MINERALOGICAL AND SEDIMENTOLOGICAL STUDIES OF INNERSHELF AND BEACH SEDIMENTS ALONG THE COAST BETWEEN PARAVUR AND KOVALAM, SOUTH KERALA, INDIA

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COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY
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April 1995

To My Dad and Mom

Xavier and Princy

DECLARATION

I do hereby declare that this Thesis contains results of research carried out by me under the guidance of Prof. P. Seralathan, Marine Geology Division, School of Marine Sciences, Cochin University of Science & Technology and has not previously formed the basis of the award of any degree, diploma, associateship, fellowship or other similar title of recognition.

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Thiruvananthapuram
April 12, 1995.

CERTIFICATE

This is to certify that this Thesis is an authentic record of research work carried out by Mr.Terry Machado under my supervision and guidance in the Centre for Earth Science Studies for Ph. D. Degree of the Cochin University of Science and Technology and no part of it has previously formed the basis for the award of any other degree in any University.

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CONTENTS

List of figures

DISTRIBUTION PATTERN OF SOME TRACE ELEMENTS:

FREQUENCY CLASS INTERVAL

LIST OF PLATES

LIST OF TABLES

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PREFACE

Continental shelf is of particular significance in marine geology , because it links the two basically different structural zones in the earth's crust; the continents and ocean basins. The shelf area has much wider importance in many fields of activity such as scientific, economic, social, political and strategic. The pace of development has ultimately put pressure on mankind to look for exploitable resources and accessibility to the continental shelf area and beyond. Added to the above, the developmental activities in the coastal area would readily and directly influence the innershelf sediments. This situation demands a thorough geological knowledge of the continental shelf area. Moreover, a successful management of the continental shelf zone requires an optimum data base on the physico-chemical nature of the shelf sediments. Although sedimentological studies were carried out along the western continental shelf of India, a well documented systematic study of the inner shelf off Trivandrum coast is still found to be lacking. Considering the physiographic settings and the vicinity of two renowned placer deposits at Chavara and Manavalakurichi, such a sedimetological inventory has become all the more vital.

In view of the above, a research programme has been drawn up to account the salient sedimentological and mineralogical aspects of the innershelf and beach sediments between Paravur and Kovalam, Trivandrum district, Kerala (latitudes 8° 7'00" to 8° 47'45" and longitudes 76° 43'00" to 77° 40'45"). The findings are presented in six chapters formatted to address the aim of this research.

Following introduction to the problem and study area, first chapter highlights the objectives of the study. The strong seasonality in precipitation, geology, drainage pattern in the hinterland and the physiographic uniqueness of this innershelf are also discussed. The literature pertaining to the study area are reviewed and the methods adopted in the field (including sample collection, bathymetric survey by continuous recording echosounder) are described.

The geomorphometry of beach and innershelf and oceanographic parameters of the study area are dealt in second chapter. Details of the coastal geomorphological structures such as barrier spits, strand plain, cliffed shoreline, pocket beaches etc, are described. Morphometric changes of the beaches in response to the monsoonal oceanographic conditions were studied based on seasonal beach profile measurements along with wave refraction diagrams. Fluorescent tracer technique (with Rhodamine-B as tracer) was used to monitor the sand movement in some beaches around Kovalam . The general trend of beach material movement for the south west monsoon is established through this study. The morphological characteristics of the innershelf are described with the help of echogram. The presence of a group of sand waves off Kovalam at 55m. depth is highlighted and their origin discussed. An attempt is being made to sectorwise classification of this innershelf based on their morphological characteristics.

In the third chapter the results of the granulometric analysis carried out on the sediments are discussed. Distribution diagrams for sand, silt and clay are presented and their relations with the coastal geomorphology and nearshore dynamics is discussed. Interrelationship between different grain size parameters in the innershelf and the beach sediments are also discussed. An attempt is made to decipher the direction of sediment movement in the innershelf area using `Z' score statistics computed from the progressive changes in moment measures. Scanning Electron Microscopic images of some quartz and heavy mineral grains are examined and inferred for the depositional environment. CM diagram for the innershelf was constructed and inferred.

The fourth chapter deals with the mineralogical aspect of the innershelf and beach sediments. Mineralogical assay was carried out for heavy minerals separated from the surficial innershelf and beach sediment samples to produce distribution maps of heavy minerals based on petrographic point counting data. Their distribution patterns are discussed with reference to the nearshore dynamics, coastal geomorphology and hinterland geology. Selected heavies and some quartz grains from beach and nearshore environments were subjected to SEM analysis and the results are inferred to deduce their mode of transport. Additional evidence for the provenance of the sediments was gathered through electron microprobe analysis of some garnet grains.

Geochemical analysis of the some selected innershelf surficial sediment samples were carried out to understand the geochemical variations of the study area are discussed in the fifth chapter. Elemental assay (Si, Al, Fe, Mg, Na, Mn, Ca, K, Cu, Ti, Zn etc,) were done and distribution diagrams were prepared for certain elements. Considering that this area is flanked by two renowned black sand deposits at Chavara in the North and Manavalakurichi in the South a detailed U and Th determinations in the surficial sediments were done. U and Th were analysed by Instrumental Neutron Activation Analysis (INAA). The results show that the U an Th contents are considerably higher off the Kovalam and Perumathura promontory.

The sixth chapter synthesises the results of this investigation and conclusions drawn based on them. The research papers were published in connection with this investigation are presented in the Annexure - I.

CHAPTER - I

INTRODUCTION

Coastal geology, an area that almost went unrecognised a couple of decades ago, is now coming to the forefront due to the present day environmental consciousness. Increased rate of developmental activities and utilisation of the coastal areas can be noticed the world over, particularly after the Industrial revolution, for reasons ranging from population pressure to unprecedented individual prosperity. Intense utilisation of coastal land through construction of building as near the sea as possible, exploitation of beach material and ensuing inevitable protection measures have all disturbed the equilibrium of this fragile but very dynamic ecosystem. Added to this, is the redoubtable threat imposed upon this system by an accelerated rise in sea level in the coming decades due to green house effect.

Shoreline retreat is purely a natural phenomenon. There is, however, severe erosion of the shore due to thoughtless human intervention. A thorough knowledge of the environment, including the factors both natural and manmade that affect the coastal zone, is essential for sustainable utilisation of its' resources without causing irreparable damage to the coastal environment. The coastal zone generally comprises many environments such as outershelf, innershelf, littoral, beach, bay, and estuarine. Of these, the beach and the adjoining innershelf are the most dynamic area upon which man depends heavily for food, transportation, recreation, mining, defence, non-conventional energy and waste disposal.

On a global perspective, detailed multidisciplinary study gains significance, particularly in coastal zone management. The study area (Fig.1.1) falls well within an unique region bordering the north Indian ocean. Behaviour of meteorological and oceanographic parameters over this area is different and therefore, any extension or extrapolation of similar studies conducted elsewhere may not hold good in its entirety. Moreover, the meteorological changes that occur in this region are more pronounced and rapid. For example, the variability of one of the well documented parameters namely the sea surface temperature (SST) exhibits a primary peak in April-May (pre monsoon) and a secondary peak in October-November (post monsoon), a minimum in January-February (stable winter monsoon) and a secondary minimum in August (stable summer monsoon). Coinciding with the change in SST a complete reversal of the atmospheric and oceanic surface circulation takes place in this region (NIO, 1982). Rainfall occurs in a strong short spell during the southwest monsoon. Increased wave activity also is felt along the southwest coast of India during this season. Thus the influence of the monsoons, particularly the wave regime, rainfall and ensuing runoff, and the reversing coastal circulation on the sedimentation pattern need to be closely looked into to fully understand the various mechanisms that affect sedimentary processes so that unmindful human intervention that adversely affects the coastal zone can be minimised.

The Kerala state, which is bounded by the Western Ghats on its east and the Arabian sea on the west, has a 560 km coastline. An unique phenomenon atypical of this coastline is the "Mud Banks" which form during the southwest monsoon, generally north of Quilon. The mud banks often cause shore erosion and hampers littoral sediment movement. The shelf south of Quilon is the narrowest and steepest section of the entire western continental shelf of India. The beaches of Kerala are mostly nourished by numerous rivers which flow down the Western Ghats, however, the sediment supply to the littoral zone of Kerala has been strongly affected by the construction of several reservoirs and unscientific sand mining of river beds.

Systematic scientific data collection over the Indian continental shelf began during the International Geophysical Year-1959. Being the least explored of the three major oceans, a joint and concerted effort was made during 1962 - 1965, by the International Indian Ocean Expedition (IIOE) and has produced a fair amount of information in almost all disciplines of oceanography. However, a systematic sedimentological database become a reality only after the Indian naval ship INS Darshak has been deployed for the purpose. Subsequently, the commissioning of R V Gaveshani, the research vessel of the National Institute of Oceanography in 1976, has paved the way for a continued and methodical data collection programme in the Indian shelf waters. Primary, but valuable, information that appeared in several publications is its outcome.

Shelf studies pertaining to the east coast of India were initiated about the same time by a small but dedicated team of marine geologists of the Andhra

University led by Prof. La Fond. As far the western shelf, marine geological investigations have been initiated mainly based on cartographical analysis of hydrographic charts and echograms which have revealed that the west coast of India is conspicuously straight due to the Pleistocene faulting (Krishnan, 1960). Rama Raju (1973) has observed that the shelf width is at its minimum (40 km) off Trivandrum and maximum (320 km) off the Gulf of Cambay. Morphological studies on the western continental shelf have indicated the presence of several small scale pinnacles with a relief ranging from 1 to 8 m height near the shelf break. Nair (1972,1974) relates this feature to the low stand of sea level. Siddiquie and Rajamanickam (1974) have also studied the morphology of the western shelf of India and report a break in shelf slope between 120 and 145 m depth.

Nair (1974) has studied the shelf sedimentation pattern and considered this shelf as an example of a drowned coast with subsequent transgressive episodes. Following this study, sediment facies of the western shelf have been further investigated by Nair et al. (1978) and Hashmi et al. (1978). These studies have suggested the existence of three distinctive sedimentary facies across the shelf viz., sand, mud and carbonate sands. Of these three facies, the first two are of recent origin whereas the carbonate sands are formed during the Pleistocene low sea level. Mineralogical investigation on the shelf edge carbonate sediments and limestone (Nair and Hashmi, 1981; Hashmi et al., 1981) has also shown that the outershelf carbonate deposits were of shallow water origin. The sedimentological and micropalaeontological studies of the outershelf limestone deposits have also indicated a shallow water condition. Nair and Hashmi (1980) have deduced that the carbonate sediments have formed during Holocene (about 10,000 years BP), under warm climatic condition with little terrestrial runoff. These findings have indicated a drastic change in climatic conditions from arid to humid which were more congenial for carbonate precipitation (Nair and Hashmi, 1980). Rao et al. (1983) have studied the clay minerals of the Kerala shelf and concluded that rather than the mode of transportation, the parent rock composition has more influence in deciding the nature of the clay minerals. Siddiquie and Rajamanickam (1979)have carried out the surficial mineralogical investigation of the western continental shelf and prepared the spatial distribution maps of some heavy minerals on the western shelf of India. Shanker et.al., (1987) have given an overall distribution of uranium in the surficial sediments of the Arabian sea and discussed it's origin.

Setty (1972, 1974) and Setty and Gupta (1972) have studied the foraminiferal assemblages of the western shelf sediments and identified relict natured sediments in the outershelf. Rao (1972, 1973) has further compared the faunal assemblage of the Arabian Sea and the Bay of Bengal and perceived faunal diversity among them. Setty and Nigam (1980) have further studied the faunal diversity and attributed it to the higher salinity and micro-environmental implications in the Arabian Sea. Nigam and Thiede (1984) have reported an important species belonging to Miocene and Pliocene from the outershelf area. Geochemical investigations by Rao et al. (1972, 1974), Murthy et al. (1973, 1980) have given an overall distribution pattern of the major and trace elements of the surficial sediments and their partition pattern of the western shelf. Subsequent study by Rao et al., (1987) have indicated the existence of an environment favourable for phosphatisation in the outershelf of the western continental shelf of India. The above investigations have instigated considerable interest to pursue sedimentological studies on the shelf.

Many of the studies cited above are fairly regionalised and confined to mid or outershelf areas. However, a few investigations on the near shore sediments especially on the mineralogical regimes off Mangalore (Siddiquie and Mallik, 1972; Mallik, 1972) and off Ratnagiri (Rajamanickam et.al.,1986; Rajamanickam and Gujar, 1984) were available. Nevertheless, they are a few and far apart. On the other hand details of well documented sedimentological investigations are existing for the innershelf on the northern part of this study area from Paravur to Cochin (Prakash, 1991; Ramachandran, 1992). Hence, the outcome of this endeavour would provide much needed continuity of database on the innershelf sedimentological characteristics for the southern Kerala coast.

Further, considering the fact that the study area (Fig1.1) forms the narrowest and the steepest section of the western continental shelf of India, an inventory of near shore sedimentology is a vital requisite. The lack of such a database is increasingly felt particularly in the light of problems and prospects such as coastal erosion, pollution monitoring in the littoral zone, exploration of placer deposits and coastal zone management. Apart from providing a buffer zone between the sea and the coast the beaches specially around Kovalam are becoming popular beach resort and tourist centre. Hence, future plans for development of the beach could involve beach replenishment. Besides, in recent years it is becoming increasingly difficult to obtain sand from beds of rivers and backwaters in sufficient quantities at an economical cost. This is due, in part, to increased land value, diminution and depletion of material caused by excessive use of nearby sources. So, in future the search for new sources would lead to exploration and exploitation of near shore sand deposits. All these points

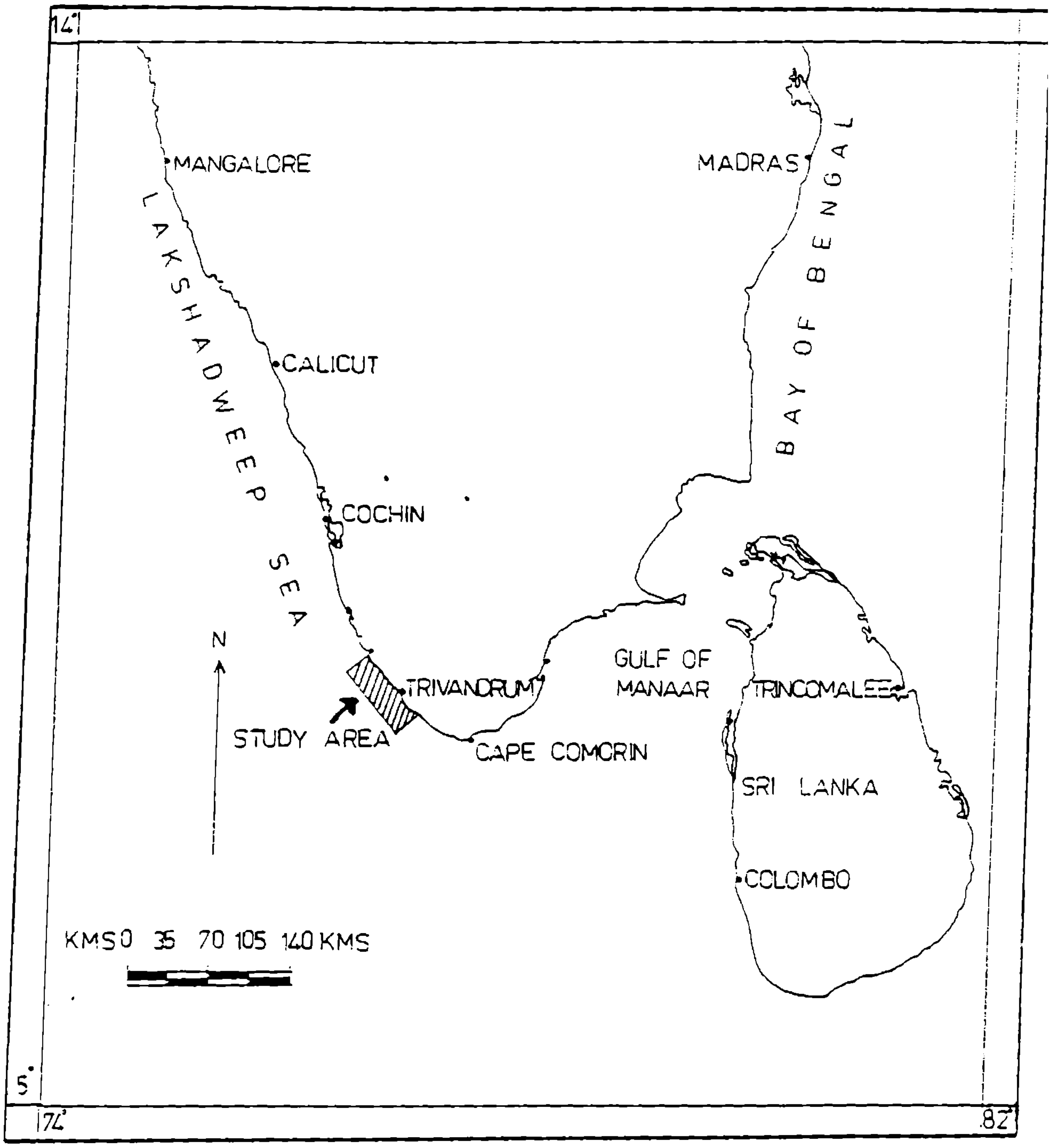


Fig. 1.1. Location of the study area

mentioned above stress the need for a systematic scientific inventory of the innershelf of the study area.

I.1. OBJECTIVES

The important objectives of this investigation are :

i) To understand the process-response aspect of the textural parameters of the surficial sediments in relation to the sedimentary processes active in the study area.

ii) To document the mineralogical assemblage of the near shore surficial sediments.

iii) To account the distribution pattern of some elements in the near shore surficial sediments.

iv) To use the above findings to infer the provenance of the near shore sediments.

I.2. GEOLOGY OF THE HINTERLAND

The hinterland of the study area is mainly composed of the Pre-cambrian crystalline basement complex that comprises products of granulite facies metamorphism, belonging mostly to khondalite suite of rocks. The khondalite suite in general constitutes garnet sillimanite gneiss ± graphite, garnet biotite gneiss and rarely calc granulite bands (Fig. 1.2). Occasional patches and bands of charnockite are seen within the gneissic terrain. Occurrences of augen gneiss are seen north of Trivandrum City (Soman et al., 1994). A detailed geological map of the hinterland bordering the study area is presented in Fig.1.2. General geological sequence of the Kerala region is given in Table 1.1.

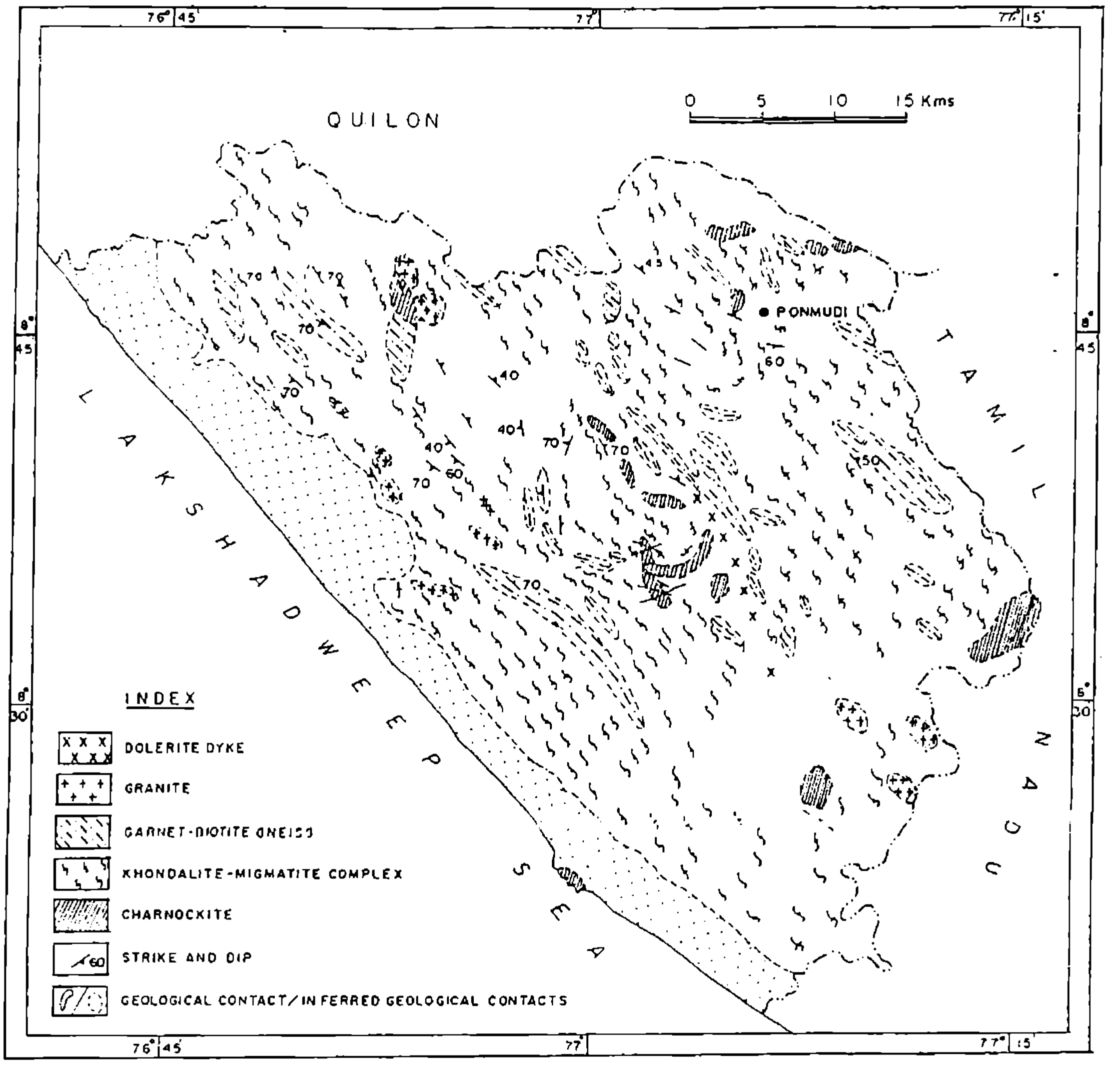


Fig. 1.2 Geology of the hinterland (After Soman, 1995, in prep.)

Table 1.1 Geological sequence of the Kerala region

ERA	PERIOD	EPOCH	AGE(MY)	LITHO-STRATIGRAPHY UNITS
	Quaternary		0.7 - 1.00	Soil,Alluvial and beach sands, peat, calcareous clay with shell etc,.
CENOZOIC				~ ~ ~ UNCONFORMITY ~ ~ ~ ~
	Pliocene			Warkalli beds
		Upper Miocene to Lower Miocene	26.0	Quilon beds
		Upper Oligocene	(?)	Vaikom beds
				~ ~ ~UNCONFORMITY ~ ~ ~
MESOZOIC	Palaeogene			
	Cretaceous		75 to 144	Basic dykes Doleritic/Gabbroic)
				~ ~ ~ ~ UNCONFORMITY ~ ~ ~
PRECAMBRIAN			460-765	Acid and alkaline intrusive
			1660	Basicintrusives (Dolerites)
			2500	Dharwar Group
				~ ~ ~ ~ UNCONFORMITY ~ ~ ~
				Sargur Group
				~ ~ ~ UNCONFORMITY ~ ~ ~ ~
			~ 3000	Khondolite Group Charnockite Group

(After Soman 1995 in prep.)

The khondalite group of rocks are medium to coarse grained and the major constituents are plagioclase, quartz, potash feldspar, garnet and sillimanite. Biotite, graphite, ilmenite, calcite and cordiorite are the minor constituents. Sphene, monazite, zircon and apatite occur as accessary minerals. Patches of garnet - biotite gneiss are seen almost throughout the hinterland of the study area with a typical mineralogical assemblage with plagioclase, quartz, potash feldspar, biotite and garnet.

Charnockite occurs as large patches extending for scores of meters around Kovalam, Vizhinjam, Mannanthala and Nedumangad. Two generations of charnockites are reported from the hinterland of the study area; one enclaves within garnet-quartz-feldspar neosomes and the other as arrested development in migmatitic gneisses (Ravindrakumar et al., 1985). However, both the generations have comparable mineralogical assemblage and consists of K-feldspar + plagioclase + quartz + orthopyroxene + garnet + biotite. Other than these two major horizons, garnet granite (garnet+feldspars+quartz neosomes) also occurs as patches, domes/sheet rocks showing both concordant and cross cutting relations with khondalites and charnockite suites. This garnetiferous granite is medium to coarse grained with typical mineralogical assemblage of quartz + feldspars+garnet ± biotite. Apatite, sillimanite, graphite, zircon and monazite occurs as accessory phase. Massive garnet-granite occurrences are known from Valichal, Vallarada, Amboori, Nedumangad in Trivandrum district. There are two sets of doleritic dyke intrusions along the major lineaments tending NNW - SSE, NE -SW and ENE - WSW (Fig.1.2). A number of minor folds tending NW -SE are decernable at the outcrop level. Chattopadhyay et al. (1993) suggest that this area experienced faulting along the axes of these folds in recent geological times and thereby influenced the topographical configuration. He also relates the geomorphic evolution of this area to the above mentioned structural features.

The Cenozoic sediments which is composed of pebble beds, sandstone, gritty clay with shells and peat and with or without streaks of black sand, forms a narrow tract along shore. This formation usually has a hard crusted lateritic capping.Many sections of coastal tracts form a series of cliff sections at Varkala and at Karichal near Kovalam. The section exposed at Karichal, 2 km south of Kovalam, is made up of cross- bedded and variegated sandstone and clay. The cliff section extends for about 2 km with pocket beaches in between. Unlike its' contemporary at Varkala this formation overlies bauxitised / lateritised khondolite and carbonaceous clay. This formation is devoid of leaf fossils (Raha and Rajendran, 1984). The exposure of Tertiary sedimentary formation seen at Varkala is also the type area for Warkalli beds (King, 1882). This formation is made up of sandstones, variegated clays and lignite bands of Miocene age (Rajendran, 1987)

I.3. DRAINAGE

The state of Kerala is being drained by 44 west flowing and 3 east flowing rivers. Of these, only three rivers drain the hinterland of study area namely Vamanapuram, Karamana and Neyyar (Fig. 1.3). All these three rivers are stream like in character with short length and major change in slope and flow. Below are given an overview of basin characteristics; followed by a brief outline of each of the three rivers.

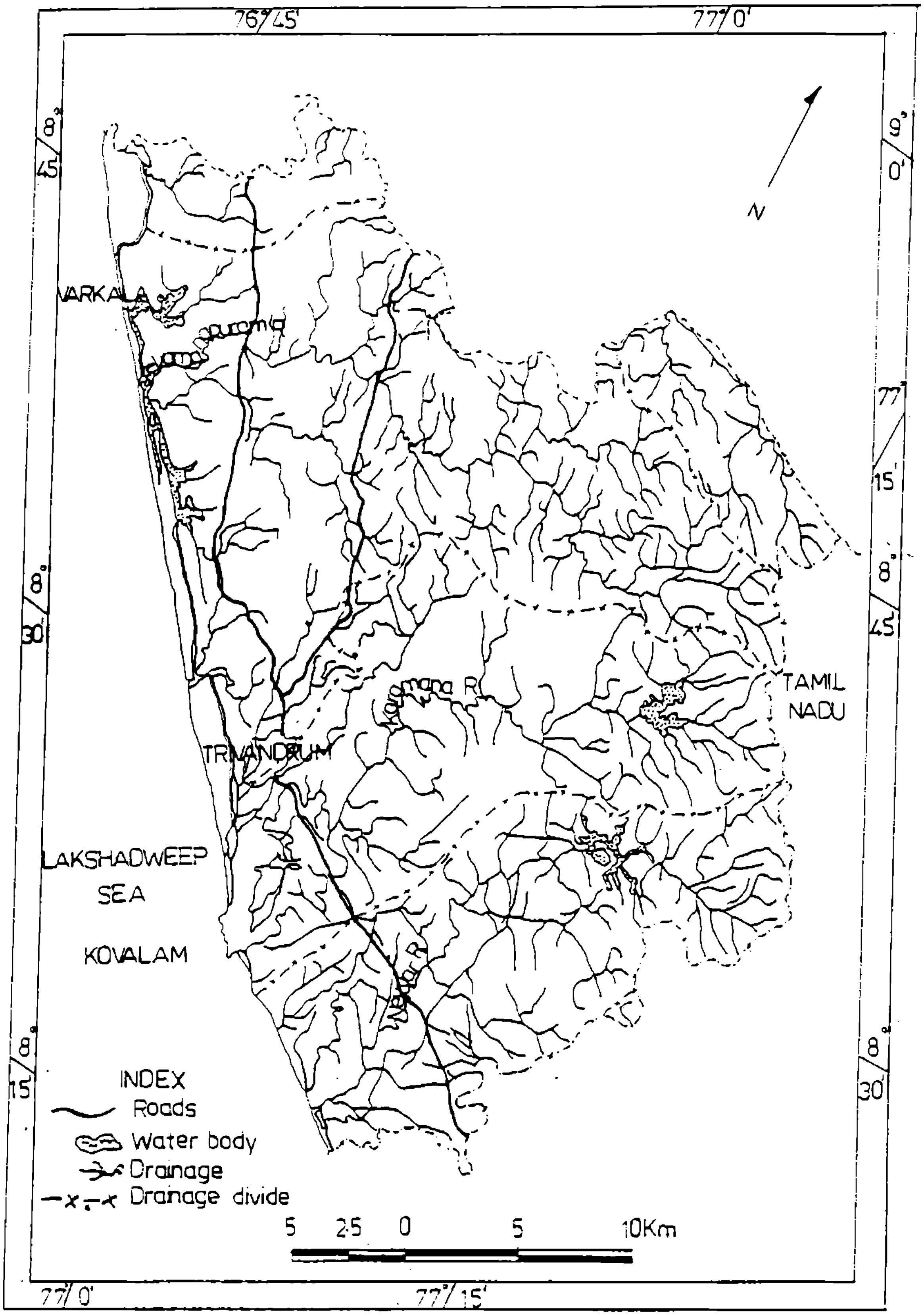


Fig. 1.3. Drainage map of the hinterland

River Basin	Area km^2	Total length km.	Drainage density km/ Km^2
Neyyar	492	92	1.23
Karamana	464	82	2.37
Vamanapuram	787	81	1.82

Neyyar :

This river originates at the Agasthyamalai the highest peak (1866 m) in the hinterland of study area. This is a sixth order basin with 15 well marked sub-basins. A significant change in drainage density from uplands to lowlands is observed and this change is attributed to the steepness of catchment area (Samsudin 1980). The rock types encountered in this basin are khondalites, charnockite with veins of pegmatite, and bands of calc gneiss.

Karamana :

The river flows in a straight NW-SE direction, athwart a strike; which may be suggestive of a structural control. Two prominent nick points, one at 150 m and the other at 700 m. coincide with the confluence of tributaries. The comparison of basin area, channel slope and sediment size indicate a dynamic equilibrium (Sinha Roy, 1979). It is a fifth order drainage basin.

Vamanapuram:

The major drainage pattern observed in Vamanapuram river basin is *dendritic*. The prevalence of this particular pattern indicates that the bed rock offers a more or less uniform resistance all over the basin. The long profile of the river is broadly a *concave upward* type (Chatopadhyaya, 1993). The relief of the whole course ranges from 0 to 1700 m., with nick points at 200, 400, 600, 700, 1000, 1200 and 1400 m elevations. Almost the entire river basin is covered by Khondalitic terrain

I.4. CLIMATE

As in the case of southwest part of India, climate of the study area and hinterland is also controlled by the western ghat orography. The respective mean annual minimum - maximum temperature of Kerala are 18.5°C and 28.5°C. Based on the pattern suggested by Indian Meteorological Department, the seasons of Kerala can be demarcated as follows:

i. Hot weather period (the pre-monsoon season): March to May.

ii. Southwest monsoon season: June to September.

iii. Retreating southwest monsoon (northeast monsoon): October to November.

i. Winter (cool weather season): December to February.

Rainfall:

In Kerala, the annual rainfall increases from south to north. Trivandrum area receives the minimum rainfall whereas the Kasargode receives the maximum. However, the hinterland of the study area receives normal rainfall (Sampath and Vinayak, 1989). The mean rainfall data for some of the gauging stations in the hinterland of the study are shown below:

Stations	SW Monsoon	NE Monsoon	Post Monsoon	Annual
Attingal	1092 mm	507 mm	401 mm	1955 mm
Nedumangad	1006 ,,	626 ,,	503 ,,	2241 ,,
Trivandrum	863 ,,	626 ,,	399 ,,	1812 ,,
Neyyatinkara	738 ,,	543 ,,	364 ,,	1654 ,,
Total %	46 %	33 %	21 %	100 %

Wind :

Similar to rains, wind velocity in the study area is also monsoon dependent. The seasonal wind roses for Trivandrum computed from the data recorded at the Trivandrum observatory are presented in Fig:1.4. Two distinct patterns are observed for the NE and SW monsoons. The wind direction during the SW monsoon are consistent from the NW quadrant, whereas in the rest of the period the directions are inconsistent. The wind velocity during SW monsoon is from 5 to 25 KMPH, whereas, during NE monsoon the speed varies from 5 to 18 KMPH.

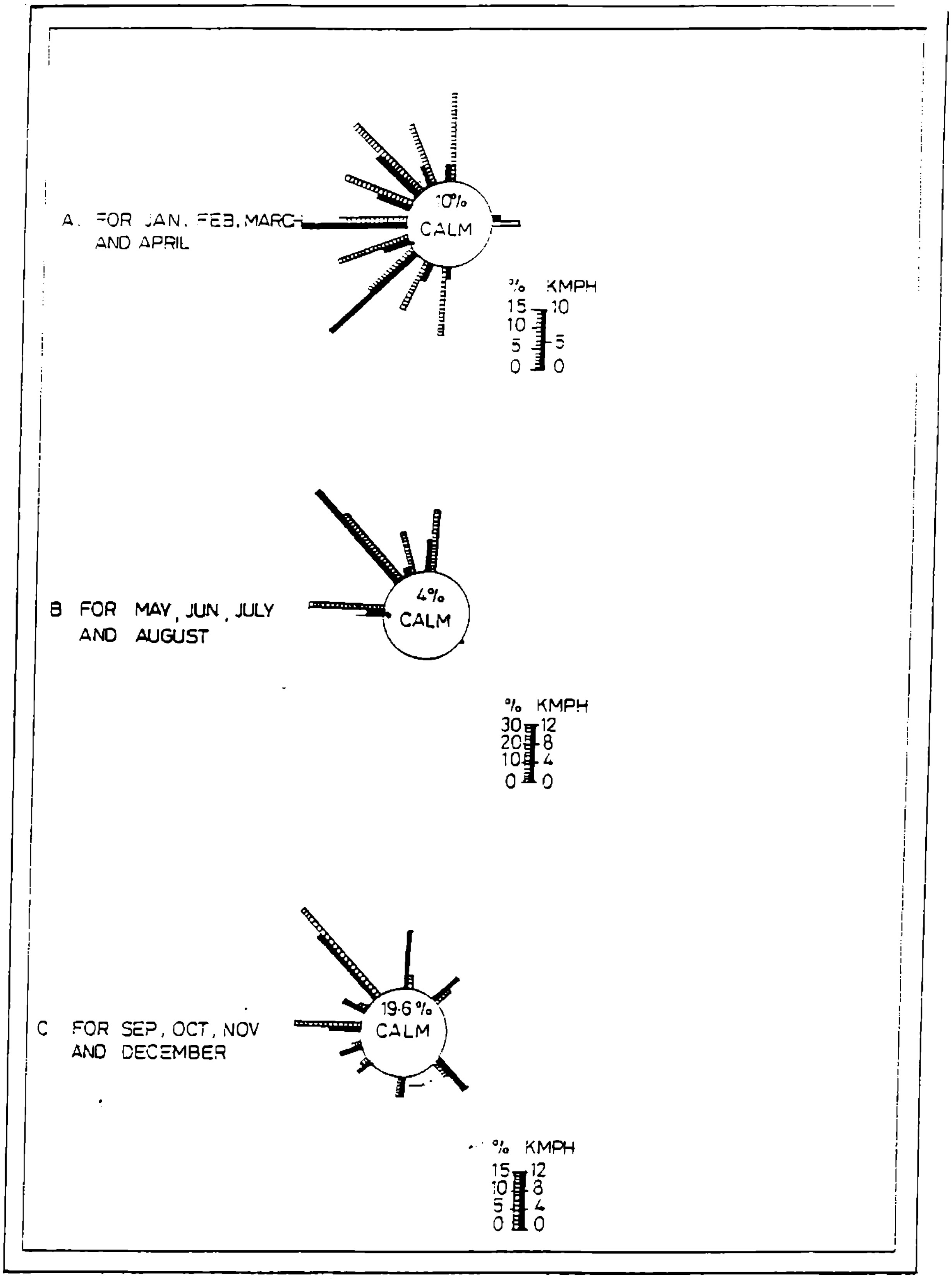


Fig. 1.4. Wind Rose for Trivandrum for different seasons

I.5. FIELD OBSERVATION AND SAMPLE COLLECTION

In the shelf, sample collection was done in the innershelf along 15 shore perpendicular profiles (1 to 15) at an approximate spacing of 3 to 5 km. and extending up to 50 m. depth. Echosounding was executed along 7 tracks. A 40 feet fishing trawler equipped with mechanised winches and davit was used for this purpose. The survey boat was steered along the pre-determined survey tracks. Sextant angles of shore based objects were taken at every ten minutes and plotted on the boat itself to fix the position of vessel. Hence, course of the boat could be corrected to ensure minimum deviation from pre-planned tracks. However, this procedure could be followed only upto the point of good visibility and thereafter, *dead reckoning* was adopted. On a clear day visibility was found to be good up to 10 km. offshore. Survey days were chosen when relatively gentle sea and wind conditions prevailed to allow running the inshore track lines as close to shore as possible. The inshore track lines reached approximately 10 m. isobath along sandy beaches but was forced to terminate at greater depths off the headlands of Kovalam and Vizhinjam. On each of 15 profiles 5 to 6 (A to E or F) sampling stations were occupied. A total of 75 sampling stations were occupied in water depth ranging from 10 to 60 m. At each stations water depth was measured by lead-line. A stainless steel Pattersson grab with 0.5 m^3 capacity was used to collect surficial sediment sample and were preserved in polythene bottles. On 7 of 15 profiles bathymetric survey with a continuous recording echosounder (SIMRAD'S skipper' with 200 Khz frequency) was carried out. As the continuous echosounding doesn't permit halts for sampling, theses profiles were ran separately. Of the seven tracks, echoprofiles for four tracks are given in Fig. 1.5. Tidal correction was applied to the recorded values. Time lag and range ratio with reference to Cochin tidal datum were found from the cotidal chart of survey of India. The position of echoprofiles and sampling stations are given in the Fig.1.5.

In order to understand the behaviour of beach dynamics, the study area was systematically monitored during the pre and post SW monsoon of 1987 (Fig.2.1). In addition, the movement of beach sand in the surf zone and beach face were also monitored by using florescent tracer technique. This experiment was carried out at 3 beaches of different geomorphological settings around Kovalam (Fig. 2.1). Procedures of the beach monitoring and tracer study are detailed in the succeeding chapter.

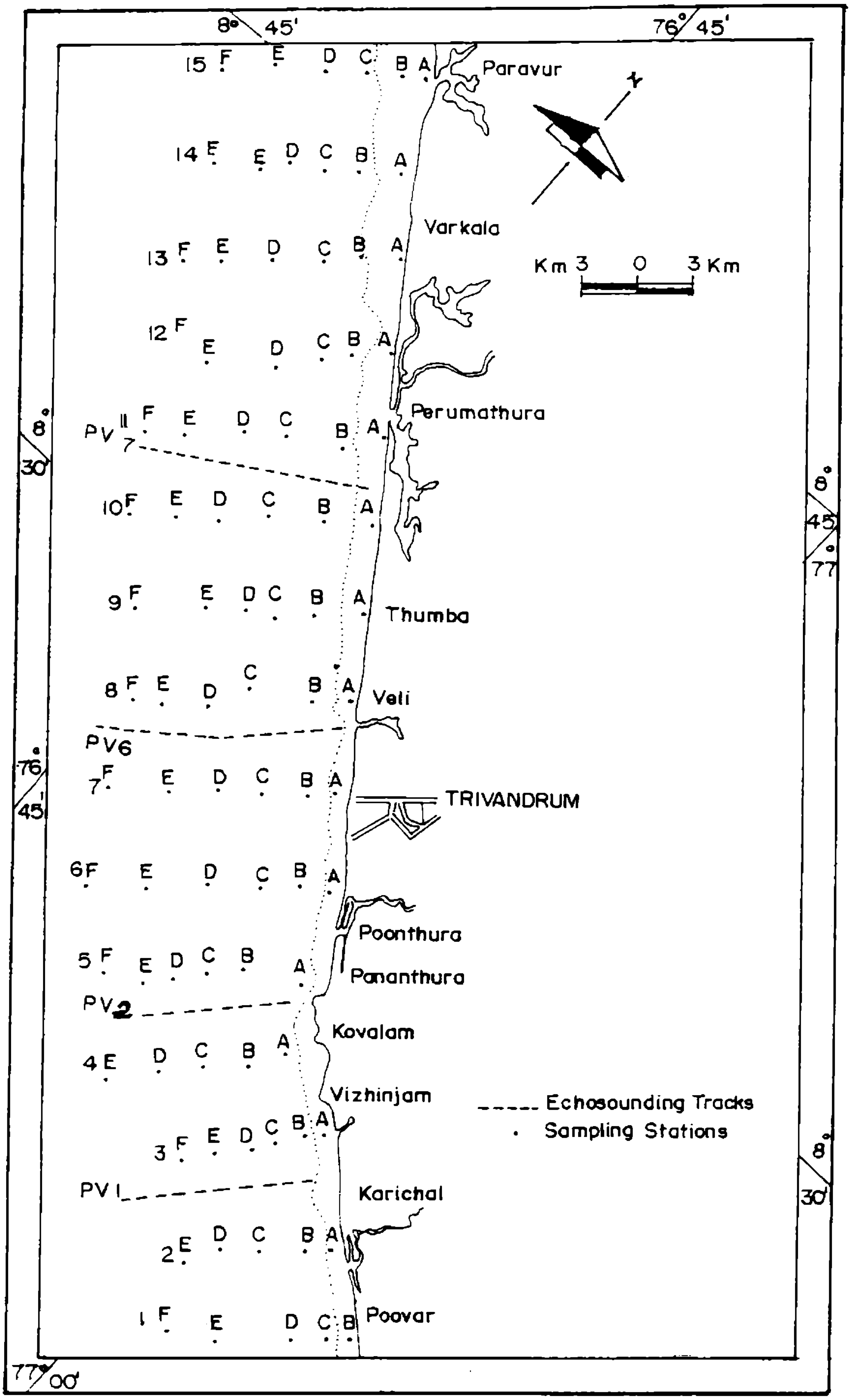


Fig. 1.5. Location of sampling stations&echo-profiles

CHAPTER - II

GEOMORPHOMETRY

II.1. INTRODUCTION

The coast bordering the study area is a "microcosm" of coastal geomorphological features usually seen in the state of Kerala such as cliffed shoreline, barrier beaches and beaches backed by strand plains. The shore line in the northern and southern ends of the study area are cliffed with pocket beaches whereas the middle part is a combination of strand plains and barrier beaches. The lower reaches of the river Neyyar forms a backwater system near Poovar. Backwater systems are also exist near Panathura and Perumathura where the rivers Karamana and Vamanapuram join the sea respectively. These Backwaters extend parallel to the shore for about 2 to 4 km. The shoreline on the seaward side of these backwaters are remarkably straight. Ahmed (1972) suggests the following succession of events as the main cause for the amazingly straightness of the shoreline of Kerala; i) during the Holocene transgression the irregular terrain at the lower reaches of the rivers underwent submergence which resulted in a "Ria" like shoreline with cliff sections and ii) subsequently accumulation of sediments in the submerged area causing the migration of depocenter. This migrating depocenter was a function of relative sea level rise which resulted in straightening of the shoreline by the growth of bars and spits on the seaward side.

There are a few cliff sections of Cenozoic sediments at Varkala and Karichal. The upper most part of this Tertiary formation is generally lateritised. A prominent promontory configuration is conspicuous at Kovalam, which shelters a fishing harbour at Vizhinjam. North of this point a stretch of strand plain with ridge-runnel topography is so prominent around Shangumugam - Veli area (Trivandrum coast). This topography extends northward up to Perumathura outlet. These strand lines could be related to periodic excursion of the sea due to transgression and regression episodes in the recent past. Further north the Vamanapuram river joins the sea through the Anjengo - Paravur backwater system. All these Backwater systems are connected to the sea through seasonal outlets and separated from the sea by a narrow barrier beach.

Considering the complexity in the physiography, a multi faceted inference, using the beach profile changes, wave refraction, tracer experiments and innershelf morphometry was attempted to understand the sedimentation processes active in this region. Sediment transport dynamics in surf zone can be categorized into two viz., (i) longshore and (ii) onshore - offshore components. It is generally believed, that the longshore component controls relatively the long - term change of profiles whereas the onshore - offshore component influences the short term profile changes that usually accompanies severe monsoonal wave climate. The onshore - offshore shifts of sand in the surf zone play a very important role in shoreline migration. Therefore, in order to get a better understanding of the process - response mechanisms operative on beaches seasonal fluctuation of beach profiles were studied. In other words, beach profile has a great bearing on coastal processes especially on littoral sediment transport.

Earlier studies in the vicinity of this stretch of beach include that of

Kerala Engineering Research Institute (1972), National Institute of Oceanography (1977), Swamy et al. (1979), Murthy and Varadachari (1980), Varma et al. (1981) Baba et al. (1982), Machado (1985), Thomas and Baba (1986) and Thomas (1988). All these studies have indicted that the onshore-offshore motion of sediments has been the dominant force that controls beach morphodynamics in this stretch. In addition, an equilibrium condition has also been attributed. However, systematic long-term monitoring of beach profile changes along with wave, current and wind parameters is non existent. Dattatri and Ramesh (1972) and Short and Hesp (1982) have studied the relationship between sediment dynamics and other environmental factors using laboratory and numerical controls. With this background in mind, an integrated study with periodic monitoring of parameters like wind, wave, current and beach morphometry of the study area was undertaken for a better understanding of textural and mineral distribution trend in the surf zone.

Fluorescent tracers and radioactive tracers have been widely used to decipher the sediment movement direction in the beaches and offshore zones. The concept of tracer experiment was developed for systems with finite area, and assumes steady transport rate and complete mixing in the direction of transport. Considering the rise and fall of astronomic tidies, waxing and waning of sea state, variations in littoral drift velocity and the onshore and offshore sediment movement, successful application of tracer study in the littoral zone seems to be fraught with problems mainly due to single experiment conducted only on a day at a particular time. In order to minimise these constrains, a "Legranian" (or experiment with spatial integration) tracer experiment was designed and conducted as recommended by Ingle (1966). The practical application of fluorescent tracers to major coastal sedimentation problems have been reviewed by a number of workers elsewhere (Seibold, 1963; Yarso, 1966; Teleki, 1966; Ingle, 1966; Brunn and Taney, 1967; Brunn, 1970; Clifton et al., 1971; Lees, 1981; Sherman et. al.,1990). Using this technique a number tracer studies have been carried out in different ports in India (Siddique and Shrivastava, 1970; Shrivastava, 1975; Shrivastava and Rao, 1976; Ray and Venkatesh, 1975; Ray et al., 1975; Venkatesh, 1973; Baba et al. 1983; Machado and Baba, 1984). However, in all these cases tracer technique was used to determine the transport direction at a particular time of a day based on one experiment. But, in this study, tracer experiments were carried out at a location for couple of times in a year, to cover the different hydrodynamic and climatic conditions.

When waves approach a shoreline at an angle, they bend at various parts of the wave front and propagate with different velocities. This bending of the wave is known as "wave refraction". In addition to the normal changes in velocity, height and length, they also undergo "refraction", i.e. they swing around and tend to conform to the bottom contour. Wave refraction, coupled with shoaling determines the wave height at a particular water depth for a given set of incident deep water wave conditions. Nevertheless, the energy distribution varies according to the spacing of the wave rays. Therefore, in order to understand the energy dispersal on the beach, wave refraction diagrams were constructed for selected strip of the study area for the dominant SW monsoon and fair weather season waves.

