%) along intermediate profile and 0.70% and 1.68% (av; 1.07%) along shallow water profile. The prominent sediment types encountered at Veli mangroves include muddy sand, sandy mud, sandy silt, clayey sand and sand of which sand and sandy mud textural units possess highest average (1.11%) of Fe. The muddy sand accomodates an average of 0.96% of Fe, silty sand 0.97%, sandy silt 1.08% and clayey sand 1.01%. The order of abundance of Fe in different textural classes are S > sM > cS > zS > mS > sZ.

The Fe values estimated for the sediments of Kochi evince the highest content of 7% and a lowest amount of 1.56%. The average Fe content is estimated as 4.5%. Comparative evaluation of Fe in Kochi and Veli unveils that, the former area possesses more than 4 fold enhancement of Fe than the latter. The iron loading along landward profile varies from 1.56% to 6.78% (av; 4.02%), intermediate profile records 2.06% to 7% (av; 4.71%) and shallow water profile shows 1.92% to 6.97% (av; 4%). The landward, intermediate and shallow water profile of Kochi shows approximately 4 fold, 5 fold and more than 3 fold enrichment of Fe than the corresponding zones of Veli mangroves. The sandy mud textural class of this region exhibits average Fe value of 6.59% and sandy silt accounts for 6.33%. The muddy sand and silty sand demonstrate mean Fe content of 3.41% and 2.94% respectively. Comparison of Fe, in the various textural units of Veli and Kochi mangrove sediments divulge that the sandy silt, sandy mud, muddy sand and silty sand textural units of Kochi shows nearly 7 fold, 6 fold, 4 fold and 3 fold enhancement than the corresponding textural units of Veli. The order of predominance of Fe contents with respect to the different textural facies of Kochi are sandy mud > sandy silt > muddy sand > silty sand. High degree of positive correlation existing between Fe Vs C-org, phosphorus and mud content are illustrated in Fig. 22.

The concentration of Fe in the surface sediments of Kannur ranges from 2.3%

to 5.49% (av; 3.71%). Profilewise distribution of Fe in the order of abundance is intermediate profile (av; 4.22%)> landward profile (av; 3.85%)> shallow water profile (av; 3.04%). The sandy mud textural unit accomodates Fe concentration from 4.94% to 6.03% (av; 5.77%), while silty sand contains 3.12% to 3.4% (av; 3.26%) and the muddy sand accounts for 2.3% to 3.1% (av; 2.8%) of Fe. Percentage levels of Fe with respect to various textural classes of the mangrove regions manifest high amount of Fe attached either with sandy mud or sandy silt. Contrary to this, the pure sandy unit of Veli is found enriched with Fe. The genetic relationship between Fe, C-org, mud content and P are depicted in Fig. 23. Comparison of Fe values for the three mangroves studied divulge that Kochi region exhibit highest Fe content (4.5%) than Kannur and Veli (1.01%) (Fig.34).

Table 18 describes the vertical variation of Fe and Mn for the sediment cores of the above three mangroves. Table 17 and 19 explains its variation with respect to different textural assemblages and ranges as well as the averages of Fe and Mn for the individual cores of Veli, Kochi and Kannur mangroves.

Vertical variation of Fe in the sediment cores of Veli region is from 1.88% to 3.78% (av; 3.09%) in VC_1 and 2.39% to 4.12% (av; 3.28%) in VC_2. Progressive decrease of Fe has been noticed in VC_1 except at a depth of 40-50 cm below the surface and no such pattern of distribution is noted in core VC_2. The muddy sand textural type accounts for the highest average of Fe content of 3.22% (2.72% to 3.78%) and the silty sand registers mean value of 2.83% (1.88% to 3.78%). However, the sandy mud, muddy sand and clayey sand textural attributes of VC_2 represent average Fe concentrations of 4.09%, 2.97% and 3.49%, respectively. Relation between Fe and P and the marginal positive covariance of Fe, with mud and C-org are given in Fig. 24.

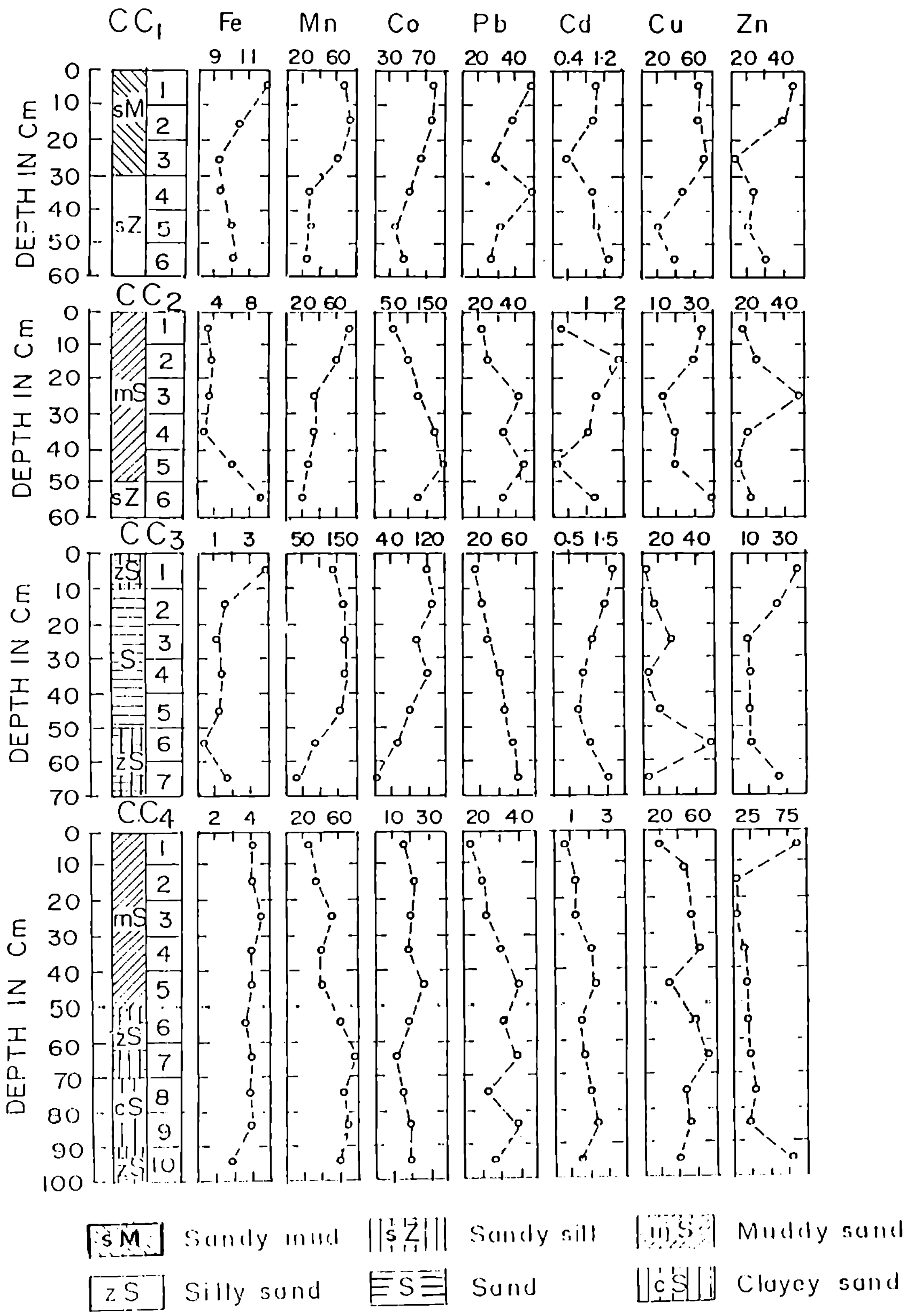

Fig. 34. VARIATION OF HEAVY METALS ALONG THE VERTICAL PROFILE OF THE SEDIMENT CORES OF KOCHI MANGROVES. (Fe in percentage and others in ppm.)

The content of Fe in Vypin (CC_1) sediments range from 9.2% to 12.4% (av; 10.27%) and that of Malippuram (CC_2) area contains mean amount of 4.4% (2.6% to 9%). But the sediments from Vallarpadam area (CC_3 and CC_4) shows an average of 1.66% and 4.05% of Fe, respectively. Its relative abundance in Kochi cores are $CC_1 > CC_2 > CC_3 > CC_4$. The sandy mud of CC_1 contains 10.67% (9.2% to 12.4%) and that of sandy silt registers an average of 9.96% (9.95% to 10.09%) of Fe. In core CC_2 the average Fe concentrations are 3.7% (muddy sand) 2.65% (silty sand) and 9% (sandy silt). However, the sand and silty sand of CC_3 accounts for an average Fe enrichment of 1.39% (0.41% to 1.47%) and 2.01% (0.41% to 3.9%). Iron content in various textural units of CC_4 are muddy sand (av; 4.28%) > clayey sand (av; 4.1%) > sandy silt (av; 3.66%). Considering all the textural units of the four cores, it is vivid that, the relative occurrence of Fe is in the order sandy mud > sandy silt > muddy sand > clayey sand > silty sand > sand. Fig. 25. brought out the strong positive correlation between C-org, mud and phosphorus with Fe content.

Fe accumulation in the sediment cores of Kannur are 3.57% to 5.27% (av; 4.11%) in KC_1, 2.5% to 5.5% (av; 3.86%) in KC_2 and 3% to 5.23% (av; 3.99%) in KC_3. The sandy mud, muddy sand and sandy silt textural facies of the core KC_1, contains an average of 4.2%, 3.5% and 4.24% of Fe, while the muddy sand, sandy mud and silty sand textural classes of core KC_2 exhibit an average Fe content of 3.99% (3.58% to 3.36%). The average Fe content for the sandy mud layer of core KC_3 is 3.99%. Relationship of Fe with mud, C-org and phosphorus are given in Fig. 26. Taking into account all the sediment cores of the three mangroves together, the Fe concentrations do not deviate much from one environment to other except in core CC_1 and CC_3 of Kochi where they show high fluctuations.

5.3.6.2 Manganese (Mn)

The distribution pattern of Mn in the sediments of Veli mangroves unveils variation from 27 ppm to 388 ppm (av; 162 ppm). The shallow water profile accounts for the highest average Mn of 211 ppm (64 ppm to 388 ppm) followed by intermediate profile, (av; 149 ppm) (60 ppm to 262 ppm) and landward profile (av; 127 ppm; 60 ppm to 320 ppm). Comparative availability of Mn in the various textural attributes are sand (av; 237 ppm) > sandy silt (av; 216 ppm) > clayey sand (av; 212 ppm) > muddy sand (av; 169 ppm) > silty sand (av; 168 ppm) > sandy mud (av; 103 ppm). The Mn accumulations in Veli are found high in sands and sand dominant species. The concentration of Mn in the sediments of Kochi varies from 40 ppm to 171 ppm (av; 98 ppm). The above mean value shows nearly 2 fold decrease than Veli. Mn distribution along the profiles reveals that the landward profile and shallow water profile show almost equal amounts (Table 16). The average Mn enrichments along the intermediate profile and shallow water profile of Kochi and Veli reveal that, the latter area shows nearly 1.5 to 2 fold increase of Mn than the former station. The sandy silt of this mangrove region registers the highest Mn (av; 123 ppm) followed by sandy mud (av; 109 ppm), silty sand (av; 94 ppm) and muddy sand (av; 84 ppm). Positive correlation of Mn with mud, Fe and phosphorus are illustrated in Table 21.

Surficial sediments of Kannur, in general, exhibit average Mn of 295 ppm (265 ppm to 334 ppm). The landward profile of Mn values range from 275 ppm to 334 ppm. (av: 304 ppm), intermediate profile records 275 ppm to 314 ppm (av; 294 ppm) and in shallow water profile, it varies between 262 ppm and 298 ppm (av; 287 ppm). Of the different textural types, sandy mud is noted for the highest content of Mn (av; 309 ppm) than muddy sand (av; 282 ppm) and silty sand (av; 279 ppm). Similar to Fe, Mn too shows high concentration in silt and clay dominated textural classes. As noted elsewhere, the positive correlation of Mn with mud and phosphorus are depicted in Table 21.

In the core samples, manganese varies from 124 ppm to 214 ppm (av; 160 ppm) in VC_1 and 120 ppm to 280 ppm (av; 187 ppm) in VC_2. The highest Mn concentration is noticed in core VC_2 compared to VC_1. The muddy sand textural unit has a mean Mn of 168 ppm and that of silty sand accounts for 143 ppm. Taking into account of the cores VC_1 and VC_2, the relative abundance of Mn in different textural classes are sandy mud (av; 250 ppm) > clayey sand (av; 195 ppm) > muddy sand (av; 168 ppm) > silty sand (av; 143 ppm). Marginally sympathetic covariance exist between Mn, C-org, phosphorus and mud content and the strong positive correlation ($r = 0.81$) of Mn with Fe are given in Table 22.

The vertical distribution of Mn in various cores of Kochi yields a wide range from 14 ppm to 169 ppm. The core CC_1 accounts for an average Mn value of 48 ppm, CC_2 shows 37 ppm, CC_3 exhibits 130 ppm and CC_4 reveal an average of 54 ppm. The ranges and averages of Mn in different textural types are furnished in Table 19. While considering all the lithofacies of the four core samples, the hierarchy of Mn in them are sand > silty sand > clayey sand > sandy mud > muddy sand > sandy silt.

Similarly, the vertical variation of Mn in the sediment cores of Kannur records an average of 214 ppm (177 ppm to 272 ppm) in KC_1, 183 ppm (143 ppm to 213 ppm) in KC_2 and 312 ppm (250 ppm to 394 ppm) in KC_3. The relative proportion of Mn are $KC_3 > KC_1 > KC_2$. In core KC_1, the muddy sand and silty sand accomodates equal amounts of Mn (217 ppm), while, an average of 204 ppm, 143 ppm and 187 ppm of Mn are encountered in sandy mud, silty sand and muddy sand textural units of core KC_2. But the core KC_3 contains Mn from 250 ppm to 394 ppm showing mean value of 311 ppm. The strong genetic relationship existing between Fe, mud content and C-org with Mn are shown in Table 22.

Discussion: The transitional elements Fe and Mn are the most abundant and wide spread constituents in all the mangrove environments studied. The present study noticed the highest Fe concentration in the surface (av; 4.5%) and core (av; 5.09%) sediments of Kochi mangroves, whereby its lowest concentration is in Veli mangroves. Considering the Mn distribution, Kannur sediments show elevated concentration of Mn (295 ppm in surface and 237 ppm in core) than Veli and Kochi regions. It is observed that, in general, Fe and Mn are enriched in silt and clay dominated textural units of Kochi and Kannur mangroves, however, its enrichment in the sand and clayey sand sediment types of Veli region could be attributed to the contribution from heavy mineral sources. The strong linear function of Fe and Mn in the regions studied indicates that these two elements are co-precipitated as insoluble ferric manganic hydrate. Such co-preciptitation of Fe and Mn is favoured by negatively charged hydrous manganese oxides in colloidal form (Rankama and Sahama, 1950; Hirst, 1962; Padmalal and Seralathan, 1993) with a consequent affinity for cations. Fe and Mn form complexes with organic compounds in the mangrove environments (Fe more effectively than Mn) and are thus considerably in the organic materials. Mn is scavanged more effectively by flocculation of hydrophilic organic colloids than by the normal bio-geo processes of particle formation. Organic particulate matter is responsible for the migration and sedimentation of many inorganic constituents. Considering the transportation and enrichment of Fe, three different models may be considered. One school of thought assumes, Fe is transported partly in solution and partly in colloidal form. When Fe loaded suspension, come into contact with oxygenated and slightly alkaline environments, the Fe is oxidised to its ferric state and hence precipitated as ferric hydroxide (Mason et al, 1963; Landergren, 1975; Sajan, 1992). The second model is based on the enrichment of Fe in living tissues of marine organisms and its subsequent release after their death and decomposition (Rankama and Sahama, 1950). The third model envisage that Fe is absorbed on to the C-org, phosphorus and mud content. The precipitation of Fe complexes in the presence of H_2S, leads to the oxygen depletion in the upper sediment layers of mangrove environments (Nelson, 1962). Moreover, Fe can be absorbed externally into clay minerals or be incorporated into the lattice structure of clay minerals. In addition to the above sources of Fe, this may be influxed into the mangrove regions from the heavy minerals and the Fe coating over quartz grains. It is generally conceded that, manganese in sedimentary cycle is leached from the drainage basin as bicarbonates (Mn HCO_3) but deposited as oxides in the form of organic or inorganic colloids, finely divided detrital grains and as cementation matrix. Correns, (1941); Sajan, (1992), considers that, Mn is biologically extracted, whereas (Sajan, 1992) favour it to be a chemical precipitate. The above elements exhibit fairly marginal covariance with phosphorus content in the three mangroves, except along the surface sediments of Kochi, which indicates their coprecipitation.

5.3.7 **Trace metals (Cu, Co, Zn, Pb and Cd)**

The concentrations of Cu, Co, Zn, Pb and Cd in the mangrove sediments of Veli, Kochi and Kannur regions are furnished in Table 15 and Table 16, depicts its maximum, minimum and average concentrations along profiles. Table 17 summarizes the ranges and averages of the above metals present in the various textural units of the three mangroves studied. Fig. 32 shows the average concentrations of the trace metals along landward profile, intermediate profile and shallow water profile. The inter relationship existing between the above trace metals Vs mud,

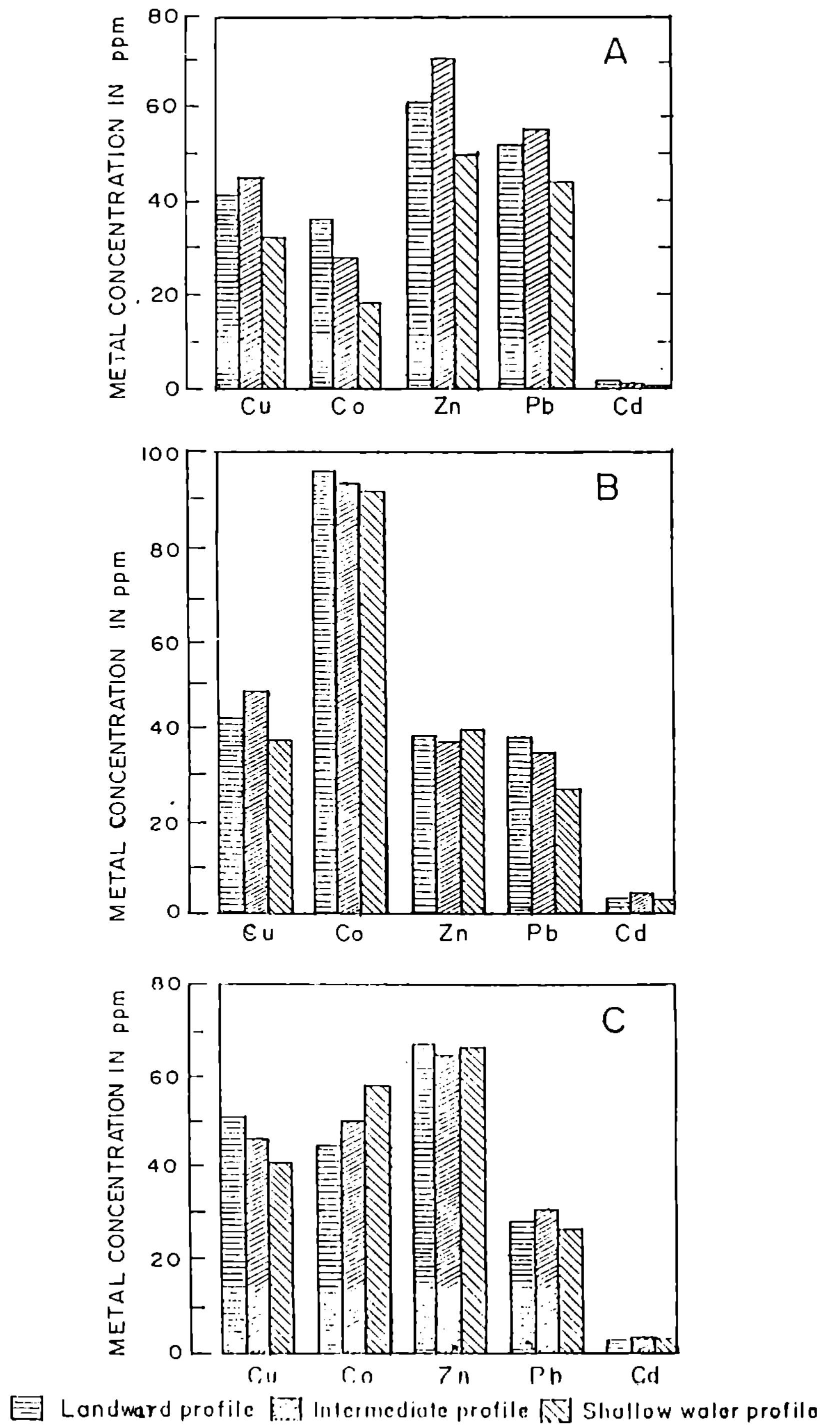

Fig. 32. THE AVERAGE CONCENTRATIONS OF TRACE METALS IN VARIOUS PROFILES OF VELI (A), KOCHI (B), & KANNUR (C) MANGROVES.

