STUDIES ON THE TEXTURE, MINERALOGY AND GEOCHEMISTRY OF THE MODERN SEDIMENTS OF THE VELLAR ESTUARY

THESIS SUBMITTED TO THE
COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY
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IN
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BY

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CERTIFICATE

I hereby certify that the Thesis entitled " Studies on the texture, mineralogy and geochemistry of the modern sediments of the Vellar estuary" submitted to the Cochin University of Science and Technology for the award of the Ph.D. Degree is a genuine and bonafide work done by Mr. P.M. Mohan, during the period 1985-1990 under my supervision.

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PREFACE

Estuarine environment is considered to be a transition zone between the fluvial and marine environments and therefore it plays an important role in the coastal and marine sedimentary system. Increasing attention has been bestowed on research in modern estuarine environment during recent years and a wealth of informations on biological, chemical, hydrographical and geological aspects of estuarine system have been gathered and lengthy syntheses of the interaction between these subjects in several modern estuaries have been published. These literature clearly indicate that a given set of estuaries can never be identical in their environments of deposition. The interactions of so many variables and differences in the physico-chemical, biological, meteorological and sedimentological conditions that exist in the different regions of our country make this problem more complicated. Hence, it is necessary to study each estuary individualy.

A cursory analysis of the existing literature on estuaries and back waters of Tamilnadu reveals that the Vellar estuary is one of the well studied estuaries with respect to biology and hydrography. However, the geological aspects are yet to be studied. Therefore, the present study intends to investigate the textural, mineralogical and geochemical aspects of the modern sediments of the Vellar estuary, Parangipettai, Tamilnadu. Since estuary is a transition zone between the fluviatile and marine environments, and it is essential to bring out the influence

of these environments on estuaries, the present study covers the fresh water river environments and other marginal environments such as tidal channel, beach, and nearshore marine environments (Lat. $11^{\circ}20'$ to $11^{\circ}30'$ N and Long. $79^{\circ}00'$ to $79^{\circ}46'$ E) which also interact with the Vellar estuarine system. Further, studies on the sediments of these environments also give a clear picture of the pre and post depositional changes of the sediments.

The thesis contains the following aspects viz., texture, mineralogy and geochemistry of the modern sediments of the Vellar estuary, which are laidout in five chapters.

The first chapter of the thesis deals with the introduction.

The variations in textural characteristics of different environments are discussed in the second chapter.

The third chapter deals with the detailed mineralogical studies of heavy, light and clay minerals.

The geochemical distribution of various major (Si, Al, Fe, Mn, Ti, P, Na, K, Ca, & Mg) and trace (Cu, Co, Ni, Zn, Cd, & Cr) elements and the factors controlling their distribution in sediments of different environments of the study area have been discussed in the fourth chapter.

Summary of the whole study and the salient conclusions drawn from the results thereof are given in the fifth chapter.

The pertinent literature is furnished under the head "References".

CONTENTS

CHAPTER:I.

INTRODUCTION

In recent times more attention is being paid to estuarine geology owing to the significant role played by the estuaries in the coastal and marine sedimentary system. While sediments brought by rivers are being transported to the sea, the estuaries trap sediments and form new environments creating a transition zone between the fluvial and marine environments. Greater attention is bestowed on research in modern estuarine environment during recent years and a wealth of information on biological, chemical, hydrographical and geological aspects of estuarine system have been gathered, and lengthy syntheses of the interaction between these subjects in several modern estuaries have been published. These literature clearly indicate that a given set of estuaries can never be identical in their environments of deposition. The interactions of so many variables and differences in the physico-chemical, biological, meteorological and sedimentological conditions that exist in the different regions of our country make this problem more complicated. Hence, it is necessary to study each estuary individualy.

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geological aspects are yet to be studied. Therefore, the present study intends to investigate the textural, mineralogical and geochemical aspects of the modern sediments of the Vellar estuary, Parangipettai, Tamilnadu. Since estuaries are the transition zone between the fluviatile and marine environments, and it is essential to bring out the influence of these environments on them. The present study covers the river (fresh water) environment and other marginal environments such as tidal channel, beach, and nearshore marine environments which also interact with the Vellar estuarine system. Further, studies on the sediments of these environments would also give an insight into the pre and post depositional changes of the sediments.

LOCATION:

The study area is located in the South Arcot District of Tamilnadu between Lat.11° 20' and 11° 30' N and Long. 79° 00' and 79° 46' E (Fig.1 & 2).

DRAINAGE:

The rivers of India are classified under three categories, based on the area of the river basin, Viz., Major river, having a catchment area of 20,000 sq km each, Medium river, having a basin area of 2,000 to 20,000 sq km and Minor river with a catchment area of less than 2,000 sq km. The Vellar river is classified as medium river (Rao, 1975), and has a total catchment area of 2975.26 sq km

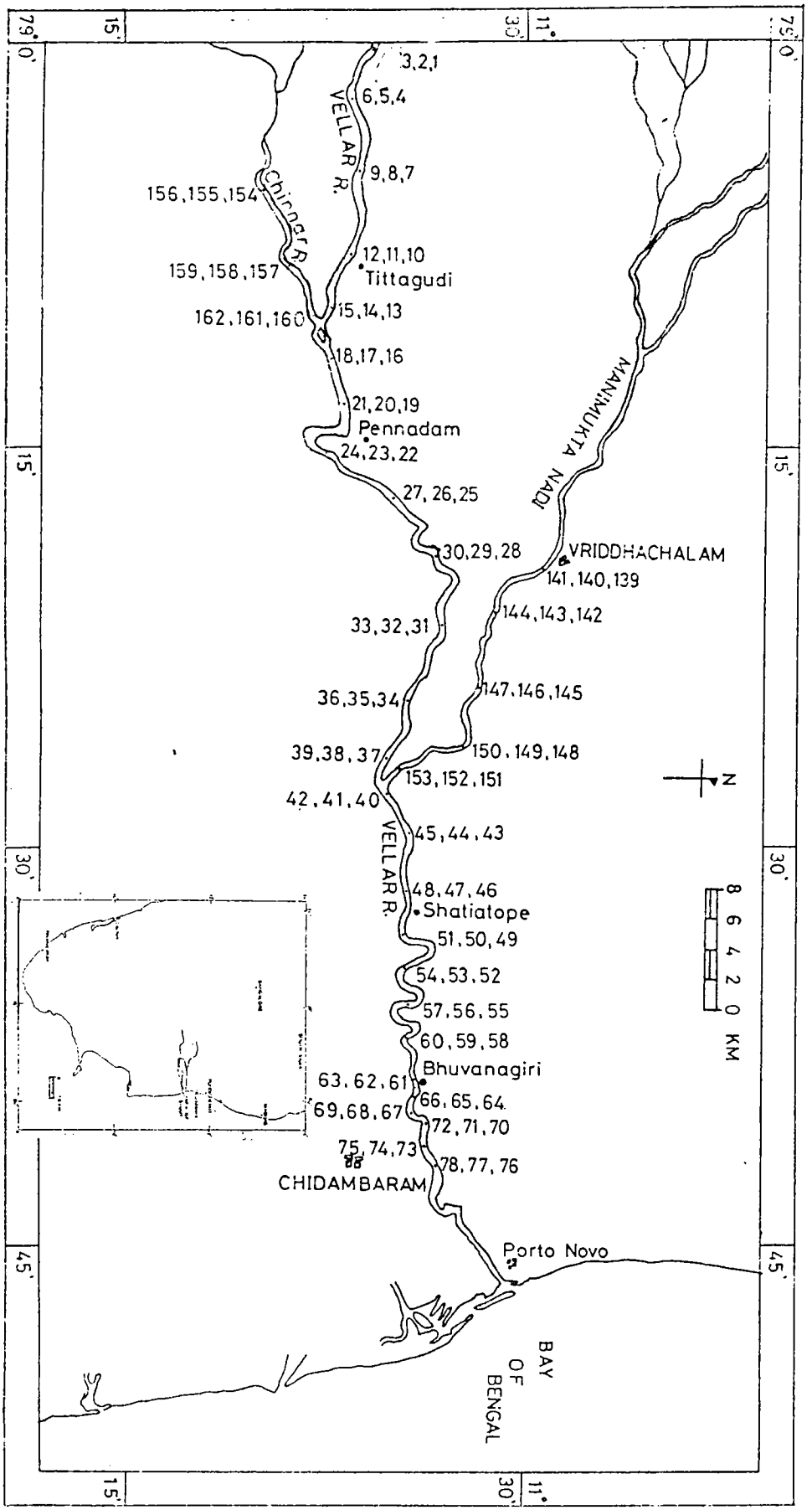


FIG. 1. SAMPLE LOCATIONS IN RIVER CHANNEL.

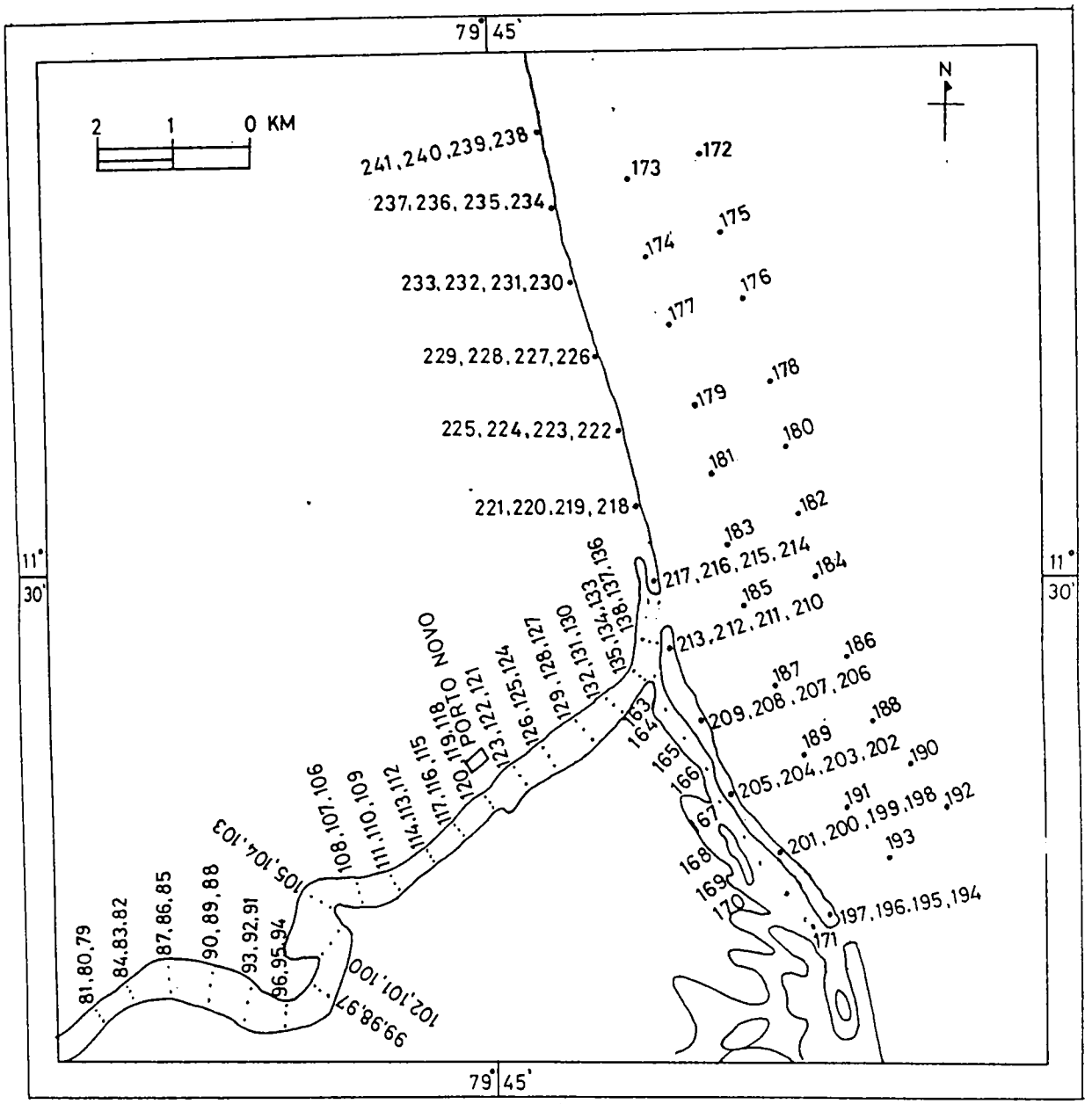


FIG. 2. SAMPLE LOCATIONS IN ESTUARY, TIDAL CHANNEL, BEACH AND MARINE ENVIRONMENTS.

(P.W.D. Record, 1990). It traverses peninsular India from west to east over 218 km., before joining the Bay of Bengal (Fig. 3). From Shatiatope anicut onwards, the Vellar flows in a northeast direction for about 40 km. and again it maintains the west to east direction, till it finally joins the sea. This is because of the uplifts of the western ghats and slight tilt of the Peninsular Indian mass to the east during the Miocene age (Krishnan, 1960). Further, this river plays a very vital role in the development of the areas through which it flows. During the pre-independence era, the Britishers used this river mouth as a minor port.

River Vellar (White river) is formed by the unification of two rivers (about six km. west of Toludur in the Vridhachalam taluk), namely, the Vasishta nadi and the Sweta nadi which rise in Salem district, Tamilnadu. The former which is named after Sage Vasishta who is stated to have performed a sacrifice on its banks, drains the Tainandamalai in Salem district and western slopes of the Kalrayans. The Sweta nadi rises in the Kollaimalai and drains the northern side of the Pachaimalai in Salem district. The Vashista nadi enters South Arcot district through the Attur Pass just south of the Kalarayans and forms the boundary between the districts of South Arcot and Tiruchirappalli, for some twenty five km. Later, it joins the Sweta nadi, the boundary still follows for another thirty two km. the course of the unified streams. Then the Sweta nadi, which now comes to be called the Vellar, strikes north - eastwards and flows through the Vriddhachalam taluk

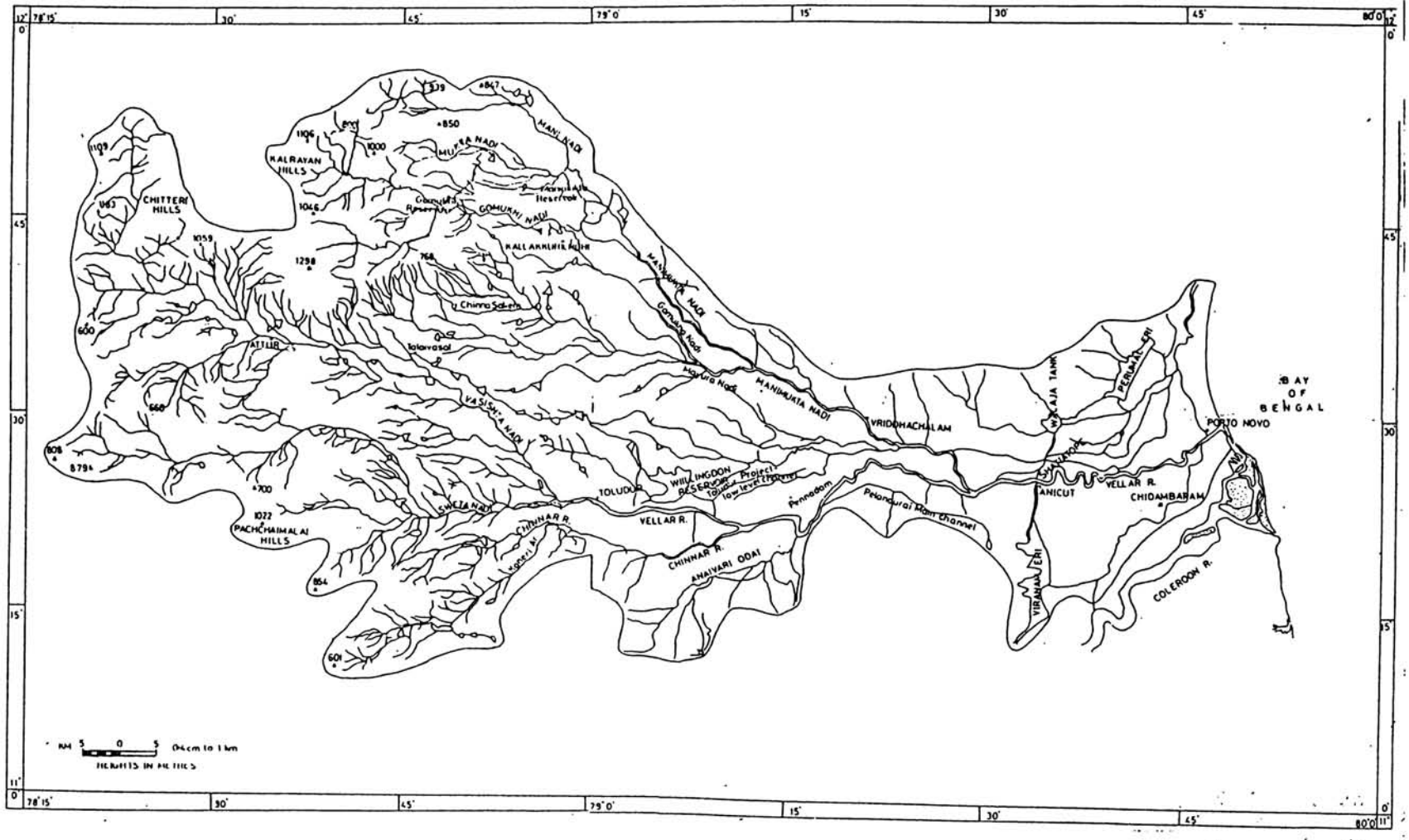


FIG: 3. DRAINAGE BASIN OF VELLAR RIVER.

where it is joined by (about six km east of Srimushnam) a considerable tributary, the Manimukta nadi, which consists of the Mani and Mukta streams that drain the northern part of the eastern slopes of the Kalrayans, and the Gomukha nadi (cow's mouth river) and the Mayura nadi (Peacock river) that rise in the southern portion of the Kalrayans. One more tributary named Chinnar river, orginated from Pachaimalai hills also joined the Vellar (between the towns of Titagudi and Pennadum).These rivers have cut for themselves deep clefts with often precipitous sides in the valleys, notably in the Tumbe valley down which the Manimukta nadi flows. After it is joined by the Manimukta nadi, the Vellar flows through the Chidambaram taluk and joins the sea immediately south of Parangipettai (Porto Novo). The Vellar receives little input from the south - west monsoon rains compared to the adequate input from north - east monsoon towards the latter part of the year. The Vellar river has an annual average maximum discharge of 75470 cusec water (P.W.D. Report, 1990). Its banks are often high and steep, and are influenced by the tides over a length of 12 to 15 km from its mouth at Parangipettai. It has anicuts at Shatiatope and Pelandurai and a regulator at Toludur (Baliga, 1962).

GEOLOGY OF THE DRAINAGE BASIN:

The drainage basin of the Vellar river

(Fig.4) consists of the following geological formations (Krishnan, 1954; G.S.I, 1976a,b).

10. Alluvium of Sub Recent to Recent.
9. Cuddalore sand stone of Mio - Pliocene.
8. Fossiliferous sand stone of Upper Cretaceous.
7. Basic dykes.
6. Granite and Pegmatites.
5. Charnockites.
4. Ultra basic rocks with magnesite and chromite.
3. Amphibolites and Pyroxenites.
2. Hornblende gneisses, steatite-chlorite-schists, quartz schists and quartz-magnetite - schists.
1. Biotite gneiss.

BIOTITE GNEISS:

The oldest rocks in this region are grey coloured foliated gneisses, generally containing good amount of biotite. They are traversed by veins of quartz, granite and pegmatite.

HORNBLENDE GNEISSES, ETC.:

The biotite gneisses are succeeded by hornblende gneisses, quartzites, quartz schists, talc schists, chlorite schists and magnetite - quartz - schists. Many of the hill masses like the Kanjamalai, Godumalai, Chitteri, Kalrayans and parts of the other hills are composed of these rocks. They may be partly of igneous and

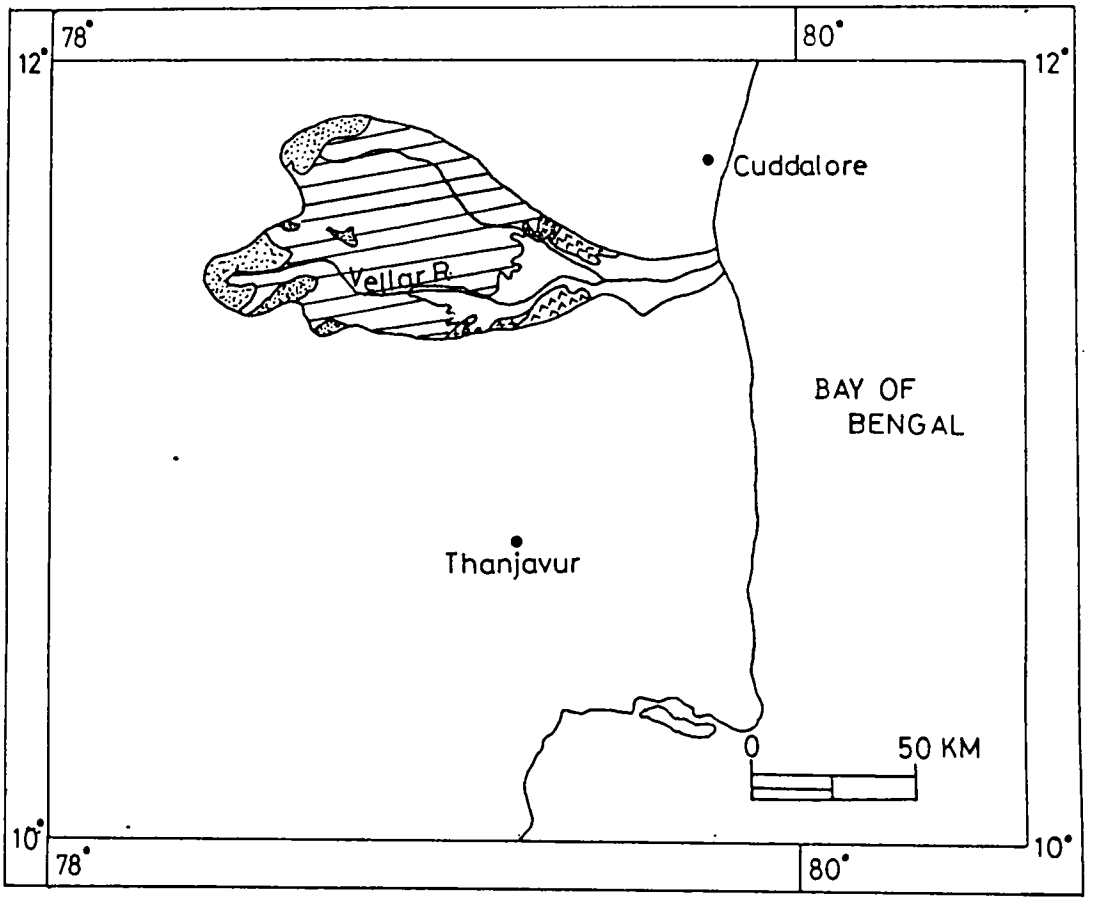


FIG. 4. GEOLOGY OF THE VELLAR DRAINAGE BASIN.

partly of sedimentary origin, but belong to the Precambrian sequences and are pre charnockitic in age.

These different rock types are frequently well foliated. The hornblende rocks are some times associated with much garnet forming garnet - amphibolites at the foot of the Kanjamalai.

AMPHIBOLITES AND PYROXENITES:

Some bands of amphibolites and pyroxenites are present in association with the above mentioned rocks.

ULTRABASIC ROCKS:

Ultrabasic intrusive and extrusive rocks are represented by metamorphic equivalents of anorthosite, pyroxenite, peridotite, dunite etc. They have suffered much alteration (e.g. the formation of magnesite and serpentine) during metamorphism.

CHARNOCKITES:

The charnockites are generally acid to intermediate in their composition and also show garnetiferous varieties (recrystallised khondalites) and some hybrid types.

GRANITE AND PEGMATITES:

Granites and associated pegmatites which are very prominent in these areas are represented by intrusive bos ses amidst the older rocks. Pegmatites and quartz veins are quite common.

DYKE ROCKS:

Basic dykes, mainly doleritic in texture and composition, are fairly common in these areas. As they cut across the other formations, they are considered to be the youngest rocks in the stratigraphic sequence.

FOSSILIFEROUS SAND STONE OF UPPER CRETACEOUS:

Overlying the Archaeans are the fossiliferous Upper Cretaceous formations mainly occurring about 10 km northwest of Virudhachalam, between the two rivers namely Manimukta and Gadilum.

CUDDALORE SAND STONE:

Overlying the Cretaceous rocks are the Cuddalore Sand stone of Mio-Pliocene age. This comprises often ferruginos, pebble bed, sand and clay with lignite seams at places and silicified wood at other places.

ALLUVIUM:

During Sub Recent to Recent time there has been the deposition of alluvium and coastal sands which are overlying the Cuddalore sand stone.

The sediment detritus from the weathering of Peninsular granite are capable of releasing the following heavy minerals: biotite, hornblende, zircon, rutile, garnet, epidote, sphene, and tourmaline. The weathering of charnockites may release the following heavy minerals to the sediments: hypersthene, augite, olivine, garnet, hornblende, monazite, zircon, ilmenite and magnetite (Pichamuthu, 1953; Chatterji, 1974). The Cretaceous formation of the coastal tract of the study area consists

largely of the reworked sediments or of chemo or organic origin.

CLIMATE:

The Indian climate is classified into four seasons, according to the Indian Meterological Department. They are as follows:

a) North east monsoon or winter season (December to February).

b) Hot weather or premonsoon season (March to May).

c) South west monsoon season (June to September).

d) Retreating south west monsoon season (October to November).

According to RamMohan (1978) this division holds good in the case of Tamilnadu too. Instead of calling the period October to November as the retreating south west monsoon season it would be more appropriate to note this also as the North east monsoon season because most of the rain fall in Tamilnadu is received in these two months. Consequently, the period December to February could be called as winter season.

The climate zone of the Vellar river basin, following the Thornthwaite (1948) classification is given in Fig.5 (after Subrahmanyam and Sarma, 1974). It is interesting to note that most of the basin has a semi arid climate. However, the coastal region enjoys the dry sub

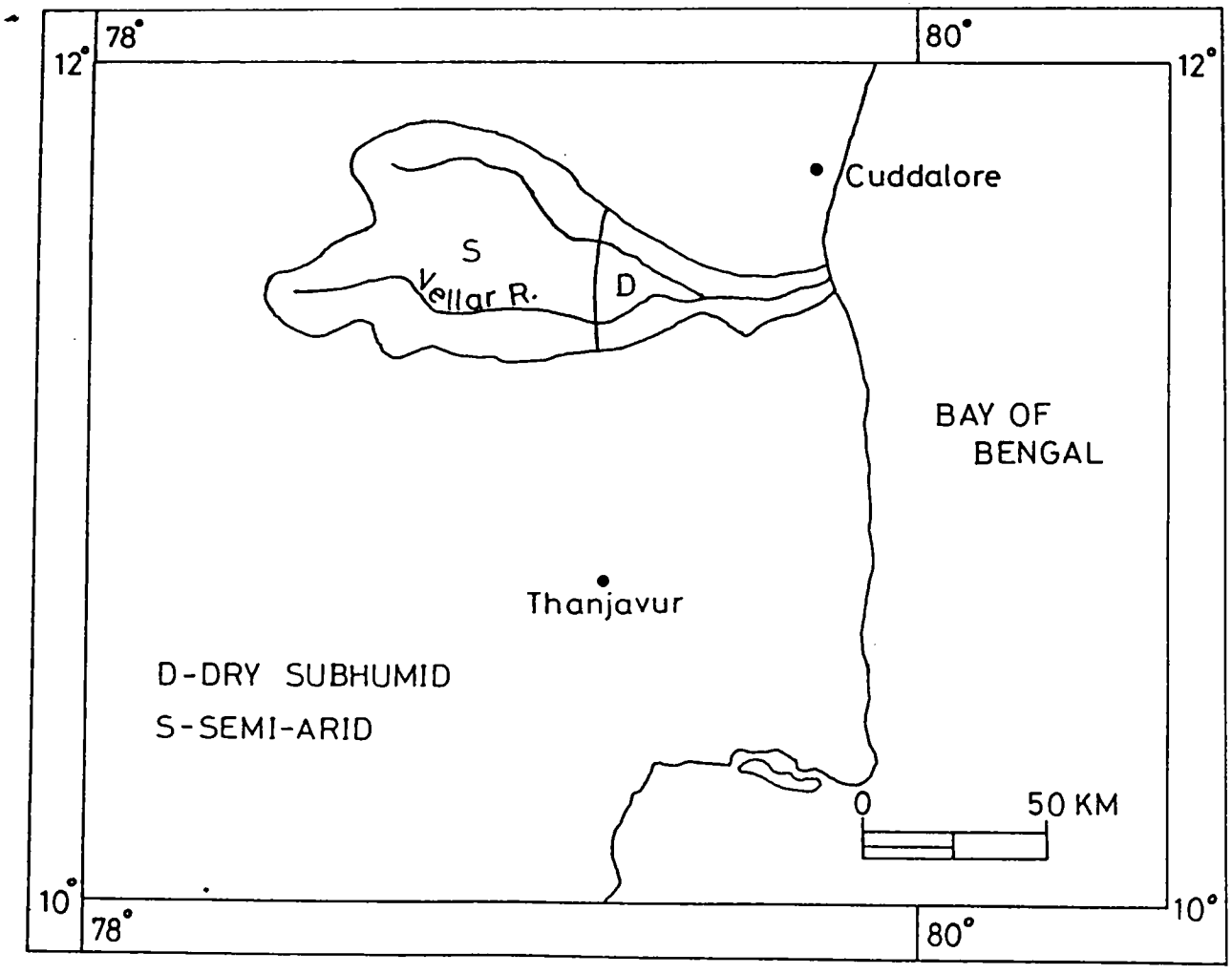


FIG.5. CLIMATIC ZONES OF THE VELLAR RIVER BASIN.

humid type of climate. Further, it is interesting to note that the sub type " d " is found in the semi arid zone. This indicates that this climatic region does not have surplus water during any season of the year on a monthly basis. In certain years, however, when the precipitation during the rainy season is much greater than the normal, local water surpluses occur for brief periods only, and these surpluses not only produce enormous surface flow resulting in inundation but also significantly contribute to ground water resources. The dry sub humid zone of the river basins have " s " sub type of moisture regime indicating moderate winter water surplus.

DEPOSITIONAL ENVIRONMENTS:

The regions of deposition and the geomorphic units in which deposition takes place are characterised by a particular set of physico - chemical and biological conditions and is called as depositional sedimentary environment. The character of sediments thus produced is determined both by the intensity of the formative processes operating on it and by the duration through which such action is continued (Pettijohn, 1957). Hence the different depositional environments, which are present in the study area are briefly described in this section in order to obtain a clear picture of the study area.

RIVER CHANNEL ENVIRONMENT:

The present study is confined to the

Vellar river and the tributaries named Manimukta nadi and Chinnar river (Fig.1). The Vellar river has two anicuts at Shatiatope and Pelandurai and a regulator at Toludur. The regulator at Toludur is located a few km downstream from the confluence of rivers Vashishta nadi and Sweta nadi. The total length of the river from the regulator at Toludur to its confluence with the sea is about 115 km, while the tributary Manimukta nadi has a length of 75 km. However, the present study is confined to this tibutary to the 25 km distance upstream from the point of unification of Manimukta nadi with Vellar river. The Chinnar tributary is 25 km long and the samples were collected only upto a distance of 10 km upstream from the point of it unification with Vellar. The Vellar river bears two types of alluvial channels namely straight and meandering. The width of the river channel is approximately 0.8 km.

ESTUARINE ENVIRONMENT:

In geomorphic terms, an estuary can be defined as, "an inlet of the sea, reaching in to the river valley as far as the upper limit of tidal rise" (Fairbridge, 1980). But in oceanographic terms, it can be defined as "a semi - enclosed coastal body of water which has a free connection with the open sea and with in which seawater is measurably diluted with fresh water derived from land drainage" (Pritchard, 1967). As per the above definitions, the Vellar estuary (Fig.2) is a true estuary with all the estuarine characters. This environment is largely governed

by two dominant factors, viz., 1) short term changes resulting from tides and 2) marked seasonal changes induced by the monsoon cycle. This estuary is influenced by semidiurnal tides throughout the year and the tidal effect extends 16 km upstream with a tidal amplitude of one metre. The maximum depth of the estuary that has been observed during sample collection is about 5 m. The width of the estuary changes from place to place. The width at the mouth of the estuary is about 600 m. During north east monsoon (October to December) the estuary is flooded. Hydrogrphically this estuary is well studied. The temperature varies from 23.5° to 36.5° c. The pH values fluctuate from 7.75 to 8.35. The salinity values range from 27.0 to 32.40 part per mile. The dissolved oxygen concentrations vary from 3.30 to 7.62 ml/l (Chandran & Ramamoorthi, 1984).

TIDAL CHANNEL ENVIRONMENT:

The tidal channel which branches from the lower part of the Vellar estuary acts as a distributary in rainy season and as a tidal communication channel in the remaining periods. The tidal channel, called as Killai tidal channel (Fig.2), branches into two. While one branch directly runs into the sea, the other joins the Coleroon Mangrove - Estuarine system. The branch which joins the sea has a length of about 15 km and an average width of about 150 m from Vellar estuarine connection. The depth ranges from 2 to 3 metre.

BEACH ENVIRONMENT:

Parangipettai [Porto Novo] beach, located in the east coast of Tamilnadu, extends from the mouth of Killai tidal channel in the south, to Annampet in the north stretching over a total length of about 11 km (Fig.2). The width of the beach ranges from 400 to 500 m. The beach shows a very clear blanket of sand with a few small heaps of sand on the back shore. Black sand concentrations are abundant in the immediate vicinity of the northern side of the Vellar estuarine mouth when compared to the south or on the northern extremity. Shell materials are also abundant on the beach.

NEARSHORE ENVIRONMENT:

The nearshore environment, lying between the low water mark to a distance of 2 km towards offshore and in the north - south direction about 11 km distance was considered for the study (Fig.2). This region has a tidal range (semi diurnal) of one metre. The maximum depth observed in the nearshore area is about 10 m. The meteorlogical conditions associated with the monsoonal systems have a great influence on the physical and chemical properties and the circulation of the surface waters in the southern part of the Bay of Bengal (La Fond, 1954; 1957; La Fond & La Fond, 1968; Murty & Varadachari, 1968; Rao & Jayaraman, 1968; Varadachari et al, 1968). Further, the Bay of Bengal experiences a well defined seasonal cycle in the pattern of circulation. The shallow marine zone of the east

coast of India undergoes greater influences by littoral and longshore currents which are formed by the seasonal cycle. The sedimentary distribution is also influenced by these currents, which are directed northward during south west monsoon and southward during north east monsoon.

REVIEW OF LITERATURE:

Estuaries are located all along the east and west coasts of India. The mouths of great rivers such as the Brahmaputra, Ganga, Mahanadi, Godavari, Krishna and Cauvery on the east coast, Zuari estuary, Kali estuary, and the extensive system of backwaters of Kerala along the west coast are classic examples of typical estuarine systems in India. Ecological studies on estuary is thus beset with difficulties since no two estuaries are alike in their characters. According to Nair (1987), the interaction of so many variables, and differences in the physico - chemical, biological, meterological and sedimentalogical conditions that exist in the different regions of our country considerably complicate the above said problem. These aspects make generalisation on estuarine studies difficult and calls for detailed studies on each estuary.

The biological, chemical and hydrological aspects of Vellar estuary was studied extensively by several workers (Ayyakkanu, 1969; Purushothama & Venugopalan, 1972; Sundararaj & Krishnamurty, 1972; Jegatheesan & Venugopalan, 1973; Chandramohan et al, 1974; Kumaraguru et al, 1980;

Subramanian et al, 1980; Chandran & Ramamoorthy, 1984). Texture, mineralogy and geochemistry of the Colleroon estuarine system of Cauvery river was studied by Seralathan (1979). Later Ramanathan et al (1988) investigated the upper stream sediments of Cauvery river and their chemical and sedimentary characters. The modern deltaic sediments in the east coast of India, such as, Godavari (Naidu, 1968), Krishna (Seetaramaswamy, 1970), Mahanadi (Satyanarayana, 1973) and Vasishta - Godavari (Dora, 1979) were studied in detail and their textural, mineralogical, and geochemical distribution were delineated. The C.N.P distribution of Hooghly estuary was studied by Ghosh & Choudhury (1987). The Chilka Lake (Venkataratnam, 1965) and the Kolleru lake sediments were studied (Ramamurty, 1972) for their clay mineral and geochemical distribution. In the west coast, the Ashthamudi lake was investigated for its sedimentary distribution, heavy mineral variation and geochemical distribution (Rao, 1968; Sajan & Damodaran, 1981; 1986; Damodaran & Sajan, 1983; Sajan, 1988). The sediments of Vembanadu lake was also studied in detail for their sedimentary distribution and chemical variation (Murty & Veerayya, 1972; Venugopal et al, 1982; Lakshmana et al, 1987; Ouseph, 1987).

International review is given in the following section. The pollution aspects of Thames estuary was investigated by Board (1973). The variation of heavy metal in river deltas of Rhine and Ems river were studied by

de Groot (1973). The trace elemental variation in the sediments of Clyde estuary (Wedepohl, 1960), Firth of Clyde (MacKay et al, 1972), Solway Firth (Perkins et al, 1973), and Seven estuary (Stoner, 1974) were determined and their impacts on the environments were delineated. The James river estuary (Nichols, 1972) Chesapeake bay (Helz, 1976; Firck et al, 1977; Sinex & Helz, 1980/81), Miramichi estuary (Willey & Fitzgerald, 1980), and Tamar estuary (Watson et al, 1985) sediments were also investigated in detail to study the interaction between different aspects of estuary.

FIELD PROGRAMME:

The field programme is described under two headings namely method of sample collection and area of sample collection.

A) METHOD OF SAMPLE COLLECTION:

The sediment samples were collected from the estuarine , tidal channel and the nearshore marine stations using a stainless steel Van Veen grab during the month of February, 1987. The samples were stored in plastic bags. Depths were noted from the graduated rope when the grab was lowered for collection. All the river and beach sediments were collected by piercing a PVC pipe having a length of 15 cm and 10 cm diameter into the sediment. During collection, bearings were taken by triangulation using land features as markers.

B) AREA OF SAMPLE COLLECTION:

The sediment samples were collected from

the river, estuary, tidal channel, beach and the nearshore marine environments.

In the river, stations were fixed from the regulator point at Toludur to the head of the estuary, at an interval of appr. 5 km. At every station, three samples viz., two from the both margins and one from the center region of the river, were collected. Within the study area of Vellar river, two tributaries namely Manimukta and Chinnar join the main river. Samples were also collected from the beds of these rivers at an interval of appr. 5 km distance.

In the estuarine part of the river extending from the mouth to the fresh water zone (15 km), stations were fixed at an interval of approximately 500 m in the first 10 km distance and at approximately 1 km interval in the remaing 5 km distance. In each station three samples were collected as in the case of the river environment. Samples were also collected from the tidal channel (Killai tidal channel), at an interval of approximately 500 m.

On the beach, stations were fixed at an interval of appr. 1 km on either side of the estuary, covering a total distance of 11 km. Four samples, corresponding to the backshore, berm crest, foreshore and low water mark were collected from each station.

In the marine region stations were fixed in a grid pattern at an interval of appr. 1 km distance. A

total number of twenty two samples were collected from the offshore area.

A total of 241 sediment samples were systematically collected from the various depositional environments of the study area.

CHAPTER:II.

TEXTURAL CHARACTERISTICS OF THE SEDIMENTS

INTRODUCTION:

Texture, the microgeometry of sediment, deals with its size and shape. Textural analysis has three objectives which include description, comparison of sediments and consequent interpretation. Extensive research have been carried out in this direction in the past few decades and repeated attempts were made to use grain size parameters to differentiate environments of deposition (Uden, 1914; Wentworth, 1931; Krumbein, 1937; Keller, 1945; Folk, 1954; Folk & Ward, 1957; Passega, 1957, 1964, 1977; Friedman, 1961; Visher, 1969; Roy & Biswas, 1975). Earlier studies largely explained the relation between grain size distributions and the depositional environments besides the processes that were responsible for their formation.

According to Uden (1914) the hydrodynamic conditions prevailing during deposition of clastic sediments control the size compostion of a sediment. Visher (1969) emphasized that the studies of granulometry of sediments would provide a separate line of supporting evidence for interpretation of clastic deposits of unknown origin.

A number of methods are reported for granulometric analysis in the literature. Most of the methods recommend either determination of shape (Krumbein,

1932) or approximation of the particle shape to spheres (Krumbein & Pettijohn, 1938) for size determinations. While most methods utilize volume frequency to determine size (Krumbein & Pettijohn, 1938; Carver, 1971; Lewis, 1984), a few prefer number frequency. Therfore, it is necessary to standardize a suitable method considering both its merits and demerits.

Several authors advocated different graphic methods for the computation of grain size analysis (Trask, 1932; Krumbein, 1936; Inman, 1952; Folk & Ward, 1957). Trask (1932) and Krumbein (1936) described the size parameters based on quartile measure in mm which is inadequate to express the chracteristics of the whole distribution since the quartile represented only 50 % of total curve. Among the other methods proposed for studying size distribution, Inman's (1952) method deals with 74% of the curve, while that of Folk and Ward (1957) method could take in to account 88% of the curve for size interpretation. In the latter years McCammon (1962) could suggest size parameters which covered 97% of the size distribution, though it is laborious and time consuming. Friedman (1962) compared the sorting measures of Trask (1932), moment measures of Inman (1952) and graphic measures of Folk and Ward (1957) and concluded that while the Inman measure is more satisfactory for poorly sorted sand stones, the Trask's coefficient of sorting is more satisfactory for describing very well sorted sand stones. The Folk and Ward sorting

measures were found to be satisfactory for the entire range of sorting characteristics. Although in theory the measures are geometrically independent, in actual practice it is usually found that for a given set of samples the measures are linked by some mathematical relationship (Folk & Ward, 1957). Perhaps these relationships and trends may offer clues to find out the mode of deposition and identify the environments by size analysis.

Passega (1957,1964) and Bull (1962) have obtained specific patterns characteristic of the agent of depostion when the coarsest one percentile grain size (C) and median grain size (M) of samples were plotted on a log - log paper. Their studies proved helpful to deliniate the character of depostion. Further, Passega (1957) also recorded certain patterns for deposits of tractive currents, quite water, beaches and turbidity currents. The FM, LM, and AM diagrams prposed by Passega et al (1967) and Passega and Byramjee (1969) would charaterize the finest fraction of a deposit. The combination of these diagrams gives a clear picture of the mode of deposition and their environments. Roy and Biswas (1975) and Seralathan (1986) also attempted to demarkate the various environments through CM diagram.

In India, number of studies were carried out to delineate the environmental significance with reference to textural parameters. The Gulf of Kutch sediments are polymodal in nature indicating that they originate from more than one source (Hashimi et al, 1978a). The sediments present in the inner western continental shelf

between Vengurla and Mangalore suggest that the rivers drain between these places do not have the capacity to transport large quantities of coarse material or alterntely they could also suggest that the coarser material carried by these rivers is trapped in the estuary so that only fine materials get accumulated on the inner shelf (Hashimi et al, 1978b). In regions off the coast, where the estuaries and lagoons are present, as on the Cochin - Quilon coast, the mean size tends to be finer as compared to those areas which are devoid of estuaries and lagoons (Hashimi et al, 1981). In the eastern coast between Cape Comorin to Tuticorin the average grain size corresponds to that of median sand with good sorting (Hashimi et al, 1981). However, off Madras coast the size ranges from median to fine sand with moderate sorting (Rao & Murty, 1968). The textural parameters of the Godavari river (Naidu, 1968), Krishna river (Seetaramaswamy, 1970), Mahanadi river (Satyanarayana, 1973), Vashsista-Godavari river (Dora, 1979), Cauvery river (Seralathan, 1979), Vembanadu estuary (Veerayya & Murty, 1974) and Hoogly estuary (Sasamal et al, 1986) were studied in detail and their environmental significance was delineated. Similary beach sediments of different areas were also studied in detail (Veerayya & Varadachari, 1975; Chavadi & Nayak, 1987; Purandara et al, 1987; Unnikrishnan, 1988).

In the present study, the characteristics of grain size distribution of the sediments of Vellar river, estuary, tidal channel, beach, and

nearshore marine environments have been analysed to delineate the transportation history and the energy condition of the depositional environment.

METHODS OF STUDY:

The dry sieving, used in the size range 63 micron to 2500 micron, is the simplest, and most widely used method of grain size analysis. Hence, the washed and dried sand samples (primary beach and river) were subjected to sieving for 15 minutes on a mechanical Ro-Tap shaker. Following the method of Folk (1966) the sieves were arranged in half phi interval in order to determine the bimodality and to study subtleties of tails. Pipette analysis was also carried out to determine the grain size of less than 63 micron (Krumbein & Pettijohn, 1938), since no single method of grain size analysis is sufficient for the determination of entire grain size range. Sediment which contains sand, silt, and clay (primary estuarine, tidal channel and selected nearshore samples), were desalted, air dried, and treated with 30 % hydrogen peroxide to remove organic matter as described by Van Andel and Postma (1954). Later a known weight (15 - 25 gms) of the sample was dispersed in distilled water with 100 to 200 ml of 0.025 N (dependupon the clay content) sodiumhexameta phosphate solution and was kept over night to disaggregate the flocculated clay particles and to dissolve any minor amount of salt which could cement the grains (Barnees, 1959; Carver, 1971). The dispersed sample was wet sieved using +230 ASTM mesh, made

upto one liter in a sedimentation cylinder and subjected to pipette analysis up to 10 phi size following the method of Krumbein and Pettijohn (1938). The material that were coarser than 63 micron size were dried and sieved. The results obtained for the samples after sieving and pipette analysis were combined into a single size frequency distribution and the cumulative weight percentages were plotted on an arithmatic probability sheet. From the graph, values of the percentiles 1, 5, 16, 25, 50, 75, 84, and 95 were recorded. Whenever the curve did not attain the 84th and 95th percentiles, extrapolation of the curves was made as suggessted by Folk (1965).

Folk and Ward (1957) inclusive graphic measures have been used in the present investigation. The size parameters were plotted against the river distance to evaluate the variations downstream. The inter relationship of size parameters were drawn with the help of scatter plots, in order to differentiate the environments and infer the processes of deposition. From inclusive graphic measures, plots of mean versus standard deviation, mean versus skewness, mean versus kurtosis, standard deviation versus skewness, standard deviation versus kurtosis and skewness versus kurtosis were plotted.

The coarsest one percentile grain size (C) against median grain size (M) of samples are plotted on a log-log paper as explained by Passega (1957, 1964) and Bull (1962). Based on CM pattern, an attempt has been made

here to identify the modes of transportation and deposition of sediments pertaining to the different environments in the study area. Similarly, as described by Passega et al (1967) and Passega & Byramjee (1969) FM, LM, and AM diagrams were plotted by taking M, the median of the grain size distribution as a constant, and the variable factors F, L, and A, the percentages by weight in the samples of grains finer than 125, 31, and 4 microns respectively. Percentages obatined for sand, silt and clay in sediment samples collected from estuary, tidal channel and nearshore sediments were plotted in a triangular diagram adopting the textural nomenclature developed by Folk (1966) to gain an insight into the general sedimentary framework of the study area.

RESULTS:

GRAIN SIZE PARAMETERS OF THE SEDIMENTS:

Results obtained from the various analyses with respect to grain size parameters of the sediments, namely, median, mean, standard deviation, skeweness, and kurtosis are presented in Table. 1 for samples from the river channel and estuary, and in Table. 2 for samples from the beach, tidal channel, and nearshore environments.

MEAN SIZE:

The average size of sediments which also represents an entire curve of the graph is called the phi mean size (MZ). The variation in phi mean size between

TABLE: 1 . Grain size parameters of Vellar River Channel, Estuary, Manimukta Nadi and Chinnar River.
M - Phi Mean. Md - Phi Median. Sd - Standard Deviation. Sk - Skewness. Ku - Kurtosis

DIS.km.	NORTH SA.No.	M	Md	Sd	Sk	Ku	CENTER SA.No.	M	Md	Sd	Sk	Ku	SOUTH SA.No.	M	Md	Sd	Sk	Ku
Vellar River																		
0	1	0.20	0.27	1.20	0.12	1.09	2	2.06	1.95	0.56	0.18	0.79	3	-0.01	0.06	1.25	-0.08	0.50
5	4	0.67	0.62	1.03	0.09	1.20	5	0.82	0.92	0.86	-0.24	1.18	6	0.45	0.67	1.40	-0.21	1.72
10	7	1.47	1.53	0.64	-0.13	1.38	8	0.80	0.99	1.17	-0.27	1.42	9	0.66	0.70	0.79	-0.23	0.88
15	10	0.82	0.94	1.01	-0.16	1.17	11	1.07	1.12	0.72	-0.09	1.14	12	1.37	1.49	0.72	-0.19	1.41
20	13	1.37	1.40	0.61	-0.03	1.33	14	1.47	1.54	0.74	-0.14	1.29	15	1.56	1.58	0.76	-0.11	1.33
25	16	1.07	1.18	0.81	-0.21	1.19	17	1.79	1.85	0.93	-0.22	0.99	18	0.75	0.79	0.74	-0.11	1.05
30	19	1.22	1.23	0.72	0.04	1.31	20	1.51	1.42	0.87	0.07	1.37	21	1.60	1.58	0.58	0.12	1.14
35	22	2.00	1.96	0.68	-0.04	0.96	23	1.42	1.36	0.87	0.06	1.20	24	1.06	1.14	0.85	-0.15	1.19
40	25	0.90	0.96	0.91	-0.10	1.11	26	1.05	1.03	0.81	0.12	1.26	27	1.51	1.52	0.56	0.00	1.29
45	28	1.16	1.22	0.84	-0.09	1.17	29	0.68	0.64	1.12	0.02	1.18	30	1.03	1.07	0.88	-0.04	1.17
50	31	1.23	1.20	0.40	0.04	1.26	32	1.03	1.09	0.98	-0.10	1.08	33	1.21	1.25	0.79	-0.03	1.28
55	34	2.05	1.94	0.65	0.11	0.86	35	1.76	1.77	0.85	-0.11	0.86	36	1.69	1.64	0.90	-0.01	0.83
60	37	2.68	2.74	0.78	-0.11	1.35	38	1.91	1.80	0.55	0.22	0.88	39	1.52	1.45	0.78	0.07	1.15
65	40	1.39	1.49	0.78	-0.19	1.57	41	1.22	1.12	0.92	0.14	1.04	42	1.28	1.34	0.74	-0.10	1.21
70	43	2.10	1.97	0.59	0.23	0.82	44	0.81	0.85	1.11	-0.05	0.95	45	1.11	1.11	0.98	0.12	1.37
75	46	1.56	1.58	0.65	-0.04	1.23	47	1.48	1.54	0.58	-0.10	1.27	48	1.57	1.58	0.94	-0.06	0.97
80	49	2.21	2.32	0.61	-0.31	0.89	50	1.57	1.47	0.77	0.11	1.03	51	1.33	1.30	0.82	0.07	1.16
85	52	1.53	1.61	0.50	-0.15	1.25	53	1.44	1.43	0.51	0.09	1.31	54	1.73	1.60	0.54	0.33	2.50
90	55	2.51	2.64	0.51	-0.56	1.99	56	2.46	2.57	0.48	-0.48	1.48	57	1.93	1.82	0.55	0.19	1.27
95	58	1.22	1.24	0.84	-0.03	1.00	59	2.78	2.78	0.25	0.13	1.72	60	2.04	1.94	0.42	0.29	0.90
100	61	3.10	2.50	2.21	0.46	2.27	62	2.55	2.68	0.51	-0.36	2.08	63	1.96	1.86	0.84	0.16	1.08
101	64	1.44	1.47	0.61	-0.07	1.37	65	1.79	1.75	0.50	0.10	1.45	66	0.95	1.07	0.87	-0.28	1.35
102	67	2.46	2.61	0.81	-0.27	1.05	68	1.73	1.69	0.74	-0.03	1.21	69	1.83	1.72	0.65	0.14	0.98
103	70	1.72	1.76	1.07	-0.23	1.19	71	1.08	1.15	0.89	-0.13	1.21	72	2.24	2.54	0.75	-0.58	0.91
104	73	1.69	1.76	1.08	-0.25	1.17	74	1.17	1.32	0.85	-0.23	1.13	75	1.46	1.46	0.62	0.05	1.38
105	76	1.30	1.43	0.88	-0.06	1.09	77	1.61	1.62	0.58	-0.02	1.27	78	1.76	1.68	0.62	0.13	1.22
ESTUARY																		
105.5	79	3.52	3.21	1.44	0.26	1.22	80	2.95	2.79	0.80	0.67	4.63	81	1.38	1.36	0.97	0.22	2.12
106	82	4.16	2.97	2.24	0.67	1.03	83	2.42	2.25	1.28	0.45	1.90	84	1.96	1.81	0.93	0.34	1.32
106.5	85	2.61	2.75	0.92	-0.12	2.02	86	2.72	2.79	1.64	0.19	2.06	87	3.07	2.91	1.33	0.36	2.13
107	88	3.10	2.84	1.27	0.59	3.10	89	2.32	2.25	1.31	0.42	2.38	90	3.16	3.59	1.78	0.61	1.24
107.5	91	3.97	3.78	0.95	0.51	3.81	92	6.98	7.46	2.12	-0.32	0.67	93	4.09	3.38	2.13	0.50	1.41
108	94	5.32	4.88	1.55	0.48	1.27	95	5.13	4.90	1.77	0.98	1.11	96	4.88	3.84	2.45	0.52	0.82
108.5	97	3.29	3.24	0.96	0.39	2.89	98	4.00	3.16	1.90	0.73	1.35	99	4.77	4.38	1.36	0.46	1.78
109	100	4.86	4.46	1.55	0.54	1.88	101	2.50	2.18	1.63	0.66	2.77	102	2.64	2.61	1.39	0.29	1.63
109.5	103	4.96	4.27	2.12	0.48	0.71	104	3.89	3.94	2.08	0.64	0.69	105	4.33	3.70	1.79	0.61	2.00
110	106	4.58	4.43	1.64	0.31	1.35	107	6.52	6.21	1.48	0.12	0.65	108	4.37	4.21	1.05	0.34	1.56
110.5	109	4.50	4.08	2.13	0.31	0.92	110	3.63	2.95	1.60	0.99	2.11	111	3.81	3.72	1.14	0.35	1.79
111	112	3.62	2.98	2.08	0.57	1.14	113	3.38	3.06	1.09	0.63	1.67	114	4.39	4.29	0.96	0.24	1.41
111.5	115	6.50	6.27	1.69	0.19	0.61	116	5.63	5.76	2.28	-0.02	0.65	117	3.87	3.40	1.14	0.62	1.14
112	118	4.53	4.29	0.81	-0.10	0.70	119	4.73	3.93	2.02	0.50	0.55	120	5.06	4.84	1.26	0.26	1.04
112.5	121	5.19	4.84	1.85	0.29	0.94	122	6.19	5.88	2.18	0.18	0.71	123	5.17	4.79	2.04	0.27	1.05
113	124	4.98	4.57	1.72	0.43	1.83	125	7.60	8.13	1.87	-0.48	0.43	126	3.28	2.88	1.54	0.63	2.15
113.5	127	4.43	3.87	1.96	0.40	1.08	128	6.71	6.38	1.83	0.20	0.70	129	3.49	2.43	1.80	1.00	1.94

TABLE: 1 . (Cont.)

DIS.km.	SA.No.	M	Md	Sd	Sk	Ku	SA.No.	M	Md	Sd	Sk	Ku	SA.No.	M	Md	Sd	Sk	Ku
114	130	5.86	6.02	1.33	0.03	1.28	131	5.92	5.67	1.47	0.19	0.76	132	4.79	4.44	2.04	0.34	1.09
114.5	133	4.07	3.74	1.64	0.36	1.19	134	5.49	4.74	1.73	0.60	1.66	135	3.47	3.00	1.39	0.61	1.34
115	136	2.49	2.60	0.95	0.06	1.63	137	3.76	3.64	1.40	0.39	1.53	138	2.42	2.56	0.40	-0.43	0.81
MANIMUKTA NADI																		
0	139	0.06	0.07	1.24	-0.03	0.84	140	-0.28	-0.23	1.73	0.00	0.63	141	-0.18	-0.24	1.67	0.11	0.75
5	142	1.02	1.07	0.64	-0.14	1.04	143	1.27	1.32	0.58	-0.16	1.24	144	0.36	0.47	1.28	-0.14	1.04
10	145	0.95	1.03	0.77	-0.21	0.99	146	0.73	0.75	0.97	-0.07	0.98	147	0.68	0.71	0.82	-0.09	0.84
15	148	1.28	1.30	0.71	-0.02	1.25	149	0.53	0.62	1.33	-0.01	0.91	150	0.64	0.67	0.92	-0.10	1.02
20	151	1.48	1.45	0.80	0.02	1.13	152	1.67	1.74	0.96	-0.21	1.34	153	0.58	0.58	1.13	0.03	1.25
CHINNAR RIVER																		
0	154	-0.03	-0.25	1.24	0.01	0.82	155	-0.04	0.10	1.07	0.06	0.93	156	0.21	0.40	1.08	0.02	1.03
5	157	0.92	1.14	1.51	-0.20	1.03	158	0.73	0.77	0.81	-0.11	1.06	159	0.42	0.27	1.49	0.06	0.77
10	160	0.46	0.48	0.94	-0.04	0.99	161	0.84	1.07	1.17	-0.31	1.15	162	1.12	1.23	0.79	-0.20	1.16

Table: 2. Grain size parameters of Beach, Tidal Channel and Nearshore sediments.

DIS.km	SA.No.	M	Md	Sd	Sk	Ku
Tidal Channel						
0.00	163	3.53	2.91	1.66	0.77	2.10
0.50	164	2.91	2.62	1.19	0.39	1.50
1.00	165	4.03	2.97	2.05	0.77	1.60
1.50	166	3.67	2.87	2.14	0.61	1.28
2.00	167	4.87	4.41	1.94	0.42	1.12
2.50	168	6.20	5.68	1.59	0.45	0.94
3.00	169	5.85	5.41	1.48	0.47	0.84
3.50	170	5.96	5.57	1.84	0.22	1.00
4.00	171	5.51	4.90	1.56	0.43	0.85
NEARSHORE						
0	173	2.19	1.64	2.55	0.39	2.12
	172	1.44	1.49	0.91	-0.17	1.83
1	174	2.55	1.92	1.80	0.67	1.90
	175	2.91	2.84	1.43	0.31	1.75
2	177	4.10	3.84	1.01	0.40	1.59
	176	2.92	2.52	2.41	0.38	1.41
3	179	3.75	3.66	0.84	0.32	1.86
	178	4.42	4.27	1.02	0.27	1.18
4	181	3.25	3.25	0.44	-0.01	0.76
	180	3.79	3.78	0.74	0.09	1.40
5	183	2.28	2.34	0.46	-0.17	0.73
	182	2.76	2.72	0.81	0.10	0.90
6	185	2.22	1.92	0.60	0.67	1.02
	184	3.18	3.01	0.60	0.52	1.44
7	187	3.25	3.21	0.44	0.14	0.75
	186	3.79	3.74	1.31	0.40	2.74
8	189	3.43	3.51	1.13	0.23	3.25
	188	4.17	4.13	1.00	0.36	2.61
9	191	3.47	3.52	0.81	0.15	1.38
	190	3.39	3.43	1.28	0.31	2.70
10	193	3.26	3.21	0.43	0.16	0.75
	192	3.20	3.05	0.58	0.45	1.05
LOW WATER MARK						
0	194	1.97	1.89	0.56	0.14	0.79
1	198	2.25	2.48	0.68	-0.44	1.20
2	202	2.43	2.58	0.50	-0.38	0.90
3	206	2.22	2.23	0.43	-0.04	0.75
4	210	2.40	2.52	0.42	-0.39	0.76
5	214	2.52	2.66	0.49	-0.31	1.47
6	218	2.41	2.54	0.43	-0.35	0.69
7	222	2.71	2.73	0.37	-0.09	1.91
8	226	2.40	2.52	0.40	-0.37	0.70
9	230	3.02	2.93	0.41	0.25	1.08
10	234	2.37	2.51	0.49	-0.35	0.74
11	238	2.49	2.66	0.59	-0.34	1.32
FORESHORE						
0	195	2.40	2.52	0.42	-0.37	0.73
1	199	2.68	2.70	0.33	-0.14	1.76
2	203	2.73	2.73	0.32	-0.01	1.95
3	207	2.47	2.58	0.39	-0.35	0.94
4	211	2.76	2.76	0.29	0.01	1.88
5	215	2.67	2.70	0.38	-0.05	1.79
6	219	2.59	2.67	0.53	-0.12	1.31
7	223	2.61	2.66	0.37	-0.16	1.90
8	227	2.50	2.61	0.34	-0.33	1.19
9	231	2.43	2.56	0.40	-0.39	0.75
10	235	2.37	2.52	0.43	-0.44	0.74
11	239	2.35	2.47	0.46	-0.33	0.76
BERM CREST						
0	196	2.01	1.90	0.50	0.23	0.73
1	200	2.72	2.72	0.25	0.05	1.41
2	204	2.55	2.63	0.45	-0.17	1.31
3	208	2.49	2.60	0.44	-0.26	1.10
4	212	2.50	2.62	0.44	-0.29	1.16
5	216	2.81	2.81	0.21	0.16	1.55
6	220	3.01	2.91	0.48	0.17	1.04
7	224	2.76	2.76	0.31	0.08	1.92
8	228	2.64	2.68	0.39	-0.10	1.82
9	232	2.58	2.66	0.38	-0.25	1.56
10	236	2.70	2.73	0.39	-0.05	2.00
11	240	2.49	2.60	0.44	-0.22	1.12
BACKSHORE						
0	197	2.02	1.90	0.48	0.30	0.81
1	201	2.62	2.68	0.40	-0.18	1.78
2	205	2.75	2.75	0.35	-0.02	2.08
3	209	2.55	2.62	0.36	-0.23	1.27
4	213	2.53	2.63	0.38	-0.33	1.25
5	217	2.79	2.80	0.25	0.15	1.74
6	221	2.61	2.69	0.47	-0.15	1.70
7	225	2.72	2.74	0.39	-0.05	1.95
8	229	2.61	2.66	0.42	-0.09	1.76
9	233	2.45	2.57	0.40	-0.50	0.85
10	237	2.35	2.43	0.42	-0.21	0.74
11	241	2.50	2.57	0.40	-0.27	0.83

environment to environment is prominent. Data presented in Fig. 6 illustrates the variation in phi mean size along the 115 km river course from Tholudur to confluence. The phi mean size increases downstream, however, the estuary shows a marked increase in size. The phi mean size is varied from -0.01 to 3.10 in fresh water river channel sediments and from 1.38 to 7.60 in estuarine sediments. The two distributries of Vellar river namely Chinnar river and Manimukta Nadi show lower phi mean sizes. The range in the Chinnar is -0.04 to 1.12 and in the Manimukta nadi it is from -0.28 to 1.67. The beach sands recorded phi values varying from 1.97 to 3.02. The variations in the mean size observation in tidal channel and nearshore environments are significant ranging from 2.91 to 6.20 in the tidal channel and from 1.44 to 4.42 in the nearshore environment.

STANDARD DEVIATION:

Standard deviation, the measure of the degree of scatter, is an indicator of the spread of data about the average. In the textural analysis, it is a measure of dispersion of the grain size distribution (McKinney & Friedman, 1970). The inclusive graphic standard deviation of the river channel and estuarine sediments are plotted against the river distance (Fig. 7). The standard deviation values slightly decrease downstream of the freshwater river channel while in the estuarine region the sorting becomes poorer. In general, except for a small percentage (12 %) which are well sorted, most of the river

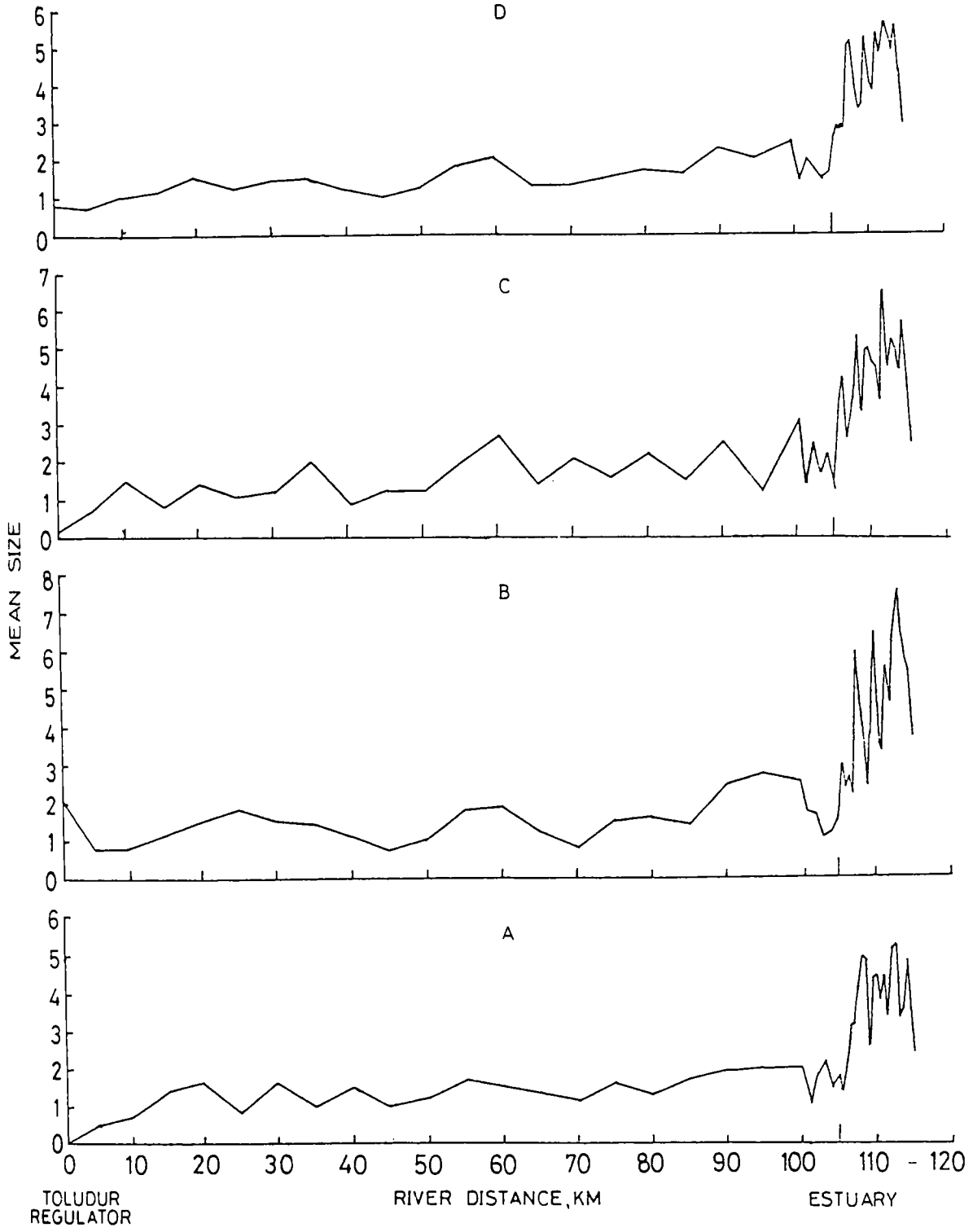


FIG. 6. DOWNSTREAM VARIATIONS OF PHI MEAN SIZE.

A-SOUTH. B-CENTRE. C-NORTH. D-AVERAGE.

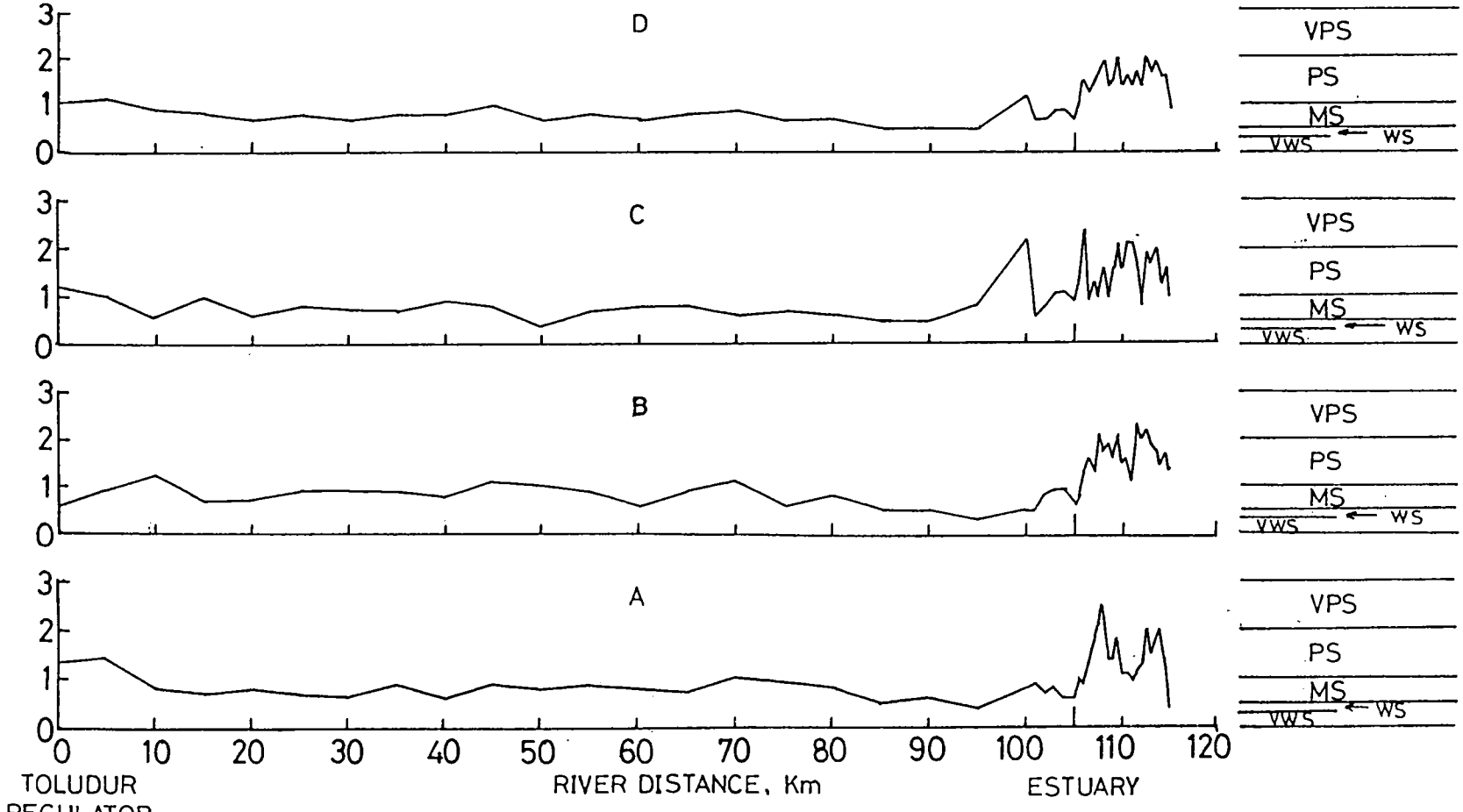


FIG. 7. DOWN-STREAM VARIATIONS OF STANDARD DEVIATION
A-SOUTH · B-CENTRE · C-NORTH · D-AVERAGE ·
VPS-VERY POORLY SORTED. PS-POORLY SORTED · MS-MODERATELY SORTED.
WS-WELL SORTED · VWS-VERY WELL SORTED.

channel sediments are moderately sorted. The standard deviation of the river channel sediments varies from 0.40 to 2.21. In the estuary, except for the few abnormal values, most of the sediments are either poorly or very poorly sorted (0.40 to 2.45). In Chinnar river and Manimukta Nadi the standard deviation ranges from 0.79 to 1.51 and 0.58 to 1.73 respectively. Majority of the beach sands are very well to well sorted with standard deviation values ranging from 0.21 to 0.68. The tidal channel sediments are predominantly poorly sorted (1.19 to 2.14) and the nearshore have wide range of sorting from well sorted to poorly sorted sediments (0.43 to 2.55).

SKEWNESS:

Skewness, a measure of the degree of symmetry, describes the tendency of the data to spread prefentially to one side of the average. In the textural analysis skewness is considered an important parameter, since it is a sensitive indicator of sub-population mixing. Different environments of Vellar estuary show marked variations in the skewness of the sediments. Most of the river channel sediments are either nearly symmetrical or positively skewed. The skewness of the river channel and estuarine sediments are plotted against the river distance (Fig. 8). A slight increasing trend is observed in river channel but there is a marked increasing trend in the estuarine region. Positively skewed to very positively skewed sediments are predominant in the estuarine region, however, very few samples are negatively or moderately

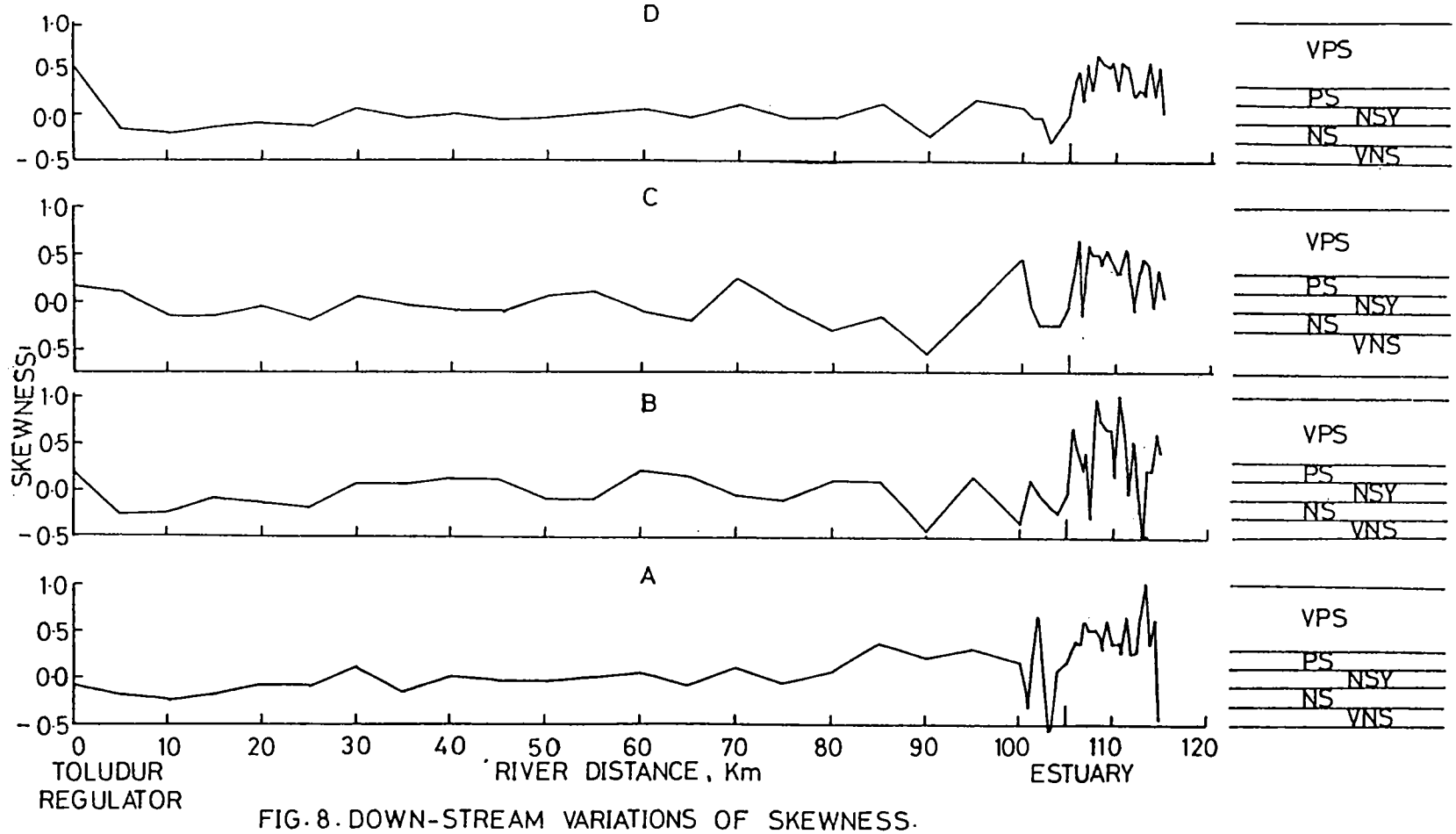


FIG. 8. DOWN-STREAM VARIATIONS OF SKEWNESS.