II.2.METHODS

II.2.1. Morphometrics of Beaches

Considering the complexity of the coastal geomorphology in the southern half of the study area beach stretch between Poovar and Veli were monitored intensively by taking profile at every km. (ie. stations 1 to 35 in Fig. 2.1). As the beaches north of Veli are straight and monotonous only selected stations at every 5 km. interval were monitored (ie. stations 36 to 73). To cover all the seasons this observation was carried out once in a month, throughout a calendar year of 1987. Beach profiles were recorded by using a dumpy level and measuring staff. Level measurements were taken at an interval of 5m. along a profile line perpendicular to beach orientation. Visual observation of breaker height, wave period and wave orientation were also done during beach profiling. Littoral drift velocity was measured in the zone immediately landward of breakers. A plastic bottle of suitable buoyancy was cast into surf zone. The point of casting was marked and distance travelled along shore by the bottle in 60 seconds was measured. Wave orientations were measured using a Brunton's Compass. The acute angle between the breaker and the coast was measured as breaker angle. A "+" sign was given for those breakers of waves approaching from southwest or west and "-" sign was given for the breakers of waves approaching from northwest. The littoral current velocity were converted to centimetre per second and plotted on a graph (Fig. 2.2). While plotting appropriate sign was given according to the direction of movement (Towards north "+" and towards south "-"). Although, these

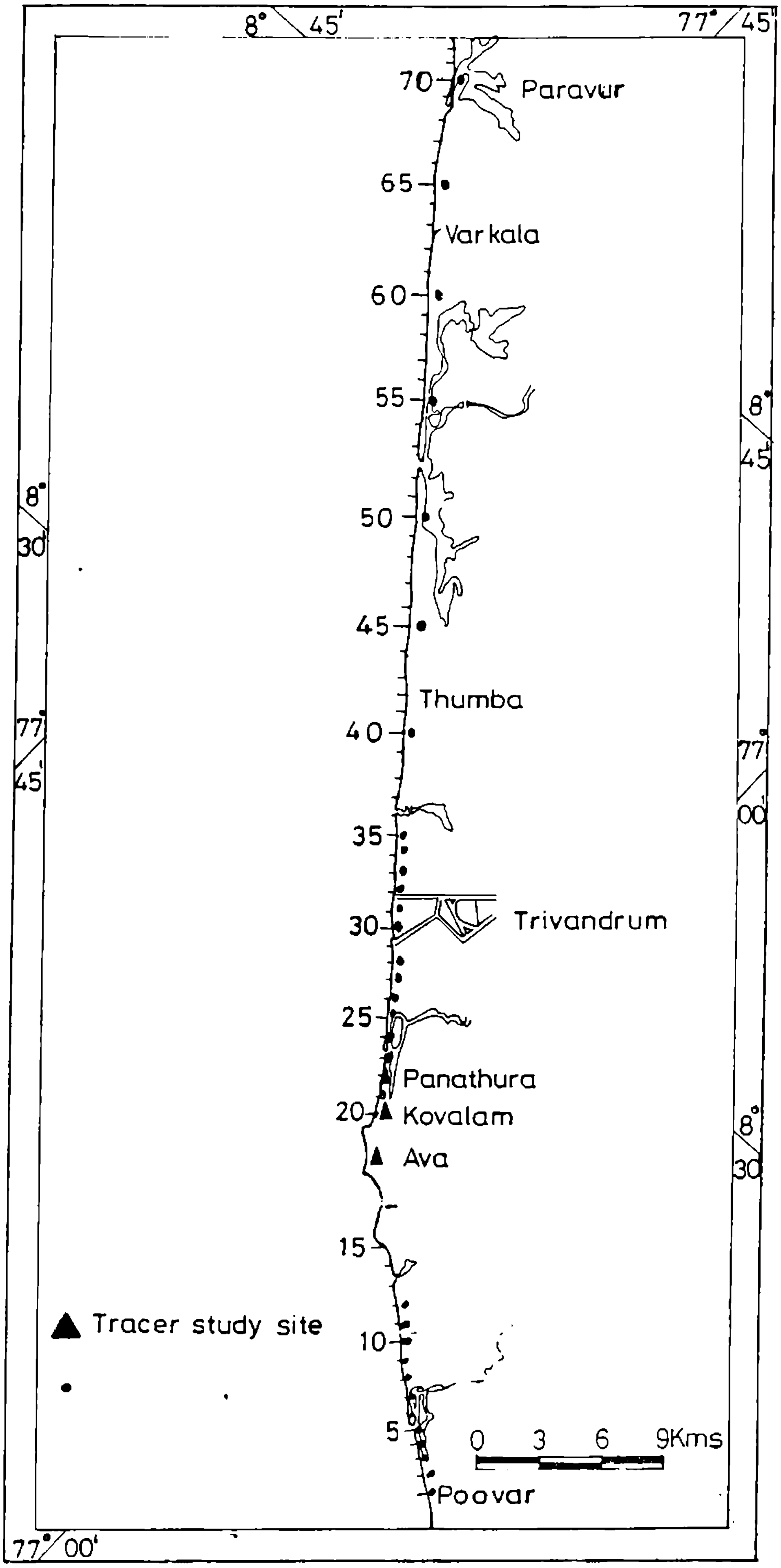


Fig. 2.1. Location of beach profiling stations & tracer study sites

observations were made in the southern half of the study area only, beach sediment samples were collected at every Km. stations from Poovar to Paravur (Fig. 2.1)

II.2.2. Beach Sediment Transport study Using Fluorescent Tracers

Locations of Tracer Study

The analysis of beach profiles of this study has indicated that the beaches around Kovalam are the most fragile and mobile ones. So, to understand the general sand mobility of beach around the Kovalam promontory three sites were chosen on the basis of geomorphic variability. Each of these beaches represented a different geomorphic setting as well as foreshore characteristics including grain size, beach slope wave incidence, current pattern etc., The selected sites were, i).Panathura barrier beach which is well exposed to severe monsoonal wave activity, ii) Kovalam beach (a semi protected beach) and iii). Ava beach a well protected pocket beach situated between the Kovalam and Vizhinjam promontories (Fig. 2.1).

Procedure for Florescent tracer technique

The author has followed procedure recommended by Ingle (1966) for the highly dynamic littoral conditions prevailed in this study area . Number of trials with different proportions of commercially available Rhodamine-B dye, Indian

Chemical Industries' Nicol clear varnish and thinner were made, and it was found that a mixture of 5 g of Rhodamine-B, 500 ml of Varnish and 500 ml of thinner was the most suitable for dying 10 kg of dried medium grained sand. This proportion was found to be good as it gave a very bright fluorescence under the ultra violet lamp. For each of the test approximately 20 kg of sand was collected from the test site, washed and dried. The dried sand was then dyed with an appropriate proportion of dye mixture as said earlier and sun dried. Moderate pestling was done to disperse the lumps. An amount of 10-15 kg of dyed sand was released at each test site.

Considering the highly dynamic nature and steepness of Panathura beach, a rapid sampling procedure using two rectangular sampling boxes of uniform volume and area were employed. The collected samples were sun dried and counted using a hand tally counter under ultra violet lamp. The number of fluorescent grains per square centimetre were corrected (increased or decreased) to represent tracer concentration at an arbitrarily selected standard elapsed time (Ingle, 1966). This was done by applying the following formula:

$$\frac{Ts}{Ta} * Ga = Ge$$

where Ts = arbitrarily chosen standard lapse time

Ta = lapse time at the moment of sample collection

Ga = absolute concentration

Ge = corrected concentration

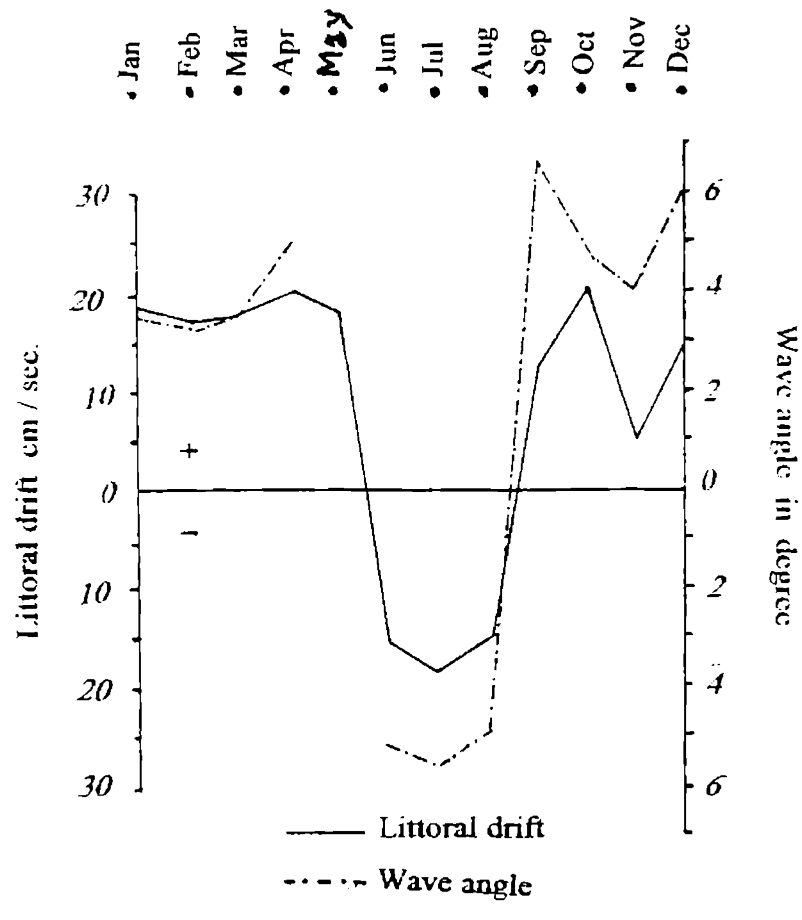


Fig. 2.2. Annual variation in breaker angel and littoral drift

Corrected tracer concentration values were plotted at their respective sample points and contoured with isolines connecting equal concentration points. Breaker height, wave period, littoral current and beach slope were measured during every tracer experiments. Breaker height was observed visually. Wave period was measured as the time required in seconds for two successive crests to pass an imaginary point. An average was found after 11 successive observations. Littoral current velocities were measured in the zone immediately landward of the breakers as described in the previous chapter. Beach slope was measured using a brunton compass.

"*Depletion rate*" was calculated for each of the experiment as recommended by Ingle (1966) and mentioned in the respective tracer distribution diagrams. Depletion rate is the rate of movement of sand removed from the grid per unit time. In order to determine this, approximate number of grains released and recovered was calculated as described below. Number of tracer grains in one gram of tracer sand was counted for thrice and the average was used to calculate the total number of grains released. After counting the number of tracer grains present within each isopleth area, total concentration was calculated. The area of overlying isopleth was subtracted from the underlying zone. The resulting area was multiplied by the value of the isopleth. In this manner number of recoverable grains was calculated. Subtracting the calculated number of tracer grains remaining in the sample grid from the total number of grains released and dividing by the lapse time, the number of grains removed from the sampling grid in unit time was calculated. The result was converted to kg min^{-1} and expressed as depletion rate.

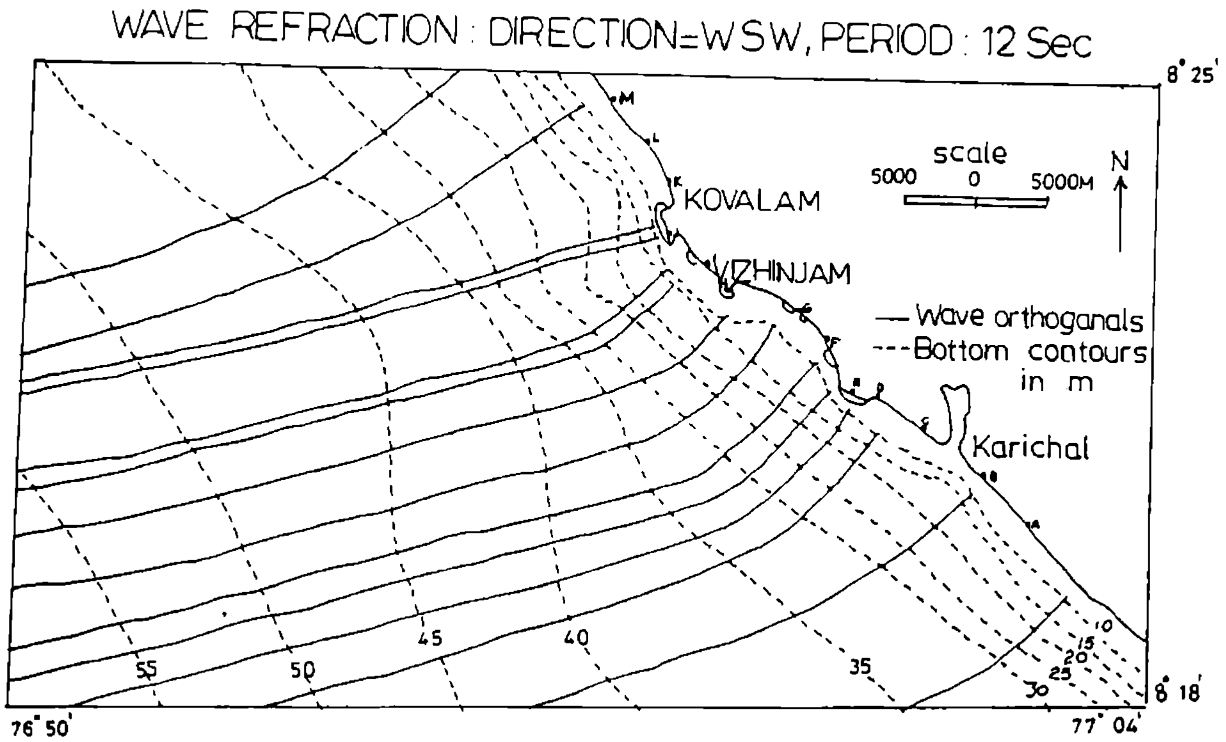


Fig. 2.3. Refraction pattern of waves during fair weather season

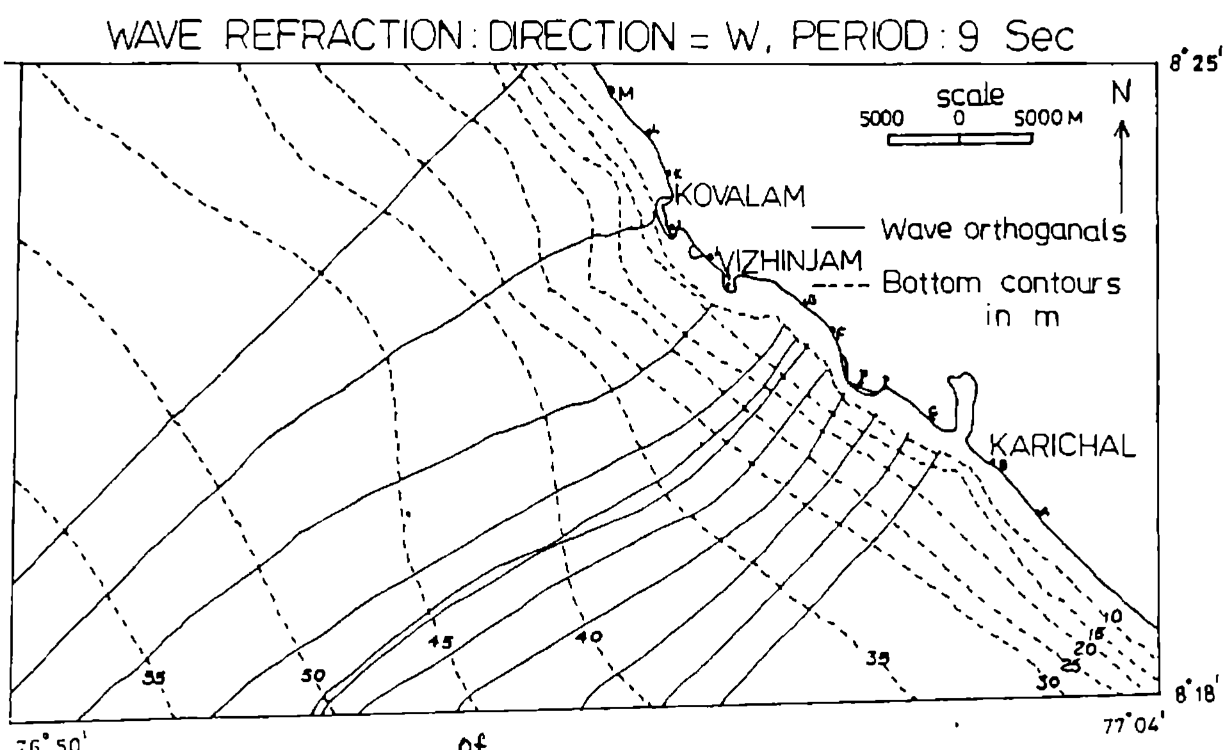


Fig. 2.4. Refraction pattern of waves during SW monsoon season

II.2.3.Wave Refraction Studies

Since beach profiling could not be carried out in pocket beaches around Kovalam, wave refraction diagrams were constructed for the dominant wave conditions prevailing in this area, to understand the distribution of wave energy and concentration on these pocket beaches. Wave rays were constructed for the 9 sec waves approaching from West (Fig2.4) and 12 sec waves from west-southwest (Fig.2.3). These waves were selected because they are the dominant waves during monsoon and fair weather seasons respectively (Thomas 1988). The spacing of wave rays were constructed according to the method of Arthur et al. (1952).

II.3.RESULTS

Beach Profiles

The coastal strip between profile stations # 1 to 10 is backed by coastal plain and agricultural land of low relief on the eastern side. The coastal plain between Kovalam and Vizhinjam is intercepted by the rocky headlands. But prominent barrier beach is seen on the north of Kovalam promontory (Fig.2.5). This barrier beach ranges in width from 50 to 100 m. Further north from Profile stations # 24 to 73 is a long stretch of sandy beach backed by a strand plain of varying width except two outlets at Perumathura and Paravur. A typical beach profile of this section is shown in Fig. 2.6.

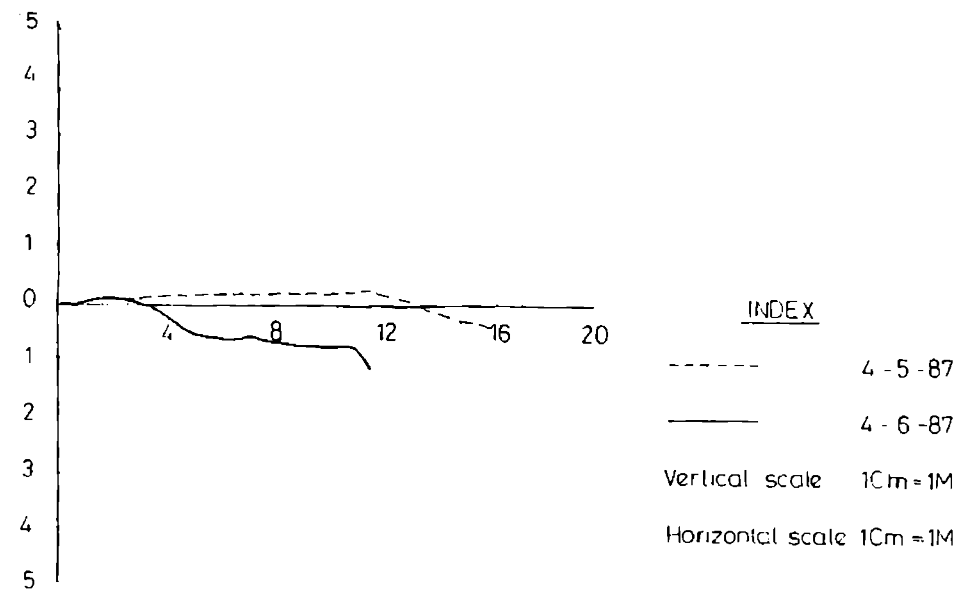


Fig. 2.5. **Beach profile at Panathura (Prof. # 22)**

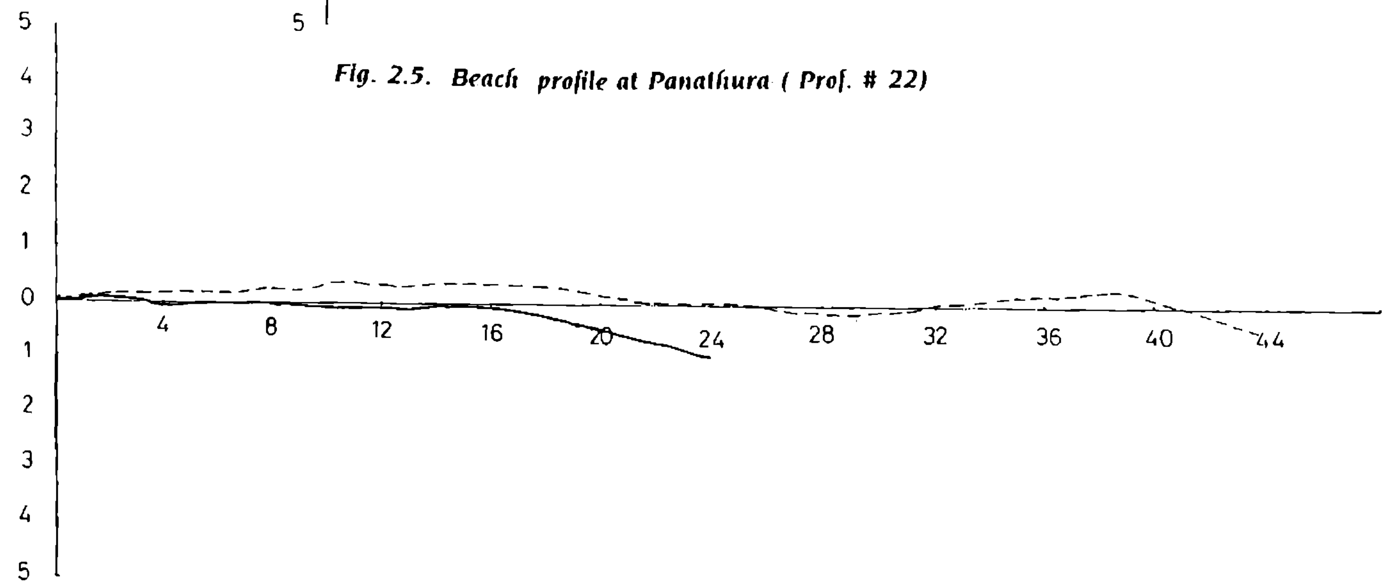


Fig. 2.6. **Beach profile at Perumathura (Prof. # 50)**

The monsoonal beach profiles were superimposed on the post monsoonal profiles and the volume of sand removed from each profile stations were calculated and presented in the Table 2.1.

Table 2.1 Sand lost during the Monsoon of '87 at different profiling stations in cubic meter per meter length of beach

Section A		*Section B*		Section - C		Section - D	
Profl. No.	Sand Removd	Profl. No.	Sand Removd	Profl. No.	Sand Removd	Profl. No.	Sand removed
1 -	65	20 -	112	25 -	42	40 -	57
2 -	76	21 -	65	26 -	28	45 -	66
3 -	62	22 -	52	27 -	84	50 -	70
4 -	88	23 -	98	28 -	48	55 -	75
5 -	75	24 -	62	29 -	95	60 -	45
6 -	40			30 -	70	65 -	51
7 -	65			31 -	88	70 -	55
8 -	13			32 -	66		
9 -	34			33 -	65		
10 -	50			34 -	66		
11 -	42			35 -	36		
12 -	33						

Profiles stations between #13 and #19 were not monitored because of their inaccessibility of being pocket beach in nature. The rest of the beaches were categorised into four sections namely A, B, C and D (Table 2.1) based on the nature of the backshore geomorphology and profiling intensity. The backshore terrain of section A (Profile 1 to 12) has a high backshore relief and is made of impermeable laterites, section B (Profiles 20 to 24) is a barrier beach backed by the backwater system of Karamana estuary, section C (Profile 25-35) is a permeable backshore with a low relief (eg. Shangumuham beach Trivandrum) and section D ie. the beach stretch north of Veli has a similar characteristic feature as that of section B and C, The average sand loss during monsoon form each of the section is as follows:

Section - A -- 53.58 m^3/m

Section - B -- 77.80 m^3/m

Section - C -- 62.50 m^3/m

Section - D - 59.80 m^3/m

The visual wave data collected during beach profiling were categorised into three groups namely pre monsoon, monsoon and post monsoon and presented in the following tables.

Table 2.2 Seasonal distribution of the percentage of frequency of occurrence of wave height and period in the study area for different seasons

A) PRE MONSOON

Wave height		0.5	1.0	1.5	2.0	2.5	3.0	3.5
P								
e	6	1.43						
r	7	1.43						
i	8	1.43						
o	9	1.43	10.71					
d	10	1.43	25.00	2.86				
	11	2.41						
sec.	12	10.71	4.29					
	13	2.41						
	14	2.14						

B) Monsoon

Wave height		0.5	1.0	1.5	2.0	2.5	3.0	3.5
P								
e	6							
r	7							
i	8	0.72	0.72	1.13				
o	9	1.45	2.90	5.56	2.90	2.90		
d	10	2.17	5.80	16.67	11.59	6.07	2.17	
Sec.	11				1.40	1.45		
	12	0.70	2.17	5.80	7.25	5.80	2.90	1.45
	13		0.36	2.17	1.45	1.45		
	14				1.45	1.45		

C) POST MONSOON

Wave height / Period Sec.	0.5	1.0	1.5	2.0	2.5	3.0	3.5
6							
7							
8	2.17						
9	1.45						
10		13.04	11.06				
11		1.45					
12	12.32	26.09	4.35				
13		7.79	6.52				
14		0.72	10.14	2.90			

II.4. DISCUSSION

Two major phases, viz., the erosional phase during monsoon (May-August) and an accretionary phase during post monsoon (September -April) are common along the SW coast of India. Between these two also there occurs a phase of lesser erosion during NE monsoon. These two major phases are discussed separately.

Erosional Phase of SW monsoon

At the onset of SW monsoon the beaches are in a fully developed state with one or more well defined berms. The monsoonal air circulation results in increased wind velocity. This wind generated `seas' travel shoreward where they collide with swells from SW resulting in a complex near shore wave climate with inconsistent wave orientation but consistent increase in wave heights (Table 2.2). Vollbrecht (1966) suggests that such condition would induce movement of sediment offshore rather than alongshore. Moreover, to initiate grain movement for sediment size with a mean size range from 1.5 - 2.0ϕ, the required threshold velocity of current is in the order of 18 to 24 cm sec^{-1}. The measured monsoonal littoral drift velocity for the study area also have the same theoretical range ie. between 15 and 24 cm sec^{-1} (Fig. 2.2). Hence, it implies that the sand grains might set in motion by the littoral currents, but the steeper and taller monsoonal waves and the steeper shoreface slope tend to propel the sediments to offshore rather than alongshore. Komar (1976) has shown that such situation would result in the formation of break-point bar. Such a bar with a runnel on the shoreward side is manifested throughout the study area. In this process the waves perform a gravity sorting as well by moving the light minerals to the break point bar and leaving the heavier black sand in the beach face. The sudden increase in black sand concentration on the beaches around Kovalam during monsoon months as reported in one of the chapter (Chapter IV) of this thesis could also be related to this phenomenon. This situation results in severe beach erosion and formation of typical storm profiles at Panathura and Kovalam as shown in Fig. 2.5.

The large difference in sediment loss by erosion between the four sections is mainly controlled by the lithology and the backshore characteristics. For example, the barrier spit between Kovalam and Karamana river mouth (section B) is composed of coarser sediments (M_z = 1.00 to 1.5 ϕ) than the other three. Such a coarse grained permeable beach with standing water body on the landward side creates an ideal situation for severe erosion (Vollbrecht 1966). Higher mean sea level due to the "seiche" and steeper waves during monsoon causes overwash on this barrier beach. The profiles recorded on this beach during monsoonal and the post monsoonal months corroborates with the concepts of reflective and dissipative beaches respectively as described by Short (1978).

Beaches between Poovar and Kovalam (Section A) is backed by lateritic cliffs and composed of medium sand. Sand lost from this section is comparatively less. This could be due to the fact that the Kovalam promontory and the Vizhinjam fishing harbour protect this section from the monsoonal waves and the littoral drift.

Similarly, in section C (Profile # 25 to 35) the sand loss is moderate (average: 62.50 m^3/m). This particular section may probably be reflect the general beach processes operative in this region. With the onset of SW monsoon the wave height increases, the wave period decreases and consequently the wave steepness increases. This situation causes drastic beach erosion leading to changes in the morphometry of the beaches. The berm crest shifts landward as the beach erodes. About 45 to 60 m of the backshore is eroded and the eroded sediment spreads over the beach face resulting in less steeper beach face / swash zone. Further erosion of sand from beach face leads to the formation of a bar. This bar appears to be ubiquitous in the study area and resembles the break point bar as described by King (1970) and Komar (1976). Section D also shows a similar erosional characteristic as that of section C with an average sand removal of 59.80 m^3/m. In spite of the presence of two backwater systems in this stretch the erosion is moderate probably due to the wider beaches and low backshore relief.

The littoral drift during SW monsoon was towards south which is opposite to the NW monsoon currents. A change in breaker angle (Fig 2.2) is attributed to change in wind direction. During October, the average current velocity reaches + 20 cm/sec. which is roughly equal to SW monsoonal drift (-20 cm/sec). However, the sand mobilisation capacity of NE monsoonal littoral drift is less dominant due to less steep dissipative beach face and the shoreward migration of break point bar.

Accretionary phase

By September the beach starts receiving long period low waves (Table 2.2). As stated earlier these waves have tendency to move the break point bar towards shore. Between stations 8 and 10 as well as between 32 and 73 (Fig. 1.4) ephemeral secondary bars have formed. This was found to be welded to swash bar in a week or so as observed elsewhere (King, 1980). As this process continue the inciting NE monsoon intervenes, and hence, wave and wind forces become inconsistent and giving rise to very complex surf zone dynamics.

An interesting feature noticed during NE monsoon is the sinuosity in shoreline in the form of giant cusps. It was very prominent between station # 31 and 73 and less prominent between station # 5 and 8. These giant cusps have a horn to horn distance of approximately 75 m with a 1 m deep steep cut at trough (Plate.). Shepard (1952) calls it as "giant cusp". Goldsmith and Colonell (1970) and Komar (1971) related this to the alongshore variation in wave energy. The shoreward moving break point bar (ephemeral sand bar) was found to be closer to the horns than troughs of these giant cusps. The tendency of the long period swells of the NE monsoon is to move the sediments shoreward and weld the break point bar with the shore. Therefore, the waves break on the beach face hence the surf zone shrinks almost to zero. This process results in accretion of beaches with a dominant berm and berm crest. This accretionary trend lasts up to April or May i.e., till the onset of succeeding SW monsoon. Similar cyclic process of sedimentation have also been reported earlier by Murthy and Varadachari (1980), Thomas and Baba (1986) and Thomas (1988) in this region.

From the above discussion it is concluded that the stretch of beach between Profile # 1 to 12 and Profile #-20 to -24 behaves similarly probably due to the similarity in the backshore characteristics. However, this study indicates that the erosional intensity differs depending on the backshore characteristics.

Tracer Experiments

The details regarding tracer experiments such as date, time of tracer release, time of sample collection, direction of net transport, depletion rate etc.,at different test sites are shown in Figs 2.7 to 2.9.

A) Panathura beach:

This beach is situated 2 km north of Kovalam headland. This barrier beach was selected for tracer study in order to understand the effect of the barrier beach as geomorphic control on the tracer mobility. Two experiments were carried out in the beach in August, 1983 and August,1984 and result are presented in the Figs. 2.7 a & 2.7 b .

A rectangular distribution pattern is observed surrounding the tracer release point for the 1983 experiment. Area covered by more than 400 as well as between 200 and 20 contours show more or less similar pattern but a tendency for seaward extension from the central portion is indicated. Major portion of the area is covered with less than 20 contours. From the distribution map it is deduced that the major transport directions are towards 300° and 339.5°. The former direction indicates that the shoreward component is stronger than the seaward component. The 339.5° component implies a northward tendency of transport that coincides with the prevailing littoral drift direction.

The August '84 tracer distribution pattern (Fig. 2.7 b) shows a central concentration with rectangular distribution of the tracers around the dump site. Ingle and Gorseline (1973) explains that such a pattern would result when the offshore-onshore movement is more dominant than the lateral movement. The maximum contour (300) is just around the release point. The area covered by

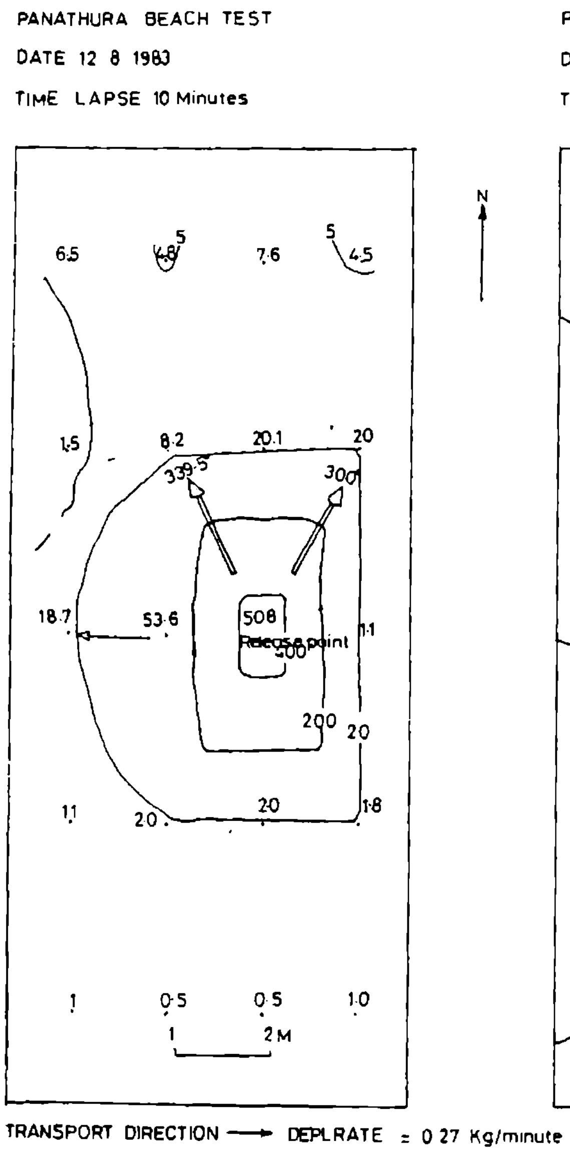


Fig. 2.7a. Tracer distribution map at Panathura

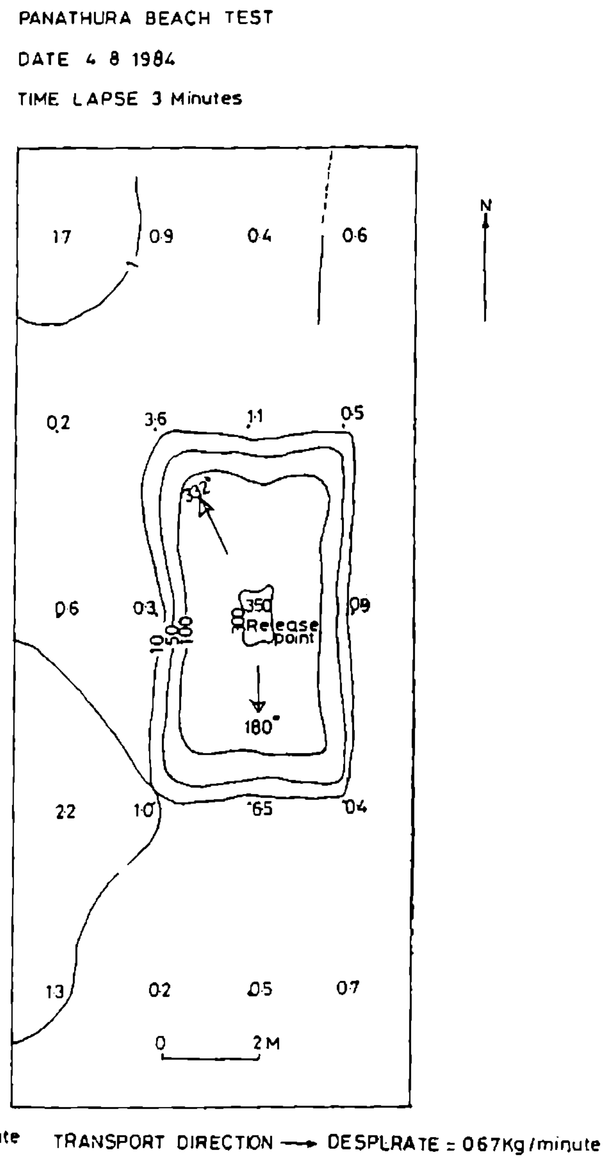


Fig. 2.7b. Tracer distribution map at Panathura

<100 contour is wide. The distribution of 10 and 100 contours form a narrow rectangular band encircling the release point. The tracer distribution map reveals that the predominant transport direction is towards 332°. However, secondary transport directions towards south and SE are also indicated by rectangular distribution pattern.

The above two tests at Panathura indicate that the onshore-offshore transport of sediment is the dominant component. In a barred shoreline like Panathura, major parameters which influence the onshore-offshore sand movement are the breaker character, wave period, wave height, incidence angle of wave, long shore drift and beach slope. The steep foreshore (10°) at Panathura and the availability of sand in the break point bar along with weak littoral drift (13 cm/sec) facilitate an onshore-offshore movement.

B) Kovalam beach

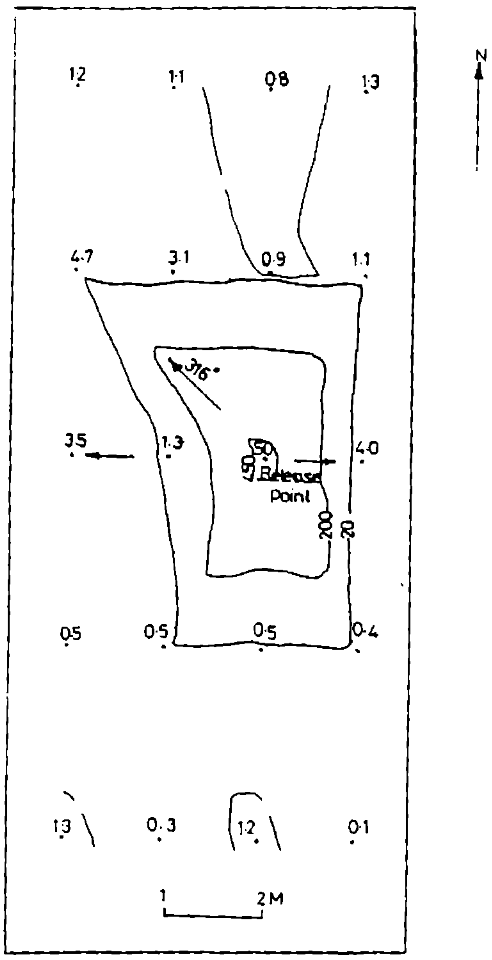
The distribution map of August '83 indicates a central spread and there is a NW extension of contours (Fig. 2.8 a). The areas covered by 200-450 contour as well as 20-200 contours extend toward NW direction. However , major portion of the area consists of <20% concentration; a small patch of less than 1% concentration exists in the northern end of the grid. From the map it is clear that major transport direction is towards 316°.

The February '84 test presents a discordant picture in which neither lateral nor onshore-offshore movement is predominant. A dominant transport direction towards 334° is indicated with a perpendicular secondary movement towards 214°. These directions indicate that the beach is in a state of equilibrium (Fig. 2.8b) .

KOVALAM BEACH TEST

DATE 12-8-1983

TIME LAPSE 30min



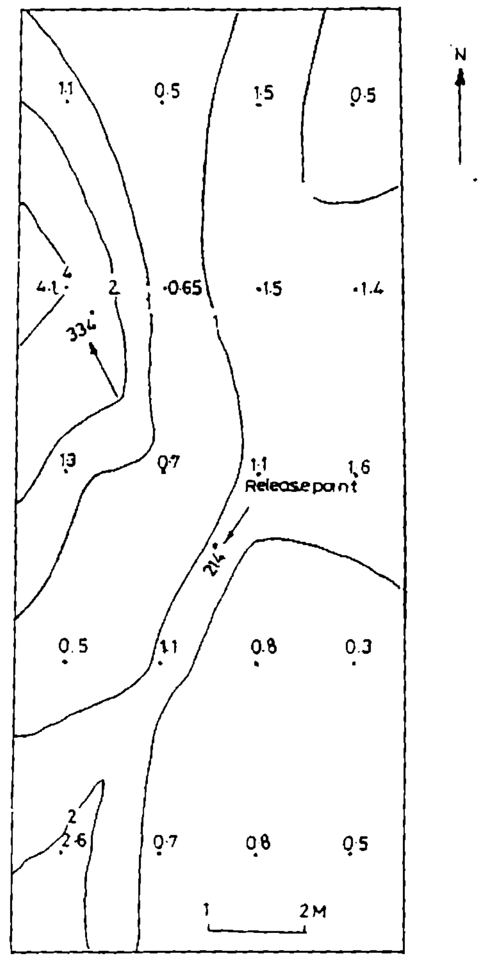
TRANSPORT DIRECTION ⟶ DEPLRATE 0 27Kg /min

Fig. 2.8a. Tracer distribution map at Kovalam

KOVALAM BEACH TEST

DATE 27-2-1984

TIME LAPSE 13min



TRANSPORT DIRECTION ⟶ DEPLRATE 0 136 Kg/min

Fig. 2.8b. Tracer distribution map at Kovalam

C) <u>Ava Beach</u>

From the August '93 test conducted at Ava beach (Fig.2.9a) it is clear that the >300 contour is entered around the dump site in a triangular fashion. There is a tendency of the grains to move shoreward. The 20, 100 and 200 contours show a NW tongue indicating major transport towards 320° The beach at Ava in August is of cuspate nature and the release point coincided with the trough of a cusp. Bowen and Inman (1969) suggest that cell circulation gives rise to cusp formation and it will not favour longshore entrainment of sediment. The tracer distribution pattern (Fig 2.9b) is clearly expressing a closed cell circulation with sand movement from trough to horn within a cusp. Low depletion is also substantiating the above observation.

The sampling points and distribution pattern for February '84 test are shown in Fig. 2.9b. The distribution map indicates a quadrangular spread of contours above 10. The 10 and 50 contours show tapering in the southeastern direction. The area covered between 1 and 10 extends towards north. The distribution patterns clearly indicates a major transport direction towards 155° and another subsidiary direction towards 183°. Though the breaker orientation is parallel to shore a feeble northerly component of littoral drift is observed. This component could be responsible for the movement of tracer in a NW direction as indicated by tracer distribution map.

Irrespective of wave direction in the open sea, the breaker orientation inside this bay (like pocket beach) has always been parallel to shore. In such condition sand movement will be entirely dependent on nearshore topography rather than the water dynamics(Longuet - Higgins and Perkin, 1962). The results of experiments at Ava beach indicate a topographically controlled sand movement because of shore parallel breakers and feeble littoral current. There were number

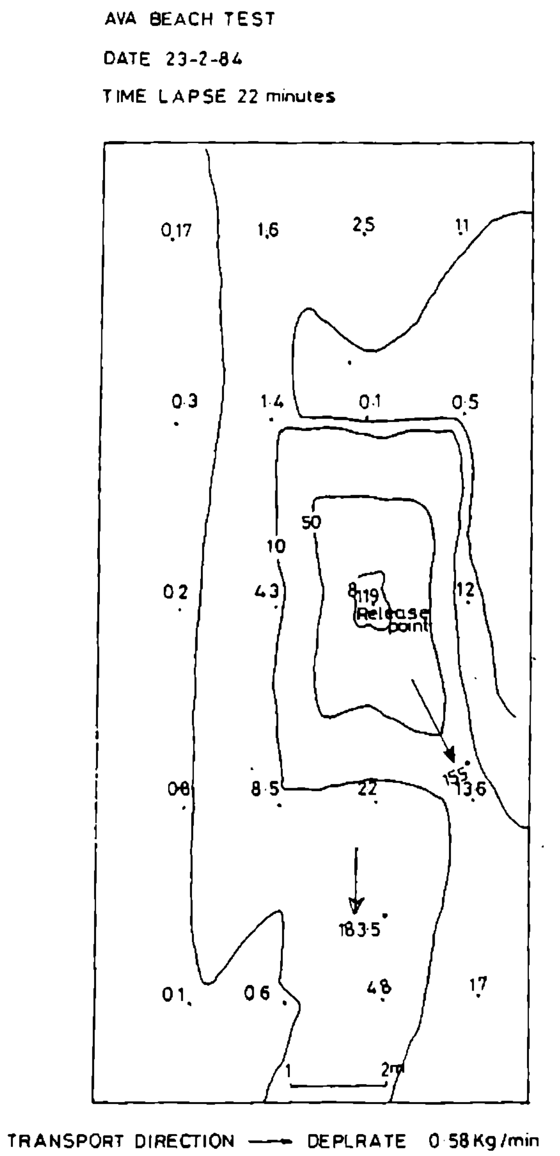


Fig. 2.9a. Tracer distribution map at Ava

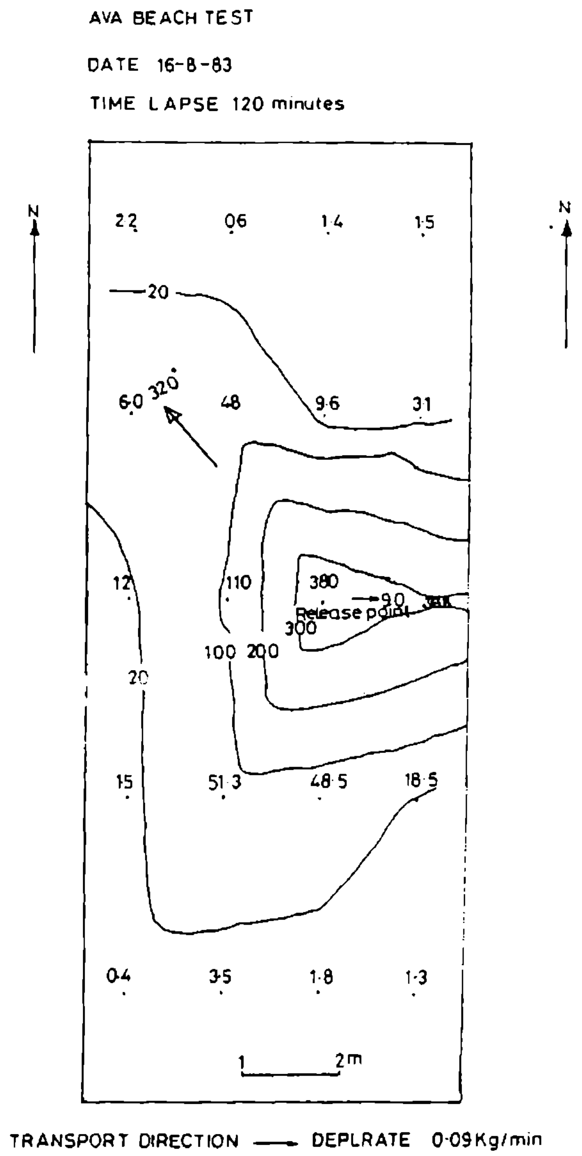


Fig. 2.9b. Tracer distribution map at Ava

of cusps with an approximate spacing of 5-6 m between horns. Silvester (1970) has conducted a series of tank experiments and concluded that when erosion on sandy beach between two headlands ceases, the resultant bay can be called as "matured" or "attained equilibrium". In this situation any incoming wave would diffract and refract between the headlands so that it would break simultaneously around the whole periphery of the bay. This implies that there would be no component of wave energy directed along shore to generate littoral drift and so no opportunity for entrainment of sediments.

In the present study the breaker orientations were invariably parallel to shore and the observed littoral drift was insignificant even under varying wave heights (0.5 m to 1.5 m). This could be intuitively attributed to the above finding of Silvester (1970). Hence, it is inferred that probability for the sand load from this pocket beach to bye-pass the Kovalam headland is almost negligible.

Wave Refraction Studies

From the wave it is inferred that closer the wave rays higher will be the energy concentration. It is found that the beaches north of Kovalam headland fall in the zone of divergence for both the monsoon and fair weather season waves whereas the beaches between Vizhinjam lighthouse and Karichal fall in the convergent zone indicating high energy concentration (Figs. 2.3 & 2.4)

From the above investigations it could be concluded that (i) southerly littoral drift during SW monsoon minimises the possibility of sand being carried over laterally northward from these beaches and (ii) In enclosed and semi enclosed beaches such as Ava and Kovalam, prevalence of rip current was observed. Such rip currents with adequate strength could entrain and move the sediment seaward. Sediments thus removed from beach could either get deposited in the near shore or reintroduced to the longshore current.

