PROVENANCE, SEDIMENTATION AND GEOCHEMISTRY OF THE MODERN SEDIMENTS OF THE MUD BANKS OFF THE CENTRAL KERALA COAST, INDIA

THESIS SUBMITTED TO THE
COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY
IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN

MARINE GEOLOGY

BY

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AUGUST 1990

DEDICATED TO MY DEPARTED FATHER

DECLARATION

I hereby declare that this thesis entitled 'Provenance, Sedimentation and Geochemistry of the Modern Sediments of the Mud Banks Off the Central Kerala Coast, India', has not previously formed the basis of the award of any degree, diploma or associateship in any University.

Cochin-682 016,
17th August 1990.

(PURANDARA. B.K.)

C E R T I F I C A T E

This is to certify that this thesis is an authentic record of research work carried out by Shri B.K. Purandara, M.Sc., under my supervision and guidance under the faculty of Marine Sciences for the Ph.D. Degree of the Cochin University of Science and Technology and no part of it has previously formed the basis for the award of any other degree in any University.

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C O N T E N T S

PREFACE

Coastal zone is one of the most dynamic and distinctive areas being the meeting place of the land, the sea and the air. Coastal zones are endowed with variety of natural resources and facilities and there has always been a zone of hectic human activity. In the coastal areas, numerous problems such as devastation of natural habitats due to erosion, pollution, siltation, over population, saltwater intrusion, flooding etc. are encountered.

The Kerala coast, which is a treasure house of many strategic minerals experiences severe erosion along long stretches of the coast and consequent impairment of the property lying in the coastal zone. However, few patches of the coastal land are preserved due to the formation of mud banks which are unique in nature along this part of the coast.

'Mud banks' are natural smooth water anchorages formed at particular locations along the Kerala Coast during the south West monsoon season. It extend outwards upto a distance of 3-4 kilometres from the shore. These are semi-circular in shape, with their northern and southern edges defined by two crescentic lines of breakers running outwards to the sea. The formation of the mud banks play a major role in moulding the social and economic set up of the coastal people by providing a stable fishing ground during the monsoon season. Mud banks affect the coastal processes by damping the waves in the following ways:

1. Traps the littoral material transported from the updrift side thereby preventing its downcoast movement.
2. Causes refraction of waves on its sides.
3. Protects the beach in particular from erosion.

Lot of literature are available regarding the formation of mud banks, its migration, physical, chemical and biological aspects. But systematic studies conducted for an understanding of the source of mud bank sediments are very limited.

Keeping in view of the above said fact, in the present doctoral work, an attempt has been made to study in detail the mud banks of central Kerala, i.e. of Narakkal, Saudi and Purakkad areas which are reported as permanent mud banks, since olden days. The studies have been conducted during the years 1985 and 1986. The primary objectives of the present study are the following:

1. To cite the provenance of the mud bank sediments of central Kerala coast.
2. To assess the influence of Vembanad lake on the formation of mud banks.
3. To understand the clay mineralogical variations of the lake and mud bank sediments.
4. To delineate the variation of the chemical constituents of the lake and mud bank sediments.

The thesis is divided into seven chapters. First chapter deals with the general introduction which includes a general description of the mud banks, its importance, location and geogrphic setting, climate, rainfall, vegetation and geomorphology of the South Kerala coast. Chapter 2 gives an exclusive description to the readers about the mud banks, its nature and formation, hydrography, suspended matter, flocculation and deflocculation, waves and currents. Recent literature available about the mud bank studies are also dealt with in this chapter. Chapter 3 deals with the material and methods, which are discussed under three heads (1) objectives of sampling (2) field methods and (3) laboratory techniques. Chapter 4 deals with the textural characteristics of the sediments. Results of the textural analysis of the sediments of different environments are presented with their respective discussion. Chapter 5 covers mineralogy of the sediments. This is divided into two parts. (1) Heavy mineral and light mineral studies and (2) clay mineralogy. Chapter 6 deals with the geochemistry of Vembanad lake and mud bank sediments. Chapter 7 gives the summary and the conclusion of the study. Figures and Tables are given in the Appendix.

ACKNOWLEDGEMENT

I express my sincere heartfelt indebtedness and gratitude to Prof. Y.L. Dora, former Director, School of Marine Sciences, Cochin University of Science and Technology and presently the Head, Department of Geology, Nagarjuna University, for his guidance and constant encouragement throughout the study. I am highly grateful to Prof. P.N.K. Nambisan, Director, School of Marine Sciences and to Prof. K.T. Damodaran, Head, Marine Geology Division for providing the facilities to carryout the research work. My thanks are due to our late Prof. S. Lakshamanan for his encouragement and suggestions during the tenure. The financial support given by the UGC under DRS Project is gratefully acknowledged.

I acknowledge my sincere gratitude to Dr. S. Sathishchandra, Director, National Institute of Hydrology, Roorkee for giving the permission to continue my research work. My thanks are also due to Dr. G.C. Mishra and Dr. P.V. Seethapathi, Scientist 'F', NIH, Roorkee for their whole hearted co-operation in completing this work.

I am grateful to Prof. V. Venkatachalapathy of Mysore University and to Prof. R.V. Ramamohan, UAS, Bangalore for the facilities and guidance to carryout the XRD and Electron microscopic studies. My thanks are also due to the Director, Wadia Institute of Himalayan Geology for the permission provided to conduct the XRF studies. I also thank Mr. Saini and N. Suresh for analysing the samples.

The words are insufficient to express my profound heartfelt indebtedness and gratitude to Mr. K.K. Ramachandran, Scientist, Centre for Earth Science Studies, Trivandrum for his continuous effort during the various stages of the work. I am grateful to Mr. M. Samsuddin, Scientist of CESS for going through the script and for his valuable suggestions. My thanks are also due to Mr. M. Thomas for his kind help and support. The co-operation rendered by Dr. V.P. Unnikrishnan, Hydrogeologist, Kerala State Ground Water Department is gratefully acknowledged.

M/s. M. Muraleedharan, Ashok Kumar, C. Srinivas Gupta and Abdual Azeez of Faculty of Marine Sciences, Cochin University of Science and Technology are thanked for their service during the field work. I also sincerely thank my friends Mr. Syriac Sebastian and Mr. Roy George, Research Scholars of the Marine Geology Division for their valuable help rendered in various stages of the work.

I sincerely appreciate and thank my friends M/s. Rm. P. Nachiappan, A.V. Shetty, T. Chandra Mohan, T. Prabhakaran Panicker, P.V.K. Nair and Mathewkutty Jose (Regional Centre, Belgaum) of National Institute of Hydrology, Roorkee for devoting their valuable time by rendering various types of helps during the study.

I wish to express my deep sense of gratitude to Mr. K. Sudhakaran Pillai for his sincere effort in completing this work. I also extend my sincere thanks to Mrs. Usha Ram and Master Aaditya Ram for their kind co-operation during the final stage of completion of the work.

(PURANDARA, B.K.)

CHAPTER - I

GENERAL INTRODUCTION

1.1. INTRODUCTION

The west coast of India, endowed with numerous havens, creeks and a narrow but fertile hinterland with coveted products, has always been a zone of trade contact between India and the West. Its location, confronting the sealane from western Asia and Europe to the Far East, has attracted genuine traders in search of precious merchandize to its coast.

From time immemorial two anchorages on the west coast of southern India have been known to mariners, one at Narakkal (north of Cochin) and another at Alleppey-Purakkad, which are perfectly quiet and smooth area while the sea outside may be tumbling in before the gales of South West monsoon. These anchorages are peculiar in being a very fine, soft, unctuous mud, which act as barrier against which the force of the waves is expended.

In these quiet waters, ships and sailors sailed safely across, the sea beneath them being less saline water due to the monsoonal rainfall. It is found that on one of the banks the smooth surface may be broken by burstings up, or huge bubble - 'cones' as they have been called - of water or mud from the sea bed, and even roots and trunks are reported to have floated up with these materials. It is further noticed that these banks or 'floating muds' are not constant in position but moves depending upon the monsoonal effects.

The Kerala coast is 570 km. long and 20 to 100 km. wide. It is narrower in the north and south and wider in the middle section. Its maximum extension is found in the valleys of the Beypore, the Ponnani (which drains the Palghat gap), the Periyar and Pamba - Achankovil rivers. In south it terminates near the rocky projection at Kanyakumari. The belted arrangement of land forms which is a characteristic feature of the Kerala coast appear here on a larger scale. The prograding aspect of the Kerala coast is also very obvious. Sand dunes of a peculiar form, locally known as 'Teris', are found almost all along the Kerala coast, except south of Kovalam where the rocks projects right up to the sea. These dunes of Pleistocene and Recent times have helped to form a large number of shallow lagoons and back waters which are locally known as 'Kayals'. Low laterite plateaus and foot hills occur east of the alluvial coastland.

The Malabar coast has a large number of streams; the Periyar, having a length of 230 km. is the longest. But most of the streams are very short; their average length is only 60 km. The earlier researchers have estimated that, the rivers of Kerala region have a total run-off of 2,500 thousand million cubic feet, i.e. 5% of India's water potential. They serve as important arteries of inland communication and provide a vast potential for hydroelectric generation and irrigation. Lakes and back waters characterise the greater part of the coast. The Vembanad Lake, stretching from Alleppey to Azhikode and having an area of 205 km^2 is the largest water basin of the area.

Regionally, the Kerala coast has the highest density and extremely higher pressure of population exhibited at Azhikode, Cochin, Ambalapuzha, Quilon and Trivandrum areas. Among these areas, Cochin has the highest density. A major part of the Kerala coast undergoes large scale erosion along long stretches of this coast and consequent serious impairment of life of those living in the coastal zone.

The mud banks, locally known as 'Chakara', a unique phenomenon reported hitherto form only in the South West coast of India, appear over restricted areas on the Kerala and south Karnataka coast during the South West monsoon season, as bodies of calm turbid water zone with a heavy load of suspended sediments. During the heavy monsoon the coastal waters are stirred up violently which is called as 'Kettavallam' by the local inhabitants. This is supposed to be one of the reason for the mass mortality of fishes as per the local fishermen. Mud bank lies closer to the beach but extend some miles seaward presenting a more or less semicircular or flat crescentic edge to the long rollers and tumbling waves of the monsoon weather.

1.2. LOCATION AND GEOGRAPHIC SETTING

'Mud banks' have been reported from the various parts along the Kerala coast. The important formations are marked on the location map (fig. 1.1), of these the most famous and well marked permanent mud banks are located one to the north of Cochin, i.e., Narakkal mud bank and the other south of Alleppey i.e., at 'Purakkad'. These are reported to form every year during the South West monsoon season.

1.3. CLIMATE, RAINFALL AND VEGETATION

Climate of the Kerala coast is mainly controlled by the two monsoons, viz. the South West monsoon and North East monsoon. The South West monsoon starts from the end of May to December, the earlier half is generally rainy season. The latter half marks the 'retreating monsoon' during which some parts of the eastern coast, particularly the Madras coast receive some rain.

The South West monsoon strikes Malabar coast and is deflected northwards by the hilly mountains present along these coasts. Generally, South West monsoon is quite effective during June to September and the wind blows roughly from the south west and frequent rains are experienced. The Western Ghat receive over 250 cm of rain during the monsoon. In December and January, the general wind blow is from the north easterly direction. During February to May, the weather is calm. October and November form a transition period between the two monsoons.

Between March and May, the predominant wind direction over the sea in this region changes gradually from NE to NW and then to West (Anonymous, 1966). In June, the winds tend to blow from directions between south west and west and increase in strength. From June to August, three quarters of all winds blow from directions between south west and west. By the end of August, directions of wind reverses but the force decreases. During October and November, the direction of the wind is between NW and ENE. This reversal of wind direction play a major role in the formation of mud banks.

The mean annual rainfall for the Kerala State is very nearly 300 cm, which is about 3 times the average rainfall of India. The hinterland of southern Kerala consist mainly of a low lateritic table land fringed on the seaward side by a narrow belt of Recent alluvial formations. Except for a thin line of arenaceous soil on the very shore of the sea in some areas, sediments are composed of a mixture of clay and sand in varying proportions. They are covered with thick vegetation of coconut trees and paddy fields.

1.4. REGIONAL GEOLOGY

1.4.1. Geomorphology of the South Kerala Coast

The coastal sedimentary basins of Kerala form part of the west coast and the Western Ghats. The laterite upland region is generally included under the coastal plains. It is mainly divided into four physiographic units from west to east as follows:-

i) The coastal strip of recent emergence with estuaries, lagoons, barrier beaches, older spits and bars, former barriers, mud flats, creek deposits, and swampy and marshy zones.

ii) Laterite upland formed by low lying flat topped hillocks between 50 to 150 m elevation above mean sea level, covering the tertiary sediments and the gneisses between the foot hills and the coast.

iii) The foot hill region of the Western Ghats comprising deeply dissected platform, including the stretch upto a height of about 1000 m above mean sea level.

iv) The high ranges of the Western Ghats rising to an elevation of 1000 m to 2500 m above the mean sea level.

The coastal area of Kerala is remarkably straight and is believed to have originated as a result of faulting during the late Pliocene (Krishnan, 1968). They contain vast stretches of sandy flats interspersed with lagoons, estuaries and low-lying reclaimed lands. Forty one west flowing rivers, most of them of the type of mountain streams, flow from the Western Ghats into the back waters and lagoons that skirt the coast. The back waters in turn are connected to the sea by inlets (at thirty four points). All coastal inlets are influenced by the movement of sediment which are brought in directly by river flow into these inlets or deposited into the inlets by longshore movements. In addition to the long stretches of sandy flats representing the old barriers, there are small and linear sandy zones which extend into the mud flats and occur within the mud flat zones. These small and linear sandy zones represent the older spits and bars. The mud flats are generally composed of clays, silty clays and shell fragments. The most prominent of the mud flats lies in the south eastern side of the Vembanad lake.

The Vembanad lake is the major estuarine system of the Kerala coast extending from Azhikode in the north and Alleppey in the south (9°28' N to 10°16' N Latitude 76°13' E to 76°30' E Longitude). The estuary is one of the important nursery grounds for commercially important penaeid prawns and support a rich fin fish and shell fish growth. The Cochin harbour is situated within the estuarine part of the lake by cutting a number of channels which enable to land ships safely. This is one of the major coastal lagoon bordered on its west by the Arabian sea and separated from it by a barrier beach. Major rivers of Kerala like Pamba, Manimala, Achankovil, Muvattupuzha, Ittupuzha and Minachil join at various points into the lake. River Periyar directly joins the sea at the northern tip of the lake.

The width of the continental shelf along the Kerala coast varies widely. Major contributors for the shelf deposits are the west flowing rivers. The muddy bottom shelves gradually form thirty to forty miles from the coast to a depth of 100 m and then it drops suddenly to 1000 m. The littoral current flows from north to south during the South West monsoon, and northward at other times. Morphologically the Kerala coast can be broadly classified into (i) rocky coast, (ii) rocky promontories with intervening sandy beaches, and (iii) sandy coasts. Out of this, the sandy coast is the most predominant type along the Kerala coast. It is more or less straight trending in a NNW-SSE direction. On the landward side of the coast, there is a series of laterite rocks backed by alluvial deposits (King, 1882, Menon, 1974). The sandy coast of Kerala shows double shoreline viz., (i) an inner irregular rocky shoreline of submergence and (ii) an outer shoreline on the seaward side of the barriers. This double shoreline feature corresponds to the 'compound shoreline' of submergence. Adopting Shepard's classification, the Kerala coast is a secondary coast influenced by the offshore fault and shaped by marine deposition.

1.4.2. **Geology of the South Kerala Coast**

The Tertiaries and Recent sediments of Kerala coast rest directly upon the Archaean Crystalline complex consisting of khondalites, leptynites, charnockites and mica-hornblende gneisses, as there are no rocks of other geological periods along the west coast. The Tertiary formations include mainly (i) Warkalli beds of variegated sandstones and clays, white plastic clays, carbonaceous clays and associated seams of lignite, and (ii) the Quilon beds consisting of fossiliferous limestones intercalated with thick beds of variegated sands, carbonaceous clays, sandy clays and sands. These are succeeded by Sub-Recent to Recent marine and estuarine formations consisting of (a) shell-bearing sands, black sticky clays and silts, (b) peat beds and peat bogs containing semi-carbonised wood, (c) older red 'teri' sands, (d) coastal sandy flats and sand bars, (e) recent accumulations of beach sands, and (f) limeshell deposits in the beds of Vembanad lake and other backwaters, in addition to laterite, soils and river alluvium (Paulose and Narayanaswamy, 1968).

Laterites occupy the hinterland of the coastal plain of Kerala and it is typical of tropical land forms. Laterite is composed mainly of hydrated oxides of iron and alumina together with those of certain elements which form the group of hydrolysates such as manganese, titanium, vanadium, zirconium etc. The silica, along with magnesia, alumina etc., contained in the original rock are removed in solution leaving behind hydroxides of iron and alumina, manganese etc. Laterites may be derived from a variety of rocks. These include alkali rocks like nepheline syenite, trachyte, intermediate and basic igneous rocks like dolerites and basalts, gneissic rocks rich in felspars and sedimentary rocks including shales and impure limestones. But most of the deposits of India are derived from dolerites and basalts of the Deccan trap formation. Elements concentrated in the laterite type of weathering are those with intermediate ionic potential (the ratio of ionic charge to the ionic radius) ranging between 3 and 10. Those with low potential, example the alkalies and the alkaline earths, form the soluble cations while those with high potential like phosphorus, nitrogen, sulphur, silica etc. form the soluble anions. The elements of intermediate ionic potential are hydrolysed and form the hydroxides of the laterite zone (Goldschmidt, 1937).

The Recent to Sub-Recent formations are confined to the coastal plains. The Sub-Recent formation consisting of high thickness of sands with shell fragments, sticky black clays, and peat beds. These occur in the low lying areas fringing tertiary beds between Quilon, Kayamkulam, Kottayam, Ernakulam and Ponnani and also between Cannanore and Nileshwar. The Sub-Recent marine and estuarine deposits are localised around the stretches of back waters and reclaimed low lands.

The Recent formations include alluvial deposits and coastal sands. The alluvial formation deposited by the flood waters occur along the major river valleys and along the margins of the mud flats.

Thus the Kerala coast, with numerous west flowing rivers cutting across the hinterland joins sea at various points either directly or through estuaries. The 'mud banks' found along the coast at certain locations are apparently unique in their formation and, it offers an excellent opportunity to study the various parameters involved in the origin and development.

CHAPTER - II

MUD BANKS

2.1. INTRODUCTION

'Mud banks' are smooth water tracts formed at certain locations along the Kerala coast during South West monsoon. They are semicircular in shape, and the northern and southern edges are defined by two crescentic lines of breakers running outwards to the sea. It extend seaward upto a distance of 3-4 km from the shore. The formation of mud bank plays a major role in moulding the social and economic set up of the coastal people of that region by providing a stable fishing ground during the monsoon season. The mud banks act as wave dampers and protect portions of the beach from erosion and help in traping the sediment which leads to the growth of the adjoining beach.

The mud banks that occur at rare intervals along the coast between Quilon and Cannanore, a distance of about 270 km are peculiar to this part of the coast and from time immemorial, have been known to mariners as safe water anchorages when compared to the adjacent waters which are under severe wave attack during South West monsoon. The prominent mud banks selected for the study are (i) Narakkal mud bank (north of Cochin) and (ii) Purakkad mud bank (south of Alleppey).

2.2. ENVIRONMENT OF SEDIMENTATION

The coastal sedimentary basins of the Kerala form the eastern margin of a bigger basin extending westward over the continental shelf.

In the nearshore, gradients are 20 to 80 m/km, where as on the shelf proper the gradients are less than 2 m/km. The sediments present in the Kerala coastal basin include primarily Miocene sediments overlain by a thin section of Quaternary sediments.

Along the study area there are four major rivers which debouches into the Vembanad lake and then to the sea. The sediments brought by the rivers first settles in the lake and then it filters out to the sea through the estuary. The estuarine region presents a different situation with a stable marine condition prevailing for major part of the year. During the monsoon period fresh to brackish water condition exists at the surface, and marine condition continues to prevail at the bottom. The estuarine region is highly productive and the underlying sediments are correspondingly rich in organic matter content. It has been indicated earlier that the estuarine region receives material from the adjacent marine environment.

The confinement of suspended matter within a certain region, combined with movement by tidal and density currents, has an important selective effect on the sediment distribution on the continental margin. In many areas distributional patterns are closely related to water movements including that of waves. Deeper portions on the shelf are often sufficiently quiet for mud deposition, but the deposits are coarse since no fine grained suspended matter is available. Conversely, muddy deposits may form in rough water if sufficient fine grained materials are supplied. A number of transgressions and regressions of the sea resulted in major lateral shifts in the sedimentary facies which are ideal for the formation of stratigraphic traps, particularly on the shallower parts of the continental shelf. A large amount of terrigenous clastic materials are found in the fluviatile and barrier beach sections of the Kerala coastal plain, deposited during the periods of regression. Further seaward from the coast, the geological succession is expected to change, mainly carbonate facies in the marine equivalents, over the continental shelf. Not much clastic materials are available from the narrow coastal drainage area and the conditions in the clear warm waters are generally favourable for organic growth in the shelf area.

2.3. HYDROGRAPHY OF THE MUD BANK REGION

Hydrography of the mud bank region is one of the most important factor in its formation. Extensive studies have been conducted along the inshore waters of the Kerala coast. Seshappa (1953 a), George (1953) and Seshappa and Jayaraman (1956) have reported the hydrographic conditions of the inshore waters at Calicut and Damodaran and Hridayanathan (1966) and Damodaran (1973) have studied some of the hydrographic features of the Narakkal mud bank region. The hydrographic investigations conducted in the mud bank region at Purakkad during 1971-73 have shown that the seasonal variations in the hydrographic parameters of the mud bank location show close relationship with the rainfall during monsoon and the seasonal heating during summer (Kurup, 1977).

The studies conducted by Damodaran and Hridayanathan (1966) show considerable depletion of dissolved oxygen in the bottom waters as against the condition prevailed at the surface layers, where it gave high values. The lowest values observed for dissolved oxygen in the bottom waters during May-June, July and August with 1.713, 0.744, 0.446 and 0.327 milligrams/litre respectively. Banse (1959) attributed similar low values of dissolved oxygen in the bottom waters due to 'upwelling' occurring along the south west coast during this season. According to him a considerable depletion of dissolved oxygen in the upwelling water may occur due to oxidation of organic matter in the shelf region during its course to the surface.

Similar studies have been conducted in the adjoining shelf area to know the variation of surface salinity and of temperature. From the studies, it is noted that the adjoining shelf area is comparatively more saline than the mud bank region. There is no significant change in the temperature both at the surface and in the bottom waters. In general, the South West monsoon and the back waters play a major role in determining the hydrographic characters of the mud bank region. It is clearly evident in the case of Narakkal mud bank.

2.4. SUSPENDED MATTER OF THE MUD BANK

The study of suspended sediment concentration were carried out elsewhere by various techniques including ultra microscopical counting (Freundlich, 1922; Schubel and Schiemer, 1969), Filtration (Schubel, 1967; Sheldon, 1972) and optical measurements (Jerlov, 1968). Along the Kerala coast, Kurup (1977) has studied the suspended matter concentration in the water column of the mud banks from the samples collected during 1972 and 1973. During April 1972, the vertical sections show suspension concentration varying between 100 mg/l and 250 mg/l at the surface and 1 m above the bottom. Suspension concentration was comparatively higher in the month of June 1972 (55 mg/l to 150 mg/l). The highest concentration was obtained at 6 km away from shore at 1 m above the bottom. During July, the concentration of suspended sediment at the surface varies between 1000 mg/l to 1300 mg/l within the 8 km range. In the bottom waters, i.e., 1 m above the bottom, they show higher concentration (1500 mg/l to 1600 mg/l). September onwards it decreases gradually. Recent studies by Ramachandran and Mallik (1985) have shown that the suspended matter concentration ranges between 21 and 212.5 mg/l at the surface where as its concentration at 1 m above the bottom ranges from 31.8 to 439.3 mg/l. Studies carried out by Purandara and Dora (1986) in the Narakkal mud bank region showed that the suspended sediment concentration varied between 100 mg/l and 900 mg/l in the surface layers whereas its concentration in the bottom waters ranged from 120 mg/l to 3600 mg/l. It is clear that the concentration increases from surface to bottom and it also shows an increase from May to July - August months and a decrease during September to December. Further studies conducted by Purandara and Dora (1987) for the Purakkad mud bank area revealed that the average value of the suspended sediment concentration (SSC) ranged between 62 and 800 mg/l at the surface, 65 and 925 mg/l in the intermediate layer and 168 and 1475 mg/l in the bottom layers. It was also noted that the concentration of suspended sediment was maximum during July-August months and decreased thereafter.

2.5. FLOCCULATION OF MUD BANK SEDIMENTS

Flocculation and deflocculation are the two important factors in the formation and disappearence of mud banks along the coast. With the onset of South West monsoon, very rough sea prevails all along the south west coast of India except in a few pockets along the Kerala coast. The mud which is churned up by some force creates an environment with excess of electrolytes from sea water (Nair, 1976). Elementary particles of colloidal or semi-colloidal dimension may contain electric charge which influences the behaviour of these clay particles in suspension are of major importance. It has been found that they usually have a negative charge, which may be explained by (i) preferential adsorption of anions, especially hydroxyl ions; (ii) cationic substitutions within the crystal lattice, and (iii) residual valences (broken bonds) at particle edges. The negative layer is balanced by a double layer of hydrated cations which tend to move away from the surface of the clay mineral, although electrostatic attraction prevents a complete escape. There is a correlation between the stability of the suspension and the electrolytic potential. The thickness of the double layer depends on the valency of the sorbed ions, the total ion concentration in the surrounding water, temperature, and pH.

If the electrolytic potential decreased below a critical value, particles conglomerate to large units and tend to settle (Berthois, 1961; Committee on Hydraulics, 1960; Whitehouse and Jeffrey, 1955). In this process, while the double layer is present, two clay particles approaching each other by Brownian movement are repelled, because, their charges are equal. Other forces, however, tend to cause the particles to approach each other. The suspensions are stable in water with a small electrolytic content by forming a thick double layer. If more electrolyte is added, the thickness and electrolytic potential of the double layer decreases, and the possibility for two particles to unite increases. Cations in the solution, moreover are exchanged for cations in the double layer. As a result, clay minerals flocculate in seawater, especially under the influence of magnesium and calcium ions. It is further noted that dissolved organic matter such as humic substances may prevent flocculation to a certain degree and this is especially evident in the case of kaolinitic clays.

Studies carried out on differential flocculation are restricted to clay minerals (Welder, 1959; Whitehouse and Jeffrey, 1955; Whitehouse and McCarter, 1958; Whitehouse et. al, 1960). Various clay minerals behave in different manner. Most commonly found clay minerals are illite, kaolinite, montmorillonite and less common clay types are vermiculite and chlorite which are generally of marine origin.

Illite particles are usually smaller than kaolinite, but are considerably larger than montmorillonite. This might in itself lead to differential settling apart from other physico-chemical differences. From the observations made by Whitehouse et. al. (1960), flocculation of kaolinites and illites are mainly completed at very low chlorinity, where as the flocculation of montmorillonite increases gradually with increasing chlorinity. This difference is because of the very stable double layer of montmorillonite. In a turbid water the various clay minerals can be transported by low current velocities and in the process illites and kaolinites may be deposited, where as montmorillonites remain in suspension.

2.6. WAVES AND CURRENTS

2.6.1. **Waves**

Most of the dynamic nature of the beach and nearshore zone is the direct or indirect result of wave action. Waves move sediments and consequently modify the bottom configuration as well as the distribution of sediment. They also generate currents which transports sediments. Deep water waves are those in which only the surface layers of the flow are disturbed by the movement of the waves and when the entire depth of water is disturbed by the waves, the waves are shallow- water waves. As waves approach shallow water, they loose energy due to bottom friction, percolation and the non-rigidity of the bottom. A wave moving from deep into shallow water continuously decreases in length and speed, while its height first decreases and then increases (Kinsman, 1965). When these waves enter into water of depth approximately equal to the wave height, the waves become unstable and break. The depth of water in which waves break and the nature of the breakers depend upon the wave steepness which is a ratio of wave height to wave length, and the slope of the beach (Weigel, 1964). A breaking wave releases a part of the wave energy in the surf zone and this energy is used up on stirring up the bottom and carrying the material into suspension. Refraction of waves takes place as soon as the wave begins to feel the bottom. It results in the change of its wave length and velocity, as the wave enters shallow water. That part of the wave which is in deeper water moves more rapidly than the part in shallower, which causes the crest to swing round parallel to the bottom contours. As the crest swing round, the distribution of energy along them ceases to be uniformly spaced. There is a concentration of energy on the head lands and dissipation in the bays.

During monsoon the entire coast is under the impact of long period waves and high breakers. Waves and wave induced currents are very important in the formation and migration of mud banks. Wave energy loss or wave damping, as manifested in height attenuation, can be caused by many factors such as bottom percolation, free surface dissipation, internal friction, bottom or boundary-layer friction and dissipation into a fluid bottom. Energy losses caused by percolation are negligible on muddy coasts since clays are highly impermeable, (Wells, 1977). Mud banks act as natural breakwaters by damping the waves. During active rainy season mud bank regions are calm and paves way for smooth manoeuvring of fishing canoes and boats.

2.6.2. Longshore Currents

The action of waves on the shore is very significant due to the generation of currents when waves approach the coast obliquely. Some of these are directly due to wave refraction, which causes zones of convergence and divergence. These currents are more pronounced in shorter waves which suffer less refraction before they reach the coast and therefore lie at a greater angle to it and can generate relatively rapid longshore current. The longshore currents observed along this part of the coast indicate alternating weak flows. The mud banks cause considerable attenuation of wave energy and decreases in wave height. Often, these waves never reach the shoreline and favour sedimentation of fine-grained material (Shenoi, 1984).

Shepard and Inman (1950) opined that shallow-water topography and shoreline configuration play a role in rip current location and development. Rips may form as the result of water piling up between the shallow sand bar and the strand line as wave move shoreward. This water moves generally parallel to the shore and converges at a topographic low where it flows seaward through a saddle in the shallow sand bar. The converging currents are called feeder currents and supply the neck of the rip current system. Beyond the rip channel, through the breaker zone, the rip current disperses into a rip head.

Rip current may be recognised as turbid plumes or bubble trains extending across the surf and breaker zones. Although they are commonly a near-surface phenomenon, rips also have been shown to entrain and transport significant quantities of sediment (Cook, 1970). Visual evidence is provided by the sediment in the turbid plumes in rip heads. According to Varma and Kurup (1969), the formation of the mud bank is the result of the interaction between the onshore and offshore transport of sediments in suspension, the former by waves and the latter by rip flows. This means that the location of a mud bank is decided by the location of converging littoral currents strong enough to cause an offshore transport of suspended sediments. Thus the shift in location of the mud bank can be considered to be caused by a shift in the location of the zone of convergence of littoral currents, which is determined by the wave refraction pattern either due to the changes in the bottom topography of the region or to the changes in the composition of the wave spectrum or both.

During the present study, a visual estimation of wave height was done and found that most of the waves approaching along the central Kerala coast lies in the range of 0.5 m - 1.5 m in height and 10-15 seconds in period. These low height and high period waves may be one of the important influencing factor in keeping the waters calm. It is also noted that the mud bank found between Malipuram and Narakkal during 1985 has been shifted during 1986 and was more active in between Malipuram and Puthuvypu. This further proves the southerly movement of mud banks.

2.7. PREVIOUS LITERATURE

The 'Mud Banks' present along the Kerala coast dates back to 1678, as per an extract from Alexander Hamilton's account of the East Indies which is contained in Pinkerton's 'Collections of Voyages and Travels' given in the Travancore Administration report of 1860. "The mud bay", Hamilton wrote "is a place that, I believe, few can parallel in the world. It lies on the shore of St. Andrea, about half a league out in the sea, and is open to the wide oceans and has neither island nor bank to break off the force of the billows which come rolling with great violence on all other parts of the coast, in the south west monsoon, but on this bank, lose themselves in a moment, and ships lie on it, as secure as in the best harbour, without motion or disturbance".

Padmanabha Menon (1924) in his book on 'The History of Kerala' mentions some of the early records of the mud banks by Dutch Admiral Stavorinus. Bristow (1938), published two volumes on 'History of Mud Banks', in which he summarised the full descriptions on appearence and disappearence of mud banks along the Kerala coast as noted by various Scientists, Engineers and Administrators. The important observations were made by the following persons: Captain Cope (A New History of the East Indies, 1775), Maltby (1860), Crawford (1860), John Castor (1861); J.J. Franklin (1861); Francis Day (1864); J. Mitchell (1864); W. King (1881); John Rhode (1886); Philip Lake (1890); J.E. Winckle (1892); G.H. Davey (1928, 1937), on Narakkal and Alleppey mud banks which are considered by them as permanent mud banks. Bristow also carried out the first scientific investigation on the problem of mud bank formation.

Various theories have been put forward to explain the formation of the mud banks. Rhode's hypothesis of 1886 (reported by Bristow, 1938) is the earliest in which the formation of the banks is attributed to a subterranean channel flow of mud from the back waters to the sea, this flow being maintained by the hydrostatic pressure head developed in the backwaters due to their higher water level during monsoon.

Philip Lake (1889; quoted in Bristow, 1938) differed from the view held by the previous observers on the source of mud for Alleppey mud bank and argued that, it is not from the backwater mud, but from an older river deposit found only at particular points along the coast. He further stated that with regard to the existence of subterranean channels, it might well be doubted whether any of these could exist in such unstable deposit as found there.

The opinions stated above leads to understand that, there is an underground discharge of water at any rate into the sea from the lagoon and river system behind the Alleppey-Purakkad coast during flood time, the inland water being at a higher level. This passage of underground water, more particularly during heavy rains, pour out with its large quantity of mud.

Bristow (1938) argued that it is impossible for the back water to rise more than a foot without flooding the lower parts of the neck of land separating the break water from the sea, at many points between Cochin and Alleppey. Besides, a head of 5 feet, the maximum possible would give a pressure of only about 21 lbs/sq. inch, which is not enough to overcome the frictional resistance set up by solids in suspension. He believed that a water bearing stratum exists at a good depth, which bring down water from the hills and crops out under the sea at varying distance from the shore, there by lifting the bottom mud above it and anything sufficiently buoyant that lies buried in the mud.

According to Ducane et al (1938), the mud of the mud bank is greenish, very oil but mixable with water, where as the mud of the back water is black and is full of vegetable debris and it is immiscible with water. This difference lead Ducane's team to conclude that the mud of the mud bank might be from an older source. They were of the opinion that the laterite alluvial sediments from the land are rundown by the rivers and are deposited in the seabed close to the shore in a regular process of river discharge and the sediment deposit thus accumulated near the coast is churned up by monsoon waves and thus the mud bank is formed.

Keen and Russel (Ducane et al, 1938) found in their experiment that the mud of the mud bank completely settled (flocculated) when salinity was greater than 20‰ and it remain suspended (deflocculated) at salinity lower than 2.5‰. They further concluded that the calming effect is due to the kinematic viscosity and thixotropic properties of the muddy suspensions produced in the monsoon. The suspended mud increases the kinematic viscosity of the medium. This factor will tend to dampen the motion of the waves on the surface and in subsurface depths.

The Admiralty charts (1961) and the recent echo surveys (Silas, 1984) indicated that there is a rocky substratum at about 75 m depth off Kerala coast. Thus it seems that the entire vast area between the foot of the hills and at about 75 m depth off the coast was almost deep basin, got subsequently filled up with mud and sand, over which a sand crust was formed at some places.

Crawford's borings at Alleppey revealed the presence of sandstone till a depth of 50 ft and then a loose mud to a depth of 80 ft, in which the 'shaft sunk of its own from 60 to 80 ft. Water bearing stratum has been observed to be associated with sandy substratum, but surface of the stratum has not been indicated in any of the boring records.

In the recent past, systematic studies have been conducted on various aspects of mud banks. Seshappa (1953 b), and Seshappa and Jayaraman (1956), have studied the phosphate of the mud bank at Calicut and noticed higher phosphate concentrations. Ramasastry and Myrland (1959) stated that the formation of mud bank is associated with upwelling and divergence near the bottom between 20-30 m along the coast line which produce vertical acceleration, with resultant lifting of the bottom waters, which carries along with its fine mud of the bottom. Nair et al. (1966) came to the conclusion that the mud deposits on the sandy beaches of the Vypeen island was from the nearshore areas, as it was composed of dredged material transported Northward from Eranakulam channel. Damodaran and Hridayanathan (1966) suggested that lowering of surface salinity and a flocculation effect caused by the same keep the mud in suspension. Dora et al (1968) stated that mud bank sediments are chiefly composed of clay particles less than 1 micron. Nair and Murthy (1968) by X-ray diffraction analysis showed that poorly crystalline kaolinite was the most abundant (60-65%) with 15 to 20% montmorillonite (saponite) and 15 to 20% illite, and trace quantities of chlorite, gypsum and quartz. It is also noted that the sediment contain 5-8% organic matter, the values being higher than in the sediment outside the bank. The effect of mud banks on shore stability has been studied by Iyer and Moni (1971) and Moni (1971) with particular reference to the Cochin and Alleppey mud banks. Thus localisation of suspended sediment takes place at the rip head. Reddy et al. (1972) has studied the wave refraction in relation to sediment movement along the coast and Kurup (1972) has studied the wave refrction in relation to sediment movement along the Kerala coast and made some observations on the movement of mud banks. Damodaran (1973) made a detailed study of the benthos of the mud banks.

Gopinathan and Qasim (1974) pointed out that they could hardly observe any strong rip currents which could stop the shoreward transport of the sediments and form mud banks. Nair (1983) analysed the important elements from the mud bank and non-mud bank areas both, sediment and water samples.

Recent investigation by Ramachandran and Mallik (1985) showed that amongst the different size classes, clay ranges between 7 to 64.8, silt, 19 to 55.8 and sand 1 to 56%. Heavy mineral concentration ranges between 0.28 to 40%. Further studies on core samples from mud banks area off Quilandy revealed that the important constituents found besides clay are iron oxide, phosphate, glauconite, pyrite, heavy minerals, forams, diatoms etc.

A study of Shenoi and Murthy (1986) on the wave damping in the mud bank region has shown that waves can completely be dissipated over a mud bank of width about 3-4 km when the kinematic viscosity increases to 1 cm^2 sec^{-1}. Waves of higher amplitude are dissipated much faster than those of lower amplitude.

Purandara et al (1986) observed a significant increase in the clay content from May to August and decrease during September to December. Mallik et al. (1988) have conducted SEM studies of the core samples indicate the fabric of clay. They have stated that, the mud banks of Kerala coast differ from mud banks reported from other muddy coasts of the world in that they do not form regular relief - forming features. The transient nature of these 'mud banks', their unpredictable periodicity and the calm and turbid nature of the fluid mud formation makes the Kerala mud banks unique in nature. Ramachandran (1989) studied geochemistry of Quilandy mud bank and suggested that apart from the physical mechanism of suspension, dispersion of the sediments as a chemical mechanism for the sustenance of suspension.

In the present context, an attempt has been made to study in detail, the mud banks of central Kerala i.e. of Narakkal, Saudi and Purakkad areas. The studies have been conducted during the year 1985 and 1986. The main objectives of the study are the following:

i) To cite the provenance of mud bank sediments of central Kerala coast.

ii) To assess the influence of Vembanad lake on the formation of mud banks.

iii) To understand the clay mineralogical variations of the lake and nearshore sediments.

iv) To delineate the variation of Chemical constituents of the lake and mud bank sediments.

CHAPTER - III

MATERIAL AND METHODS

3.1. OBECTIVES OF SAMPLING

In order to decipher the provenance of the mud bank sediments, sediment samples were collected from the rivers Pamba, Manimala, Minachil, Muvattupuzha and also from the downstream region of the Periyar. Rock samples were collected from the river catchment areas to substantiate source rock in the hinterlands of the coastal region.

Surface sediment samples were collected from the Vembanad lake during pre-monsoon and post-monsoon periods to understand the contribution of the lake to the neighbouring sea. This will enable in citing the source of the mud bank sediments.

Detailed systematic sediment sampling of the mud banks off Narakkal, Saudi, Alleppey - Purakkad area and also from the neighbouring shelf zone were carried out. Survey was conducted during May, June, July, August, September and December along the coast at a distance of 1-1.5 km away from the shore. This is mainly to study the textural, mineralogical and chemical changes of the sediment during pre-monsoon and post-monsoon periods.

In addition to this beach sands were collected at selected intervals along Narakkal - Purakkad coast during pre-monsoon, and post-monsoon periods. This will enable to identify the distribution of detrital minerals along the coast of central Kerala and may yield information about the source.

3.2. FIELD METHODS

Field studies were conducted during the year 1985 and 1986. During 1985 March-April, systematic survey of the rivers viz. Pamba, Manimala, Minachil, Muvattupuzha and Periyar (downstream) were carried out. Samples were collected from the mid stream channel at an interval of 2 km from the barmouth upto 30 km upstream. Thereafter samples were collected at an interval of about 5 km to 10 km upto the point of origin of the rivers. More than 100 samples were collected from the rivers (fig. 3.1 to 3.4).

During May-June 1985, just before the onset of South West monsoon, sediment samples were collected from the Vembanad lake at selected locations along the larger axis of the lake, from the barmouth to the upper reaches (fig. 3.5 a). In the wider regions 3 samples across were also collected. Sample collection was repeated during the post-monsoon period (fig. 3.5 b). This is to document variation of textural, mineralogical and geochemical assemblages in the sediments.

Systematic survey of the nearshore region was done during 1985 and 1986. During 1985, the study was conducted only for Narakkal and Saudi mud banks whereas during 1986, the study was extended upto Alleppey - Purakkad region (fig. 3.6). It was carried out to assess the change occurring at Narakkal from year to year.

Surface sediment samples were collected using Van Veen Grab and few core samples were also collected using Phleger corer. Water sampling for suspended sediments were carried out using Hi-Tech water bottles at different depths.

Sampling and surveys were carried out using RV Nautilus, RV Saggitta and also Country Crafts. A total of 130 surface sediment samples from the lake and 240 samples from the mud bank region and 160 samples from the beach were collected, and selected samples were subjected to laboratory investigations. Colour, Lithology, Particle size and plasticity of the sediments were noted in the sediment log sheet on board along with pH of water.

The most salient features regarding the geology of the area in and around all the places of the drainage basin, lake and sea were recorded. The Physiographic features, such as drainage pattern, morphology of the river, soil characteristic and vegetation were also noted.

3.3. LABORATORY INVESTIGATIONS

3.3.1. Textural Analysis

Textural analyses include both sieve analysis and pipette method (Krumbein and Pettijohn, 1938). Beach sands and river sediments were subjected to sieve analysis. The sediments collected from the Vembanad lake and mud bank region was subjected to both sieve analyses and pipette analyses. For pipette analysis known quantities of dried sediments were dispersed overnight in a solution of sodium hexameta phosphate. The silt and clay fractions were separated by sieving the dispersed sediments through a 230 mesh sieve. The coarse fractions retained in the sieve were dried and analysed.

The sieve and pipette analysis data were combined to get the cumulative weight percentages, which in turn, were plotted on an arithmatic probability paper taking grain-size in micron along the X-axis and cumulative weight percentiles along the Y-axis.

Grain-size parameters like mean, median, standard deviation (sorting coefficient), skewness and kurtosis were calculated using the formulae of Folk and Ward (1957).

Passega (1957) has used two parameters, the coarsest percentile (C) and the median (M) obtained from the grain-size distribution curves of sediments to produce individual patterns characteristic of their respective deposition agents. When they are plotted in microns on a double logarithmic graph paper 'C' indicates the upper limit of competency of the depositional agent, provided that a complete range of sizes was supplied for transport. In order to study these different sedimentary environments CM diagrams were drawn for each suite of sediments.

3.3.2. Mineralogical Studies

The mineralogical studies of the selected samples of the beach sands and river sediments were conducted to cite the provenance of the incoming sediments. Heavy and light minerals from +250, +125, +63 micron fractions were separated and treated with 6N HCl and SnCl solution to remove iron coatings and carbonates. Then it is washed with acetone, dried and then weighed heavy and light minerals separately.

3.3.2.1. Heavy Mineral Analysis

Heavy mineral suites from the above size grades for the samples were mounted on glass slides. The minerals on each slide were counted using a mechanical stage on a petrographic microscope. The identification of heavy minerals such as opaques, garnets, sillimanite, pyroxenes, zircon, monazite, rutile and quartz were done by the standard methods. The respective percentages of different groups of minerals in the entire heavy mineral fraction for each size grade and their relative proportions were calculated.

3.3.2.2. Light Mineral Analysis

In order to trace the provenance of the light mineral suite of the river sands and to assess their relative stabilities, quartz, potash felspar and sodalime felspar proportions were determined. Only very few light mineral fractions from the downstream region of the rivers were stained by using felspar staining method (Heyes and Klugman, 1959). The method, briefly, involves the exposing of light mineral grains to the fumes of hydrofluoric acid for 15 minutes and then treating them with the solutions of sodium cobaltinitrite and eosine 'B'. By this treatment, the potash felspars are stained orange yellow and the soda-lime felspars pink, while the quartz grains remain unaffected.

3.3.2.3. Mineralogical Studies of Rock Types

Thin sections of the rock samples were prepared by using different size grades of Carborandum powder and finally it was mounted on the glass slides and studied under the petrological microscope making use of conventional methods.

3.3.2.4. Clay Mineral Investigations

The clay mineral composition was determined by X-ray diffraction from oriented aggregates on glass slides. Each of the field samples was dispersed in distilled water and without adding any dispersing agent. By repeated decantation, any soluble salt in the sediment were removed and stable clayey suspension was formed. The thin moist film of oriented clay particles on the slide, prepared by allowing less than 2 micron fraction of the above suspension to settle on a glass slide, was air-dried and X-rayed. Initially the slides were run at room temperature and under controlled high and low humidity, but additional patterns were made after treatment with ethylene glycol and also after heat treatment at 350°C. From the diffractograms by using Bragg's equation, $n\lambda = 2d \sin \theta$ clay mineral composition was found out.

3.3.3. **Electron Microscopic Studies**

For this study, grain size less than 2 micron of the sample was suspended in a distilled water to have a thin dilute suspension. The clay particles were well dispersed. The supernatant solution was taken and was resuspended in distilled water. The above operation was repeated until clear drop of the suspension was obtained and observed under the electron microscope. A plastic film was coated on copper grids. A thin carbon coating was made on the plastic film in order to make the film more stable against the electron beam. A micro drop of pure clay suspension was gently mounted on the grid and after one minute the excess liquid was removed by using filter paper. The material was introduced into the electron microscope for observation. A 25 micron objective aperture was inserted for providing necessary contrast in the image. Liquid nitrogen in the anticontaminator was used to arrest the contamination growth on the specimen during the time of observation. An accelerating voltage of 50 KV with contrast enhancement specimen catridge was used to examine the clay minerals of the sample.

3.3.4. Chemical Studies of Sediments

3.3.4.1. Organic Matter Content

The total organic matter in the sediment was determined by Elwakeel and Riley (1957) method in which all the organic matter was oxidised by chromic acid (Wet oxidation method) and the excess or unused acid was determined by titrating with standard ferrous ammonium sulphate solution. The total organic matter is obtained by multiplying organic carbon values by a factor of 1.724 (corresponding to 58% carbon) which is recommended by soil chemists.

3.3.4.2. Calcium Carbonate Content

Total Calcium Carbonate is determined by Herrin's et al. method (1958) which involves the treatment of the sediment sample with sulphuric acid and the excess acid was found out by titrating with standard sodium hydroxide. The percentage is obtained by multiplying the difference in titre values of the sample and the blank solution by 5.

3.3.4.3. Major and Trace Elements Analysis

The geochemical investigations have been carried out for the major and trace elements. Major elements were determined by using X-ray Fluorescence spectrophotometer. Instrument used is EDAX EXAM SIX and Philips PV 9100, Energy dispersive X-ray fluorescence system (Tube - RH, working KV = 20 KV, Current - 100 Microamp). The sample was prepared by treating 1 gm of the sediment with 8 to 9 gms of Boric acid in the form of pellets. These pellets were introduced into the apparatus for determining the concentration of the major elements.

Trace elements like Ni, Cu, Co, Zn were determined by atomic absorption spectrophotometer. Based on the principle that the light from a modulated hollow cathode lamp emits a sharp line spectrum of the element to be determined passes through the flame into which the atomic vapour of the sample to be analysed is nebulised. The light then passes through a monochromator which insolates the required resonance line and into a photo multiplier tube detector to an amplifier and read out facility.

CHAPTER - IV

TEXTURE

4.1. INTRODUCTION

The determination and interpretation of particle grain-size has a fundamental role in hydraulics, geomorphology and sedimentology. For many years sedimentoligists used grain-size trends to identify sedimentary environments. Survey of the extensive literature on this subject illustrate the steady progress that has been made towards the goal. Many excellent contributions have been made during the past few decades, each providing new approaches and insights into the nature and significance of grain-size distributions. Only within the past few decades, grain-size distributions were related to the depositional processes responsible for their formation. The study of textural parameters of the sediments is of paramount utility in differentiating various depositional environments and thereby interpreting the origin of ancient clastic deposits.

Sediment granulometry of modern environments have been extensively studied using grain-size statistics. Reviews of this work have been given by Folk and Ward (1957); Folk (1966); Friedman, (1961, 1967); Mason and Folk, (1958) and Moila and Weiser (1968). The grain-size characteristics of a sedimentary deposit are dependent on sedimentary processes as defined by (i) Winnowing, (ii) selective deposition from sediment in transport and (iii) total deposition of sediment in transport, and characteristics of its source deposit. The relative changes or trends of these characteristics, defined by mean grain-size, sorting and skewness can be used to identify both sources and deposits within a system of related environments (Mclaren, 1981).

Earlier workers, Trask (1932), and Krumbein (1936) defined the size parameters based on quartile measures in millimeter but they represent only 50% of the total curve and are therefore, inadeuqate to express the characteristics of the whole distribution. Subsequent methods proposed by Inman (1952) and modified by Folk and Ward (1957) take into consideration the extreme ends of the size distribution curves and can be applied to normal as well as non-normal curves. The method of Inman (1952) deals with 74% of the population and the method formulated by Folk and Ward (1957) takes into account 88% of the population and is, therefore, more accurate. However, McCommon's (1962) method which covers 97% of the size distribution, is time consuming. By comparing the sorting measures of Trask with Inman's method and also with that of graphical measures of Folk and Ward, Friedman (1962) concluded that, the Inman measure is more satisfactory for describing the sorting of moderate to poorly sorted sandstones, the Trask's coefficient of sorting is more satisfactory only for describing very well sorted sandstones, but the sorting measures of Folk and Ward appear to be satisfactory for the entire range of sorting characteristics. In the present context the method described by Folk and Ward (1957) have been adopted. Textural analysis by the graphic method has been attempted by a number of workers (Dora, 1978; Folk, 1966; Isophording, 1970, 1972; Jaquet and Vernet, 1976; Jones, 1970; Seetharamaswamy (1970); Seralathan (1979); Swan, et al. (1978).

South Kerala rivers have been studied by Unnikrishnan (1987), and Mallik et al (1987). In the present study, selected rivers of the central Kerala are considered in order to know the influence of river sediments on the lake and neighbouring shelf area. Textural parameters of the river sediments are presented in the table 4.1.

4.2. RIVER SEDIMENTS

4.2.1. **Results**

4.2.1.1. Pamba River

The size frequency distribution of various grain-size parameters of Pamba river sediments are presented in the figures 4.1.. The mean size of the Pamba river sediments vary between -1.12 to 10.72 phi. It is found that in the upstream region, the sediment size varies from granule to fine sand, of which the most dominant group is the coarse sand to fine sand which constitutes about 55.56%. Silty sediments are missing in the river. The sorting of the sediments varies widely between well sorted to very poorly sorted grade. At few places skewness differs markedly in the downstream area i.e. from a distance of 22 km onwards and shows very poor sorting. Majority of the sediments are platykurtic to mesokurtic.

River distance versus textural parameters are shown in figures 4.2a to 4.2d. In general, the grain-size decreases with the river distance.

From the scatter plots (fig. 4.3 a to 4.3 e), it is observed that in the upstream region initially sorting becomes poorer and it is comparatively better sorted in the further downstream. Finer sediments are more negatively skewed than the coarser sediments. The kurtosis value increases with the decrease of grain-size in the upstream area, but in the downstream region it shows uniform distribution. The well sorted sediments show high positive skewness and the low values (nearing symmetry) of the skewness are found to be associated with low values of kurtosis (Leptokurtic).

4.2.1.2. Minachil River

Textural analysis of the sediment shows that 90% of the sediments are polymodal and 10% are bimodal. The size frequency distribution with grain-size parameters are graphically presented in the figure 4.4. It can be noted that the sediment size varies between the size of a granule and that of a fine sand. Coarse sand is the most dominating size (54.35%). Majority of the sediments are poorly sorted, positively to very positively skewed and are platykurtic to mesokurtic.

River distance versus grain-size parameters (figure 4.5 a to 4.5 b) show that the sediments are coarser in the upper reaches (between 65 and 40 km). Between 30 and 20 km the sediments show uniform distribution. Thereafter in the downstream direction, the grain-size again decreases. It is found that the sorting is poorer in the middle portion of the river course than in the upstream region. Here, the sediments are mostly nearly symmetrical. However, most of the sediments are positively skewed very close to the river mouth. Kurtosis values show a decreasing trend in the downstream direction.

From the scatter plots (figure 4.6 a to 4.6 e) it is inferred that the sediments become better sorted with the decrease of grain size, negatively skewed and platykurtic. From the figure 4.6 d it can be noted that as the sorting becomes poorer, skewness value decreases. It is also noted that the negatively skewed sediments have a high kurtosis values when compared to the nearly symmetrical to positively skewed sediment. In the case of upstream sediments, as the skewness increases, kurtosis decreases.

4.2.1.3. Muvattupuzha

The grain-size analysis of the Muvattupuzha sediments show that 83.33% are polymodal and the remaining 16.67% are biomodal in nature.