C-org, Fe and P for the three mangroves are discussed in the following paragraphs.

Table 18 summarises vertical variation of trace metals in the sediments cores of the study area and the Table 19 and 25 describes its variation with respect to different textural units and ranges as well as averages for individual cores, respectively. Figs. 33-35 illustrate trace metal variation with depth along the different sediment cores. The interrelationship of trace metals (Co Zn, Pb and Cd) with Fe and Mn for the three mangroves are given in Table 22. Table 23 gives the results of heavy metal analysis of International Standards (G2 and SCO-1) and Table 24 furnishes the comparative evaluation of heavy metal concentrations in the mangrove sediments of study areas with that of some mangrove and other estuarine sediments. Fig 36 compares the various heavy metal levels for the individual cores of Veli, Kochi and Kannur mangroves. The significance and major observations of trace metals are discussed in the following sections.

5.3.7.1 Copper (Cu)

Copper is one of the essential elements for plants and animals and occurs in nature as monovalent and divalent forms. However at elevated concentration this metal turns to be toxic to the recipient organisms (Flemming and Trevors, 1989). In sediments, Cu reaches from many sources, but the lionshare is from the natural weathering of residual or transported materials and anthropogenic sources. The total amount of Cu in sediments, its chemical forms, mobility and availability to the food chain, etc play an essential role, in understanding a range of problems affecting crops, animals and possibly human - health. The average abundance of this metal in lithosphere is 70 ppm while the values for earth's crust ranges from 24 to 55 ppm (Baker, 1990).

Table - 23

Heavy metal analysis of international standards

G2 and SCO -1

	Fe	Mn	Co	Pb	Cd	Cu	Zn
G2							
Observed	1.83	28	8	10	0.031	13	84
	(0.03)	(0.002)	(0.24)	(0.42)	(0.001)	(0.63)	(1.25)
Published (1)	0.185	26	5.5	8	0.39	12	85
Published (2)	1.90	25	7.0	12	--	12	87
SC0-1							
Observed	4.39	531	--	--	--	44	97
	(0.003)	(0.015)				(0.016)	(0.02)
Certified	4.5	554	--	--	--	46.4	98.8

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

Paranthesis: Standard deviation for triplicate measurements.

Table - 24

Comparative evaluation of heavy metal concentrations in the mangrove sediments of Veli, Kochi and Kannur areas with that of some other mangrove and estuarine sediments as well as some international reference samples.

Sample	Nature of Sample	Reference	Fe	Mn	Co	Pb	Cd	Cu	Zn
			%	ppm					
Veli mangroves	Bulk	Present Study	1.01	162	30	48	1.2	40	62
Kochi mangroves	Bulk	Present Study	4.50	98	93	31	1.6	41	39
Kannur mangroves	Bulk	Present Study	3.71	295	52	28	2.1	47	66
Kumarakom mangroves	Bulk	Badarudeen et al (1996)	3.52	452	--	118	2.7	48	236
Cauvery mangroves	Bulk	Seralathan (1979)	6.56	1900	16	81	--	72	92
Cooleroon estuary	Clay	Seralathan (1979)	6.58	3130	14	62	--	95	119
Central Vembanad estuary	Bulk	Padmalal (1992)	4.39	366	20	14	4	31	90
Central Vembanad estuary	Sand	Padmalal (1992)	1.09	143	10	14	1	6	30
Central Vembanad estuary	Silt	Padmalal (1992)	7.32	533	29	25	6	44	151
Central Vembanad estuary	Clay	Padmalal (1992)	8.32	480	32	32	6	53	173
Vellar estuary	Bulk	Mohan (1990)	3.94	5245	48	--	7	49	196
Vellar estuary	Clay	Mohan (1990)	6.55	5245	71	--	3	41	196
Nearshore sediments	--	Wedepohl (1978)	--	--	--	--	--	48	95
Deepasea clays	--	Turekian (1972)	--	--	--	--	0.4	250	195
Shale	--	Turekian (1972)	--	850	19	--	0.3	45	95
Average crustal concentration		Baker (1990)	--	--	25	13	0.2	55	70

Table - 25

Ranges and averages of various chemical parameters in the core sediments of Veli, Kochi and Kannur mangroves.

Core No.		C-org	Fe	P	Mn	Co	Pb	Cd	Cu	Zn
					(ppm)					
Veli mangroves										
Core VC1	Max.	3.20	3.78	1.33	214	33	55	2	92	80
	Min.	0.74	1.88	0.16	124	4	16	1	15	44
	Average	2.26	3.09	0.738	150	22	37	1	47	63
Core VC2	Max.	3.39	4.12	2.1	280	42	95	3	81	71
	Min.	1.10	2.39	0.80	120	13	16	1	28	48
	Average	2.94	3.28	1.19	187	25	50	2	42	66
Kochi mangroves										
Core CC1	Max.	7.94	12.4	8.34	72	89	49	1	54	39
	Min.	6.40	9.2	4.23	24	31	27	<1	13	11
	Average	6.98	10.27	5.82	48	59	35	1	37	27
Core CC2	Max.	5.98	9.00	5.62	69	23	43	1	40	50
	Min.	1.75	2.60	1.10	14	3.0	19	<1	10	2
	Average	3.03	4.40	2.1	37	14	31	1	24	22
Core CC3	Max.	2.01	3.9	1.82	169	143	63	2	50	38
	Min.	0.64	0.41	0.7	38	12	16	1	10	10
	Average	1.28	1.66	1.31	130	94	40	1	21	21
Core CC4	Max.	3.62	4.7	3.10	81	28	43	2	70	90
	Min.	1.54	2.98	1.71	24	13	13	1	20	9
	Average	2.31	4.05	2.28	54	20	31	2	49	30
Kannur mangroves										
Core KC1	Max.	5.79	5.27	1.55	272	90	50	5	77	77
	Min.	3.56	3.5	0.27	177	74	28	2	56	70
	Average	5.32	4.11	0.76	214	81	42	3	70	74
Core KC2	Max	4.85	5.5	2.81	212	85	60	2	87	78
	Min.	1.85	2.52	1.58	143	55	22	<1	57	60
	Average	2.63	3.86	2.26	183	68	41	1	65	67
Core KC3	Max.	6.00	5.23	2.37	394	110	60	3	85	96
	Min.	5.78	3.00	0.40	250	75	38	1	57	71
	Average	5.94	3.99	1.19	312	88	49	1	74	82

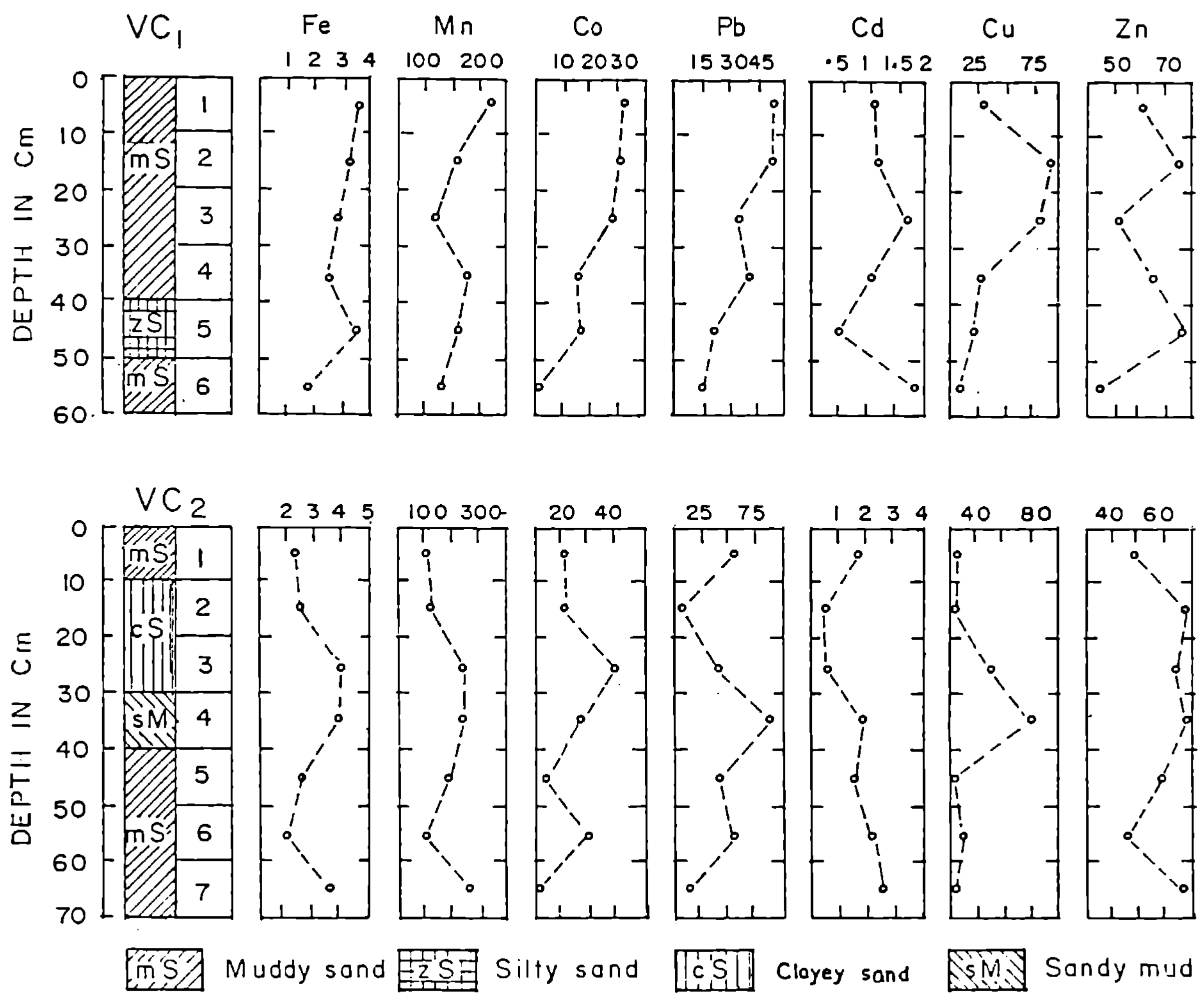

Fig. 33. VARIATION OF HEAVY METALS ALONG THE VERTICAL PROFILE OF THE SEDIMENT CORES OF VELI MANGROVES. (Fe in percentage and others in ppm.)

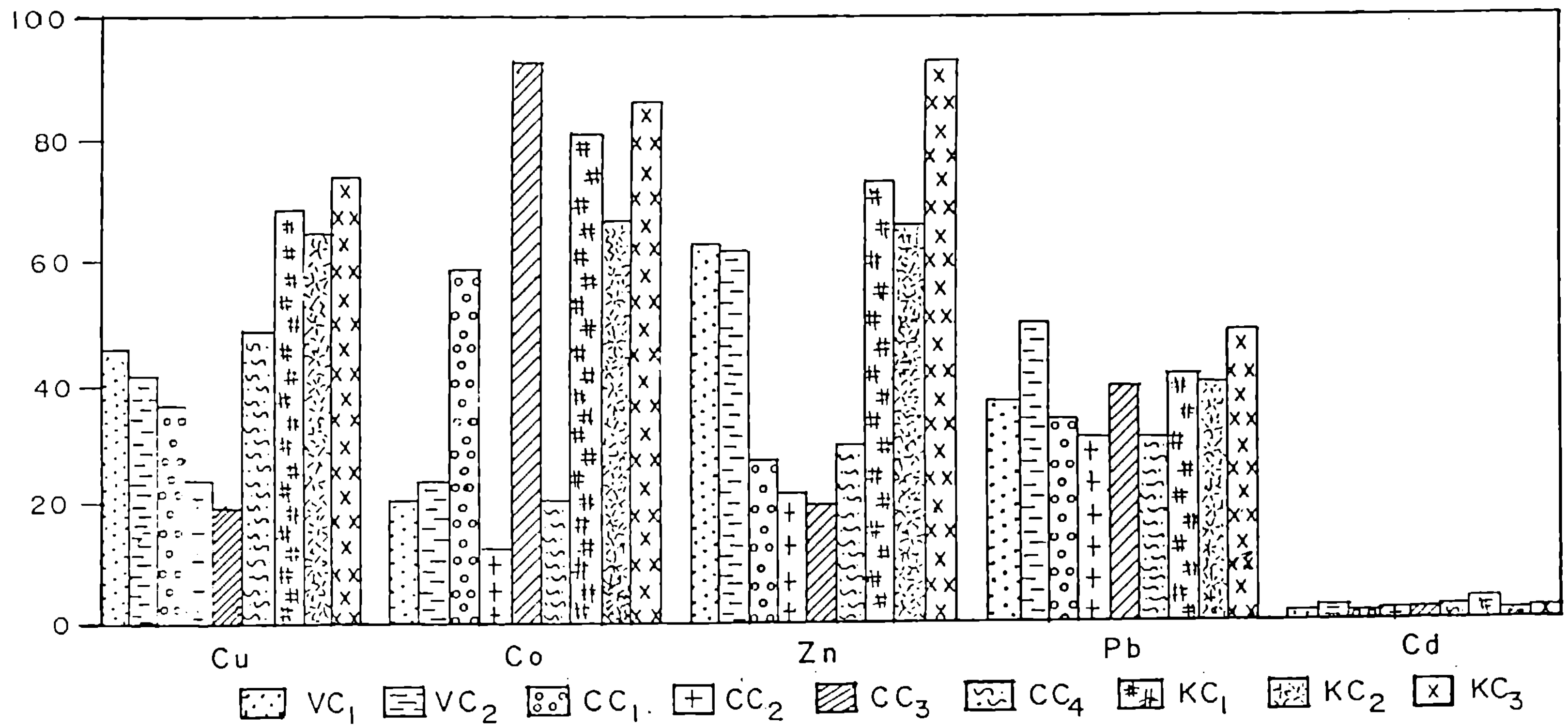

Fig. 36. A COMPARATIVE VISION OF THE AVERAGE CONCENTRATION OF TRACE METALS IN THE VARIOUS CORES RECOVERED FROM VELI, KOCHI AND KANNUR MANGROVES.

The surface sediments of Veli show an average of 40 ppm of Cu, (20 ppm to 81 ppm). The Cu concentration along profiles divulges that, intermediate profile (av; 46 ppm) predominates slightly over the landward profile (av; 42 ppm) and marginally over the shallow water profile (33 ppm). Of the different textural parameters of Veli, the clayey sand and sand comprise the highest and lowest concentrations of Cu. It amounts in various textural classes of the sediments and are of the order clayey sand > sandy mud > muddy sand > silty sand > sandy silt > sand. Sediments of Kochi mangroves exhibit copper concentrations from 12 ppm to 71 ppm (av; 41 ppm). From Table 16, it is clear that both Veli and Kochi regions contain almost similar Cu concentrations. Like wise, Veli and Kochi area too evince predominance of Cu along intermediate profile (av; 49 ppm) over landward profile (av; 44 ppm) and shallow water profile (av:31 ppm). Considering the various textural types of Kochi , the sandy silt and silty sand accomodate enhanced value of Cu (av; 47 ppm) than the sandy mud or muddy sand (av;36 ppm), (Table 17). However, the silty sand and muddy sand accounts for Cu concentration of 47 ppm and 36 ppm, respectively. The enrichment of Cu in the surface sediments of Kannur varies from 19 ppm and 77 ppm (av; 47 ppm). Contrary to the above two environments, Kannur shows higher content of Cu along landward profile (av; 52 ppm) than intermediate (av; 47 ppm) and shallow water profile (av: 41 ppm). It is observed that the intermediate and shallow water profiles of the three mangroves studied exhibits a gradual decrease of Cu concentration from the intermediate profile to the shallow water profile. The sandy mud textural type shows mean Cu content of 67 ppm whereas the muddy sand and silty sand accounts for equal concentrations (av; 27 ppm). Its enrichment in the surface sediments of this ecosystem shows strong positive relationship with mud and C-org (Table 21). By comparing the amounts of Cu in the three mangroves, it is vivid that, Kannur marks the highest content, followed by Kochi and Veli.

Table 21[❖]

Correlation matrix of various geochemical parameters in the surface sediments of Veli, Kochi and Kannur mangroves.