BATHYMETRY AND INNERSHELF MORPHOLOGY

Bathymetric survey of this innershelf reveals a generally featureless subtle morphology. However, a significant observation was a few and isolated shore parallel sand waves recorded in the seaward end of the profile PV2 off Kovalam at about 50 to 55 m (Fig:1.5 & Plate.1). These sandwaves were of approximately 500 m. wavelength with a height between crest and trough of about 5 m. On the sonographs these sand waves show asymmetry with the steep face directed landward. As far as is known, this type of sand wave is not reported earlier in the innershelf zone of the study area. Although such linear sand waves received attention elsewhere little is known about their origin, evolution and internal structure (Duane et al., 1972; Swift, 1975 Harris, 1989). Their presence off the Kovalam headland bears significance because their location coincides with the steepest innershelf section of the western continental shelf and these large scale bed forms may be the vehicles by which sediments escape to outershelf. The bottom processes that are responsible for the formation and possible migration of these feature remain to be understood. However such feature elsewhere (Morang and McMaster, 1980) were considered to be genetically related to very long period wave conditions. Similarly, Kurian and Ramachandran (1994) have studied the wave characteristics off Trivandrum and reports that the monsoonal waves off Trivandrum are capable of disturbing bottom sediments at 42 m depth. Hence, this feature could be directly related to the monsoonal wave action. The localised nature of the feature is evident from the fact that this feature is not recorded on any other profile. Other than the profile off Kovalam, rest of profiles were devoid of any observable feature indicating uniformity in "process-response" dominion. However, the echo-profile taken off Veli (PV-6, Plate:1) shows a minor terrace like feature recorded as topographic high at about 60 m. depth which may be representing a gradational platform constructed by the outbuilding sediment flushed out of the Vamanapuram river.

A remarkable difference in bathymetry between the hydrographic chart (Chart No. 222, 1971) and the present echosounding records is noticed. This discrepancy could be attributed to the SW monsoonal water dynamics and the geomorphic settings of the area (Machado and Vasudevan 1984). Another interesting observation is the variation in slope between the shallower and deeper portion of the innershelf. At about 30 m depth the slope appears to be suddenly flattens seaward (Table 2.3).

Table: 2.3 Slope difference between the shallower and deeper parts of innershelf.

Prof. No	Slope between 0 and 30m depth	Slope between 30 and 50m depth
PV 1	1:49	1:476
PV 2	1:65	1:301
PV 3	1:41	1:397
PV 6	1:80	1:460
PV 7	1:65	1:447
PV 8	1:94.5	1:377
PV 9	1:100	1:287

The difference in slope between the shallower and deeper portion of the innershelf seems to be more prominent in the profiles taken off and south of Kovalam promontory (the southern sector) and clearly manifested in the Plate. The lack of uniformity in slope between the shallower and deeper sectors suggests that the energy expenditure for slope modification is of different degree and mode. That is to say, the deeper areas (30 to 50 m) are quite beyond the reaches of near shore coastal current as suggested by Machado and Vasudevan (1984). Apart from the shore normal slope difference, variation in slope along the shore is also noticeable. The profiles taken in the section south of Veli are steeper than the northern ones. This difference is conspicuous in the echoprofiles presented in the plate:1; the profile PV-3 recorded off Kovalam is comparatively much steeper than the profile PV-7 recorded off Veli. Moreover, the echoprofiles taken on the southern sectors (PV-1 & 3) show higher signal attenuation zone as indicated by broader reflectance line, whereas the northern sector profiles (PV-6 & 7) indicate sharp line of reflectance (Plate 1). This difference in thickness of reflectance line could be indicating that the sea floor of southern sector is occupied by comparatively coarser sediment (which is a better a attenuator) than the northern sector.

Therefore, it is suggested that the study area can be divided into two major geomorphically controlled sectors. The *southern sector* is extending approximately from Poovar to Veli and the area north of it could be stated as *northern sector*. As would be seen in the next chapter, the sediments in these two sectors exhibited distinctly different sedimentological parameters.

CHAPTER - III

GRANULOMETRY

III.1. INTRODUCTION

Throughout the first half of the twentieth century, the discipline of sedimentology, as we now know it, lay moribund. Though the fundamental differences between the structure and texture of sedimentary basins have been brought to light by a structural geologist early as 1930 (Baily 1930), the idea of turbidity flow, which evolved in the late '50s and early '60s, is the one that has given the impetus to modern sedimentology. Another stimulus that rejuvenated the interest in sedimentology is the oil industry. In fact the first fruit of the multidisciplinary study on sedimentology has come from the study of modern sediments of the northwest Gulf of Mexico by Shepard et al., (1960). After this, several other investigations by Oil companies, Universities and Oceanographic Institutions have proved that there are, and have always been, many sedimentary environments which posses characteristic sedimentary facies. Therefore, by the end of the 1960s sedimentology has been firmly established as a discrete discipline of the earth sciences.

Size is perhaps the most striking property of detrital sediments. This has been well understood by the early workers and they have proposed several grade scales that divide sediments into a spectrum of size classes (Udden, 1914, Trask, 1930). However, the most widely accepted scale is that of Wentworth (1922), which has been later refined by Krumbein (1934). Krumbein (1934), while retaining the grade scales of Wentworth, converted the size boundaries into ϕ (Phi) values by a logarithmic transform using the formula:

$\phi = -Log_2 d$;

Where, d is the diameter.

Griffiths (1951) has proposed ϕ percentile deviation as a measure of dispersion which is more sensitive to fluctuation in the tails of the cumulative percentile curve. Followed by this, Inman (1952) computed the mean, median and sorting measure by using different percentiles. He too, has recognised that the error of observation associated with each percentile value increases towards the tail of the distribution.

Folk and Ward (1957) have made a significant contribution to the development of graphic measures by proposing unique formulae to calculate graphic mean, standard deviation, skewness and kurtosis. They have proposed the formulae based on seven percentiles (5th, 16th, 25th, 50th, 75th, 84th and 95th) derived from the cumulative probability curve. The most vital part of their contribution is the making of verbal scales for sorting, skewness, and kurtosis for comparison of sediments from different environments. Although, McCammon (1962) has proposed statistically significant formulae for mean and sorting, these formulae have failed to impress sedimentologists due to the cumbersome procedure involved in its computation. Friedman (1961, 1962, 1967) has introduced moment measures by determining the moments of each size class. He has also argued that the moment measures can be more effective than the graphic measures in delineating environments. However, his failure to induct a descriptive verbal scales for different parameters has made it difficult to relate sedimentary deposits in terms of their textural attributes.

The interpretation of depositional environment based on grain size measures has been, and still is, a fundamental goal of sedimentology. Nevertheless, a fool proof technique using textural parameters to interpret transportation processes and depositional environment is still eluding the sedimentologists. In reality, most sediments do not strictly follow log-normality and this deviation from Gaussian model has given rise to various environmental interpretations (Folk and Ward, 1957; Friedman, 1961). Further, some workers (Visher, 1969; Glaister and Nelson, 1974; Middleton, 1976) have interpreted the subpopulation as representative of a specific transport mode (traction, intermittent suspension i.e. saltation and suspension) and the relative concentrations each one suggesting particular depositional environments. Blatt et al. (1980) have argued that it is not a surprise for the process specific populations and subpopulation to occur in a sedimentary facies; however, many other authors have failed to achieve similar interpretations (Garrow, 1982; Anderson et al., 1982). There are at least two reasons for such disagreement. (i) The process of erosion-deposition encompasses complex functions involving many variables, including grain morphodynamics and hydrodynamics of the media that are intrinsically random and (ii) the imprint of the source characteristics on the characteristics of the deposits. The texture of sediments depends largely on the characteristics of a transporting /depositing agents (Passega, 1957). He has used the relationship between the one percentile and the median percentile populations of a sediment to interpret the mode of a sediment transport in different environments.

Booth (1973) has used the polynomial trend surface maps of moment measures to understand the dispersal mechanism of sediment deposits. Similarly, progressive changes in grain size parameters from source to sink have also been reported by many authors (Krumbien 1938; Stapor and Tanner, 1975; McLaren 1981). Using the methods described above attempts have already been made in the innershelf off Kerala (Prithiviraj and Prakash, 1991; Ramachandran, 1992) to delineate the sediment transport trend. Since the sediment transport systems serve as filters whose sediment outputs differ systematically from the inputs, such transport systems may be identified in nature based on circumstantial evidence. The trends are usually observed as mostly subtle gradients in grain size parameters, mineral composition and other petrographical attributes. Therefore, to derive a conceptual frame work of the detrital sediment regime, it is important to decipher the signatures reflected as textural parameters in sediments deposits. Keeping the importance of the sediment textures in mind, documentation of the textural composition and interpretation of granulometric properties of the surficial sediments in the study area is presented in this chapter.

III.2. METHODS

The innershelf and beach sediments mostly comprise of sand. The sediment samples were treated with dilute HCl to remove shell fragments and then soaked in a 10% H_2O_2 solution to remove organic material. The sand fractions from shelf and beach were subjected to dry sieving in a Ro-Tap sieve shaker, at a sieve interval of 0.5ϕ, for 15 minutes. The sand fraction retained in each sieve was weighed. The $<4\phi$ fraction, wet sieved through ASTM 230 mesh was subjected to pipette analysis following Carver (1971). Since sand grains having the size range between 1 mm and 1.5 mm are the most suitable for scanning electron microscope analysis (Krinsly and Morgolis, 1971), representative quartz, garnet and opaque grains within the specified size grade were selected and treated with dilute HCl and $SnCl_2$ to remove carbonate and iron coatings (Gillieson, 1981). The grains were mounted on a metallic stud using double sided adhesive tape and gold coated in a standard vacuum evaporator. Using a JEOL SEM 4000 model available at the Regional Research Laboratory, Trivandrum, the grains were examined and photographed.

III.3 RESULTS

III.3.A INNERSHELF

III. 3. A. 1)Sediment Distribution

Figures 3.1, 3.2 and 3.3 illustrate the distribution of sand, silt and clay in the study area. The study area is divided into southern (profiles 1-7) and northern (profiles 8-15) sectors as in the previous chapter (refer Fig 1.3) to figure out the results effectively.

SAND:

Dominant constituent of the shelf sediment is sand of medium to fine sand range. Sand content at various stations varies from 66.56 % to 95.87 % with an average of 84.68 %. Areas of highest sand concentration (>85%) are mostly aligned linearly, adjacent to the shore line within a water depth of <25 m. However, an isolated patch with >75% sand content is seen in deeper areas of the shelf in

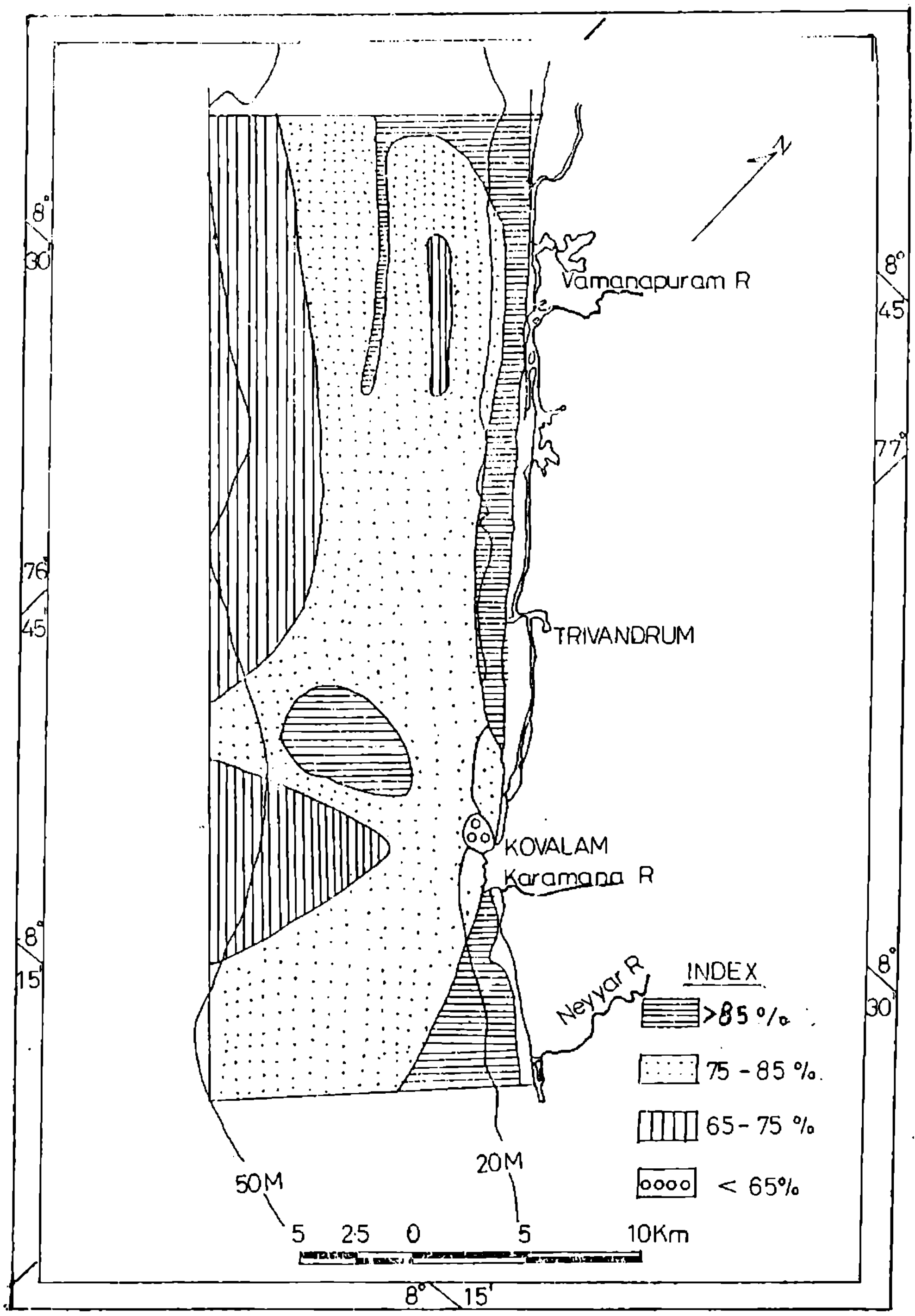


Fig. 3.1 Distribution of sand in the innershelf region

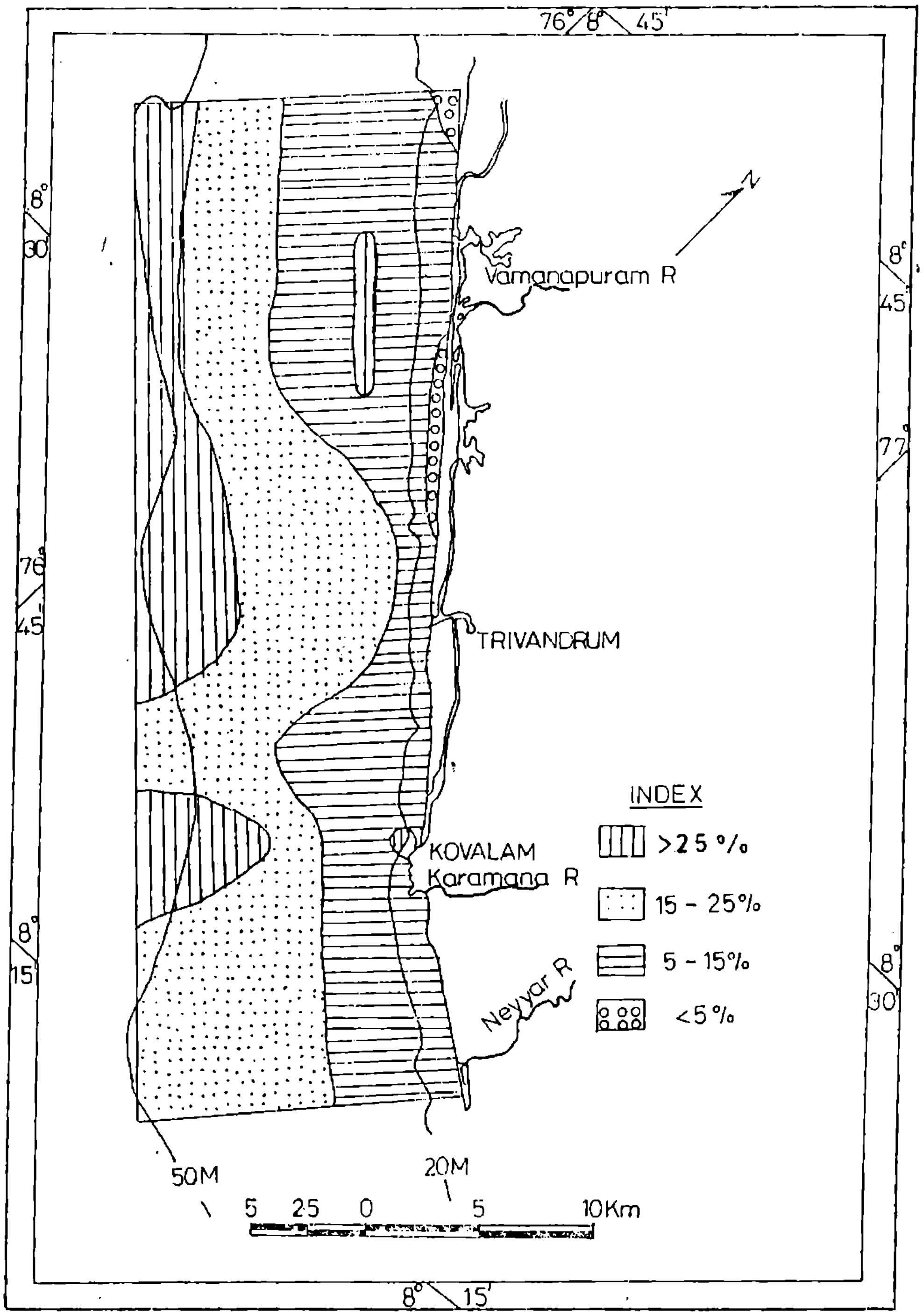


Fig. 3.2 Distribution of silt in the innershelf region

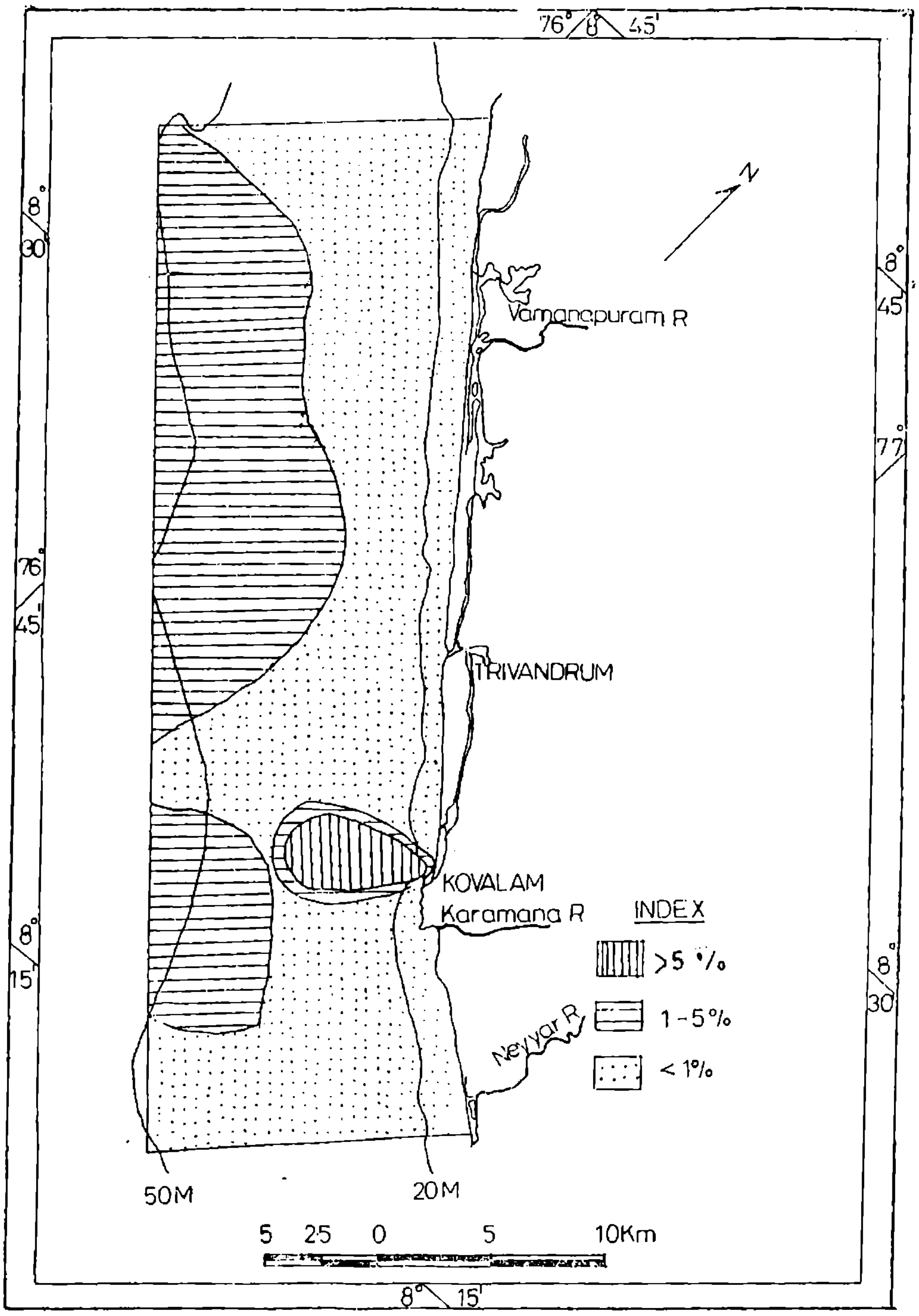


Fig. 3.3 Distribution of clay in the innershelf region

the southern sector NW off Kovalam. Areas with moderate amount of sand (<75%) are generally observed beyond 40m. water depth. A sand deficient pocket (<65%) is located close to the Kovalam promontory. Regional distribution pattern of sand (Fig. 3.1) suggests that the northern sector generally exhibits a gradation of seaward decreasing sand content.

SILT:

Silt is the second largest constituent of the surficial sediments followed by sand. It ranges form 3.68 % to 32.12 % with an average of 14.00%. (Table: 3.1) silt dominates beyond 30m isobath. An area of lowest silt concentration (<5%) is recorded in a linear zone off the Perumathura outlet However, an area of high silt content (>25%) is also observed around 25m. isobath off Vamanapuram river. Compared to northern sector, southern sector reveals a slight complex picture of silt distribution (Fig.3.2).

Clay:

Clay is the least abundant among the three constituents of the surficial sediment samples and varies from near zero (0.03%) to a maximum of 8.88 %. Zones of comparatively higher clay content (>5%) is restricted to water depths of >40 m and in a pocket immediately north of the Kovalam promontory. Regionally, the clay content shows an increasing trend seaward (Fig.3.3) .

Textural Composition:

Another type of sediment classification discussed in this thesis is based on the textural composition (Lewis, 1983). This, essentially, is the

Table 3.1 Textural Parameters, Sand:Mud ratio & sand-silt-clay % of Innershelf sediments

Sam No.	Mean Size ϕ	Std. Dev. ϕ	Skew.	Kurt.	Sand %	Silt %	Clay %	Sand/Mud Ratio	Textural Description
E1	2.71	0.60	0.19	0.70	79.30	19.88	0.61	3.87	Sand
D1	2.92	0.78	0.18	0.87	82.30	17.21	0.49	4.65	Sand
C1	2.91	0.88	0.10	0.69	93.56	5.96	0.48	14.53	Sand
B1	3.01	0.66	0.10	0.96	95.23	3.98	0.79	19.96	Sand
A1	3.32	0.62	-0.17	1.28	95.08	4.12	0.80	19.33	Sand
E2	2.67	0.94	0.15	0.65	79.89	19.54	0.45	4.00	Sand
D2	2.91	0.83	0.14	0.86	80.25	18.96	0.79	4.06	Sand
C2	3.12	0.69	0.10	0.89	82.65	16.87	0.48	4.76	Sand
B2	3.13	0.63	-0.20	1.09	91.56	8.41	0.03	10.85	Sand
A2	3.21	0.39	-0.22	0.92	95.69	3.68	0.63	22.20	Sand
F3	3.05	0.90	-0.10	0.83	80.23	19.42	0.34	4.06	Sand
E3	3.19	0.70	-0.14	0.98	80.25	19.54	0.21	4.06	Sand
D3	3.28	0.72	-0.23	1.10	81.25	17.86	0.89	4.33	Sand
C3	3.58	0.65	-0.31	1.40	85.69	13.58	0.73	5.99	Sand
B3	3.08	0.68	-0.09	1.05	91.25	7.86	0.89	10.43	Sand
A3	3.73	0.70	0.06	0.89	94.56	4.86	0.58	17.38	Sand
E4	3.04	0.67	-0.10	1.02	72.65	24.89	2.46	2.66	Silty-Sand
D4	3.08	0.68	-0.06	1.05	75.23	23.86	0.90	3.04	Sand
C4	3.18	0.70	-0.03	1.12	80.56	15.25	4.19	4.14	Sand
B4	3.33	0.73	-0.01	1.25	93.23	5.87	0.90	13.77	Sand
A4	3.85	0.85	0.07	1.05	95.25	3.89	0.86	20.05	Sand
F5	2.92	0.89	-0.16	0.72	69.36	27.25	3.39	2.26	Silty Sand
E5	2.75	0.61	0.30	0.89	72.56	24.25	3.19	2.64	Silty Sand
D5	2.65	0.58	0.13	0.69	74.58	19.45	5.97	2.93	Sand
C5	3.19	0.77	0.11	1.06	79.36	15.65	4.99	3.84	Sand
B5	3.32	0.73	-0.09	1.98	66.56	24.56	8.88	1.74	Silty Sand
A5	3.51	0.77	-0.23	1.56	69.52	24.53	5.95	2.28	Silty Sand
F6	2.85	0.63	-0.29	0.96	77.58	20.25	2.17	3.46	Sand
E6	2.90	0.64	0.09	0.86	93.25	5.96	0.79	13.81	Sand
D6	3.08	0.68	0.08	1.25	95.24	4.52	0.24	20.01	Sand
C6	3.58	0.69	-0.23	1.09	80.36	18.56	1.06	4.10	Sand
B6	3.56	0.75	-0.28	1.13	82.56	16.54	0.90	4.73	Sand
A6	3.69	0.42	-0.29	1.56	82.95	16.58	0.47	4.87	Sand
F7	3.12	0.69	-0.03	0.98	79.85	18.56	1.59	3.96	Sand

Cont....

Table 3.1 Textural Parameters, Sand:Mud ratio & sand-silt-clay % of Innershelf sediments

Sam No.	Mean Size ϕ	Std. Dev.ϕ	Skew.	Kurt.	Sand %	Silt %	Clay %	Sand/Mud Ratio	Textural Description
E7	3.76	0.54	-0.22	1.28	77.96	19.56	2.43	3.55	Sand
D7	3.48	0.77	-0.31	1.56	85.21	14.25	0.54	5.76	Sand
C7	3.48	0.77	-0.35	1.25	84.25	15.45	0.30	5.35	Sand
B7	3.28	0.72	-0.36	1.56	92.20	7.52	0.28	11.82	Sand
A7	3.95	0.42	-0.39	0.99	91.24	8.52	0.24	10.42	Sand
F8	3.97	0.87	-0.31	1.89	80.25	17.25	2.50	4.06	Sand
E8	2.89	0.64	0.23	1.25	81.21	16.25	2.54	4.32	Sand
D8	3.43	0.75	0.09	1.50	84.06	15.23	0.71	5.27	Sand
C8	3.29	0.63	-0.06	1.11	90.23	9.23	0.54	9.24	Sand
B8	3.02	0.66	-0.04	0.89	90.25	9.12	0.63	9.26	Sand
A8	3.43	0.75	-0.02	0.86	94.58	5.23	0.19	17.45	Sand
F9	2.67	0.59	-0.04	0.60	71.20	24.23	4.07	2.52	Silty Sand
E9	2.91	0.84	-0.10	0.79	71.25	24.85	3.09	2.55	Silty Sand
D9	3.44	0.48	-0.31	1.25	82.25	17.25	0.50	4.63	Sand
C9	3.89	0.86	-0.34	1.09	82.41	17.02	0.57	4.69	Sand
B9	3.90	0.86	-0.38	1.65	84.52	14.58	0.90	5.46	Sand
A9	3.87	0.85	-0.38	1.90	94.56	5.12	0.32	17.38	Sand
F10	3.85	0.85	-0.32	1.29	70.54	24.56	4.90	2.39	Silty Sand
E10	3.82	0.84	-0.31	1.25	79.42	17.58	3.00	3.86	Sand
D10	3.78	0.83	-0.20	1.24	84.25	14.56	1.19	5.35	Sand
C10	3.76	0.55	-0.24	1.21	85.45	13.82	0.73	5.87	Sand
B10	3.56	0.78	-0.24	1.19	88.62	10.56	0.82	7.79	Sand
A10	3.44	0.77	-0.25	1.11	95.45	4.25	0.30	20.98	Sand
F11	3.95	0.87	-0.22	1.23	82.52	14.52	2.50	4.85	Sand
E11	3.67	0.38	-0.18	1.03	81.54	14.25	4.12	4.44	Sand
D11	3.47	0.55	-0.12	1.25	89.56	10.25	0.19	8.58	Sand
C11	3.24	0.71	-0.13	1.19	67.54	32.12	0.34	2.08	Sand
B11	3.09	0.56	-0.14	1.12	85.24	13.98	0.78	5.78	Sand
A11	2.89	0.64	-0.14	0.98	95.87	3.87	0.24	23.33	Sand
F12	3.01	0.82	-0.39	1.12	80.21	18.25	1.24	4.12	Sand
E12	3.60	0.72	-0.38	1.35	83.25	16.25	0.45	4.99	Sand
D12	3.68	0.63	-0.36	1.41	86.54	12.54	0.92	6.43	Sand
C12	3.73	0.82	-0.28	1.30	71.00	28.54	0.40	2.45	Silty Sand
B12	3.81	0.84	-0.18	1.12	86.21	13.25	0.54	6.25	Sand

Cont....

Table 3.1 Textural Parameters, Sand:Mud ratio & sand-silt-clay % of Innershelf sediments

Sam No.	Mean Size ϕ	Std. Dev. ϕ	Skew.	Kurt.	Sand %	Silt %	Clay %	Sand/Mud Ratio	Textural Description
A12	3.93	0.38	-0.10	1.23	91.00	8.21	0.79	10.11	Sand
F13	3.68	0.52	-0.29	1.02	85.25	14.52	0.23	5.78	Sand
E13	3.53	0.66	-0.28	1.09	86.25	13.52	0.23	6.27	Sand
D13	3.33	0.73	-0.29	1.02	86.52	12.54	0.94	6.42	Sand
C13	3.26	0.68	-0.29	1.04	89.25	10.25	0.50	8.30	Sand
B13	3.20	0.70	-0.27	1.01	91.21	8.52	0.21	10.45	Sand
A13	3.17	0.68	-0.26	1.06	94.21	5.23	0.56	16.27	Sand
F14	3.78	0.55	-0.20	1.21	81.45	16.34	2.12	4.41	Sand
E14	3.73	0.82	-0.23	1.15	83.57	15.34	1.04	5.10	Sand
D14	3.69	0.81	-0.22	1.10	88.45	11.23	0.32	7.66	Sand
C14	3.67	0.42	-0.07	1.01	90.12	9.56	0.32	9.12	Sand
B14	3.54	0.57	-0.16	1.32	92.45	7.25	0.30	12.25	Sand
A14	3.07	0.68	-0.16	1.15	95.68	4.25	0.07	22.15	Sand
F15	3.95	0.87	-0.21	1.15	81.25	17.32	1.40	4.34	Sand
E15	3.91	0.57	-0.03	1.07	84.57	15.34	0.03	5.50	Sand
D15	3.89	0.86	-0.20	1.10	88.25	11.23	0.52	7.51	Sand
C15	3.79	0.83	-0.52	1.21	90.25	9.56	0.19	9.26	Sand
B15	3.76	0.83	-0.56	1.24	92.25	7.25	0.50	11.90	Sand
A15	3.88	0.68	-0.56	1.42	95.00	4.25	0.75	19.00	Sand
Max	3.97	0.94	0.30	1.98	95.87	32.12	8.88	23.33	
Min	2.65	0.38	-0.56	0.60	66.56	3.68	0.03	1.74	
Avg	3.39	0.70		1.14	84.68	14.00	1.29	7.97	
Std	0.37	0.13		0.26	7.60	6.67	1.58	5.72	

Table 3.2 Size parameters of shelf sediments (Monment measure)

Sam No.	Mea Size	Std. Dev.	Skew	Kurt		Sam No.	Mean Size	Std. Dev.	Skew	Kurt
1B	3.32	0.62	-0.17	1.28		13C	3.26	0.68	-0.04	1.04
1D	2.91	0.88	0.12	0.69		13E	3.53	0.66	-0.2	1.09
1E	2.92	0.78	-0.19	0.87		13F	3.68	0.52	-0.11	1.02
2A	3.97	0.39	-0.22	0.92		14A	3.07	0.68	-0.26	1.15
2B	3.13	0.63	-0.2	1.09		14B	3.54	0.57	-0.16	1.32
2D	2.91	0.83	-0.14	0.86		14C	3.87	0.42	-0.07	1.01
2F	2.67	0.94	0.28	0.65		14F	3.78	0.55	-0.25	1.21
3A	2.73	0.7	0.06	0.89		15A	3.88	0.68	-0.62	1.42
3C	3.58	0.65	-0.31	1.4		15B	3.76	0.43	-0.07	1.24
3F	3.19	0.9	-0.29	0.83		15E	3.71	0.57	-0.2	1.07
4A	3.85	0.47	-0.18	1.05		9C	3.29	0.63	-0.06	1.11
4F	3.04	0.82	-0.23	0.84		9D	3.94	0.48	-0.31	1.25
5A	3.51	0.76	-0.33	1.12		9E	2.91	0.84	-0.1	0.79
5C	3.19	0.77	-0.24	1.06		10A	3.44	0.77	-0.25	1.11
5F	2.92	0.89	-0.16	0.72		10C	3.76	0.55	-0.24	1.21
6A	3.69	0.42	0.02	0.93		11B	3.09	0.56	-0.14	1.12
6B	3.56	0.75	-0.36	1.13		11D	3.47	0.55	-0.12	1.25
6C	3.58	0.69	-0.24	1.09		11E	3.9	0.38	0	1.03
7A	3.95	0.42	-0.24	0.99		12A	3.93	0.38	-0.07	0.99
7E	3.76	0.54	-0.22	1.28		12D	3.78	0.63	-0.36	1.41
8C	2.94	0.67	-0.2	0.96		13A	3.17	0.68	-0.26	1.06
9C	3.29	0.63	-0.06	1.11		13C	3.26	0.68	-0.04	1.04
9D	3.94	0.48	-0.31	1.25		13E	3.53	0.66	-0.2	1.09
9E	2.91	0.84	-0.1	0.79		13F	3.68	0.52	-0.11	1.02
10A	3.44	0.77	-0.25	1.11		14A	3.07	0.68	-0.26	1.15
10C	3.76	0.55	-0.24	1.21		14B	3.54	0.57	-0.16	1.32
11B	3.09	0.56	-0.14	1.12		14C	3.87	0.42	-0.07	1.01
11D	3.47	0.55	-0.12	1.25		14F	3.78	0.55	-0.25	1.21
11E	3.9	0.38	0	1.03		15A	3.88	0.68	-0.62	1.42
12A	3.93	0.38	-0.07	0.99		15B	3.76	0.43	-0.07	1.24
12D	3.78	0.63	-0.36	1.41		15E	3.71	0.57	-0.2	1.07
13A	3.17	0.68	-0.26	1.06						

Table 3.3 Summary of Number of Pairs Producing Transport Trends

	North Trend	South Trend
At 15 m. depth		
Case -B	N = 78 X = 2 Z =- 2.65	N = 78 X = 2 Z =- 2.65
Case - C	N = 78 X = 24 Z = 4.88#	N = 78 X = 24 Z = 2.65#
At 30 m. depth		
Case -B	N = 78 X = 1 Z = - 3	N = 78 X = - 4 Z = - 1.97
Case - C	N = 78 X = 13 Z = 1.11	N = 78 X = 18 Z = 2.83#
At 45 m. depth		
Case -B	N = 78 X = 2 Z =- 2.65	N = 78 X = 6 Z = - 1.28
Case - C	N = 78 X = 8 Z = - 0.6	N = 78 X = 22 Z = 4.20#

\# -- Significant at 0.01 level

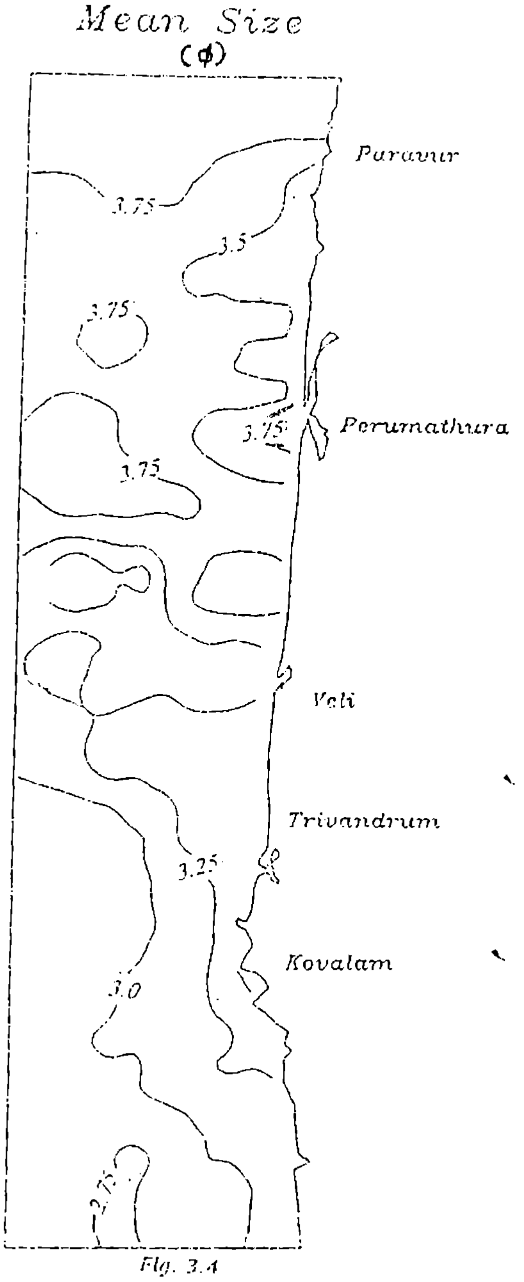


Fig. 3.4

Distribution of mean size of innershelf sediments

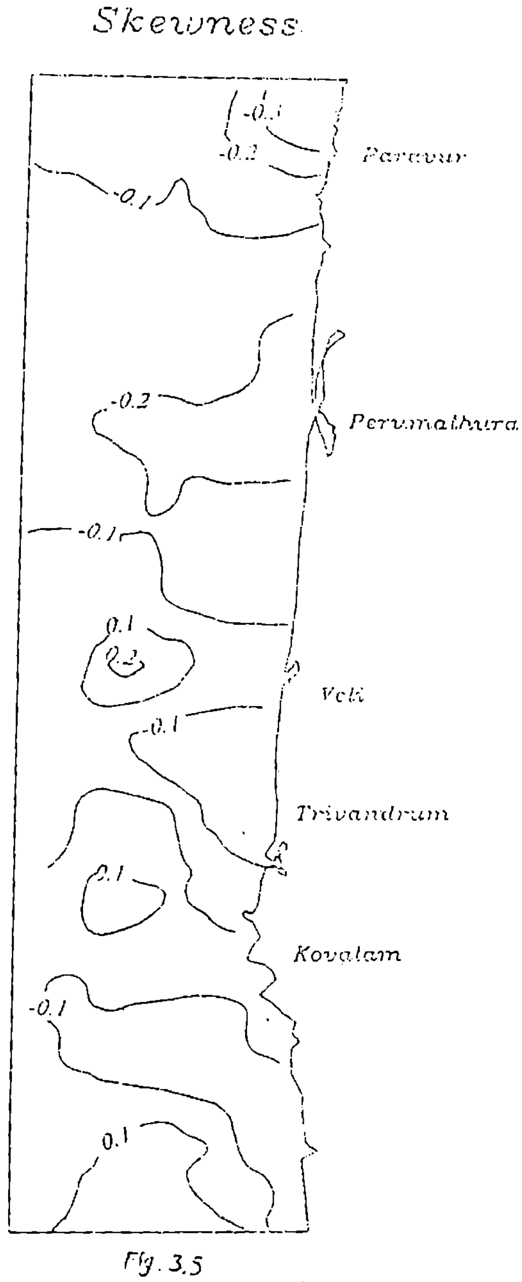


Fig. 3.5

Distribution of skewness of innershelf sediments

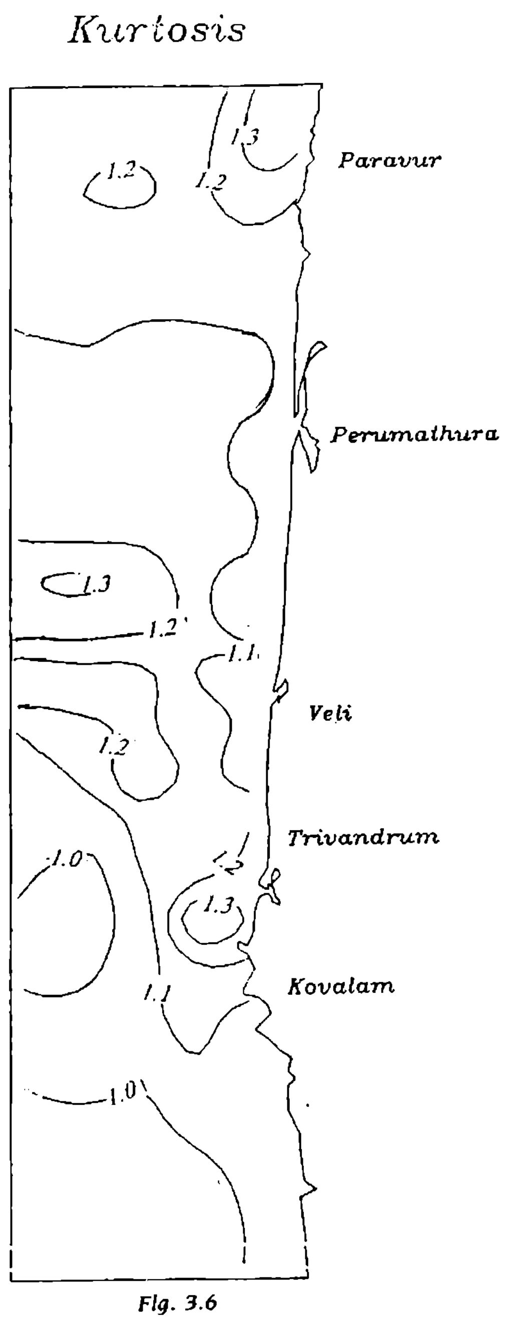


Fig. 3.6
Distribution of kurtosis of the innershelf sediment

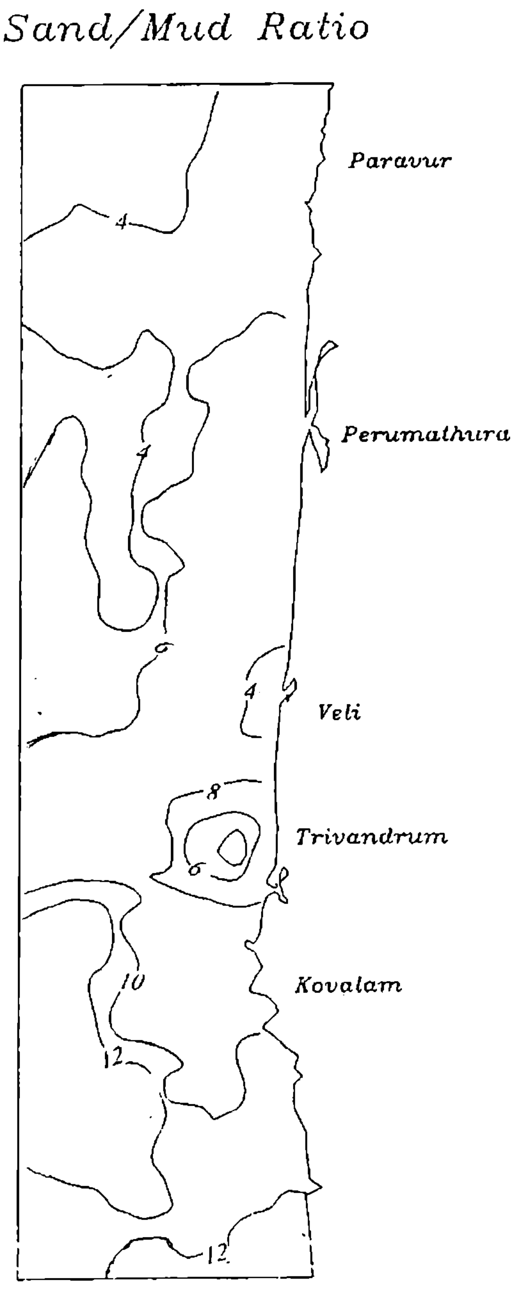


Fig. 3.6A
Distribution of sand:mud ratio in the innershelf sediment

modification of grade composition discussed above. It is simply a loquacious expression of grade abundance based on weight percentage of sand, silt and clay. The innershelf samples of this study area fall within just two categories viz., sand and silty sand (Table 3.1). Only a couple of small pockets of silty sand are observed off Kovalam and Perumathura.

III. 3. A. 2) SIZE PARAMETERS

Reconstruction of depositional environment of a sedimentary deposit is found to have significant bearing on the grain size. Therefore, to understand the size related physical properties of the innershelf sediments, graphic parameters viz., mean, standard deviation, skewness and kurtosis are computed as recommended by Folk and Ward (1957). These parameters are given in Table 3.1.

Mean size

The mean size of the innershelf sediments (Table 3.1) varies between 2.65 ϕ and 3.97 ϕ. This narrow variation in mean size is possibly the reflection of limited spectrum of dynamics operating on the innershelf. The bar chart (Fig. 3.7) shows bimodal distribution with peaks at 3 ϕ and 3.75 ϕ grades. Of the two, the 3 ϕ grade is slightly dominant than the other. Areal distribution of mean size shows that the 3 ϕ size class occurs in a narrow zone between the shore and 30 m contour in the southern sector (Fig. 3.4). However, a trend reversal is noticeable in the southern sector (off and south of Kovalam promontory). The transition is revealed by the

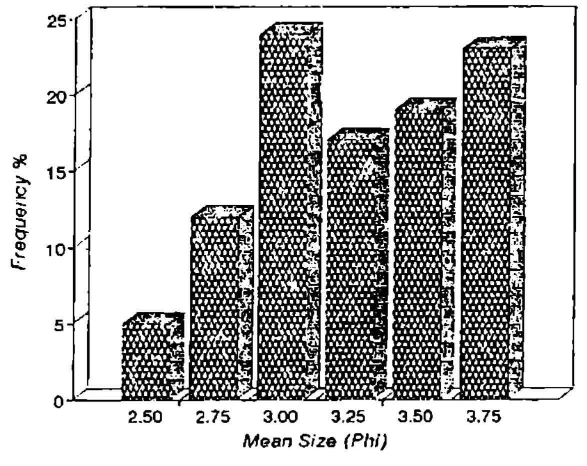


Fig. 3.7 Frequency Distribution of mean size of Innershelf sediment

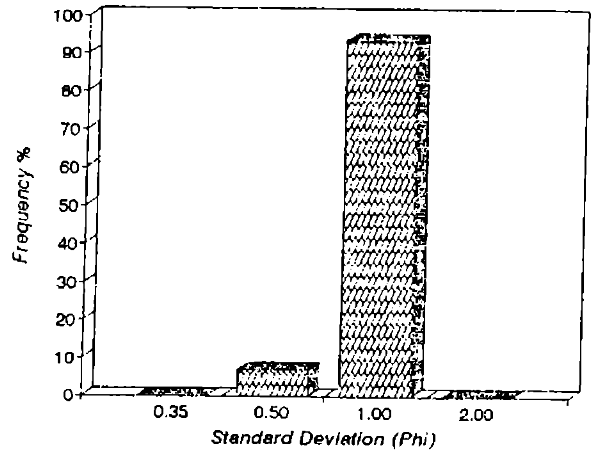


Fig. 3.8 Frequency distribution of standard deviation of Innershelf sediment

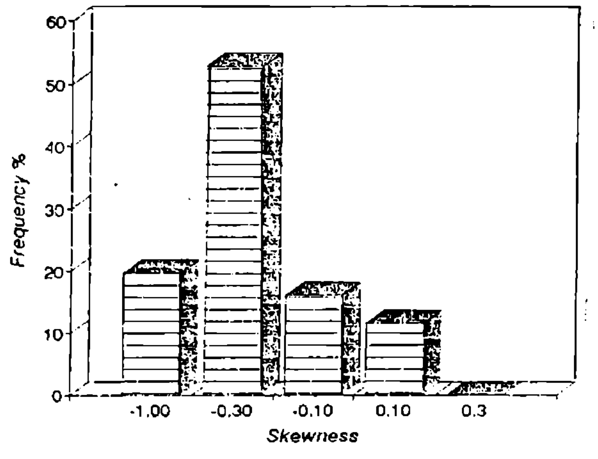


Fig. 3.9 Frequency distribution of skewness of Innershelf sediment

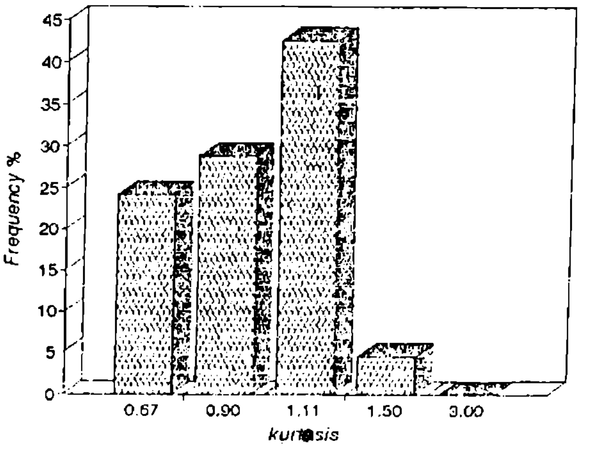


Fig. 3.10 Frequency distribution of kurtosis of Innershelf sediment

shore normal isoline of 3.25 ϕ contour off Veli. However, a few isolated patches of coarse sediments are seen in the northern sector as well.