The size frequency distribution of various parameters are presented in the figure 4.7. In general, the grain-size of the sediments varies from the size of granule to clay. Majority of the sediments are between the size grade of very coarse sand and coarse sands. Very fine sands are present in insignificant quantity and silt is completely absent as in the case of Pamba Ar and Minachil Ar. Sediments are mainly moderately to poorly sorted, very negatively to very positively skewed and very platykurtic to very leptokurtic in their distribution.

A pictorial representation of the variation of grain-size parameters with the distance are shown in figure 4.8 a to 4.8 b.

The binary plots are represented in the figure 4.9 a to 4.9 e. The relationship between the graphic skewness and phi mean size shows that as the grain-size decreases the skewness becomes negative. It is observed that the upstream sediments are positively skewed and the downstream sediments are negatively skewed. Phi mean size with the kurtosis forms a direct relationship. With the decrease of grain-size, sediment becomes mesokurtic to leptokurtic. The downstream sediments are platykurtic in nature. In the plot between graphic standard deviation and graphic kurtosis it is found that initially when the sediments are sorted, it becomes leptokurtic. Further decrease in the kurtosis value indicates that, the kurtosis becomes more and more platykurtic. But in the downstream region kurtosis again increases.

4.2.1.4. Periyar

River distance versus phi mean size, standard deviation, skewness and kurtosis are presented in the figure 4.10 a to 4.10 d. From the plot it is observed that sediments are very fine near the bar mouth i.e. upto 4 km upstream and beyond that there is a sharp increase in the grain-size with intermittent highs and lows. The sediments are very poorly sorted near the river mouth and further upstream sorting increases. The skewness exhibits a varying trend between negative and positive skewness. The kurtosis value increases with distance from the mouth upto 6 km upstream and suddenly declines and moves gradually upto 22 km and then shows rise and fall towards further upstream.

Scatter plots drawn between the textural parameters are shown in the figure 4.11 a to 4.11 d. The plot (figure 4.11 d) of standard deviation versus skewness reveal that as the sorting decreases, skewness becomes negative. It is further noted that the poorly sorted sediments are positively skewed.

4.2.2. Discussion

The size analysis of the sediments collected from various rivers, namely Pamba, Minachil, Muvattupuzha, Periyar reveal that the downstream sediments are very fine in size and the upstream sediments are medium to coarse grained. This is clear from the polymodal nature of the sediments in the upstream. The decreasing tendency of grain-size towards downstream has been attributed to various processes by a number of authors, like Krumbein (1941), Pettijohn (1957), Plumley (1948), Reineck and Singh (1980), and Russell and Taylor (1937).

The relatively coarser size of the sediment in the upstream region may be due to the greater turbulent motion in the middle of the river, which facilitates finer materials to be kept in suspension for outward transport. On the otherhand, in the downstream side in addition to the general decrease in competency, there is a gradual increase in depth of the river and as such at the bottom, the stream flow is not as effective as on the upstream side in keeping the finer material in suspension. Due to the comparatively stagnant nature of the waters at the bottom and the effect of flocculation in the saline waters of the estuary, fine clayey materials settles down. Near the confluence the bottom sediments generally get admixtured and concentrated with different grades of sediments. Due to the combined effect of sea and the rivers much of the silt and clay are kept in suspension without allowing it to settle down.

From the river distance versus grain-size parameter plots, a considerable decrease in the grain-size of the downstream sediments are observed. The distribution of sediments in the downstream show wide variations. This is more pronounced in the river Pamba where there is a sudden change of grain-size at a distance of 22 km from the river mouth. This is attributed to the change in river pattern and also due to the confluence of Puthan Ar which supplies comparatively finer sediments to the main stream by depositing the coarser sediments in the meandering course. It can also be explained on the basis of irregular mixing up of the estuarine and nearshore sediments. The mixing up process is influenced by the tidal currents, waves and coastal currents which push the sediment toward the estuarine region and from there it reaches the river mouth and vice versa.

In general, Unnikrishnan (1987) attributed the downstream decrease in the grain-size to the abrasion and progressive sorting of the sediments. The rate of abrasion is dependent on the resistance of the minerals. The size of both the downstream and upstream sediments becomes coarser from north towards south except in the Pamba river. The varied nature of the river Pamba may be due to the following reasons. Compared to the other two rivers, it is one of the longest rivers. The major rivers like, Manimala and Achankovil, join the river so that the local river discharge is quite high. Though the river Periyar is the longest, the coarser grain-size may be due to its direct contact with the sea. The turbulent nature of the waves and currents winnow away the finer sediments leaving behind the coarser materials as lag deposits. The Pamba Ar, which debouches into the Vembanad estuary at its southern most point contains fine sediments. Tidal cycles also plays an important role in the sediments in the downstream portion of the river.

Sorting of the sediments generally depend upon the distance it travelled provided there is no mixing of sediments. The farther it travels the better sorting it shows. The progressive sorting or differential transport of the sediments can be due to the progressive decline in the competency of the river (Pettijohn, 1957; Russell, 1939). Interaction of several factors like, fluvial morphology (river pattern), gradient of the river bed and the quantum of water discharge causes the progressive downstream decrease in the competency of stream channel.

Fluctuation in the competency of a transporting agent are generally controlled by the seasonal variations in the river discharge. A decrease in river discharge and its competency, may also occur due to the branching of distributaries. With fluctuations in competency, the largest grains are moved only occassionally, whereas the smallest may be transported farther. Such difference in transportation may result in the lagging behind of the larger particles resulting in a progressive downstream decrease of grain-size in a stream channel (Russell, 1939).

In the present study, it is noted that the sediments in all the four rivers in the downstream region are poorly sorted to very poorly sorted. The upstream sediments of Pamba, Minachil and Muvattupuzha show almost a constant value and are poorly sorted. The coarseness and poor sorting of the sediments may be due to its high energy conditions, relative proximity of the source area and the influx of sediments from the tributaries. The poor sorting of the sediments towards Pamba Ar from Muvattupuzha, are noted both in the downstream and upstream region. Generally, river sands display better sorting towards downstream due to progressive sorting based on size. Here instead, in the downstream area, a complex distribution pattern are observed. This may be due to its sharp decrease in the competency of the transporting agent, intensive mixing of sediments in the river mouth and an increase in depth. Inman (1949) has suggested that once a sediment has attained a maximum sorting value any further fall in competency will entail an increase in fine particles in the sediment which will then round the turn on the curve and sorting of it will worsen.

The skewness of the sediments vary between very positive to very negative values both in the upstream and downstream region. In general, most of the downstream sediments show a negative skewness or nearly symmetrical distribution. Martins (1965) has attributed the negative skewness of sediments to:

(i) Addition of material to the coarser terminal, or (ii) subtraction of fines from the normal population. In the upstream region majority of the sediments are positively skewed and nearly symmetrical. The positive skewness indicates a relative increase of the coarse admixtures in the sediments over the fine while in the case of negative skewness the converse is true. It has also been said by Cadigan (1961), by convention, poorer sorting in the coarser half is measured as negative skewness'. Here the sediments mostly consists of sands. It is presumed that the deposition of considerable amount of silt and clay gives rise to the presence of two subequal modes of coarse and fine particles in most of the samples resulting in platykurtic sediments. The increase of kurtosis value at some places may be due to the admixing of influxes of deposits transported into the site of deposition under varied levels of competency.

From the scatter plot of phi mean and standard deviation shows a close correlation between the two parameters. The downstream sediments except at the river mouth show high degree of sorting. The sediments of the upstream region show a better sorting in the downstream direction. It can be noticed that there is a wide scatter of few points towards the finer grades which may be primarily due to flocculation of the finer clays (Griffith, 1951). Some of the large vertical scattering in the standard deviation values for nearly same phi mean size may be probably due to relatively greater sensitivity of sorting values to slight changes in the tails of the size distribution curves. The sharp increase in the polymodality of the sediments and hence decrease in the sorting value may be due to abrupt fluctuations in the competency of the river, depth and also other factor such as tides and currents especially in the river mouths.

Phi mean size versus skewness shows that the majority of the sediments are negatively skewed in the downstream region and a reverse case is noticed in the upstream section. This clearly indicates that the phi mean size controls the change of skewness character. It is inferred from the study that, as the phi mean size increases, skewness value is decreased, though there are exceptions at few points. Folk and Ward (1957) have generalised that the pure modal fractions are in themselves nearly symmetrical. The mixing of the two modes produces negative skewness if the finer mode is most abundant and positive skewness, if the coarser mode is abundant. From the studies, it can be stated that the bomodality is presumably due to the sudden changes in the energy of the transporting agent.

Varying trends of relationship between phi mean and kurtosis, may be because of the subtraction of materials from the coarser tail. The addition of very fine grains give rise to two sub equal or nearly equal modes in the sediments, thus narrowing the difference between sorting in the central parts and tails of the distribution thereby displaying a platykurtic nature. Dora (1978) observed the same sort of textural characteristics for the Vasishta distributary sediments.

The inter-relationship between skewness and kurtosis shows that there is a general tendency of decrease in kurtosis with the increase of skewness. As the skewness moves from negative to positive, it becomes more and more platykurtic.

The graphic plot of standard deviation versus kurtosis shows an increase in kurtosis with the decrease of standard deviation. As the sorting increases (standard deviation decreases) kurtosis also increases.

Generally, moderate to well sorted sediments are mostly mesokurtic. This is due to the fact that the well sorted sands which are nearly unimodal will have very poorly sorted sediments and the alternate increase and decrease in the values of kurtosis with worsening of sorting may be due to the progressive addition of finer particles gradually giving rise to the sediments of different degrees of bimodality. Folk and Ward (1957) also made similar observations in the Brazos river bar sediments and remarked that 'worst sorting is found in the bimodal mixtures with equal amounts of the two modes, and these also have lowest kurtosis values. Highest kurtosis value is found in those samples with one mode dominant and the other very subordinate, having moderate sorting. Unimodal sediments produce normal kurtosis and are relatively better sorted.

Clastic sediments are transported by water in different ways (Passega, 1957, 1964). The deposit formed by a graded suspension when turbulence decreases, it is characterised by a value of 'C', the one percentile proportional to the value of M, the median (Passega, 1957). The close relationship between C and M indicates that as soon as the coarsest grains are settled, they are buried by the suspension sediment, which prevents these grains from rolling (Passega, 1964).

The CM pattern drawn (fig. 4.12) for rivers of the central Kerala closely resembles the pattern of river Mississippi. The pattern shows that the river sediments are mainly transported either as graded suspension or bottom suspension with minor rolling and uniform suspension. It was also assumed that particles of graded suspension are lifted by bottom turbulance and that sort of sorting of the deposit is due to settling out of a bottom current (Passega & Byramjee, 1969). It is also stated that the diameter of the coarsest grain of a graded suspension deposit indicates slow bottom currents. Sediments in the deposits having median values lower than 15 micron never show proportionality between C and M. They are too fine to be sorted by bottom currents.

Hence, the uniform suspension is shown by fine particles of the downstream region where the competency of the river decreases and depth of water increases.

4.3. TEXTURE OF THE VEMBANAD LAKE SEDIMENTS

The Vembanad lake is the largest lake in Kerala which extends from an area south of Kodungallur to Alleppey. Murthy and Veerayya (1972) described the Vembanad lake as a coastal lagoon having a length of 65 km and covering an area of 20,461 hectors. The lake is connected to the Lakshadweep sea at Cochin, while all along the rest of its length it is separated from the sea by barrier beaches. Textural analysis of the Vembanad lake were carried out by Jos Anto (1971), Purandara et al (1987) and Murthy and Veerayya (1972).

4.3.1. **Results**

From the textural analysis, (table 4.2 a and 4.2 b) it is noted that in general, the sediments are immature and the phi mean size varies between 2.5 to 10.55 during pre-monsoon. The average value is 8.21 in the pre-monsoon and 6.4 for the post-monsoon sediments. The phi median ranges from 2.6 - 10.12 during pre-monsoon and the average value is 8.1. Whereas during the post-monsoon, the phi value ranges between 2.05 to 9.05, with the average value of 6.40. Majority of the sediments are very poorly sorted both during the pre-monsoon and post-monsoon seasons. The standard deviation value varies between 1.39 phi and 4.54 phi (pre-monsoon) and 1.95 phi and 3.85 phi (post-monsoon). The value of skewness varies between -0.38 to 0.48 and the average value is 0.15 phi. Lake sediments are platykurtic in nature. The kurtosis value ranges from 0.55 to 0.98 phi during pre-monsoon and 0.31 to 0.98 phi during post-monsoon. The average value is found to be 0.75 and 0.64 during the pre-monsoon and post-monsoon respectively. From the above results it is found that the sediments are coarser during post-monsoon and finer during pre-monsoon season. Sorting of the sediments is poorer during post-monsoon and it is comparatively better sorted during pre-monsoon season. The kurtosis value shows a decrease from pre- monsoon to post-monsoon season.

Triangular diagrams (fig. 4.13 a and 4.13 b) were drawn for both pre-monsoon and post-monsoon sediments to facilitate classification of the sediments.

The size frequency diagram (Fig. 4.14 and 4.15) drawn for Vembanad lake sediments show that the lake sediments are mainly composed of fine sands to fine clays. During pre-monsoon, the percentage of clay is dominant (9 ϕ -10ϕ) and the percentage of fine sand to fine silt are less in the case of pre-monsoon sediments than the post-monsoon sediments. Post-monsoon sediments are chiefly composed of silt sized particles.

The distribution of standard deviation shows that the sediments are moderately to extremely poorly sorted in nature. It is found that 98.33% of the post-monsoon sediments are very poorly sorted and the remaining 1.67% are poorly sorted. In the case of pre-monsoon sediments 90% of the sediments are very poorly sorted, 5.71 % are extremely poorly sorted and rest of the sediments are poorly sorted.

The frequency distribution of the skewness values (fig. 4.14 c) indicate that among the pre-monsoon sediments mainly, 57.14% are positively skewed, 17.14% are nearly symmetrical and 14.29% are very positively skewed. On the otherhand, in the post-monsoon sediments 63.33% are positively skewed, 26.67% are very positively skewed, 5% nearly symmetrical, 3.3% very negatively skewed and 1.67% negatively skewed in nature.

From the frequency distribution of kurtosis (fig. 4.14 d), it is found that 65.71% are platykurtic, 5.72% are mesokurtic and 28.57% are very platykurtic, whereas in the post-monsoon (fig. 4.15 d) 51.67% are platykurtic, 45% are very platykurtic, 3.33% are mesokurtic.

From the fig. 4.16, it is observed that the mean value of the sediments are widely varied. The pre-monsoon sediments show a better sorting than the post-monsoon sediments. During pre-monsoon a cluster of sediments falls in the size range of 9-10 phi. In the case of post-monsoon season, sediments are distributed almost equally over a wide range of size classes ranging from the size of a fine sand to clay.

In the scatter plot, fig. 4.17, the variation of grain-size with skewness value is shown. It is found that the skewness value decreases with the increase of phi mean value. The post-monsoon sediments almost show a constant relation of skewness with the phi mean size and also its variation is comparatively lesser than the variation found in the case of pre-monsoon sediments.

From the binary plot, fig. 4.18, it is noted that the value of kurtosis shows a constant relation with phi mean size both during pre-monsoon and post-monsoon season. The sediments are mostly platykurtic in nature.

From the figure 4.19 it can be noted that skewness value shows a decrease with the increase in the sorting characteristics. The clustering of the value is seen between 2 phi and 4.0 phi. Majority of the sediments exhibit a positive skewness whereas beyond this value it moves towards the negative side.

The inter-relationship between graphic skewness with graphic kurtosis fig. 4.20 are highly complicated. There is no definite pattern with the corresponding parameter. There is a general tendency to show a decrease of kurtosis with the increase of skewness.

The CM diagram were drawn for both pre-monsoon and post-monsoon sediments to draw a relationship between the transportation and sedimentation pattern of the lake sediments. (fig. 4.21 a and 4.21 b).

4.3.2. **Discussion**

From the grain-size analysis of the Vembanad lake sediments, it is observed that the sediments are generally of fine sediments with the composition of silty clays or clayey silts and also with an admixture of sand. Only exceptional areas are marked by coarse sediments or medium to coarse sands. Textural characteristics of pre-monsoon and post-monsoon sediments reveal that the pre-monsoon sediments are relatively finer than the post-monsoon sediments. Spatial variation of textural parameters are very significant. Based on the phi mean size, the pre-monsoon sediments can be divided into four zones.

In the estuarine zone extending from the estuarine mouth to the Perumbalam area, where the phi mean size of the sediments varies between 8.8 to 10.55 phi. This is mainly a clayey zone. The existence of very fine sediments may be due to the incursion of sediments from the sea during tidal actions and estuarine circulation process. Moreover, due to the presence of the Cochin harbour channels, the depth of occurrence is high. In addition to this, the dredging operation taking place in the area also give rise to the accumulation of finer sediments.

Northern zone extending from the north of the estuarine mouth to the northernmost part of the Vembanad lake where river Periyar, joins the sea. In this zone, the phi mean size of the sediments varies between 6.8 to 9.8 and the average phi mean size is 8.77. This is also an accumulating zone where most of the sediments are derived from the adjoining sea during its movement through canals and estuarine mouths. The riverine sediments transported through the river Periyar also contribute the finer sediments.

Central zone extending from Perumbalam to Thanneermukkam is a region of coarser sediments where the phi mean size varies between 2.5-9.9. The average phi mean size is 6.48.

Southern zone is chiefly composed of fine sediments of silty clays/clayey silts extending from the southern part of Thanneermukkam to the Alleppey region with a grain size 6.8-9.8 phi. The average phi mean size of the sediment is 8.68. The accumulation of fine sediments in this region is mainly due to the deposition of sediments that are transported and deposited by major rivers like Muvattupuzha, Minachil and Pamba.

The post monsoonal sediments follows a similar trend but they are relatively coarser than the pre-monsoon sediments. The following are the characteristics of the different zones.

1. Estuarine zone which contain fine sediments composed of silty clays and clayey silts. The grain-size varition is between 6.15 to 8.95 ϕ . The average phi mean size is 7.31.

2. North zone extending from the north of estuarine mouth to the northern most part of the lake where it joins the river Periyar. The phi mean size of the sediments vary between 6.85 to 9.8 and the average phi mean size is 7.68.

3. Central zone extending between Perumbalam and Thanneermukkam is a region with comparatively very coarse grained sediments. That is an admixture of sand-silt-clay in quite varying proportions and generally the sand content is very high. In the central part of the lake the sediment size ranges from 2.00 to 4.45 but near the river mouths still finer sediments are distributed which varies from 2.0-5.5. The average phi mean size of the sediments is 4.13.

4. The southern zone from Thanneermukkam to Alleppey region is chiefly composed of coarser grained sediments when compared to the northern zone but finer than the central zone. The phi mean size ranges from 5.12-7.85 and the average grain size is 6.76. But still finer sediments are reported from the river mouth areas.

While comparing the sediments of pre-monsoon and post monsoon, it is found that the pre-monsoon sediments are relatively better sorted than post-monsoon sediments. The very poorly sorted nature of the post-monsoon sediments may be due to the intermixing of riverborne finer sediments brought in suspension towards the monsoonal season. The sorting of the sediments varies widely both during pre-monsoon and post-monsoon seasons. Majority of the sediments are very poorly sorted and the rest of the sediments either poorly sorted or extremely poorly sorted. This very poor sorting of the sediments show the unstable energy conditions and multiple source of the sediments.

Generally the sediments of the lake are positively skewed thereby showing contribution from the river sediments. In sheltered quiet waters and in deeper waters where the bottom sediments are not disturbed by bottom currents or wave base surge, the skewness of the sands are positive (Duane, 1964). In areas of intermittent winnowing actions or fluctuating energy conditions, the bottom currents show local variation in the sign of skewness. Though there is a general tendency of decreasing skewness with the increase of phi mean, it changes due to the various factors which controls the estuarine sedimentation. Usually, it is suggested that unimodal sediments normally have a symmetrical distribution. Pure medium to fine sand mode samples are mostly unskewed in nature. However, the presence of secondary coarser sand or gravel mode makes the distribution negative, whereas secondary silt or clay mode makes it positive.

Folk and Ward (1957) and Cadigan (1961) have expressed that, if the central part of grain-size distribution is relatively better sorted than that of average in the tails, the distribution will be positively skewed and leptokurtic. The converse is true for platykurtic distribution. For the sediments in which the degree of sorting both in the central part of the distribution and at the tails is of the same order are mesokurtic. The lacustrine sediments are mainly platykurtic in nature. As explained by Folk and Ward (1957), it can be stated that the addition of very minor proportion of another mode to a unimodal sediment worsens the sorting in the tails. The sorting in the central part remains good and thus make the deposit leptokurtic. Any further addition of the new mode results in a strongly bimodal deposit, and if the two modes are subequal then the sample becomes platykurtic. The intermixing of silt and clay particles may give rise to the presence of subequal modes of coarse and fine particles in most of the samples resulting in platykurtic sediments.

The correlation between graphic standard deviation and graphic skewness shows that there is a tendency for an increase in skewness with the decrease in the sorting. It is also noted that relatively more negatively skewed nature of the pre-monsoon sediments may be due to its finer size and poorer sorting.

The CM pattern drawn for the pre-monsoon and post-monsoon sediments (fig. 4.21 a and 4.21 b) show that the segment PM is missing during the pre-monsoon and post-monsoon seasons. In the case of pre-monsoon sediments, it contains 'QR' and 'RS' segments. Cluster of very fine sediments are noted due to its constant mean size and percentile values. In the pre-monsoon season, majority of the sediments are grouped below the coarsest percentile of 31 micron and the median less than 3 micron. The total sediments in uniform suspension and graded suspension are less. The plot drawn for post-monsoon sediments indicates that the sediments are transported mostly by uniform suspension and graded suspension. The maximum size of the grains transported is 650 micron in size during pre-monsoon and it is 420 micron during post-monsoon season.

4.4. TEXTURAL STUDIES OF THE MUD BANK SEDIMENTS

4.4.1. Results

The 'Mud Bank', an unique phenomenon that appear close to the shore along the Kerala coast, at certain locations during the south-west monsoon season. The textural characteristics of the mud bank sediments were discussed by number of earlier workers, Dora et al., (1968), Kurup (1977); Mallik and Ramachandran (1984); Nair (1976) and Purandara and Dora (1987).

The grain-size analysis show that the dominant textural class is clays and silty clays in the mud bank sediments, (fig. 4.22 a and 4.22 b) whereas the shelf sediments are composed of silty clays and clayey silts. Further investigation on the monthly variation of clay content in the mud bank region reveal that the clay percentage in the mud bank area increases from May to August and there is a considerable decrease in its content from September to December (fig. 4.23). Textural parameters of the Narakkal and Purakkad mud bank sediments are shown in the table 4.3 and 4.4 respectively.

The size-frequency diagram, (fig. 4.24) drawn for Narakkal mud bank show that the sediment size ranges from coarse silt to very fine clays (less than 1 micron). The maximum concentration is observed between 8 to 11 phi which covers 83.75% in the Narakkal area and 82.36% in the Purakkad region. Rest of the sediments are distributed in the coarser size grades.

The distribution of standard deviation (fig. 4.24 b) show that the mud bank sediments are very poorly sorted in nature.

The frequency distribution of skewness values (fig. 4.24 c) indicate that the majority of the mud bank sediments are negatively skewed to very negatively skewed in nature. In the Narakkal mud bank, 67% moves towards the negative side and the rest in the positive direction whereas in the Purakkad mud bank around 69% shows a negative trend.

The frequency distribution diagram (fig. 4.24 d) of kurtosis shows that, majority of the sediments are platykurtic in nature.

The binary plots were drawn between different grain-size parameters of the mud bank and adjoining shelf sediments.

From the plot, (fig. 4.25), it can be noticed that as the size decreases the sediments become better sorted. Even though both mud bank and shelf sediments are very poorly sorted in nature, mud bank sediments are found to be comparatively better sorted than the shelf sediments. Sorting increases from May to August and it shows a declining trend after September.

The plot phi meansize versus skewness (fig. 4.26), shows a clear cut differentiation of mud bank sediments from that of the shelf sediments. Majority of the sediments from the mud bank region are negatively skewed and only very few of them vary between negative and a very slight positive skewness character. The shelf sediments are generally positively skewed. Out of the 20 shelf sediments analysed for textural parameters, 7 are very positively skewed, 4 positively skewed, 6 nearly symmetrical and only three of them are negatively skewed. Similar results are obtained for Purakkad mud Bank sediments.

There is no distinct relationship between phi meansize and kurtosis(fig. 4.27). In general they show an increase in the value of kurtosis with the decrease in phi meansize. The shelf sediments are very platykurtic to very leptokurtic.

The mud bank sediments are more negatively skewed and the shelf sediments are positively skewed (fig. 4.28). The general variation of the sediments show that sorting decreases with the decrease of skewness value.

There is no definite relationship between skewness and kurtosis (fig. 4.29). Majority of the sediments are very platykurtic to mesokurtic in nature. However, few of the mud bank sediments and shelf sediments varies widely between very platykurtic and very leptokurtic ranges. The positively skewed sediments mostly are platykurtic to mesokurtic in their distribution.

The studies on mud bank sediments carried out during 1986, for the Purakkad-Alleppey region also exhibit similar sort of characteristics (fig. 4.30 to 4.33). When compared with the mud bank sediments of the previous year, the sediments collected during 1986, from the Narakkal-Saudi area are found to be comparatively very coarser in nature (table 4.5). The wave activity increases and the suspended sediment concentration decreases considerably during this year.

4.4.2. Discussion

The 'mud banks' are calm, turbid water zone with heavy load of suspended sediments which dampen the waves and protects portions of the beach from erosion (Kurup, 1977).

From the results it can be seen that the phi mean size of the sediments is quite high i.e. the sediments are very fine in nature and the sediments with a phi mean size lesser than 1 micron are more than 50%. Suspended sediment concentration varies between 100 mg/l and 900 mg/l in the surface layers. The concentration in the bottom most layer ranges from 120 mg/l to 3600 mg/l, which indicate the very fine size of the sediments. It can be presumed that the deposits of very fine clayey sediments during the South-West monsoon season may be brought by various rivers of central Kerala and discharge through the Vembanad estuary under varied levels of competency. During the process a thorough mixing of the well-sorted and poorly sorted sediments takes place which lead to the formation of a bimodal to polymodal deposit. The negative skewness is observed in sands of the littoral, beach and tidal inlet environments. In areas of intermittent winnowing action or fluctuating energy conditions, the bottom sediments show local variation in the sign of skewness (Duane, 1964). The wide variation found in the textural parameters may be due to the addition of a subordinate silt-clay mode to the original sediment.

In the mud banks, very fine clayey sediments are accumulated during the South-West monsoon season. The suspended sediment concentration in the Alleppy-Purakkad area is relatively lower than the Narakkal mud bank region. The value ranges from 62 mg/l to 800 mg/l in the surface layer, 65-925 mg/l in the middle layer and 168 to 1475 mg/l in the bottom layers. The suspended sediment concentration increases from May to July-August months and decrease during September to December. This may be due to the differential settling of suspended matter due to increased salinity (Kurup, 1977). Decrease of sediment load may also be associated with the offset of monsoon, which causes a large scale decrease in wave activity along the coastal region.

From the scatter plots drawn for the mud bank sediments, it can be inferred that the mud bank sediments and shelf sediments are very poorly sorted. The mud bank sediments are comparatively better sorted than the shelf sediments. The poorer sorting of the shelf sediments may be due to the variable current velocities and turbulence during deposition while relatively better sorting of the mud banks shows smooth stable currents.

The mud bank sediments are found to be coarser in the Narakkal region during the year 1986, when compared to the previous year mud bank sediments. The South-West monsoon may be weak in the year 1986 which could be one of the cause for triggering the formation of mud banks. The following agents may be responsible for this unique phenomenon which was also suggested by Mallik et. al. (1984).

1. Rainfall: The mean annual rainfall for the Kerala State as a whole is nearly 3000 mm, which is about 3 times the average rainfall of India. So the rainfall initiates the process of erosion and transportation with high competency through the river basins.

2. Salinity: The studies by various authors, Damodaran et. al. (1966), Kurup (1977) and Purandara et al. (1986) reported high reduction of salinity in the mud bank region during the South-West monsoon. This decrease in surface salinity may be capable of keeping the finer muds in suspension.

3. Wind: Seasonal reversal of the wind circulation is of special interest of study over Kerala. During December and January, generalised direction of wind is from north-east. Between March and May, the major direction of wind changes from NE to NW and then to West. By June the wind strength increases and blow from directions between south west and west. Month of August marks a decreased wind speed with a change in the direction of the wind. During North-East monsoon season (October-November), the direction of wind is between north-west and ENE.

4. Rivers and Lakes: During the South-West monsoon, the overflow-

ing rivers of central Kerala are the major contributors of the sediments through the lake and estuary. These over loaded sediments brought by rivers as suspension and bed load may be filtered through the estuarine mouth and will be transported to the nearshore zone. The transportation of sediments through such a long distance will bring very finer sediments and may remain in suspension due to the lower salinity. Due to high concentration of suspended sediments, waves are unable to reach the coast and are dampened completely. This process is very clear from the results discussed above that the accumulation of sediments increases from May to August and again it decreases. Furthermore, it explains that the accumulation of sediments in the low energy environment as the waves cannot reach the shore. The transportation of sediments through various environments are depicted in the figure 4.34 and 4.35. This clearly indicates the gradual decrease of grain-size when transported to the sea through river basin and estuary.

From the above discussion, it can be surmised that the formation of mud banks are associated with the said processes which are peculiar in their form along the Kerala coast. Besides, this wave refraction as suggested by Kurup (1977) and the reversal of current may favour the localised formation of mud banks and also the movement of mud banks from palce to place.

4.5. TEXTURAL CHARACTERISTICS OF THE BEACH SANDS

Beach is one of the most dynamic environments. The changes to which beaches are subjected may be seasonal or longer in duration. The changes may be as short as a single tidal cycle or even occur from one crashing wave to the next.

There are no real geographically imposed limits on beach development. A beach will form virtually any place where the land and sea meet, where sediment is available, and where a site is available for sediment accumulation. Beaches are by far the most widely distributed of any of the coastal sedimentary environments.

It is not possible to provide practical size limits for beaches. A beach is by its very nature, long and narrow feature in its usual development, with its length upto several hundred times its width. The actual shape and orientation of the beach itself is dependent on a number of variables including the direction of wave energy approach, littoral drift, the material comprising the beach, and the overall shape and composition of the coast.

In the beaches, different textural parameters reflect the mode and energy of the transporting medium. Friedman (1961) explained that the wave which deposits sediments on beaches have a greater competency than the wind which transports dune sands.

Unnikrishnan (1987) studied the textural parameters of south Kerala beach sands and found similarities with the beach sands studied elsewhere (Friedman, 1961; Mason and Folk, 1958; Sestini, 1967). Shepard and Young (1961) compared the textural characters of beaches with that of the dune sands. Naidu (1968) related the differences of grain-size parameters to the hydrodynamic conditions of the mainland, beach, dunes and offshore barrier sands of the Godavari delta. The textural characteristics of north Kerala coast are explained by Samsuddin (1986).

4.5.1. Results

Presently, the studies were conducted during pre-monsoon and post-monsoon seasons and its textural variations are depicted in the form of scatter plots and the results are presented in the table 4.6.

In the scatter plot, phi meansize versus standard deviation (fig. 4.36 and 4.37), the variations of grain-size parameters from pre-monsoon season to post-monsoon season are inferred. The sediments of different sub-environments behave differently. There is no significant change in the backshore and berm sediments of the beach during pre-monsoon and post-monsoon seasons. The foreshore sediments are relatively finer in size and better sorted in nature whereas the sediments of the low water mark show wide variations in their nature and are relatively poorly sorted. It is further noted that in the pre-monsoon season, the low water mark sediments are more poorly sorted than the post-monsoon sediments.

The skewness value is closely dependent upon the phi mean size, (fig. 4.38 and 4.39). The post-monsoon sediments are negatively skewed whereas the pre-monsoon sediments show a symmetrical distribution and positive skewness. Interestingly, the foreshore sediments are more positively skewed than the sediments of other environments. The region between the negative and positive skewness characters are known as flux (Duane, 1964).

The phi mean size and kurtosis does not show any clear cut relationship (fig. 4.40 and 4.41). However, it is found that the kurtosis varies widely between very leptokurtic to platykurtic. There is no significant change between the two parameters during different seasons.

In the plot between standard deviation and skewness (fig. 4.42 and 4.43), pre-monsoon and post-monsoon sediments show vertical distribution and are mostly clustered above 0.00. In the pre-monsoon sediments as the skewness value decreases the standard deviation increases or in other words sorting decreases. This is more pronounced in the case of post-monsoon sediments.

There is no definite pattern or relationship to each other in the four beach sub-environments, however, it can be observed that the sorting becomes poor, when the kurtosis changes from leptokurtic to platykurtic. In the fig. 4.44 and 4.45, the relationship between the two parameters are depicted. It clearly indicates that there are no major changes in the distribution pattern during pre and post-monsoon seasons.

In the fig. 4.46, the pre-monsoon sediments show an almost vertical distribution in a narrow zone of skewness (skewness value 0 to 0.5ϕ). The kurtosis value exhibits wide fluctuation during pre-monsoon season. In the post-monsoon sediments fig. 4.47, it shows a gradual change from positive to negative skewness and there is a decline in the kurtosis value with the increase of skewness.

4.5.2. **Discussion**

Various authors discussed about the grain-size parameters of the south Kerala beach sands. Purandara et al (1987); Rao (1963) and Unnikrishnan (1987); have studied the south Kerala beach sands in deatil. Based on present results, an attempt is made to explain various physical factors that control the sediment transport and deposition.

The mean grain-size of beach sands is a function of the incident wave energy and the nature of available sand. Thus the mean size variation can be related to changing energy levels and local sand sources or a combination of both. The average grain-size of all four sub environments of beaches show that the material comprises predominantly of medium sand with a range from coarse to very fine sand. According to Reineck and Singh (1980), coarser sediments are present in high energy environments and finer sediments in the low energy environment. It is suggested that there are terrigenous deposits which are derived from the Western Ghat region through west flowing rivers in low energy environments. Grain-size variation is a function of wave energy and it is in a downdrift direction. Finkelstein (1982) describing the crenulate bay beaches of Alaska noted that the grain-size is maximum at the centre of beaches and decreases towards the shadow zone and tangential end, because the wave refraction diagrams and the grain size data indicate a high wave energy at the centre of beaches. According to Inman (1952) and Krumbein, et al. (1934) the largest sediment particles at any beach are concentrated at the plunge point of breaking waves with a decreasing grain size both towards sea shore, across the surf and swash zone.

It is observed that beach sands are relatively finer during May and also immediately after the offset of monsoon. This finer size of the sediments may be due to the deposition of sediments by waves and currents along the beaches at certain places.

Most of the beach sands are moderately sorted. The range of standard deviation is from well sorted to poorly sorted. Generally, the better sorting of the sediments could be due to the constant action of waves and currents. Finkelstein (1982) has related the sorting of sediments to beach slope and constructive wave activity. The better sorting in beaches was due to the continued exposure of beaches to waves for longer duration.

The skewness value of the pre and post-monsoon sediments varies widely. However, majority of the sands are nearly symmetrical in nature. In general, some of the beach sands are positively skewed. The positive skewness in beach sands as in the case of river sands may be because of the infiltration of fines. The occurrence of more negatively skewed sediment during the month of September may be because of the accumulation of finer sediments due to the formation of mud banks.

The beach sands of central Kerala are mesokurtic to platykurtic in distribution, though the value range from very platykurtic to very leptokurtic population.

Generally, the backshore and berm are not affected during pre-monsoon and post-monsoon seasons. As the swell waves transports and deposit sands of all grades, the beach sediment become poorly sorted in both the seasons. Because of its lessened carrying capacity, waves deposit majority of the fine sediments in the beach thereby imparting poorer sorting to the sediments.

CHAPTER - V

MINERALOGY

5.1. INTRODUCTION

One of the prime goals of studying the quantitative mineralogy of sediment is to evaluate the relative importance of the source of sediments. The clastic sediments are the insoluble residues left after the chemical breakdown and disintegration of pre-existing rocks (Pettijohn, 1957). Relief and climate are the two main factors which affect the maturity of minerals and thereby the composition of the sedimentary deposits.

The sources of the present cover of the seabed, the degree and mechanisms of reworking and indications of net transport within the sedimentary environment (both past and present) can be understood from the distribution pattern of heavy minerals. Research into the factors generating heavy mineral concentrations has been stimulated by placer exploration. It has long been appreciated that mineral grains are sorted according to size, shape and density. However, the local hydraulic conditions that induce such sediment sorting is not well understood. Rubey (1933) was among the first to describe the importance of particle density for heavy mineral accumulation and invoked fall velocity as the segregating mechanism. He employed the term hydraulic equivalence, and used the concept to explain the common association of small high-density with larger, low-density mineral grains. Rittenhouse (1943) and McIntyre (1959) have also used hydraulic equivalence in their studies of heavy mineral deposits.

In the present context, heavy and light minerals of the various environments are studied in order to understand the source of the nearshore sediments. For this purpose heavy and light mineral studies of the rivers, viz., Pamba, Manimala, Minachil, Muvattupuzha and Periyar, Vembanad lake and nearshore regions were carried out.

Clay is essentially a weathering product of the physical disintegration and chemical decomposition of the igneous rocks and of some types of metamorphic rocks. Keller (1970) has pointed out that clay minerals are the reactive responses of geological materials to energies characterising certain environments with time. Moreover, the composition and distribution of clay minerals have been used as indicators of sediment dispersal in the marine environment (Biscaye, 1964; Griffin et al, 1968). Semiquantified XRD results are obtained for different environments in order to get an insight into the source and dispersal of the sediments.

5.2. RESULTS

5.2.1. **Mineralogical Studies of the River Sediments**

Heavy and light mineral studies of the Pamba, Manimala, Minachil, Muvattupuzha and Periyar rivers show that there are clear evidences of size dependence on the segregation of heavy/light minerals. For the convenience of description of the three size grades for which the heavy mineral separation were carried viz. 500 to 250 micron,

+250 to 125 micron and 125 to 63 micron are designated as coarse, medium and fine fractions. The percentage of heavy minerals are less in the coarse and fine fraction when compared to the medium fraction. The highest percentage of heavy minerals are noted in the Periyar in all the three size classes of coarse, medium and fine. The lowest percentage of heavy minerals are noticed in the Minachil ar sediments in the coarse and medium fractions. But in the fine size grade, the Muvattupuzha sediments show minimum concentration of heavy minerals. In general, all the river sediments contain maximum concentration of heavy minerals in medium fraction.

Among the heavy minerals the maximum percentage is noted in the coarse, medium and fine fractions of the Periyar sediments (the values are 47.91, 55.9 and 37.97). The minimum percentage of 1.38 and 14.11 are noted in the coarse and medium fractions of Minachil and 11.23% of heavy minerals are noted in the fine fraction of Muvattupuzha. A comparative study have shown that Periyar and Pamba are having a higher proportion of heavy minerals compared to the other three rivers. The individual heavy mineral percentages present in the river sediments are shown in Table 5.1.

5.2.1.1. Heavy Mineral Composition

The average percentage of heavy minerals are represented in the figures (5.1 to 5.5). The major minerals present in the river sands are opaques, hornblende, hypersthene, zircon, sillimanite, mica garnet, augite/diopside, rutile and monazite.

In all the three fractions, the dominant mineral is opaque. Opaques in the coarse fraction show a decrease from Periyar towards Minachil ar and again it increases towards further south. Hornblende is the dominant mineral next to opaques in the Periyar and Muvattupuzha but in the Minachil, Manimala and Pamba, the percentage of hypersthene is more than that of hornblende, and hypersthene is comparatively very less in the Periyar. Minerals like mica and garnets are distributed in all the rivers. The maximum percentage of mica is noted in the Minachil sediments and garnets in the Manimala. Mica follows an increasing trend towards Minachil, from where it decreases further south. Sillimanite shows an almost even distribution in all the rivers under study. Zircon is very less in Periyar and Muvattupuzha and it is predominantly seen in the Manimala and Pamba rivers. Monazite is distributed considerably in the coarse fraction of Pamba and Manimala.

In the medium size, the opaques are more dominant and it is maximum in Periyar (average 70.18%) and decrease in their abundance in Muvattupuzha, Minachil and Manimala. Again there is slight increase in the opaque percent in Pamba (average 53.68%). Hornblende is not found in Periyar, whereas it is significant in other rivers. The percentage of hypersthene is maximum in Minachil and minimum in Periyar. Sillimanite and garnet follows a similar trend of distribution as in the case of coarse fraction but with a lesser percentage of occurrence. The mineral zircon is present in all the rivers in significant quantity. The maximum percentage is noted in the Manimala and the minimum percentage is recorded from Minachil. Monazite is also distributed in all rivers and the maximum percentage distribution is noticed in the Manimala and minimum in Minachil. The distribution of mica is uneven and the maximum noted is in the Muvattupuzha and minimum in Manimala.

In the finer fraction, the percentage of opaques decrease and in this size grade Minachil shows maximum percentage and Periyar shows minimum. Hornblende and hypersthene bears a uniform distribution. Hornblende is found maximum in Periyar and minimum in Pamba. A significant increase in the percentage of zircon is noted in all the rivers and the maximum percentage is recorded in Muvattupuzha and minimum in Pamba. Monazite and Sillmanite show even distribution of garnets because garnets are less abundant in the finer fractions. Rutiles are present in considerable amounts in Periyar, Muvattupuzha and Pamba. It is found to be absent in the Minachil and Manimala. The minerals like Hornblende and garnets are found in different forms and colours. Apart from the majority of colourless garnets and pink garnets, the rare varieties of violet and green are also present in very few samples. The opaque minerals are mostly ilmenite. The coloured hornblendes are the dominant ones.

5.2.1.2. Heavy Mineral Variations from North to South

The variation of different mineral grains in the different size grades are observed and it reveals the trend of variation of all the minerals from north to south. The mineral garnet shows an increase towards south, but it shows a slight decrease in Pamba. The trend is uniform in all the three size grades. However, in the Manimala, it is absent in the finer fraction and it again appears in Pamba. Larger the size of the minerals such as zircon, sillimanite and monazite, the lesser the percentage and the opposite is true in the case of mica.

Heavy minerals like kyanite, apatite, tourmaline, staurolite, chlorite and epidote are seen in minor quantities and they almost show uniform distribution.

5.2.1.3. Light Mineral Studies

The average percentages of light minerals which shows the count of quartz, potash flespar and sodalime felspar and also the ratios between quartz/total felspar and potash felspar/sadalime felspar are presented in the table 5.2.

In the figure 5.6, the variation of light minerals in the different size grades are represented for various rivers. Quartz is the most dominant mineral among all the light minerals. The average percentage of quartz is 91.21, potash felspar, 6.01 and sodalime felspars, 2.78. The ratios of various light minerals denote the relative stabilities of the minerals. It is found that quartz-felspar ratio is maximum in the Muvattupuzha and minimum in Manimala. Potash felspar/ sodalime felspar show a variation with a general ups and downs. The maximum value is noted in Muvattupuzha and minimum in the Minachil.

5.2.2. **Mineralogical Studies of the Vembanad Lake Sediments**

The estuary which acts as a sediment reservoir, plays an important role in elucidating many processes occurring within the lake, including borderland and groundwater drainage basin. In order to know the sources of sediments, it is useful to distinguish (i) the minerals brought into the lake by surface water (streams and overland flow), shore erosion and aeolian processes (allogenic fraction) (ii) the minerals originating from processes occurring within the water column (endogenic fraction); (iii) the mineral resulting from processes that occur within the sediments once deposited (authigenic fraction). Generally in the detrital fractions, the mineralogy of each grain is rather independent of the sorrounding grains as the source-area is mineralogically complex and weathering conditions may vary vividly in geographically adjacent areas (Blatt, 1967). Therefore, it is important to study the constituents of the sediments which will aid in deciphering the depositional history of a sedimentary basin.

In the Vembanad lake, the distribution pattern of heavy mineral is quite varied. The heavy mineral content shows a different trend in concentration. The northern part of the Vembanad lake contains a high percentage of sillimanite, opaques and hornblende and it is almost comparable with the values of the Periyar which also shows a high percentage of opaques and hornblende. As we proceed southwards of the estuarine region it shows very high percentage of sillimanite. On the contrary, the percentage of hornblende and pyroxenes are comparatively very less whereas in the deeper parts it is negligible. In the central and southern region of the lake, mineral assemblages show resemblence to that of river sediments. The average percentage of heavy minerals in different zones of the Vembanad Lake are presented in the table 5.3. The heavy/light mineral percentage is found to be 39.13 : 60.87 in the 250-125 micron fraction.

5.2.3. Mineral Analysis of Beach Sands

The beach sands of Kerala are well known for their economic importance especially the strategic minerals like ilmenite, rutile, zircon, monazite etc. It may be proper if we give a brief account of the provenance of these beach sands in the present context. From the studies conducted for both pre-monsoon and post-monsoon sediments, it is observed that there is a wide variation in mineralogy which could be due to the multiple source of sediments. The heavy mineral separation was carried out only for 250-125 micron fraction.

5.2.3.1. Heavy - Light Mineral Ratios

The heavy : light mineral ratio of pre-monsoon sediments are 19.25 : 80.75. During the post-monsoon season, the ratio has increased to 43 : 57. This increase in heavy mineral concentration may be due to the availability of monsoonal sediments brought by the major rivers and also from the offshore supply of waves and currents. In the study area, Puthuvypu, Malipuram, Narakkal and Beach Road show a comparatively high percentage of heavy minerals. Whereas at Taikal, Fort-Cochin, Alleppey, Kannamaly and Chellanam areas, light minerals are predominant.

5.2.3.2. Heavy Mineral Composition

The beach sands from Narakkal to Purakkad are composed of hornblende, opaques, hypersthene, sillimanite, zircon, kyanite, rutile, mica, garnet and monazite. The average percentage occurrences during pre-monsoon and post-monsoon are given in table 5.4a and 5.4b. Hornblende is the most dominant mineral during both pre-monsoon and post-monsoon seasons, however, the percentage of hornblende increases during the post-monsoon season. The frequency variation of mineral percentages in different beaches show that hornblende varies from 37.95 to 59.55 during pre-monsoon and 35.47 to 61.44 during post-monsoon. In general, the pre-monsoon sediments show a gradual decrease in the percentage of hornblende from Narakkal to Purakkad, except at Kannamaly and Taikal where it shows considerable increase in the distribution. The percentage of opaques are higher during pre-monsoon and shows an increase in percentage from Narakkal to Beach Road and then it decreases at Kannamaly. Thereafter, it follows an intermittent highs and lows. In the post-monsoon sediments, it is found to be unevenly distributed and the maximum percentage of 18.26 is noted in Puthuvypu with minimum of 6.52 at Kannamaly. The mineral hypersthene increases during post-monsoon compared to the pre-monsoon season. The minerals like sillimanite, kyanite, zircon, rutile and monazite does not show any significant change during the pre-monsoon and post-monsoon seasons. There is a considerable decrease in the percentage of mica from pre-monsoon to post-monsoon season. During the pre-monsoon season, the percentage of mica mainly biotite varied between 4.96

at Taikal, to 14.55 at Kannamaly and during post-monsoon season it ranges from 0.22, at Beach-Road to 4.31 at Chellanam. Notable quantities of garnets are recorded both during pre-monsoon and post-monsoon season. The percentage of garnet varies from 3.2, at Alleppey, to 7.58 at Chellanam during pre-monsoon season. But during post-monsoon season the maximum percentage of 8.65 is observed at Purakkad and minimum of 1.8 at Alleppey.

5.2.3.3. Light Minerals

The most dominant light mineral is quartz with an average of 98.48% during pre-monsoon and 89.84% during post-monsoon seasons. Sodalime felspar is the least occurring one, both during pre and post-monsoon seasons. There is a significant change in the percentage of quartz from pre-monsoon to post-monsoon. It decreases, from pre to post-monsoon in converse to the percentages of potash felspar and sodalime felspars. Table 5.5 a and 5.5 b show the average distribution of light minerals at various locations along the coast during pre-monsoon and post-monsoon seasons.

5.2.4. Heavy Mineral Distribution in the Innershelf Sediments

The heavy minerals present in the coarse fraction of the innershelf sediments are chiefly composed of opaques, hornblende, hypersthene, sillimanite, mica, garnets, tourmaline, zircon, monazite and rutile. Figure 5.7 shows the average heavy mineral percentage in the innershelf sediments. The heavy-light mineral ratio is found to be 14.85 : 85.15.

5.2.5. Clay Mineralogy

Till forth we have seen the distribution of heavy minerals in the major rivers of central Kerala which are the main contributors to the vembanad lake and to the nearshore zone. A detailed study of clay minerals are presented here because the mud banks are chiefly composed of clays and silty clays. In order to understand the provenance of mud bank sediments, it is quite essential to study the clay minerals of the rivers, lake and the mud banks.

The results obtained from the semi-quantification of the XRD indicates an abundance of kaolinite and montmorillonite followed by illite and gibbsite. The quantitative summary of the clay mineral distribution in the different environments are dealt below.

5.2.5.1. Rivers

XRD analysis were carried out for Pamba, Minachil, Muvattupuzha and Periyar. In general, the river sediments have an high percentage of kaolinite over montmorillonite. A higher percentage of kaolinite is observed in the Pamba followed by Periyar, Muvattupuzha and Minachil. Clay mineral percentage is given in table 5.6. The highest percentage of montmorillonite is noted in the Minachil (30.22%) and minimum of 18.55% is found in the Periyar. Illite is found maximum (7.31%) in Periyar and minimum in Pamba (2.20%). Gibbsite is maximum in Muvattupuzha (10.08%) and minimum (3.77%) in the Minachil.

5.2.5.2. Vembanad Lake

The average percent distribution of the four principal clay mineral entities in the Vembanad lake surficial sediments are shown in table 5.6. Kaolinite being the dominant clay mineral in the lake showing a range of 50.22% to 67.12% with an average value of 56.29%. This is followed by montmorillonite ranging between 18.49 and 38.52% (average, 32.72%). Variation in the illite percent is from 6.41 to 9.60 and gibbsite from 1.6 to 5.48. The average content of illite and gibbsite amounts to 7.99 and 2.98% respectively.

5.2.5.3. Mud Bank

5.2.5.3 a. Surficial Sediments: Sediment samples collected during different months have been subjected to the analysis. Temporal variations have been observed in their clay mineral content. Kaolinite being the dominant clay mineral behave in contrast to the montmorillonite content. It shows variation from 42.75% to 62.4% with a mean value of 51.21%. Montmorillonite having an average value of 36.71% deviates between 25.55 and 43.67%. In these sediments, illite is the next dominant clay mineral over gibbsite (average value 9.57 and 2.5% respectively). The maximum percentage of illite observed is 12.88 and the minimum 6.75. Gibbsite varies between 0.7 and 4.13%.

5.2.5.3 b. Sediment from the Seaward Side of the Mud Bank: Even in the seaward edge of the mud bank region, kaolinite continues to dominate over the montmorillonite and both show an average percentage of 49.59 and 35.84 respectively. But an increase in the amount of illite to 12.83% and a decrease in the gibbsite content to 1.76% are also observed.

5.2.5.3 c. Suspended Sediments from Mud Bank: This is the first data set on the suspended sediment clay mineralogy. It is most significant to note that unlike any other environments discussed, hitherto, the suspended sediment clay mineralogy shows presumably an interesting picture with a high percentage of montmorillonite over kaolinite. Montomorillonite content is 57.48% followed by kaolinite (30.96%). Illite and gibbsite percentages are 10.42 and 1.14 respectively.

5.2.5.4. Electron Micrographic Studies

5.2.5.4 a. Kaolinite: Electron micrographs of well crystallined kaolinite show well formed six sided flakes, frequently with a prominent elongation in one direction. Certain of the edges of the particles are beveled instead of being at right angles to the flake surface. Occassionally the particles appear to be twinned. In poorly crystallined kaolinite, the particles show less distinct six sided flakes. The edges of the flakes are somewhat ragged and irregular.

5.2.5.4 b. Montmorillonites: Electron micrographs of montmorillonite show irregular fluffy masses of extremely small particles. In some cases, the larger masses appear to be stackings of flake shapped units without regular outlines.

5.2.5.4 c. Illites: Illites generally show small poorly defined flakes, commonly grouped together in irregular aggregates. Some of the flakes have a distinct hexgonal outline. Some illites show no evidence of flakes with hexagonal outlines. Such flakes have irregular, but well defined outlines and are characterised by a uniform thickness. The electron micrographs of illites resemble to those of some montmorillonites. The particles of illite are, however, larger and thicker and have better defined edges. Lath shaped illites are also common. The hexagonal flakes associated with the laths are probably kaolinites (Electron micrographs are affixed in plate 1 to plate 3).

5.3. DISCUSSION

5.3.1. Provenance Studies of the Heavy Mineral Assemblages

Heavy mineral studies have been carried out in order to decipher the provenance of coastal sediments. The earlier studies on heavy minerals were carried out by Basu, (1975, 1977); Basu and Suttern, (1975); Blatt, (1967); Briggs et al., (1962); Briggs, (1965); Carver, (1971); Curt Peterson et al. (1982); Dora and Borreswara Rao, 1969; Duyverman (1981); Edelman, (1933); Folk, 1974; Force, (1980); Jones and Davies (1979); Kidwai et al (1981); King (1972); Leupke, (1980); Mallik, (1976, 1978, 1987); Shepard (1973); Shepard and Young (1961); Siddique and Rajamanickam (1979) and Siddique et al. (1979).

Several factors operate to produce progressive changes in the mineral composition of sediments, in addition to changes resulting from the introduction of new material. These factors are (1) differential abrasion and weathering during transport and (2) progressive sorting on the basis of specific gravity, shape and size.

It has been commonly supposed that progressive compositional changes in both sand and gravel would occur due to unequal resistance of several components of these materials to abrasion. Such selective abrasion would result in progressive and systematic elimination of the softer and more cleavable materials and complimentary enrichment of the harder and more durable components.