A-SOUTH. B-CENTRE. C-NORTH. D-AVERAGE.

VPS-VERY POSITIVELY SKEWED. PS-POSITIVELY SKEWED. NSY-NEARLY SYMMETRICAL.

NS-NEGATIVELY SKEWED. VNS-VERY NEGATIVELY SKEWED.

skewed. The skewnes range from -0.56 to +0.46 in the river channel sediments and in the estuarine sediments it varies from -0.48 to +1.00. The skeweess values of the Chinnar and Manimuktha Nadi vary from -0.31 to +0.06 and -0.21 to +0.22 respectively. In the beach, about 10 % of the samples are positively skewed, rest of the samples being very negatively skewed to nearly symmetrical (-0.50 to +0.30). Most of the tidal channel sediments are very positively skewed (+0.22 to +0.77). In the nearshore, the skewness ranges from negative to very positively skewed (-0.17 to +0.77).

KURTOSIS:

Kurtosis measures the ratio of the sorting in the extremes of the distribution compared with the sorting in the central part. The kurtosis values are plotted against the river distance (Fig. 9). The values vary from platy to very lepto kurtic but majority of the points lie in the meso kurtic region. In the estuarine sediments the kurtosis ranges from very platy to extremely lepto kurtic. The respective values of kurtosis in the river and estuarine sediments varied from 0.50 to 2.50 and 0.43 to 4.63 respectively. The samples of Chinnar river and Manimukta Nadi show a narrow range of kurtosis from 0.77 to 1.16 and 0.63 to 1.34 respectively. The kurtosis of beach sands vary from platy kurtic to lepto kurtic (0.69 to 2.08). In the tidal channel, the kurtosis ranges from platy to very lepto kurtic (0.84 to 2.10) and in the nearshore environment

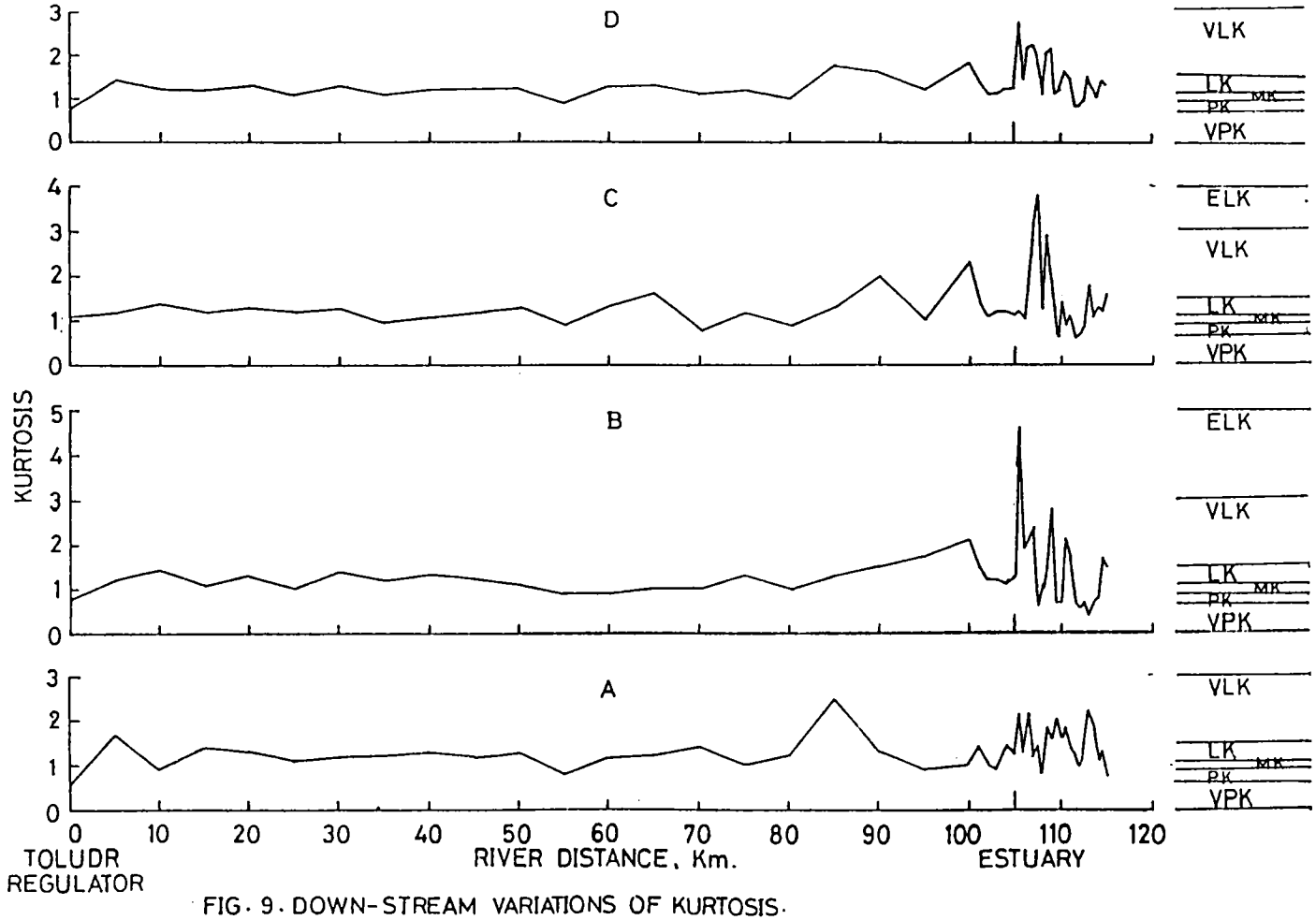


FIG. 9. DOWN-STREAM VARIATIONS OF KURTOSIS.
A-SOUTH. B-CENTRE. C-NORTH. D-AVERAGE.
ELK-EXTREMELY LEPTOKURTIC. VLK-VERY LEPTOKUTIC. LK-LEPTOKURTC.
MK-MESOKURTIC. PK-PLATYKURTIC. VPK-VERY PLATYKURTIC.

it ranges from 0.73 to 3.25 i.e. platy kurtic to extremely lepto kurtic.

SCATTER PLOTS:

An attempt has been made to highlight the mode and environment of deposition. The scatter plots constructed with different size parameters have a geological significance in identifing the environment and mode of deposition. In this study, two sets of scatter diagrams have been plotted. One is a pure sand mode where the data were obtained only from sieving, the environments falling in to this group being river channel and beach. The second set of scatter plots represent the estuarine, tidal channel and nearshore environments, for which the data obtained from both sieving and pipette analyses are considered.

MEAN SIZES VERSUS STANDARD DEVIATION:

The scatter plot between meansize and standard deviation (Fig. 10) for river and beach sediments gives a part of " V " shapped pattern with flattened left limb. Between the size range of 2.0 to 2.8 phi, the river sediments are moderately sorted, while the beach sand shows well to very well sorting. When phi mean size increases, the sorting of the sediments also shows an improvement. The scatter plots of mean size versus standard deviation of the estuary, tidal channel and nearshore sediments are presented in Fig. 16. In all the environments an increasing trend of standard deviation is observed along with an increase in the phi mean size. In the estuarine sediments, the increase in

the phi mean size led to a change in the sorting from moderate to very poor. The tidal channel has poorly to very poorly sorted sediments with large mean size. The nearshore sediments are well to moderately sorted with low mean size.

MEAN SIZE VERSUS SKEWNESS:

Mean versus skewness plots of the river and beach sediments show a sinusoidal pattern (Fig. 11). Most of the river channel sediments are nearly symmetrical to negatively skewed and the beach sediments are very negatively skewed to nearly symmetical. Mean versus skewness plots of estuarine, tidal channel, and nearshore sediments also show a simillar type of sinusoidal pattern (Fig. 17). From the plot it is observed that most of the estuarine sediments are positively to very positively skewed and a few samples are nearly symmetrical. The sediments of the tidal channel are positive to very positively skewed. However, the nearshore sediments are in the range of negatively skewed to very positively skewed.

MEAN SIZE VERSUS KURTOSIS:

Results presented in Fig. 12 suggests that majority of the river and beach sediments are lepto kurtic to very lepto kurtic, while few samples are platy kurtic to meso kurtic. The pattern of the plot is sinusoidal. In the case of estuarine, tidal channel, and nearshore sediments the plot (Fig. 18) shows only a part of the " U " shaped curve which evinces a wide range of mean size and kurtosis values. Morover, the kurtosis values

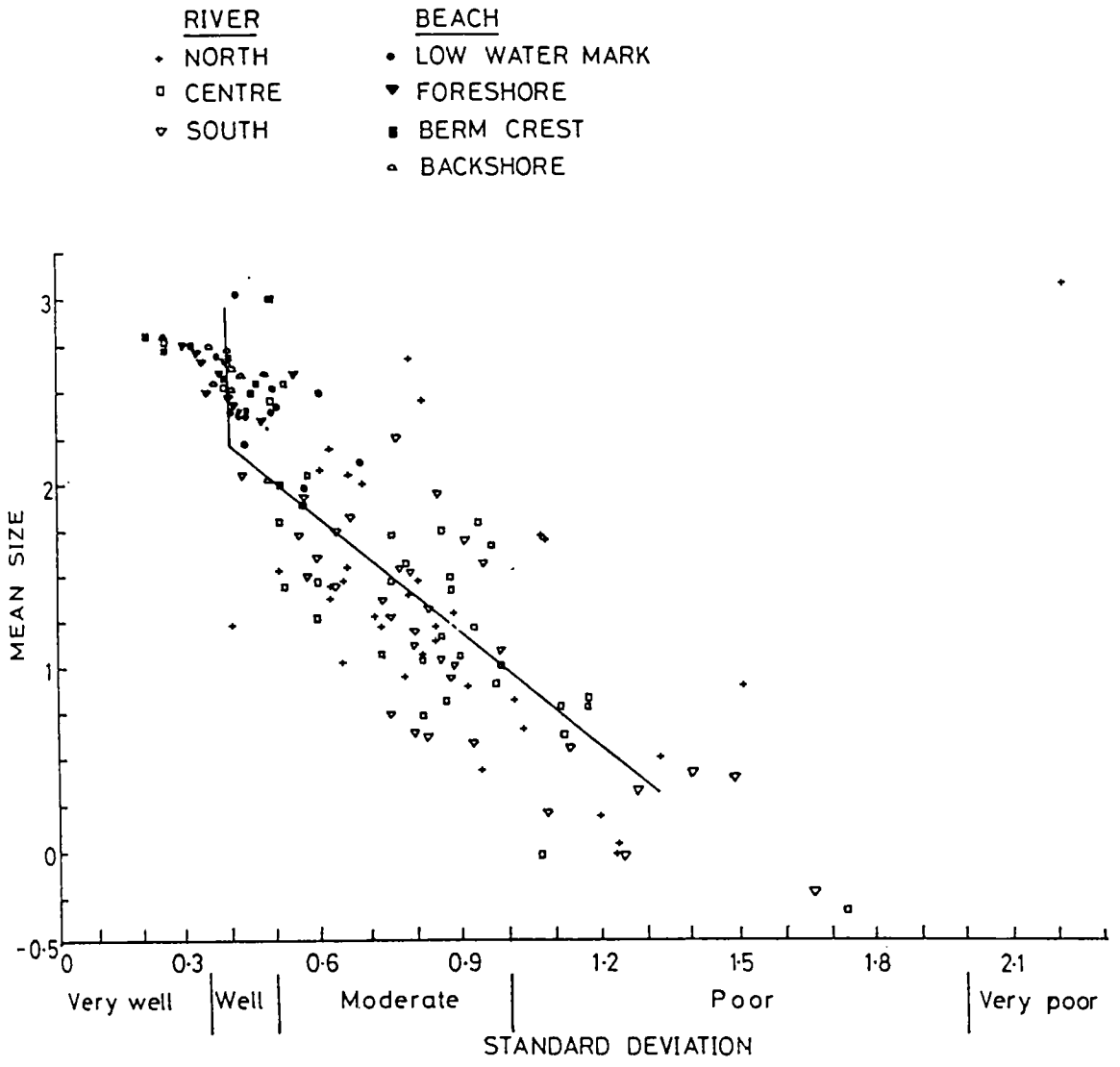


FIG. 10. SCATTER PLOT OF PHI MEAN SIZE VS. STANDARD DEVIATION.

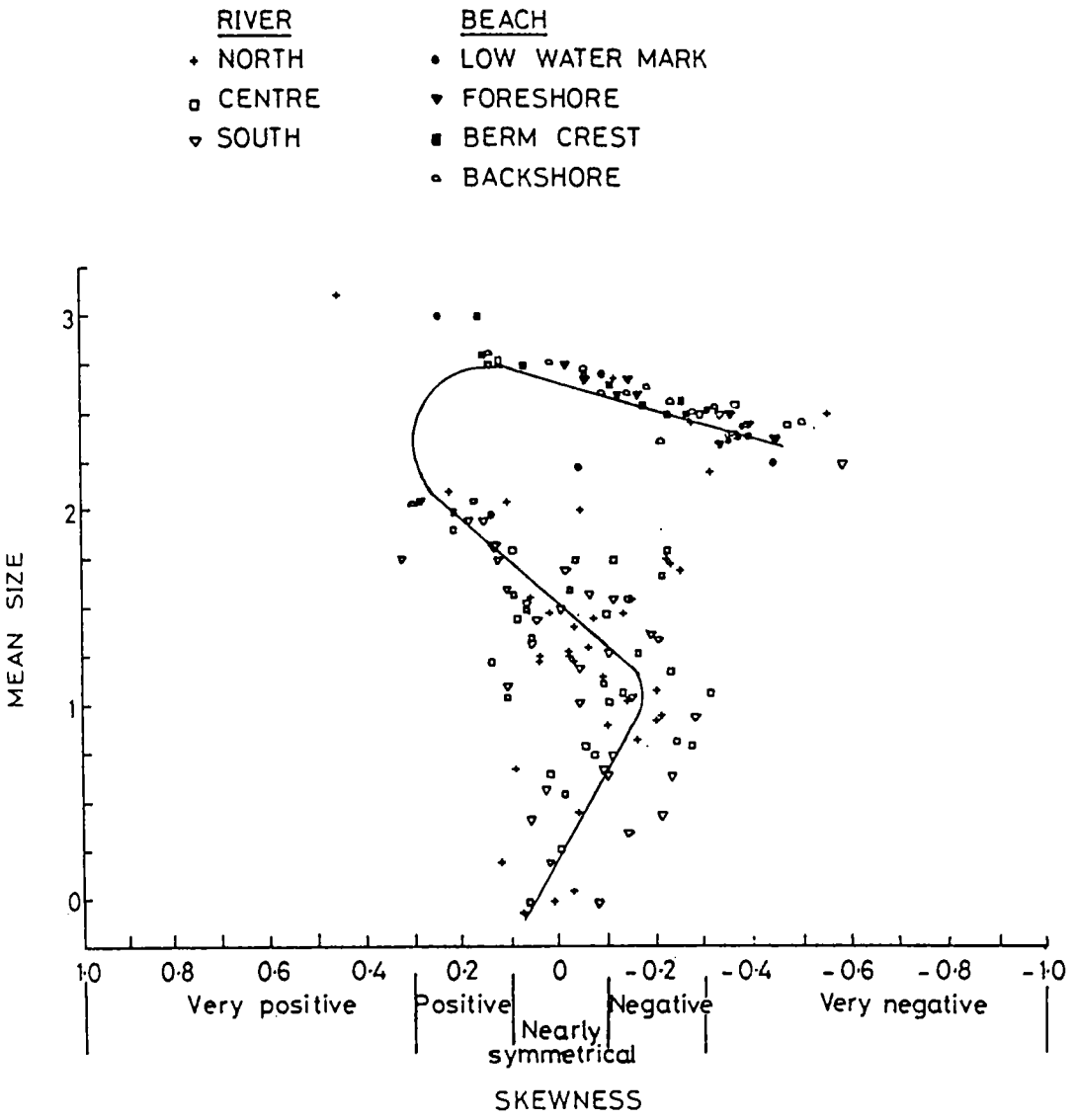


FIG. 11. SCATTER PLOT OF PHI MEAN SIZE VS. SKEWNESS.

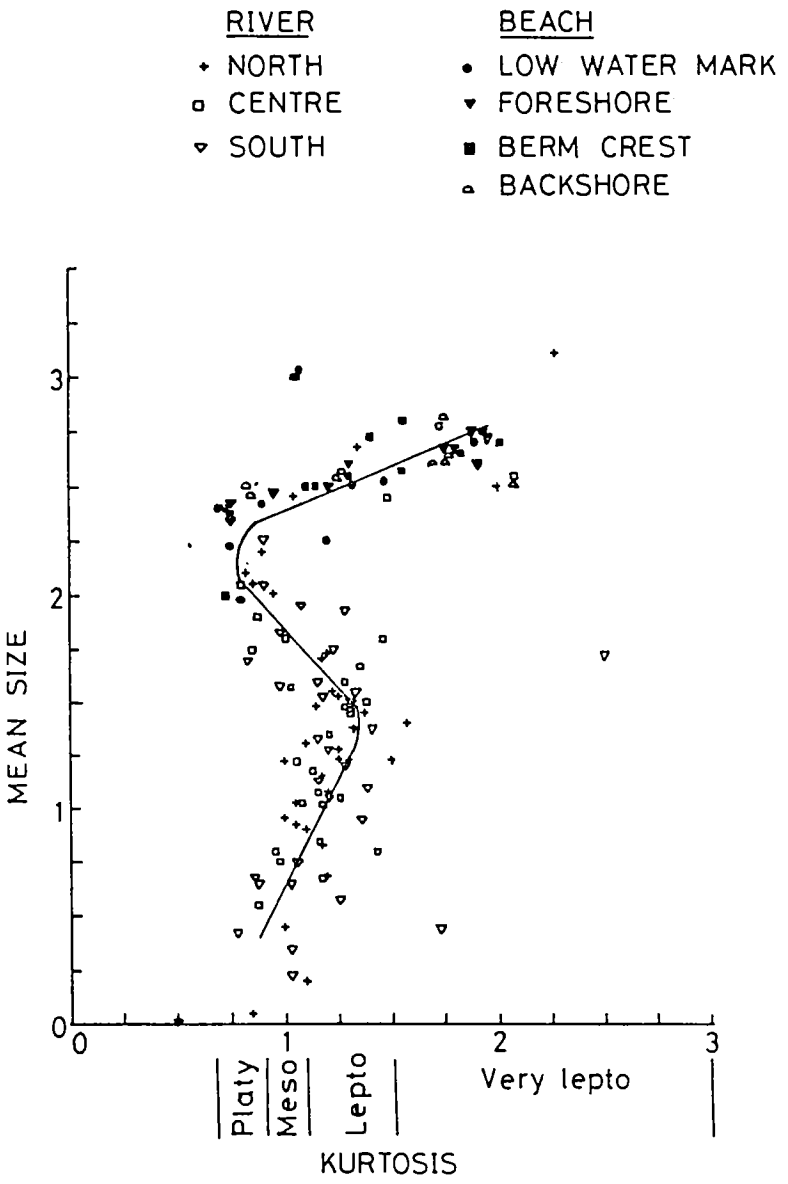


FIG. 12. SCATTER PLOT OF PHI MEAN SIZE VS. KURTOSIS.

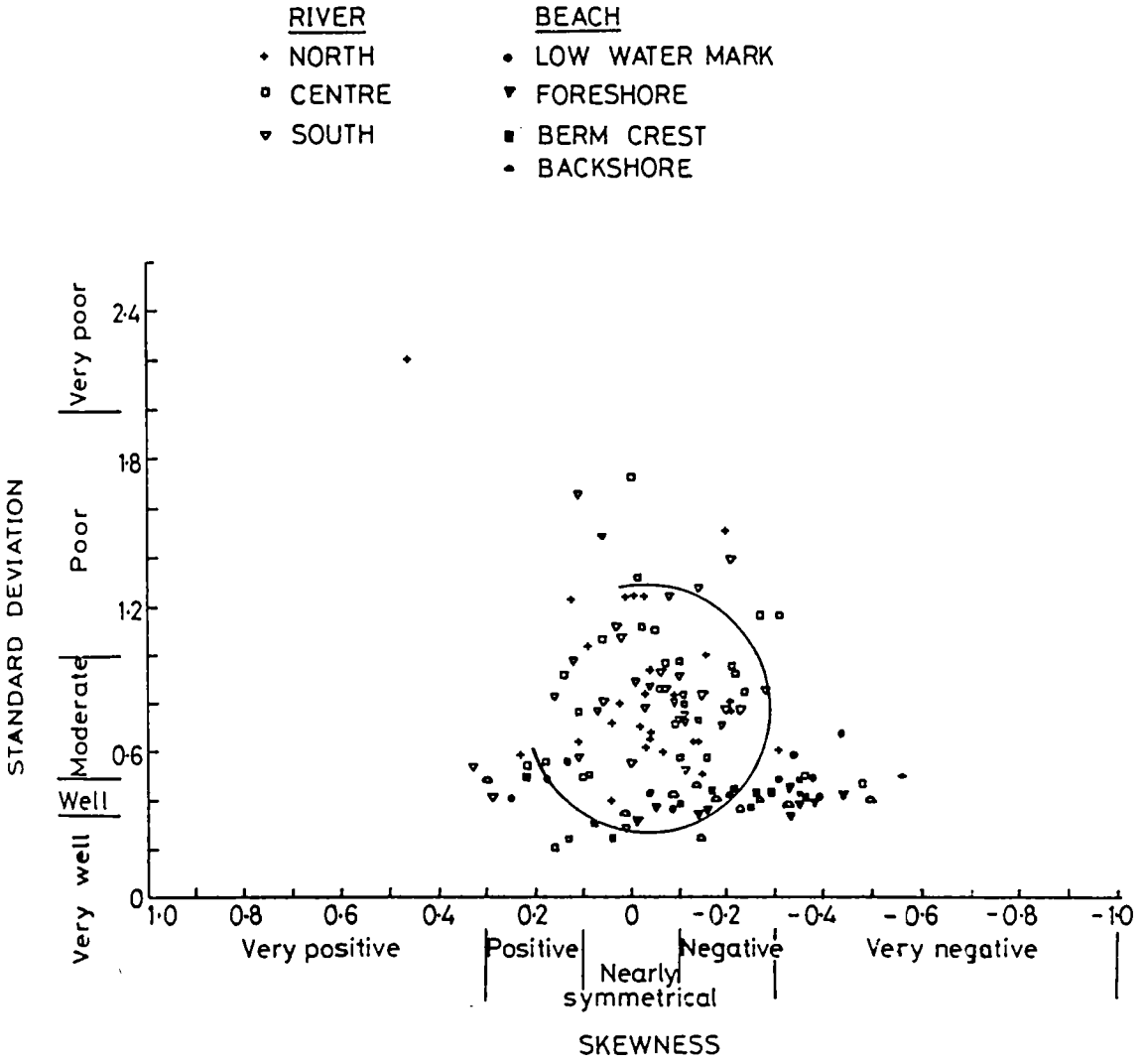


FIG. 13. SCATTER PLOT OF STANDARD DEVIATION VS. SKEWNESS.

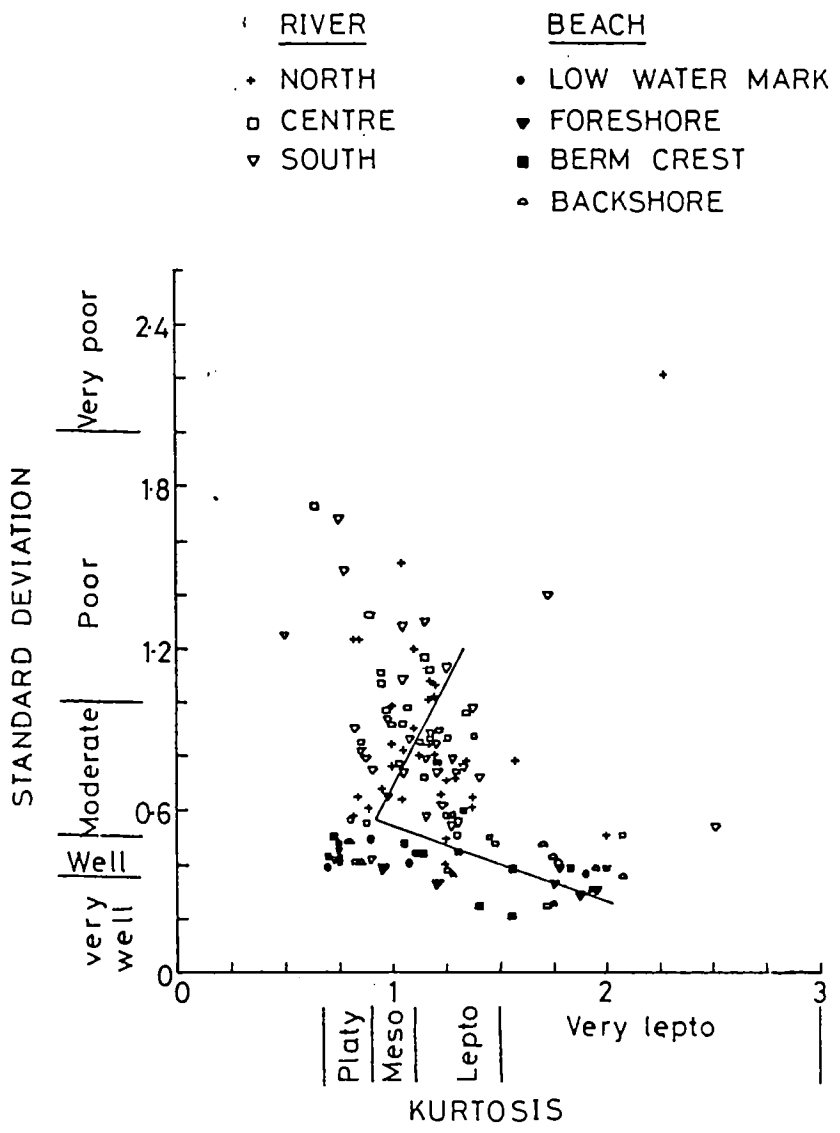


FIG. 14. SCATTER PLOT OF STANDARD DEVIATION VS KURTOSIS.

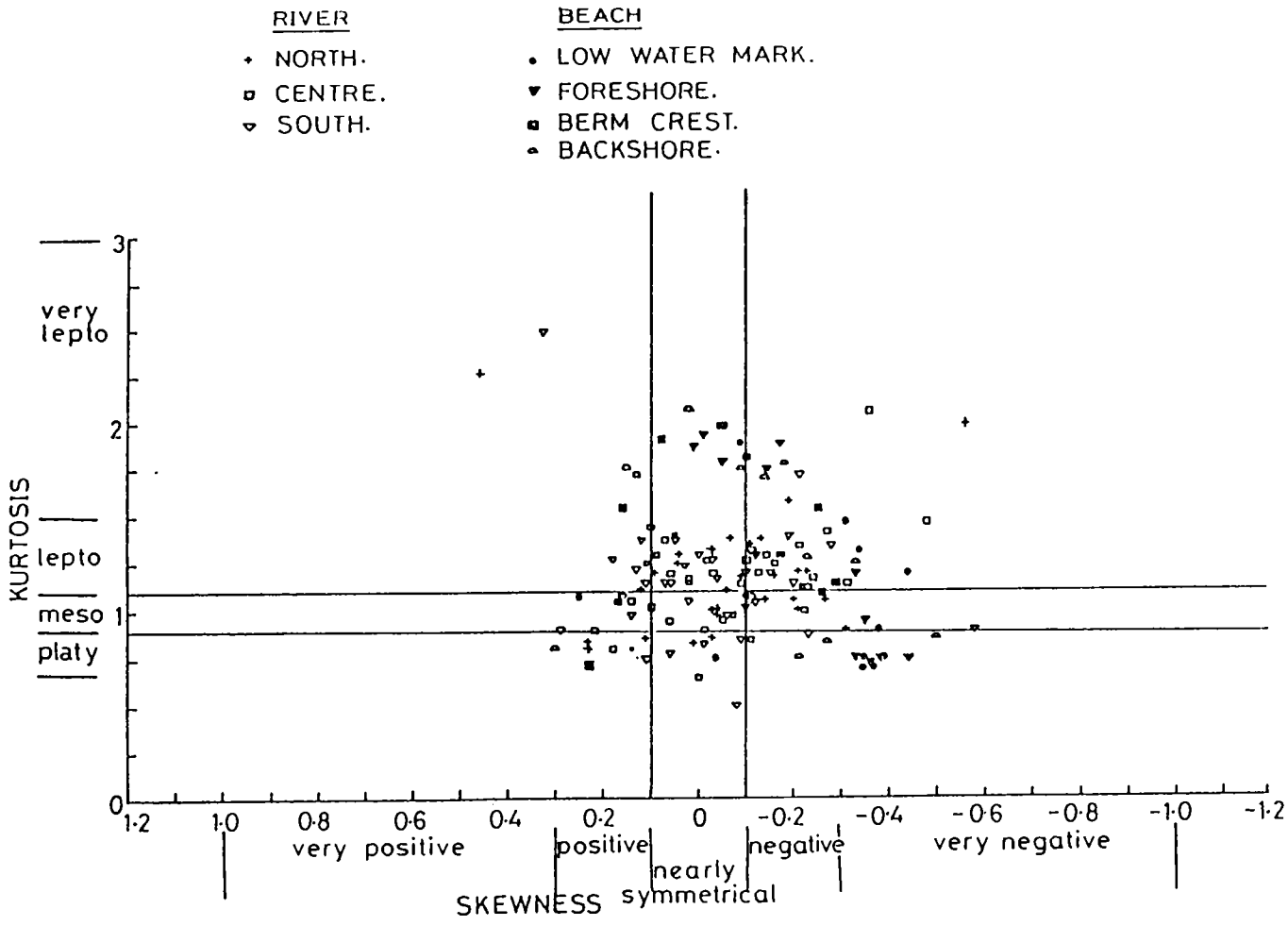


FIG. 15. SCATTER PLOT OF SKEWNESS VS. KURTOSIS.

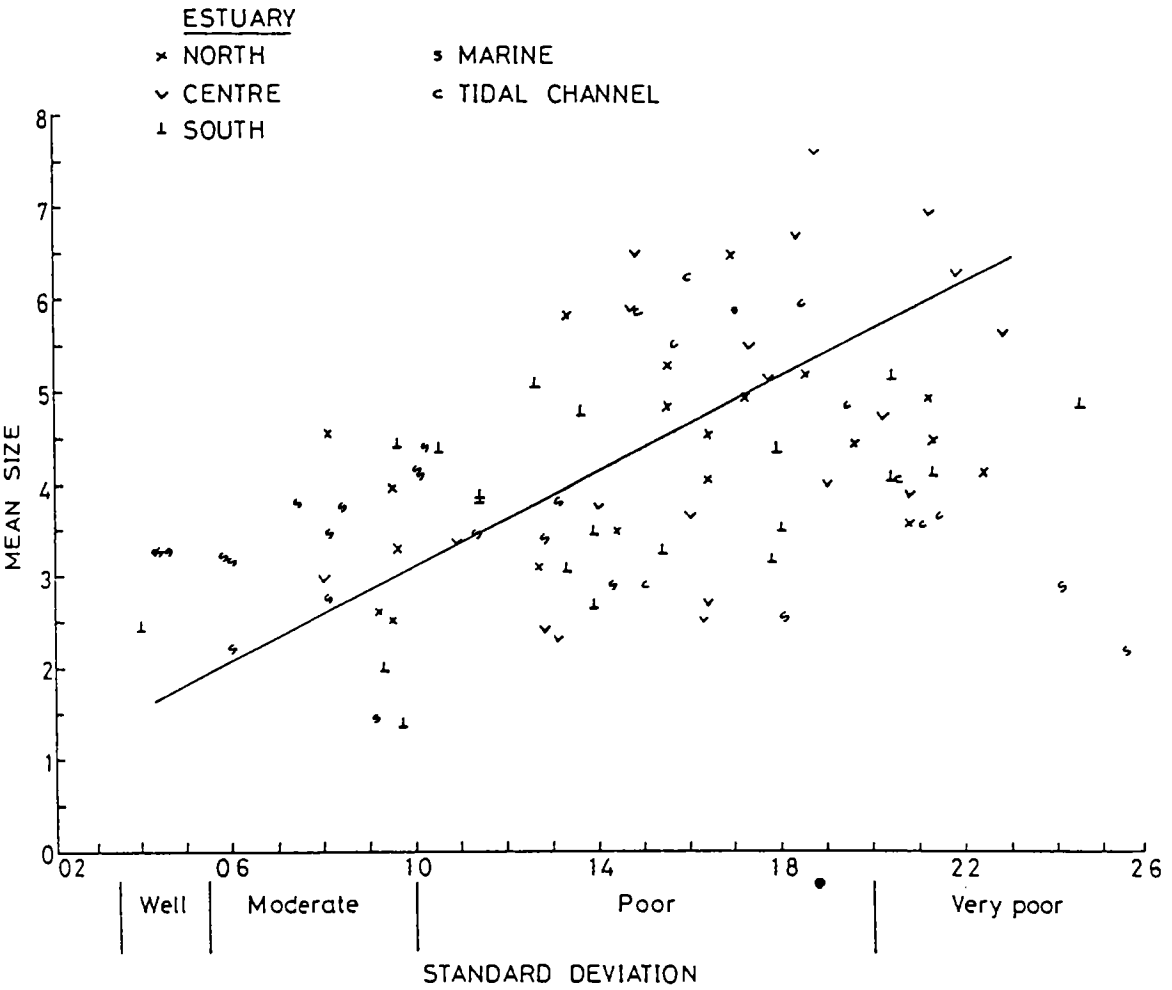


FIG. 16. SCATTER PLOT OF PHI MEAN SIZE VS. STANDARD DEVIATION.

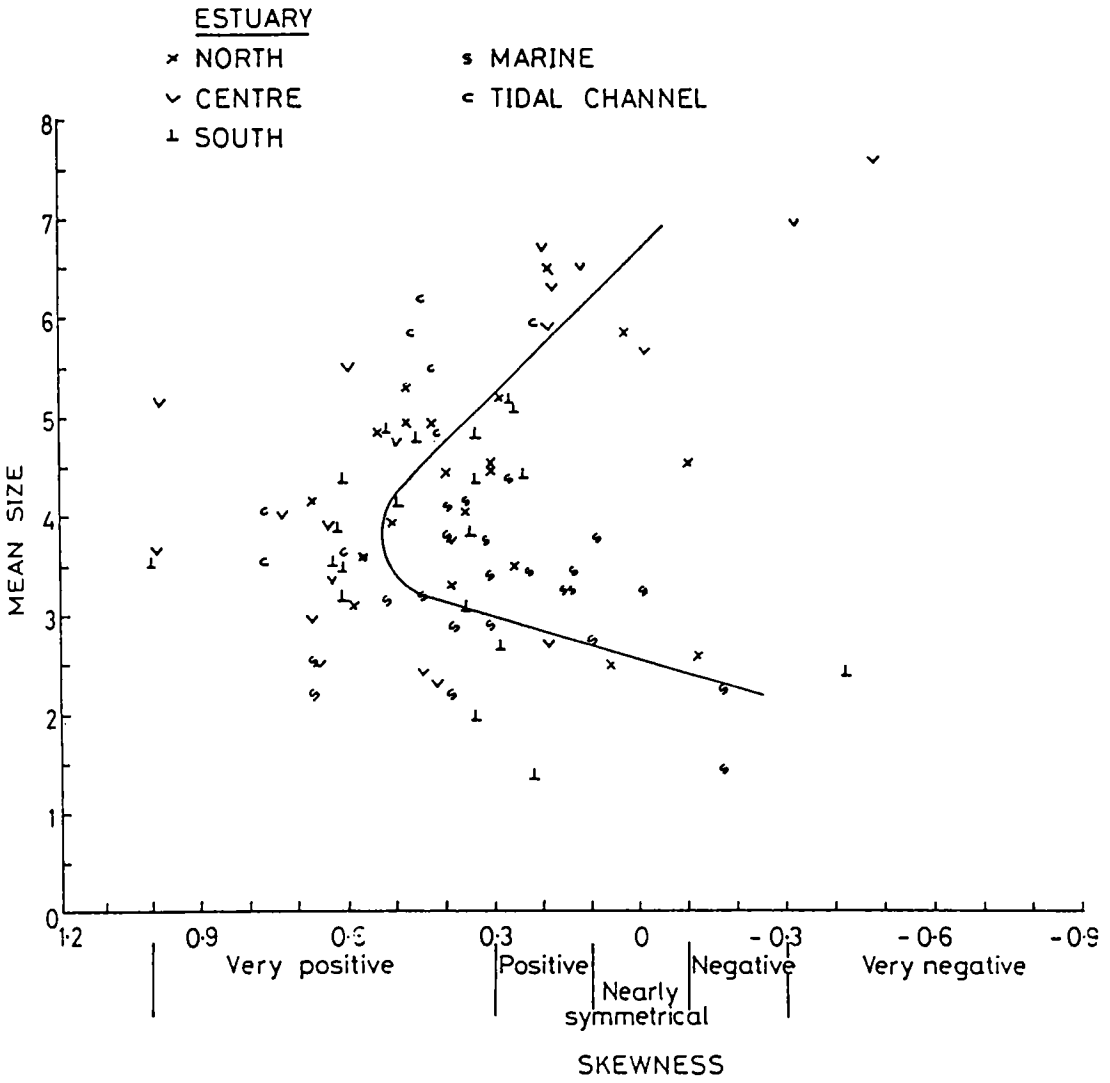


FIG. 17. SCATTER PLOT OF PHI MEAN SIZE VS. SKEWNESS.

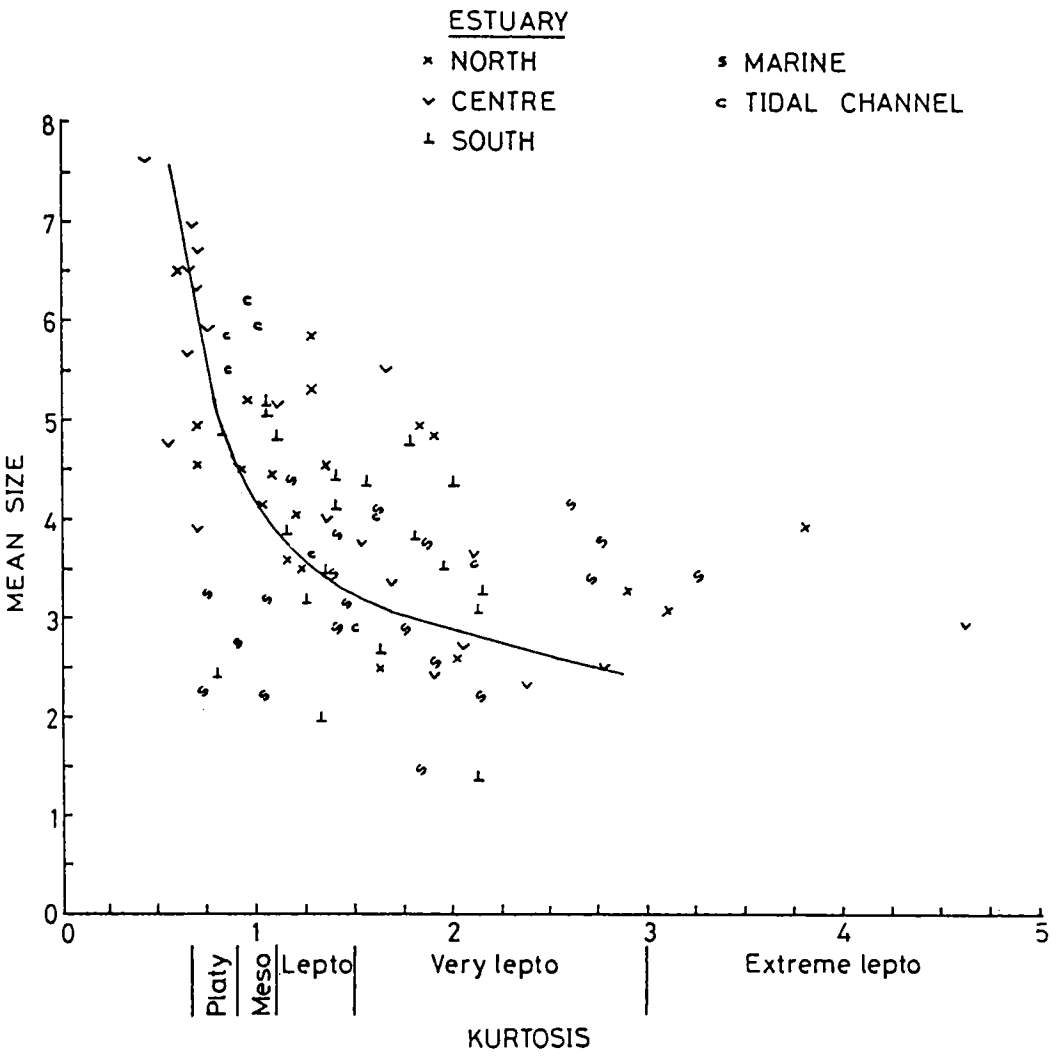


FIG. 18. SCATTER PLOT OF PHI MEAN SIZE VS. KURTOSIS.

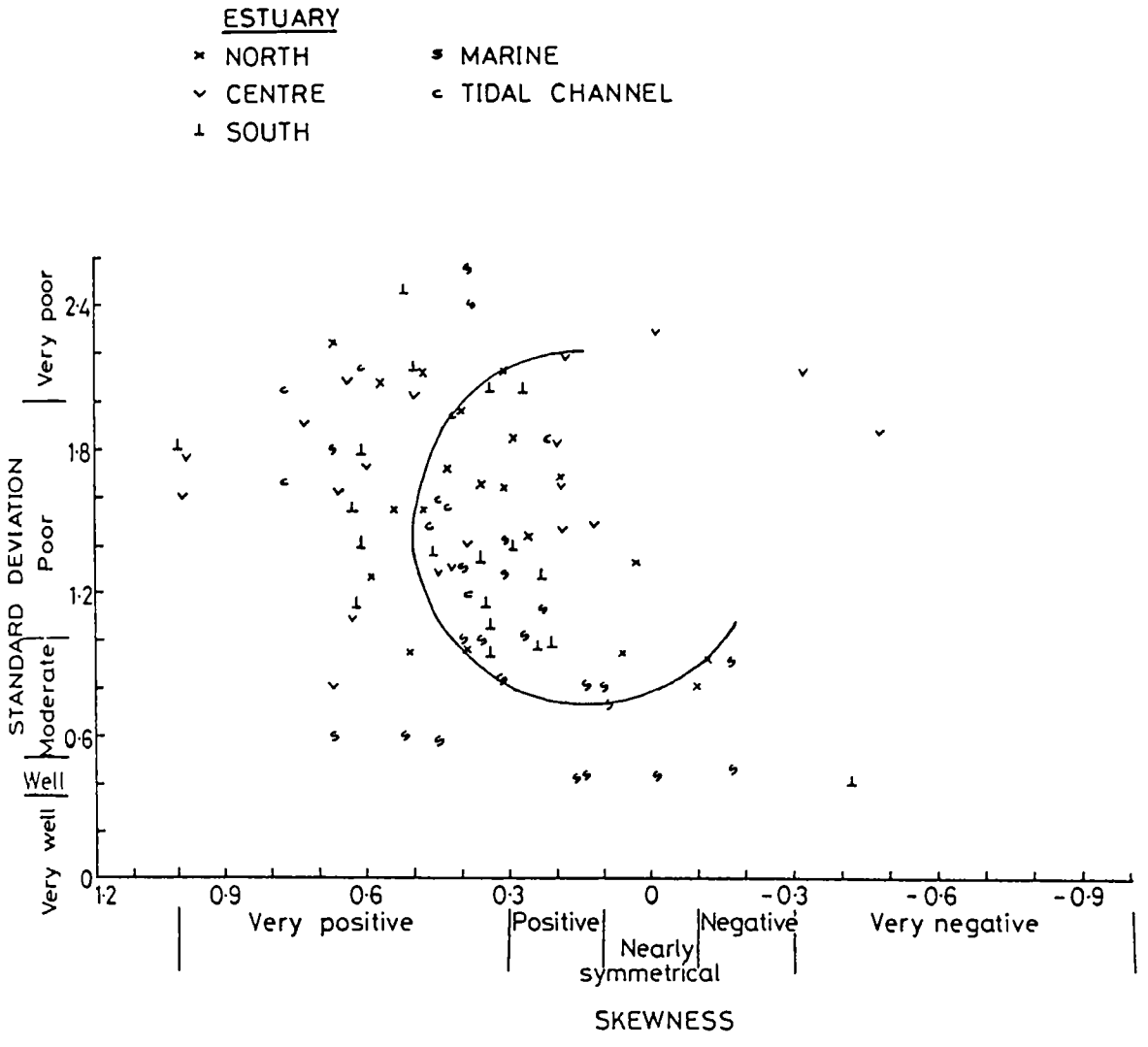


FIG. 19. SCATTER PLOT OF STANDARD DEVIATION VS. SKEWNESS.

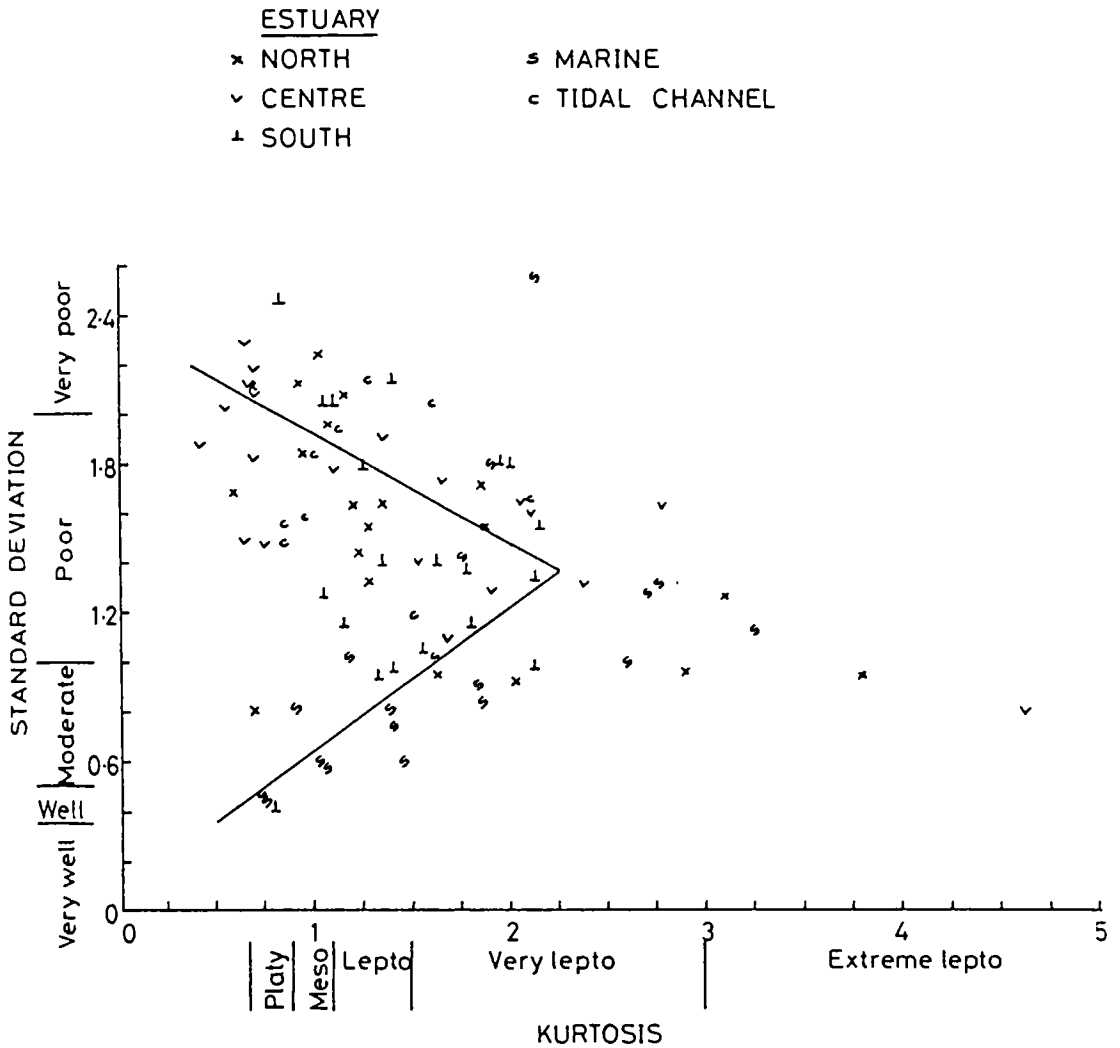


FIG. 20. SCATTER PLOT OF STANDARD DEVIATION VS. KURTOSIS.

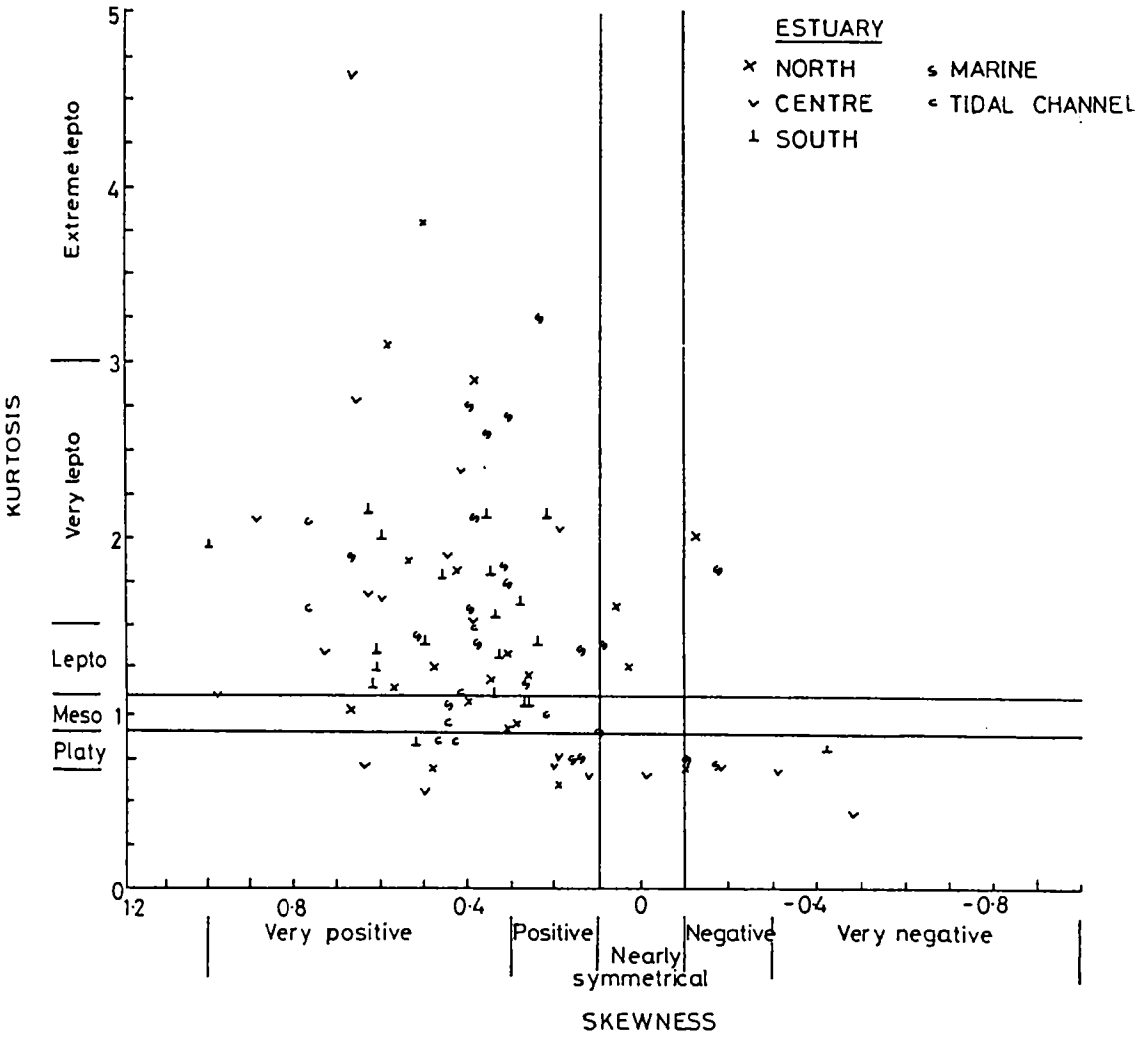


FIG. 21. SCATTER PLOT OF KURTOSIS VS. SKEWNESS.

decrease from extremely lepto kurtic to very lepto kurtic as the phi mean size increases.

STANDARD DEVIATION VERSUS SKEWNESS:

The scatter plot constructed using the standard deviation and skewness (Fig. 13) for the sediments of river and beach exhibit a semi circualr pattern. Eventhough, the whole diagram fitted well, the left hand side of the upper part leaves a slight gap due to the less amount of very positively skewed samples with a standard deviation ranging from 0.60 to 1.40. From this plot it can be observed that while the river channel sediments are well to moderately sorted, the beach sediments are very well to well sorted. Since there exists a mathematical relation between standard deviation and skewness, the variables cast a scatter trend in the form of nearly circular ring. In the case of estuarine, tidal channel, and nearshore sediments the plot (Fig. 19) displays a semi circular pattern. This illustrates that majority of the samples are positive to very positively skewed and the corresponding sorting is moderate to very poor.

STANDARD DEVIATION VERSUS KURTOSIS:

The standard deviation versus kurtosis scatter plot of river and beach is casting an inverted " V " shape trend (Fig. 14). The well to very well sorted sediments show meso to very lepto kurtic nature. A " V " shaped pattern is obtained for the estuarine, tidal channel, and nearshore sediments (Fig. 20). The estarine and tidal channel sediments are moderately to very poorly

sorted with kurtosis values indicating very platy kurtic to extremely platy kurtic nature. On the other hand, majority of the nearshore sediments are well to moderately sorted with platy kurtic to extremely lepto kurtic in nature.

SKEWNESS VERSUS KURTOSIS:

In the scatter plot of skewness versus kurtosis (Fig. 15), the areas with in the range of normal curve are shown by a diagonal line. In the present study, for river and beach sediments, half of the sample points are present in the "normal" curve, leaving the rest away from normality. But in the case of estuarine, tidal channel, and nearshore sediments, the plot reveals that (Fig. 21) very few samples are present in the "normal" curve.

SAND, SILT, AND CLAY CONTENTS OF THE SEDIMENTS:

Data presented in Table.3 illustrates the presence of the sand, silt, and clay contents in sediments of the different environments of the Vellar river basin, while their distribution is displayed in triangular diagram (Fig.22).

A high proportion of sand is present at the head of the estuary with silt and clay as subordinate. The sand proportion decreases towards the confluence (Fig.22A). The silt content is comparatively lower than the clay content in the downstream direction. However, the central part of the estuary shows a very clear decreasing

Table: 3 . Sand, Silt and Clay contents in the Vellar Estuary, Tidal Channel and Nearshore sediments.

	NORTH			CENTER			SOUTH		
DIS.km	SA.NO	SAND %	SILT %	CLAY %	SA.NO	SAND %	SILT %	CLAY %	SA.NO	SAND %	SILT %	CLAY %
Estuary												
100.00	61	71.80	9.00	19.20	62	96.70	2.30	1.00	63	92.00	7.40	0.60
105.50	79	65.10	28.50	6.40	80	91.20	4.50	4.30	81	94.60	5.40	0.00
106.00	82	40.40	19.40	40.20	83	70.00	6.30	23.70	84	92.60	6.90	0.50
106.50	85	85.20	3.50	11.30	86	81.00	4.00	15.00	87	67.30	11.80	20.90
107.00	88	71.10	8.30	20.60	89	73.90	8.50	17.60	90	48.90	20.00	31.10
107.50	91	66.40	20.50	13.10	92	4.90	13.80	81.30	93	53.80	20.20	26.00
108.00	94	7.80	45.30	46.90	95	12.00	34.40	53.60	96	32.30	17.90	48.80
108.50	97	82.70	6.20	11.10	98	45.60	15.30	39.10	99	25.30	47.70	27.00
109.00	100	25.10	42.80	32.10	101	69.30	1.20	29.50	102	74.60	7.90	17.50
109.50	103	27.10	23.80	49.10	104	24.60	15.00	60.40	105	50.50	12.10	37.40
110.00	106	21.10	30.20	48.70	107	3.00	23.10	73.90	108	32.70	44.70	22.60
110.50	109	29.80	24.30	45.90	110	52.60	13.50	33.90	111	61.10	24.90	14.00
111.00	112	42.90	18.90	38.20	113	59.80	13.40	26.80	114	30.00	48.20	21.80
111.50	115	0.30	20.80	78.90	116	11.30	17.00	71.70	117	42.80	32.00	25.20
112.00	118	31.60	48.90	19.50	119	27.60	18.40	54.00	120	13.00	49.50	37.50
112.50	121	19.00	30.00	51.00	122	6.50	24.20	69.30	123	18.30	31.30	50.40
113.00	124	22.70	53.60	23.70	125	2.70	14.10	83.20	126	75.20	10.50	14.30
113.50	127	45.50	28.80	25.70	128	1.50	35.80	62.70	129	75.80	10.60	13.60
114.00	130	1.60	37.50	60.90	131	3.00	34.00	63.00	132	26.60	34.50	38.90
114.50	133	47.50	32.10	20.40	134	9.00	46.70	44.30	135	53.10	22.20	24.70
115.00	136	87.20	4.40	8.40	137	53.90	26.80	19.30	138			

TIDAL CHANNEL			
SA.NO	SAND %	SILT %	CLAY %
163	64.10	16.00	19.90
164	71.60	12.90	15.50
165	54.90	18.20	26.90
166	57.60	18.40	24.00
167	29.00	30.80	40.20
168	0.40	40.30	59.30
169	1.30	40.40	58.30
170	6.30	37.50	56.20
171	3.80	41.30	54.90

NEARSHORE			
SA.NO	SAND %	SILT %	CLAY %
173	74.20	11.80	14.00
174	59.00	10.70	30.30
175	80.70	17.20	2.10
176	62.60	14.50	22.90
178	39.30	52.80	7.90
180	67.00	30.50	2.50
182	94.10	4.90	1.00
184	89.90	8.80	1.30
186	65.30	25.40	9.30
188	40.60	49.30	10.10
189	87.20	2.30	10.50
190	84.30	7.40	8.30
191	82.90	16.60	0.50
192	89.50	8.00	2.50

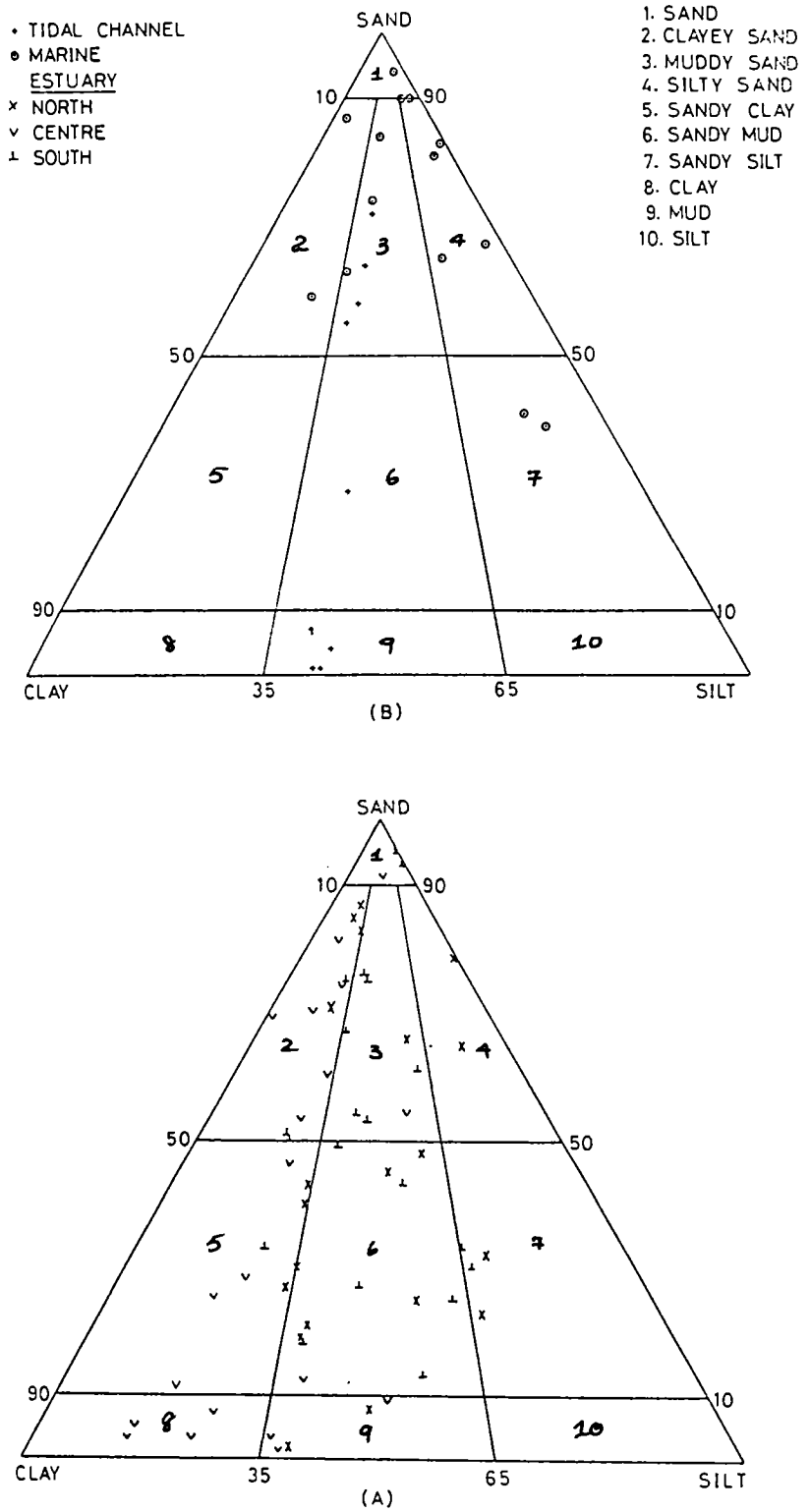
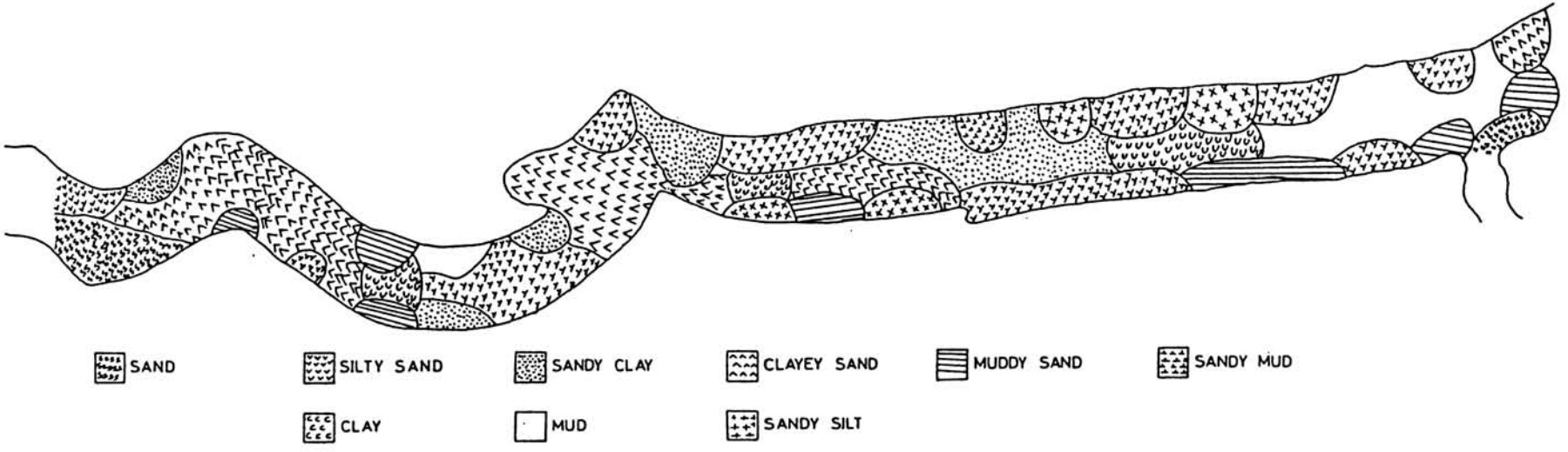


FIG. 22. TRIANGULAR DIAGRAMS SHOWING SAND-SILT-CLAY CONTENT IN (A) ESTUARY AND (B) TIDAL CHANNEL AND MARINE SEDIMENTS. (NOMENCLATURE AFTER FOLK, 1968)



FIG·22·A· SEDIMENTARY MAP OF VELLAR ESTUARY.

trend of sand and increasing trend of clay content. The tidal channel sediments show a high degree of compositional variability and are composed of large quantities of muddy sand and mud with low percentages of sandy mud. The marine sediments, collected from nearshore regions, show a very little amount of clay content compared to silt, which is considerably high.

DISCUSSION:

In the present study, the characteristics of grain size distribution of the sediments of Vellar river, estuary, tidal channel, beach, and nearshore marine environments have been studied to delineate the energy condition of the depositional environments existing in those regions. The results of the above analysis are discussed in this section.

MEAN SIZE:

A general increase of phi mean size or decrease in grain size along the downstream direction is the prominent feature observed in the present study. However, the northern and southern sides of the study area show undulating changes of grain size, while the central part demonstrates a gradual decreasing trend. The decrease in grain size in the direction of transport in a river channel is mainly due to the differential transport as stated by Scheidegger (1961) and Allen (1965), as well as by abrasion as described by Theil (1940). Normally, these two processes operate together and bring about a decrease in the mean

size. Moreover, during transport the edges and surfaces of the larger materials are rounded and smothered, and their size is reduced in the down current direction. Eventhough, different schools of thought regarding (Theil, 1940; Berthosis & Portier, 1957; Kuenen, 1959; 1960a; 1960b; Allen, 1965) the size reduction by abrasion exist, results of the present study reveal, that a travel of 150 km by the sediments do not account for abrasion as the sole reason for size reduction. Consequently, the differential transport may be accomplished as a decisive mechanism that brings about a decrease in the grain size downstream.

In a stream channel, a progressive decrease or increase in the speed of the water movement, governed by the seasonal variations in the mean discharge, leads to the differential transport of the sediment. Hence, the change in mean discharge of water may be accounted as the most important factor that has caused progressive downstream decrease in the competency of the Vellar estuary. Moreover, the fluvial morphology of the river also plays an important role in the grain size reduction in the Vellar river sediments. The braided nature of the river course, particularly in the lower reaches affects the competency of the river considerably. Thornbury (1954) and Leopold & Wolman (1957) also explained that the change of straight channel pattern to a braided one generally indicates the inability of a stream to carry all its load. Further, the changes in the straight channel, besides affecting the

competency of the transporting agent, leads to the deposition of coarse fraction and transportation of fine fractions downstream. However, the bank full discharges of river normally have high competency for transportation of the sediments of all size in the entire range of the river channel. When the flood recedes, the coarsest particles which can not be moved by river current are deposited in the banks, while the medium to fine size grains are carried away by the currents downstream and are deposited there causing a systematic enrichment of these size grades.

The abrubt change of grain size profiles observed in northern and sourthern sides of the study area can be attributed to the following process. The larger grains start to roll faster and further at a lower angle of slope than the smaller ones (Brush, 1965). At the same time, a particle of small settling velocity will be thrown faster and further in the transporting medium. This gives rise to two different lateral sorting processes, that produce large discontinuties in settling velocity distributions and probably results in the bimodal distribution as stated by Taira & Scholle (1979). Moreover, there are two anicuts constructed across the river i.e. at 38 km and 78 km of the river. The phi mean size increases in the upstream direction of the anicut and immediately decreases considerably downstream. This is due to the anicut, which restricts the speed of the water. Consequently the finer particles deposit in the upstream direction and the phi mean size decreases downstream.

The sediments of estuary show a considerable increase in phi mean size than river channel due to high percentages of silt and clay. However, at the head of the estuary, the sediments are mainly sand and silty sand and their mean size is considerabely low. This is attributed by the river current which loses its energy further downstream due to the variation in salinity, increase of depth and sustained resistance offered by the tidal processes. A similar type of changes are noticed by Dyer (1979) and Seralathan (1979) in their respective study area. Moreover, the sediments mean size becomes less in the mouth region where constant wave and tidal action carry away the fine particles offshore, and leaving the coarse particles behind.

In general, though the grain size parameters did not record any marked changes for the beach, there exists a significant variation from the low water mark to back shore. The low water mark samples consists of coarser size, which decreases up to berm crest while the back shore samples exhibit a slight increase in the size. The beach sediments, which lie in high energy zone, are winnowed out the fine constituents towards the berm crest by the constant wave action and in the backshore by wind action. A similar type of explanation was given by Sastry et al (1987) for the variation of grain size in the respective study area. This difference in size distribution may be manifested by the breaking wave which derives the

suspended materials along with the sediment load partly from lower forshore and partly from sediment transported by rolling in the form of turbulent sheer flow. These particles move up the sloping beach face, and get settled there, while the water that has not percolated in to the sediment flows back down the slope. Friedman & Sanders (1978) and Samsuddin (1986) also explained a similar mechanism for the movement of sediments in the foreshore. During this movement, the finer matter is carried upslope leaving behind the coarse materials in low water mark zone and consequently the grain size decreases from the low water mark to foreshore.

The vigours churning action of the current and waves affect the higher proportion of fine population leading to the deposition of fine particles in the relatively calm areas. This clearly shows the variation in the textural parameters of the tidal channel sediments. The sediments contain higher proportioan of sand near the estuary, whereas silt and clay are noticed far away from the estuary. This is because of the constant movement of the tidal currents in the estuary which leads to the removal of fine particles and the deposition of sand near the estuary while silt and clay are deposited far away. This was supported by the statement of Hails and Hoyt (1969), who said that in the high energy environments, such as the tidal inlet and channels, fine grained fractions are removed by wave action and strong curents, whereas away from the

estuary, the tidal curent activity is reduced considerabely leading to the deposition of silt and clay.

The phi mean sizeof nearshore marine sediments vary from 1.44 phi to 4.42 phi among individual samples and most of them lie between the phi values 2 to 4.

Within the study area the northern parts of the two stations recorded lower phi mean size (1.44 & 2.19) as compared to the southern parts. However, the stations near the Vellar estuarine mouth display a reduction in phi mean size compared to other stations. This is due to the region being affected by the constant movements of the tidal current which prevent the deposition of fine sediments. Moreover, the grain size of the nearshore sediments does not decrease considerably when compared to the general trend of the marine sediments elsewhere. This is the consequence of the constant wave action zone where all the nearshore stations laid.

STANDARD DEVIATION:

For the river channel sediment the standard deviation values slightly decrease downstream or in other words the sorting of the sediments improves slightly. This increase in sorting is mainly due to the differential transport of the sediments which favours the deposition of coarser fractions upstream and finer particles downstream. The presence of coarser fractions impart an ill-sorted character to the sediments upstream compared to those downstream. However, according to Inman (1949), once sediment attains maximum sorting values, any further fall in competency results in the increase of fine particles and in

a poor sorting. In the present study, it is observed that the gentle decrease in the standard deviation without any abrupt change indicates the absence of considerable amount of very fine particles. But, sudden increase of standard deviation at 100th km in northern side may be due to the addition of fine particles.

Results presented in Fig.9 suggest that sorting of a sediments is a close function of mean size. The points are arranged in an incomplete "V" shaped curve (with a flattend left limb). All the river samples laid on the right limb of the incomplete "V" shaped curve suggest that the sediments are increasingly poorly sorted towards coarse sand mode and well sorted towards fine sand mode. Inman (1949), Griffiths (1951), and Pettijohn (1957) have shown a simillar relationship between the mean size and sorting. However, the wide lateral scattering of points (Fig.10) in the river channel sediments observed in the present study are due to the variation in the content of the the finer particles. Moreover, the phi values between 0.75 to 2.25 cast a large vertical scattering in the standard deviation accomplished by relatively greater sensitivity of sorting with a slight change in the fine mode which affect the "tails" of the size distribution.

The sediments become poor to very poorly sorted from the Vellar estuarine head to mouth region consequent to the mixing of two or three modes in equal amounts. However, the presence of some moderately sorted

sediments in the northern side of the estuary indicates that they escaped from the intermixing of predominant fine mode either by local processes within the estuary or due to the tidal currents. The scatter plot presented in Fig.16 demonstrated the increase in phi mean size with the addition of fine mode that leads to poor to very poor sorting. It may be due to the fact that the estuary acts as a trap for the sediments and consequently its energy condition is lesser than that in the river channel, leading to the prevention of an effective sorting which further results in the increase of phi mean size and poor sorting values.

In general, moderate to very well sorting is seen in the beach sediments which also increases from low water mark to berm crest i.e. moderate to very well sorted. Since the range of size is confined to sand (Fig.10), it produced only one limb of the "V" with a flattend left side. Further, the plot also resembles the pattern as obtained by Folk and Ward (1957). The flattened side of the plot suggests that the sediments of beach are hybrid sediments consisting of a mixtures of modes. Generally, the hybrid sediments are poorly sorted, wherever those in the present study are well sorted. As ex plained by Folk and Ward (1957) this might be due to the environment where efficient sorting takes place.

The tidal channel has poorly to very poorly sorted sediments with large phi mean size. This is because of the increase of silt and clay content. Further, it explains that the environment is comparatively calm. In

the case of nearshore environments, sediments are well to poorly sorted with low mean size. Since the sediments are mainly coarse in nature with less amount of fine sediments gives a moderate to well sorting. Moreover, the nearshore environment which is subjected to high rate of deposition and severe turbulence also make these sediments to good sorted one.

SKEWNESS:

The skewnes values (Fig.8) indicate that there is an overall increase in the river channel and a sharp rise from estuarine head to mouth region. In the river channel, the upstream sediments are negatively skewed and downstream, they are symmetrical. However, in the cent ral and northern side some of the samples show positively skewed sediments. The upstream sediments mainly consisting of coarse fraction with less amounts of fine mode yield negative skewness. A similar type of changes were noticed by Folk & Ward (1957), Cadigan (1961) and Martins (1965) in their respective study area. Moreover, two modes mixed in equal amount would alter the skewness to symmetical. When the sediments reach downstream, the fine mode increase significantly and shifts the skewness to positive. Further, as explained by Friedman (1961) and Martins (1965) the positive skewness accounts for the transportation of the sediment generally in one direction i.e. downstream. A sinusoidal pattern is obtained from the plot (Fig.11) which is similar to that of Brazos river

sediments (Folk & Ward, 1957). This supports the above discussion that the change of mode from coarse to fine would shift the skewness from negative to positive. Further, the standard deviation vs skewness plot (Fig.13) shows a semi circular pattern, which is almost similar to that of Folk & Ward (1957) and McKinney & Friedman (1970), also supports the above said explanation.

In the estuarine region although the sediments are mainly positive to very positive skewed, the very positively skewed sediments are abundant. This is mainly due to the addition of high amount of silt and clay mode to the sand mode. Friedman (1967) and Cronan (1972) had made similar observation and noted that polymodal sediments can show variable skewness values depending on the specific proportions of component sub-populations. However, the presence of a few nearly symmetrically skewed samples in the estuary indicate an equal proportion of different modes. In the scatter plot of mean size vs skewness (Fig.17) the points are arranged in a sinusoidal curve which explains that the positive to very positive skewness is due to the predominance of silt and clay mode in the sediments. The standard deviation vs skewness plot (Fig.19) supports the above said discussion and also explains that the fine mode is dominant, the rest being subordinate.

The tidal channel sediments show very positive (dominant) to positive skewness. This is because of the predominance of silt and clay mode in the sediments (Figs.17 & 19). In the nearshore marine sediments skewness

values range from negative to very positively skewed. Primarily, the sediments with a dominant coarse mode show very negative skewness while the fine mode predominant sediments show the negative skewness. However, modes which are subequal in nature, lead to nearly symmetrical skewness (Figs.17 & 19).

KURTOSIS:

Kurtosis values for the Vellar river channel (Fig.9) sediments in the upstream do. not show any marked changes and a majority of the sediments are leptokurtic in nature. However, the downstream freshwater region recorded a wide variation from meso to very lepto kurtic. Leptokurtic sediments are prominent in the centeral and northern side of the river. Folk and Ward (1957) and Cadigan (1961) while classifying kurtosis, stated that if the central part of the grain size distribution is relatively better sorted than that of the average in the tails, the distribution is called lepto kurtic, whereas the converse is true in the case of platy kurtic. The meso kurtic consists in the central part of the size distribution curve, a sediment sorting that is similar to that of the average in the tails. In the light of above definitions, it is pro ounded that the upstream sediments are centrally better sorted than the tails. The mean size vs kurtosis plot (Fig.12) gives a sinusoidal pattern which is similar to those obtained by Folk and Ward (1957) and Cronan (1972). It explains that the mixing of sediments with that of other

finer or coarser mode i.e. more than 75 to 90 percent accomplished the lepto kurtic nature to the sediments. The standard deviation vs kurtosis plot (Fig.14) shows an inverted "V" shape trend suggests that the river sediemnts are pure sand mode with moderate to well sorted and have lowest kurtosis. The skewness vs kurtosis plot (Fig.15) explains that the sand mode is dominant and the other fine one is subordinate.