Veli mangroves

	Mud	C-org	$CaCO_3$	Fe	P	Mn	Co	Pb	Cd	Cu	Zn
Mud	1.000										
C-org	0.874	1.000									
$CaCO_3$	-0.351	-0.256	1.000								
Fe	0.075	-.022	-.301	1.000							
P	0.864	0.867	-.351	.080	1.000						
Mn	-0.187	-.268	-.133	-.050	-.217	1.000					
Co	0.255	.290	-.083	.241	.185	-.623	1.000				
Pb	0.125	.073	-.020	.046	.062	-.043	.372	1.000			
Cd	-0.049	-.083	-.066	-.037	-.105	.139	-.086	-.359	1.000		
Cu	0.035	.064	-.177	.181	.031	-.365	.512	.102	-.207	1.000	
Zu	0.013	.280	-.043	-.220	.087	.089	.232	.359	-.096	-.047	1.000

Kochi mangroves

	Mud	C-org	$CaCO_3$	Fe	P	Mn	Co	Pb	Cd	Cu	Zn
Mud	1.000										
C-org	.953	1.000									
$CaCO_3$	.481	.563	1.000								
Fe	.869	.883	.379	1.000							
P	.856	.883	.516	.843	1.000						
Mn	.344	.393	.187	.439	.473	1.000					
Co	-.120	-.144	-.023	-.240	-.135	.143	1.000				
Pb	.033	.093	-.147	.187	.025	-.156	-..213	1.000			
Cd	.166	.162	.046	.166	.171	.072	.305	.015	1.000		
Cu	.052	.089	.0293	-.046	-.051	-.044	-.008	-.123	.194	1.000	
Zn	.470	.567	.592	.482	.517	.359	-.038	.178	-.100	.144	1.000

Kannur mangroves

	Mud	C-org	$CaCO_3$	Fe	P	Mn	Co	Pb	Cd	Cu	Zn
Mud	1.000										
C-org	.956	1.000									
$CaCO_3$	.695	.601	1.000								
Fe	.783	.801	.247	1.000							
P	.758	.803	.393	.598	1.000						
Mn	.377	.467	.417	.432	.203	1.000					
Co	.790	.808	.417	.622	.827	.426	1.000				
Pb	.767	.764	.283	.891	.552	.478	.641	1.000			
Cd	.536	.587	.369	.386	.533	.348	.769	.449	1.000		
Cu	.973	.968	..619	.783	.821	.359	.770	.782	.464	1.000	
Zn	.820	.789	.461	.615	.737	.284	.682	.663	.320	.854	1.000

❖ Refer appendix at page

The cores Vc_1 and Vc_2 of Veli region show slightly an elevated values of Cu (av; 47 ppm and 42 ppm, respectively) than its surface sediments. As seen from Table 22, Cu exhibits positive covariance with mud, Fe and C-org. The decreasing abundance of mean Cu in the sediment cores of Kochi are, 49 ppm in Vallarpadam (CC_4), 37 ppm in Vypin (CC_1), 25 ppm in Malippuram (CC_2) and 21 ppm in Vallarpadam (CC_3). Considering the four cores of Kochi together, the relative abundance of copper percieved as silty sand > sandy mud > clayey sand > muddy sand > sandy silt > sand (Table 19). Copper shows marginal co-existence with phosphorus and iron (Table 22). Depthwise variation of Cu in the cores of Kannur averages about 69 ppm in KC_1, 65 ppm in KC_2 and 74 ppm in KC_3. Comparison of the total averages of Cu in the three mangroves reveal that, Kannur area manifests more than 2 fold enhancement than Kochi and nearly double the concentration than Veli. Like the surface sediments, core sediments too demonstrate a linear variation of Cu with mud, C-org and Fe (Table 22)

5.3.7.2 Cobalt

Cobalt is one of the important metals which is related to the industrial civilization. In nature, this metal is mostly abundant in unstable ferromagnesian minerals like pyroxenes, amphiboles, biotite etc (Smith, 1990) and hence cobalt in sediment and sedimentary rocks reflects the composition of the source rock from which they have been derived. Co is characteristically more able to migrate than other trace metals (Nriagu, 1980). In sediments, it is stable in the presence of Nitrogen 'donor' molecules. It can easily be oxidised in hypergene zones and can be converted to the trivalent state. The fate of Co is strongly influenced by aqueous reactions with soluble species and with particulates. Cobalt is relatively scarce in the earth's crust, but the human body requires vitamin B12, which is a cobalt (III) complex to form

Table- 22[*]

Correlation matrix of various geochemical parameters in the core sediments of Veli, Kochi and Kannur mangroves.

Veli mangroves

	Mud	C-org	$CaCO_3$	Fe	P	Mn	Co	Pb	Cd	Cu	Zn
Mud	1.000										
C-org	.977	1.000									
$CaCO_3$	-.021	-.047	1.000								
Fe	.570	.515	.007	1.000							
P	.554	.513	-.239	.191	1.000						
Mn	.397	.370	-.164	.819	.321	1.000					
Co	.372	.374	.091	.504	.120	.227	1.000				
Pb	.642	.698	-.053	.315	.522	.241	.550	1.000			
Cd	.138	.271	-.200	-.192	.310	.121	-.309	.206	1.000		
Cu	.498	.543	-.107	.400	.014	.121	.606	.465	-.076	1.000	
Zn	.288	.203	-.160	.733	-.122	.483	.166	.045	-.447	.288	1.000

Kochi mangroves

	Mud	C-org	$CaCO_3$	:	P	Mn	Co	Pb	Cd	Cu	Zn
Mud	1.000										
C-org	.984	1.000									
$CaCO_3$	.516	.474	1.000								
Fe	.943	.959	.500	1.000							
P	0922	.906	.352	.921	1.000						
Mn	-.368	-.433	-.135	-.456	-.302	1.000					
Co	.063	-.012	.042	-.033	.103	0823	1.000				
Pb	.350	.309	.388	.254	.285	.097	.199	1.000			
Cd	-.367	-.331	-.307	-.258	-.244	.058	-.125	-.443	1.000		
Cu	.186	.190	.057	.299	.375	-.251	-.153	-.161	.188	1.000	
Zn	.541	.548	.171	.546	.564	.109	.423	.197	.033	.072	1.000

Kannur mangroves

	Mud	C-org	$CaCO_3$	Fe	P	Mn	Co	Pb	Cd	Cu	Zn
Mud	1.000										
C-org	.987	1.000									
$CaCO_3$	-2.93	-.242	1.000								
Fe	.188	.185	.040	1.000							
P	-.617	-.643	-.276	-.073	1.000						
Mn	.701	.647	.-535	.371	-.243	1.000					
Co	.666	.606	-.359	.491	-.210	.772	1.000				
Pb	.435	.468	-.100	.151	-.116	.387	.334	1.000			
Cd	.191	.247	.620	.076	-.519	-.209	.110	-.105	1.000		
Cu	.363	.344	-.258	.259	-.257	.411	.465	.481	.108	1.000	
Zn	.686	.635	-.327	.228	-.448	.599	.488	.366	.021	.695	1.000

[*] Refer appendix at page

Appendix of tables 21 and 22

	VELI		KOCHI		KANNUR	
	r Values	Level of Significance	r Values	Level of Significance	r Values	Level of Significance
Surface sediments	0.24 to 0.29	0.1 to 0.05	0.32 to 0.38	0.1 to 0.05	0.46 to 0.53	0.1 to 0.05
	0.29 to 0.34	0.05 to 0.02	0.38 to 0.45	0.05 to 0.02	0.53 to 0.61	0.05 to 0.02
	0.34 to 0.37	0.02 to 0.01	0.45 to 0.49	0.02 to 0.01	0.61 to 0.66	0.02 to 0.01
	0.37 to 0.46	0.01 to 0.001	0.49 to 0.60	0.01 to 0.001	0.66 to 0.78	0.01 to 0.001
	> 0.46	< 0.001	> 0.6	< 0.001	> 0.78	< 0.001
Core sediments	0.44 to 0.51	0.1 to 0.05	0.29 to 0.35	0.1 to 0.05	0.36 to 0.42	0.1 to 0.05
	0.51 to 0.59	0.05 to 0.02	0.35 to 0.41	0.05 to 0.02	0.42 to 0.49	0.05 to 0.02
	0.59 to 0.64	0.02 to 0.01	0.41 to 0.45	0.02 to 0.01	0.49 to 0.54	0.02 to 0.01
	0.64 to 0.76	0.01 to 0.001	0.45 to 0.55	0.01 to 0.001	0.54 to 0.65	0.01 to 0.001
	> 0.76	< 0.001	> 0.55	< 0.001	> 0.65	< 0.001

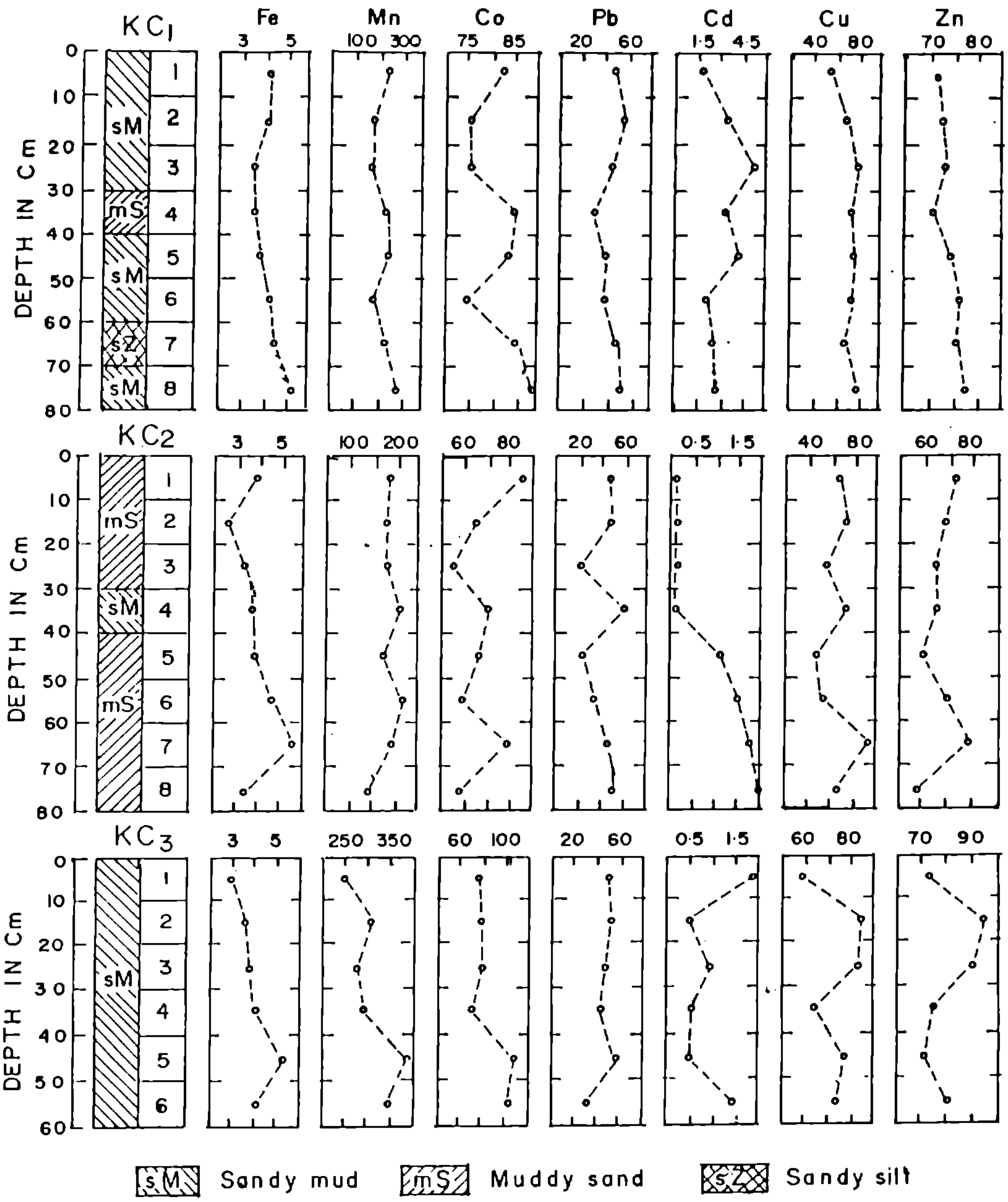

Fig. 35. VARIATION OF HEAVY METALS ALONG THE VERTICAL PROFILE OF THE SEDIMENT CORES OF KANNUR MANGROVES (Fe in percentage and others in ppm.)

haemoglobin. Having the ability to occupy low symmetry sites in enzymes, cobalt (II) is an enzyme activator (Rose, 1983).

Lateral distribution of cobalt in the sediments of Veli, varies between 11 ppm to 55 ppm (av; 30 ppm). Its relative average proportion along profiles (Fig. 32) are of the order as landward profile (av; 37 ppm) > intermediate profile (av; 29 ppm) > shallow water profile (av; 19 ppm). Of the various textural units the sandy mud contains an average cobalt of 35 ppm and accomodates mean Co of 19 ppm. It shows marginal positive variation with mud, C-org and Fe (Table 21). Contrary to the variations of other trace metals of Kochi, cobalt shows wide ranges from 12 ppm to 141 ppm (av; 93 ppm). This mean value exhibits more than 3 times enrichment to that of Veli region. Average cobalt concentration does not show much variation along profiles. The landward profile, intermediate profile and shallow water profile show approximately 2.5 fold, 3 fold and 4 fold enrichment of Co than the respective profiles of Veli. Sediments of Kannur, varies between 20 ppm and 70 ppm of cobalt and shows average value of 52 ppm. Like the Cu distribution, cobalt too shows a gradual depletion of its concentration from intermediate to shallow water profile except in Kannur, where it shows marginal increase along shallow water profile. The average cobalt concentration of this region reveals nearly 2 fold decrease than Kochi and 3 fold increase than Veli surface sediments. Inter relationship between cobalt with mud, C-org and phosphorus (Table 21) exemplifies strong positive correlation and marginal covariance with Fe (Table 21).

Sediment cores VC_1 and VC_2 of Veli shows wide variations of Co from 4 ppm to 33 ppm (av; 22 ppm) in the former and 13 ppm to 42 ppm (av; 25 ppm) in the latter. Vertical variation of this metal shows progressive depletion downwards and no such variation noticed in VC_2 (Fig. 33). Cobalt shows comparatively less amounts in VC_1 and VC_2 when compared with other metals (Cu, Zn and Pb). Among the different textural assemblages, the clayey sand (av; 32 ppm) and muddy sand (av; 11 ppm) exhibit highest and lowest Co content (Table 19). This metal enumerates marginal significance with mud, C-org and Fe and no significant relation with phosphorus (Table 22). The mean cobalt content in the cores of Vypin (CC_1) Malippuram (CC_2), and Vallarpadam (CC_3 and CC_4) are 59 ppm, 14 ppm, 94 ppm and 20 ppm, respectively. By taking, the above mentioned four cores together, the cobalt concentration in the various textural units are as sand (av; 116 ppm) > sandy mud (av; 78 ppm) > silty sand (av; 64 ppm) > sandy silt (av; 40 ppm) > muddy sand (av; 22 ppm) > clayey sand (av; 19 ppm) and their ranges are provided in Table 19. The amount of Co in CC_2 reveals more than 4 fold, 7 fold and 1.5 fold decrease than CC_1, CC_3 and CC_4, respectively. Vertical variation of this metal in the sediment cores of Kannur (KC_1, KC_2 and KC_3), ingeneral, accounts for an average of 81 ppm, 68 ppm and 88 ppm, respectively (Table 23). Its availability in the above cores is expressed as $KC_3 > KC_1 > KC_2$. Cobalt shows positive affinity with mud ($r = 0.66$), C-org ($r = 0.606$) and Fe ($r = 4.91$).

5.3.7.3 Zinc (Zn)

Zinc is an essential, beneficial element, in human metabolism (Vallee, 1957). In nature, it is often associated with sulphides of other metals, especially Pb, Cu, Cd and Fe. The major sources of Zn pollution in estuarine and mangrove environments are the weathering and washing off overburden, spills, discharge from industrial plants, domestic and industrial sewages (Oliver and Cosgrove, 1975). This transition metal is known to be involved in a number of enzyme systems in aquatic and terrestrial biota (Vallee, 1959; Bryan, 1964) making it an essential micro nutrient. The daily requirement of Zn in children is 0.3mg/kg, deficiency of which leads to growth retardation (Rose, 1983). However, like other elements, Zn can be toxic, if introduced in high enough concentration (Eisler and Wapner, 1975). The toxicity of Zn compounds in estuarine sediments is modified by several environmental factors, particularly dissolved O_2 and temperature. Both an increase in temperature and a reduction in dissolved oxygen increase the toxicity of Zn. The incipient lethal level, the level beyond which organisms can no longer survive is 420 g/ liter of Zn. Thus it is important to understand the different ways, forms, and rates, this metal is introduced, distributed and removed in the estuarine and mangrove environments.

The lateral variation of Zn in the surface sediments of Veli, averages about 62 ppm (22 ppm 86 ppm) and its distribution along intermediate profile (av; 73 ppm) is higher than landward profile (av; 63 ppm) and shallow water profile (av; 52 ppm). Variation of Zn with respect to textural facies are listed in Table 17. The surface sediments of Kochi mangroves reveal wide variations from 15 ppm to 91 ppm with mean Zn value of 39 ppm, which is 1.5 times less than Veli sediments. The average Zn levels along the profiles of Kochi does not show much variation and it demonstrates 1.5 fold and nearly 2 fold decrease of Zn than the landward profile and intermediate profile of Veli region. The sediments of this area follows strong positive correlation of Zn with mud (r = 0.470), C-org (r = 0.567), Fe (r = 0.482) and P (0.517), (Table 21). Mangrove sediments of Kannur yields levels of Zn from 48 ppm to 87 ppm (av; 66 ppm). Similar to Kochi, here too, the three profiles does not exhibit much variations (landward profile 67 ppm, intermediate profile 65 ppm and shallow water profile 67 ppm). Highest amount of this metal (av; 67 ppm) is found incorporated with sandy mud followed by muddy sand (av; 60 ppm) and silty sand (av; 27 ppm). Comparative evaluation of Zn in sediments of the three mangroves reveal that, its concentration is more or less equal in Veli and Kannur and shows nearly 2 fold enhancement than Kochi mangroves. The correlation between Zn Vs C-org, phosphorus and mud gives strong linear affinity and shows only marginal significance with Fe (Table 21).

The cores VC_1 and VC_2 register variation of Zn from 44 ppm to 80 ppm (av; 63 ppm) and 48 ppm to 71 ppm (av; 63 ppm). The average loading of Zn in the surface and core sediments do not reveal much variations. The amount of Zn in different textural facies of the two cores are sandy mud (av; 71 ppm) > clayey sand (av; 69 ppm) > muddy sand (av; 64 ppm) > silty sand (av; 62 ppm). Zn shows marginal positive bearing with mud (r = 0.288), C-org (r = 0.203) and strong with Fe and Mn (Table 22). Variation of Zn with depth follows no regular pattern (Fig.34) at Kochi and shows highest average concentration of 30 ppm in CC_4 (Vallarpadam) followed by CC_1 (Vypin) (av; 27 ppm), CC_2 (Malippuram) (22 ppm) and CC_3 (Vallarpadam) (av; 21 ppm). The total average of Zn in the four cores of Kochi shows more than 2 fold decrease than Veli. Inter elemental correlation reveals strong positive relation with Mud, C-org, P and Fe (Table 22). The relative enrichment of Zn in the three cores of Kannur are KC_3 (av; 93 ppm)> KC_1 (av; 74 ppm) > KC_2 (av; 67 ppm). Though many textural facies encountered, the sandy silt (av; 75 ppm) accounts for highest amount of Zn in KC_1, muddy sand contains highest Zn in KC_2 (av; 68 ppm) and sandy mud gives maximum Zn concentration in KC_3 (av; 81 ppm). It gives good positive correlation with C-org (r = 0.635), mud (r = 0.686) and Mn (r = 0.599)

5.3.7.4 Lead (Pb)

The average concentration of Pb on the surface of the earth is 16ppm (Davis 1990). A large part of it is discharged into surface waters through mining. smelting, refining as well as from the production and uses of Pb based products. Lead is rapidly incorporated into suspended and bottom sediments and ultimately reaches the aquatic sediments. Pb enters in aquatic environments through precipitation, dust fallout, erosion and leaching of soil as well as municipal and industrial waste disposals. Once Pb has entered into the aquatic environment, its mobility and distribution will be closely controlled by its chemical forms and it interacts detrimently with aquatic life. Lead, when incorporated into sediments, will develop low mobility and hence once contaminated the sediment is liable to remain polluted with lead. Its toxicity in sediments is affected by pH, hardness, organic material and presence of other metals. Stable complexes of Pb is resulted from the interaction with carboxyl and amine co-ordination sites found in living matter. In addition, plants especially certain species of mangroves grown on Pb rich aquatic sediments incorporate Pb into their cells.