The felspars, pyroxenes and amphiboles, are classified as minerals which are particularly susceptible to abrasive action and alteration than most other common detrital minerals. Quartz, rutile, zircon, tourmaline and others are on the other hand, more resistant to abrasion as well as to the ordinary action of chemical weathering. It is a common observation that homogeneous fractions can be extracted from complex mineral mixtures by various sorting processes. Progressive sorting action may also produce changes in mineral composition along the direction of transport. Such sorting may be on the basis of specific gravity, shape or size. It can be noted that a sediment transported dominantly by suspension should show progressive increase, in the direction of travel, in the amount of flaky or flat minerals such as mica. If the particles are moved dominantly by rolling, those possessing a high degree of spherecity will outrun the others. Sediment from a given source area, as it moves out and away from the source, becomes diluted by materials from other areas or places. The progressive dilution of a given constituent, might be mistaken as an evidence for reduction by abrasion or the result of selective weathering.

In the case of river sediments, the heavy and light minerals are contributed from different sources through the distributaries of the rivers. This process causes considerable variation in the relative grain-size. It is presumed that the relative size difference in the predominant constituents of the heavy and light minerals and the possible dearth of heavy minerals in the finest sand size could be an important result of these processes.

Most of the central Kerala rivers show very high percentage of heavy minerals in the size grade of medium fraction and it is slightly less in the finer fraction and is least in the coarse fraction. The decrease of heavy minerals in the downstream direction may be attributed to the extremely finer size of the sediments. Generally there is a decrease in the opaques and garnets in the downstream sediments (finer fraction) and an overall increase in the amphiboles, pyroxenes, sillimanites and epidotes may be due to the decrease in the competency of the river. The opaques and other denser minerals tend to lag behind the relatively lighter heavy minerals like amphiboles, pyroxenes and sillimanites on the upstream side. This results in a continuous downstream enrichment of the heavy minerals with relatively lower specific gravity.

Heavy mineral studies of the Vembanad lake shows that the sillimanite is the most dominant mineral followed by opaques, hornblende and hypersthene along with other minerals such as zircon, monazite, tourmaline, garnet, mica (mainly biotite) etc. (figure 5.8). Relatively higher amount of hornblende, hypersthene and sillimanite are distributed in the estuarine region of the lake with less amount of opaques, but they are more in the river mouths. This clearly indicates that opaques being the denser minerals, remain mostly at the site of deposition, whereas less denser minerals are transported further to the estuarine mouth and then to offshore. Rubey (1933) stated that grains of different densities if deposited together should have the same velocities or the denser minerals smaller by an amount predictable on the basis of settling velocity equation. It is observed that the concentration of mica (biotite) is more in the eastern part of the lake, near the river joining points and it is decreasing towards the central and western part. This shows that eastern part of the lake is a low energy zone beyond which the transportation is meagre as evidenced from the distribution pattern of biotite which is considered by earlier workers as an indicator of the current direction. It is noted that the mineral rutile is distributed significantly in the Vembanad lake. Rutile could be from the rivers and/or from the nearshore zone carried by tidal currents. Darby (1984), observed that estuaries can receive sand from both the river and offshore as well as from older coastal deposits outcroping along the estuary. The relative abundance of sillimanite, hornblende and pyroxenes in the coarse fraction of the Vembanad lake could be due to selective abrasion of relatively unstable minerals. Hand (1964) and White and Williams (1967) observed a non-hydraulic equilibrium in modern sands caused due to selective sorting of the grains.

Studies conducted by Mallik et al (1987), Unnikrishnan (1987) etc. noticed a significant proportion of opaques and zircon in the sediments of Peiryar. The adjoining beaches of Periyar river mouth also showed considerable amount of opaques. The present study shows relatively high amount of opaques, hornblende and sillimanite with considerable amount of hypersthene and mica. The concentration of various heavy mineral may be attributed to the differential settling of the heavy minerals due to their variable physical properties (Komar and Wang, 1984; Pettijohn, 1957; Sallenger, 1979).

When the fluvially derived sediments enter the nearshore zone, the denser heavy minerals like opaques and zircons will settle quickly due to the reduction in the fluid velocity as a result of the interaction of marine and continental processes. The remaining less denser minerals like hornblende and sillimanite would be carried farther and deposited away from the shore. High content of opaques in the adjacent shelf area may be due to the erosion of beach sands which contain abundant heavy minerals. From the above studies, it can be suggested that these minerals have been derived from the Charnockites, granite gneisses, khondalites and pegmatites of Western Ghats and adjoining foot hills.

The provenance studies of beach sands are mainly based on the rocks of the continental area. Provenance study for the Indian beaches were attempted by Krishnan and Roy (1945), Siddique and Rajamanickam (1979) and Siddique et al (1979) and have suggested the Deccan traps as the source rocks for the sediments of Bombay and near by beaches. Their study revealed that, during South West monsoon season, the competency of streams increases and it brings large quantities of sediments derived from the Deccan traps which consists of amphiboles, pyroxenes, magnetite, ilmenite etc.

Along the Kerala Coast, the studies of the heavy mineral provenance are very limited. Damodaran (1971) studied about the origin of the heavy mineral sands of the Kanyakumari coast and traced the source of the heavy minerals to the granitic gneisses, garnetiferous gneisses, charnockites and pyroxene granulites of the Western Ghats. Unnikrishnan (1987) studied in detail, the provenance of beach sands of South Kerala and referred that the beach sands are distributed mainly by the west flowing rivers of the South Kerala.

In the present study, the beach sands of pre-monsoon and post-monsoon season are compared. It is found that there is a considerable increase in the percentage of hornblende and hypersthene during post-monsoon season. As suggested by Purandara et al (1987), the abundance of hornblende and hypersthene during post-monsoon season may be due to the speedy disintegration of the hard rocks, such as charnockites and hornblende gneisses dumped along the shore for the construction of groines and seawalls on the beach face. The presence of high proportion of angular grains of hornblende and hypersthene in the South Kerala beach sands lend support to the above observation. In addition to the above facts the increase in the percentage of garnet indicates that the beach sands are derived from the river born sediments.

Considerable depletion of mica is observed during post-monsoon season. This could due to the occurrence of mud banks along the coast. During the monsoon, the presence of mud bank is characterised by high suspensates and probably small flaky minerals are kept in suspension and this gets transported offshore. This explains the decrease in the percentage of mica.

Thin section studies of the rock samples collected from the drainage basin of the river Periyar is mainly composed of charnockites, gneisses, granites, migmatites, dykes etc. The minerals present are opaques, hornblende, pyroxene, zircon, mica, sillimanite, garnets, rutile, tourmaline etc. These minerals show a close resemblence to the mineral of the beach sands present around the Narakkal area. The other rivers mentioned above directly debouch into the Vembanad lake and from there into the sea. The minerals present in the thin sections of the rocks show similarity in their distribution with the sediments of the beach sands adjoining the lake and also with the coarse fraction of the lake sediments. The observations made by Unnikrishnan (1987) for the south Kerala beach sands showed that the garnets, pyroxenes and mica show slight decrease in percentage but sillimanite, zircon and monazite show slight increase in percentage towards downstream of the majority of the rivers. The main rock types present in the drainage basin are gneisses, charnockites and dykes. Laterites are mostly distributed in the midland terrain. Unnikrishnan (1987) reported cordierite bearing gneisses along the Achankovil river basin. It is stated that because of its instability, cordierite is not transported much and thereby it is absent on the beaches.

5.3.2. Clay Mineral Assemblages

There are two principal kinds of situations in whcih clay minerals are found.

1. Clays are produced by alteration of minerals as rocks weather insitu as a result of chemical leaching that has caused mainly by rain water, ground water, and drainage.
2. The altered original minerals may be removed by erosion and redeposited.

Clay minerals are formed as a result of chemical alteration of primary rock forming minerals. Felspars and some ferromagnesian minerals vary in their stability and susceptibility to alteration. The geochemical envrionment in which these minerals are found can modify their composition and structure in ways that are not yet completely understood. Different type of clay minerals develop from alumino-silicates, depending on the weathering environment. Generally, in an alkaline environment felspar alters first to montmorillonite and will be stable in a dry climate. With chemical leaching, in a well-drained moist climate, the initial montmorillonite will change first to halloysite and then to kaolinite. If leaching continues further for a long time, the kaolinite loses silica and gibbsite results.

Very high percentage of kaolinite is reported from the river sediments. The predominance of kaolinite in the river sediments is noteworthy and can be attributed to the source rocks and soils in the drainage basins. Weaver (1959) has observed that the general distribution of clay minerals through the geologic section is probably first a function of tectonics and then type of rocks. This primary relation is modified by climate, syngenesis, preferential segregation, epigenesis and metamorphism. These various processes operate with varying efficiency throughout geologic time and are capable of making the clay suite-source relation.

The results given above vividly indicate wide variation in the principal type of clay minerals in different environments. The variation of clay minerals in different environments are summarised in the figure 5.9. Kaolinite shows a steady depletion from the river sediments to the mud bank suspension. The highest percentage is observed in the river sediment could be released from the weathering of laterite which are abundant in kaolin (Nair et al 1981; Narayanaswamy and Ghosh, 1987).

The sudden decrease in the percentage of kaolinite from 63.93 to 56.29 in the Vembanad lake marks a transition between terrestrial to the marine environment. In the mud bank sediments, kaolinite decreases to 51.21% and towards the periphery of the mud bank it is as low as 49.59%. But the distribution pattern of montmorillonite shows an inverse relationship with that of kaolinite by exhibiting an increase from river to the marine environment. Though the percentage of kaolinite in the sediments brought in by the rivers into the estuary is high, the physico-chemical characteristics alter the composition by the estuarine circulation and salinity differences. It is evident from the results that the marine environment is rich in montmorillonite and the landward portion is rich in kaolinite. During the tidal circulation the montomorillonite rich suspension is brought into the estuarine portion from the marine environment. The increase in the amount of montmorillonite towards offshore observed in the present study confirms the observation made previously by Rao et al, (1983) and Nair et al., (1982). In rapidly moving water, the various clay minerals may be transported without differentiation but at low current velocities kaolinite may be deposited, whereas montmorillonite, remains in suspension. The difference may be greater in fresh and brackish water than in saline water (Postma, 1967). The fact that the grain size of the montmorillonite is finer than kaolinite and illite as demonstrated by the settling velocity study of the minerals (Whitehouse et al, 1960), it tends to remain in suspension longer and the size segregation of the clay minerals results (Gibbs, 1977). This could be the reason for the small amount of montmorillonite in the shallower region and an enrichment towards seawards. Nair et al (1982) has given an explanation for the anomalous increase of montmorillonite towards offshore stating that it is transported from north by South West monsoon drift where the montmorillonite content is high. A study based on the 'd' spacing by Rao et al (1983), of the innershelf montmorillonite (unglycolated) is between 14.97 Å (5.9, 2θ) to 14.7 Å (5.4, 2θ) to 15.5 Å (5.7, 2θ). In order to test the hypothesis, Rao et al (1983) compared 'd' spacing of the montmorillonite from the sediments of the continental shelf between Bombay and Ratnagiri with those of the 'd' spacing of the montmorillonite from the outershelf of Kerala. This work support the contention that a part of the montmorillonite is derived from the north. They attributed the difference of 'd' spacing to the diagenetic changes taking place after deposition. Kaolinite shows a gradual offshore decrease with lowest abundance on the seaward side of the mud bank and in the suspended sediments of the mud bank. Rao et al (1983) explained the distribution of kaolinite parallel to the coast, and reported that more abundant off the estuarine regions when compared to the non-estuarine regions, i.e. on the shelf south of the Vambanad lake. This change in distribution reflects the fact that the lake receives the drainage of rivers which are abundant in kaolinite. Whereas towards south of Cochin, rivers are few. This is well proved in the present case because of the relative abundance of kaolinite in the river followed by estuarine sediments.

Under normal conditions the river may carry highly weathered clays, derived largely from soil material. This material might be deposited relatively nearshore whereas during periods of flooding, the river would obtain much of its clays from the relatively fresh outcrop material (Weaver, 1958b). This latter material would be transported further out to sea than the material carried during the low-water stage and therefore the muds would show variations in the relative amounts of the different clay minerals and in the stability of various types of clay minerals with increasing depth from the river mouth. Such variations in the composition of the river clay detritus would be most pronounced in regions of relatively large relief but would also be of importance in areas where tributaries of a major river drained through a variety of different source areas. A major flood by one of the tributaries could cause considerable change in clay suite customarily transported by the main river.

Illite also shows a steady increase from land to marine environment except that unlike montmorillonite, the illite concentration of the mud bank suspension is not as high as that of the peripheral sediments of the mud bank. Illite rich continental slope off Kerala was also reported by Rao et al. (1983) stating that these low energy environments facilitates illite accumulation. One of the source for illite contribution was identified as outcrops of aragonite cemented sandstone and limestone which contains substantial amount of illite.

Though gibbsite occurs as a minor clay mineral, its concentration in the river sediments is high and follows the same relationship with that of kaolinite in the other environments. Grim (1968) pointed out that gibbsite is of continental origin along with kaolinite and is a common product of laterites in humid tropical zones. Narayanaswamy and Ghosh (1987) and Nair et al. (1981) from a study of the mineralogical assemblages of laterites have observed gibbsite, kaolinite and montmorillonite in a relatively decreasing order of abundance.

Suspended sediments from the mud banks show maximum enrichment of montmorillonite over other clay minerals. Though illite follows a sympathetic pattern of occurrence with montmorillonite in other environments, in the suspended sediments, the illite concentration does not show the same enrichment pattern as montmorillonite. This is a clear indication of differential settling pattern proposed by Whitehouse et al. (1960). Illite particles are usually smaller than kaolinite, but are considerably larger than montmorillonite. Experiments have shown that flocculation of kaolinite and illite is mainly completed at very low chlorinity whereas flocculation of montmorillonite increases gradually with increase in chlorinity. This preferential settling of montmorillonite over the other clay minerals is attributed to the very stable double layer of montmorillonite. Mud bank formation coincide with the monsoon season and the salinity reduction (less than 20%o) due to precipitation is an obvious factor as reported from Purakkad mud bank (Kurup and Varadachari, 1975; Damodaran and Hridayanathan, 1966). Since the settling rate of montmorillonite is low compared to the other clay minerals in the salinity depleted zones of mud bank, montmorillonite is found to be abundant in the suspension giving rise to a maximum M/K ratio of 1.86.

The temporal variation of montomorillontie and kaolinite in the mud bank sediments are illustrated in the figure 5.10. Contrasting behaviour of kaolinite to montmorillonite is obvious. The depletion in the amount of kaolinite from May to August through June and July is compensated, by the addition of montmorillonite from May to August. The peak of the development of mud bank (August) yields a subequal proportion of montomorillonite and kaolinite. Following the cessation, the kaolinite content again increases thereby marking a depletion in the montmorillonite content. In general, the montmorillonite content in the nearshore is presumed to be derived from the hinterland, but its enrichment towards the peak of the monsoon denotes a change in source of the sediments. Though the maximum discharge of water and sediments through the rivers is during monsoon and the river sediments are enriched with kaolinite over montmorillonite, the nearshore region shows decrease in the percentage of kaolinite. Rao et al (1983) pointed out that the outershelf area is abundant in montmorillonite and also the present study shows a seaward increase of montmorillonite. Hence, it is possible that the storm conditions existing along the south west coast induces small waves which can move unconsolidated surficial muddy sediments from the offshore towards the nearshore. The observations made by Mallik et al, (1988) and Ramachandran and Mallik (1985) corraborates the above view and points to the fact that the dispersal pattern of the fine sediments suggests transportation of mud from offshore. They opined that the localised mud deposition pattern could be caused by coverging currents.

An overview of the above discussion indicates the pattern of clay mineralogical assemblages in the different environments studied. An interplay of the source rock and the climatic conditions designates the pattern of change from river to the marine environment. The gradual depletion of kaolinite marks the transition in the physico-chemical conditions from fluviatile to marine environment.

Energy of the various environments and the granulometry of the clay minerals plays a vital role in the variation of their distribution in the different environments. Contribution from the terrestrial sources are very important as a source of sediments for mud banks. The study shows that the onshore transportation of mud during the triggering of monsoon helps in the development of mud bank. After the cessation, Ramachandran (1989), has observed that mud is getting removed from the nearshore and are carried away by the longshore and offshore currents. Hence it is presumed that the deposition during mud bank and removal following it, is a recurring annual phenomenon controlled by the flow regimes of the innershelf.

CHAPTER - VI

GEOCHEMISTY

6.1. INTRODUCTION

Sediments are extremely important in the marine environment since they act as 'traps' for chemical elements. Recent works in the coastal marine environment has indicated that the increased geochemical cycling of metals by man can be well documented through sedimentological studies. Special attention has been paid to the modern continental margin sediments by geochemists, because the physical, chemical and biological conditions are more variable in these sediments than on the continents or in the deep seas.

In many areas, geochemical studies are hindered by a lack of information about the natural environment. Parcitularly, the nearshore environments are the important removal sites for several elements from sea water because the accumulation rates are very much higher and the various environmental factors are much more different from those found in the open ocean.

The concentration of a given element in a sediment is governed by its concentration in, and the relative proportions of, the various components. Many elements show tendencies to be partitioned between two or more mineral components in the sediment and the distribution of a given element cannot be described in terms of mineralogy alone. There is also a very significant elemental partitioning effect brought about by a textural control on the mineralogy of sediments. This factor is of critical importance for nearshore sediments in view of their extreme textural variability. Hirst (1962) observed that the range of chemical compositions in the sediments are controlled by variations in the proportions of the major minerals, i.e. quartz, feldspar, illite, montomorillonite, kaolinite and in those of the minor amounts of heavy minerals. Exceptions to this were found for the distribution of iron, calcium and manganese.

. Geochemical analysis of major and trace elements were carried out for the estuarine and mud bank sediments. The role of estuarine sediments are very important for the supply of dissolved and solid material to the ocean. Garrels and Mckenzie have estimated about 250 x 10^{14}g year^{-1} of material enters the oceans from the continents of which 210 x 10^{14}g year^{-1} material is transported via rivers and estuaries. Almost 85% of all soluble and particulate weathering products pass through the estuarine environment before entering coastal waters. Therefore, the estuaries and lagoons which form the transition zones between fluvial and marine environments constitute an important stage in the transport of sediments from continents to oceans. Further, they also serve as traps for a portion of the solid continental weathering products. They represent a situation in which sedimentary detritus during its transport to oceans can undergo modifications through several processes operating in these systems resulting in enrichment or impoverishment of various trace elements in the bottom sediments (Murthy and Veerayya, 1981).

6.2. RESULTS

6.2.1. Geochemistry of Bulk Sediments

6.2.1.1. Calcium Carbonate

Percentage of calcium carbonate in the Vemband lake sediments are shown in table 6.1. In the northern part of the estuarine mouth, the percentage of calcium carbonate is found to be high when compared to the southern part of the lake. The distribution of calcium carbonate in the river mouths is very low. The average percentage of calcium carbonate in the estuarine sediments is 3.06%. Very high percentage of calcium carbonate is reported from the Alleppey area (9%).

Distribution of calcium carbonate in the mud bank sediment is estimated to be very high. The percentage varies between 1.25 to 11.75. The minimum value (1.25%) is noted in the suspended sediments.

6.2.1.2. Organic Matter

In the Vembanad lake, the organic matter percentage varies between 1.7 and 11.73. Based on organic matter percentage, two zones can be distinguished in the lake: (i) Northern part of the lake extending from Azhikode to Thanneermukkam area with high percentage of organic matter. (ii) Southern zone extending from Thanneermukkam to Alleppey region. In the central part of the lake, the sediments are coarser in size, and show high precentage of organic matter but relatively very low percentage is recorded near the river mouths. Estuarine region shows high organic matter content. The relationship of organic matter with clay percentage is shown in the diagram 6.1. Table 6.1 shows the distribution of organic matter in the Vembanad lake.

The distribution of organic matter is very high in the mud bank sediments (Table 6.2 a, b). It shows a gradual increase from May to August and a considerable decrease during September and December. In the Narakkal-Saudi area, the maximum value of 6.01% is noted during August. The studies conducted during July and August, 1986, shows a significant change. The organic matter percentage noticed is 4.06 and 4.72 respectively.

Organic matter content in the Alleppey-Purakkad area show similar sort of variation. In general, it is found that the occurrence of organic matter is quite high in the area but the value varies between a minimum percentage of 1.88 and a maximum of 6.15% during August. The percentage distribution of organic matter is shown in the Table 6.2 b and figure 6.1 shows the variation of organic matter with clay percentage.

6.2.1.3. Major and Trace Element Studies

The bulk chemical analysis were carried out only for limited number of samples from the mud bank area (table 6.3). Chemistry of the lake sediments were not carried out since a good amount of data exists in the literature on Vembanad lake sediments. The studies conducted by Mallik and Suchindan (1984), mainly concentrated on the chemistry of the water leachable fraction (Group A) and solution prepared by dissolving the residue in nitric acid and hydrogen peroxide (Group B). They found a very high amount of organic matter, iron, manganese, phosphates and calcium. The earlier report on the trace elements from the bulk sediment analysis by Murthy and Veerayya (1981) showed an increase in the values of Fe, Mn, Ti, Ni, Co and Cu, with decrease in grain size. However, the present study is concentrated mainly to assess the association of chemical constituents in the clay sized fractions (2 microns).

6.2.2. Geochemistry of the Clayey Sediments

For a better understanding of the geochemical processes, clay fractions (less than 2 microns) of the estuarine and mud bank sediments were subjected to chemical analysis (table 6.4). The fine sediment population is an exchange medium scavenging the water column and also a reservoir of minor and trace elements. It has been documented by many workers that the exchange of these elements between water and sediment by sorption or desorption takes place essentially in the fine sediment population (Wakeel and Riley, 1961 and Degens, 1965). The frequency percentage versus chemical concentration of the various elements are presented in the figure 6.2 and 6.3.

6.2.2.1. Phosphorus

Vembanad lake sediments show high amount of phosphorus. In the lake sediments the phosphate increases in the southward direction. The minimum percentage is noticed in the vicinity of river Periyar, i.e. 0.54. The value increases to 0.65 in the estuarine region and further increase is noticed upto the Minachil ar. Here the maximum percentage of 0.85 is recorded and further in the southern part of the lake near Pamba ar mouth, it again decreases to 0.70. A minimum value of 0.05 is encountered in the eastern margin of the lake.

The distribution of phosphorus in the mud bank region shows an average percentage of 0.60. It is observed that there is no significant monthly variation in the percentage of phosphorus. However, it is found that the percentage is quite high in the Alleppey-Purakkad region. The minimum value of 0.28% is noted in the core sample of 1 m length collected from Malipuram area. The maximum value of 0.92 is noted in the Alleppey region. The suspended sediments also show a high phosphorus percentage of 0.82. The inter-relationship of phosphorus with iron is shown in Figure 6.4.

6.2.2.2. Total Iron

The total iron percentage in the Vembanad lake is determined and the results show a significant change in the percentage distribution between the sediments of Vembanad lake and mud bank sediments. The average distribution of total iron in the Vembanad lake sediments is 11.89%. The maximum percentage is noted in the northern most region of the lake (12.6%) followed by 12.34% in the southern most part of the lake. The minimum value is noted in the estuarine (mixing zone) region (11.11%) and it shows an increase towards the southern side.

In the mud bank sediments, the distribution is found to be very high. It can be noted that the percentage is comparatively less during the month of May, i.e. just before the onset of monsoon. The values are considerably high during July-August months. The average value is 14.24% and the maximum value reported is 18.17% off Alleppey, during August at a distance of 8 km from the shore. The minimum value of 12.38% is noted during May in the Narakkal-Saudi area. Its inter-relationship are shown in the figures 6.5 and 6.6.

6.2.2.3. Manganese

The average distribution of Manganese in the Vembanad lake is found to be 0.08%. The maximum prcentage is noted at the northern part of the lake(0.09%)and a minimum is in the vicinity of the Minachil ar (0.06%). It shows a well defined relation with the distribution of iron. A maximum of 0.17% is noted in the eastern margin, at the northern part of the Vembanad lake. The minimum of 0.04% is noticed in the vicinity of river Periyar.

The average distribution in the mud bank area is 0.09%. There is no significant variation in the percentage of manganese. The maximum value (range between 0.06% and 0.15%) is recorded from the Alleppey-Purakkad area. The core sample and the suspended sediment sample also show a resemblance with the surficial sediments in their concentration. The inter-relationships are plotted in the figures 6.7 and 6.8.

6.2.2.4. Titanium

From the results it is found that the percentage of titanium both in the Vembanad lake and mud bank sediments are quite high. The average percentage of Titanium in the Vembanad lake is 1.02. The percentage increases towards the south and it decreases in the vicinity of Minachil ar and again increases in the southern region. The maximum value noted at the Muvattupuzha region (1.12%) and the minimum value is 0.88% near the Minachil ar area.

The average distribution in the mud bank sediments is 1.09%. There are no noticeable variations in the sediments, however the maximum percentage is noted during July-August months. The distribution of Titanium is also high in the offshore direction. The relationship of titanium with iron and manganese are shown in figures 6.5 and 6.8.

6.2.2.5. Sodium

The average percentage of sodium in the Vembanad lake is 3.98. It is found that the percentage of sodium is maximum (4.90%) in the mixing zone of the lake. It is also noted that the concentration of sodium is comparatively higher in the northern part of the estuarine mouth. Minimum percentage of 3.12 is noted in the southern most part of the estuary.

The percentage of sodium is higher in the mud bank sediments, when compared to the lake sediments. The average percentage of sodium in the mud bank sediments is 4.29. There is no considerable change in the distribution of sodium. The maximum percentage of sodium noted is 5.08 in the month of July 1986 from the Narakkal-Saudi area. The minimum concentration found in the area is 3.78%. Inter-relationship of sodium with potassium is shown in the figure 6.9.

6.2.2.6. Potassium

The percentage of potassium is low when compared to sodium. The average percentage is found to be 1.55 in the Vembanad lake. The maximum percentage is found in the estuarine region (1.83%). The minimum percentage is in the Pamba ar mouth region (1.26%). In all other areas it shows almost an uniform distribution.

The average percentage of potassium in the mud bank sediments is 1.70. The distribution of potassium does not exhibit any significant change. The maximum value of 2.03% is recorded during July 1986, from the Narakkal-Saudi area. It shows a close sympathetic relationship with sodium. The minimum value of 1.43% is noted during August, 1986 in the same area. All other values show close similarity in their distribution.

6.2.2.7. Magnesium

The average percentage distribution of Magnesium in the Vembanad lake is 4.72. The values range from 2.07 to 9.58%. The maximum percentage is noted in the Muvattupuzha river mouth area (9.58%). It shows an increase in the percentage towards further south. The minimum percentage is noted in the northern part of the lake (2.07%). In general, the percentage is high towards the southern part of the lake than in the northern and estuarine mouth regions.

The average percentage in the mud bank sediments is 4.25. The value ranges from 3.3% to 9.58%. It is also observed that the percentage of Magnesium is relatively higher in the Narakkal-Saudi area. Magnesium shows a positive relationship with titanium.

6.2.2.8. Silica and Alumina

The average distribution of silica and alumina in the lake sediments are 45.11 and 20.52 percentage respectively. The maximum percentage of silica noted is 54.9 in the estuarine area and the minimum value is 41.44. The silica percentage increases towards south, to the river mouth of Muvattupuzha, upto 46.68% and then decreases further south.

The maximum percentage of alumina noted is 27.07 in the northern part of the estuary and a minimum value of 17.38% in the estuarine (mixing zone) region, but here it shows a reverse trend in the distribution, that is, it shows a decrease towards south and again increases from the southern part of Muvattupuzha mouth.

The average percentage of silica and alumina present in the mud bank sediments are 43.53 and 20.84 respectively. The maximum percentage of silica noted is 46.73 during the month of May and the minimum value of 40.78 is noted for sediments, collected from 8 kilometers off the coast. The maximum percentage of alumina present in the sediment is 23.02 and the minimum value is 17.91. The monthly variations are not significant but the mud bank sediments of 1986, show higher percentage of silica when compared to the previous year. The inter-relationship between silica and alumina are shown in the diagram (fig. 6.10).

6.2.2.9. Trace Element Studies

Important trace elements determined are copper, cobalt, nickel and zinc. Trace elements represent only a small fraction of less than 0.1% of the sediments.

6.2.2.9 a. Copper: The average concentration of copper in the sediments is found to be 115 ppm in the Vembanad lake sediments. The maximum and minimum values are noted in the southern and northern parts of the lake, respectively. The value ranges between 51 ppm and 271 ppm.

The mud bank sediments show higher concentration of copper than lake sediments. The average percentage of distribution of copper is 14.3 ppm. The maximum value recorded is 229 ppm and the minimum value is 83 ppm. It is further noticed that the concentration of copper is high in the Narakkal-Saudi area when compared to the southern part of the coast (Alleppey-Purakkad region).

6.2.2.9 b. Cobalt and Nickel: The distribution of cobalt and nickel shows a very high concentration in the Vembanad lake than the mud bank sediments. The average concentration of cobalt and nickel in the Vembanad lake is found to be 60.40 ppm and 111.13 ppm. The maximum value of cobalt is recorded in the vicinity of Minachil ar (75.67 ppm) and nickel (137 ppm) is noted in the southern most part of the lake. The concentration is found to be relatively less in the northern part of the estuary than the southern part. The concentration is relatively higher in the estuarine region.

The average values of cobalt and nickel in the mud bank sediments are 24.66 ppm and 75.56 ppm respectively. There is no significant variation in their distribution throughout. The maximum value of cobalt is 75 ppm in the suspended sediments and the minimum value noted is 12 ppm in the surficial sediments of the mud bank region. The maximum concentration of nickel is 132 ppm found in the Alleppey-Purakkad region during August and the minimum value recorded is 32 ppm during May in the Narakkal-Saudi area.

6.2.2.9 c. Zinc: The average value of zinc in the estuarine sediments is 53.3 ppm. Here, it shows gradual increase in the concentration towards south. The minimum average value is near the river Periyar (34.5 ppm) and it is maximum in the Pamba river mouth region with a concentration of 70.83 ppm.

The concentration is relatively lesser in the mud bank sediments than the lake sediments. The maximum concentration estimated is 74 ppm and the minimum value is 20 ppm. It can be noticed that the sediments collected during May-June show a relatively lesser concentration of zinc and maximum is reported during the month of August.

6.3. DISCUSSION

6.3.1. **Geochemistry of Bulk Sediments**

6.3.1.1. Calcium Carbonate Distribution

The geological problems relating to the conditions of formation of limestones have greatly stimulated the study of calcium carbonate in the marine sediments. This is mainly because, most of the limestones were formed under marine environmental conditions. Calcium carbonate content of sediments from a shelf is a function of carbonate productivity and the rate of influx of terrigenous material (Rao, 1978).

A review of literature shows three broad sources for the calcium carbonate in the fluvial and deltaic deposits:

1. Calcareous mineral and sediments derived from continental rocks;
2. Shell fragments and tests of calcareous organisms, and;
3. Inorganic and organic precipitation from the overlying waters of the depositional environment.

Variations of calcium carbonate in the estuary i.e. higher percentage in the southern part and lesser in the northern part may be attributed to:

1. Excessive discharge of river sediments in the northern part.

Low values of calcium carbonate in the river mouth sediments may be related to high rate of sedimentation and the nature of the substratum.

2. Various physico-chemical processes taking place in the mixing zone of the estuary;
3. Continuous dredging operations may affect the biogenic activity in the region.

Mud bank region is calm due to wave dampening. Hence, it favours biological processes by sheltering the various organisms including fishes. During May-June the percentage of calcium carbonate is less, this could be due to the increased wave activity marking the onset of monsoon which does not permit the accumulation of carbonate. During July - August months the wave dampening makes the nearshore less turbulent and this explains the reason for the increase in the amount of calcium carbonate and decrease thereafter. Photosynthesis and respiration by organisms may bring about calcium carbonate co-precipitation from the overlying waters by effecting the carbon dioxide influx as this area is highly productive. Cloud (1965) has observed that certainly any biological process which affects the amount of carbon dioxide in solution disturbs carbonate equilibria. Therefore, it is possible that part of the calcicm carbonate in the marine environment might be due to precipitation as a result of photosynthetic carbon dioxide intake by plants and respiration by organisms. Relatively high values of carbonate in the offshore region may be either due to the strong currents leading to non-deposition of terrigenous material or due to the limited supply of terrigenous material. In addition to this, carbonate content in the marine sediments show a general increase with depth.

6.3.1.2. Organic Matter

The important factors controlling the organic matter accumulation in sediments are (i) the supply of organic matter to the environment of deposition; (ii) rate of deposition of organic and inorganic constituents; (iii) texture of the sediments. According to Trask (1932), silt contains twice as much clay and four times as much organic matter as sands. Trask (1939) stated that the main cause of the increase of organic matter in fine particle is the similarity in settling velocity of both organic constituents and fine particles. Carter and Mittern (1978) stated that the increase in organic carbon with decreasing grain-size may be due to the co-sedimentation of particulate organic matter with small mineral grains. It could be also due to the enhanced surface adsorption of organic matter because of the greater surface area of fine sediment grains. Suess (1973) demonstrated that the increase in organic carbon and nitrogen with decreasing grains-size is linearly related to the surface area of mineral grains.

The very high content of organic matter and its variation in the Vembanad lake sediments are attributed to the following causes. In this ecosystem, the organic production is favoured by:

1. Vegetation around the Vembanad lake especially, mangrove swamps;
2. Texture of the sediments, brought by number of west flowing

rivers, which are fine in nature; and

3. Degree of oxidation-due to oxygen deficient ecosystem prevailing in different part of the lake, the degradation of organic matter is less in this area and hence the high amount is encountered here. In Cochin harbour area in addition to the above factors, disposal of waste from the city may also contribute to the enrichment of organic matter.

The relatively higher percentage of organic matter in the northern part of the estuary may be due to the denser planktonic and benthic population, salinity differences and the thicker vegetation around the area. In the southern part of the estuary, the fresh water conditions and the coarse bottom sediments could be responsible for depletion in the organic matter content compared to the northern part. Besides this, currents and depth of occurrence play an important role in the accumulation of organic matter.

Organic matter distribution in the mud bank sediments is found to be very high. Generally, marine clays have the higher percentage of organic matter and the reason for this may be the high adsorbing capacity of the clays or the hydrobiological conditions prevailing in the marine environment. Especially the enrichment of organic matter during the mud bank season clearly indicates an increase in the primary productivity and also in benthic activities prevailing in the inner-shelf (Damodaran, 1973). During the active mud bank season, the coastal water becomes calm and turbid, and extremely finer size of the sediments favours the sedimentation of organic matter. Furthermore, Kuenen (1965) has stated that deposits exceptionally rich in organic matter are encountered in areas where upwelling waters fertilise the surface layers of open ocean. In addition to the high planktonic and benthic population, some other factors such as low temperature and low oxygen content give rise to the high organic matter. Santhanam (1977) stated that the temperature and dissolved oxygen of the marine zone are found to be lower than in the other environment and therefore oxidation of organic matter will not be high. According to Sanders (1956), in general all clay minerals except Kaolin bind organic matter.

Relatively lesser percentage of organic matter is recorded during 1986 which clearly shows a bearing on the coarser size of the sediments.

6.3.1.3. Major and Trace Elements

To understand the chemical and physical partitioning of the chemical elements in the bulk sediments of the mud bank, cluster analysis was carried out. The concentration of various chemical elements in the bulk sediments are shown in the Table 6.3. Correlation matrix has been worked out between the size grades, organic matter, $CaCo_3$, major and trace elements. The matrix of correlation as represented in the Table 6.5 shows a control of grain-size in segregating many of the chemical elements. The control of grain size over the geochemical variations of sediments have been reported by several workers (Zhao et. al., 1981). Hirst (1962) also observed a similar nature for the sediments of Gulf of Paria. Ramachandran (1989) from a comparative study of textural classes versus the elemental concentration reported that along the Quilandy nearshore area, a size dependent factor on elemental speciation was evident. From the correlation matrix, it is found that sand is showing a high positive correlation only with silica, though a low level correlation is observed with copper and cobalt. Similarly, clay is showing high positive correlation with many of the elements barring a few, such as silica and titanium, with which it shows highly negative relationship. Silt shows high positive correlation with silica and titanium. Aluminium shows a high positive correlation with all major elements except titanium. The relationship of phosphorus with iron, manganese and sodium are highly significant and it shows a negative relationship with potassium. Manganese percentage also bears a similar relationship with sodium and potassium as in the case of phosphorus. Sodium yields a high positive correlation with potassium but both sodium and potassium exhibit a strong negative relation with titanium. Among trace elements cobalt shows a positive correlation with Nickel and zinc. Figure (6.11) shows the dendrogram from the analysis. The significant clustering observed are summarised below:

1. There is a strong group comprising of clay, organic matter, iron, manganese, potassium, aluminium, sodium and phosphorus. It is evident from the significant loading of the elements, that the clay rich sediments are abundant in organic matter and phosphorus owing to the large surface area of clay particles. The clay fraction is abundant in aluminosilicates (clay minerals) showing a sympathetic

relation with aluminium, sodium and potassium. A direct correlation of iron with alumina indicates that the iron is held in the structural positions of the aluminium silicates. As pointed out by Hirst (1962), manganese is also showing a direct relationship with iron suggesting their concentration in the clays. It has been reported that manganese is held in lattice positions in the alumino silicates and/or as dispersed oxides in close association with iron phases.

2. The second group contains Co, Ni and Zn which in turn is related to the first group. This geochemical speciation could be inter-related to both dispersed oxide phase and also to the aluminium silicate factor. It was observed by Price and Wright (1971) and Wright (1972) from a study of terrigenous sand and mud that, the elements Nickel and Zinc were preferentially enriched in the clay fractions containing different clay minerals. Calvert and Price, (1970) have observed biogenic precipitation of Nickel and Zinc in organic rich muds.

3. The third group consists of silt and titanium. This association could be due to the abundance of titanium bearing detrital mineral in the silt fractions. Such an association of titanium with silt fraction was reported as early as 1925 from the data published by Grout.

4. The last significant group showing the direct control of sand over the partitioning of silica is also evident from the dendrogram. From the chemical data it is conspicuous that there is a decrease in the SiO_2/Al_2O_3 ratio from sand to clay fraction indicating a larger proportion of free quartz in the coarser fractions.

The calcium carbonate does not show any relationship with any other constituents. The analysis was conducted without removing the shell fragments from the sediments. Copper due to its association with some of the clay minerals, behaves in a different manner. Rao et al., (1974) stated that montmorillonite accounts for higher content of Cu than Kaolinite clays. Thus the variation of copper is attributed to the difference in the terrigenous input of the sediments and its variation in the clay minerals.

6.3.2. **Geochemistry of the Clayey Sediments**

6.3.2.1. Phosphorus

Phosphorus is one of the important constituent in the lake sediments. This is because, phosphorus is the most limiting factor for primary production in most fresh-water environments. The increased phosphorus loading to lakes during recent decades, from cultivated land, domestic and industrial sewage, has therefore, been crucial for the eutrophication processes (Rohrlich et al., 1969; Golterman, 1977). Large amounts of the phosphorus entering a lake are metabolized in the lake water and then deposited in the sediments. Phosphorus is deposited in the sediments as:

a) Allogenic apatite minerals;

b) Organic associates, partly as structural elements of settling dead organisms, but also in humic complexes;

c) Precipitates together with inorganic complexes, like iron or aluminium hydroxides or as coprecipitate together with calcite.

Generally, the content of inorganic phosphorus is considerably hgiher than the content of organic phosphorus. The inorganic fraction consists mainly of non-apatite inorganic phosphorus, but in sediments in calcareous regions, apatite phosphorus might be dominant. The characteristics of the sediments depend on bottom dynamics, morphometry, hydraulic loading, water movements, tropic state and composition of allogenic material, etc. The total phosphorus concentrations in sediments generally increase with increasing water depth as a result of a more or less continuous transport of material from shallow zones of erosion and transport to the deeper accumulation areas. Consequently, different types of phosphorus compounds are found in different environments.

Distribution of phosphorus is also determined by the texture of the sediments. The fine grained sediments, viz., silty clays and clayey silts have higher concentration in the estuarine region. This could be due to the mixing and physioco-chemical processes taking place in the estuary. In the southern part of the estuary, factors such as texture, organic matter and iron content might be controlling the fixation of phosphorus.

The increased content of phosphorus in the sediments is contributed by the decay of organic matter, diffusion, desorption, and leaching. The high concentration of phosphates in the mud bank sediments may be the result of upwelling. According to Bushinski (1964), the waters rich in phosphate, which is essential for the development of organic life can either come from land through rivers or from deeper parts of the sea through upwelling. The river derived phosphorus is immediately assimilated by plankton and subsequently deposited on the bottom, and very little can be carried away to the deeper parts of the sea. The high phosphorus content reported from the sediments off Alleppey-Purakkad area may be due to the entrapment of the river derived phosphorus through assimilation and subsequent deposition by the profuse growth of organic life. Phosphorus may also be fixed with iron as ferric phosphate in the form of chemogenous compounds.

6.3.2.2. Total Iron

Iron in water, river or sea, is transported in the form of ferric oxide hydrosol stablised by organic colloids (Moore and Maynard, 1929). The flocculation of iron in water increases with salinity with the high content of electrolytes (Castano and Garrels, 1950; Moore and Maynard, 1929). In a high E_h condition, ferrous iron and ferrous hydroxide are oxidised and precipitated as Fe_3 + and Fe $(OH)_3$, respectively (Krumbein and Garrles, 1952; Mason, 1958). It is found that the percentage of iron is comparatively higher in the marine sediments than in the estuarine sediments.

The very high content of iron may be due to flocculation. When river water containing high content of iron is mixed with sea water, flocculation takes place. This may explain the high content of iron in the estuarine and northern part of the lake. In the intermediate zone the concentration is relatively lesser which may be due to the fresh water occurring in that area. It is assumed that the CO_2 rich weathering solution of continental origin readily dissolves ferrous iron from the mineral matter of the continental rocks and transports the iron under acid reducing conditions as ferrous iron in association with bicarbonate ion, on reaching the highly oxygenated regions, the iron content in these solutions is oxidised to ferric state and gets precipitated as Fe_3 + and Fe $(OH)_3$ under favourable condition. Iron reacts with other elements also and forms different inorganic compounds.

In addition, to the above facts, the high content of iron in the mud bank sediments can also be due to the surplus value of Fe_2O_3/ Al_2O_3 ratio (0.52) which indicates the presence of authigenic iron bearing minerals (Calvert, 1976).

6.3.2.3. Manganese

There has been much speculation and controversial opinions on the origin and the manner in which manganese is incorporated into hydrolysate sediments. However, it is generally conceded that manganese in sedimentary cycle is leached from the drainage basin as bicarbonates [$Mn(HCo_3)$] but deposited as oxides in the form of organic and inorganic colloids, finely divided detrital grains and as cementation matrix. Correns (1941) claims that manganese is biologically extracted, while Kuenen (1941) considers that manganese is a chemical precipitate.

There is no significant change in the percentage of manganese both in the lake and mud bank sediments. The variation of mangnese is due to the greater solubility of manganese than iron in natural water and consequently gets precipitated earlier in the form of hydroxide while manganese is carried further in solution till high oxidising conditions are met with. Such a separation of manganese from iron was reported in sedimentary process by many workers (Krauskopf, 1957; Krumbein and Garrels, 1952 and Marchandise, 1956).

Although more manganese is present in river water and sea water than titanium, the content of MnO is lower than TiO_2 in recent sediments. This indicates greater solubility of manganese in waters than titanium.

6.3..2.4. Titanium

In natural waters, the amount of reported titanium is very low, in sea water it is 1 ppm, in lake waters (marine) 1.6 ppm and in river waters (North America) 13.2 ppm.

Titanium in the sediments are considered as an index of sedimentation rates and in elucidating their genesis has been mentioned by several authors (Goldberg, 1954; Goldberg and Arrhenius, 1958). The high amount of titanium found in the estuary and marine sediments may be due to their excess supply from the river borne sediments which contains generally high amount of titanium. It is also believed that the bulk of the titanium is incorporated during terrestrial weathering in the clay fraction at the time of its formation as substantiated by Goldschmidt (1954) and Degens (1965). According to Chester (1965), 'Ti' is known to migrate into the sediments by the neoformation of anatase. In view of this, a part of the titanium which may also go into solution as cations during weathering gets readily hydrolysed and precipitated as anatase hydrous oxide.

6.3.2.5. Sodium and Potassium

It has been generally observed that the potassium content is relatively lower than that of sodium both in the estuarine and mud bank sediments. As sodium and potassium are not precipitated by hydrolysis (Goldcehmidt, 1937; Heier and Adams, 1963), it is convincible that in the clay fractions sodium and potassium are tied up in clay minerals either by adsorption/or by cation exchange. From the studies it is revealed that the percentage of sodium is high in the mixing zone of the estuary and also in the mud bank sediments. The increase of sodium in the saline region may be due to the replacement of calcium by sodium as stated by Sayles and Mangelsdorf (1977) and therefore, the high increase of sodium in the estuarine and mud bank sediments is justifiable. The comparatively higher concentration of sodium than potassium may be due to the following reasons:

a). The large amount of colloidal size particles which would enhance the overall adsorption of sodium;

b) High content of salts containing sodium derived from more solutions;

c) The presence of significant amount of suitable clay mineral to fix preferentially sodium, and

d) The slow rate deposition of the clays to absorb sodium from the overlying water.

Several authors have noted that the river clays with calcium and potassium as exchangeable ions will convert to sodium and magnesium forms, shortly after they are transported into seawater (Potts, 1959; Russell, 1970). According to Weaver (1967), clay minerals absorb more sodium and magnesium than potassium from the seawater. Sayles and Mangelsdorf (1977) found that half of the exchange sites of clays in sea water are occupied by Na, little of it being inherited from the river clay. Thus from the above discussion, it is quite reasonable to presume that the river clays after reaching the marine environment have adsorbed more sodium into their structures than any other elements.

6.3.2.6. Magnesium

The highest concentration of magnesium in the marine environment may be due to higher availability of magnesium ions in the overlying water and the higher fixation in clay minerals especially in smectite and chlorite. Experimental data given by Russell (1970) indicate that upon prolonged soaking of montmorillonite will take up magnesium from sea water when pH values are greater than 8. Moreover, Weaver (1967) stated that clay minerals are adsorbing more sodium and magnesium than potasium from the seawater. Most probably the preferential fixation of magnesium over calcium and potassium is being brought by either relatively higher adsorption capacity of the clays over Ca and Mg and by the larger cation exchange of Mg for Ca^{++} and K^{+} in clay minerals.

6.3.2.7. Silica and Alumina

These are the two important constituents of the clay minerals. Silica and alumina in the estuarine sediments exhibits an inverse relationship with each other. Silica also shows an antipathetic relation with iron, manganese and titanium but indicates positive response with sodium and potassium. Alumina bears strong negative relationship with sodium and potassium but shows a sympathetic relationship with most of the other elements.

In the case of mud bank sediments, the silica and alumina exhibits a highly inverse relationship (r = -0.92). It shows only weak negative correlation with the Na and K elements.

6.3.2.8. Trace Elements

6.3.2.8 a. Copper: The mobility of copper is high in solution and occurs as copper ions. It is removed from the solution as sulphide in reduzate sediments and as copper oxy salts in high pH environments.

Number of authors have pointed out the association of copper with soft parts of organisms as organo complexes (Revelle et al., 1955). Adsorption of copper by marine organisms has also been contended by many authors (Krauskopf, 1956; Rankama and Sahama, 1950). This can clearly explain the high amount of copper in the mud bank sediments which may be due to the higher primary productivity. A part of copper may also be fixed in clay minerals. Such a fixation of copper by clay minerals by adsorption and cation exchange has been pointed out by Goldberg and Arrhenius (1958), Wakeel and Riley (1961) and Hirst (1962).

The high amount of copper in the marine sediments can also be explained due to high content of copper in association with montmorillonite and illite and low content of copper with kaolinite (Rao et al. 1974). This is true as in the case of mud bank sediments where the kaolinite percentage decreases with increase of montmorillonite.

6.3.2.8 b. <u>Cobalt and Nickel</u>: In nature generally, cobalt occurs in the di- and trivalent states where as nickel occurs in the divalent state. Cobalt is characteristically able to migrate more readily than nickel. The enrichment of cobalt in the estuarine and marine environment may be due to the enrichment of humic acids produced by the decaying of plant materials and to a certain extent due to the contribution of organisms. Cobalt also shows an increasing trend with iron and this may be due to the adsorption of cobalt by hydrated ferrous oxide (Krauskopf, 1956). Kharkar et al. (1968) have stated that trace elements like cobalt and others which have been adsorbed from solution by clay minerals suspended in river water are desorbed in sea water. The geochemical properties of nickel determine its relationship to manganese and iron. Nickel is able to replace magnesium isomorphically, especially in silicates and to lesser extent in metasilicates (Fersman, 1959) because of their similar ionic radii. Besides iron and magnesium, it can also substitute for sodium in silicate minerals. Nickel with magnesium and silicon can travel long distances in water and gets precipitated as complex hydrous silicates with layer lattices when the water is neutralised. Rankama and Sahama (1950) noted that, unlike iron and manganese, nickel tends to be in solution and is carried to longer distances and deposited in the hydrolysate sediments. Clay mineral composition also plays an important role in the accumulation of cobalt and nickel.

6.3.2.8 c. Zinc: Zinc can diadochically replace ferrous iron and magnesium in the silicate mineral structure because of the similar ionic radii of iron and magnesium, (Rankama and Sahama, 1950). In regions of humid climate where continental sediments show neutral or acid reaction, there is an increase in migration of zinc but in alkaline and low humidity regions the migration of this element is low (Sankov, 1961). The variation in the percentage of zinc may be also due to the clay mineral variation of the sediments besides which factors such as organic matter, salinity etc also leads to the change in concentration of the element.

6.3.3. Cluster Analysis

To summarise the whole process of chemical partitioning of clay sediments, cluster analysis was carried out for both Vembanad estuary and mud bank sediments. The inter-relation of the chemical elements in the Vembanad lake (table 6.6) gives two major significant groups, first one comprising of alumina, copper, cobalt, nickel and zinc and second one sodium and potasium which in turn is related to silica. In the first group, the relation between copper, cobalt, nickel and zinc shows high similarity but the relationship with Al is not highly significant. Since, Na, K and silica are behaving in contrast to the first group, it indicates an enrichment or sorption of the elements in the first group within the estuarine environment. This also gives a clue that apart from these elements being present in the lattices of clay minerals they are present as dispersed oxide and organic rich phases in the clay sediments. The association of Na and K, with silica indicate that these elements are 'lattice-held' and associated with alumino-silicates (fig. 6.12).

The clustering of the chemical constituents of the clay fractions in the mud bank sediments are shown in the figure 6.13. There is a strong correlation (table 6.7) between Al, Fe and Mn, Na, K and Ti and Co, Ni and Zn. From the comparative study of average concentration of the elements in the two environments, it is found that there is a higher concentration of Fe and Mn in the marine environment compared to the estuary, where as, Co, Ni and Zn shows an enrichment in the estuarine sediments. The lesser amount of Co, Ni and Zn in the marine environment can be attributed to the depletion in the amount of organic matter which has been discussed above. The salinity factor accelerates the desorption process of cobalt in the marine environment (Murthy and Veerayya, 1981). Though the trace elements are associated with organic matter, copper is found to be more in the marine environment and it shows a low degree of positive correlation with Mn. The flocculation experiment conducted by Zhiging et al. (1987) pointed out that with the increase of salinity the flocculation rate of copper reaches 76% compared to other trace elements such as zinc which shows only 28%. Copper which normally exist in the inorganic form behaves different from that of other elements as evidenced from the present study. Though the organic matter is less in the marine clays copper is enriched in the marine environment converse to Co, Ni and Zn. The strong association of Fe and Mn indicates an hydrogenous precipitation of hydrated oxides of iron and Mn from sea water and they are dispersed in the fine grained sediments. Murthy et al. (1981) has observed that major part of the Fe and Mn are non-lithogenous in origin and they are abundant in the innershelf region and it is attributed to the flocculation of colloids containing Fe and Mn oxides supplied by the rivers.

Na and K having very significant values are correlated with titanium pointing out its terrigenous dependence and are mostly abundant in the mineral phases.

CHAPTER - VII

SUMMARY AND CONCLUSIONS

This chapter summarises all the important and interesting observations. Main conclusions are drawn here from the integration of the results presented in the previous chapters. The studies deal with texture, mineralogy and geochemistry of the rivers, lake, mud banks and adjacent nearshore sediments between Azhikode and Purakkad along the central Kerala coast. In the present study, an attempt has been made to understand the source of the sediments for the formation of the mud banks along this coast.

Primarily the thesis is divided into six chapters based on the different aspects of the study. The first chapter includes general introduction of the study area, location, geographic setting, climate, rainfall, vegetation and geomorphology of the coast.

An exclusive treatment of mud banks have been dealt in the second chapter. The nature, theories of its formation, hydrography, suspended sediment distribution and behaviour of the suspensates through flocculation and deflocculation mechanisms are discussed in the chapter. Published literature since 1938 to 1989 forms the basis of the chapter and physical parameters such as waves and currents in this nearshore region have also been included to give a complete account of the phenomenon which is unique to the coast.

The method of study and the different analytical techniques are described in the third chapter. Detailed account of the observations are made under three subheadings, vez., (i) Objectives of sampling; (ii) field methods; and (iii) laporatory technqiues. The instruments used for the field studies as well as for the laboratory investigations are also discussed here. Textural studies of the sediments of different environments such as rivers, lake, beach, mud bank and adjoining nearshore region are documented in chapter 4.