However, when the sediments reach downstream, through the estuarine head to mouth, the silt and clay mode mix with sand mode which results in a wide range of kurtosis through platy to extremely lepto kurtic. These variations mainly depend upon the admixture of various percentages of different modes and their changes in the curve. Moreover, the estuarine environment has low effective sorting energy and hence the mixtures of different modes retain their individual characters. When such an assorted sediment is analysed, it normally gives a wide range of kurtosis according to the relative proportion of modal population. The mean size vs kurtosis plot (Fig.18) shows only part of "U" shaped curve as shown by Folk and Ward (1957) and Cronnan, (1972). A "V" shaped pattern is obtained for the standard deviation vs kurtosis plot (Fig.20). The skewness vs kurtosis plot is shown in Fig.21. These figures explain that the variations of kurtosis depends upon the mixture of different modes in different proportions.

Most of the beach sediments are platy to very lepto kurtic in nature. The meso and lepto kurtic samples are very less. Extreme high or low values of kurtosis imply that the sediment achieved good sorting in the high energy environment of the beach. According to Folk and Ward (1957) the unimodal sediments have kurtosis values of near unity, while the small subsidiary mode manifest a strong lepto kurtic nature with kurtosis values greater than unity. The present observation of average kurtosis of the beach sediments of 1.29, adds supports to the above mentioned fact. The kurtosis vs mean, standard deviation, and skewness plots (Figs.12, 14, & 15) also supplement the fact that the beach sediments are mixtures of two modes with coarser mode dominant, while the other is subordinate.

In the tidal channel sediments, kurtosis ranges from platy to very lepto kurtic. As explained by different workers (Folk & Ward, 1957; Mason & Folk, 1958; Folk, 1966; Spencer, 1968) the platy kurtic nature suggests a mixing of two population in subequal amounts, while the lepto kurtic connote the presence of one dominant and one subordinate population and meso kurtic insinuate the presence of equal proportion of the two modes. Therefore, the presence of these distributions - platy, meso, and lepto kurtic demonstrate that different stages of sorting in the grain size distribution prevail in this environments. The Figs.18, 20, & 21, also add support to the above said explanations.

The kurtosis of nearshore marine sediments shows a wide range from platy to extremely lepto kurtic. Very lepto kurtic is dominant and platy and lepto kurtic are equally distributed. The meso and extremely lepto kurtic are very few in number. The dominant coarse mode gives rise to very lepto kurtic sediment and the platy kurtic strongly indicates the mixing of two modes.

SAND, SILT, AND CLAY CONTENTS OF THE SEDIMENTS:

A high proportion of sand is present at the head of the estuary with silt and clay as subordinate. The sand and silt proportion decreases towards the confluence and clay content increases. The central part of the estuary, in particular, shows a very clear decreasing trend of sand and increasing trend of clay content. This may be due to the existence of a low hydraulic energy condition in the central part, than in the north and southern side. The variation seen in the north and southern side may be attributed to the influence of ebb and flood currents. These currents can lead to transportation of sediment in opposite directions on either sides of the estuary. As explained by Dyer (1979) the tidal flows may be distinctly separated into ebb and flood channel, the waters tending to flow up in one channel and down in the other, with the sediment following the same circulation system. This circulation forms an effective restriction to the penetration of coarse material into the central part of the estuary. In addtion, as explained by Bagnold (1973,1974)

and Carling (1981), the local constrictions would create coarse patches and widen the depostion of mud. The low silt percentage is a consequence of the mean grain size being less than 100 micron size of sand that can go directly into suspension when the threshold of bed load transport is exceeded. Subsequently this suspension load is carried to offshore and deposited in the calm waters.

The tidal channel sediment shows a high degree of composition variability and is composed of large portion of muddy sand and mud and low percentages of sandy mud. This clearly defines that the variations are due to the hydraulic fluctuations prevailing in the tidal channel. Sand dominant sediments are recorded in the dynamic regions and mud concentrations are in other regions.

The nearshore marine sediments show a very little amount of clay content compared to the silt. This may be due to the significant wave - energy in the nearshore, which would tend to maintain clay particles in suspension and consequently enrich the silt and sand in the sediment.

CM PATTERNS:

Bottom currents which are capable of transporting sediments are of two types. They are tractive currents and turbidity currents. Tractive currents are capable of transporting their load either by rolling or by suspension. Turbidity currents consist entierly of

suspension load, since they flow only for a limited time and are so rapid that they cannot be followed by rolling grains. Rivers, marine currents and waves touching bottom are tractive currents. According to Passega (1964), in tractive currents, the loads of fine and coarse sediments act largely independent of each other and a complete model of tractive currents consists of several segments " N - O - P - Q - R - S " representing the different modes of transport. This pattern is produced in the logarithmic plots of the coarsest one percentile grain size "C" and the median grain size "M" of deposits (Table. 4). Considering the above mentioned facts, CM diagram for the different environments of the Vellar river basin sediments have been prepared and are discussed.

RIVER CHANNEL AND ESTUARY:

The CM pattern of the Vellar river channel and estuarine sediments (Fig.23) exhibit segments of tractive currents " NO - OP - PQ - QR - RS ", similar to that reported by Passega (1964) and Bull (1962). The river channel sediments consists of " NP - OP - PQ - and QR ", segments of tractive current. This indicates that majority of the river sediments are transported by rolling and suspension and a small part by graded suspension. The segment NO represents the coarsest bed materials, which are larger than 5000 microns of C, and are mainly moved by rolling only. The OP region consists of 3900 to 5000 microns of C, which are moved by rolling and suspension. PQ represents sediments rang ing from 3900 to 1500 microns of

Table: 4. One Percentile (C) and Median (M) of River channel, Estuary, Beach, and Tidal Channel and Nearshore Sediments.

NORTH			CENTER			SOUTH		
SA.No.	C micr	M micr	SA.No.	C micr	M micr	SA.No.	C micr	M micr
VELLAR RIVER								
1	5300.00	830.00	2	655.00	258.00	3	5300.00	960.00
4	3300.00	650.00	5	4250.00	530.00	6	5500.00	630.00
7	1790.00	347.00	8	5200.00	505.00	9	2480.00	615.00
10	4370.00	520.00	11	4200.00	460.00	12	2050.00	355.00
13	1310.00	380.00	14	2150.00	345.00	15	2350.00	335.00
16	2390.00	440.00	17	3050.00	278.00	18	2290.00	580.00
19	1650.00	425.00	20	2180.00	375.00	21	1160.00	335.00
22	2100.00	258.00	23	2050.00	390.00	24	4000.00	455.00
25	2750.00	515.00	26	1800.00	490.00	27	1110.00	350.00
28	2200.00	430.00	29	4950.00	640.00	30	2500.00	475.00
31	1000.00	435.00	32	2600.00	470.00	33	2050.00	420.00
34	910.00	260.00	35	4050.00	294.00	36	1660.00	320.00
37	540.00	150.00	38	643.00	288.00	39	1850.00	365.00
40	2830.00	355.00	41	2400.00	460.00	42	1940.00	395.00
43	650.00	255.00	44	2830.00	555.00	45	2170.00	465.00
46	1180.00	335.00	47	1030.00	345.00	48	1810.00	335.00
49	830.00	200.00	50	1260.00	362.00	51	1780.00	405.00
52	920.00	328.00	53	950.00	370.00	54	710.00	330.00
55	2050.00	161.00	56	1140.00	168.00	57	680.00	283.00
58	2150.00	423.00	59	283.00	146.00	60	530.00	261.00
61	5050.00	177.00	62	650.00	156.00	63	2150.00	275.00
64	1580.00	362.00	65	910.00	298.00	66	4250.00	475.00
67	930.00	164.00	68	2350.00	310.00	69	915.00	303.00
70	4700.00	295.00	71	2750.00	450.00	72	4375.00	172.00
73	5000.00	295.00	74	2620.00	400.00	75	1000.00	363.00
76	2680.00	370.00	77	965.00	326.00	78	800.00	312.00
ESTUARY								
79	599.00	108.00	80	440.00	145.00	81	1710.00	390.00
82	480.00	128.00	83	590.00	210.00	84	1300.00	285.00
85	710.00	149.00	86	690.00	145.00	87	710.00	133.00
88	440.00	140.00	89	490.00	210.00	90	275.00	83.00
91	172.00	73.00	92	144.00	5.70	93	3600.00	96.00
94	119.00	34.00	95	177.00	33.50	96	350.00	70.00
97	435.00	106.00	98	305.00	112.00	99	215.00	48.00

SA.No.	C micr	M micr
TIDAL CHANNEL		
163	285.00	133.00
164	475.00	155.00
165	318.00	128.00
166	730.00	137.00
167	162.00	47.00
168	60.00	19.50
169	80.00	23.50
170	177.00	21.00
171	215.00	33.50
NEARSHORE		
172	3650.00	357.00
173	5100.00	320.00
174	760.00	265.00
175	505.00	140.00
176	1780.00	174.00
177	780.00	70.00
178	280.00	52.00
179	177.00	79.00
180	275.00	73.00
181	710.00	105.00
182	405.00	152.00
183	445.00	197.00
184	305.00	124.00
185	470.00	265.00
186	173.00	75.00
187	212.00	108.00
188	149.00	57.00
189	350.00	88.00
190	305.00	93.00
191	315.00	87.00
192	325.00	121.00
193	192.00	108.00

Table: 4. (Cont.)

SA.No.	NORTH C micr	M micr	SA.No.	CENTER C micr	M micr	SA.No.	SOUTH C micr	M micr	SA.No.	C micr	M micr
100	155.00	45.50	101	450.00	220.00	102	565.00	164.00			
103	250.00	52.00	104	162.00	65.00	105	345.00	77.00			
106	250.00	46.50	107	63.00	13.50	108	170.00	54.00			
109	480.00	59.00	110	405.00	129.00	111	350.00	76.00			
112	405.00	127.00	113	320.00	120.00	114	177.00	51.00			
115	63.00	13.00	116	260.00	18.50	117	300.00	67.00			
118	210.00	51.00	119	300.00	66.00	120	157.00	35.00			
121	400.00	35.00	122	230.00	10.70	123	520.00	36.00			
124	280.00	42.00	125	107.00	3.50	126	485.00	135.00			
127	700.00	68.00	128	80.00	12.80	129	380.00	131.00			
130	85.00	16.50	131	103.00	19.50	132	350.00	46.00			
133	485.00	74.00	134	118.00	37.00	135	400.00	125.00			
136	610.00	165.00	137	340.00	80.00	138	320.00	170.00			
MANIMUKTA NADI											
139	5100.00	950.00	140	7800.00	1175.00	141	5300.00	1180.00			
142	2030.00	475.00	143	2100.00	400.00	144	5390.00	720.00			
145	2350.00	490.00	146	2650.00	595.00	147	2570.00	610.00			
148	1790.00	405.00	149	5100.00	650.00	150	3250.00	630.00			
151	1640.00	365.00	152	2650.00	300.00	153	4750.00	670.00			
CHINNAR RIVER											
154	5000.00	1190.00	155	5300.00	930.00	156	5100.00	760.00			
157	4750.00	455.00	158	2650.00	585.00	159	5550.00	830.00			
160	2850.00	715.00	161	5090.00	475.00	162	2230.00	425.00			
LOW WATER MARK			FORESHORE			BERM CREST			BACKSHORE		
SA.No.	C micr	M micr	SA.No.	C micr	M micr	SA.No.	C micr	M micr	SA.No.	C micr	M micr
194	630.00	270.00	195	373.00	174.00	196	525.00	268.00	197	471.00	268.00
198	680.00	179.00	199	305.00	154.00	200	243.00	152.00	201	329.00	156.00
202	478.00	167.00	203	299.00	151.00	204	339.00	162.00	205	314.00	149.00
206	444.00	213.00	207	332.00	167.00	208	334.00	165.00	209	311.00	163.00
210	390.00	174.00	211	285.00	148.00	212	340.00	163.00	213	332.00	162.00
214	480.00	158.00	215	298.00	154.00	216	220.00	143.00	217	257.00	144.00
218	350.00	172.00	219	406.00	157.00	220	308.00	133.00	221	335.00	155.00
222	315.00	151.00	223	318.00	158.00	224	320.00	148.00	225	305.00	150.00
226	348.00	175.00	227	310.00	164.00	228	302.00	156.00	229	319.00	158.00
230	308.00	131.00	231	336.00	170.00	232	320.00	158.00	233	350.00	168.00
234	430.00	176.00	235	395.00	174.00	236	300.00	151.00	237	360.00	185.00
238	555.00	158.00	239	415.00	180.00	240	325.00	165.00	241	382.00	169.00

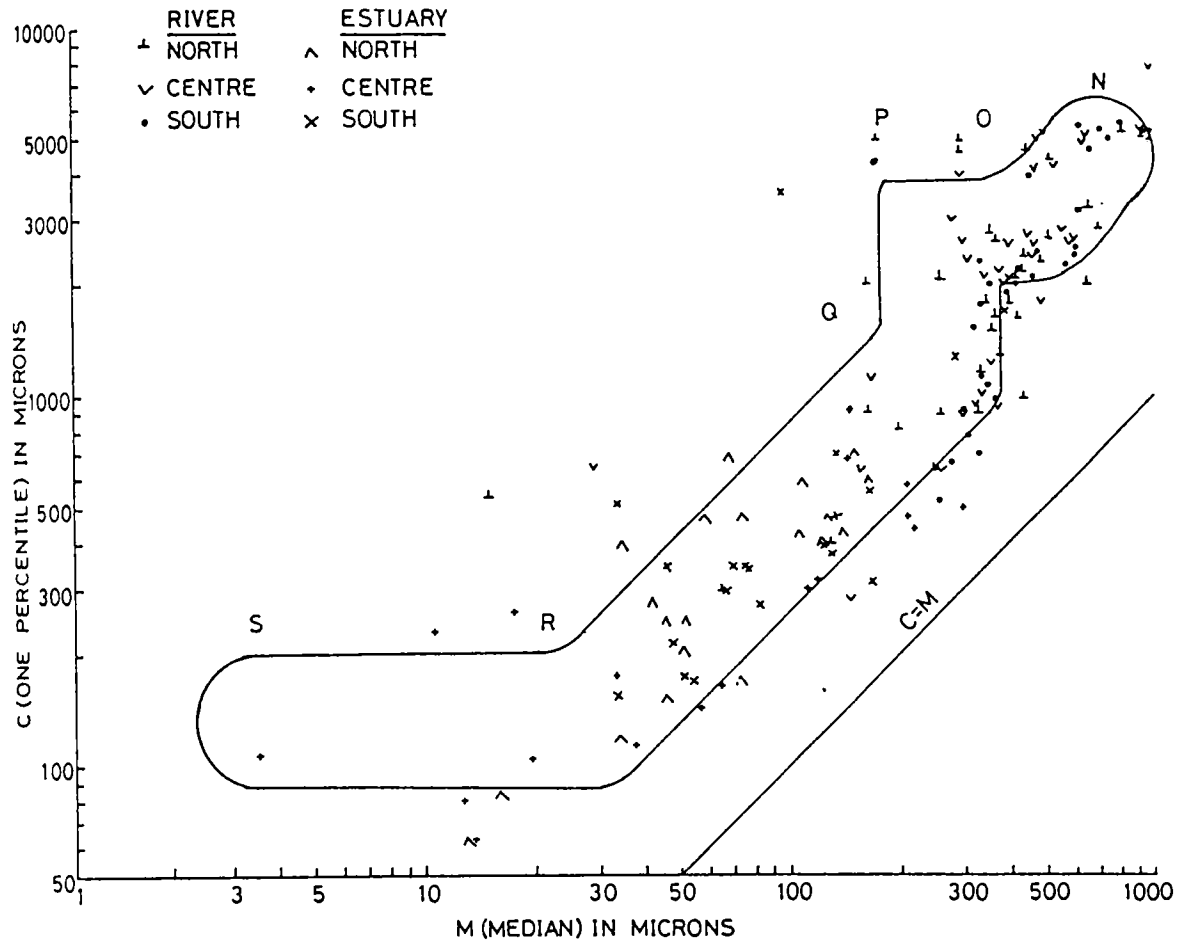


FIG. 23. CM PATTERNS OF RIVER CHANNEL AND ESTUARY

C, and indicate that particles were moved predominantly by traction i.e. suspension and rolling. The segment QR is parallel to the limit C = M between 1500 to 280 microns. Deposits of this segment were probably in suspension part of the time and hence the coarse grain size produced well sorted sediments. In the whole, the river channel sediemnts are highly restricted by the admixture of silt and clay due to high turbulence and therefore the sediments show low phi mean size and well to moderate sorting. Since the river channel sediments are mainly sandy nature the RS segment is totally missing.

On the other hand, the estuarine sediments display only QR and RS segments and the majority of the samples are present in QR segment while the RS segment contains few samples. The segment QR is parallel to limit C = M between 1500 to 200 microns. Since the deposists of this segment were probably in suspension part of the time, the coarse grain sizes produced well sorted sediments. However, the axis of the long rectilinear pattern of QR, is located at a considerable distance away from the limitting line. So, the sample points within this pattern represent the poorly sorted, clay and silt dominant deposits. Most of these particles are carried in suspension, and a decrease in velocity and depth of flow tends to drop some of the coarsest material along with some matrix. Moreover, as explained by Bull (1962) the low C and M values probably represent the deposition of finest

particles at a low velocity compared to that at which the coarse material is deposited.

BEACH:

CM pattern of beach sediment observed in the present study is similar to that of Passega's (1957) model of beach sands. Most of the beach sands are closer and also parallel to the limit C = M, indicating their graded suspension transport. However, maximum number of sample points are concentrated near the minimum median line, which is generaly an area of good sorting. Some beach sediments consist mostly of fine sand to which a small amount of much coarser grains are added. These sediments are represented by points situated fairly near the minimum median line and are at a considerable distance from the limit C = M, consequently yielding a broad shape to the pattern. Further, Fig.24.A also explains that the low water mark sediments consists of coarse grains compared to the other part of the beach and these sediments are well sorted.

TIDAL CHANNEL:

The CM plot of the tidal channel sediments show only QR and RS segments (Fig.24.B.). This pattern almost resembles Passega's (1957) model - Holland and DesMoins formation of Iowa. The points which fall in the QR segment mainly represent samples from the confluence of Vellar estuary and the tidal channel, which consists of coarser sediment as compared to other stations owing to the moderate to strong ebb and flow currents. However, samples from the deep and protected areas of the channel are

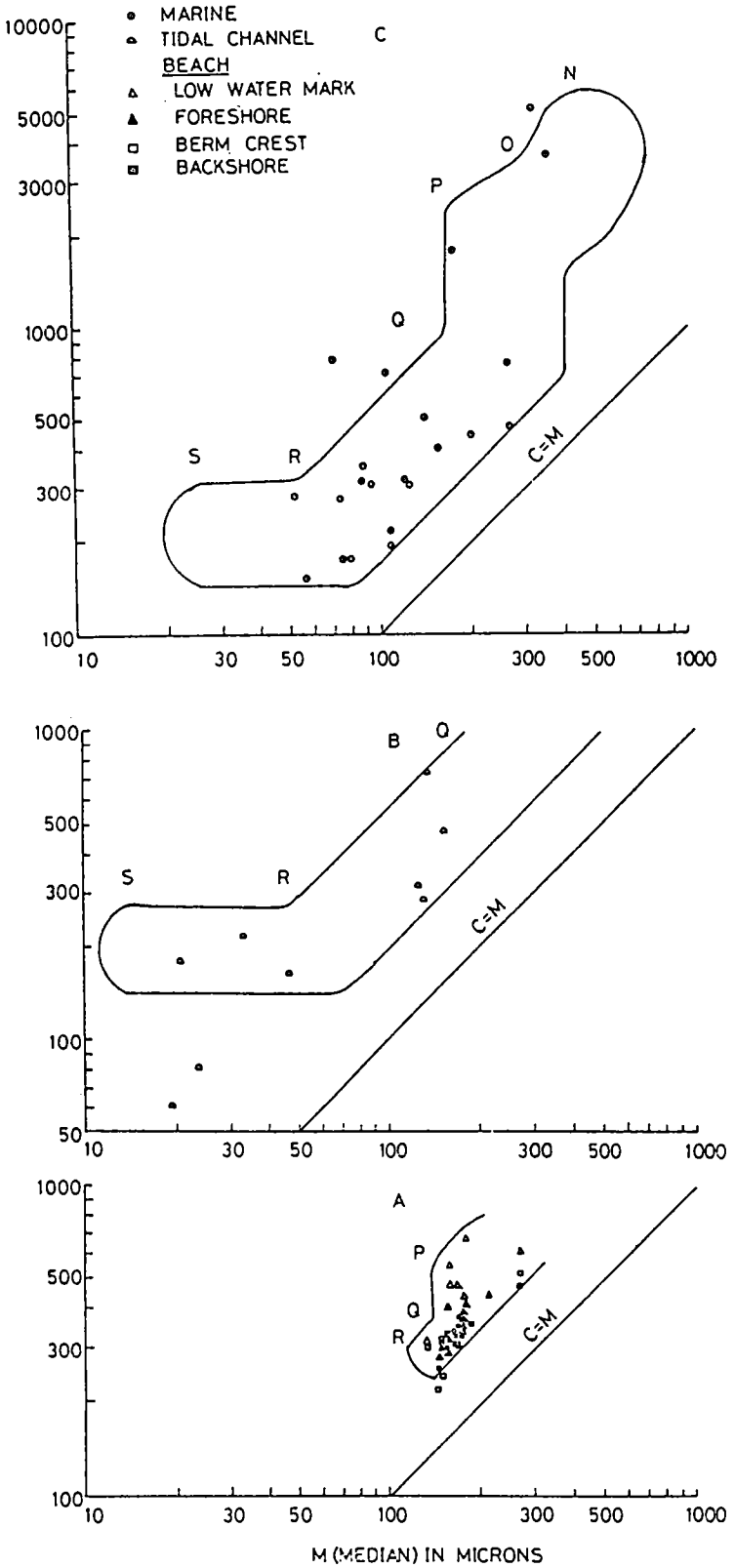


FIG. 24. CM PATTERNS OF (A) BEACH, (B) TIDAL CHANNEL AND (C) MARINE.

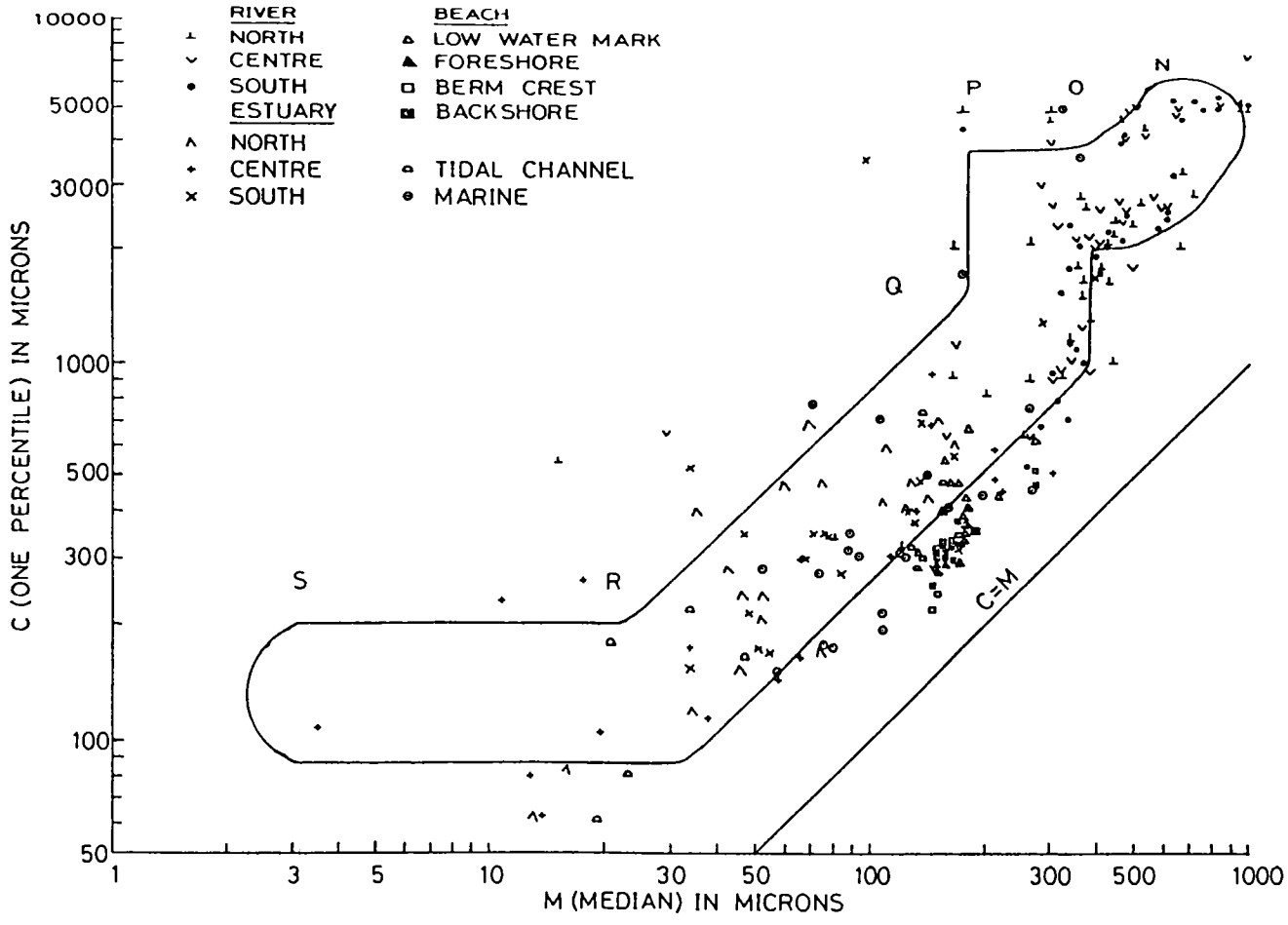


FIG. 25. COMPREHENSIVE CM PATTERNS OF VELLAR RIVER CHANNEL, ESTUARY, BEACH, TIDAL CHANNEL AND MARINE SEDIMENTS.

represented by segment RS, which consists of uniform suspension. Thus the whole pattern of the tidal channel environment appears to be a part of the tractive current. However, the currents are not as strong as the river currents and hence the maximum C and M are only 730 and 155 microns respectively.

NEARSHORE MARINE ENVIRONMENT:

The nearshore marine sediments display all the segments of CM pattern (Fig.24.C). However, most of the samples fall in the QR segment and the remaining segments consist of a few samples only. This may be due to the fact that the samples which were collected from nearshore where the wave action is distinctive, and as a result, the bottom sediment show high percentage of sand. As explained by Passega (1957) in the shallow marine areas, the segment QR is usually fairly long. In the near bottom zone of the current, turbulence is relatively high and the suspension sediments are considerably coarser than those carried by top of the current. Moreover, when sediments of all sizes are available to the tractive current for transportation, the tractive current pattern may be terminated on the coarser side around segment NO and directed toward line C = M. Therefore, this segment probably determines the upper limit of the size that can be transported by traction. The maximum size particles are likely to be bypassed by the remaining load and therefore winnowed and sorted.

FM, LM, AND AM DIAGRAMS:

Along with CM pattern, other plots such as FM, LM, and AM diagram (Figs.26 & 27.) were plotted, in which F, L, and A respectively, are the percentages by weight in the samples of grains finer than 125, 31, and 4 microns. These represent the finest fractions which can provide additional information for characterizing sediments, their transport and deposition in different environments.

In the present study the FM, LM,and AM diagrams of different environments show that the points are a little more scattered than the diagrams of Passega and Byramjee (1969). This may be due to the addition of a certain quantity rolled grains sufficient enough to affect the median. However, accounting Passega and Byramijee (1969), the presence of a small percentage of rolled grains in the deposits does not alter the conclusion drawn from the FM, LM, and AM diagrams. It is clear that the FM diagram which is not very steep at the center, indicates that the sediments are poorly sorted. Moreover, the FM and LM diagrams show almost similar shape but the displacement of LM diagram towards left suggests that the graded suspension is active in these samples. Further, the concave patterns of LM and AM diagrams, which are similar in nature to that of graded suspension diagram explained by Passega and Byramijee (1969), also confirm the above fact. The tidal channel sediments also indicate similar pattern as that of estuarine sediments. However, the nearshore sediments display a steeper FM diagram due to the availability of good sorted

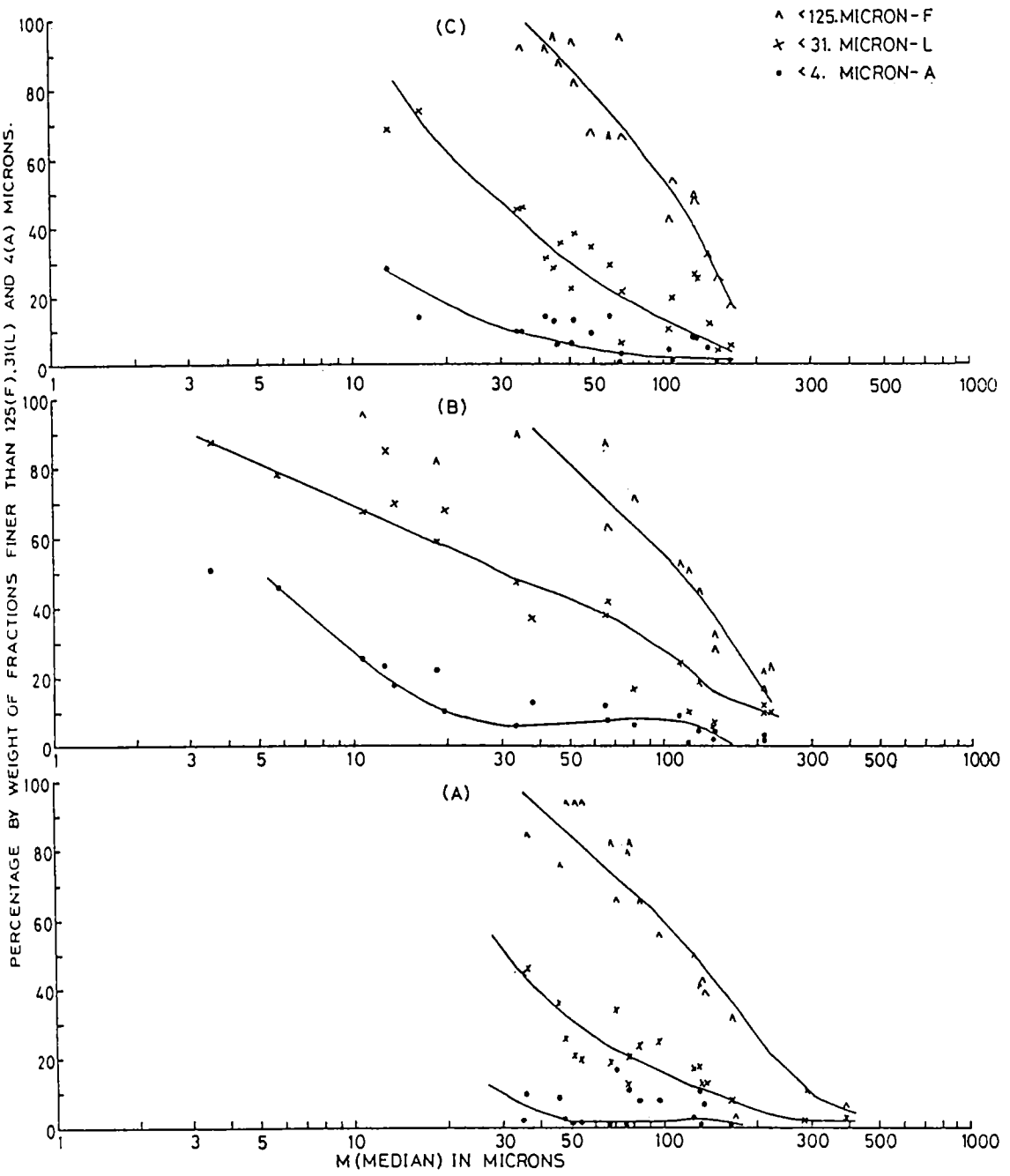


FIG. 26. FM, LM AND AM DIAGRAMS OF (A) SOUTH, (B) CENTRE, (C) NORTH OF ESTUARY.

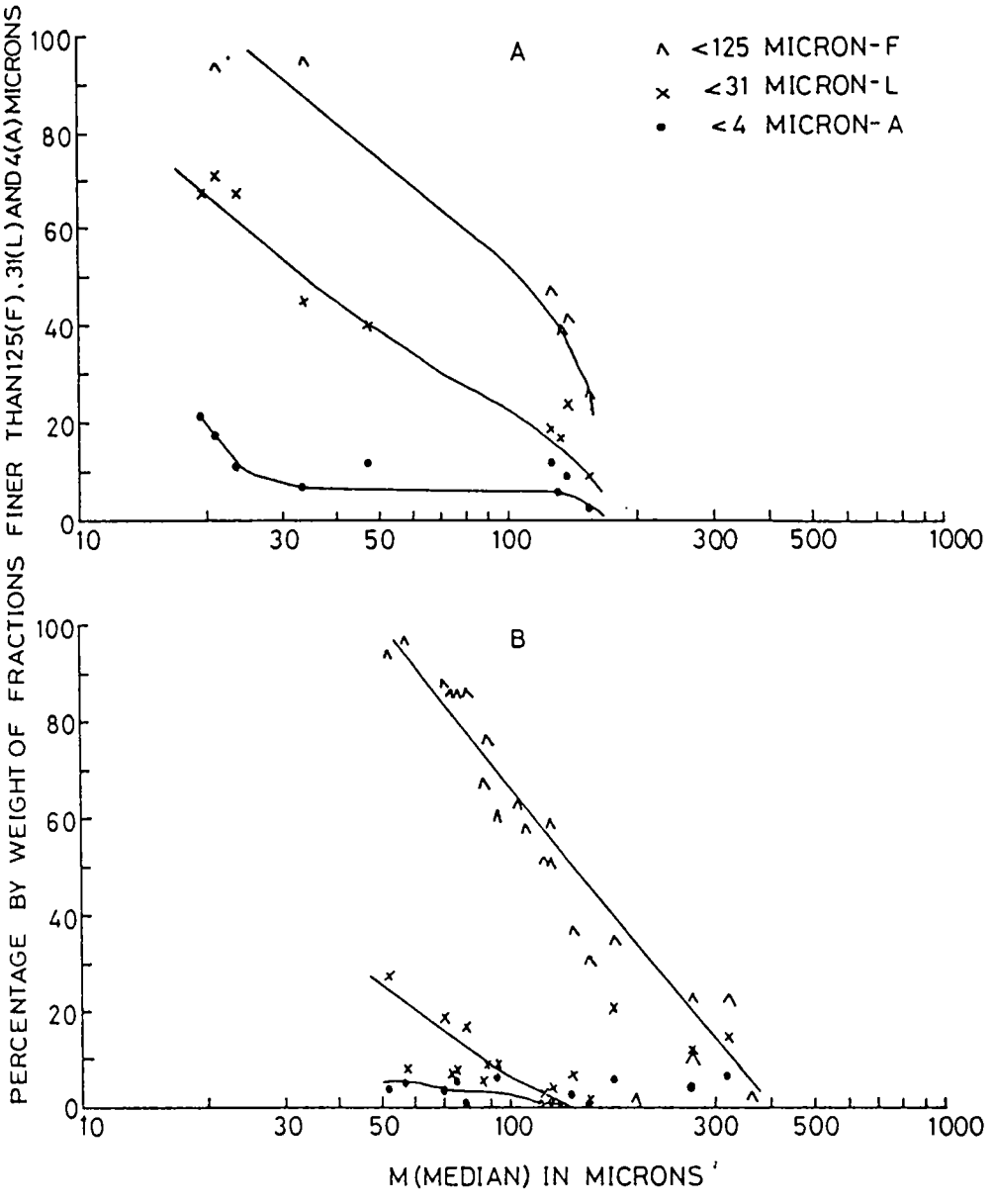


FIG. 27. FM, LM AND AM DIAGRAMS OF (A) TIDAL CHANNEL, AND (B) MARINE.

sediments. But the LM and AM diagrams are similar to those of estuary.

ENVIRONMENTAL IDENTIFICATION:

Roy and Biswas (1975) and Seralathan (1986) attempted to demarcate the various environments through CM diagram. Based on this, in the present study, the sample from all the five environments are plotted together to bring out the relative variation in the mode of transport in the whole of the Vellar river basin and the various environments are identified. It is noted that most environments miss one or more segments from the Passega's tractive current pattern.

Results presented in Fig.25. indicate that the pure sands with or without an admixture of silt and clay fall in the NO - OP - PQ and upper part of QR segments only. This gives the clue that the samples are primarily from the river channel environment while a few nearshore marine samples and some sandy samples of estuary are also present. However, most of the river sands which are considered to be close to source, fall in the highly turbulent environment of the tractive current, NO - OP - PQ segments, only. In the beach, the low water samples which are comparatively coarser than other segments fall in the middle of the QR segments. However, the remaining part of the beach samples fall out of the QR segments but closer to the limt C = M. This proves that the beach samples are of finer grade than the river and nearshore marine samples and

are best sorted than any other environment samples. The middle and lower part of the QR segments mainly consist of estuarine sediments, and few tidal channel and nearshore marine samples. Deposits of this segment were probably in suspension part of the time, and also the coarser grain size produced well sorted sediments. However, the axis of the rectilinear pattern of QR segments located at a considerable distance away from the limitting line, demonstrates the poorly sorted clay and silt dominant deposits. The well sorted fine grade sands fall in the other side of the QR segments, but closer to the limit C=M (some nearshore marine samples also fall in this category). Morover, few estuarine and tidal channel samples fall in the RS segment, which consists of uniform suspension as a consequence of low turbulence that exists in a few estuarine and tidal channels locations.

As explained by Seralathan (1986), it is concluded that, given a set of environments which receive their material from a single source, it is possible to identify their systematic changes with the character of sediments (size, sorting, and environment of depositon) from one environment to the other or from source to sink. In these circumstances the CM pattern could be highly informative.

CHAPTER : III.

MINERALOGICAL COMPOSITION OF THE SEDIMENTS

INTRODUCTION:

Minerals, the natural inorganic substances, have a definite internal atomic structure, and they aggregate to form rocks and sediments. They are classified as rock forming minerals, economic minerals and detrital minerals based on their genesis and importance. The present study mainly deals with detrital minerals. These are normally classified as heavy and light minerals on the basis of their specific gravities. The study of these minerals in the sediments elucidate the nature and character of the source rock and highlight the events that influence the kind and character of sediments from the outside of the sedimentary basin, besides casting more light on the palaeogeography of ancient time. The mineralogical analysis of both the light and heavy detrital fraction of the sediments is of great value in unravelling the complex erosional history of a sediment source and shifts in drainage pattern. Studies on the light minerals are most useful when the source area consists mainly of either sedimentary or low rank metamorphic rocks, as in the case of earliest stage of uplift and erosion during the formation of a mountain range. Heavy mineral studies, on the other hand, are most helpful when erosion has proceeded to deeper metamorphic and igneous rocks. Based on this method, some times, both the erosional and tectonic history of the

surrounding land mass and the depositional history of the basin have been worked out simultaneously (Van Andel, 1958).

The modification of mineralogical assemblages in the basin is primarily governed by four main factors: 1) weathering in the source area and in the depositional basin, 2) mechanical destruction during transportation, 3) selective sorting of mineral according to size and density, and 4) chemical destruction after deposition (Van Andel, 1959). The importance of modification of the heavy mineral assemblage by weathering has been discussed and emphasised by many authors (Weyl,1949; 1952; Van Andel and Postma, 1954; Pettijohn, 1957; Van Andel, 1959). These studies emphasize the fact that heavy minerals can indeed be selectively eliminated by weathering. The second factor, which could modify the compostion of heavy mineral assemblages is selective mechanical destruction during transportation (Cozzens, 1931; Friese, 1931; Theil, 1940; Pettijohn, 1957; Van Andel, 1957; Kuenen, 1959, 1960a, 1960b). Studies on this factor conclude that the selective mechanical destruction during transportation required very large time and energy to accumulate heavy minerals. The composition of the heavy mineral assemblages of sediment can be modified by sorting according to density and size during transportation and deposition (Rubey, 1933; Rittenhouse, 1943; Van Andel, 1958; Poole, 1958; Van Andel, 1959). The high density zircon,

rutile minerals are always abundant in fine size sediments while pyroxenes and hornblende occupy the coarse sediments. These variations mainly depend on the size and density of the minerals. The fourth factor is the post-depositional destruction of minerals due to the intrastratal solution. This factor was extensively studied by Pettijohn (1941, 1957). Van Andel (1959) suggests that the intrstratal solution plays a minor role in the alteration of mineral assemblages. This alteration appears to be a surface rather than a subsurface effect.

A number of major river systems have been studied indetail, worldwide, for their heavy mineral variation downstream. In India, detailed studies on heavy mineral variation were restricted to a few major river system which include, Godavari (Naidu, 1968), Krishna (Seetaramaswamy, 1970), Mahanadi (Satyanarayana, 1973), Vasishta-Godavari (Dora, 1979), and Cauvery (Seralathan, 1979). Unlike the studies concerning river systems, extensive work has been carried out on the heavy mineral variation in beach and marine environments. These studies reveal that the concentration of heavy minerals are higher along the Kerala Coast than the other part of Indian coast (Tipper, 1914; Brown and Dey, 1955). Similar type of deposits with varying composition of minerals were also identified in Ratanagiri, Maharashtra coast (Krishnan and Roy, 1945; Roy, 1958), Tinnaveli, Ramnad and Tanjore, Tamilnadu (Jacob, 1956); Visakhapatnam, Yarda, Waltair and Bhiminipatnam, Andhra (Mahadevan and Rao, 1958; Borreswara

Rao and La Fond, 1958) and the coastal areas of Orissa (Officers, 1949). In the offshore regions, the richest deposits were along the coast of Neendakara to Kayamkulam in Kerala (Prabhakar Rao, 1968). High concentration of placer deposit were identified along the Konkan coast (Mane and Gowade, 1954; Siddiquie et al, 1979; and Siddique et al, 1982). In the east coast, heavy mineral variation in the delta and shelf sediments between Vishakapatnam and the Penner river was reported by Mallik (1968). Extensive studies on the offshore heavy mineral variation are fewer for the east coast as compared to those for the west coast.

The minerals less than two micron size, classified as clay (clay minerals), have plate like crystals with layered lattice structures showing high ion exchange capacity. Owing to this property, clay minerals have an important role in the nature of sedimentation, chemistry, and deposition of sediments. This simplified ion exchange process is complicated by various factors like, quality and type of cations present in solution, pH, Eh, type of the clay mineral, size, etc.. This process further gets intricated when river born clay comes into contact with estuarine waters. Number of authors have studied different aspects of clay minerals in different localities (Grim, 1953; Nelson, 1958; Powers, 1959; Rolfe et al, 1960; Weaver, 1960; Whitehouse et al., 1960; Hirst, 1962a; Biscaye, 1964; Parham, 1964). In the western continental shelf of India, nearshore sediments show higher amounts of kaolinite and

gibbsite while in the offshore, montmorillonite is predominant. This variation is attributed by size seggregation of minerals (Nair et al., 1982; Purnachandra Rao et al., 1983). A major quantity of illite and quartz with a minor amount of montmorillonite, kaolinite and feldspar were observed in the north western part of the Bay of Bengal. This variation is attributed to the high rate of sedimentation from Ganges-Brahmaputra river system (Ramamurthy and Shrivastava, 1979). The studies on clay minerals from Visakhapatnam to Ganges emphasize that the sediments which are derived from Ganges do not reach the shelf off the pennisular rivers (Rao et al., 1988). The Chilka lake sediments display a high amount of Montmorillonite consequent to the enormous supply of weathered product by Mahanadi river (Venkatrathnam and Rao, 1970). The Cauvery deltaic sediments also exhibit montmorillonite as a dominont mineral. In the marine facies, the clay minerals like kaolinite and illite are abundant in nearshore while they decrease outershelf. These variance are manifested by the differential flocculation and / or size seggregation (Seralathan and Seetaramaswamy, 1982).

The available literature demonstrates the paramount importance of the mineralogical studies of the detrital constituents of the sediments in elucidating the depostional history of a sedimentary basin and their source. Hence, the present study aims at studying the mineralogical

composition of the Vellar river, estuarine, and their beach, and nearshore marine sediments.

METHODS OF STUDY :

In all 241 samples were collected from the study area of which 100 samples were selected for the heavy mineral studies. In the river and estuarine environments samples from the central part of the channel were considerd for the study. Along the beach, stations were fixed at an interval of 1 km on either side of the Vellar estuary, covering a total distance of 11 km and four samples from each station corresponding to the backshore, berm, forshore, and low water line were considered. In the nearshore environment all the samples were selected for the study. Heavy minerals of different size grades (500-250, 250-125, 125-62 microns) of sand were separated employing the bromoform technique (Krumbein and Pettijohn, 1938) and were weighed. Later, the heavy minerals were cleaned with dilute HCl (10 %) and stannous chloride to remove carbonate and iron oxide coating. Representative amounts of the heavy residues of each of the three size grades were taken for slide preparations after coning and quartering. The grains were mounted on a glass slide in canada balsam. Petrographic analyses consisting of identification and point counting of heavy mineral grains were carried out along random line traverses. One hundred heavy mineral grains were point-counted in order to determine the opaque - translucent ratios. An additional 200 translucent heavy

mineral grains were counted to estimate the abundance of pyroxene, hornblende, garnet, epidote, zircon, rutile, kyanite, micas, etc. All point counts were performed by the same operator. A few representative samples were studied under the ore microscope to identify the opaque constituents. Different parameters like amphibole / garnet ratio, shape index and density index were calculated as described by Rittenhouse (1943), Flores and Schideler (1977).

In light mineral study, the quartz and various feldspar contents were calculated. For identifying the different types of feldspars, staining method was adapted. Hayes and Klugman (1959) staining method was followed in the present study. In this method, the light fraction was first mounted on a glass slide with cannada balsam and etching was carried out using hydrofluric acid fumes. The etched grains were subsequently treated with concentrated solution of cobaltinitrite for two minutes. Then the rinsed and dried grains were treated with 0.5 % eosine B, which subsequently stains the soda lime feldspars with pink and potash feldspars with orange-yellow colours respectively. Quartz remains unaffected. About 300 to 400 grains were identified and point - counted. The number percentages of quartz and feldspars were estimated and the quartz / feldspars ratios calculated.

Eighteen representative sediment samples were selected from the river, estuarine, tidal channel, and

nearshore environments for clay mineral study. Salts were freed from samples by repeatedly washing with distilled water. Once the natural suspension was attained, the clay fraction (<2 micron) was decanted from stable sediment suspension. The organic matter and carbonates were removed by treating with hydrogen peroxide and dilute acetic acid. Then, the clay were mounted on glass slides as oriented aggregates by smear technique (Carroll, 1969). The clays were air dried, glycolated and analysed by Philips X-ray diffractometer, using Ni-filter and Cu K alpha radiation.

Based on the procedure given by Biscaye (1964, 1965) the identification and quantification of clay minerals were carried out. The peaks (after glycolation) and weighing factors used were 17 Å peak area for montmorillonite, 4 times the 10 Å for illite and 2 times the 7 Å peak area for kaolinite respectively.

HEAVY MINERALS:

DESCRIPTION OF THE HEAVY MINERALS :

The salient features of the various heavy minerals observed in the present study are given below.

PYROXENES:

Hypersthene formed the abundant variety in this class of minerals. Mostly the grains are prismatic or tabular. They exhibit pleochroism, varying from blu ish brown to reddish brown and also from pink to green. Few augite grains with prismatic faces are also present.

HORNBLENDE:

Hornblende is the most abundant heavy mineral. There are two types, a blue green variety and a brownish green variety. Of the two types, the blue green variety is more abundant. The grains are prismatic and elongated.

GARENTS:

Generally, the garnet grains are angular, subangular and subrounded. There are two varieties, colourless to pale pink and pink. Colourless to light pink garnets are predominant followed by pink garnets. Some grains show inclusions.

OPAQUES:

Opaque mineral grains constitute a good proportion in the finest fractions and are mostly rounded or subrounded. The opaques consist of magnetite, ilmenite and chromite.

ZIRCON:

Zircon grains are prismatic with pyramidal termination and subrounded characters. Grains are colourless. Zoning is often observed. The refractive index is fairly high.

EPIDOTE:

Epidotes are subangular to subrounded grains. They show fairly high relief and faint pleochroism. They are yellowish green in colour and most of the grains exhibit high order interference colours.

KYANITE:

Kyanite grains are usually elongated with angular to subangular shape. Conspicuous cross cleavages in the grain account for the steplike appearence. The grains are generally colourless and show oblique extinction.

MONAZITE:

Monazite occurs as rounded grains with light yellow colour. Their high refractive index results in dark boundary around the grains. A few grains are faintly pleochroic.

RUTILE:

Most of the grains of this mineral are prismatic with pyramidal terminations. Grains exhibit blood red colour with high refractive index and are characterized by straight extinction.

SILLIMANITE:

These grains are short, prismatic to irregular and colourless. They show good relief and straight extinction.

BIOTITE:

It occurs mostly as prismatic flakes with honey-brown colour.

ALTERED MINERALS:

The minerals that show high degree of alteration are classified in this catagory. The shape and colour of most of the altered minerals suggest that they are either hypersthene or hornblende.

RESULTS:

The total heavy mineral percentages and individual mineral percentages in the three size grades are shown in Tables.5 & 6. It is evident from these tables that weight percentages of heavy minerals are high in the fine size grade compared to other grades, irrespective of the type of samples. Results presented in Fig. 28 indicate that weight percentages of heavy minerals, in each of the three size grades, decrease downstream.

The total heavy mineral variation in beach samples with distance is presented in Table.7 & Fig. 29. The study reveals that the amount of heavy minerals in sediments of the foreshore, berm crest, and backshore areas are comparatively higher than those in the sediments of the low water mark (LWM) area, particularly in the median and fine size grades. From Fig. 29, it is inferred that the heavy mineral content, in all the fractions, are relatively high in station 6 on the northern side of the Vellar mouth, as compared to those in stations on the southern side. Similar type of changes are also noticed in the southern part of the beach near the northern side of the tidal channel mouth (station No.2). The LWM and bermcrest show an overall increase of heavy mineral percentages towards northern side. In the backshore, it decreases slightly while in the foreshore it indicates a prominent decreasing trend towards north. In the nearshore sediments,

TABLE: 5. WEIGHT PERCENTAGES OF HEAVY MINERALS IN VELLAR RIVER, ESTUARY AND NEARSHORE SEDIMENTS

DIST. km	SAMPLE NO	MESH SIZE	%
VELLAR RIVER			
0	2	>60	6.60
		>120	19.00
		>230	84.14
5	5	>60	9.26
		>120	39.98
		>230	46.03
10	8	>60	11.03
		>120	57.04
		>230	86.04
15	11	>60	19.35
		>120	56.93
		>230	65.07
20	14	>60	7.65
		>120	31.63
		>230	75.20
25	17	>60	12.30
		>120	36.46
		>230	90.74
30	20	>60	11.03
		>120	34.69
		>230	53.74
35	23	>60	7.07
		>120	22.53
		>230	79.01
40	26	>60	6.81
		>120	21.72
		>230	66.85
45	29	>60	11.11
		>120	34.36
		>230	72.44
50	32	>60	10.14
		>120	27.35
		>230	73.05
55	35	>60	5.60
		>120	26.80
		>230	74.90
60	38	>60	21.98
		>120	71.51
		>230	94.78
65	41	>60	5.70
		>120	10.51
		>230	56.87
70	44	>60	7.45
		>120	21.04
		>230	85.22
75	47	>60	1.94
		>120	9.95
		>230	36.97
80	50	>60	4.57
		>120	15.08
		>230	84.71
85	53	>60	2.84
		>120	30.71
		>230	70.52
90	56	>60	2.72
		>120	12.33
		>230	91.25
95	59	>60	1.92
		>120	8.82
		>230	72.26
100	62	>60	1.89
		>120	8.09
		>230	78.37
103	71	>60	1.47
		>120	10.88
		>230	24.76
ESTUARY			
106	83	>60	1.28
		>120	7.16
		>230	21.20
107	89	>60	1.83
		>120	11.55
		>230	25.05
108	95	>60	N.A
		>120	10.05
		>230	6.58
109	101	>60	1.68
		>120	15.36
		>230	13.05
111	113	>60	N.A
		>120	16.11
		>230	41.76
112	119	>60	N.A
		>120	28.61
		>230	59.01
115	137	>60	N.A
		>120	2.97
		>230	7.78
MANIMUKTA NADI			
0	140	>60	12.19
		>120	39.58
		>230	59.73
5	143	>60	3.92
		>120	24.03
		>230	35.38
10	146	>60	4.68
		>120	22.98
		>230	49.67
15	149	>60	7.45
		>120	22.85
		>230	52.68
20	152	>60	4.08
		>120	12.06
		>230	69.53
CHINNAR RIVER			
0	155	>60	4.60
		>120	12.20
		>230	25.58
5	158	>60	4.67
		>120	8.31
		>230	4.16
10	161	>60	5.38
		>120	40.99
		>230	87.04
NEARSHORE			
0	172	>60	0.62
		>120	7.34
		>230	15.77
	173	>60	0.26
		>120	10.45
		>230	12.42
1	175	>60	N.A
		>120	1.89
		>230	13.65
	174	>60	0.61
		>120	3.86
		>230	14.57
2	176	>60	N.A
		>120	1.39
		>230	8.03
	177	>60	N.A
		>120	2.46
		>230	1.06
3	178	>60	N.A
		>120	N.A
		>230	1.00
179		>60	N.A
		>120	1.55
		>230	2.70
4	180	>60	N.A
		>120	3.74
		>230	6.85
181		>60	N.A
		>120	1.97
		>230	3.48
5	182	>60	2.18
		>120	7.08
		>230	8.11
183		>60	1.51
		>120	9.13
		>230	53.69
6	184	>60	N.A
		>120	5.13
		>230	23.49
185		>60	1.35
		>120	6.05
		>230	32.92
7	186	>60	N.A
		>120	2.90
		>230	5.45
187		>60	N.A
		>120	4.61
		>230	11.80
8	188	>60	N.A
		>120	N.A
		>230	4.51
189		>60	N.A
		>120	6.56
		>230	7.94
9	190	>60	N.A
		>120	9.54
		>230	26.08
191		>60	N.A
		>120	6.37
		>230	18.87
10	192	>60	8.72
		>120	9.81
		>230	32.53
193		>60	1.22
		>120	5.45
		>230	15.43

TABLE: 6. NUMBER PERCENTAGES OF HEAVY MINERALS IN THE THREE SIZE GRADES OF VELLAR RIVER, ESTUARY AND NEARSHORE SEDIMENTS.

>60 - 0.5 to 0.25 mm, >120 - 0.25 to 0.125 mm, >230 - 0.125 to 0.062 mm.

PY-PYROXENE. BRGHB-BROWN GREEN HORNBLENDE. SI-SILLIMANITE. RU-RUTILE.
OP-OPAQUES. BLGHB-BLUE GREEN HORNBLENDE. EP-EPDOTE. AG-ALTERED MINERALS.
MO-MONOZITE. CGA-COLOURLESS GARNET. BI-BIOTITE.
ZI-ZIRCON. PGA-PINK GARNET. KY-KYANITE.
* - NOT AVAILABLE

DIST. km	SAMPLE NO	MESH SIZE	PY	BRGHB	BLGHB	CGA	PGA	OP	SI	MO	ZI	EP	BI	KY	RU	AG
	VELLAR RIVER															
0	2	>60	1.86	2.79	76.78	15.17	2.79	0.62	*	*	*	*	*	*	*	*
		>120	5.34	11.52	42.98	26.12	3.93	9.27	0.56	*	*	*	*	*	*	0.28
		>230	4.57	2.42	9.14	29.57	1.61	51.34	0.27	0.54	0.54	*	*	*	*	0.28
5	5	>60	4.51	4.20	69.37	17.12	3.30	1.20	*	*	*	*	*	*	0.30	*
		>120	5.02	5.02	25.07	32.45	6.49	25.66	*	*	*	*	*	0.30	*	*
		>230	2.45	2.45	17.79	20.55	0.92	54.60	0.61	*	0.31	*	0.31	*	*	*
10	8	>60	1.34	4.01	63.37	23.80	6.15	1.34	*	*	*	*	*	*	*	*
		>120	3.10	6.67	17.86	36.90	4.52	30.24	*	*	*	*	*	0.48	*	0.24
		>230	2.54	1.85	4.85	25.87	3.23	60.28	0.23	0.23	*	*	*	*	*	0.92
15	11	>60	0.58	2.92	63.27	27.99	4.96	*	*	*	*	*	*	*	0.29	*
		>120	4.13	3.49	15.24	36.19	5.71	33.33	0.64	*	0.64	*	*	*	*	0.64
		>230	3.04	5.17	9.73	23.71	1.82	53.19	0.91	*	1.82	*	*	*	*	0.61
20	14	>60.	2.49	7.48	71.07	15.21	3.24	*	*	*	*	*	*	*	*	0.50
		>120	3.39	5.37	28.53	33.90	3.96	23.16	0.28	*	*	*	0.28	0.28	*	0.85
		>230	*	3.34	8.34	26.25	2.39	58.71	0.24	0.48	*	*	*	*	*	0.24
25	17	>60	3.57	8.57	54.64	23.93	7.14	2.14	*	*	*	*	*	*	*	*
		>120	6.43	7.90	23.98	30.12	5.85	24.85	0.29	0.29	*	*	*	0.29	*	*
		>230	0.89	1.48	7.97	23.30	2.36	62.83	0.30	*	0.59	*	*	0.30	*	*
30	20	>60	1.65	9.67	59.20	18.63	8.26	1.89	0.47	*	*	*	*	*	*	0.24
		>120	4.02	7.51	19.57	28.95	12.33	25.73	1.34	*	*	*	*	*	*	0.54
		>230	3.77	6.78	20.35	24.12	2.01	40.96	0.50	*	0.75	*	*	0.25	*	0.50
35	23	>60	4.66	8.49	65.75	13.15	7.40	*	0.27	*	*	*	*	*	0.27	*
		>120	5.18	8.03	29.02	24.87	8.55	21.50	0.26	0.26	*	0.52	*	0.26	*	1.55
		>230	1.21	5.83	17.48	23.30	4.61	45.15	0.49	0.73	0.24	*	*	*	0.24	0.73
40	26	>60	3.34	8.21	59.88	15.50	10.33	2.13	*	*	*	0.61	*	*	*	*
		>120	4.94	6.11	35.76	27.04	9.01	15.99	0.29	*	*	*	*	0.87	*	*
		>230	1.67	3.90	22.01	21.45	1.39	46.52	0.56	0.56	0.28	*	*	*	*	1.67
45	29	>60	1.64	4.37	45.36	26.23	14.48	7.10	0.27	*	*	*	*	*	*	0.55
		>120	2.80	4.40	21.80	27.80	8.40	33.00	0.40	0.60	*	0.20	*	0.20	0.20	0.20
		>230	1.84	1.53	11.32	20.49	3.67	58.72	0.92	0.61	0.61	*	*	*	0.31	*
50	32	>60	3.10	6.20	50.99	17.47	18.03	3.94	0.28	*	*	*	*	*	*	*
		>120	4.96	6.31	25.68	25.45	7.66	28.38	*	*	*	0.22	*	*	0.22	1.13
		>230	2.28	0.76	10.38	28.35	1.01	54.43	1.27	0.25	0.51	*	*	*	*	0.76
55	35	>60	2.28	5.82	63.29	17.22	10.13	0.76	*	0.25	*	*	*	*	*	0.25
		>120	5.02	3.43	25.34	29.45	8.68	26.26	0.69	0.23	*	*	*	*	0.23	0.69
		>230	2.36	3.54	14.62	24.76	4.48	49.06	0.24	0.24	0.47	*	*	*	*	0.24

TABLE: 6. (CONT.)

DIST. km	SAMPLE NO	MESH SIZE	PY	BRGHB	BLGHB	CGA	PGA	OP	SI	MO	ZI	EP	BI	KY	RU	AG
60	38	>60	1.09	5.00	40.22	36.30	12.17	5.22	*	*	*	*	*	*	*	*
		>120	1.50	1.75	5.26	25.56	11.78	52.88	0.25	*	0.75	*	*	*	0.25	*
		>230	0.53	0.53	4.49	18.47	0.79	71.77	0.26	1.85	0.79	*	*	*	0.26	0.26
65	41	>60	3.65	7.79	65.45	16.30	4.87	1.95	*	*	*	*	*	*	*	*
		>120	5.58	7.65	52.48	17.98	3.72	11.16	0.41	*	*	*	*	0.21	*	0.83
		>230	2.11	3.61	23.19	24.40	0.90	45.18	*	*	0.60	*	*	*	*	*
70	44	>60	0.96	4.33	66.83	20.67	5.77	0.96	0.24	*	*	*	*	*	*	0.24
		>120	4.38	7.14	35.71	27.42	5.30	18.89		0.69	*	*	*	*	*	0.46
		>230	2.04	2.62	13.12	17.78	2.04	60.64	*	0.29	0.29	*	*	*	0.58	0.58
75	47	>60	3.33	6.65	76.72	7.36	4.28	0.48	0.24	*	*	*	*	*	*	0.95
		>120	6.82	9.18	50.12	17.41	6.35	7.77	0.24	0.71	*	*	*	*	*	1.41
		>230	4.62	8.21	28.72	26.41	1.03	28.97	0.77	0.26	*	*	*	*	*	1.03
80	50	>60	2.28	5.32	60.76	16.46	10.89	2.03	*	0.25	*	*	*	*	0.51	1.52
		>120	3.97	8.53	33.14	26.98	9.72	16.67	0.20	0.20	*	*	*	*	*	0.60
		>230	1.24	5.69	5.45	28.22	2.23	55.20	0.74	0.74	0.25	*	*	0.25	*	*
85	53	>60	1.74	5.97	70.90	11.94	6.22	1.24	*	*	*	0.25	*	*	*	1.74
		>120	5.98	2.99	18.48	28.53	7.07	34.24	*	0.54	*	*	*	*	*	2.17
		>230	1.99	5.22	8.21	22.89	3.98	54.73	*	0.75	0.75	*	*	*	*	1.49
90	56	>60	2.60	5.73	55.73	22.14	9.64	3.13	0.26	*	*	*	0.26	*	*	0.52
		>120	6.35	7.87	35.53	28.43	7.87	11.42	0.51	0.51	*	*	*	0.25	*	1.27
		>230	2.43	3.24	3.77	26.69	4.31	55.80	0.27	1.62	*	*	*	*	0.54	1.35
95	59	>60	4.63	5.85	68.29	5.61	3.80	4.63	*	*	*	*	5.37	*	*	1.71
		>120	9.28	6.89	49.10	20.06	5.39	5.39	0.30	0.60	*	0.30	*	*	*	2.70
		>230	3.99	5.54	10.42	29.93	4.21	44.12	0.22	0.22	*	0.22	*	*	*	1.11
100	62	>60	4.87	3.75	70.41	6.74	8.24	0.38	2.25	0.38	*	0.75	1.87	*	*	0.38
		>120	8.15	7.30	44.66	19.94	5.34	8.43	*	0.56	0.28	*	*	0.28	*	5.06
		>230	2.80	3.50	10.72	25.41	6.06	48.95	0.47	1.17	0.47	*	*	*	0.23	0.23
103	71	>60	4.10	6.15	71.75	7.29	5.01	1.14	0.91	*	*	0.23	*	*	*	3.42
		>120	5.56	9.28	41.99	25.46	6.58	9.11	0.84	*	*	*	*	0.51	*	0.68
		>230	4.74	5.69	16.83	28.44	3.32	36.02	0.95	0.71	0.71	0.24	0.95	*	0.47	0.95
	ESTUARY															
106	83	>60	2.80	4.90	77.62	6.99	4.90	0.70	1.05	*	*	*	*	1.05	*	*
		>120	3.17	2.59	51.87	18.16	4.32	16.72	0.58	*	*	0.58	1.73	0.29	*	*
		>230	5.04	5.88	44.82	24.09	3.92	13.73	0.84	0.28	0.28	*	0.56	*	*	0.56
107	89	>60	3.88	3.28	82.99	7.46	1.79	0.30	0.30	*	*	*	*	*	*	*
		>120	5.26	2.63	43.95	20.00	9.21	18.42	0.26	*	*	0.26	*	*	*	*
		>230	5.19	2.47	38.77	22.22	2.47	26.67	0.25	0.49	0.49	0.25	0.25	0.25	*	0.25
108	95	>60	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>120	5.39	4.10	61.42	8.84	1.08	12.72	1.51	0.86	*	1.08	1.94	0.86	*	0.22
		>230	2.79	3.79	45.31	18.76	3.59	20.36	1.60	0.20	*	1.60	0.60	1.20	*	0.20
109	101	>60	3.11	8.37	76.32	6.46	4.31	0.48	0.48	*	*	0.48	*	*	*	*
		>120	6.63	2.71	42.47	24.70	7.23	14.16	1.51	*	*	0.30	*	*	*	0.30
		>230	3.36	4.93	70.63	8.30	0.45	9.42	1.57	*	*	1.12	*	0.22	*	*

TABLE: 6. (CONT.)

DIST. km	SAMPLE NO	MESH SIZE	PY	BRGHB	BLGHB	CGA	PGA	OP	SI	MO	ZI	EP	BI	KY	RU	AG
111	113	>60	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>120	7.99	6.15	51.84	22.75	4.30	3.69	1.43	*	0.21	0.62	*	0.82	*	0.21
		>230	2.70	2.10	19.76	27.84	2.99	41.62	0.60	0.30	0.60	0.90	*	0.30	*	0.30
112	119	>60	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>120	4.40	4.20	21.20	36.60	8.60	22.00	1.60	0.40	0.40	*	*	0.60	*	*
		>230	1.64	1.85	14.99	28.13	4.93	44.35	1.64	*	0.62	1.64	0.21	0.41	*	*
115	137	>60	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>120	4.70	2.69	70.25	7.83	3.36	3.13	2.01	*	*	1.34	3.13	0.67	*	0.90
		>230	4.96	4.96	53.53	13.06	1.31	15.93	2.61	*	0.26	1.04	0.78	1.04	*	0.52
	MANIMUKTA NADI															
0	140	>60	1.70	3.39	51.13	23.73	4.52	15.25	0.28	*	*	*	*	*	*	*
		>120	3.30	6.31	19.82	22.52	1.80	45.35	*	*	*	*	*	*	0.30	0.60
		>230	0.57	0.86	9.46	14.33	0.29	71.92	*	0.57	0.86	*	*	*	0.29	0.86
5	143	>60	1.74	8.46	73.13	10.45	3.23	2.99	*	*	*	*	*	*	*	*
		>120	6.11	8.61	46.39	21.67	3.61	13.61	*	*	*	*	*	*	*	*
		>230	1.64	3.28	28.69	22.13	0.27	42.35	0.27	0.27	0.27	*	*	0.27	*	0.55
10	146	>60	1.79	6.85	80.06	7.74	1.79	1.19	0.60	*	*	*	*	*	*	*
		>120	5.94	4.46	32.92	25.00	5.94	24.75	*	*	0.50	*	*	*	*	0.50
		>230	1.62	1.89	26.15	25.61	1.08	42.05	*	*	0.81	*	*	*	*	0.81
15	149	>60	1.48	5.02	64.31	20.65	2.66	5.90	*	*	*	*	*	*	*	*
		>120	2.86	4.76	28.89	25.40	2.22	35.56		*	0.32	*	*	*	*	*
		>230	0.84	0.84	16.29	17.70	0.84	62.36	*	0.28	0.28	*	*	*	0.28	0.28
20	152	>60	1.02	4.57	77.41	12.18	3.55	1.27	*	*	*	*	*	*	*	*
		>120	5.03	5.03	48.15	19.58	1.32	19.05	1.06	*	*	*	*	*	*	0.79
		>230	3.52	2.82	18.31	19.95	1.41	51.64	1.17	0.24	*	*	*	0.47	*	0.47
	CHINNAR RIVER															
0	155	>60	2.76	5.76	65.92	6.52	19.05	*	*	*	*	*	*	*	*	*
		>120	4.33	8.41	55.53	15.14	13.46	2.40	0.24	*	*	*	*	0.24	*	0.24
		>230	1.51	4.82	32.53	32.23	10.84	17.77	*	0.30	*	*	*	*	*	*
5	158	>60	1.33	3.97	65.12	8.61	20.97	*	*	*	*	*	*	*	*	*
		>120	5.41	7.22	63.40	6.70	14.18	2.58	0.52	*	*	*	*	*	*	*
		>230	2.59	1.72	33.33	28.45	9.77	22.70	0.29	0.29	0.29	*	*	0.29	*	0.29
10	161	>60	1.26	3.37	52.00	12.63	30.32	*	0.21	*	*	*	*	*	0.21	*
		>120	3.53	4.62	20.65	26.36	23.10	21.47	*	*	*	*	*	*	0.27	*
		>230	0.51	0.77	3.86	19.28	13.11	61.70	*	*	0.77	*	*	*	*	*
	NEARSHORE															
0	172	>60	1.28	1.28	68.59	3.85	8.33	12.18	1.92	*	*	1.92	*	0.64	*	*
		>120	1.54	0.77	8.95	5.88	1.54	76.73	0.77	0.51	0.26	3.07	*	*	*	*
		>230	0.72	3.60	16.31	4.32	0.72	67.15	2.16	0.24	2.64	1.68	*	0.48	*	*

TABLE: 6. (CONT.)

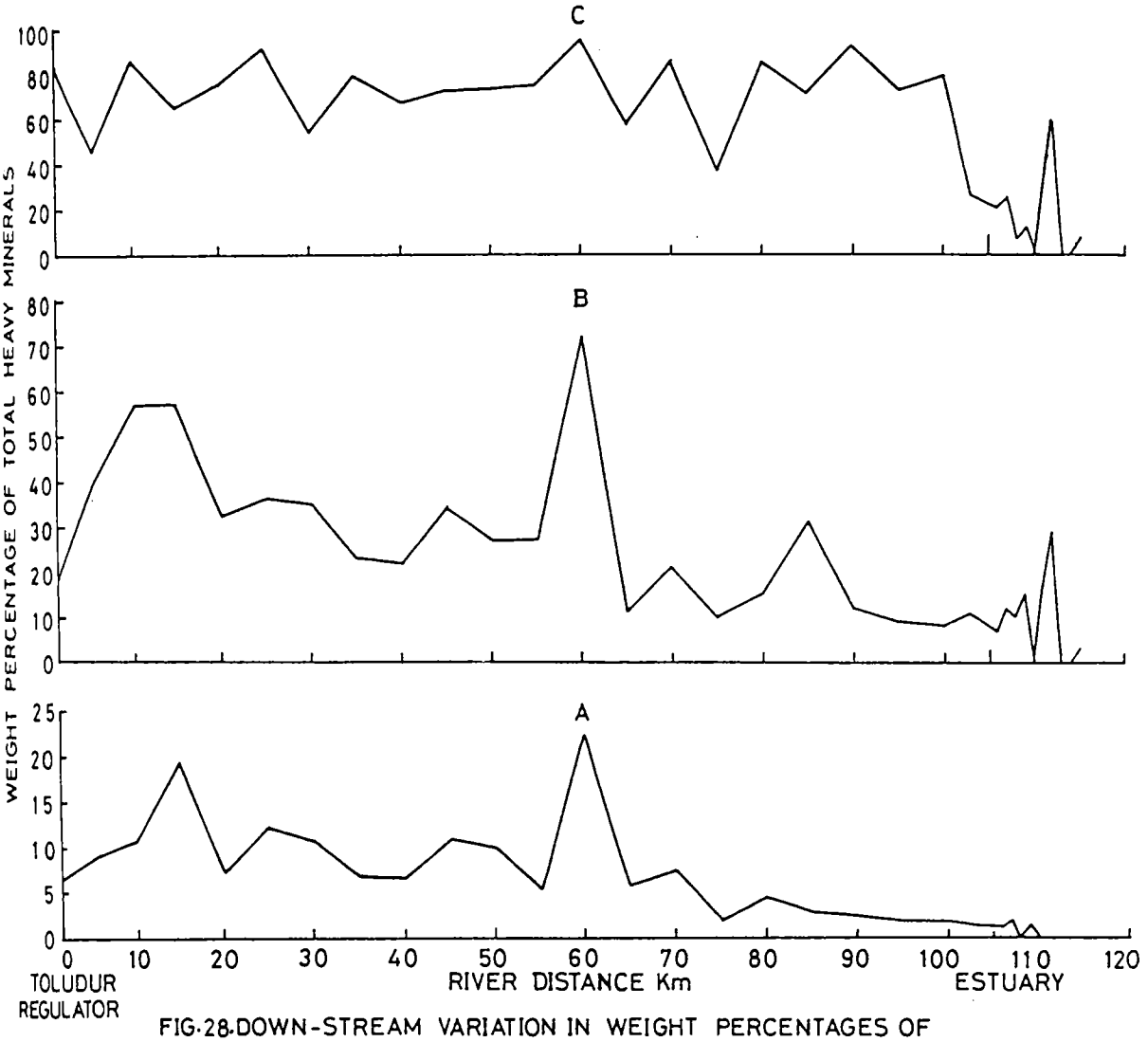
DIST. km	SAMPLE NO	MESH SIZE	PY	BRGHB	BLGHB	CGA	PGA	OP	SI	MO	ZI	EP	BI	KY	RU	AG
	173	>60	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>120	0.51	2.05	15.09	3.84	1.79	70.08	1.79	0.26	0.26	3.33	*	0.26	*	0.77
		>230	4.72	4.72	50.39	5.77	1.05	26.77	3.68	*	0.53	0.79	*	0.79	*	0.79
1	175	>60	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>120	3.74	2.10	69.63	2.57	0.94	9.81	3.04	*	*	5.37	0.23	2.10	*	0.47
		>230	2.96	2.96	53.25	11.24	1.48	21.89	1.48	0.30	*	2.37	0.59	1.48	*	*
	174	>60	3.81	2.86	77.14	2.86	1.91	5.71	0.95	*	*	1.91	*	*	*	2.86
		>120	0.30	1.82	22.49	2.43	1.22	67.78	0.91	*	0.91	1.52	0.30	*	*	0.30
		>230	1.67	3.33	45.83	10.56	*	32.50	1.94	0.56	0.28	1.67	0.56	0.56	0.28	0.28
2	176	>60	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>120	7.54	5.60	73.97	4.14	1.22	1.46	1.70	*	*	2.19	0.49	0.73	*	0.97
		>230	2.21	4.70	68.23	8.23	0.55	13.26	0.28	*	*	1.11	1.11	0.55	*	*
	177	>60	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>120	5.05	3.03	74.75	2.27	0.25	6.82	1.26	0.25	0.25	0.51	4.55	0.51	*	0.51
		>230	1.77	4.43	53.98	13.86	2.07	18.88	2.66	0.30	0.30	1.48	*	0.30	*	*
3	178	>60	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>120	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>230	2.70	4.60	58.38	15.41	1.08	12.97	2.16	0.27	*	1.89	0.54	*	*	*
	179	>60	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>120	6.39	5.37	72.63	3.07	0.51	1.79	1.54	*	*	0.26	7.67	0.26	*	0.51
		>230	2.71	5.12	51.81	14.76	1.21	20.48	1.51	0.30	0.30	1.21	0.60	*	*	*
4	180	>60	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>120	4.07	4.07	76.08	3.82	1.53	2.80	1.53	0.25	0.25	2.04	2.80	0.76	*	*
		>230	2.11	5.72	68.07	8.43	1.51	8.43	2.11	*	0.30	0.90	1.21	1.21	*	*
	181	>60	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>120	2.36	7.33	73.52	5.44	*	6.15	1.18	0.47	*	0.47	1.89	*	*	1.18
		>230	3.28	5.97	52.84	14.03	2.69	14.93	2.69	0.30	0.60	1.79	*	0.60	*	0.30
5	182	>60	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>120	3.80	2.69	47.65	10.52	4.25	28.19	1.57	0.22	*	0.45	*	0.45	*	0.22
		>230	4.15	4.66	54.15	15.03	3.11	13.99	1.30	0.26	0.78	1.81	*	0.52	*	0.26
	183	>60	3.87	2.68	81.85	6.55	3.57	0.30	0.89	*	*	*	*	0.30	*	*
		>120	4.02	4.49	43.26	14.18	8.27	22.46	1.18	0.71	*	0.95	*	*	*	0.47
		>230	0.99	4.44	33.83	17.04	3.70	35.31	1.24	0.74	0.74	1.73	*	0.25	*	*
6	184	>60	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>120	5.05	6.06	68.69	7.83	3.03	4.55	2.02	0.25	*	1.01	*	1.01	*	0.51
		>230	1.61	4.83	50.40	19.57	2.95	15.55	3.22	*	0.27	0.80	*	0.80	*	*
	185	>60	3.19	2.61	85.80	2.32	3.77	*	0.58	0.29	*	0.87	*	0.29	*	0.29
		>120	2.67	5.88	67.91	9.89	4.28	4.28	2.14	*	*	1.07	0.27	0.80	*	0.80
		>230	2.83	4.52	52.83	16.67	1.70	15.25	2.83	0.56	0.28	1.13	*	0.85	*	0.57
7	186	>60	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>120	3.11	3.73	73.03	1.66	0.62	4.15	1.45	0.21	*	0.83	8.51	0.83	*	1.87
		>230	1.61	4.60	71.72	7.13	2.07	5.75	2.76	0.46	*	2.53	0.69	0.69	*	*
	187	>60	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>120	8.09	3.43	80.39	1.47	1.23	1.47	2.70	*	0.25	0.25	*	*	*	0.74
		>230	3.89	3.02	56.16	12.96	1.73	13.61	5.40	0.43	0.22	1.73	*	0.43	*	0.43

TABLE: 6. (CONT.)