The surface sediments of Veli exhibit wide ranges of Pb from 16 ppm to 103 ppm (av; 48 ppm) and its deviation along profiles divulge that the intermediate profile (av; 54 ppm) predominates over landward profile (av; 51 ppm) and shallow water profile (av; 45 ppm). Veli region is compounded by several textural units, out of which the clayey sand and sand accomodates the highest (av; 71 ppm) and lowest (av; 20 ppm) Pb contents. The north-north eastern part of the region is marked by the general depletion of Pb in three profiles which might be owing to the predominance of sand dominant textural facies. Lateral variation of lead in the sediments of Kochi mangroves ranges from 11 ppm to 56 ppm (av; 31 ppm) and its distribution along the profiles in the order of abundance is landward profile (av; 38 ppm) > intermediate profile (av; 34 ppm) > shallow water profile (av; 26 ppm). Pb enrichment in different textural units reveal its predominance in sandy mud (av; 39 ppm) followed by silty sand (av; 36 ppm) muddy sand (av; 30 ppm) and sandy silt (av; 21 ppm). In, the mangrove sediments of Kannur, Pb varies between 17 ppm and 39 ppm (av; 28 ppm) and shows 1.5 fold decrease than Veli mangroves. The landward profile and shallow water profile show almost equal amounts of Pb and a gradual decrease of its concentration is noticed from intermediate profile to shallow water profile as in the case of Co and Cu (Table 16). Lead in the, Kannur mangrove sediments exhibit positive correlation with mud (r = 0.767), C-org (r = 0.764), Fe (r = 0.891) and Phosphorus (r = 0.552).

Sediment cores of Veli shows an average Pb concentration of 37 ppm (16 ppm to 55 ppm) in VC_1 and 50 ppm (16 ppm to 95 ppm) in VC_2. The former core reveals progressive decrease of Pb except at a depth of 30-40 cm below the surface where no such relation exist in VC_2. The muddy sand textural facies of VC_1 exhibits 2 fold increase of Pb than silty sand layer and the sandy mud unit of VC_2 shows 3 fold enhancement than the clayey sand and muddy sand layers. Pb shows a positive variation with mud (r = 0.642), C-org (r = 0.698) and P (r = 0.522). The average Pb content in the sediments of Vypin (CC_1), Malippuram (CC_2) and Vallarpadam (CC_3 and CC_4) areas are 35 ppm, 31 ppm and 36 ppm, respectively. Variation of Pb with respect to various textural units are furnished in Table 19. Positive correlation of Pb with mud, C-org and Phosphorus are exemplified from Table 22. The average Pb accumulation in the sediment cores of Kannur do not show much deviation and exhibit mean values of 42 ppm, 41 ppm and 49 ppm in KC_1, KC_2 and KC_3, respectively. Considering the textural units of all the above cores, the relative variation of Pb in different textural facies are of the order sandy mud > silty sand > sandy silt > muddy sand. Interelematal correlation gives a positive affinity of Pb with C-org, mud and Mn.

5.3.7.5 Cadmium (Cd)

The environmental toxicology of cadmium has attracted a lot of attention in recent years. While a number of excellent informations exist on cadmium toxicity in human beings and animal species, few detailed attempts have been made to relate the toxicological aspects and the bio-geochemical features of the metal in the ecosystems. Cadmium is a potentially hazardous pollutant in the environment, and chronic human exposure to low concentrations of this element may cause serious illness and possibly death (Friberg et al, 1971; 1973). Its average concentration in the earth's crust is estimated to be 0.1 ppm (Bowen, 1979). The production and industrial utilization of cadmium are continuing to increase throughout the industrialized world with a concurrent increase of cadmium residue in the environment (Nriagu, 1980; Page and Bingham, 1973). As a result, there is an urgent need to understand the sources of emission and their direct or indirect interaction with sediments, water and plants (especially mangroves) so that some criteria can be developed for assessing potential environmental hazards in aquatic biota or in human populations. For this reason, there is a critical urgency to define the role of mangrove sediments and species in aquatic systems, in the accumulation, transfer, effects and ultimate fate of this metal in mangroves. By studying the lateral variation of Cd local sources of pollution can be determined and its variation with depth often uniquely preserve the historical sequence of pollution intensities. Cadmium reaches the aquatic environments mainly from the mining and smelting of Cd and Zn, from metallurgical industries, and burning of fossil fuels (Hutton, 1982). Page et al, (1987) computed that, igneous and metamorphic rocks of the earth's crust have a cd content ranging from 0.1ppm to 0.3 ppm and 0.3 ppm to 11 ppm, respectively.

Lateral variation of cadmium in surface sediments of Veli shows an average of 1 ppm (< 1 ppm to 2 ppm) and reveal no marked deviations in their contents along the landward, intermediate and shallow water profiles. The textural classes, clayey sand and sand exhibit average Cd of 1 ppm. Sediments of Kochi mangroves reveal average cadmium of 2 ppm (< 1 ppm to 3 ppm) and does not show much variation along the three profiles. Highest enrichment of cadmium is encountered in the sandy silt textural facies of both Veli and Kochi regions. Of the three mangroves studied, Kannur region shows wide cadmium variation from < 1 ppm to 6 ppm (av; 2 ppm). This average value of Cd is 1.5 times higher than Veli and Kochi. Similar to the behaviour of Cu, Co and Pb, Cadmium also shows an elevated enrichments along intermediate profile than shallow water profile in all the mangroves studied.

The average contents of Cd in the sediments of Veli reveal that the core VC_2 (av; 2 ppm) predominates over VC_1 (av; 1 ppm). Similarly, the cores from Kochi, viz, CC_3 and CC_4 of Vallarpadam shows elevated concentration (av; 2 ppm) than the Vypin(CC_1), (av; 1 ppm) and Malippuram (av; 1 ppm) regions. Core KC_1, KC_2 and KC_3 of Kannur mangroves divulge the average Cd values of 3 ppm, 1 ppm and 2 ppm, respectively. Variations of Cd with respect to the various textural units for the above three mangrove environments are furnished in Table 19.

Discussion: The investigation on trace metals associated with Veli, Kochi and Kannur mangroves reveal that, trace metals (Cu, Co, Zn, Pb and Cd) in the three environments behave differently and gives different relationships with other geochemical such as C-org, Fe, P and with textural classes viz. silt and clay elements. In general, the interrelationship of the above trace metals reveals positive correlation with Fe, C-org or mud content and signifies only marginal positive relation with phosphorus in most cases. The sympathetic and antipathetic behaviour of trace metals with the above (Table 21) could be due to the variation of Physico-chemical parameters such as salinity, temperature, Eh-pH, and availability of other metal complexes operating in these environments. It is noted that the metals Cu, Co, Pb and Cd exhibit slightly elevated concentrations along intermediateprofile than the shallow water profile owing to either the particle control or the chemical removal mechanism. The winnowing activity of tidal waves removes the above trace metal scavenged by the finer particles from the landward profile towards shallow water profile or they may be desorbed from sediments when it comes in contact with saline waters.

Sediments of Veli shows strong linear relation between Cu and Fe in core sediments and marginal co-existence in surface sediments. Kochi sediments impart no significant relation with the above parameters and exhibit marginal relation along cores. Kannur sediments demonstrate strong linear existence between Cu and Fe, C-org, phosphorus and mud in surface sediments. Seralathan , (1979) obtained similar type of dissimilar behaviour of Cu with Fe, P and mud in the mangrove sediments of cauvery riven basin. Wedephol, (1978) stated that high concentrations of Cu can be adsorbed on clay minerals, iron oxide and organic matter. El-wakeel and Riley, (1961) and Hirst, (1962 b), Rao and Swamy, (1995) pointed out that Cu can be fixed by clay minerals through adsorption and cation exchange property. During estuarine mixing, Cu is released from clay minerals to the overlying waters (Forstner and Wittmann, 1983). It is established that, the Eh-pH changes and salinity variations in the overlying waters strongly influence the geochemical behaviour of Cu in aquatic sediments (Aston and Chester, 1976). The strong linear relationship of Cu with clay minerals suggest that Cu is fixed mainly in montmorillonite both in the lattice as well as in the form of oxide coatings since montmorillonite is having a higher adsoption capacity.

Cobalt establishes strong linear relationship with C-org and Fe in the surficial sediments of Veli and Kannur and the core sediments of Kochi. This might be attributed to the enrichment of cobalt by humic acid produced by the decaying of mangrove vegetation (Szalay, 1964) and to a certain extent due to the contribution of organisms. The positive covariance with C-org and clay minerals viz. montmorillonite at Veli and Kannur also suggest that Co may be of non-detrital origin. Positive correlation of Fe and Co could be due to the desorption of Co by hydrated $Fe_2 0_3$ (Krauskopf, 1956). The progressive depletion of Co in core VC_1 of Veli may be explained on the desorption of Co from clay minerals. Kharkar et al, (1968) have stated that, trace elements such as cobalt which have been adsorbed from solution by clay minerals might have been suspended in estuarine waters and desorbed in seawater. Cobalt is less efficiently desorbed from oxides of Fe and Mn than it was from clay minerals. The marginal positive existence of Co with P and at certain stations with Fe suggest the lack of control of these parameters in Co distribution. Thus, the Co density in the present sediments is controlled not only by ionic proxying in the caly mineral lattice but also by other aforesaid mechanisms. A similar observation was made by Kalesha, (1980) for the Kakinada - Pentakota shelf sediments.

Zn bears strong positive affinity with C-org, mud content and Fe. Shimp et al, (1970, 1971) have made detailed studies on the factors controlling the Zn concentration in estuarine sediments and obtained strong positive correlation with C-org and concluded that it has a prominent role in concentration of Zn in sediments through biological processes. Among the three mangrove sediments studied, the highest Zn concentration is either with silt or clay dominated textural facies. However, few sample locations exhibit paradoxical observations. Padmalal, (1992) obtained linear relation of Zn with silt and clay dominated sediments. The abundance of Zn in mud predominant sediment is due to the increased surface area of fine particulates (Williams et al; 1978). Further, the Fe/Mn complexes, clay minerals and organic coating over these particulates also scavenge significant amount of Zn. Zn has great affinity towards sulphur. Since mangrove regions show prevalence of reducing environments, which inturn might have favoured the higher concentrations of Zn. It is assumed that Zn in fine grained sediments is precipitated as sulphides (Lu and Chen, 1977). A part of Zn is adsorbed either by ferrous sulphate or oxide as it has shown positive correlation with Fe. The marginal relation of Zn and P in the three mangroves presumably due to its enrichment in phosphates as suggested by Rankama and Sahama, (1950). Remarkably high accumulation of Zn in the pure sandy unit of Veli could be attributed to the contribution from detrital minerals. In addition to the above sources, heavy minerals like magnetite can also contribute Zn.

Lead gives strong linear co-existence with C-org and mud, and exhibits marginal correlation with P and Fe. Pb may be carried in solution in acidic conditions and in alkaline environments, the Pb ion becomes hydrolised and Co precipitated as hydroxides of more abundant elements or absorbed by clays. It is adsorbed more strongly and more consistently by hydrated ferric oxides. Wedephol, (1978) opined that Pb can effectively be carried out by kaolnite than montmorillomite. The increased levels of kaolinite and Pb in mud dominated sediments of mangrove environments suggest the association of this metal with kaolinite. Appreciable amounts of Pb enters into aquatic environments through weathering of rocks (Paul and Pillai, 1983 b). The aforesaid conclusion can very well be ascertained from speciation studies that, more than 60-90% of Pb in the mangroves of Veli, Kochi and Kannur are bound with lithogenous fractions. The toxic metal Pb accumulates in the surface and core sediments of the three mangroves studied and its concentration levels are well above the toxic limits.

Analysis of the relative abundance of Cd in mangrove environments reveals that, considerable amount of it is found associated either with silt or mud dominated textural facies. This environment exhibits strong linear covariance with C-org and Fe and marginal significance with P and mud. Anomalously elevated accumulation of Cd (6ppm) observed in the north-eastern sector of Kannur, might be resulted from the localised pollution. The most sensitive change in the behaviour of Cd is within the pH range 6 to 8. At a pH of 8.1 the Cd adsorption is suppressed and the desorption processes is enhanced.

5.3.8 **Trace Metal Speciation**

Recent decades underlined the relevance and paramount importance of heavy metal speciation studies in aquatic environments. (Chen et al, 1976; Hong and

Forstner, 1984; Rapin, 1984). Trace metal levels in the environment and their fractionation in different chemical phases can be delineated using these studies. Further such investigations provide information about the mobility, bioavailability and factors controlling the concentration of toxic metals in sediments as well as in water column (Calmano and Forstner, 1983). According to Rapin, (1984) the sequential extraction procedures also throw enough light on the history of metal inputs, diagenetic transformations within the sediments and the reactivity of heavy metal species of both natural and anthropogenic origin. Early investigations on sediment associated trace metals were confined to the partitioning of metals into detrital and non-detrital fractions only (Hirst and Nicholls, 1958; Gad and Lerich, 1966). Further development was in the direction of chemical extraction procedures for the separation of metals associated with ferromaganesium minerals, carbonates and adsorbed trace elements of pelagic sediments (Chester and Hughes, 1967; Nissenbaum, 1972). Though many limitations are encountered, partitioning provides knowledge on the relative phasial distribution of heavy metals in aquatic sediments. A five step sequential extraction technique was introduced by Tessier et al, (1979). This scheme facilitated the distinction between exchangeable, easily reducible, moderately reducible, organically bound and residual metal fractions. The chemical technique was based on the three groups of components occuring in fluvial systems which are potentially able to enrich the metals in sediments. In this chapter an attempt has been made to understand the various chemical species of some selected heavy metals, viz cobalt, lead, copper, cadmium and zinc in the mangrove environments of Veli, Kochi and Kannur regions. (Only some representative samples have been subjected to speciation studies).

The percent distribution of cobalt, lead, copper, cadmium and zinc in the various chemical phases of the mangrove sediments at Veli, Kochi and Kannur are given in Table 26.

Table - 26

Concentration of heavy metals in various chemical phases of some selected samples of Veli, Kochi and Kannur mangroves

(values are expressed in percentages)

	Metals analysed	Easily exchan-geable	Carbonate bound	Organic bound	Fe/Mn bound	Lattice bound
Veli mangroves						
Landward profile (sample 9.a)	Co	0.32	0.49	1.42	11.54	86.3
	Pb	7.15	6.7	0.62	5.23	80.29
	Cu	12.18	0.82	3.03	6.9	76.96
	Zn	1.66	4.64	9.43	16.64	67.61
Intermediate profile (sample 9.b)	Co	BDL	1.82	8.19	5.71	82.88
	Pb	9.76	5.80	2.27	7.91	74.26
	Cu	5.96	BDL	12.47	12.20	69.37
	Zn	1.59	3.64	8.33	16.31	70.13
Shallow water profile (sample 9.c)	Co	BDL	19.77	13.37	5.91	60.95
	Pb	3.75	13.53	2.81	7.03	72.88
	Cu	1.97	BDL	0.91	4.38	92.74
	Zn	1.59	3.64	8.33	16.31	70.13
Kochi mangroves						
Landward profile (sample 18.a)	Co	0.53	12.25	8.9	6.4	71.95
	Pb	2.84	2.34	0.31	7.21	87.3
	Cu	BDL	7.62	7.53	10.00	74.85
	Zn	0.11	1.17	2.90	1.98	93.84
Intermediate profile (sample 18.b)	Co	2.87	2.05	8.41	5.58	81.09
	Pb	9.64	9.24	1.97	5.42	73.70
	Cu	1.15	6.31	8.10	21.70	62.74
	Zn	0.11	2.39	1.55	1.70	94.25
Shallow water profile (sample 18.c)	Co	1.18	4.01	7.67	5.39	81.75
	Pb	BDL	10.50	6.03	3.82	80.27
	Cu	2.14	9.93	25.01	11.55	51.38
	Zn	0.40	6.35	28.22	4.53	60.50
Kannur mangroves						
Landward profile (sample 26.a)	Co	BDL	3.21	5.58	3.98	87.23
	Pb	4.68	5.04	11.97	14.13	64.18
	Cu	6.62	11.65	12.44	9.03	60.27
	Zn	3.99	13.07	4.72	9.17	69.05
Intermediate profile (sample 26.b)	Co	3.14	3.14	2.69	5.94	85.09
	Pb	0.59	4.55	0.66	4.45	89.75
	Cu	17.70	17.70	9.63	15.14	39.83
	Zn	BDL	BDL	9.79	16.25	73.95
Shallow water profile (sample 26.c)	Co	BDL	BDL	14.19	13.05	72.76
	Pb	2.68	6.55	5.24	6.88	78.65
	Cu	BDL	5.33	7.23	24.19	63.25
	Zn	BDL	0.26	5.82	9.44	84.48

BDL = Below Detection Level.

5.3.8.1 Cobalt

The landward profile sediments of Veli región shows 0.32% of cobalt in easily exchangeable phase, however, it does not exist in detectable levels either in intermediate or shallow water profiles. Appreciable amounts of cobalt is found associated with shallow water sediments particularly in the carbonate (19.77%) and C-org (13.37%) bound forms. The enrichment of cobalt in the Fe/Mn phase of landward profile sediments are rather high (11.54%) compared to the intermediate profile (5.71%) and shallow water profiles (5.91%). In fact, the lionshare of Co confines to the residual fractions of this environment showing an average of 76.71% (60.95% to 86.3%). The three profiles landward profile, intermediate profile and shallow water profiles are marked by the dominance of sand textural assemblages which appears to be the predominant contributing factor in controlling the speciation of cobalt, indicating its close relationship with textural classes of sediemnts.

The detected levels of cobalt associated with exchangeable fractions along landward, intermediate and shallow water profiles of Kochi mangroves are 0.53%, 2.87% and 1.18%, respectively. The intermediate and shallow water sediment detects approximately 6 and 3 times decrease in the content of cobalt compared to the landward sediments. The cobalt linked with C-org phase, tends to show no significant variation along the profiles (Table 24). The dominant part of cobalt is linked with the lattice bound form (landward profile = 71.96%, intermediate profile = 81.09% and shallow water profile = 81.75%).

The landward and shallow water profiles of Kannur mangroves contain cobalt well below the detection level in the exchangeable fraction and exhibits 3.14% along the intermediate profile. The landward profile accomodates 3.21% and intermediate profile encompases 3.14% of Co in the carbonate phase and no part of this metal occured along shallow water profile.

Regarding the organically bound metal fraction along the shallow water profile (14.19%) shows 5 fold and more than 2 fold higher values comparing its concentration along intermediate profile and landward profile, respectively. A gradual increasing trend was given by this metal from landward profile to shallow water profile on comparing with reducible (Fe/Mn) bounds (Table 24). Similar to the sediments of Veli and Kochi, the lithogenous bound fractions of the mangrove sediments show higher value of approximately 82% of cobalt.

5.3.8.2 lead

Speciation studies of Veli mangroves reveal that on an average scale, the exchangeable, carbonate and Fe/Mn, phases of lead are comparable, in which the former expresses an average content of 6.89%, while the latter two manifest a mean of 8.67% and 6.72%, respectively. However, the lithogenous fraction dominates sevaral folds and it accomodates an average of 75.81% of Pb, while the organic bound form unfolds considerably depleted amounts, all along the sediment profiles (0.62% - 2.5%).

However, in the case of Kochi mangroves, the content of lead along the landward and intermediate profiles bounded with carbonate (av; 5.79%) and exchangeable (av; 6.24%) phases are roughly parallel, whereby its concentration goes far below detection level in the easily exchangeable phase and shows 10.5% of Pb attached with carbonate bound. The lattice bound metal fractions of lead (av; 80.42%) found, predominates over all other species and the reducible stage exhibits, a mean value of 5.48%. Similar to Veli sediments, the organically bound Pb fractions of Kochi are found depleted considerably.

Speciation results of lead in the sediments of Kannur, perceives a gradual decrease from the residual to easily exchangeable phases showing their relative abundance as lattice bound (av; 77.52%) > reducible bound (av; 8.48%) > origanically bound (av; 5.96%) > carbonate bound (av; 5.3%) > easily exchangeable (av; 2.65%).