The grain-size parameters of the river sediments show a general downstream decrease in the grain-size with medium to coarse grained sands in the upstream to very fine sands in the downstream. A polymodality is noted for majority of the upstream sediments. Though there is a variation in the textural attributes of the downstream sediments in the four major rivers, in general the sediments are poorly sorted. Upstream portions of the rivers show a similarity in their granulometric parameters. A high energy regime and proximity of the source area results in the coarseness and poor sorting of the sediments in the upstream side. A wide fluctuations in the skewness values from very negative to very positive is observed irrespective of the course of the river. Kurtosis of the river sediments decreases towards the south of the study area. Percentage of platykurtic sediments increases from Periyar towards Minachil and a decrease is noted in the Pamba ar sediments. The rivers of the southern region show a decrease in the kurtosis which could be due to the relatively lesser amount of coarser particles. CM pattern of the river sediment denotes a transportation mechanism, mainly as graded suspension or bottom suspension. Minor amount of rolled materials in the upper reaches and uniformly suspended sediments around the confluence is also indicated in the CM pattern

A dominance of silty clays and clayey silts are observed in the distribution pattern of the Vembanad lake sediments. The presence of zones containing medium to coarse sands in the lake are sparse. A comparison of the pre-monsoon and post-monsoon sediment distribution shows that the pre-monsoon sediments are finer with an improved sorting over the post-monsoon sediments. This is an index of mixing of sediments in the lake. The principal contribution of sediments by the rivers into the lake are during the monsoonal months. The dispersal of the coarser sediments in the lake during the monsoon results in the comparative coarseness of the post-monsoon sediments over the pre-monsoon sediments. The CM pattern shows that during post-monsoon the sediments are mostly transported by uniform and graded suspension. The pre- monsoon sediments being finer results in the reduced concentration of uniform and graded suspension compared to the post-monsoon.

The mud bank sediments are chiefly composed of clays and silty clays. The sediments collected seaward of the zone of occurrence of mud banks are coarser compared to the mud bank sediments. The percent distribution of clay sized materials increases from May to August and decreases from September to December in the mud bank region. A better sorting and a higher value of negative skewness are observed for mud bank sediments compared to the sediments beyond this zone.

The micro-environmental delineation of granulometric characteristics of the beach sediments are attempted. The size varies from coarse to very fine sand. It is observed that beach sands are relatively finer during May and immediately after the offset of monsoon. Most of the beach sands are moderately sorted and nearly symmetrical.

Chapter 5, is mainly dealt under two heads, (i) Heavy mineral assemblages; and (ii) clay mineralogical studies.

Heavy mineral studies of the central Kerala rivers indicate a high percentage of heavies in the medium size fraction, a moderate amount in the fine fraction and least percentage of occurrence in the coarse fraction. Generally, there is a decrease in the opaques and garnets in the finer sediments. An overall increase in the percentage of amphiboles, pyroxenes, sillimanite and epidote is noticed in the fine fraction. This could be due to the decrease in the competency and differential sorting based on the availability of these minerals in the sediments being transported. The important heavy minerals noted in the river sediments are opaques, hornblende, hypersthene, zircon, sillimanite, biotite, garnet, augite/diopside, rutile and monazite.

The coarse fraction studies of the Vembanad lake shows high percentage of sillimanite followed by opaques, hornblende, hypersthene, zircon, mica, garnet, tourmaline, monazite, rutile, chlorite and kyanite. The distribution of heavy mineral assemblages in the different zones, viz., Periyar, Estuarine, Muvattupuzha, Minachil and Pamba show concurrence with the percentage of heavy minerals of the contributing river.

The beach sands of pre-monsoon and post-monsoon are studied for their mineral distribution. The heavy-light mineral ratio of pre-monsoon sediments are 19.25 : 80.75 and in the post-monsoon, the ratio has increased to 43 : 57. This increase in the heavy mineral concentration could be due to the availability of heavies in the sediments brought by the rivers during the monsoon. The beach sands from Narakkal to Purakkad are chiefly composed of hornblende, opaques, hypersthene, sillimanite, zircon, kyanite, rutile, mica, garnet and monazite in their order of abundance.

The petrographic studies of the rock samples from the catchment areas of the drainage basin show a close resemblence to the heavy minerals of the rivers, lake, beach and innershelf sediments in their composition.

Geology of the catchment areas of the central Kerala rivers are presented in the table 7.1. It is found that in all the river sediments opaques, hornblende, hypersthene, zircon and sillinanite are the most dominating minerals. The abundance of these minerals are attributed to the source rocks such as charnockites and gneisses. The dominant mineral opaque is the quite common mineral in all the rocks and hornblende and hypersthene might have mainly derived from the gneisses and charnockites. A high amount of zircon is present in all the river sediments. This can be possibly from the charnockites and also it occurs as an important minor constituent in all the rocks. Sillimanite forms one of the important constituent in the river sediments. The khondalites and other gneissic rocks forms the important source rocks for the sillimanites. In addition to the above minerals, garnet, mica, augite/diopside, monazite, rutile etc. are also found in the river sediments.

In the Vembanad lake sediments, the concentration of sillimanite is very high when compared to the river sediments. Sillimanite being relatively a less denser mineral, it is widely distributed in the Vembanad lake which is a low-energy environment. Opaques and other high density minerals remains in the river mouth region.

In the beach sands, there is a considerable increase in the percentage of hornblende and hypersthene during post-monsoon season. The abundance of hornblende and hypersthene could be due to the disintegration of the hard rocks, such as charnockites and hornblende gneisses dumped along the shore for the construction of groines and sea walls on the beach face.

Clay mineralogical studies indicate that the dominant clay mineral is kaolinite followed by montmorillonite, illite and gibbsite in the rivers, lake, mud bank and in the adjacent nearshore areas. The percentage of kaolinite shows a decrease towards the marine environment. It is suggested that an interplay of the source rock and the climatic conditions designate the pattern of change from river to the marine environment. The gradual depletion of kaolinite percentage from terrestrial to marine environment could be due to the physico-chemical characteristics of the environment. Mainly, the circulation pattern and salinity differences segregates the clay minerals.

An enrichment of montmorillonite towards the marine environment could be due to the following reasons. The grain-size of the montmorillonite being smaller compared to the other clay minerals, the amount of montmorillonite supplied through the estuarine system is comparatively more. This is evidenced by the sequential increase of montmorillonite content from river to estuary to marine environment. The montmorillonite content in the mud bank suspension is found to be high. This could be due to the flocculation of kaolinite and illite at low chlorinity, whereas the flocculation of montmorillonite takes place at high chlorinity. This preferential settling of montmorillonite is attributed to the very stable double layer of montmorillonite. Apart from this, the previous studies have shown that the outershelf area is rich in montmorillonite content which is believed to be from the northern part of the western shelf carried to the south by southwest monsoon drift. Onshore transport during the onset of monsoon can also account for the increase of montmorillonite in the nearshore area. Thus essentially, the nearshore sediment deposition is a function of sediment supply from the hinterland by the rivers and also by deposition from the offshore favoured by the littoral current regime.

Chapter 6 deals with the geochemistry of the sediments. Elemental variation in the bulk sediments of mud bank region show two significant groups of clustering. (1) A strong group comprising of clay, organic matter, iron, manganese, potassium, aluminium, sodium and phosphorus. Significant loading of these elements show that the clay rich sediments are abundant in organic matter and phosphorus owing to the large surface area of clay particles. The clay fraction is abundant in alumino silicate thus indicating sympathetic relation ship with aluminium, sodium and potassium. A direct correlation of iron with alumina indicates that the iron is held in the structured lattices of the alumino silicates. The second group containing cobalt, nickel and zinc in turn is related to the first group. This geochemical speciation could be inter-related to the dispersed oxide phase and also to the aluminium silicate factor.

Cluster analysis of the clay sediments of the Vembanad lake and mud bank sediments show that, in the lake the inter-relation of the chemical elements gives two major significant groups, the first one comprises of aluminium, copper, cobalt, nickel and zinc and the second one is that of sodium and potassium which in turn is related to silica. In the first group, the relation between copper, cobalt, nickel and zinc show high correlation values but its relationship with aluminium is not highly significant. Since sodium, potassium and silica are behaving in contrast to the first group, it indicates an enrichment of the first group elements in the estuarine environment.

The clustering of the mud bank sediments show a strong correlation between aluminium, iron and manganese; sodium, potassium and titanium; and cobalt, nickel and zinc. The comparative study of average concentration of the elements in the two environments show that there is a higher concentration of iron and manganese in the marine environment compared to the lake, whereas, cobalt, nickel and zinc show an enrichment in the lake sediments. Though the trace elements are associated with organic matter, copper is found to be more in the marine environment. The association of copper is attributed to the difference in the terrigenous input and its variation in the clay minerals.

The following are the important conclusions drawn from the study.

1. Mud bank formation is found only at certain localities of the Kerala coast during the active South-West monsoon season.
2. Mud bank sediments are chiefly composed of clays and silty-clays. The clay content increases towards the peak of the mud bank formation and decreases thereafter. Wide variations are observed in the textural pattern of the rivers and lake sediments. A fining up pattern of sediment grain-size from terrestrial to marine environment is significant.
3. An interplay of source and hydraulic control is observed in concentrating different heavy minerals in the rivers, lake and nearshore sediments. This is indicative of a substantial terrigenous input into the nearshore area.
4. Clay mineralogical studies of the rivers, lake and mud bank sediments reveal that the dominant clay mineral is kaolinite followed by montmorillonite, illite and gibbsite. The sequential decrease of kaolinite and increase of montmorillonite from river to marine environment is very striking. This is suggestive of an additional input of sediments from offshore apart from the land derived part through rivers.

5. Geochemical analysis of the Vembanad lake and mud bank sediments show that the iron and manganese are widely distributed both in the lake and mud bank sediments. The strong association of iron and manganese indicate a hydrogenous precipitation from seawater and they are dispersed in oxide phases in the fine grained sediments.

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Appendix - I

LIST OF FIGURES

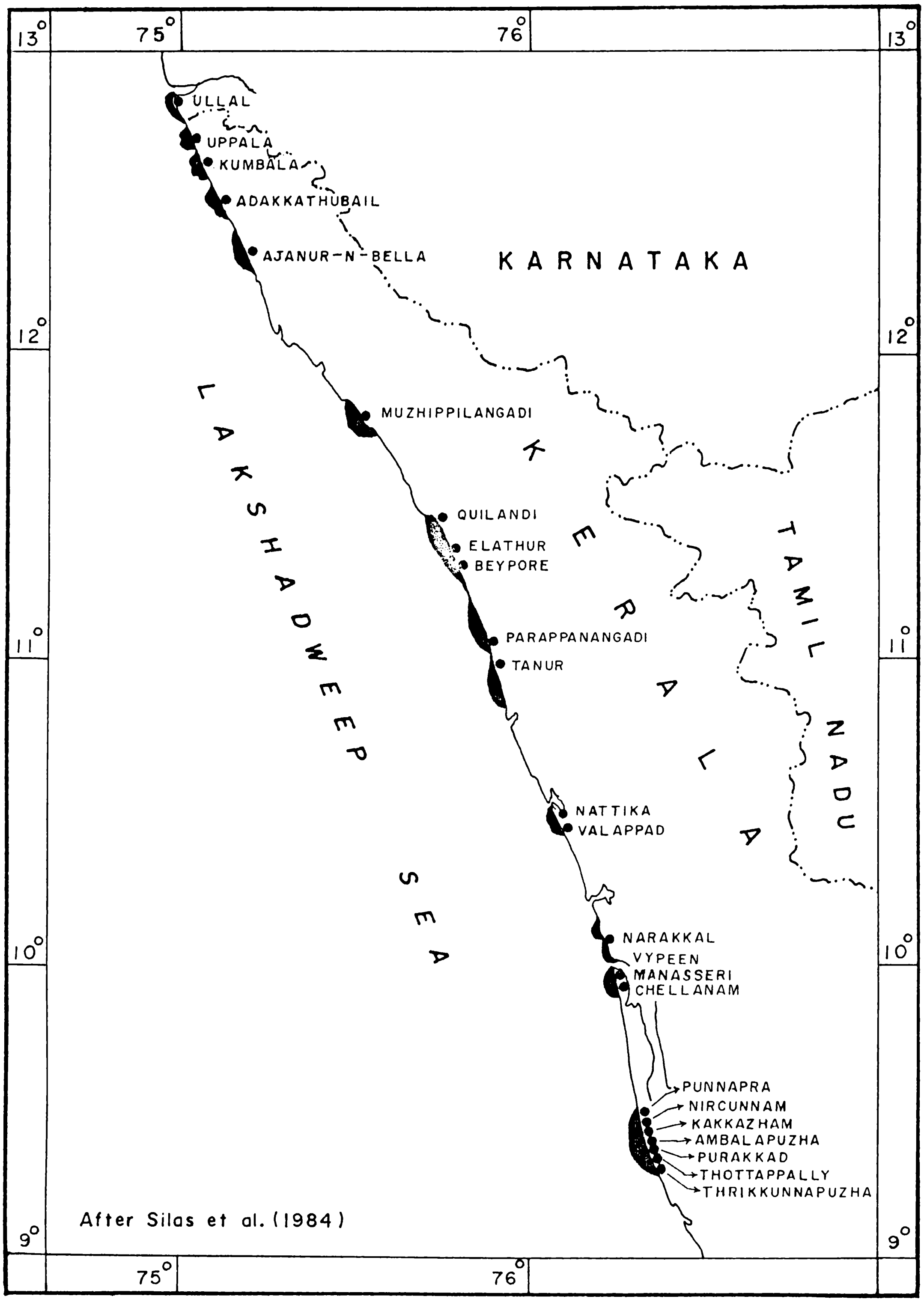


FIG. 1.1. AREAS OF MUDBANK FORMATION ALONG THE KERALA–KARNATAKA COAST.

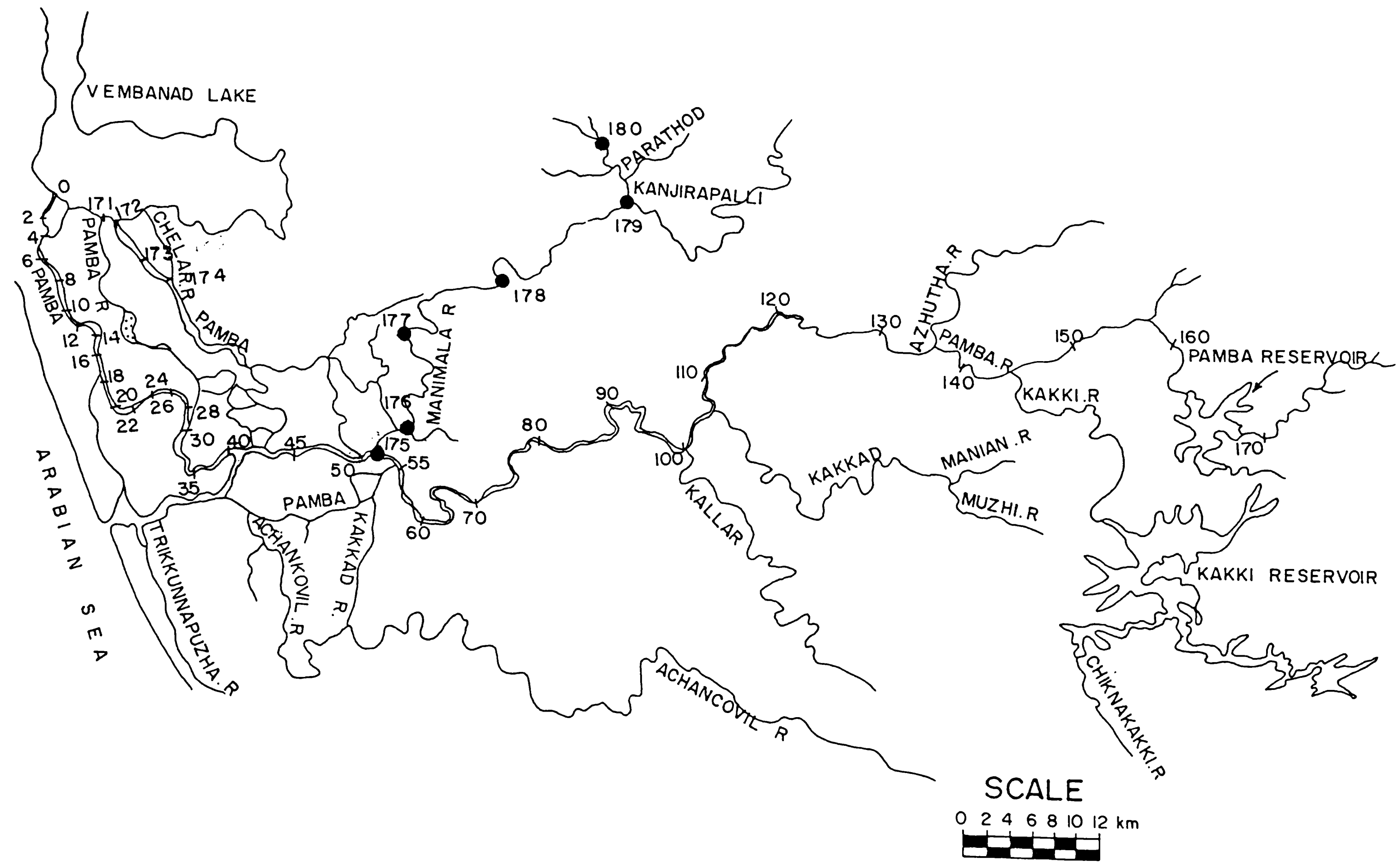


FIG. 3·1 PAMBA RIVER SYSTEM

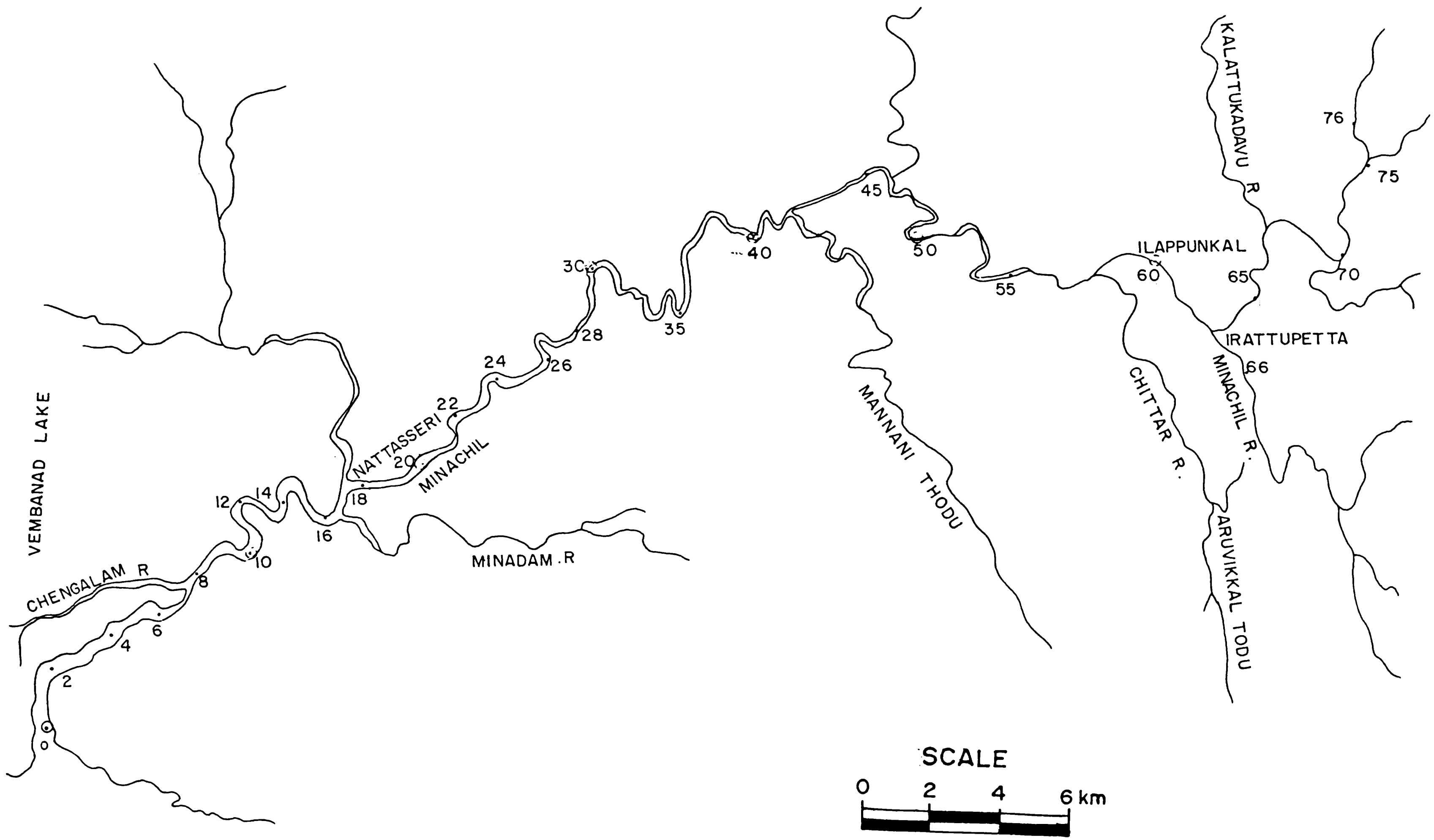


FIG. 3·2 MINACHIL RIVER SYSTEM

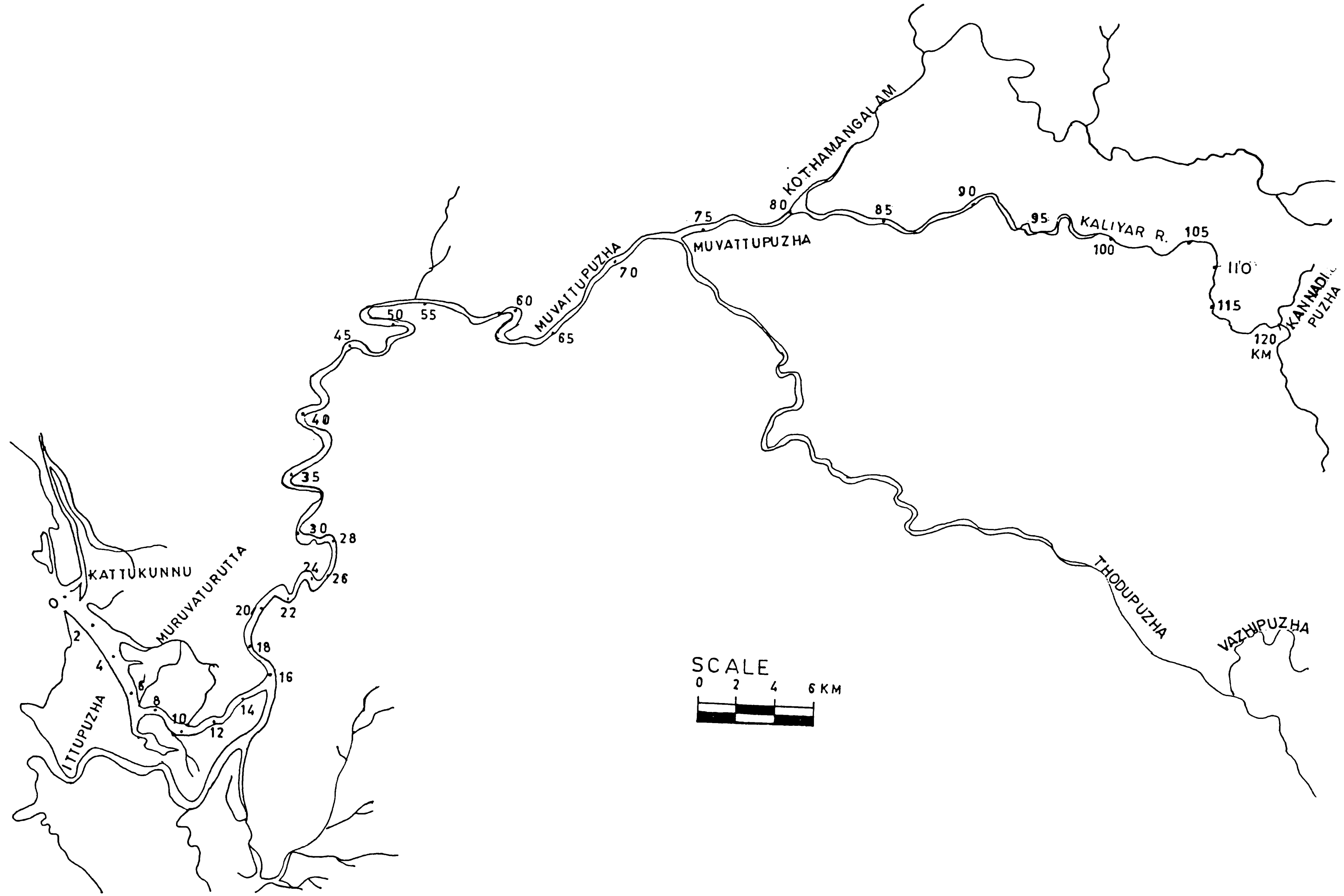


FIG. 3.3 MUVATTUPUZHA RIVER SYSTEM

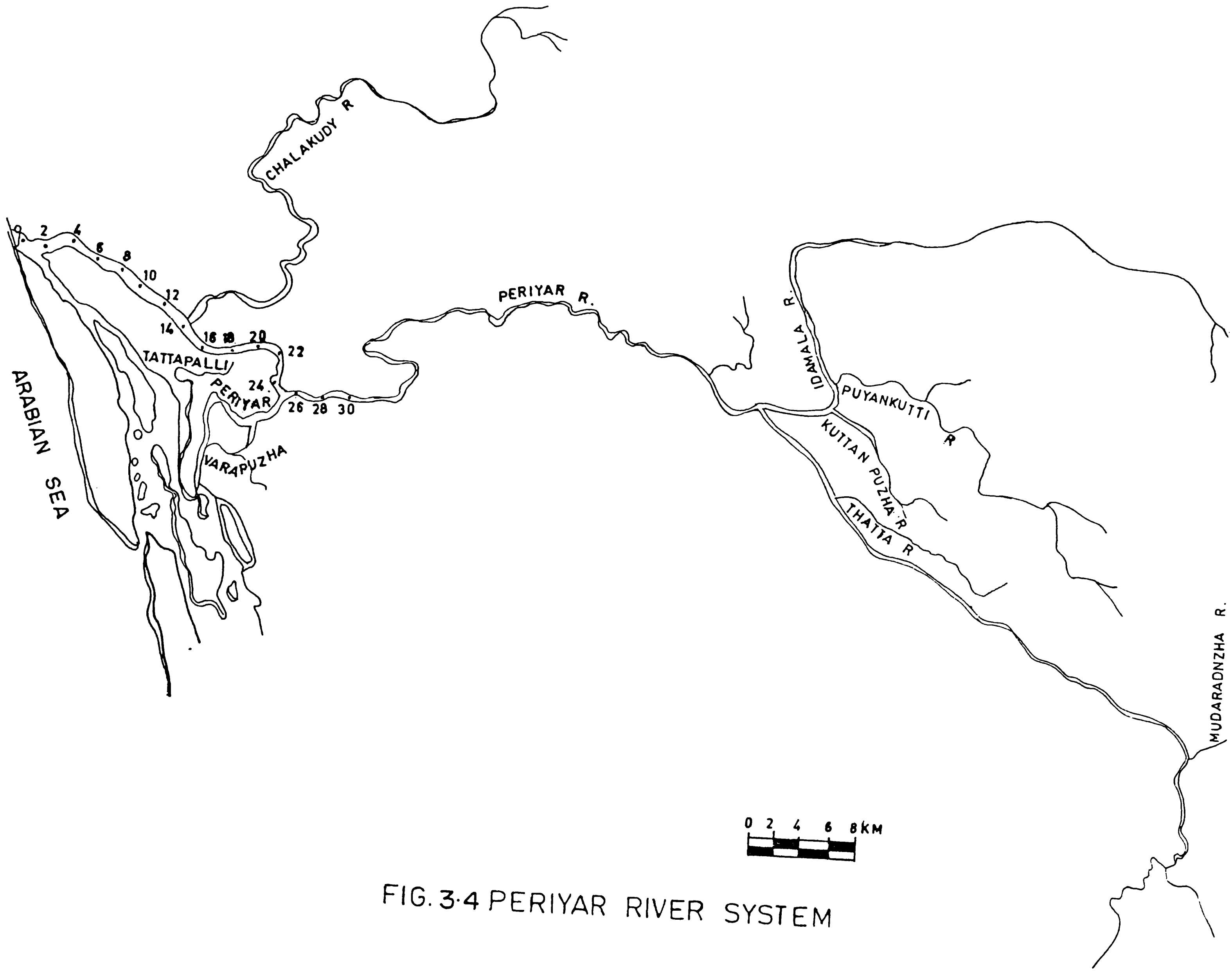


FIG. 3·4 PERIYAR RIVER SYSTEM

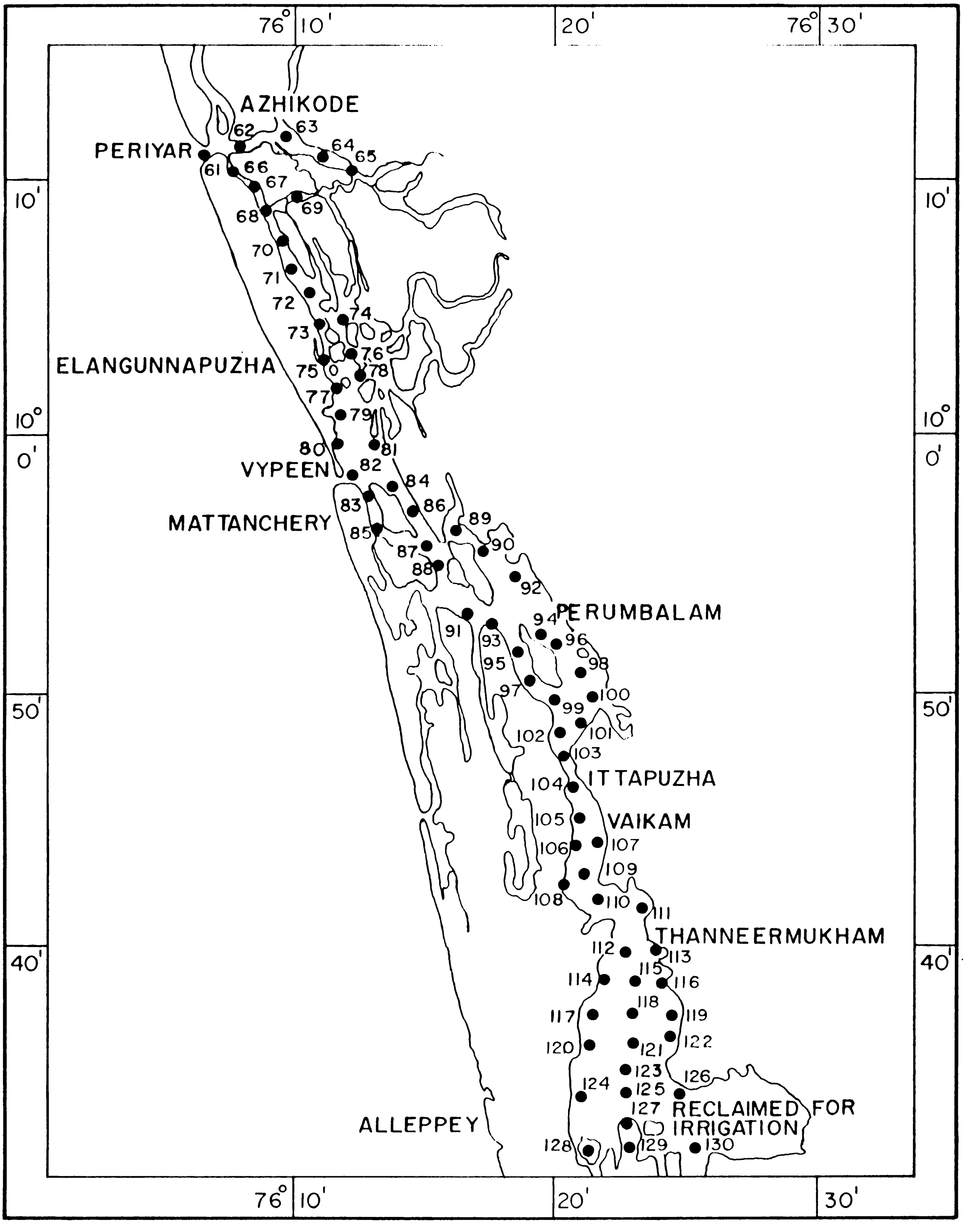


FIG_3_5a. SAMPLING LOCATIONS OF VEMBANAD LAKE SEDIMENTS (PRE-MONSOON)

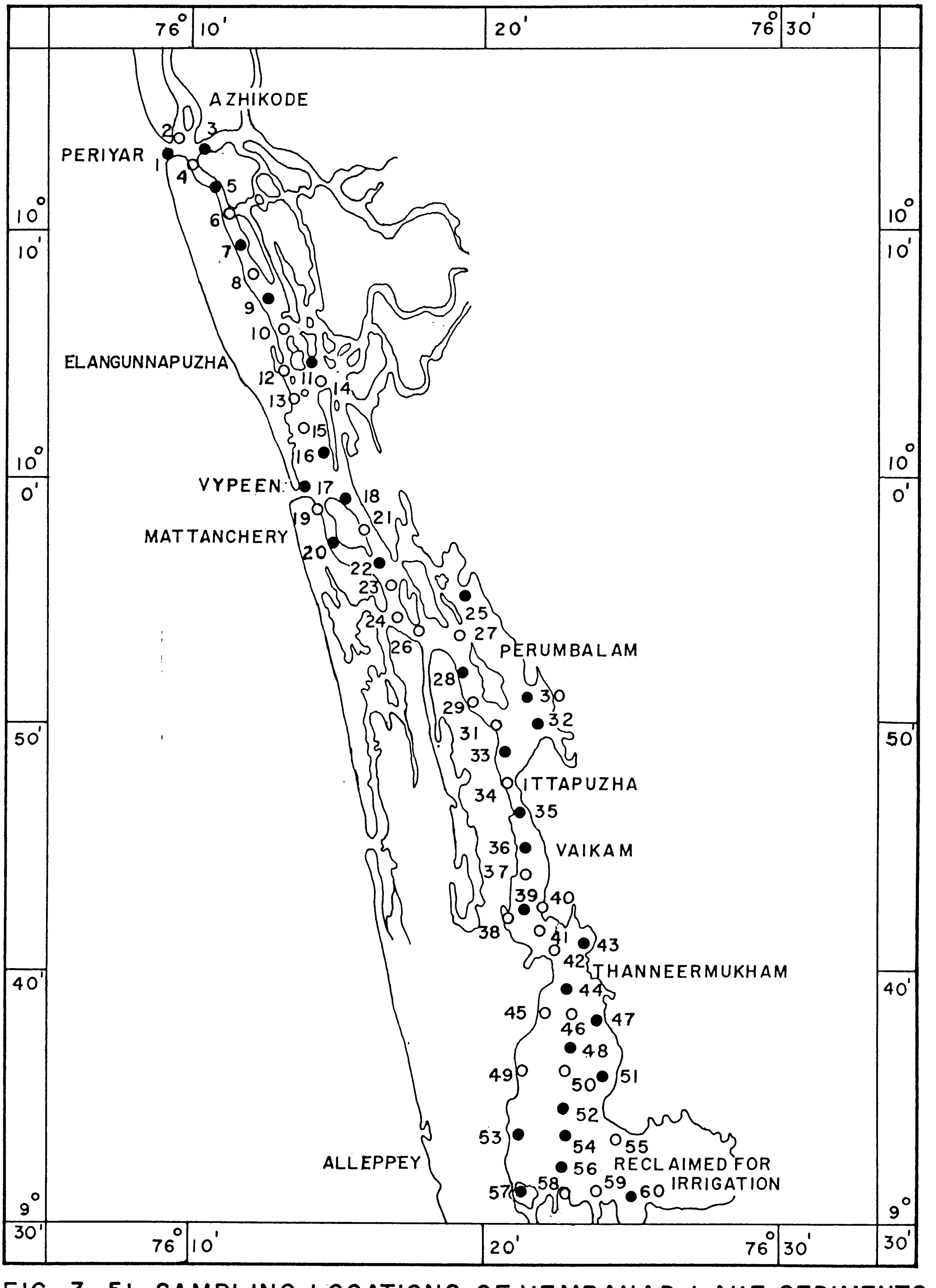


FIG_3_5b. SAMPLING LOCATIONS OF VEMBANAD LAKE SEDIMENTS (POST-MONSOON)

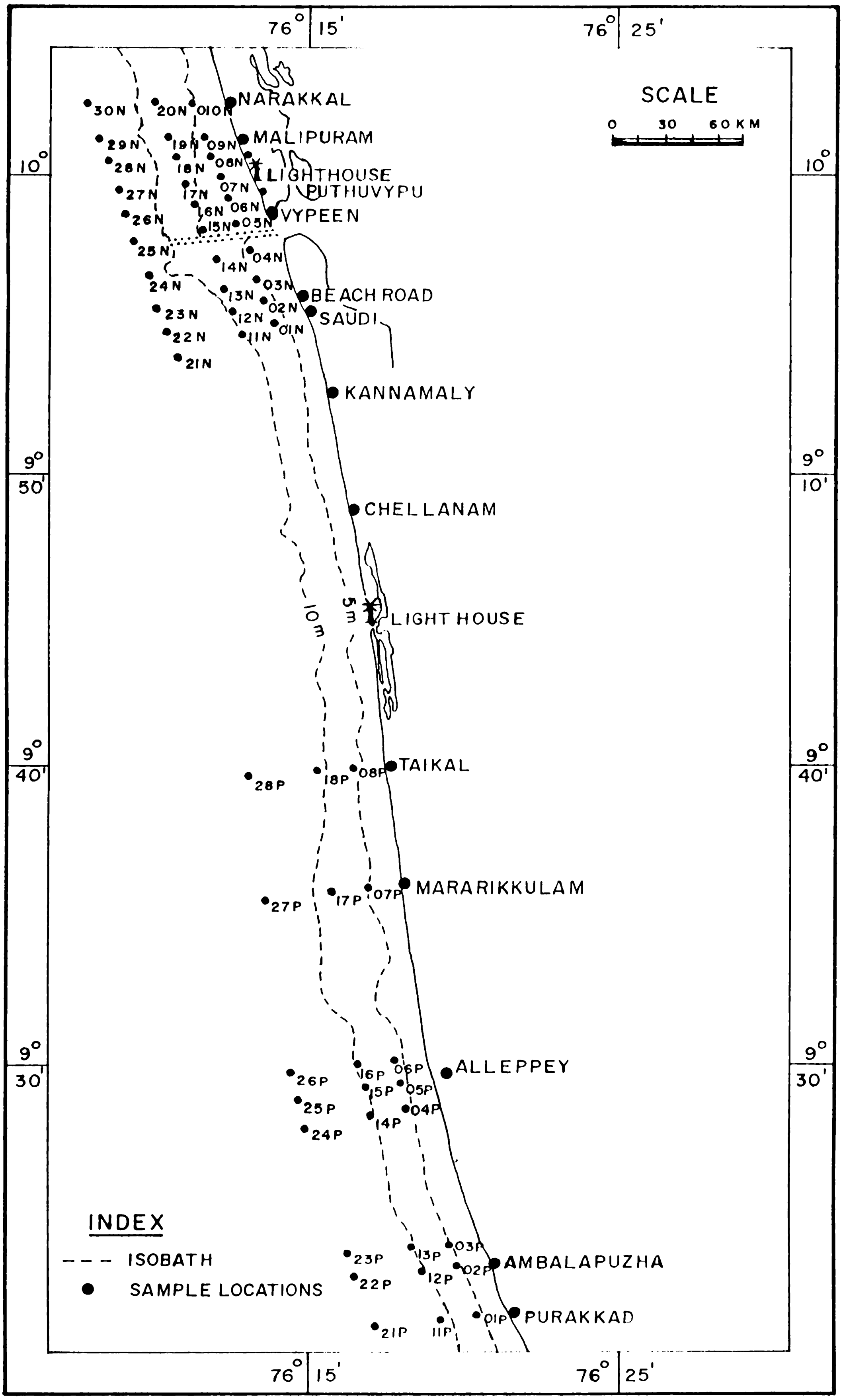


FIG. 3.6. SAMPLING LOCATIONS OF THE MUDBANK SEDIMENTS

PAMBA AR

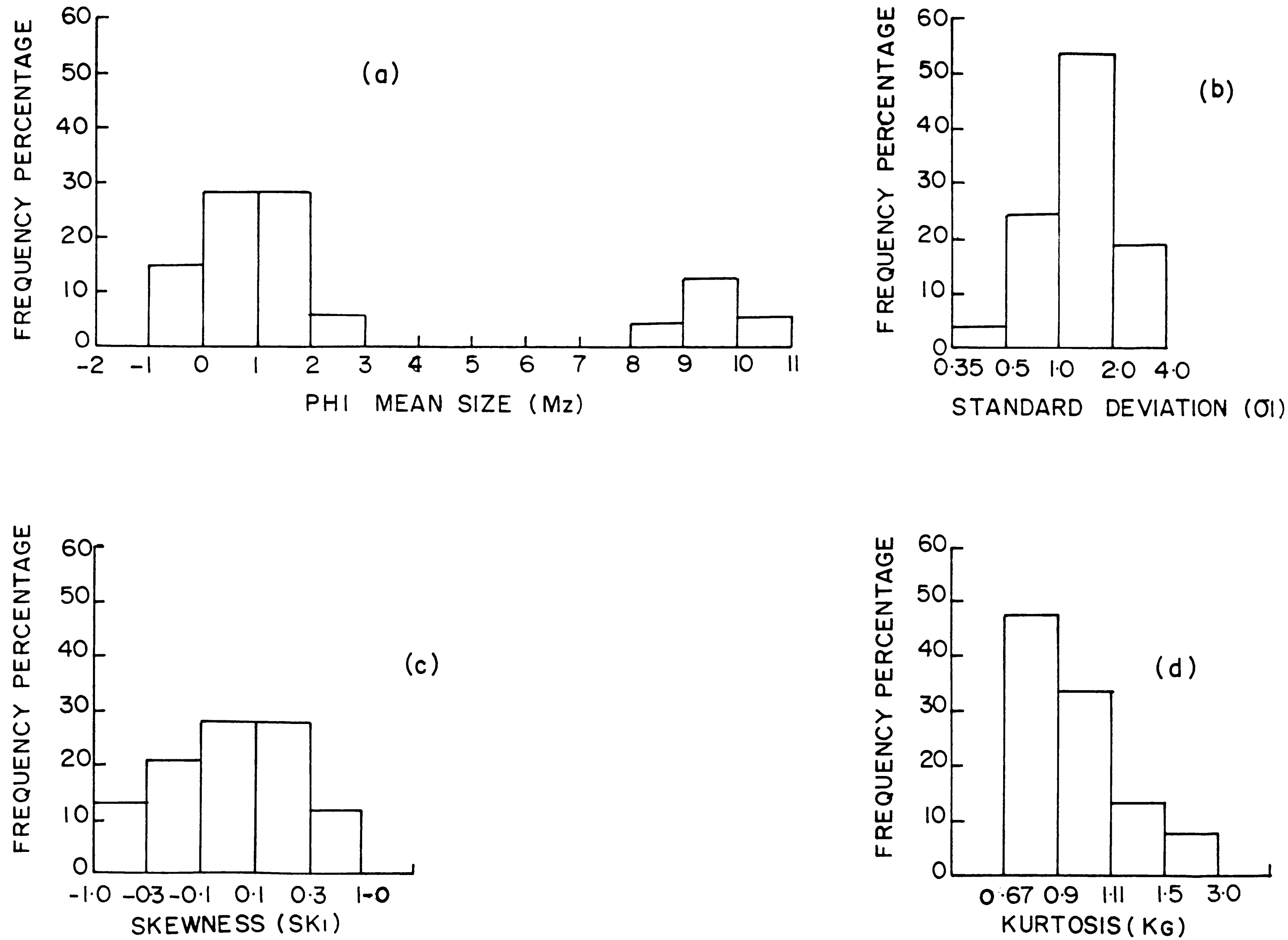


FIG. 4·1 FREQUENCY DISTRIBUTION IN% Vs GRAIN SIZE PARAMETERS

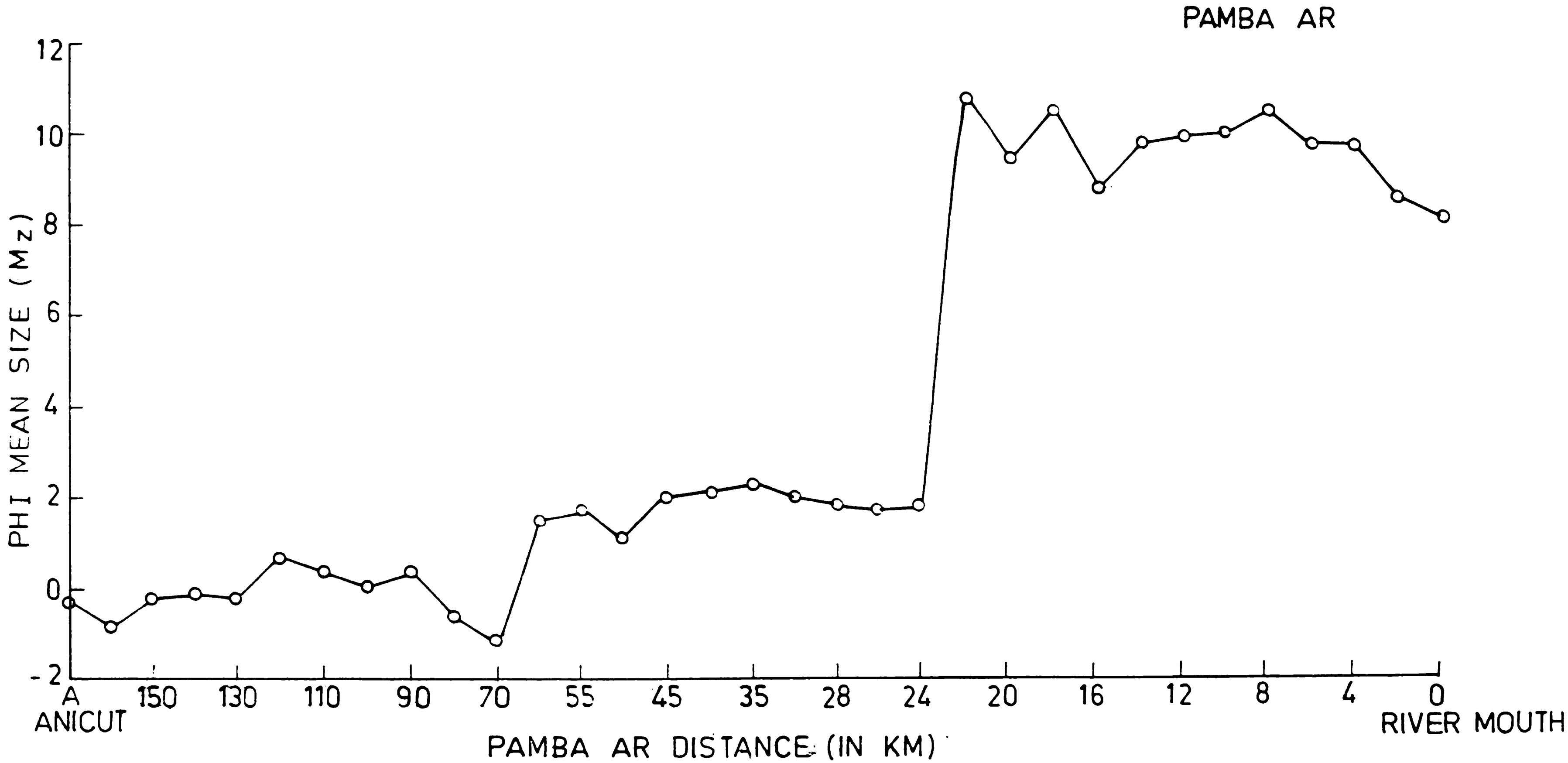


FIG. 4·2a PHI MEAN SIZE (M_z) Vs PAMBA AR DISTANCE (IN KM)

FIG.4·2b STANDARD DEVIATION (σI) Vs PAMBA AR DISTANCE IN KM

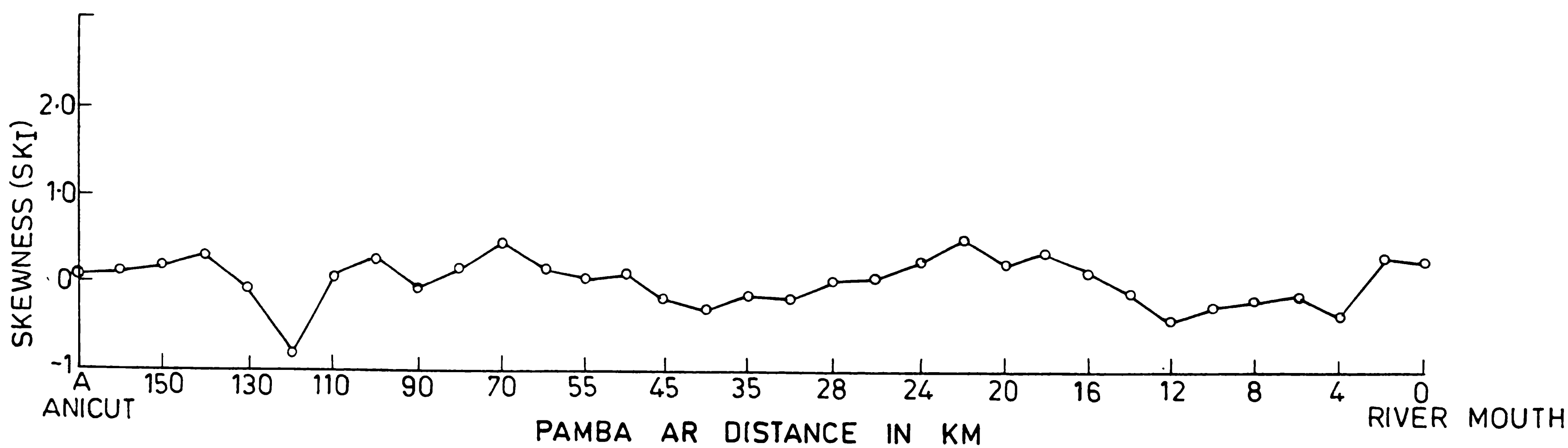


FIG. 4·2c SKEWNESS (SKI) Vs PAMBA AR DISTANCE IN KM

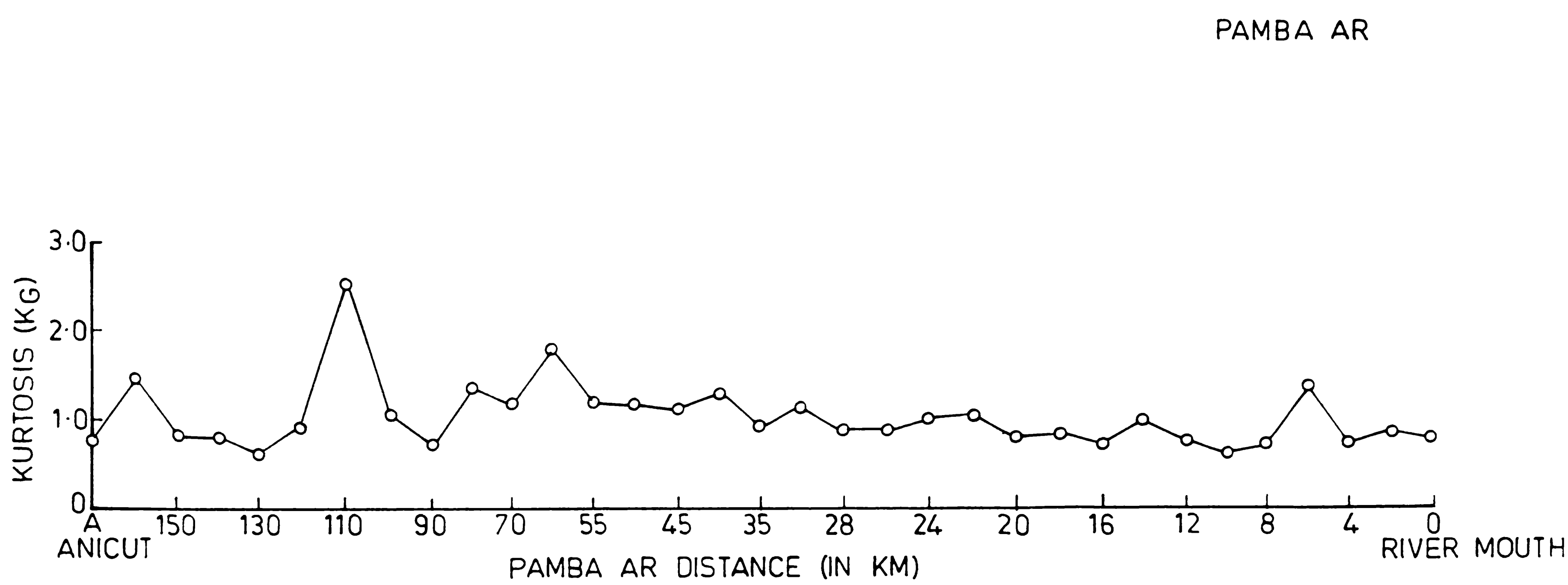


FIG 4·2d KURTOSIS (K_G) Vs PAMBA AR DISTANCE (IN KM)