DIST. km	SAMPLE NO	MESH SIZE	PY	BRGHB	BLGHB	CGA	PGA	OP	SI	MO	ZI	EP	BI	KY	RU	AG
8	188	>60	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>120	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>230	7.60	2.77	64.06	11.98	*	5.99	5.30	*	0.23	0.92	*	0.46	*	0.69
	189	>60	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>120	7.29	3.39	65.63	0.78	0.26	1.56	2.87	0.52	0.52	0.26	10.68	*	*	6.25
		>230	5.47	3.39	70.83	8.07	0.78	3.65	4.43	0.52	*	0.78	0.26	0.26	*	1.56
9	190	>60	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>120	4.20	4.69	72.10	6.42	2.22	4.20	2.47	0.25	0.25	1.24	*	0.99	*	0.99
		>230	1.96	1.96	49.39	15.65	1.47	24.45	2.69	0.24	0.24	0.49	*	0.24	*	1.22
	191	>60	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>120	3.96	3.26	77.39	3.26	2.10	2.80	4.66	0.23	0.47	0.93	*	0.23	*	0.70
		>230	1.71	1.43	46.86	18.00	4.00	23.43	1.43	0.86	*	1.14	*	1.14	*	*
10	192	>60	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		>120	5.91	1.97	74.02	7.09	1.58	4.33	3.54	0.39	*	0.79	*	*	*	0.39
		>230	2.14	1.34	50.80	10.96	1.87	22.46	3.48	4.01	*	0.80	*	1.07	0.27	0.80
	193	>60	2.13	3.19	53.19	2.13	2.13	5.32	1.06	*	*	*	10.85	*	*	*
		>120	5.95	2.43	74.32	5.41	0.27	2.70	5.14	0.54	*	*	*	1.62	*	1.62
		>230	2.06	2.58	46.39	12.11	3.35	27.84	2.84	1.29	0.52	1.03	*	*	*	*

TABLE: 7. WEIGHT PERCENTAGES OF HEAVY MINERALS IN BEACH SEDIMENTS.

DIST. km	SAMPLE NO	MESH SIZE	%
LOW WATER MARK			
0	194	>60	0.56
		>120	3.68
		>230	38.32
1	198	>60	0.25
		>120	1.84
		>230	21.55
2	202	>60	0.15
		>120	0.42
		>230	14.60
3	206	>60	0.68
		>120	2.67
		>230	38.14
4	210	>60	1.05
		>120	3.46
		>230	49.28
5	214	>60	0.44
		>120	6.04
		>230	62.97
6	218	>60	0.33
		>120	1.96
		>230	25.90
7	222	>60	0.57
		>120	2.90
		>230	31.02
8	226	>60	0.78
		>120	1.46
		>230	20.74
9	230	>60	0.45
		>120	1.31
		>230	9.10
10	234	>60	0.49
		>120	1.88
		>230	32.85
11	238	>60	0.28
		>120	1.79
		>230	18.66
FORESHORE			
0	195	>60	6.01
		>120	21.26
		>230	86.10
1	199	>60	1.26
		>120	3.08
		>230	34.70
2	203	>60	25.68
		>120	40.18
		>230	90.22
3	207	>60	4.36
		>120	17.66
		>230	84.85
4	211	>60	6.41
		>120	17.02
		>230	88.38
5	215	>60	1.52
		>120	11.64
		>230	88.15
6	219	>60	7.36
		>120	38.67
		>230	94.69
7	223	>60	1.58
		>120	9.18
		>230	84.33
8	227	>60	2.32
		>120	4.32
		>230	51.79
9	231	>60	1.18
		>120	3.08
		>230	54.65
10	235	>60	0.52
		>120	1.66
		>230	43.68
11	239	>60	0.74
		>120	2.44
		>230	41.82
BERM CREST			
0	196	>60	1.05
		>120	7.91
		>230	69.61
1	200	>60	3.69
		>120	12.45
		>230	89.91
2	204	>60	11.53
		>120	39.61
		>230	93.85
3	208	>60	3.11
		>120	15.04
		>230	90.35
4	212	>60	2.96
		>120	12.34
		>230	92.66
5	216	>60	2.82
		>120	9.48
		>230	67.12
6	220	>60	8.55
		>120	75.11
		>230	98.83
7	224	>60	5.47
		>120	15.69
		>230	93.43
8	228	>60	8.79
		>120	22.47
		>230	94.35
9	232	>60	2.93
		>120	12.25
		>230	90.28
10	236	>60	3.25
		>120	15.46
		>230	95.64
11	240	>60	6.26
		>120	13.99
		>230	90.12
BACKSHORE			
0	197	>60	1.15
		>120	5.88
		>230	56.10
1	201	>60	6.02
		>120	20.73
		>230	89.30
2	205	>60	18.30
		>120	38.74
		>230	93.89
3	209	>60	5.50
		>120	16.50
		>230	90.01
4	213	>60	2.89
		>120	8.78
		>230	82.19
5	217	>60	1.61
		>120	9.52
		>230	62.98
6	221	>60	5.00
		>120	40.28
		>230	94.91
7	225	>60	5.76
		>120	20.34
		>230	91.80
8	229	>60	6.43
		>120	23.58
		>230	95.98
9	233	>60	2.36
		>120	10.35
		>230	92.44
10	237	>60	2.35
		>120	8.27
		>230	86.04
11	241	>60	2.90
		>120	10.45
		>230	84.61



FIG·28·DOWN-STREAM VARIATION IN WEIGHT PERCENTAGES OF TOTAL HEAVY MINERALS.

A-0·500-0·250 MM. B-0·250-0·125 MM. C-0·125-0·062 MM.

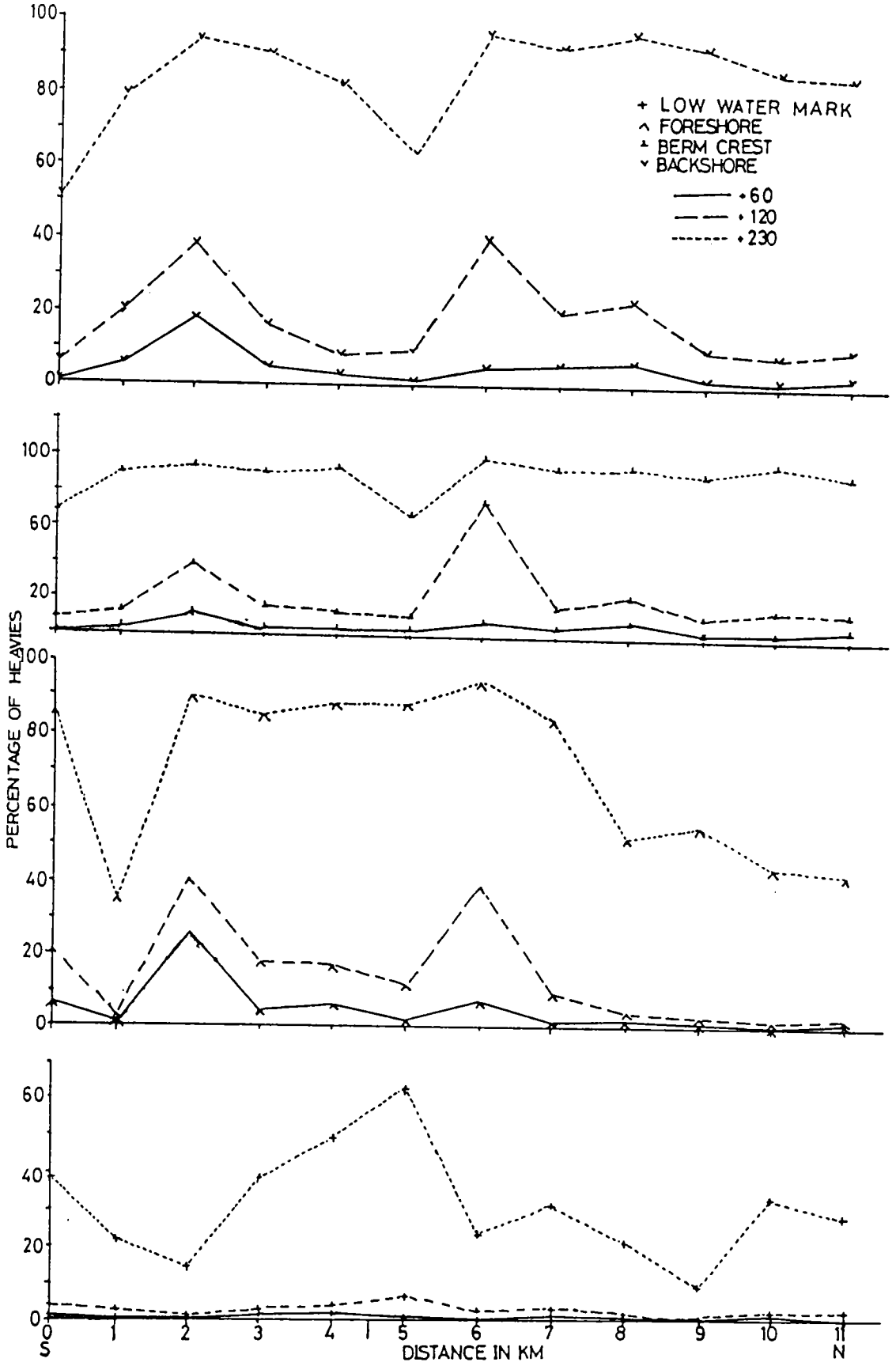


FIG. 29. TOTAL HEAVY MINERAL VARIATION ALONG THE BEACH

significant level of weight percentage of heavy minerals are present in the medium and fine size grades.

Data presented in Figs. 30, 31, and 32 illustrate respectively the downstream variation of the three size grades (500 -250, 250 -125, and 125-63 microns) of pyroxenes, hornblendes, garnets, and opaques. While pyroxenes and hornblendes record an increasing trend downstream, garnets and opaques demonstrate a decreasing trend. The variation of pyroxenes, amphiboles, garnet, and opaques in the beach samples are presented in Table. 8 & Figs. 33, 34, 35, & 36 respectively. The results show that amphibole is the most abundant mineral in all size grades, the amount decrease towards the northern side. Medium size grade contains high amount of pyroxenes than the coarse and fine size grades. In the median size grade, the LWM, foreshore, and berm crest samples show less amount of pyroxene than those of the backshore. Moreover, an over all increase in the pyroxene content is discernible towards northern side. The fine size grade contains high amount of garnet than the coarse and medium size grades. In the coarse and medium size grades, garnet contents decrease towards the northern side. However, except in the foreshore, samples from all other areas show an increase towards the northern side. The coarse and medium size grades contain, either small or nil amount of opaques. But the fine size grade shows a good amount of opaques. An over all decrease is observed for the opaques towards the northern side, whereas in the berm crest the converse condition prevails.

TABLE: 8. NUMBER PERCENTAGES OF HEAVY MINERALS OF BEACH SANDS

PY-PYROXENE BRGHB-BROWN GREEN HORNBLENDE SI-SILLIMANITE RU-RUTILE

OP-OPAQUES BLGHB-BLUE GREEN HORNBLENDE EP-EPDOTE AG-ALTERED MINERALS

MO-MONOZITE CGA-COLOURLESS GARNET BI-BIOTITE

ZI-ZIRCON PGA-PINK GARNET KY-KYANITE

LWM-LOW WATER MARK FSH-FORESHORE BC-BERMCREST BSH-BACKSHORE.

DIST. S-N	IN km	SAMPLE NO	MESH SIZE	PY	BRGHB	BLGHB	CGA	PGA	OP	SI	MO	ZI	EP	BI	KY	RU	AG
		LWM															
	0	194	>60	5.03	5.33	85.21	0.30	0.89	*	1.18	*	*	0.59	0.30	*	*	1.18
			>120	4.79	7.18	79.26	2.13	0.53	*	2.66	*	*	0.27	*	1.33	*	1.86
			>230	4.91	6.39	50.37	8.60	2.70	14.74	3.93	2.46	0.25	1.72	*	0.25	0.25	3.44
	1	198	>60	0.75	6.77	87.97	*	*	*	*	*	*	*	1.50	*	*	3.01
			>120	6.68	8.07	74.65	0.92	*	1.84	1.38	0.46	*	0.46	0.69	1.15	*	3.69
			>230	5.88	6.34	69.68	4.53	0.23	2.94	4.53	1.81	*	0.68	*	0.23	*	3.17
	2	202	>60	1.08	8.11	63.24	*	*	0.54	3.24	0.54	*	*	9.73	*	*	13.51
			>120	6.14	5.41	79.61	1.72	0.49	*	0.98	0.25	*	0.49	*	0.25	*	4.67
			>230	5.68	6.17	69.63	4.44	1.24	2.22	5.43	1.98	*	*	*	0.49	*	2.72
	3	206	>60	2.31	4.62	86.99	0.29	0.29	*	0.29	*	*	0.29	*	*	*	4.91
			>120	4.96	7.05	82.51	0.78	0.26	*	1.31	*	*	*	*	1.04	*	2.09
			>230	1.90	9.24	51.90	10.33	5.16	11.14	2.45	2.17	0.27	0.82	*	1.09	*	3.53
	4	210	>60	1.70	10.44	75.73	0.24	1.21	0.49	1.21	0.24	*	*	*	*	*	8.74
			>120	4.43	10.87	75.45	2.41	0.81	0.40	0.81	0.60	*	0.20	0.20	0.20	*	3.62
			>230	4.54	9.31	53.22	10.98	2.39	10.74	3.10	2.15	0.24	0.72	*	0.24	0.24	2.15
	5	214	>60	2.63	8.83	64.92	6.92	2.63	2.39	0.48	0.24	*	0.24	5.97	*	*	4.77
			>120	2.09	11.49	52.48	18.02	3.92	3.13	1.04	1.31	0.52	0.78	*	*	*	5.22
			>230	2.87	8.85	30.47	20.57	6.25	26.04	0.78	0.78	0.52	*	*	0.78	*	2.08
	6	218	>60	1.19	28.57	50.89	0.30	1.19	2.68	0.89	*	*	*	8.63	0.30	*	5.36
			>120	6.08	8.76	68.86	4.62	0.49	1.95	2.19	0.73	*	*	1.46	*	*	4.87
			>230	3.68	6.82	44.88	14.96	1.05	19.69	2.63	1.05	*	*	*	0.26	0.26	4.20
	7	222	>60	3.76	30.99	54.46	1.88	0.47	*	*	*	*	*	0.94	*	*	7.51
			>120	5.25	8.50	76.00	4.75	0.75	0.75	1.00	0.25	*	*	1.00	0.25	0.25	1.25
			>230	4.35	10.49	49.11	11.51	1.54	14.32	4.09	0.51	*	*	*	*	0.51	3.58
	8	226	>60	3.47	24.65	60.76	*	*	1.04	0.35	*	*	*	*	*	0.35	9.38
			>120	4.92	12.18	68.15	1.64	*	0.23	0.94	*	*	*	0.47	*	*	11.48
			>230	3.36	12.47	55.64	9.35	2.16	9.59	0.48	3.84	0.24	0.96	*	0.24	0.24	1.44
	9	230	>60	0.47	13.62	14.09	0.47	*	1.88	*	*	*	*	61.03	*	*	7.98
			>120	7.06	11.92	62.91	2.43	0.22	2.65	0.88	0.66	*	*	1.10	*	*	10.16
			>230	5.94	11.40	42.04	14.96	3.56	13.54	3.09	0.71	0.95	0.48	*	0.24	*	3.09
	10	234	>60	5.00	48.89	32.22	*	*	*	*	*	*	*	0.56	*	*	13.33
			>120	6.50	20.34	53.11	1.70	*	*	1.13	1.41	*	*	*	*	*	15.82
			>230	2.56	16.77	38.78	13.84	4.19	11.74	1.47	2.73	0.21	0.63	*	*	0.42	6.71
	11	238	>60	6.10	58.54	7.32	*	*	*	*	*	*	*	18.29	*	*	9.76
			>120	14.51	24.80	32.72	2.11	*	*	0.26	0.79	*	*	1.06	*	*	23.75
			>230	12.47	22.99	34.35	9.42	1.39	5.82	2.77	0.83	*	*	*	*	*	9.97
		FSH															
	0	195	>60	4.15	5.07	78.34	2.54	4.61	*	2.54	*	*	0.46	*	0.69	0.23	1.38
			>120	2.75	6.98	63.21	5.50	8.25	3.17	3.17	4.23	*	1.48	*	0.42	*	0.85
			>230	1.83	4.34	23.29	13.70	6.85	44.29	1.83	2.51	*	0.46	*	*	*	0.91

TABLE: 8. (CONT.)

DIST. S-N	IN km	SAMPLE NO	MESH SIZE	PY	BRGHB	BLGHB	CGA	PGA	OP	SI	MO	ZI	EP	BI	KY	RU	AG
	1	199	>60	1.83	6.81	82.98	1.83	1.31	*	0.79	*	*	0.79	0.52	0.52	*	2 62
			>120	5.92	10.66	73.46	0.71	0.95	1.19	1.19	0.24	*	*	0.24	0.47	*	4.98
			>230	4.15	7.42	56.08	12.17	1.19	6.83	3.86	2.37	*	1.48	*	0.59	*	3.80
	2	203	>60	2.59	8.41	71.98	6.03	4.53	0.22	1.94	0.86	*	1.51	*	0.86	*	1.08
			>120	3.22	8.16	66.95	6.65	3.00	0.64	6.01	1.72	*	0.64	*	0.43	*	2.58
			>230	2.39	3.91	35.00	21.09	7.17	20.22	3.91	2.17	0.22	1.30	*	0.65	*	1.96
	3	207	>60	1.61	9.38	79.36	1.34	0.54	0.54	1.61	*	*	0.80	*	0.54	*	4.29
			>120	6.23	5.24	73.07	3.74	1.00	0.75	2.74	1.00	*	2.00	*	1.50	*	2.74
			>230	2.03	7.61	34.52	16.24	9.39	21.57	2.79	0.76	*	0.76	*	0.51	*	3.55
	4	211	>60	3.23	7.97	79.96	3.23	1.51	0.65	0.65	*	*	*	*	*	*	2.80
			>120	5.64	7.69	74.87	3.59	1.28	0.77	1.80	1.28	*	1.03	*	0.26	*	1.80
			>230	3.78	7.85	41.28	10.47	5.81	23.55	4.07	0.58	*	0.87	*	*	0.29	1.45
	5	215	>60	4.93	8.69	73.94	2.35	1.41	1.41	0.70	*	*	*	0.24	0.24	*	6.10
			>120	4.64	9.71	43.04	11.39	6.33	19.83	1.69	0.21	0.42	0.42	*	*	0.21	2.11
			>230	0.67	3.78	8.00	15.11	7.56	59.11	1.78	2.22	1.11	*	*	0.22	*	0.44
	6	219	>60	3.48	6.15	52.67	16.85	9.89	3.48	1.34	0.54	*	*	*	*	*	5.62
			>120	3.51	5.26	20.18	29.17	5.48	31.36	0.88	2.63	0.22	0.44	*	*	*	0.88
			>230	0.82	2.19	4.38	17.26	1.64	69.04	1.10	2.19	0.55	*	*	*	0.55	0.27
	7	223	>60	4.67	16.82	57.01	2.49	4.05	0.94	0.31	*	*	*	*	*	*	13.71
			>120	5.65	8.11	72.97	3.44	2.46	*	2.70	0.98	*	*	*	0.98	*	2.70
			>230	4.81	7.75	24.60	19.79	6.69	27.81	3.74	2.14	0.27	*	*	0.80	0.27	1.34
	8	227	>60	3.06	21.83	57.64	0.87	0.44	*	1.31	*	*	*	0.87	*	*	13.97
			>120	3.69	16.89	65.96	3.69	0.79	0.26	*	*	*	1.06	0.79	*	*	6.86
			>230	3.31	11.71	46.57	10.69	5.85	13.23	1.78	2.80	0.26	0.76	*	0.76	*	2.29
	9	231	>60	2.60	40.52	32.71	1.12	1.86	*	0.37	*	*	*	0.37	*	*	20.45
			>120	4.32	24.05	54.60	3.51	1.08	0.54	2.16	0.54	*	*	*	*	*	9.19
			>230	4.48	11.94	44.78	15.42	2.74	13.43	3.48	0.75	*	*	*	*	*	2.98
	10	235	>60	4.92	59.47	24.24	*	0.38	0.38	1.14	0.38	*	*	1.14	*	*	7.96
			>120	5.78	20.72	49.16	3.13	*	0.48	0.72	0.96	0.48	*	0.24	*	*	18.31
			>230	5.54	17.13	50.88	9.82	2.27	5.04	1.01	1.51	0.50	*	*	*	*	6.30
	11	239	>60	16.96	45.58	16.96	*	0.35	*	0.35	0.71	*	*	1.06	*	*	18.02
			>120	21.08	25.30	35.24	0.60	*	*	0.90	*	*	*	*	*	*	16.87
			>230	10.69	22.01	32.29	12.37	3.56	8.81	1.68	2.52	*	*	*	*	*	6.08
		BC															
	0	196	>60	1.97	8.71	82.30	1.12	2.53	*	1.12	0.28	*	*	*	0.28	*	1.69
			>120	5.41	6.08	61.99	3.72	6.08	7.26	2.70	1.89	*	1.69	*	0.68	0.34	2.20
			>230	4.29	6.31	35.61	5.81	7.83	31.82	2.27	1.77	0.51	0.76	*	1.01	*	2.02
	1	200	>60	4.65	6.98	82.85	1.74	0.87	*	0.58	*	*	0.29	*	0.58	*	1.45
			>120	4.23	9.16	75.12	2.58	0.70	1.17	2.82	0.47	*	0.94	*	0.70	*	2.11
			>230	4.31	7.55	42.86	13.48	4.85	17.79	2.43	1.89	*	1.62	*	*	0.54	2.70
	2	204	>60	1.87	7.23	76.22	4.20	5.59	*	0.70	0.23	*	1.17	*	0.23	*	2.56
			>120	3.94	7.28	65.35	8.07	2.36	2.76	3.54	1.77	*	1.18	*	1.18	*	2.56
			>230	2.55	5.49	22.94	16.67	7.26	37.26	2.16	1.77	0.78	0.39	*	0.20	0.39	2.16
	3	208	>60	2.80	7.13	81.43	0.25	2.04	2.04	0.76	*	*	0.51	*	0.25	*	2.80
			>120	4.69	8.48	75.22	1.79	1.12	1.34	1.56	0.89	*	1.12	*	1.56	*	2.23
			>230	3.21	8.55	33.12	14.10	6.20	24.15	2.35	1.92	0.43	0.64	*	1.50	0.86	2.99

TABLE: 8. (CONT.)

DIST. S-N IN km	SAMPLE NO	MESH SIZE	PY	BRGHB	BLGHB	CGA	PGA	OP	SI	MO	ZI	EP	AT	KY	PU	AG
4	212	>60	3.99	7.10	78.94	3.10	3.33	*	*	0.22	*	0.22	*	*	*	3.10
		>120	4.90	6.70	72.94	5.16	2.84	2.84	0.77	0.52	*	1.29	*	*	*	2.06
		>230	2.30	5.75	23.85	16.09	3.74	41.38	1.72	2.30	0.86	*	*	0.29	*	1.72
5	216	>60	5.22	5.22	74.78	6.52	1.30	*	0.87	*	*	*	2.17	0.44	*	3.48
		>120	6.24	11.27	61.63	10.31	2.88	3.12	1.20	1.44	*	*	*	0.24	*	1.68
		>230	3.12	8.58	37.82	18.13	3.31	20.86	1.95	2.14	1.37	0.20	*	0.59	*	1.95
6	220	>60	4.17	6.04	52.92	20.21	9.79	1.25	0.21	0.83	*	0.21	*	*	*	4.38
		>120	2.28	3.29	11.39	25.32	9.62	43.54	0.76	2.53	*	*	*	*	*	1.27
		>230	0.74	1.24	4.21	15.35	3.71	72.03	1.24	0.99	0.25	*	*	*	0.25	*
7	224	>60	4.27	15.24	67.38	1.83	0.92	*	1.22	*	*	*	0.31	*	0.31	*	8.54
		>120	2.98	9.23	71.43	2.38	2.98	1.19	0.89	0.60	*	*	*	0.60	*	7.74
		>230	4.93	7.51	25.59	18.78	8.92	29.11	1.64	1.88	0.47	*	*	0.47	*	0.70
8	228	>60	4.45	17.47	62.67	1.03	0.69	*	0.69	*	*	*	*	*	*	13.01
		>120	3.81	15.70	59.87	9.64	2.47	0.22	1.35	0.90	*	1.35	*	*	*	4.71
		>230	1.44	6.90	16.95	23.28	10.35	37.07	1.44	1.46	*	*	*	*	0.86	0.29
9	232	>60	1.90	21.68	51.22	1.63	*	1.08	*	*	*	0.27	0.27	*	*	21.95
		>120	3.15	21.79	55.12	5.25	*	1.05	0.26	0.26	*	0.79	0.26	*	*	12.07
		>230	0.27	12.10	26.61	16.67	7.53	32.53	0.81	1.61	*	0.81	*	*	*	1.08
10	236	>60	9.00	28.75	32.50	1.50	*	0.50	1.50	0.25	0.25	*	0.50	*	*	25.25
		>120	11.35	25.41	43.24	4.60	1.35	1.08	2.16	2.43	*	*	*	*	*	8.38
		>230	2.55	10.46	21.17	25.26	4.34	31.89	1.28	1.79	0.26	*	*	0.26	0.26	0.51
11	240	>60	32.05	29.17	20.83	1.60	*	0.96	1.28	1.92	*	*	*	*	*	12.18
		>120	28.19	28.92	18.87	3.19	0.74	1.96	2.70	3.19	0.98	*	*	0.74	0.25	10.29
		>230	9.49	9.98	11.19	10.98	6.81	36.00	1.70	1.22	0.73	*	*	*	0.73	3.16
	BSH															
0	197	>60	2.76	6.06	86.23	0.28	1.10	0.28	0.83	*	*	1.10	*	*	*	1.38
		>120	6.63	4.92	71.02	4.17	3.41	1.71	3.03	0.95	*	1.52	*	0.76	*	1.89
		>230	2.74	5.47	32.84	10.20	3.98	31.84	3.98	4.98	*	1.00	*	0.25	0.25	2.49
1	201	>60	2.67	5.56	79.11	2.67	5.11	0.67	1.78	*	*	1.33	*	*	*	1.11
		>120	4.91	6.39	58.72	8.85	5.16	9.09	3.19	0.74	*	0.25	*	0.74	*	1.97
		>230	2.63	5.46	35.76	9.90	3.43	37.78	2.83	1.21	*	0.20	*	0.40	0.20	0.20
2	205	>60	3.03	5.05	75.76	3.79	8.33	*	1.77	0.51	*	*	*	1.01	*	0.76
		>120	4.73	5.63	69.37	3.83	5.41	1.80	2.25	0.90	*	1.35	*	1.35	*	3.38
		>230	2.53	8.51	24.37	14.02	7.36	34.71	2.53	3.22	0.23	0.69	*	0.46	0.69	0.69
3	209	>60	5.35	12.47	74.61	1.78	2.00	0.22	0.67	*	*	0.67	*	*	*	2.23
		>120	6.02	7.74	74.19	3.23	2.15	1.08	1.72	0.43	*	1.94	*	*	*	1.51
		>230	2.36	8.12	26.44	16.23	6.28	32.20	2.62	1.57	*	1.57	*	*	0.52	2.09
4	213	>60	1.54	10.03	76.09	1.03	2.31	1.54	0.51	0.77	0.26	*	*	0.26	*	5.66
		>120	3.46	10.80	63.50	7.13	2.81	3.24	2.59	1.73	0.22	0.22	*	0.65	*	3.67
		>230	1.71	10.94	33.85	12.99	7.35	25.47	2.05	2.74	0.17	0.34	*	0.34	0.34	1.71
5	217	>60	3.47	14.20	57.10	6.94	1.58	3.47	1.26	*	0.32	*	6.94	0.32	*	4.42
		>120	6.57	8.69	58.69	13.62	1.17	2.35	2.11	1.88	*	*	*	0.24	*	4.70
		>230	3.98	6.96	32.01	20.08	4.57	25.25	2.39	1.59	*	*	*	*	*	3.18

TABLE: 8 (CONT.)

DIST. S-N IN km	SAMPLE NO	MESH SIZE	PY	BRGHB	BLGHB	CGA	PGA	OP	SI	MO	ZI	EP	BI	KY	RU	AG
6	221	>60	2.66	8.72	69.98	8.48	5.57	0.24	0.24	0.24	*	*	*	*	0.24	3.36
		>120	5.47	8.71	50.25	18.16	6.97	2.99	2.99	1.49	*	*	*	1.24	0.50	1.24
		>230	1.29	2.95	12.18	18.64	5.54	52.40	3.14	2.21	0.19	*	*	*	0.55	0.92
7	225	>60	5.43	14.70	64.86	1.60	0.96	*	0.64	*	*	*	*	*	*	11.82
		>120	6.42	17.04	59.01	7.41	1.98	1.48	0.99	0.74	0.25	0.25	*	*	*	4.44
		>230	1.90	7.11	20.38	22.43	6.79	35.70	1.42	1.90	0.32	0.63	*	0.16	0.32	0.95
8	229	>60	3.19	21.45	51.30	4.06	6.96	0.58	0.29	0.29	*	*	*	*	*	11.88
		>120	0.88	16.47	57.65	12.35	5.59	2.35	0.88	0.59	*	*	0.29	0.29	*	2.65
		>230	1.12	5.13	16.07	18.75	6.92	48.44	1.34	1.56	*	0.22	*	*	0.22	0.22
9	233	>60	3.33	25.93	44.82	2.22	0.37	*	0.37	*	*	*	*	*	*	22.96
		>120	3.08	18.46	60.39	5.00	3.08	1.54	0.39	*	0.39	0.77	*	*	*	6.92
		>230	2.16	12.07	22.52	20.00	7.03	30.99	1.08	1.08	0.36	0.36	*	*	0.18	2.16
10	237	>60	8.93	35.71	30.66	*	0.60	*	1.19	0.30	*	*	*	*	*	22.62
		>120	13.02	29.36	34.07	2.49	*	*	1.39	1.11	*	*	*	*	*	18.56
		>230	7.68	16.43	21.61	19.29	5.72	24.46	0.89	1.61	0.18	*	*	*	0.18	1.96
11	241	>60	19.12	26.02	35.42	0.94	*	0.31	*	0.31	*	*	2.51	*	*	15.36
		>120	18.58	32.52	29.43	4.65	*	1.12	2.66	3.76	*	*	*	*	*	7.30
		>230	13.33	15.48	12.14	22.86	5.00	22.38	1.43	6.67	0.71	*	*	*	*	*

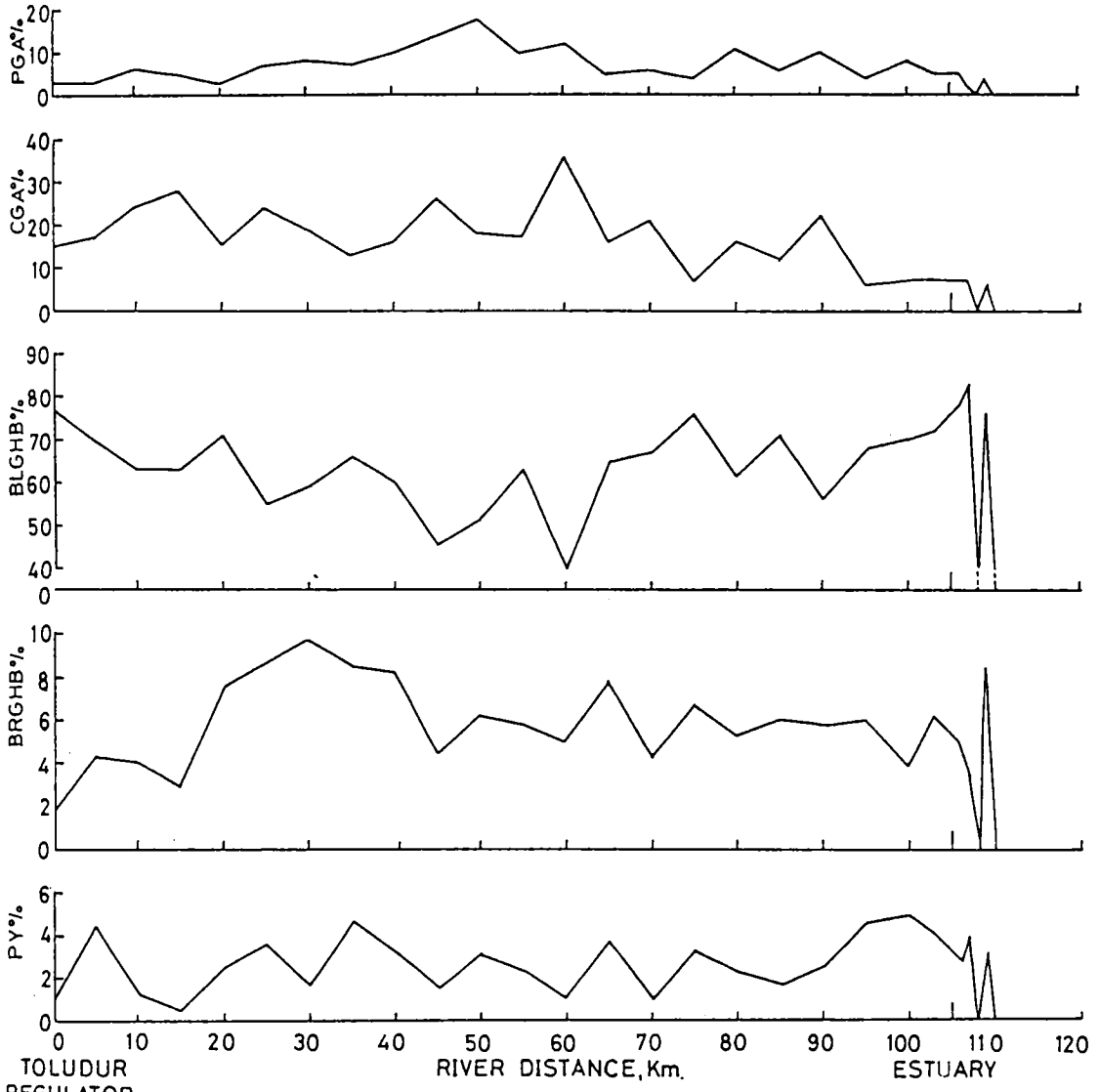


FIG. 30. DOWNSTREAM VARIATIONS OF PYROXENE, HORNBLENDE AND GARNET IN THE VELLAR RIVER(0·500-0·250 MM).
PY-PYROXENE. BRGHB-BROWN GREEN HORNBLENDE. PGA-PINK GARNET.
BLGHB-BLUE GREEN HORNBLENDE. CGA-COLOURLESS GARNET.

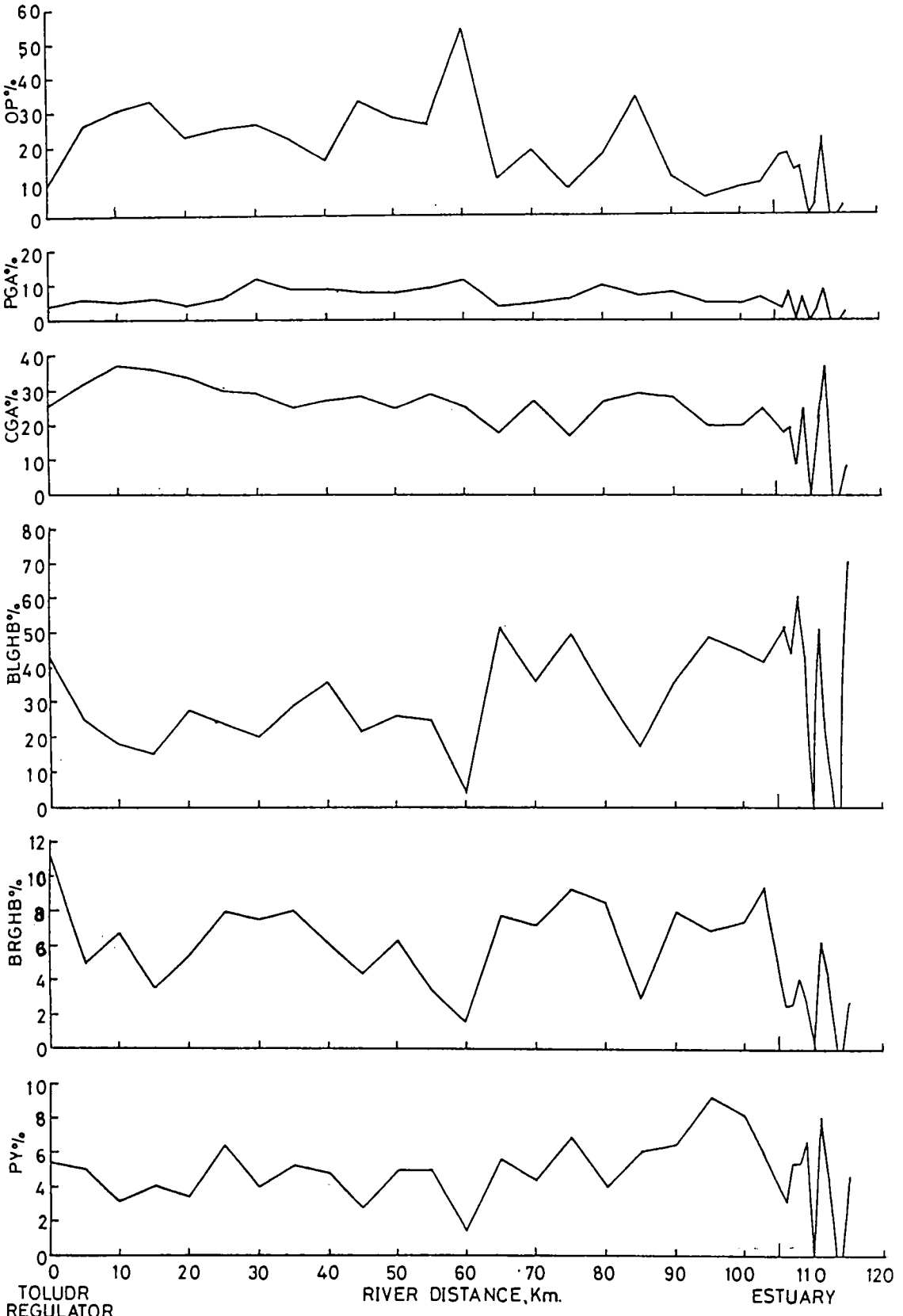


FIG. 31. DOWNSTREAM VARIATIONS OF PYROXENE, HORNBLENDE, GARNET, AND OPAQUE IN THE VELLAR RIVER (0·250 0·125 MM).

PY-PYROXENE. BRGHB-BROWN GREEN HORNBLENDE. CGA-COLOURLESS GARNET. BLGHB-BLUE GREEN HORNBLENDE. PGA-PINK GARNET. OP-OPAQUE.

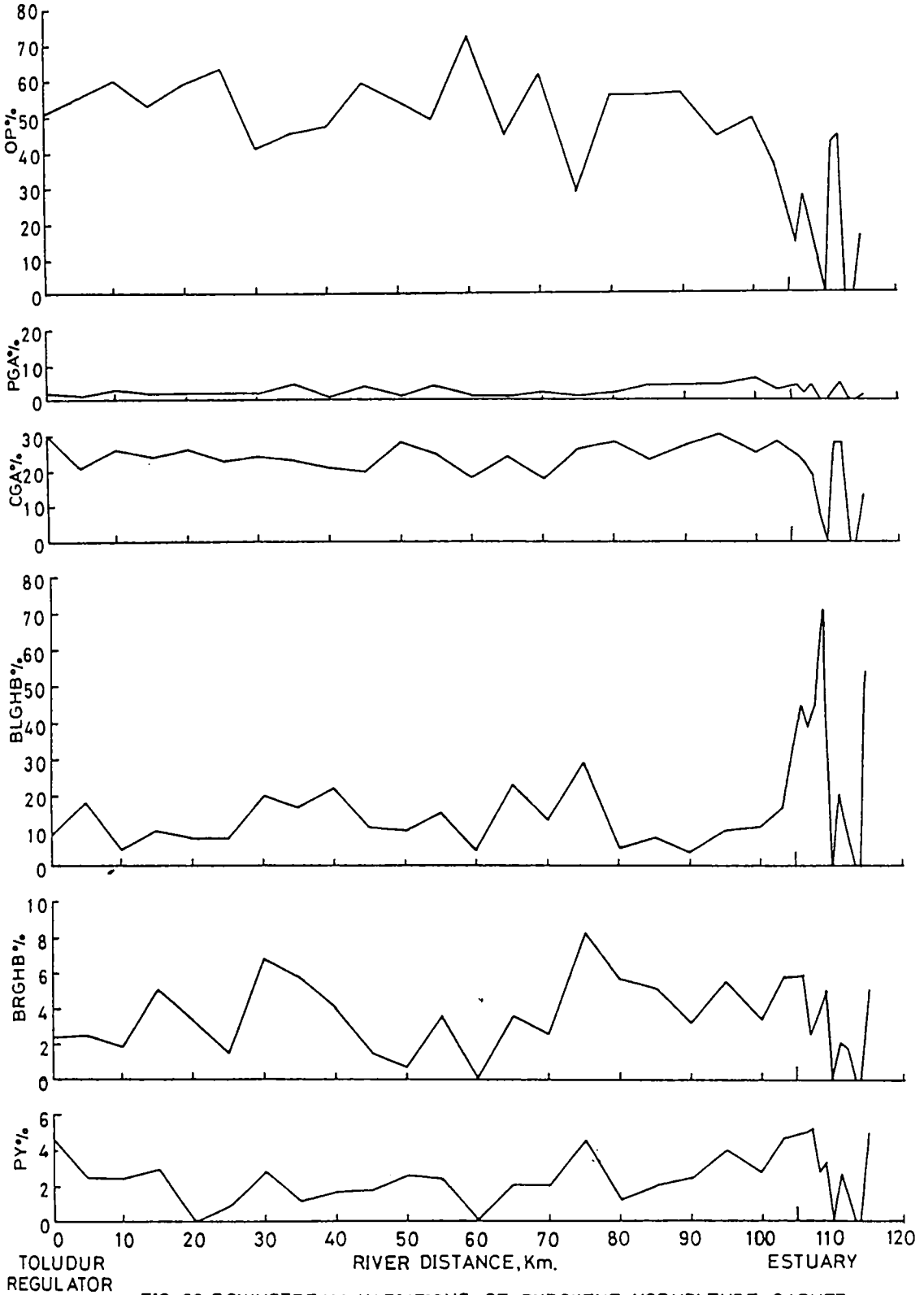


FIG. 32. DOWNSTREAM VARIATIONS OF PYROXENE, HORNBLENDE, GARNET AND OPAQUE IN THE VELLAR RIVER (0·125-0·062MM).

PY-PYROXENE. BRGHB-BROWN GREEN HORNBLENDE. CGA-COLOURLESS GARNET.

BLGHB-BLUE GREEN HORNBLENDE. PGA-PINK GARNET. OP-OPAQUE.

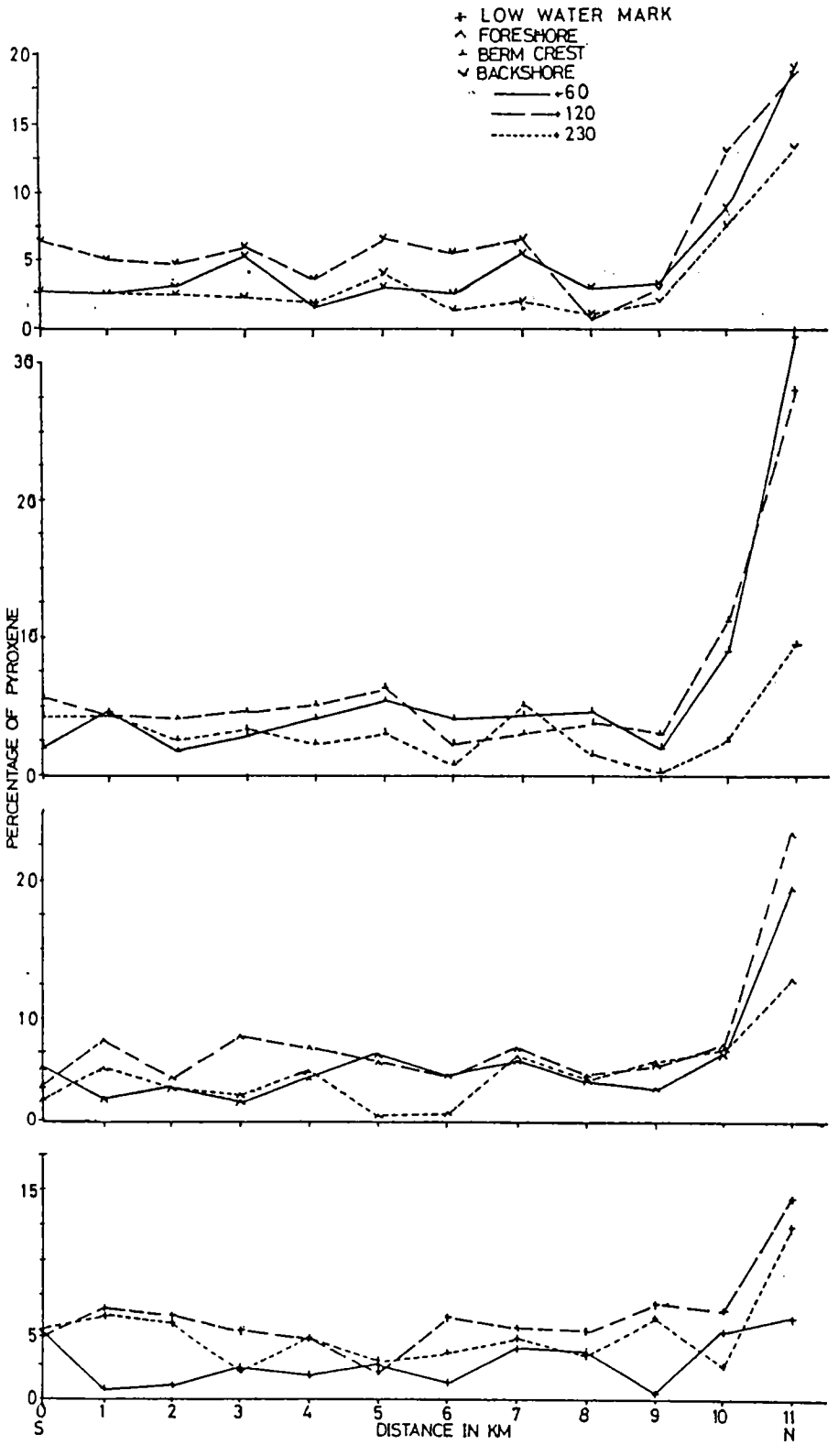


FIG. 33. VARIATION OF PYROXENE DISTRIBUTION ALONG THE BEACH.

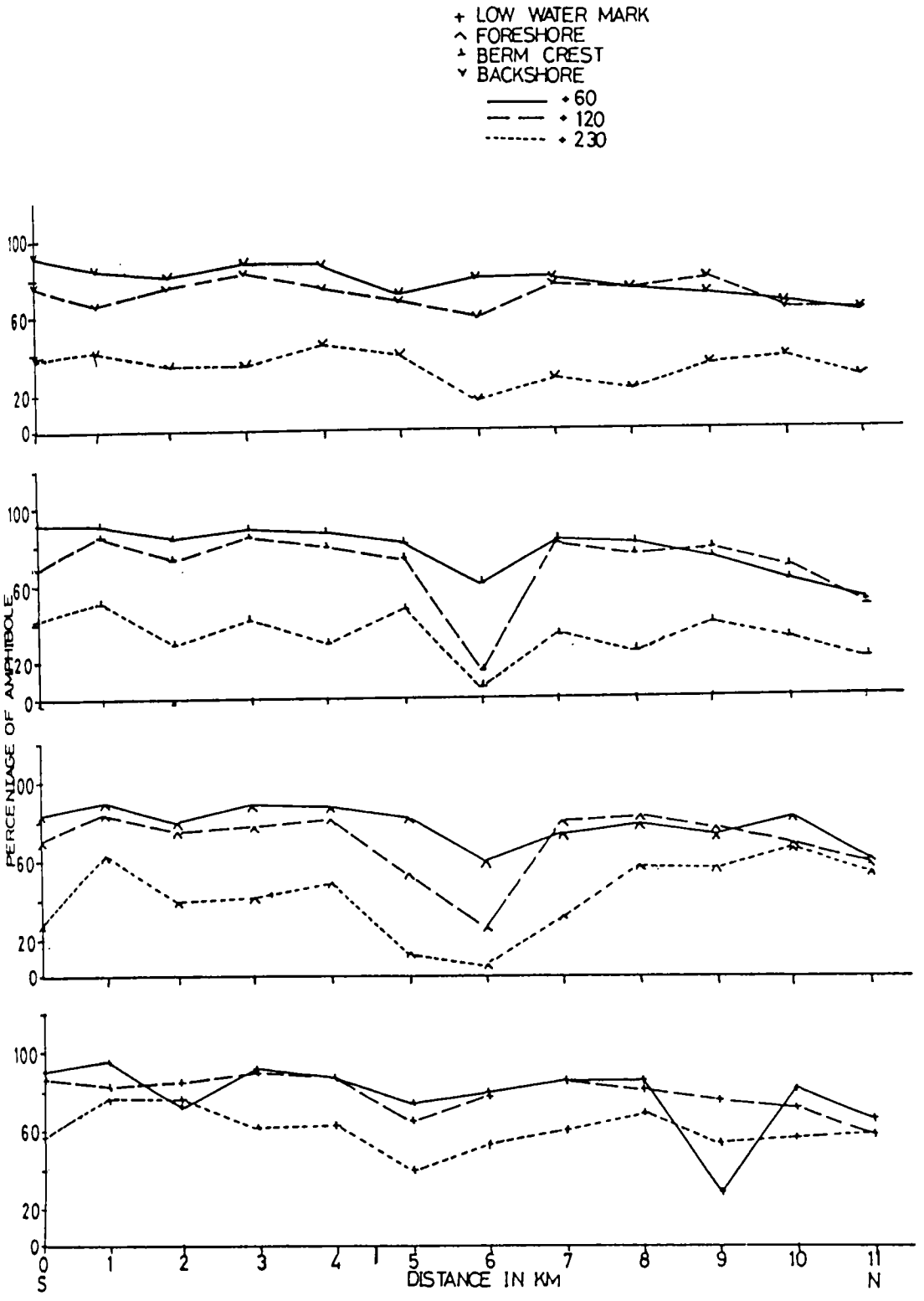


FIG.34. VARIATION OF AMPHIBOLE DISTRIBUTION ALONG THE BEACH.

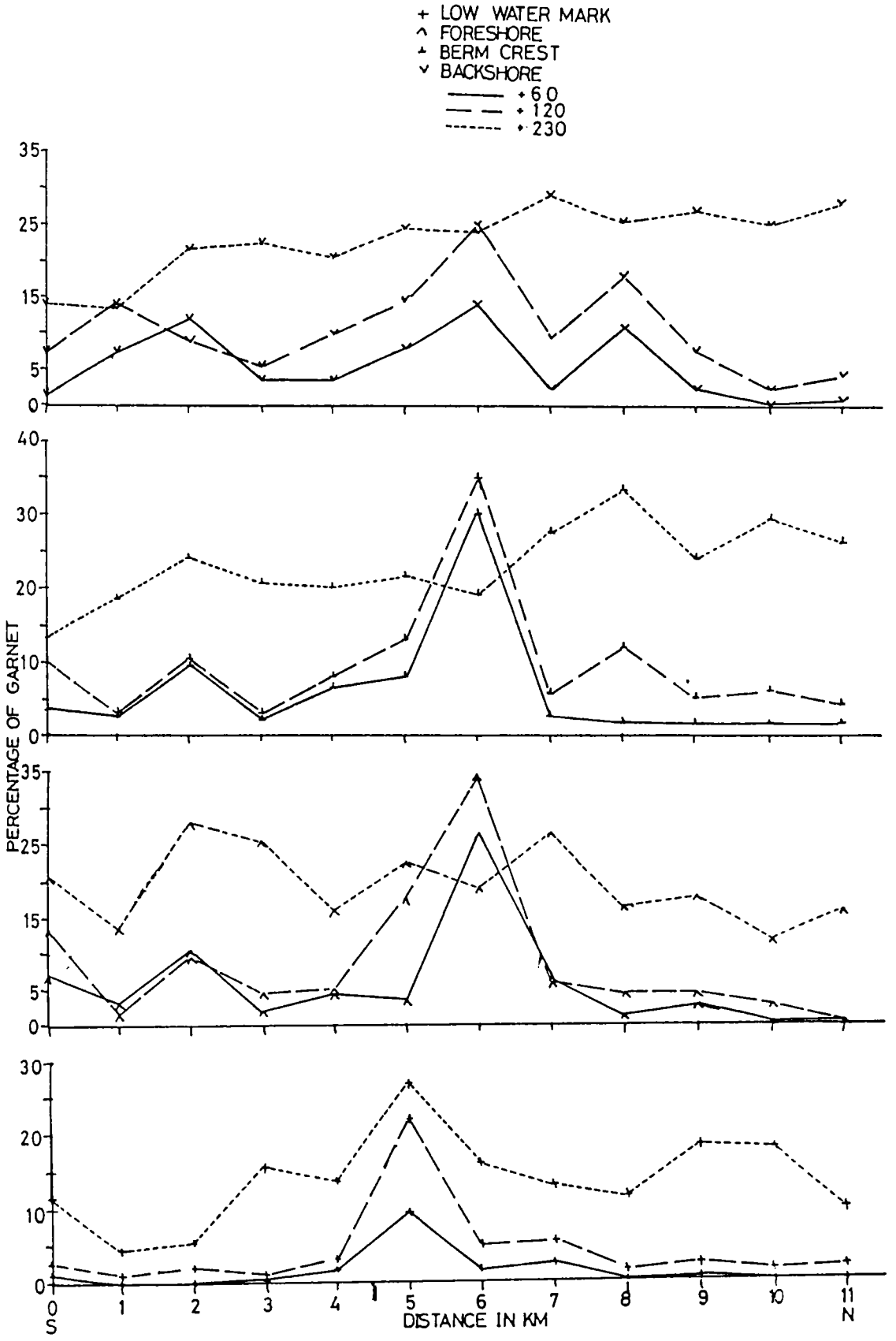


FIG.35. VARIATION OF GARNET DISTRIBUTION ALONG THE BEACH.

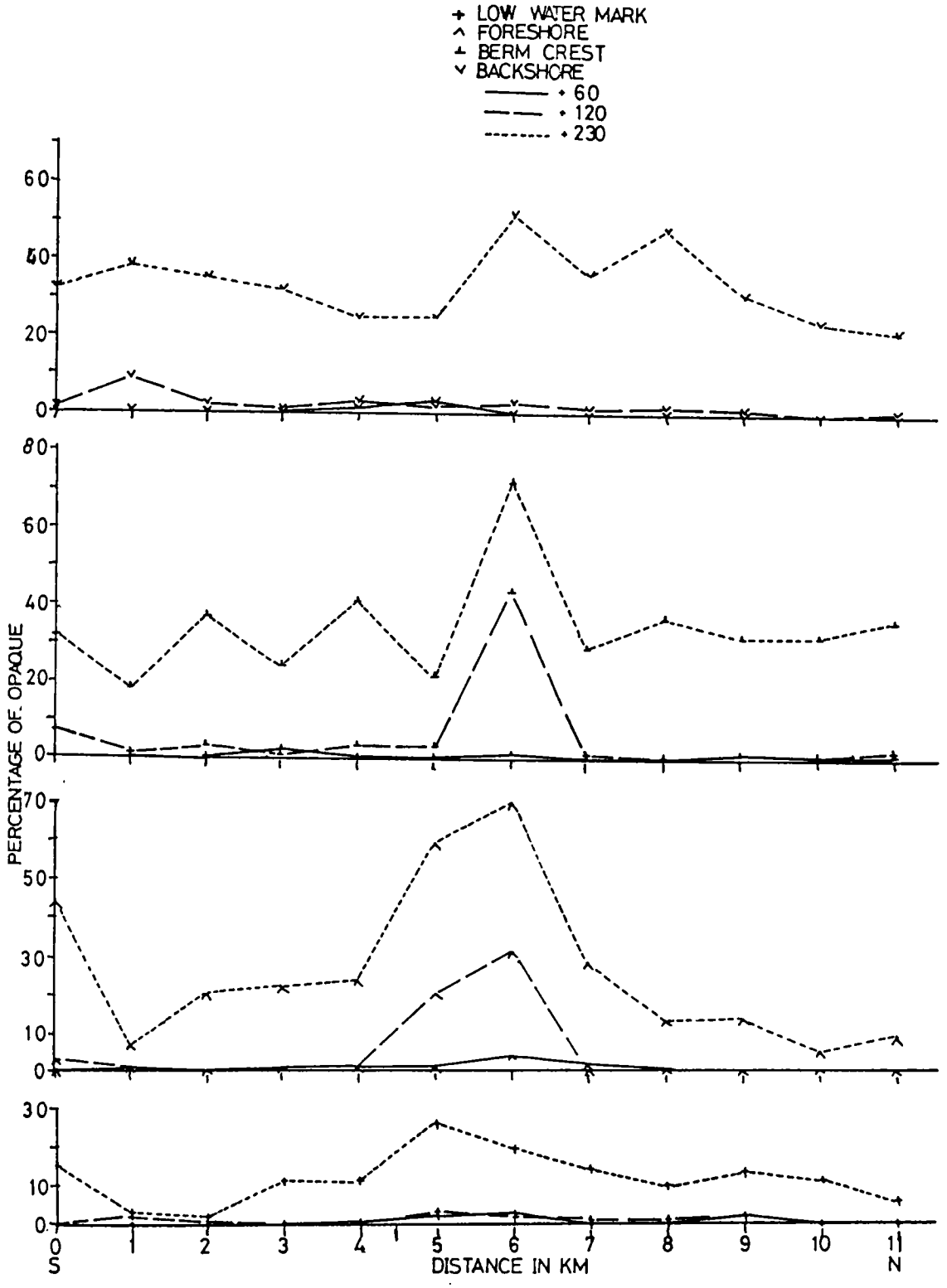


FIG.36. VARIATION OF OPAQUE DISTRIBUTION ALONG THE BEACH.

In marine sediments, the medium and fine size grades recorded abundant number percentages of hornblende, less number percentages of pyroxenes and nearly equal number percentages of opaques and garnets.

The amphibole / garnet ratios for the three size grades are plotted against river distance (Fig. 37). It is observed that the ratios increase downstream. Fig. 38 illustrates the amphibole / garnet ratios of LWM, foreshore, berm crest, and backshore. In general, an increase is noticed towards northern side, except in the LWM area where the sediments show small amphibole / garnet ratio. The shape and density index of the three size grades (Fig.39) decrease downstream, and Figs 40, & 41 show variations in shape index and density index of minerals of the LWM, foreshore, berm crest and backshore areas of the beach. In general, the shape index and density index decrease northward of the estuary mouth. The minor mineral groups (zircon, epidote, sillimanite, rutile, monazite, kyanite, biotite and altered minerals) show relatively low variability and no significant variation is observed in river, estuarine, beach and nearshore sediments.

DISCUSSION:

The concept of hydraulic equivalence as formulated by Rubey (1933) states that grains of different densities, if deposited together, should have the same

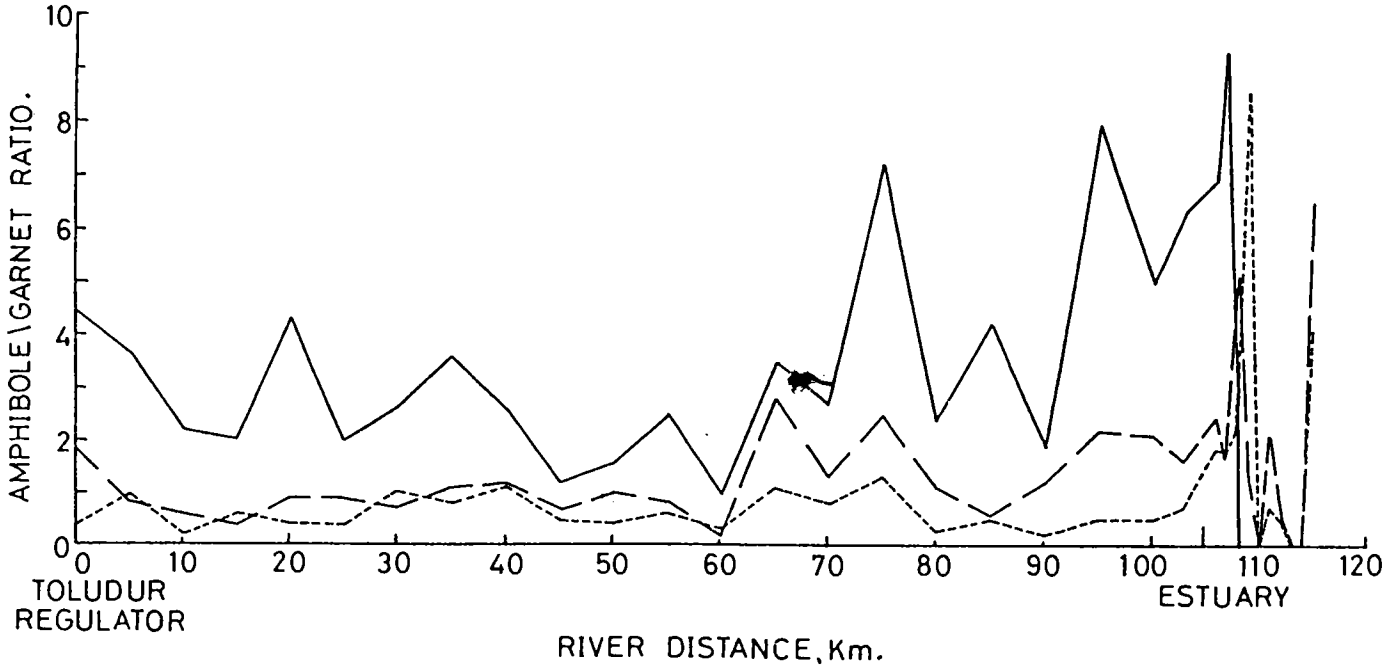


FIG. 37. DOWNSTREAM VARIATIONS OF AMPHIBOLE\GARNET RATIO.

—— 500-250 MM. — — 250-125 MM. ..... 125-062 MM.

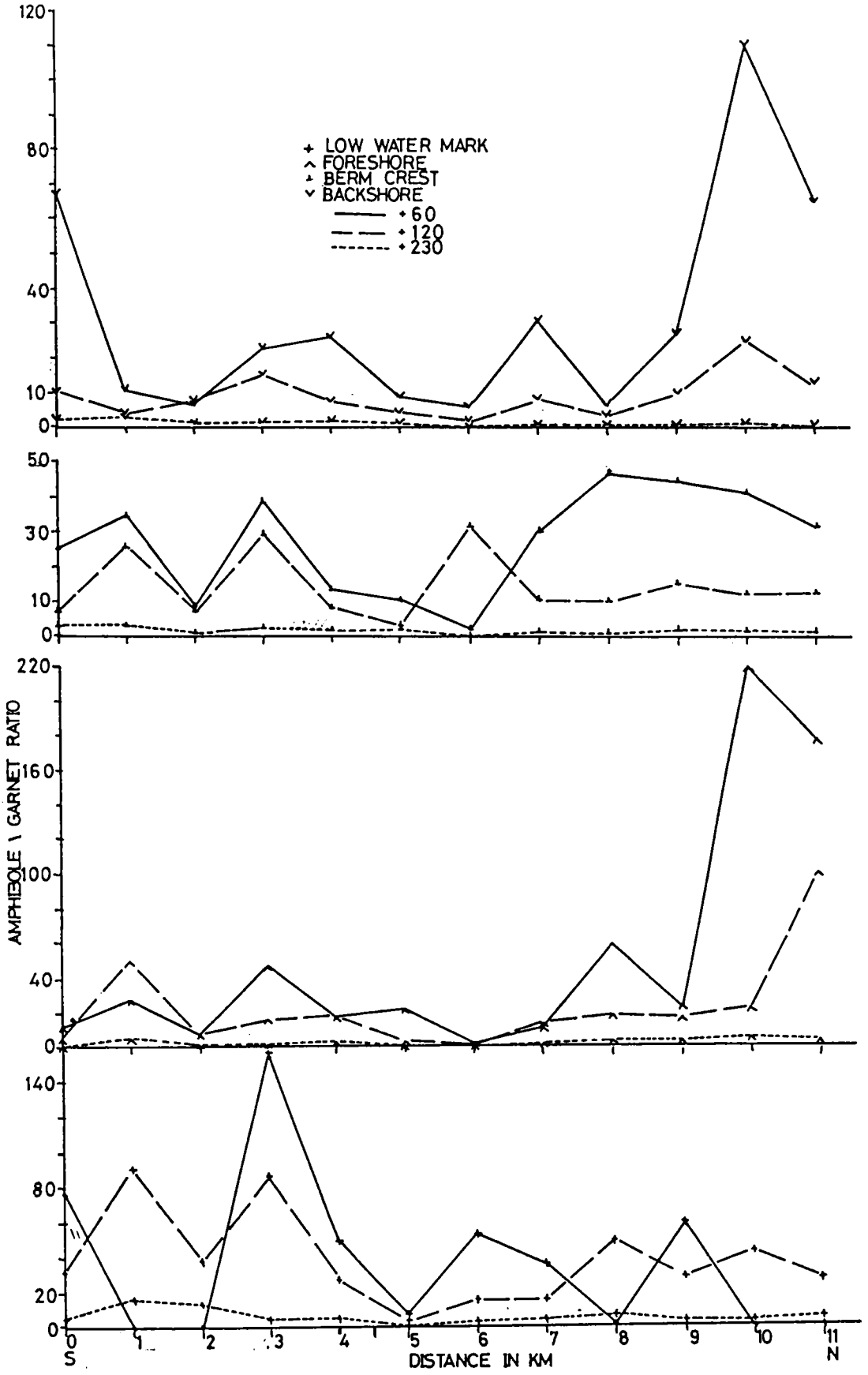


FIG.38. AMPHIBOLE/GARNET RATIO ALONG THE BEACH.

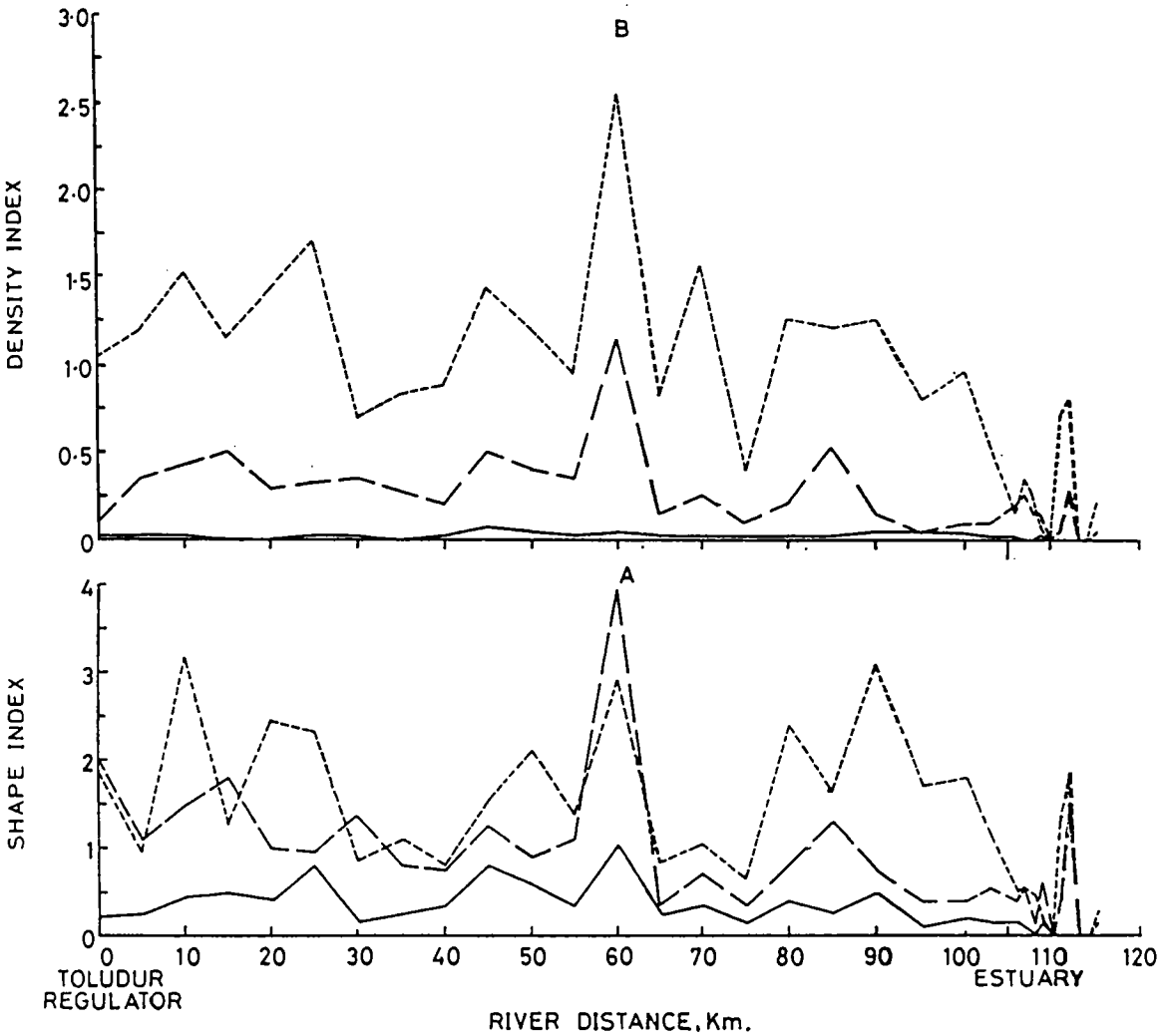
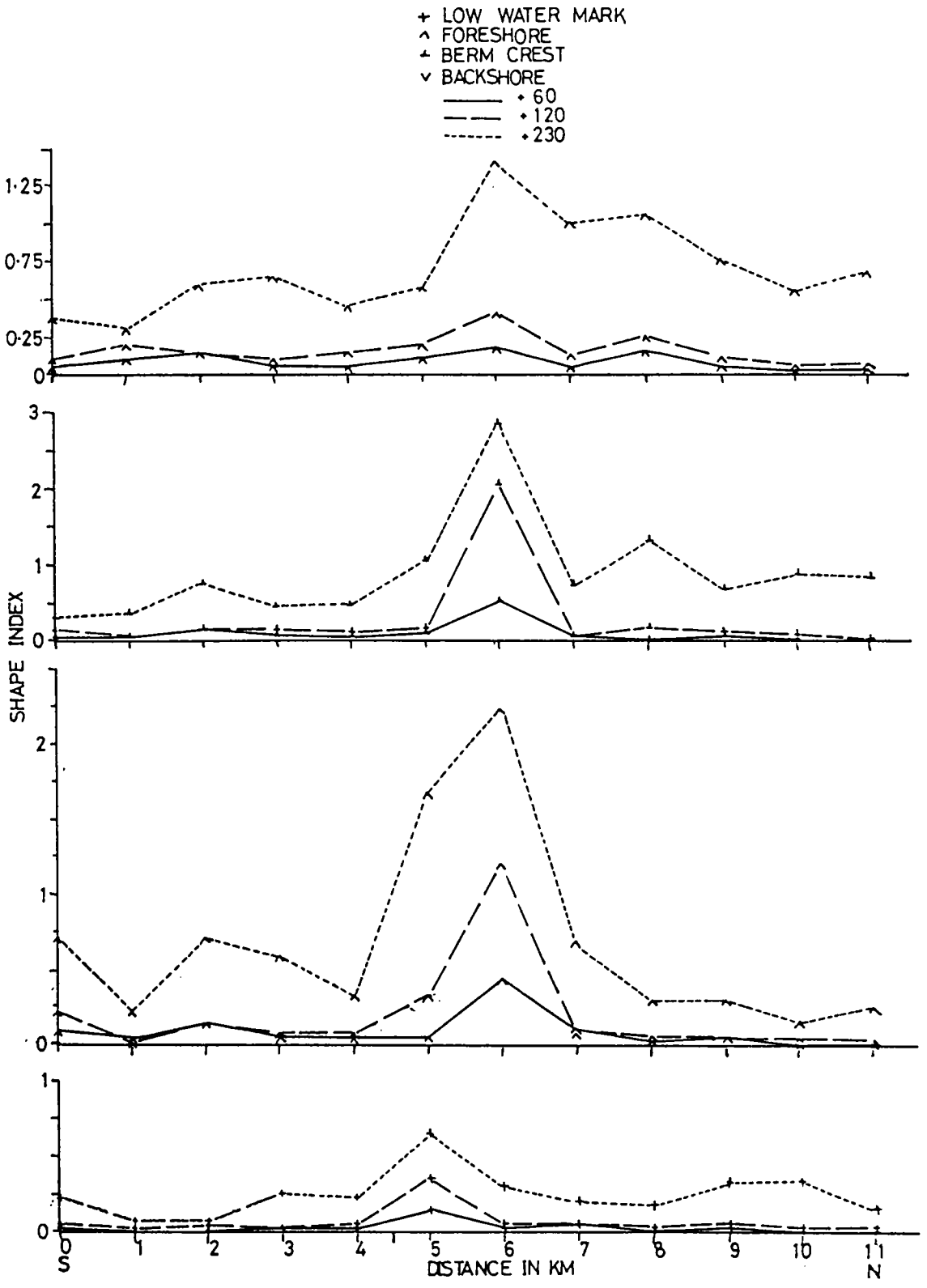


FIG. 39. DOWNSTREAM VARIATIONS OF SHAPE INDEX AND DENSITY INDEX.

A - SHAPE INDEX. B - DENSITY INDEX.

—— 500-250 MM. — — 250-125 MM. ------ 125-062 MM.



FIG·40·VARIATION OF SHAPE INDEX ALONG THE BEACH.