Standard Deviation:

Sorting of sediments can be expressed by various statistical practices. The simplest of these is the measure of the degree of dispersion called as standard deviation. Ever since Folk and Ward (1957) proposed the phi deviation measure to categorize the sorting, it is being widely adopted by sedimentologists. Sediments of the study area range from well sorted (0.38 ϕ) to moderately sorted (0.94 ϕ) (Table 3.1and Fig. 3.8). Most of the study area are covered by moderately sorted sediments (hence the distribution map for standard deviation is not prepared) and are confined mainly to the northern sector. Only a few samples (7 no.) with well sorted tendency are observed off Perumathura, Paravur and areas south of Kovalam promontory.

Skewness:

The third important aspect of grain size analysis is the measure of degree of lopsidedness. That is, the samples weighted towards the coarser end-member are said to be positively skewed and samples weighted towards the fine end are said to be negatively skewed. The bar chart (Fig.3.9) shows that more than 50% of the sediments of the study area are `negatively skewed' and about 20% are `very negatively skewed'. The skewness values range from -0.56 to 0.30 (Table 3.1). Sediments in the southern sector vary from `nearly symmetrical' to `negatively skewed'; whereas, the northern sector sediments are predominantly `very negatively skewed' (Fig. 3.5).

Kurtosis:

Kurtosis is the index of degree of peakedness. Nearly 45% of the shelf sediments are leptokurtic whereas, the platykurtic (23%) and mesokurtic (26%)sediments are almost equally distributed (Fig. 3.10). The area south of Kovalam promontory is generally covered both by platykurtic and mesokurtic sediments whereas, the sediments of northern sector show a tendency for leptokurtic nature (Fig. 3.6).

SCATTER PLOTS

It is well established that the physical processes involved in deposition and erosion of sediments influence the grain size parameters. Therefore, the signatures left by the physical processes upon sediments could be deciphered by careful diagnosis of interrelationship among the size parameters. The trend analysis of scatter plots between the graphic measures is a well known tool to understand such details. Distinctive patterns of scatter plots of size parameters of the southern and northern sectors were analysed by invoking separate symbols and curve fitting to them . A "PC" based, polynomial curve fitting software was used for this purpose.

Mean size Vs. Standard deviation.

The plot of mean size Vs. standard deviation (Fig. 3.11) does not readily reveal any significant trend. The curve for the southern sector samples

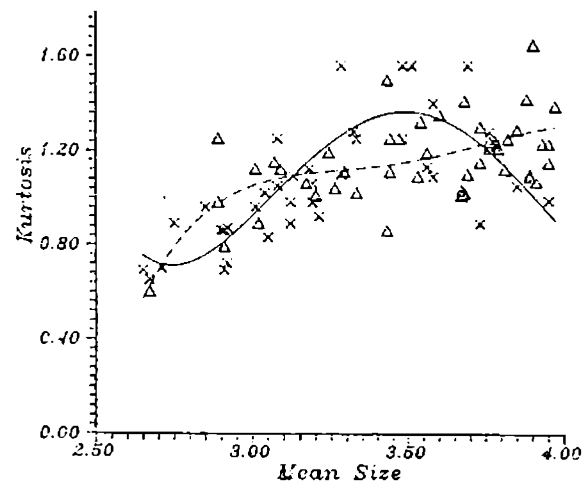


Fig. 3.13 Mean size Vs. kurtosis cross plot for innershelf sediment

Solid curves - Sourthern Sector

Dashed lines - Northern sector

△ - Southern sector

X - Northern Sector

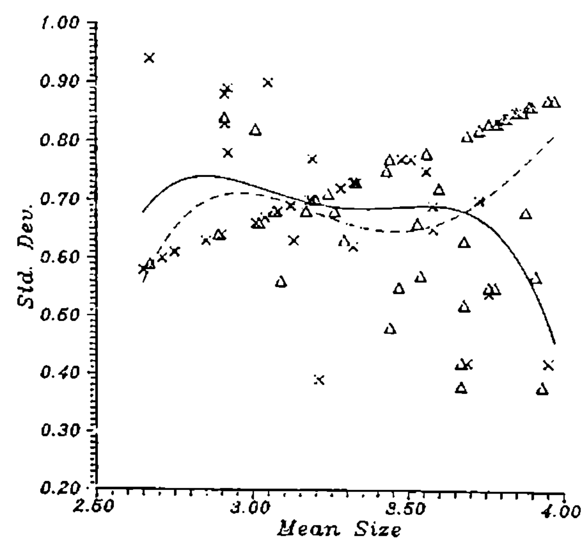


Fig. 3.11 Mean size Vs. standard deviation cross plot for innershelf sediment

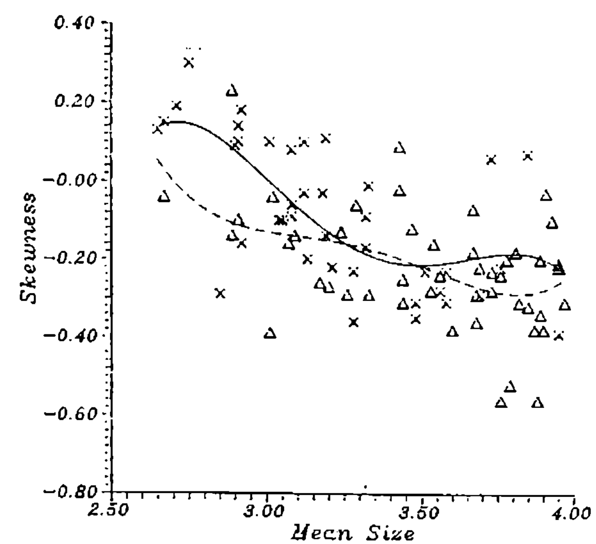


Fig. 3.12 Mean size Vs. skewness cross plot for innershelf sediment

appears to be an inverted "U" shape suggesting a limited variation in grain size distribution. However, the sinusoidal curve with a peak on the right for the northern sector (possibly representing a part of a "M" shaped curve) indicates a wide range of sediment size.The opposing trend of the two curves on the finer side (>3.65ϕ) imply that the finer fractions from the southern sector are better sorted than their counterparts in the northern sector.

Mean size Vs. Skewness

This plot shows only the left arm of a broad "U" shaped curve. Such a truncated sinuosity in a skewness Vs. mean size plot suggests polymodal mixing (Cronan 1972). Skewness become more and more negative with decrease in grain size. Shapewise the curves of the two sectors do not show much variation (Fig. 3.12).

Mean size Vs. Kurtosis

The plot for the southern sector samples exhibits a broad inverted "U" trend , which shows that beyond 3.5 ϕ the kurtosis values of the sediment decrease once again. On the other hand the northern sector sediment show a steady increase of kurtosis value with increasing ϕ values (Fig. 3.13).

Standard Deviation Vs. Skewness

Though the standard deviation and the skewness of the sediments are closely related to mean size; this plot for the southern and northern sectors (Fig. 3.14) fails to show any relationship among them. This may be due to the fact the

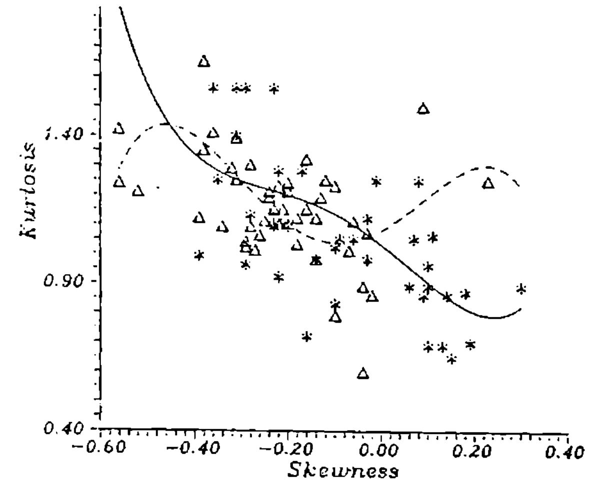


Fig. 3.16 Skewness Vs. kurtosis cross plot for innershelf sediment

Dashed lines - Northern sector

Solid curves - Sourthern Sector

* Southern sector

Δ Northern Sector

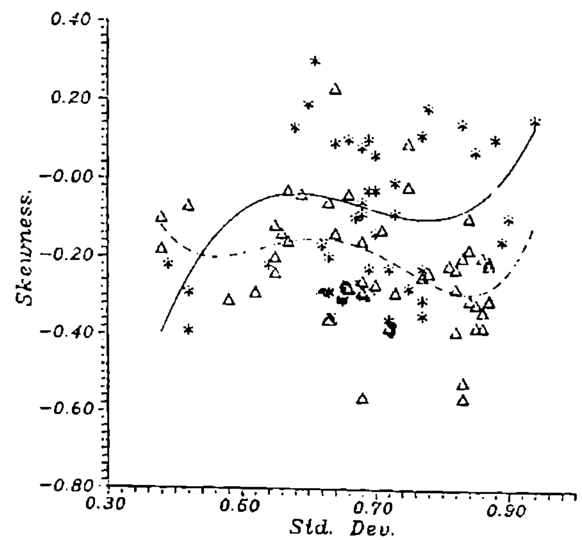


Fig. 3.14 Standard deviation Vs. skewness cross plot for innershelf sediment

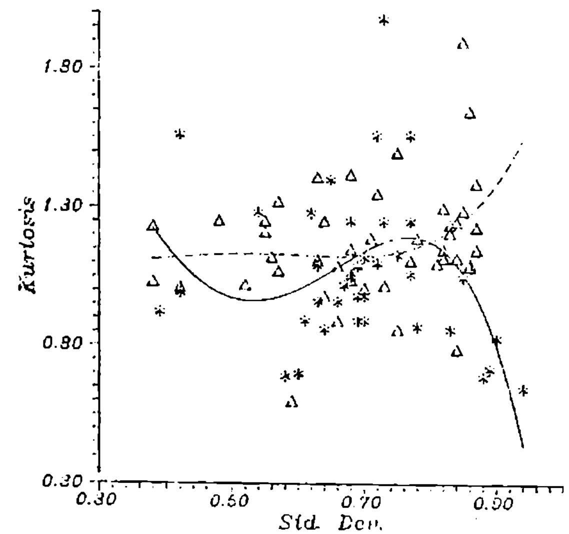


Fig. 3.15 Standard deviation Vs. kurtosis cross plot for innershelf sediment

coarser fraction from the southern sector is moderately sorted, whereas the finer fraction of the northern sector is well sorted.

Standard deviation Vs. Kurtosis

This plot. (Fig:3.15) for the southern sector shows a sinuosity implying that the sorting worsens when the kurtosis becomes platykurtic. This situation is quite common in a high energy coarse grained environment (Creager, 1963). The northern sector shows a more or less inverted "U" curve which suggests that, when the sorting worsens the kurtosis become leptokurtic. This is just opposite to the behaviour of the southern sector sediments. This could be due to the abundance of finer sediments in the northern region.

Skewness Vs. Kurtosis

This plot for the southern sector sediments swings towards left with slight sinuosity showing a negative correlation of kurtosis with that of skewness. It is interesting that only a very few samples show a normal trend as described by Folk and Ward (1957). In the northern sector only the neutrally skewed sediments appear to be mesokurtic . When the skewness is disturbed the sediments show a tendency for platykurtic (Fig. 3.16).

III.3.B) BEACH

SIZE PARAMETERS

Table 3.1A Size parameters of beach sediment

MONSOON					POST MONSOON				
Prof.#	MZ	SD	SK	KR	Prof.#	MZ	SD	SK	KR
0	1.39	0.93	0.06	0.98	0	1.65	0.94	-0.11	0.79
2	1.61	0.59	-0.19	1.02	4	1.86	0.74	-0.26	1.00
6	1.59	0.63	-0.10	1.02	6	1.47	0.94	0.07	0.87
8	1.03	0.66	0.23	1.21	8	1.51	0.87	-0.09	0.89
10	1.03	0.63	0.16	1.34	10	2.14	0.69	-0.12	1.38
12	1.45	0.67	0.19	1.09	12	2.23	0.78	-0.01	0.89
14	1.73	0.73	-0.37	0.83	14	1.40	1.01	0.19	0.89
16	1.05	0.65	0.11	0.99	16	2.38	0.76	-0.14	1.01
18	1.22	0.59	0.32	0.75	18	2.31	0.56	0.17	1.12
20	2.31	0.56	0.17	1.12	26	1.65	0.56	-0.06	1.12
22	2.21	0.74	0.13	0.98	29	2.44	0.65	0.10	0.93
24	2.53	0.55	0.18	0.95	30	1.76	0.50	-0.13	1.33
26	2.49	0.70	-0.05	1.31	32	1.80	0.44	-0.04	1.30
28	1.86	0.65	0.11	1.21	34	1.80	0.44	-0.04	1.30
30	1.45	0.58	0.25	1.09	36	1.76	0.49	-0.12	1.28
32	1.57	0.50	-0.13	1.12	38	1.70	0.46	-0.10	1.49
34	2.45	0.50	0.22	1.07	40	1.48	0.44	-0.41	0.86
36	1.66	0.59	0.00	1.34	42	1.21	0.68	-0.02	0.97
38	1.63	0.44	-0.21	1.40	44	1.53	0.56	-0.31	1.32
40	1.57	0.46	-0.23	1.26	46	1.99	0.41	-0.05	1.01
42	2.22	0.68	0.02	1.02	48	2.13	0.66	-0.13	1.03
44	1.55	0.55	-0.10	1.30	50	2.24	0.47	-0.04	1.52
46	1.78	0.80	0.01	1.44	52	2.33	0.44	0.12	1.50
48	1.66	0.89	-0.14	1.34	54	2.39	0.46	0.16	1.21
50	1.39	1.04	0.48	0.90	56	1.81	0.69	-0.09	1.10
52	1.07	0.87	0.19	1.28	58	1.60	0.65	-0.19	0.77
54	1.81	0.69	-0.09	1.10	60	1.79	0.66	-0.22	1.18
56	1.60	0.65	-0.19	0.77	62	1.74	0.75	-0.28	0.90
58	1.79	0.66	-0.22	1.18	64	1.86	0.94	-0.18	1.09
60	1.74	0.75	-0.28	0.90	66	1.54	1.20	-0.19	0.82
62	1.86	0.94	-0.18	1.09	68	2.56	0.90	-0.18	1.02
64	1.54	1.20	-0.19	0.82	70	1.74	0.88	0.00	0.77
66	2.56	0.90	-0.18	1.02	72	2.45	0.63	0.06	1.03
68	1.74	0.88	0.00	0.77	73	1.61	0.76	-0.11	0.81
70	2.45	0.63	0.06	1.03					
72	1.61	0.76	-0.11	0.81					
73	1.58	0.85	-0.16	0.94					
Avg	1.72	0.71		1.08	Avg	1.88	0.68		1.07
Max	2.56	1.20	0.48	1.44	Max	2.56	1.20	0.19	1.52
Min	1.03	0.44	-0.37	0.75	Min	1.21	0.41	-0.41	0.77

MZ=Mean Size, SD=Standard Deviation, SK=Skewness, KR=Kurtosis

Mean Size:

The mean size of the beach sediment ranges from 1.03 ϕ to 2.56 ϕ for the monsoon season (July), where as the mean size of the fair weather (December) season samples ranges from 1.26 ϕ to 2.56 ϕ (Table 3.3). A comprehensive illustration of the size parameters behaviour during monsoon and fair weather season is shown in Figs. 3.17 & 3.18. It is worth noting that the grain size of beach sediments does not reflect the distinctiveness for northern and southern sectors as observed in innershelf sediments. The coarsest grain size encountered during the monsoon and the post monsoon seasons are 1.03 ϕ and 1.21ϕ respectively where as the finest size remains 2.56 ϕ for both the seasons. Fine sands are observed during monsoon season around pocket beaches.

Standard Deviation:

The standard deviation of beach sediments varies between 0.44ϕ and 1.2ϕ for monsoonal samples and between 0.41ϕ and 1.2ϕ for post monsoon samples. Similar to the mean size, sorting index also does not show any spatial variation. However, the monsoonal samples are marginally better sorted than the post monsoon samples (Figs. 3.17 & 3.18).

Skewness:

Generally, the monsoonal beach sediments exhibit positive skewness particularly in the southern sector; whereas the northern sector beach sediments show negative skewness. This pattern is similar to the trend displayed by the innershelf sediments. This possibly suggests a difference in energy levels on the beaches of northern and southern sectors during monsoon season. The post monsoon sediments generally show negative skewness especially around pocket beaches (Figs. 3.17 & 3.18).

Kurtosis:

Unlike the skewness, kurtosis of the beach sediments does not show any similarity with their innershelf counterpart. Kurtosis of the monsoonal sediments are generally, leptokurtic. However, kurtosis of the post monsoon beach sediments especially the continuous beach stretch between the Varkala and Kovalam promontories change from lepto to very leptokurtic; whereas the kurtosis of the pocket beach sediments around Kovalam and Varkala promontories does not change with seasons (Figs. 3.17 & 3.18).

SCATTER PLOTS

Mean size Vs. Standard deviation

The plots for the monsoonal and post monsoonal samples are distinctly different (Fig. 3.19). Almost all the post monsoonal samples are within the moderately sorted category, nevertheless, the coarser end of the monsoonal curve shows better sorting, whereas the finer end as moderately sorted.

Mean size Vs. Skewness

Though the monsoonal curve resembles the post monsoonal curve, the later shows wider variability. There are two prominent peaks seen in the post monsoonal plot at 1.25 ϕ and 2.75 ϕ. (Fig. 3.20).

Mean size Vs. Kurtosis

This plot for both the monsoon and post monsoon samples indicates sinuosity however, the monsoon curve is symmetrical whereas the other is not. That is to say that both the finer and coarser fractions of the monsoon samples are leptokurtic. However, with the onset of post monsoonal accretionary phase the finer fractions tend to be mesokurtic (Fig. 3.21).

Standard Deviation Vs. Skewness

As expected this plot resembles the mean size Vs. skewness plot. The range of skewness varies widely for the post monsoon samples which results in variable sinuosity in the two plots (Fig. 3.22).

Standard deviation Vs. Kurtosis

The plot shown in the Fig: 3.23 display a negative correlation for the standard deviation and kurtosis for both the monsoon and post monsoon samples. These curves also indicate that when sorting in the tail is worst the beach sediment appears to have platykurtic tendency during both the seasons.

Skewness Vs. Kurtosis

The monsoonal and post monsoonal plots are almost similar in shape; except that the post monsoonal curve has a steeper left armed inverted "U". Therefore this curve generally suggests that during the monsoon season the negatively skewed sediments are mesokurtic but when the skewness is transcends to positive, the kurtosis drastically changes to platykurtic.

III.4. DISCUSSION

During the past decade of research on continental shelf sedimentation, evidences have accumulated strong to show that the beaches and estuarine sand might have contributed at least in part, to the shelf sediments. Evidence pointing to an immediate onshore source is largely indirect, i.e., only through sediment budget calculations and some statistical treatment of grain size data. Though it is reported that medium to fine sands of this study area are of terrigenous origin (Siddique and Rajamanikam 1971 and 1979), the exact extend of sediment contribution from the shore has always been an elusive figure. It is further complicated by the fact that the sand and mud must be considered separately because of diverse modes and energies of transportation involved. Sand being the dominant sediment type in this innershelf, emphasis will be made mainly on that particular category of sediments. Further, the Kovalam headland and the existence of considerable difference in innershelf gradient between the northern and the southern sectors might have effects on the sediment distribution pattern of the study area.

The northward fining of sediment grade, as indicated by the sand, silt and clay distributions (Figs. 3.1, 3.2, 3.3), is in conformity with the distribution patterns of the mean size, skewness and kurtosis. A similar northward decreasing grain size trend in the innershelf north of the study area was earlier observed by Prakash (1991). Sand distribution pattern just NW of Kovalam promontory in the southern sector (Fig. 3.1) depicts an elliptical isolated pattern (with >85% sand and ~ 7 x 5 km. dimension) The long axis of this ellipse is roughly oriented along the dominant SW monsoonal wave direction (NW / W). Krumbein and Sloss (1956) have also established the possibility of coarser sand transport over a bed of finer sediment. This sand shoal should have been derived from the Kovalam-Panathura barrier beach stretch, which experiences severe erosion during the SW monsoon season, and subsequent transport by rip flows over a bed of finer silty sand. The existence of rip current in this area is reported by Thomas and Baba (1986) from a study of wave surge intensity during the SW monsoon period. Therefore, the seaward tending sand salient clearly reflects seaward transport of sand during SW monsoon season. Since the sampling was done during pre SW monsoon period it is to infer that the waves of fair weather seasons have no or little influence on the distribution pattern of sand in this sector. This sand salient is also recorded as a slight topographic shoal in the echogram (Plate 1). However, this seaward transport observed at this particular section may be a highly localised phenomenon. Because z- score statistical studies and micromorphological observation (discussed in a later section of this thesis) suggest dominant shore parallel transport for this innershelf. The clay mineral study by Ramaswamy and Nair (1989 and 1994) also show a similar shore parallel sediment transport trend.

The most striking observation made on the southern sector is the seaward coarsening of sediment size. Such a tendency is not so significant in the northern sector. Further, the distribution of sand and mud ratio reveals that the entire innershelf of the northern sector is covered by the ratio of <10 whereas, the ratio for most of the southern sector is >10. The sand salient as discussed above is covered mostly by 15 and 17 ratio contours implying the mud deficiency. Another observation is that, the southwestern corner show a seaward coarsening of size (Fig. 3.4) with a lower sand:mud ratio (<9).

Although the northern sector is characterised by higher mud content the distribution pattern of the sand:mud ratio shows an increasing sand content shoreward and southward (Fig. 3.6A). The transition between the two sectors takes place around Veli outlet where, a shore normal -6- isoline is seen to be reaching the coast. The sand:mud pattern could be due to the composite processes involving the SW monsoon hydrodynamics and morphometry of this coast.

The distribution pattern of silt in the northern sector shows a long isolated patch of silt concentration, off the Vamanapuram river outlet This silt could have been derived from the Vamanapuram river (and the Perumathura backwater system) during SW monsoon season. These silt deposits were not disturbed by the long period swells of post monsoon. Existence of such zones of finer sediments were reported not only off an estuarine outlet but also in the shallow marine environments which are dominated by very coarse sand (Dias and Nittrouer, 1984; Frisly and Ganmai, 1991). The small pocket of higher silt content, north of Kovalam promontory is due to the shelter provided by the Kovalam headlands which obstruct the strong SW monsoonal (southeasterly) littoral currents.

The plot of mean size Vs. standard deviation for innershelf sediments (Fig. 3.11) does not readily reveal any significant trend. Only a sinusoidal trend is traceable with a peak on the right side of the plot for the northern sector. This could probably due to the presence of sediments from two different environments of deposition. In the mean size Vs. skewness plot (Fig. 3.12) the curve for northern sector sediments starts almost at symmetrical skewness however, the southern sector curve starts at +0.2 skewness and dips towards negative side. The above variation could be ascribed to the higher percentage of coarser sediments found in the southern sector.

The nature of sorting and mean size values reflect the complexity in textural distribution patterns in the innershelf. The distribution of grain size in the northern sector shows a general seaward decreasing trend, but the southern sector portrays a trend reversal. The sediment sorting is also differs between the sectors (Table. 3.1); especially finer sediment of the northern sector are better sorted than the southern sector (Fig. 3.11). This could be due to the introduction of finer sediments into shelf by the monsoonal coastal currents and from inland through Vamanapuram river. Southerly transport of sediments during monsoon were proposed by many earlier workers (Chandramohan and Nayak, 1992; Ramaswamy and Nair, 1994). Considering the diversity shown by the distribution diagrams, a monotonical trend of interrelationship among the grain size parameters of the sediments between the two sectors is not obvious.

The observation made above goes against the general concept of "size graded shelf" based on the textural equilibrium proposed by Swift (1970). He postulated that the average particle size of shelf sediment should decrease with increasing water depth. In such a condition, the sediment size at each point along the shelf profile is considered as in equilibrium. However, the applicability of the size graded shelf idea was first questioned by Shepard et al., (1960) who noticed a general absence of seaward size gradation on modern shelves; later this view was amplified by several workers (Curray, 1965; Emery, 1968; Swift et al., 1971). These workers have incorporated the dynamic aspect of sediment reworking and suggested the term "palimpsests" for reworked relict sediments. However, they have also pointed out that such terms are applicable only for sediments of deeper relict shelves that are out of modern hydraulic regime. Therefore, it is inferred that the textural dispersal pattern encountered in the study area is the result of modern shelf morphology that responds to the erosional / accretional episodes operating on this innershelf. This observation is further supported by the existence of finer mode on the down drift side of the Kovalam promontory during southeasterly directed monsoon current. Therefore, the salient observed off Kovalam promontory and the linear sand stretch off Vamanapuram river could be related to the modern sedimentary processes and can not be of palimpsest nature.

As discussed in the previous sections, it is evident that the nature of sedimentation in the southern and northern sectors are different. Our knowledge on the hydrography of the area particularly the current velocity of bottom waters is too imperfect to understand the relationship between the bottom water dynamics and sedimentation. However, it is known that the monsoonal waves in this innershelf area could disturb the sediments even at depths of over 40m. (Machado and Vasudevan, 1988; Kurian and Ramachandran,1994) and the SW monsoonal coastal currents are exceptionally strong and directed southwards (Chandramohan and Nayak, 1992). Therefore, the in-situ wave regime and SW monsoon currents could combinely be effective and responsible for the above said distribution patterns of sediments. Further evidence of complex sedimentary processes associated with the hydrography and the geomorphology of this innershelf is apparent from the distinctive behavioral pattern of the interrelational curves of the sediment size parameters for the two sectors.

In contrast to the innershelf sediments, the textural parameters of the beach sediments show a substantially lower degree of variability among the two sectors. Even then, the sectorisation adopted to discuss the innershelf sedimentation trend is also adopted for the beach environment of the study area (considering the variation in innershelf and nearshore morphology and the wave dynamics). Generally, the mean size of beach sediments remains higher during the monsoonal months and particularly so along the barrier beaches at Panathura. The textural variations for the "monsoon" and "post monsoon" periods appear to depend on the local geomorphic setting and the nature of the sediment as well. For instance, the mean grain size for the pocket beaches around Kovalam (profile # 18 to 20) and Varkala (profile # 66 to 70) cliff sections remains constantly finer during the monsoon and post-monsoon seasons (Figs. 3.17 & 3.18). This anomalous expression is due to the high content of fine black sand placers in these beaches. However, the mean size in pocket beaches does not show any appreciable fluctuation with seasons as observed elsewhere (Liu and Zarillo, 1993; Medina et al., 1994). One reason that results in the lack of coarser grains in the pocket beaches could be the absence of the break-point bar itself between and off the cliffed beaches.

Sortingwise the monsoonal samples are better sorted than the post monsoon samples. The better sorting is due to the removal of fine sands during monsoon period whereas the welding process of break-point bar to the fair weather berm during post monsoon period leads to moderate sorting by the addition of fine sand from the bar to beach face. In general, in the open beaches, selective sorting processes during monsoon leads to the concentration of the dense, finer sized as placers and the removal of the lighter, coarser grains seaward. Later, the post monsoonal swells once again move the finer material from the breaker point towards the beach face. In the cross plots, almost all the post monsoonal samples of the beach (Fig. 3.19) are within the moderately sorted category, nevertheless, the coarser end of the monsoonal curve shows better sorting, whereas the finer end is moderately sorted. This behaviour of the monsoonal curve could be due to the selective removal of fine from the berm by the waves and rip currents towards offshore. The post monsoonal curve shows moderate sorting due to the addition of finer sediments to the beach face from the bars which are in the process of migration towards beach.

Generally, the monsoonal beach sediments of the southern sector exhibit positive skewness; whereas the northern sector beach sediments show negative skewness. This pattern is similar to the trend displayed by the innershelf sediments. This could possibly suggest a difference in energy level on the beaches of two sectors during monsoon season. That is to say that the steeper innershelf of the southern sector causes the wave to break closer to beaches than the gently sloping northern sector innershelf. Kurtosis of the post monsoon beach sediments of the straight beaches between the Varkala and Kovalam changes from mesokurtic

Dashed curve - Post - Monsoon Samples

Solid curve - Monsson Samples

O *Monsoon Samples*

X *Post - Monsoon Samples*

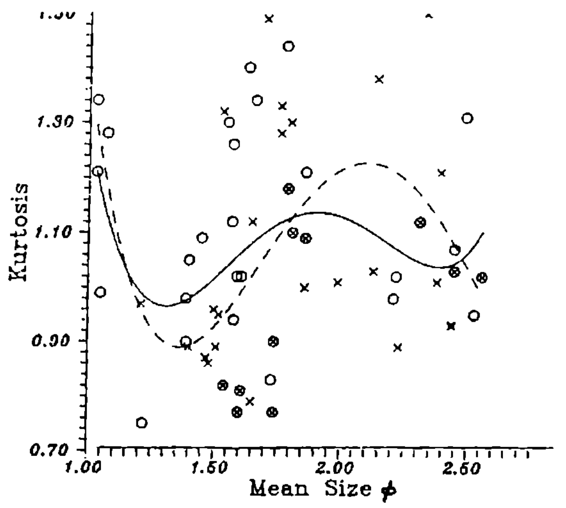


Fig. 3.21

Mean size Vs. kurtosis cross plot for beach sediment

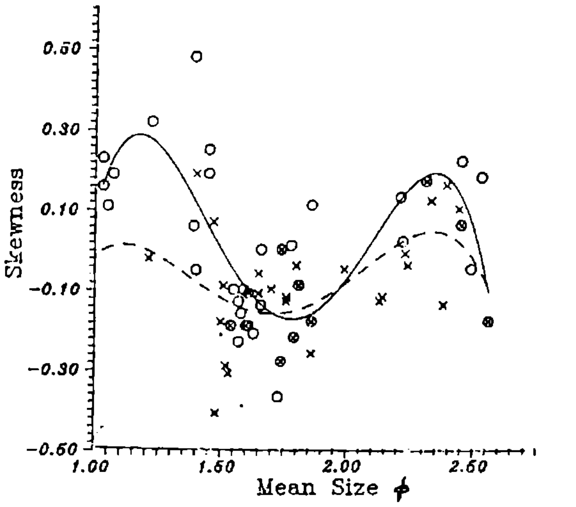


Fig. 3.20 *Mean size Vs. skewness cross plot for beach sediment*

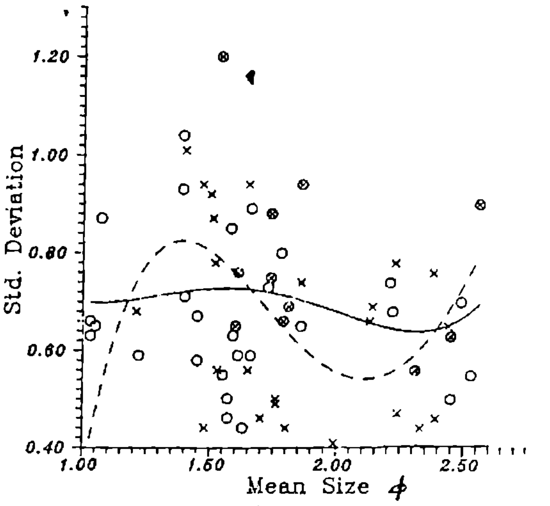


Fig. 3.19

Mean size Vs. standard deviation cross plot for beach sediment to very leptokurtic; whereas the kurtosis of the pocket beach sediments around the Kovalam and Varkala promontories does not show any change with season. This discrepancy may be related to the morphology of the break-point bars which occur consistently off the continuous stretch of sandy beaches rather than off the cliffed beaches. That means, with the on set of the post monsoonal swells the break-point bars are getting eroded there by loosing their finer sand. The finer sand thus removed were deposited on the growing berm which resulted in leptokurtic nature. There are two prominent peaks of kurtosis values seen in the post monsoonal plot at 1.25 ϕ and 1.50 ϕ, that could be due to the selective sorting of the post monsoonal long period swells that move the sediment from the break-point bar shoreward (Fig. 3.21). Moreover, this period witnesses a wider surf zone resulting in the formation of multiple bars. Guza and Thronton (1982) have explained that such a situation would result in a swash-backwash motion on the beach, which in turn segregate the coarser fractions on the swash limit. Therefore, the increasingly positive skewness indicated by the post monsoonal period is attributed to the nature of wave action operative during that period and not necessarily due to coarsening of the sediment.

III. 4. A) SEDIMENTATION PROCESSES

The preceding sections generally show the complexity in the sedimentation process active in the study area. However, a clear concept that explains the nature of sedimentation is still elusive and remains enigmatic. Therefore, in the forthcoming section an attempt is being made to answer a few questions posed by

Dashed curve - Post - Monsoon Samples

Solid curve - Mousson Samples

O - *Monsoon Samples*

X - *Post - Monsoon Samples*

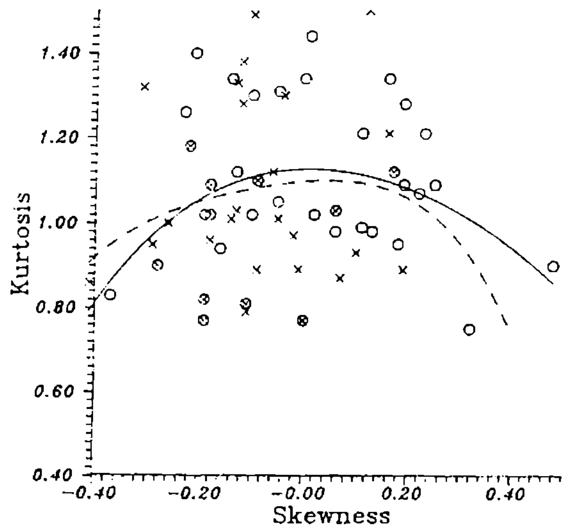


Fig. 3.24 ***Skewness Vs. kurtosis cross plot for beach sediment***

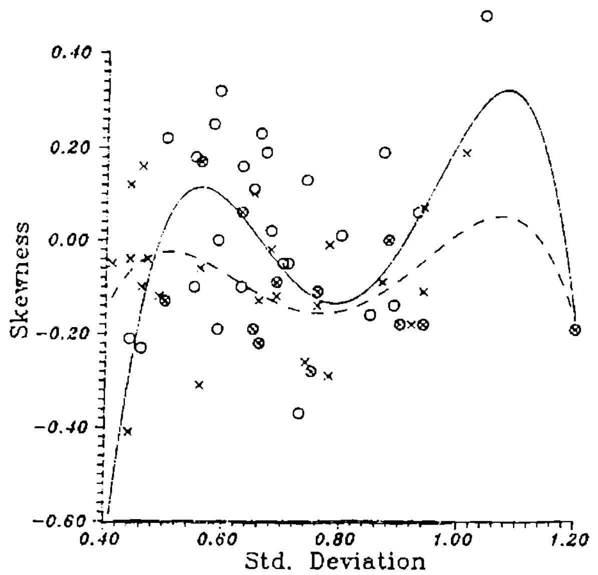


Fig. 3.22 ***Standard deviation Vs. skewness cross plot for beach sediment***

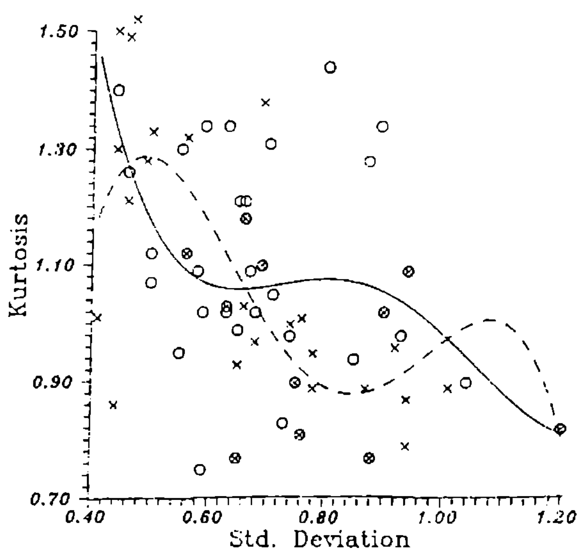


Fig. 3.23 ***Standard deviation Vs. kurtosis cross plot for beach sediment***

the textural and granulometric patterns discussed earlier. To this end, established methods such as "CM diagram" professed by Passega (1964), and "Z" score statistics professed by McLaren (1981) are adopted.

CM Diagram

The ability to identify and describe depositional processes and/or depositional environments from sediment grain size characteristics have been the subject of discussion which invokes much controversy too right from 1890 (Udden, 1898) till today (Visher 1969; Syvitski and Murray, 1977; Tucker and Vacher, 1980; Nechaev et al., 1994). However, it is widely accepted that the finer and coarser fractions in a sedimentary basin could be deposited by different modes and hence they are statistically interrelated. Passega (1957) made use of this principle to explain that the one percentile (C) and median (M) of a grain size population are related and could suggest the mode of transport. Passega (1957, 1964) has divided the general pattern of CM diagram into different segments by points N, O, P, Q, R and S, each representing a different agents of transportation and deposition.

Certain assumptions of the CM method were questioned by Vandenberg (1975) and were satisfactorily answered by Passega (1977). There are two types of sediment at motion that result in deposition of sediments. One is characterized by bottom turbulence competent enough to support the coarsest particles in motion. As the turbulence subsides, the coarsest particles settle. The second type of current is the surface currents which could carry only the finest sediment but has little or no influence on the bottom sediments. The CM diagram of the present study indicates that most of the sediments of the innershelf are transported and deposited by graded suspension. Only a few sediments of the southern sector fall in the PQ (bed load) and RS (uniform suspension) segments. Passega (1977) has shown that the sediments influenced by the QR segment is parallel to the limit C=M (Fig. 3.25) and so suggests that bottom turbulence be effective at the site of deposition as discussed earlier. Sediments in the PQ and QR segments indicate that the currents have considerable influence over the sediments. The sediments of PQ, QR segments are better sorted than RS sediments.

Sediment transport in the innershelf

Several techniques have been adopted by several workers to decipher the clues implied in the distribution patterns of certain aspects such as grain shape, mineralogy, chemistry, sand/mud ratio, isotope geochemistry, trace element etc., (Mazullo and Crisp, 1985; Griffin et al., 1968; Shideler, 1979; Holems, 1982). However, on a shelf with highly complex hydromechanics such as this study area, the behaviour of surficial sediments is equally complex and unpredictable. Moreover, factors that could mask the relationship between grain size and hydrodynamics, such as annual reversal of currents and waves are also prevalent in the area dealt. Despite, it is clear from the preceding section that using many aspects of sedimentary processes, it could be possible to distinguish the sedimentological characteristics manifested by the northern and sectors. However, the direction of sediment transport could not be established.

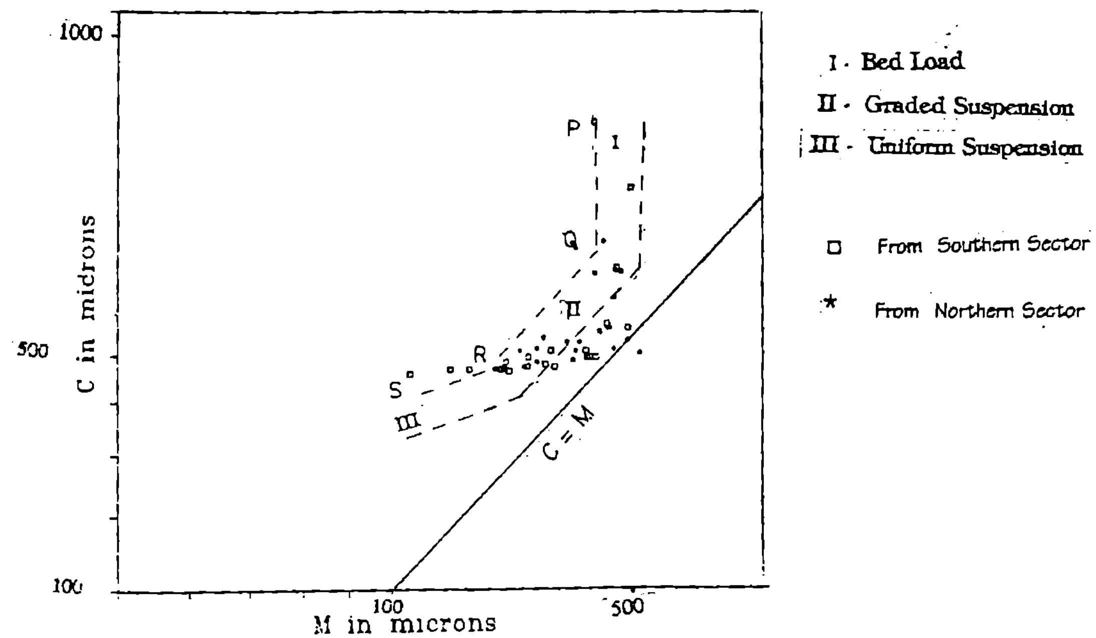


Fig. 3.25 CM diagram for innershelf sediment

Therefore, an attempt has been made here to imply the dominant direction of sediment transport with the help of a transport model suggested by McLaren and Bowels (1985). This model is based on certain statistical considerations of the textural aspect of the sediments. In this model (which will from now on be referred as "McLaren's model") the distribution of sediment in transport is related to their source by a sediment transfer function, which defines the relative probability that a grain in each class interval will be eroded and transported. McLaren and Bowels (1985) have shown that, depending on energy level of the transfer function, in down stream direction, sediments become either coarser, better sorted and more positively skewed ("Case C") or finer, better sorted and more negatively skewed ("Case B"). In recent years the "McLaren's Model" has been subjected to trials in varied environments and found valid in many of them. (McLaren and Little, 1987; McLaren and Poweys, 1989; Prithiviraj and Prakash, 1989; Masselink, 1992; Ramachandran, 1992).

Thirteen samples each from three shore parallel isobaths were selected for this exercise. They are aligned approximately along the 15 m, 30 m and 45 m isobaths. Since moment measures are recommended by McLaren and Bowels (1985) for finding the sediment pathways the mean, standard deviation and skewness were computed using the formulae of Friedman (1967) by a simple macro in a "PC" based spreadsheet (Table 3.2). As mentioned earlier the "McLaren's Model" assumes that, if one sample is compared with another with respect to their mean size, sorting and skewness, then there could exist eight possible trends i.e., compared to sample 1, sample 2 may be (1)finer (F), better sorted (B)and more negatively skewed (-); (2) coarser (C), more poorly sorted (P) and positively skewed (+); (3) F, B, +; (4) F, P, -; (5) F, P, +; (6) C, P, -; (7) C, B, -; or (8) C, B, +. For each of these trends the probability of random occurrence is p = 0.125.

According to McLaren's model only two trends can be indicative of transport directions, namely (i) F, B, - (Case B) and (ii) C, B, + (Case C). Of these two cases, the "Case C" which is associated with coarsening tendency with an improved sorting and more positively skewed distribution in the direction of transport suggests a high energy regime, whereas, "Case-B" the fining of sediment size with progressively increasing sorting values and increase in negative skewness in the direction of transport signifies a low energy environment. Either of these two cases, which satisfies the random probability of 0.125 can be used to figure out the transport direction using the following hypothesis namely;

H_o: when, p< 0.125, there is no preferred direction of transport.

H_1: when, p> 0.125, transport is occurring in a preferred direction

A "Z-test" (Spiegel, 1961) was used as a determinant either to accept or reject H_1 hypothesis. H_1 will be accepted only when Z is >1.645 at 0.05 level of significance or >2.33 at 0.01 level of significance, when,.

$Z = x - Np/\sqrt{Npq}$

Where,

x = observed number of pairs representing a particular case in one of the two opposing directions,

N = $(n^2 - n)/2$, the total number of possible unidirectional pairs, where, `n' is the number of samples in the sequence,

p = the one eighth probability of occurrence either Case B or C, i.e., = 0.125,

q = probability of not occurring transport in a particular direction = (1 - p) = 0.875.

Largely, this investigation suggests,

(i) a dominant southerly transport of sediments in deeper area beyond 30 m. and,

(ii) the shallower reaches (15m) of the innershelf suggest two equally dominant transports in exactly opposite directions (Fig. 3.26, Table 3.3).

The results of the deeper sections agree very much with the theoretical predictions (Sylvester, 1962), numerical modelling (Chandramohan and Nayak, 1989) and clay mineralogical interpretation (Ramaswamy and Nair, 1994). The bidirectional trend observed in the shallower section (at 15 M.) could be due to the influence of littoral drift which is reported to be annually reversible (Machado, 1987; Thomas, 1989).

It is therefore, concluded that the observations in the transacts of deeper sections at 30 m. and 45 m. are truly representing the prevailing net sediment transport trend. Whereas, the sediments along the 15 m. contour is highly influenced by the littoral currents and the rips that are active during SW monsoon. The presence of mud only in the northern sector and coarse grained sediment in the south also adds weightage to this finding. Moreover, since the sediment sampling was done during the post monsoon period, it could be suggested that only SW monsoon currents that are dominant in this innershelf and directed southwards is responsible for the net sediment transport in the study area. Whereas the post SW monsoonal currents have no or little influence on the sediment distribution pattern in the study area.

Transport Direction

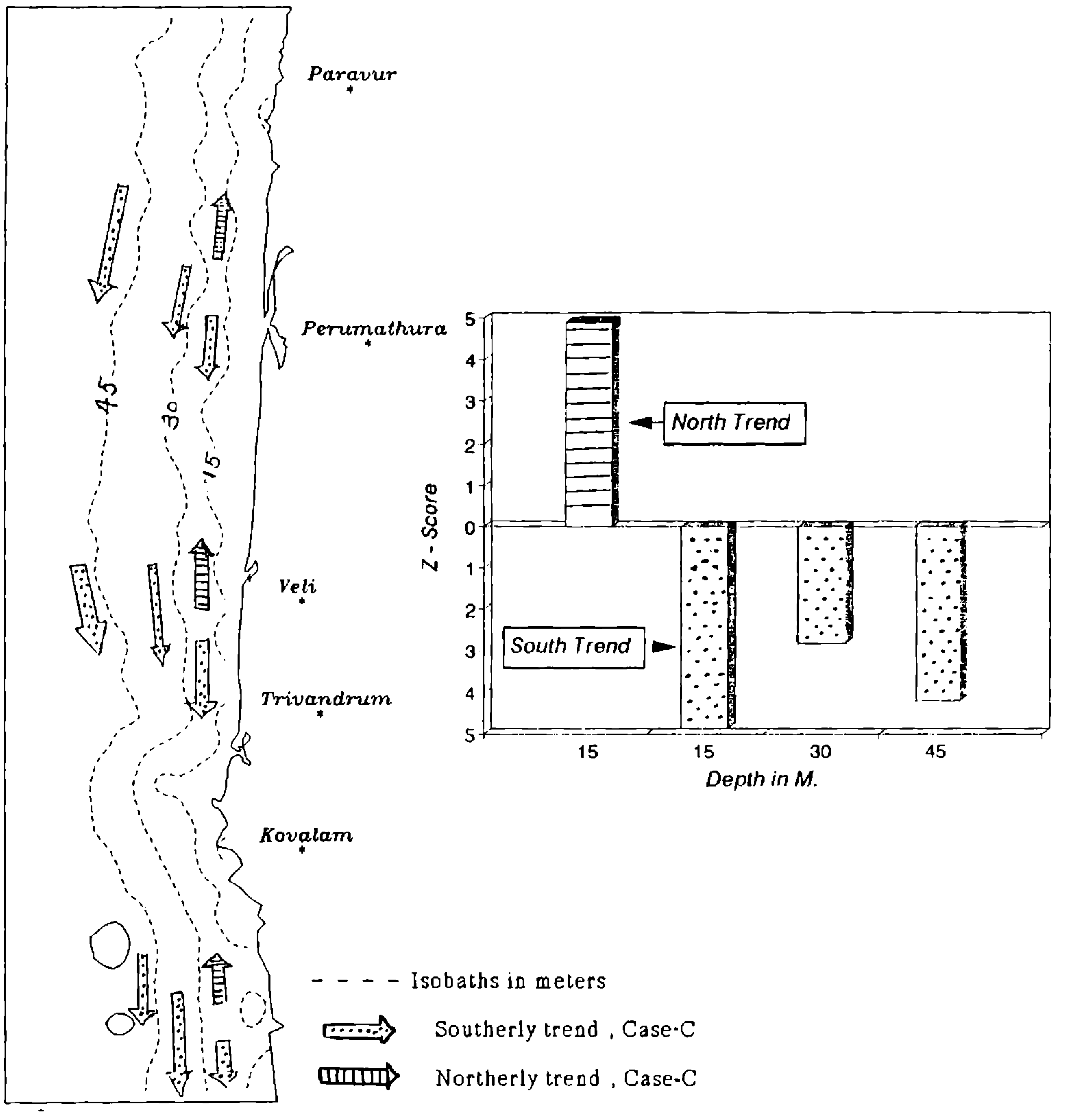


Fig. 3.26 Sediment transport direction derived from McLaren's model

Micro Morphology of sediment grains

Many workers who are pioneers in the field of surface texture studies have established that sometimes an individual or a group of surface textures of a monocrystalline quartz grain could be related to a particular mode of transportational or depositional processes (Krinsly and Donahue, 1968; Krinsley and Morgolis, 1969; Morton, 1985) and this postulation has been proved through experimental simulation of environments as well. Apart from quartz grains, heavy mineral grains are also found to be recording scars typically related to the environment of deposition (Israel et al., 1974; Gravanor et al., 1978; Mallik, 1986). Considering the abundance of heavies in the innershelf and the beaches of the study area, an attempt has been made to study the photomicrographs of garnet, ilmenite, kyanite, sillimanite and quartz.