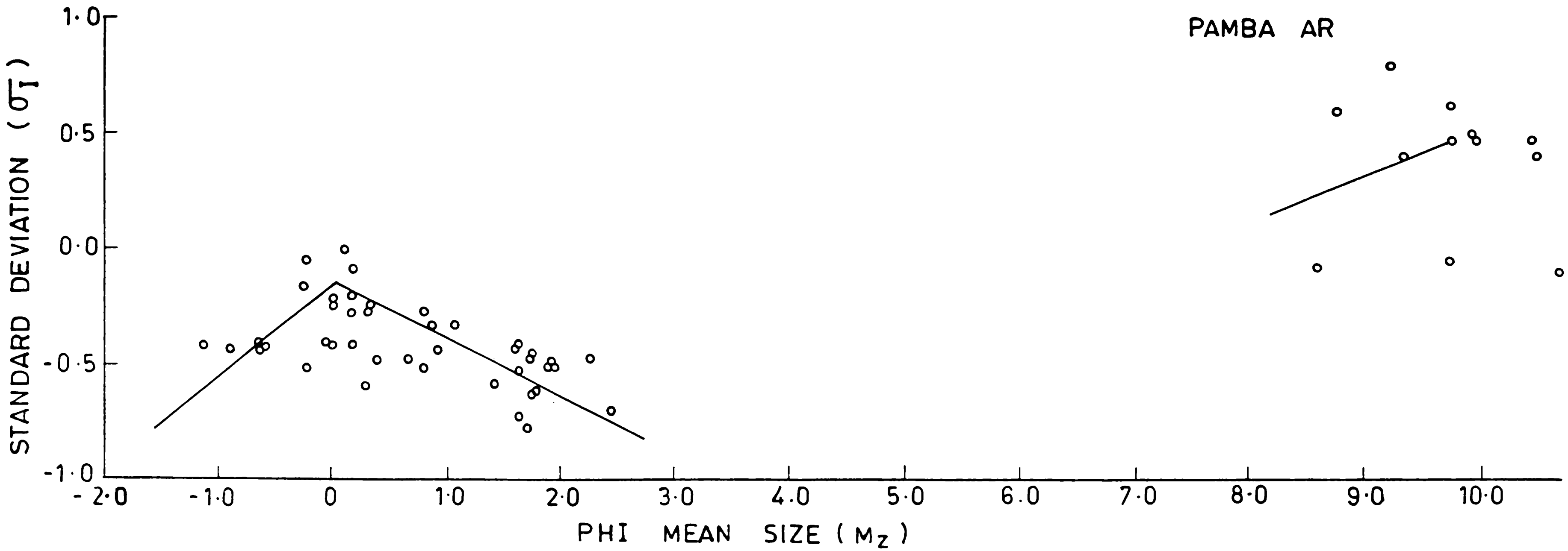


FIG 4·3 a PHI MEAN SIZE (Mz) Vs. STANDARD DEVIATION (σ_I)

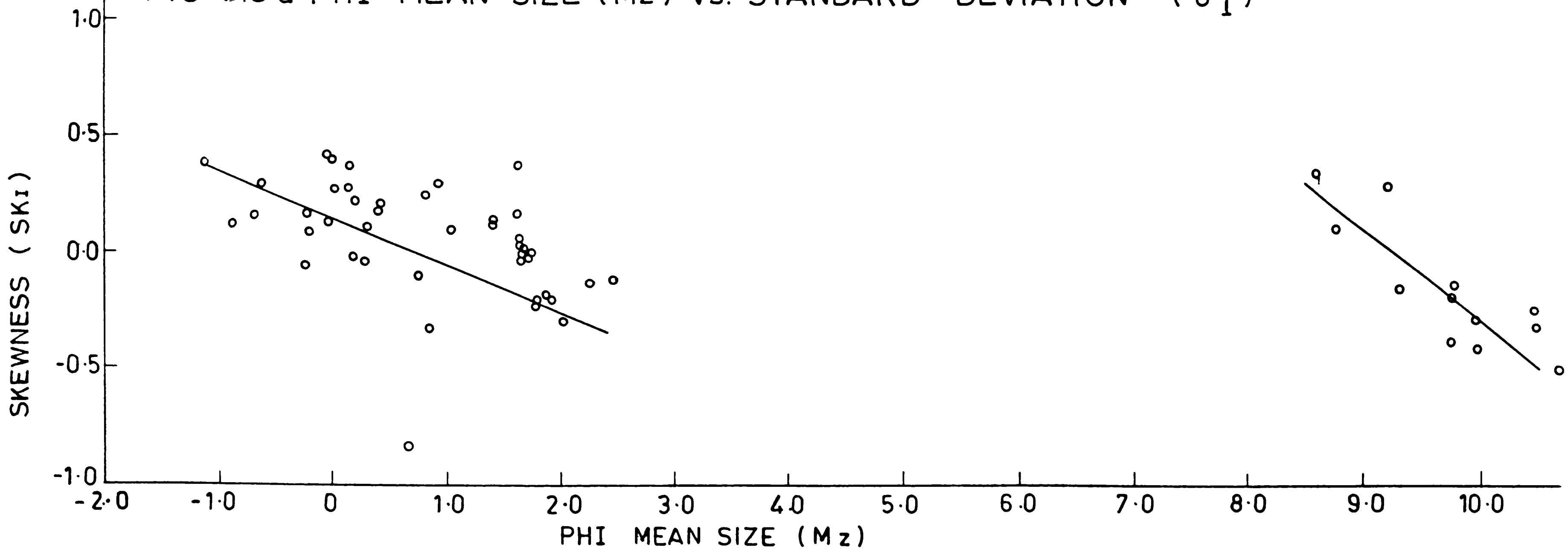


FIG 4·3b PHI MEAN SIZE (Mz) Vs SKEWNESS (SKI)

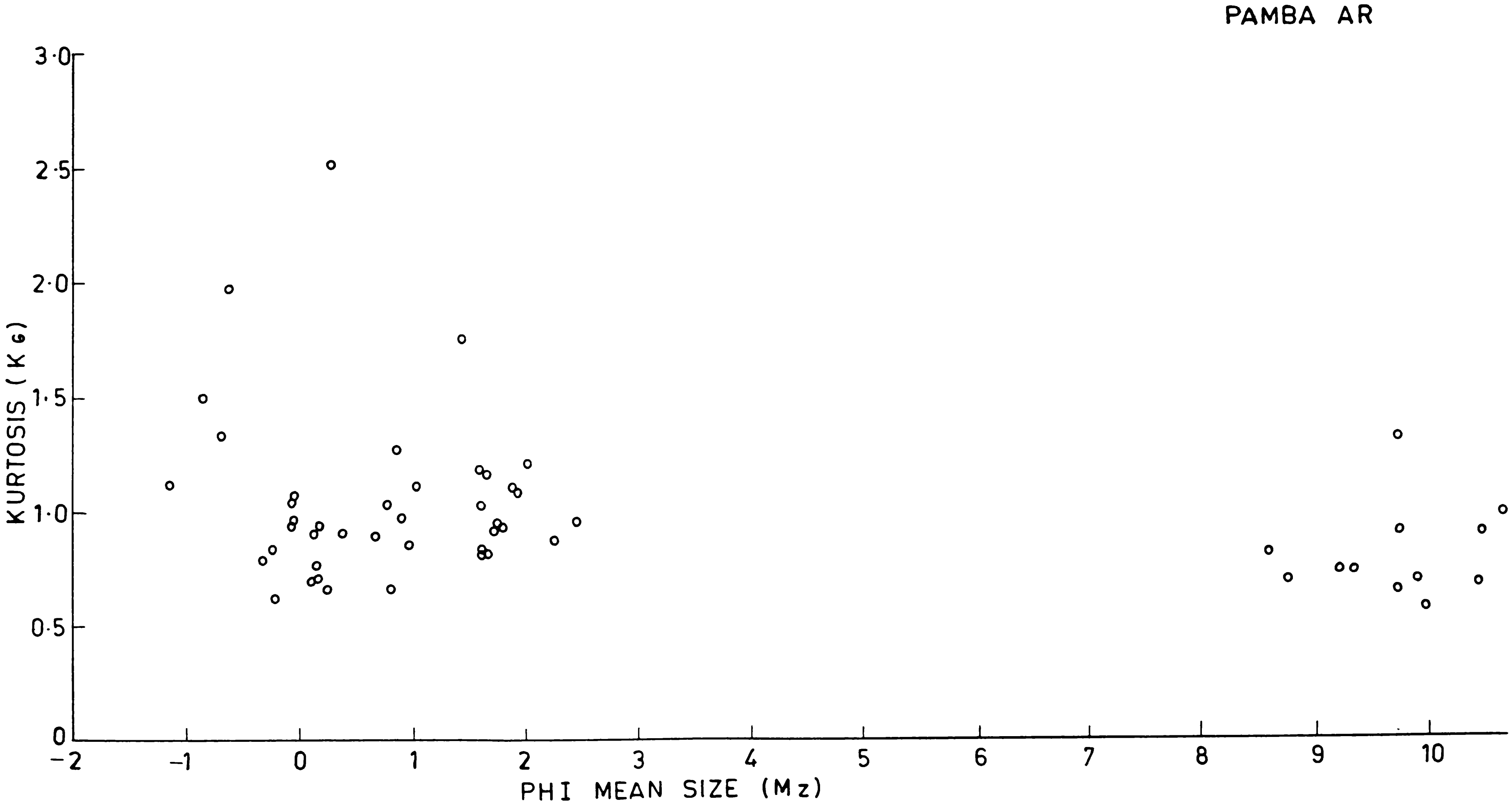


FIG 4·3c PHI MEAN SIZE Vs KURTOSIS (K_G)

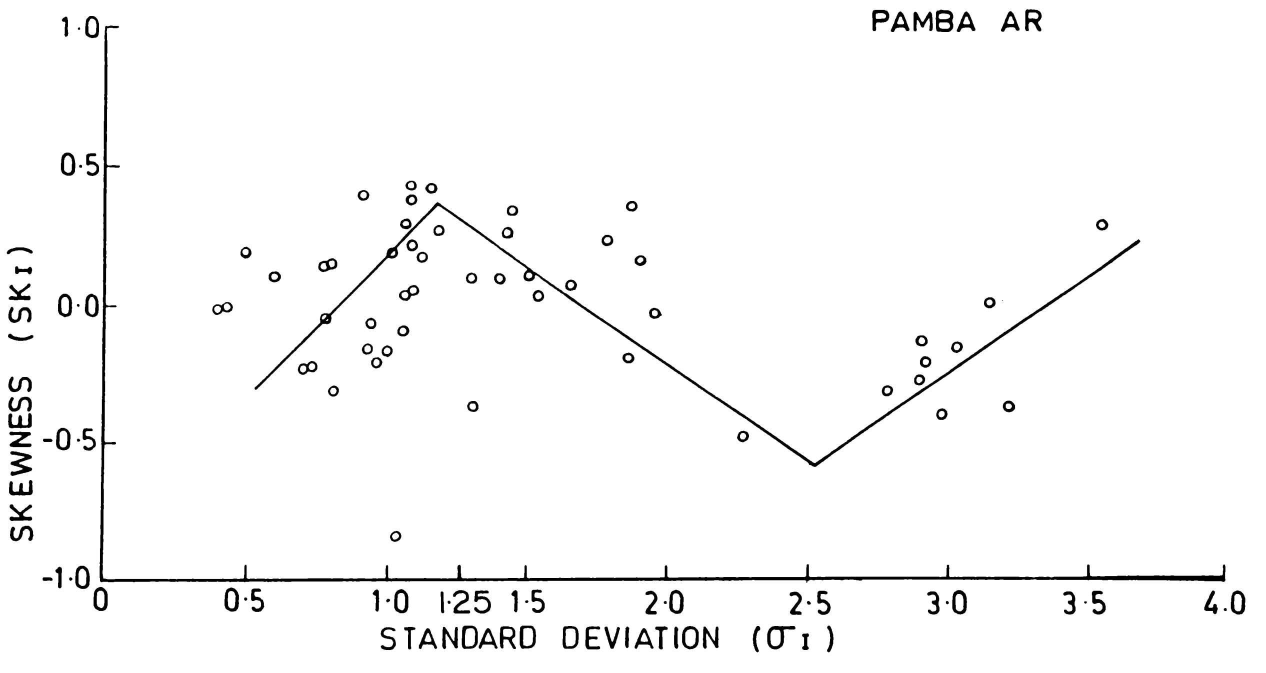


FIG4·3d STANDARD DEVIATION (σI) Vs SKEWNESS (SKI)

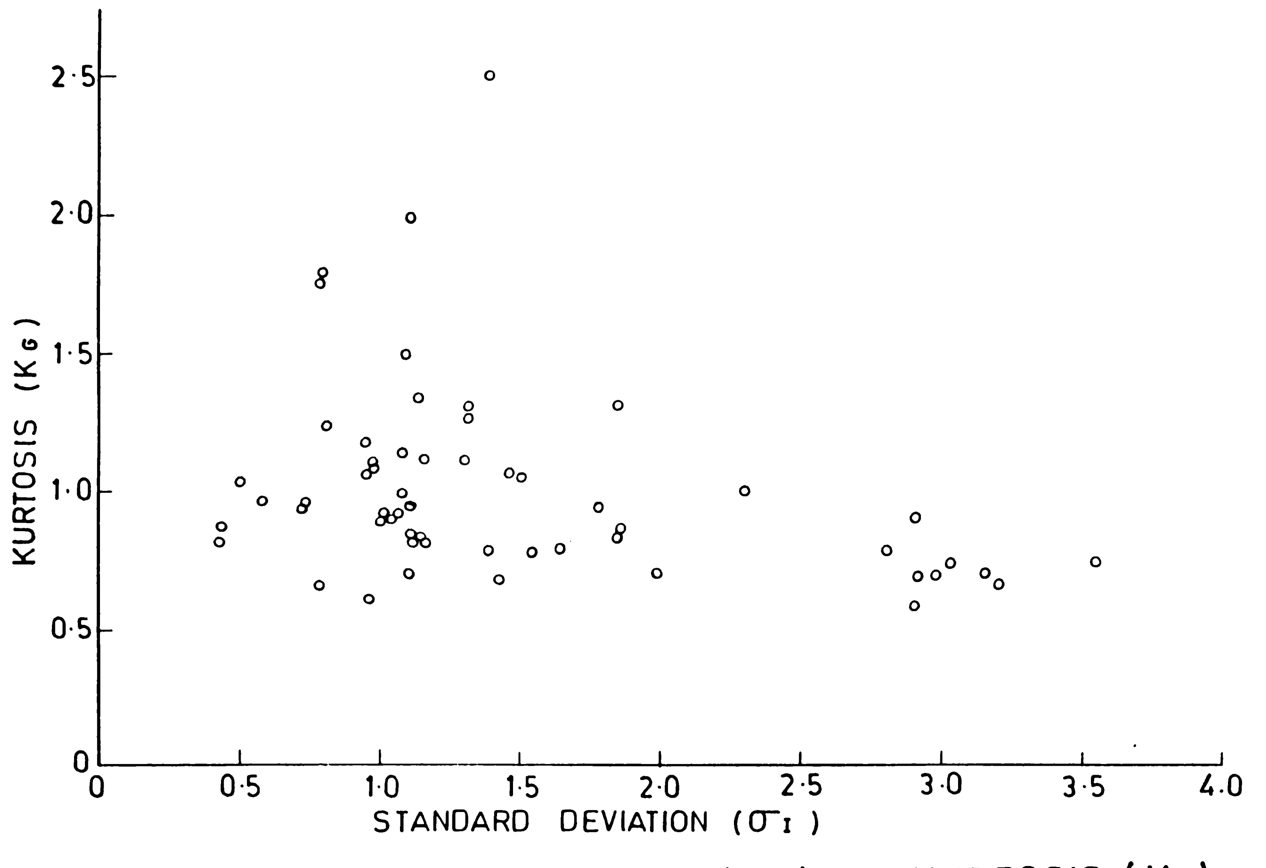


FIG4·3e STANDARD DEVIATION (σI) Vs KURTOSIS (KG)

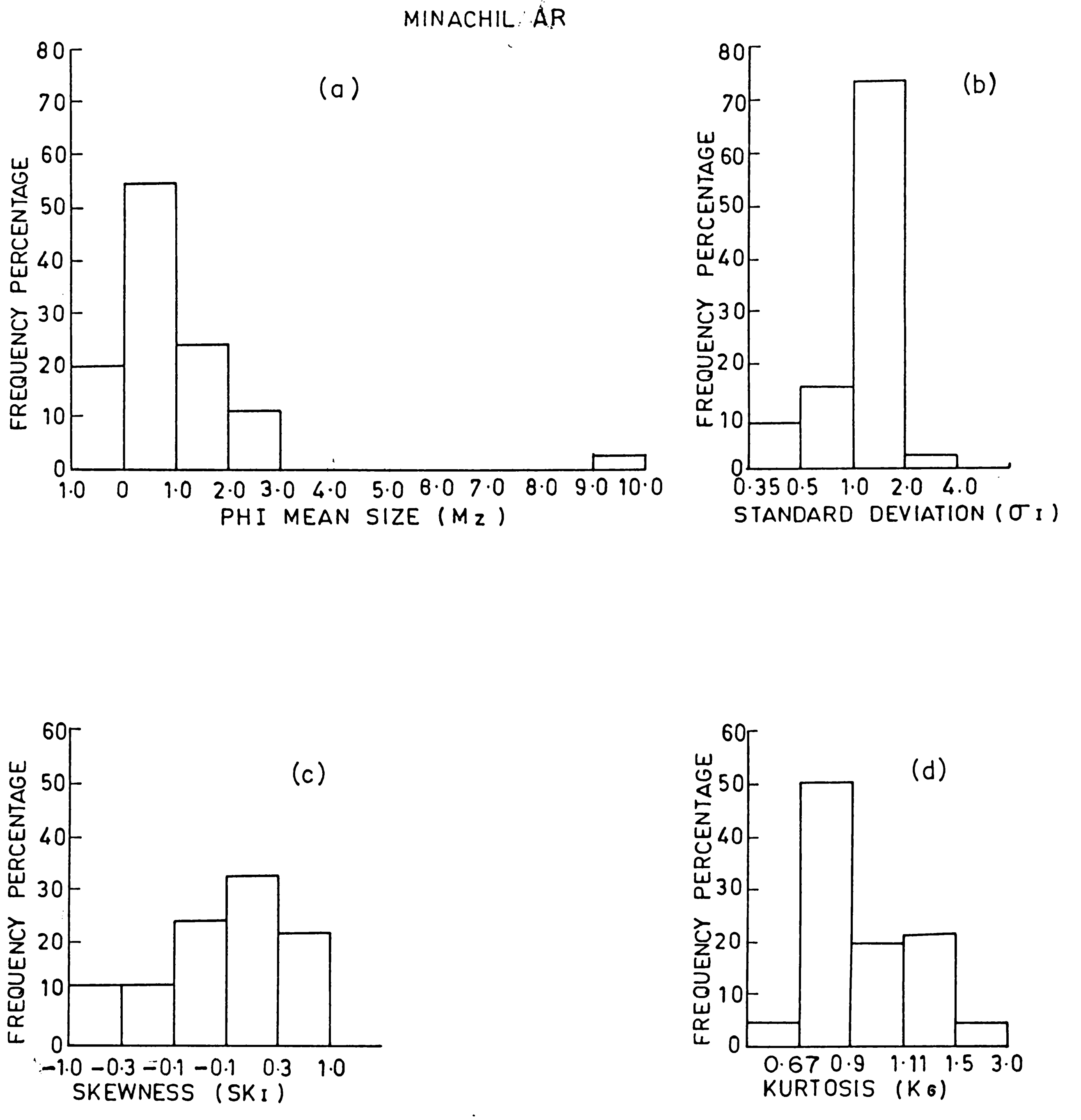


FIG.4·4 FREQUENCY DISTRIBUTION (IN %) Vs GRAIN SIZE PARAMETERS

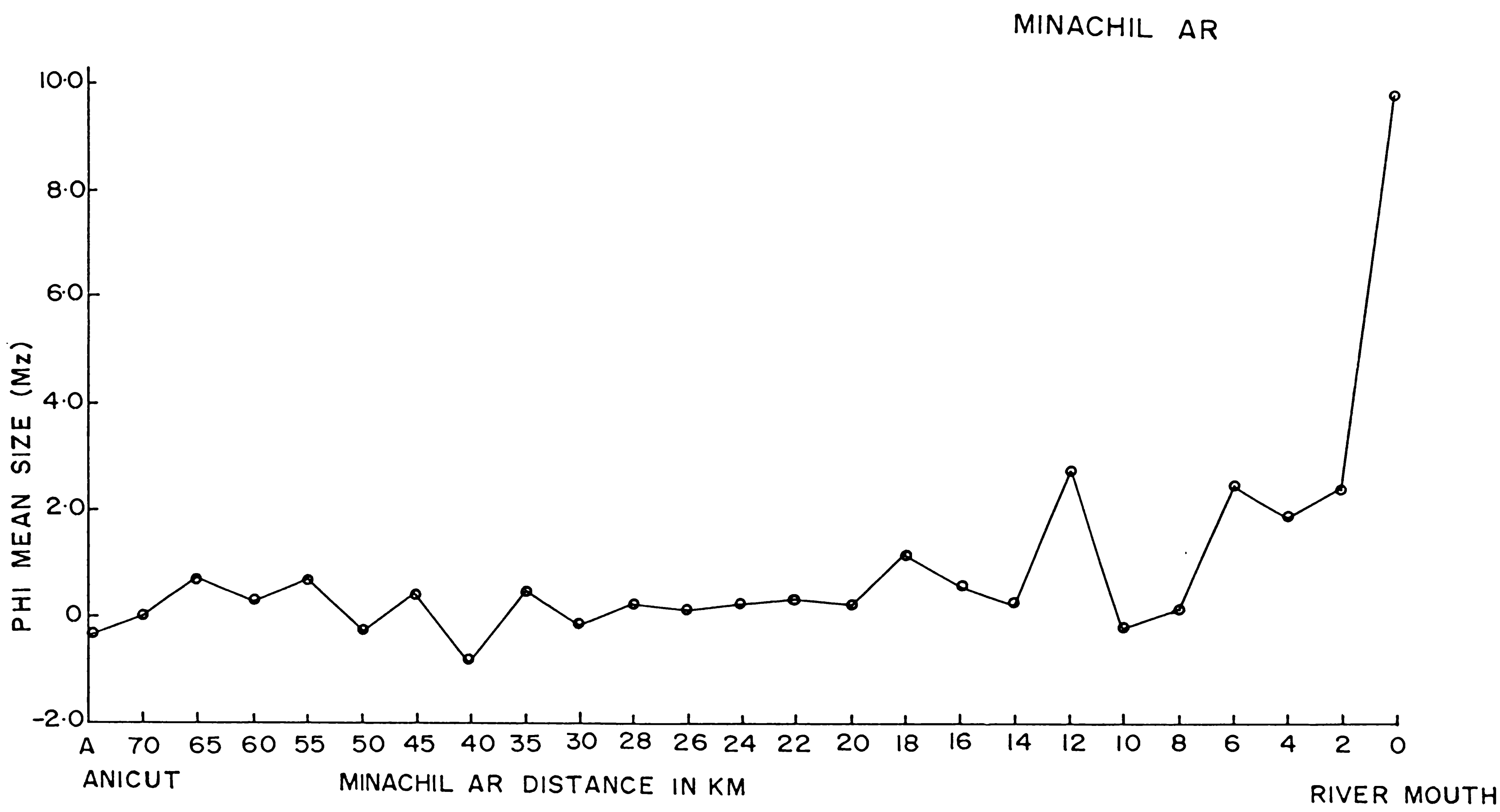


FIG. 4·5a. PHI MEAN SIZE (Mz) Vs MINACHIL AR DISTANCE (IN KM)

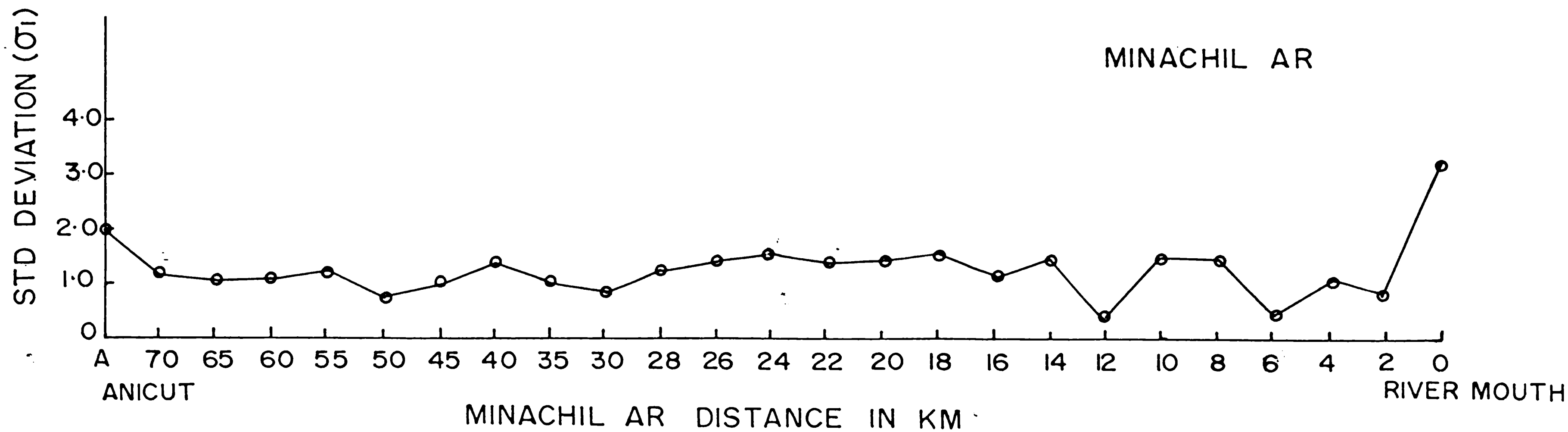


FIG. 4·5b. STD DEVIATION (σ_1) Vs MINACHIL AR DISTANCE (IN KM)

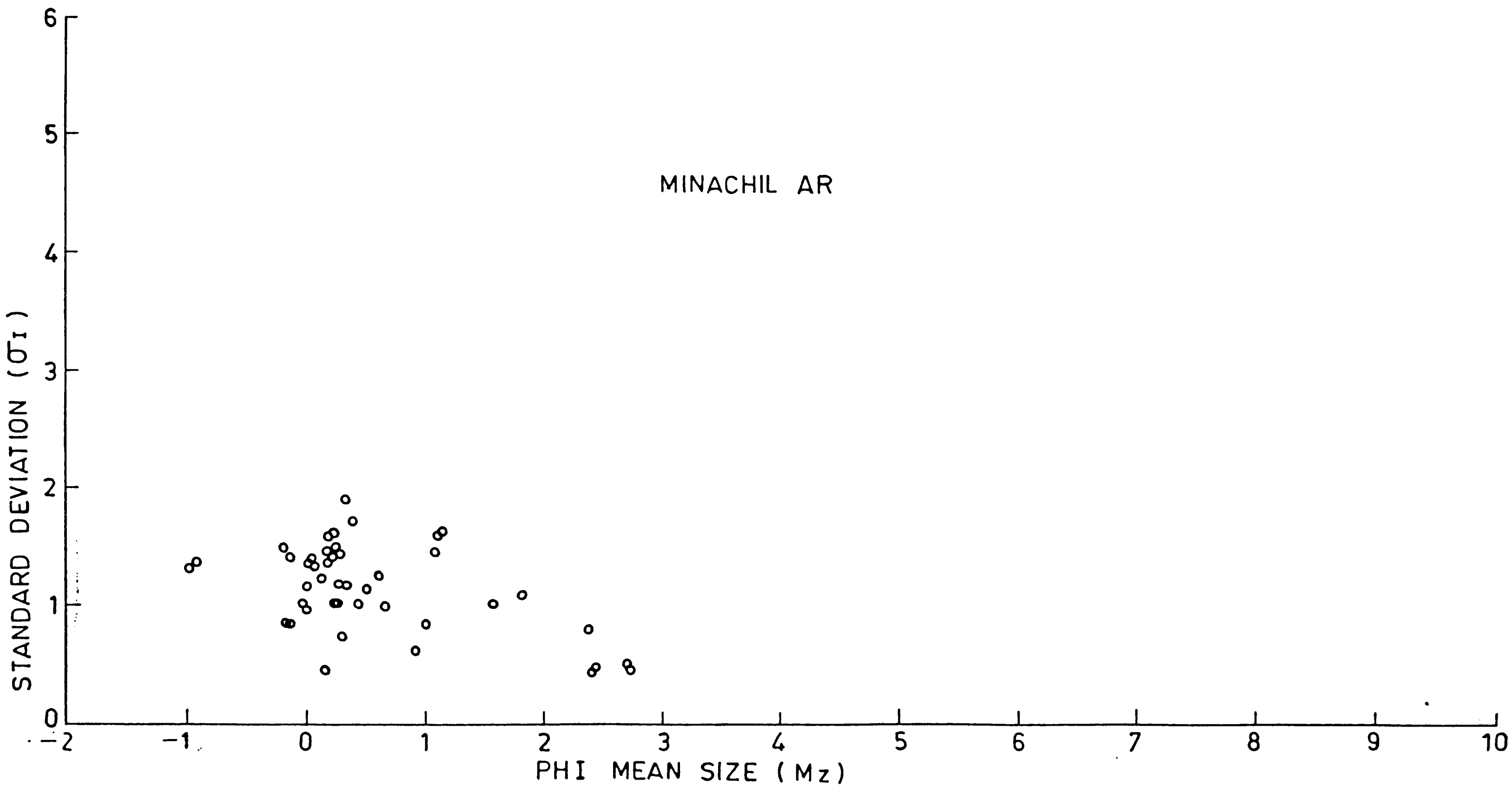


FIG.4·6a PHI MEAN SIZE (Mz) Vs STANDARD DEVIATION (σ_I)

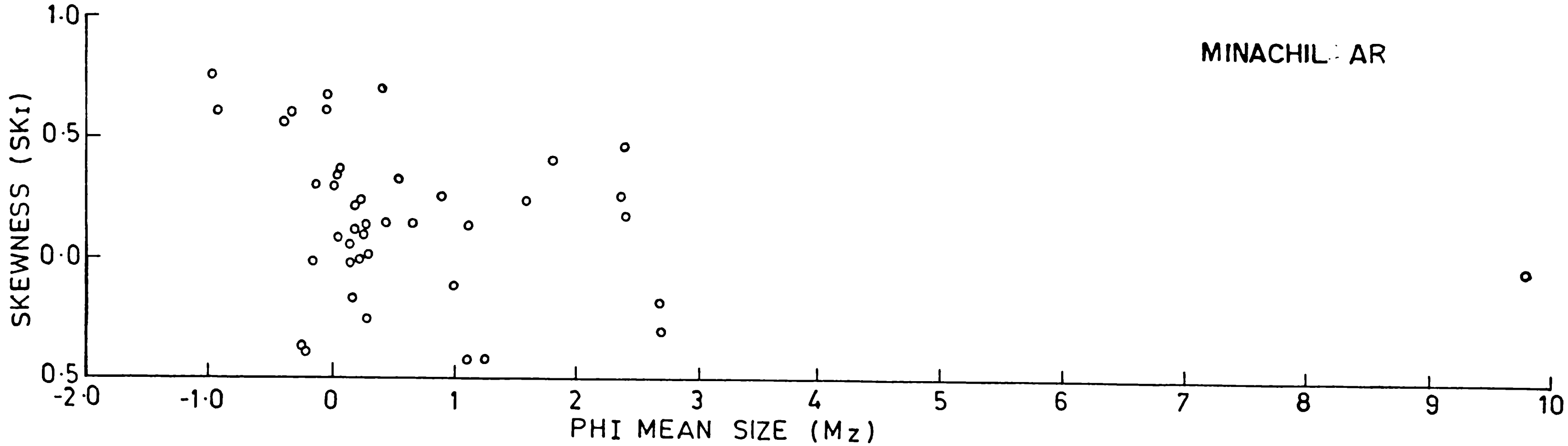


FIG.4·6b PHI MEAN SIZE (Mz) Vs SKEWNESS (SKI)

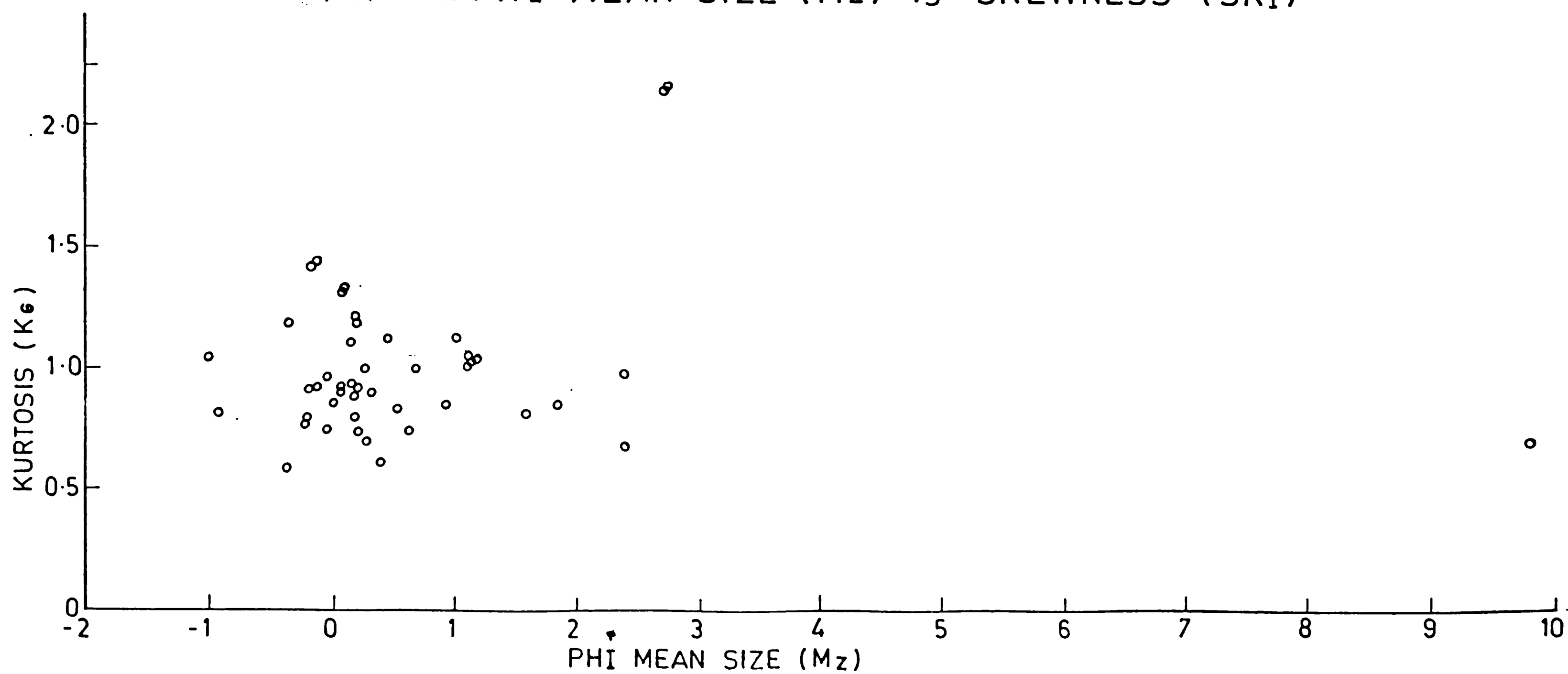


FIG.4·6c PHI MEAN SIZE (Mz) Vs KURTOSIS (KG)

MINACHIL AR

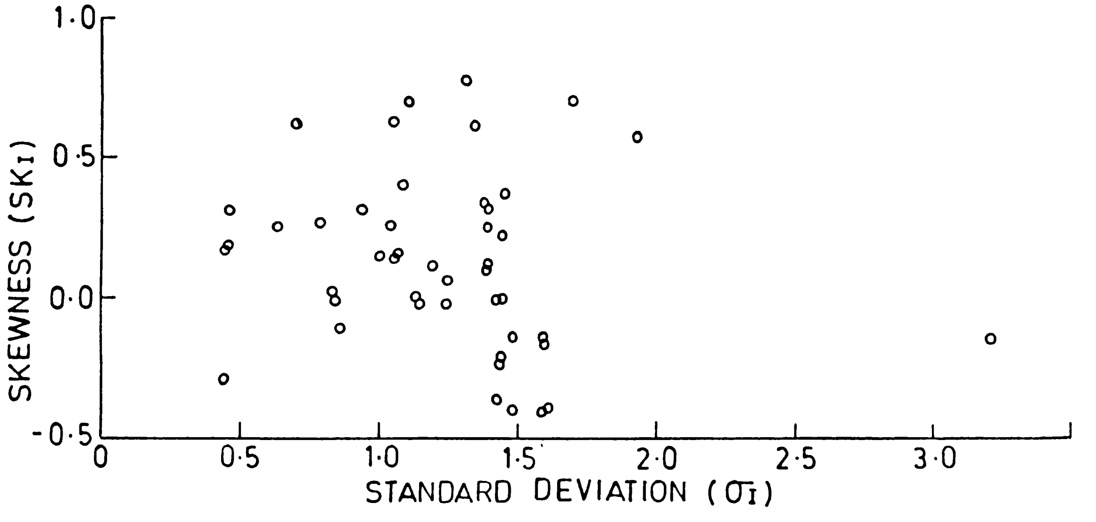


FIG4·6d STANDARD DEVIATION (σI) Vs SKEWNESS (SKI)

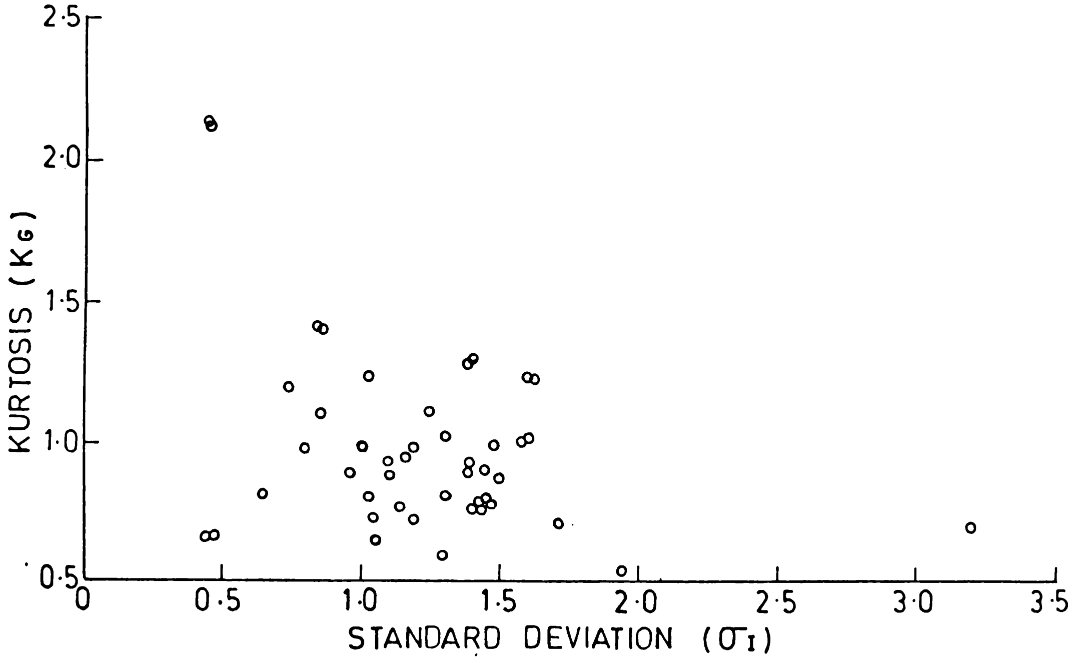


FIG.4·6e STANDARD DEVIATION (σI) Vs KURTOSIS (KG)

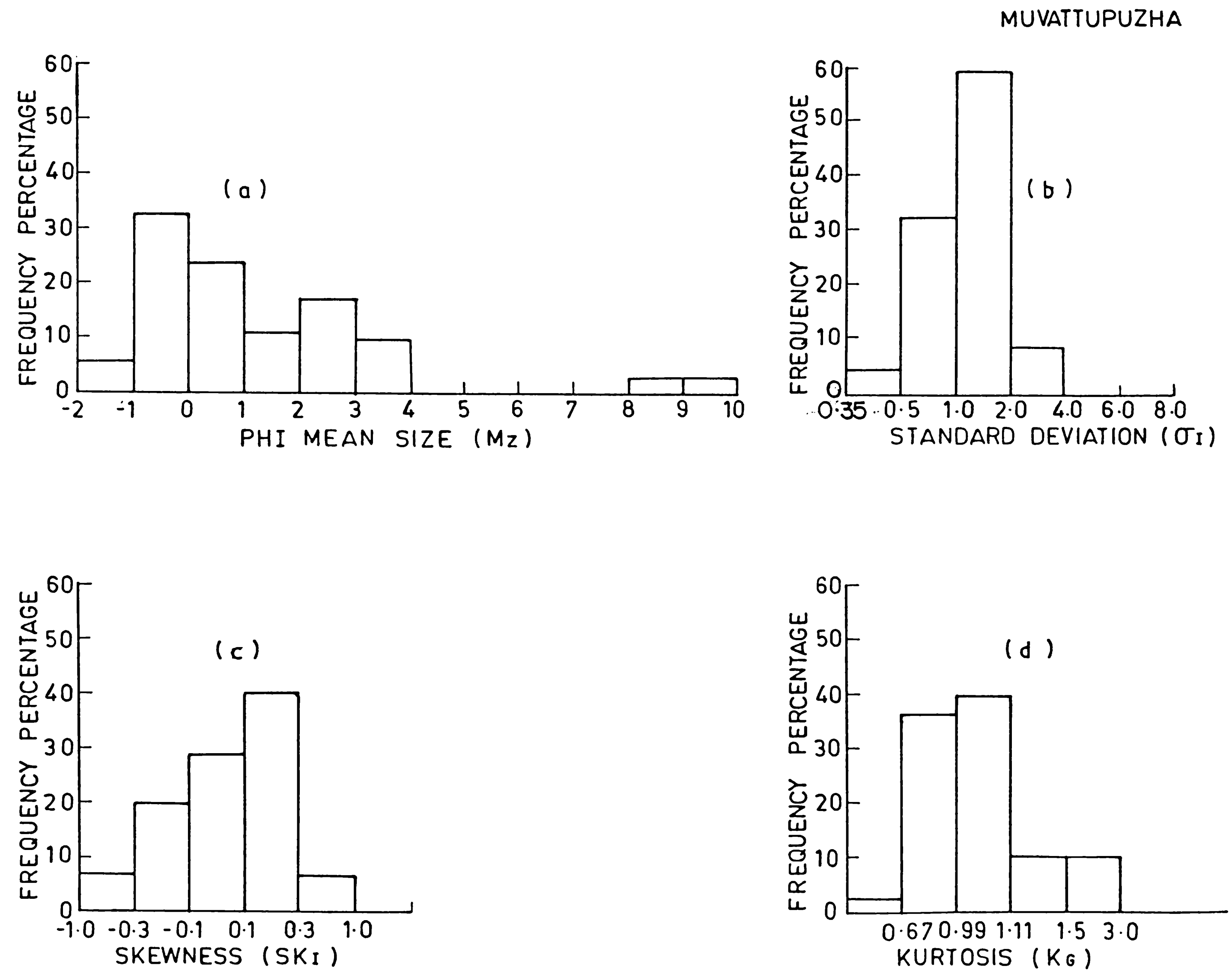


FIG 4·7 FREQUENCY DISTRIBUTION (IN %) Vs GRAIN SIZE PARAMETERS

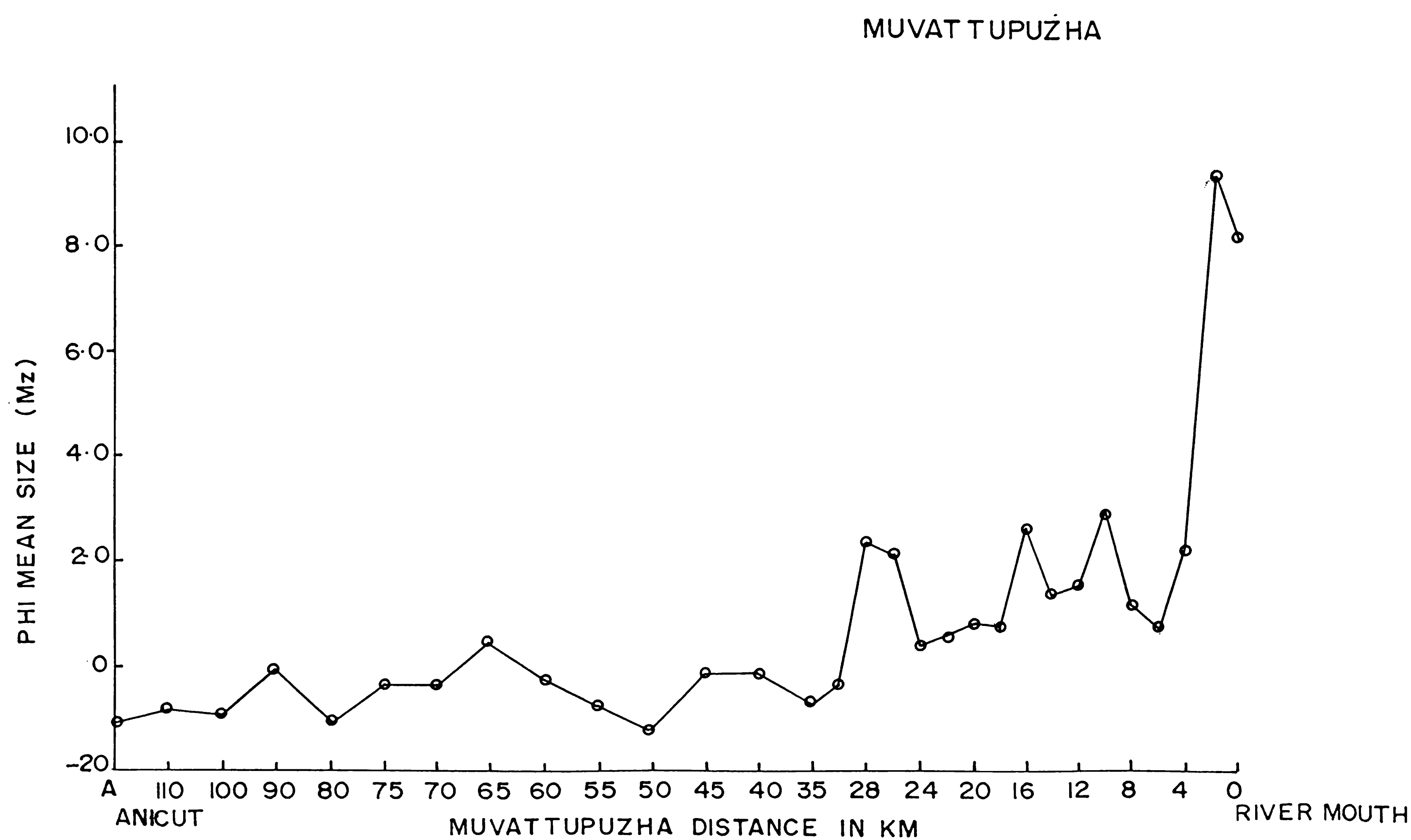


FIG. 4·8a PHI MEAN SIZE (Mz) Vs MUVATTUPUZHA DISTANCE (IN KM)

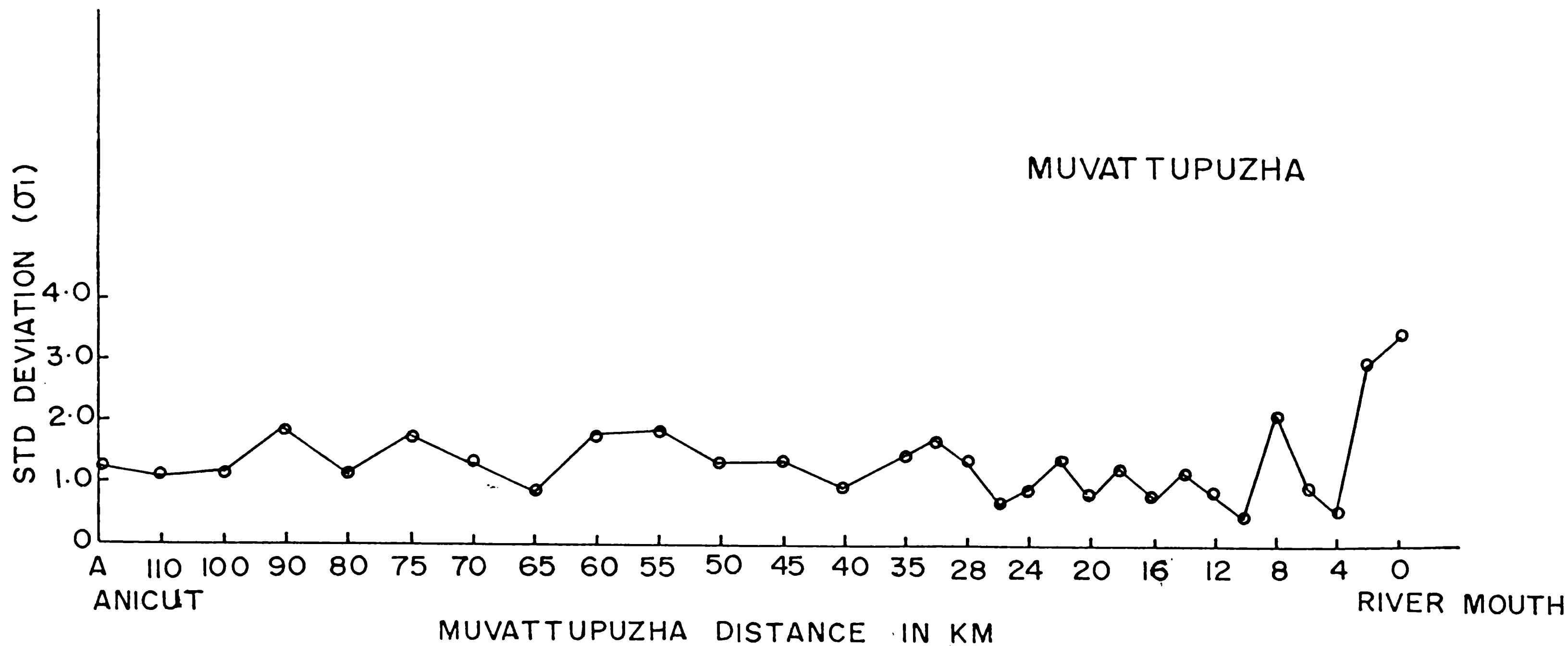


FIG. 4·8b. STD DEVIATION (σi) Vs MUVATTUPUZHA DISTANCE (IN KM)

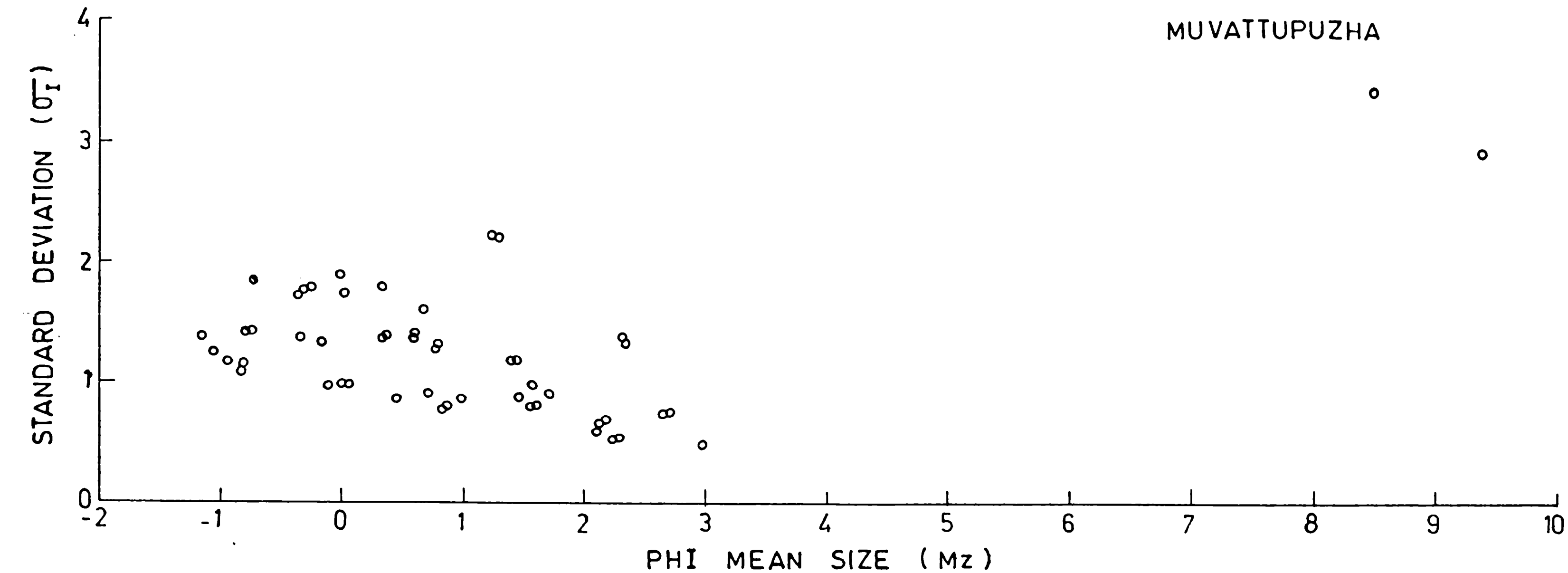


FIG.4·9a PHI MEAN SIZE (Mz) Vs STANDARD DEVIATION (σ_I)

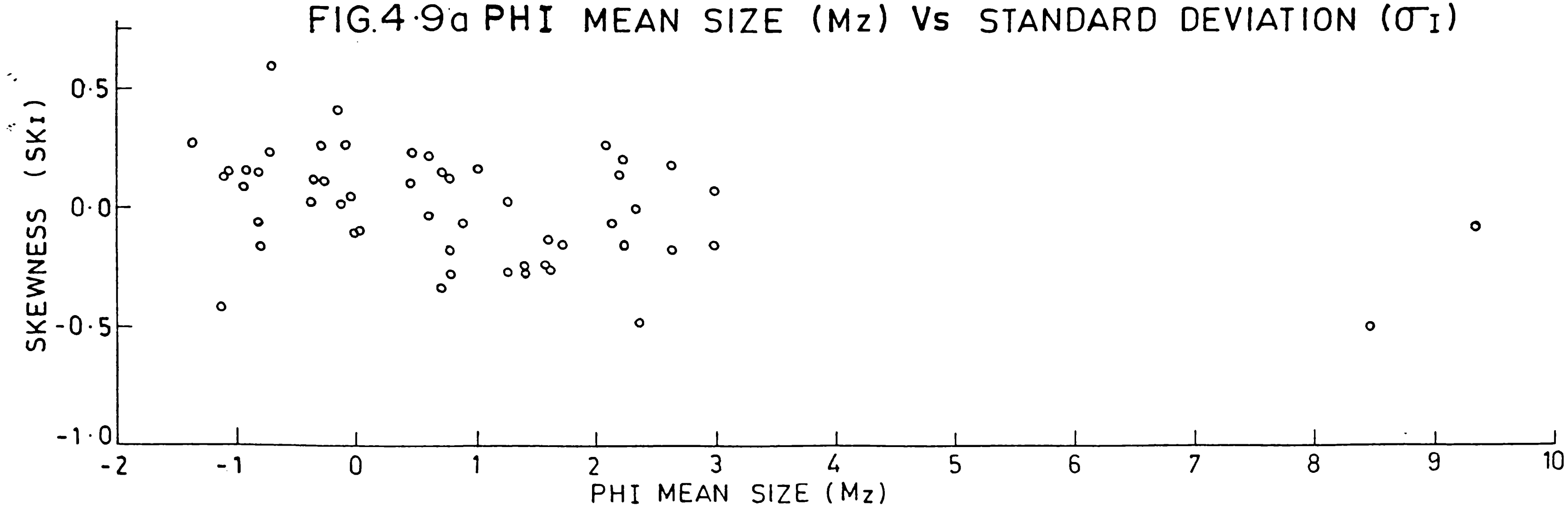


FIG.4·9b PHI MEAN SIZE (Mz) Vs SKEWNESS (SKI)