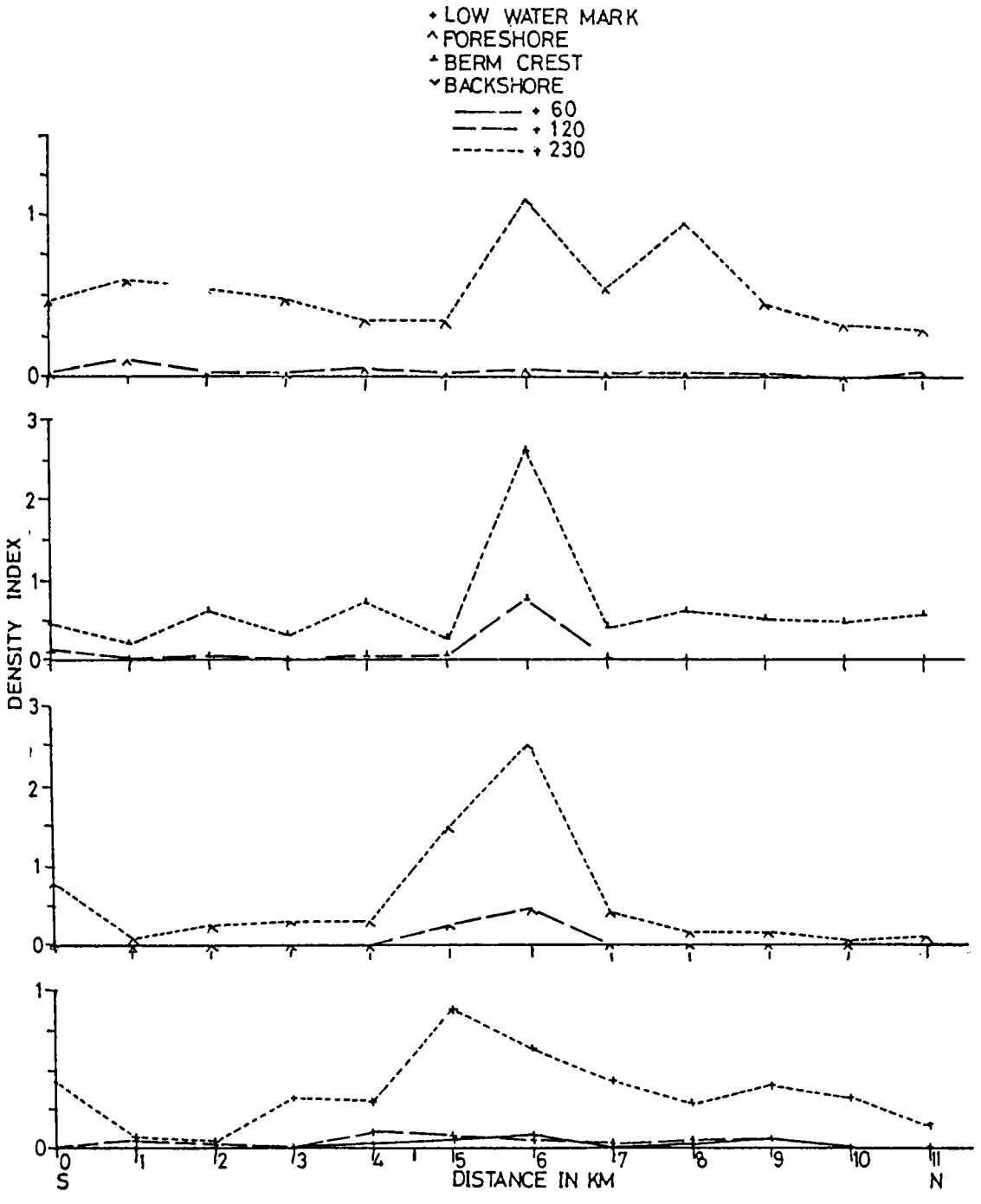


FIG. 41. VARIATION OF DENSITY INDEX ALONG THE BEACH.

settling velocities, or the denser mineral should be smaller by an amount which can be predicted based on settling velocity equations. Based on this theoretical analysis, it is proved that, with respect to quartz, the grain size distribution of heavy minerals would be displaced towards the finer size, the exact amount depending upon the density, size, shape, availability of heavy mineral grains and the nature of deposition medium. Rittenhouse (1943) observed that, in Middle Rio Grande, the size distribution curves of heavy minerals and light minerals were similar in form, and were displaced towards the finer sizes. This is because, given a set of hydraulic conditions, medium to fine size of heavy minerals with greater specific gravities tend to be deposited with quartz and other lighter minerals of larger sizes. The hydraulic equilibria maintained by the heavy and light minerals are due to either the availability of coarser heavy minerals like that of light minerals or the absence of coarse lighter minerals (Engelhardt, 1940; Van Andel, 1950; Briggs, 1965). Hand (1964) observed that selective sorting based on size, density and shape of grains resulted in non-hydraulic equilibrium conditions between heavy and light minerals. Further, the heavy minerals once deposited are more difficult for entrant to transportation than hydraulically equivalent quartz. Therefore, heavies, moving by saltation with lights, would tend to be smaller than the sizes predicted by settling velocities. These heavies are further shielded from currents by larger quartz

grains and thus remain behind while the larger quartz is moved.

In general, the weight percentages of total heavy minerals show a decreasing trend downstream in the three size grades (500 - 250, 250 - 125, and 125 - 63 microns) and the finer size shows a higher percentage of heavies than the coarser size grade. The present observations suggest that the medium to fine size heavies are deposited along with coarser light minerals in the upstream whenever the competence of the river decreases. This results in an increase in the percentage of heavies in the upstream and converse downstream. Density also helps to settle minerals faster in the upstream region. Similar type of observation was noted by Pollack (1964) in the South Canadian River channel, and explained it on the basis of size - density hydraulic equivalence relationship. Lowright et al (1972) accounted two reasons for the heavy mineral concentration upstream. Firstly, the larger grains of lighter minerals project higher up in to the zone of fluid flow which increases the area of the grain exponentially upward. This helps the current, during flow, to carry more light minerals and leave heavies on the same place. Secondly, the light minerals which are comparatively abundant in the sediment than heavies, help the current to avail light minerals constantly. Therefore, the light minerals move downstream leaving the heavies in the depositional basin. It shall be concluded that the downstream decrease of heavies in the three size grades may

be due to the following factors, viz., 1) after deposition, the heavies are not easily entrant to transportation by subsequent low energetic flow, 2) they are shielded by the coarser lighter minerals, 3) the smallest light minerals do not settle in the water column at the place where a heavy mineral of the same size settles, because of the density difference. This leads to the deposition of heavies in the upstream and transportation and deposition of lighter mineral farther downstream.

CAUSES FOR DOWNSTREAM VARIATION IN MINERALOGY:

Downstream variations in the number percentages of the most predominant heavy minerals such as, pyroxenes, hornblende (blue green and brownish green), garnet (colourless and pink), opaques and altered minerals, in the 500 - 250, 250 - 125, and 125 - 63 microns size grades respectively were observed (Figs. 31, 32, & 33). In general the downstream variations of heavy mineral assemblages in sediments depending on the size, shape, density etc., were explained in detail (Rittenhouse, 1943; Pettijohn, 1957). However, in the present study, influence of size is not considered to analyse the variation of heavy minerals downstream since heavy minerals were estimated in three size grades and not as bulk. So, factors such as sorting based on specific gravity and shape of the minerals were alone considered. Heavy mineral variability due to selective abrasion seems to be rather trifle. Moreover, in general, only minor chemical weathering effects on

ferromagnesiam minerals were noted petrographically during this study. Similar type of weathering of heavy minerals were observed by Rittenhouse (1943) and Shideler and Flores (1980) in Rio Grande river. Therfore, it appears that the observed mineral variability is mainly attributable to source rock and hydraulic effects.

The heavy mineral variations along the river channel due to the influence of each of the above factors are discussed below.

PROGRESSIVE SORTING OF HEAVY MINERALS BASED ON THEIR SPECIFIC GRAVITIES:

Decreasing concentration of opaques and garnets downstream and the increasing concentration of amphiboles and pyroxenes in the three size grades observed in the present study could be explained by relating the differences in the specific gravity with the predominant heavy mineral assemblages. Since opaques (magnetite sp.gr. 5.2, ilmenite sp.gr. 4.7, and chromite sp.gr. 4.5) and garnets (sp.gr. 3.5 to 4.3) are heavier than amphiboles (hornblende sp.gr. 3.4) and pyroxenes (hypersthene sp.gr. 3.4, augite sp.gr. 3.33), the former will settle quickly during deposition whereas the remaining minerals of less specific gravity will be carried still farther down and deposited. Moreover, the high competency of the upstream water does not permit settling of the relatively low specific gravity minerals in the upstream. This results in the increased concentration of comparatively high specific gravity minerals (opaques, garnet) upstream and low specific

gravity minerals (amphiboles, pyroxenes) downstream. In addition, once deposited, these heavies cannot be easily entrant to the transportation by the less competent water. But, during flood season, if at all some heavies are lifted by the high energy water, they could only be those that have relatively low specific gravity. These heavies are then transported downstream. The density index, which shows a decreasing trend downstream (Fig. 39) also suggests that the opaques which are heavier than the non opaques are deposited upstream in large amounts and at reduced levels in the downstream. It may be suggested that garnet which also shows high specific gravity among the non - opaques may get deposited along with opaques (Rubey, 1933; Rittenhouse, 1943). Rubey (1933) has postulated that relatively lighter and heavier species of heavy minerals were sorted based on specific gravity and formed different assemblages. Rittenhouse (1943) also pointed out that " two grains of different densities would not be picked up with the same frequency or bounded at the same speed " .

PROGRESSIVE SORTING OF HEAVY MINERALS BASED ON THEIR SHAPE:

The downstream variation of heavy minerals can be expounded by the difference in shape which is one among the dominant factors that affect the downstream variation. From the literature, it is eivdent that when particles of same density and volume but of different shape

settle through a column of liquid, the particles with greatest sphericity will have the highest settling velocity because of least surface area (Rittenhouse, 1943; Pettijohn, 1957). Briggs et al (1962) contended that both density and shape of minerals are important factors in sorting of the heavy minerals downstream. Sheideler (1975) also strongly supported the fact that the shape factor along with other factors influences the mineralogical variations.

In the present study, it is observed that opaques and garnets are decreased, and amphiboles and pyroxenes increased downstream. This can be elucidated based on the variations in shape in the different heavy minerals. During flood all the median to fine sand size particles are carried away by the river in a suspension state (primarily as wash load). However, when the river's turbulence and competency decrease that will immediately affect the transportation of the sand particles. Moreover, the particles are not allowed to settle at the same place, but are in suspension for a period of time. In a circumstance where all the factors except density and shape are constant for the minerals which are in suspension, the higher density minerals will settle first along with the more spherical shape minerals and the less spherical and comparatively low density mineral will be in suspension for some more time (Rittenhouse, 1943). In the present study, the comparatively spherical nature influences the high density opaques and garnet to settle faster in the upstream regions. The amphiboles and pyroxenes which are prismatic

in shape with comparatively low density would settle slower than the above said minerals, which therefore, are transported downstream and deposited. Pettijohn (1957) also concluded that under suspension transport, the more spherical particles tend to be deposited, whereas less spherical particles tend to be carried away. Shideler and Flores (1980) also observed similar type of hydraulic shape sorting in Rio Grande river.

Moreover, the increase in amphibole / garnet ratios in the three size grades of Vellar river sediments (Fig. 37) may be also attributed to the continuous decrease in the competence of the river downstream. Owing to this, comparatively high specific gravity and sphericity garnets are deposited in the upstream than the amphiboles. Presumably this is due to the hydraulic shape sorting, and not due to selective abrasion. Pettijohn and Ridge (1933) have drawn a similar conclusion in the Cedar Point Spit, Lake Erie. Later investigators (Otto, 1938; Seibold, 1963) also studied the linear variation in the hornblende - garnet ratios and observed an increase in their ratios in the direction of transport.

Further, the decreasing trend which prevails in shape index downstream in the three size grades of Vellar river sediments (Fig.39) also provides supplementary evidence to the above explanation. Based on the above discussion it can be inferred that the decrease in opaques and garnets downstream of Vellar river is due to the

relatively more spherical nature. Further more, the increase of amphiboles and pyroxenes can be attributed to the prismatic nature of these minerals.

DOWNSTREAM CHANGES IN HEAVY MINERALS DUE TO SELECTIVE ABRASION:

Reduction of the pebble size feldspar to sand size grade during transportation evidences the selective wear (abrasion) and subsequent elimination of heavy minerals in the sand size grade. However, Pettijohn (1957) proposed that in a given conditions of rigour, the relatively softer and more cleavable minerals wear out more easily with a complementary enrichment in harder and more durable components. Therefore, it would be appropriate to consider the effect of selective abrasion while sorting out the factors that lead to progressive changes in heavy minerals and their quantity along the Vellar river. Friese (1931) determined the durability of considerable number of minerals and assigned a numerical value to the abrasion resistance of each mineral. Cozzens (1931) and Theil (1940) explained that the rate of wear of common minerals is a function of hardness. The more abundantly available heavy minerals aranged in the decreasing order of durability are given as garnet, opaques, amphiboles, sillimanite and pyroxenes (Friese, 1931; Theil, 1940; Dana, 1960). Based on the above order, one would expect the number percentage of garnet and opaques in any one of the three size grades of the Vellar river to increase downstream and that of amphiboles and pyroxenes to decrease. But in the present

study the results were in contrary to the above expectation. This suggests that abrasion does not play any major role in sorting of the various heavy minerals along the 115 km distance of the Vellar river. Most geologists agree that selective abrasion is neither the sole nor the major cause to bring about the progressive sorting of the minerals downstream. Whetten et al (1969) also explained that there is little or no mechnical breakdown by abrasion of minerals or rock fragments in low to moderate gradient stream. In case of Vellar river, because of its low gradient and the short distance, it could be inferred that the processes of abrasion did not play a prominent role during its dispersion. The variation in composition is due to source and local reworking. Moreover, abrasion is maximum in high gradient mountain streams and is negligible in low gradient streams.

DOWNSTREAM VARIATIONS OF LESS ABUNDANT HEAVY MINERALS:

The other heavy minerals such as sillimanite, monazite, zircon, epidote, biotite, kyanite, rutile and altered minerals are less abundant in the Vellar river, which constitute less than 10 % in the three size grades. All these minerals show no specific trends of three size grades along downstream. But sillimanite in 125 - 63 micron size grade shows a slight increase along downstream. Epidote and zircon are relatively enriched in finer fraction than in coarser fraction.

The above results suggest that the less abundant heavy minerals such as sillimanite, monazite, zircon, epidote, biotite, kyanite, rutile and altered minerals do not follow any of the known distribution pattern. The absence of detectable provinvcial differences among other minor mineral groups might be partially attributed to the low levels of their occurrence. Moreover, their absence or less amount also adds support to the inference that provincial variations in source rocks are only of minor importance in establishing the total heavy mineral variability.

Moreover, the variation in the heavy minerals of the sediments of the distributaries of Vellar river, namely Manimukta Nadi and Chinnar river are similar to that of Vellar river. So, these factors do not influence any mineralogical variation in the Vellar river.

HEAVY MINERALS IN BEACH AND MARINE SEDIMENTS:

The weight percentage of heavy minerals in the three size grades of the beach are given in Table.7. In all the samples the coarse fractions contain less amount of heavies than the fine fractions. Samples from the LWM, foreshore, berm crest, and backshore areas show a comparatively high percentage of heavy minerals in all the three size grades in stations 5 & 6 which are in the immediate vicinity of the northern side of the river mouth. The heavy minerals that are brought by the rivers accumulate generally in the mouth. But in the present case

their concentration in the northern side of the mouth is as a result of the well known northerly current as stated by Borreswara Rao and LaFond (1958), Mallik (1968), and Seralathan (1979), which carries the sediment northwards and deposits them in stations 5 & 6. The increasing concentrations of heavies towards north in the LWM are due to the winnowing action of the strong backwash which removes light minerals constantly and concentrate the heavies in the LWM resulting in the increase of light fractions in the fore shore sediments. However, in the berm crest, this may be due to the effect of strong landward wind which removes light sands from the bermcrest and deposit them in the backshore as stated by Sastry et al, (1987).

There is a marked variation in the individual number percentages of heavy minerals along the beach in the three size grades. The coarse size grades contain abundant hornblende and pyroxenes. Garnet is less and the opaqes are very few. In medium to fine size, the hornblende content reduces considerably and opaques and garnet percentages markedly increase, whereas in the medium size, pyroxene is more. This can be explained on the follwing lines: The amphibole and pyroxenes are rock forming minerals, and hence present always in the rocks as major constituents with larger sizes. But the garnets and opaques present are comparatively of smaller size and amount. The rocks disintegrate and liberate more amphiboles and pyroxenes and less opaques and garnet. Moreover, when

these minerals are transported to the depositional basin, amphiboles and pyroxenes are reduced in size to a limited extent by physical processes as well as disintegrated by chemical weathering and persumably removed by leaching or solution as stated by Pettijohn (1975). But in the case of opaques and garnets, transportation results in the reduction of their size only. Thus the coarser fractions are abundant in amphiboles and pyroxenes while the finer ones are rich in garnet and opaques.

As regards the individual heavy mineral variation in the northern side stations, the decrease in the coarser amphiboles and finer opaques may be due to the hydraulic equivalence of coarser amphiboles and comparatively finer, high density opaques. That is to say, the fine opaques may sink rapidly than the medium to coarse size amphiboles. Bateman (1953) demonstrated that small fragments of pumice saturate and sink in water much more rapidly than large fragments. Sallenger (1979) also explained the same mechanisem. Further, the amphiboles and opaques are deposited simultaneously against the currents due to the larger size of the former and higher density of the latter. This leads to high concentration of amphiboles and opaqes in the stations that lie very near to the mouth, whereas the medium size pyroxenes and the fine size garnet show an increasing trend towards north. This explains the fact that these two minerals, which are in hydraulic equivalence, are less competent to deposit against the currents - a feature attributed to the known northerly

direction of littoral currents, which carry the sediments northwards. The differential grain entrainment through size and density variation, highlighted by many authors like Barrie (1981) Komar and Wang (1984) Reid and Frostic (1985), also play a role in heavy mineral enrichment.

The decrease of heavy minerals northward in the direction of littoral drift is better explained in terms of differntial transport rates with denser grains moving along shore less rapidly than the fall-equivalent light ones as propsed by Hand (1967), and Barrie et al (1988).

The amphibole / garnet ratio (Fig.38) decreases whereas the shape and density indices (Figs. 40 & 41) increase towards north. This variation is due to less amount of hornblende and opaques in the north. Moreover, the increasing density index adds support to the inference that the overall non-opaques is comparatively less incorporation than the opaques.

Results obtained for the southern beach i.e in the southern side of the river mouth suggest that the changes are similar to those in the northern side.

In the marine sediments, the medium to fine size grades recorded abundant number percentages of hornblende, less number percentage of pyroxenes and comparatively equal number percentages of opaques and garnets (the coarse size grades were almost absent in so many samples). In general, no changes are observed in the

fine size grade of individual heavy minerals. However, the northern side of the nearshore region shows an increasing trend of opaques and decreasing trend of garnets, pyroxenes and amphiboles in the medium size grades. The more heavy opaques observed in the northern side can be explained on the basis of the Everts's (1973) hypothesis, later confirmed by Sallenger (1979), which states that the larger grains can be transported over a stable bed of smaller grains when the shear stress is less than that necessary to initiate movement of the smaller grains. Under these circumstances coarse grains may be more easily transported than fine grains by the northerly longshore currents. This concept adds evidence to the increase of median size opaques towards northern side. The minor heavy minerals did not show any significant changes in the nearshore sediments.

PROVENANCE:

Based on the above study of heavy minerals and their relative abundances in the river channel, estuary, beach, and the nearshore sediments, the probable source rocks of these minerals are identified.

The heavy mineral assemblages of the environments under study consist predominently of hornblende (blue green and brown green), garnets (colourless and pink), opaques and pyroxenes in increasing order of abundance. The less abundant minerals include zircon, epidote, kyanite, rutile, sillimanite, monazite, biotite and the altered minerals.

Based on Pettijohn's (1975) description of detrital mineral suites characteristic of source rock type, the blue green hornblende variety is characteristic of high rank metamorphic rocks. However, hornblende is also derived, to a certain extent, from the acid igneous suite. Garnet is also one of the by products of high rank metamorphic rocks. As stated by Mallik (1968) the colourless to pale pink garnet is mainly derived from khondalite (garnet-biotite schists and gneisses) and pink variety is characteristic of charnockite. Magnetite, ilmenite and chromite are constituents of opaques, which are usually derived from high rank metamorphic and basic igneous rocks. Pyroxenes are normally liberated from the basic igneous rocks. Epidote, kyanite, sillimanite, and biotite are also derived from high rank metamorphic terrain as well. Zircon and monazite are charcteristics of acid igneous rocks.

The homogeneous occurrence of the four dominant heavy minerals namely hornblende, garnets, opaques and pyroxenes in each of the environments suggests that the chief contributors are mainly high grade metamorphic rocks and basic igneous rocks. Based on this conclusion it is suggested that the sediments present in the environmnets under study may be derived from their origin point namely Chitarai, Tainandamalai, Kalrayans, Kollaimalai and Pachaimali hills, where in the rock types mainly consist of biotite gneisses, hornblende gneisses, magnetite quartzite, charnockite, granite, ultrabasic and basic intrusives

(Krishnan, 1954; and G.S.I., 1976a,b). Further, since these sediments do not contain any major constituents of reworked or chemo or organic minerals, it may concluded that the Cretaceous and Tertiary formations have not supplied any major constituents of minerals to these environments.

Moreover, that the heavy mineral suites have not altered significantly in the river channel, estuary, beach and nearshore environments is a fact suggestive of the minimum or rather nill influence of the external agencies. The sediments appear to have originated from a single provenance.

LIGHT MINERALS:

QUARTS / FELDSPAR RATIOS:

The quartz / feldspar ratios, which are determined in the three size grades (500 -250, 250 -125, and 125 - 63 microns) of the Vellar river are given in Table 9. The quartz /feldspar ratios vary from 3.33 to 8.82 in coarse size grade, from 2.03 to 7.89 in medium size grade, and from 0.93 to 13.64 in fine size grade. It is observed that the ratios of the three size grades increase downstream.

CAUSES FOR VARIATION OF QUARTZ / FELDSPAR RATIOS:

An increasing trend in the quartz / feldspar ratios in all the size grades is observed downstream. The increase of quartz content relative to feldspar in downstream is not due to the process of selective sorting, as the specific gravities of quartz and

TABLE: 9. QUARTZ \ FELDSPAR RATIO IN DOWNSTREAM.

DIST. km	SAMPLE NO	MESH SIZE	QZ\FS RATIO
VELLAR RIVER			
0	2	>60	3.85
		>120	2.03
		>230	0.93
5	5	>60	3.80
		>120	2.83
		>230	1.90
10	8	>60	3.33
		>120	2.73
		>230	1.32
15	11	>60	4.00
		>120	2.11
		>230	3.06
20	14	>60	5.00
		>120	2.75
		>230	3.37
25	17	>60	4.62
		>120	5.77
		>230	2.83
30	20	>60	5.17
		>120	4.76
		>230	5.66
35	23	>60	3.33
		>120	2.83
		>230	5.36
40	26	>60	5.26
		>120	3.57
		>230	5.00
45	29	>60	4.84
		>120	4.05
		>230	2.08
50	32	>60	3.53
		>120	4.69
		>230	4.35
55	35	>60	5.56
		>120	3.53
		>230	4.69
60	38	>60	6.67
		>120	5.45
		>230	13.64
65	41	>60	6.00
		>120	1.56
		>230	7.69
70	44	>60	4.92
		>120	4.48
		>230	6.67
75	47	>60	4.62
		>120	6.12
		>230	3.03
80	50	>60	3.85
		>120	2.66
		>230	2.04
85	53	>60	5.66
		>120	3.03
		>230	3.61
90	56	>60	5.26
		>120	5.08
		>230	2.46
95	59	>60	4.00
		>120	3.75
		>230	3.19
100	62	>60	6.52
		>120	5.88
		>230	6.52
103	71	>60	6.82
		>120	2.83
		>230	2.52
ESTUARY			
106	83	>60	8.82
		>120	5.26
		>230	4.11
107	89	>60	5.26
		>120	6.12
		>230	3.95
108	95	>60	*
		>120	3.61
		>230	4.23
109	101	>60	7.50
		>120	5.08
		>230	6.67
111	113	>60	*
		>120	5.08
		>230	5.88
112	119	>60	
		>120	3.75
		>230	3.52
115	137	>60	3.53
		>120	7.89
		>230	2.56
MANIMUKTA NADI			
0	140	>60	5.66
		>120	3.13
		>230	6.82
5	143	>60	5.66
		>120	2.48
		>230	3.06
10	146	>60	3.57
		>120	3.70
		>230	4.17
15	149	>60	4.55
		>120	2.65
		>230	5.88
20	152	>60	4.05
		>120	4.41
		>230	1.59
CHINNAR RIVER			
0	155	>60	4.41
		>120	4.69
		>230	2.97
5	158	>60	3.95
		>120	2.17
		>230	1.70
10	161	>60	3.90
		>120	4.11
		>230	0.79
		>120	4.11
		>230	0.79

feldspars are nearly the same, ie., 2.65 and 2.70 respectively. As the other factors like size and specific gravity of the two minerals are constant, it can be resaonably inferred that the over all increase in the quarts / feldspar ratios in the three size grades may be due to the selective abrasion. It is a known fact that feldspar is less durable than quartz in any particular size. The increae in quartz / feldspar ratio in the finer fraction indicates that feldspars in this grade are subjected to greater abrasion than the medium and coarser fraction. This indicates that abrasion is more effective in the fine sands. The above findings agree well with the earlier investigations (Russell, 1937; Pettijohn, 1957; Pollack, 1964; Seibold, 1963). According to Pettijohn (1957) the mineralogical maturity of a sediment may be expressed by its quartz content, since most of the quartz grains are generally associated with feldspars. As all the feldspars have not disappeared from the sediments it can be concluded that the sediment has not attained full maturity.

CLAY MINERALS:

RESULTS:

The clay minerals data are given in Table 10, from which the following features are elucidated.

MONTMORILLONITE:

The most abundant clay mineral in the sediments of the Vellar river and its estuary is

TABLE: 10. Percentages of clay minerals in the Vellar River, Estuary, Tidal channel, and Marine sediments.

Distance in km	Sample No	Montmorillonite	Kaolinite	Illite
	River basin			
75	47	77.03	22.97	0
100	62	62.01	37.99	0
103	71	80.75	19.25	0
	av.	72.26	26.74	0
	Estuary			
106	83	78.98	21.02	0
107	89	70.43	29.57	0
109	101	77.00	23.00	0
110	107	82.11	17.89	0
111	113	72.92	27.08	0
113	125	74.13	25.87	0
115	137	66.39	33.61	0
	av.	74.57	25.43	0
	Tidal channel			
	166	72.10	27.90	0
	170	73.61	26.39	0
	av.	72.86	27.15	0
	Marine			
	174	62.32	37.68	0
	175	58.11	41.89	0
	183	46.71	46.51	6.78
	182	53.36	43.29	3.35
	191	50.19	43.19	6.62
	190	54.62	40.66	4.72
	av.	54.22	46.60	5.37

montmorillonite. The average concentration of montmorillonte in the freshwater river channel is 72.26 % . The estuarine and tidal channel sediments show an average content of 74.57 % and 72.86 % montmorillonite respectively. In general, the concentration of montmorillonite increases slightly downstream except in the mouth region. The marine samples show an average of 54.22 % montmorillonite.

KAOLINITE:

The next dominant clay mineral is kaolinite, which show the highest concentrarion in the nearshore marine sediments (av.46.60 %) followed by that in the tidalchannel (av.27.15 %), river (av.26.74 %), and estuaine sediments (av.25.43 %). In contrast to montmorillonite, the concentration of kalonite shows an decreasing trend downstream.

ILLITE:

Illite is virtually absent in the river, estuary, tidalchannel, and northern sector of the marine sediments. Only the sediments of central and southern sectors of the nearshore marine environment show a signifigant content of illite (av.5.37 %).

DISCUSSION:

The distribution of clay minerals in different environments of the study area can be explained by the fact that the detrital clay minerals undergo some changes in the depositional environments due to differential flocculation and or size seggregation or diagenesis.

Different researchers (Grim, 1958; Nelson, 1958; Powers, 1959; Johns & Grim, 1958; Milne & Early, 1958) have explained that the montmorillonite content decreases with consequent increase of illite and or/ chlorite in saline water environment as a result of diagenesis. However, in the present study the downstream increase of montmorillonite and the decrease of kaolinite and the absence of illite indicate that above variation is not due to diagenesis. Moreover, in the nearshore region the increase of montmorillonite content and decrease of kaolinite and illite towards offshore area also explain that diagenesis did not take place even in the high salinity water. A similar type of changes have also been reported in Cauvery deltaic sediments (Seralathan, 1979; Seralathan & Seetaramaswamy, 1982). Grim et al (1949), Grim (1950, 1968) and Griffin & Ingram (1955) have stated that kaolinite is unstable in alkaline waters and therefore it would alter to illite or chlorite in estuarine and marine sediments. However, in the present study illite does not occur in the estuarine environment (chlorite is not at all recorded in the study area). The percentage of illite is low (av. 5.37 %) and that of kaolinite is high in the nearshore marine environments (av. 46.60 %). The above two factors show that the lateral variations of clay mineral are not due to diagenesis. On the other hand, detrital source is the overall dominating factor influencing the clay mineral distrubution in the study area. Many authors like Tagart &

Kaiser (1960), Weaver (1960) and Biscaye (1964) opined that comparatively the detrital source is the dominating factor than the diagenesis for the distribution of clay minerals in the depositional area. The overall increase of montmorillonite content in the Vellar river and estuary can also be explained in the following way. The rocks which have considerable amount of magnesium release it upon weathering. Owing to poor drainage or low rainfall, the released magnesium remains in the weathering zone and montmorillonite is produced as the alteration product (Grim, 1968). During flood season this would be brought to the river and deposited downstream.

In the present study the kaolinite content of the Vellar river (av. 26.74 %) and estuarine (av. 25.43 %) sediments are relatively higher than those of the neighbouring Cauvery delta sediments (river av. 3.3 % and estuarine av. 10.2 % - Seralathan & Seetaramaswamy, 1982). Eventhough both the main drainage basins of Cauvery and Vellar are formed by almost simil ar type of rocks, the variation in the kaolinite is prominent in the Vellar river. This variation can be attributed mainly to the contribution by Manimukta Nadi, the distributry of Vellar, which drains the red soils in and around Neyveli Town. The red soils upon intensive weathering leads to the formation of kaolinite (Negalschmidt et al, 1940; Biscaye, 1965; Fairbridge, 1967). Moreover, the overburden in the Neyveli lignite field which consists mainly of white clay upon mining might have eroded and deposited in the river. This

process may also increase the kaolinite content. From the above explanation it may be inferred that the kaolinite formation is mainly controlled by the drainage basin rock types as stated by Griffin (1962) and Grim (1968).

The clay mineral varition downstream may be explained on the following lines. The larger amount of montmorillonite and kaolinite in the riverine sediments is largely influenced by the source. But in the case of estuarine the decrease in kaolinite content and increase in the montmorillonite content are because of the variation in the salinity of water i.e as described by Whitehouse et al (1960), slight increase of salinity (around 4 ‰) would completely flocculate and deposit the kaolinite by differential settling. That results in the abundence of kaolinite in the head region of the estuary and consequent decrease in further downstream. However, montmorillonite will have floc sizes varying over the entire salinity range. This would help montmorillonite to remain in suspension for a long period and distribute all over the estuary and cause deposition by natural settling with a slight increasing trend downstream. As explained by Gibbs (1977), montmorillonite has the smallest size, while 10 Å mica have the greatest size and kaolinite, the intermediate size. This would also help montmorillonite to remain in suspension for long time than kaolinite. The variation in the mouth region is because of the constant wave action which carry

the smallest size montmorillonite to calm deep waters and leaves the kaolinite to deposit in the nearshore.

A nominal amount of illite has been observed only in the central and southern sector of the nearshore sediments. This may be explained either by the conversion of montmorillonite to illite due to absorption of more K+ from the saline water as explained by Grim (1958), Hirst (1962a), and Parham (1964) or by the transportation of illite from the southern side by the longshore current to the study area where it might finally get deposited. The latter explanation is more appropriate in the present study, as the Vellar river and estuarine sediments do not show any illite content, whereas the neighbouring Cauvery deltic sediments contain comparatively more illite in the nearshore sediments thus emphasising that the longshore current has transported the illite from the southern side. Moreover, due to the less amount of illite available in the sediments off Cauvery delta, it is unable to reach further north of Vellar estuarine mouth. Based on the above said explanation it is concluded that the origin of illite in the present study area is from the Cauvery deltaic sediments.

In the marine eivironments, kaolinite and illite contents decrease towards offshore and a reverse condition prevails in the case of montmorillonite. This can be explained on the basis of differential flocculation as stated by Whitehouse et al (1960) and size seggregation as explained by Gibbs (1977) which act on the clay mineral simultaneously. As a result the coarse kaolinite and illite

settle quickly in the nearshore regions while fine montmorillonite with slow flocculation settles still seaward.

From the above discussion, it is concluded that the clay minerals in the river and estuary have come from the weathering of the magnesium rich rocks, red soils, and from the erosion of clay formation from the Neyveli lignite field. Their distribution in the estuarine and marine environments depends mainly on the differential flocculation and size seggregation. Further, the study explains that the illite content present in the marine sediment does not originally come from the drainage basin of Vellar river. Its origin is here by interpretted from Cauvery delta. Moreover, it is also observed that the diagenetic processes have insignificant effect on clays in the area under investigsation.

CHAPTER:IV.

GEOCHEMISTRY OF THE SEDIMENTS

INTRODUCTION:

Modern geochemistry includes studies on the qualitative and quantitative distribution of chemical elements in minerals, ores, rocks, soils, water, and atmosphere, and their circulation on the basis of the properties of their atoms and ions. The understanding of the distribution of elements in the sedimentation sequence was great ly enhanced by the introduction of the term "ionic potential" into geochemical discussions, as this quotient of ionic charge and radius gave a general clue to the distribution of elements in the process of weathering and sediment formation. Equally importance is given to the problems of oxidation and reduction for the distribution of the many elements which can exist in different natural environments in various stage of oxidation, such as iron, manganese, vanadium, chromium or sulphur, as very clearly tabulated in a work by Goldschmidt (1962) and others.

The process of weathering, and sediment formation are preparatory stages in the formation of sedimentary rocks. The study of sediments and the study of sedimentary rocks are thus in many cases closely interrelated. Both in sedimentary rocks and hydrolystate sediments the fixation of ions by crystalline clay mineral is governed, to a large extent, by the interaction of

polarization forces arising from the electrical fields associated with the surfaces of the clay particles and more or less polarizable ions or ion hydrates. Therefore, in ion exchange and adsorption on clay particles in soils and sediments not only the size of the ions involved is important, but also their polarizability (Noll, 1930; Jenny, 1932, 1941; Grim, 1953; Engler et al, 1977; Gast, 1977; Dyer, 1979; Bohn et al, 1979; Mayer & Fink, 1980; Seralathan, 1987).

The organic matter and carbonate content in the sediments play a great role in the distribution of chemical elements in various environments. So the geochemical studies also include the study of distribution of organic matter and carbonate content in the sediments (Willey, 1976a,b; Aston & Hewitt, 1977; Hyne, 1978; Seralathan & Seetaramaswamy, 1979; Willey & Fitzgerald, 1980). There exists a close relationship between modern geochemistry and pure and applied biology as the circulation and distribution of several elements, in nature, are similar to biochemical processes in which both plants and animals are involved. Some of the dominant geochemical factors of our time result from the activities of modern man - agriculture, mining and industry. Trace metals, owing to their greater significance either as nutrients or toxic materials to living organisms, have gathered larger attention by scientists in the recent times. Among them boron, cobalt, copper, zinc, and iodine are nutritionally

important while fluorine, arsenic, cadmium, and seleneium are considered as toxic metals (Taylor, 1974; Grieve & Fletcher, 1977; Borole et al, 1977; Mayer & Fink, 1980; Paropkari et al, 1980; Klinkhammer & Bender, 1981; Voutsinou-Taliadouri & Satsmadjis, 1982; Hirst & Aston, 1983; Davis - Colley et al, 1984; Murty et al, 1985; Pragatheeswaran et al, 1986; Seralathan, 1987; Ramanathan et al, 1988).

Both major and trace elements present in different environments take part in the chemical interactions involving dissolved and particulate phases. In this part, attention is paid on the geochemically relative trace elements. Trace elements found in the sediments of different environments, orginate from two principal sources, namely, those associated with solid and colloidal material, and those in solution. With regard to the trace elements associated with solid material a significant distinction could be made between these elements held in lattice position within detrital mineral, and those held in surface and inter- sheet (i.e. non-lattice) positions owing to the differences in their behaviour. The changes in physico-chemical parameters such as pH, Eh and ionic strength of the different environments along with the processes that include the interaction between dissolved and particulate forms affect the elements held in non-lattice positions. Kharkar et al (1968), based on his laboratory experiments, proved that some trace elements adsorbed from solution by clay minerals in the river environment are

released, to a greater or lesser extent, on contact with sea water, probably through ion exchange reaction involving the major cations, such as Na^{+} and Mg^{2+}. The effect of desorption on trace elements varies from one element to another. The trace elements which are in solution may be removed by a number of processes which include re-adsorption by inorganic and organic detritus, and incorporation into biota. Once taken up by detritus and organisms they may either get deposited within the estuary, or be carried in suspension to coastal and oceanic areas (Burton & Liss, 1976).

Sediments introduced in to the nearshore environments are mainly the weathered products of the continents, transported to the depositional sites by streams and rivers. Many of the elements in marine sediments can have more than one source and often associated with more than one host mineral. Considerable attention has been bestowed on the elemental distribution in marine environments, compared to that for elemental distribution in the sediments of aquatic environments in the continent. However, the economic importance and the potential vulnerability of the various elements to the impact of industrial and urban development led more and more investigators to study their elemental distributions (Garrells et al, 1975; Subramanian et al, 1980; Seralathan, 1987).

Hence, to understand the prevailing physico chemical, and to a little extent, the biological conditions, in different environments and the role they play in controlling the fixation and migration of the chemical constituents of sediments, the geochemical study of the bulk and clay fraction of the sediments of the Vellar river, estuary, tidal channel and nearshore environments have been carried out.

METHODS OF STUDY:

Samples for the geochemical analyses were collected from Vellar river, estuarine, tidal channel and nearshore environments. Geochemical analyses were carried out in the bulk sediments and clay fractions (less than 2 micron size). A total of 31 stations including 11 stations at an interval of approximately 10km from the river bed, and 20 stations at an interval of approximately 0.5km from the estuary were selected for the bulk chemical study. For the clay fraction study, stations that provided enough amount of clay were considered in the river while in the estuary the stations were fixed at an intervals of 1km. In river and estuary every station has three samples, i.e, north, central, and southern side of the river or estuary. All the samples of the above said stations were considered for the major elemental study. However, in the river and estuary, owing to larger number of samples, only those in the central part of these environments were considered for the analysis of trace elements in bulk and clay fraction. In

the tidal channel and nearshore environments 9 and 22 stations respectively were selected for the bulk chemistry study. For clay chemistry, four stations were selected in the tidal channel and in the nearshore, the stations which provided enough amount of clay were considered. All the above said stations of tidal channel and nearshore were considered for the major and trace element study.

The sediment samples were first washed with distilled water repeatedly to remove salt content. Later, a part of the washed samples was kept for drying as bulk, while subjecting the rest to wet sieving. In the natural suspension, less than 63 micron size materials were subjected to the settling velocity method, for the separation of less than 2 micron size particles (Carver, 1971). The clay fraction thus separated was dried in an air oven between 50-55 C and then powedered in an agate mortar. The bulk sediments were powedered in an agate mortar and passed through a 180 ASTM mesh sieve (Maxwell, 1968). The powdered clay and -180 mesh bulk samples were stored in a acid cleaned, air tight polyethelene container.

The powdered bulk and clay fractions were subjected to digestion for preparation of "Solution B". The digestion was carried out using concentrated hydrofluoric acid, sulphuric acid and nitric acid (all Analar Grade), according to the method of Maxwell (1968). Since most of the samples have high organic contant, a constant amount of concentrated perchloric acid was also

added to the above said acid mixture (Energlyn & Brealy, 1971). Platinum crucible and platinum tipped tongs were used for the digestion. The final solution was made up to 250ml in sulphuric acid medium and stored in acid cleaned polyetheylene container. This solution was used to estimate Na, K, Ca, Mg, Mn, P, Ti, Total Fe, and trace elements Cu, Co, Ni, Zn, Cr, and Cd. "Solution A" was prepared by fusion method (Maxwell, 1968) using NaOH for the analysis of Si and Al. The "Solution A and B" were prepared also for USGS reference standard rock sample No. "W2" in replicate. The organic carbon content and carbonate content were also estimated. The methods and the instruments employed in the chemical analysis of the sediments in the present study are as below:

	CONSTITUENT	METHOD\INSTRUMENT	REFERENCE
1	Organic carbon	Volumetric	Wakeel & Riley, 1957.
2	Carbonate	Volumetric	Hutchinson & MeClennan, 1947.
3	Silica	Molybdenum blue complex/Spec.Phot. 650 mμ.	Shapiro & Brannock, 1962.
4	Alumina	Alizrin red-S complex/Spec.Phot. 475 mμ.	Shapiro & Brannock, 1962.
5	Total Fe	Orthophenanthroline Spec.Phot. 560 mμ.	Shapiro & Brannock, 1962.
6	Manganese	Potassium periodate Spec.Phot. 525 mμ.	Maxwell, 1968.

7	Titanium	Hydrogen peroxide Spec.Phot.400 mμ.	Energlyn & Brealy, 1971.
8	Phosphorus	Molybdo vanado-phosphoric acid-complex±Spec.Phot. 430 mμ.	Shapiro & Brannock 1962.
9	Sodium & Potassium.	Flame Photometer.	Scott, 1939.
10	Calcium & Magnesium.	Titrimetric - EDTA method.	Welcher, 1961.
11	Cu, Co, Ni, Zn, Cr, & Cd.	Atomic absorption Spectrophotometer.	

INSTRUMENT	MAKE & MODEL NO.
Spectrophotometer (visible range)	Systronic-106.
Flamephotometer	Systronic-121.
Atomic Absorbtion Spectrophotometer	Perkin-Elmer-2380.

ORGANIC CARBON:

The organic matter content of the sediment was oxidized with known quantity of chromic acid and the amount of acid consumed was determined by running a titration against ferrous ammonium sulphate, using diphenylamine as indicator.

CARBONATE:

The sample was treated with known amount of HCl acid and the excess acid used was determined by titration with standard NaOH using bromothymol blue as an internal indicator.

SILICA:

Silica was analysed using "Solution A" (Shapiro & Brannock, 1962). A known amount of "Solution A" was mixed with ammonium molybdate solution, tartaric acid solution and reducing solution (which consisted anhydrous sodium sulfite, 1-amino-2-naphthol-4-sulfonic acid, and sodium bisulfite). Absorbance of the solution was measured at 650 mμ.

ALUMINA:

As in the case of silica, "Solution A" was used for the determination of alumina (Shapiro & Brannock, 1962). The coloured complexes of calcium aluminium alizarin red-S formed by the reaction of Solution A with calcium chloride-hydroxelamine hydrochloride mixture, potassium ferricyanide solution, sodium acetate-acetic acid buffer, thioglycolic acid mixture and alizarin red-S solution. The absorbance was determined at 475 mμ and an emperical correction of Ti was carried out.

TOTAL IRON:

A known amount of "Solution B" was mixed with Hydroxylamine hydrochloride, Ortho phenathroline solution and Sodium nitrate solution. The reddish orange O-phenathroline ferrous complex formed was measured at 560 mμ (Shapiro & Brannock, 1962).

MANGANESE:

A mixture of sulphuric acid and orthophosphoric acid along with potassium periodate was used to convert manganese ions to permanganic acid. The

intensity of this pink colour was determined at 525 mµ (Maxwell, 1968).

TITANIUM:

The intensity of yellow colour formed by the reaction of titanium ion with sulphuric acid and hydrogen peroxide was determined at 400 mµ (Energlyn & Brealy, 1971).

PHOSPHORUS:

The ammonium molybdo vanadate solution on reacting with phosphorus in the "Solution B" formed a yellow molybdo vanado phosphoric acid complex. Its absorbance was measured at 430 mµ (Shapiro & Brannock, 1962).

SODIUM AND POTASSIUM:

A known amount of "Solution B" was treated with ammonium solution and ammonium carbonate and filtered to remove interfering elements like iron, titanium etc. This solution was made upto a known amount and the sodium and potassium were determined using the flame photometer (Scott, 1939).

CALCIUM AND MAGNESIUM:

These elements were determined by combined titrimetric method (Welcher, 1961). Before titration the sample solution was treated with ammonium solution, filtered and finally made upto a knowm amount. Later, a part of the solution was treated with ammonium chloride and ammonium buffer solution, sodium hydroxide

solution and potassium cyanide solution, and titrated against disodium EDTA using erichrome black T as indicator (red to blue). From this titration values, total calcium and magnesium value were computed. The second titration with EDTA was carried out subsequent to the treatment of the remaing part of the solution with triethnolamine, potassium cyanide and sodium hydroxide and murexide-napthol green B as indicator (Olive green, through grey, to sudden blue). The second titration yields the calcium value. Magnesium value was computed by the subtraction of calcium value from the total calcium and magnesium value.

TRACE ELEMENTS:

Cu, Co, Ni, Zn, Cr, and Cd were estimated using atomic absorption spectrophotometer, Perkin-Elmer 2380. The samples were directly aspirated into the flame (Air-Acetylene fuel mixture) and using the absorption mode, the corresponding absorption in the digest was determined. Later, the absorption was converted into concentration.

RESULTS AND DISCUSSION:

ORGANIC CARBON:

Organic matter mainly consists of organic carbon. In the present study, since all the geochemical data are given in the elemental form, except carbonate, which is formed by different elements, the organic matter is also expressed as organic carbon.

Results obtained for organic carbon

content of the sediment samples collected from different environments are presented in Table.11. The bulk sediments of river, estuary, tidal channel and the nearshore areas recorded organic carbon contents of 0,03 %, 0.66 %, 0.86 %, and 0.39 %, respectively, while the clay fraction of the sediments from these areas have given organic carbon contents of 0.67 %, 0.91 %, 0.93 %, and 1.22 % respectively. The data are presented in Fig. 42, which suggests an increasing trend downstream in bulk and clay fractions.

The organic carbon in any ecosystem depends primarily on the biologically mediated processes for its production and destruction. These biological processes, besides causing significant changes in the oxygen and carbon dioxide concentrations of aqatic environments, also alter the Eh and pH of the system which consequently alter speciation of many chemical constituents (Sverdrup et al, 1955; Parsons & Seki, 1970). Hence, in the following paragraphs, the origin and cycling of organic carbon in Vellar river, estuary, tidal channel, and nearshore environments are discussed.

The variation in organic carbon content in the sediments depends on 1) the supply of organic matter to the environment of deposition, 2) rate of deposition of organic and inorganic constituents, 3) rate of decomposition and 4) texture of the sediments (Sverdrup et al, 1955). In the present study, both the absence and the very low amount of organic carbon content in the bulk sediments of the river could be attributed to the absence of a source which can

TABLE: 11. PERCENTAGES OF ORGANIC CARBON AND CARBONATE CONTENT IN THE SEDIMENTS OF THE DIFFERENT ENVIRONMENTS.

NORTH RIVER CHANNEL			
DIST.KM	ST.NO	Oc	Car
10	7	0	3
20	13	0	2
25	16	0	2
35	22	0	4
45	28	0	4
55	34	0.35	1
75	46	0	3
80	49	0	2
90	55	0	2
100	61	0	7
103	70	0	7

CENTER RIVER CHANNEL			
DIST.KM	ST.NO	Oc	Car
10	8	0	5
20	14	0	1
25	17	0	2
35	23	0	2
45	29	0	1
55	35	0.25	2
75	47	0	6
80	50	0	2
90	56	0	2
100	62	0	6
103	71	0.15	8

ESTUARY			
DIST.KM	ST.NO	Oc	Car
105.5	79	0.25	3
106	82	1.6	2
106.5	85	0.35	3
107	88	0.2	4
107.5	91	0.3	4
108	94	0.55	3
108.5	97	0.05	5
109	100	0.3	7
109.5	103	1.1	8
110	106	0.9	4
110.5	109	0.5	9.5
111	112	0.7	7
111.5	115	1.15	9
112	118	0.85	7
112.5	121	1.1	8
113	124	0.9	6.5
113.5	127	0.6	9
114	130	1.15	12
114.5	133	0.8	10
115	136	0.3	10

ESTUARY			
DIST.KM	ST.NO	Oc	Car
105.5	80	0.05	4
106	83	0.35	5
106.5	86	0.3	3
107	89	0.35	4
107.5	92	0.1	5
108	95	0.7	6
108.5	98	0.5	7.5
109	101	0.5	8
109.5	104	0.75	9.5
110	107	1.1	8
110.5	110	0.4	7
111	113	1.05	6
111.5	116	1.13	9
112	119	1.15	9
112.5	122	1.5	10
113	125	1.45	9
113.5	128	1.45	10
114	131	1.25	11
114.5	134	2.1	9.5
115	137	0.65	8

SOUTH RIVER CHANNEL			
DIST.KM	ST.NO	Oc	Car
10	9	0	5
20	15	0	4
25	18	0	14.5
35	24	0	2
45	30	0	2
55	36	0.45	2
75	48	0	6
80	51	0	2
90	57	0	3
100	63	0	4.5
103	72	0	6.5

TIDAL CHANNEL			
DIST.KM	ST.NO	Oc	Car
0.5	163	0.55	7
1	164	0.2	7
1.5	165	0.45	8
2	166	0.25	9
2.5	167	0.55	8
3	168	1.3	7
3.5	169	1.85	9.5
4	170	1.05	13
4.5	171	1.5	10

TABLE: 11. (CONT.)

ESTUARY

DIST.KM	ST.NO	Oc	Car
105.5	81	0.1	5
106	84	0.1	4
106.5	87	0.45	6
107	90	0.1	3
107.5	93	0.15	1
108	96	0.45	11.5
108.5	99	0.2	8
109	102	0.2	6
109.5	105	0.35	7
110	108	0.35	7
110.5	111	0.4	9
111	114	0.65	6
111.5	117	0.65	8.5
112	120	1.55	8.5
112.5	123	1.25	11
113	126	0.35	9
113.5	129	0.6	12
114	132	0.95	7.5
114.5	135	0.5	6
115	138	0	8

NEARSHORE

DIST.KM	ST.NO	Oc	Car
0	173	0.85	22.5
1	174	1.1	12
2	177	0.7	8
3	179	0.45	6
4	181	0.5	7.5
5	183	0.35	3
6	185	0.25	1
7	187	0	2
8	189	0.05	1
9	191	0	1
10	193	0	1
0	172	0.6	15.5
1	175	0.55	13
2	176	0.9	16
3	178	0.65	7
4	180	0.6	4.5
5	182	0.45	4
6	184	0.25	1
7	186	0.25	1
8	188	0	1
9	190	0.05	1
10	192	0	1

NORTH CLAY RIVER CHANNEL

DIST.KM	ST.NO	Oc	Car
35	22C	0.5	3
45	28C	0.25	3
55	34C	1.45	3
90	55C	0.65	6
100	61C	0.25	9
103	70C	0.85	8

SOUTH CLAY RIVER CHANNEL

DIST.KM	ST.NO	Oc	Car
35	24C	0.4	4
45	30C	0.15	3
55	36C	1.15	4
90	57C	0.75	6
100	63C	0.7	10
103	72C	0.9	8.5

ESTUARY

DIST.KM	ST.NO	Oc	Car
106	82C	1.95	4
107	88C	0.9	5.5
108	94C	0.8	5
109	100C	0.65	3
110	106C	0.65	6
111	112C	1	5
112	118C	1.1	5.5
113	124C	0.9	9
114	130C	0.85	10
115	136C	1.25	8

ESTUARY

DIST.KM	ST.NO	Oc	Car
106	84C	0.8	4.5
107	90C	0.15	5
108	96C	0.7	5
109	102C	1.2	5
110	108C	0.8	3
111	114C	0.8	4.5
112	120C	1	6
113	126C	0.95	11
114	132C	1.05	9
115	N.A		

TABLE: 11. (CONT.)

CENTER CLAY RIVER CHANNEL

DIST.KM	ST.NO	Oc	Car
35	23C	0.35	4
45	29C	0.05	4
55	35C	1.25	3
90	56C	1	7
100	62C	0.7	10
103	71C	0.7	9

ESTUARY

DIST.KM	ST.NO	Oc	Car
106	83C	0.95	2
107	89C	0.9	7
108	95C	0.75	6
109	101C	1.05	6
110	107C	0.85	5
111	113C	0.9	6.5
112	119C	1.05	6
113	125C	0.8	11
114	131C	1.1	10
115	137C	1.35	11.5

TIDAL CHANNEL CLAY

DIST.KM	ST.NO	Oc	Car
1	164C	0.9	10.5
2	166C	0.9	8.5
3	168C	0.85	8.5
4	170C	1.05	10

MARINE CLAY

DIST.KM	ST.NO	Oc	Car
0	173C	1.4	10
1	174C	1.35	10
2	N.A		
3	N.A		
4	181C	1.35	10
5	183C	0.9	8
6	N.A		
7	N.A		
8	189C	0.85	8
9	N.A		
10	N.A		
0	N.A		
1	175C	1.5	11
2	176C	1.3	11
3	178C	1.35	11
4	180C	0.9	11
5	182C	1.3	10
6	184C	1.25	9
7	186C	1.3	9
8	188C	1.35	8
9	190C	1.2	8
10	192C	1.25	8

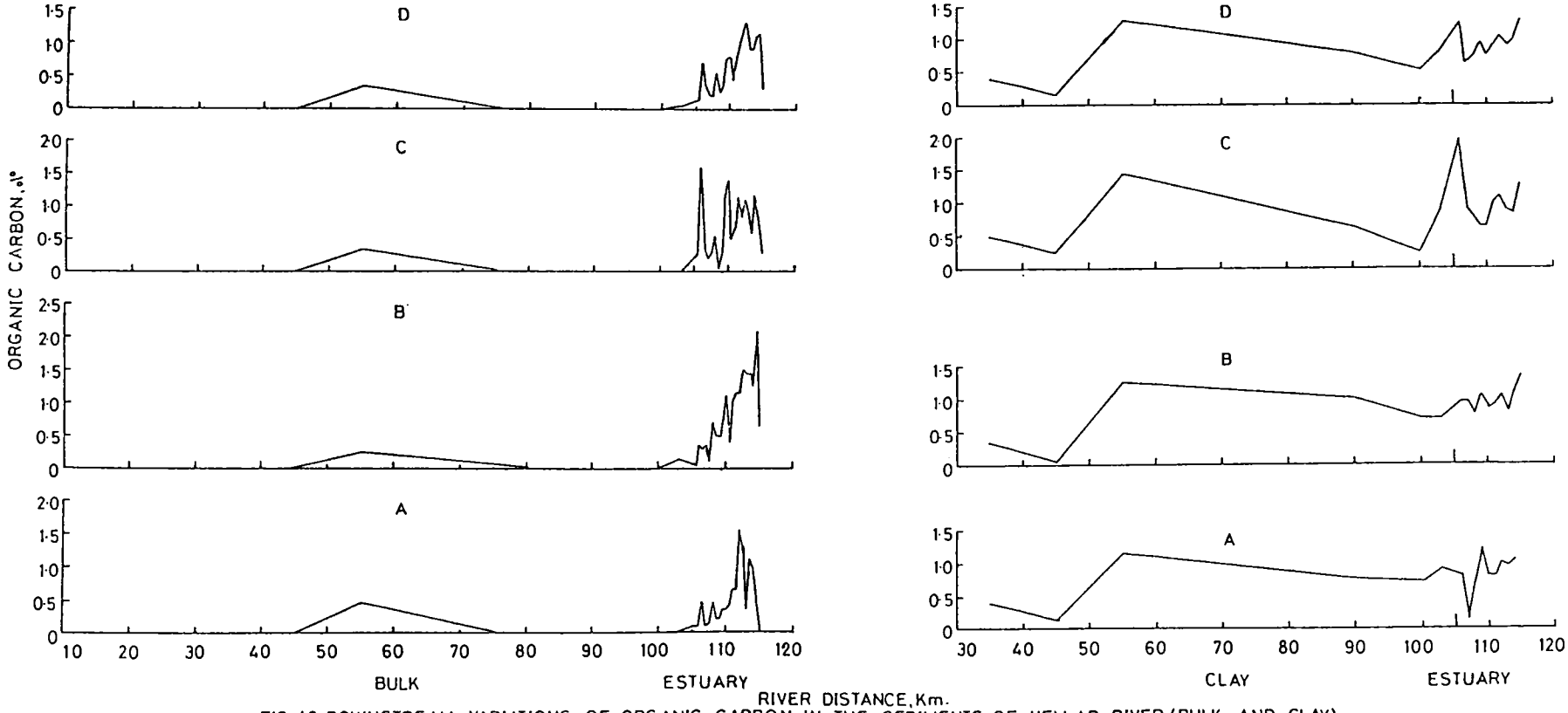


FIG. 42. DOWNSTREAM VARIATIONS OF ORGANIC CARBON IN THE SEDIMENTS OF VELLAR RIVER (BULK AND CLAY).
A-SOUTH. B-CENTRE. C-NORTH. D-AVERAGE.

supply organic matter to the environment. Even if it is available in small amounts, it would be easily destroyed by the prevailing oxic conditions in this environment. Similar results were also reported in Muvattupuzha river sediments (Balchand & Nambison, 1986). Comparatively, the estuarine bulk sediments show a higher amount of organic carbon. The increased organic carbon content in the estuary is possibly accomplished by the high productivity of the region besides the huge population of biota of estuary. Further, the rates of deposition of the organic and inorganic constituents are more in this environment, which result in the retarted decompostion of organic matter and in its better retainment. Moreover, the fine texture of the sediments reported in this environments, also enhances the retainment of the organic carbon. The variation of organic carbon content in the central, northern, and southern sectors are mainly due to the effects of tidal current movements which are observed normally on both the northern and southern sides of the estuary leaving the central portion undisturbed. This leads to an increase in the deposition of organic matter besides not allowing the deposited organic matter to be destroyed by oxidation. The tidal channel sediments contain high amount of organic carbon due to the conditions existing in the tidal channel which are similar in nature to those of the estuarine environments.

The nearshore bulk sediments show comparatively low amount of organic carbon than those of the

estuarine and tidal channel environments. Eventhough, the nearshore environment is having more productivity with high rate of deposition of organic and inorganic constituents and slow rate of decomposition than the estuarine and tidal channel environments, owing to the coarse nature of sediments, the organic matter is unable to retain more in the sediments. Further, due to the high turbulence of water nearshore, the organic matter of the sediments would be oxidized by the water. Hence the organic carbon content is very less in the nearshore environments.

It is observed that the overall organic carbon content in the clay fraction is higher than that in the bulk sediments. Within the environments, the nearshore environment shows a high percentage of organic carbon in the clay fraction (1.22 %) followed by tidal channel (0.93 %), estuarine (0.91 %) and riverine (0.67 %) environments. In general, clay fraction absorbed more organic carbon. Further, clay contains normally four times as much as organic matter as sand does (Trask, 1932). According to Trask (1939), the main cause of the increase of organic matter in fine sediments is the similarity in the settling velocities of the organic constituents and fine sediments, whereas Carter and Mittern (1978) explained that the increase in organic carbon with decreasing grain size may be either due to the co-sedimentation of particulate organic matter with small mineral grain or due to the enhanced surface adsorption of organic matter owing to the greater surface area of finer grains of the sediment. Suess (1973)

also observed that the increase in organic carbon and nitrogen with decreasing grain size is linearly related to the surface area of mineral grains. Earlier reports (Pusch, 1973; Rashid & Brown, 1975; Busch & Keller, 1982) suggest that the organic substances in sediments off Peru and Chile, was an outcome of the aggregation of clay particles to form an open micro structural network. From the above studies it is clear that the fine nature of the clay fraction results in high amount of organic carbon content.

The variation of organic carbon in the clay fraction of marine, estuarine, tidal channel, and riverine might be influenced by the large amount of primary production and the variation of clay minerals in these environments. Because of the high primary production, in the nearshore, estuary and tidal channel environments, the planktons which existed in the similar size range of clay would deposit more in these environments and increase the organic carbon content in the clay fraction. Moreover, the clay size spores and pollens also increase the organic carbon content in clay, as has been reported in Cilicia Basin (Sigel et al, 1978; Shaw & Evans, 1984).

The clay minerals also help to increase the organic carbon content. The nearshore environment shows a higher amount of kaolinite followed by tidal channel and estuarine environments. The organic carbon content is also following the same pattern of variation. As explained by Gibbs (1977) the larger size of kaolinite compared to

montmorillonite facilitates more absorption of organic carbon to the kaolinite mineral than the montmorillonite. Further, Dyer (1972) described that the kaolinite mineral would floc easily with slight increase of salinity whereas, montmorillonite would not. This also helps to increase organic carbon content by trapping the organic matter in the floc and retains it for long time without destruction. But in the case of river sediment, eventhough the kaolinite content is present in considerable amount, the less availability of the organic matter to the sediment leads to its poor concentration. The above observation leads one to propose that the clay mineralogical variation may also influence the variation in organic carbon content in the sediments.

CARBONATES:

The carbonate content of bulk sediments, on an average, was maximum in the tidal channel sediments (8.72 %). This is followed by the sediments in the estuary (7.06 %), marine (5.91 %), and river (3.80 %). In the clay fraction the carbonate content in the various environments decreased in the following order: marine (9.40 %), tidal channel (9.38 %), estuary (5.83 %) and river (5.81 %). Fig. 43 shows the downstream variation of carbonate content in bulk and clay fraction. Both the bulk and clay fraction show an increasing trend downstream.

The variation in carbonate content in the bulk sediments is mainly due to the shell fragmnets and tests of organisms, inorganic and organic precipitation, and

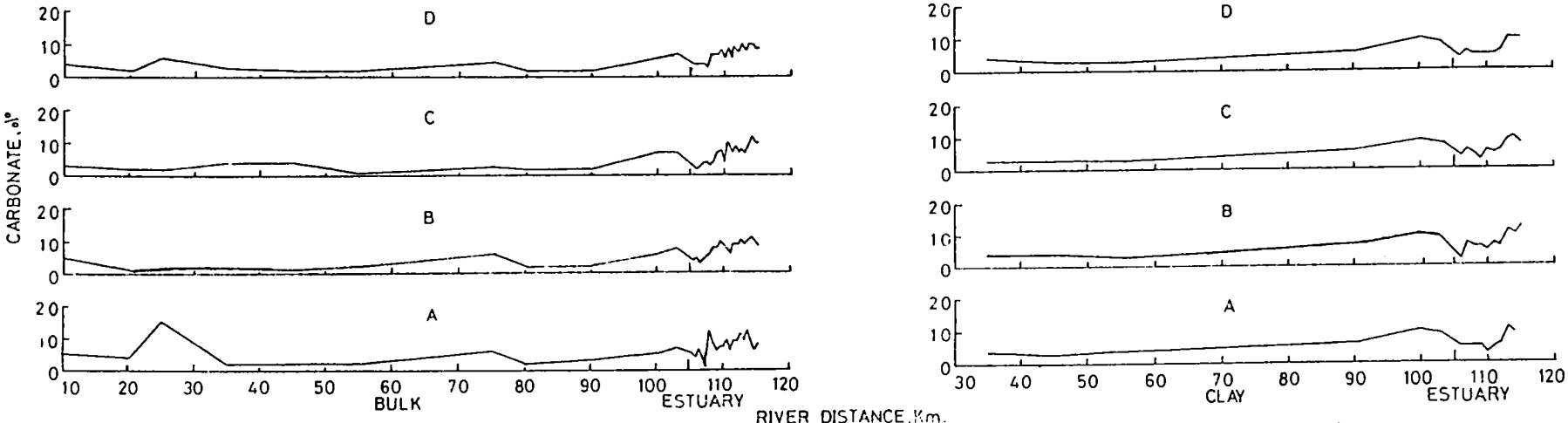


FIG.43. DOWNSTREAM VARIATIONS OF CARBONATE IN THE SEDIMENTS OF VELLAR RIVER (BULK AND CLAY).

A-SOUTH. B-CENTRE. C-NORTH. D-AVERAGE.

the supply of carbonate minerals by the rivers. The variation of carbonate content in the bulk sediments of the river can be explained as follows. The river sediments show number of small broken shell fragments and very small gastropods. Further, inorgainc precipitation may also result as the fertilizers in the nearby paddy fields on reaching the river react with the water and precipitate iron and manganese as carbonates. However, the estuarine environment showed a high amount of carbonate content consequent on the abundance of shell fragments of molluscan and other shells with a number of zooplankton tests. As explained by Cloud (1965) and Nair & Pylee (1968), chemical precipitation induced by photosynthesis and respiration of large number of organisms also causes addition to the carbonate budget. The variation of carbonate in the sediments of the tidal channel also can be explained on similar lines. The positive correlation of carbonate with Mn, Al, Ca, and organic carbon supports the above suggestions (Tables. 14, 16, 17, 19 & 20). The nearshore sediments show a comparatively less amount of carbonate than the estuarine and tidal channel sediments. This may be due to the shell fragments and tests of organisms of the nearshore sediments being removed to deeper places by constant wave action. Hence the availability of shell fragments is reduced considerably and consequently reduced their carbonate content. Variations of carbonate content in the clay fraction were minimum in the river and estuarine environments. This is possibly due to

the fact that the composition of the clay mineral i.e montmorillonite is not altered considerably in these environments and also less amount of clay size tests of organism are avilable in these environments. But in the case of tidal channel and nearshore environments along with the montmorillonite, the clay size zooplankton test, and to a certain extent the precipitation of carbonate might increase the carbonate content.

MAJOR ELEMENTS:

PHOSPHORUS:

Results of the analysis of phosphorus are presented in Table. 12. In general, average phosphorus content was comparatively high in the nearshore (65 ppm) sediments. This was less in tidal channel (41 ppm), estuarine (34 ppm) and river (28 ppm) sediments. In the clay fraction, the average phosphorus levels were 95 ppm, 55 ppm, 52 ppm, and 29 ppm in the nearshore, tidal channel, river and estuarine sediments respectively. The Kakinada Bay sediments (less than 63 micron) shows almost similar values (10 - 50 ppm) of phosphorus (Shenoi, 1960). However, the average phosphorus concentration in clay (< 4 micron) is much lower than the values reported for Boga Vagre in Gulf of Paria (299 ppm, Hirst, 1962b), Godavari (159 ppm, Naidu, 1968), Krishna (89 ppm, Seetaramaswamy, 1970), mean value of east coast of India (663 ppm, Rao, 1971), Mahanadi (137 ppm, Satyanarayana, 1973), the different environments of Cauvery delta - marine (487 ppm), tidal channel (382 ppm), estuary

TABLE: 12. CONCENTRATIONS OF MAJORE ELEMENTS (Si, Al, Fe, Mg, Ca, Na, K, Ti, P, Mn) IN THE SEDIMENTS (BULK AND CLAY) OF VELLAR RIVER, ESTUARY, TIDAL CHANNEL, AND NEARSHORE ENVIRONMENTS (PPM).

RIVER (NORTH-BULK)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
10	7	378063	12244	15627	27228	4803	7511	4219	1804	34	1613
20	13	377222	13143	17047	27228	6404	6109	3616	3820	46	1613
25	16	386053	7545	27465	22852	4803	4907	3014	1167	23	2420
35	22	366288	14798	14206	43274	4803	6609	3415	7003	23	807
45	28	378904	15676	20836	23825	5603	5107	2913	4881	57	807
55	34	377642	11167	14206	36953	4803	6509	3415	5306	74	807
75	46	397828	6979	21309	17990	4803	4607	1909	1910	0	4841
80	49	381007	6302	10418	41329	4803	8011	3717	6684	97	7261
90	55	379745	6302	15627	39870	4002	7110	3215	6791	57	6454
100	61	364185	4672	25098	40843	4002	5007	1909	3396	0	6454
103	70	381427	9771	25571	19935	4803	5207	3014	1061	6	3227

ESTUARY (NORTH-BULK)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
105.5	79	311197	23380	38356	42788	4803	8612	3918	2971	6	6454
106	82	277134	18920	42618	46677	4803	7711	6329	1804	34	807
106.5	85	312459	18937	41671	41330	4002	6910	3616	3183	23	6454
107	88	324234	20134	36936	26742	7204	8212	4219	3714	29	807
107.5	91	289750	24737	34568	54943	6404	9113	4520	1698	103	1613
108	94	257789	26474	44512	46671	7204	8512	4420	2122	69	2420
108.5	97	308674	21524	44039	33549	6404	8813	4018	5199	57	6454
109	100	288068	27394	37883	30631	4803	11316	6530	1804	23	807
109.5	103	263677	26488	41198	44732	4002	8011	6630	1910	74	807
110	106	261574	26944	42618	43274	4803	8312	5224	2334	46	4841
110.5	109	251481	25312	52562	43760	3202	6409	3817	2228	23	6454
111	112	283021	21740	38830	45219	4803	7811	4822	2759	6	5648
111.5	115	228772	25893	66295	27228	3202	4707	3315	1910	51	11295
112	118	276714	24602	32201	46191	7204	11316	6429	2441	6	6454
112.5	121	260312	26412	46880	32576	4002	7110	4621	2016	17	13715
113	124	303628	24998	32674	37925	5603	11116	6329	2653	57	807
113.5	127	277975	25004	35515	39384	4803	8412	4721	1804	34	7261
114	130	248958	26022	44512	46677	4803	6609	4520	2016	11	5648
114.5	133	272508	26160	38830	31118	3202	9814	5224	2016	40	2420
115	136	304469	18563	22730	55915	7204	8612	5023	1167	0	4034

RIVER (CENTRE-BULK)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
10	8	374281	12404	20836	27228	4803	6009	3616	2865	17	7261
20	14	373437	14017	14206	33549	4803	6910	3918	4881	29	1613
25	17	377642	12488	21783	31691	4002	5308	2511	849	11	9681
35	23	380166	6944	12312	43760	4803	6810	3817	2228	23	4034
45	29	373016	8235	17047	34035	6404	5708	3415	1804	29	2420
55	35	378904	12207	15627	31118	5603	6109	3315	3396	74	1613
75	47	405819	6013	13259	24311	4002	5608	3014	637	0	4841
80	50	378063	9915	16574	37439	4803	6609	3616	2865	51	4034

TABLE: 12.(CONT.)

	90	56	388156	9268	14206	29659	5603	8412	3616	3714	29	4034
	100	62	348205	13360	32674	39379	4002	7511	3114	3714	6	5648
	103	71	404557	4342	14206	20421	4002	4206	2712	743	6	4034

ESTUARY (CENTRE-BULK)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
105.5	80	308674	20716	42145	51539	4002	7911	3516	3395	86	7261
106.0	83	345261	13242	26044	35008	4002	7611	3918	1910	11	807
106.5	86	311197	22003	37883	36953	4002	7811	4119	2122	46	8068
107.0	89	328440	19031	33621	19449	9606	7411	4219	2122	34	807
107.5	92	242650	26013	42618	45219	2401	5908	3717	2122	69	6454
108.0	95	254845	26481	44512	45705	5603	8212	4420	2016	23	1613
108.5	98	284283	25022	34568	32576	7204	8913	5525	1592	91	4841
109.0	101	301946	21192	34095	48136	3202	7411	4520	1910	23	807
109.5	104	253163	26267	42145	35494	4803	7010	4320	1592	91	807
110.0	107	219520	27297	54456	40356	5603	6309	4119	2228	40	5648
110.5	110	283022	24501	43092	43760	4803	7210	4420	2016	11	8068
111.0	113	277975	22008	52089	38411	5603	8412	4721	5199	17	4841
111.5	116	229193	25095	59192	44246	3202	5508	3717	2334	46	9681
112.0	119	257369	23943	44039	45705	6404	6409	4621	5199	11	5648
112.5	122	227090	26605	55404	31118	2401	7010	4018	2228	17	14522
113.0	125	239286	25538	47827	49552	4803	6409	4520	2016	6	6454
113.5	128	242230	26916	54456	31118	4803	5708	3817	1698	34	5648
114.0	131	246014	26565	47827	45219	4803	6209	4822	1804	63	6454
114.5	134	257789	24925	34567	35494	5603	9313	5324	1910	86	2420
115.0	137	272929	24755	31727	48146	6404	104149	5475	1486	0	2420

RIVER (SOUTH-BULK)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
10	9	374281	12510	17521	34035	4803	6109	3918	1273	17	807
20	15	373016	10835	17521	38411	6404	6409	3918	3926	17	2420
25	18	380586	10990	23677	26256	4803	2704	1406	637	34	7261
35	24	386894	7762	17047	35980	7204	6409	3616	2334	23	1613
45	30	376381	10262	13259	44732	4002	6409	3717	2228	34	807
55	36	379325	9660	18941	32090	4803	6710	3516	3289	57	807
75	48	386053	7750	23203	24797	4002	5007	2511	2441	0	4841
80	51	381848	10504	17521	35980	3202	7110	3616	1910	23	1613
90	57	395726	8468	9944	31118	5603	7310	3817	318	0	4034
100	63	398670	7383	17047	21394	3202	4907	2612	1379	5	4034
103	72	351149	12820	33621	29659	5603	6109	3014	2228	6	3227

ESTUARY (SOUTH-BULK)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
105.5	81	386053	5978	20362	43274	2401	3805	2813	955	0	4034
106.0	84	351990	25555	20836	27714	4002	6309	3415	1594	11	807
106.5	87	283442	25249	42618	37822	4002	8412	4822	1379	23	9681
107.0	90	295217	26841	35515	39870	1601	10615	5726	1804	46	807
107.5	93	283022	25585	39304	43760	4002	8612	5425	1486	51	7261
108.0	96	255687	25639	46880	46677	4002	7911	4420	2441	34	1613

TABLE: 12.(CONT.)

108.5	99	295638	24174	31727	48135	6404	8312	4320	1804	74	4841
109.0	102	317505	19857	26992	48136	5603	9013	5425	1379	11	807
109.5	105	298161	25488	24359	37439	4002	11617	6429	1804	63	807
110.0	108	286386	25534	42145	43760	7204	11516	6027	1273	34	4841
110.5	111	284283	25570	41671	49594	6404	9313	4520	2441	23	4034
111.0	114	285966	25318	44986	40843	6404	11016	5726	1379	0	2420
111.5	117	301946	25312	34095	43274	6404	9514	4520	2228	46	8068
112.0	120	267041	25293	38830	47163	4002	9614	5726	2441	46	4034
112.5	123	264518	26229	47647	34521	6404	6910	4018	2016	23	14522
113.0	126	311197	20235	35042	45219	6404	9413	5123	4138	0	5648
113.5	129	307833	24400	28412	42301	8005	8112	4822	1592	46	6454
114.0	132	254425	25557	35989	40843	4803	9113	5525	1804	69	7261
114.5	135	288489	22311	28886	40356	4803	9213	6128	2547	80	3227
115.0	138	331734	17628	14680	39384	5603	9413	6027	1061	0	1613

TIDAL CHANNEL (BULK)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
0.5	163	304048	24935	39304	29173	8005	9213	5927	1804	63	4034
1.0	164	314562	21820	26044	52512	4803	9313	6429	1061	29	807
1.5	165	293535	25742	38356	29659	7204	9614	6630	1273	34	1613
2.0	166	292274	23847	34568	57374	6404	9013	5927	1592	63	2420
2.5	167	274190	25629	42145	42788	4002	10014	6831	2547	40	1613
3.0	168	238445	26779	51142	56401	5603	7511	4822	1698	29	4034
3.5	169	263256	26418	51615	35008	2401	8112	5123	2971	51	3227
4.0	170	250640	26467	48774	45707	4803	7711	4922	2228	0	3227
4.5	171	261574	26667	49721	36466	3202	7611	5826	2334	57	4034

NEARSHORE (BULK)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
0	173	325916	18584	23203	34521	17610	4907	3215	1698	11	4034
1	174	327599	16758	29832	31604	8005	5007	3918	2016	51	807
2	177	320870	26336	26044	40356	7204	11016	5625	2122	46	1613
3	179	316244	25774	30306	39384	8005	11917	6329	1698	80	2420
4	181	333486	24585	22256	40356	6404	10195	5625	1061	29	807
5	183	351149	18280	21873	40843	4803	8011	5525	2016	40	4034
6	185	351149	19617	19415	40843	4002	8612	5525	955	69	3227
7	187	325496	24322	29359	35008	6404	12918	8137	1698	120	3227
8	189	317085	24014	34095	39384	6404	11917	7434	1273	86	807
9	191	297320	18872	57771	31604	5603	11316	6530	10186	80	8874
10	193	325916	20269	36936	26256	5603	11917	7233	2971	86	2420
0	172	364185	18805	18941	31118	8805	3205	2712	2334	63	7261
1	175	349887	16947	24624	35980	6404	7210	4420	2228	29	1613
2	176	346702	17695	26044	43760	9606	5908	4119	1592	91	2420
3	178	306992	26211	30780	52025	7204	11216	5726	2228	74	2420
4	180	316664	25372	29833	44732	5603	10615	5625	2334	40	807
5	182	342738	20953	25098	39870	4803	8312	5123	1486	0	807
6	184	321711	23006	35042	43274	4002	9714	5425	3289	34	3227
7	186	311618	25566	32674	38411	6404	14120	8539	1698	97	807
8	188	320449	24693	37883	36466	6404	7711	3918	2971	126	807

TABLE: 12.(CONT.)