5.3.8.3 Copper

The Veli mangroves show roughly similar concentrations of Cu in exchangeable, organically bound and reducible Fe/Mn species highlighting an average concentrations of 6.7%, 5.4% and 7.82%, respectively. However, copper does not occur in detectable levels in the carbonate stage both in intermediate and shallow water profiles and shows 0.81% along the landward profile. The level in residual fraction is rather very high and this enhancement in concentration (av; 79.67%) is accompanied by a corresponding decrease in the level of other four species.

The estimated level, associated with lithogenous bounds of Kochi sediments reveals an average Cu value of 62.99%. A gradual augmentation in mean copper concentration is persistently observed from exchangeable to carbonate, organic, reducible and lattice bounds. Exchangeable fraction demonstrates below detection values along landward profile and shows an average of 1.09% whereby its counterparts are 7.97%, 13.54% and 14.44% in the carbonate, organic and Fe/Mn phases, respectively.

The copper content in the residual fraction of Kannur mangroves is comparatively low (av; 54.45%) and the average concentration is comparable with the residual fractions of other stations. This depletion in the accumulation might have resulted due to the corresponding enhancements in other metallic bound species. A distinct feature noted in the speciation of the mangrove sediments of Kannur is that, this region stands out for higher Cu accumulation in Fe/Mn (av; 16.12%), carbonate (av; 11.55%) and exchangeable (av; 8.10%) bounds compared to the same species fractions of Kochi or Veli environments. Rather, the organic phase accomodates an average of only 9.76% of Cu. An important observation in the copper speciation is the increased levels of Fe/Mn bound copper, probably indicating the reduced environments prevailed in the region. The change in speciation may be linked with biological production. The proportions of the various copper species vary between stations, indicating the ability of copper species to interchange under different environmental conditions. It is worth to note that the mobility of this metal is more related to detrital fraction through mineralisation.

5.3.8.4 Zinc

The five metal fractions estimated from the sediments of Veli, Kochi and Kannur mangroves reveal that, the residual Zn exceeds the concentration of other four metal species determined. Exchangeable zinc is present in the mangrove sediments of Veli and Kannur together with all other four fractions, in different proportions indicative of species transformation. Exchangeable fractions show below detection values along the intermediate profile of Veli and intermediate profile and shallow water profiles of Kannur. But its counterparts at Kochi are meager and shows 5 to 7 fold decrease than Veli and Kannur. However, the carbonate bound zinc fractions of the three environments are roughly similar and shows as average of 3.14%, 3.3% and 4.46%, respectively for Veli, Kochi and Kannur. Though wide ranges (1.55% to 28.22%) of organically bound zinc fractions are encountered along the profiles of the three mangrove regions analysed, they in general, exhibit an average Zn value between 6.77% to 10.89%. Among the three stations, Kochi environment reveals low amount of reducible bound Zinc (av; 2.73%) wherein the other two stations record appreciably higher values (11.84 and 11.62) which are in similar. The lattice bound Zn fractions of Kochi (av; 82.84) predominates over Kannur (av; 75.82%) and Veli (av; 73.33%).

Discussion: The ability to accumulate heavy metals in various chemical phases of sediments greatly depend on particle/grain size, composition of the sediment and the physico-chemical conditions like turbulance, temperature, pH, and concentrations of organic and inorganic complexing agents (Calmano and Forstner, 1983). Particles of detrital and anthropogenic origin coated with hydrous Fe-Mn oxides affect the interaction processes (Forstner, 1976; Jones and Bowser, 1978). Estuarine reactivity is such that, exchangeable species are subject to severe changes. The form of cobalt is below detection level in certain profiles of Veli and Kannur environments, whereas it represents in all the three profiles of Kochi, though available in substantially low amount. Lead, generally shows considerable affinity in the exchangeable form, and occur in all the stations except the shallow water profile of Kochi. Exchangeable copper is present in all stations, except that of the intermediate profile and shallow water profile of Kochi and Kannur. The distribution of different metal species appears to be regulated by the presence of other competing strongly binding phases. Copper, as an element is distinguished by its biological regulation in sediments (Louma and Jenne, 1977), sustains continued bio-removal in mangroves environment as well as in estuaries. Zinc is yet another metal found involved in the above processes and occurred considerably in all stations.

Out of the four metals considered for the study, cobalt shows its association in carbonate bound fractions of all stations except along the shallow water profile of Kannur. The metal exhibits a persistant increase from landward profile to shallow water profile at Veli region. It demonstrates varying affinity with carbonate phase of Kochi and Kannur mangroves. The selective build-up of lead is observed in all fractions of the three mangrove environments. Copper in the carbonate stage is present in the three profiles of all three mangroves studied, but the amounts are slightly elevated than the exchangeable bounds. Like other metals, Zn also behaved in the similar manner in the carbonate bound facies.

The metal species are known to vary widely in distribution and content in aquatic environments. They also reflect the status of sedimentary processes that influence metal behaviour and reveal the natural levels as well as those superimposed by external stresses. An attempt to quantify the enrichment factors of cobalt associated with organic carbon phase indicates a gradual increase from landward profile to shallow water profile of Veli, and a noted decrese from landward profile to shallow water profile of Kochi, whereby no such pattern is observed for Kannur.

In the light of speciation studies, it is observed that, the copper linked with C-org phase is found distributed in the sediments of the three environments, at an elevated level compared to exchangeable and carbonate bounds. Lead and zinc also show enhanced amounts in the organic phase, and the zinc is known for its affinity for detrital, bio - matter on sediment beds, especially the mud dominated types. The organic bound Pb exemplifies progressive enhanced concentrations from the landward, to shallow water profiles of Veli and Kochi mangrove sediments whereas Kannur region is totally devoid of such distribution pattern. The peculier behaviour of Pb and Zn compared with Cu and Co illustrates its high tendency for incorportation within the facies of existing sediment types.

The metal accumulations with the Fe/Mn phase are comparatively high and ingeneral, occupies second position next to lattice bounds. Although no definite conclusions can be drawn as to why uniform metal levels are maintained within this phase, the role of adsorption on Fe/Mn flocs determines metal behaviour under oxidising conditions. It can also be noted that, anthoropogenic effects are not readily reflected in the reducible phase alone. Gupta and Chen, (1975) have expressed the view that, under oxidising environments, the relative variations in the fraction of metal in sediments exhibit only minor changes. It can also be inferred that, neither changing environmental conditions, nor changing grain size from sandy to mud, has any influence on the level of this metal fraction.

In an earlier study, Paul and Pillai, (1983) have stated that, most of the metals have large association with the residual fractions in estuaries and related environments. The present investigation too, support this view revealing exceptionaly high association of cobalt, lead, copper and zinc in the lithogenous phases compared to the other chemical phases. While considering the three mangrove environments together, the lattice bound metal fractions varies between 40% and 94%. Detailed examination on the relation of various metals bounded with lithogenous phase of the three mangrove sediments reveals that approximately 78% of Co, Pb and Zn is associated with lattice bounds and 66% of Cu found bound with residual fraction.

Concentration levels of cadmium in all the metal phases investigated goes far below detection limits and hence it is not discussed.

CHAPTER 6

MANGROVES AND MANGROVE ENVIRONMENTS

6.1 INTRODUCTION

The coastal zone is considered as one of the most important and fragile ecosystems of the world in terms of its density of population, but because of increased productivity and biodiversity. Estimates say that over 90% of the fishing products come from this zone (MEF, 1987) which inturn helps to equate the protien requirements of human being to a greater extent. Interestingly, many of the tropical and sub-tropical coastal zones of the world host a special stock of trees and shrubs with unique physiological characteristics and special adaptations. These halophitic coastal forests are designated as mangroves. Studies on mangroves reveal that, they have a prime role in protecting the coastal and nearshore environments and regulating the climate and also the level variability of toxic contaminants discharged into these environments from industrial and urban centres, (Chapman, 1976; Delacerd, 1983; and Michael Mastellar, 1996).

In view of the above, an attempt has been made in this investigation to document the various mangrove plants and its associates of Veli, Kochi and Kannur areas and also to analyse the heavy metal bearing of leaves and stems. The heavy metal levels of the major species are evaluated in terms of the average metal concentrations in sediments of the respective areas to have a proper insight into the bio-geochemical cyclicity of heavy metals through mangrove vegetation.

6.2 REVIEW OF LITERATURE

Review of literature indicates that, although ample information exist on the biological aspect of mangrove environments of the world, no precise and conclusive studies have so far been made systematically on their geochemical aspects. Studies on the seasonal effects of oil pollution on mangrove vegetation has been carried out by Baker, (1969; 1971) and Cowell, (1969). Studies on the Cd adsorption and growth of various plant species, influenced by solution of Cd concentration was done by Page et al, (1972). Subramanian and Venugopalan, (1993) estimated the phosphorus and iron distribution in two mangrove species with respect to their environment. Pollution aspects of As, Cu, Zn and Mn in the marine flora of coastal and estuarine water around Goa have been carried out by Zingde et al, (1976). Some serious attempts have been made by Gulati and Sayeeda, (1979) to estimate the accumulation of U, B, N_2, K and P in the leaves of mangrove around Goa. Importance of mangroves in the coastal zone management and marine pollution around Indian coastlines have been described by Subramonian and Abidi, (1993). Bhosale, (1979) described the trace elemental distribution of mangrove leaves of Goa region. Jagatap, (1987) attempted the seasonal distribution of organic matter in the mangrove environments of Goa. Chakrabarti et al, (1984) assessed the levels of certain heavy metals like Zn, Cu, Pb, Hg and Cd in the mangrove species of Sunderbans. Kotima and Bhosale, (1979) have reported the chemical composition of mangrove leaves and sediments of Deogad and Mumbra creeks of Ratnagiri, Maharashtra. Basha, (1991) presented the documents on the distribution of mangroves in Kerala. However, the hydrographical and species composition of three mangrove ecosystems of Kerala have been performed by Thomas and Fernandez, (1993), while Mohanan and Ramachandran, (1998) carried out the zonation and species distribution of mangroves throughout the Kerala coast.

6.3 THE COMMON MANGROVES AND MANGROVE ASSOCIATES

a. ***Acanthus ilicifolius*** Linn. (Acanthaceae)

This is a perennial gregarious shrub often attaining 2m height. It is moderately distributed in Veli, Kochi and Kannur regions, and shows high tolerance to various ecological parameters. It is often called Sea-Holly. Stems are often provided with aerial roots. The heteromorphic leaves are entire and free from spiny lobes with sinuate margin. Leaves are oppositely arranged, oblong or ovate, coriaceous, spiny, narrowed at the base, spiny at apex, with lateral nerves and midribs. Petioles short, with 2 stipule like spines at the base. The simple or branched inflorescence is axillary and bear flowers 3 to 4cm long. The fruits are capsule with two-celled ovules, spreading explosively to release the seeds. Flowering during April-Decem ber and fruiting during July-February. Regeneration is by reniform seeds. In view of shrubby growth and close setting, the plant forms a good fence in mangrove forested ecosystems.

b. ***Excoecaria agallocha*** Linn. (Euphorbiaceae).

Evergreen glabrous trees or shrubs grow to a height of 6 m or more with an acrid milky juice. They occur commonly along mangrove patches of Kochi and Kannur regions. It also occurs along estuarine banks, canals, creeks and tidal forests. It prefers to grow on a muddy terrain with a little sand. Wood is soft, light and taproot is insignificant. Lateral roots spreading like snakes intermingled each other, subterranean roots produce elbo-shaped pegs of knobs of pneumatophroes with white lenticles. Leaf is alternate, thickly coriaceous, elliptic to ovate, glabrous green shiny with some what crenulate margin. Inflorescence is catkin like, spikes with unisexual fragrant flowers. Fruit depressed, globose with fleshy albumen and flat cotyldons. Flowering during February to August and fruiting during June to January. Wood is very light, much used for packing box and in paper industry.

c. ***Bruguirea gymnorrhiza*** (Linn.) Savingy (Rhizophoraceae)

Trees reaching to a height of 4-8m, and confined to the inter-tidal regions of Kochi mangroves. Stem is shortly buttressed with many geniculate pneumatophores, which helps in anchorage and for gas exchange. Leaves are oppositely arranged, elliptic, oblong, ovate, thick, coriaceous, dark green, entire. Young branches smooth, marked towards the apex with scars of fallen leaves and stipules. Inflorescence, solitary, calyx tubes ribbed and flowers scarlet. Fruit is one celled, one-seeded, coriaceous and crowned. Flowering is during January-December and fruiting is during April-September. Regeneration is through viviparous seedlings, fruits are dispersed by tides and regenerate under *Rhizophora* species. Fruits do not germinate under the canopy of mother plant. Its bark yields tannin and the wood is very hard and used as fuel.

d. ***Rhizophora mucronata*** Lam. (Rhizophoraceae)

Trees, often reaching up to 12m height and found commonly in the mangrove zones of Kochi and Kannur regions. They survive even in higher degrees of tidal effects and prefer to be along the banks. Aerial roots show interesting features (stilt roots) and hangs out from the main tree and forms branches (plate XIV). Leaves are opposite, elliptical, long mucronate, coriaceous, glabrous, entire and with large stipules. Flowers in axillary cymes, fruits pendulous, seeds germinating on the tree, radicle elongate and perforating the apex of the fruit. Flowering during August to

PLATE XIV - *Rhizophora mucronata*
PROFUSELY DEVELOPED STILT ROOTS ANCHORING THE PLANT ON MUDDY SUBSTRATUM.

December and fruiting mid October to April. Regeneration restricted to the banks and never found more than a few meters distant from the mother plant. Used as a source of tannin, obtained from the bark of the tree; wood is dark red, very hard and used as an excellent fuel.

e. ***Rhizophora apiculata*** Blume. (Rhizophoraceae)

Trees reaching to a height of 5-8m, stem base without tap root and supported by stilt roots. They occur along the intertidal zones of Kannur mangrove swamps. The aerial roots are branched and sympodial. Leaves are opposite elliptical oblong, sub-lanceolate or ovate lanceolate, coriaceous, apiculate at apex and crenulate at base. Inflorescence is cymes with 2-sessile flowers, 1 to 1.2 cm long and yellow in colour. Fruit is smooth, cylindrical, pointed and curved towards the apical end. Flowering from June to October and fruiting from September to March. Germination of seedling is through viviparous hypocotyles. They embed themselves in the mud below the parent tree when they fall. They are carried into shallow water and mostly establish itself on higher grounds than *Rhizophora mucronata*. It is a well known fuel wood in many coastal areas.

f. ***Kandelia candel*** (Linn.) Druce (Rhizophoraceae)

Trees reaching to a height of 5-6m, stem base flesh coloured, found more or less common as a pioneer along the intertidal zones of Kannur mangroves, and rarely exposed to high tides. Stilt roots present from the under surface of the inclined stem base. Dark reddish brown, wood soft and peels in thick flakes. Stem is buttressed. Leaf is oppositely arranged, coriaceous, oblong, obtuse, entire, deep green above and pale beneath, with rounded apex. Cymes axillary, flowers large, 5 lobed calyx, petals cream.

Fruit one celled, one seeded with persistent reflexed calyx lobes, germination viviparous. Flowering from January to December and fruiting from April to January. Wood is used as a fuel.

g. ***Sonneratia caseolaris*** (Linn.) Engl. (Sonneratiaceae)

A coloniser on accreting mud flats along estuarine and riverine beds (plate XV). Luxurient growths are recorded from the mangrove zones of Veli. Wood is grey, soft and also, even grained. *Sonneratia caseolaris* gives out root excrescenes with even softer wood. Sap wood straw coloured one, heart wood has a pink tinge. Pneumatophores erect to a height of 1m. Salt excluding glands are seen on the leaf surface. Leaves are opposite, entire, obvate or elliptical. Apical hydathode is present through which excess of salt is excluded. Inflorescence is solitary. Flowers, petals magenta coloured seeds are angular small and curved. Flowering during February to July and fruiting from July to January. Regeneration through seeds, very few grow to seedling stage. The fruit is used as a poultice in sprains and swellings. The plant is a best fuelwood, and also used for making corks.

h. ***Avicennia officinalis*** Blume. (Verbenaceae)

Trees with good crown growth, reaching up to a height of 8m, recorded from the interior mangrove zones of Veli and Kannur. Pneumatophores are pleanty, pencil like and are negatively geotropic (plate XVI). Leaves are opposite, obvate or coriaceous, dark green above, silvery papillose beneath, acute at apex. Inflorescence is terminal or as axillary congested cymes. Flowers up to 1cm long, yellow and fragrant. Fruit is broadly ovoid, compressed, beaked or green almond shaped. Flowering from June to September and fruiting from September to March. Regeneration is through incipient vivipary. The leaves are used as fodder while the trunk

PLATE XV - *Sonneratia caseolaris*.
A TYPICAL COLONISER ON ACCRETING MUD FLATS OF INTERTIDAL ZONES.

as fuel. The wood also could be used as excellent timber, building, boat making etc.

i. ***Avicennia marina*** (Forsk). Vierh. (Verbenaceae)

Trees reaching to a height of 8m. Extensively developed formations of *Avicennia marina* are recorded under high saline silty soils. This species occupy more than 50% of the total mangrove area in Kannur. The plant is much branched, and bark thin yellowish grey. Aerial roots are very rare, when present 3-10cm long, negatively geotropic, straight, not branched or hooked (plate XVI). Salt excreting glands are present on leaves. Leaves are opposite, elliptic, coreaceous, dark green shining above, yellowish papillose beneath. Inflorescence is capitate, flower 2-4cm across, yellowish, fragrant. Fruit is rusty brown in colour. Flowering from May to December and fruiting during January to March. Regenerate sporadically and is not a coloniser on newly formed mud banks. It is used as fuel wood.

j. ***Derris trifoliata*** Lour. (Fabaceae)

A common climber along the coastal estuaries, salt water creeks and mangrove swamps, usually twining on the trees of *Rhizophora mucronata* and other species. Leaves are imparipinnate, alternate, 25 cm long, stipule, minute, opposite and rigidly subcoriaceous in nature. Inflorescence is receme. Flower 1- 1.2 cm long, pink, bracteate and bracteolate. Fruit is obliquely rounded, rarely oblong, and 1-2 seeded. Flowering from June to December and fruiting from October to February. Regeneration is through seeds. Seeds are good fish poison.

k. ***Cerbera odollam*** Gaertn. (Apocyanaceae)

A small sized tree, common in Veli, having milky poisonous latex. This plant

PLATE XVI - AN ASSOCIATION OF *Avicennia officinalis* and *Avicennia Marina.*

is also found in swamps, back waters and dominates the inlands of the intertidal banks, where fresh water influence is less. Leaf is alternate, long leathery (plate XVII), acute, narrow at the base. Inflorescence is a terminal or pseudo terminal cyme. Flower is large, white with yellow throat and fragrant. Fruit is sub globose, large, single seeded, smooth, green, pericap very thick, fibrous and woody. Seeds broad and compressed. Flowering from April to November and fruiting from September to March. Regeneration is by seeds. Fruits are poisonous.

l. ***Acrostichum aureum*** Linn. (Pteridaceae)

True aquatic fern, common along Veli and Kannur mangroves. The Rhizome is erect, short, stout, woody, simply pinnate with large entire pinnae, thick coreaceous, glabrescent, venation close and uniform, reticulate without included veinlets. Sporangia borne in pinnae of the distal end or on distinct fronds, found throughout the year. Common in subtropical coastal areas and rarely under fresh water conditions. It is a secondary formation in mangrove habitats especially in disturbed regions (plate XVIII).

m. ***Vitis vitiginea*** Linn. (Vitaceae)

Weak stemmed, erect or climbing herbs, found along the intertidal zones of Veli. Leaves up to 10 x 10cm simple or palmately lobed or angled, cordate at base, irregularly serrate, pubescent. Flowers in leaf opposed cymes. Fruit about 7mm across, ablong, bluish. Common in marshes, canals, fences and walls etc. Flowering during May to July. Stem of this plant contains large quantities of water.

n. ***Premna serratifolia*** Linn. (Verbenaceae)

Erect or straggling shrubs, found usually along Veli mangroves.