In general, the quartz grains from the southern sector are smooth, well rounded and almost featureless; compared to the quartz grains of the northern sector are sub angular. This discrepancy could be attributed to the comparatively steeper gradient and more dynamic shelf environment prevailing in the southern sector than the one on the north. Moreover, the absence of mechanical features such as "v" pits and striations which are related to the process of wave action suggests that these grains are confined to areas outside the wave base. The absence of "V" pits also further rule out the probability for onshore - offshore movement of sediments in the study area. The only observable dynamics related micro feature is seen in a grain from sample # C9 off Perumathura, as a disk shaped breakage as seen in Plate 3.1, could be related only to subterranean eolian impact (Margolis and Krinsley, 1974). Such feature on quartz grains is also reported from the northern innershelf of Kerala (Samsuddin et al., 1992).

However, features related to chemical dissolution manifested on grains are observed from both the sectors. Irregular "V" pits suggestive of chemical dissolution, are prevailing in sample # D3 (Plate 3.2) and # E8 (Plate 3.3). Genesis of this feature could be related to the rapid solubility of silica at higher pH environment (8 to 9). Some workers have used these features as an indicator of marine environment (Blackater and Pilkey, 1974; Ly, 1978). Apart from quartz, heavy minerals also exhibit some interesting surface features. Similar to quartz the heavies also do not show any wave dynamics related micro features in the southern sector. Almost all the grains are surrounded to rounded except the garnets and sillimanite that are angular and lenticular respectively. Conchoidal fractures in garnets were conspicuous (Plate 3.4). The kyanite exhibits rhomboidal cleavage whereas the sillimanite shows fibrous cleavages (Plate 3.5). The most interesting observation is the preservence of mamillated surfaces (Plate 3..7) and irregular 'V' pits (Plate 3.8) of garnet from sample C3, which again confirms that these sediments are not subjected to high wave action. Therefore it is suggested that there is no major transport of sediments towards offshore in this region as evidenced by McLaren's Model study, micro morphology of sediment grains and by the lack of any semblance between the granulometric parameters of the innershelf and beach sediments. It is suggested that even if there are offshore movement of sediments the prevailing strong southerly currents tend to transport the sediments alongshore.

CHAPTER - IV

MINERALOGY

IV.1. INTRODUCTION

In the study of sediments greater significance has been given to mineralogy owing to its economic importance. Their role as an indicator of provenance and depositional history of sediments is also considered as very important. Among the mineralogical investigations, heavy mineral analysis is one of the most important and widely used techniques in the determination of provenance. Several heavy mineral species have been reported by many workers from the western continental shelf of India (Mallik et al., 1976; Siddique and Mallik, 1972; Mallik, 1981) and particularly from the innershelf of this study area (Mallik et al., 1987; Senthiappan et al., 1987; Nambiar and Unnikrishnan, 1987). The value of the technique lies not only in the number of possible minerals, but also in that many of them have restricted paragenesis that positively identify the involvement of particular parent rocks. Because of this sensitivity in constraining source rock lithology, heavy mineral assay is widely applied to modern and ancient siliciclasts.

During transportation, minerals are subjected to abrasion processes that could affect the relative abundances of minerals with different mechanical stabilities. Though there are many simulated experimental evidences that enabled the determination of relative mechanical stabilities for detrital minerals (Thiel, 1940; Dietz, 1973) of late, extensive field studies have suggested that the such estimated abrasive index have little significance in the natural environment (Morton and Smale, 1990). Later, a potentially more important process takes place during alluvial storage in the form of diagenesis; whereby, many of the unstable minerals are eliminated in the fluviatile, particularly estuarine and/or backwater system. The effectiveness of the above processes have been studied and explained by Johnson et. al. (1991) on bulk mineralogy and by Morton and Johnson (1993) on heavy mineral assemblage on a down stream suite. Therefore, considering the number of backwater systems and heavy mineral placer deposits in the vicinity of this study area, heavy mineral study in the innershelf and beach is highly significant.

Another important factor is hydraulics. The hydrodynamic conditions at the time of transportation and deposition affect the relative abundances of minerals with different hydraulic properties. Variation in hydraulic behaviour results from differences in the density, size and shape of heavy mineral grains. Ever since Rubey (1933) has conclusively demonstrated that change in hydraulic conditions induce marked variations to heavy mineral suites, there have been extensive works on this topic (Rittenhouse, 1943; Pomerancblum, 1966; Middleton, 1967; Singerland, 1977 & 1984; Komar and Wang, 1984 etc.,) to substantiate Rubey's findings. Although the effects of all these processes have still not been fully evaluated, there are abundant evidences (Morton and Smale, 1990; Johnson et al., 1991; Morton and Johnson, 1993) to show that, either singularly or in combination, they can modify heavy mineral assemblages to the extent that the nature of the source material is no longer apparent.

Therefore, to counteract the effects of the overprinting factors as discussed above, it is necessary to identify and quantify those features of heavy mineral assemblages that are the true reflectors of the mineralogy of the source rocks. The usual procedure of achieving this is by carrying out *varietal studies*. These are studies that concentrate on the variations shown by an individual mineral or a group of minerals. As the *varietal studies* minimize the density and stability range within the population under investigation, the data obtained by varietal studies are essentially independent of variations in hydraulics and diagenetic conditions, hence, are considered as the representative of source material.Therefore, in this investigation, an attempt is being made to identify:

(i). the provenance for the sediments of the study area and

(ii). the factors which control the mineralogical variation.

IV.2. METHODS

IV.2. A. Heavy mineral quantification

As the innershelf of the study area is dominated by sand grade (medium to fine), the mineralogical investigation is restricted to sand fraction only. Further, most of the heavy separations were made in the fine and very fine sand class because of their abundance in this area and for effective comparison. Lewis, (1984), after a comprehensive review of the literature, also recommends 250µ - 63µ class interval as the most suitable size for heavy mineral assay. The selected samples (41 no.) were thoroughly washed through a 230-ASTM sieve to remove silt and clay. The heavies were separated from the lighter ones using "Bromoform" (sp. gr. of ~2.89) and their total percentage were calculated. Heavies from the bulk were then mounted on a glass slide using Canada balsam. Grains were scanned under a petrographic microscope attached with an automatic point counter. The counting was done by line method and the weight percentage of individual minerals were calculated. . Further, the opaques from 13 samples were selected and mounted on baklite, identified (ilmenite & magnetite) under incident light microscope and counted. Based on the point counting data, distribution maps were prepared for some selected heavy minerals. As certain heavy minerals notably rutile and zircon occur as relatively smaller grains (Milner 1962; Komar and Wang 1984)(unlike garnet and tourmaline which are frequently found abundant in larger size classes). Heavy mineral separation was also carried out on some selected (17 no.); in two fractions (250 to 125µ and 125 to 63µ) to understand the potentiality of size dependant variability between these fractions

IV. 2. B. Varietal Studies

Varietal studies, the true reflector of the source rock mineralogy, were carried out to reconstruct the relative abundance of minerals. Unlike other studies varietal studies are unbiased. For example, the classification based on grain shape involves determining several characteristics such as angular, sub-angular, euhedral, sub-euhedral, subrounded etc., and problems are inevitable in classifying some of the grains in a population. Problems in such subjective techniques depend partly on internal consistency of the analyst, which may increase considerably when comparing data from several analysts . Similarly, provenance interpretation of a sediment suite is based independently on a single species, which may lead to biased interpretation. Moreover, there are several processes that are potentially capable of influencing the composition of heavy mineral suites such as weathering in source area, mechanical processes during transit, hydraulic conditions during deposition and diagenesis in the depositional basin (Hubert, 1971).

Therefore, recently, varietal studies which compares the relative abundance of mineral species have gained importance and were successfully adopted both for translucent (Morton, 1991) and opaque minerals (Grigsby, 1990; Basu and Molinaroli, 1991). One of the vital criteria for the success of the varietal studies is the determination of relative proportion of heavy minerals which behave in similar way during the processes of transportation and deposition. Many authors have successfully used this technique to establish provenance for detrital heavy minerals such as zircon (Krynine, 1946), tourmaline (Poldervaart, 1955), apatite (Morton, 1986) and garnet (Morton, 1994).

It is established that the aspect of conventional heavy mineral analysis, which most closely reflect the nature of source area, is the ratios of stable minerals with similar hydraulic behaviour. Conventional heavy mineral data are generally calculated by undertaking a count of 100 to 200 detrital grains from the residue retrieved from the heavy liquid. Although, this approach gives a good characterisation of the entire mineral suite the errors associated with the abundance of individual minerals is significant, particularly for minerals occurring in small amounts. Consequently, if mineral ratios are calculated using these data the result produced would not reflect the true nature of the source rock. In order to produce more accurate data that can be used with confidence to interpret provenance, each individual ratio must be determined on the basis of separate counts using, a minimum of 100 grains per mineral pair (Morton, 1994). To avoid the problem of infinite values (obtained from a normal ratio determination). where a second mineral of the pair be absent from the assemblage, the minerals with comparably equal abundance were only to be selected. Other criteria considered density ratio and differential density percentage as given below:

Mineral pairs	Habit	Density	Density ratio	Density differential %
Apatite	Equant/			
	Prismatic	3.23		
Garnets	Equant	4.10	0.78	22
Zircon	Equant/			
	Prismatic	4.65	0.91	9
Monazite	Equant	5.10		
Sillimanite	Prismatic	3.25	0.90	10
Pyroxenes	Prismatic/	3.58		
	Equant			

(Density values for garnets and pyroxenes are obtained from the mid-range values for the series taken from Deer et al. 1978)

Even though the density differential percentage for certain heavy minerals of this study ranges from 2% (zircon:spinel) to 33% (tourmaline:zircon); as these pairs donot satisfy the other parameters such as abundance, habitat etc., these pairs were not considered. While grouping the minerals for index calculation the primary consideration was their abundance in any particular rock type. For this purpose sillimanite and pyroxenes which are paragenetically related to the two dominant clans of rocks in the hinterland (metamorphosed khondalite/sillimanite geneses and the charnockite respectively) were selected as reference index (SPi). Similarly, apatite and monazite which are more abundant in charnockite type of rocks were indexed respectively against garnet and zircon which are more abundant in khondalite and garnet-sillimanite gneiss.

Index	*Mineral pair*	*Index determination*
GAi	garnet/apatite	100 x garnet count/(total garnet + apatite)
ZMi	zircon/monazite	100 x zircon count/(total monazite + zircon)
SPi	sillimanite/pyroxene	100 x sillimanite count/(total sillimanite + pyroxene)

The ratios given as index values are given in Table 4.2 and plotted in Fig.4.1. These indexes provide a good reflection of source area characteristics because they are comparatively immune to alteration during the sedimentary cycle. Moreover, they are not affected by processes during and after sedimentation and so could be directly match sediment source material , even for suites of first cycle origin that have been affected by diagenetic processes. Because of the distinctiveness of the sedimentological parameters seen in the southern and northern sectors, samples from these sectors were plotted with different symbols.

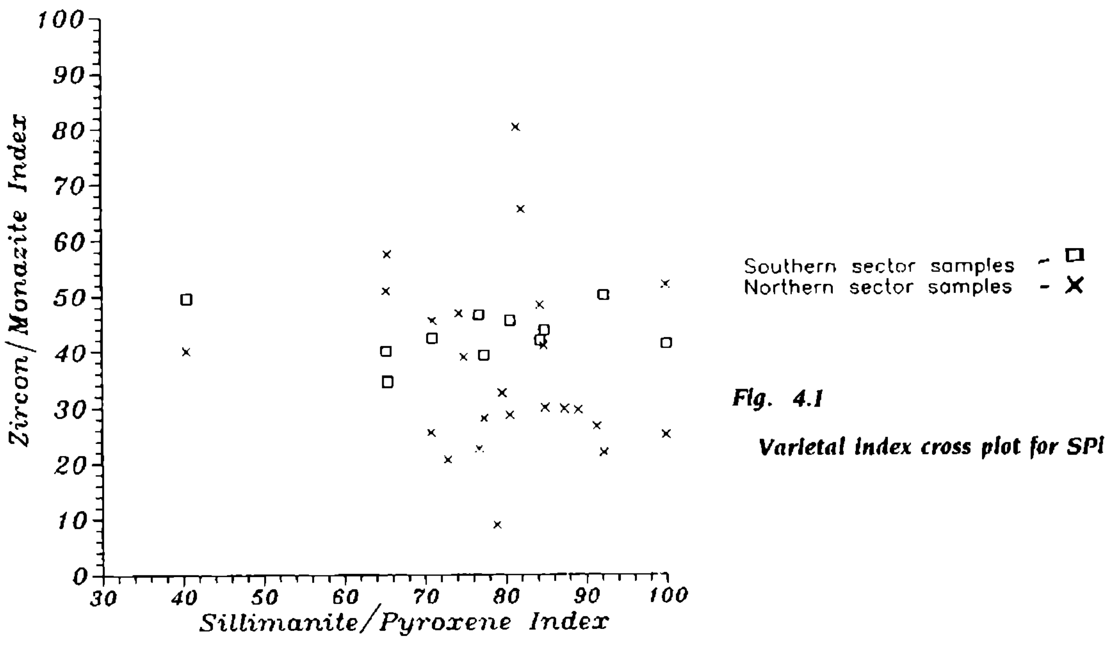


Fig. 4.1

Varietal index cross plot for SPI Vs. ZMI

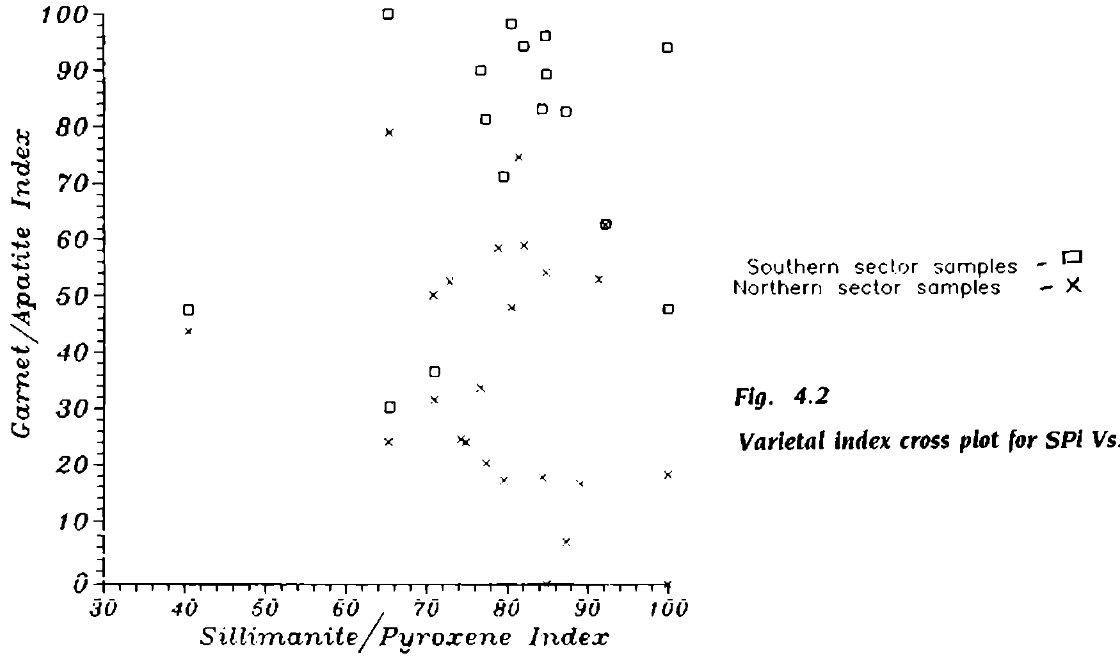


Fig. 4.2

Varietal index cross plot for SPI Vs. GAI

IV.2. C. Electron Microprobe Analysis

Despite the distinctive advantages of varietal studies, it is necessary to consider some other important criteria also before making use of the heavy mineral data to decipher provenance. One of the criteria is involve features of the conventional heavy mineral data that are directly acquired from the source area and are not affected by any of the sedimentary processes. One aspect that satisfies these required criteria in a fluviatile environment is the determination of the relative proportions of minerals that behave similarly during the processes of deposition. They should, therefore, have similar mechanical and chemical stability and similar hydraulic behaviour; narrower these differences, more realistic would be the inference. For this purpose, there cannot be any mineral pair that is more suited than the different varieties of a single mineral group such as garnet (Morton and Hallsworth, 1994). Moreover, garnet is the most ubiquitous heavy mineral in the hinterland rock types of the study area (Santosh, 1987). Therefore, to understand the distribution pattern of garnet varieties in the innershelf, microprobe analysis was carried out on 66 garnet grains. The grains were picked up under a binocular microscope using a needle. Garnets from 125µ - 63µ size grade only was selected, so as to eliminate the hydraulic differentiation. Elemental analysis of garnet grains was done on a "CAECA" electron microprobe available at the Bhaba Atomic Research Centre, Trombay. It was operated at a low voltage of 15 kV, with a counting time of 15 seconds and beam width of 1µ to 4µ.. Beam drift was checked and corrected from time to time. All standards used were synthetic compounds. Analysis includes elements such as Si, Al, Ca, Mg, Ti, Cr, Fe, Ni, Na and K and oxides include SiO_2, Al_2O_3, Cr_2O_3, Fe_2O_3, FeO, MgO, CaO, MnO, Na_2O, K_2O, NiO, which were sufficient to find out the type of garnets being analysed. Various analytical precautions recommended by Anderson (1973) were followed. Single point analysis was done for 66 garnet mono-crystals.

IV.3. RESULTS

IV. 3. A. Heavy mineral content in the innershelf sediments

Almost all the analyzed samples contain heavy minerals, though in small amount. The weight percentage of heavy minerals in the bulk sediments varies from <1% to 9.8%.

Aerial distribution pattern of total heavies (Fig. 4.3) shows that the higher concentration of heavies (7-9%) is mainly confined to 20-40 m isobaths northwest of the Kovalam promontory. Concentration of heavies ~ 5% is also observed extending in a linear zone between depths of 20 to 30 m off the Veli - Paravur stretch. An interesting observation is that the heavy mineral percentage decreases with depth and towards the area south of the Kovalam promontory. Among the heavies, ilmenite dominates the heavies followed by sillimanite and aragonite. Garnet, rutile, monazite, zircon, hornblende, pyroxenes, kyanite, tourmaline, actinolite / tremolite, biotite, muscovite, leucoxene, glauconite and occasional pyrite form the minor constituents. Their range, average and standard deviation are shown in Table 4.1. For preparing the distribution map and later discussion the different minerals coming under the group of pyroxene, amphibole

Table . 4 - 1 Percentage of heavy minerals in inner shelf sediment

Sam No.	Tot. HM	Opaq	Ilmn	Magn	Sill	Arag	Mona	Zirn	Pyro Clno	Grnt	Appa	Horn	Epid	Musc	Kyan	Pyro Orth	Rutl	Unid	Anda	Trem Actn.	Aug/ Diop	Biot	Star	Sphn	Glau	Tour	Total %
E1	1.89	11.70	10.98	0.72	17.43	23.34	4.20	3.50	7.90	2.50	5.14	3.10	5.64	2.80	2.00	2.76	2.30	1.70	0.00	1.40	0.00	1.37	0.00	0.00	1.15	0.00	99.93
D1	2.25	38.70	36.00	2.70	20.80	8.00	3.20	2.45	3.20	5.60	1.50	1.12	0.00	0.00	0.30	4.30	3.04	2.36	0.00	1.44	1.23	1.12	0.00	0.32	0.50	0.80	99.98
C1	2.35	26.67	25.80	0.87	20.75	1.26	19.50	5.66	5.03	1.26	2.51	0.00	4.40	0.70	5.60	1.26	1.25	2.20	1.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99.95
D2	2.20	33.25	31.57	1.68	17.54	25.34	8.87	2.14	0.00	0.38	1.75	1.16	1.75	0.97	2.33	0.00	1.36	0.00	0.97	0.58	0.00	0.00	0.00	0.00	0.90	0.00	99.29
C2	2.30	33.90	28.43	5.47	23.75	0.30	10.45	7.25	3.33	2.58	2.20	0.60	0.00	2.10	0.45	0.00	2.75	5.44	0.00	0.00	4.25	0.61	0.00	0.00	0.00	0.00	99.96
A2	3.35	32.23	28.76	3.47	11.62	8.23	8.32	4.23	10.56	3.54	4.56	0.56	1.08	4.23	2.98	6.53	1.42	0.00	0.00	0.35	0.00	0.56	0.00	0.00	0.52	0.00	99.52
D3	3.69	33.56	32.54	1.02	16.56	9.68	10.51	4.20	2.86	1.69	1.85	5.60	1.00	2.65	2.56	1.13	1.13	0.00	1.16	1.20	0.00	0.65	0.56	0.00	0.00	0.00	98.55
B3	2.30	30.58	29.56	1.02	24.30	6.80	4.40	4.10	3.25	1.20	5.70	0.50	7.20	0.00	0.15	1.26	2.70	7.70	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	100.00
A3	3.60	29.40	25.65	3.75	16.30	23.60	6.80	1.90	0.82	2.16	1.30	1.92	4.56	2.10	1.80	0.55	1.20	0.00	1.70	1.10	0.00	0.50	1.15	1.00	0.00	0.00	99.86
C4	4.65	20.23	19.54	0.69	19.33	27.23	3.00	3.10	9.00	1.00	3.20	3.80	3.60	1.50	1.30	1.30	0.00	0.00	0.00	1.80	0.00	0.60	0.00	0.00	0.00	0.00	99.99
B4	5.50	42.56	38.64	3.92	16.42	1.24	5.80	2.25	4.16	1.30	5.20	0.64	3.52	3.52	3.50	0.64	0.00	6.60	1.20	0.32	0.00	0.00	0.00	0.00	0.00	0.50	99.37
A4	6.68	37.23	34.65	2.58	26.58	7.60	2.90	5.50	5.30	3.56	2.50	0.70	0.00	1.20	1.30	0.50	1.20	0.00	0.85	0.50	0.00	0.00	0.54	0.50	0.00	0.00	98.46
D5	6.45	27.35	25.45	1.90	14.25	13.25	14.32	6.10	0.00	0.00	5.21	3.50	1.41	2.56	2.54	2.53	2.20	0.00	1.24	1.23	0.00	0.50	1.20	0.00	0.00	0.00	99.39
B5	9.85	37.01	35.54	1.47	31.25	8.23	3.65	3.95	0.00	0.00	4.80	1.16	2.00	0.00	0.54	0.00	0.00	0.20	0.00	0.00	4.89	0.00	1.60	0.00	0.00	0.00	99.28
A5	8.27	37.12	34.65	2.47	28.92	7.92	3.28	4.73	2.65	1.78	3.65	0.93	1.00	0.60	0.92	0.25	0.60	0.10	0.43	0.25	2.45	0.00	1.07	0.25	0.00	0.00	98.87
F6	5.83	26.92	25.76	1.16	17.58	16.53	11.19	4.74	0.45	0.31	4.18	3.37	1.56	2.19	2.54	2.10	1.95	0.00	1.15	1.23	0.00	0.50	1.04	0.00	0.00	0.00	99.52
D6	5.16	24.46	23.65	0.81	21.07	15.38	7.60	3.84	3.98	0.93	4.59	4.68	2.28	1.69	2.77	1.42	0.98	0.00	0.58	1.27	0.00	0.53	0.52	1.28	0.00	0.00	99.64
C6	4.50	22.00	19.45	2.55	24.56	14.23	4.00	2.55	7.50	1.56	5.00	6.00	3.00	1.20	3.00	0.75	0.00	0.00	0.00	1.30	0.00	0.56	0.00	2.56	0.00	0.00	99.77
B6	5.80	47.95	43.54	4.41	11.04	6.62	9.78	0.95	2.00	2.21	1.58	0.95	3.47	4.31	4.73	0.95	1.26	0.00	1.26	0.32	0.00	0.00	0.00	0.00	0.00	0.00	99.38
E7	5.20	26.49	25.43	1.06	20.92	19.80	8.06	3.38	0.90	0.62	3.16	3.23	1.72	1.82	2.54	1.67	1.70	0.00	1.07	1.23	0.00	0.50	0.00	0.00	0.00	0.00	99.65
C7	3.50	22.23	21.43	0.80	20.20	9.83	10.80	9.50	7.00	1.48	4.60	2.80	0.00	0.70	0.80	0.00	0.50	0.00	8.00	0.46	0.00	0.70	0.40	0.00	0.00	0.00	100.00
A7	4.23	58.25	52.54	5.71	7.50	0.80	10.10	3.45	2.29	1.60	1.60	0.80	0.63	2.19	3.10	0.80	1.06	4.30	0.27	0.53	0.00	0.53	0.00	0.00	0.00	0.00	99.70
D8	3.95	25.63	23.65	1.98	27.58	26.35	1.80	0.65	1.80	1.23	1.10	2.96	2.02	1.07	2.53	0.80	1.20	0.00	0.89	1.23	0.00	0.50	0.56	0.00	0.00	0.00	99.90
C8	6.50	53.62	51.34	2.28	13.56	0.00	9.78	2.52	5.05	1.10	1.00	2.21	0.63	1.89	3.40	0.00	1.58	0.00	1.43	0.63	0.00	0.32	0.00	0.00	0.00	0.00	98.72
B8	4.89	38.23	35.65	2.58	31.25	0.56	1.50	6.12	4.90	3.50	1.21	2.50	1.50	1.10	1.90	2.20	1.20	0.00	0.00	0.85	0.00	0.35	0.00	0.00	0.00	0.00	98.87
C9	3.54	20.70	19.43	1.27	20.00	21.87	6.00	4.40	4.80	2.00	3.50	3.80	2.80	0.90	2.50	0.80	1.40	0.00	1.50	1.00	0.00	1.40	0.00	0.00	0.60	0.00	99.97
B9	4.96	20.20	18.34	1.86	16.23	5.60	7.40	3.90	19.30	4.00	9.30	2.96	1.50	1.10	1.80	3.10	0.00	0.00	1.00	1.20	0.00	1.40	0.00	0.00	0.00	0.00	99.99
D10	3.23	33.60	31.32	2.27	26.97	13.18	4.33	3.76	1.66	4.88	0.55	2.61	1.01	2.79	1.27	0.40	1.38	0.00	0.45	0.62	0.00	0.25	0.28	0.00	0.00	0.00	99.95
B10	3.80	27.97	25.32	2.65	19.23	5.97	6.40	4.47	9.49	3.99	4.43	2.08	1.22	2.07	1.62	3.36	1.76	0.76	0.49	0.73	2.14	0.75	0.15	0.00	0.26	0.00	99.33
E11	2.86	37.58	35.98	1.60	26.66	6.59	5.59	5.32	1.59	6.70	0.28	2.44	0.51	3.64	0.63	0.20	1.47	0.00	0.22	0.31	0.00	0.13	0.14	0.00	0.00	0.00	99.97
B11	3.21	29.41	28.65	0.76	17.69	4.27	7.40	5.74	7.41	3.06	3.38	0.58	1.08	2.30	1.72	8.53	2.09	1.50	0.00	0.35	4.25	0.59	0.00	0.00	0.52	0.00	99.84
F12	2.68	39.57	37.65	1.92	26.50	3.29	6.22	6.09	1.56	7.61	0.14	2.35	0.25	4.07	0.32	0.10	1.52	0.00	0.11	0.15	0.00	0.06	0.07	0.00	0.00	0.00	99.98
C12	3.27	37.08	31.43	5.65	24.01	2.71	7.02	5.86	3.29	5.63	1.16	1.81	1.20	4.01	1.06	1.68	1.40	0.38	0.06	0.16	1.06	0.18	0.04	0.00	0.13	0.00	99.93
A12	3.86	34.60	32.43	2.16	21.52	2.13	7.83	5.62	5.03	3.65	2.18	1.28	2.14	3.95	1.80	3.27	1.29	0.75	0.00	0.18	2.13	0.29	0.00	0.00	0.26	0.00	99.88
F13	2.50	41.56	39.43	2.13	26.35	0.00	6.85	6.87	1.52	8.52	0.00	2.26	0.00	4.50	0.00	0.00	1.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99.99
B13	4.50	39.78	37.54	2.24	25.36	0.00	8.25	5.50	2.65	4.23	0.98	1.98	3.20	5.60	1.89	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99.92
E14	3.03	39.34	38.67	0.67	29.28	0.00	7.37	6.83	1.04	6.51	0.00	1.75	2.49	2.53	0.28	0.77	1.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	99.34
A14	4.20	37.72	34.65	3.07	24.80	0.00	7.53	4.87	2.83	4.02	0.49	3.77	4.22	3.40	1.73	3.45	0.65	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.18	99.94
F15	3.56	37.12	35.73	1.39	32.21	0.00	7.89	6.78	0.56	4.50	0.00	1.23	4.98	0.56	0.56	1.54	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	98.68
C15	3.73	36.39	33.54	2.84	28.22	0.00	7.35	5.51	1.78	4.15	0.00	3.40	5.11	0.88	1.06	4.22	0.66	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.30	99.32
A15	3.90	35.65	33.61	2.04	24.23	0.00	6.80	4.23	3.00	3.80	0.00	5.56	5.23	1.20	1.56	6.89	0.80	0.00	0.00	0.00	0.00	0.65	0.00	0.00	0.00	0.36	99.96
MAX	9.85	58.25	52.54	5.71	32.21	27.23	19.50	9.50	19.30	8.52	9.30	6.00	7.20	5.60	5.60	6.89	3.04	7.70	8.00	1.80	4.89	1.40	1.60	2.56	1.15	0.80	100.00
MIN	1.89	11.70	10.98	0.67	7.50	0.00	1.50	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	98.46
AVG	4.19	33.31	31.07	2.23	21.71	8.48	7.12	4.49	3.94	2.93	2.57	2.31	2.21	2.11	1.84	1.71	1.23	0.83	0.68	0.58	0.55	0.41	0.23	0.14	0.12	0.06	99.60
STD	1.66	8.96	8.32	1.32	5.83	8.44	3.37	1.79	3.62	2.09	2.08	1.48	1.79	1.38	1.21	1.83	0.74	1.85	1.29	0.53	1.26	0.39	0.41	0.46	0.26	0.16	0.45

Opaq = ilmn+Magn

Tot.HM	Total Heavy minera
Opaq-	Opaque
ilmn	ilmenite
Magn-	Magnetite
Sill-	Sillimanite
Arag-	Aragonite
Mona-	Monazite
Zirn-	Zircon
Pyro.Clino	Clino Pyroxene
Grnt-	Garnet
Appa-	Appatite
Horn-	Hornblende
Epid-	Epidote
Musc-	Muscovite
Kyan-	Kyanite
Pyro.Orth	Ortho Pyroxene
Rub-	Rutile
Unid-	Unidentified
Anda-	Andalusite
Term/Actn	Tremolite/Actinolite
Diop-	Augite/Diopsite
Biot-	Biotite
Star-	Staroulite
Sphn-	Sphene
Glau-	Glauconite
Tour-	Tourmaline

Distribution pattern of some heavy minerals in innershelf sediments

Total Heavies

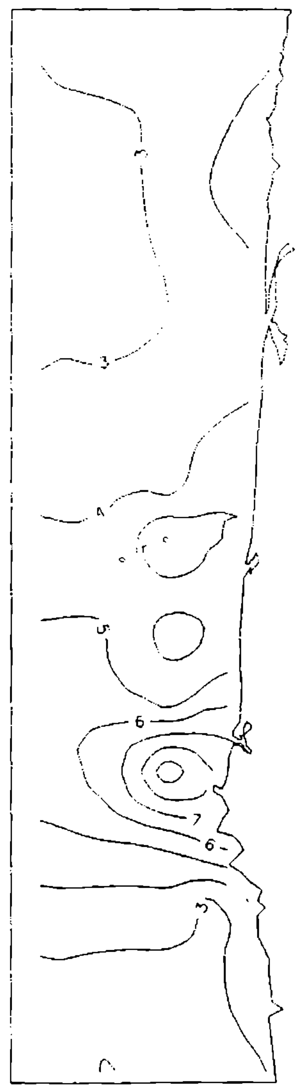


Fig. 4.3

Opaques

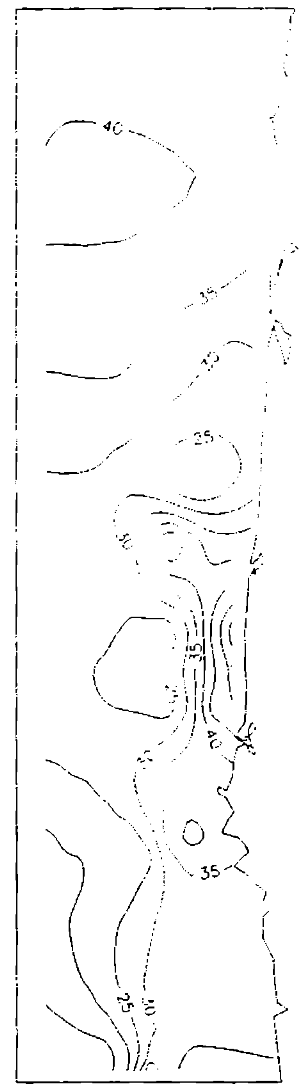


Fig. 4.4

Ilmenite

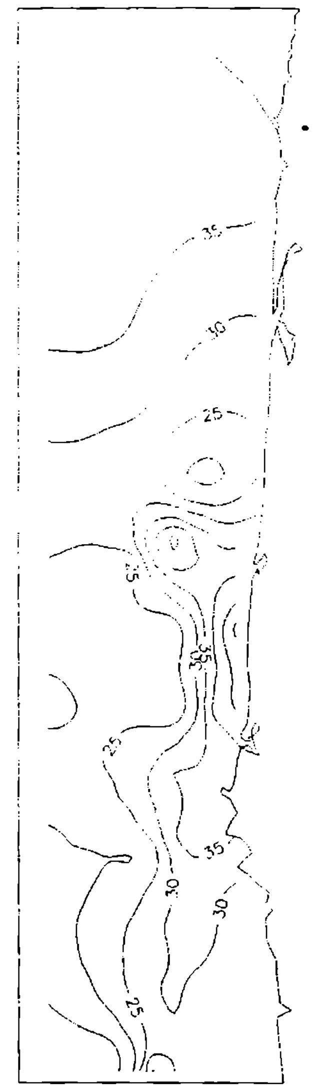


Fig. 4.5

Magnetite

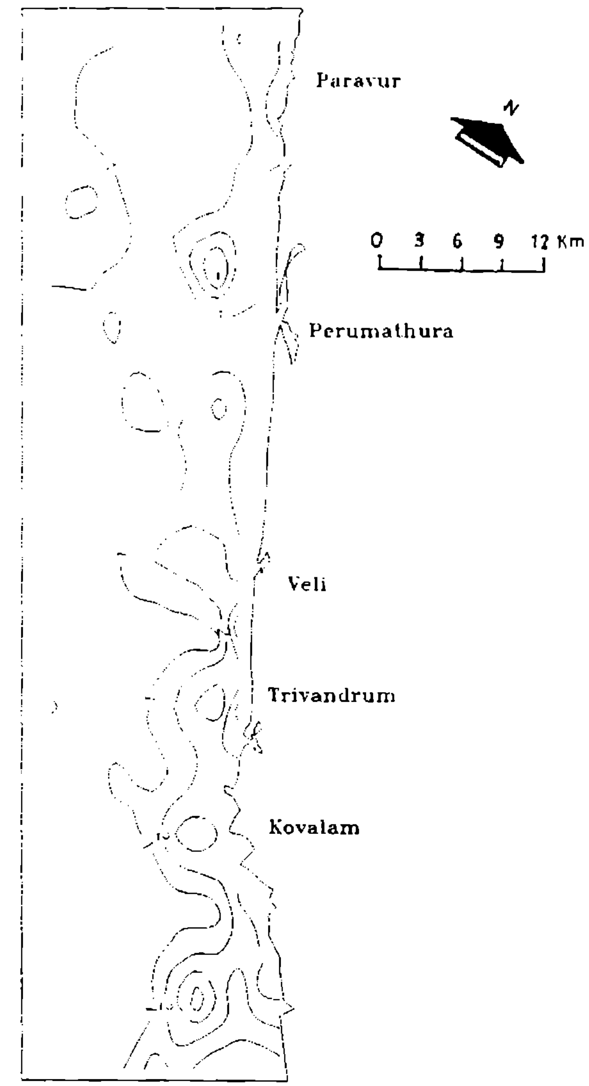


Fig. 4.6

and opaques are grouped under their respective groups. Almost all the individual species of heavy minerals shown a distribution pattern resembling the general total heavy mineral distribution in the study area. However, carbonate distribution pattern indicates an increasing trend towards southwest of Kovalam. The characteristics of some of the major heavy minerals of the study area in their order of abundance are described below. The distribution pattern of some selected minerals are also presented in Figs. 4.3 to 4.14.

Opaques: Opaques form the major constituent of the heavies. Distribution of opaques (Fig.4.4) indicates comparatively higher concentration (30 to 40%) in the northern sector. Ilmenite and magnetite are the chief constituents of opaque fraction. Ilmenite is the dominant opaque mineral, grains were subhedral to euhedral, brownish or pinkish tint were identifiable under reflected light. Ilmenite grains exhibited rare dark brown internal reflection which were anisotropic with greenish grey tint under crossed nicol (Fig. 4.5). The least abundant opaque is magnetite with greenish or greyish brown color without internal reflection and isotropic under reflected light (Fig. 4.6).

Sillimanite: Generally grains were colourless and elongated. Some short and equidimentional grains were also encountered. Symmetrical extinction, higher birefringence and positive elongation were some of the distinctive criteria used to differentiate sillimanite form kyanite and andalusite. Distribution of sillimanite (Fig.4.7) suggests preferential adherence to the coarser southern sector sediments.

Distribution pattern of some heavy minerals in innershelf sediments

Silimanite

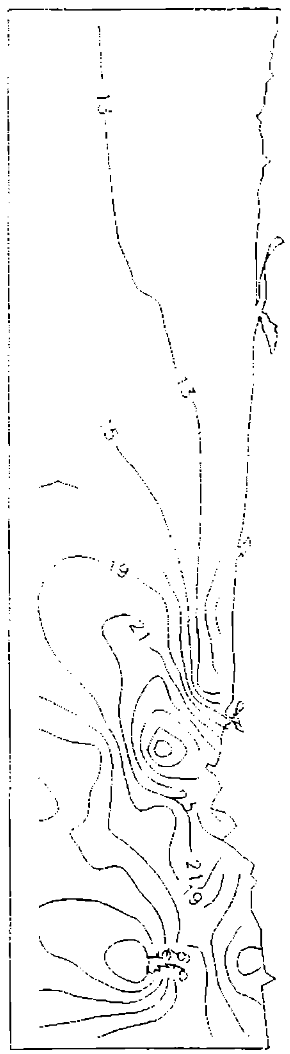


Fig. 4.7

Pyroxenes

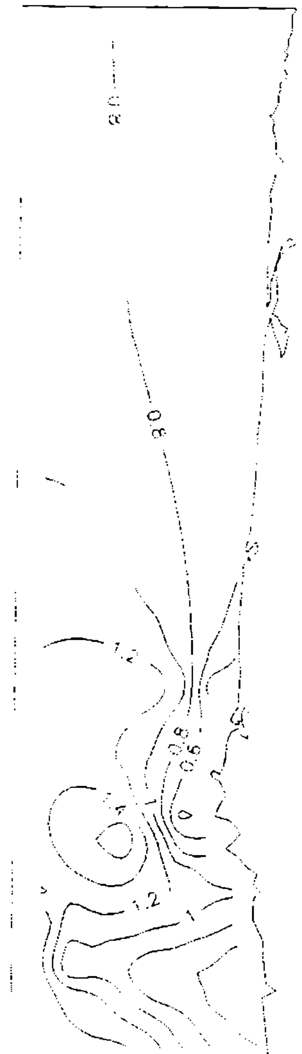


Fig. 4.8

Kyanite

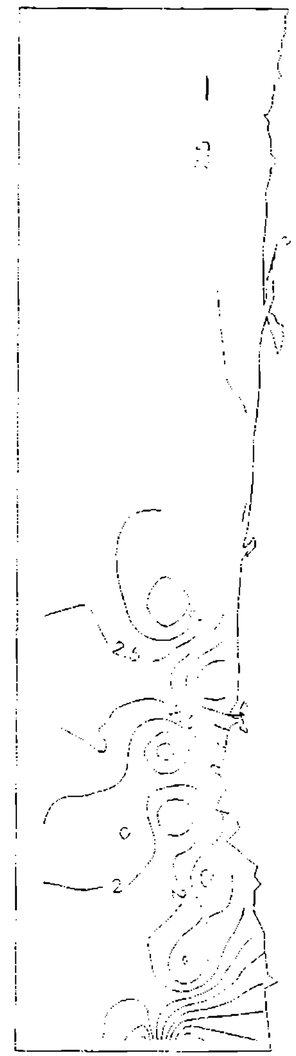


Fig. 4.9

Rutile

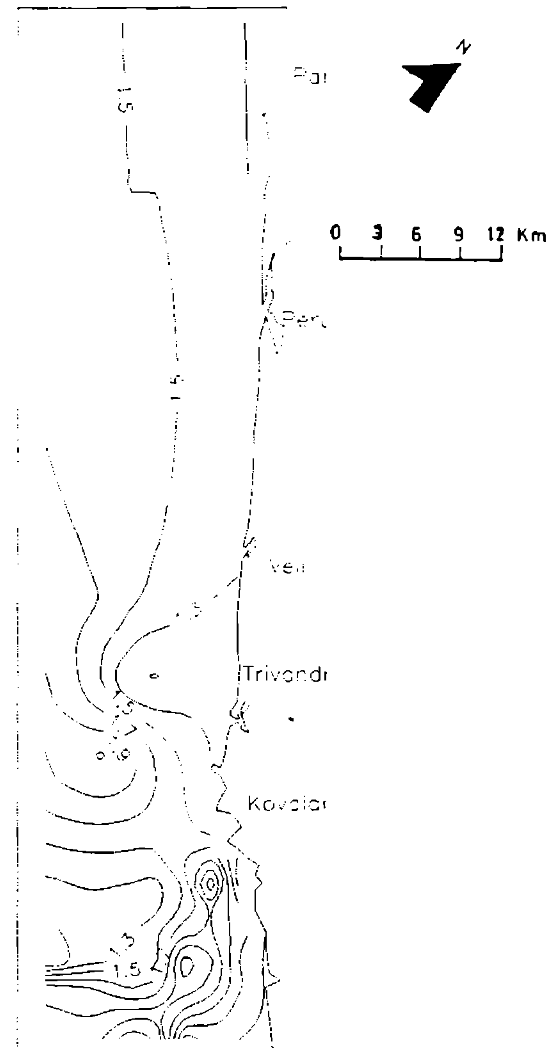


Fig. 4.10

Aragonite: The only carbonate mineral encountered in this study is aragonite, which were colourless, showing imperfect cleavage and typical twinkling nature under polarised light. Like sillimanite carbonate distribution also show higher concentration in the coarser sediments of the southern sector (Fig.4.11).

Garnets : Occurred as broken specs. The specs were fresh, angular to sub-angular with conchoidal fracture and isotropic. Dark brown, brown, and pink verities were accounted (Fig. 4.12).

Monazite: Of all the heavies, monazite was readily identifiable because of its typical high degree of roundness and very high relief (Plate 4.1). Some grains were faintly pleochroic from colourless to very light yellow. Monazite distribution appears to be indicating more adherence to the northern sector sediments than the south (Fig: 4.13).

Zircon : Grains were ellipsoidal and identified by straight extinction, very high relief and birefringence. Some grains showed smoky nature. Although the grains were generally colourless, some brownish grains were also seen. Zircon is concentrated more in the northern sector sediments (Fig.4.14).

Rutile : Most of the grains were prismatic with rounded edges. Identified with different shades of blood red colour, very high relief and straight extinction, pale yellowish to reddish brown internal reflection.Unlike most of the other heavies rutile did not show any preferential concentration in any of the two sectors (Fig. 4.10).

Distribution pattern of some heavy minerals in innershelf sediments

Aragonite

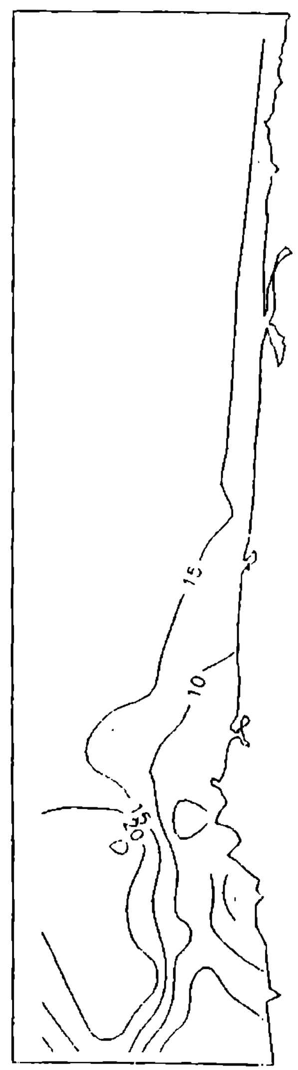


Fig. 4.11

Garnet

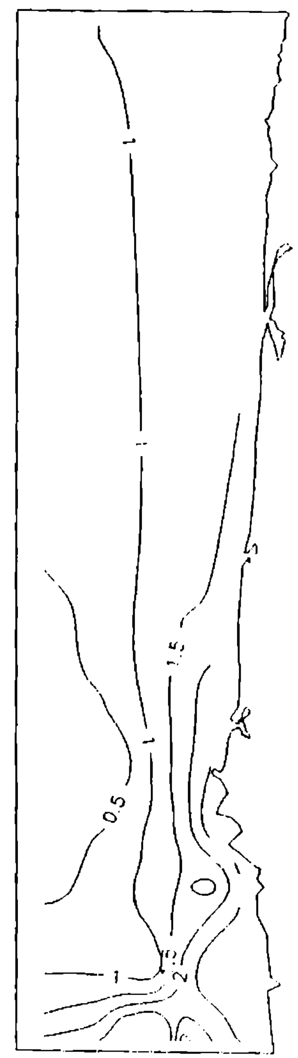


Fig. 4.12

Monazite

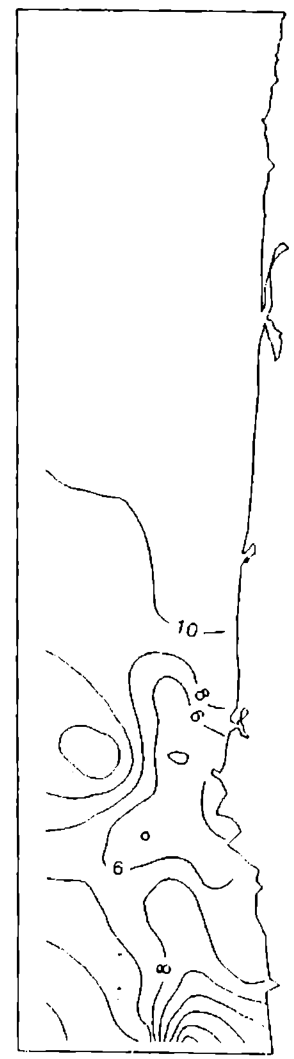


Fig. 4.13

Zircon

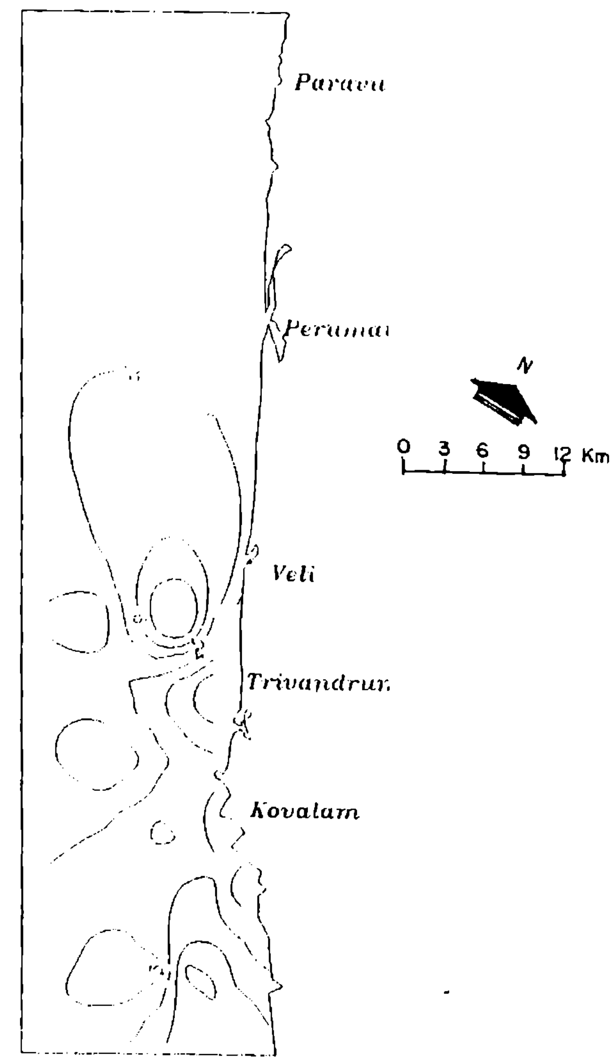


Fig. 4.14

Pyroxenes : The most common variety of the pyroxene was hypersthene. Hypersthene was identified by the characteristic pink to green pleochroism, straight extinction and perfect cleavages. Some clinopyroxene, mostly augite and diopsite, were also identified and quantified (Fig. 4.8).