	9	190	302787	18708	53089	41329	4802	10315	6027	8913	74	5648
	10	192	331383	19032	40724	25770	5603	10916	6630	4457	97	7261

RIVER (NORTH-CLAY)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
35	22C	229193	24400	61559	36466	8028	3705	2813	1592	46	3227
45	28C	226249	28763	72924	47163	10406	4807	3516	2016	46	1613
55	34C	229193	28791	72924	46677	9606	3004	3114	1592	46	9681
90	55C	224988	28929	68662	27714	11206	6509	2813	1592	51	10488
100	61C	219946	29946	57771	30632	8005	3305	4018	849	137	6454
103	70C	230875	28135	67242	29659	5603	5207	3114	1061	46	7261

ESTUARY (NORTH-CLAY)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
106	82C	222885	28936	55404	40843	1601	2303	5324	1486	6	2420
107	88C	222885	27567	64874	42301	2401	2604	3014	1273	51	2420
108	94C	224988	27360	60612	47650	1601	3605	2210	1273	17	11295
109	100C	222044	27775	70083	35008	3202	3205	3717	1273	23	9681
110	106C	224146	27746	65348	37895	2401	3104	3014	1698	0	4841
111	112C	226249	27179	64400	41329	1601	5908	3717	1910	51	4034
112	118C	219941	27636	66768	38898	2401	3305	4119	1273	34	4034
113	124C	222464	27651	71504	34035	800	3705	4320	1061	23	1613
114	130C	224988	27705	63927	26256	1601	6409	3918	1273	46	4841
115	136C	224988	28135	66295	32090	1601	4707	4320	1061	23	4034

RIVER (CENTRE-CLAY)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
35	23C	224988	28783	65348	52512	11206	3405	2813	1698	46	1613
45	29C	233398	30491	69136	48622	9606	5408	3516	2016	46	2420
55	35C	233819	29627	68189	53484	8805	2904	3315	1486	46	10488
90	56C	223726	26993	70556	34521	9606	7210	2712	1592	51	5648
100	62C	219946	29946	57771	30632	8005	3305	4018	849	137	6454
103	71C	230875	28003	67242	30631	4803	4406	3014	955	69	7261

ESTUARY (CENTRE-CLAY)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
106	83C	224567	26516	64874	37925	2401	3805	3415	1486	23	6454
107	89C	222464	27829	67716	38898	1601	3205	3114	1486	40	4034
108	95C	225829	28273	62033	41329	2401	4006	2913	1061	17	8874
109	101C	220782	27761	63927	39384	3202	3505	3415	1486	34	1613
110	107C	230875	27553	60613	34035	2401	7110	3516	1486	0	4841
111	113C	222885	27803	67715	37925	1601	5708	4219	849	51	5648
112	119C	225408	27816	64400	45705	1601	5007	4320	1698	34	4841
113	125C	226249	27429	63927	38411	3202	3805	3616	1273	17	4034
114	131C	220362	27691	68662	29659	4002	6509	4520	1486	51	4841
115	137C	224146	28189	65821	29659	3202	6209	5224	1273	23	2420

TABLE: 12.(CONT.)

RIVER (SOUTH-CLAY)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
35	24C	229193	25082	64401	35980	9606	3805	2813	1698	46	3227
45	30C	230875	29820	77659	46677	8005	3805	3616	1698	34	3227
55	36C	220782	29365	72924	41815	11206	3004	3415	1273	46	8068
90	57C	209007	32967	60139	29659	8805	4506	2712	1167	46	13715
100	63C	223305	34425	66768	26742	5603	3004	2913	1061	46	6454
103	72C	227511	27989	67715	32576	5603	3705	3114	1167	34	8874

ESTUARY (SOUTH-CLAY)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
106	84C	223305	27360	65348	37439	3202	2704	2712	1273	17	8068
107	90C	220782	27982	74345	34035	1601	3906	3817	1273	29	4841
108	96C	223305	27622	63453	41329	3202	2604	2310	1486	17	9681
109	102C	218259	27732	65348	41356	3202	3305	3215	1910	34	5648
110	108C	223726	27705	65348	30145	1601	4406	3315	1273	0	6454
111	114C	222885	27803	66295	37925	1605	3705	3516	849	34	7261
112	120C	224146	27858	65821	41815	1601	3906	4018	1061	29	3227
113	126C	221203	27954	65348	38898	3202	3805	4420	1698	46	2420
114	132C	225408	27691	67715	27228	2401	5808	4320	1486	86	4841

NEARSHORE (CLAY)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
0	173C	216997	28673	62507	28687	4002	4006	4320	1273	74	4034
1	174C	215315	28121	58718	33549	4803	5308	4119	212	57	4841
2	N.A										
3	N.A										
4	181C	203119	27512	73871	41329	4002	5207	4371	1061	86	4841
5	183C	203540	27312	65821	40356	4002	7210	4119	955	69	2420
6	N.A										
7	N.A										
8	189C	196391	27457	74819	25770	4002	4106	2813	849	69	7261
9	N.A										
10	N.A										
0	N.A										
1	175C	204381	27069	73871	36466	4803	3004	3516	1486	97	4841
2	176C	222464	28162	72451	30145	4803	3205	4520	1698	91	14522
3	178C	209848	28004	76239	40356	4002	2403	2732	1698	80	12102
4	180C	203119	27124	75765	35980	4803	4707	3616	1698	86	6454
5	182C	201437	26973	70793	35494	4803	3205	2310	849	109	4034
6	184C	206904	26752	75765	41329	4803	4006	3817	1061	97	8874
7	186C	203960	24359	68189	28687	4803	4506	4219	1273	166	11295
8	188C	209848	27975	69136	26742	6404	3205	4520	1379	172	11295
9	190C	201858	27539	70556	27228	4803	3505	4420	1698	149	11295
10	192C	206904	25295	69610	26742	4803	4106	2612	849	103	6454

TIDAL CHANNEL CLAY

DISTAN	STATI	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
1	164C	228352	28120	66768	34035	800	3705	4520	1273	63	3227
2	166C	223726	27968	65348	35980	1601	4406	4219	1486	63	4034
3	168C	228772	27906	64401	35008	2401	4406	4018	1379	46	6454
4	170C	226249	27630	64400	34035	2401	3906	4018	1379	46	8874

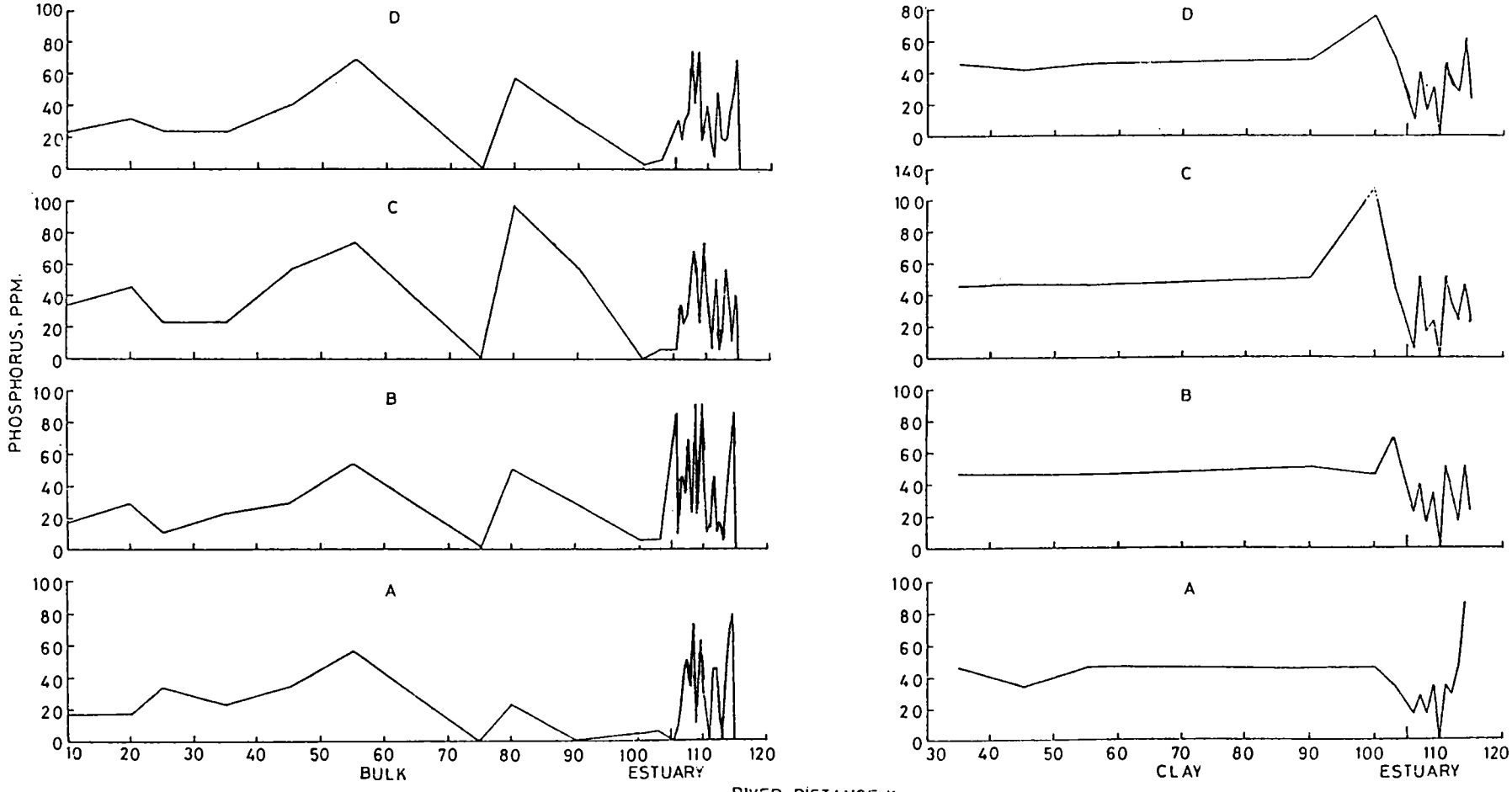


FIG.44. DOWNSTREAM VARIATIONS OF PHOSPHORUS IN THE SEDIMENTS OF VELLAR RIVER (BULK AND CLAY).

A-SOUTH. B-CENTRE. C-NORTH. D-AVERAGE.

(375 ppm), and river (332 ppm) (Seralathan, 1979), and Ashtamudi lake (1091 ppm, Sajan, 1988). The value of phosphorus versus river distance is represented in Fig. 44. The bulk sediemnts show an increasing trend and clay fractions show an decresing trend downstream.

Phosphorus contents in Vellar river, estuary, tidal channel, and nearshore sediments and their distribution can be elucitated in terms of the phosphorus content of biota and their incorporation into the sediments after death, the differential adsorption of phosphorus by adsorbents and dissolved phosphate in the overlying waters. In sediments, largely, phosphorus is available in the forms of calcium phosphate and ferric phosphate. Part of phosphorus may also be fixed in clay minerals and organic matter.

Abundance of phosphorus in the nearshore environment can be explained on the following lines. Phosphorus is a biophile element (Landergren, 1954) and it is an inevitable constituent of cytoplasm. In the marine environment, biota involved in the food chain, consequent to the biomagnification of elements, provide a carrier mechanism for the transfer and transport of elements from the overlying body to the bottom sediments through organic matter after their death (Rankama & Sahama, 1950; Wakeel & Riley, 1961; Arrhenius, 1963; Bushinsky, 1964). However, the highly significant negative correlation observed between P and organic carbon in the present study indicates that the phosphorus fixation was not carried out through organic

matter. This leads to the second avenue, the phosphorus fixation with iron as ferric phosphate (chemogenous compounds). The strong positive covariance exhibited by phosphorus and iron (Table. 20) besides evincing a geochemical relationship between these two constituents, denotes that the phosporus, precipitated as ferric phosphate, is adsorbed by hydrous ferric oxide. According to Arrhenius (1952) the ferric phosphate formation or adsorption of phosphorus is favoured primarily by the adsorption of negatively charged phosphate ions by ferric compounds and positively charged ferric hydroxide sols, which is present in sediment facilitating the fixation of phosphorus by adsorption. Further, as suggested by Goldschmidt (1962), the oxidation of Fe^{2+} to Fe^{3+} favours the fixation of phosphorus as a very insoluble basic or normal ferric phosphate or perhaps ferric phosphoric acid. Moreover, the formation of ferric phosphate by the primary adsorption of negatively charged phosphate (PO_4^{3-}) ions on the positively charged ferric hydroxide ($Fe(OH)_3$) in solutions was mentioned by different authors (Mason, 1958; Vinogradov, 1959; Hirst, 1962b; Towe & Bradley, 1967; Williams et al, 1976; Seralathan & Seetaramaswamy, 1979). Bapat (1968) also experimentaly demonstrated the special role of iron in phosphate adsorption in soils. The above studies clearly indicate a close geochemical affinity between phosphorus and iron, and suggests that phosphorus is fixed in this environment as ferric phosphate at a significant level.

An insignificant relationship demonstrated by phosphorus with calcium and a strong negative correlation between carbonate, show that phosphorus is least fixed as calcium phosphate in this environment. Phosphorus content of the bulk sediments in the estuarine and tidal channel does not show any relationship between Fe, Ca, and organic carbon. Hence, it may be said that the phosphorus content observed in those environments might be brought from either the river or the nearshore waters.

The phosphorus of river (bulk) sediments showed a positive correlation between Ca and organic carbon and a negative correlation between carbonate and Fe. This varied observation in phosphorus in this environment is probably the outcome of reduced input of phosphorus from living resources, which are comparatively less in number in the overlying water body of the river. The positive correlation observed between phosphorus and organic carbon in this environment is most likely influenced by animal feces through sewage and remains of plants. Landergren (1954), Rajamanickam & Setty (1973), Sasamal et al (1986), Lakshmanan et al (1987) also postulated a similar type of explanation, for the increase of phosphorus. Phosphorus addition to river sediments through fertilizer brought by the excess water from nearby paddy fields in the form of calcium phosphate, may also be considered as influencing factor in this environment. These observations are in agreement with the model study of cycle

of phosphorus (Lerman, 1979), which states that the effect of the increased use of fertilizers may be very noticeable on a "local scale". Hence the variation in phosphorus levels in the river sediments might be attributed to the organic waste and the excess fertilizer used on the land.

The low value of phosphorus in the estuarine and nearshore sediments can be explained on following line. While studying the seasonal variation of phosphorus in sediments of Vellar estuary by Seshappa (1953) and Rajendran & Venugopalan (1973), it was found that invariabley the lowest content of phosphorus during post monsoon season as observed here. In the present study, samples were collected during Feberuary, ie. the post monsoon period. This variation is because of the sudden change in salinity during the northeast monsoon period (Oct - Dec), which releases the adsorbed and interstitial phosphorus fraction from the bottom sediments (Seshappa, 1953; Rajendran & Venugopalan, 1973) and impoverishes the phosphorus content when the freshwater flow ceases at the close of the monsoon.

The variation of phosphorus content in the clay fraction of different environments can be explained on the following lines. It is reported that phosphorus is adsorbed on clay mineral (Grim, 1953; Naidu & Dora, 1967; Weaver & Wampler, 1972; Paropkari et al, 1981). The Kaolinite is known to fix phosphorus (PO_4^{3-}) better than the other clay minerals like montmorillonite, illite, etc (Carroll, 1959; Robinson, 1962). Kelley (1948) observed

that the fixation of PO_4^{3-} by kaolinite was higher at pH levels above 7.0. Smectite also favours the fixation of PO_4^{3-} ions to a little extent by anion exchange in acid condition, when compared to the alkaline conditions, where it is insignificant (Wey, 1953). Therefore it is inferred that the high percentage of kaolinite content in the nearshore sediments might have led to a higher amount of phosphorus in the clay fraction. The high positive correlation of phosphorus with Ca (Table.28) also advocates that precipitation of calcium phosphate to a certain extent influences the phosphorus budget. The tidal channel sediments contained only moderate amount of phosphorus concentration, because of the moderate amount of kaolinite content. But in the estuary, the phosphorus concentration was very less in the clay fraction because of the influence of the sudden change in salinity (NE monsoon), which releases the adsorbed and interstitial phosphorus fraction from clay.

In the river, the moderate amount of phosphorus was accounted by the fixation of phosphorus with kaolinite in addtion the montmorillonite, which also facilitated the fixation of phosphorus, where the pH was less than 7.0 (Wey, 1953).

IRON, MANGANESE, AND TITANIUM:

The concentration of Fe, Mn, and Ti in bulk and clay fraction are presented in Table.12. In general, the highest content of iron in the bulk sediment is

observed in the estuary (39386 ppm) followed by tidal channel (38474 ppm), nearshore (31124 ppm), and in river (18433 ppm) sediments. In the clay fraction, the highest content of iron is in nearshore (70541 ppm) environment followed by river (68154 ppm), estuary (65454 ppm) amd tidal channel (65229 ppm) environments. Iron in the clay fraction (<4 micron) of different environments of the study area observed to be higher than the average values of iron reported for the Boga Vagare in Gulf of Paria (18290 ppm, Hirst, 1962b), Godavari (23344 ppm, Naidu, 1968), Krishna (25074 ppm, Seetaramaswamy, 1970), mean values of east coast of India (22002 ppm, Rao, 1971), Mahanadi (23245 ppm, Satyanarayana, 1973), Cauvery delta - marine (23401 ppm), estuary (23351 ppm), tidal channel (22474 ppm), and river channel (28046 ppm) environments (Seralathan, 1979), and Ashtamudi lake (22684 ppm, Sajan, 1988).

In the bulk sediments, the estuarine (5245 ppm) and the tidal channel (2779 ppm) sediments show highest and lowest levels of Mn respectively. Mn content of river and nearshore environments were 3631 ppm and 2970 ppm respectively. On an average, the highest content of Mn in the clay fraction is observed in the nearshore (7638 ppm) area followed by river (6454 ppm), tidal channel (5647 ppm), and estuarine (5245 ppm) sediments. The average content of Mn in the clay fraction is comparatively very higher than that of Gulf of Paria (516 ppm, Hirst, 1962), Godavari (1330 ppm, Naidu, 1968), Krishna (633 ppm, Seetaramaswamy, 1970), Mahanadi (418 ppm, Sathyanarayana, 1973), Cauvery delta-

estuary (3130 ppm), river (2630 ppm), tidal channel (2320 ppm) and marine (1880 ppm) sediments (Seralathan, 1979), and Asthamudi lake (362 ppm, Sajan, 1988).

The bulk sediments of the river shows the highest amount of Ti (2833 ppm), while the nearshore, estuary, and tidal channel sediments contained 2783 ppm, 2186 ppm, 1945 ppm of Ti respectively. The average content of Ti in clay fraction of river, tidal channel, estuary and nearshore sediments are 1380 ppm, 1380 ppm, 1355 pmm, and 1203 ppm respectively. The Ti content of clay fraction in the present study areas is comparatively lesser than that of Godavari (4050 ppm, Naidu, 1968), Krishna (4750 ppm, Seetaramaswamy, 1970), Mahanadi (5300 ppm, Satyanarayana, 1973), Cauvery delta- marine (4710 ppm), river (4090 ppm), estuary (3760 ppm), and tidal channel (3180 ppm) sediments (Seralathan, 1979) and Ashtamudi lake (3903 ppm, Sajan, 1988).

The downstream variation of Fe, Mn, and Ti in bulk sediments and clay fraction are given in Figs.45, 46, and 47 respectively. An increasing trend is noticed downstream for Fe and Mn content in bulk sediments, while it recorded a decreasing trend in clay fraction. The Ti in bulk sediments shows a decreasing trend when compared to clay fraction which displays almost no variation downstream.

In the present study, the increasing trend of iron content in the bulk sediments downstream (Fig.45.) indicates a higher oxidative precipitation of iron

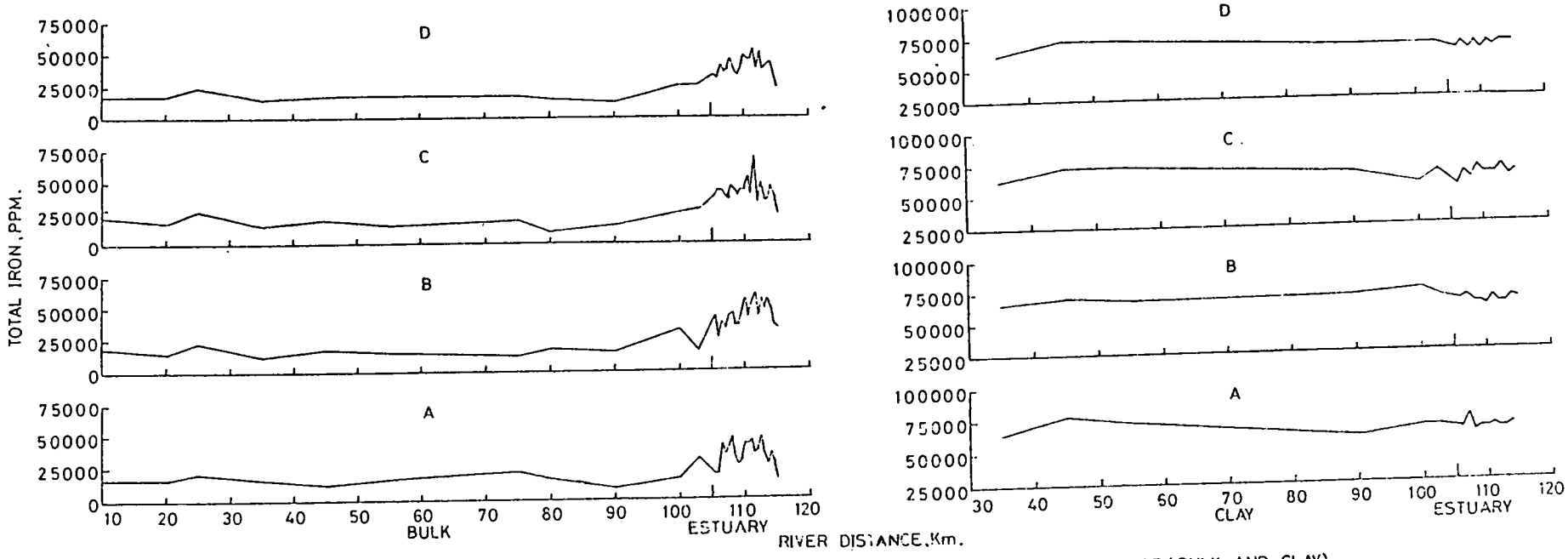


FIG. 45. DOWNSTREAM VARIATIONS OF TOTAL IRON IN THE SEDIMENTS OF VELLAR RIVER (BULK AND CLAY).

A- SOUTH. B-CENTRE. C- NORTH. D- AVERAGE.

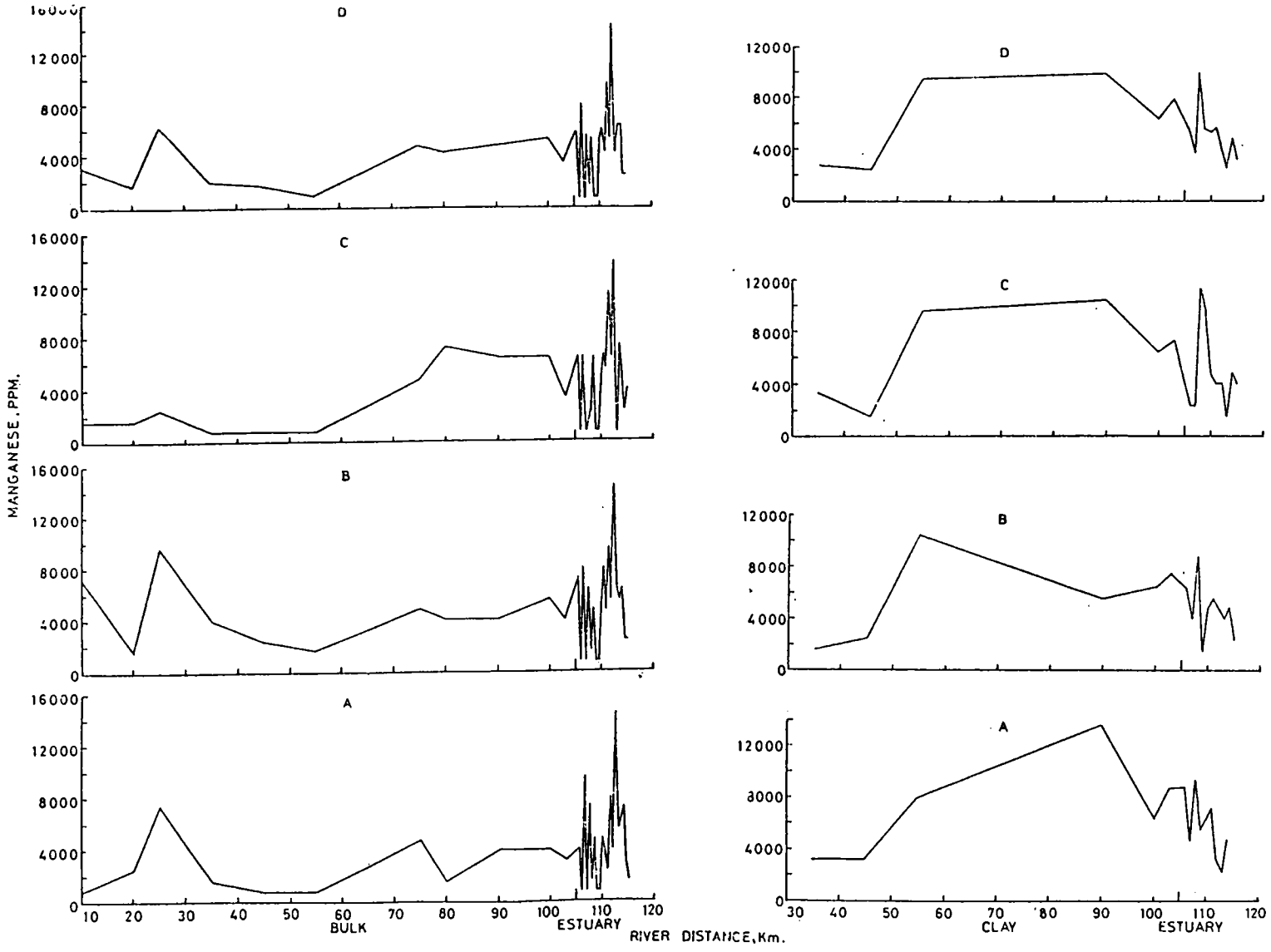


FIG. 46. DOWNSTREAM VARIATIONS OF MANGANESE IN THE SEDIMENTS OF VELLAR RIVER (BULK AND CLAY).
A-SOUTH. B-CENTRE. C-NORTH. D-AVERAGE.

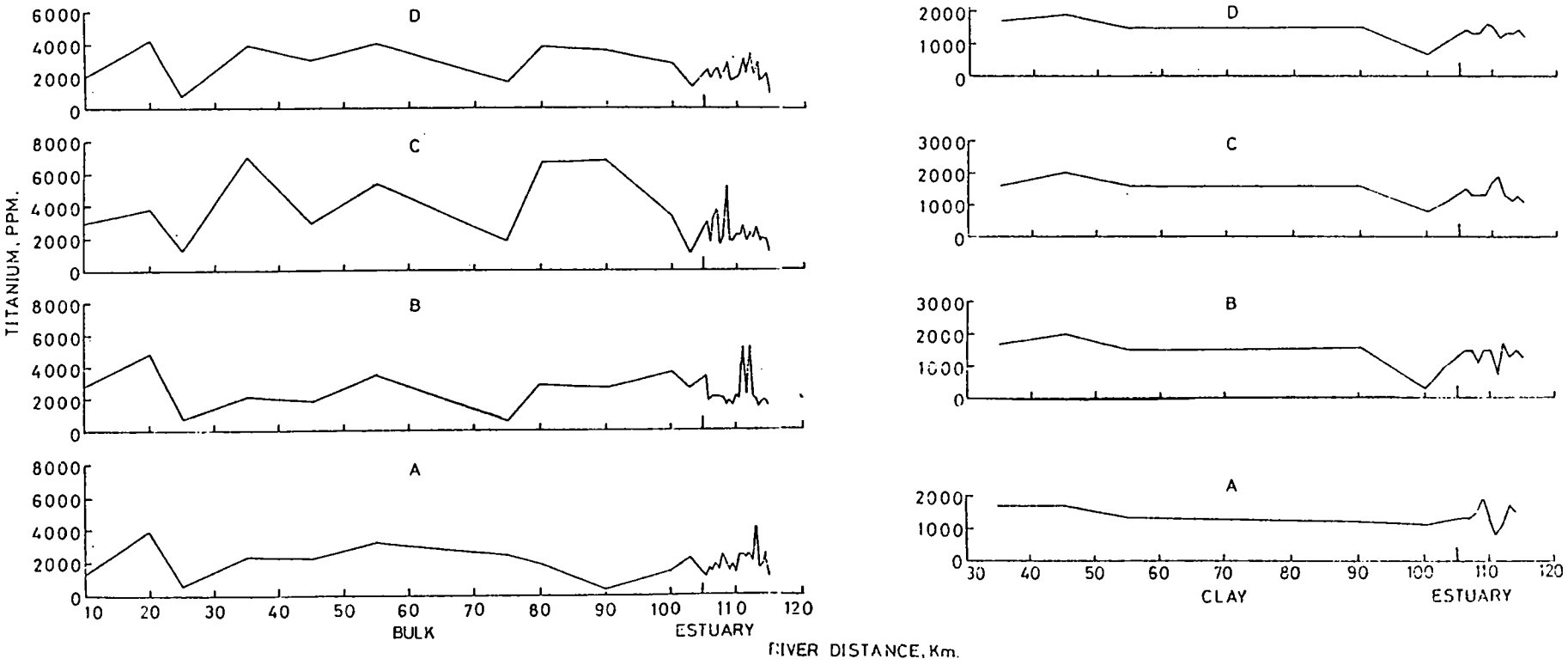


FIG. 47. DOWNSTREAM VARIATIONS OF TITANIUM IN THE SEDIMENTS OF VELLAR RIVER (BULK AND CLAY).
A-SOUTH. B-CENTRE. C-NORTH. D-AVERAGE.

as Fe^{3+} and $Fe(OH)_3$ manifested mainly by the low depth coupled with higher aeration associated with rapid turbulence. This high oxidation potential results in the precipitation of $Fe(OH)_3$ in high acidic condition, i.e. at pH-3 (Landergren, 1975). Further, as suggested by Reinson (1975) and Rao & Raman (1986), the high amount of heavy minerals in the river environment also facilitated the increase in iron content in this environment. Starting from the estuarine head to mouth, the iron content showed a marked increasing trend. The enhancement of iron is because of the following facts. It is well known that the saline region, where the pH is relatively alkaline, as compared to the river, contains the precipitates of iron in high amount (Copper, 1937; Castano & Garrels, 1950; Krumbein & Garrels, 1952; Huber & Garrels, 1953; Mason, 1958). Further, as postulated by Krumbein & Garrels (1952) and Willey (1976b), the higher Eh of estuary might have oxidised and precipitated the ferrous iron and ferrous hydroxide to Fe^{3+} and $Fe(OH)_3$ respectively. It may also be noted that while mixing with sea water in the estuary, the negatively charged iron bearing organic matter colloids react rapidly with sea water cations and form a precipitate. A similar type of explanation was given by Boyle et al (1977) for the increase of iron content in the alkaline environment. Very fine organic residues have a close affinity to fix iron and other cations by adsorption since iron forms an important micro - constituent of all living tissues (Webb & Fearon, 1937; Rankama & Sahama, 1950). When

the tissues are deposited in the sediment, the negatively charged iron reacts with sea water and forms the precipitate. In several estuaries the above said mechanism of removal of iron from solutions is reported (Jenne, 1968; Coonley et al, 1971; Windom et al, 1971; Boyle et al, 1974; Gadde & Laitinan, 1974; Forbes et al, 1976; Subramanian & D'Anglejan, 1976; Willey, 1976a,b; Holliday & Liss, 1976). So, the organic carbon also plays an important role in the increase of iron content in the estuary under study. This can be supported by the high positive correlation of iron with organic carbon (Tables. 17 & 19).

The tidal channel and estuarine bulk sediments show an almost equal amount of Fe content. Since conditions in the tidal channel are almost similar to those in the estuary, the factors which affect the estuary also influenc this environment. In the nearshore bulk sediments iron content lies inbetween river and estuarine values. Since the nearshore sediments are comparatively coarser, and show no correlation between Fe and organic carbon (Table.16) this could suggest that the variation of iron content is due to the contribution of estuarine sediments and the mineralogical composition of the sediments.

In the bulk sediment Mn content, like that of Fe, recorded an increasing trend downstream (Fig.46.). This relationship, leads one to infer that the overall iron content might be influenced by the formation of ferric and manganic hydroxide sols as ferric manganic

hydrate. Further, as suggested by Rankama & Sahama (1950), Garrels (1953), Landergren (1954), Seralathan & Seetaramaswamy (1987) the dissolved bicarbonates and the collidal hydroxides of manganese will get precipitated with increase of pH downstream. Garrels (1960) states that divalent Mn is readily oxidised to quadrivalent state when the solution comes into contact with the atmospheric or dissolved oxygenated area, and is precipitated as $Mn(OH)_2$ or finely divided MnO_2. This results in the precipitation of Mn in the river sediments. The divalent Mn is deposited as trivalent and quadrivalent compounds even in acidic and oxidation condition. However, the constant change in acidity results on the solubilization of Mn as bicarbonate ($Mn(OH)_3$) from river and its deposition in the estuary, where the condition is alkaline and oxic. This fact is evidenced by the high significant positive correlation of Mn with Fe and organic carbon (Tables.15, 17, & 19).

The tidal channel and nearshore millieu, which have high alkalinity and oxic conditions, recorded less Mn content in the bulk sediments. This might be probably due to the deposition of considerable amount of land derived Mn in the estuarine environment resulting in the reduction of Mn in these areas, under these circumstances, though conditions favourable for precipitation exist, the Mn content in sediments is found to be less.

The Ti content in bulk sediments downstream showed a decreasing trend (Fig.47). This is

because of the variation in the mineralogical composition as suggested by Willey & Fitzgerald (1980). Titanium in modern sediments has diverse origin - minerogenous (terrigenous and hydrogenous) and‡or biogenous origin (Correns, 1937, 1954; Griel & Robinsen, 1952; Goldberg, 1954). Since, the present study does not show any positive correlation between Fe and organic carbon, it might be inferred that they had their origin from terrigenous instead of from hydrogenous or biogenous sources. In sediments of terrigenous origin, the titanium minerals, possesing higher densities, are deposited more upstream than downstream. Hence the high amount of Ti upstream of the river and low in the estuarine region (downstream). Willey & Fitzgerald (1980) also noted similar type of changes in their study area. The prominenet decrease of Fe, Mn and Ti contents of the bulk sediments at the mouth of the estuary (Figs.45, 46 & 47) is due to that the currents and turbulance at the confluence might have dispersed considerabley the flocculated particles to the sea before settling, as stated by Sholkovitz (1976) and Seralathan & Seetaramaswamy (1987) in their study area. Since the tidal channel sediments are very fine in nature, the availability of titanium mineral is low and there is a reduction in the concentration of Ti in this environment. In the nearshore environment, the tianium minerals (illmenite, rutile) present in the beach, contribute to the high concentration of titanium in this environment. Seralathan (1979) also suggests a similar explanation for

the avialbility of high amount of titanium in the marine sediments.

Clay fractions show high amount of Fe content than the bulk sediments. Loring and Nota (1968) also observed highest total Fe, Mn, and Ti in the finest grain size, in Gulf of St.Lawrence. The iron content in the clay fraction of different environments did not show much variation. However, the nearshore region recorded a slightly higher amount of iron. The clay mineral assemblage in the sediments from various environments are montmorillonite, kaolinite, and illite. The role of clay mineral in the fixation of iron in various environments is rather difficult to assess precisely, because of the change in composition from one to the other. In general, it is stated that iron may be fixed up in notable amount by all clay mineral except kaolinite, which has lowest cation exchange capacity (Carroll, 1959; Nelson, 1962) and permit very low ionic substitution (Grim, 1953; Warshaw & Roy, 1961; Deer et al, 1962; Murty et al, 1978b). In the remaining clay minerals, montmorillonite can accomadate more iron in its lattice because of the inter atomic structure, which holds much of inter layer water, and high negative charge. Further, they have the highest cation exchange capacity among all clay minerals. In their lattice structure, the Mg^{2+} or Al^{3+} can be replaced by Fe^{2+} or Fe^{3+} respectively (Hirst, 1962b). Moreover, as suggested by Burton & Liss (1976), a coating of iron oxide on the surface of clay also enhances the iron content of clay fraction.

The overall variation of iron content in the clay fractions mainly depends upon the adsorption and coating of their surface since much variation in the depositional environments was not observed. The positive correlation of iron with K and Mg and strong negative correlation of iron with organic carbon (Tables.24, 23, & 25) support the above mentioned statement.

The Mn content in the clay fractions varied depending upon the iron content irrespective of their environments. Ti concentration also, does not show much variation in the clay fractions of different environments. Since, it is rather difficult to evaluate the role of clay minerals in controlling the concentration of Mn and Ti in different environments, it is presumed that the Mn and Ti content was either absorbed or adsorbed by the structure of the clay or the surficial iron oxide coating. Mn and Ti are decreased in the estuarine mouth due to the currents and turbulence at the confluence which might have dispersed the flocculated particles of Mn and Ti considerably to the sea before allowing them to settle on the bottom sediments. Sholkovitz (1976), and Seralathan & Seetaramaswamy (1987) also postulated a similar explanation for the variation of Mn and Ti in their study areas. The above said factors are envinced by the positive correlation of Fe with Ti and Mn, and Ti with Mn on clays (Table.28).

SODIUM AND POTASSIUM:

Results presented in Table.12 indicate that the bulk sediments from the nearshore sediments contained the highest level of Na (9408 ppm). This is followed by the tidal channel (8679 ppm), estuarine (8204 ppm) and river sediments (6095 ppm), whereas the clay fraction does not show much variation in the various environments indicated above and is reported in the range of 4106 ppm to 4244 ppm. The present results on Na content in clay fractions of nearshore, estuary and tidal channel environments are comparatively lower than the values reported for different environments of Cauvery delta - marine (9880 ppm), estuary (8390 ppm), and tidal channel (7330 ppm) sediments (Seralathan, 1979) and Ashtamudy lake (7663 ppm, Sajan, 1988). Whereas the Cauvery river environment recorded lower value of Na (1980 ppm) than the Vellar river.

The maximum concentration of K, in bulk sediments, is recorded in the tidal channel (5826 ppm) sediments followed by the nearshore (5607 ppm), estuarine (4795 ppm), and river (3233 ppm) sediments, whereas in the clay fraction, the K content shows a slight variation in tidal channel (4194 ppm), estuary (3745 ppm), nearshore (3735 ppm) and river (3047 ppm) environments. The observed concentration of K in clay fraction are comparatively higher than that reported for Cauvery delta sediments - marine (3660 ppm), tidal channel (3260 ppm), estuary (3240 ppm), and river (2180 ppm) environments (Seralathan, 1979) and

Ashtamudy lake (3707 ppm, Sajan, 1988). Data presented in Figs. 48 & 49 with respect to Na and K, in bulk and clay fraction, indicates that both the elements increase downstream.

The variation of Na and K in the bulk sediments of different environments of the study area mainly depends on the combined effect of several factors such as 1) mineralogical composition of the sediments, 2) latteral variation in the salinity of water and adsorption and/or replacing capacity of individual elements, and 3) salt present in the sediment pore solution.

1. MINERALOGICAL COMPOSITION OF THE SEDIMENTS:

While the heavy minerals get deposited upstream, the light minerals like quartz and feldspar increase downstream. Moreover, the fine fractions called clay minerals also increase abundantly downstream. In these conditions, the increasing trend of Na and K in the bulk sediments downstream depends mainly on the mineralogy and texture of the sediments. In the nearshore sediments, while the heavies get deposited in the beach by wave action, the light minerals are deposited in the nearshore areas which leads to the increase of Na and K in this environments. Ramanathan et al (1988) also postulated a similar explanation for the variation of Na & K in the sediments of Cauvery estuary. The increase of fine fraction (clay) also

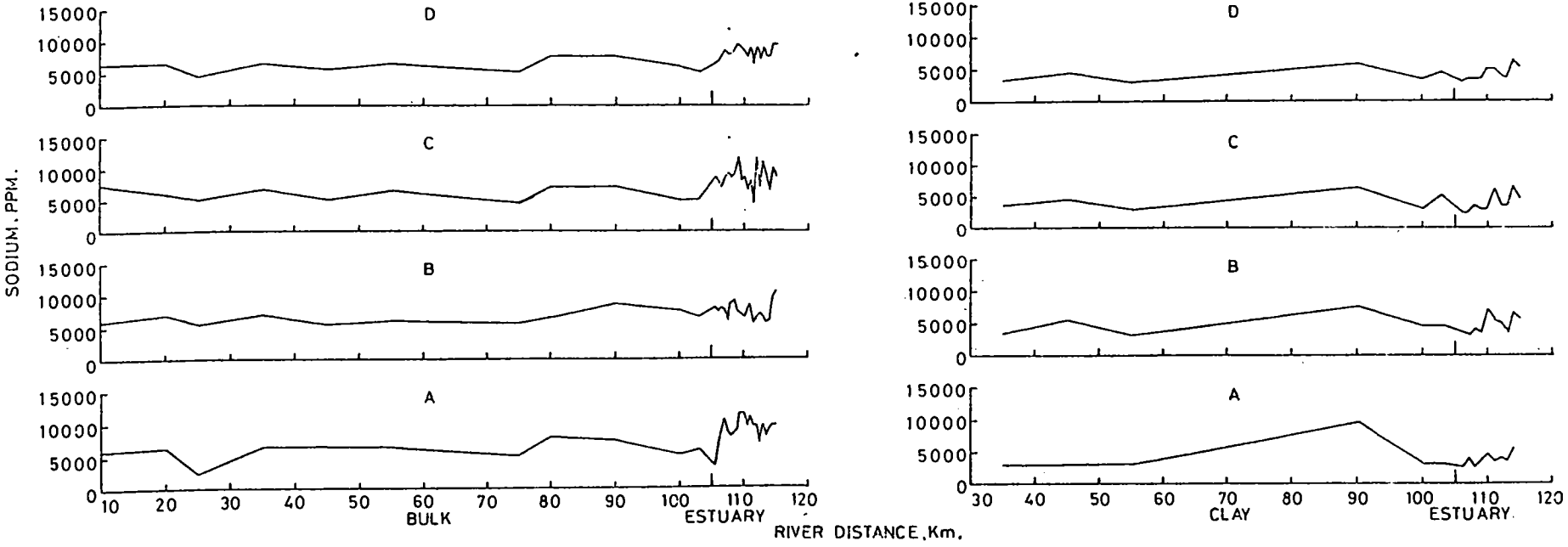


FIG. 48. DOWNSTREAM VARIATIONS OF SODIUM IN THE SEDIMENTS OF VELLAR RIVER (BULK AND CLAY).
A-SOUTH. B-CENTRE. C-NORTH. D-AVERAGE.

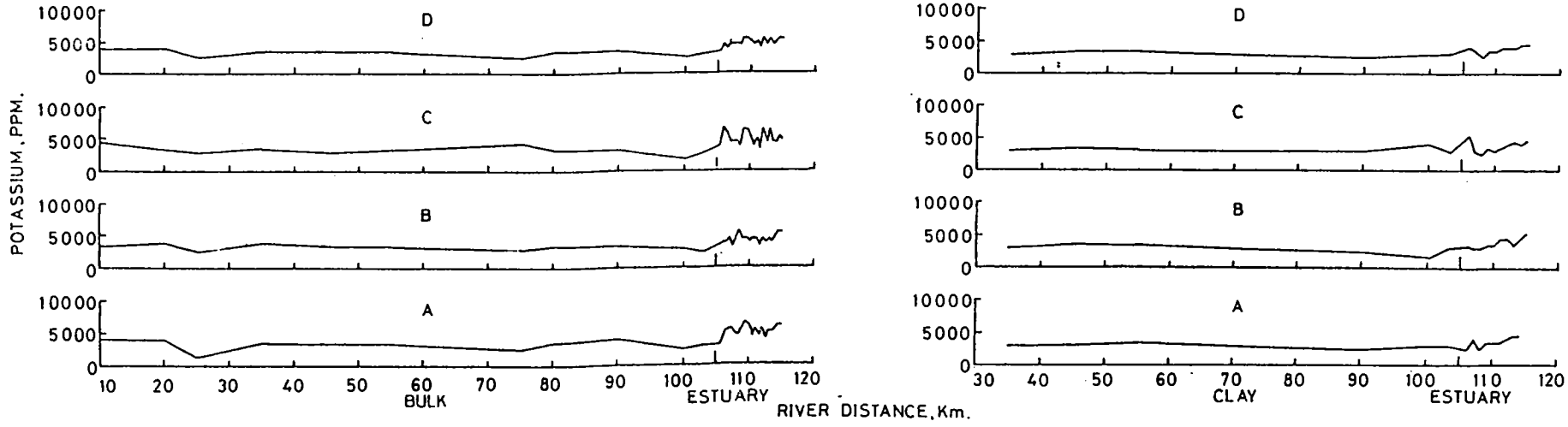


FIG. 49. DOWNSTREAM VARIATIONS OF POTASSIUM IN THE SEDIMENTS OF VELLAR RIVER (BULK AND CLAY).

A-SOUTH. B-CENTRE. C-NORTH. D-AVERAGE.

influence these elements by adsorption /or ion exchange processes.

2) LATERAL VARIATION IN THE SALINITY OF WATER AND ADSORPTION AND/OR REPLACING CAPACITY OF INDIVIDUAL ELEMENTS:

The lateral variation of salinity in the different environments affects largely the fine sized texture i.e, clay minerals. According to Nelson (1962), in the presence of several ions at different concentrations in a solution, the ion which has the highest relative concentration would be able to enter into the clay mineral structure more readily. Moreover, it would even be able to displace all other ions, whose ionic concentrations are lower in the solution, from the above structure. Further, some clay minerals, like montmorillonite, sorbed the cations, like K^+, in a non exchangeable or difficult exchangeable state (Grim, 1953). These processes also add up the Na and K content in the above sediments.

The positive correlation of Na with K and, Na and K with Mg, Ca, P, Al and Si (Tables.14, 15, 16, 17, 18, 19, 20, & 21) evidences the foregoing explanation.

3) SALTS PRESENT IN THE SEDIMENT PORE SOLUTIONS:

The bottom sediments of different environments of the study area contain pore waters in their pore space. As suggested by Seralathan (1979) and Sajan (1988) when the salinity of the pore water increases, the sediments may also adsorb more Na and K from pore water and

this leads to the increased content of Na and K in them.

The Na and K content of clay fraction showed almost similar concentration in all the environments. It is clear that the concentrations mainly depend upon the chemical composition of the clay minerals. Further, it is conceivable that in the clay fraction of different environments, Na and K are tied up in clay minerals either by adsorption and/or cation exchange. While the monovalent cation could get exchange sites in clay minerals in solutions of high salinity, they unsuccesfully to do so in dilute solutions where divalent cations could succeed (Nelson, 1962). This clearly expounds the slight increase in the Na and K ions in the high salinity region indicating that, the Na ion has more affinity than K ion, and sodium can also replace Ca ion in the clay mineral. Sayles & Mangelsdorf (1977) also suggest a similar explanation for the relationship between clay mineral and Na and K concentration. The clay mineral montmorillonite, can fix significant amount of Na in its lattice structure which leads to the increased level of Na in the clay fraction. Further, in the high saline water the montmorillonites exchange their Ca^{2+} and K^{+} ions with Mg^{2+} and Na^{+} forms (Potts, 1959; Carroll & Starkey, 1960; Holland, 1965; Keller, 1963; Russel, 1970). According to Weaver (1967), clay minerals absorb more Na and Mg than K from the sea water. The above exchange process could be the reason for

the observed variation of Na and K in the nearshore marine sediments.

The observed high ccontent of K in the clay fraction of tidal channel sediments could be due to the deposition of abundent mangrove plants which in turn do conribute rich organic residue and consequently increased K concentration.

The above said observations are evinced by the positive correlation obtained for Na with K, and K with organic carbon, Mg, Fe, Al, and P.

CALCIUM AND MAGNESIUM:

Results obtained for the concentration of calcium and magnesium in the bulk and clay fraction of different environments of the present study area are shown in Table.12. The nearshore bulk sediments recorded the maximum concentration of Ca (6804 ppm) followed by tidal channel (5159 ppm), estuary (5070 ppm) and river channel (4851 ppm) sediments, whereas in clay fraction, fresh water river channel environment records maximum Ca content (8539 ppm) followed by nearshore (4643 ppm), estuary (2215 ppm) and tidal channel (1801 ppm) environments. The present results on Ca content in clay fractions of river and nearshore environments are comparatively very high than the values reported for Cauvery river (6840 ppm) and marine (3310 ppm) environments (Seralathan, 1979). Whereas the Ca values recorded for estuary and tidal channel are lower than that reported for Cauvery estuary (2910 ppm and tidal channel (2170 ppm) (Seralathan, 1979) and Asthamudi lake

(14223 ppm, Sajan, 1988).

The Mg content, in the bulk sediments, show a highest amount in tidal channel (42810 ppm), followed by nearshore (37859 ppm), estuary (36729 ppm) and river (31602 ppm) environments. However, in the clay fraction, the river channel (37573 ppm) hold the highest concentration of Mg followed by estuary (36005 ppm), tidal channel (34765 ppm) and nearshore (33257 ppm) environments. The observed concentration of Mg in clay fraction are comparatively very much higher than that reported for Cauvery delta sediments - marine (6760 ppm), estuary (6160 ppm), tidal channel (5710 ppm) and river (5520 ppm) environments (Seralathan, 1979), and Asthamudi lake (15138 ppm, Sajan, 1988).

The downstream variation of calcium and magnesium content respectively are presented in Figs.50 & 51. In the bulk sediments, Ca and Mg show an increasing trend downstream, whereas in the clay fraction, while Ca shows a decreasing trend, Mg shows an increasing trend downstream.

The higher concentration of Ca is observed in the nearshore, estuarine and tidal channel bulk sediments may be due to the carbonate content available in these environments. In fact, the calcium precipitated in the alkaline environment as a carbonate and the different types of shell fragments contribute Ca to the bulk sediments. Sajan (1988) has also stated that the carbonate variation in the Ashtamudi lake is because of the high

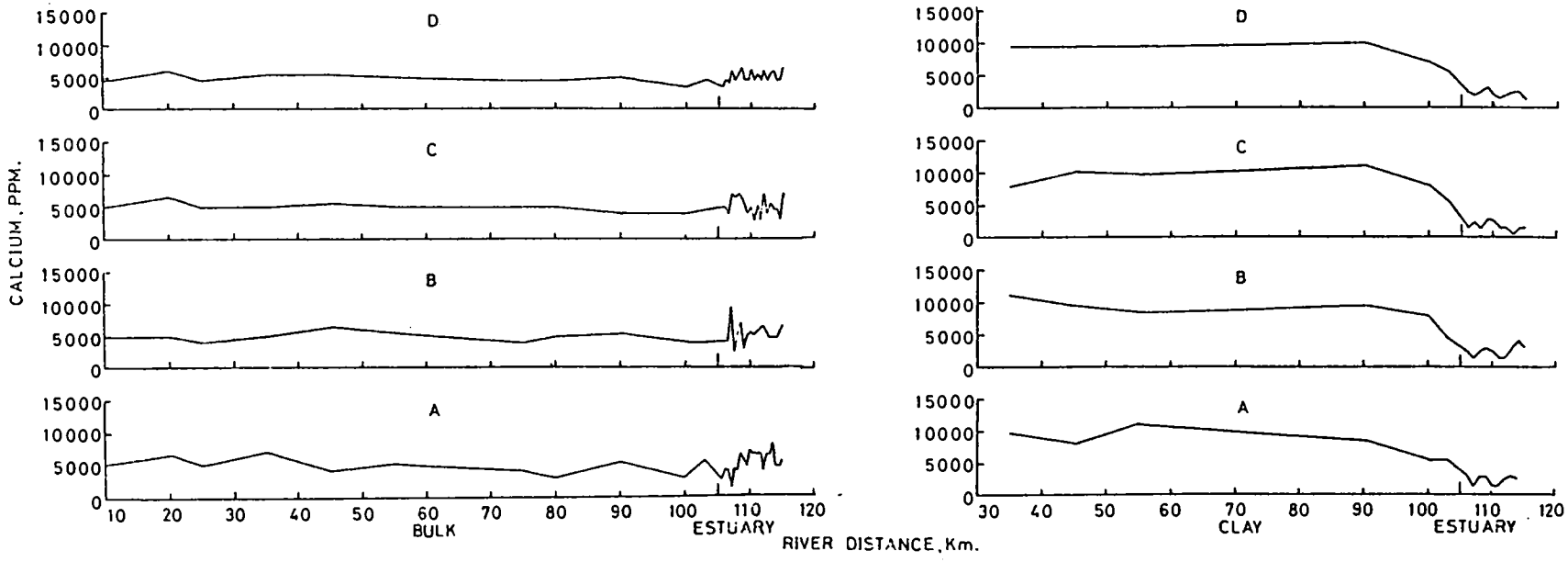


FIG. 50. DOWNSTREAM VARIATIONS OF CALCIUM IN THE SEDIMENTS OF VELLAR RIVER (BULK AND CLAY).

A-SOUTH. B-CENTRE. C-NORTH. D-AVERAGE.

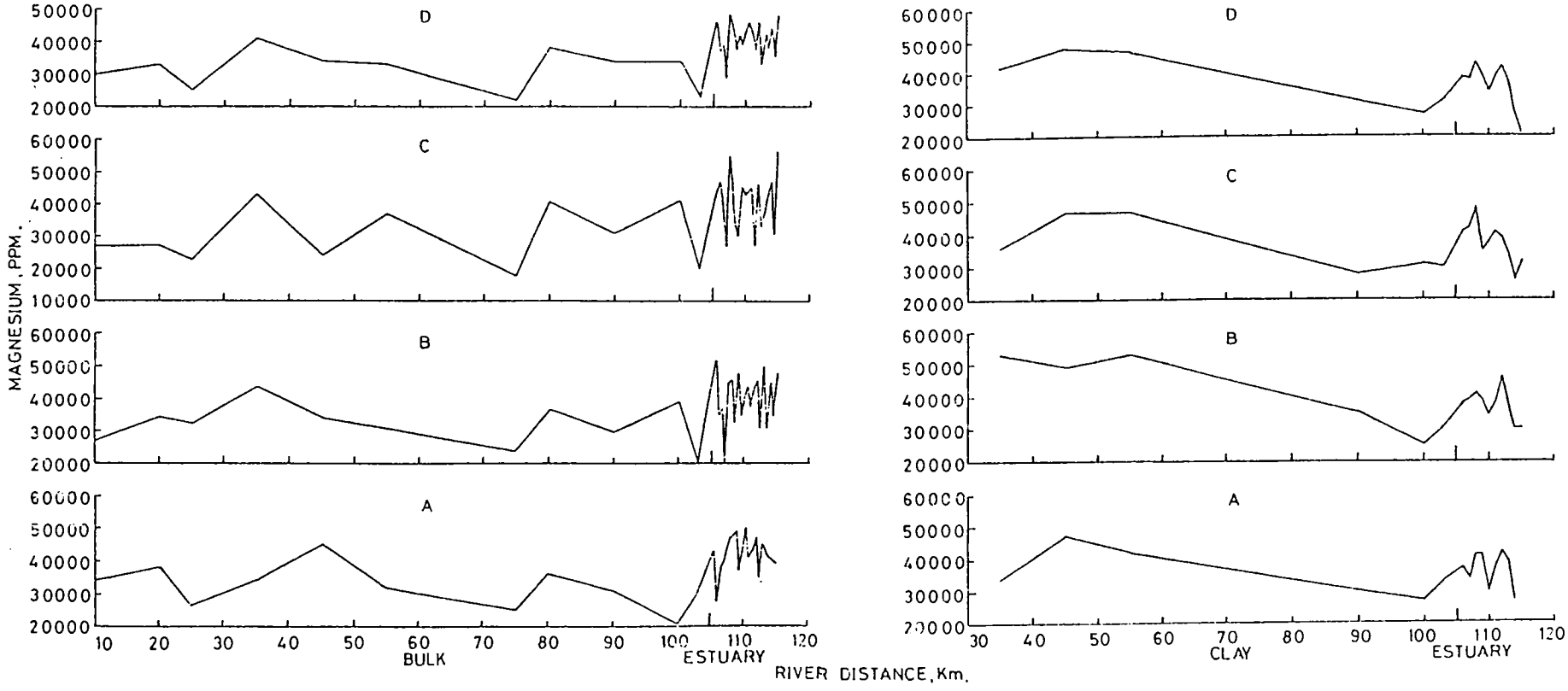


FIG. 51. DOWNSTREAM VARIATIONS OF MAGNESIUM IN THE SEDIMENTS OF VELLAR RIVER (BULK AND CLAY).
A-SOUTH. B-CENTRE. C-NORTH. D-AVERAGE.

amount of shell fragments. Moreover, the fine size clay minerals also contribute significant amounts of Ca. This observation is evinced by the positive correlation obtained for Ca with organic carbon, carbonate, Na and K (Tables.15, 17, 19, & 20).

Comparatively the river channel records lesser levels of Ca content than other environments. This may be attributed to the presence of acidic environments which leads to the solubilisation of carbonate to a certain extent. Further, the positive correlation of Ca with P, K, and Al suggests that the Ca available in this environment derived from the calcium phosphate and certain extent by the clay minerals.

In the clay fractions, the river clays contain more Ca than the remaining environments owing to the predominance of montmorillonite. This observation is in agreement with the report of Sverdrup et al (1955), who stated that the concentration of Ca ions is generally higher than the Na ions in fresh water clays. The downstream decrease in Ca content in the clay fraction towards more saline waters of the estuarine region may be due to the larger replacement of Ca^{2+} by Na^{+}, K^{+} and Mg^{2+} in the montmorillonite clay mineral.

The clay minerals present in the tidal channel have not been much disturbed by salinity variation for long time. This might result in the change of Ca ion by Na, K, and Mg. Due to this process clay of this environment shows very low amount of Ca content. The nearshore clay fraction

displays a moderate amount of Ca content, which is higher than that of estuarine and tidal channel environments. Goldschmidt (1962), Nelson (1962), and Sayles & Mangelsdorf (1977) stated that since common ions such as Ca^{2+} and H^{+}, inherited from the soil environment by adsorption on the surface of clay particles, are replaced by the most abundant ions in the sea water (Na^{+} and Mg^{2+}), a low content of Ca is usually expected in the clays of nearshore environment. However, in the present study, a high amount of Ca is recorded in this environment, which may be due to the significant incorporation of clay sized calcium carbonate and calcium phosphate materials by precipitation and the very fine tests of planktons made up of calcium carbonate in the sediments. The positive correlation obtained for Ca with P in nearshore sediments and negative correlation of Ca with Mg in the estuarine sediments (Tables.11, 13, & 24) strongly evince the foregoing discussion.

The variation of Mg content downstream in bulk sediments may be due to the presence of Mg bearing minerals in the river sediments, which are concentrated more in the upstream and give rise to high amount of Mg in the chemical constituents of the sediments. Ramanathan et al (1988) also reported that the variation of Mg in the sediments is because of the availability of Mg bearing minerals. In the downstream, while the heavy mineral content is reduced to certain extent, the clay mineral content increases abundantly adding more Mg to this

environment. Moreover, as stated by Nelson (1962), Drever (1974) and Seralathan & Seetaramaswamy (1987) the absorbtion of Mg ion by clay mineral in the alkaline environment also helps to increase the Mg content. The above explanations are evinced by the strong positive correlation of Mg with Na, K, and Ti in the sediments (Tables. 14, 16 & 17). It was suggested earlier that the constant availability of Mg in the water (Carballo et al, 1987) and also high Mg/Ca ratio in the water (Muller et al, 1972), enhance the magnesium carbonate content in the environment. The above statement is supporting the high level of Mg observed in the present study. In the Vellar estuarine environment high amount of Mg content was reported in water samples (Palanishamy, 1986). The increase of Mg content in the tidal channel may also be accounted by the large amount of Mg in the water and the presence of magnesium carbonate shell fragments. Rao (1978) also stated that the Mg carbonate shell fragments in the sediments increase the Mg content. In the nearshore environment Mg concentration in bulk sediments might be due to the mineralogical composition of the sediments. Further, as postulated by Durgaprasada Rao & Behairy (1983), the organic processes lead to the formation of different forms of Mg-carbonate cements as a fresh water diagenesis, not only in completely or intermittently exposed areas, but also in nearshore environment where the periodic influx of fresh water is prominent, which would also increase the Mg content.

The overall increase of Mg content

downstream, in clay fraction, is probably attributable to a progressively larger fixation of Mg^{2+} in clay mineral especially in montmorillonite. Muller (1964) has stated that Ca rich fresh water clays preferentially adsorb Mg in brackish water. Grim (1953) also pointed out that increased adsorption of Mg by montmorillonite is more in the high pH condition. Thus, it is clear that the increase of Mg content downstream is due to the larger fixation of Mg^{2+} in the vacant Ca^{2+} site in montmorillonite. However, the mouth of the estuary, tidal channel and nearshore environments recorded comparatively lesser amounts of Mg content than river and estuary. Weaver (1967) and Russel (1970) stated that upon prolonged soaking, montmorillonite would take up Mg^{2+} from sea water especially when pH values are greater than 8 and get fixed. Consequently, the expected levels of Mg content in the sediments are higher than in the other environments. In the present study the results are contrasting the above phenomenon, which is probably due to an increase of kaolinite content in these places leading to a reduction in the Mg content in overall clay fractions. The clay mineral studies in this area, show high amount of kaolinite which supports the above said explanation. Further, clay size coralline algae and foraminiferal tests which are considered to be made up of high Mg carbonate (Rao, 1978) also can contribute Mg to the clay fraction.

SILICA AND ALUMINA:

The highest content of silica in bulk

sediments was observed in the river (379797 ppm) followed by nearshore (327607 ppm), estuary (282323 ppm) and tidal channel (276948 ppm), whereas, in the clay fraction, the content of silica was around 226775 ppm, 225616 ppm, 223605 ppm, and 193503 ppm in tidal channel, river, estuary and nearshore respectively.

The aluminium content in bulk sediments was high in the tidal channel (25367 ppm) followed by the estuary (23788 ppm), nearshore (21564 ppm) and river (9896 ppm). In the clay fraction, of the different environments, the levels of Al were 28788 ppm, 27906 ppm, 27809 ppm, and 27222 ppm, in river, tidal channel, estuary, and nearshore respectively. The downstream variation of Si and Al respectively in the bulk and clay fraction are shown in the Figs. 52 & 53.

The silica content in bulk sediments show decreasing trend downstream owing to the variation in the texture and mineralogy of the sediments. In the downstream, the texture becomes very fine, resulting in the increase of the clay and silt content. As explained by Sholkovitz (1978) and Ramanathan et al (1988), the above said variation affects the total silica content in the river and estuarine region. The tidal channel, which is also similar in physico chemical conditions to that of estuary, shows almost equal concentration of silica. The nearshore sediments show higher amount of Si concentration due to the texture and mineralogy (i.e. the coarse texture and less abundance of clay). Willey (1976a,b) also suggested a

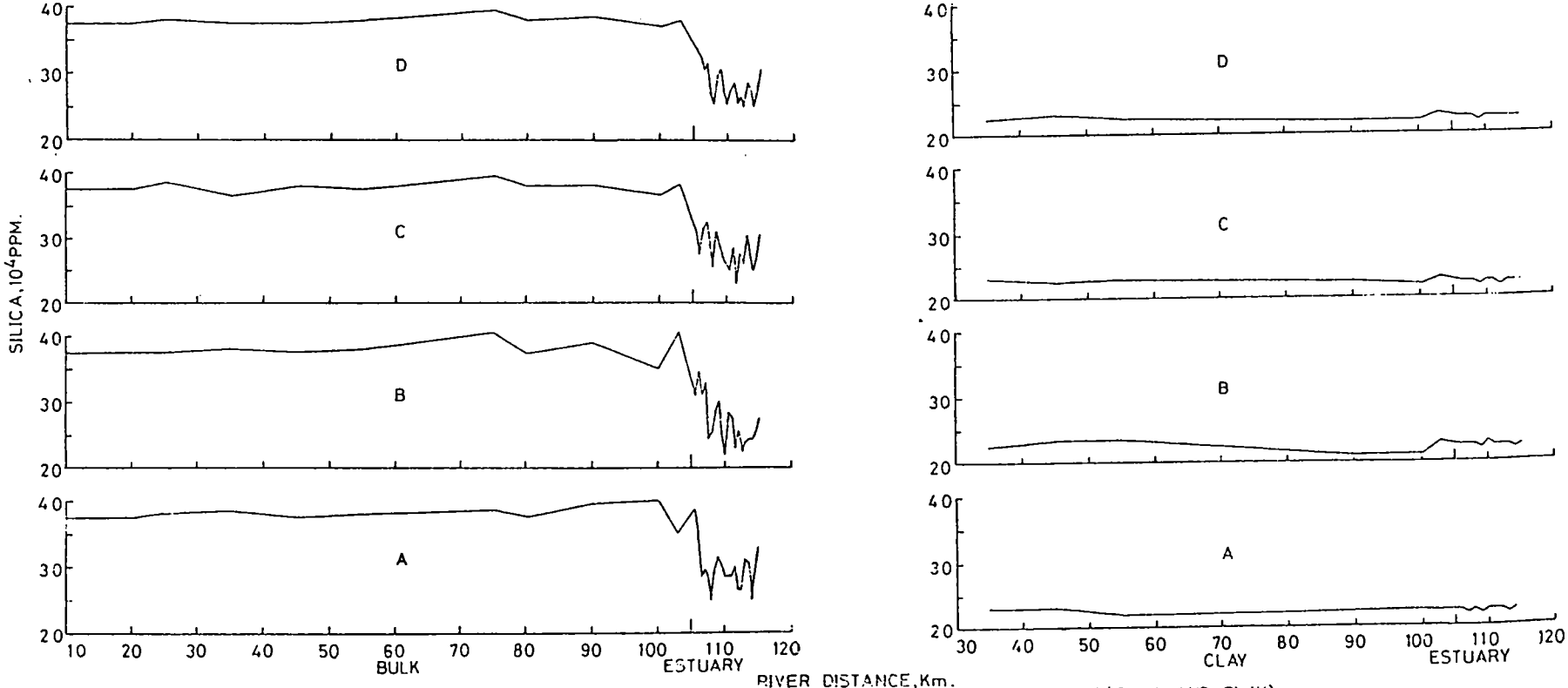


FIG. 52. DOWNSTREAM VARIATIONS OF SILICA IN THE SEDIMENTS OF VELLAR RIVER (BULK AND CLAY).
A-SOUTH. B-CENTRE. C-NORTH. D-AVERAGE.

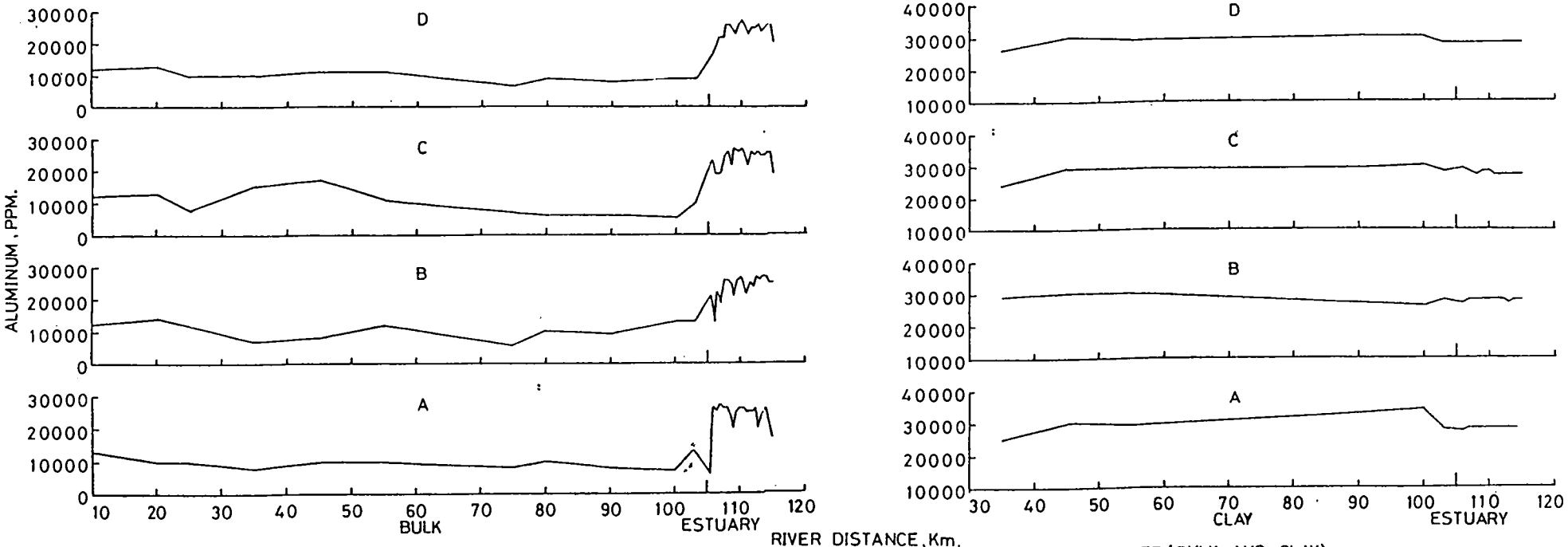


FIG. 53. DOWNSTREAM VARIATIONS OF ALUMINIUM IN THE SEDIMENTS OF VELLAR RIVER (BULK AND CLAY).

A-SOUTH. B-CENTRE. C-NORTH. D-AVERAGE.

similar explanation for the variation of Si concentration in the sediments. The significant negative correlation shown by Al, Fe, Mg, organic carbon, and carbonates, and positive correlation of Ca, Na, and Ti with Si (Tables.14, 15, 16, 17, 18, 19, & 20) adds ample evidence to the above said processes.

In the clay fraction, the river, estuary and tidal channel display a slight variation of Si content owing to the variation of clay mineral percentage in these environments. The significant positive correlation of Si with Na, K, and negative correlation with Al, Fe, P and organic carbon confirm the above mentioned discussion. The nearshore environment shows a marked decrease of Si content. It may be due to the increase in the kaolinite content which contained low silica and high Al than montmorillonite.

The aluminum concentration of bulk sediments shows an increasing trend downstream due to an increased amount of clay fraction. The tidal channel also recorded a high amount of Al content as a result of the high amount of clay content. Willey (1976a,b), Murty et al (1978b) Mascarenhas et al (1985) also explained that the increase of clay mineral resulted in the increase of Al content in the sediment. In the nearshore a slight decrease of Al was observed due to a less amount of clay available in these bulk sediments. The positive correlation of Al with Ca, Fe, Na, P, Carbonate, Organic carbon and Mg (Tables.14. 15, 16, 17, 18, 19, & 20) adds evidence to this.

In the clay fraction, the Al concentration shows a slight decreasing trend downstream which contradicts the theoritical trend. This is because, in the estuary and tidal channel waters, where exchangeable ions are very active and high in amount, the Al is exchanged by some other ions in the structure of the clay mineral. So the Al concentration in the clay fraction is reduced considerably. The nearshore clay fraction shows a comparatively less amount of Al. Since in this area also the cation exchange is very active, the Al concentration is reduced. The above said explanations were evinced by the positive correlation of Al with K, organic carbon Fe, and Mn (Tables.23, 25, & 28).

TRACE ELEMENTS:

In this section, attention is paid on the geochemically relaveant trace elements namely copper, cobalt, nickel, zinc, chromium and cadmium. The present study is an attempt to elucidate the different processe influencing the trace element composition of the bulk and clay fraction of sediments in the river, estuarine, tidal channel and nearshore environments (Table 13).

COPPER:

The estuarine sediments contain the highest amount of Cu (48.7 ppm) followed by tidal channel (27.25 ppm), nearshore (20.18 ppm) and riverine (7.1 ppm) sediments (Table.13). In the clay fractions, the maximum Cu content is observed in the nearshore (111.6 ppm) sediments

followed by river (64.17 ppm), tidal channel (50.5 ppm), and estuarine (40.7 ppm) environments. The observed levels of Cu in the clay fraction of river, estuary, and tidal channel environments are lower than those of the Krishna (398 ppm, Seetaramaswamy, 1970), Mahanadi (121 ppm, Satyanarayana, 1973), Cauvery deltaic sediments - river (122 ppm), estuary (94.5 ppm), tidal channel (93.3 ppm) sediments (Seralathan, 1979), and Asthamudi lake (89.21 ppm, Sajan, 1988). Further, the Cu content of the nearshore is lesser than the inner shelf off the east coast of India (209.3 ppm, Rao & Rao, 1973) and higher than that off the west coast of India (47 ppm, Rao et al, 1974).

Cu content in the bulk sediments of different environments are comparatively lesser than that in the clay fractions. The Cu content in bulk sediments shows an increasing trend downstream (Fig.54). In the fresh water environment Cu is found to be associated with Fe and Mn (Table.18). It is well known that Cu is consistently adsorbed by the hydrated Fe_2O_3 and MnO_2 (Krauskopf, 1956). However, in the estuarine region, where there is a two fold increase in the Fe and Mn content, the Cu content does not show any positive relation with Fe and Mn. This may be due to the fact that river born adsorbed Cu by iron and manganese oxides and on clay minerals are desorbed in the estuarine region as stated by Borole et al (1977) and Seralathan (1987). The desorbed Cu may be now asssociated with organic matter, P and carbonates Si and Al and deposit, which is evinced by

TABLE: 13. CONCENTRATION OF TRACE ELEMENTS (CU, Ni, Zn, Cr, Cd, Co) IN THE SEDIMENTS (BULK AND CLAY) OF VELLAR RIVER, ESTUARY, TIDAL CHANNEL AND NEARSHORE ENVIRONMENTS (PPM).

N.D = NOT DETECTED

RIVER (CENTRE-BULK)

DIST.	ST.NO	Cu	Ni	Zn	Cr	Cd	Co
10	8	5	110	96	267	N.D	N.D
20	14	5	73	165	267	4	N.D
25	17	3	146	201	367	8	28
35	23	7	110	92	233	4	28
45	29	4	146	99	233	4	28
55	35	7	73	99	300	4	14
75	47	8	110	86	167	4	28
80	50	8	146	83	200	4	14
90	56	10	73	89	267	4	28
100	62	18	146	188	300	8	28
103	71	3	73	86	167	8	14

ESTUARY (CENTRE-BULK)

DIST.	ST.NO	Cu	Ni	Zn	Cr	Cd	Co
105.5	80	38	37	201	200	8	43
106.0	83	6	73	175	167	4	43
106.5	86	26	110	155	267	4	43
107.0	89	8	220	185	200	8	43
107.5	92	49	73	178	233	4	43
108.0	95	31	73	185	267	8	43
108.5	98	88	256	195	233	4	43
109.0	101	9	73	135	233	4	43
109.5	104	109	256	241	267	4	43
110.0	107	40	220	191	200	12	71
110.5	110	25	220	178	200	8	57
111.0	113	5	256	238	367	12	57
111.5	116	29	220	178	200	8	57
112.0	119	18	220	185	300	8	28
112.5	122	43	146	205	267	8	57
113.0	125	101	330	221	200	8	43
113.5	128	51	256	238	167	12	57
114.0	131	82	366	241	200	8	43
114.5	134	105	256	201	133	8	43
115.0	137	27	146	188	133	8	57

TIDAL CHANNEL (BULK)

DIST.	ST.NO	Cu	Ni	Zn	Cr	Cd	Co
1.0	164	5	73	122	200	4	43
2.0	166	46	220	152	267	4	43
3.0	168	32	183	162	367	4	57
4.0	170	26	220	198	300	4	43

TABLE: 13.(CONT.)