PLATE XVII - A TWIG OF *Cerbera odollam* - COMMON IN KERALA BACK WATERS.

PLATE XVIII - *Acrostichum aureum* - A COMMON AQUATIC FERN DEVELOPED IN A DISTURBED MANGROVE AREA.

Leaves 10 x 7 cm, ovate, acute at apex, base obtuse - subcordate, glabrous. Flowers in terminal corymbs, white secented. Fruits about 2mm across, globose. Fairly common along backwaters and canals in lower elevations. Flowering during February to June.

o. ***Barringtonia racemose*** (Linn.) Spreng (Lecythidaceae)

Trees about 5 m high (Plate XIX), leaves 15-30 x 6-14 cm, elliptic-oblonge, acuminate, acute-obtuse at apex, cuneate at base, crenate on margins; lateral nerve about 15-18 pairs. Flowers in about 30 cm long, pendulous racemes, scarlet-red. Fruits about 6 x 4 cm , ovoid. Common along canals, evergreen forests and along backwaters. Almost throughout the year.

6.4 HEAVY METALS IN MANGROVE LEAVES AND STEMS

6.4.1 Veli mangroves

A total of 9 mangroves and mangrove associates (leaves and stems only) has been subjected to heavy metal (Fe, Mn, Co, Cu, Pb, Cd and Zn) analysis and the results are presented in Table 27. Of this, four species, viz-*Acrostichum aureum*, *Barringtonia racemosa, Acanthus ilicifolius* and *Avicennia officinalis,* abbreviated hereafter as ABAA group together constitute > 75% of the mangrove cover and hence controls significantly the biogeochemical cycling of heavy metals. In addition to ash method of sample preparation, the major species included under the group ABAA are subjected to heavy metal analysis in dry weights as well (Table 28).

The concentration of Fe in the leaf of mangroves and mangrove associates

PLATE XIX - *Barringtonia racemosa* -
A TYPICAL MANGROVE ASSOCIATE.

Table - 27
Trace metal concentrations in the leaves and stems (ashed samples) of various mangrove species of Veli, Kochi and Kannur regions

Environment/ samples	Fe (%)	Mn	Co	Pb	Cd (ppm)	Cu	Zn
VELI MANGROVES							
Leaf							
Vitis vitiginia	0.51	887	190	79	BDL	76	156
Sonneratia caseolaris	1.65	2268	330	40	BDL	101	305
Derris trifoliata	1.47	3165	132	40	9.0	153	393
Cerbera odollam	1.19	5413	132	78	12.0	179	92
Premna serratifolia	1.01	2299	99	119	4.0	165	280
Acrostichum aureum	0.51	1278	22	158	6.0	25	194
Barringtonia racemosa	0.69	1536	242	56	3.0	127	512
Acanthus ilicifolius	0.41	1031	144	80	12.0	144	385
Avicennia officinalis	0.69	495	77	79	3.0	140	167
Stem							
Vitis viniginia	0.23	1062	99	119	BDL	153	372
Sonneratia caseolaris	1.19	3041	99	158	BDL	204	412
Derris trifoliata	1.28	2907	441	79	3.0	432	442
Cerbera odollam	0.50	6073	276	119	6.0	331	604
Premna serratifolia	1.10	2371	110	158	3.00	114	224
Acrostichum aureum	1.19	258	165	238	3.00	280	261
Barringtonia racemosa	1.05	1041	396	40	BDL	483	531
Acanthus ilicifolius	0.59	1753	408	119	6.00	432	350
Avicennia officinalis	0.18	509	42	158	BDL	76	194
KOCHI MANGROVES							
Leaf							
Avicennia officinalis	0.55	510	55	42	2	68	146
Rhizophora mucronata	0.59	1236	170	130	1	70	140
Bruguiera gymnorrhiza	1.11	1062	140	45	<1	180	170
Acanthus ilicifolius	0.78	9.73	290	60	1	140	160
Excoecaria agallocha	0.43	864	260	40	<1	67	230
Stem							
Avincennia officinalis	0.72	612	38	96	2	55	163
Rhizophora mucronata	0.59	1081	180	140	1	33	100
Bruguiera gymnorrhiza	0.56	1044	120	100	<1	125	150
Acanthus ilicifolius	0.26	916	280	52	1	120	162
Excoecaria agallocha	0.23	742	260	40	1	150	221

Environment/ samples	Fe (%)	Mn	Co	Pb	Cd	Cu	Zn
				(ppm)			
KANNUR MANGROVES							
Leaf							
Avincennia marina	1.05	308	29	28	BDL	33	220
Excoecaria agallocha	0.43	3628	75	22	BDL	87	262
Derris trifoliata	0.24	2568	120	56	3	20	210
Kandelia candel	0.27	2778	75	28	2	27	142
Rhizophora mucronata	0.74	648	125	56	BDL	87	178
Rhizophora apiculata	1.01	635	105	48	3	92	155
Acrostichum aureum	0.92	535	25	BDL	3	54	47
Acanthus ilicifolius	1.83	559	50	28	BDL	33	232
Avincennia officinalis	0.27	1749	25	28	4	47	127
KANNUR MANGROVES							
Stem							
Avicennia marina	0.49	211	22	83	3	32	287
Excoecaria agallocha	0.32	3062	25	56	BDL	141	351
Derris trifoliata	0.20	2074	100	35	3	53	374
Kandelia candel	0.19	2244	78	56	5	87	178
Rhizophora mucronata	0.12	543	150	46	2	64	86
Rhizophora apiculata	0.82	652	104	52	3	85	142
Acrostichum aureum	0.24	235	25	BDL	1	38	107
Acanthus ilicifolius	0.11	357	26	28	5	80	150
Avicennia officinalis	0.23	712	35	29	2	47	124

BDL - Below Detection Level.

varies between 0.41% *(Acanthus ilicifolius)* and 1.65% (*Sonneratia caseolaris*). The average concentration of Fe in the major mangrove species, ABAA, is computed as 0.58%. The content of Fe in the stem varies considerably (Table 27) wherein, the *Avicennia officinalis* accounts for the lowest enrichment (0.18%) while *Derris trifoliata*, the highest (1.28%). The ABAA group together constitute an average of 0.75% of Fe against the sediment average of 1.01%.

Manganese exhibits wide variation both in leaves and stems. The common mangrove associate, *Cerbera odollam* records the highest Mn value of 5413 ppm which is about 30 times the enrichment compared to the average concentration of Mn in sediment. However, the lowest Mn concentration is recorded in *Avicennia officinalis* (495 ppm). The ABAA group exhibits an average concentration of 1085ppm of Mn in the leaf and 890ppm in the stem. Like leaves, the stem of *Cerbera odollam* records the highest value (6073 ppm) of Mn whereas *Acrostichum aureum* shows the minimum (258 ppm) value. The average Mn concentration in the ashed samples is of the order of 6 times and 12 times higher compared to that in dry weights (leaf, av; 16 ppm; stem, av; 73 ppm).

Cobalt varies between 22 ppm (*Acrostichum aureum*) and 330 ppm (*Sonneratia caseolaris*) in leaf and between 42ppm (*Avicennia officinalis*) and 396 ppm (*Barringtonia racemosa*) in stem. The enrichment of this metal in the ABAA group averages 12 ppm and 252 ppm, respectively in leaves and stems of the ashed samples and 19 ppm and 20 ppm, respectively in the leaves and stems of the dried samples. Cu also exhibits a similar variation in leaf [25 ppm (*Acrostichum aureum*) -179 ppm (*Cerbera odollam*)] and in stem [76 ppm (*Avicennia officinalis*) - 483 ppm (*Barringtonia racemosa*)]. The ABAA group concentrates an average of 109 ppm of Cu in leaf and 318 ppm of Cu in stem against the average sediment concentration of 40 ppm. The enrichment of Cu in this group, in general, varies from

Table - 28

Concentrations of heavy metals in the dried vegetal parts of Veli, Kochi and Kannur areas.

Area	Mangrove species	Sample type	Fe (%)	Mn	Co	Pb	Cd	Cu	Zn
				(ppm)					
Veli	*Acrostichum aureum*	Leaf	0.07	172	3	21	1	3	26
		Stem	0.06	14	9	13	BDL	15	14
	Barringtonia racemosa	Leaf	0.14	321	50	12	1	27	107
		Stem	0.08	77	29	3	BDL	36	39
	Acanthus ilicifolius	Leaf	0.04	100	14	8	1	14	37
		Stem	0.06	164	38	11	1	40	33
	Avicennia officinalis	Leaf	0.07	54	8	9	BDL	15	18
		Stem	0.01	32	3	10	BDL	5	12
Kochi	*Avicennia officinalis*	Leaf	0.06	56	6	5	BDL	7	16
		Stem	0.04	39	2	6	BDL	3	10
	Rhizophora mucronata	Leaf	0.1	216	30	23	BDL	12	24
		Stem	0.03	59	10	8	BDL	2	5
	Acanthus ilicifolius	Leaf	0.04	49	15	3	BDL	7	8
		Stem	0.02	53	16	3	BDL	7	9
	Excoecaria agallocha	Leaf	0.02	48	14	2	BDL	4	13
		Stem	0.03	86	30	5	BDL	17	25
Kannur	*Avicennia marina*	Leaf	0.11	34	3	3	BDL	4	24
		Stem	0.04	16	2	6	BDL	6	22
	Excoecaria agallocha	Leaf	0.04	347	7	2	BDL	8	25
		Stem	0.01	112	1	2	BDL	5	13
	Acanthus ilicifolius	Leaf	0.35	69	10	5	BDL	6	45
		Stem	0.02	55	4	4	1	12	23
	Derris trifoliata	Leaf	0.06	690	32	15	1	5	56
		Stem	0.01	117	6	2	BDL	3	21

BDL = Below Detection Level

3 ppm (*Acrostichum aureum*) to 40 ppm (*Acanthus ilicifolius*) in dry weight with a mean content of 15 ppm in leaf and 24 ppm in stem. The average Cu content of 19 ppm in the dry vegetal parts of ABAA group reveals 2 fold decrease than the average copper content in sediments. An overall evaluation of cobalt and copper enrichment in the leaves and stems of the major mangrove (ABAA) reveals that, the metals are enriched 2 to 4 times in leaves and 7 to 8 times in stems compared to the sediments.

The metal Pb is enriched more than three times (158 ppm) in the foliae and about 5 times (238 ppm) in the stem of *Acrostichum aureum* (the most dominant species covering 35% of Veli mangroves), compared to sediment average of 48 ppm. The second Pb maxima is observed in the *Premna serratifolia* which accounts for 119 ppm in leaf and 159 ppm in stem. The lowest Pb values are observed in the fairly dominant species *Barringtonia racemosa* (leaf 50 ppm; stem 40 ppm). The most dominant ABAA group of plants record an average of 101 ppm of Pb in leaf and 139 ppm in stem. Apart from Fe and Mn, Zn is the next dominant heavy metal analysed. *Barringtonia racemosa* record the highest Zn concentration both in leaf (512 ppm) and in stem (531 ppm). The species like *Derris trifoliata, Acanthus ilicifolius* and *Sonneratia caseolaris* cross over 300 ppm of Pb both in leaf and stem (Table 27). *Avicennia officinalis* records the lowest Zn concentration (leaf 167 ppm and stem 194 ppm). The most dominant (*Acrostichum aureum*) ABAA group record an average concentration of 315 ppm in leaf and 334 ppm in stem against sediment average of 62 ppm. The concentration of Pb (av; 11 ppm) and Zn (av; 36 ppm) in dry mangrove foliae shows several fold decrease compared to the ashed samples. Compared to the other trace metals, Cd is present only in very low concentrations both in the leaf and in the stem and further the concentration of this metal is below detection limit in most of the samples. However, the highest concentration of this metal both in leaf and stem are recorded in the mangrove species *Acanthus ilicifolius* and the mangrove associate *Cerbera odollam* (Table 25).

6. 4. 2 **Kochi mangroves**

Five species, Viz- *Avicennia officinalis, Rhizophora mucronata, Bruguirea gymnorrhiza, Acanthus ilicifolius* and *Excoecaria agallocha* have been analysed for its heavy metal bearing which together share >80% and are abbreviated as AREA for detailed discussion as they claim a lionshare of the organic detritus of Kochi mangrove environments.

The ranges in the concentration of Fe and Mn are 0.43 (*Excoecaria agallocha*) - 1.11% (*Bruguiria gymnorrhiza*) and 864 ppm (*Excoecaria agallocha*) - 1236 ppm (*Rhizophora mucronata*) in the leaves and 0.26% (*Excoecaria agallocha*) - 0.59% (*Rhizophora mucronata*) and 742 ppm (*Excoecaria agallocha*)- 1081 ppm (*Rhizophora mucronata*) in stems, respectively. The most abundant species group, AREA, averages 0.59 of Fe and 896 ppm of Mn in leaf and 0.45 of Fe and 838 ppm of Mn in stems. But on dry weight basis, the Fe varies from 0. 02% to 0.1% (av; 0.04%) and Mn from 39 ppm (*Avicennia officinalis*) to 86 ppm (*Excoecaria agallocha*).

The concentration of Co varies from 55 ppm to 290 ppm in leaf and 38 ppm to 280 ppm in stem (Table 27). The group AREA accounts for an average of 194 ppm in leaf and 190 ppm in stem against the sediment average of 93 ppm. Cu on the other hand ranges between 67 ppm to 180 ppm in leaves and 33 ppm to 120 ppm in stems. The plants grouped under AREA records slightly over two times the enrichment (leaf 86 and stem 90 ppm) compared to that in sediments (av; 41 ppm). But the dry mangrove vegetal parts of AREA group shows Co concentration of 16 ppm and 15 ppm in leaf and stem, respectively, which is of 2 fold decrease compared to that in sediments.

In leaves, the maximum concentration of Pb is recorded in the *Rhizophora mucronata* (130 ppm) and minimum in *Excoecaria agallocha* (40 ppm) whereas in stem the maximum and minimum are recorded in *Rhizophora mucronata* (140 ppm) and *Acanthus ilicifolius* (20 ppm), respectively. The average concentration of this metal in leaves and stems in the AREA group of plants is 68 ppm and 82 ppm, respectively. Compared to sediment concentration, the Pb accumulation in the leaf (av; 8 ppm) and stem (av; 6 ppm) of AREA group exhibits 8 and 14 fold depletion. Like the Veli mangroves, Zn is enriched considerably in the leaves and stems of the Kochi mangroves as well. The lowest Zn value is recorded for the species *Rhizophora mucronata* (140 ppm) and the highest for *Excoecaria agallocha* (230 ppm). The average Zn concentration computed for the most common species grouped under AREA accounts for 170 ppm in leaf and 162 ppm in stem. The average enrichment of Zn in the leaf and stem (ash weight) of AREA group reveal 11-13 times higher concentration than in the dry vegetal parts. The metal Cd, though present in lower amounts is distributed in all plants studied. The concentration varies between < 1 ppm and 2 ppm in leaves and < 1 ppm and 2 ppm in stems.

6.4.3 **Kannur mangroves**

A total of 9 true mangroves and its associates have been subjected to heavy metal analysis from the Kannur mangrove areas. They include *Avicennia marina, Excoecaria agallocha, Derris trifoliata* and *Acanthus ilicifolius* constituting >75% of the floral population and is categorised as AEDA for easy description. The remaining includes *Kandelia candel, Rhizophora mucronata, Rhizophora apiculata, Acrostichum aureum* and *Avicennia officinalis*.

The Fe varies from 0.24% (*Derris trifoliata*) to 1.83% (*Acanthus ilicifolius*) while Mn values vary from 308 ppm (*Avicennia marina*) to 2778 ppm

(*Kandelia candel*) in leaves. The respective ranges of Fe and Mn in the stem are 0.11% (*Acanthus ilicifolius*) to 0.82% (*Rhizophora apiculata*) and 211 ppm (*Avicennia marina*) to 3062 ppm (*Excoecaria agallocha*), respectively. The AEDA group of mangroves exhibit an average Fe and Mn concentration of 0.89% and 1566 ppm in leaves and 0.28% and 1426 ppm in stems against the sediment average of 3.71% of Fe and 295 ppm of Mn. The Mn enrichment in this group shows 5 times the enhancement in leaf and stem compared to sediments (av; 295 ppm). However, the Fe concentration exhibits several fold depletion compared to sediments (Table 27). Contrary to ashed samples the concentration of Fe and Mn in dried samples show wide variations (0.01% to 0.35% of Fe and 16 ppm to 690 ppm of Mn).

Cobalt content varies from 25 ppm to 125 ppm in leaves and 22 ppm to 150 ppm in stems. The lowest concentration of Co in stem is recorded by the most dominant species *Avicennia marina*. The average cobalt concentration in leaf (70 ppm) and stem (63 ppm) is slightly higher than that of the sediment average (52 ppm). The Co in dry weight constitute mean content of 13 ppm in leaf and 3 ppm in stem of AEDA group. Amounts of Pb in AEDA group shows an average of 69 ppm in leaves and 43 ppm in stems and reveals that, the leaves of this group (AEDA) exhibits nearly 2 fold accumulation of Pb than the other less abundant species. The mean Pb content in leaf (av; 35 ppm) and stem (av; 48 ppm) of Kannur mangroves are well above the sediment average of 28 ppm. The dried counterparts of AEDA demonstrate nearly 5 -14 times the enrichment compared to ashed samples.

The contents of Cu shows a minimum of 20 ppm in the leaf of *Derris trifoliata* to a maximum of 92 ppm in the leaf of *Rhizophora apiculata*. However, it varies from 38 ppm to 141 ppm in the stems of *Acrostichum aureum* and *Excoecaria agallocha*, respectively. The average enrichment of Cu in the 9 species (Table 27) of Kannur divulge higher values in stem (av; 75 ppm) than in leaves (av; 53 ppm) against the mean sediment Cu value of 47 ppm. The AEDA group of flora demonstrates an average Cu concentration of 43 ppm in leaf and 83 ppm in stem. Zn exhibits wide variation both in leaf and stem of Kannur mangroves. The highest Zn accumulation in leaf and stem is exhibited by the member *Excoecaria agallocha* of AEDA group. In leaves, it varies between 47 ppm (*Acrostichum aureum*) and 262 ppm (*Excoecaria agallocha*). The Zn accumulation in stem shows a minimum of 86 ppm (*Rhizophora mucronata*) to 374 ppm (*Derris trifoliata*). In general, the mean Zn concentration in leaves and stems (av; 175 ppm and 222 ppm, respectively) show more than 2 fold and 3 fold enhancement than the average sediment concentrations of Zn in the sediments. However, the amount of Cu (av; 6 ppm) and Zn (av; 29 ppm) in the dry parts of AEDA plants are several times lesser than that accumulated in ashes. By comparing the Zn accumulations in ash weight of the ABAA, AREA and AEDA group of mangroves, it is vivid that, the ABAA group (av; 315) predominates over AEDA (av; 232 ppm) and AREA (av; 169 ppm) groups.

Compared to other trace metals, cadmium goes below detection level in the leaves and stems of majority of the plants of AEDA group except in *Derris tri foliata*, which records equal concentration (3 ppm) in both leaf and stem. Cadmium content, in general, varies between 2 ppm and 4 ppm (av; 3 ppm) in leaf and 1 ppm to 5 ppm (av; 3 ppm) in stem. Its concentration shows moderately elevated values than the average sediment (2 ppm) concentration. Cadmium concentration in the dried samples of AEDA group is not more than 1 ppm.