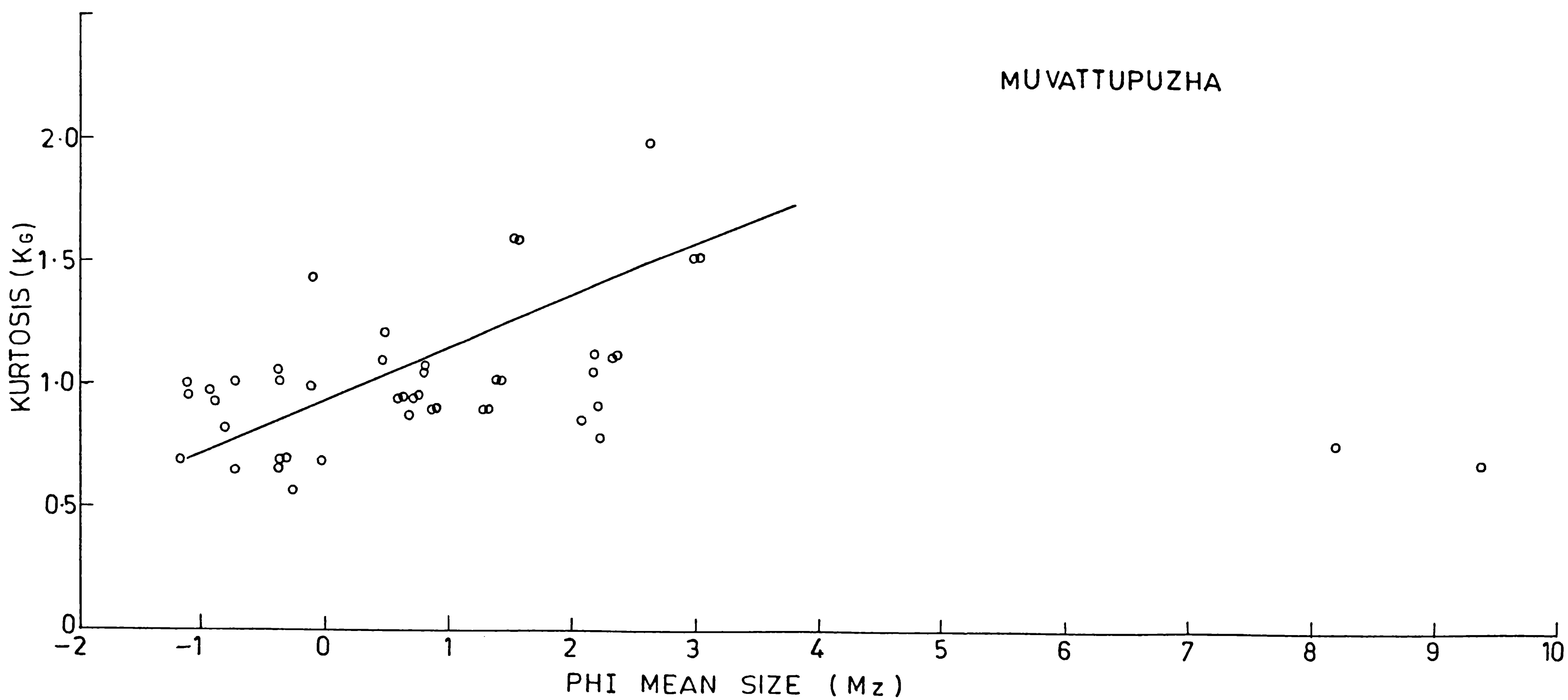


FIG.4·9c PHI MEAN SIZE (M_z) Vs KURTOSIS (K_G)

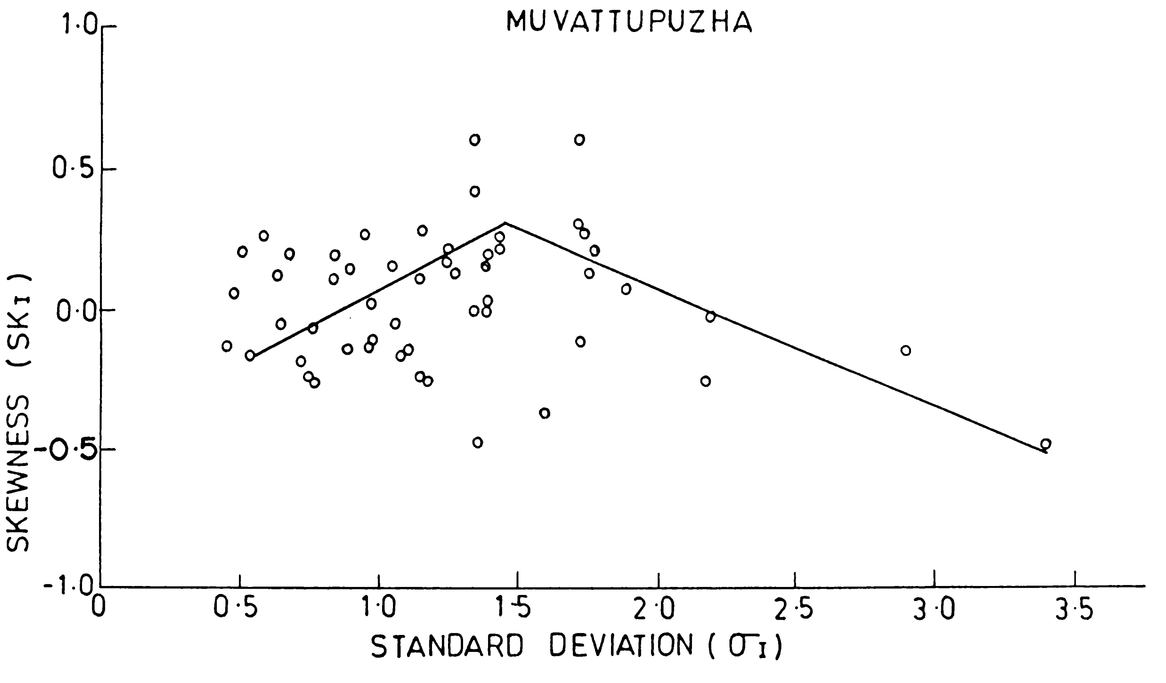


FIG.4·9d STANDARD DEVIATION (σ_I) Vs SKEWNESS (SK_I)

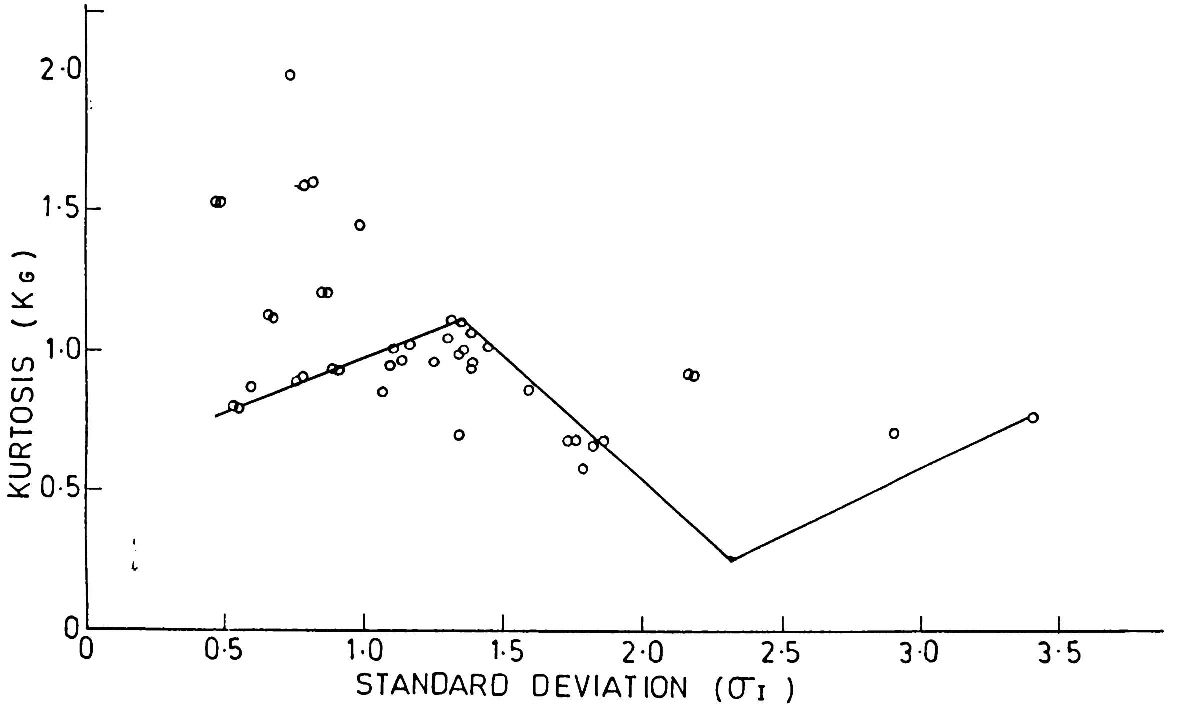


FIG.4·9 e STANDARD DEVIATION (σ_I) Vs KURTOSIS (K_G)

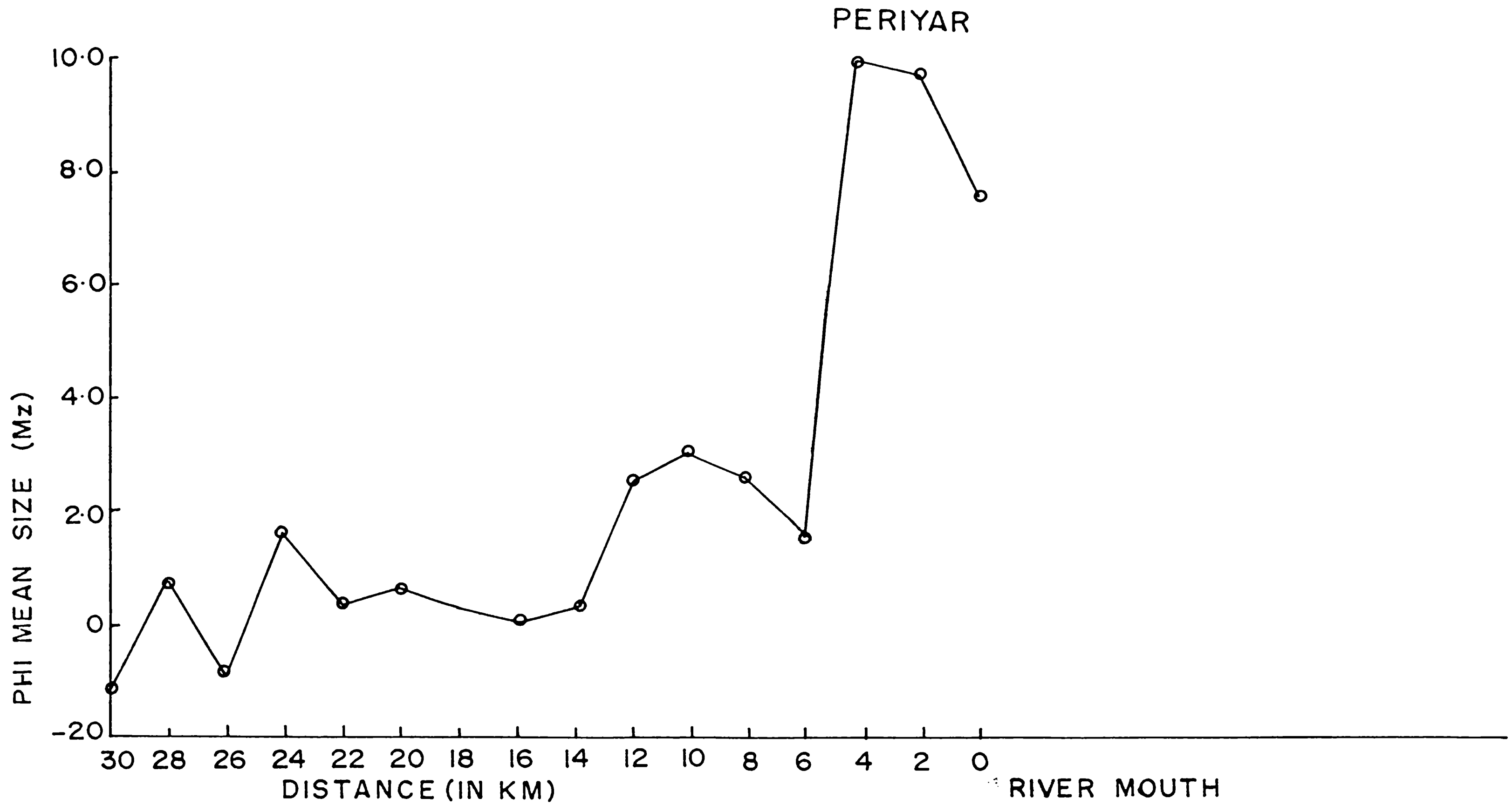


FIG. 4·10a. VARIATION OF PHI MEAN SIZE IN THE DOWNSTREAM REGION.

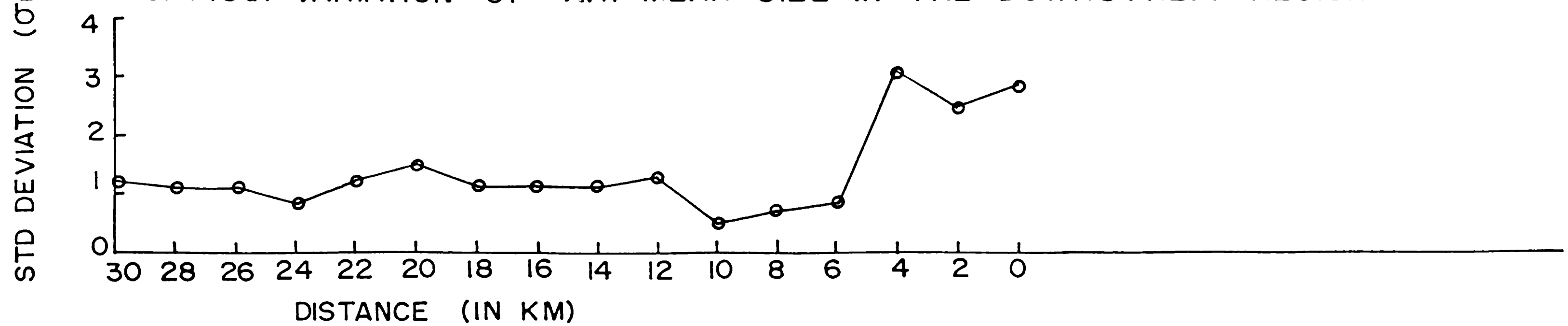


FIG. 4·10b. VARIATION OF STD DEVIATION IN THE DOWNSTREAM REGION

PERIYAR

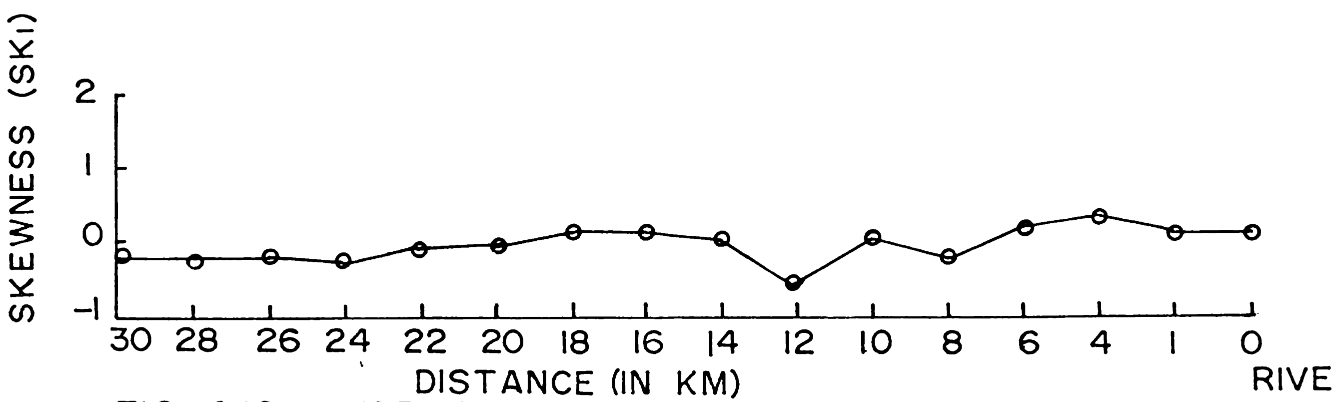


FIG. 4·10c VARIATION OF SKEWNESS IN THE DOWNSTREAM REGION

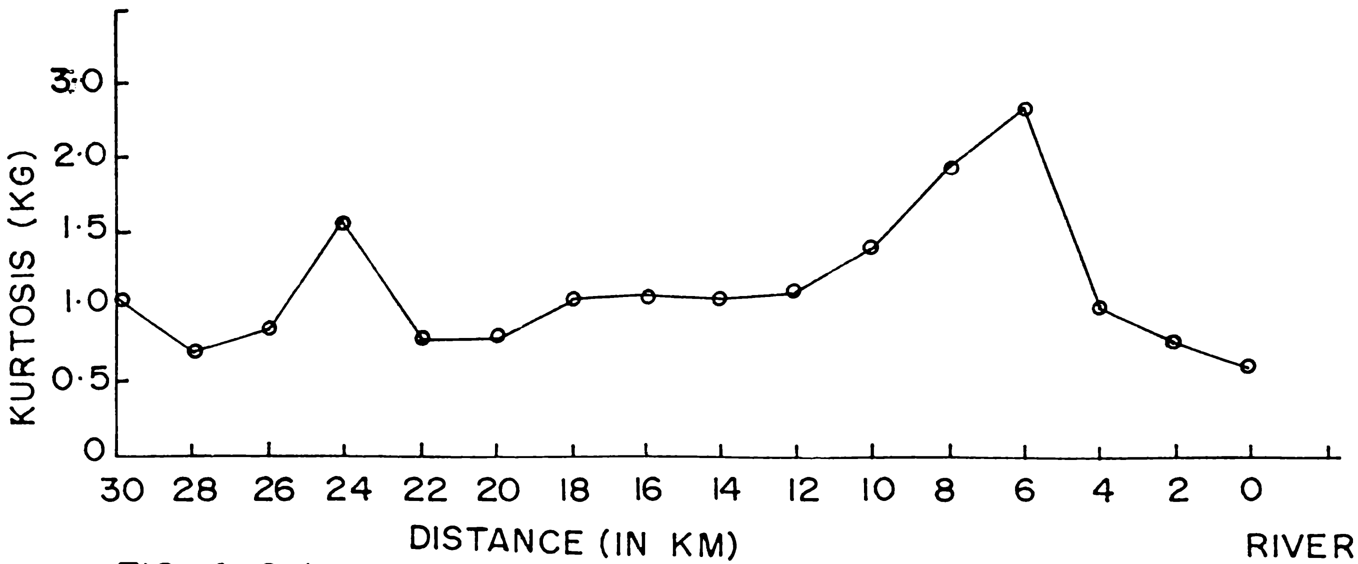


FIG. 4·10d. VARIATION OF KURTOSIS IN THE DOWNSTREAM REGION

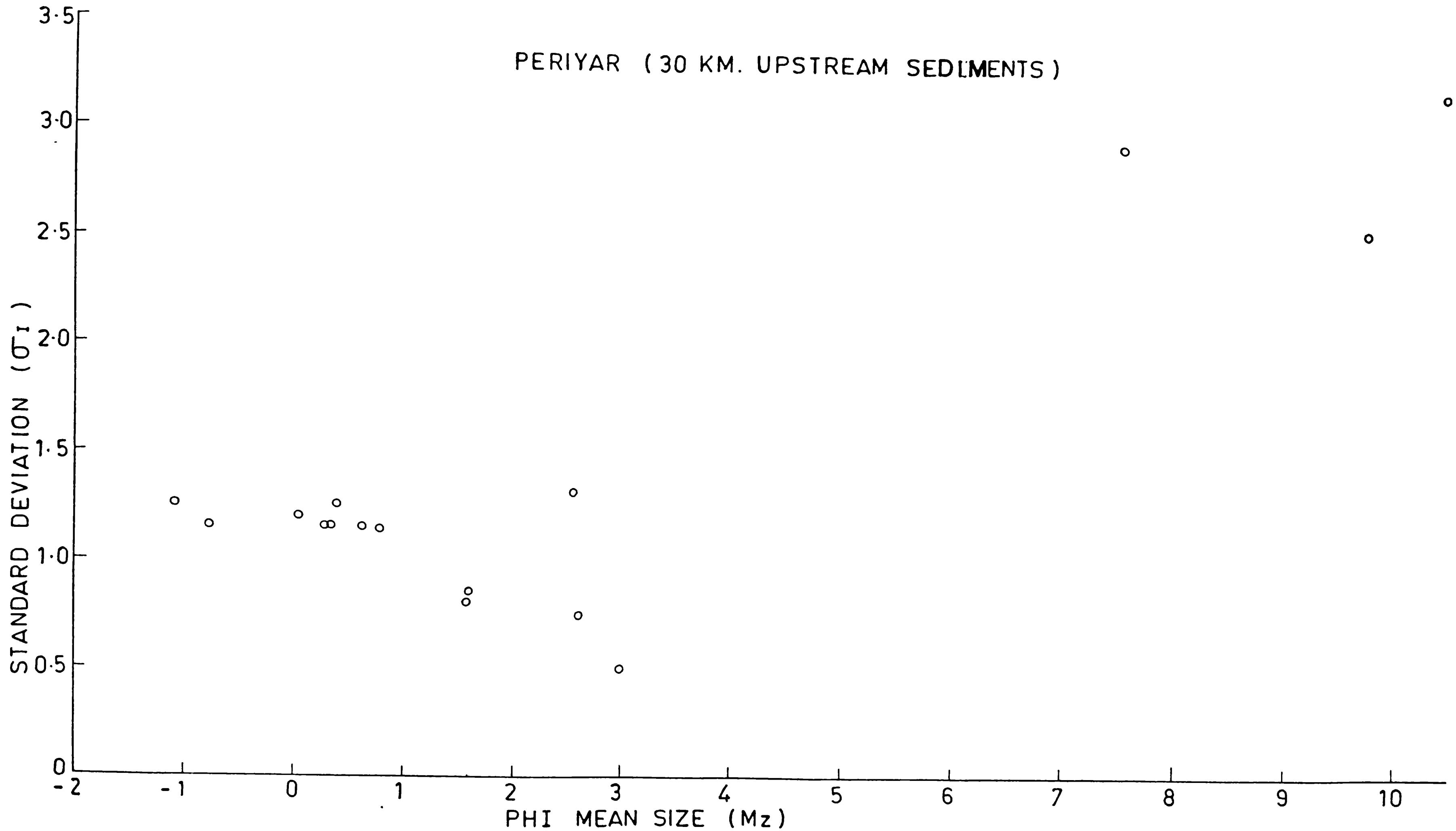


FIG.4:11a PHI MEAN SIZE (Mz) Vs STANDARD DEVIATION (σ_I)

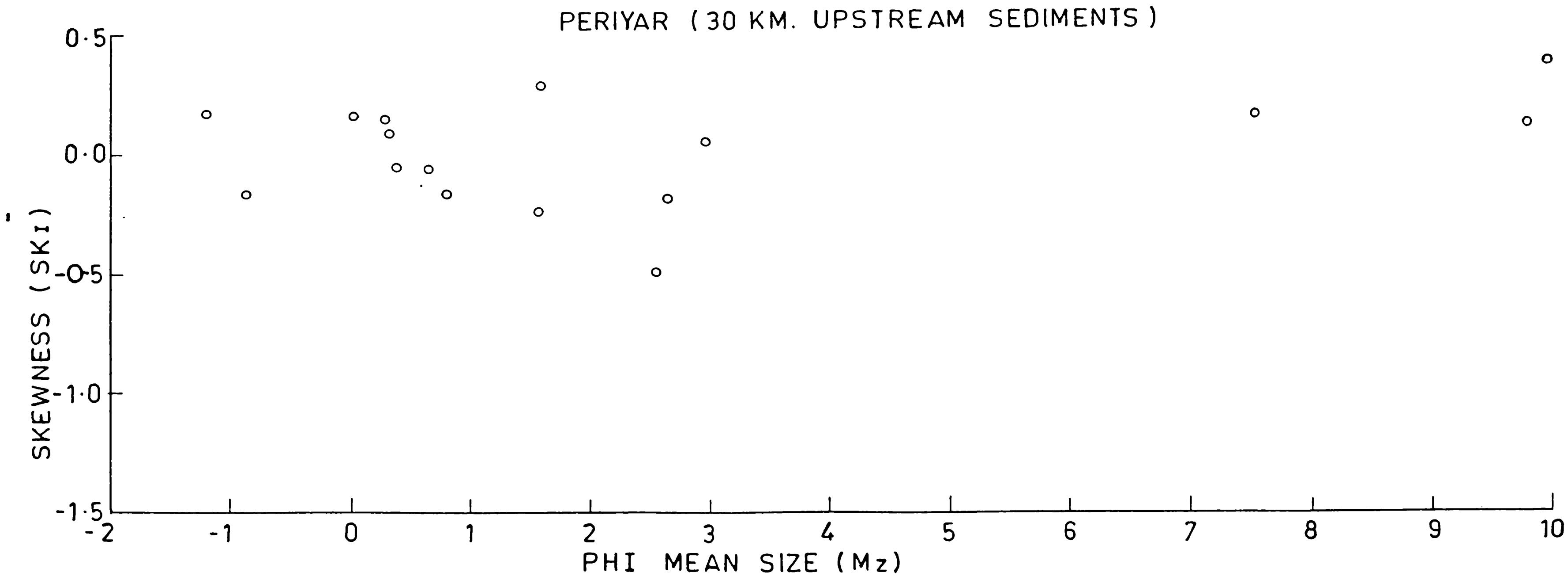


FIG.4.11b PHI MEAN SIZE (Mz) Vs SKEWNESS (SKI)

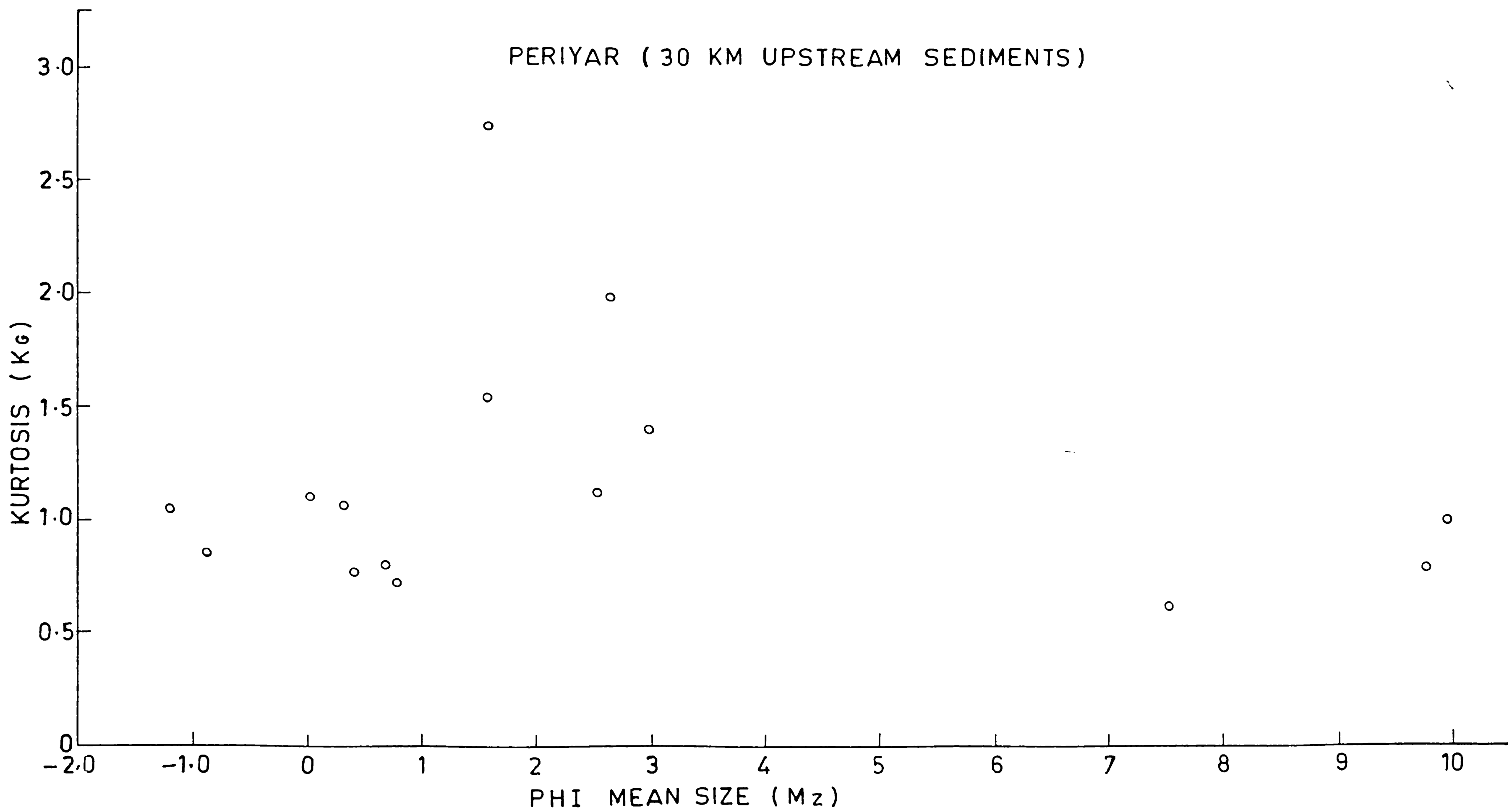


FIG. 4.11c PHI MEAN SIZE (Mz) Vs KURTOSIS (KG)

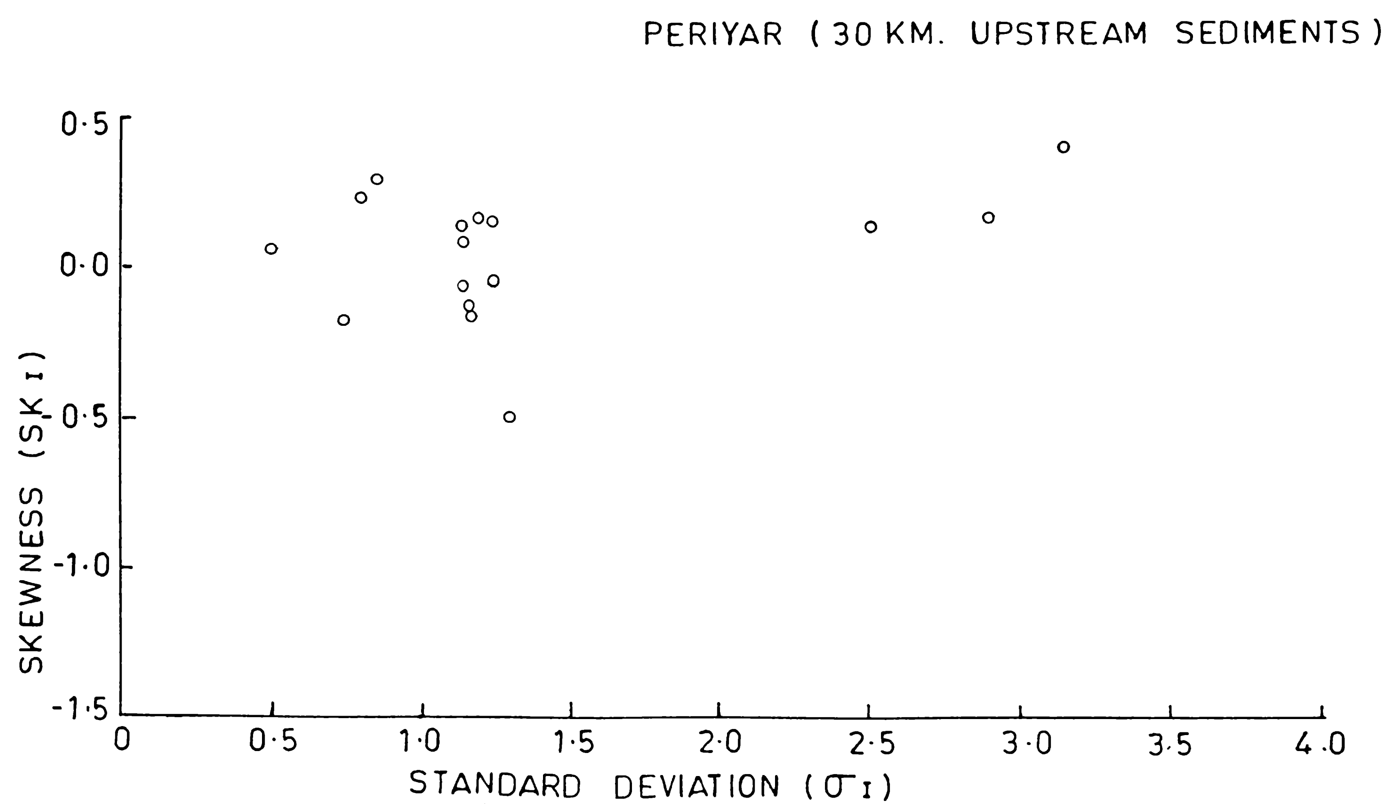


FIG. 4·11d STANDARD DEVIATION (σ_I) Vs SKEWNESS (SK_I)

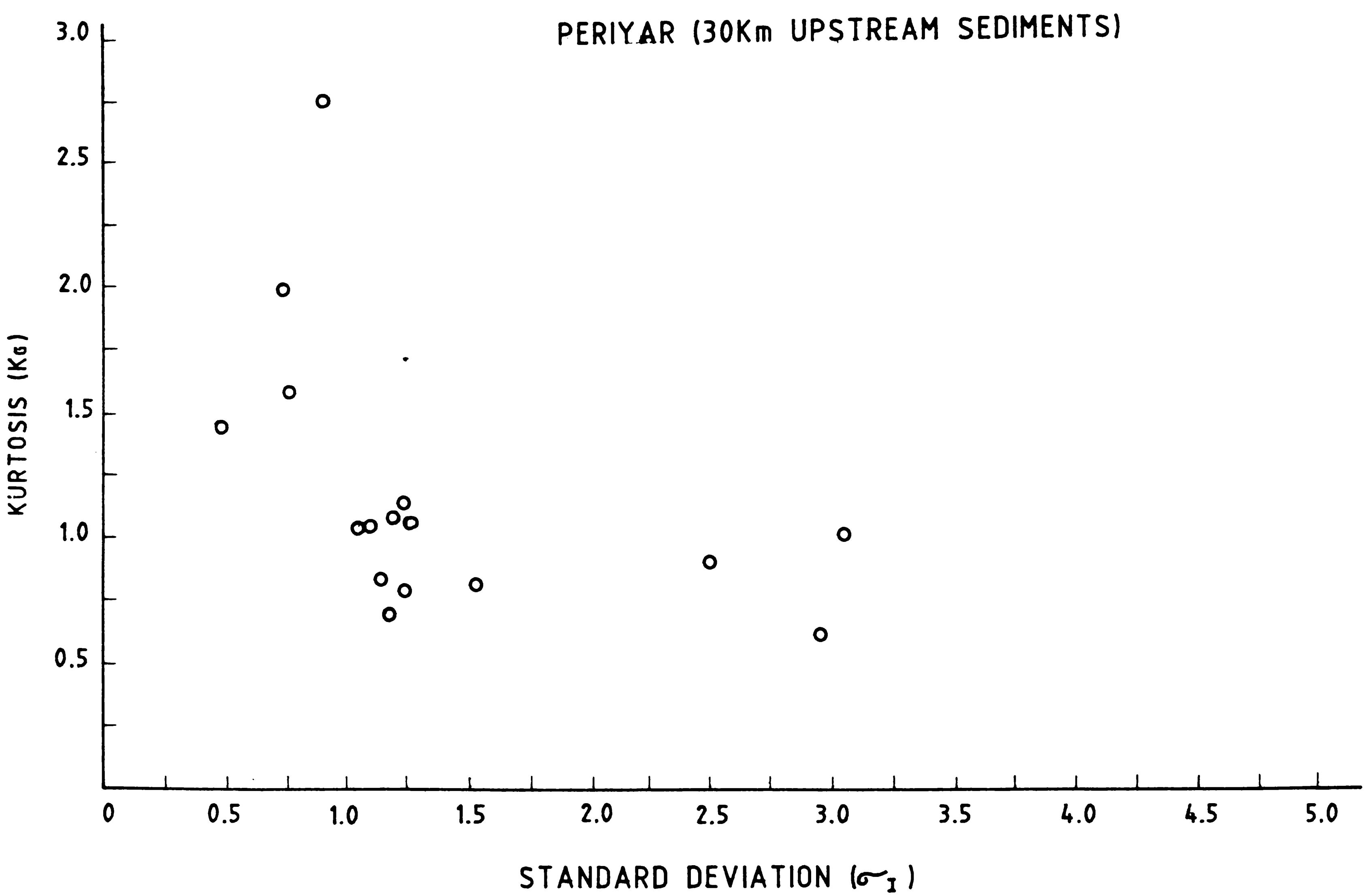


FIG. 4.11e STANDARD DEVIATION (σ_I) Vs KURTOSIS(K_G)

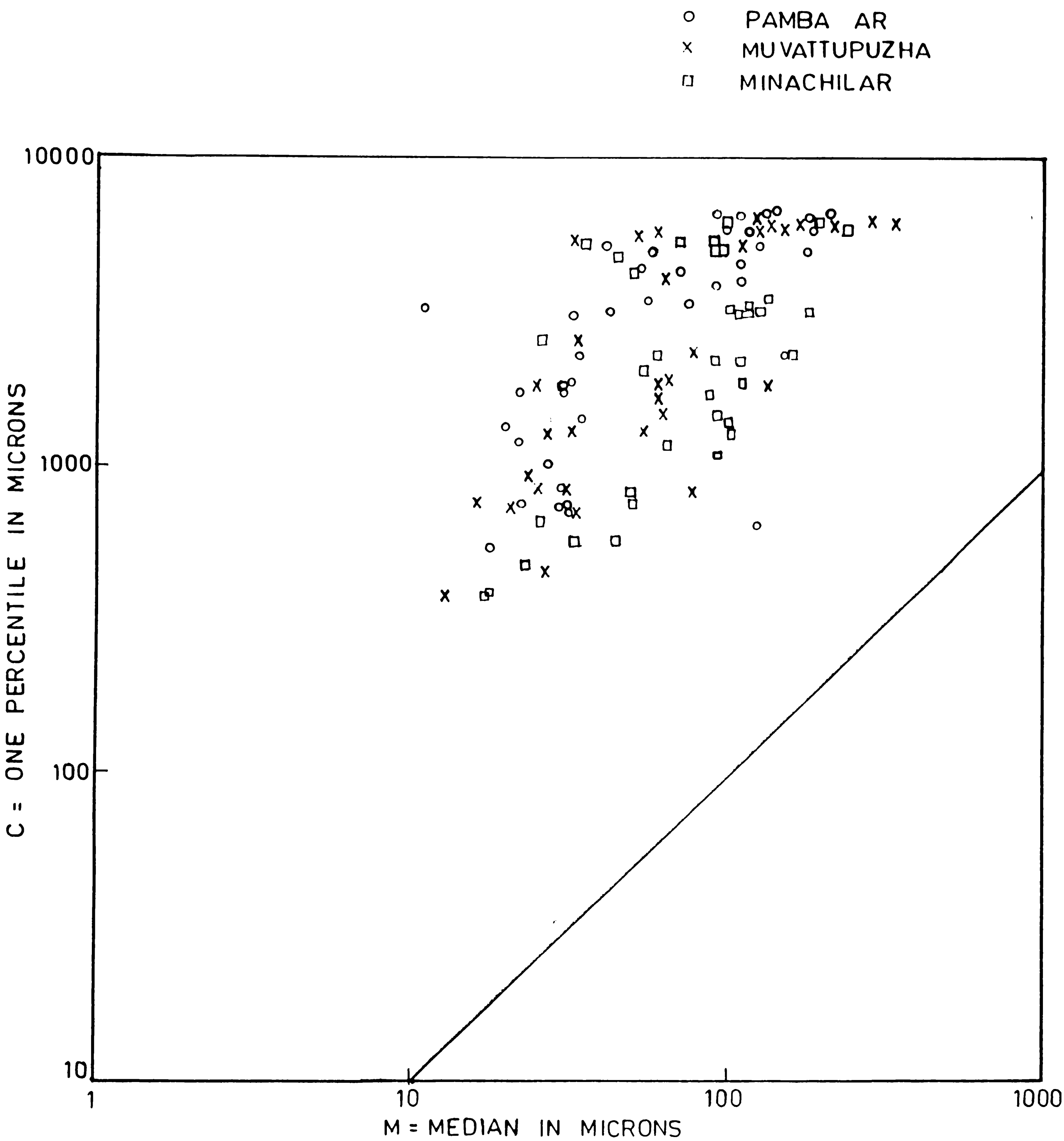


FIG.4·12 TYPICAL CM DIAGRAM OF RIVER SEDIMENTS

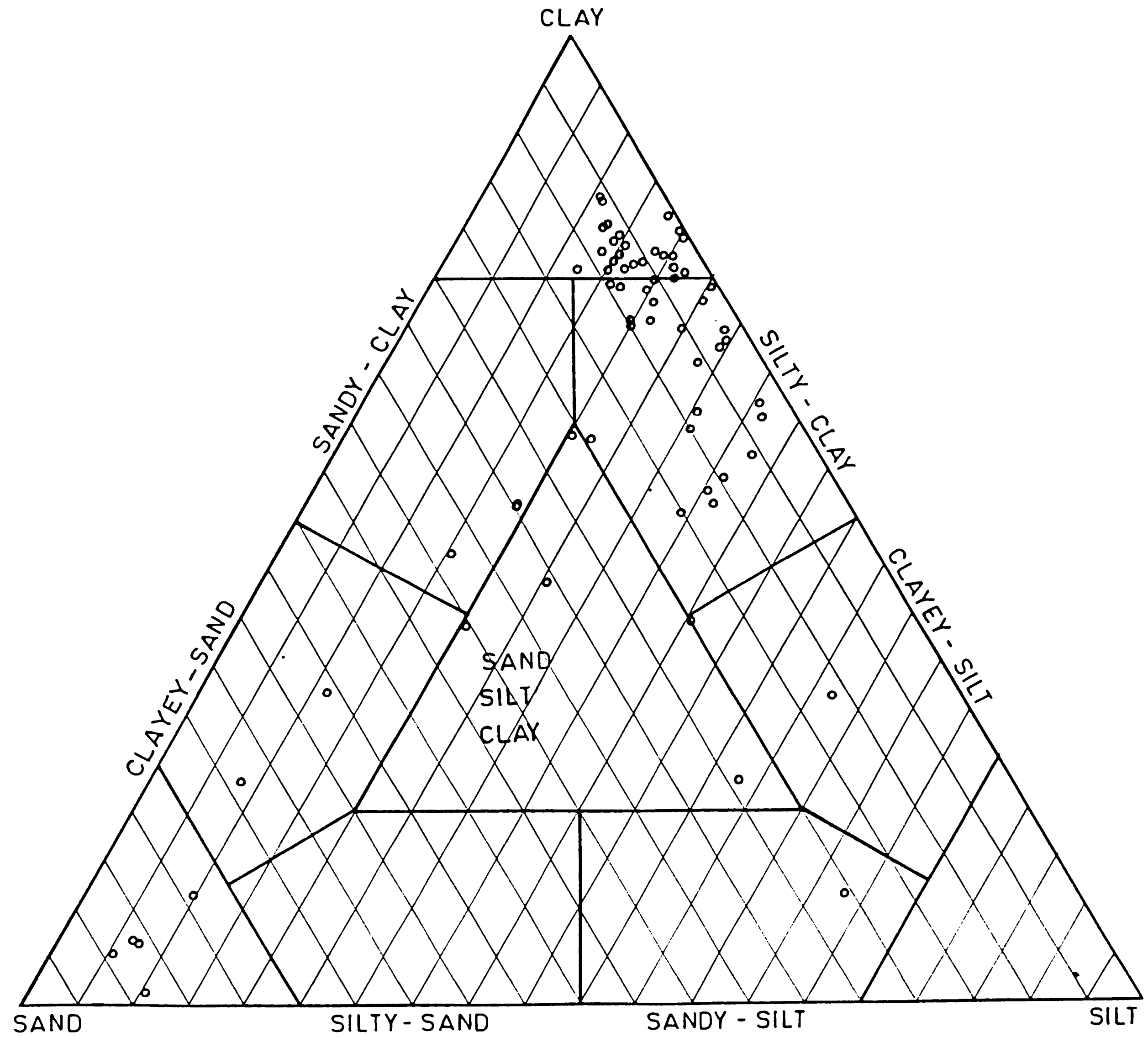


FIG.4·13 a SAND-SILT-CLAY CONTENTS OF THE VEMBANAD LAKE SEDIMENTS
(PRE-MONSOON)

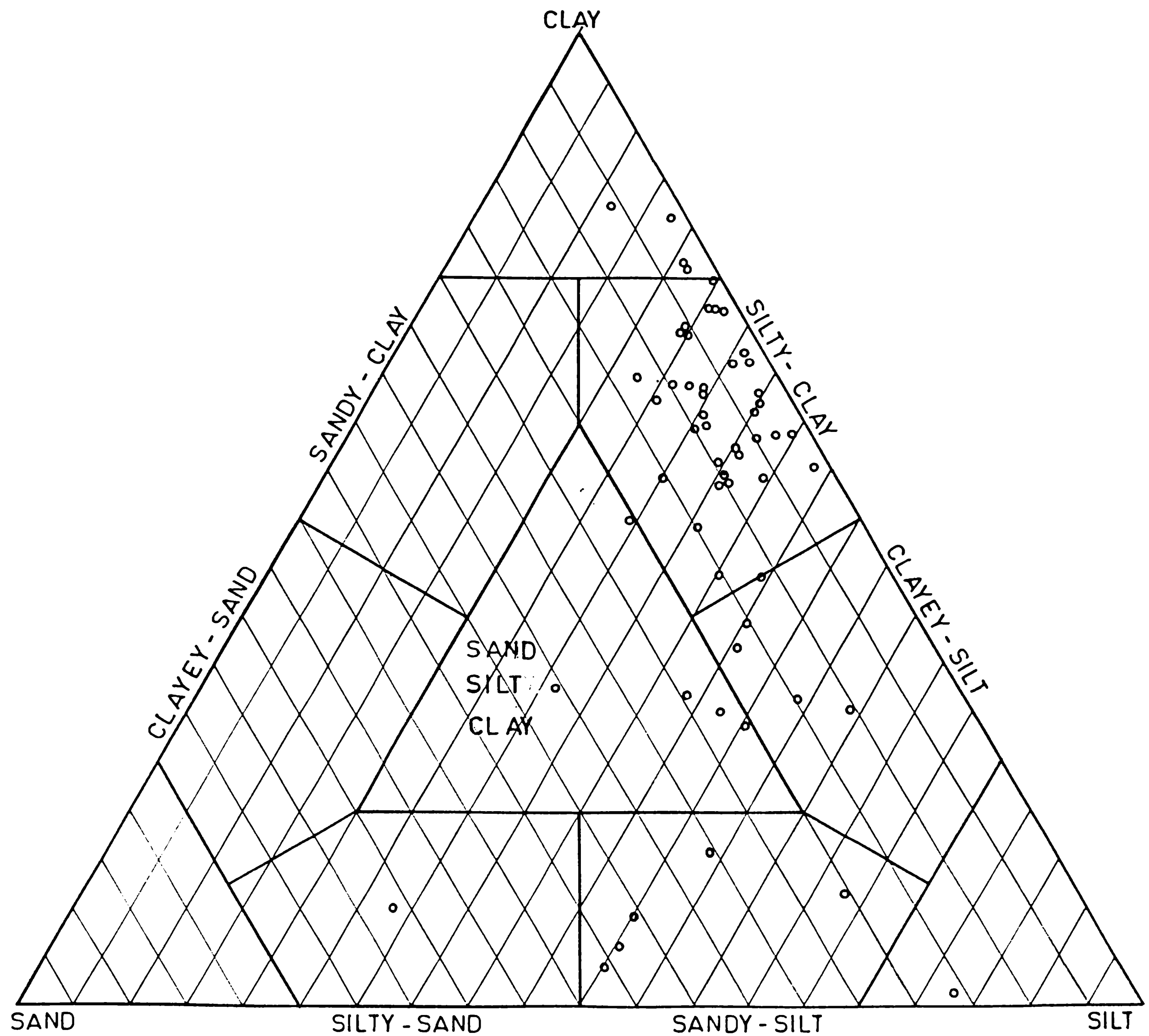


FIG.4·13b SAND-SILT-CLAY CONTENTS OF THE VEMBANAD LAKE SEDIMENTS
(POST-MONSOON)

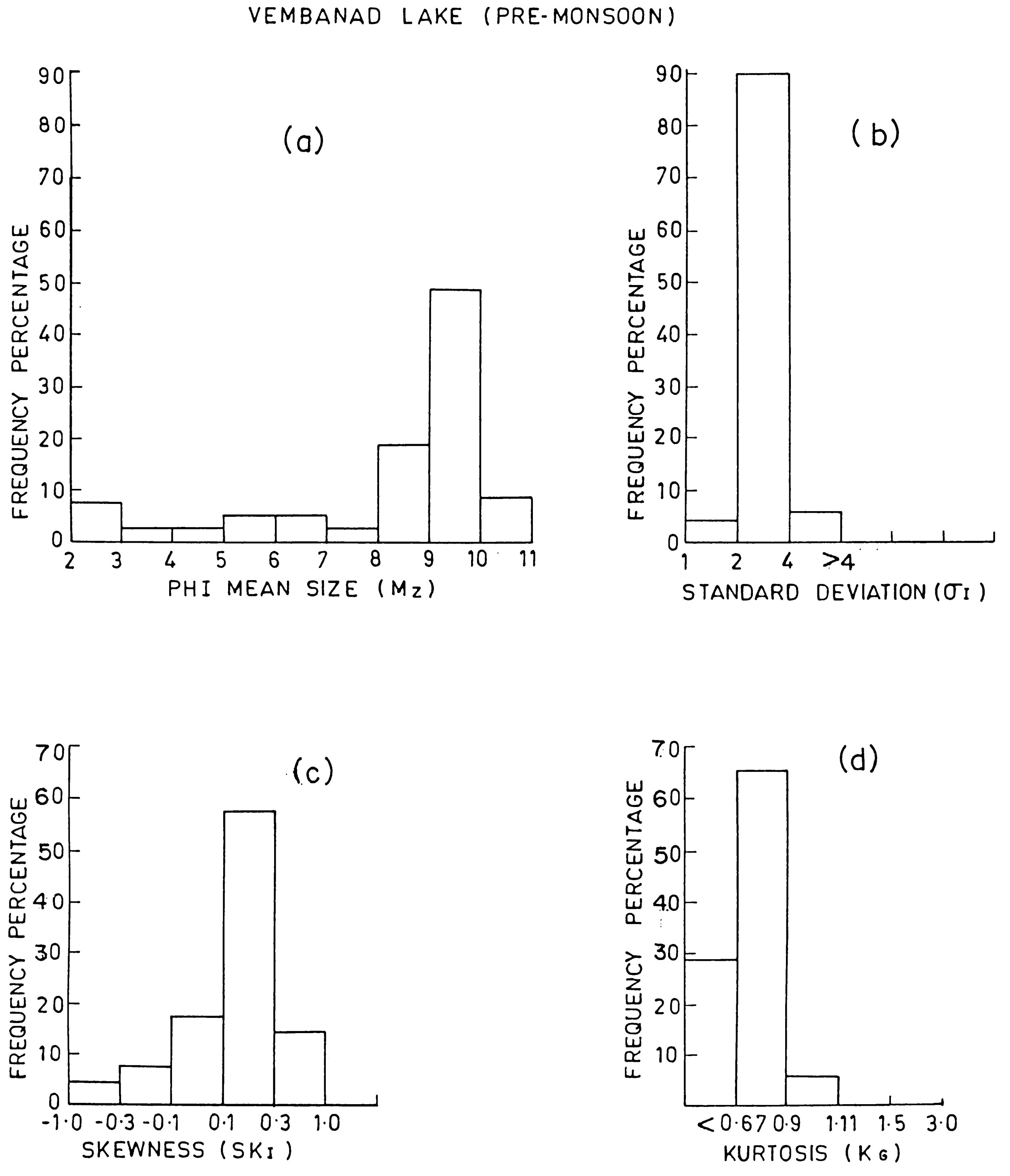


FIG. 4·14 FREQUENCY DISTRIBUTION (IN %) Vs GRAIN-SIZE PARAMETERS.