NEARSHORE (BULK)

DIST.	ST.NO	Cu	Ni	Zn	Cr	Cd	Co
0	173	58	110	142	167	12	43
1	174	2	110	142	233	4	43
2	177	2	73	139	233	4	28
3	179	47	110	218	233	4	43
4	181	10	110	109	200	4	43
5	183	2	37	119	233	4	14
6	185	14	110	122	333	N.D	28
7	187	40	146	158	300	4	28
8	189	43	183	228	300	8	29
9	191	41	183	205	500	8	14
10	193	10	220	155	400	4	28
0	172	20	110	234	133	4	14
1	175	1	73	109	200	4	28
2	176	42	110	155	200	4	42
3	178	27	110	211	267	4	42
4	180	2	110	139	267	4	43
5	182	20	110	99	267	4	28
6	184	9	110	241	200	4	14
7	186	4	73	205	200	4	14
8	188	15	110	178	400	4	28
9	190	21	146	198	467	4	14
10	192	14	146	168	467	4	28

RIVER (CENTRE-CLAY)

DIST.	ST.NO	Cu	Ni	Zn	Cr	Cd	Co
35	23C	46	146	182	200	4	85
45	29C	52	330	185	333	N.D	100
55	35C	111	403	287	400	4	114
90	56C	81	256	330	267	4	100
100	62C	42	146	254	167	N.D	100
103	71C	53	256	198	267	4	114

ESTUARY (CENTRE-CLAY)

DIST.	ST.NO	Cu	Ni	Zn	Cr	Cd	Co
106	83C	50	220	195	267	4	85
107	89C	56	293	254	267	4	71
108	95C	56	183	165	300	N.D	71
109	101C	61	220	175	300	N.D	100
110	107C	28	110	168	300	4	71
111	113C	48	220	185	300	N.D	71
112	119C	32	256	172	267	4	57
113	125C	32	146	290	267	8	71
114	131C	13	220	175	333	4	57
115	137C	31	183	178	333	4	57

TABLE: 13.(CONT.)

NEARSHORE (CLAY)

DIST.	ST.NO	Cu	Ni	Zn	Cr	Cd	Co
0	173C	61	146	284	267	4	85
1	174C	40	293	195	267	4	71
4	181C	160	256	624	400	N.D	114
5	183C	115	220	492	300	N.D	100
8	189C	94	183	383	300	N.D	100
1	175C	157	256	472	333	8	100
2	176C	57	220	238	300	8	85
3	178C	97	220	393	333	4	114
4	180C	211	256	630	367	4	100
5	182C	105	146	495	267	4	85
6	184C	162	256	627	300	4	128
7	186C	140	183	469	333	4	100
8	188C	135	256	521	233	4	128
9	190C	78	220	475	333	4	128
10	192C	62	220	317	233	N.D	114

TIDAL CHANNEL (CLAY)

DIST.	ST.NO	Cu	Ni	Zn	Cr	CD	Co
1	164C	57	220	172	267	4	100
2	166C	43	183	168	267	N.D	71
3	168C	52	220	191	267	4	114
4	170C	50	220	281	267	4	85

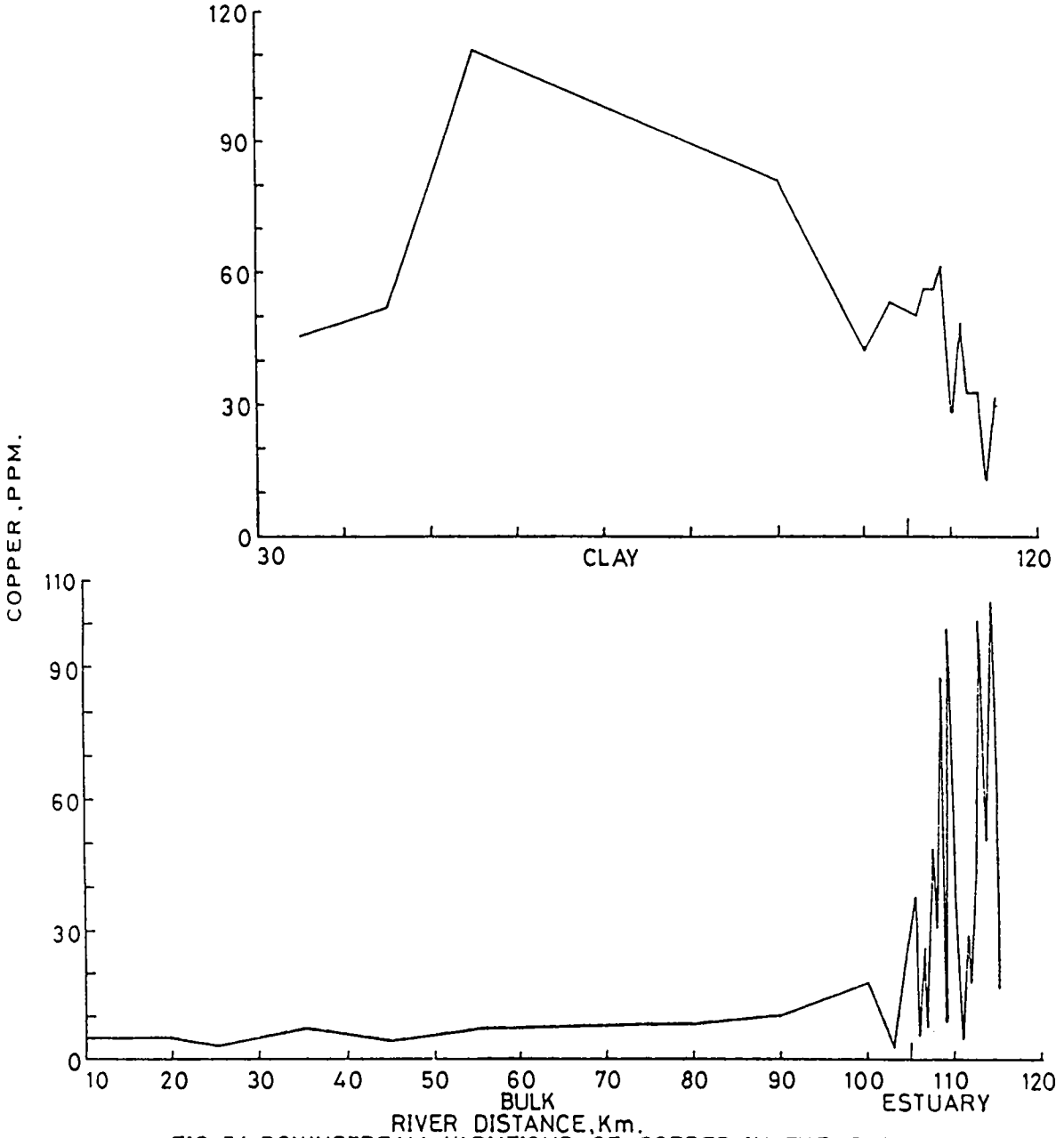


FIG. 54. DOWNSTREAM VARIATIONS OF COPPER IN THE SEDIMENTS OF VELLAR RIVER (BULK AND CLAY).

the positive correlation observed by Cu with those constituents (Table. 19). It has been stated that Cu is derived from the soft parts of organisms that contain organo-copper complex such as the respiratory pigment haemocyian found in the blood of many marine invertibrates (Ravelle et al, 1955; Goldberg, 1965). Further, the humic acid which adsorb s Cu in large amount (Reimer & Toth, 1970) and tests of organisms which also accumulate Cu would provide Cu content to the sediments. In the marine environment only Ca shows significant positive correlation with Cu.

The clay fraction contains high amount of Cu which shows a decreasing trend downstream. The higher concentration of Cu in the clay fraction of river may be the consequence of the significant amount of montmorillonite content, which has high cation exchange capacity than the other clay minerals. It is stated that montmorillonite has high exchange capacity, especially for cations such as Cu and Zn in acid and neutral solutions (Reimer & Toth, 1970). Eventhough, considerable amount of montmorillonite is present in the estuarine and tidal channel compared to the riverine environment, the reason for the reduced Cu content in former environments is because of the desorption of Cu in the brackish and saline waters as reported by Borole et al (1977) and Seralathan (1987). The highest amount of Cu in the clay fraction of nearshore environment might be contributed by clay mineralogical variations. However, interestingly in the nearshore,

kaolinite is more in amount, which adsorbs lesser amount of Cu than montmorillonite and illite, as explained by Hirst (1962b), Venkatarathnam & Tilak (1968) Reimer & Toth (1970), Rao (1971), and Rao et al (1974). When these minerals are grouped together they enhance the Cu content in the sediment. The positive correlation of Cu with Fe and Mg (Table.28) suggests that a part of Cu may be associated with Fe and Mg phases also.

COBALT AND NICKEL:

The cobalt content in the bulk sediments of the various environments are 47.85 ppm (estuary), 46.5 ppm (tidal channel), 28.95 ppm (nearshore), and 19.1 ppm (river channel). The cobalt contents in the clay fractions are high in the nearshore (103.47 ppm) environment followed by river (102.17 ppm), tidal channel (92.5 ppm) and estuarine (71.1 ppm) environments. The present results are comparatively higher than those reported for river Mahanadi (21 ppm, Satyanarayana, 1973), inner continental shelf off east coast of India (21 ppm, Rao & Rao, 1973) and different environments of Cauvery deltaic sediments - river (24.1 ppm), marine (21.2 ppm), estuary (14 ppm), and tidal channel (11.3 ppm) (Seralathan, 1979).

The highest content of Ni in the bulk sediment is observed in estuary (190.35 ppm) followed by tidal channel (174 ppm), nearshore (118.18 ppm) and river channel (109.64 ppm) environments. The Ni content in the clay fraction of river channel, nearshore, tidal channel and

TABLE: 14. INTER ELEMENTAL CORRELATION MATRIX FOR THE RIVER SEDIMENTS (NORTH-BULK).

	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Or	Car
Si	1.0000											
Al	-0.2277	1.0000										
Fe	0.1671	-0.2376	1.0000									
Mg	@-0.7050	-0.1581	$-0.5893	1.0000								
Ca	0.1409	@0.6735	-0.1011	-0.4229	1.0000							
Na	-0.2500	0.0700	*-0.8784	@0.6050	-0.0878	1.0000						
K	-0.1681	0.4672	@-0.6415	0.2041	0.3233	*0.8007	1.0000					
Ti	-0.4266	0.1423	*-0.7514	*0.8078	-0.0865	$0.5882	0.2668	1.0000				
P	-0.0262	0.1403	*-0.7418	0.4176	0.2064	@0.7025	@0.6100	@0.6578	1.0000			
Mn	0.1161	*-0.8836	-0.0105	0.3055	$-0.5833	0.1331	-0.3700	0.1402	0.0307	1.0000		
Or	-0.0482	0.1138	-0.2784	0.2064	-0.0362	0.1263	0.1369	0.1909	0.3796	-0.3293	1.0000	
Car	-0.3741	-0.0905	$0.5679	-0.0996	-0.2608	-0.4597	-0.4826	-0.3308	@-0.6594	0.1537	-0.3893	1.0000

SIGNIFICANCE LEVEL * = 1%, @ = 5%, $ = 10%.

TABLE: 15. INTER ELEMENTAL CORRELATION MATRIX FOR THE ESTUARINE SEDIMENTS (NORTH-BULK).

	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Oc	Car
Si	1.0000											
Al	*-0.6465	1.0000										
Fe	*-0.6707	0.3334	1.0000									
Mg	0.0029	-0.2106	@-0.4423	1.0000								
Ca	@0.4911	-0.3284	*-0.6021	0.3343	1.0000							
Na	@0.4678	0.1235	*-0.7195	0.0519	@0.4756	1.0000						
K	0.0259	0.1820	@-0.4774	0.1560	0.1408	*0.6730	1.0000					
Ti	@0.5137	-0.3271	0.0804	$-0.3874	0.2160	0.0469	-0.3318	1.0000				
P	-0.1315	0.3126	0.1683	0.0348	0.0717	0.0550	0.0470	0.0105	1.0000			
Mn	-0.3739	0.1245	@0.4994	-0.2260	-0.3505	@-0.5356	@-0.5466	0.0625	-0.3555	1.0000		
Oc	*-0.6513	0.2465	0.3500	0.0244	$-0.4167	-0.2748	$0.3911	@-0.4565	0.0084	0.1232	1.0000	
Car	@-0.4639	0.3558	0.0819	-0.0767	-0.3352	-0.1496	0.0327	$-0.3920	-0.2873	0.2925	0.2125	1.0000

SIGNIFICANCE LEVE * = 1%, @ = 5%, $ = 10%.

TABLE: 16. INTER ELEMENTAL CORRELATION MATRIX FOR THE RIVER SEDIMENTS (SOUTH-BULK).

	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Oc	Car
Si	1.0000											
Al	*-0.8462	1.0000										
Fe	@-0.6999	0.4513	1.0000									
Mg	-0.3081	0.3201	-0.3939	1.0000								
Ca	-0.2509	0.0859	0.0525	0.2767	1.0000							
Na	-0.0676	0.0073	-0.4134	$0.5844	0.1988	1.0000						
K	-0.0889	0.1077	-0.5142	@0.7132	0.2893	*0.9280	1.0000					
Ti	-0.3810	0.0553	0.1755	0.3813	0.2468	0.3098	0.3475	1.0000				
P	-0.1422	0.1977	-0.0901	0.3933	-0.0022	-0.0129	0.0369	0.3230	1.0000			
Mn	0.2192	-0.1844	0.3248	@-0.7118	-0.0884	*-0.7770	*-0.8573	-0.4802	-0.3617	1.0000		
Oc	-0.0270	-0.0429	-0.0046	-0.0066	-0.0190	0.1995	0.1156	0.4016	@0.7135	-0.3318	1.0000	
Car	-0.1672	0.2906	$0.5260	-0.5192	-0.0378	*-0.8988	*-0.8532	-0.4027	-0.0469	*0.8216	-0.2433	1.0000

SIGNIFICANCE LEVE * =1%, @ = 5%, $ = 10%.

TABLE: 17. INTER ELEMENTAL CORRELATION MATRIX FOR THE ESTUARINE SEDIMENTS (SOUTH-BULK).

	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Oc	Car
Si	1.0000											
Al	*-0.7607	1.0000										
Fe	*-0.7884	*0.5783	1.0000									
Mg	-0.2233	-0.1416	0.2470	1.0000								
Ca	-0.1882	0.2184	0.1758	0.2244	1.0000							
Na	@-0.4993	*0.5648	0.2482	0.1808	0.2416	1.0000						
K	$-0.4407	0.3618	0.0535	0.1274	0.0900	*0.8793	1.0000					
Ti	-0.3154	0.2139	0.2856	0.2598	0.1594	0.1631	0.0622	1.0000				
P	@-0.4951	@0.4459	0.0892	0.1132	-0.0550	0.2760	0.3351	0.1091	1.0000			
Mn	-0.3493	0.1709	@0.4781	-0.1044	0.3299	-0.2423	-0.2670	0.1009	0.0928	1.0000		
Oc	*-0.6071	0.3572	@0.5112	0.0396	0.2050	0.0880	0.0894	0.2866	0.2267	@0.5099	1.0000	
Car	-0.3156	0.1150	0.2243	0.2417	*0.5948	-0.0174	-0.1161	0.3737	-0.0041	0.2874	@0.4809	1.0000

SIGNIFICANCE LEVEL * = 1%, @ = 5%, $ = 10%.

TABLE: 18. INTER ELEMENTAL CORRELATION MATRIX FOR THE RIVER SEDIMENTS (CENTRE-BULK).

	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Oc	Car	Cu	Ni
Si	1.0000													
Al	*-0.7654	1.0000												
Fe	*-0.7614	$0.5645	1.0000											
Mg	@-0.7000	0.3433	0.2617	1.0000										
Ca	-0.1469	0.0538	-0.3079	0.1943	1.0000									
Na	-0.4833	0.4182	0.1760	$0.5600	0.2901	1.0000								
K	-0.2639	0.2147	-0.3086	0.4815	$0.5344	@0.6292	1.0000							
Ti	$-0.5937	@0.6824	0.1729	0.4242	0.3418	*0.7668	@0.7163	1.0000						
P	-0.1619	0.2939	-0.2673	0.2697	@0.6341	0.2278	0.4328	0.4690	1.0000					
Mn	-0.0883	0.1559	0.4922	-0.1028	$-0.5708	-0.1885	$-0.5392	-0.4343	$-0.5554	1.0000				
Oc	0.2517	-0.0983	-0.1978	-0.3510	0.1190	-0.3747	-0.2580	-0.0398	0.5146	-0.3873	1.0000			
Car	0.3063	-0.3875	0.2645	$0.5502	@-0.6613	-0.4079	$-0.5220	-0.4139	@-0.6115	0.2889	0.1746	1.0000		
Cu	-0.5147	0.2603	$0.5999	0.4191	-0.1647	@0.6763	0.1143	0.4326	-0.0735	-0.0121	-0.1782	0.2102	1.0000	
Ni	-0.4816	0.1415	$0.5689	0.4625	-0.1132	-0.0498	-0.2280	-0.2822	-0.2131	0.4897	$-0.5348	-0.0906	0.2098	1.0000
Zn	$-0.6012	@0.6766	@0.6651	0.2784	-0.3916	0.1102	-0.3180	0.1973	-0.2777	0.4226	-0.2410	-0.1063	0.2211	0.3276
Cr	@-0.6275	*0.7948	$0.5326	0.3174	0.0530	0.2818	-0.1257	0.3298	0.1661	0.4047	-0.0119	-0.4135	0.1221	0.1813
Cd	-0.0451	-0.1057	0.3627	0.0038	-0.4976	-0.2280	@-0.7151	-0.3079	-0.3353	0.2176	0.1527	0.2928	0.1879	0.1815
Co	0.0351	-0.3744	0.1302	0.2547	-0.0001	0.1383	-0.3780	-0.4309	-0.2726	0.2000	-0.2142	-0.0232	0.3382	0.4144

	Zn	Cr	Cd	Co
Si				
Al				
Fe				
Mg				
Ca				
Na				
K				
Ti				
P				
Mn				
Oc				
Car				
Cu				
Ni				
Zn	1.0000			
Cr	*0.7435	1.0000		
Cd	$0.5400	0.1752	1.0000	
Co	0.0749	0.0542	0.4658	1.0000

SIGNIFICANCE LEVEL * = 1%, @ = 5%, $ = 10%.

TABLE: 19. INTER ELEMENTAL CORRELATION MATRIX FOR THE ESTUARINE SEDIMENTS (CENTRE-BULK).

	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Oc	Car	Cu
Si	1.0000												
Al	*-0.8952	1.0000											
Fe	*-0.7720	*0.6229	1.0000										
Mg	-0.2218	0.1922	0.1112	1.0000									
Ca	0.2685	-0.1067	-0.3195	$-0.4211	1.0000								
Na	0.0497	0.0427	-0.3220	0.2244	0.2158	1.0000							
K	-0.0010	0.1817	$-0.3836	0.0078	@0.5136	@0.4679	1.0000						
Ti	0.0318	-0.1653	0.2636	0.1757	0.0918	-0.1889	0.0783	1.0000					
P	-0.0576	0.1972	-0.0701	-0.1296	-0.0284	-0.2974	0.0084	-0.2098	1.0000				
Mn	@-0.4519	0.3774	*0.6584	0.1017	@-0.4955	-0.1989	-0.3381	0.1571	-0.0547	1.0000			
Oc	*-0.6366	@0.4798	@0.4664	-0.1070	0.0011	-0.0869	0.2883	0.0561	-0.0679	0.2085	1.0000		
Car	*-0.7046	*0.6137	0.4333	0.0857	-0.1146	0.0414	0.3190	-0.1506	-0.0031	0.1788	*0.7791	1.0000	
Cu	@-0.4571	@0.5408	0.0803	0.0028	-0.0123	-0.1178	0.3261	$-0.4031	*0.6006	0.0157	@0.4531	@0.5275	1.0000
Ni	$-0.4287	$0.4264	0.3532	-0.2007	0.3733	-0.1208	$0.4166	0.0043	0.0853	0.0779	*0.6284	*0.6345	@0.5510
Zn	$-0.4189	$0.3899	$0.4390	-0.1550	0.1450	-0.0689	0.1077	0.1154	0.2186	0.0855	@0.4902	@0.4809	@0.5432
Cr	-0.0564	0.0586	0.3098	-0.0085	-0.0680	-0.3632	-0.0805	*0.6562	-0.0873	0.1758	-0.1098	-0.1612	-0.2334
Cd	$-0.4256	0.3265	*0.6315	-0.0296	0.2445	0.0430	-0.0389	0.3662	-0.3051	0.2179	@0.5210	0.2800	-0.1319
Co	-0.3718	0.2998	@0.5043	-0.0940	0.1293	0.2155	-0.1321	-0.1769	-0.2167	0.3206	0.1872	0.1643	-0.1533

	Ni	Zn	Cr	Cd	Co
Si					
Al					
Fe					
Mg					
Ca					
Na					
K					
Ti					
P					
Mn					
Oc					
Car					
Cu					
Ni	1.0000				
Zn	*0.6650	1.0000			
Cr	0.0318	0.0989	1.0000		
Cd	$0.3887	@0.4794	-0.0012	1.0000	
Co	0.1076	0.1431	-0.1693	*0.5827	1.0000

SIGNIFICANCE LEVEL * = 1%, @ = 5%, $ = 10%.

TABLE: 20. INTER ELEMENTAL CORRELATION MATRIX FOR THE NEARSHORE SEDIMENTS (BULK).

	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Oc	Car	Cu
Si	1.0000												
Al	@-0.4751	1.0000											
Fe	*-0.7531	-0.0270	1.0000										
Mg	-0.1563	@0.4562	-0.2233	1.0000									
Ca	0.0554	-0.1578	-0.2860	0.1217	1.0000								
Na	*-0.6436	*0.6455	@0.4387	0.1284	@-0.4688	1.0000							
K	@-0.5025	@0.4515	$0.3949	-0.0203	@-0.4732	*0.9437	1.0000						
Ti	@-0.5257	-0.2805	*0.8846	-0.2264	-0.2274	0.1684	0.1344	1.0000					
P	-0.2981	0.2212	@0.4242	-0.2093	-0.1873	$0.3975	@0.4410	0.1910	1.0000				
Mn	-0.0080	@-0.4622	@0.4325	$-0.4113	0.0344	-0.1220	-0.0597	*0.6876	0.1534	1.0000			
Oc	0.3039	-0.1693	*-0.5766	0.2788	*0.5568	*-0.6014	*-0.6346	@-0.4337	@-0.5256	-0.3047	1.0000		
Car	$0.4028	$-0.3631	@-0.5166	0.0160	*0.8328	*-0.7341	*-0.7304	-0.3132	@-0.4279	-0.0147	*0.8212	1.0000	
Cu	-0.2232	-0.0057	0.1530	0.0016	*0.5607	-0.0104	0.0079	0.1048	0.2064	0.2784	-0.0390	0.2669	1.0000
Ni	$-0.3861	-0.0584	*0.5880	@-0.4383	-0.0908	0.3138	$0.3621	$0.4188	$0.3903	0.2836	@-0.5132	-0.3203	$0.3958
Zn	@-0.4489	0.2713	@0.4520	0.0400	-0.0138	0.2321	0.1959	0.3264	@0.4596	0.3409	-0.2950	-0.2042	0.3350
Cr	@-0.4746	-0.1053	*0.8108	-0.3271	@-0.4303	$0.4050	$0.3940	*0.7228	@0.4885	$0.4208	*-0.7120	*-0.6462	0.0593
Cd	-0.3324	-0.1066	0.2220	-0.1991	*0.6891	-0.1132	-0.1106	0.2020	-0.1908	0.2004	0.0854	$0.3868	*0.6105
Co	-0.0141	0.1804	-0.3535	0.2233	@0.4627	-0.1389	-0.2393	@-0.4776	-0.1436	@-0.4817	*0.5847	@0.4660	0.2482

	Ni	Zn	Cr	Cd	Co
Si					
Al					
Fe					
Mg					
Ca					
Na					
K					
Ti					
P					
Mn					
Oc					
Car					
Cu					
Ni	1.0000				
Zn	0.3187	1.0000			
Cr	*0.6289	0.1054	1.0000		
Cd	0.2543	0.1807	-0.0364	1.0000	
Co	-0.0162	-0.3395	-0.2685	0.0979	1.0000

SIGNIFICANCE LEVEL * = 1%, @ = 5%, $ = 10%.

TABLE: 21. INTER ELEMENTAL CORRELATION MATRIX FOR THE TIDAL CHANNEL SEDIMENTS (BULK).

	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Oc	Car
Si	1.0000											
Al	*-0.8382	1.0000										
Fe	*-0.9084	*0.9495	1.0000									
Mg	-0.1756	-0.3476	-0.2070	1.0000								
Ca	0.4770	-0.2751	-0.4579	-0.0749	1.0000							
Na	@0.7688	-0.5635	@-0.7259	-0.1931	0.3976	1.0000						
K	@0.7233	-0.5109	@-0.6880	-0.2386	0.2297	*0.8930	1.0000					
Ti	-0.5748	$0.6399	@0.7413	-0.2937	@-0.7003	0.3308	-0.3401	1.0000				
P	0.3639	-0.1275	-0.1208	-0.2599	0.1047	0.2225	0.2706	0.1151	1.0000			
Mn	$-0.5895	@0.6685	@0.7443	-0.1801	-0.0280	@-0.7392	@-0.7214	0.4197	0.2202	1.0000		
Oc	@-0.7748	@0.7621	*0.9003	-0.2111	$-0.6612	@-0.7865	@-0.7004	@0.7302	-0.0216	@0.6704	1.0000	
Car	-0.4829	0.4205	0.4625	-0.0283	-0.4005	-0.5045	-0.4484	0.4788	-0.4126	0.2377	0.3970	1.0000

SIGNIFICANCE LEVEL * = 1%, @ = 5%, $ = 10%.

TABLE: 22. INTER ELEMENTAL CORRELATION MATRIX FOR THE RIVER SEDIMENTS (NORTH-CLAY).

	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Oc	Car
Si	1.0000											
Al	-0.5625	1.0000										
Fe	0.4863	0.2121	1.0000									
Mg	0.2713	-0.0488	0.6081	1.0000								
Ca	-0.3176	0.2501	0.4689	0.3508	1.0000							
Na	0.0663	0.1260	0.2876	-0.4750	0.2541	1.0000						
K	-0.7118	0.6145	-0.3317	0.0854	-0.1216	-0.4096	1.0000					
Ti	0.3156	-0.2589	0.7037	0.6778	0.6962	0.2047	-0.4092	1.0000				
P	@-0.8596	0.4676	-0.7247	-0.3555	-0.1644	-0.3721	@0.8137	0.6945	1.0000			
Mn	-0.0195	0.4239	0.1390	0.3933	0.1256	0.2112	-0.2696	-0.3356	0.0313	1.0000		
Oc	0.5953	0.0248	0.5006	0.2484	-0.0445	-0.1914	-0.4604	0.0298	-0.4472	0.6529	1.0000	
Car	-0.4680	0.4880	-0.5620	$-0.7952	-0.4943	0.1906	0.4538	@-0.8882	0.6703	0.3376	-0.2455	1.0000

SIGNIFICANCE LEVEL * = 1%, @ = 5%, $ = 10%.

TABLE: 23. INTER ELEMENTAL CORRELATION MATRIX FOR THE ESTUARINE SEDIMENTS (NORTH-CLAY).

	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Oc	Car
Si	1.0000											
Al	-0.2233	1.0000										
Fe	-0.2893	-0.4803	1.0000									
Mg	-0.0172	-0.1736	-0.4333	1.0000								
Ca	-0.3986	-0.0623	0.1728	0.0994	1.0000							
Na	@0.6386	-0.4077	0.1394	-0.5143	-0.3686	1.0000						
K	-0.2854	@0.7282	-0.1053	-0.4401	-0.2751	-0.0009	1.0000					
Ti	0.3888	-0.1628	-0.3518	0.3489	0.1456	0.1463	0.1218	1.0000				
P	0.1300	-0.5413	0.2179	-0.1381	-0.0118	0.5409	-0.1074	0.0161	1.0000			
Mn	0.1571	-0.3136	-0.0241	0.2631	0.3921	0.0151	$0.6001	-0.0319	-0.1982	1.0000		
Oc	-0.1009	*0.7981	@-0.6500	0.1071	-0.3359	-0.2182	@0.7566	0.0191	-0.2004	-0.4647	1.0000	
Car	0.2475	-0.1104	0.2862	@-0.6848	$-0.6170	$0.5708	0.1278	-0.4113	0.2241	-0.3989	-0.1387	1.0000

SIGNIFICANCE LEVEL * = 1%, @ = 5%, $ = 10%.

TABLE: 24. INTER ELEMENTAL CORRELATION MATRIX FOR THE RIVER SEDIMENTS (SOUTH-CLAY).

	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Oc	Car
Si	1.0000											
Al	-0.5885	1.0000										
Fe	0.6045	-0.1454	1.0000									
Mg	0.4727	-0.4598	@0.8303	1.0000								
Ca	-0.2274	-0.3526	0.1029	0.5268	1.0000							
Na	-0.3638	-0.0847	-0.4619	-0.0825	0.0464	1.0000						
K	0.4935	-0.1479	*0.9800	@0.8555	0.1653	-0.3741	1.0000					
Ti	0.5957	-0.6674	0.4084	0.7242	0.4138	0.2207	0.3539	1.0000				
P	-0.5562	0.2378	-0.5503	-0.4162	0.4632	-0.1591	-0.5828	-0.2428	1.0000			
Mn	@-0.8966	0.4853	-0.5749	-0.5185	-0.0147	0.3881	-0.4265	$-0.7373	0.2372	1.0000		
Oc	-0.4855	0.1707	-0.2192	-0.3214	0.1359	-0.3659	-0.1152	$-0.7505	0.3264	0.6307	1.0000	
Car	-0.1682	0.5137	-0.4263	@-0.8469	$-0.8052	-0.2430	-0.4652	$-0.8103	0.0461	0.3499	0.3686	1.0000

SIGNIFICANCE LEVEL * = 1%, @ = 5%, $ = 10%.

TABLE: 25. INTER ELEMENTAL CORRELATION MATRIX FOR THE ESTUARINE SEDIMENTS (SOUTH-CLAY).

	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Oc	Car
Si	1.0000											
Al	-0.3190	1.0000										
Fe	-0.1790	0.4976	1.0000									
Mg	-0.4536	0.0429	-0.3961	1.0000								
Ca	-0.3193	-0.4512	-0.4930	0.3639	1.0000							
Na	0.4145	0.3300	0.3347	@-0.7927	-0.4589	1.0000						
K	0.0728	@0.6942	0.4018	-0.3428	-0.3538	@0.7465	1.0000					
Ti	-0.5507	-0.0122	-0.1789	0.0959	@0.7450	-0.0480	0.0003	1.0000				
P	0.1647	0.2197	0.2082	-0.3478	0.1145	$0.6630	$0.6570	0.2428	1.0000			
Mn	0.1504	@-0.7074	-0.3184	0.0780	0.2189	-0.5159	*-0.9139	-0.1702	-0.4490	1.0000		
Oc	0.0366	-0.2372	@-0.7081	0.1712	0.3776	0.1659	0.1426	0.3724	0.3344	-0.1986	1.0000	
Car	0.0462	0.3681	-0.0034	-0.0704	0.3484	0.3959	@0.6973	0.4111	@0.7551	$-0.6486	0.3138	1.0000

SIGNIFICANCE LEVEL * = 1%, @ = 5%, $ = 10%.

TABLE: 26. INTER ELEMENTAL CORRELATION FOR THE RIVER SEDIMENTS (CENTRE-CLAY).

	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Oc	Car	Cu
Si	1.0000												
Al	0.2783	1.0000											
Fe	0.6323	-0.3986	1.0000										
Mg	0.5157	0.4229	0.3398	1.0000									
Ca	-0.1863	0.1601	0.1312	0.6632	1.0000								
Na	-0.0727	-0.5513	0.5974	-0.3302	0.0876	1.0000							
K	-0.1042	$0.8018	-0.6943	-0.1543	-0.1790	-0.4363	1.0000						
Ti	0.4138	0.1530	0.6546	$0.7375	$0.7404	0.3624	-0.3444	1.0000					
P	-0.6453	0.2386	@-0.9032	-0.6603	-0.3709	-0.3070	0.7263	$-0.7837	1.0000				
Mn	0.2254	-0.0817	-0.0204	-0.1995	-0.5459	-0.2756	0.1822	-0.5367	0.1880	1.0000			
Oc	-0.0460	-0.4079	0.0828	-0.1669	-0.2430	-0.0796	-0.1403	-0.4071	0.0576	@0.8743	1.0000		
Car	-0.5966	-0.2931	-0.5469	*-0.9699	-0.6503	0.1201	0.2779	@-0.8419	$0.7940	0.1688	0.4067	1.0000	
Cu	0.4402	-0.1626	0.5269	0.3547	0.0777	0.0333	-0.2399	0.1923	-0.4554	0.6949	$0.7806	-0.4735	1.0000
Ni	@0.8545	0.1845	0.6619	0.4096	-0.1061	0.1022	-0.0288	0.3784	-0.5504	0.5003	0.3257	-0.5459	$0.7701
Zn	-0.2680	-0.4139	0.1524	-0.2361	0.0680	0.3398	-0.0940	-0.1366	0.0762	0.5838	@0.8244	0.1182	0.6858
Cr	@0.8801	0.1837	0.6949	0.5149	-0.0256	0.0610	-0.0993	0.4502	-0.6344	0.4453	0.2958	-0.6429	$0.7775
Cd	0.1518	$-0.7362	0.4954	0.1489	-0.0477	0.0395	@-0.8474	0.0003	-0.5525	0.2869	0.5377	-0.2205	0.4976
Co	0.5471	-0.0223	0.2138	0.2567	*-0.7662	-0.0728	0.1657	-0.4073	0.0329	@0.8510	0.5661	0.1753	0.5323

ERR

	Ni	Zn	Cr	Cd	Co
Si					
Al					
Fe					
Mg					
Ca					
Na					
K					
Ti					
P					
Mn					
Oc					
Car					
Cu					
Ni	1.0000				
Zn	0.2483	1.0000			
Cr	@0.9911	0.1969	1.0000		
Cd	0.1389	0.2515	0.2029	1.0000	
Co	0.6744	0.2862	0.6046	0.1547	1.0000

SIGNIFICANCE LEVE * = 1%, @ = 5%, $ = 10%.

TABLE: 27. INTER ELEMENTAL CORRELATION MATRIX FOR THE ESTUARINE SEDIMENTS (CENTRE-CLAY).

	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Oc	Car	Cu
Si	1.0000												
Al	-0.107°	1.0000											
Fe	*-0.7887	0.0218	1.0000										
Mg	0.1203	-0.0253	-0.2984	1.0000									
Ca	-0.2668	-0.0130	0.0516	@-0.6554	1.0000								
Na	0.2893	0.1910	0.0078	$-0.6212	0.2170	1.0000							
K	-0.2104	0.2313	0.4394	-0.5194	0.2975	@0.6480	1.0000						
Ti	0.0258	-0.3214	-0.1008	0.0943	0.1097	-0.0552	-0.0056	1.0000					
P	*-0.8645	0.1308	*0.8930	-0.0128	-0.0466	-0.0656	0.3166	-0.1111	1.0000				
Mn	0.3074	-0.0898	-0.2098	0.3007	-0.3340	-0.0445	-0.4068	-0.3612	-0.1397	1.0000			
Oc	-0.4151	0.1887	0.4041	-0.4981	0.3749	0.3626	*0.8228	0.2808	0.2892	$-0.6132	1.0000		
Car	-0.2192	0.5103	0.3404	-0.4891	0.5431	0.2470	$0.5712	-0.1750	0.1645	-0.4355	0.4013	1.0000	
Cu	-0.1946	0.0065	-0.1276	0.5476	-0.4644	@-0.7523	@-0.6480	-0.2591	0.0305	0.1236	-0.3450	-0.5174	1.0000
Ni	@-0.6971	0.0370	@0.6704	0.3528	-0.3904	-0.4503	0.0068	0.2380	@0.7530	-0.0741	0.2134	-0.1638	0.3581
Zn	-0.0057	-0.2425	0.1924	0.1109	-0.0240	-0.5147	-0.2612	-0.0157	-0.0199	-0.1919	-0.3363	0.3384	0.0679
Cr	-0.2522	0.4839	0.1919	*-0.7647	$0.6001	@0.6668	$0.5747	-0.2640	0.1572	-0.1793	$0.5550	0.4659	-0.4024
Cd	0.3145	-0.3762	0.0129	-0.1990	0.2382	0.0449	0.1767	0.4185	-0.2942	-0.2235	0.0401	0.4014	$-0.5806
Co	-0.1532	-0.3954	-0.2804	0.2748	0.0064	$-0.5759	$-0.6196	0.0047	-0.1195	-0.1510	-0.2937	-0.5360	@0.7226

	Ni	Zn	Cr	Cd	Co
Si					
Al					
Fe					
Mg					
Ca					
Na					
K					
Ti					
P					
Mn					
Oc					
Car					
Cu					
Ni	1.0000				
Zn	0.0638	1.0000			
Cr	-0.2736	$-0.5592	1.0000		
Cd	-0.2239	@0.6548	-0.3118	1.0000	
Co	0.0046	0.0511	-0.2914	-0.3766	1.0000

SIGNIFICANCE LEVEL * = 1%, @ = 5%, $ = 10%.

TABLE: 28. INTER ELEMENTAL CORRELATION MATRIX FOR THE NEARSHORE SEDIMENTS (CLAY).

	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Oc	Car	Cu
Si	1.0000												
Al	0.4351	1.0000											
Fe	-0.4144	-0.1320	1.0000										
Mg	-0.0942	0.1219	0.2917	1.0000									
Ca	0.1488	-0.1110	-0.0606	0.3650	1.0000								
Na	-0.1755	-0.1227	-0.4325	0.2601	-0.3249	1.0000							
K	0.4187	0.2591	-0.3571	-0.0804	0.2277	0.3000	1.0000						
Ti	0.0926	0.1123	@0.5462	-0.0204	0.1142	$-0.4954	0.2126	1.0000					
P	-0.1660	-0.4334	0.0786	-0.4304	*0.6990	-0.3406	0.2570	0.3653	1.0000				
Mn	0.3000	-0.0447	0.3492	0.3183	0.3730	@-0.5673	0.2232	@0.5831	@0.5219	1.0000			
Oc	$0.4959	0.0771	-0.1918	0.0371	0.2636	$-0.5084	0.1655	0.0647	0.2476	0.1558	1.0000		
Car	0.4068	0.3012	0.2109	$0.4424	-0.1924	-0.3165	-0.0555	0.3226	0.3749	0.0219	0.3785	1.0000	
Cu	$-0.4988	-0.2738	@0.5791	$0.4697	0.1477	0.0966	0.0376	0.3300	0.2074	-0.0955	-0.1996	0.1709	1.0000
Ni	0.1245	0.1284	0.0678	0.3426	0.3315	0.1868	0.3249	-0.0654	-0.0865	0.0639	0.0809	0.1231	0.2836
Zn	@-0.6311	-0.2449	@0.5717	$0.4766	0.1264	0.1201	0.0270	0.2714	0.3118	-0.1021	-0.2313	-0.0877	*0.8993
Cr	-0.3392	-0.0430	$0.5084	$0.4981	-0.4341	0.1340	0.1823	0.4177	0.1024	0.0423	-0.1370	0.4121	@0.5755
Cd	$0.5074	0.2098	0.0716	-0.0204	0.3748	@-0.5823	0.2321	$0.4894	0.1954	0.4155	@0.5261	@0.6211	0.0143
Co	-0.3748	-0.1954	@0.5208	0.0481	0.2817	-0.2064	0.0657	0.3860	@0.5210	0.3699	-0.0366	$-0.4634	0.3920

	Ni	Zn	Cr	Cd	Co
Si					
Al					
Fe					
Mg					
Ca					
Na					
K					
Ti					
P					
Mn					
Oc					
Car					
Cu					
Ni	1.0000				
Zn	0.1806	1.0000			
Cr	0.2110	@0.5183	1.0000		
Cd	0.1077	-0.1814	0.0209	1.0000	
Co	0.2412	@0.6012	0.1473	-0.2304	1.0000

SIGNIFICANCE LEVEL * = 1%, @ = 5%, $ = 10%.

estuary is 256.17 ppm, 222 ppm, 210 ppm, and 205.1 ppm respectively. The levels of nickel content in clay fractions (<4 micron) of the Gulf of Paria (15 to 47 ppm, Hirst, 1962), inner continental shelf off west coast of India (53 ppm, Murty et al, 1970), shelf off east coast of India (86.3 ppm, Rao & Rao, 1973), Cauvery deltaic sediments - tidal channel (122.5 ppm), estuary (120.6 ppm), river (119.2 ppm) and marine (119 ppm), (Seralathan, 1979) and Ashtamudi lake (141.71 ppm, Sajan, 1988) are found to be lesser than the present observations made for the different environments of the study area. Data presented in Figs.55 & 56 depict an increase of Co and Ni content in the bulk sediments and a decrease in clay fraction, downstream.

The increasing trend of Co, in the bulk sediments downstream may be due to the fixation of Co in sediments by hydrous manganese and iron oxide, as stated by Krauskopf (1956), Jenne (1968), and Rao & Setty (1976). This is evinced by the significant positive correlation of Co with Fe (Table.19). The tidal channel bulk sediments show Co content whose levels are equal to those in the estuary owing to the similarity in their depositional conditions. The nearshore sediments display a slight decreasing amount of Co than that in estuarine and tidal channel, probably as a consequence of the less amount of Fe present in this environment. The positive correlation of Co with organic carbon, Ca, and carbonate (Table.20) elucitate that the marine organisms and shell fragments contribute

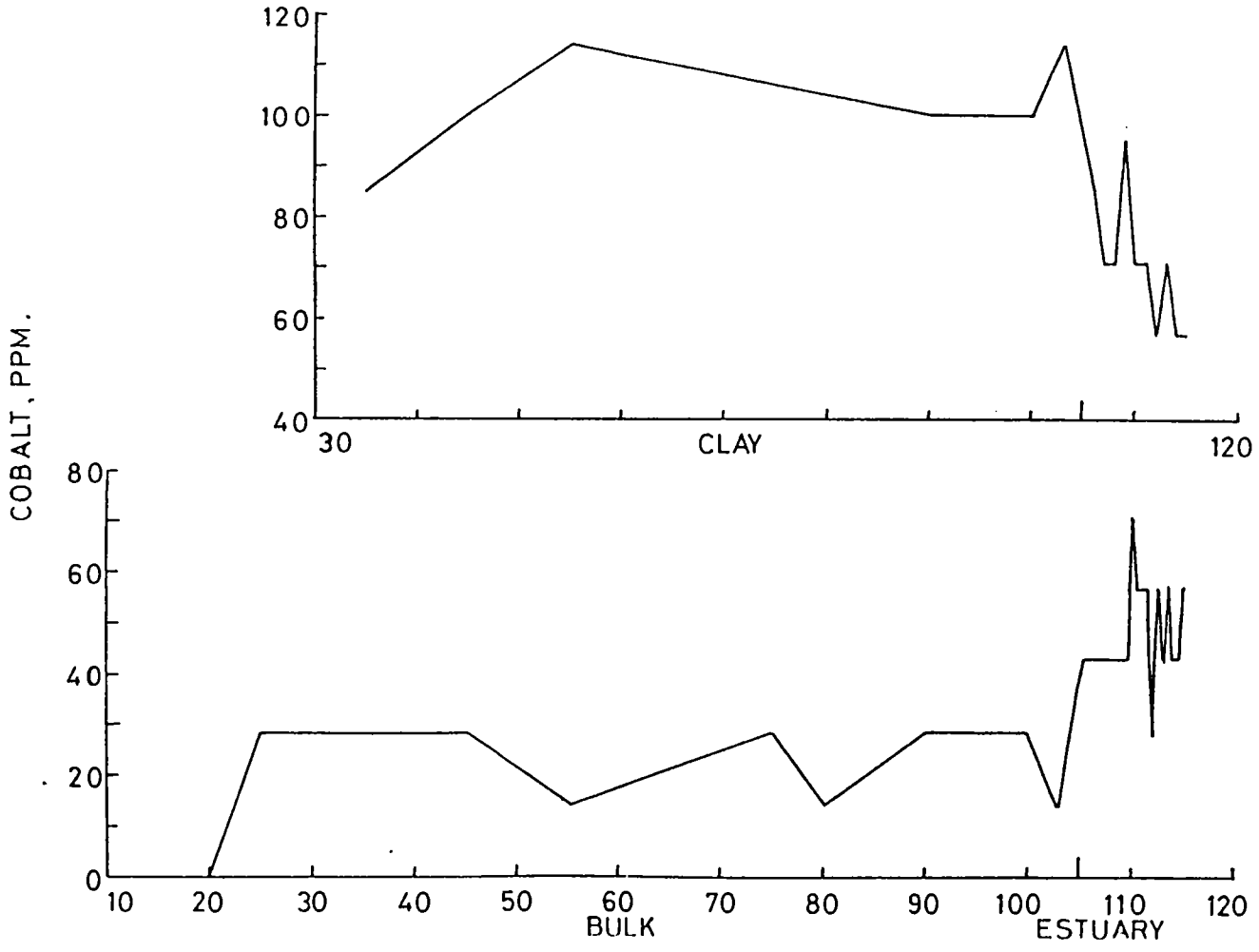


FIG. 55. DOWNSTREAM VARIATIONS OF COBALT IN THE SEDIMENTS OF VELLAR RIVER (BULK AND CLAY).

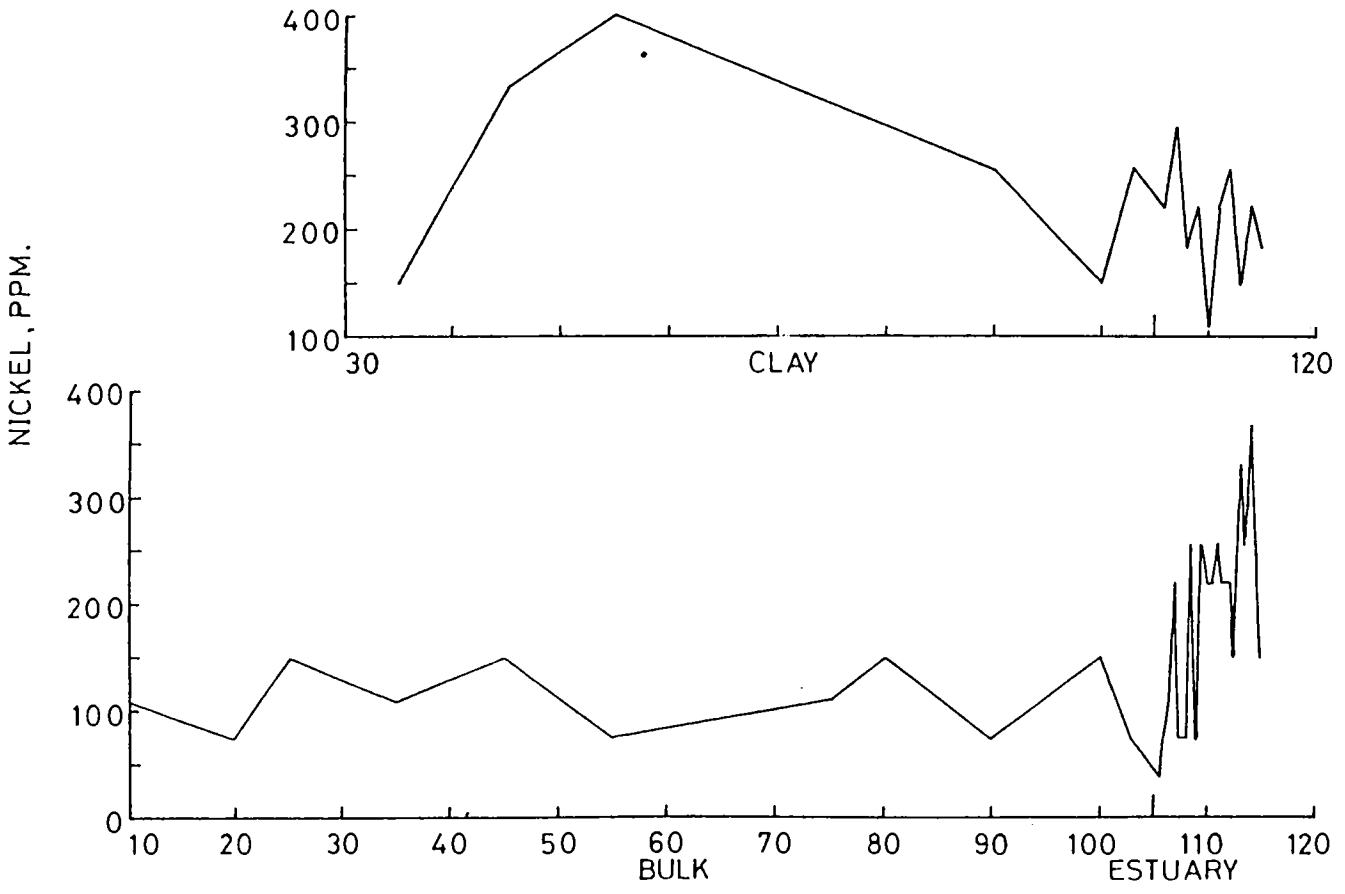


FIG. 56. DOWNSTREAM VARIATIONS OF NICKEL IN THE SEDIMENTS OF VELLAR RIVER (BULK AND CLAY).

significantly to the increase in Co in this environment in addition to Mn and Ti (Table.20).

The clay fraction holds high concentration of Co than in the bulk sediments which display a decreasing trend downstream, as a result of desorption of Co from clay minerals and oxides of Fe and Mn. Kharkar et al (1968) and Borole et al (1977) stated that trace elements like Co, adsorbed from solution and suspendent in river water by clay minerals, are desorbed in sea water. Moreover, the concentration of Co desorbed from river transported clay particles on contact with sea water, is reduced to half the level that prevailed in the fresh water. O'Connor & Kester (1975) proved that a high pH and high Mg^{2+} ions in the solution would lead to the replacement of Co from the clay mineral by magnesium. The above explanation adds support to the present observation of reduced Co content in the estuarine region. Eventhough, the conditions in the tidal channel and nearshore sediments are almost similar to those in the estuary, in respect to their pH and Mg^{2+} ions, the high amount of Co could have attributed to the increasing amount of Fe and P in the clay content of these two environments, which has adsorbed more Co from the water against the general trend of desorption. This is evidenced by the significant positive correlation of Co with Fe and P (Table.28). Carbonate content also shows significant positive correlation with Co (Table.28).

The downstream increase of Ni in bulk sediments is the consequence of the increase in Fe content.

This is supported by the statement of Jenne (1968) that Ni fixation is caused mainly by the hydrous iron oxide. As explained by Goldschmidt (1962) and Chester (1965), in the estuarine environments,the organic matter also plays a key role in the fixation of Ni in the sediments. Further, the carbonate of the shell fragments may also concentrate Ni and contribute to the bulk sediments. The positive correlation of Ni with Fe, organic carbon and carbonate (Table.18 & 19) testify those processes. The tidal channel and nearshore environments show a slight decrease in the amount of Ni owing to the decreasing trend of iron observed in these environments. This was evinced by the highly significant positive correlation of Ni with Fe (Table.20).

In general, the clay fractions show a high amount of Ni content than in bulk sediments. The Ni content is slightly more in river clay than that in the other three environments,where almost equal concentration of Ni is found. Among the clay minerals, montmorillonite can hold significant amount of Ni either by adsorption or by ion exchange mechanism. Hirst (1962b) stated that the Ni would be retained whenever Mg is retained in the formation of montmorillonite. Further, Hawkins and Roy (1963) have also observed high amount of Ni concentration in the montmorillonite than the other clay minerals. It is therefore infered that the river clay which contains considerable amount of montmorillonite naturally display a high amount of Ni. In the other environments,

- the desorption of Ni (Borole et al, 1977) leads to reduction in the Ni content in the clay fraction. However, observed positive correlation by Ni with Fe and P in the estuarine region suggests that Ni might have associated with ferric phosphate also (Table.27).

ZINC:

The highest level of Zn in the bulk sediments is observed in estuarine sediments (195.7 ppm) followed by marine (167 ppm), tidal channel (158.5 ppm), and river (116.73 ppm) sediments. In the clay fraction, the Zn concentration is presented in a decreasing order of abundance, nearshore (441 ppm) environment followed by river (239.33 ppm), tidal channel (203 ppm), and estuarine (195.7 ppm) environments. The observed levels of Zn in clay fractions are higher than those reported concentrations for Cauvery deltaic sediments - river (119.2 ppm), estuary (118.6 ppm), marine (111.9 ppm), and tidal channel (103.4 ppm) sediments (Seralathan, 1979), while they are lesser than that reported for Asthamudi lake sediments (316.43 ppm, Sajan, 1988).

An increasing trend of Zn in the bulk sdeiments and decreasing trend in the clay fraction downstream are observed (Fig.57). The increasing trend of Zn in the bulk sediment could be attributed to the changes in the iron content. Zn can diadochicaly replace ferrous iron and magnesium in the silicate mineral structure on account of a similarity in the ionic radii of iron and magnesium (Sakov, 1961). Moreover, the hydrous iron and

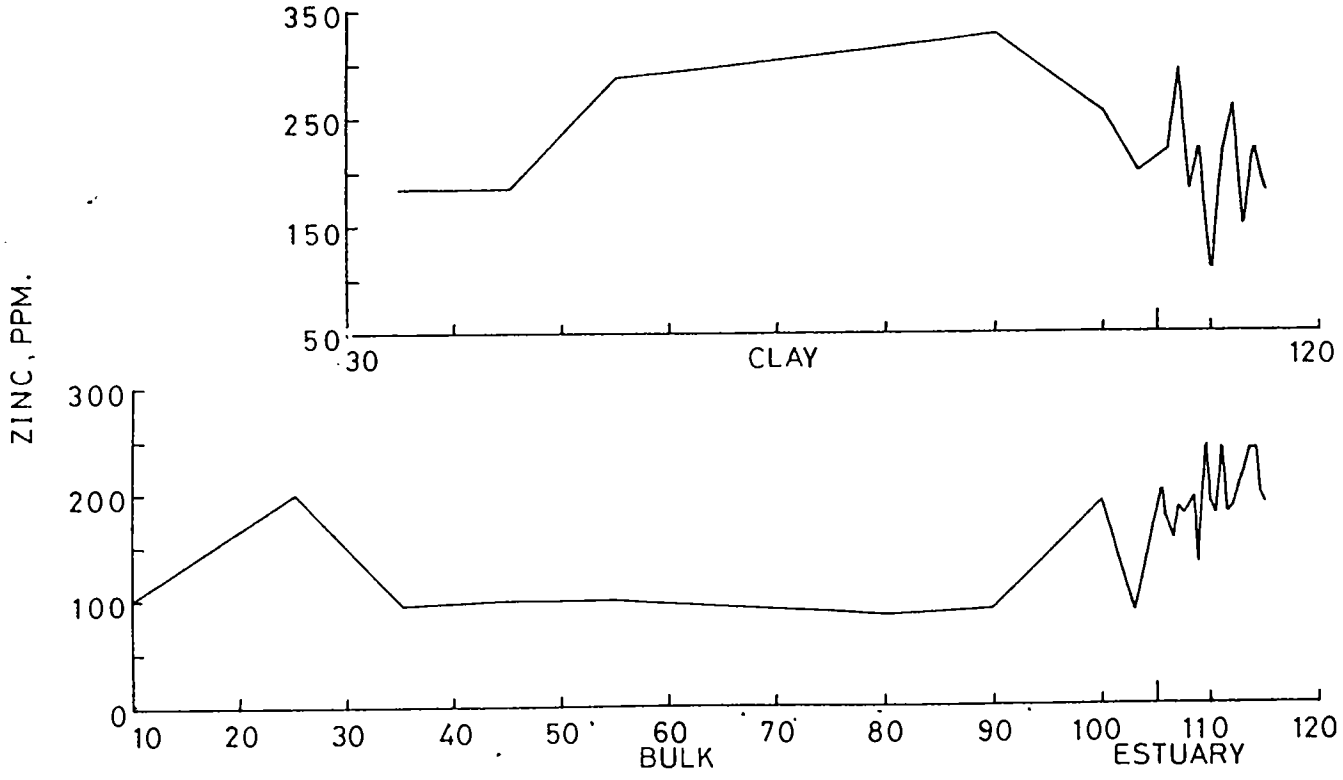


FIG. 57. DOWNSTREAM VARIATIONS OF ZINC IN THE SEDIMENTS OF VELLAR RIVER (BULK AND CLAY).

manganese oxides also adsorb Zn (Jenne, 1968; Willey, 1976a,b). The adsorption of copper and zinc on hydrous manganese oxide takes place as a result of the interchange with manganese (Loganathan & Burau, 1973). Hence, there is an increase in the amount of Zn in the estuarine environment. The organic matter also scavenges the Zn and concentrates it in to the sediments. Over and above these factors, as stated by Noddack (1935), the shell fragments also concentrate Zn in the bulk sediment. In the tidal channel and nearshore environments the decrease of iron content is reflected in the decrease of Zn content. The significant positive correlation of Zn with Fe, organic carbon and carbonate (Tables.18, 19, & 20) adds support to the above processes.

Generally, clay fractions show a high amount of Zn than bulk sediments, demonstrating a decreasing trend downstream, probably due to the adsorption of Zn by montmorillonite in the acidic river channel than the alkaline estuarine environment. Montmorillonite concentrates zinc due to their higher ionic exchange capacity (Seralathan, 1979). Further, as described by Kharakar et al (1968) and Borole et al (1977) Zn is desorbed from the riverine clay particles when they interact with sea water and concequently reduced in their concentration. The tidal channel and the estuarine environments where conditions are similar show almost equal concentrations of Zn. The slight increase in the amount in the tidalchannel may be due to the

organic matter, which also concentrates Zn in this environment. The nearshore clay fraction shows a high concentration of Zn due to the availability of montmorillonite and illite minerals and larger amount of organic carbon and iron oxide in clay fraction. Chester (1965) experimentally proved that illite can remove Zn from sea water and concentrate in the sediment. The positive correlation of Zn with organic carbon, and Fe recorded in the present study testify the foregoing explanation.

CHROMIUM:

Chromium content in the bulk sediments of the various environments are around 286.36 ppm (nearshore), 283.5 ppm (tidal channel), 251.64 ppm (river), and 221.7 ppm (estuary), whereas in the clay fraction, Cr is present at levels of 291 ppm (nearshore), 272.33 ppm (river), 267 ppm (tidal channel), and 263.4 ppm (estuary). The observed levels of Cr in the clay fraction are higher than those in the Gulf of Paria (75 ppm, Hirst, 1962), Mahanadi (129 ppm, Satyanarayana, 1973), inner continental shelf off east coast of India (103.7 ppm, Rao & Rao, 1973), and Cauvery deltaic sediments - river (240 ppm), tidal channel (173 ppm), and marine (148 ppm) sediments (Seralathan, 1979), whereas the Cr level observed in the Cauvery estuary (271 ppm, Seralathan, 1979) and Asthamudi lake (289.12 ppm, Sajan, 1988) sediments were slightly higher than the observations in the present study. The downstream variation of Cr in the bulk and clay fraction is presented in Fig.58 which show a decreasing trend downstream.

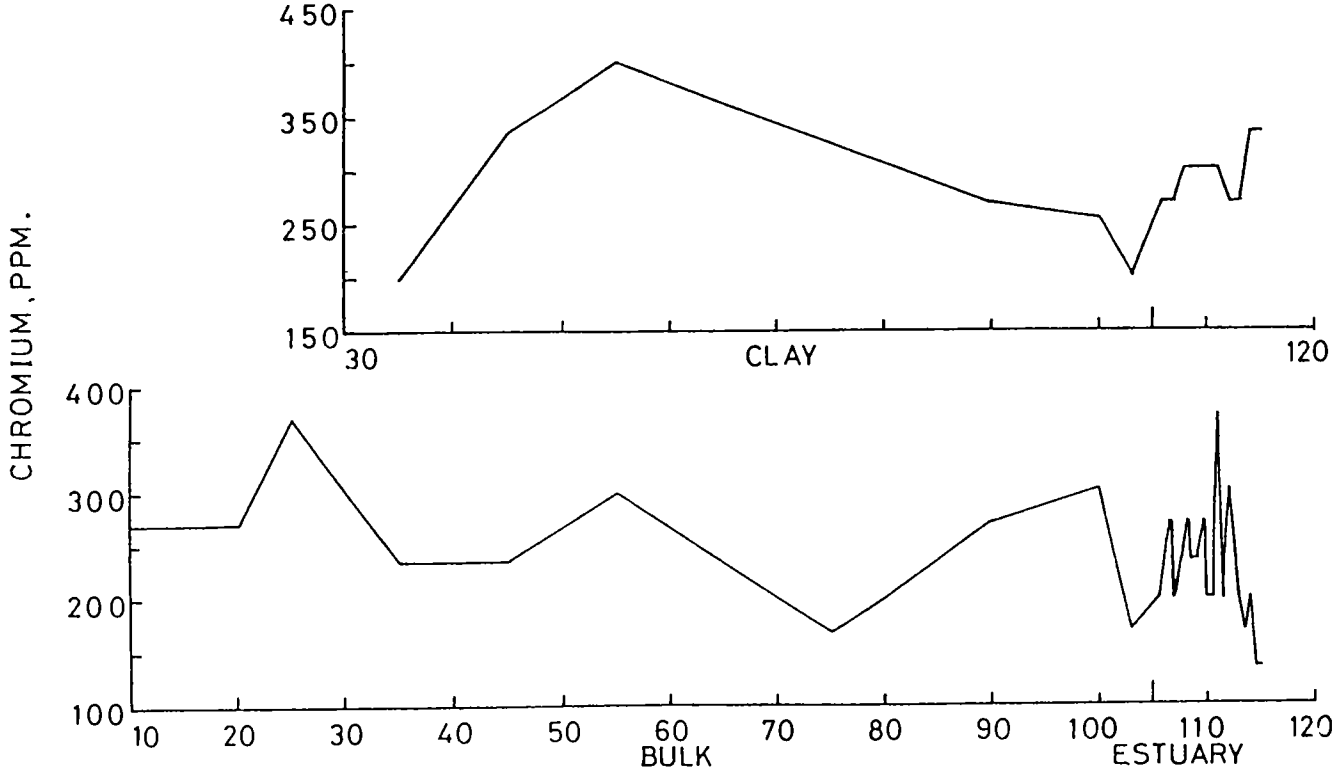


FIG. 58. DOWNSTREAM VARIATIONS OF CHROMIUM IN THE SEDIMENTS OF VELLAR RIVER (BULK AND CLAY).

The variation of chromium concentration in the bulk sediments downstream may be due to the mineralogy of the sediments and concentration of iron and mangnesium. The chromium bearing minerals contribute chromium to the bulk sediments (Reinson, 1975; Mayer & Fink, 1980; Rao & Raman, 1986). Since these minerals are too heavy, they are deposited more in the upstream than in the estuarine part of the river. Consequently there is an increase in the chromium content upstream. The tidal channel and nearshore bulk sediments show relatively high concentrations of Cr than river and estuarine sediments due to the richness of clay minerals and iron oxide. Seralathan (1979) stated that Cr^{3+} could be expected to proxy more readily for Fe^{3+} than Al^{3+}, and that Cr^{2+} exhibits diadohy with Mg^{2+} in magnesium rich minerals. Further, as explained by Rankama & Sahama (1950) the high amount of Fe and Mn also facilitates addition of more amount of Cr in these environments. The significant positive correlation of Cr with Fe, Al, and Ti evidences above said explanations (Tables.18, 19, & 20).

The concentration of Cr in the clay fraction did not show much variation in different environments. This leads to the conclusion that a variation in clay minerals percentage in the sediments of these environments results in the slight variation of Cr concentration. Chromium demonstrates a positive relationship with kaolinite and iron oxide. Thus in the

river all the above three parameters are high while they are lower in the estuarine and tidal channel environments. In the nearshore environment the highest contents of both kaolinite and Cr than other environments leads to the inference that kaolinite would have concentrated more Cr. Additionally Cr show positive correlation with Fe and Mg (Table.28) suggest that the said phases also concentrate Cr.

CADMIUM:

The cadmium concentration in the bulk sediments observed in estuarine, river, nearshore, and tidal channel are 7.4 ppm, 4.73 ppm, 4.6 ppm, and 4 ppm respectively. In the clay fraction, the concentration of Cd in the different environments are 4 ppm, 4 ppm, 3.5 ppm, and 3.2 ppm in river, tidal channel, nearshore and estuary environments rspectively. The observed levels of Cd in the clay fraction are higher than the levels of reported values in Asthamudi lake (1.63 ppm, Sajan, 1988).

The bulk sediments show comparatively high amount of Cd than clay fraction. An increasing trend is observed downstream (Fig.59) due to the adsorption by iron oxide coating on the mineral surface. Aston & Chester (1973) and Davies-Colley et al (1984) have suggested that the oxide coatings formed on detrital particles in the estuaries may remove trace elements from solution and prevent trace element desorption from ion exchange sites. The organic matter also adsorp Cd and concentrate it in the bulk sediments. Moreover, the pH of sea water also play a role in the concentration of Cd in the estuarine

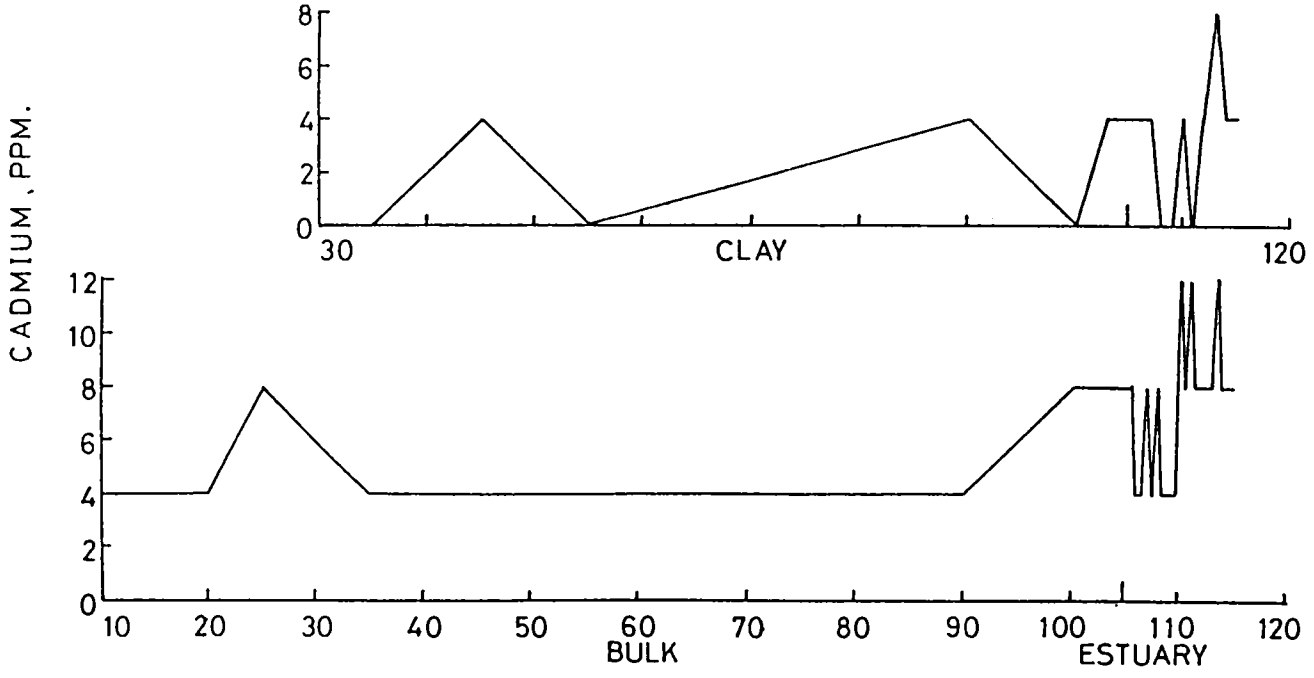


FIG. 59. DOWNSTREAM VARIATIONS OF CADMIUM IN THE SEDIMENTS OF VELLAR RIVER BULK (AND CLAY).

environment. Normally the estuarine water shows a pH in the range of 8-10. In this condition the elemental Cd becomes the stable solid $CdCO_3$ and gets deposited in the sediments (Burton & Liss, 1976) and later adsorbed by iron oxide. The slight decrease of Cd in tidal channel and nearshore bulk sediments may be due to the less amount of Cd available in this water, which gets deposited in the estuarine environment owing to the precipitation of elemental Cd in the stable phase. The significant positive correlation of Cd with Fe, organic carbon, and Ca supports these explanations (Tables.19 & 20).

A slight variation of Cd (3-4 ppm) in the clay fractions from the different environments may be due to the level variability of adsorption of Cd on the iron oxide. Since clay minerals are not a significant adsorbent to Cd in their lattice structure (Davis-Colley et al, 1984) their variation does not account for the changes in the Cd content. However, in the nearshore environments organic matter and carbonates also aid in the concentration process of Cd in the clay fraction. This is evinced by the significant positive correlation of Cd with organic carbon and carbonate content in the nearshore environments (Table.28).

FACTOR ANALYSIS:

Factor analysis, is a generic term that describes a variety of mathematical procedures applicable

to the analysis of data matrices, and is also regarded as a deep and mystrerious methodology of great complexity. Although developed by experimental psychologists in the 1930s and 1940s, it is applied in various branches of scientific enquiry. Mathematically, a factor refers to one of a number of things that yield a product when multiplied together. Another use of the word is to refer some sort of theoretical or hyphothetical casual variable. Although the former meaning is applied to the method; the later may also be occasionally applied to the results of the method (Klovan, 1975). Factor analysis is concerned with interpreting the structure of the variance - covariance matrix obtained from a collection of multivariate observations. It is of two types, namely, R-mode and Q-mode analyses. When the primary purpose of the investigation is to understand the inter-relationships among the attributes, the analysis is said to be an R-mode problem. If the primary purpose is to determine inter-relationships among the entities, then it is referred to as Q-mode analysis.

In the present study, the R-mode factor analysis has been employed for the geochemical data. The geochemical data are divided into two groups. The first group includes the data obtained for the major elements alone. While the second one includes data recorded for the major and trace elements together. These data are analysed using a Fortran program for factor analysis (Davis, 1973), which is executed on a Personal Computor. In the present

study, only the factors that explain at least 3% of the variance are considered (after Davis, 1973; Joreskog et al, 1976). As explained by Davis (1973), as there is little agreement as to what showed constitute a significant factor loading, only rotated loadings greater than 0.1 (because larger number of data) are considered for the interpretation of factors.

RESULTS AND DISCUSSION:

In the first group (major elements alone), of the 12 factors, 8 factors alone account for 95 percent of the cummulative variance (Table.31). Whereas, in the second group (major and trace elements), of the 18 factors 11 facotrs account for 94 % of the cummulative variance. Loadings of variables on the principal components are given in Figs. 60 & 61.

Based on the above results, the following factors are identified as the main cause for the variation in major and trace elements constituents in the different environments of the study area. The first eight factors are common to both major, and major-trace elements groups, despite the minor variations within variables. Hence these factors are explained commonly. The first factor, Grain size - Si factor, has positively influenced the Si followed by Ca, Na, K, and Ti and has negatively affected Al, Fe, P, Mn, Organic carbon, Carbonate and all trace elements except cd. The second factor, Al factor, has led to the increase of the Al content along with Mg, Na,

TABLE: 31 EIGENVALUES OF A)MAJOR ELEMENTS GROUP AND B)MAJOR AND TRACE ELEMENTS GROUP.

A). MAJOR ELEMENTS GROUP.

Elements	Eigenvalues	Percent of trace	Cumulative Percent of trace
Si	4.0800	33.9960	33.9960
Al	2.3190	19.3240	53.3200
Fe	1.3300	11.0840	64.4040
Mg	1.0670	8.8900	73.2940
Ca	0.8790	7.3230	80.6160
Na	0.8180	6.8130	87.4290
K	0.5400	4.5030	91.9320
Ti	0.4200	3.5000	95.4330
P	0.3730	3.1120	98.5450
Mn	0.0840	0.7030	99.2480
OC	0.0730	0.6050	99.8530
CAR	0.0180	0.1470	100.0000

B).MAJOR AND TRACE ELEMENTS GROUP.

Elements	Eigenvalues	Percent of trace	Cumulative Percent of trace
Si	6.3829	35.4607	35.4607
Al	2.0580	11.4333	46.8939
Fe	1.6723	9.2903	56.1843
Mg	1.5293	8.4964	64.6806
Ca	1.3599	7.5549	72.2355
Na	1.0677	5.9317	78.1672
K	0.8530	4.7389	82.9060
Ti	0.6002	3.3345	86.2405
P	0.5600	3.1113	89.3519
Mn	0.5076	2.8199	92.1718
OC	0.3621	2.0116	94.1833
CAR	0.3321	1.8450	96.0284
Cu	0.2315	1.2863	97.3146
Ni	0.1917	1.0647	98.3793
Zn	0.1250	0.6943	99.0736
Cr	0.0883	0.4905	99.5641
Cd	0.0570	0.3168	99.8810
Co	0.0214	0.1190	100.0000

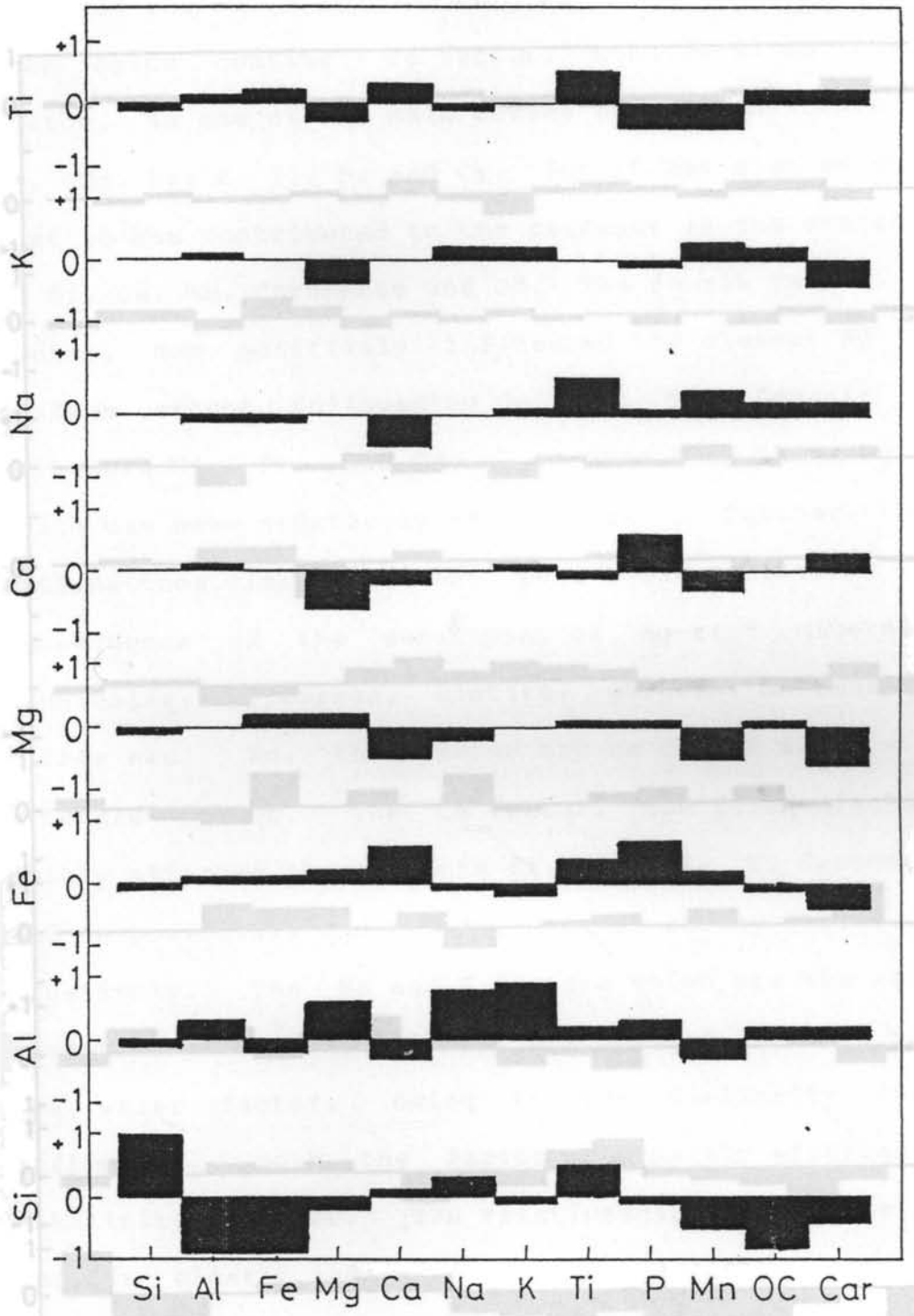


FIG. 60. LOADINGS OF VARIABLES (MAJOR ELEMENTS GROUP)

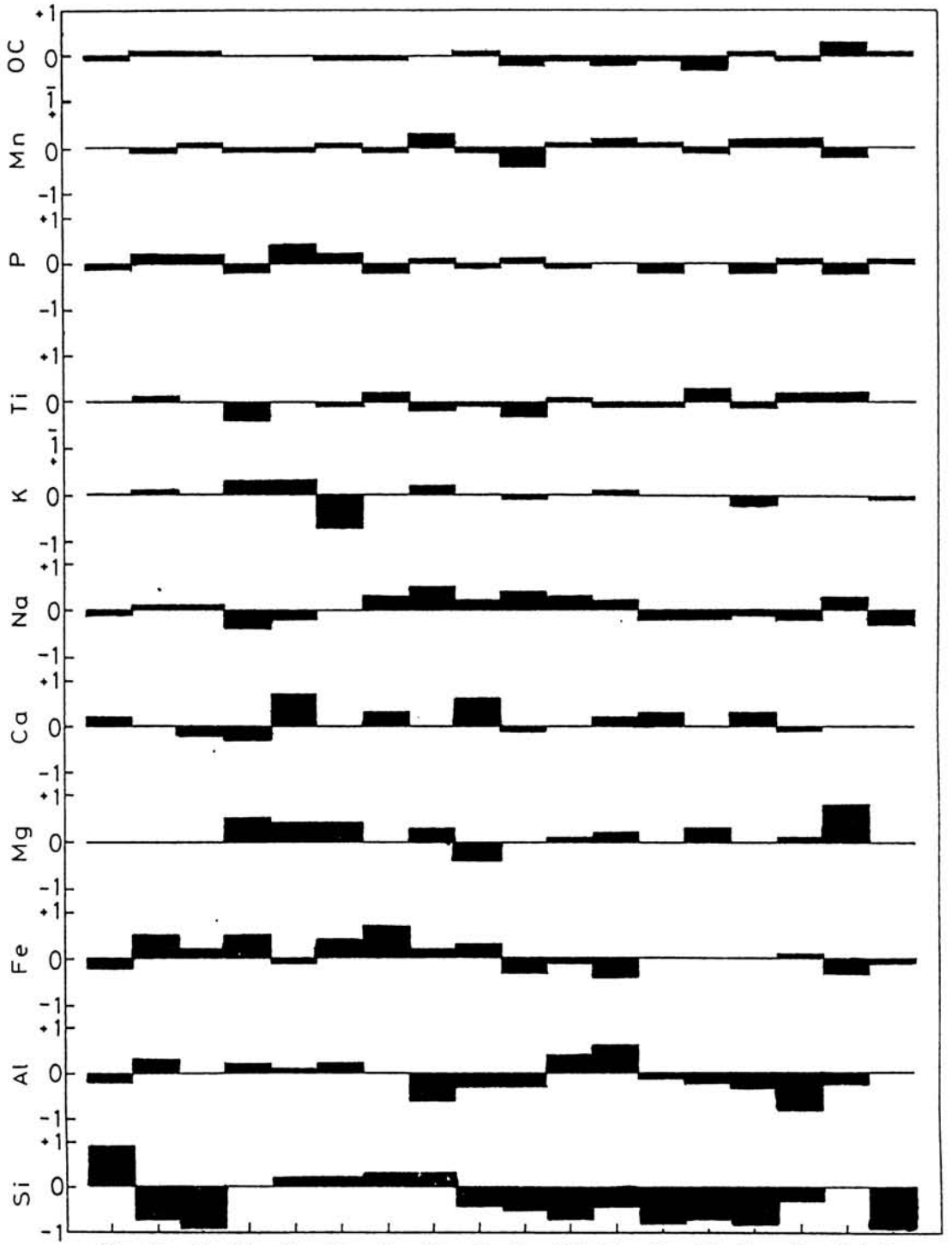


FIG. 61. LOADINGS OF VARIABLES (MAJOR AND TRACE ELEMENTS GROUP)

Organic carbon and Carbonate. On the contrary, it has affected the Si, Ti, P, Mn, Cu, Ni, Zn, Cr, and Cd. The iron oxide coating - Fe factor, considered as the third factor, is one of the main causes for the enrichment of Al, Fe, Mg, Na, K, Ti, P, and Cr. But it may also be suggested that it has contributed to the decrease in the concentration of Si, Ca, Mn, Carbonate and Cd. The fourth factor, i.e. Mg factor, has positively influenced the element Mg to the maximum extent followed by Ca, Na, Ti, Organic carbon, carbonate Ni, Cr, and Cd, whereas P is the only element which has been negatively influenced. Further, the above explanations clearly suggest that these variations are the consequence of the enrichment of Mg-rich minerals like amphiboles, pyroxenes, biotite, garnets, montmorillonite, illite etc. So, this factor may be called as Mg - Mg rich minerals factor. The Ca factor, the fifth factor, has mainly affected the elements Si, Ca, K, P, Carbonate, Cu, and Zn positively and Fe, Mg, Organic carbon and Cr elements negatively. The Na and K factors which are the sixth and seventh factors respectively, are grouped together and named Sea water factor, owing to the similarity in their influences. Both the factors are mainly affected by the alkalinity of water. The relationship between the Na and K factors clearly indicates that they mutually interact and positively influence the elements like Al, Ti, Carbonate. In addition to the above elements, Na alone affects positively elements like Fe, K, P, Mn, Organic carbon, and Cd, and K alone enriches the elements Mg and Ca. The Na factor

negatively influences the elements Si, Mg, Ca, and all trace elements except Cd while the K factor adversely affect s the elements Na, Mg, Zn and Co. The eighth factor, i.e. Ti factor exerts a positive influence on the elements K, Ni, Cr, Cd and a negative influence on Mg, Ti, P, Organic carbon and Zn.