6.5 HEAVY METALS IN MANGROVES Vs SURFACE SEDIMENTS

The heavy metals are enriched several folds in ash compared to the dried samples as the process of ashing concentrates the metals. Table 27 shows heavy metal values in the ash concentrates of the various species of mangroves and mangrove associates of Veli, Kochi and Kannur areas. In Veli, the four major species on an average basis exhibits 6-7 times and 12-19 times the enrichment of heavy metals in ashed leaves and stems, compared to the dried counterparts. An evaluation of the heavy metal enrichment in the mangrove species with respect to the surface sediments indicates that all the heavy metals are, in general, enriched in sediments than the dried vegetal samples. The only exception is Mn, which show slight similarity particularly in leaf to that of sediments. In sediments heavy metal reaches from many sources like terrestrial inputs through mineral phases, industrial effluents, urban sewages, chemical precipitation and also decomposition of organic litter contributed by the mangrove leaves and other vegetal remains. From the speciation analysis of heavy metals (Chapter 5), it is clear that considerable amount (>70%) (Table 26) of heavy metals are associated with lattice bound forms indicating dominance mineralogic paths to the heavy metals. The poor correlation of organic carbon with various heavy metals in Veli and Kochi mangroves (Table 21) indicates that mangrove litter and other organic detritus do not influence much in the distribution pattern of heavy metals compared to texture, mineralogy and urban contributions in Veli mangroves.

In Kochi mangroves, the heavy metals are enriched 9 to 13 fold in ashed samples compared to their dried counterparts (Table 28). Like Veli mangroves, here too, the heavy metals are enriched more in sediments than dried leaves and stems. However, the content of Mn shows some similarity with that of Veli.

Although heavy metals are added to the sediments from the decomposition of mangrove - borne litter, the other sources of heavy metals are actually masking the said contribution of heavy metals. This is reflected well in the matrix analysis of sediments depicted in Table 21. In Veli and Kochi regions, organic carbon rich particulates are reaching from other sources like urban, agricultural and industrial sources as well. All these, complicated significantly the heavy metal supply from the decomposed organic products borne from mangroves. This might be the reason for the low degree of correlation of organic carbon with other heavy metals, Table 21.

In Kannur mangroves, the heavy metals are accumulated 5-7 times in the ashed samples of the leaf and 13-19 times in stems compared to the dried counterparts. Like the other mangrove environments studied, the dried mangrove vegetal parts of Kannur also exhibit substantially lower heavy metal values compared to sediments. The matrix analysis of heavy metals in the surface sediments of Kannur (Table 21) gives significant correlation with organic carbon and mud. It clearly indicates the role of decayed mangrove detritus, trapped effectively by mud in regulating the heavy metal dispersal at Kannur mangroves.

6.6 CLUSTER ANALYSIS AND POLLUTION ASSESSMENTS

Eleven parameters such as mud, organic carbon, $CaCO_3$, Fe, P, Mn, Co, Pb, Cd, Cu and Zn in the surface sediments of the three mangrove environments are subjected to cluster analysis to find out the interrelationship existing among them. (Figs. 37- 39)

The sediments of Veli mangroves generally give two major clusters of parameter groups with several subgroups. (Fig 37). The major group I, encompasses all the parameters devoid of $CaCO_3$, Mn and Cd which obviously form the second

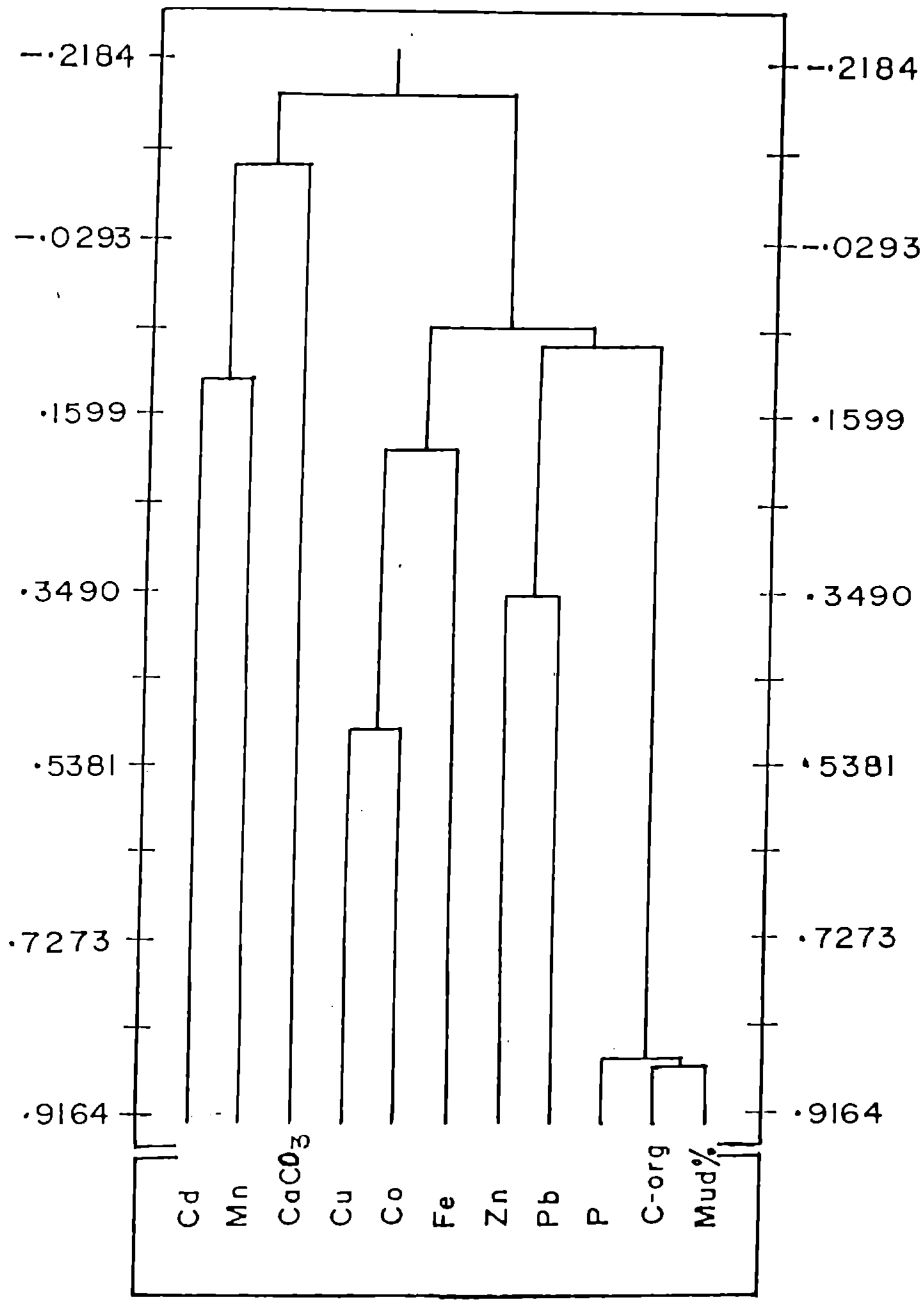

Fig. 37. DENDROGRAM SHOWING THE INTERRELATIONSHIPS EXISTING AMONG VARIOUS CHEMICAL PARAMETERS OF VELI MANGROVES.

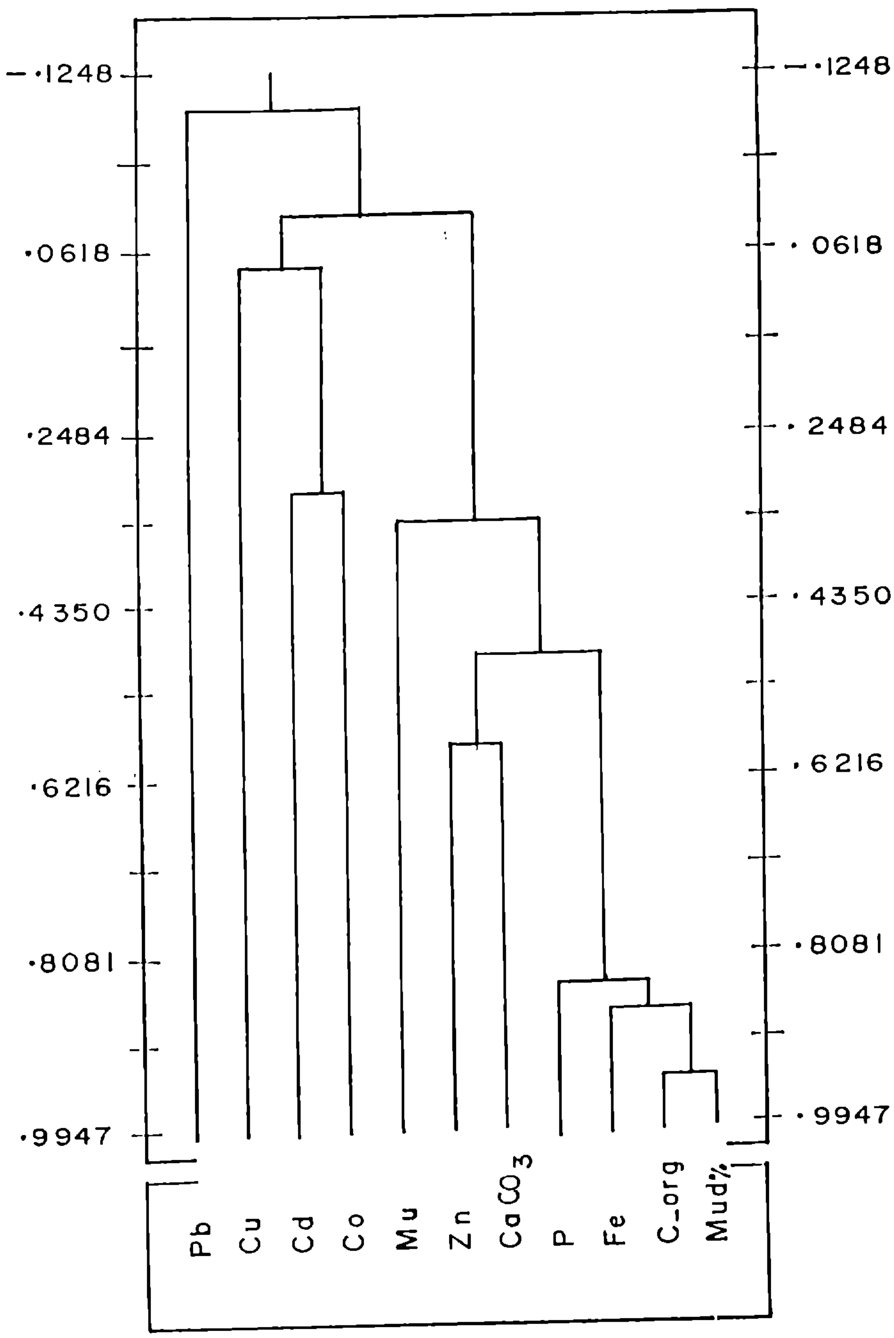

Fig. 38. DENDROGRAM SHOWING THE INTERRELATIONSHIPS EXISTING AMONG VARIOUS CHEMICAL PARAMETERS OF KOCHI MANGROVES.

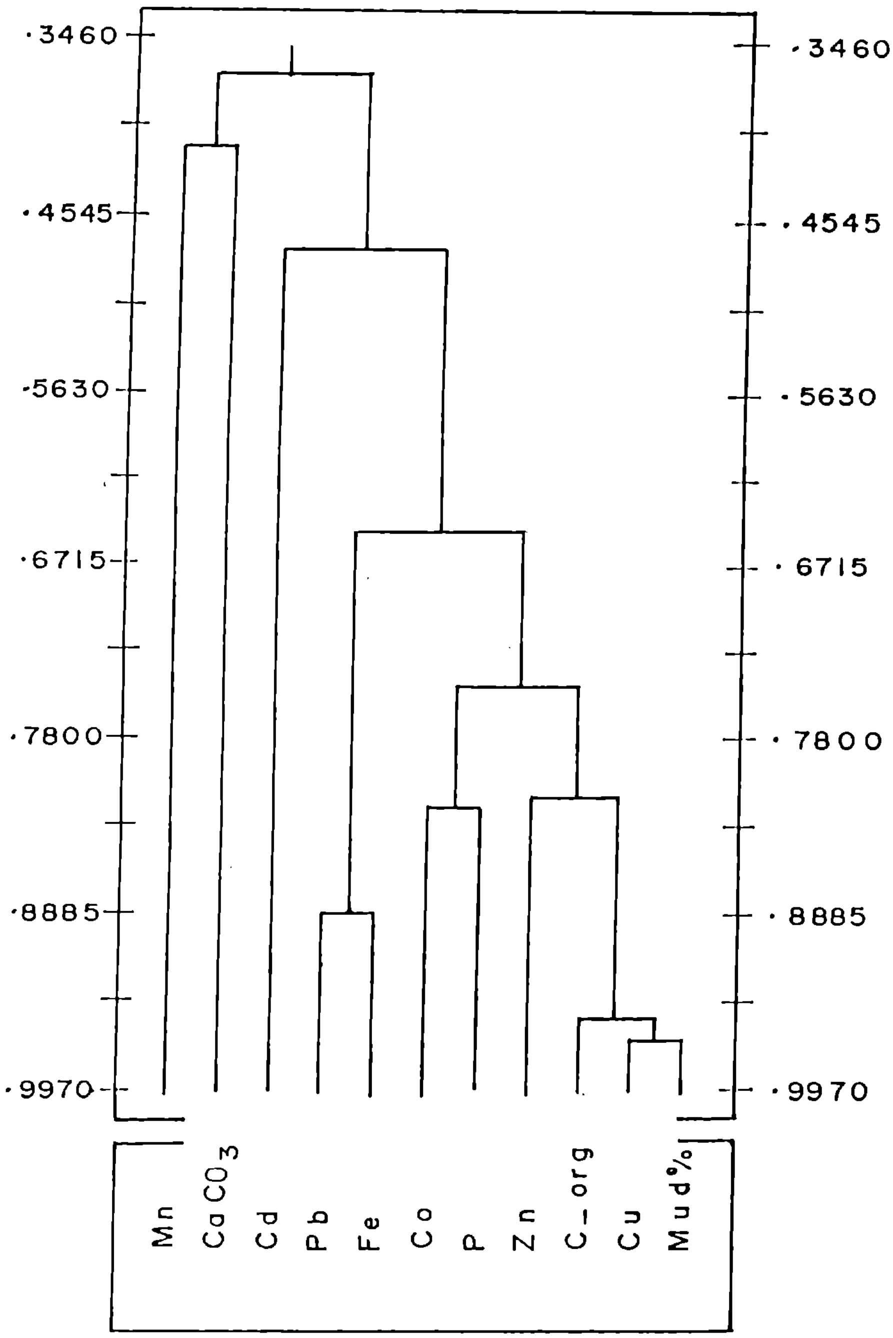

Fig. 39. DENDROGRAM SHOWING THE INTERRELATIONSHIPS EXISTING AMONG VARIOUS CHEMICAL PARAMETERS OF KANNUR MANGROVES.

major group. In group I, the mud percent is coupled with organic carbon at very significant level (0.87%) indicating either the similarity in the depositional characteristics of these parameters in mangrove environments or the ability of mud particles to trap organic carbon decomposed mainly from the mangrove vegetation or even both. The nutrient element P, also links at a very significant level to the above parameters, reflecting the source/association of this nutrient element. Lead and zinc form another subgroup and link with the mud-C-org-P subgroup at marginal level. The subgroup formed by Co and Cu links with Fe first which in turn be coupled with the former subgroup. The group II of Veli reflects the marginal control of $CaCO_3$ over the distribution of Mn and Cd. It is well known that the shells (the chief $CaCO_3$ form in sediments) of the molluscs and other organisms have the power to assimilate certain trace metals like Mn and Cd (Babukutty and Jacob Chacko, 1994).

The dendrogram constructed for the surface sediments of Kochi mangroves reveals a gradational coupling pattern of the major groups(Figs. 38). The Group I includes mud, C-org, Fe, P, $CaCO_3$, Zn and Mn). The major groups again contain subgroups of different orders. Like the case of Veli mangroves, here also the organic carbon holds significant bearing over the mud percent. Fe and P are linked with this sub units at significant levels. The $CaCO_3$ - Zn sub unit is linked with the former group at marginally significant level. This peculiar clustering of $CaCO_3$ over mud, C-org group indicates that the $CaCO_3$ form is very fine (lime mud) and associated with mud fraction. A similar occurrence of $CaCO_3$ in the mangrove sediments has been reported from Kumarakam area (located 40 km south of the study area) by Badarudeen et al (1996). Co, Cd and Cu from another major group (Group II), which is linked only to Pb.

Unlike the former two mangrove environments, the one at Kannur exhibits a unique pattern in the clustering of various chemical parameters. All the heavy metals (except Mn and Cd) are coupled directly or indirectly with the mud, C-org and P. (Fig 39). It indicates that the organic matter derived primarily by the decomposition of mangrove litter, in turn trapped in the mud fractions, has a significant bearing over the dispersal of heavy metals(except Mn and Cd) and nutrient elements in the Kannur mangroves. The metal Mn exhibit very marginal affinity with $CaC0_3$ and forms another group. This group is linked to the group I through the sole element Cd.

An overall evaluation of the clustering pattern of various parameters of Veli-Kochi and Kannur mangroves reveals that at Veli, the heavy metals do not exhibit considerable bearing over the mud organic carbon - phosphorus group. This could be either due to the mineralogic bearing or due to the flux of heavy metals by various industries located in the vicinity of Veli mangroves. In Kochi, though there is a marginal control in the distribution pattern of Fe, Zn and Mn by sediment texture, organic carbon and P, the metals Co, Cu, Cd and Pb behaves differently. This might be due to an external control (Ouseph, 1992), (presumbably industrial ?) over the distribution of these metals. From Fig. 40, it is clear that the upper areas of Vembanad estuary host several chemical industries, which can contribute a substantial amount of heavy metals to the mangrove sediments. Contrary to the above two mangrove areas, the heavy metals (except Mn and Cd) in the surface sediments of Kannur areas exhibit a marked bearing on sediment texture and organic carbon (Table.21). This indicates that Kannur mangrove is comparatively least polluted and the heavy metal levels in sediments are controlled mainly by the mangrove flora rather than external sources.