Amphiboles : Hornblende was the common amphibole present, which were of different shades of green. Green to brown and light brown to dark brown pleochroic verities were observed. Lesser amounts of actinolite / tremolite were also noticed by their fibrous appearance and pale yellow to green pleochroism (Plate).

Epidote : Grains were in yellowish shades. Faintly pleochroic from pale yellow to pale green. Grains were exhibiting high relief, low birefringence, perfect cleavage, well developed striations parallel to y-axis.and of tabular nature.

Kyanite : Kyanite was identified by their high relief, low birefringence, tabular nature, perfect '010' cleavage and inclined extinction (Fig. 4.9, Plate).

Biotite : Brown to reddish brown variety, strongly pleochroic (light brown to dark brown) and low birefrengence grains of biotite were noticeable.

Tourmaline : Grains were rounded to sub-rounded with dark brown colour showing strong brown to yellow pleochroism, straight extinction, moderate relief, moderate birefrigence.

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IV. 3. B. Varietal Studies

Results of varietal study and the cross plots are shown in Table 4.2 and Fig 4.1 and 4.2. The SPi Vs. ZMi does not show any distinctive grouping for the two sectors however, a slight grouping tendency is observed in SPi Vs. Gab cross plot.

IV. 3. C. Electron Microprobe Analysis of garnet

Results of electron microprobe analysis of garnets were plotted on two separate ternary plots to know if there is any compositional difference for garnets from the two sectors. (Fig:4.15). Garnets from both the sectors have fallen in a narrow field of 60 to 80% almandine and 20 to 40% pyrope while the other garnets constituting less than 10%. Details of percentage distribution of different garnet verities calculated based on 24 oxygen basis is given in the Table 4.3.

IV.4. DISCUSSION

IV. 4. A. Innershelf

Generally all heavies indicate a seaward decreasing trend. Except garnets, sillimanite and aragonite, all other heavies are concentrated in the northern sector. This tendency could not be exclusively related to the hinterland petrography, because the aerial distribution of heavies in a highly dynamic

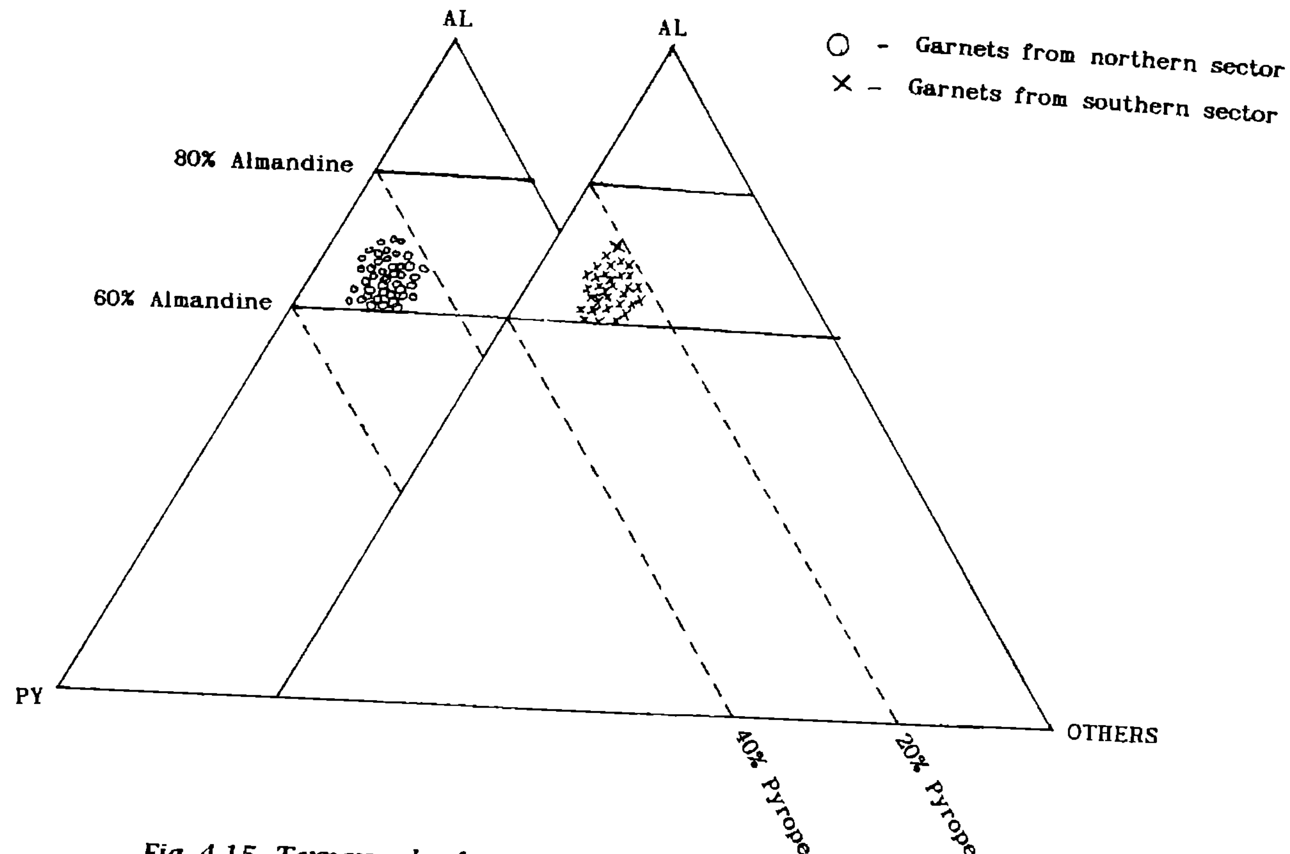


Fig. 4.15 Ternary plot for the garnet population from the two sectors determined by electron microprobe analysis.

Table No:4.2 Varietal index of heavy minerals

S. No.	SPi	GAi	ZMi
E1	70.96	31.25	45.45
D1	65.41	78.87	57.45
C1	76.74	33.42	22.50
D2	98.65	17.84	24.97
C2	84.82	53.97	40.96
A2	40.47	43.70	40.09
D3	80.58	47.74	28.55
B3	84.35	17.39	48.24
A3	92.25	62.43	21.84
C4	65.24	23.81	50.82
B4	77.38	20.00	27.95
A4	82.09	58.75	65.48
D5	84.92	0.00	29.87
B5	96.89	0.00	51.97
A5	90.88	32.78	59.06
F6	87.34	6.85	29.74
D6	79.60	16.90	32.42
C6	74.86	23.78	38.93
B6	78.91	58.31	8.85
E7	89.08	16.31	29.51
C7	74.26	24.34	46.80
A7	70.82	50.00	25.46
D8	91.39	52.79	26.53
C8	72.86	52.38	20.49
B8	81.49	74.31	80.31
C9	78.13	36.36	42.31
B9	42.01	30.08	34.51
D10	92.90	89.86	46.51
B10	61.54	47.39	41.16
E11	93.71	96.06	48.75
B11	55.93	47.52	43.68
F12	94.12	98.22	49.49
C12	82.84	82.92	45.47
A12	72.19	62.58	41.80
F13	94.55	99.65	50.07
B13	90.54	81.19	40.00
E14	94.18	98.98	48.08
A14	79.82	89.12	39.27
F15	93.88	98.76	46.22
C15	82.48	99.88	42.84
A15	71.01	98.34	38.35

SPi- Sillimanite/Pyroxene index
GAi- Garnet/Apatite index
ZMi- Zircon/Monazite index

TABLE 4.3 TYPES OF GARNETS IN % (Microprobe data)

Spot No	ALMAN	PYROP	ANDRA	GROSS	SPASS	UVARO	Fe/Mn	Total
B9	64.62	32.06	1.92	0.17	1.04	0.19	0.67	100.00
C9	69.00	26.92	2.73	0.00	1.10	0.25	0.72	100.00
D9	68.78	27.66	2.36	0.00	1.02	0.18	0.72	100.00
E9	68.36	27.07	3.45	0.00	1.12	0.00	0.72	100.00
A10	69.10	27.47	2.19	0.00	1.24	0.00	0.72	100.00
B10	69.53	27.17	2.18	0.00	1.06	0.06	0.72	100.00
C10	70.55	25.84	2.70	0.00	0.90	0.00	0.75	99.99
D10	69.49	26.05	3.43	0.00	1.03	0.00	0.73	100.00
A11	70.62	26.34	1.93	0.00	1.02	0.09	0.73	100.00
B11	70.39	25.48	3.33	0.00	0.75	0.05	0.74	100.00
C11	70.15	26.67	2.20	0.00	0.98	0.00	0.73	100.00
A12	63.73	33.18	2.09	0.00	0.96	0.03	0.66	99.99
B12	63.57	33.38	2.06	0.00	0.99	0.00	0.66	100.00
C12	63.63	32.80	2.27	0.00	1.29	0.00	0.66	99.99
D12	62.89	32.22	3.96	0.00	0.90	0.03	0.66	100.00
E12	63.74	32.90	2.21	0.00	1.15	0.00	0.66	100.00
A13	74.76	17.64	2.16	4.09	1.33	0.02	0.81	100.00
B13	74.64	17.95	1.27	4.64	1.50	0.00	0.81	100.00
C13	74.94	17.53	0.29	5.90	1.22	0.10	0.81	99.98
D13	75.05	17.27	1.11	5.23	1.34	0.00	0.82	100.00
E13	75.39	17.32	1.04	5.26	0.99	0.00	0.82	100.00
A14	66.15	30.72	0.57	1.67	0.89	0.00	0.69	100.00
B14	65.25	31.70	0.20	1.71	0.96	0.18	0.68	100.00
C14	64.54	31.93	2.36	0.00	1.08	0.09	0.67	100.00
D14	64.82	31.79	1.33	0.70	1.15	0.20	0.67	99.99
A15	65.09	31.57	1.45	0.61	1.16	0.12	0.68	100.00
B15	61.68	35.21	1.52	0.97	0.59	0.02	0.64	99.99
C15	63.14	34.35	0.00	2.39	0.07	0.00	0.65	99.95
D15	63.03	33.95	0.02	2.22	0.78	0.00	0.65	100.00
MAX	75.39	35.21	3.96	5.90	1.88	0.34	0.82	
MIN	61.28	17.27	0.00	0.00	0.07	0.00	0.64	
AVG	66.61	29.51	1.80	0.93	1.07	0.07	0.70	
STD	3.84	4.63	0.84	1.39	0.35	0.09	0.05	

ALMAN=Almandine, PYROP=Pyrope,
ANDRA=Andradine, GROSS=Grossularite,
SPASS=Spassartite, UVARO=Uvarovite

innershelf environment like this could be influenced by many factors such as currents, waves, bottom topography and coastal geomorphology. Moreover, it is clear from the discussion in chapter II and III that the Kovalam headland acts as a barrier for the southerly currents and sediment movement. This investigation further shows that the heavies are concentrated in the northern sector just north of Kovalam. Earlier also many workers (Chandramohan and Nayak, 1984) have observed that the dominant and the strongest currents in this innershelf is directed towards south. Similarly, many authors have indicated that the strongest sediment movement vector is towards south (Ramasamy and Nair, 1994) . From the above inference it is evident that the availability of a particular mineral is not the only criterion that controls distribution of heavies in this innershelf but the other factors, such as hydrodynamics, physiography and hydraulic behaviour of the heavies play a vital roll in controlling the distribution pattern of heavy minerals. In such circumstances conventional heavy mineral distribution studies may not reflect the real situation because the ratios of hydraulically equivalent minerals would not behave similarly in a given hydrodynamic conditions.

The bar chart (Fig. 4.17) shows that heavy mineral content in finer fraction (<125 μ) is higher than in coarser fraction (>125 μ). The difference is increasing with the increasing content of heavies in a sample i.e. higher the heavy content higher will be the difference. Due to these reasons varietal studies within the finer fraction was carried out. The varietal plot of ZMi Vs. SPi fails to discriminate the northern and southern sectors. Although zircon is more stable even in deep burial conditions, it is susceptible to dissolution in an acidic environment (Larsen and Poldervart 1957). There is, therefore, a possibility that the

ZMi values may not accurately reflect the source area characteristics, as the values may have been modified during weathering and transportation. Hence, the low ZMi and high SPi values for southern sector samples could be due to many factors such as the tabular structure, feeble presence of zircon, which could enable them to get easily diluted by quartz and other major light minerals. Another reason for the complexity in this plot may be due to the mixing of heavies with other sources ordinating from farther north of this study area. Perhaps the availability of sillimanite in copious amount is reflected in the high value SPi and presumably, indicating the high erosion vulnerability of garnet-sillimanite gneiss terrain. Determination of provenance sensitive mineral ratio for the southern sector samples produced much clearer picture. Very high values of GAi for the southern sector samples is perhaps suggesting that apart from garnet-sillimanite gneiss, some other sources possibly the granulite from the hinterland of the southern Trivandrum district may be contributing significant amount of garnet to the sediments of southern sector.

Thus, based on mineral ratio study, it seems reasonable to suggest a three pronged control for the heavy mineral distribution in this innershelf:

i) the hydrodynamics of the shelf waters in combination with the local physiography which in turn is related to the climatic condition.

ii) the hydraulic equivalence and other morphodynamic factors of the heavy minerals.

iii) the availability and stability of particular mineral in the parent rock.

The pie diagrams (Fig.4.16) shows the generalised distribution of rock types in the hinterland of the northern and southern sectors. The availability of some heavy minerals in each of the rock types present in the hinterland is given below.

Heavy Mineral	Khondalite	Charnockite	Gneiss	Cenozoic Sediments	Others
Opaques	•	•	•	•	±
Sillimanite	•				
Garnet	•	±	•		±
Zircon	•	•	•		
Monazite	•	•			±
Pyroxenes		•			•
Hornblende		•	±		
Apatite		•			
Kyanite	•	±			
Tourmaline		±	±		

• - Present ; ± - *May be present; Others include granite, granulite, basic dykes, pegmatite etc.,*

The pie diagrams (Fig. 4.16) do not show any major variation in the hinterland petrological constituents of the two sectors except, a marginally larger coverage of khondalites (primarily a garnet-sillimanite gneiss) in the southern sector than the north. This may be effected only in the distribution of sillimanite and garnets in the southern sector. However, in spite of the fact that the hinterland of the southern sector is comparatively better drained (by Neyyar and Karamana rivers) than the northern sector (Vamanapuram river); the wide discrepancy in the heavy mineral distribution between the two sectors cloud only, be related to the other physiographical and hydrodynamical factors.

A further evidence of differentiating mineral composition of the southern and northern sectors is based on the detrital garnet geochemistry carried out through electron microprobe analysis. Although, the study of a single mineral group rather than the entire suite, reduces the effect of hydraulics and diagenesis to a minimum, variations caused by the above changes can not be completely ruled out because a mineral group may consists of species with different densities and stabilities. However, in garnets, the density differences between the two end members is relatively narrow ie. from 3-6 to 4.3, and so garnet is selected for microprobe analysis.

The microprobe analysis shows that both the southern and northern sectors sediments have garnet suites dominated by almandine followed by pyrope and andradite contents. Results of the microprobe analysis, plotted in the ternary plots (Fig.4.15), donot indicate any differences among garnets between southern and northern sectors. Uvarovite grains also noticed in a few offshore samples (D and 11 E). This clearly indicate a distant source , since there is no source rock for the chrome garnet in the hinterland of the study area. Pilkey (1979) also stated that presence of a very unusual heavy mineral may possibly hint at other sources. Possibly uravavite might have been derived from the `deccan traps' which is the only nearest uvarovite bearing formation (Sethna and Mousavi, 1994). Traces of uvarovite is confirmed in the microprobe analysis (Table 4.3).

TABLE 4.3 TYPES OF GARNETS IN % (Microprobe data)

Spot No	ALMAN	PYROP	ANDRA	GROSS	SPASS	UVARO	Fe/Mn	Total
A1	61.63	34.28	0.74	2.19	1.16	0.00	0.65	100.00
B1	61.28	34.47	1.35	1.47	1.42	0.00	0.65	99.99
C1	61.32	34.58	2.11	0.62	1.31	0.05	0.64	99.99
D1	61.38	34.60	1.04	1.68	1.30	0.00	0.64	100.00
A2	62.44	34.14	1.00	1.66	0.76	0.00	0.65	100.00
B2	65.11	31.85	1.61	0.02	1.40	0.00	0.68	99.99
C2	65.21	31.63	1.62	0.19	1.35	0.00	0.68	100.00
D2	64.44	32.08	2.18	0.00	1.29	0.00	0.67	99.99
A3	72.59	23.43	2.19	0.95	0.83	0.00	0.76	99.99
B3	72.82	23.06	3.18	0.00	0.95	0.00	0.76	100.01
C3	72.78	23.14	0.97	2.30	0.97	0.02	0.76	100.18
D3	72.53	23.31	1.92	1.34	0.90	0.00	0.76	100.00
E3	72.84	23.01	1.23	2.17	0.75	0.00	0.76	100.00
A4	63.70	32.40	0.70	1.33	1.68	0.19	0.67	100.00
B4	63.79	32.10	1.10	1.03	1.77	0.18	0.67	99.97
C4	62.69	32.29	2.92	0.00	1.88	0.22	0.67	100.00
D4	63.96	32.29	1.53	0.63	1.51	0.07	0.67	99.99
E4	63.32	32.59	2.27	0.00	1.82	0.00	0.67	100.00
A5	67.56	29.25	0.00	1.83	1.19	0.17	0.70	100.00
B5	67.34	29.40	1.95	0.15	1.15	0.00	0.70	99.99
C5	66.78	29.12	2.68	0.00	1.26	0.16	0.70	100.00
D5	67.25	29.19	2.36	0.00	1.19	0.00	0.70	99.99
E5	67.49	28.88	1.48	0.44	1.54	0.16	0.71	99.99
A6	64.70	32.56	2.23	0.00	0.46	0.04	0.67	99.99
B6	66.09	31.44	1.87	0.15	0.35	0.09	0.68	99.99
C6	64.90	32.57	1.43	0.38	0.46	0.25	0.69	99.99
D6	64.60	32.18	2.51	0.00	0.71	0.00	0.67	100.00
E6	64.87	32.27	1.91	0.00	0.59	0.33	0.67	99.97
A7	64.40	31.71	1.57	1.06	1.25	0.00	0.67	99.99
B7	64.00	32.07	1.40	1.26	1.27	0.00	0.67	100.00
C7	64.31	31.72	1.41	1.00	1.55	0.01	0.67	100.00
D7	64.43	31.83	2.17	0.41	1.16	0.00	0.67	100.00
A8	64.31	31.95	1.73	0.70	1.31	0.00	0.67	100.00
B8	66.31	30.43	2.00	0.00	0.95	0.30	0.69	99.99
C8	65.80	30.83	2.38	0.00	0.64	0.34	0.68	99.99
D8	64.86	31.80	2.42	0.00	0.77	0.15	0.67	100.00
A9	66.07	31.27	1.38	0.82	0.46	0.00	0.68	100.00
B9	64.62	32.06	1.92	0.17	1.04	0.19	0.67	100.00

In general the compositional variation observed in microprobe analysis clearly indicates the dominance of almandine over pyrope and others. Two sources of almandine could be predicted, i) the high grade metamorphic terrain which consists of garnet - sillimanite gneiss and ii) acid granites or migmetites. The lesser amount of pyrope could have been derived from the basic rocks such as charnockites. The large difference in quantity of these two type of garnets can be due to, the susceptibility of khondalites for erosion, abounds in garnet. Moreover, the area of coverage of khondalites in the two hinterland is also considerably higher.

IV. 4. B. Beach

The heavy mineralogical assemblage of the beach sediments of the study area was evaluated in terms of total heavy content from 21 samples collected from the mid water line of the beach face. The objective of the determination of heavies in the beach is to find out any similarity or dissimilarity with that of the offshore distribution. . As the finer fraction of the beach sediments contain more heavies, only the total heavies in the bulk sediments of beach was done. Result of the analysis is given in Table 4.4. Earlier studies, envisage that the beach deposits are replenished with every monsoon (Tipper, 1914, Aswathnarayana, 1964; Nambiar and Unnikrishnan, 1989; Mallik et al., 1987) have led to the belief that there could be a considerable offshore resource for heavy mineral. Heavy minerals of the beach sand in the order of abundance are opaque, sillimanite garnet, zircon, monazite and kyanite. The minor amounts of

Table 4.4 Percentage of heavies at beach profile stations

Stn.	Heav	Arag	Opaq	Grnt	Sill	Mon	Zirc	Pyro	Ruti	Othe	Totl
2	8.32	70.45	12.56	5.43	3.12	0.56	0.87	3.01	2.80	1.20	100.00
4	12.54	54.54	10.23	6.36	5.65	1.34	3.54	4.34	4.30	9.70	100.00
6	18.65	62.45	9.80	12.34	4.76	1.12	2.04	3.20	2.30	1.45	99.46
8	14.32	54.34	8.97	16.73	6.54	2.76	2.13	3.86	1.23	3.42	99.98
10	16.31	46.43	18.43	14.24	7.54	3.45	3.21	4.32	2.12	0.00	99.74
12	28.45	33.21	46.76	8.76	6.74	2.45	0.85	1.23	0.00	0.00	100.00
18	69.56	2.87	78.54	11.02	2.34	4.56	0.65	0.00	0.00	0.00	99.98
20	39.75	9.03	68.76	8.98	2.34	8.76	2.12	0.00	0.00	0.00	99.99
22	25.43	18.71	64.12	6.45	4.32	4.54	1.86	0.00	0.00	0.00	100.00
24	21.23	22.12	65.37	6.06	2.32	2.10	0.93	1.10	0.00	0.00	100.00
26	28.32	39.43	38.43	8.65	4.53	2.45	3.21	3.10	0.00	0.00	99.80
28	10.32	25.54	31.23	14.32	7.54	8.54	3.20	4.32	4.35	0.05	99.09
35	9.67	28.32	28.32	3.45	8.65	8.76	4.32	4.32	12.43	1.43	100.00
40	11.90	42.65	21.23	6.54	6.18	4.32	5.43	3.42	10.23	0.00	100.00
45	7.65	54.32	20.32	7.54	6.43	5.05	3.21	1.43	1.65	0.00	99.95
50	7.65	72.34	14.12	5.43	4.43	2.45	1.23	0.00	0.00	0.00	100.00
55	16.43	68.25	18.23	4.32	5.43	2.34	0.00	0.00	1.43	0.00	100.00
60	12.24	42.00	32.45	12.56	8.65	3.43	0.00	0.00	0.00	0.00	99.09
65	19.67	26.45	49.04	13.43	5.43	5.65	0.00	0.00	0.00	0.00	100.00
70	22.32	12.34	47.54	15.43	6.23	9.65	3.21	3.45	2.13	0.00	99.98
73	45.78	7.89	53.32	12.43	7.54	6.54	4.32	3.21	2.32	2.13	99.70
Max	69.56	72.34	78.54	16.73	8.65	9.65	5.43	4.34	12.43	9.70	
Min	7.65	2.87	8.97	3.45	2.32	0.56	0.00	0.00	0.00	0.00	
Avg	21.26	37.79	35.13	9.55	5.56	4.32	2.21	2.11	2.25	0.97	
Std	14.70	21.08	21.31	3.89	1.91	2.67	1.54	1.74	3.27	2.20	

Heav - Total Heavy Minerals, Arag - Aragonite, Opaq - Opaque Minerals, Grnt - Garnet, Sill - Sillimanite, Mon - Monazite, Zirc - Zircon, Pyro - Pyroxene, Ruti - Rutile , Othe - Other Heavy Minerals, Totl - Total ferromagesian minerals, staurolite, epidote, hypersthene were also found. The variation of heavy mineral along the coast is depicted in Fig. 4.18. The heavy mineral assemblage in beach resembles that of offshore pattern i.e., opaques are followed by sillimanite, garnet. Presence of some kyanite in beach sediment makes it pertinent to stress that in the absence of a kyanite bearing high grade metamorphic rocks in the hinter land. These kyanites could be derived from reworking of Cenozoic Warkalli beds, these beds were reported to be kyanite and staurolite bearing.

The general heavy mineral distribution pattern shows that similar to the innershelf the beach stretch north of headlands (Kovalam, Ava and Varkala) are enriched. Therefore, it is inferred that the differences in the magnitude of placer accumulation in this coastal stretch are primarily due to concentration of sand as a function of shoreline geometry, wave climate and current pattern. However, the mineral sorting processes dependent on density, size and relative rate of sediment supply are also likely to be important factors in controlling placer accumulation. (Plate 3)

Further, the total heavies show two - three prominent peaks north of Kovalam, Vamanapuram river outlet and at Varkala possibly implies land resource for the later two areas. The high concentration in the pocket beach around and north of Kovalam indicate the trapping of heavies by the headland. Similar to total heavies the opaques follow suit. The high content of aragonite exclusively in the southern region is essentially proves that the aragonite is from a offshore source. ie. from the shells. While discussing the heavy minerals and texture it has been stated that the SW part of the shelf is of coarse grained sediments with high aragonite content. Hence, transport of other heavy minerals to the beach during SW monsoon is a distinctive possibility considering the strong wave action. Earlier Ramachandran and Kurian (1994) have stated that the S monsoon waves could disturb bottom sediments even at depth >40m. The offshore contribution could have been one of the causes for the similarity of heavy mineral distribution in the innershelf and beach.

CHAPTER - V

GEOCHEMISTRY

V.1. INTRODUCTION

Several decades of research work on continental shelf, indicates that the innershelf is a temporary sink for any material washed off from hinterland. Most clastics spent at least some time in this dynamic environment before being washed off to deeper areas. Therefore, knowledge on the innershelf sedimentary environment would not be complete without the geochemical information. Moreover, a good geochemical database can effectively contribute to understand many aspects of the innershelf sedimentology. Apart from providing supportive information for mineralogical and granulometric studies, it also helps to understand the quality of an environment. Many investigations in costal environment have pointed out that the high concentration of trace metals in nearshore sediments can directly be related to anthropogenic activities (Carmody et al., 1973; Helz et al., 1979). Further although many elements in an optimum concentration are essential for sustaining biota in innershelf region, they could turn toxic at larger concentrations. Even though such a catastrophe of biological degradation is comparatively less frequent in highly dynamic innershelf such as this study area; constant input of heavy metals like Ti which is being discharged into this littoral zone from a titanium dioxide factory situated near Veli area can cause irreparable damage to the biosphere (Machado and

Suchindan, 1986). Therefore, while discussing the origin of trace metals should be given utmost attention in relation to industrial out put in addition to source materials. Of course the physico chemical and the biological conditions may play a vital role in controlling the fixation and migration of chemical constituents of sediments especially in near shore environments.

Further many authors have found that the finer cohesive sediments in nearshore region are the primary medium which harbour trace metal pollutants (Burkit et. al., 1972; Slatt 1976; Cosma et. al 1979). Hence, geochemical investigation was carried out to know the distribution of major and trace elements, and the causes of variation thereby to substantiate influence made in the preceding chapters regarding the sedimentary processes operative in the innershelf . An attempt is also made to identify the influence of industrial effect on elemental concentration in this region.

In addition the presence of two important black sand placer deposits on either side of this study area (Manavalakurichi in the south and Chavara in the north) makes the information on distribution patterns of strategic elements like U and Th in this innershelf more significant and interesting. Further, such information would substantiate the relation between the marine processes and the contribution made from heavy minerals. Therefore, U and Th content in surficial sediment samples were also given due importance and analysed.

V.2. METHODS

Selected surficial sediments (48 no.) were powdered and subjected to various chemical analysis. The samples were processed by carbonate fusion for the estimation of major elements (Vogel, 1978). Quantification of silica was carried out by hydrofluorisation. Estimation of Al_2O_3, CaO and Mgo were carried out by EDTA method, Fe_2O_3 by potassium dichromate method; P_2O_5 and TiO_2 by colorimetric method. Flame photometric method was used for the estimation of Na_2O and K_2O. Thirty nine samples were treated with HF and perchloric acid and were analysed for the content of Mn, Cu, Co, Cr, Ni , Cd, Pb, Zn, Ba, Sr, Rb, Be, Li, Mo and V using an Atomic Absorption Spectrophotometer (AAS).

U and Th were analyzed by Instrumental Neutron Activation Analysis (INAA) as recommended by Hevesey and Levi (1936). INAA is a nondestructive procedure recognised as valuable method for analysing rock and marine samples (Potts et al., 1985). In this procedure simultaneous irradiation and sequential counting of both the standard and samples are essential. Therefore, this was carried out using the "Apsara" reactor facility available at the Bhaba Atomic Research Centre at Trombay. Heavy mineral fraction separated from the bulk sample was milled to pass through ASTM 200 mesh and packed in polythene vials. These vials were irradiated in nuclear reactor for 12 hours along with the standard of known composition. Then the samples and standard were cooled for 4 days and counted using a coaxial Ge (Li) detector with an efficiency of 25 %, coupled to a multichannel analyzer. After proper reduction of data, taking into account the counts relating to respective peaks and backgrounds, U & Th contents in the samples were calculated. This output have been recalculated on a carbonate-free-basis (c.f.b.) to eliminate the diluting effect of $CaCO_3$ as recommended by Boström et al.(1971).

V.3. RESULTS

The concentration of the major elements are given in Table 5.1. The. maximum , minimum, average and standard deviation for each of the elements are also given at the end of each column. The correlation matrix between different constituent are given in Table 5.2. The distribution of major elements are given in Figs. 5.1 to 5.7. SiO_2 ranges from 38.20% to 92.08% with an average of 71.82%. Contrary to the expectation, high SiO_2 is not found to be associated with the coarser sediment in the southern sector. Comparatively higher (>80%) values of SiO_2 are noticed as patches in the finer (silt and clay) sediments of northern sector. SiO_2 depleted zones are found south of Kovalam headland. The frequency distribution shows that >75% of the samples have >80% of SiO_2 (Fig.5.8).

Higher values of Al_2O_3 are found to be associated in areas where finer sediments dominate near the Kovalam headland and off the

TABLE 5.1 MAJOR ELEMENTS IN INNERSHELF SEDIMENTS IN %

S. No.	SiO2	Fe2O3	Al2O3	Ca0	MgO	Na2O	K2O	TiO2	P2O5
E1	75.80	2.56	1.53	5.32	4.60	0.68	0.12	0.66	0.01
C1	84.40	1.92	2.04	4.20	1.80	0.63	0.11	0.58	0.01
B1	79.60	2.40	4.59	2.80	4.00	0.66	0.28	1.33	0.01
E2	45.80	2.23	1.02	26.04	6.60	0.48	0.48	0.08	0.33
D2	44.20	1.60	2.04	22.68	4.60	0.63	0.08	0.08	0.01
F3	49.40	3.19	1.02	21.00	5.00	0.55	0.22	0.33	0.03
E3	58.20	3.35	2.04	15.40	3.20	0.32	0.30	1.07	0.03
C3	38.27	3.40	1.53	24.92	4.20	0.66	0.09	0.66	0.01
E4	53.80	2.40	1.02	15.80	0.74	0.15	0.75	0.01	0.16
D4	38.20	3.56	2.02	15.90	11.40	0.74	0.25	0.58	0.01
C4	66.80	3.72	2.55	4.20	7.48	0.70	0.14	0.66	0.01
B4	63.20	3.04	4.59	9.52	4.00	0.70	0.28	0.99	0.01
A4	77.85	2.39	3.06	5.04	1.80	0.26	1.25	1.16	0.05
E5	80.40	2.44	1.53	6.44	1.44	0.70	0.15	0.58	0.01
C5	54.20	3.36	1.02	15.96	4.60	0.68	0.10	0.66	0.01
B5	54.10	3.54	1.53	13.72	6.00	0.65	0.10	0.58	0.01
A5	70.70	3.44	4.59	6.72	2.80	0.68	0.10	0.99	0.01
F6	73.20	4.16	2.55	5.04	3.40	0.65	0.14	1.49	0.01
E6	67.60	2.24	1.53	10.64	3.00	0.70	0.28	0.58	0.03
B6	68.40	4.36	3.57	5.32	5.00	0.68	0.26	0.83	0.01
E7	82.54	2.44	3.06	2.52	2.62	0.47	0.28	0.66	0.03
C7	66.20	4.00	1.53	10.64	3.00	0.68	0.15	0.99	0.01
F8	69.80	4.32	1.53	5.04	5.20	0.65	0.09	1.16	0.01
D8	67.10	2.39	2.04	8.86	4.80	0.51	0.30	0.86	0.03
B8	85.62	1.96	3.64	1.80	0.38	0.00	0.06	0.33	0.03
A8	90.12	1.76	2.04	1.40	1.40	0.28	0.12	1.16	0.03
E9	69.40	2.88	2.55	10.26	1.60	0.72	0.15	0.50	0.01
C9	87.40	1.28	2.55	3.03	2.20	0.61	0.08	0.08	0.01
A9	79.00	3.49	3.56	3.08	2.80	0.47	0.45	1.07	0.04
F10	46.20	3.84	1.53	18.20	6.20	0.63	0.07	0.58	0.03
D10	72.00	2.58	1.53	6.44	4.60	0.70	0.14	0.58	0.01
B10	84.90	3.40	1.02	5.56	1.20	0.80	0.14	1.46	0.01
E11	78.80	2.72	1.53	11.04	2.80	0.65	0.09	0.99	0.01
C11	92.08	0.96	1.02	1.40	1.00	0.38	0.12	0.33	0.03
A11	82.50	2.88	2.55	3.34	1.40	0.63	0.14	1.68	0.01
F12	87.80	1.28	2.04	2.24	1.60	0.32	0.24	0.33	0.03
D12	76.50	2.55	2.04	7.00	2.00	0.32	0.22	1.16	0.03
B12	89.66	2.08	1.52	1.68	1.00	0.25	0.05	1.65	0.03
E13	81.00	2.24	2.55	4.48	1.60	0.66	0.26	0.58	0.01
C13	88.60	1.44	0.51	2.80	1.60	0.63	0.10	0.58	0.01
A13	90.90	0.96	1.02	1.68	2.50	0.61	0.09	0.08	0.01
F14	84.78	1.60	2.04	2.52	1.80	0.47	0.28	0.66	0.02
D14	78.44	2.71	3.06	1.40	5.20	0.53	0.60	0.66	0.04
B14	71.60	3.83	10.00	3.36	3.00	0.50	0.28	1.32	0.03
F15	80.20	2.87	2.04	4.48	2.00	0.28	0.43	0.99	0.05
C15	89.10	1.44	2.04	2.24	0.60	0.24	0.15	1.07	0.05
B15	85.40	2.92	1.53	4.76	0.60	0.66	0.10	1.49	0.01
A15	75.50	4.95	7.13	3.92	0.60	0.31	0.94	2.31	0.05
MAX	92.08	4.95	10.00	26.04	11.40	0.80	1.25	2.31	0.33
MIN	38.20	0.96	0.51	1.40	0.38	0.00	0.05	0.01	0.01
AVG	72.44	2.73	12.80	7.75	3.15	0.54	0.24	0.81	0.03
STD	14.64	0.94	72.53	6.55	2.14	0.18	0.23	0.48	0.05

Table 5.2 Correlation matrix for major elements

	SiO2	Fe2O3	Al2O3	CaO	MgO	Na2O	K2O	TiO2	P2O5	Sand%	Depth
SiO2	1.00										
Fe2O3	-0.45	1.00									
Al2O3	0.18	0.16	1.00								
CaO	-0.92	0.23	-0.35	1.00							
MgO	-0.72	0.50	-0.04	0.50	1.00						
Na2O	-0.26	0.46	-0.03	0.18	0.46	1.00					
K2O	-0.07	-0.08	0.16	0.06	-0.08	-0.38	1.00				
TiO2	0.40	0.35	0.30	-0.46	-0.20	0.10	-0.05	1.00			
P2O5	-0.27	-0.18	-0.22	0.42	0.09	-0.33	0.44	-0.37	1.00		
Sand%	0.37	-0.19	0.28	-0.33	-0.29	-0.13	0.21	0.44	-0.09	1.00	
Depth	-0.01	0.05	-0.12	0.04	0.00	-0.02	-0.05	-0.16	0.14	-0.14	1.00

Distribution pattern of some major elements

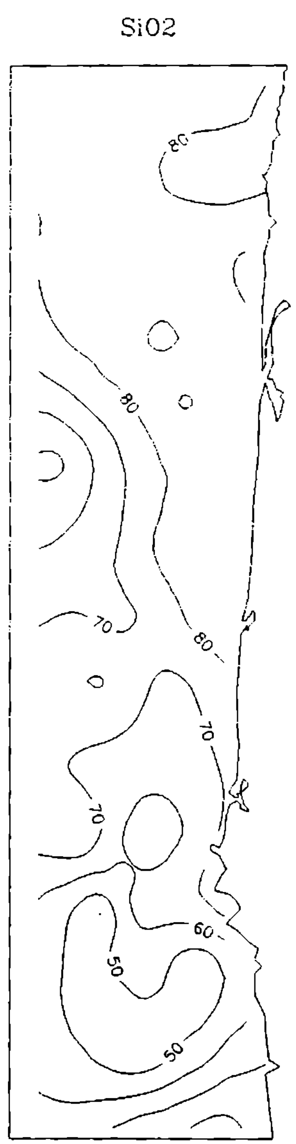


Fig. 5.1

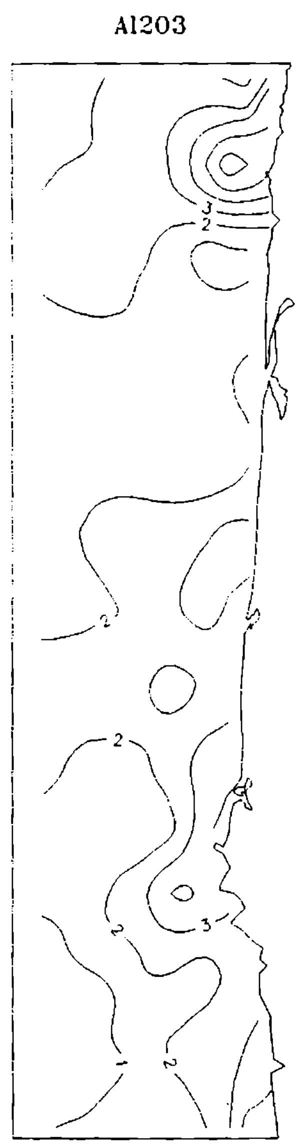


Fig. 5.2

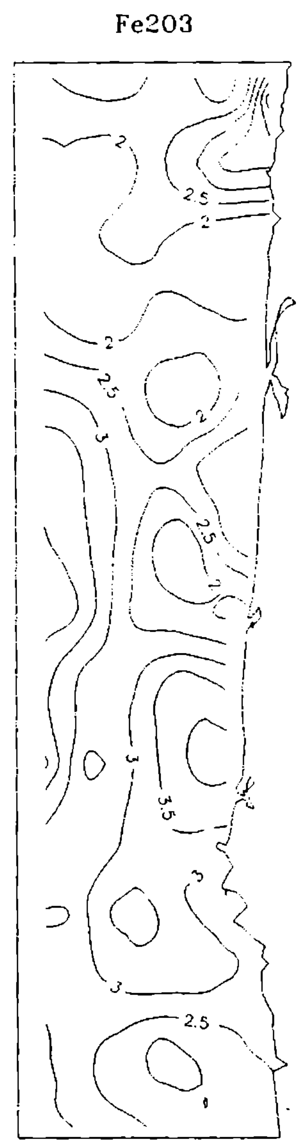


Fig. 5.3

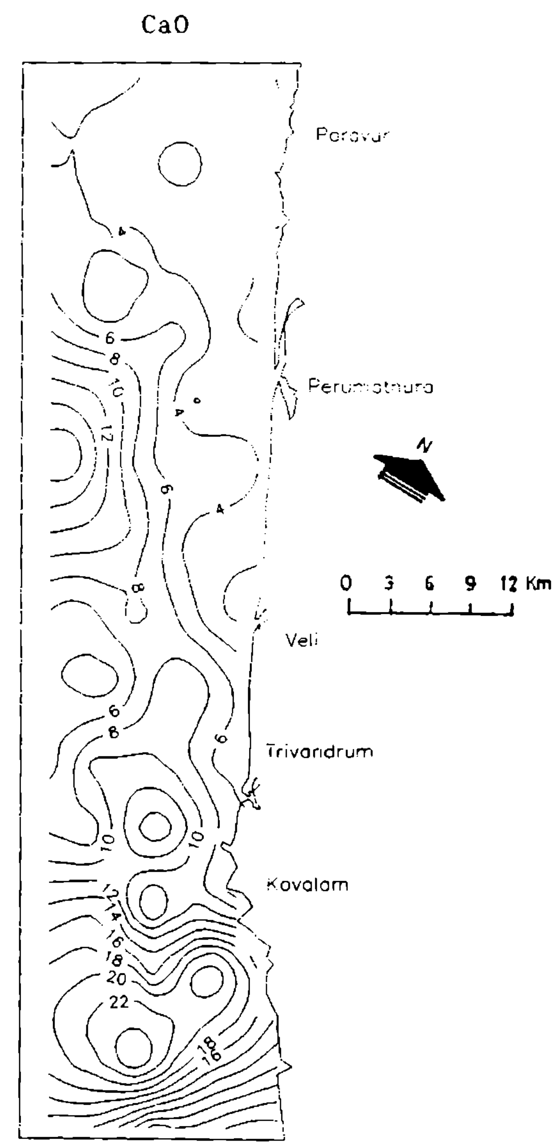


Fig. 5.4

Distribution pattern of some major elements

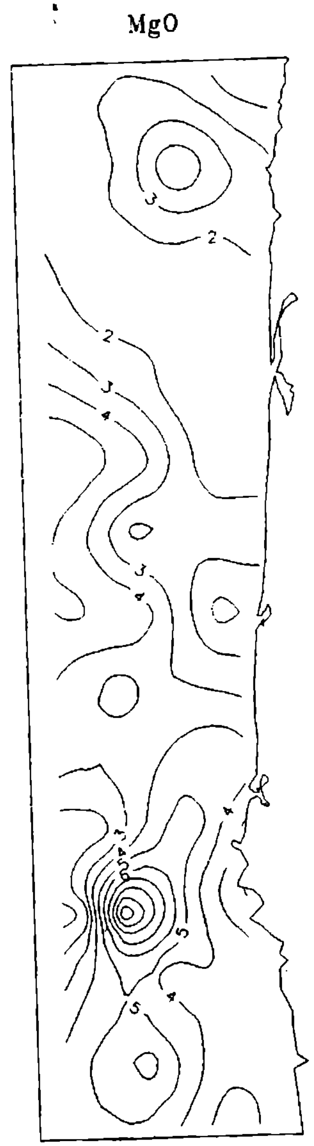


Fig.5.5

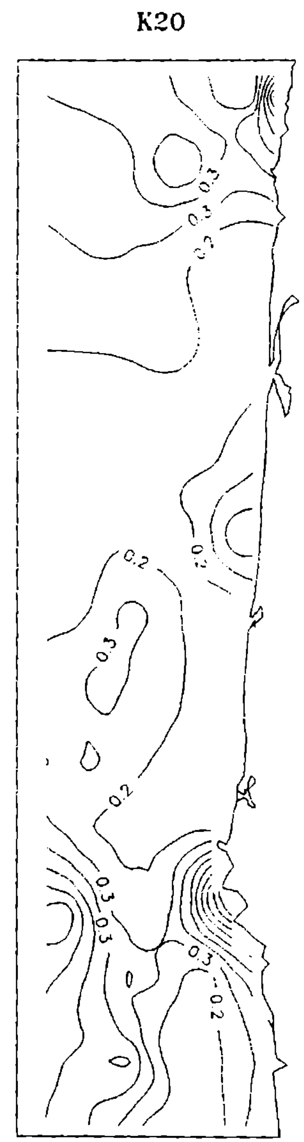


Fig. 5.7

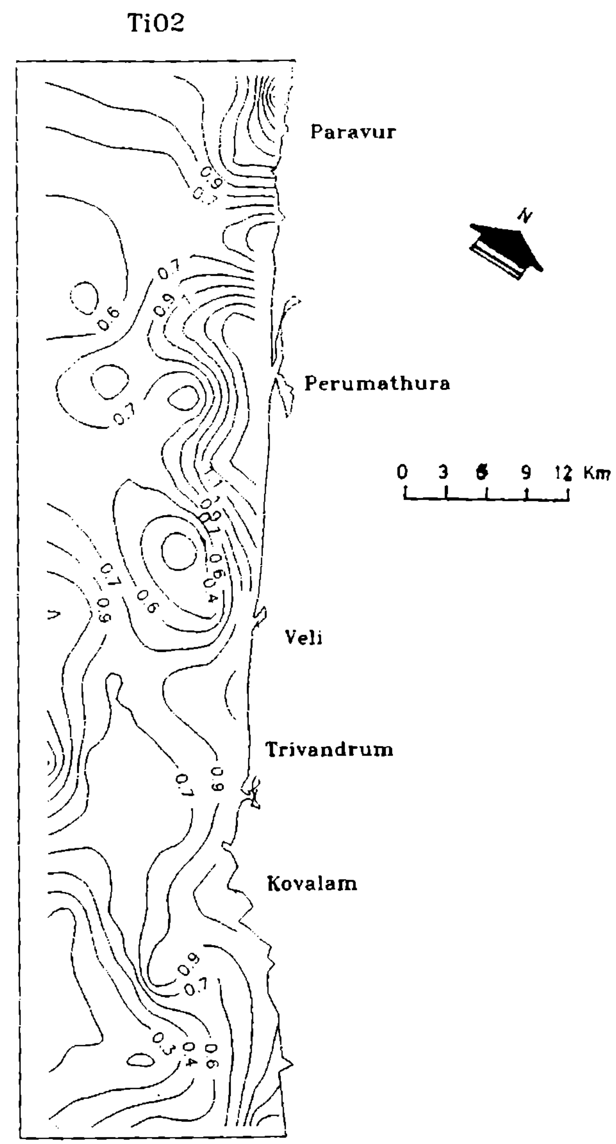


Fig. 5.6

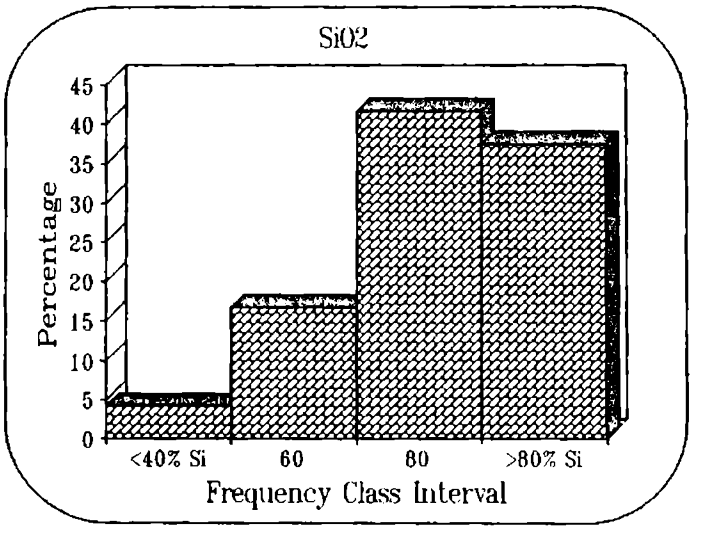


Fig. 5.8

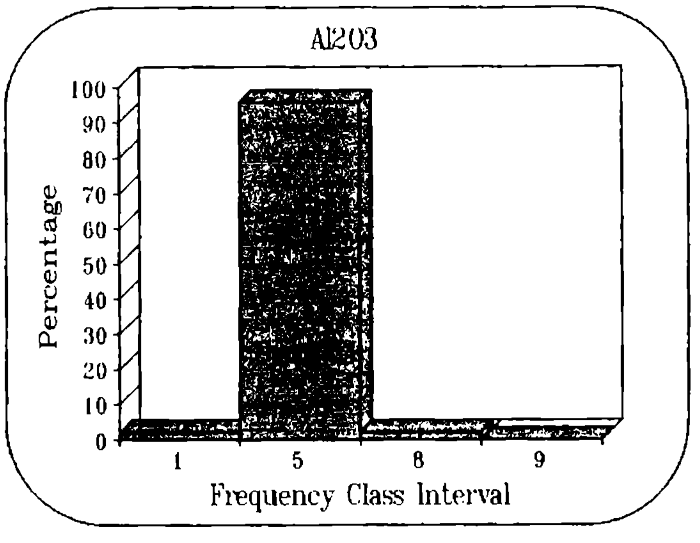


Fig. 5.9

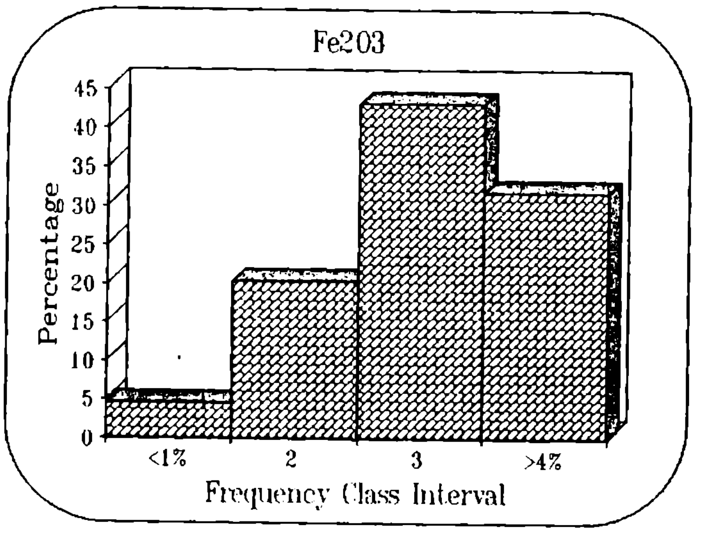


Fig. 5.10

mouth of the Veli and Paravur backwaters . The frequency distribution shows that 40% of the samples contain 3% of Al_2O_3 (Fig.5.9).