The second group (major-trace elements) is further influenced by three more factors, namely, P - factor, Mn oxide - Mn factor and Organic matter - Organic carbon factor. The P - factor positively influences the enrichment of Al, Fe, Ca, Na, Ti, Co and negatively influences the following elements, namely Si, Mg, K, P, Carbonate, Cu, Zn, and Cd. Mn oxide - Mn factor, which is considered as one of the influential factors in the enrichment of elements in the sediments has positively affected only Na, Ti, Organic carbon, Carbonate, Cu, Zn, & Cr while Al, Mg, K, P, Mn, Ni, and Cd are influenced negatively. The last factor called Organic matter - Organic carbon factor, leads to the enrichment of the elements Al, Fe, Cd and it has adversely affected the concentration of Si, K, Mn, Carbonate, Ni, and Cr.

From the above study it is clear that the eleven factors mentioned above, influence the variation of the concentrations of major and trace elements. Further, this analysis also supports the earlier explanation given in the prceeding section for the variation of different elements.

POLLUTION ASPECTS OF THE GEOCHEMICAL STUDY:

The term trace element is rather loosely used in current literature to designate the elements which occur in small concentrations in natural biological systems. It is a known fact that trace quantities of certain elements exert a positive or negative influence on plant, animal, and human life. The present day concern over the quality of the environment has given rise to various terminology which are used to represent trace elements. Thus, other terms such as "trace metals", "trace inorganics", "heavy metals", "micro element", and "micro nutrient", synonymous with the term trace elements are widely used .

Without the participation of metal ions no organic life can develop and survive. The major ions such as sodium, potassium, magnesium and calcium are essential to sustain biologic life. Further, six metals (Mn, Fe, Co, Cu, Zn, & Mo), chiefly transition metals, are also essential for optimal human growth, development, achievement and reproduction (Vahrenkamp, 1973). However, these trace metals which are essential for life become toxic when their concentrations exceed the optimum nutritional need, i.e. between 40- and 200- fold (Venugopal & Luckey, 1975). This is called as metal toxicity. The accumulation of toxic substance from the environment to the humans mediates through the food chain. The alteration of natural environments, air, water,and soil renders them

offensive or deleterious to man and his asthetic senses, and to animals, fish or crops which man wishes to preserve. However, some degree of alteration of the environment is a necessary consequence of human activities. But such alteration are not considered as pollution until they reach a limit of tolerance (Tully, 1966). According to Rennie (1966), "any substance that is common or foreign to soil systems, which by its presence causes adverse effects, directly or indirectly, on the productivity of the soil (the productivity includes the yield and quality parameters of the food products produced) is called a soil pollutant".

In general, it is possible to distinguish between five different sources from which metal pollution of the environment originates: 1) geologic weathering, 2) industrial processing of ores and metals, 3) the use of metals and metal components, 4) leaching of metals from garbage and solid waste dumps, and 5) animal and human excretions which contain heavy metals (Forstner & Wittmann, 1979). While locating the source metal input in the aquatic environments, a distinction is often made between diffused non - point and point sources. Rural areas are considered as non - point sources, since the metal supply originates from vast regional areas. However, a substantial fraction of urbanized areas may also be included in the non point sources. Nonetheless, in highly industrialized zones it is often possible to pinpoint the source of localized effluent discharges responsible for

metal cotamination. Sediment analysis in particular is a unique technique to trace such point sources of metal pollution.

Sediment analyses, which normally do not furnish quantitative data on the absolute degree of pollution, however, indicate relative factors of enrichment and source of pollution in the aquatic environment. Hence, in the present study an attempt was made to assess the pollution in different environments of study area, taking into consideration the major and trace element levels obtained for both bulk and clay fractions. The enrichment factor was determined for the elements in both bulk sediments and clay fractions (Table.29). The enrichment factor is defined here as EF =(X/Fe) sediment / (X/Fe) earth's crust, where X/Fe is the ratio of the concentration of element X to Fe (Zoller et al, 1974; Forstner & Wittmann, 1979). Iron was chosen as the element for normalization since anthropogenic sources are small compared to natural sources (Helz, 1976; Sinex & Helz, 1981). The average earth's crust elemental concentration were compared with the elements available in the sediment. A value of unity denotes no enrichment or depletion of elements relative to earth's crust. The average earth's crust values used here were from Taylor's (1964) crustal abundance data.

RESULTS AND DISCUSSION:

Results presented in Table.29 represent the range of enrichment of major and trace elements and their averages which indicate that Si in the bulk and Mg and Mn in

TABLE 29. ENRICHMENT FACTORS FOR VELLAR RIVER, ESTUARY, TIDAL CHANNEL AND NEARSHORE SEDIMENTS.

RIVER (NORTH-BULK)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
10	7	4.84	0.54	1.00	4.21	0.42	1.15	0.73	1.14	0.12	6.12
20	13	4.43	0.53	1.00	3.86	0.51	0.85	0.57	2.21	0.14	5.61
25	16	2.81	0.19	1.00	2.01	0.24	0.43	0.30	0.42	0.04	5.22
35	22	5.16	0.71	1.00	7.36	0.46	1.11	0.65	4.87	0.09	3.37
45	28	3.64	0.51	1.00	2.76	0.36	0.58	0.38	2.31	0.15	2.30
55	34	5.32	0.54	1.00	6.29	0.46	1.09	0.65	3.69	0.28	3.37
75	46	3.73	0.22	1.00	2.04	0.31	0.52	0.24	0.89	0.00	13.46
80	49	7.31	0.41	1.00	9.59	0.63	1.83	0.96	6.34	0.50	41.30
90	55	4.86	0.28	1.00	6.16	0.35	1.09	0.55	4.29	0.20	24.48
100	61	2.90	0.13	1.00	3.93	0.22	0.48	0.20	1.34	0.00	15.24
103	70	2.98	0.26	1.00	1.88	0.25	0.49	0.32	0.41	0.01	7.48

ESTUARY (NORTH-BULK)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
105.5	79	1.62	0.42	1.00	2.70	0.17	0.54	0.28	0.77	0.01	9.97
106.0	82	1.30	0.30	1.00	2.65	0.15	0.43	0.40	0.42	0.04	1.12
106.5	85	1.50	0.31	1.00	2.40	0.13	0.40	0.23	0.75	0.03	9.18
107.0	88	1.76	0.37	1.00	1.75	0.26	0.53	0.31	0.99	0.04	1.29
107.5	91	1.68	0.49	1.00	3.84	0.25	0.63	0.35	0.49	0.16	2.77
108.0	94	1.16	0.41	1.00	2.53	0.22	0.46	0.27	0.47	0.08	3.22
108.5	97	1.40	0.33	1.00	1.84	0.20	0.48	0.25	1.17	0.07	8.69
109.0	100	1.52	0.49	1.00	1.95	0.17	0.71	0.46	0.47	0.03	1.26
109.5	103	1.28	0.44	1.00	2.62	0.13	0.46	0.43	0.46	0.10	1.16
110.0	106	1.23	0.43	1.00	2.45	0.15	0.47	0.33	0.54	0.06	6.73
110.5	109	0.96	0.33	1.00	2.01	0.08	0.29	0.20	0.42	0.02	7.28
111.0	112	1.46	0.38	1.00	2.81	0.17	0.48	0.33	0.70	0.01	8.62
111.5	115	0.69	0.27	1.00	0.99	0.07	0.17	0.13	0.28	0.04	10.10
112.0	118	1.72	0.52	1.00	3.47	0.30	0.84	0.54	0.75	0.01	11.88
112.5	121	1.11	0.39	1.00	1.68	0.12	0.36	0.27	0.42	0.02	17.34
113.0	124	1.86	0.52	1.00	2.80	0.23	0.81	0.52	0.80	0.09	1.46
113.5	127	1.57	0.48	1.00	2.68	0.18	0.57	0.36	0.50	0.05	12.12
114.0	130	1.12	0.40	1.00	2.53	0.15	0.35	0.27	0.45	0.01	7.52
114.5	133	1.40	0.46	1.00	1.94	0.11	0.60	0.36	0.51	0.06	3.69
115.0	136	2.68	0.56	1.00	5.94	0.43	0.90	0.60	0.51	0.00	10.52

RIVER (CENTRE-BULK)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Cu	Ni	Zn	Cr	Cd	Co
10	8	3.59	0.41	1.00	3.16	0.31	0.69	0.47	1.36	0.04	20.65	0.25	3.96	3.71	7.21	0.00	0.00
20	14	5.26	0.67	1.00	5.71	0.46	1.16	0.74	3.39	0.11	6.73	0.36	3.86	9.34	10.58	79.26	0.00
25	17	3.47	0.39	1.00	3.52	0.25	0.58	0.31	0.38	0.03	26.34	0.14	5.03	7.42	9.49	103.38	2.89
35	23	6.18	0.39	1.00	8.59	0.53	1.32	0.84	1.79	0.10	19.42	0.58	6.71	6.01	10.65	91.46	5.12
45	29	4.38	0.33	1.00	4.82	0.51	0.80	0.54	1.05	0.09	8.41	0.24	6.43	4.67	7.70	66.05	3.70
55	35	4.85	0.53	1.00	4.81	0.49	0.93	0.57	2.15	0.25	6.12	0.46	3.51	5.10	10.81	72.05	2.02
75	47	6.12	0.31	1.00	4.43	0.41	1.01	0.61	0.47	0.00	21.64	0.62	6.23	5.22	7.09	84.92	4.76
80	50	4.56	0.41	1.00	5.46	0.39	0.95	0.59	1.71	0.16	14.42	0.49	6.61	4.03	6.79	67.94	1.90

TABLE: 29.(CONT.)

90	56	5.46	0.45	1.00	5.04	0.54	1.41	0.69	2.58	0.11	16.83	0.72	3.86	5.04	10.58	79.26	4.44
100	62	2.13	0.28	1.00	2.91	0.17	0.55	0.26	1.12	0.01	10.24	0.56	3.35	4.63	5.17	68.92	1.93
103	71	5.70	0.21	1.00	3.47	0.38	0.71	0.51	0.52	0.02	16.83	0.22	3.86	4.87	6.62	158.52	2.22

ESTUARY (CENTRE-BULK)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Cu	Ni	Zn	Cr	Cd	Co
105.5	80	1.46	0.34	1.00	2.95	0.13	0.45	0.22	0.80	0.11	10.21	0.92	0.66	3.84	2.67	53.43	2.30
106.0	83	2.65	0.35	1.00	3.25	0.21	0.70	0.41	0.72	0.02	1.84	0.24	2.10	5.40	3.61	43.23	3.72
106.5	86	1.64	0.40	1.00	2.36	0.14	0.49	0.29	0.55	0.07	12.62	0.70	2.18	3.29	3.97	29.72	2.56
107.0	89	1.95	0.39	1.00	1.40	0.39	0.53	0.34	0.62	0.05	1.42	0.24	4.91	4.43	3.35	66.98	2.88
107.5	92	1.14	0.42	1.00	2.56	0.08	0.33	0.23	0.49	0.09	8.97	1.18	1.29	3.36	3.08	26.42	2.27
108.0	95	1.15	0.41	1.00	2.48	0.17	0.44	0.27	0.45	0.03	2.15	0.71	1.23	3.34	3.38	50.59	2.18
108.5	98	1.64	0.50	1.00	2.28	0.28	0.62	0.43	0.45	0.14	8.30	2.61	5.56	4.54	3.79	32.57	2.80
109.0	101	1.77	0.43	1.00	3.41	0.13	0.52	0.36	0.55	0.04	1.40	0.27	1.61	3.18	3.85	33.03	2.84
109.5	104	1.20	0.43	1.00	2.03	0.15	0.40	0.28	0.37	0.12	1.13	2.65	4.56	4.60	3.57	26.72	2.30
110.0	107	0.81	0.34	1.00	1.79	0.14	0.28	0.20	0.40	0.04	6.15	0.75	3.03	2.82	2.07	62.03	2.94
110.5	110	1.31	0.39	1.00	2.45	0.15	0.40	0.28	0.46	0.01	11.10	0.59	3.83	3.32	2.61	52.26	2.98
111.0	113	1.07	0.29	1.00	1.78	0.15	0.39	0.24	0.99	0.02	5.51	0.10	3.69	3.67	3.97	64.85	2.46
111.5	116	0.77	0.29	1.00	1.81	0.07	0.22	0.17	0.39	0.04	9.69	0.50	2.79	2.42	1.90	38.05	2.17
112.0	119	1.17	0.37	1.00	2.51	0.20	0.35	0.28	1.17	0.01	7.60	0.42	3.75	3.38	3.84	51.14	1.43
112.5	122	0.82	0.33	1.00	1.36	0.06	0.30	0.20	0.40	0.02	15.53	0.79	1.98	2.98	2.71	40.65	2.32
113.0	125	1.00	0.37	1.00	2.50	0.14	0.32	0.25	0.42	0.01	8.00	2.16	5.18	3.72	2.35	47.09	2.02
113.5	128	0.89	0.34	1.00	1.38	0.12	0.25	0.19	0.31	0.03	6.15	0.96	3.53	3.52	1.73	62.03	2.36
114.0	131	1.03	0.38	1.00	2.28	0.14	0.31	0.27	0.37	0.07	8.00	1.76	5.74	4.05	2.35	47.09	2.02
114.5	134	1.49	0.49	1.00	2.48	0.22	0.64	0.41	0.55	0.13	4.15	3.11	5.56	4.68	2.17	65.15	2.80
115.0	137	1.72	0.53	1.00	3.67	0.27	7.83	0.46	0.46	0.00	4.52	0.87	3.45	4.77	2.36	70.98	4.05

RIVER (SOUTH-BULK)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
10	9	4.27	0.49	1.00	4.69	0.37	0.83	0.60	0.72	0.05	2.73
20	15	4.26	0.42	1.00	5.30	0.50	0.87	0.60	2.21	0.05	8.19
25	18	3.21	0.32	1.00	2.68	0.28	0.27	0.16	0.27	0.08	18.17
35	24	4.54	0.31	1.00	5.10	0.57	0.90	0.57	1.35	0.07	5.61
45	30	5.68	0.53	1.00	8.15	0.41	1.15	0.76	1.66	0.14	3.61
55	36	4.01	0.35	1.00	4.09	0.34	0.85	0.50	1.72	0.16	2.52
75	48	3.33	0.23	1.00	2.58	0.23	0.51	0.29	1.04	0.00	12.36
80	51	4.36	0.41	1.00	4.96	0.25	0.97	0.56	1.08	0.07	5.46
90	57	7.96	0.58	1.00	7.56	0.76	1.75	1.03	0.32	0.00	24.04
100	63	4.68	0.30	1.00	3.03	0.25	0.69	0.41	0.80	0.02	14.02
103	72	2.09	0.26	1.00	2.13	0.23	0.43	0.24	0.65	0.01	5.69

ESTUARY (SOUTH-BULK)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
105.5	81	3.79	0.20	1.00	5.14	0.16	0.45	0.37	0.46	0.00	11.74
106.0	84	3.38	0.84	1.00	3.21	0.26	0.72	0.44	0.76	0.03	2.30
106.5	87	1.33	0.41	1.00	2.14	0.13	0.47	0.30	0.32	0.03	13.46
107.0	90	1.66	0.52	1.00	2.71	0.06	0.71	0.43	0.50	0.07	1.35
107.5	93	1.44	0.45	1.00	2.69	0.14	0.52	0.37	0.37	0.07	10.95
108.0	96	1.09	0.37	1.00	2.41	0.12	0.40	0.25	0.51	0.04	2.04

TABLE: 29.(CONT.)

108.5	99	1.86	0.52	1.00	3.67	0.27	0.62	0.37	0.56	0.13	9.04
109.0	102	2.35	0.50	1.00	4.31	0.28	0.80	0.54	0.50	0.02	1.77
109.5	105	2.45	0.72	1.00	3.71	0.22	1.14	0.71	0.73	0.14	1.96
110.0	108	1.36	0.41	1.00	2.51	0.23	0.65	0.39	0.30	0.04	6.81
110.5	111	1.36	0.42	1.00	2.88	0.21	0.53	0.29	0.58	0.01	5.74
111.0	114	1.27	0.38	1.00	2.19	0.19	0.58	0.34	0.30	0.00	3.19
111.5	117	1.77	0.51	1.00	3.07	0.25	0.67	0.36	0.65	0.07	14.02
112.0	120	1.38	0.45	1.00	2.93	0.14	0.59	0.40	0.62	0.06	6.16
112.5	123	1.11	0.38	1.00	1.75	0.18	0.35	0.23	0.42	0.03	18.06
113.0	126	1.78	0.40	1.00	3.12	0.25	0.64	0.39	1.17	0.00	9.59
113.5	129	2.17	0.59	1.00	3.60	0.38	0.68	0.46	0.55	0.09	13.46
114.0	132	1.41	0.49	1.00	2.74	0.18	0.60	0.41	0.50	0.10	11.96
114.5	135	2.00	0.53	1.00	3.38	0.23	0.76	0.57	0.87	0.15	6.62
115.0	138	4.52	0.82	1.00	6.48	0.52	1.53	1.11	0.71	0.00	6.51

TIDAL CHANNEL (BULK)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Cu	Ni	Zn	Cr	Cd	Co
0.5	163	1.55	0.43	1.00	1.79	0.28	0.56	0.41	0.45	0.09	6.08	0.00	0.00	0.00	0.00	0.00	0.00
1.0	164	2.42	0.57	1.00	4.87	0.25	0.85	0.66	0.40	0.06	1.84	0.20	2.10	3.77	4.32	43.23	3.72
1.5	165	1.53	0.46	1.00	1.87	0.25	0.60	0.47	0.33	0.05	2.49	0.00	0.00	0.00	0.00	0.00	0.00
2.0	166	1.69	0.47	1.00	4.01	0.25	0.62	0.46	0.45	0.10	4.15	1.36	4.78	3.54	4.35	32.57	2.80
2.5	167	1.30	0.42	1.00	2.45	0.13	0.57	0.44	0.60	0.05	2.27	0.00	0.00	0.00	0.00	0.00	0.00
3.0	168	0.93	0.36	1.00	2.66	0.15	0.35	0.25	0.33	0.03	4.67	0.64	2.69	2.55	4.04	22.02	2.51
3.5	169	1.02	0.35	1.00	1.64	0.06	0.37	0.27	0.57	0.05	3.71	0.00	0.00	0.00	0.00	0.00	0.00
4.0	170	1.03	0.37	1.00	2.26	0.13	0.38	0.27	0.45	0.00	3.92	0.55	3.39	3.27	3.46	23.09	1.99
4.5	171	1.05	0.37	1.00	1.77	0.09	0.37	0.32	0.46	0.06	4.81	0.00	0.00	0.00	0.00	0.00	0.00

NEARSHORE (BULK)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Cu	Ni	Zn	Cr	Cd	Co
0	173	2.81	0.55	1.00	3.59	1.03	0.50	0.37	0.72	0.03	10.30	2.56	3.56	4.92	4.05	145.58	4.17
1	174	2.20	0.38	1.00	2.56	0.36	0.40	0.35	0.67	0.09	1.60	0.07	2.77	3.83	4.40	37.74	3.25
2	177	2.46	0.69	1.00	3.74	0.38	1.01	0.58	0.80	0.09	3.67	0.08	2.10	4.29	5.04	43.23	2.42
3	179	2.09	0.58	1.00	3.14	0.36	0.94	0.56	0.55	0.14	4.73	1.59	2.72	5.79	4.33	37.15	3.20
4	181	3.00	0.76	1.00	4.38	0.39	1.09	0.68	0.47	0.07	2.15	0.46	3.71	3.94	5.06	50.59	4.35
5	183	3.21	0.57	1.00	4.51	0.30	0.87	0.68	0.91	0.10	10.93	0.09	1.27	4.38	6.00	51.48	1.44
6	185	3.62	0.69	1.00	5.08	0.28	1.06	0.77	0.49	0.19	9.85	0.74	4.25	5.05	9.66	0.00	3.25
7	187	2.22	0.57	1.00	2.88	0.30	1.05	0.75	0.57	0.22	6.51	1.39	3.73	4.33	5.75	38.35	2.15
8	189	1.86	0.48	1.00	2.79	0.25	0.83	0.59	0.37	0.14	1.40	1.29	4.09	5.38	4.95	66.05	1.85
9	191	1.03	0.22	1.00	1.32	0.13	0.47	0.30	1.74	0.07	9.10	0.73	2.38	2.85	4.87	38.98	0.55
10	193	1.76	0.38	1.00	1.72	0.21	0.77	0.53	0.79	0.12	3.88	0.28	4.47	3.38	6.10	30.49	1.71
0	172	3.85	0.68	1.00	3.97	0.63	0.40	0.39	1.22	0.18	22.72	1.08	4.36	9.94	3.95	59.45	1.66
1	175	2.84	0.47	1.00	3.53	0.35	0.70	0.48	0.89	0.06	3.88	0.04	2.23	3.56	4.57	45.73	2.56
2	176	2.66	0.46	1.00	4.06	0.50	0.54	0.43	0.60	0.19	5.51	1.65	3.17	4.79	4.32	43.23	3.72
3	178	1.99	0.58	1.00	4.08	0.32	0.87	0.50	0.71	0.13	4.66	0.90	2.68	5.51	4.88	36.58	3.15
4	180	2.12	0.58	1.00	3.62	0.25	0.85	0.51	0.77	0.07	1.60	0.07	2.77	3.75	5.04	37.74	3.25
5	182	2.73	0.57	1.00	3.84	0.26	0.79	0.55	0.58	0.00	1.91	0.82	3.29	3.17	5.99	44.86	2.51
6	184	1.84	0.45	1.00	2.98	0.15	0.66	0.42	0.93	0.05	5.46	0.26	2.36	5.53	3.21	32.13	0.90
7	186	1.91	0.54	1.00	2.84	0.27	1.03	0.70	0.51	0.16	1.46	0.13	1.68	5.05	3.45	34.46	0.96
8	188	1.69	0.45	1.00	2.33	0.23	0.49	0.28	0.77	0.18	1.26	0.41	2.18	3.78	5.94	29.72	1.66

TABLE: 29.(CONT.)

9	190	1.14	0.24	1.00	1.88	0.12	0.46	0.31	1.66	0.07	6.30	0.40	2.06	3.00	4.95	21.21	0.59
10	192	1.63	0.32	1.00	1.53	0.19	0.64	0.44	1.08	0.13	10.57	0.35	2.69	3.32	6.46	27.65	1.55

RIVER (NORTH-CLAY)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
35	22C	0.74	0.27	1.00	1.43	0.18	0.14	0.12	0.26	0.04	3.11
45	28C	0.62	0.27	1.00	1.56	0.19	0.16	0.13	0.27	0.03	1.31
55	34C	0.63	0.27	1.00	1.55	0.18	0.10	0.12	0.22	0.03	7.87
90	55C	0.66	0.29	1.00	0.98	0.22	0.23	0.11	0.23	0.04	9.05
100	61C	0.76	0.35	1.00	1.28	0.19	0.14	0.19	0.15	0.13	6.62
103	70C	0.69	0.29	1.00	1.07	0.11	0.18	0.12	0.16	0.04	6.40

ESTUARY (NORTH-CLAY)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
106	82C	0.80	0.36	1.00	1.78	0.04	0.10	0.26	0.26	0.01	2.59
107	88C	0.69	0.29	1.00	1.58	0.05	0.10	0.13	0.19	0.04	2.21
108	94C	0.74	0.31	1.00	1.90	0.04	0.14	0.10	0.21	0.02	11.04
109	100C	0.63	0.27	1.00	1.21	0.06	0.11	0.14	0.18	0.02	8.19
110	106C	0.69	0.29	1.00	1.40	0.05	0.11	0.12	0.26	0.00	4.39
111	112C	0.70	0.29	1.00	1.55	0.03	0.22	0.16	0.29	0.04	3.71
112	118C	0.66	0.28	1.00	1.41	0.05	0.12	0.17	0.19	0.03	3.58
113	124C	0.62	0.26	1.00	1.15	0.02	0.12	0.16	0.15	0.02	1.34
114	130C	0.70	0.30	1.00	0.99	0.03	0.24	0.17	0.20	0.04	4.49
115	136C	0.68	0.29	1.00	1.17	0.03	0.17	0.18	0.16	0.02	3.61

RIVER (CENTRE-CLAY)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Cu	Ni	Zn	Cr	Cd	Co
35	23C	0.69	0.30	1.00	1.94	0.23	0.12	0.12	0.26	0.04	1.46	0.72	1.68	2.24	1.72	17.23	2.93
45	29C	0.68	0.30	1.00	1.70	0.19	0.19	0.14	0.29	0.04	2.07	0.77	3.58	2.15	2.71	0.00	3.26
55	35C	0.69	0.30	1.00	1.90	0.18	0.10	0.13	0.22	0.04	9.12	1.67	4.44	3.39	3.30	16.51	3.76
90	56C	0.63	0.26	1.00	1.18	0.18	0.24	0.10	0.22	0.04	4.74	1.18	2.72	3.76	2.13	15.96	3.19
100	62C	0.76	0.35	1.00	1.28	0.19	0.14	0.19	0.15	0.13	6.62	0.74	1.90	3.54	1.63	0.00	3.90
103	71C	0.69	0.28	1.00	1.10	0.10	0.16	0.12	0.14	0.06	6.40	0.81	2.86	2.37	2.24	16.75	3.82

ESTUARY (CENTRE-CLAY)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Cu	Ni	Zn	Cr	Cd	Co
106	83C	0.69	0.28	1.00	1.41	0.05	0.14	0.14	0.23	0.02	5.90	0.79	2.55	2.42	2.32	17.36	2.95
107	89C	0.66	0.28	1.00	1.39	0.03	0.11	0.12	0.22	0.03	3.53	0.85	3.25	3.02	2.22	16.63	2.36
108	95C	0.73	0.31	1.00	1.61	0.05	0.15	0.13	0.17	0.01	8.48	0.92	2.21	2.14	2.72	0.00	2.58
109	101C	0.69	0.30	1.00	1.49	0.07	0.13	0.14	0.23	0.03	1.50	0.98	2.58	2.20	2.64	0.00	3.52
110	107C	0.76	0.31	1.00	1.36	0.05	0.28	0.16	0.24	0.00	4.73	0.47	1.36	2.23	2.79	18.58	2.64
111	113C	0.66	0.28	1.00	1.35	0.03	0.20	0.17	0.12	0.04	4.94	0.73	2.44	2.20	2.49	0.00	2.36
112	119C	0.70	0.30	1.00	1.71	0.03	0.19	0.18	0.26	0.03	4.45	0.51	2.98	2.15	2.33	17.48	1.99
113	125C	0.71	0.29	1.00	1.45	0.07	0.14	0.15	0.20	0.01	3.74	0.51	1.71	3.65	2.35	35.23	2.50
114	131C	0.64	0.28	1.00	1.04	0.08	0.23	0.18	0.21	0.04	4.18	0.19	2.41	2.05	2.73	16.40	1.87
115	137C	0.68	0.29	1.00	1.09	0.07	0.23	0.21	0.19	0.02	2.18	0.48	2.09	2.18	2.85	17.11	1.95

TABLE: 29.(CONT.)

RIVER (SOUTH-CLAY)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
35	24C	0.71	0.27	1.00	1.35	0.20	0.14	0.12	0.26	0.04	2.97
45	30C	0.59	0.26	1.00	1.45	0.14	0.12	0.13	0.22	0.02	2.46
55	36C	0.61	0.28	1.00	1.39	0.21	0.10	0.13	0.17	0.03	6.56
90	57C	0.70	0.38	1.00	1.19	0.20	0.18	0.12	0.19	0.04	13.52
100	63C	0.67	0.35	1.00	0.97	0.11	0.11	0.12	0.16	0.04	5.73
103	72C	0.67	0.28	1.00	1.16	0.11	0.13	0.12	0.17	0.03	7.77

ESTUARY (SOUTH-CLAY)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn
106	84C	0.68	0.29	1.00	1.38	0.07	0.10	0.11	0.19	0.01	7.32
107	90C	0.59	0.26	1.00	1.11	0.03	0.13	0.14	0.17	0.02	3.86
108	96C	0.70	0.30	1.00	1.57	0.07	0.10	0.10	0.23	0.01	9.04
109	102C	0.67	0.29	1.00	1.53	0.07	0.12	0.13	0.29	0.03	5.12
110	108C	0.68	0.29	1.00	1.11	0.03	0.16	0.14	0.19	0.00	5.85
111	114C	0.67	0.29	1.00	1.38	0.03	0.13	0.14	0.13	0.03	6.49
112	120C	0.68	0.29	1.00	1.54	0.03	0.14	0.16	0.16	0.02	2.91
113	126C	0.68	0.29	1.00	1.44	0.07	0.14	0.18	0.26	0.04	2.19
114	132C	0.67	0.28	1.00	0.97	0.05	0.20	0.17	0.22	0.07	4.24

NEARSHORE (CLAY)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Cu	Ni	Zn	Cr	Cd	Co
0	173C	0.69	0.31	1.00	1.11	0.09	0.15	0.19	0.20	0.06	3.82	1.00	1.75	3.65	2.40	18.01	3.06
1	174C	0.73	0.33	1.00	1.38	0.11	0.22	0.19	0.04	0.05	4.89	0.70	3.75	2.67	2.56	19.18	2.72
4	181C	0.55	0.25	1.00	1.35	0.07	0.17	0.16	0.14	0.06	3.88	2.22	2.60	6.79	3.05	0.00	3.48
5	183C	0.62	0.28	1.00	1.48	0.08	0.26	0.17	0.14	0.06	2.18	1.79	2.51	6.01	2.57	0.00	3.42
8	189C	0.52	0.25	1.00	0.83	0.07	0.13	0.10	0.11	0.05	5.75	1.29	1.84	4.12	2.26	0.00	3.01
1	175C	0.55	0.25	1.00	1.19	0.09	0.10	0.13	0.20	0.07	3.88	2.10	2.60	5.14	2.54	30.49	3.05
2	176C	0.61	0.27	1.00	1.01	0.09	0.11	0.17	0.23	0.07	11.88	0.81	2.28	2.64	2.33	31.08	2.64
3	178C	0.55	0.25	1.00	1.28	0.07	0.08	0.10	0.22	0.06	9.41	1.30	2.17	4.15	2.46	14.77	3.37
4	180C	0.54	0.24	1.00	1.15	0.09	0.15	0.13	0.22	0.06	5.05	2.85	2.54	6.69	2.73	14.86	2.97
5	182C	0.57	0.26	1.00	1.21	0.09	0.11	0.09	0.12	0.08	3.38	1.52	1.55	5.62	2.12	15.91	2.70
6	184C	0.55	0.24	1.00	1.32	0.09	0.13	0.14	0.14	0.07	6.94	2.19	2.54	6.66	2.23	14.86	3.80
7	186C	0.60	0.24	1.00	1.02	0.10	0.16	0.17	0.18	0.13	9.82	2.10	2.01	5.53	2.75	16.51	3.30
8	188C	0.61	0.28	1.00	0.93	0.13	0.11	0.18	0.20	0.13	9.68	2.00	2.78	6.06	1.90	16.29	4.17
9	190C	0.57	0.27	1.00	0.93	0.09	0.12	0.17	0.24	0.11	9.49	1.13	2.34	5.41	2.66	15.96	4.09
10	192C	0.59	0.25	1.00	0.93	0.09	0.14	0.10	0.12	0.08	5.49	0.91	2.37	3.66	1.88	0.00	3.69

TIDAL CHANNEL (CLAY)

DIST.	ST.NO	Si	Al	Fe	Mg	Ca	Na	K	Ti	P	Mn	Cu	Ni	Zn	Cr	CD	Co
1	164C	0.68	0.29	1.00	1.23	0.02	0.13	0.18	0.19	0.05	2.86	0.87	2.47	2.07	2.25	16.86	3.37
2	166C	0.68	0.29	1.00	1.33	0.03	0.16	0.17	0.22	0.05	3.66	0.67	2.10	2.07	2.30	0.00	2.45
3	168C	0.71	0.30	1.00	1.31	0.05	0.16	0.17	0.21	0.04	5.94	0.83	2.56	2.39	2.33	17.48	3.99
4	170C	0.70	0.29	1.00	1.28	0.05	0.14	0.17	0.21	0.04	8.17	0.79	2.56	3.51	2.33	17.48	2.97

bulk and clay fraction of river, estuary, tidal channel, and nearshore sediments are higher than the crustal average. Ti in the bulk sediments of river alone showed an enrichment. Among the trace elements, while Cu shows a depletion, the remaining elements Co, Ni, Zn, Cr, and Cd have displayed enrichment compared to the crustal abundance. In general, the bulk sediments show, comparatively more enrichment of trace elements than the clay except in the tidal channel where the case is reverse.

The average concentration of heavy metal content of Vellar river, estuary, tidal channel, and nearhore environments are compared with both the polluted and unpolluted British estuaries, and with the nearshore sediment data given by Wedepohl (1960) and also with average crustal element concentration (Taylor, 1964). The concentration of trace metals in the present study area were more than the unpolluted estuaries, average nearshore sediments and average crustal concentration but it is less than the polluted estuaries (Table.30).

Results of the present study suggest that the different environments of the study area are not polluted and the observed concentrations were due to the variation in mineralogy, the contribution by source rocks, and the physico-chemical enrichment of trace elements in the different environments. The trace elements of the bulk sediments show high concentrations than in clay fraction owing to the mineralogical composition of the sediments,

TABLE:30 TRACE ELEMENTAL CONCENTRATION OF SEDIMENTS FROM POLLUTED AND UNPOLLUTED ESTUARIES, AVERAGE NEARSHORE SEDIMENTS AND AVERAGE CRUSTAL CONCENTRATIONS (ALL VALUES IN PPM).

ELEMENT	*SOLWAY FIRTH <204 MIC.	*FIRTH OF CLYDE <204 MIC.	*SEVERN ESTUARY <61 MIC.	*CLYDE ESTUARY (SILT)	*AVERAGE NEARSHORE SEDIMENT	*AVERAGE CRUSTAL CONC.	VELLAR ESTUARY (BULK)	VELLAR ESTUARY (CLAY)
Cu	10.0	37.0	38.0	225.0	48.0	55.0	48.7	40.7
Co	16.0	34.0	7.0	60.0	13.0	25.0	47.9	71.1
Ni	38.0	50.0	36.0	69.0	55.0	75.0	190.4	205.1
Zn	63.0	165.0	280.0	1680.0	95.0	70.0	195.7	195.7
Cr	35.0	64.0	71.0	624.0	100.0	100.0	221.7	263.4
Cd	1.0	3.4		7.0		0.2	7.4	3.2

* - Burton & Liss, 1976.
+ Taylor, 1964.

APPENDIX

A)AVERAGE CONCENTRATION OF MAJOR AND TRACE ELEMENTS (PPM), ORGANIC CARBON AND CARBONATE CONTENT (PERCENTAGE), IN THE SEDIMENTS (BULK AND CLAY) OF VELLAR RIVER, ESTUARY, TIDAL CHANNEL AND NEARSHORE ENVIRONMENTS.

ELEMENT	RIVER		ESTUARY		TI.CH.		N.SHORE	
	BULK	CLAY	BULK	CLAY	BULK	CLAY	BULK	CLAY
Si	379797	225616	282323	223605	276948	226775	327607	193503
Al	9896	28788	23788	27809	25367	27906	21564	27222
Fe	18433	68154	39386	65454	38474	65229	31124	70541
Mg	31602	37573	36729	36005	42810	34765	37859	33257
Ca	4851	8539	5070	2215	5159	1801	6804	4643
Na	6095	4166	8204	4244	8679	4106	9408	4113
K	3233	3047	4795	3745	5826	4194	5607	3735
Ti	2833	1380	2186	1355	1945	1380	2783	1203
P	28	52	34	29	41	55	65	95
Mn	3631	6454	5245	5245	2779	5647	2970	7638
OC	0.03	0.67	0.66	0.91	0.86	0.93	0.39	1.22
CAR	3.80	5.81	7.06	5.83	8.72	9.38	5.91	9.40
Cu	7.10	64.17	48.70	40.70	27.25	50.50	20.18	111.60
Co	19.10	102.17	47.85	71.10	46.50	92.50	28.95	103.47
Ni	109.64	256.17	190.35	205.10	174.00	210.75	118.18	222.00
Zn	116.73	239.33	195.70	195.70	158.50	203.00	167.00	441.00
Cr	251.64	272.33	221.70	263.40	283.50	267.00	286.36	291.00
Cd	4.73	4.00	7.40	3.20	4.00	4.00	4.60	3.50

B)AVERAGE ENRICHMENT FACTORS FOR VELLAR RIVER, ESTUARY, TIDAL CHANNEL AND NEARSHORE SEDIMENTS (BULK AND CLAY).

ELEMENT	RIVER		ESTUARY		TI.CH.		N.SHORE	
	BULK	CLAY	BULK	CLAY	BULK	CLAY	BULK	CLAY
Si	4.49	0.68	1.53	0.68	1.39	0.70	2.30	0.59
Al	0.43	0.30	0.42	0.29	0.42	0.29	0.51	0.27
Mg	4.61	1.36	2.61	1.38	2.59	1.29	3.20	1.14
Ca	0.39	0.17	0.18	0.05	0.18	0.04	0.33	0.09
Na	0.88	0.15	0.58	0.15	0.52	0.15	0.75	0.14
K	0.53	0.13	0.34	0.15	0.39	0.17	0.51	0.14
Ti	1.70	0.20	0.55	0.21	0.45	0.21	0.81	0.17
P	0.09	0.05	0.05	0.02	0.05	0.04	0.11	0.08
Mn	12.06	5.77	6.89	4.70	3.77	5.16	5.89	6.37
Cu	0.42	0.98	0.86	0.64	0.30	0.79	0.70	1.60
Co	2.63	3.48	2.24	2.47	1.22	3.19	2.31	3.30
Ni	4.85	2.86	2.75	2.30	1.44	2.43	2.93	2.37
Zn	5.46	2.91	3.25	2.42	1.46	2.51	4.53	4.99
Cr	8.43	2.29	2.69	2.54	1.80	2.31	5.14	2.43
Cd	79.25	11.07	40.89	13.88	13.43	12.96	43.22	13.86

that is, the bulk sediments contain ore minerals like magnetite, ilmenite, etc., with other ferro-magnesium minerals. These minerals contribute to the increase in the concentration of the above elements in bulk sediments. However, in the clay fraction, the concentration of elements is due to the cation exchange and adsorption and absorption of trace elements from water column by the iron and manganese oxides coating on the surface of the clay minerals. In general, the clay fraction used to show high concentration of trace elements than bulk sediments. However, in the present study the opposite trend is observed and therefore it implies that the variations are not because of pollution. Further, the banks of this river and estuary are neither industrialized nor urbanized as compared to other rivers and estuary.

Earlier reports on heavy metals in India mainly dwelled on their levels in biota. For sediments, studies mainly deal with the geochemistry of the sediments in the different environments (Naidu, 1968; Seetaramaswamy, 1970; Satyanarayana, 1973; Murty et al, 1978; Seralathan, 1979; Murty & Veerayya, 1981). But these studies did not emphasize on the background data for various environments. The establishment of background data is of prime importance to ascertain the extent of pollution in the sediments of different environments. So, the data of the present study may be considered as the background data for the different environments.

CHAPTER:V.

SUMMARY AND CONCLUSION

The following conclusions have been drawn from the textural, mineralogical and geochemical studies of the modern sediments of the Vellar river drainage basin and its surrounding environments.

The overall decreasing grain size along the 115 km distance of the river course is mainly due to the decreasing competency of the water, and to a lesser extent, due to abrasion. The moderately sorted sediments in the fresh water river channel and the poorly sorted sediments in the estuary are close functions of the mean size of sediments. In the estuary, the addition of silt and clay modes to the sand mode renders them poorly sorted. The change in skewness from nearly symmetrical to positive in river channel is the consequence of the progressive addtion of fine population down stream. Kurtosis did not show any significant change in river channel. Mostly, the river channel sediments are meso kurtic but the estuarine sediments are prdominantly of lepto and very lepto kurtic. In general, the variation in sorting, skewness and kurtosis along the river channel are closely related to mean size. The beach sands are charcterised by the mean size in the range of medium to fine sand, with well sorted, very negatively skewed to nearly symmetrical skewness, and abundant platy to very lepto kurtic. The tidal channel

sediments show a short range of mean size with an abundance of poorly sorted, and very positively skewed. However, the kurtosis ranges from platy to very lepto kurtic. The above variations are due to the constant movement of the tidal currents which lead to the removal of significant amount of fine particles from the tidal channel and also the deposition of sand near the juncture of tidal channel and estuary and silt and clay in calm area. The nearshore marine sediments show comparatively wide range of phi mean size and are well sorted to poorly sorted, with negative to very positive skewness. Eventhough, the kurtosis varies from platy to extremely lepto kurtic, very lepto kurtic sediments are predominant. The above variations are due to an environment which is subjected to a high rate of deposition besides the severe turbulence prevailing in the area.

A high proportion of sand is present at the head of the estuary with silt and clay as subordinates. The sand proportion decreases towards the confluence. The silt content is comparatively lower than the clay content downstream. However, the central part of the estuary shows a very clear decreasing trend of sand and increasing trend of clay content. This is attributed to the existence of a low hydraulic condition in the central part, compared to that in the northern and southern sides. The variation seen in the northern and southern sides may be due to the influence of ebb and flood current. These currents can transport the sediments in opposite directions on either

side of the estuary which results in the removal of fine size.

The tidal channel sediments show a high degree of compostional variability and are composed of a large proportion of muddy sand and mud and low percentages of sandy mud. This clearly indicates that these variations are due to the hydraulic fluctuations prevailing in the tidal channel. The nearshore marine sediments show a very little clay content compared to the high silt content. This may be due to the significant wave - energy in the nearshore, which would tend to maintain clay particles in suspension and consequently increase the silt and sand content in the sediment.

The CM pattern of the river channel and estuarine sediments indicate that the majority of the river sediments are transported by rolling and suspension and a small part by graded suspension. But the estuarine sediments are transported mainly by graded suspension. Data on the beach sediments suggest that these are also transported by graded suspension. The tidal channel deposits are the consequence of tractive currents, which are not as strong as the river currents. The nearshore marine sediments are deposited under combined action of tractive currents and graded suspension. The FM, LM, and AM diagrams along with CM patterns characterise the grain size image of these deposits.

Hornblende, garnets, opaques and pyroxenes are the dominant constituents in the heavy mineral

assemblages with minor amounts of zircon, epidote, sillimanite, rutile, monazite, kyanite, biotite and altered minerals. In all the environments, the fine size grade (125 to 62 micron) contains a higher proportion of heavy minerals compared to medium and coarse size grades. The decrease of heavy minerals downstream is explained on the basis that the heavy minerals once entrained in the sediments are not carried away by susbsequent currents, and the size - density settling velocity principle also plays a role in the deposition of heavy minerals upstream. The overall number percentage increase in amphiboles and pyroxenes and decrease in opaques and garnets downstream in the three size grades are mainly due to the differences in their density and the decreasing competency of the currents. The increase in amphiboles / garnets ratio and decrease in density index and shape index downstream have been attributed to the difference in the density and the shape of the minerals. The greater resistivity of quartz, compared to feldspar leads to the increase of quartz / feldspar ratio, in the three size grades, downstream. This suggests that the sediments are not matured. In the beach and nearshore environments, the variations in heavy mineral concentrations are mainly due to their hydraulic equvalence, longshore currents and the source rocks. Based on the mineralogical study, it is suggested that the chief contributors of these minerals are mainly high grade metamorphic rocks and basic igneous rocks. Based on this conclusion it is proposed that

the sediments may be derived from their origin point namely Chitarai, Tainandamalai, Kalrayans, Kollaimalai and Pachaimalai hills, where the rock types mainly consist of biotite gneisses, hornblende gneisses, magnetite, quartzite, charnockite, granite, ultrabasic and basic intrusives. Moreover, that these heavy mineral suites have not altered signifigantly in the river channel, estuary, beach and nearshore environments is a fact suggestive of the minimum or rather nill influence of the external aspects.

The different environments of Vellar river basin divulge that montmorillonite is the most dominant clay mineral followed by kaolinite. Illite is present only in the southern and central sectors of the nearshore marine environment. It is inferred that the sources for clay minerals are magnesium rich rocks, red soils, and the overburden of Neyveli lignite deposits. From the study, it is deduced that differential flocculation and size seggregation have played a significant part in the formation of the clay minerals.

The organic carbon content in the bulk sediments of the river channel and nearshore marine environments is negligible or nil. But in the tidal channel and estuarine environments it shows a comparatively higher amount owing to the size of the sediments, i.e. finer the sediment, greater the organic carbon and organic production of these environments. In clay fraction, the nearshore marine, tidal channel and estuarine environments contain high amount of organic carbon than the river channel due to

the hydrobiological conditions existing in these environments, which in turn is reflected in the high production of planktons that is normally available in the size range of clay. Clay minerals may also lead to the increase of the organic carbon content in the clay fraction. The carbonate content in the bulk and clay fraction of different environments is mainly due to the availability of carbonate mineral and carbonate shell material.

The geochemical distributions of Si, Al, Fe, Mg, Ca, Na, K, Ti, P, and Mn in the bulk and clay fractions of the sediments of the different environments have been discussed in relation to the pysico - chemical conditions of the depositional environments, organic matter, carbonate content and clay minerals. In the nearshore marine sediments, the phosphate in bulk sediments is deposited with iron as ferric phosphate. However, in the river it may be contributed by organic waste and the excess fertilizer used on land. The tidal channel and esturaine environments show that the phosphate in bulk sediments comes from organic sources of these environments as well as from river or marine sources. The variation of phosphate in the clay fraction mainly depends upon its clay mineralogy. The iron in the bulk sediments of the river and nearshore environments depends on the mineralogy of the sediments and the precipitation of ferrous hydroxide. However, in the estuarine and tidal channel bulk sediments, organic matter also helps to increase the iron content besides the above

sources. The clay fraction displays high amount of iron, probably due to the adsorption of iron in the lattice position and the coating on the surface of clay minerals. Manganese and titanium show a similar distribution like iron; furthermore, these two are also associated with the oxides of iron so that factors which affect iron also affect these elements.

The variation in the distribution of Na and K in the bulk sediments are closely related to the mineralogical composition of the sediments, variation of salinity in the water coloumn and the salt content of the pore solution. However, in the clay fraction, the slight variation among environments is the result of ion exchange in the lattice of clay mineral composition. Ca concentration in the bulk sediments of the various environments shows that the variation is influenced by the amount of shell fragments available in the sediments. However, in the clay fraction, the variation is attributed to the mineralogy of the clay fraction and the availability of clay size planktonic calcareous tests. The variation of Mg concentration in the bulk and clay fraction of the sediments of different environments may be due to the mineralogy of bulk and clay fractions and the avialability of $MgCO_3$ shell fragments. The Si and Al concentrations in the bulk and clay fraction of the sediments of different environments demonstrate that their variations are manifestations of the mean size of the sediments i.e. the availability of clay mineral. When the amount of clay content reduces the

concentration of Al decreases whereas Si increases. Further, when the clay minerals are available in large quantity, the Al content increases and Si content decreases.

The trace elements Cu, Co, Ni, Zn, Cr, and Cd are correlated with major elemnets, carbonates, organic carbon and clay minerals. In general, the presence of significant quantities of iron and manganese in the different environments plays an important role in the adsorption of the above said trace elements in those oxides. The organic carbon also helps to concentrate these materials in these environments. However, clay minerals play an important role in the trace element concentration, through cation exchange, by fixation of these elements in their lattice structure. In the bulk sediments, mineralogy of the sediment also helps to concentrate trace elements along with the above said factors.

The R - mode factor analysis has yielded the identification of eleven factors such as grain size-Si factor, Al factor, iron oxide coating-Fe factor, Mg-Mg rich minerals factor, Ca factor, Na and K factors, Ti factor, P factor, Mn oxide-Mn factor, and organic matter-organic carbon factor which influence the concentration of elements in the sediments. Among the above factors the first eight factors are common to both the groups, while the last three factors influence only the major and trace elements group. These factors supplement the explanation offered in the

preceding section, for the variation in geochemical elemental concentration of the sediments.

In general, the bulk sediemnts of estuary contain highest amounts of Cu, Co, Ni, Zn, and Cd; while the nearshore sediemnts hold larger amount of Cr compared to the other environments. However, in the nearshore environments, clay faction contains the highest amount of Cu, Co, Zn, and Cr. But in the case of Ni, river clay shows higher amounts and for Cd estuarine clay hold larger amount than the other environments.

The trace element concentrations of different environments of Vellar river show slightly higher amount than the unpolluted estuaries. However, it is concluded that these concentrations are due to the variations in the mineralogy of the sediments, the contribution of source rocks and the physico - chemical enrichments of trace elements in the different environments. Hence there is no trace elemental pollution in these environments by anthropogenic sources, in addition to the fact that there are no major industries located on the banks of this river. Based on the above reasons it is suggested that the present data can be considered as a background data for the different environments of the study area.

These studies reveal that the variation in texture, mineralogy and geochemistry of the sediments are useful in characterising the sediments in different environments of the Vellar river basin. The studies on the trace elements suggest a real mechanism of the

sediment - water - biota interactions. Morover, the present study invokes some interest on the future study of the clay mineral variation and the carbonate mineral variation in this area. It is hoped that the data presented in this thesis regarding the texture, mineralogy and chemistry of the sediments of the different environments of the Vellar river basin may be used to differentiate the paleoenvironment, which could positively have an identical geological setting to that of the modern Vellar river basin. In addition, the trace metal concentration can be used as background data for the future studies in this area as well as elsewhere.

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* Not refered to the original.

PLATE. I.

A. Hornblende in 0.250 - 0.125 mm size (plane polarized light).

B. Hornblende in 0.250 - 0.125 mm size (under crossed nicols).

PLATE. I.

A

B

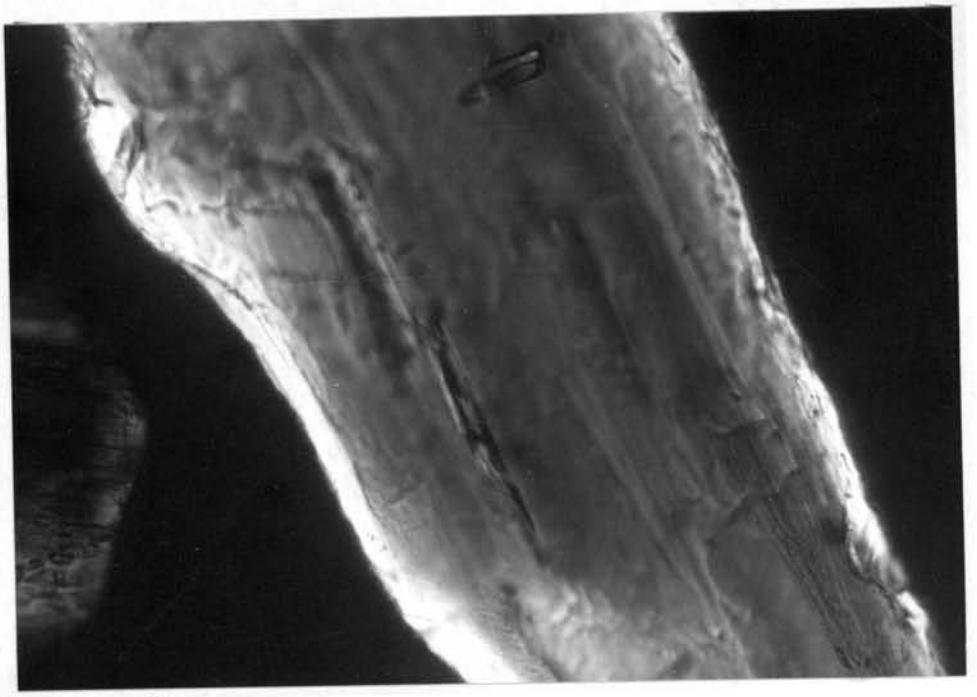


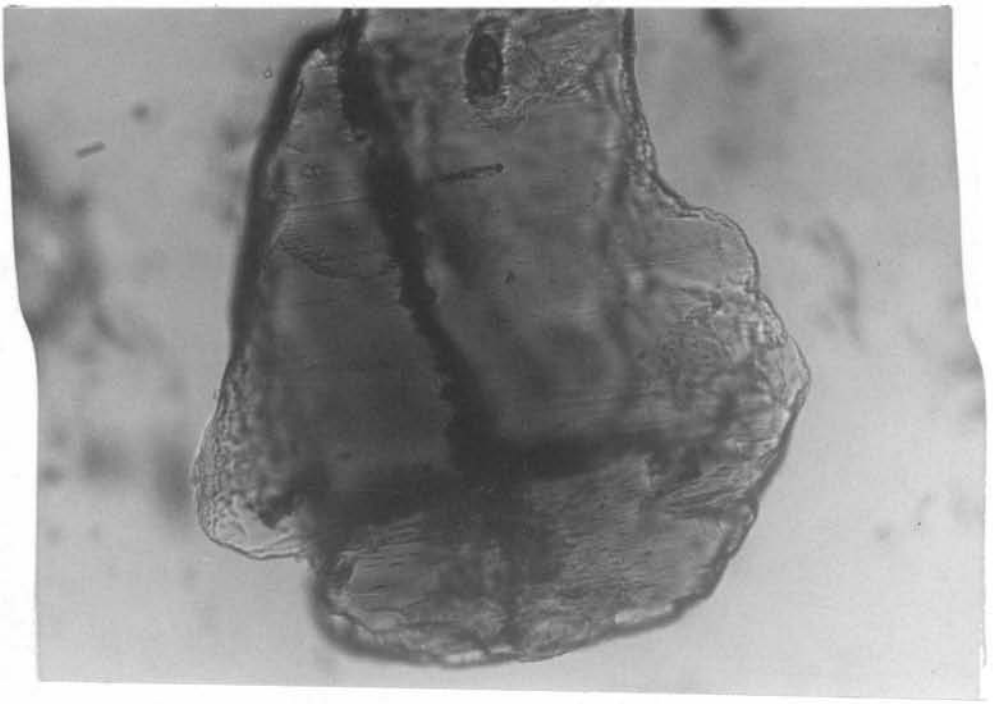
PLATE. II.

A. Hypersthene in 0.250 - 0.125 mm size (plane polarized light).

B. Hypersthene in 0.250 - 0.125 mm size (under crossed nicols).

PLATE. II.

A



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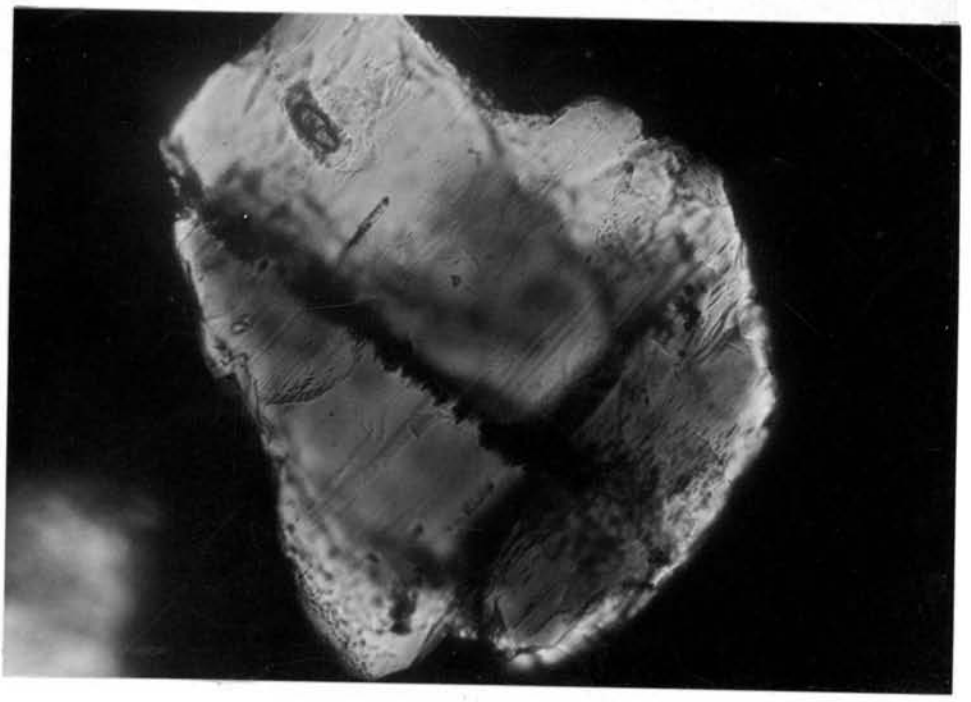


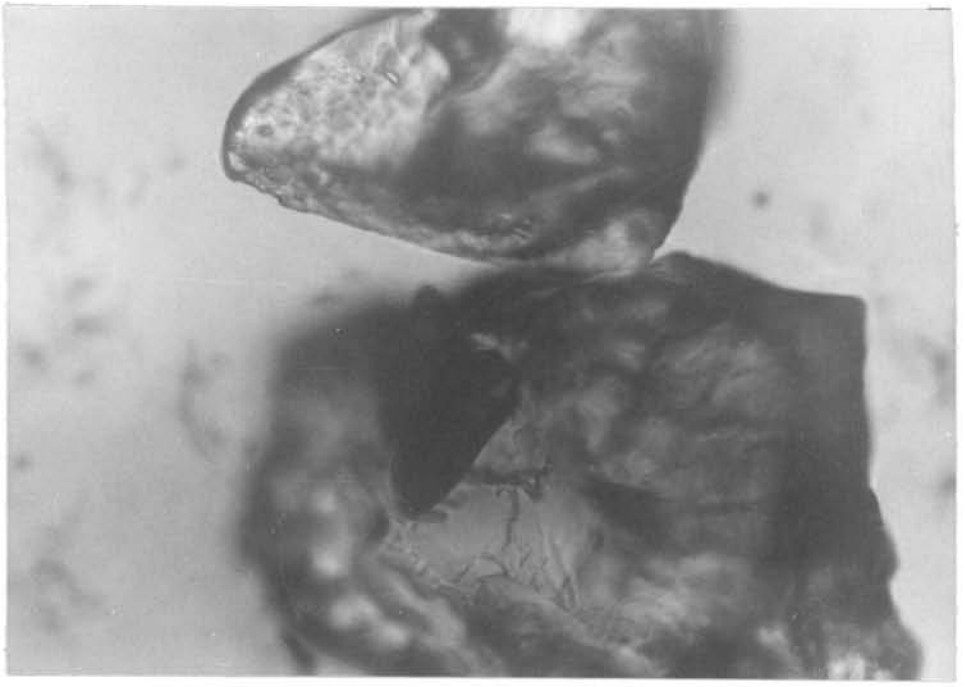
PLATE. III.

A. Garnet in 0.250 - 0.125 mm size (plane polarized light).

B. Opaque in 0.125 - 0.063 mm size (plane polarized light).

PLATE. III.

A



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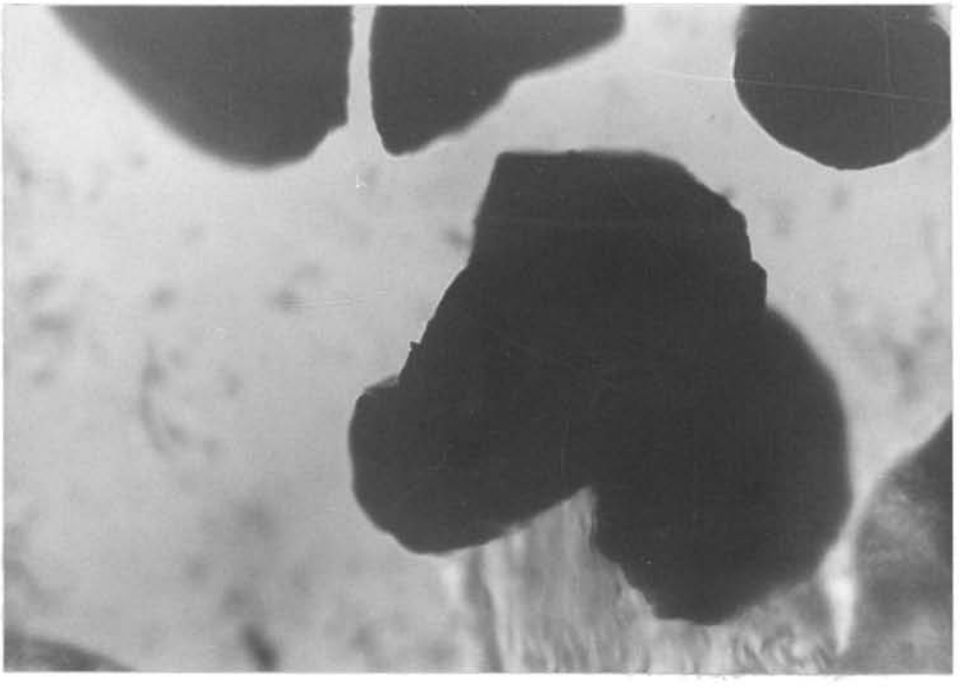


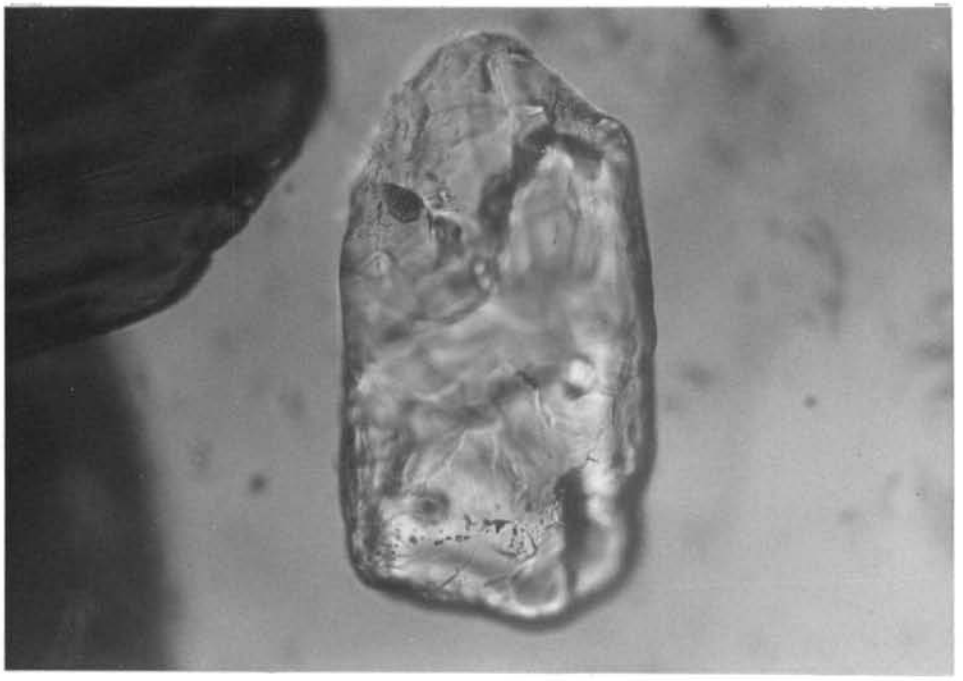
PLATE. IV.

A. Zircon in 0.250 - 0.125 mm size (plane polarized light).

B. Zircon in 0.250 - 0.125 mm size (under crossed nicols).

PLATE. IV.

A



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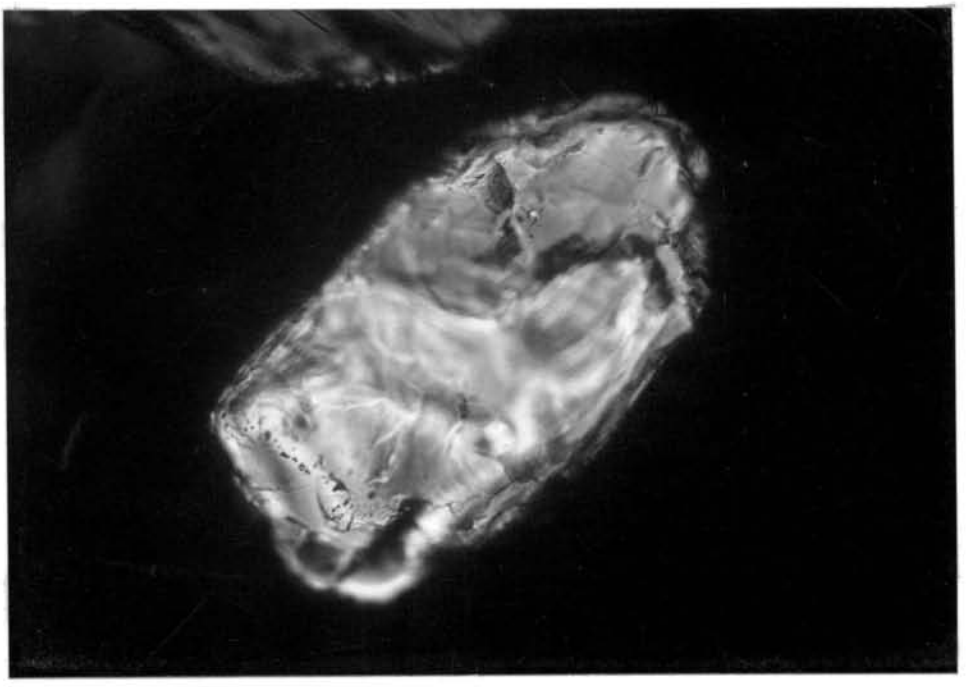


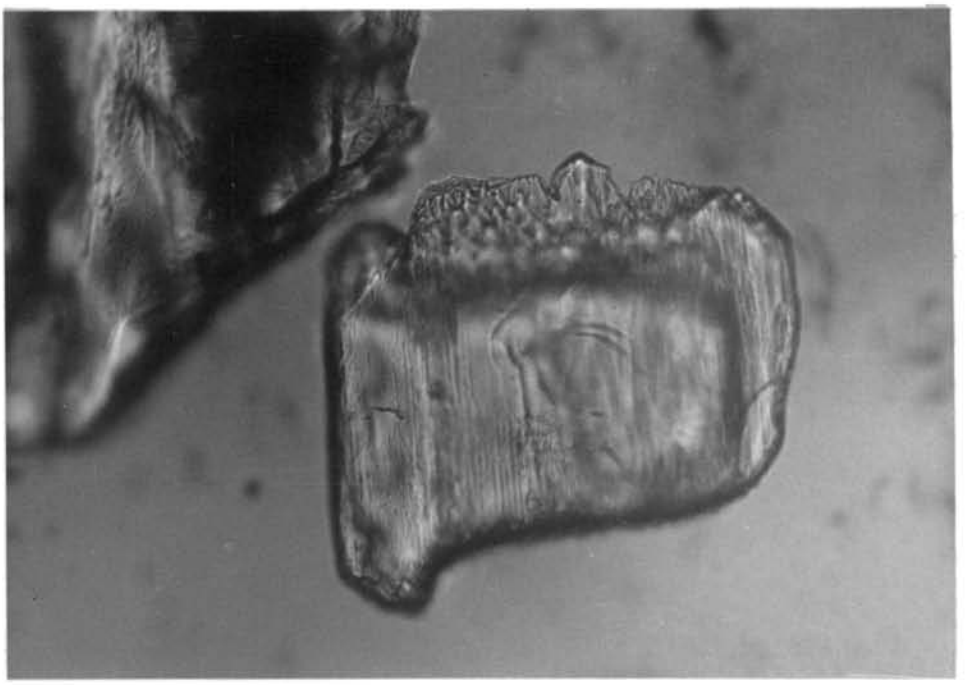
PLATE. V.

A. Sillimanite in 0.250 - 0.125 mm size (plane polarized light).

B. Sillimanite in 0.250 - 0.125 mm size (under crossed nicols).

PLATE. V.

A



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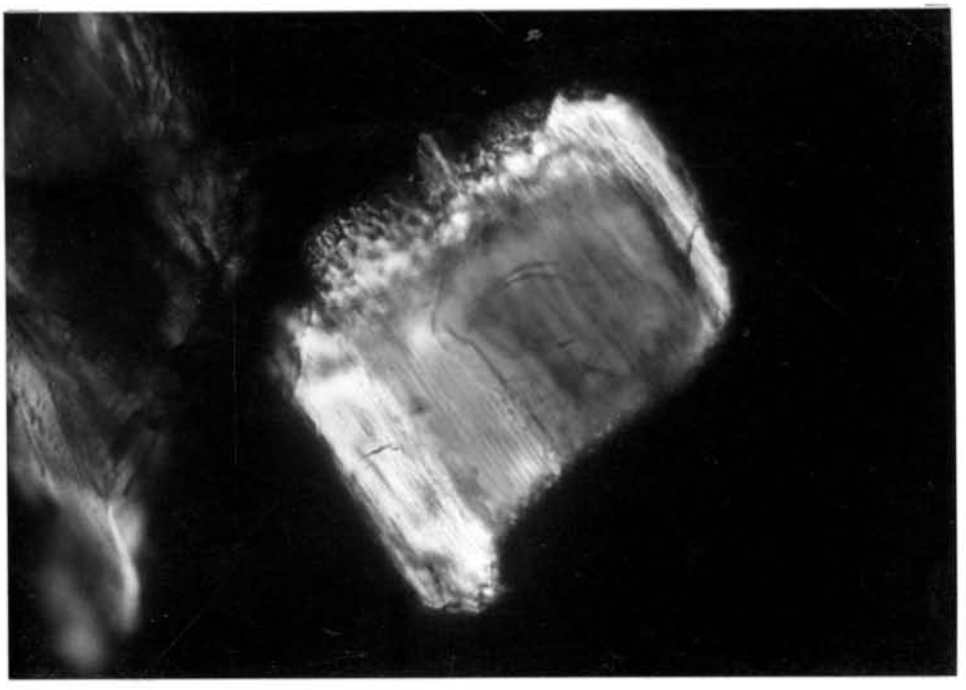


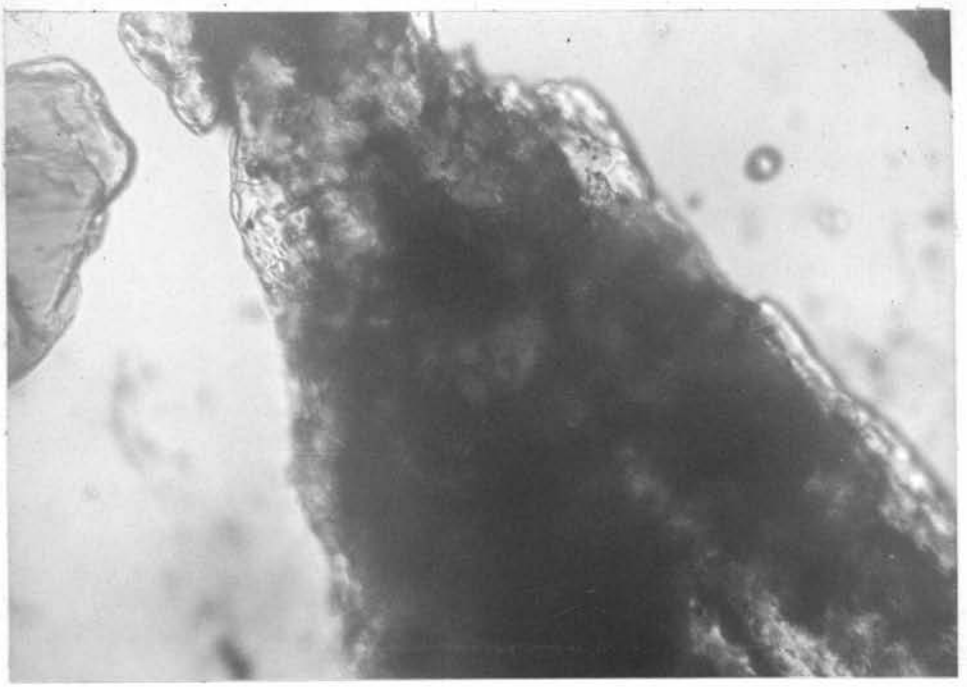
PLATE. VI.

A. Altered minerals in 0.250 - 0.125 mm size (plane polarized light).

B. Altered minerals in 0.250 - 0.125 mm size (under crossed nicols).

PLATE. VI.

A



B