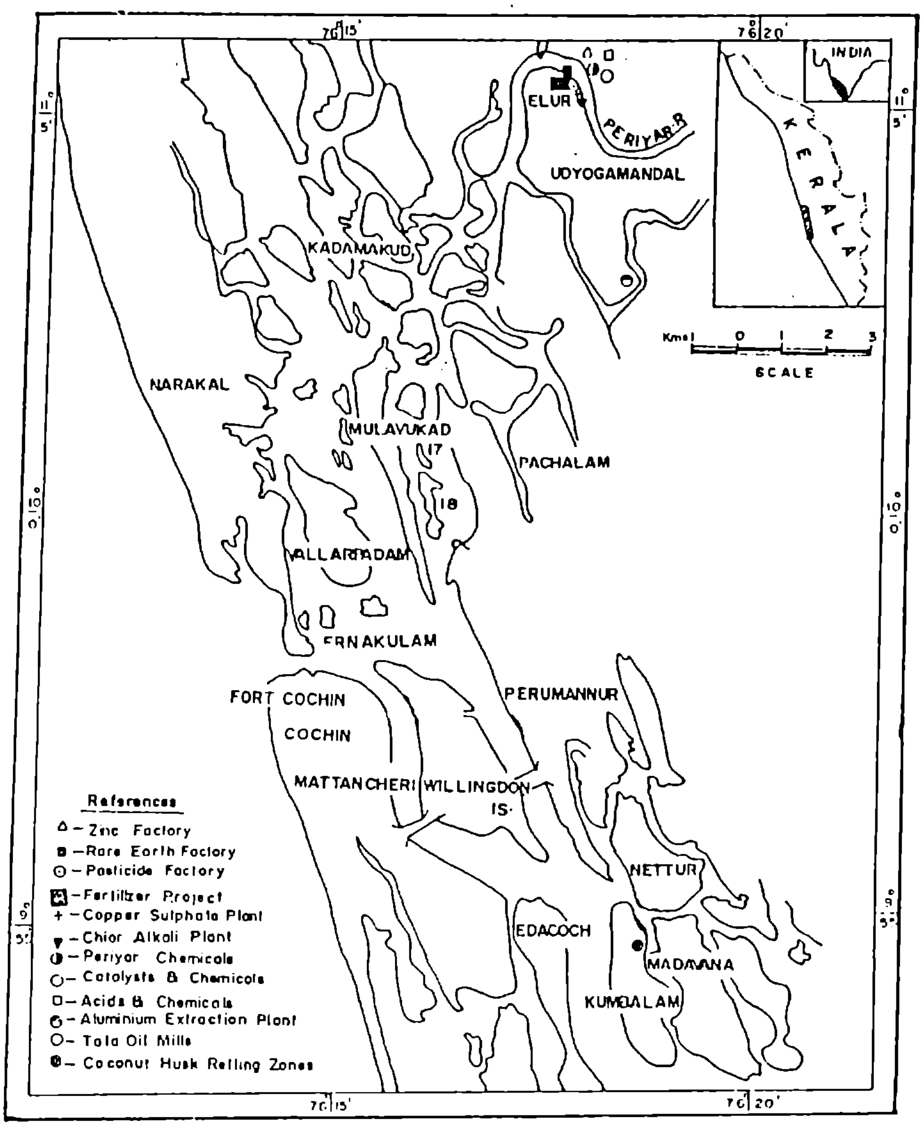

Fig. 40. LOCATION MAP SHOWING MAJOR INDUSTRIES AROUND KOCHI.

CHAPTER 7

SUMMARY AND CONCLUSIONS

This investigation deals with the sedimentological and geochemical characteristics as well as the heavy metal concentrations in leaves and stems of the major mangroves and mangrove associates of three important mangrove environments of Kerala such as Veli (Lat. 8° 30' 0" - 8° 31'30" N and Long. 76° 52' 30" - 76° 54' 0"E), Kochi (Lat. 9°59' 0"-- 10° 11' 30" N and Long. 76° 14' 0" - 76°16' 0"E) and Kannur (lat. 12°3' 30" -- 12° 5' 30 " N and Long. 76° 13' 0" - 76° 14° 30" E).

The grain size of sediments vary considerably in the three mangroves studied and characterised by the predominance of medium - fine sand over other sand grades. The intermediate and shallow water profiles of Veli account for substantially high content of sand compared to the landward profile. Texturally, this environment is complex and is floored mainly by muddy sand (mS) and sandy mud (sM) which together constitute 70% of the sediment substratum. Other sediment types include sandy silt (sZ), silty sand (zS), clayey sand (cS) and sand (S). The mangrove sediments of Kochi exhibit an average sand content of 65%, followed by silt (av; 23%) and clay (av; 12%). Similar to Veli mangroves, sediments of Kochi mangroves are also texturally complex and composed mainly by muddy sand (mS) and silty sand (zS) (>70%). The other textural types include sandy mud (sM), clayey sand (cS), sandy silt (sZ) and sand (S). The overbearing of mud dominated textural facies at Vypin region could be attributed to the prevalence of a low energy hydrodynamic regime also promoted by the luxurient mangrove vegetation there. Occurrence of sand dominant textural unit at the Malippuram mangrove region reflects the intensity of tidal activity to which the sediments are subjected. Like Malippuram mangroves, the sediments of Vallarpadam also exhibit the overbearing of sand dominant textural classes scattered along the south west, central and north-eastern parts of this mangroves.

Analysis of sand fractions in the core sediments of Veli reveals predominance (70 - 90%) of coarse to fine sands. It is indicative of a high energy depositional regime prevailing in the neighbourhood of the cores VC_1 and VC_2. The content of silt in both the cores are almost the same (av; 14% in VC_1 and 16% in VC_2). The core recovered from Vypin is composed of sediments of two textural facies, viz: the sandy mud (sM) and sandy silt (sZ). The core CC_2 of Malippuram is sand dominant and is texturally not so complicated in its sedimentary record. The sand, silt and clay contents of the core varies between 26% and 93% (av; 76%), 6% and 51% (av; 16%) and 1% and 23% (av; 8%), respectively. The two cores of Vallarpadam (CC_3 and CC_4) exhibit complex association of textural classes along the vertical profiles. The core KC_1 of Kannur exhibits mainly two textural attributes which include sandy mud (sM) and muddy sand (mS) while the core KC_2 is sand dominant and is sedimentologically not so complicated compared to KC_1. The core KC_3 does not show any variation in its sediment characteristics. It is composed entirely of sandy mud (sM) with average sand, silt and clay contents of 28%, 42% and 31%, respectively. The homogenity in the textural types of the core as well as the dominance of mud over the other size grades indicate the existence of a regular hydroperiod with rapid siltation in the core sites studied.

The sediment substratum of Veli mangrove shows phimean value between 1.1 and 5.6. They are moderately sorted to very poorly sorted in nature. The sediments of this ecosystem are, generally, fine to very fine skewed and exhibit kurtosis values between 0.51 and 2.29 (very platy to very lepto kurtic). The moderately sorted to very poorly sorted sediments of Kochi mangroves show mean values between 2.16 ϕ and 5.03ϕ. They are symmetrically to very finely skewed (0.03 - 0.67) and show variation of kurtosis from 0.68 to 2.98 (platy to very leptokurtic). Sediments of Kannur mangroves are poorly sorted and show mean values between 1.83ϕ and 5.56ϕ (av; 2.67ϕ). Majority of the sediments are very fine skewed with very platy to lepto kurtosis (0.5 to 1.4). The sediment cores of Veli show variation of phimean values between 1.8 and 4 with standard deviation values between 1.50 ϕ and 2.98 ϕ. They are, ingeneral, fine to very finely skewed and platy to very lepto kurtic in nature. The sub-samples of the sediment cores of Kochi mangroves show variation of mean values between 1.77 ϕ and 5.6 ϕ . They are fine to very fine skewed (0.01 to 0.53) and moderately to very poorly sorted (0.81 ϕ to 2.96 ϕ). The kurtosis values vary between 0.79 and 2.62 (Platy to very Leptokurtic).

Bivariate plots of phimean versus standard deviation and phimean versus skewness do not give any specific pattern. The plots of phimean against standard deviation exhibit a general linear trend which indicate, poor sorting as the phi mean decreases. Cross plots of phimean versus skewness also do not show any specific trend due to the drastic differences in the mean values of the mangrove sediments. Bivariate plots of standard deviation versus skewness give a linear trend whereas standard deviation against kurtosis for the sediments of Veli and Kochi exhibit similarity and no such specific trend is obtained for the sediments of Kannur. Cross plots of skewness and kurtosis show wide variation in all the three mangrove environments studied.

The plots of C versus M do not exhibit any specific pattern like that of the classic model of Passega, (1964). Instead, the plots fall within the I, II, III, IV, V and VII indicating complexity of the hydrodynamic regime which caused the deposition and subsequent reworking of the mangrove sediments. This pattern reflects suspension and rolling (I-III) as well as graded and uniform suspension (IV, V and VII) modes sediment transportation. Sediment population representing diverse categories of the said transportational mechanisms also exemplify the complexity in the hydrodynamic processes operating in the mangrove environments of the study areas.

Surface textural studies of quartz grains exhibit well defined features. Quartz sands of Veli are subhedral in outline and with partially smooth edges. The angularity of grains indicates moderate distance of transportation whereas the 'V' patterns show higher intensity of subaquous collisions. The morphological overprints depicted on quartz grains of Veli reveal a complex pattern of transportational history. Quartz grains of Kochi exhibit sub-angular to sub-rounded outline. Morphological overprints of upturned plates impact dishes, and stepped furrows are indicative of the complex history of transportation/deposition of the grains. The subrounded to rounded nature of theKannur sands with impact signatures of different genetic episodes, solution structures, conchoidal fractures, V-shaped patterns and linear and curved grooves etc., are some of the micro relief features identified from the grains of Kannur mangroves.

The total heavy minerals in the fine sands of Veli show a wide range of values (from 1.95% to 7.6%, mean 4.83%). The total heavy minerals in the very fine sands ranges from 9.46% to 35.25% (mean = 20.53%). A comparative evaluation of THM in the above two sand fractions reveals that the very fine sediments are enriched in higher proportions of THM compared to that in fine sands. The spatial analysis of heavy minerals shows higher THM values towards shallow water profile indicating the role of tidal waters in concentrating the heavy minerals in sediments. Contrary to Veli mangroves, the mangrove environment at Kochi exhibit little uniformity in their dispersal pattern. Here, the shallow water profile concentrates higher contents of heavies in fine as well as in very fine sands. Mangrove sediments of Kannur exhibit gradual increase in heavies from the south west to north east along the landward as well as shallow water profiles in fine and very fine sands. Heavy minerals present in the very fine sand fraction ranges between 1.99% to 8.23%. In core sediments, the heavy minerals of VC_2 shows more than 7 times the enrichment compared to VC_1. The heavies in the fine sands of KC_2 record higher amount than that of KC_3 (i.e., approximately 3-7 fold increase).

Heavy mineralogical constitution of the sediments of the three mangrove ecosystems encompasses a spectrum of minerals which include hornblende, hypersthene, zircon and sillimanite as major minerals and biotite, garnet, monazite, kyanite and rutile as the minor minerals. Opaques are abundant in the fine and very fine sands of all the three mangroves. The surface and core sediments of Veli show an average opaque content of 68% and 73%, respectively. Unlike Veli, the Kochi sediments show comparatively lower values of opaques. Sediment cores of Kannur record substantially high amount of opaques at lower depths than the deeper parts, both in fine and very fine sand categories. The content of hornblende in the fine sands of Veli shows an average of 0.73% whereas it is totally absent in the very fine sands of both surface and core sediments. In Kochi, its content in the fine and very fine sands are almost equal. Considering the amounts of hornblende in the sediments of the three mangroves together, it is vivid that the Kochi mangroves exhibit highest percentage followed by Kannur and Veli.

Hypersthene is generally absent in Veli and it averages about 16.74% in Kochi and 5.3% in Kannur. Biotite and zircon are either absent or their enrichment is very low in the mangroves studied. The sediments of Veli and Kochi areas show average sillimanite contents of 24% and 3.3% in the fine sands and 22% and 10% in very fine sands. The contents of monazite in both the sand fractions lie between 1% and 3%. Garnet is totally absent in Veli whereby the very fine sands of Kochi record higher amounts in fine sands than in very fine sands. The Kannur sediments exhibit a reverse pattern in the abundance of garnet.

The matrix analysis of the heavy minerals reveals that THM exhibit a significant positive loading on opaques and monazite whereby the amphiboles and pyroxenes exhibit a negative relation. The garnet exhibits a positive relation with rutile ($r = 0.47$) in fine sands while negative with very fine sands. Furthermore the hornblende and hypersthene exhibit a strong bonding themselves as they represent the light heavy category of low energy regime.

An assessment of the major heavy mineral suites of the three mangroves studied bringsout unique mineralogical associations, inturn reflecting the provenance characteristics of sediments. The Veli mangroves, is exhibited by opaque - sillimanite association, Kochi by opaque - hornblende - hypersthene association and Kannur by opaque - hornblende - sillimanite association.

Clay mineral constitution of the mangrove sediments indicates dominance of kaolinite over montmorillonite, illite and gibbsite. The average kaolinite content in the intertidal zones of VeliI, Kochi and Kannur regions are 77.94%, 42.57% and 49.67%, respectively. Next to kaolinite, montmorillonite occupy the second position among the clay mineral suite. Sediments of Kochi exhibit comparatively high content of montmorillonite and shows more than 3 fold enhancement than Veli. Of the three mangroves, sediments of Kochi exhibit relatively higher percentage of illite compared to the other two areas. Gibbsite is recorded only in nominal amounts in all the three areas.

The present investigation reveals that, mangrove sediments of Veli, Kochi and Kannur indicate highly varied pH values for both surface and core sediments. The values of pH for the sediments of Veli are less 5.08 to 7.75 in surface and 6.84 to 7.65 in core sediments. The pH values of Kochi ranges from 6.2 to 8.2 in surface sediments and 5.96 to 8.95 in core sediments. The ranges of pH values in Kannur are 6.5 to 7.81 in surface sediments and 5.9 to 7.41 in core sediments .

The organic carbon (C-org) distribution in the mangrove sediments of Veli, Kochi and Kannur regions are primarily controlled by the textural attributes of the sediments. In Veli, the average C-org in different sediment type reveal their relative order of abundance as sZ > sM> mS> cS>zS > S. The organic carbon content of Kochi varies between 0.52% and 4.89% (av; 2.62%) and yields more or less similar values along intermediate and shallow water profiles. However the sediments of Kannur show C-org variation from 1.99% to 6.03% (av; 4.01%) and divulge that the northeastern segment is marked by higher content of C-org compared to southwest segment. The association of C-org in the finer sediments of the mangroves studied might be due to the enhanced surface area of the finer particles. The core sediments of the above mangroves reveal higher C-org accumulations at lesser depths and persist no uniformity in its variations further downwards.

Estimation of the phosphorus in the sediments of the three mangroves shows the predominance at Kochi over Veli and Kannur. The sediments of Kochi show nearly 6 times the enrichment of phosphorus compared to Veli and approximately 2 times the enrichment than Kannur. Sediment cores of Kochi shows approximately 3 fold enrichment of phosphorus than Veli and 2 fold enrichment than Kannur. Variation of phosphorus in the 3 mangroves may be attributed to the higher content of organic detritus in the sediments.

Spatial distribution of $CaCO_3$ varies between 3% to 15% (av: 7.75%) in Veli, 5% to 20% (av; 12.7%) in Kochi and 4% to 18% (av; 11.16%) in Kannur mangroves. The $CaCO_3$ content originate either from autochtonus or allochtonus sources which reflects the differences in the environmental conditions of depositions. The waxing and waning of $CaCO_3$ with depth are suggestive of rapid changes in the sedimentary environment resulted due to the influx of terrigenous materials.

The sediments recovered from Veli Mangroves exhibit 0.8% to 8% of Na (av; 2.75%) while K shows substantially lower ranges (0.3% to 2.1%; av; 1.02%).

The relative abundances of Na and K along the profiles are of the order shallow water profile > intermediate profile > landward profile. The average concentration of the Na and K in the sediments of the Kochi are 2.14% and 1.48% and that of Kannur 2.43% and 5.36%, respectively. The enhanced values of Na and K in the mangrove environments studied might be attributed to the ions present in the aqueous solutions that fill in the pore spaces of sedimentary particles. Elevated value of Na over K is due to the ability of former cation to fix with clay minerals.

The present investigation records highest Fe concentration in the surface (av:4.5%) and core (av:5.09%) sediments of Kochi mangroves, whereby the lowest concentration is at Veli. Considering the Mn distribution, Kannur sediments show elevated accumulation (295 ppm in surface and 236 ppm in core) than Veli and Kochi regions. It is observed that the Fe and Mn are enriched in silt and clay dominated textural units of Kochi and Kannur mangroves, however, its enrichment in the sand and clayey sand, sediment types of Veli region could be attributed to the contribution from heavy mineral sources a feature also investigated by Padmalal amd Seralathan, (1995) elsewhere.

Trace metals (Cu, Co, Zn, Pb and Cd) are associated with the sediments of Veli, Kochi and Kannur mangroves exibit different relationship with other geochemical and textural parameters, such as C-org, Fe, P and mud. It is noted that, the metals Cu, Co, Pb, and Cd exhibit slightly elevated concentrations along intermediate profile than the shallow water profile owing to either the particle control or the chemical removal mechanism. Matrix analysis shows that many of the trace metals give positive correlations with Fe, C-org or mud content, signifying their phasial association. The progressive depletion of cobalt in the sediment cores of Veli may be due to the desorption from clay minerals. Zn bears strong positive affinity with C-org, mud content and Fe. The sediments of the 3 mangroves studied delineates highest Zn concentration either with silt or clay dominated textural facies. Remarkably high accumulation of Zn in the pure sandy unit of Veli could be attributed to the contribution from detrital minerals. The toxic metal Pb accumulates in surface and core sediments of the mangroves studied and its concentration levels are well above the toxic limits. Detectable levels of Cd is present in all the environment.

Heavy metal speciation studies of the mangrove sediments of Veli, Kochi and Kannur show exceptionally high association of cobalt, lead, copper and zinc with lithogenous phases compared to easily exchangeable, organic bound, carbonate bound and Fe/Mn bound phases. While considering the three mangroves together, the lattice bound metal fraction varies between 40% and 94%. Various metals bounded with lithogenous phases of mangrove sediments reveal that approximately 78% of Co, Pb and Zn and 66% of Cu are found associated with the lithogenic fraction.

In the present investigation a total of 15 mangroves and mangrove - associates are identified and listed from Veli, Kochi and Kannur mangroves. They are *Acanthus ilicifolius, Excoecaria agallocha, Bruguiera gymnorrhiza, Rhizophora mucronata, Kandelia candel, Sonneratia caseolaris, Avicennia officinalis, Avicennia marina, Derris trifoliata, Cerbera odollam, Acrostichum aureum, Vitis vitigenia, Premna serratifolia* and *Barringtonia racemosa.*

Analysis of heavy metals (Fe, Mn, Co, Cu, Pb, Cd and Zn) in the leaf and stem of mangrove and mangrove associates vary widely. It is observed that heavy metal concentrates several times in ashed samples compared to dried plant parts. The mangrove sediments receive heavy metals from many sources like terrestrial inputs, mineral phases, industrial effluents, urban sewages, chemical precipitations and also from the decomposition of organic litter contributed by mangrove leaves and other vegetal remains. Cluster analysis reveals that, although heavy metals are added to the sediments from the decomposition of mangrove - borne litters, the other sources of heavy metals tend to mask this source in the mangrove environment of Veli and Kochi. In Veli, the major mangrove species (the species covering morethan 75% of the total mangrove vegetation) on an average basis exhibits 6-7 times and 12-19 times the enrichment of heavy metals in ashed leaves and stems compared to their dried counter parts. An evaluation of heavy metal enrichment in the mangrove species with respect to the surface sediments indicates that all the heavy metals are, in general, enriched in sediments than the dried vegetals samples. The poor correlations of organic carbon with various heavy metals in Veli and Kochi mangroves indicate that, mangrove litter and other organic detritus do not influence much in the distribution pattern of heavy metals compared to texture, mineralogy and urban contributions in the Veli mangroves. In Kochi mangroves, the heavy metals are enriched 9 to 13 fold in ashed samples compared to the dried counterparts. Like Veli mangroves here too, the heavy metals are enriched more in sediments than in dried leaves and stems. In Kannur mangroves, the heavy metals are accumulated 5-7 times in the ashed samples of the leaf and 13-19 times in stems compared to their dried counterparts. Pollution assessment studies using cluster analysis unveil that, the mangrove environments of Veli and Kochi are severely polluted compared to Kannur.

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* Cross reference