Iron content ranges between 0.96% and 4.95% Patches of higher iron content are conspicuous around and south of the industrial outlet (TTP) near Veli. But for the anomalous concentration of iron off the TTP sewage outlet, the Fe_2O_3 distribution (Fig.5.3) generally follows that of Al_2O_3. Frequency distribution of Fe_2O_3 (Fig.5.10) shows that samples having more 3% and 4% Fe_2O_3 predominate in this area. CaO concentration varies between 1.40% and 26.04% with an average of 8.12%. At certain locations in the southern sector high CaO (>22%) patch is noticeable. Sporadic patches of showing high CaO content are observable in the northern sector (Fig. 5.4). Frequency distribution displayed in Fig.5.11 shows that about 50% of the sample show CaO content more than 5%.

The average concentration of MgO is 3.26%. Distribution pattern varies from the southern sector to northern sector. MgO is appear to be associated with the coarser sediments of southern sector (Fig. 5.5). The distribution pattern of MgO more or less follows the distribution pattern of CaO. TiO_2 is found to be concentrated in an linear zone parallel to the coast and closer to the shore. However, remarkably anomalous concentration (>1.4%) is recorded for the sediments collected near the industrial waste

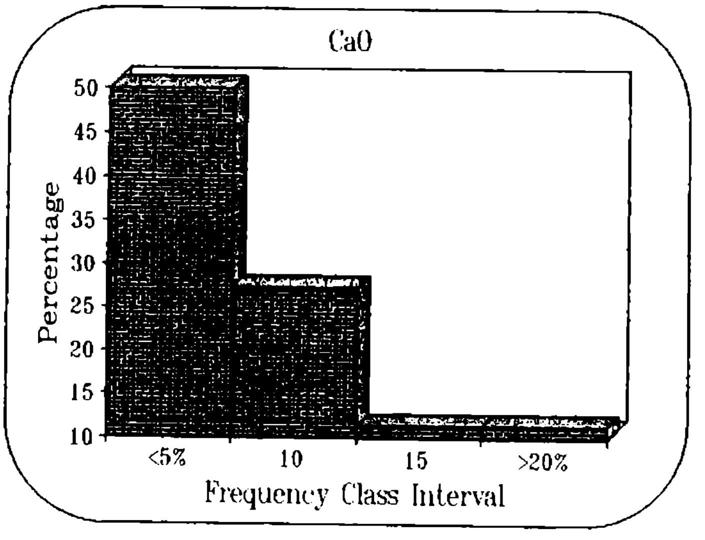


Fig. 5.11

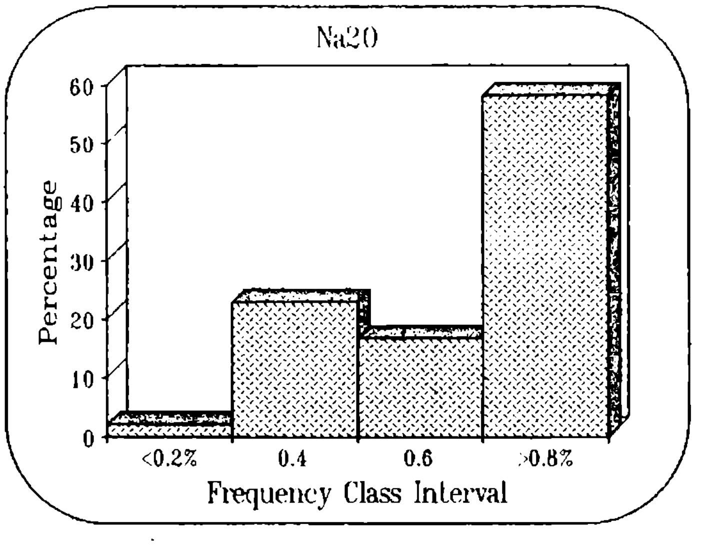


Fig. 5.12

outlet. Seaward reduction in concentration of TiO_2 is also conspicuous (Fig. 5.6). About 50% of the samples contain 1 to 1.5% of TiO_2 (Fig. 5.14).

Na_2O concentration varies widely from 0.15% to 0.8% with an average of 0.55%. In contrast to MgO and CaO distribution, Na_2O appears to be more concentrated in the finer sediments of northern sector. Distribution pattern of K_2O doesnot show any preferential adherence in the innershelf. However, depletion of K_2O is appear to be manifested in and around the industrial outlet near Veli. Frequency distribution of Na_2O and K_2O are given in Figs. 5.12 and 5.13.

Trace elements

The results of the trace elements and their maximum, minimum, average and standard deviation values are given in the Table 5.3. The spatial distribution pattern of these elements are given in Figs. 5.15 to 5.25 and frequency distribution of these elements are given Fig. 5.26 to 5.38. Mn content ranges from 339 to 29 ppm with an average of 146ppm. In 50% of the samples Mn ranges from 100 to 200 ppm (Fig.5. 30). In 75% of the samples concentration of Co is between 20 and 40 ppm. Frequency distribution of Pb (Fig.5.31) shows that 55% of the samples analysed have a concentration of 25 to 50 ppm: whereas 25% of the samples have 50 to 100 ppm. Extraordinary values of 2837 ppm maximum and 781 minimum

Table 5.3 Trace metal content in innershelf sediments in ppm

S. No.	Cd	Zn	Ni	Co	Mn	Pb	Cu	Cr	Be	V	U	Th
E1	3.80	283	5.00	22.00	110	45.00	296	65.00	1.00	165.00	1.12	9.92
C1	1.70	120	44.00	26.00	278	56.00	80	89.00	1.50	150.00	0.62	4.90
E2	4.20	343	55.00	27.00	112	44.00	346	74.00	1.10	100.00	2.26	15.23
D2	3.30	1244	50.00	25.00	140	287.00	1537	93.00	1.00	100.00	2.26	14.40
A2	1.60	10	30.70	13.90	66	38.00	2	38.00	0.00	0.00	1.69	7.57
F3	2.10	518	68.00	38.00	139	31.00	316	2.10	2.10	160.00	1.01	29.14
C3	9.90	23	69.80	64.80	86	66.00	4	55.00	0.60	0.00	0.95	16.75
B3	3.80	14	43.20	80.60	70	49.00	1	46.00	0.00	0.00	1.10	19.56
E4	3.40	152	66.00	32.00	152	42.00	49	109.00	1.20	110.00	1.03	34.43
A4	2.30	30	67.60	23.50	180	51.00	8	91.00	0.00	0.00	10.99	156.78
F5	11.60	16	72.90	72.40	103	72.00	3	74.00	0.50	0.00	0.64	3.79
E5	2.50	11	61.80	18.20	85	35.00	0	26.00	0.00	0.00	0.78	2.94
A5	1.80	103	60.00	30.00	207	37.00	62	118.00	1.70	160.00	5.02	81.31
F6	3.50	45	41.00	32.00	62	4.00	23	45.00	3.00	180.00	3.93	36.85
D6	4.00	114	74.00	39.00	123	24.00	33	88.00	3.60	190.00	0.88	12.48
C6	6.80	29	64.40	57.10	71	67.00	4	73.00	0.20	0.00	3.07	19.65
A6	2.80	21	40.30	24.40	85	44.00	3	54.00	0.00	0.00	4.80	23.92
F7	0.80	176	68.00	30.00	135	24.00	144	105.00	203.00	160.00	1.85	14.58
D7	9.00	23	55.90	52.90	104	64.00	2	64.00	0.00	0.00	4.21	48.49
C7	3.00	93	59.00	40.00	113	36.00	39	82.00	2.90	190.00	2.51	11.30
A7	3.60	425	56.00	33.00	255	72.00	742	182.00	1.80	290.00	7.56	46.52
F8	4.00	101	82.00	40.00	152	26.00	65	125.00	3.10	210.00	2.81	22.86
B8	2.50	6	32.30	12.80	29	27.00	0	21.00	0.10	0.00	0.85	4.37
A8	2.70	172	94.00	42.00	271	81.00	48	170.00	3.00	390.00	7.08	46.58
E9	1.30	108	69.00	39.00	128	30.00	75	100.00	2.20	140.00	1.27	6.53
B9	2.30	181	68.00	34.00	141	69.00	81	124.00	2.90	210.00	0.89	2.89
A9	2.40	37	33.70	25.20	159	58.00	3	98.00	0.00	0.00	13.75	86.65
D10	5.30	20	41.10	31.40	52	47.00	1	52.00	0.60	0.00	0.86	7.42
F11	3.00	268	62.00	33.00	139	33.00	36	108.00	2.70	200.00	0.46	9.41
E11	1.40	264	56.00	33.00	256	110.00	223	111.00	2.40	170.00	0.85	16.16
E12	3.30	33	41.90	28.50	65	49.00	3	48.00	0.00	0.00	1.10	9.12
D12	2.70	19	32.30	27.50	81	45.00	1	63.00	0.00	0.00	1.80	41.57
F13	2.25	211	65.50	34.00	151	30.50	37	122.00	2.95	195.00	0.23	4.71
A13	2.90	321	49.00	25.00	339	18.00	595	127.00	1.50	150.00	2.25	17.35
F14	1.50	154	69.00	35.00	163	28.00	37	136.00	3.20	190.00	0.96	12.54
A14	2.30	3	24.90	20.30	152	48.00	2	67.00	0.00	0.00	7.01	77.38
E15	0.30	89	72.00	40.00	174	30.00	62	129.00	2.50	170.00	3.01	18.32
D15	3.20	83	71.00	39.00	167	45.00	37	129.00	3.40	220.00	2.99	18.28
A15	3.40	41	43.00	39.70	330	61.00	3	25.00	0.20	0.00	30.91	168.43
MAX	11.60	1244	94.00	80.60	339	287.00	1537	182.00	203.00	390.00	30.91	168.43
MIN	0.30	3	5.00	12.80	29	4.00	0	2.10	0.00	0.00	0.23	2.89
AVG	3.39	151	55.37	34.90	144	51.88	128	85.34	6.56	107.69	3.52	30.28
STD	2.299	216	17.49	14.198	74	42.894	280	40.156	31.89	100.99	5.312	37.239

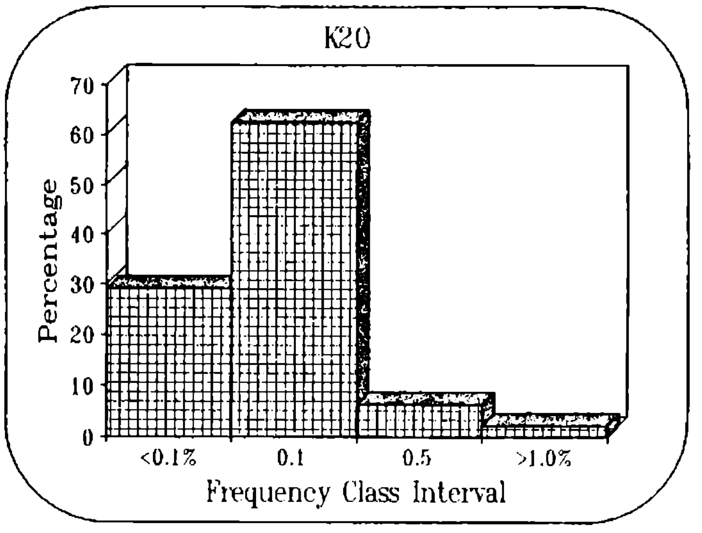


Fig. 5.13

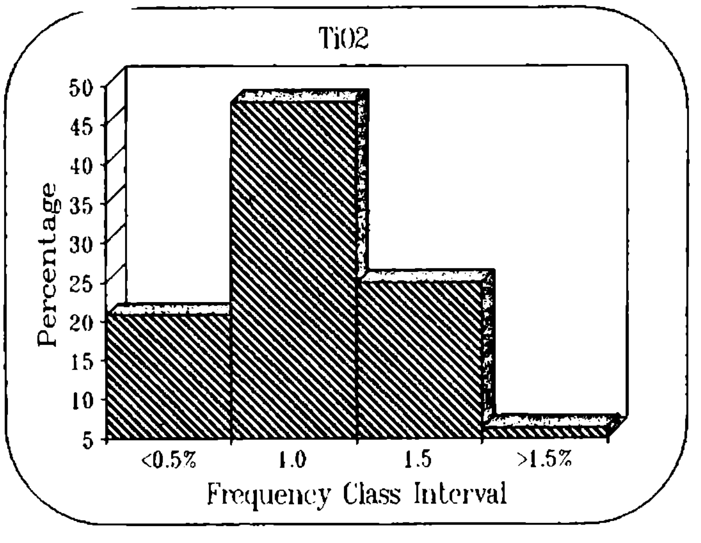


Fig. 5.14

Distribution pattern of some Trace elements

Manganese

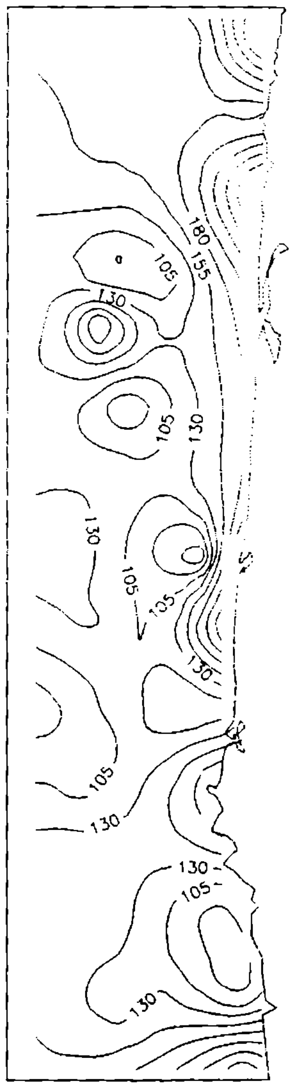


Fig. 5.15

Copper

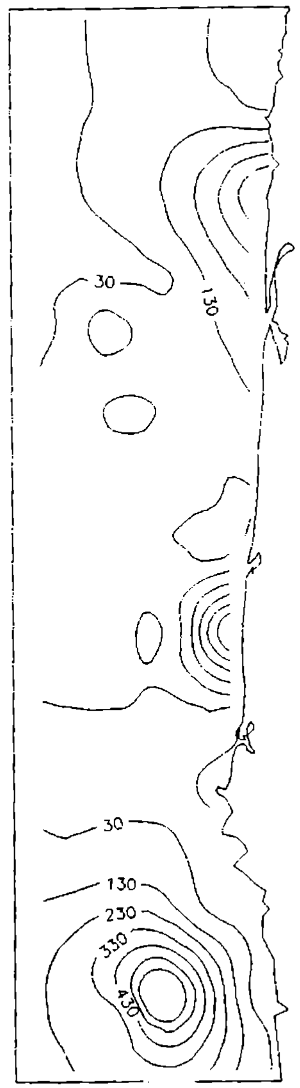


Fig. 5.16

Cobalt

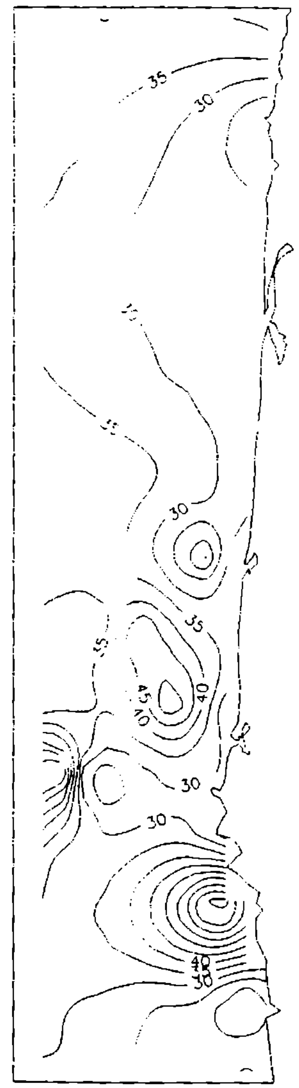


Fig. 5.17

Chromium

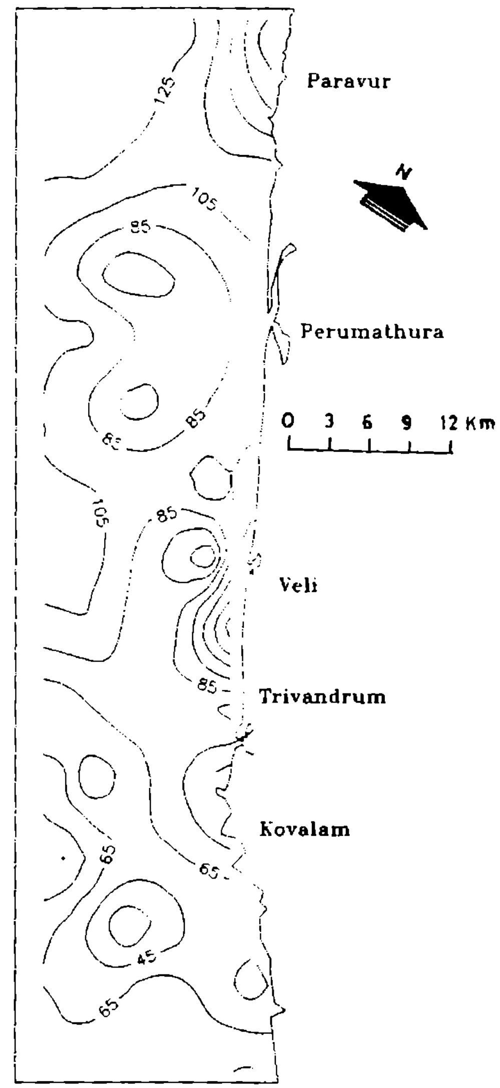


Fig. 5.18

Distribution pattern of some Trace elements

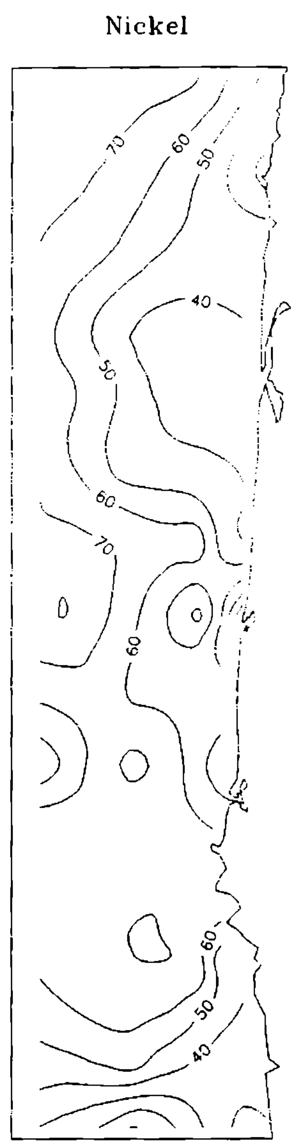


Fig. 5.19

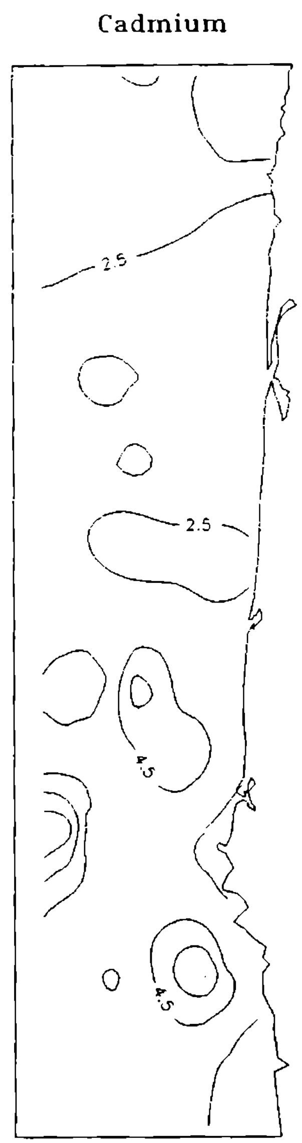


Fig. 5.20

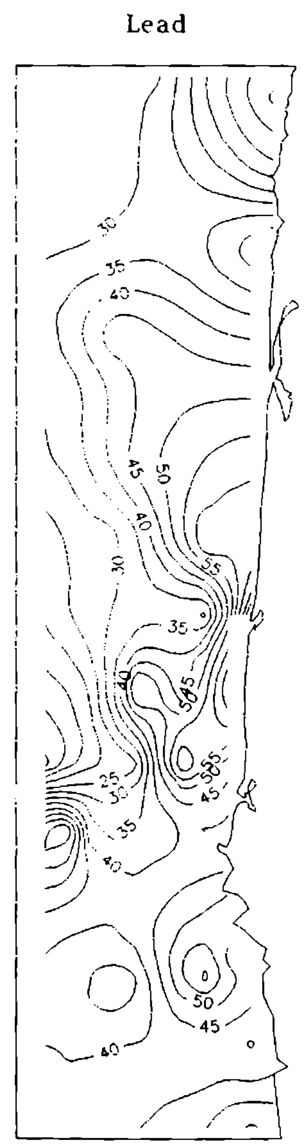


Fig. 5.21

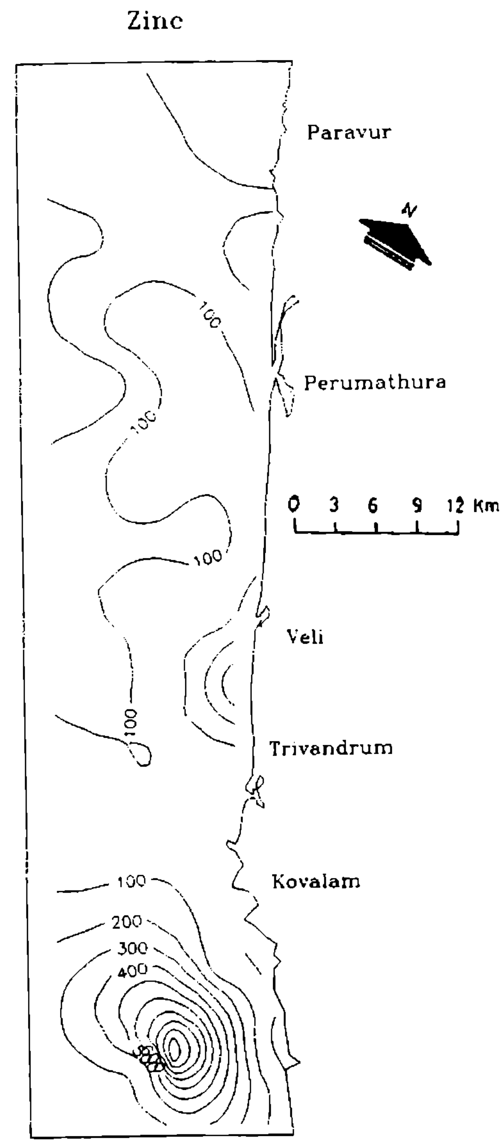


Fig.5.22

Distribution pattern of some Trace elements

Titanium

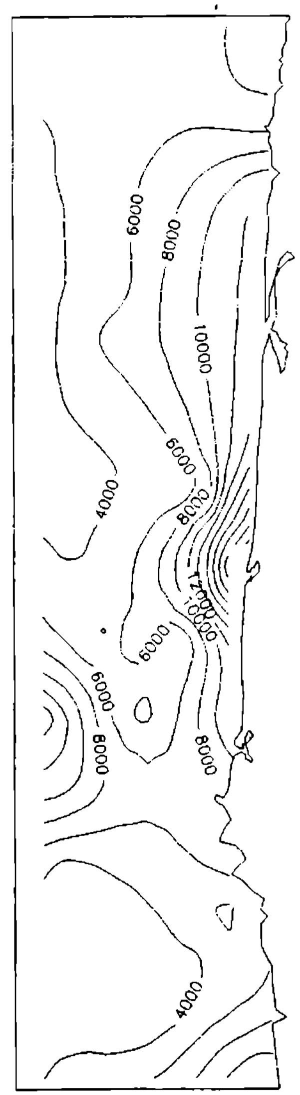


Fig.5.23

Thorium

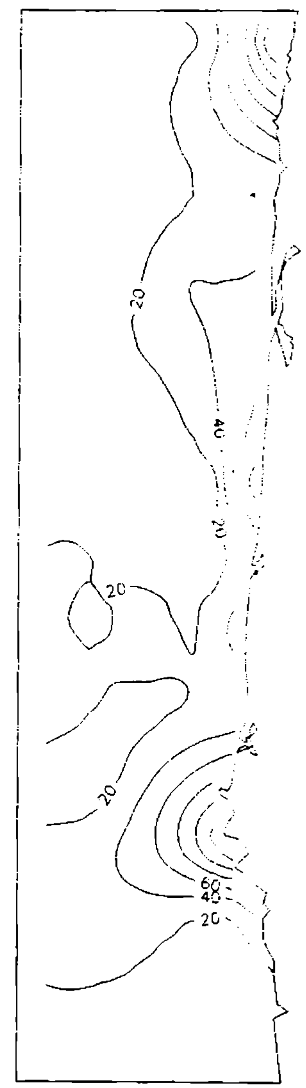


Fig.5.24

Uranium

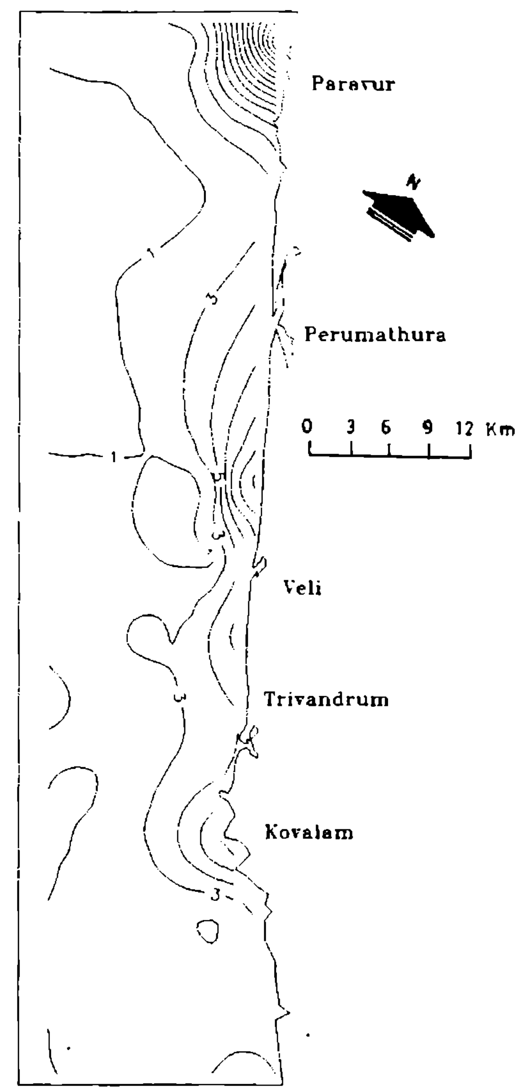


Fig.5.25

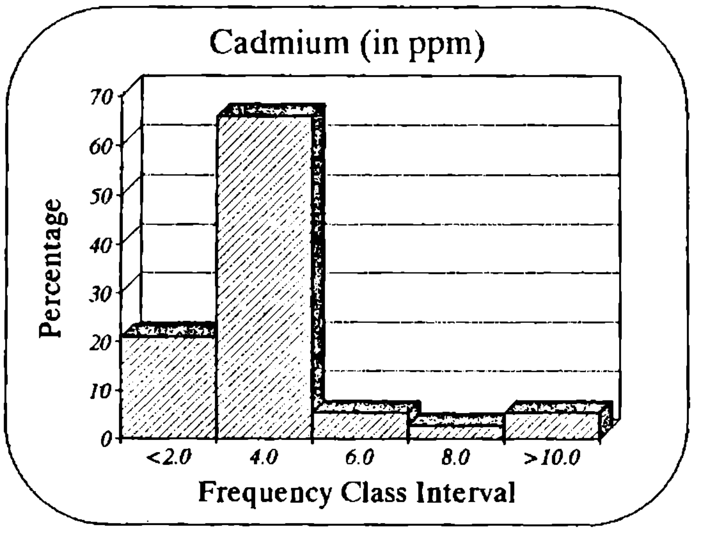


Fig. 5.26

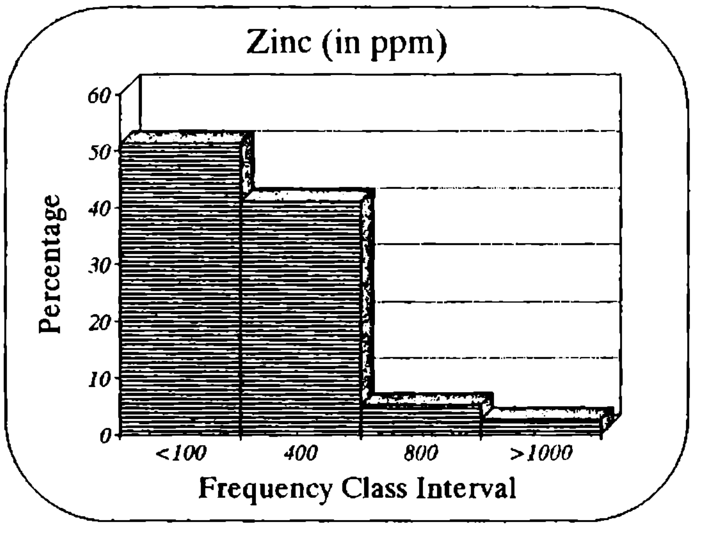


Fig. 5.27

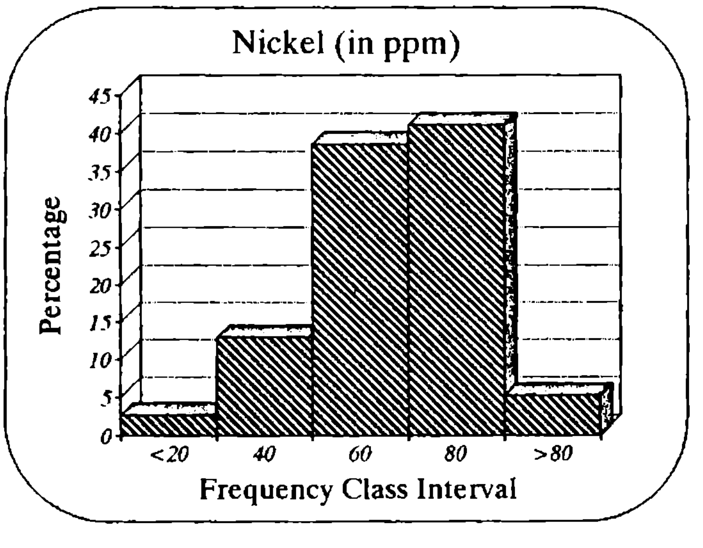


Fig. 5.28

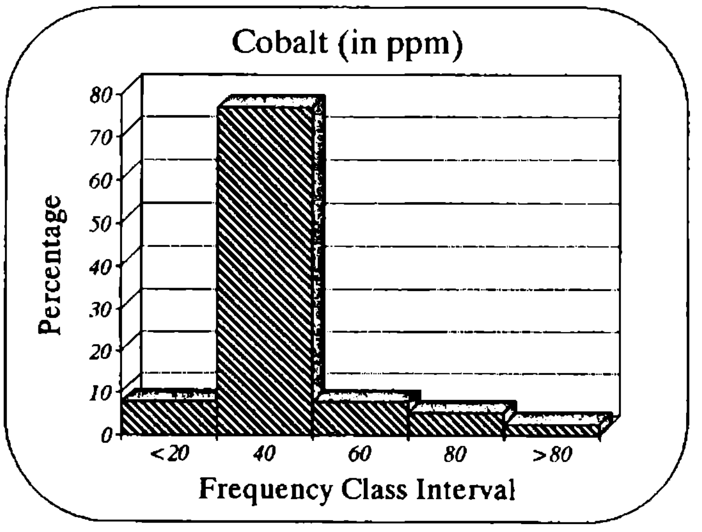


Fig. 5.29

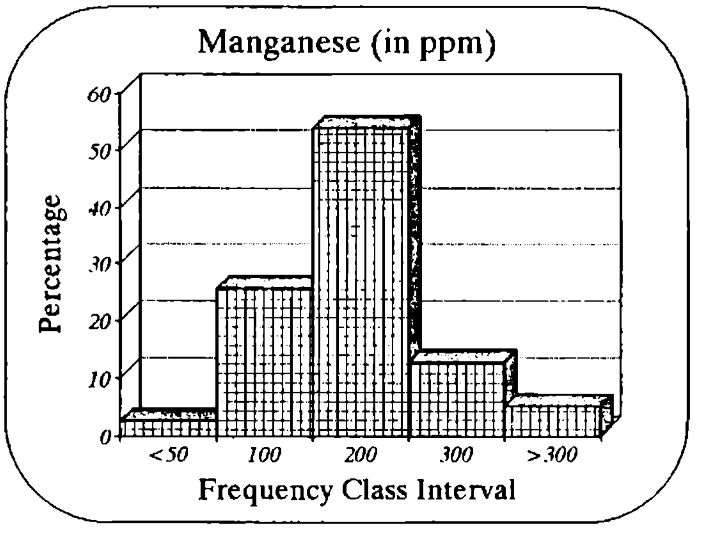


Fig. 5.30

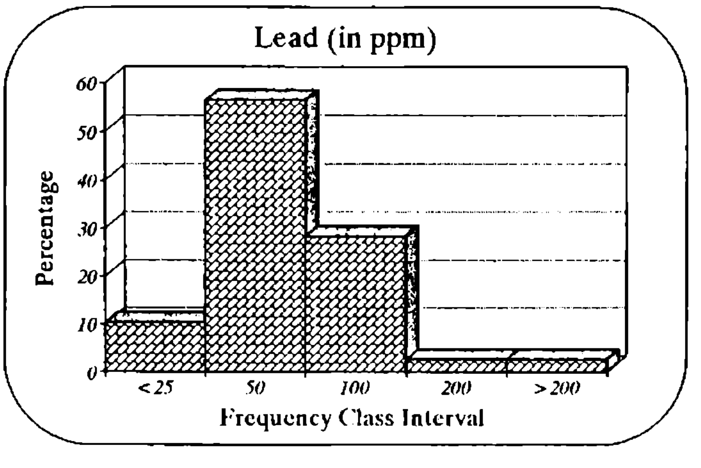


Fig. 5.31

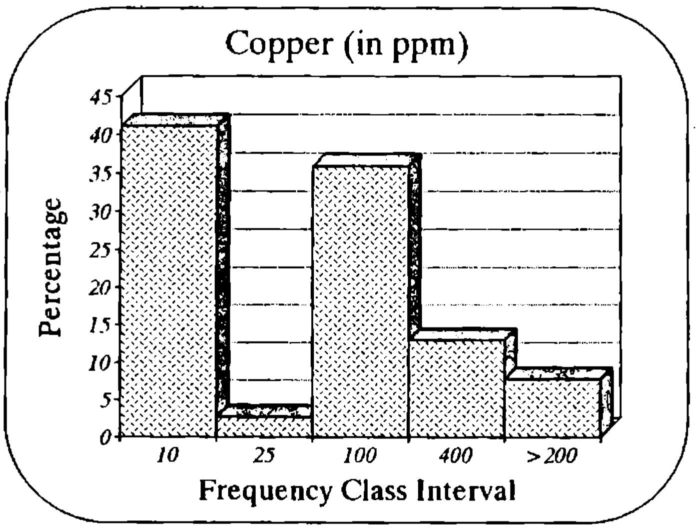


Fig. 5.32

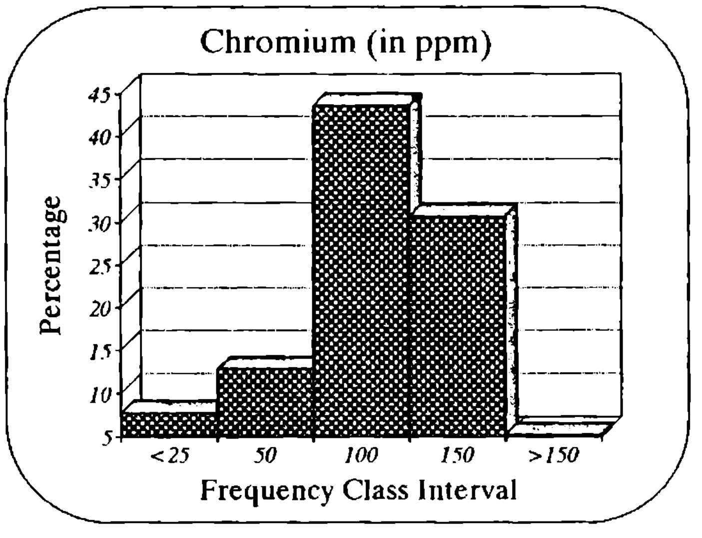


Fig.5.33

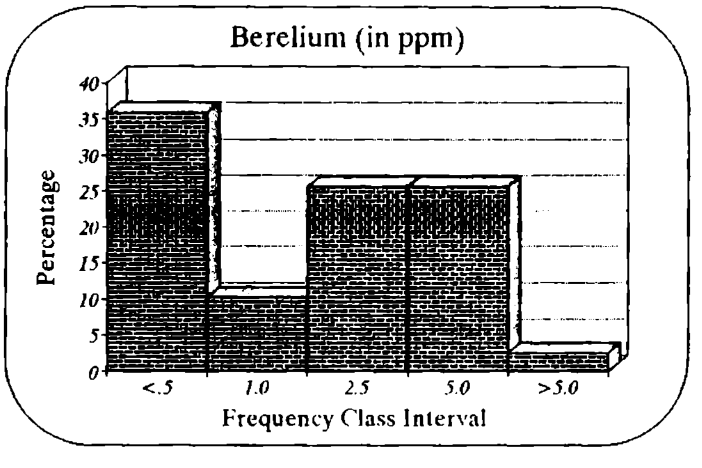


Fig.5.34

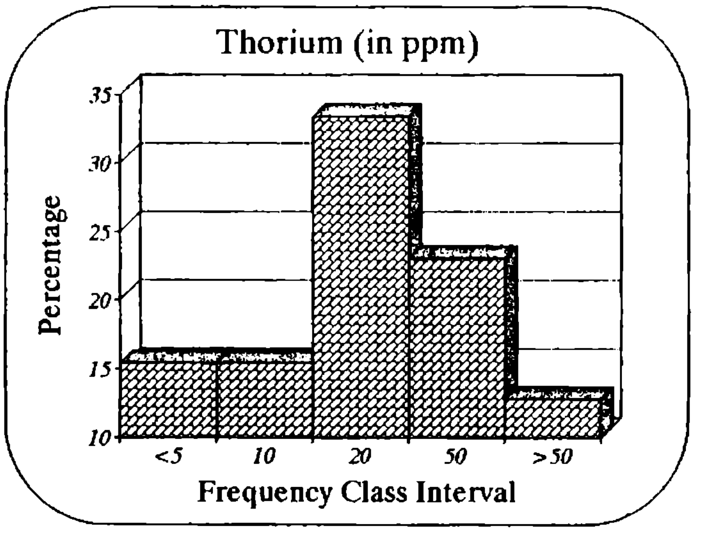


Fig.5.35

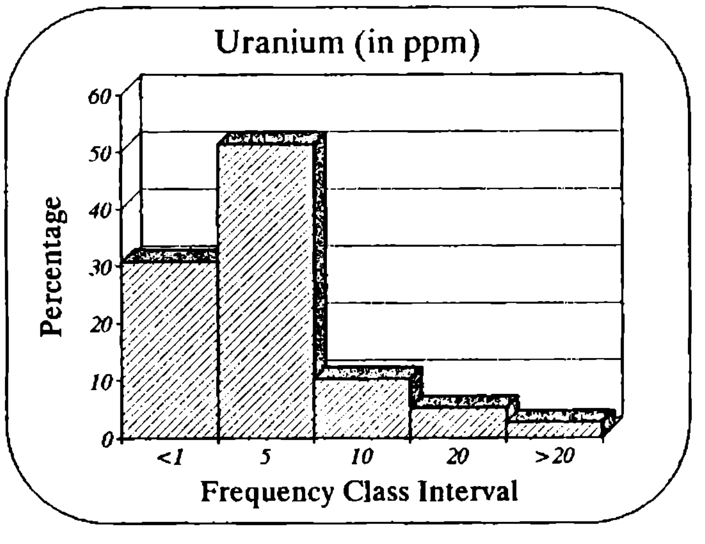


Fig.5.36

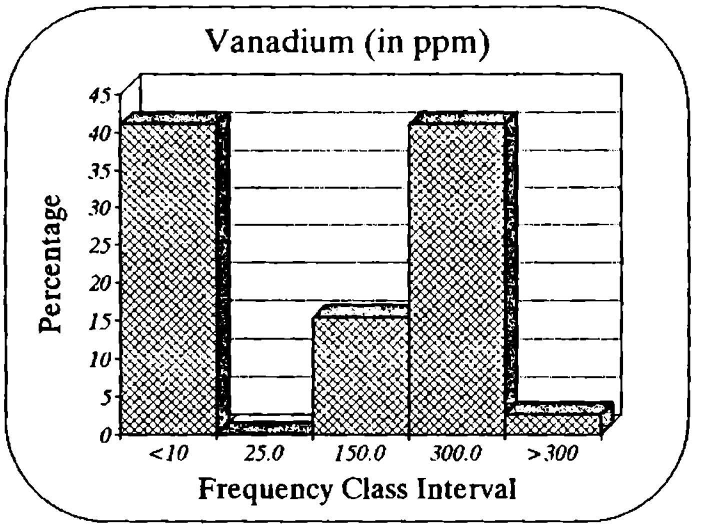


Fig.5.37

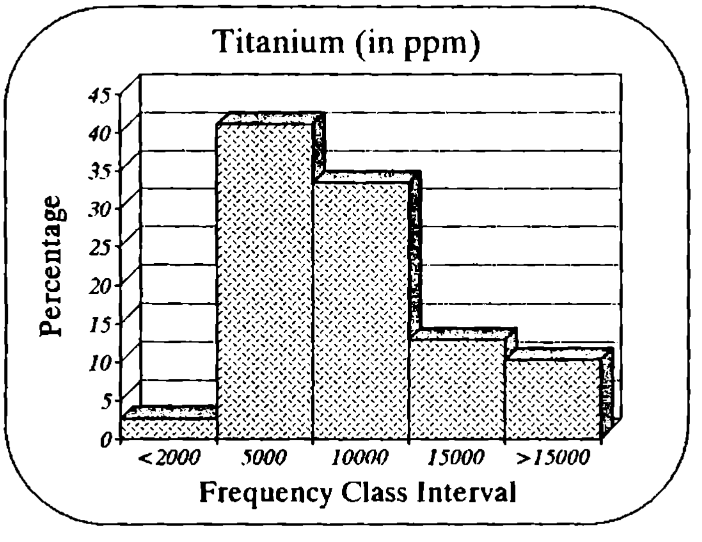


Fig.5.38

with 2320 ppm average was observed for Ti. Nearly 40% of samples have a value of 2000 to 5000 ppm. (Fig.5.38)

Cr concentration ranges between 182 to 2 ppm with an average of 88.3 ppm. The frequency distribution bar chart (Fig.5.33) shows a well defined single peak 45% between 50 and 100 ppm.

Cu concentration ranges between 1537 and 0.1 ppm, with an average of 162ppm. Frequency distribution of Cu shows two breaks at 40% and 35% with concentration at 0-10 and 25-100 blocks. (Fig.5.32).

35% to 40% of the samples analysed have Ni concentration ranging between 40 to 80 ppm. (Fig.5. 28) A maximum concentration of 94 ppm to minimum concentration of 24.9 ppm are observed for Ni with an average of 58.0% and standard deviation of 17.44.

Zn concentration varies very widely between 1244 and 3.3 ppm with an average of 177.49 ppm. However 50% of samples have Zn concentration of 0-100 ppm (Fig. 5. 27). Cd concentration varies between 11.6 ppm and 0.3 ppm. With an average of 3.64. However. >60% of the samples analysed have Cd concentration of 20 to 40 ppm. (Fig.5. 26).

V ranges between 390 ppm and 0 with an average of 112. 5 (Fig.5.37). Insignificant values range from 20 to 0 ppm were observed for Be.

Generally, distribution pattern of uranium resembles that of clay distribution. Three pockets of uranium high is observed, viz., i) around the Kovalam headland, ii) close to the sewage outlet of an industrial waste outlet near Veli and iii) in the vicinity of Vamanapuram river outlet. The isolines of thorium distribution spatially resembles that of uranium.(Figs.5.24 and 5.25). The frequency distribution diagram of Th shows that nearly 33% of the samples have 10 to 20 ppm of Th, (Fig.5.35) whereas nearly 50% of the samples analysed have 1 to 5 ppm of U (Fig. 5.36) respectively.

5.4. DISCUSSION

The range and concentration of chemical composition of a sediment regime is largely texture dependent. There is also a very important elemental partioning effect controlled by the texture of the sediment, it is more so in a nearshore environment due to the extreme textural variability (Calvert 1976). Further, the "Law of grain-size control" on the geochemical variation of sediments professed by Zhao Yiang et al., (1981) is an important factor. In the light of the above distribution of various major and trace elements are discussed in relation with grain size and other factors.