VEMBANAD LAKE (POST-MONSOON)

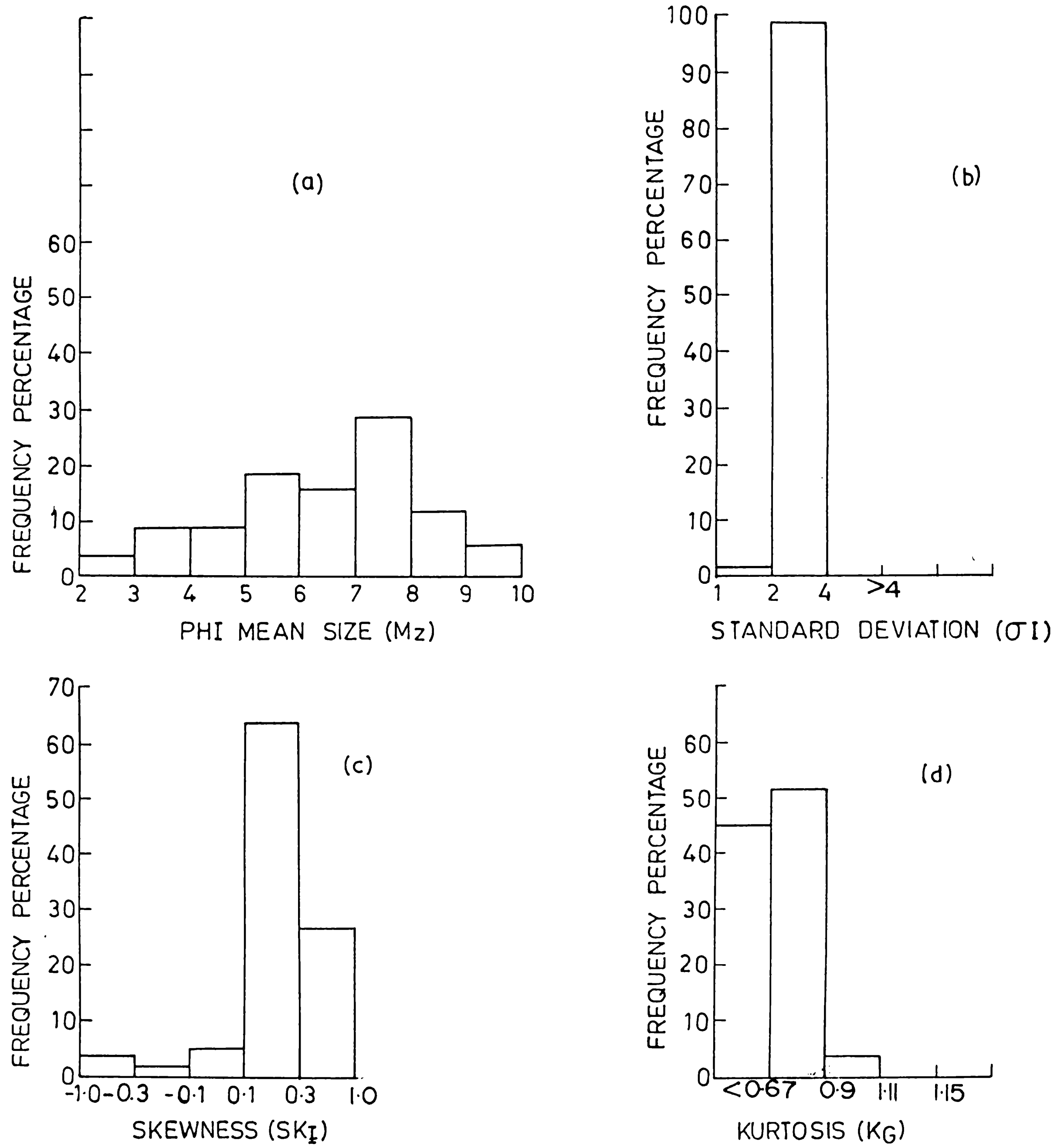


FIG 4·15 FREQUENCY DISTRIBUTION (IN %) Vs GRAIN-SIZE PARAMETERS

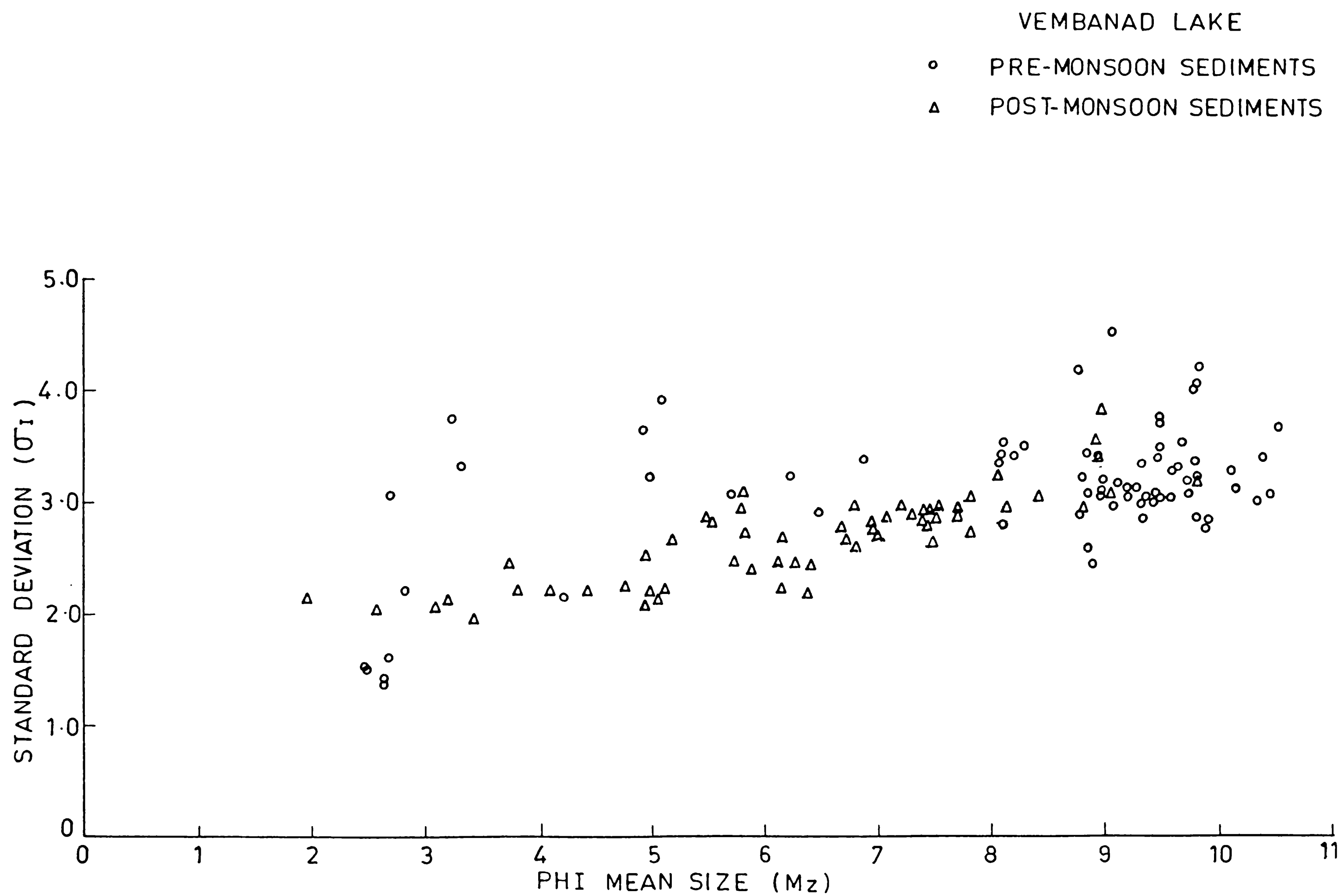


FIG. 4·16 PHI MEAN SIZE (Mz) Vs STANDARD DEVIATION (σ_I)

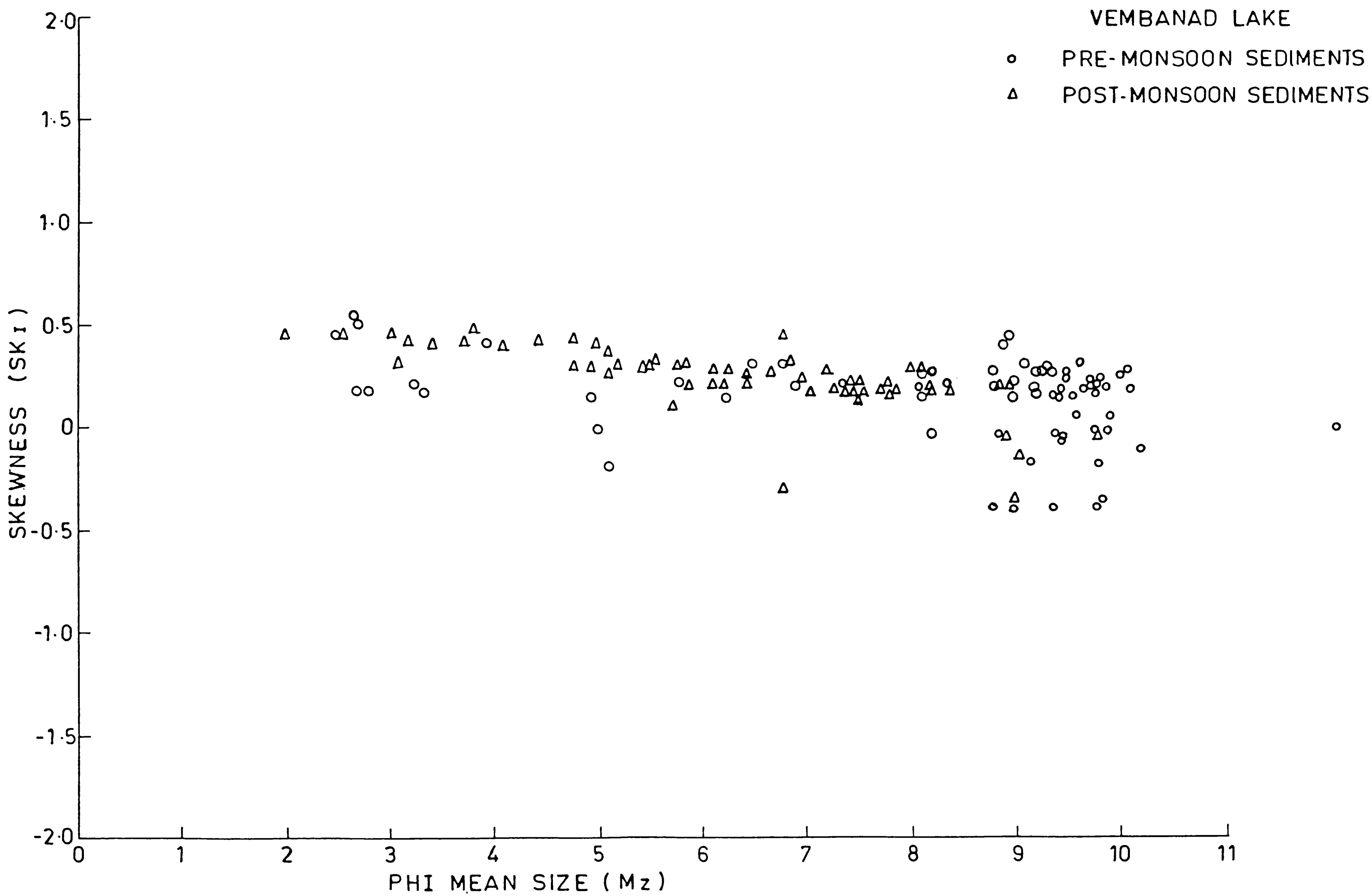


FIG.4·17.PHI MEAN SIZE (Mz) Vs SKEWNESS (SK_I)

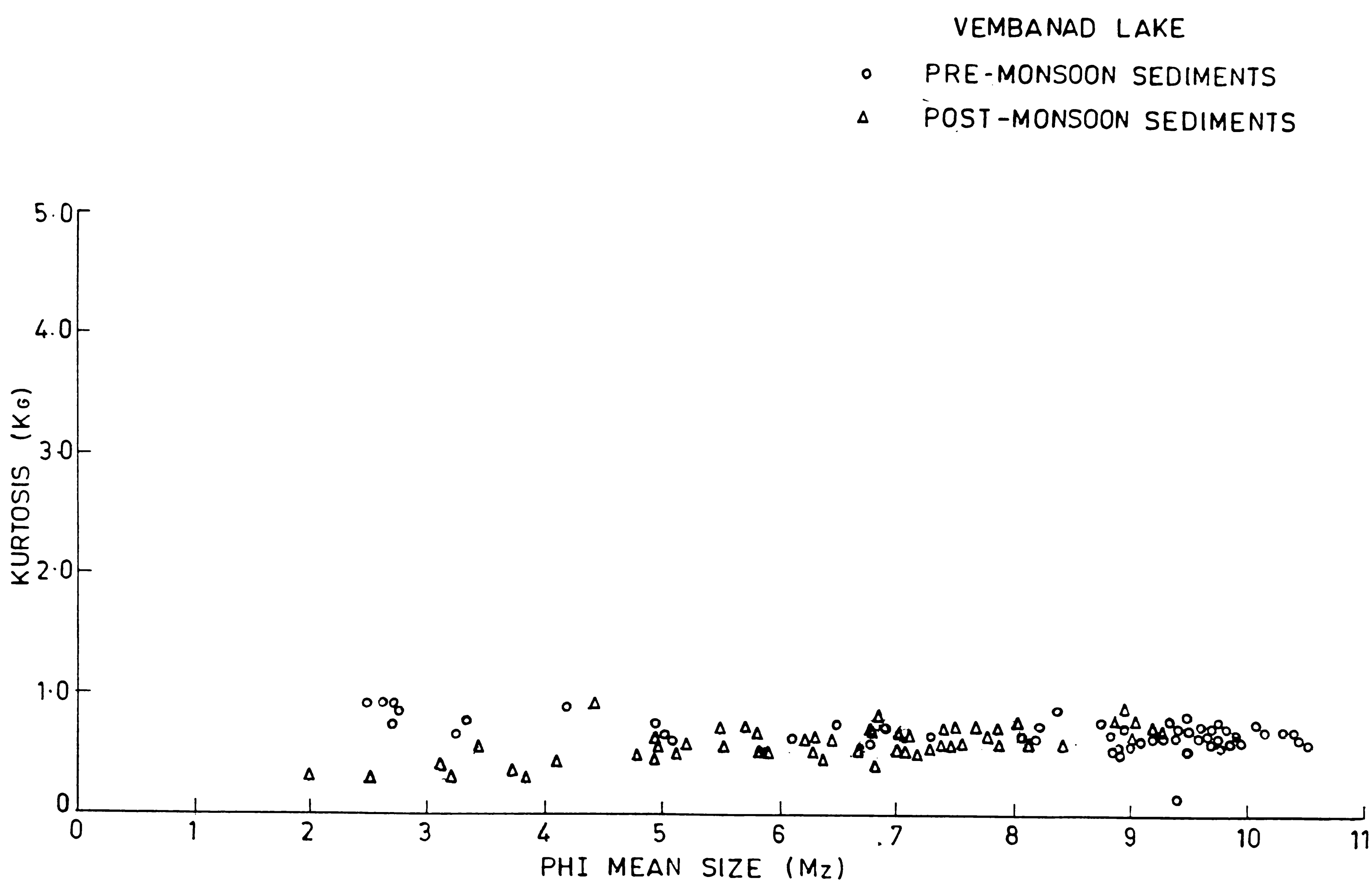


FIG.4·18 PHI MEAN SIZE (Mz) Vs KURTOSIS (KG)

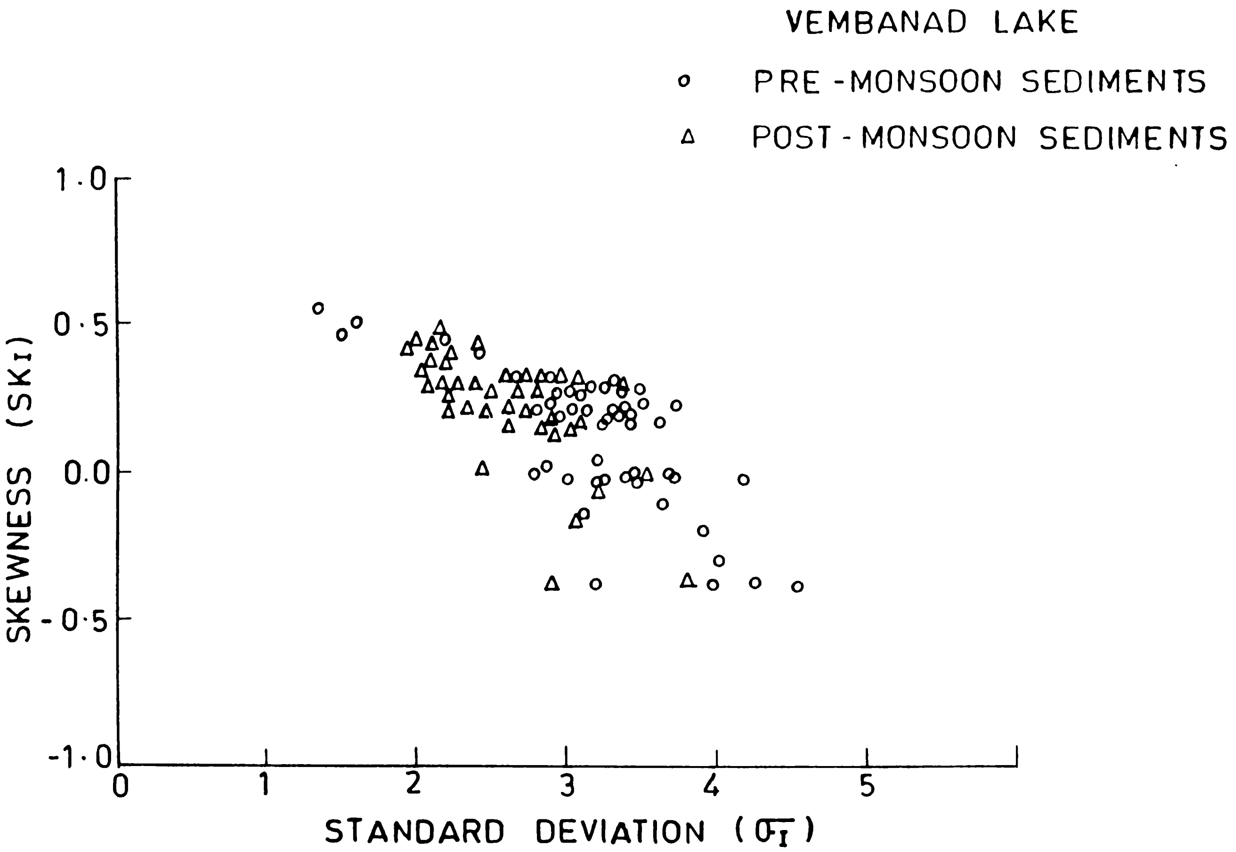


FIG.4·19 STANDARD DEVIATION (σ_I) Vs SKEWNESS (SK_I)

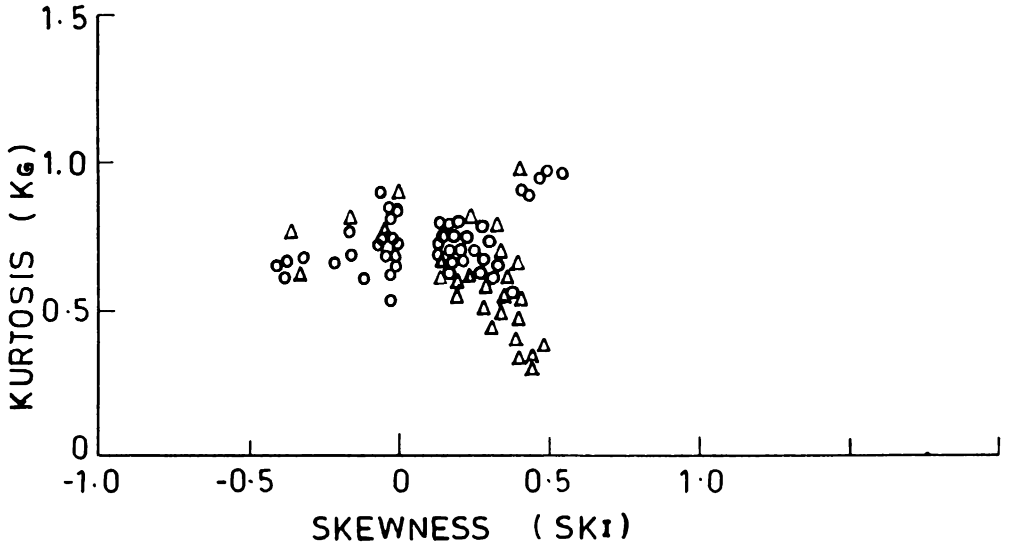


FIG.4·20 SKEWNESS (SK_I) Vs KURTOSIS (K_G)

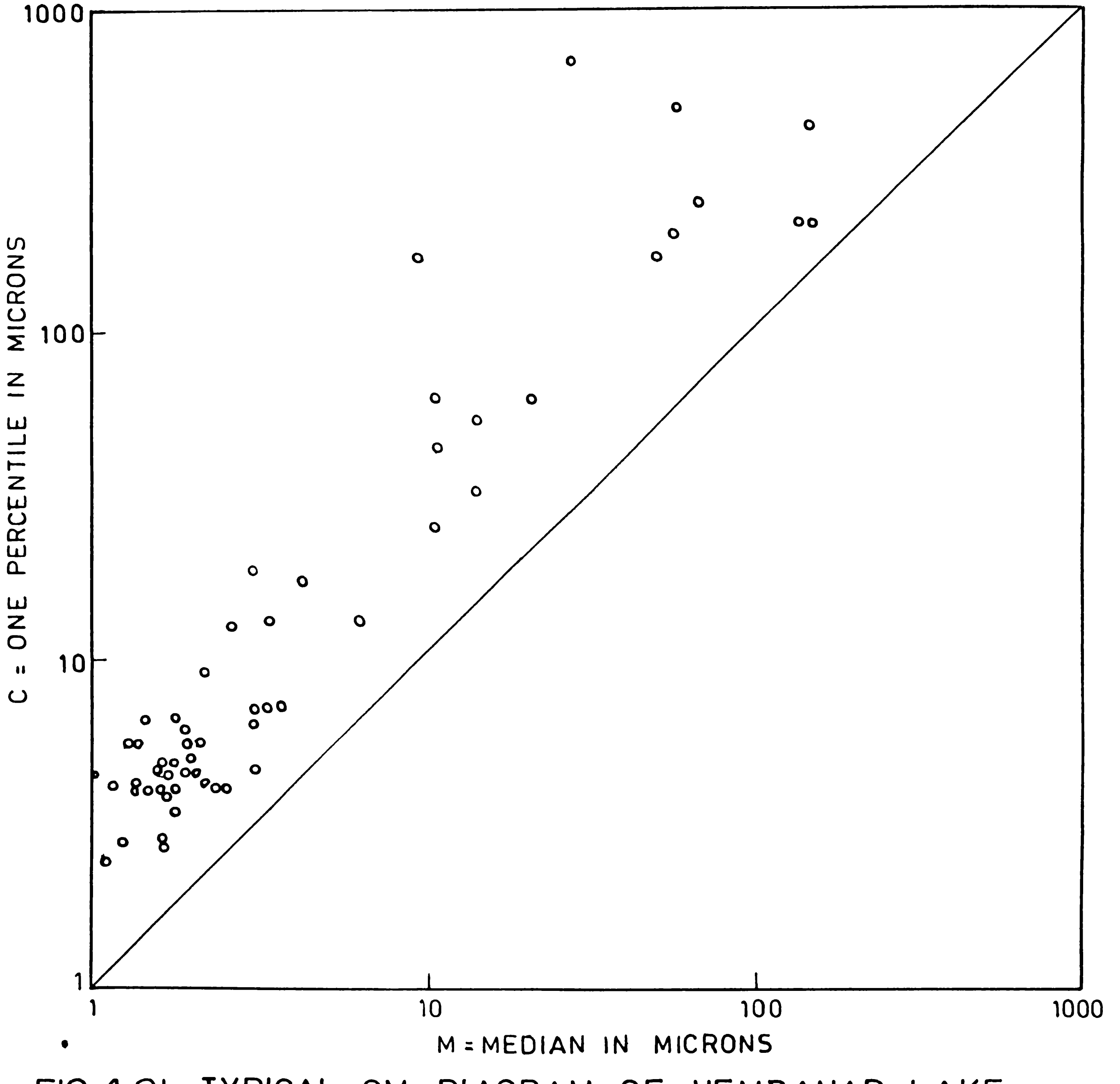


FIG. 4·21a TYPICAL CM DIAGRAM OF VEMBANAD LAKE SEDIMENTS (PRE-MONSOON)

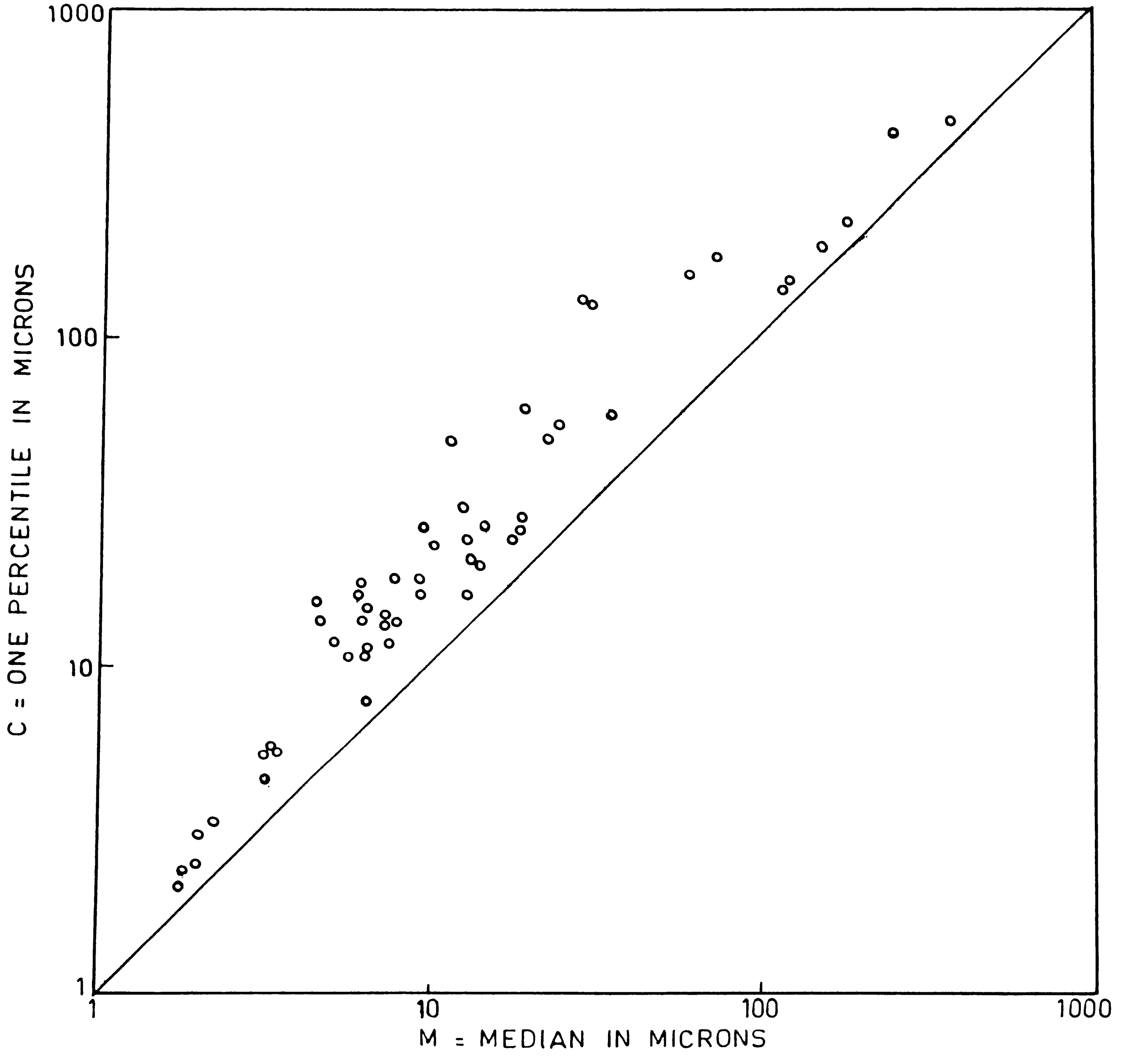


FIG.4·21b TYPICAL CM DIAGRAM OF VEMBANAD LAKE SEDIMENTS (POST-MONSOON)

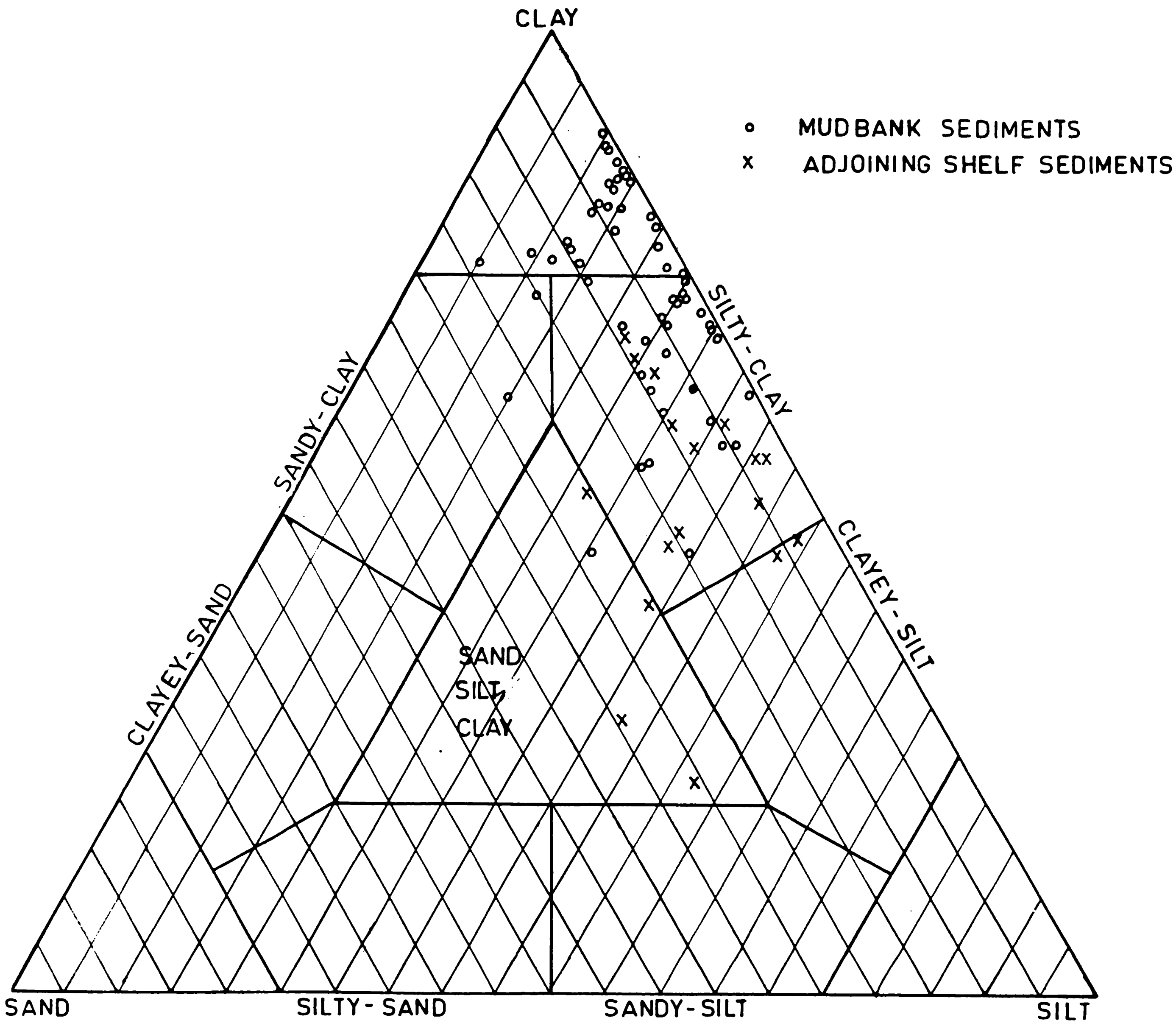


FIG.4.22a SAND-SILT-CLAY CONTENTS OF NARAKKAL MUDBANK AND ADJOINING SHELF SEDIMENTS

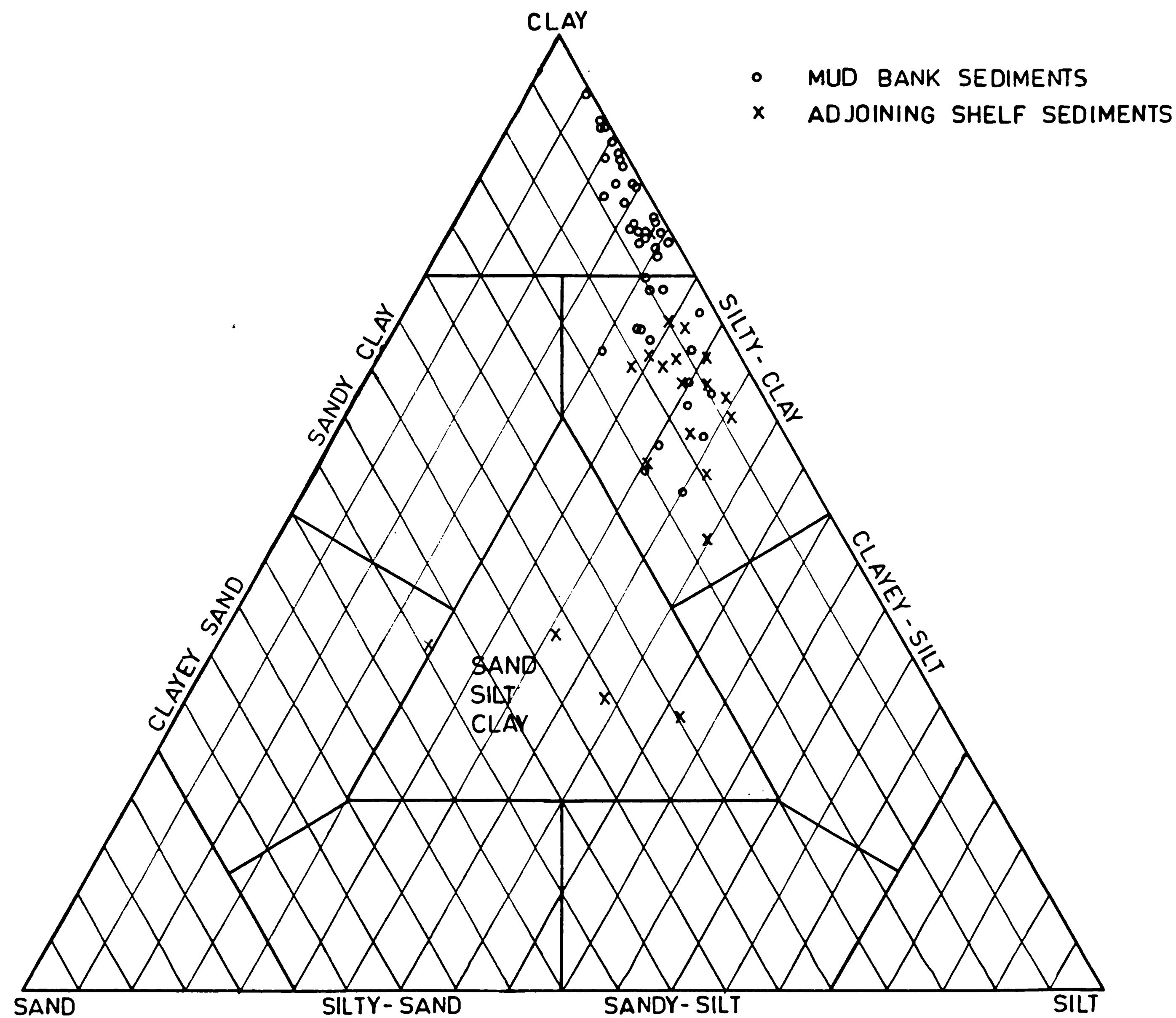


FIG.4·22b SAND-SILT-CLAY CONTENTS OF PURAKKAD MUDBANK AND ADJOINING SHELF SEDIMENTS

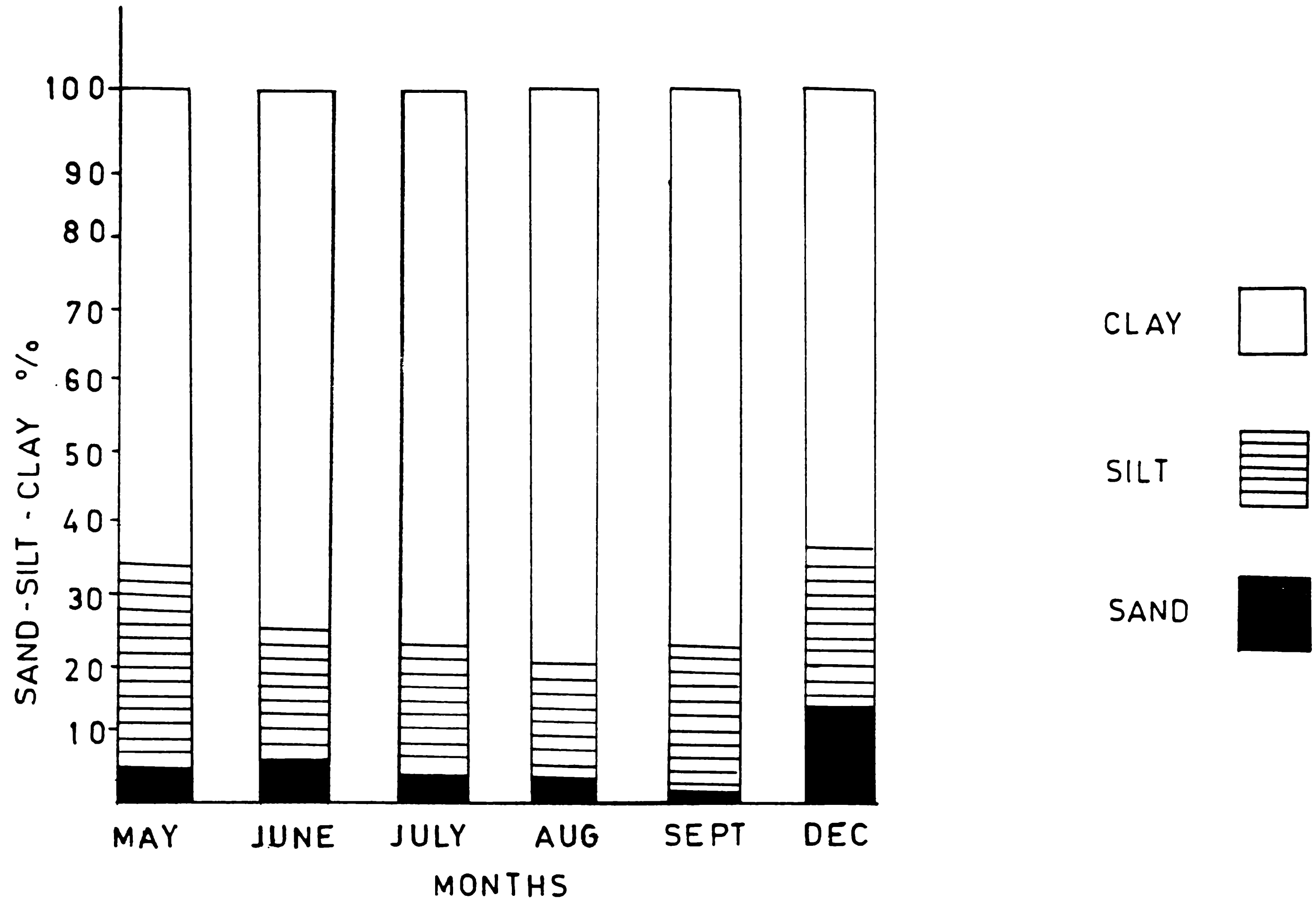


FIG.4·23 TEMPORAL VARIATIONS OF SAND - SILT - CLAY % IN THE NARAKKAL MUD BANK REGION

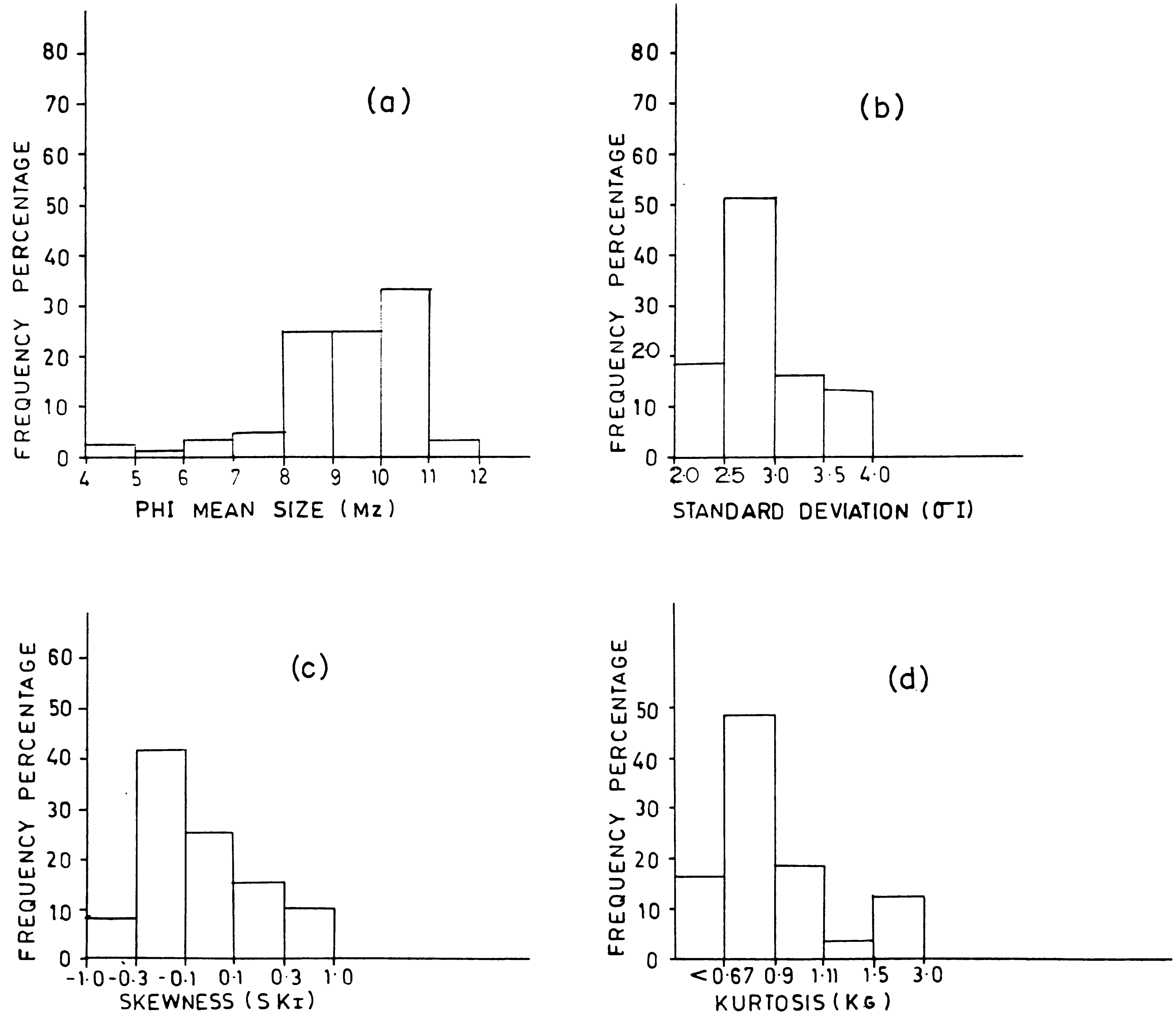


FIG.4·24 FREQUENCY DISTRIBUTION IN% Vs GRAIN SIZE PARAMETER OF NARAKKAL MUD BANK SEDIMENTS

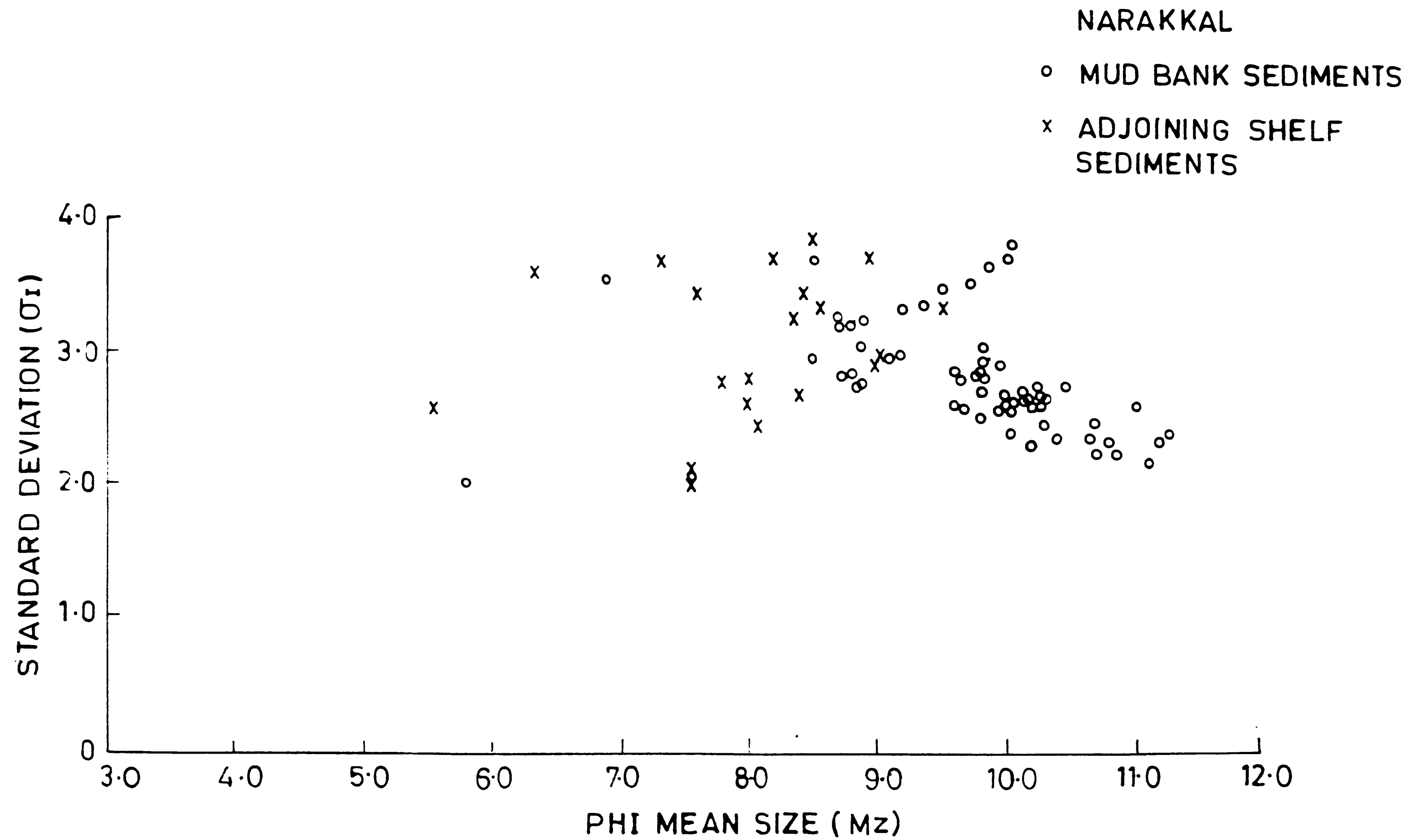


FIG. 4·25 PHI MEAN SIZE (Mz) Vs STANDARD DEVIATION (σ_I)

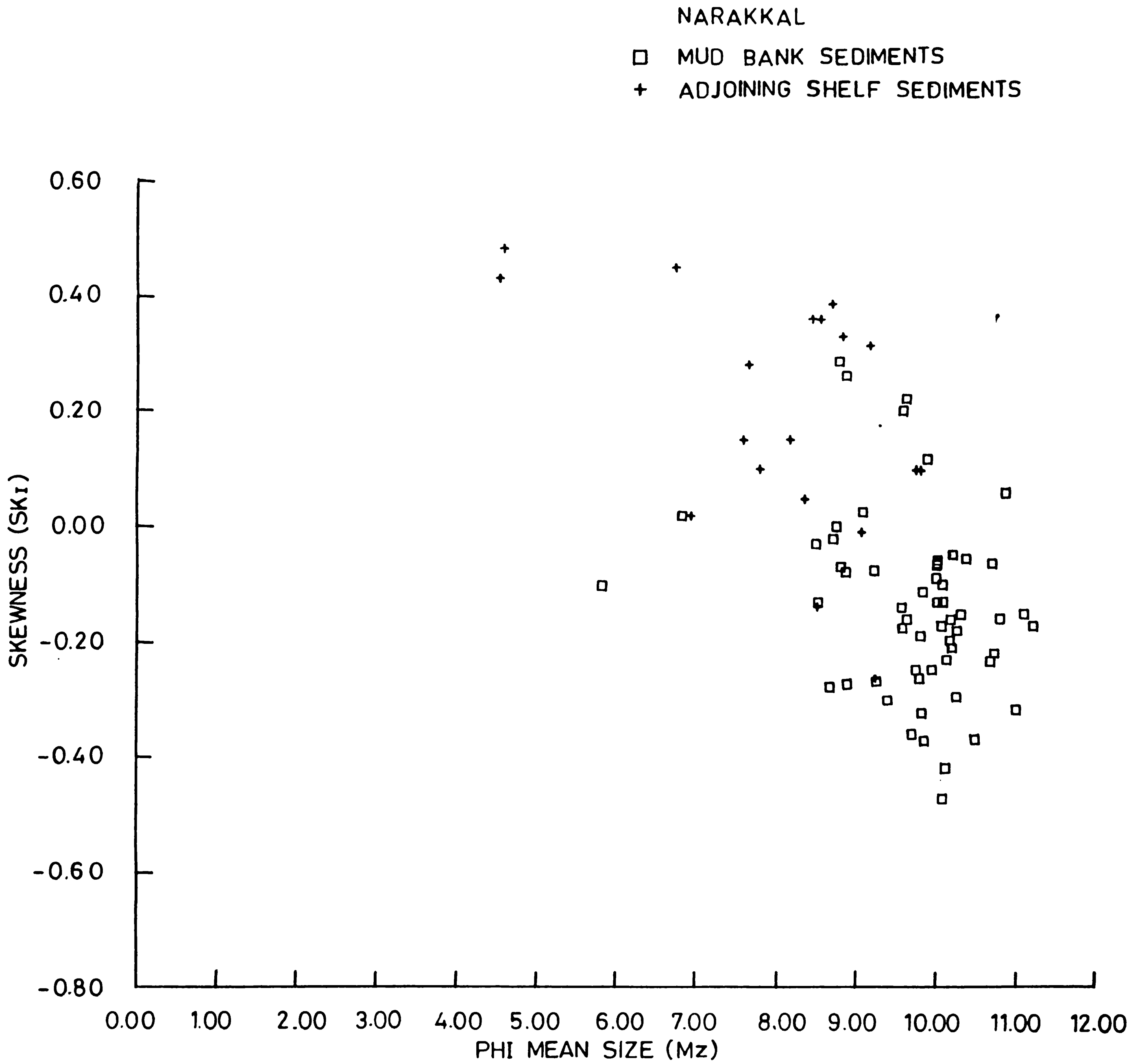


FIG.4·26 PHI MEAN SIZE (Mz) Vs SKEWNESS (SKI)

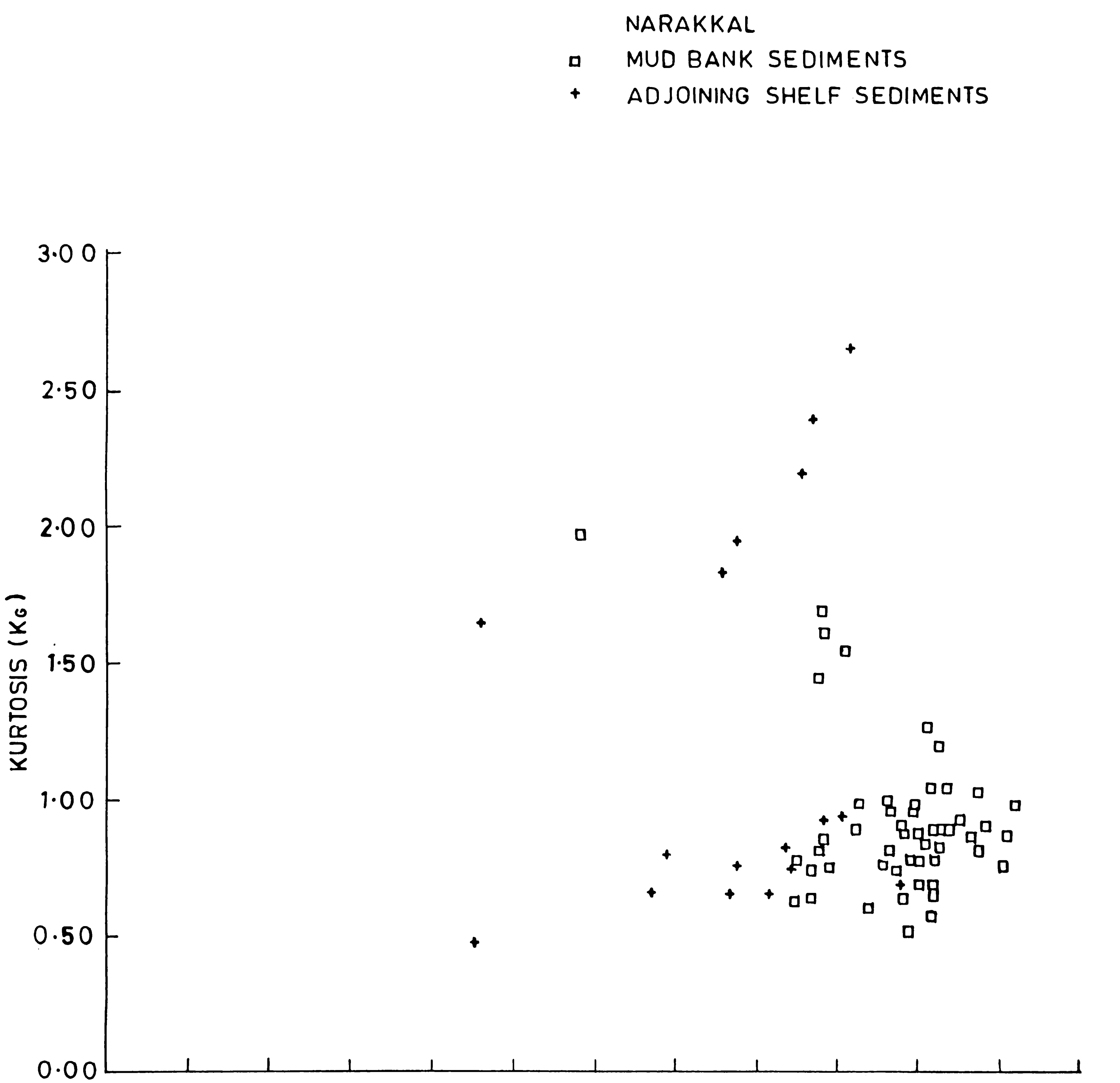


FIG.4·27 PHI MEAN SIZE (Mz) Vs KURTOSIS (K_G)