SiO_2 and Al_2O_3

Silica is the most dominant constituent of the innershelf sediments. Further one would expect a high concentration of silica in sand rich southern sector. Contrary to such an expectation silica is found to be enriched on the northern sector sediments where a high concentration of fine sediment is recorded. This shows that the coarser sediments of the southern sector are not predominantly of quartz sand (Fig.3.1) but of other constituent also. Although nearly 75% of the total samples showing more than 80% sand predominate in this area the meagre correlation of sand with silica (0.37. Table.5.2) attest the above conclusion that the silica is being diluted by other constituent especially in the southern sector by CaO (Table 5.1). The CaO is present in this area as aragonite as discussed in the mineralogy chapter (IV). Generally the carriers of silica in this area is detrital quartz and siliceous skeletons. The high concentration of Si on the northern sector could be the commulative contribution from sand, silt and clay, where Si could be present as finely divided particles in silt and clay. Moreover, there is no dilution of silica by CaO in the northern sector ι, because of the unfavourable conditions prevailing in the northern sector for CaO enrichment (See section CaO). Al_2O_3 is not a major component of this study area. It varies from 0.51% to 10% with an average of 2.57% (Table 5.1). More than 90% the samples show Al_2O_3 content with 5%. The distribution diagram (Fig.5.2) shows that most of Al_2O_3 concentrated closer to the coast. Hence

Al_2O_3 is principally derived from allumino-silicates of detrital origin, however, contribution from authigenic processes can not be ruled out (Cronan, 1980). Heath and Dymond (1977) suggested that Al can be used to normalise other elements because Al is usually found to be attached with clay hydrolysate fraction. Relative behaviour of major elements will usually reveal significant differences in composition of a sedimentary basin. SiO2/Al2O3 ratio ranges from 173 to 0.14. This ratio gradually increases with the sand content. This behaviour of SiO2/Al2O3 ratio suggests a larger proportion of free quartz in coarser fraction. The sand rich zones south of Kovalam headland posses a very high value indicating insignificant presence of feldspar and total domination of detrital quartz.

Fe_2O_3:

Iron is one of predominant component of clay lattices and probably represents metalliferous fraction of the sediments. It is found that the iron content in this marine sediment is relatively low with a maximum value of 4.95% (Table 5.1). Most samples (45%) show Fe_2O_3 around 3%. Fe_2O_3 is found to show a negative relation with SiO_2 as shown in the Table 5.2 which may be suggesting that the iron is coated on coarser particles irrespective of composition. This ratio of $Fe_2O_3/Al_2O_3$was found to be anomalously high particularly in sediments off the industrial waste outlet near Veli which may be suggestive of external source in addition to the lattices of alumino silicates. The industrial waste pumped into this region is found to contain sulphuric acid and ferrous sulphate and when this mixture introduced into coastal waters it makes the fine particulate iron matters into ferric hydroxide which can easily form a coating on coarser sediments (Madhupratap et al., 1979). An interesting finding of this study is that, though Fe_2O_3 is showing a negative correlation with SiO_2 (r=O.45), it show positive correlation with that of sand percentage. This shows that (i) pollutant ferric hydroxide forms a coating on the coarser sediments irrespective of its' composition, and (ii) heavy minerals contribute a major portion of Fe_2O_3 to the sediments. Since iron bearing ilmenite, magnetite, hornblende, pyroxenes and garnets abound in this study area these heavy minerals accounts for the bulk of the iron content in the sediments.

CaO, MgO, Na_2O and K_2O.

Since the chemical analysis was carried out on the bulk sediments without removing the shell material, the CaO content in the sediments becomes imminent to be a function of both non-carbonate CaO present in the alumino-silicates and CaO from carbonate sediments. The southern part of the study area registers the highest concentration of CaO (>15%, Fig.5.4) which coincides with the sand dominated zone of high shell debris consisting mostly of mollusc made of aragonite. The CaO content range from 1.4% to 26.04. Lack of uniformity in the CaO content of the sediments in the study area is indicated by a positive correlation with the sand content and negative correlation with silt and clay contents. The low value of CaO recorded in the sediment samples collected close to the Veli industrial waste outlet could be attributed to the inhospitable environment that hampers the shell growth as found by Menon et al., (1979). As the industrial waste waters found to be acidic due to the admixture of sulphuric acid and ferrous sulphate, (Madupratap et.al, 1979) dissolutions of calcarious materials is very much imminent. The low content of calcium in the northern-fine sediment-sector (Fig.5.4) could also be due to cation exchange processes ie. Ca is being replaced by Na, in clays (Sayles and Mangeldsdort 1977). The poor correlation between CaO and Na_2O (Table 5.2). As discussed earlier the aragonite coarse sands are the main reason for the CaO concentration in the southern sector.

Percentages of MgO ranges between 0.38% to 11.40% with an average of 3.26%. Most of the samples (43%, Table. 5.1) show magnesium content <2% value. MgO is slightly enriched in southern sector especially off Kovalam promontory. This could be attributed to the shell rabbles and carbano-lithic crusts which could be seen abundant on the rock outcrops around Kovalam. A second MgO rich pocket is seen in southern sector. In general, absorption of magnesium is facilitated by clay minerals due to the abundance of Mg cation. Especially, at higher pH (Russel, 1970). Weaver

(1967) has contented that clay minerals absorb more Na and Mg than K from seawater, Sayles and Mangelsdort (1977) have also stated that Mg is an important exchangeable cation is sea water next to Na. The slight positive correlation of Mg with silt and clay proves that a part of Mg is associated with clay size particles.

The distribution diagram of Na_2O and K_2O indicate that these oxides are preferably enriched in areas where fines are concentrated. As said in the preceding paragraphs it is expected that fine sediments especially clay minerals control the distribution of these oxides. But K_2O does not show any positive correlation with clay content. Therefore, a major part of K_2O in the sediment is probably due to organic residue derived from plant materials (Seralathan 1979) and from feldspars. The low K_2O values observed off the Veli area again indicate that K rich feldspars could have been leached by the polluted environment in that area.

The pollution load of this area has widely been evaluated by many researchers, (Menon et al., 1979; Rao and Rao 1979; Madhuprathap et al., 1979; Vijayamohan et al., 1984) and some metals (Ti, Mn, Ni, Cr and Cu) are found to be particularly related to the industrial pollution in this study area (Machado and Suchindan 1986).

Titanium

Titanium distribution reveals a high concentration off the Veli region where the clay content is also found to be high. Generally, the distribution pattern of Ti largely resembles, that of clay distribution in this area. Such a selective adsorbence of trace metals in finer sediments has been earlier reported from the northern part of the west coast of India (Nair et al., 1978; Paropkari et al., 1978). The average Ti content in the clay fraction of the marine sediments off the Krishna, Mahanadi and Cauvery deltas respectively are 0.48%, 0.53% and 0.47% (Seetaramaswamy, 1970, Satyanarayana, 1973 and Seralathan and Seetaramaswamy, 1987). The Ti content in the bulk sediments off the Cochin, Alleppey areas are 0.7% and 0.5 % respectively. (Prakash 1992; Ramachandran, 1992). Hence, the abnormally high content of Ti in the present study area especially of Veli (1.4%) cannot solely be attributed to clay content alone, but possibly from other sources as well. Contributions from the rivers which join the study area cannot be very high as they drain through a terrain of charnockite, khondalite, garnet-sillimanite gneiss and granite. Moreover, though there is a placer deposit of ilmenite and rutile at Chavara, contribution of Ti by those heavies by hydrolyzates could not also be significant because of their high resistance to weathering. The additional source could possibly be the Travancore Titanium Products Ltd. (TTP). Vijayamohana et al., (1984), have analysed the industrial waste by TTP located at Veli and reported about

1.5% of Ti concentration. Therefore, a major portion of Ti in the surficial sediment of the study ara could have been derived from the industrial sludge which is being disposed off the Veli beach.

Halcorw et al., (1973) have carried out pollution studies in an industrially polluted coast in England and concluded that the trace metals are the best indicator of extension of industrial waste contamination in the shelf sediments. Therefore, it could be inferred that the industrial waste from the TTP at Veli contaminates the nearshore area especially the regions south of the outlet than the north. This phenomenon could be related to the dominant long shore current and sediment transport towards south as described in the preceding chapters. Ti exhibits a negative correlation with depth (r = 0.42). The positive correlations with the total heavies (r - 0.41) and with opaques (r = 0.3) indicate that a considerable amount of Ti is from the heavies, especially from ilmenite and magnetite and rutile which forms part of opaques. Earlier Chandrasekar (1992) has reported that TiO_2 content in ilmenite (av. 42.78%) and magnetite (av.15.35%) are very significant.

Copper & Lead

Cu is one of the trace metals that is readily absorbable in marine sediments under high water temperature and low pH conditions (Bryan

Table 5.4 Correlation matrix for trace elements

	Cd	Zn	Ni	Co	Mn	Pb	Cu	Cr	Be	V	U	Th	Ti
Cd	1												
Zn	-0.142	1											
Ni	0.109	0.057	1										
Co	0.643	-0.169	0.423	1									
Mn	-0.287	0.233	0.222	-0.09	1								
Pb	0.143	0.73	-0.013	0.039	0.116	1							
Cu	-0.073	0.939	-0.063	-0.185	0.263	0.739	1						
Cr	-0.213	0.22	0.499	0.025	0.545	0.106	0.232	1					
Be	-0.277	0.099	0.324	-0.029	0.093	-0.153	0.031	0.299	1				
V	0.072	-0.258	0.432	0.521	0.324	-0.109	-0.232	0.576	0.034	1			
U	-0.057	-0.121	-0.129	-0.047	0.476	0.062	-0.058	-0.062	-0.141	0.629	1		
Th	-0.075	-0.153	-0.087	-0.079	0.418	0.019	-0.105	-0.041	-0.175	0.289	0.837	1	
Ti	0.002	-0.189	0.063	-0.114	0.206	-0.049	-0.11	0.207	-0.125	0.696	0.128	0.107	1

1976). Such high temperature (>o) and low pH (1 to 2) with high redox potential condition is reported to be prevalent at the site of the industrial waste disposal point at Veli (Madhupratap et al., 1979). Moreover, Cu and Zn are found to be easily adhered to sources because the river Vamanapuram drains mainly through a Khondalite terrain with 0.012% Ni and 0.01% Cr (Soman, 1984).

Uranium & Thorium

U and Th contents are shown in Table 5.3. Recently, Padmalal has found that the average Th content of the Muvattupuzha river and central Vembanad estuary are as 67.98 ppm and 2.78 ppm respectively. U and Th are found to be concentrated in pockets which are rich in finer sediments. Concentration of U and Th are found off the Kovalam headland as well as off the Veli industrial waste outlet and Vamanapuram river outlet. The fine size preferred concentration of these elements could be attributed to presence of organic carbon which usually is associated with the fine sediments, which help in fixation and harbouring of these elements (Mo et al., 1973). Moreover, many authors have found that U can get fixed in nearshore sediments under anaerobic condition. Hence, the high U concentration seen around the industrial waste outlet can be related to the anaerobic condition (Menon et al., 1979). Borole et al., (1982) have suggested that when fresh water mixes with the sea water, U can get adsorbed in the MnO_2 lattices. Such a mixing is inevitable in a estuarine mouth where high Mn concentration is also reported in this area (Machado and Suchindan 1987). Therefore, it could be postulated that the area off Vamanapuram river outlet offers excellent environmental condition for fixation of U.

The percentage isolines of Th are spatially resembling that of U indicating that the Th rich monazite and zircon are deposited in this shoreface ambience. The bearing of Th contents on monazite and zircon have earlier been established by Parthasarathy and Sankaradas (1976). Monazite was compared with depth, a very insignificant negative correlation is resulted. Whereas, both the U and Th indicate strong negative correlation with depth. Zircon also does not show a good positive correlation with U and Th. Such an intrigue relationship among of these variables circumstantially imply that, the distribution of U and Th are controlled not only by monazite, but possibly by the fine sediment and organic matter as well.

PLATE . 1. ECHOGRAMS OF SOME SHORE PERPENDICULAR ECHOPROFILES

(SEE FIG. 1.5 FOR LOCATION)

PLATE 2 EROSIONAL BERM NEAR KOVALAM

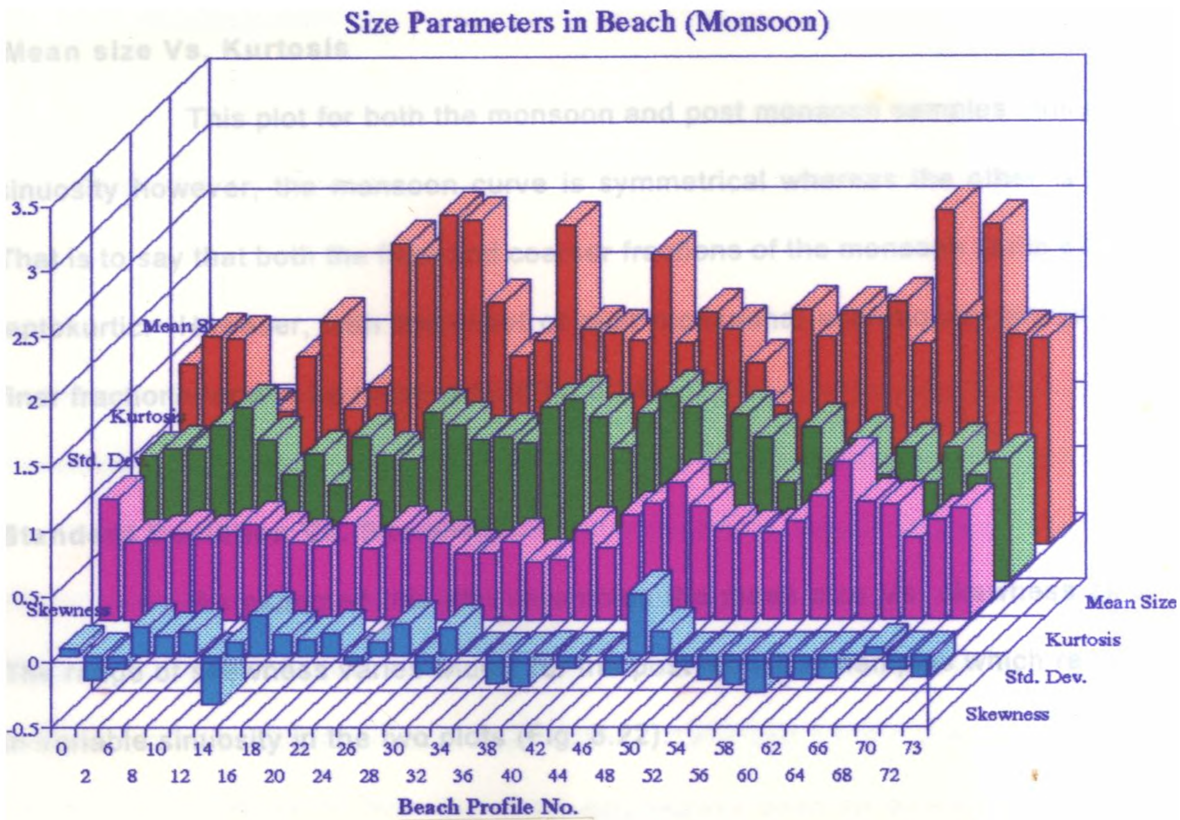


Fig. 3.17

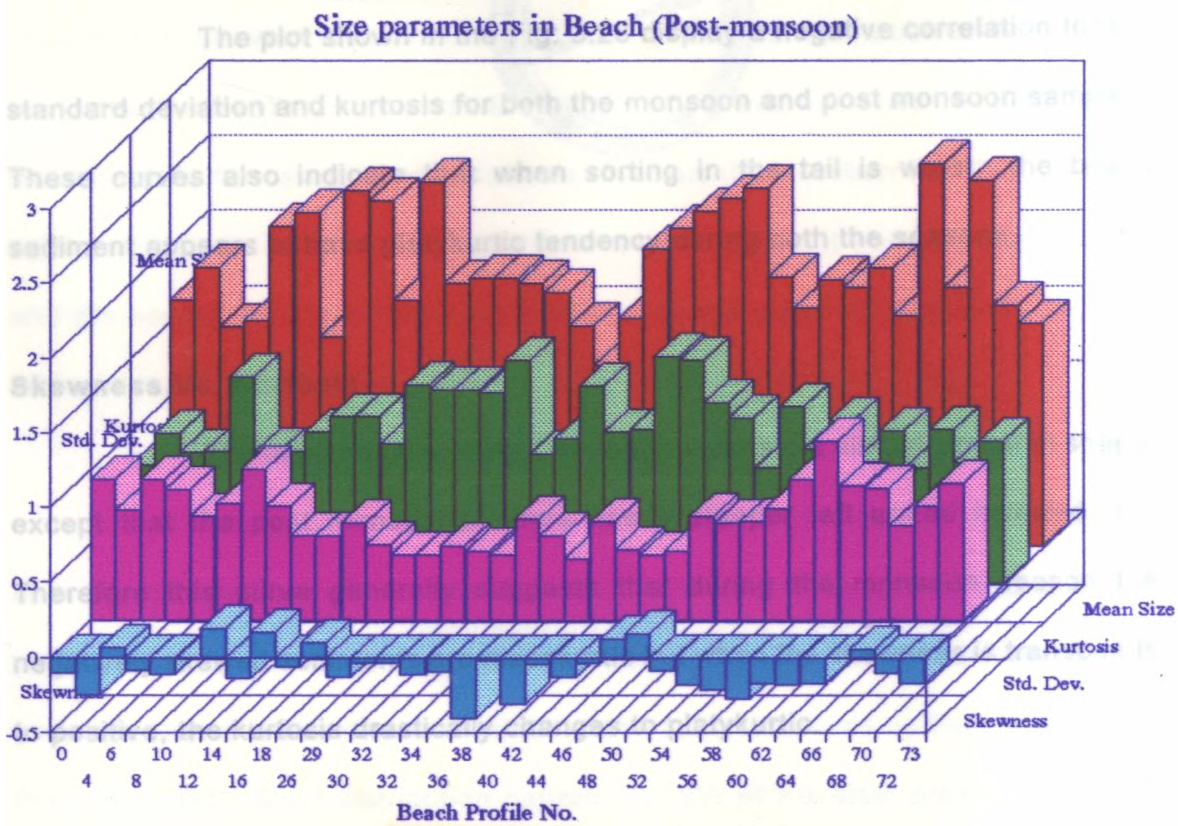


Fig. 3.18

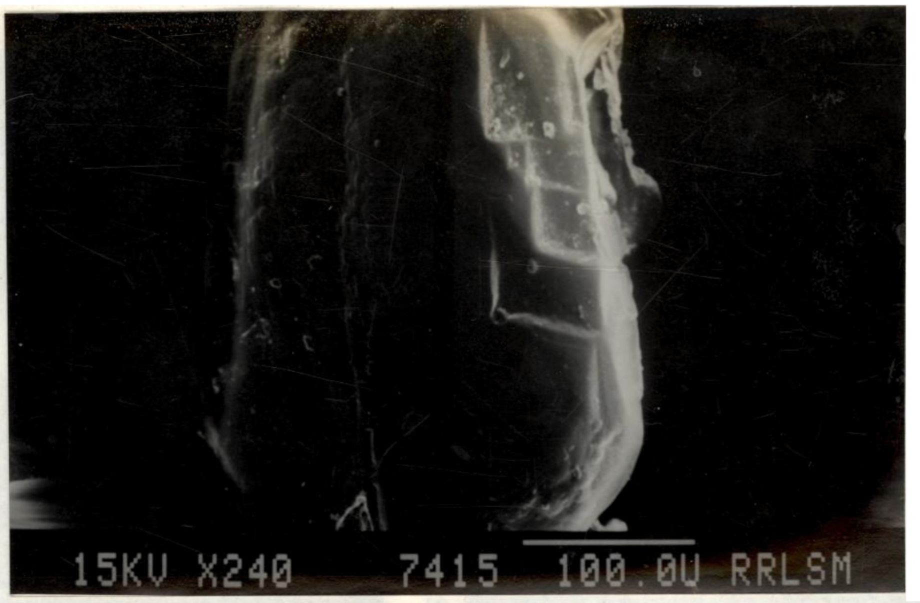


PLATE 3.1 MICRO MORPHOGRAPH SHOWING DISC SHAPED BREAKAGE

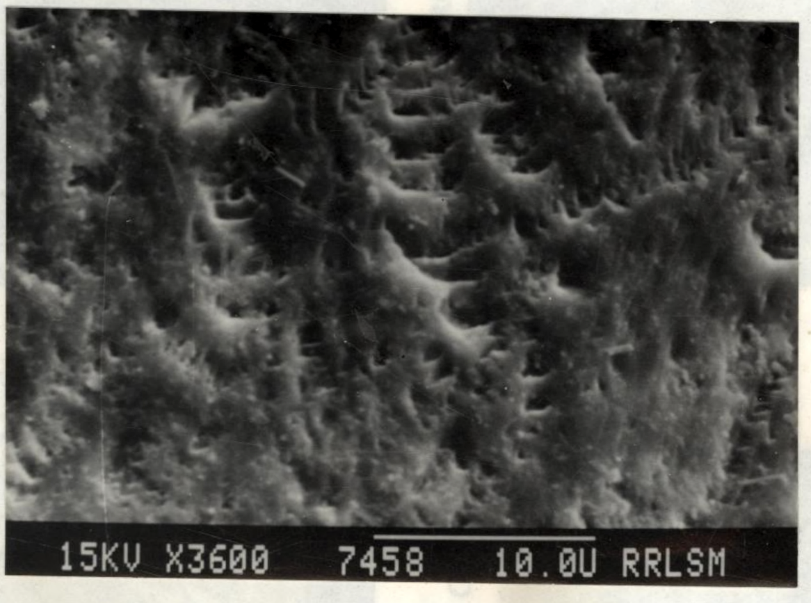


PLATE 3.2 IRREGULAR "V" PITS

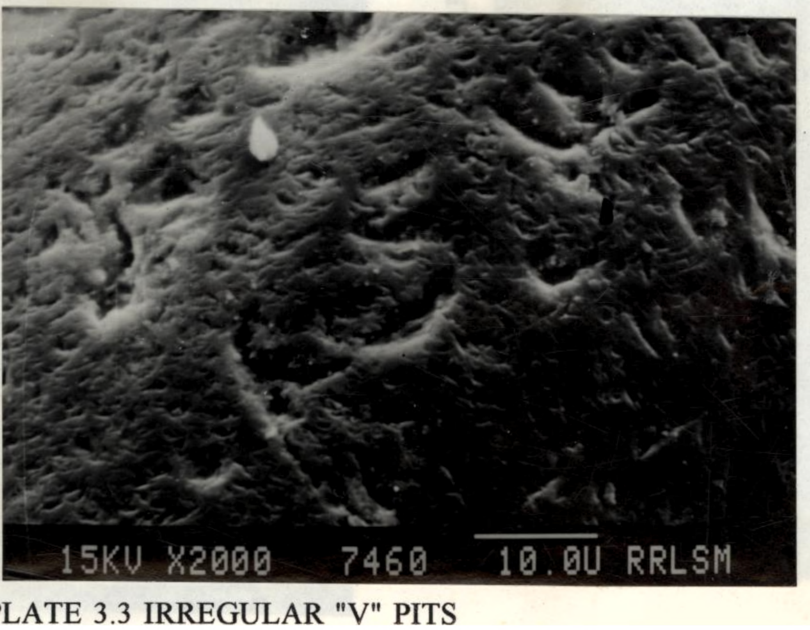


PLATE 3.3 IRREGULAR "V" PITS

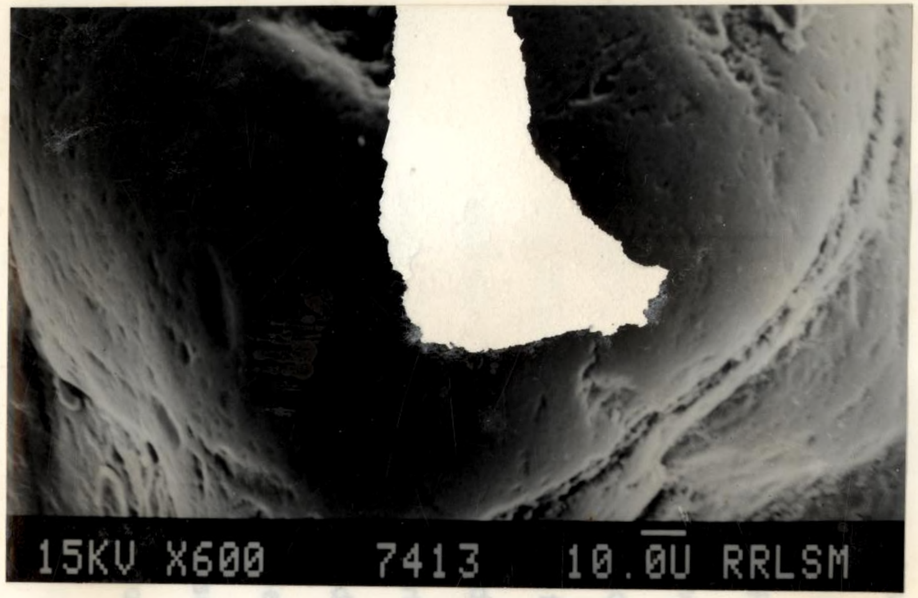


PLATE 3.4 CONCHOIDAL FRACTURE IN GARNET

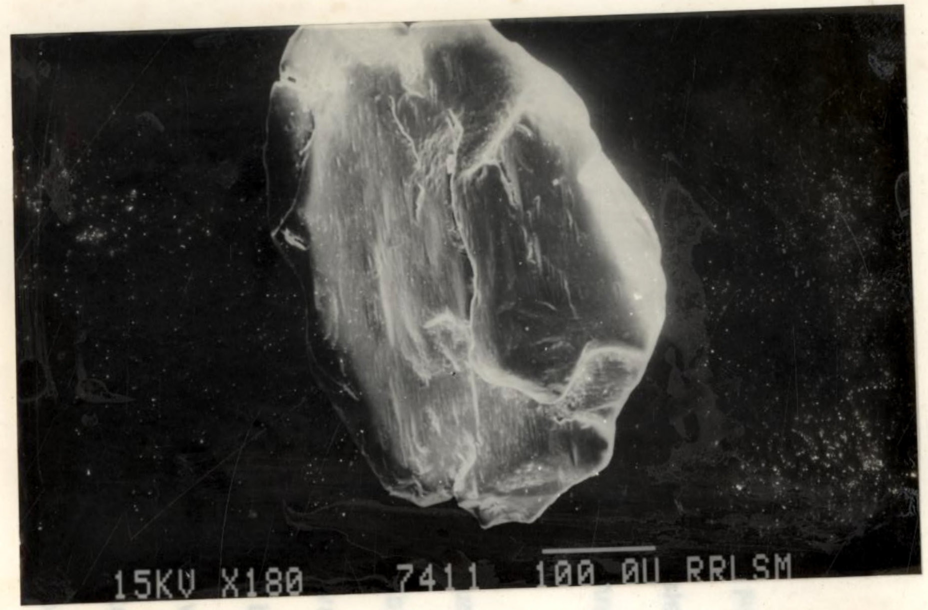


PLATE 3.5 FIBROUS CLEAVAGE OF SILLIMANITE

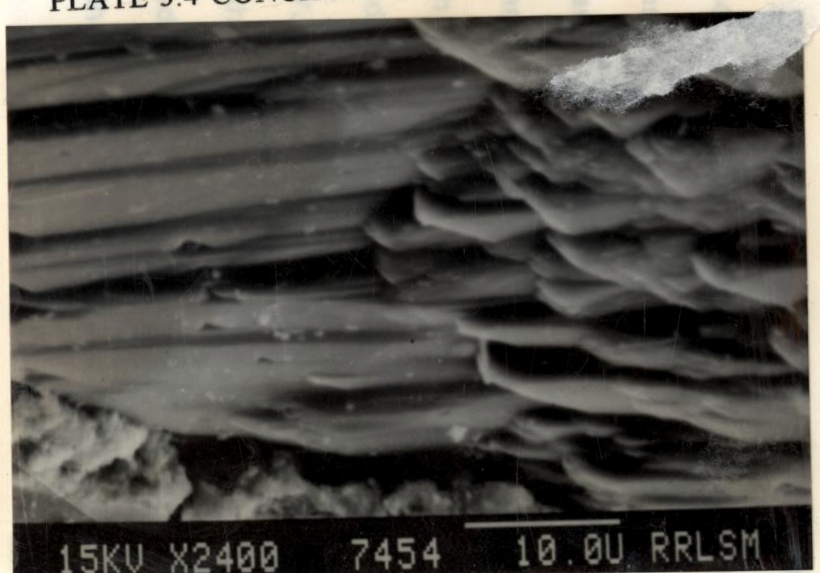


PLATE 3.6 MAMILLATED SURFACE ON GARNET

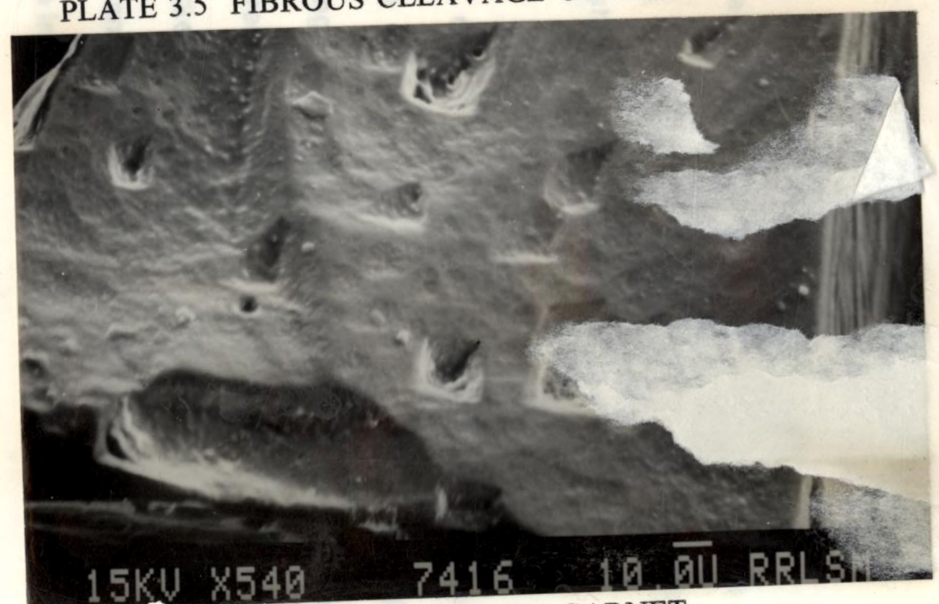


PLATE 3.7 IRREGULAR "V" PITS ON GARNET

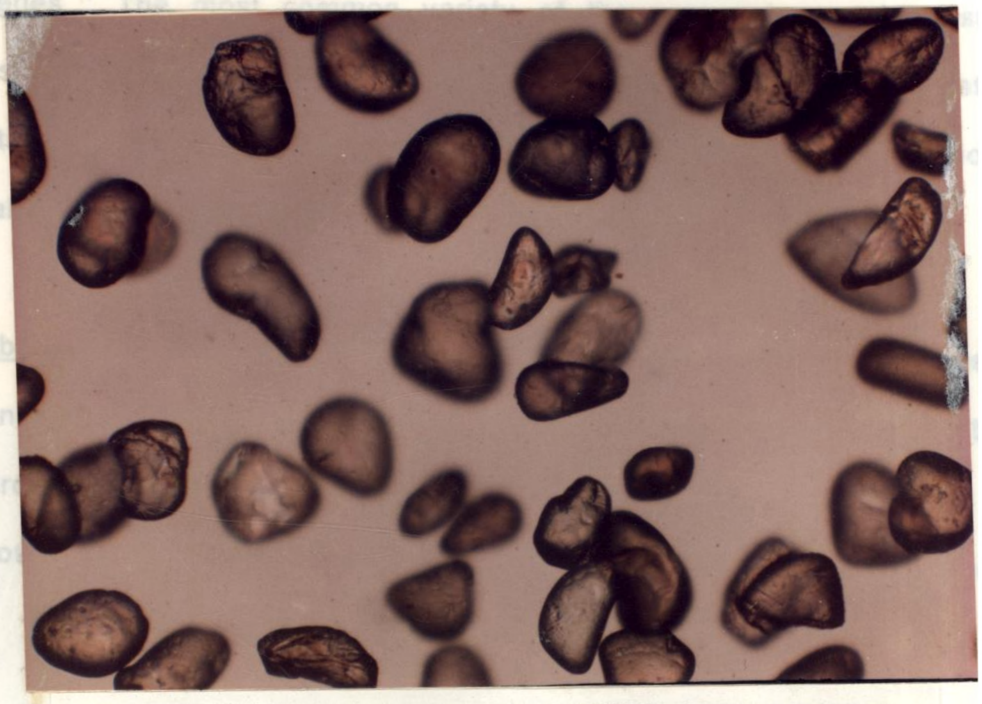


PLATE 4.1 WELL ROUNDED MONAZITE GRAINS

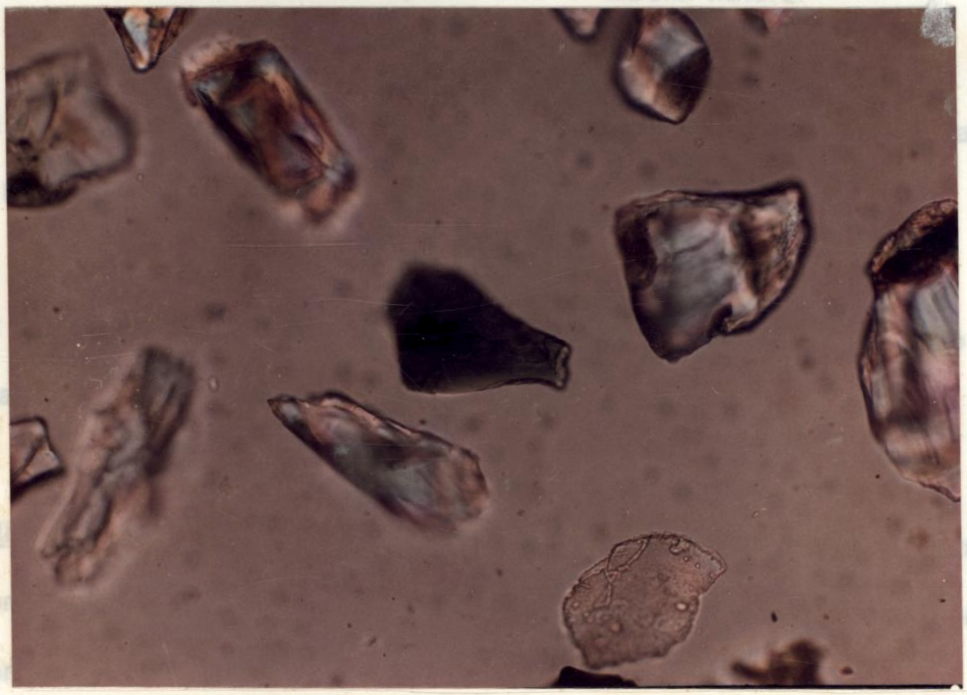


PLATE 4.2 HORNBLENDE UNDER POLARISED LIGHT

PLATE 4.3 KYANITE UNDER POLARISED LIGHT

Fig. 4.17 Heavy mineral % in coarser & finer fractions of sediments

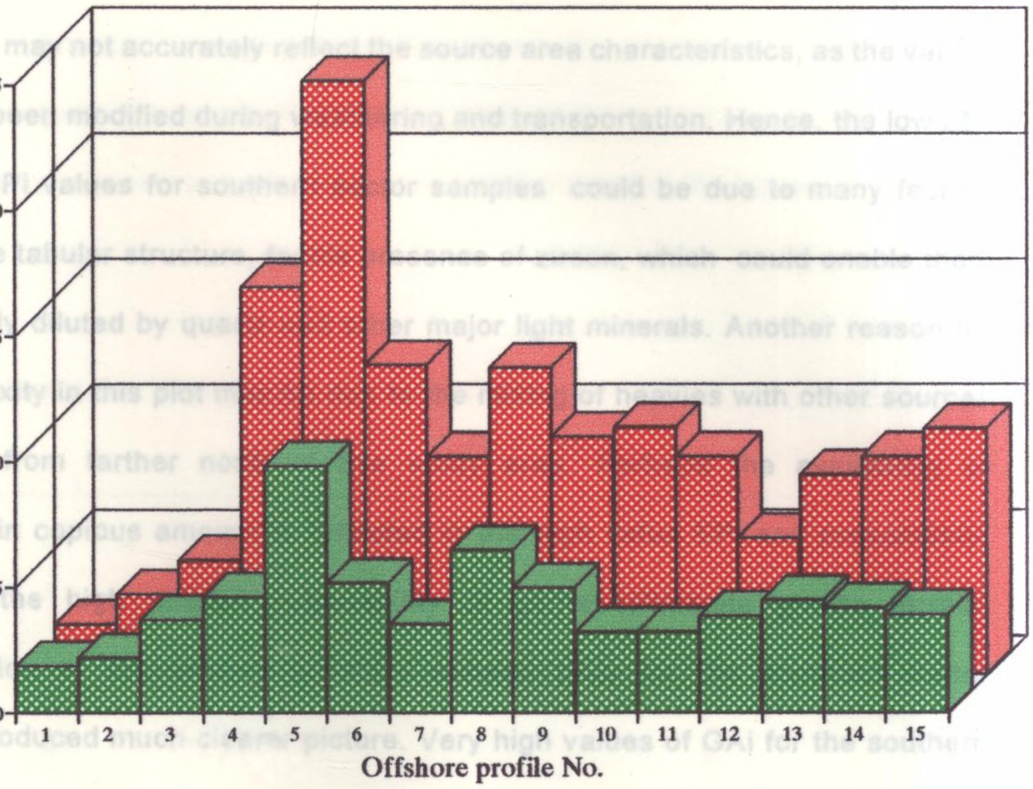
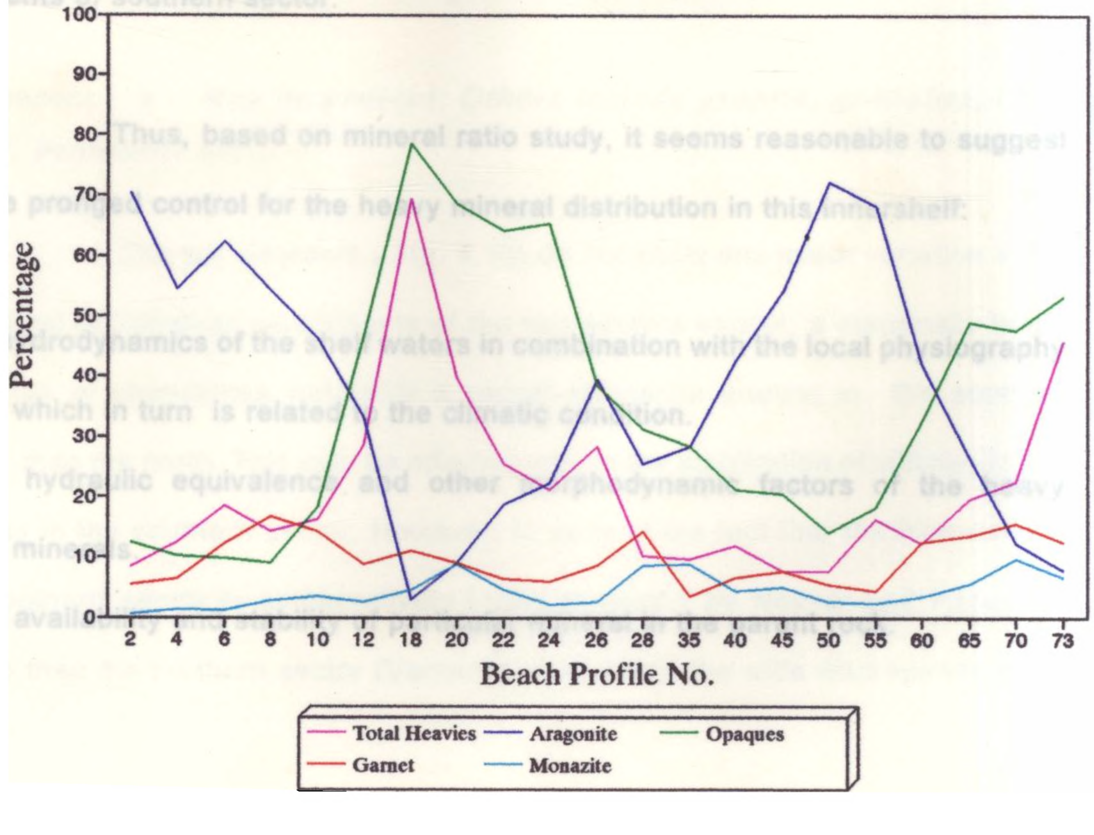


Fig. 4.18 Distribution of Some Heavy Minerals in Beaches



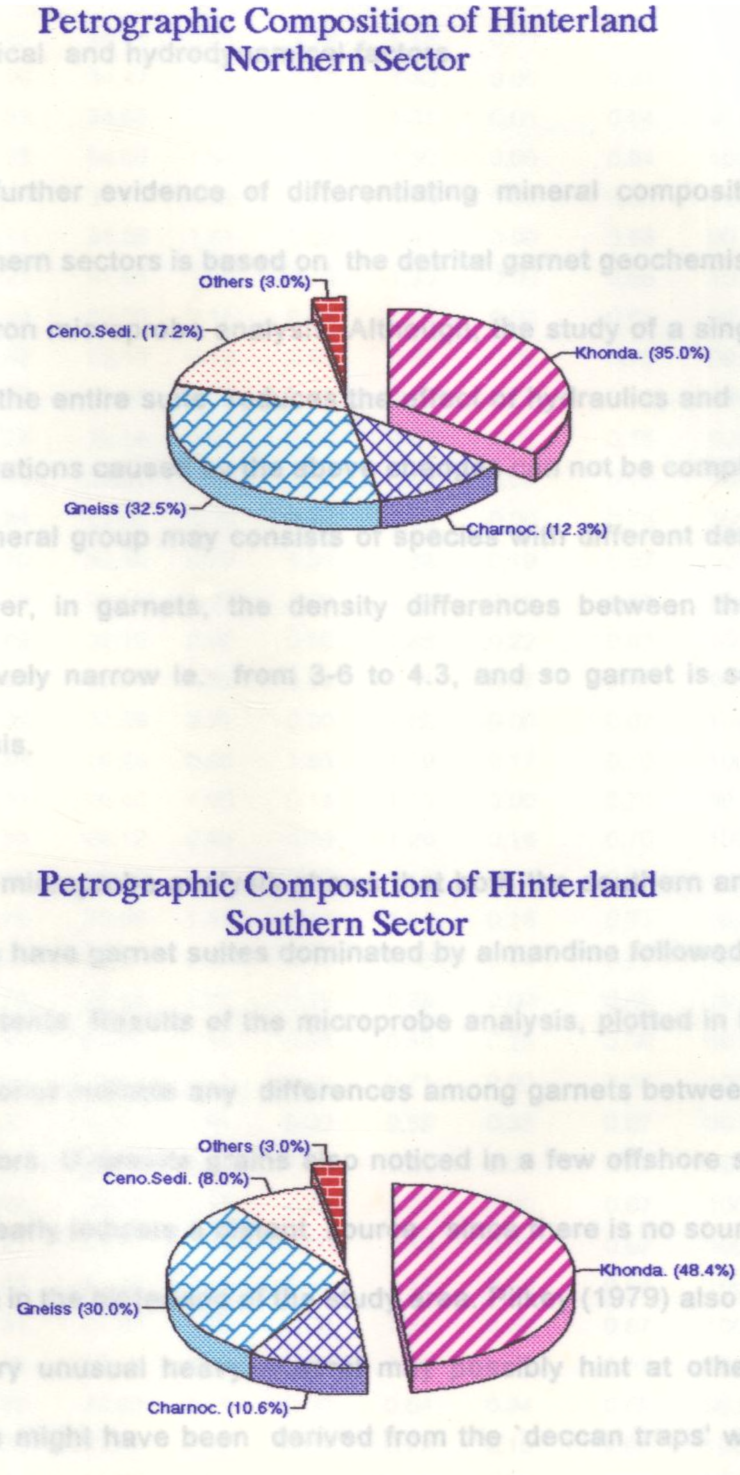


Fig. 4.16 Pie diagram showing the distribution of different rock types in the hinterland of the study area

PLATE 3 BLACK SAND LAMINAE IN A POCKET BEACH NEAR KOVALAM

CHAPTER - VI

SUMMARY AND CONCLUSIONS

Studies on geomorphometry, texture, mineralogy and geochemistry of the innershelf of Trivandrum coast, reveals the following. The geomorphometric study indicates that the study area portrays a microcosmic perspective of the coastal geomorphology of Kerala consisting of cliffed beaches, pocket beaches, barrier beaches and beaches backed by strand plains. Cliffed beaches are encountered in the southern end around Kovalam and Varkala in the northern end of the study area. Number of pocket beaches are also seen in between the cliff sections around Ava, Vizhinjam and Varkala. Intensive beach profile studies reveal that the barrier beaches undergo more severe erosion during SW monsoon and accretion during post monsoon period. The fluorescent tracer study using Rhodamine-B reveals that the dominant sediment movement in the swash and littoral zones during SW monsoon is towards immediate seaward and southward which leads to formation of break point bar and severe erosion of fair weather berm. The tracer studies during post monsoon period indicate a diagonally dominant shoreward movement. This confirms that the monsoonal break point bar is in the process of disintegration and shoreward migration which leads to the formation of fair weather berm.

Wave refraction study suggests possibility of rip current around Kovalam headland. The innershelf morphology deduced from echograms shows that the southern inshore reaches of the study area is more steeper than the northern sector. Based on this the study area could be divided into southern and northern sectors. This information of this study area is reported for the first time. Further, nature of the bottom deciphered from the echoprofiles indicated that the southern sector is made up of coarser sediment than in the northern sector.

Textural studies has shown that the sand is the dominant component of the study area. Particularly on the southern sector whereas the northern sector has comparatively higher mud content . A sand salient is observed off Kovalam. The variation in grain size between the sectors is attributed mainly to variation in slope characters. The boundary between these two sectors is found to be approximately off Veli backwater system. Mean size distribution showed a bimodality which resulted in contrasting behaviour of textural parameters of the two sectors. The granulometric analysis of the beaches showed that the monsoon sediments are coarser than the post monsoon sediments. Such variation was not conspicuous in the pocket beaches which was attributed to the presence of heavy mineral placers which are predominantly finer . Monsoonal sediments are better sorted and more positively skewed.

The sediment transport pathways in the innershelf are worked out using McLaren's model, based on "Z" score statistics. It highlights the existence of a bidirectional transport at 15 m. isobath and a major southward transport for 30 m. and 45 m. isobaths. Microstructure studies using "SEM" reveal that, quartz, garnet, ilmenite and kyanite are smooth and featureless in the southern sector which probably is suggestive of a outside wave base regime. This information could be deduced from the absence of wave action related features.

Heavy mineral content of both the beach and innershlef sediment shows semblance of spatial distribution to each other. The heavy mineral assay indicates that the innershelf and beach sediments constitute predominantly, opaque, sillimanite, and aragonite. Garnet, rutile, monazite, zircon, hornblende, pyroxene and tourmaline were found as minor constituents. Garnet, sillimanite and aragonite were found to be more concentrated in the southern sector and the others in the northern sector. It could be inferred that the promontories act as barriers to the dominant southerly current and force the heavies to settle on the upstream side of these headlands. Moreover, the difference in shelf gradient between the two sectors is also possibly playing a major role in distribution the heavies and finer sediments in the northern sector.

The varietal studies of some of the relatively abundant heavy minerals suggested that the hydrodynamics of the region and morphodynamics of the coast are the major factors that determine the distribution patterns of some of the heavy minerals in the innershelf. This study further indicated that the khondalite and garnetiferous gneiss are the main contributors followed by charnockite, to the heavy mineral suites in the innershelf. The presence of kyanite in the beach sediments suggests a source in the vicinity of beach probably the Tertiary formation. The definite presence of uvarovite suggest that the contribution from distant sources could not be ruled out. The electron microprobe analysis of garnets indicated that almandine and pyrope are the two members of the garnet series present in the study area. However, this does not indicate any sectorial distinctiveness in their distribution.

The distribution pattern of SiO_2 shows that the concentration is more on the northern sector. The finer fractions show a relative enrichment than the coarse fraction dominated in the southern sector. The low concentration of SiO_2 in the southern sector is mainly due to the dilution by aragonite. Although the textural parameters show that the southern sector sediment is predominantly coarse grained, the geochemical results show that the coarser sediments are not exclusively of quartz sand. The distribution of Fe_2O_3 has a linear relationship with grain size, but a negative correlation with SiO_2. This may be due to the coating of ferric hydroxide on the coarser grained particles, irrespective of the composition. Distribution pattern of Cu and Ti shows preferential adherence to nearshore sediments, particularly around the industrial waste outlet of the Travancore Titanium Products Ltd., situated on the Veli beach. This distribution pattern of these elements further suggests that the pollutants are transported towards south, which is in accordance with the general longshore current direction.

Annexure - I

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