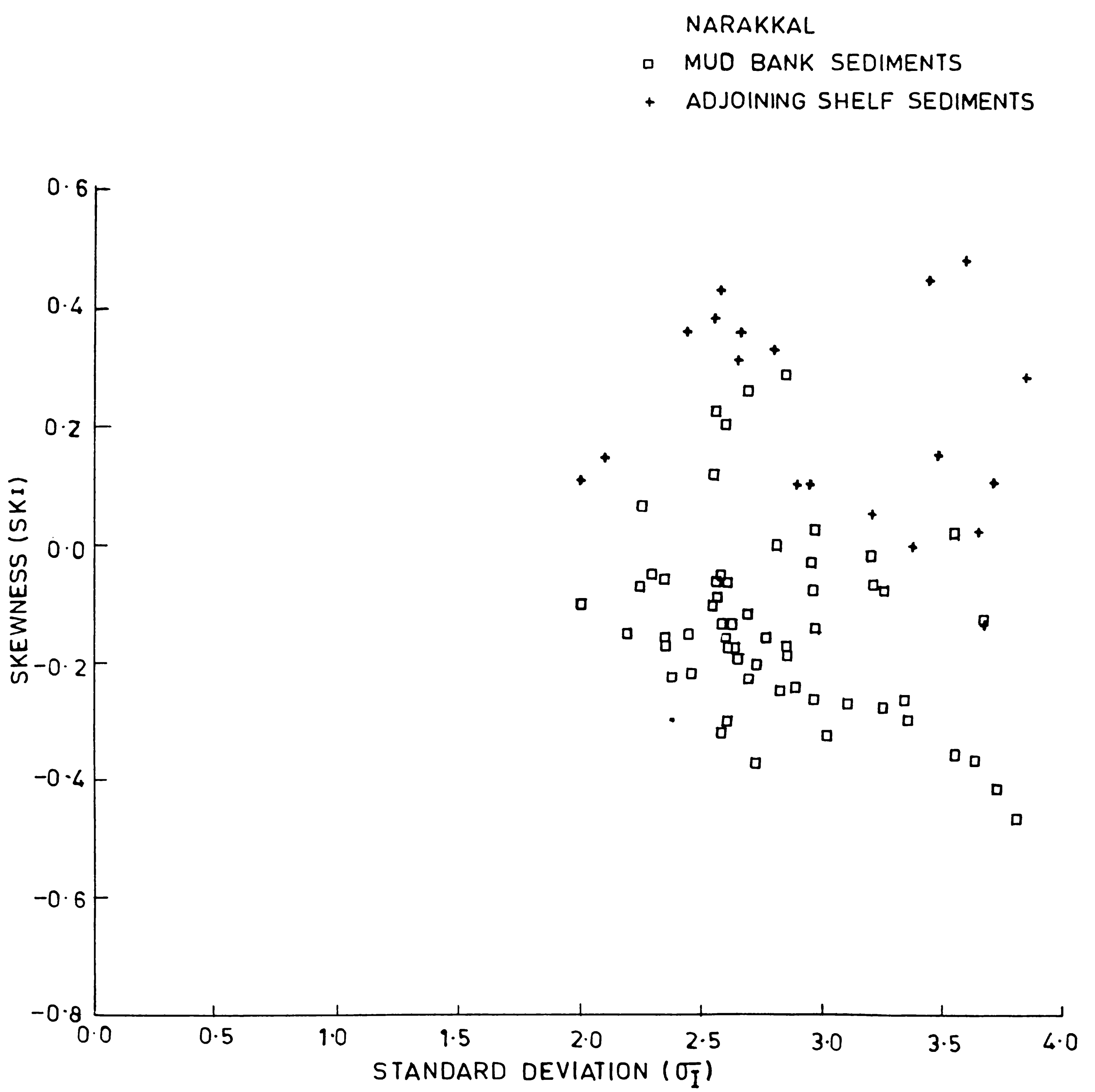


FIG. 4·28 STANDARD DEVIATION (σI) Vs SKEWNESS (SKI)

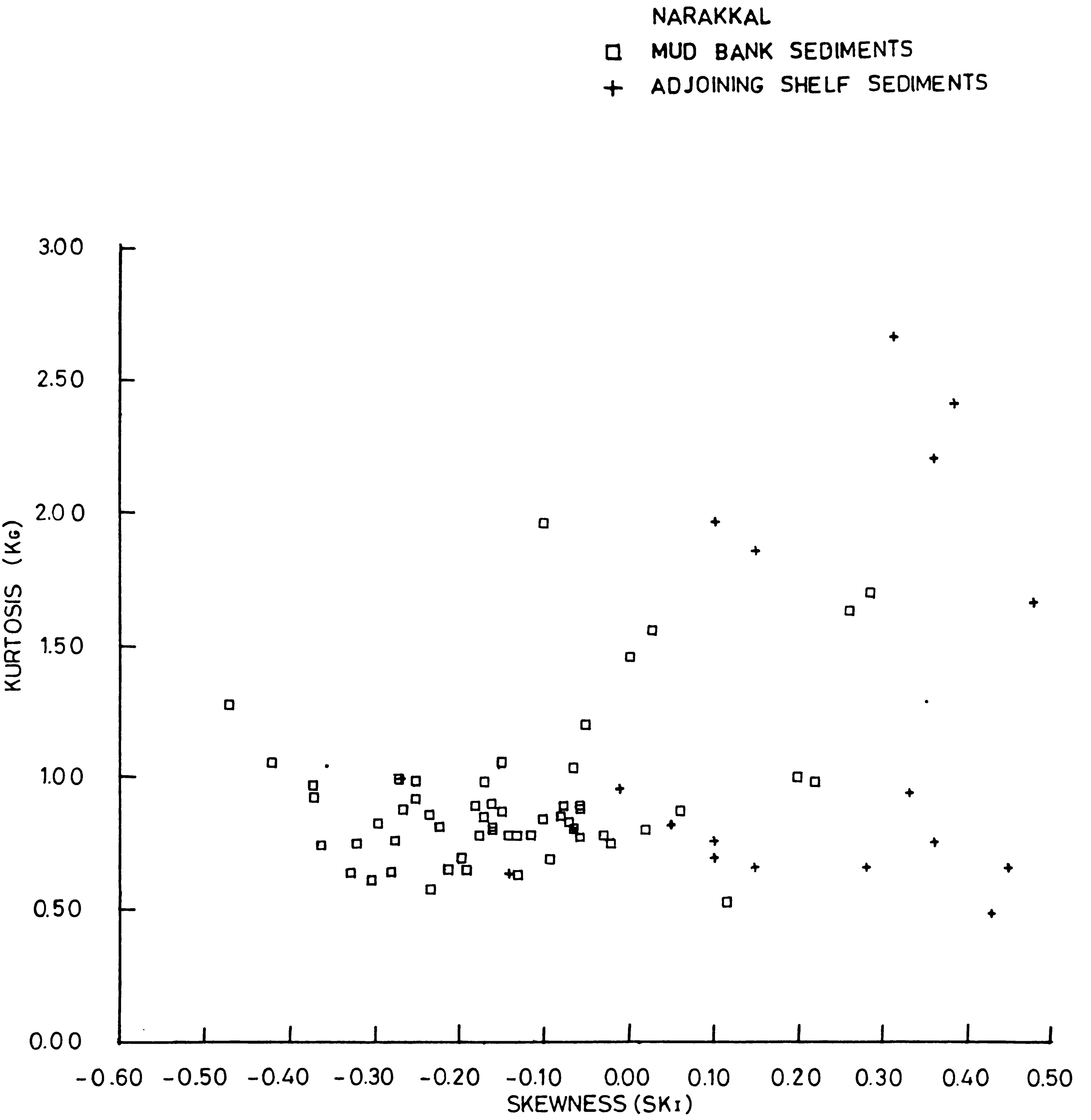


FIG. 4·29 SKEWNESS (SKI) Vs KURTOSIS (KG)

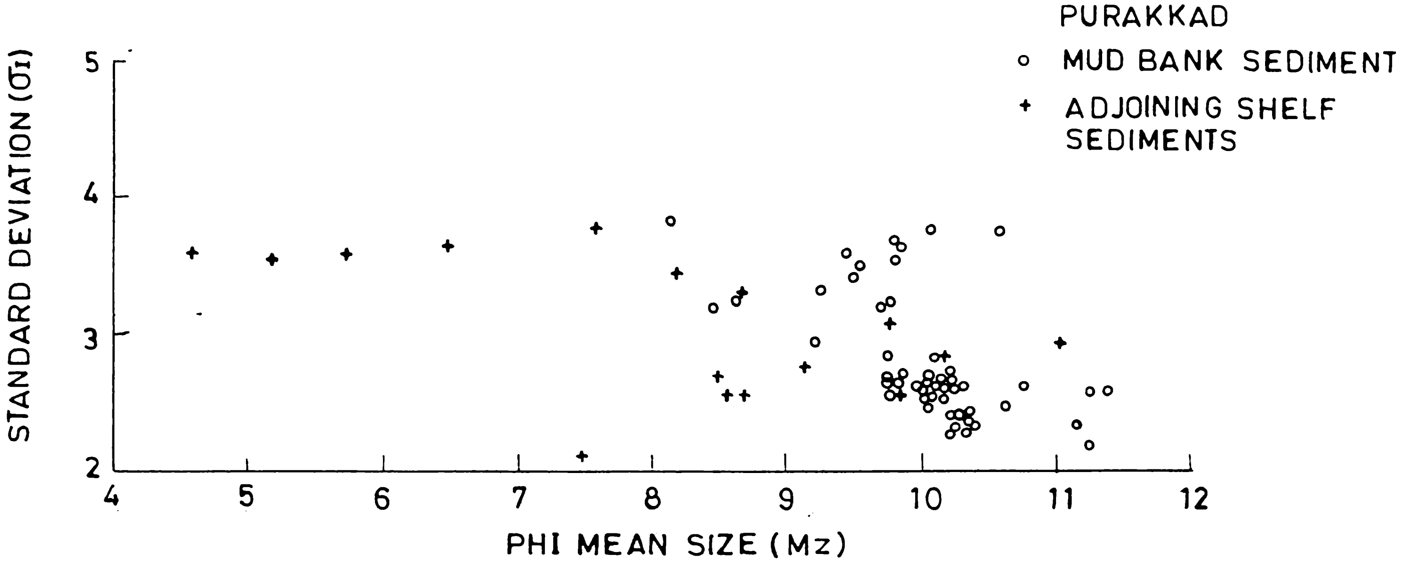


FIG.4·30 PHI MEAN SIZE (Mz) Vs STANDARD DEVIATION (σ_I)

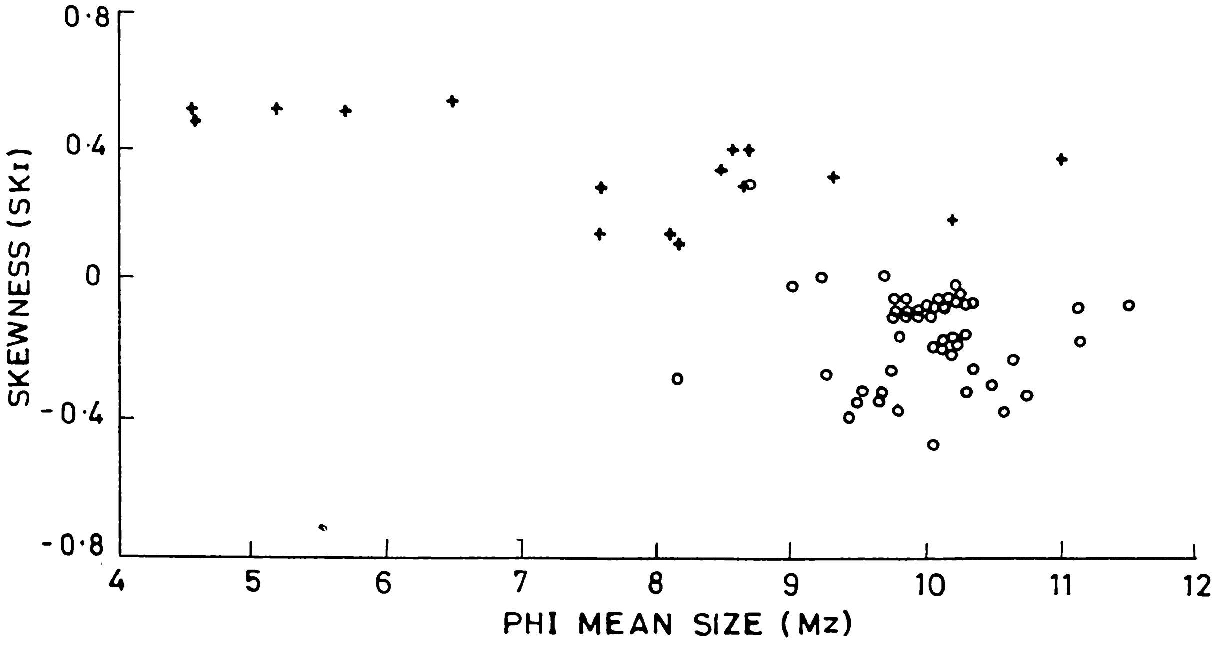


FIG.4·31 PHI MEAN SIZE (Mz) Vs SKEWNESS (SKI)

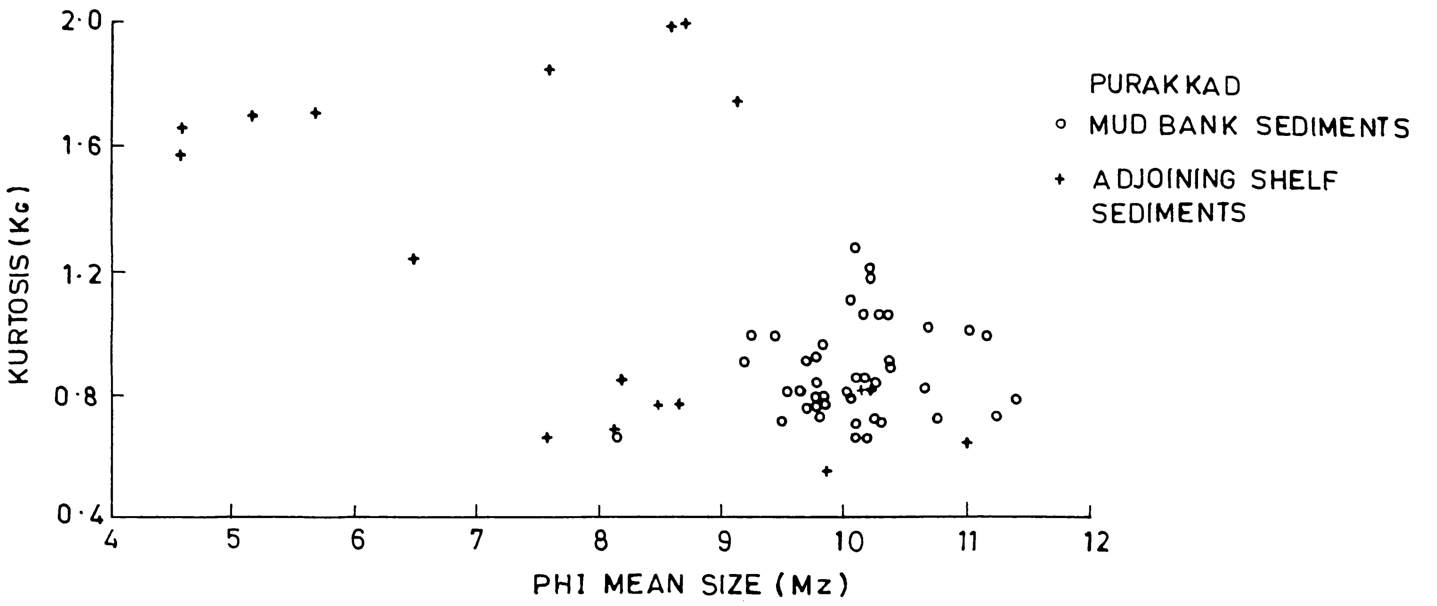


FIG.4·32 PHI MEAN SIZE (Mz) Vs KURTOSIS (KG)

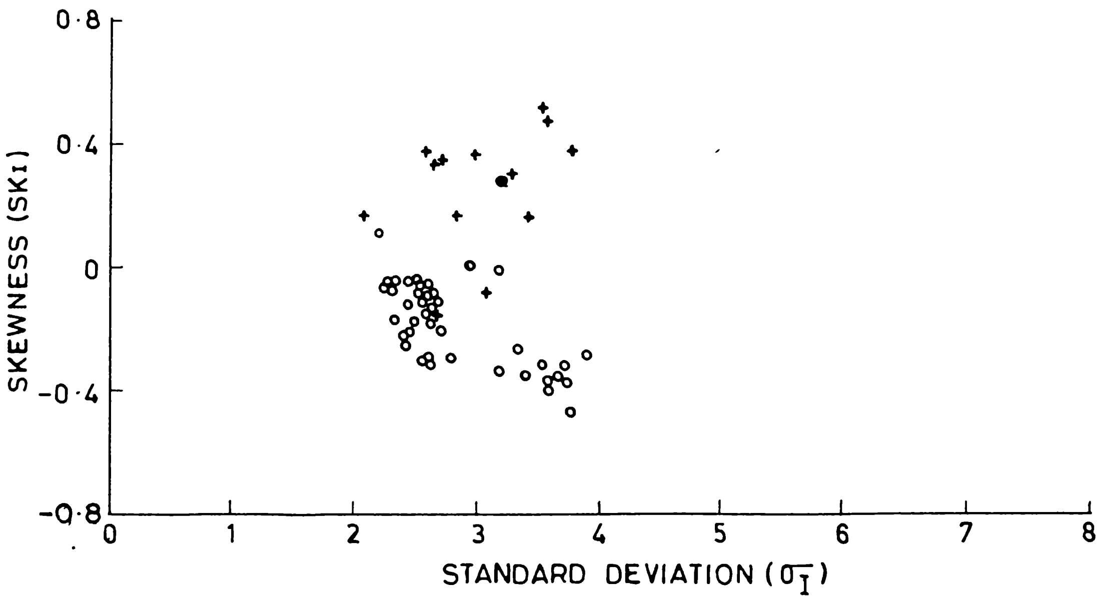


FIG.4·33 STANDARD DEVIATION (σ_I) Vs SKEWNESS (SKI)

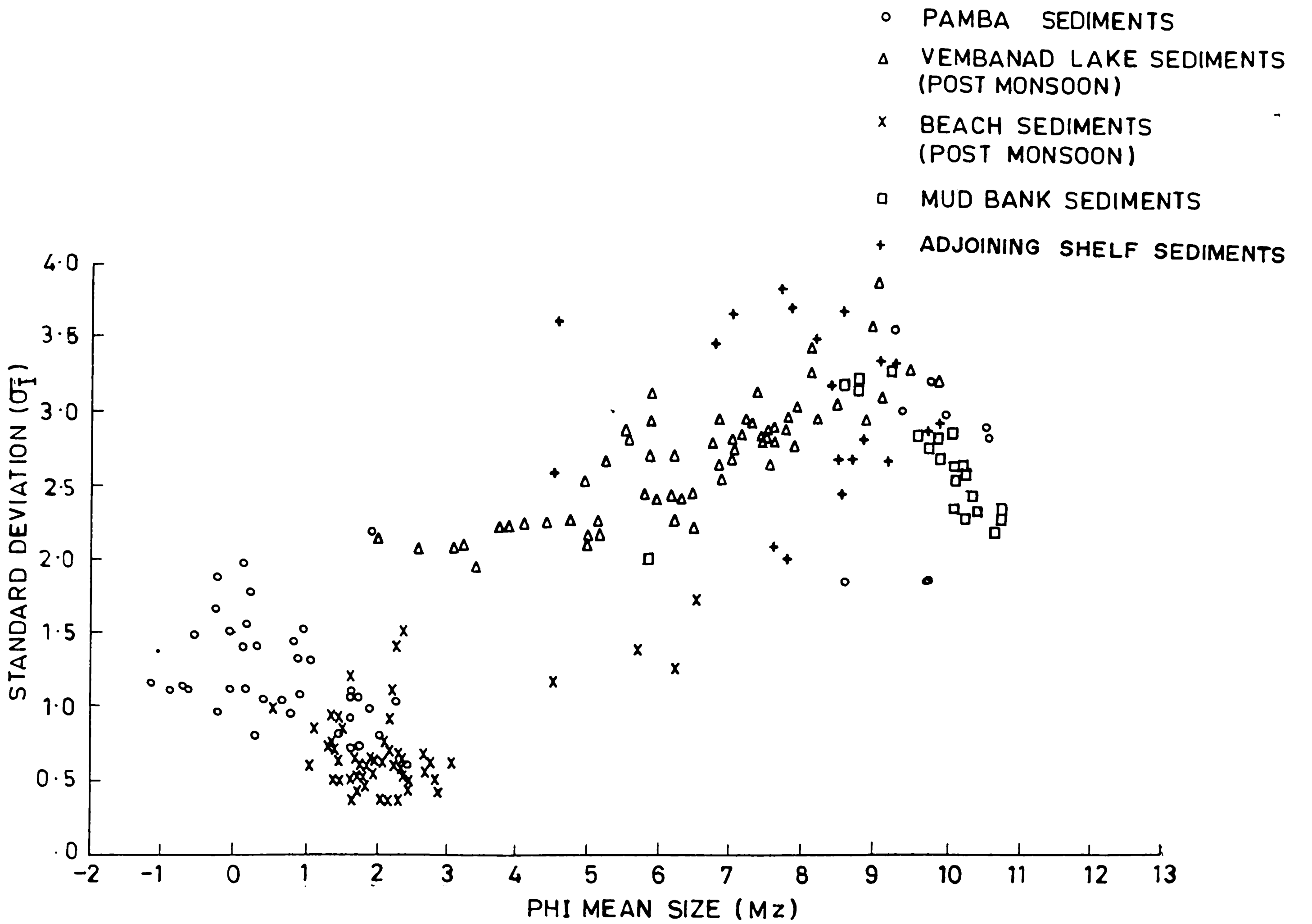


FIG 4.34 PHI MEAN SIZE (Mz) Vs STANDARD DEVIATION (σ_I)

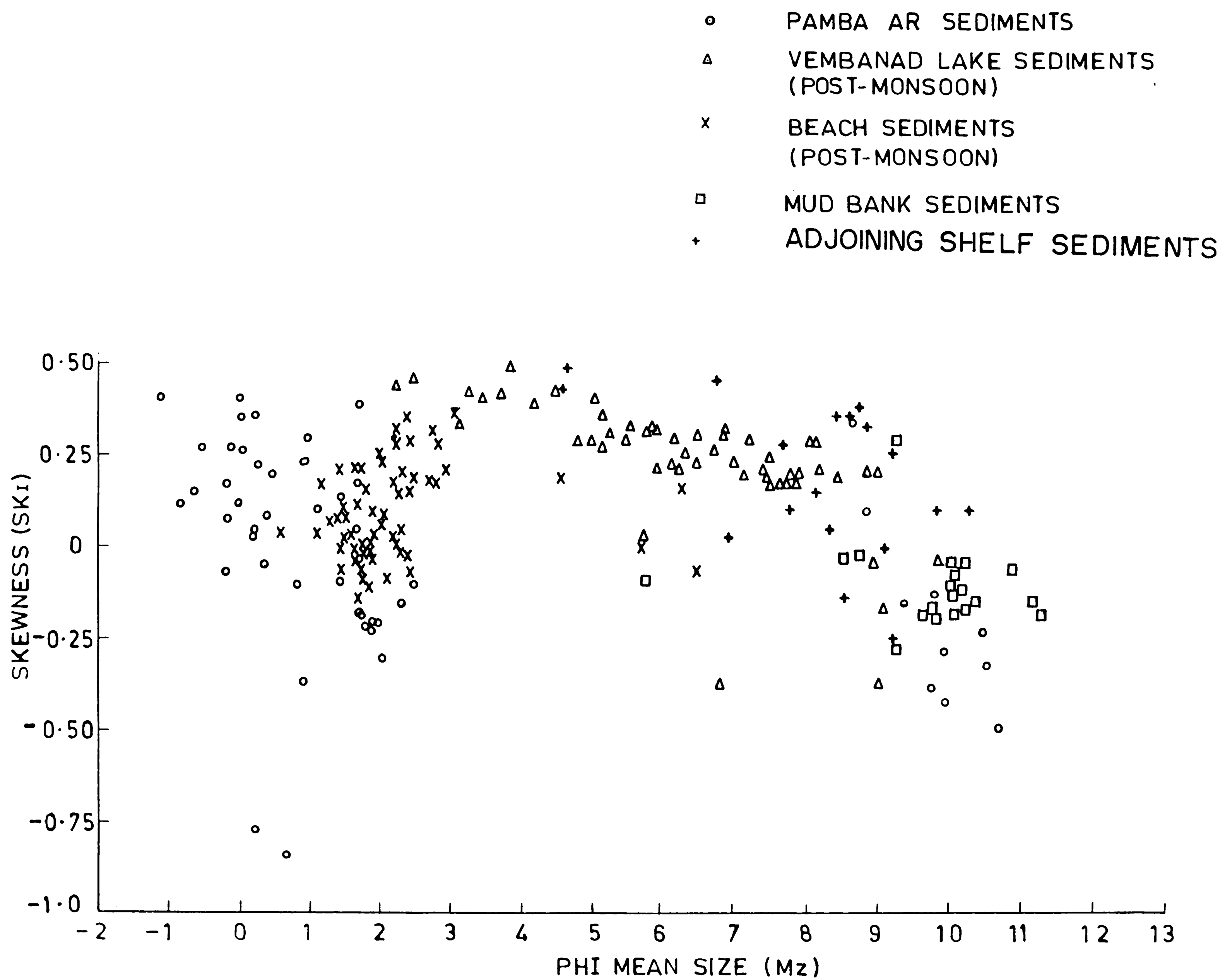


FIG.4·35 PHI MEAN SIZE (Mz) Vs SKEWENESS (SKI)

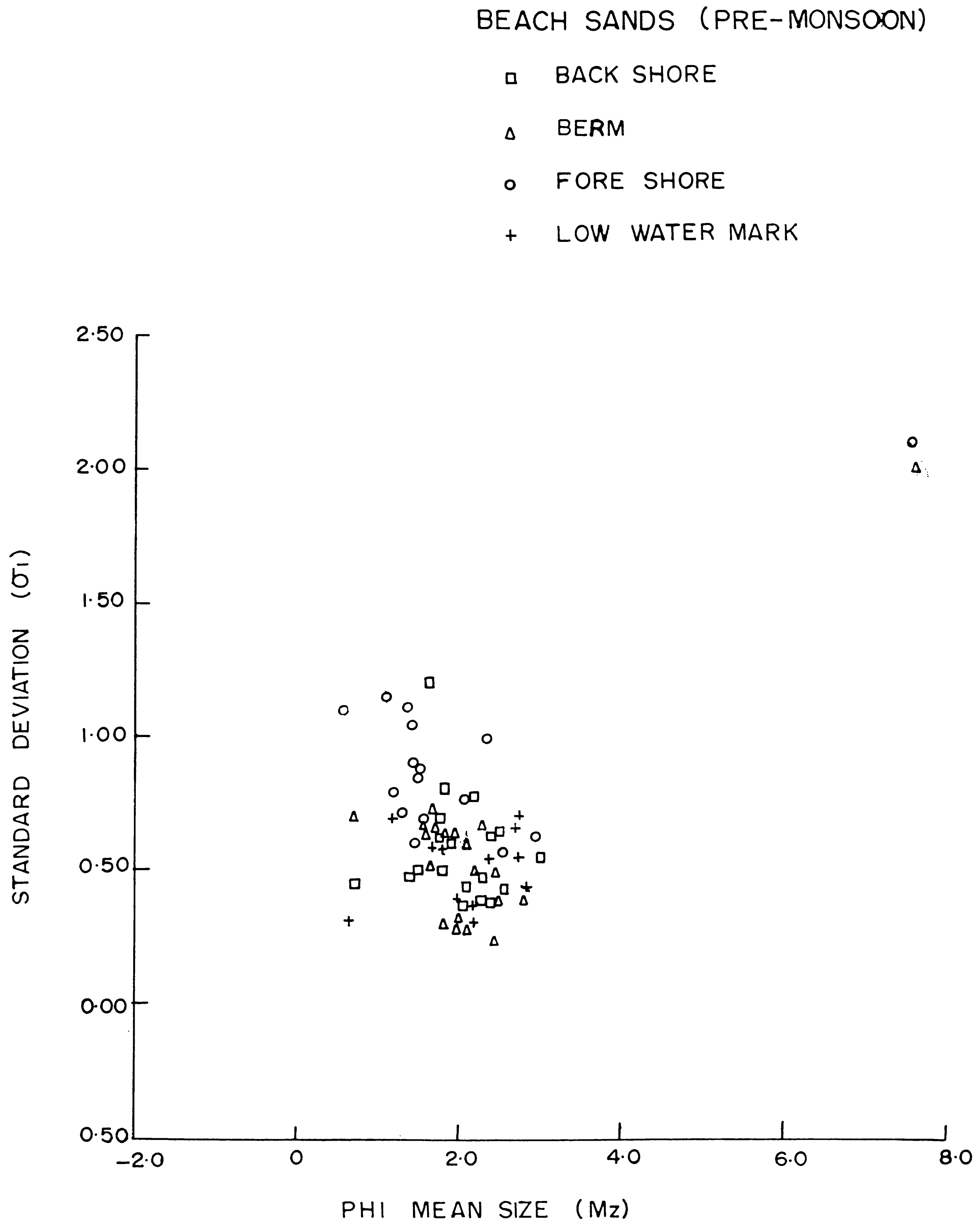


FIG. 4·36. PHI MEAN SIZE (Mz) Vs STANDARD DEVIATION (σI)

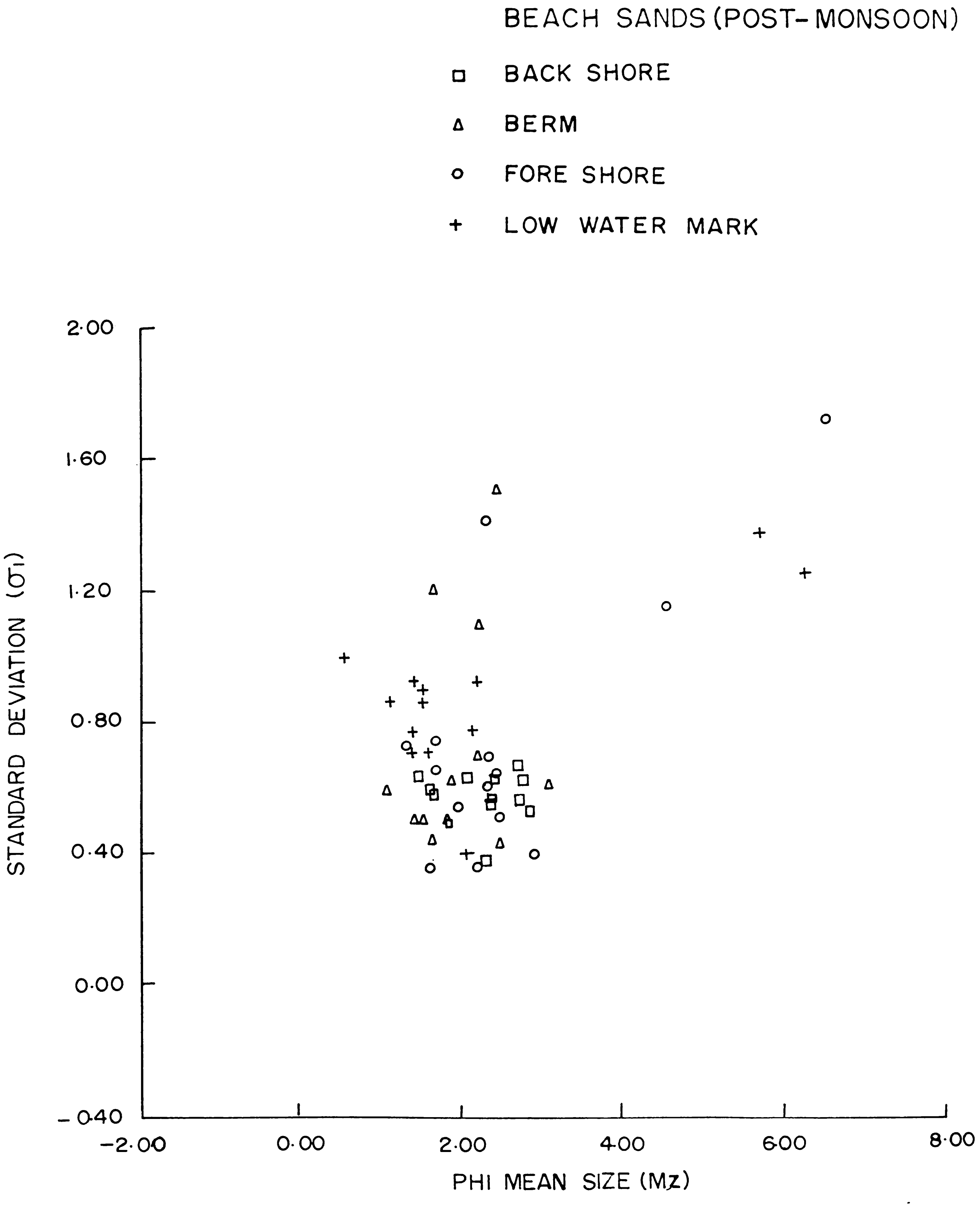


FIG. 4·37. PHI MEAN SIZE (Mz) Vs STANDARD DEVIATION (σ1)

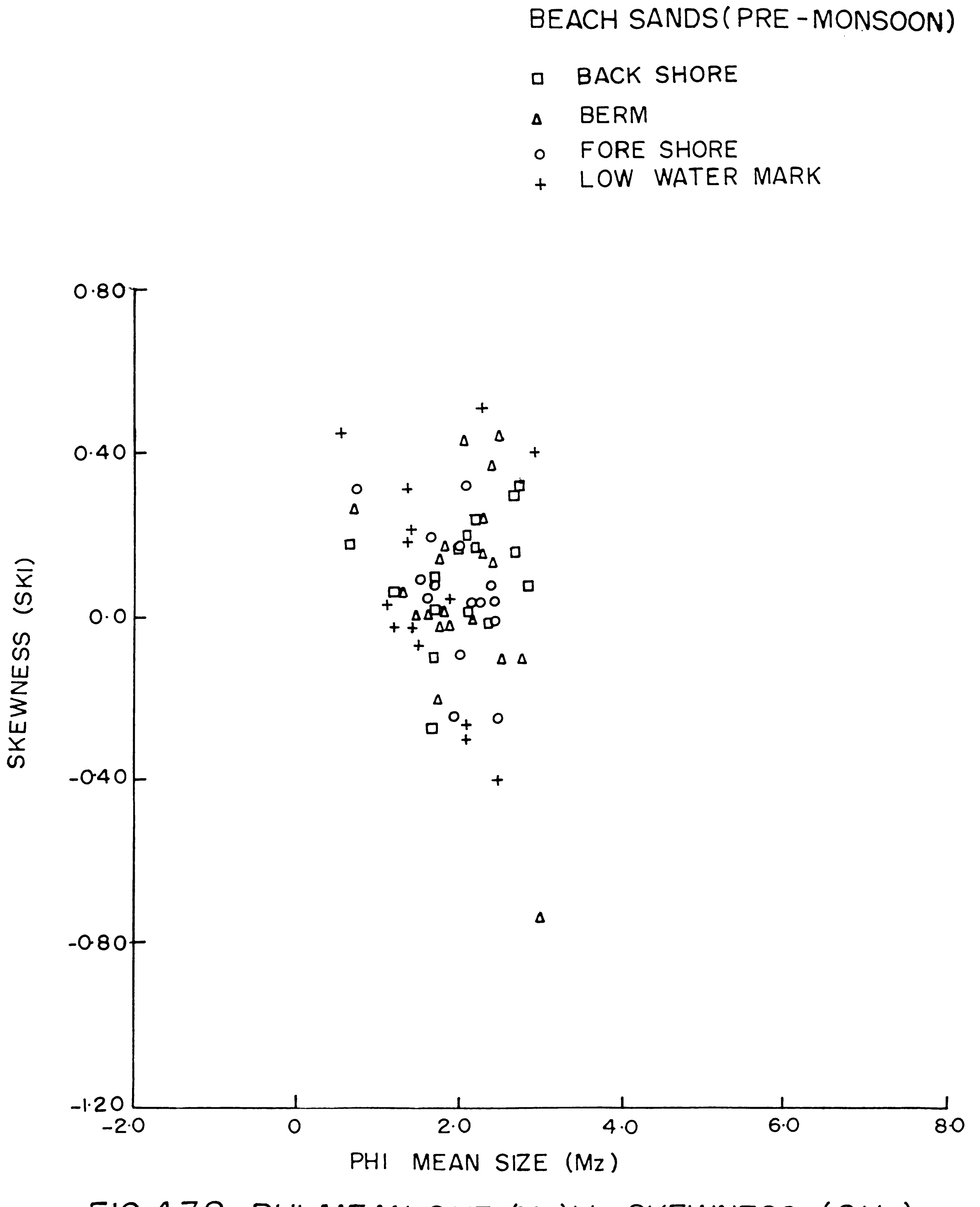


FIG. 4·38 PHI MEAN SIZE (Mz) Vs SKEWNESS (SK_1)

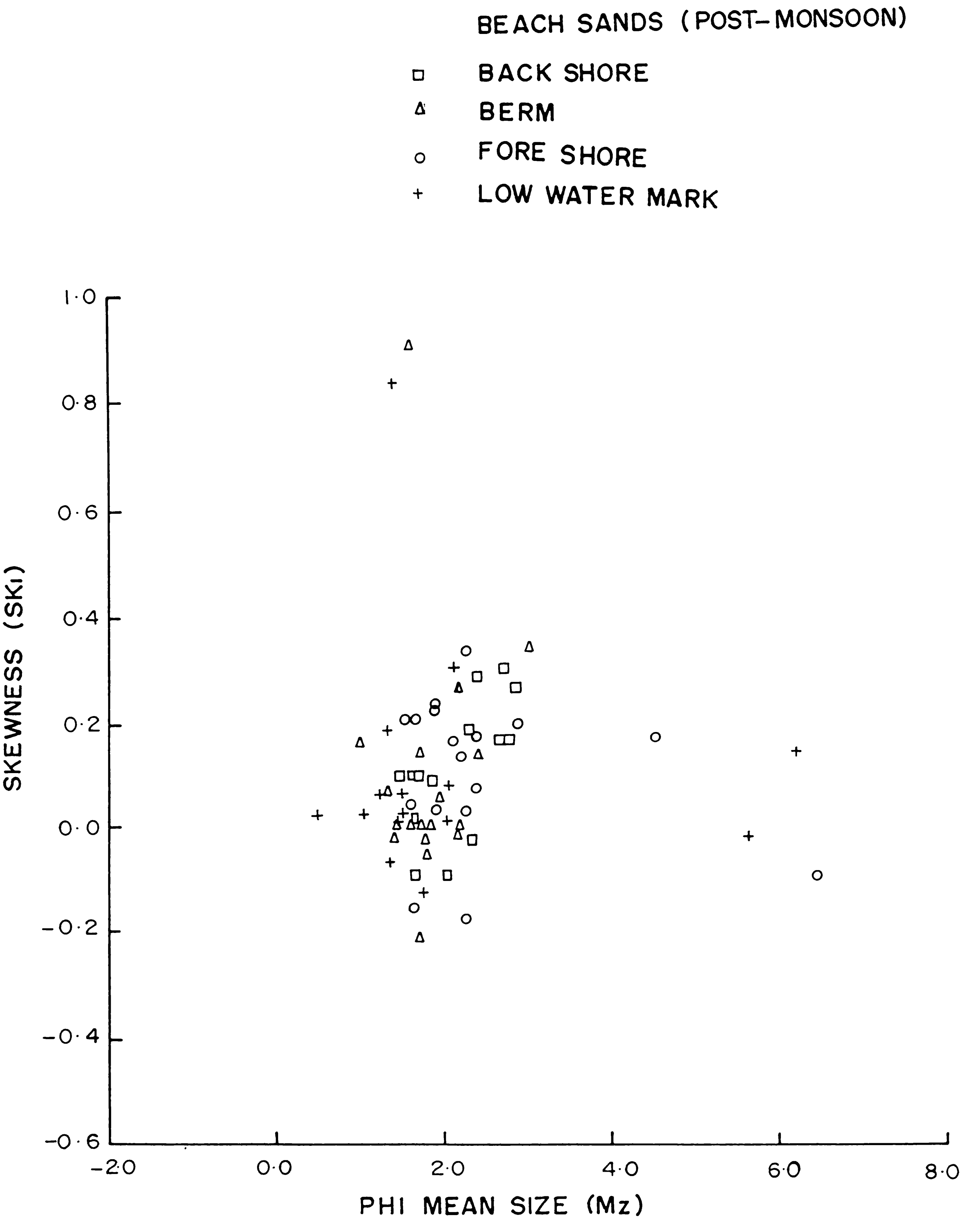


FIG. 4·39 PHI MEAN SIZE (Mz) Vs SKEWNESS (SKI)

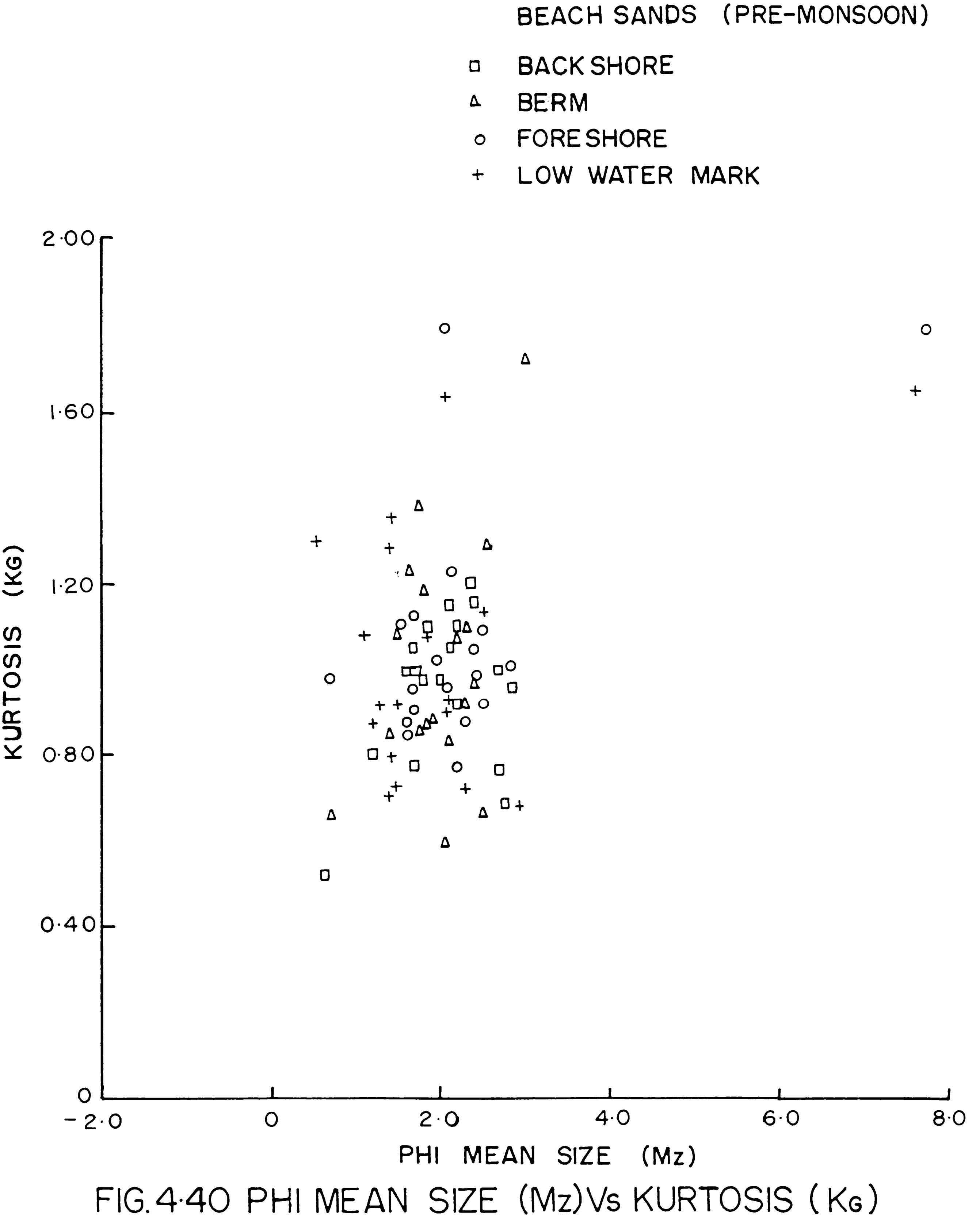


FIG. 4·40 PHI MEAN SIZE (Mz) Vs KURTOSIS (KG)

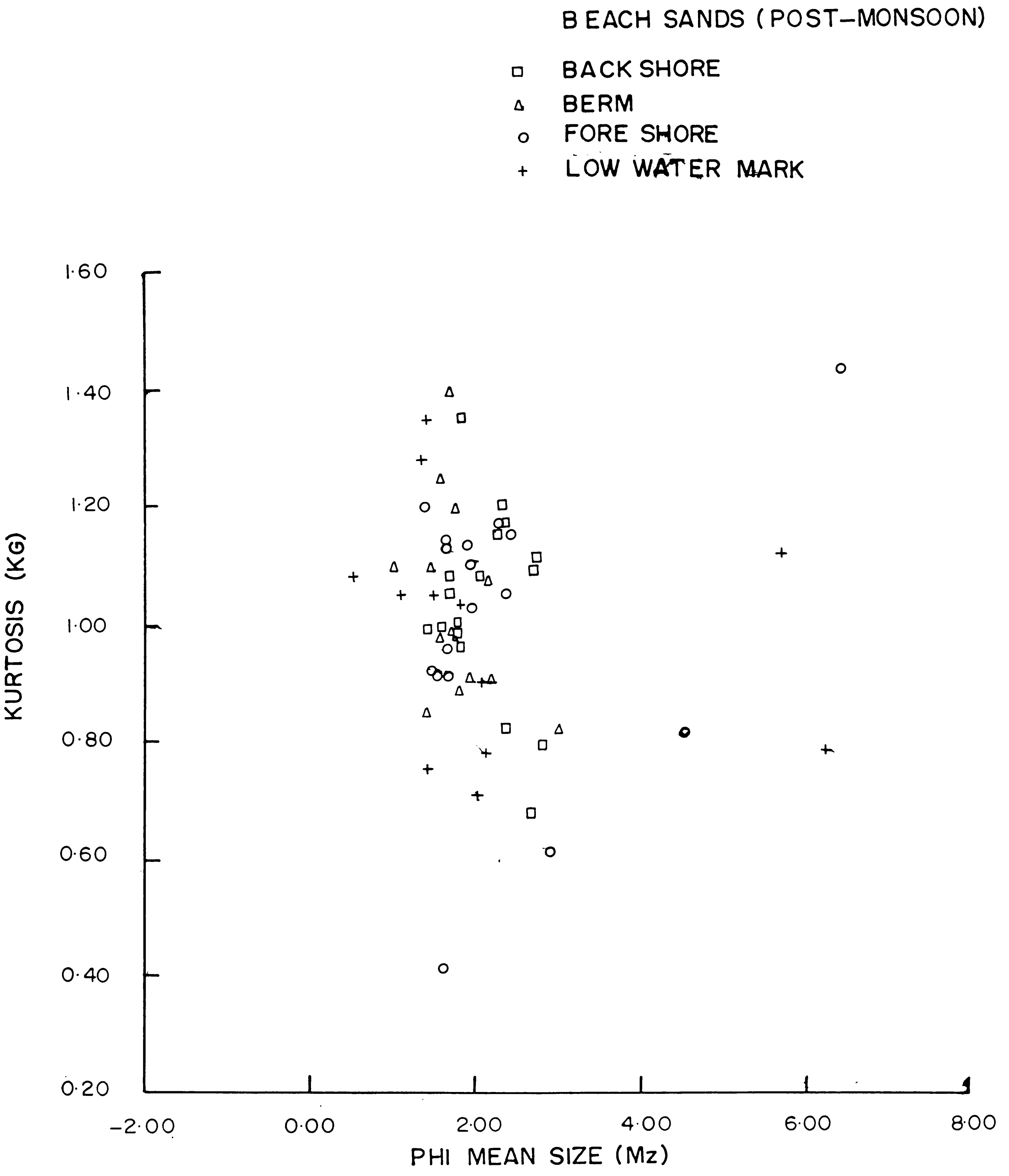


FIG.4·41 PHI MEAN SIZE (Mz) Vs KURTOSIS (KG)

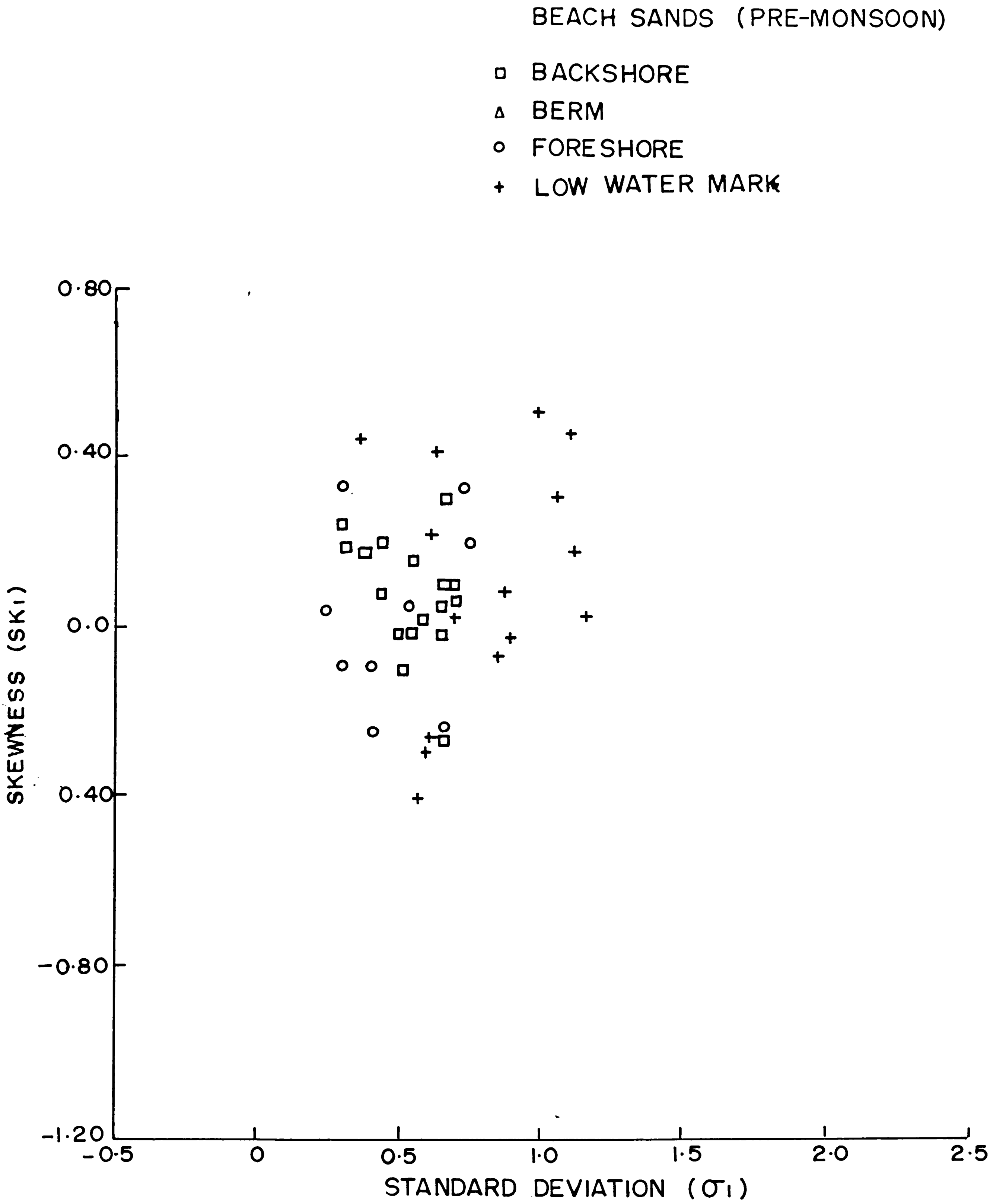


FIG. 4·42 STANDARD DEVIATION (σI) Vs SKEWNESS (SKI)

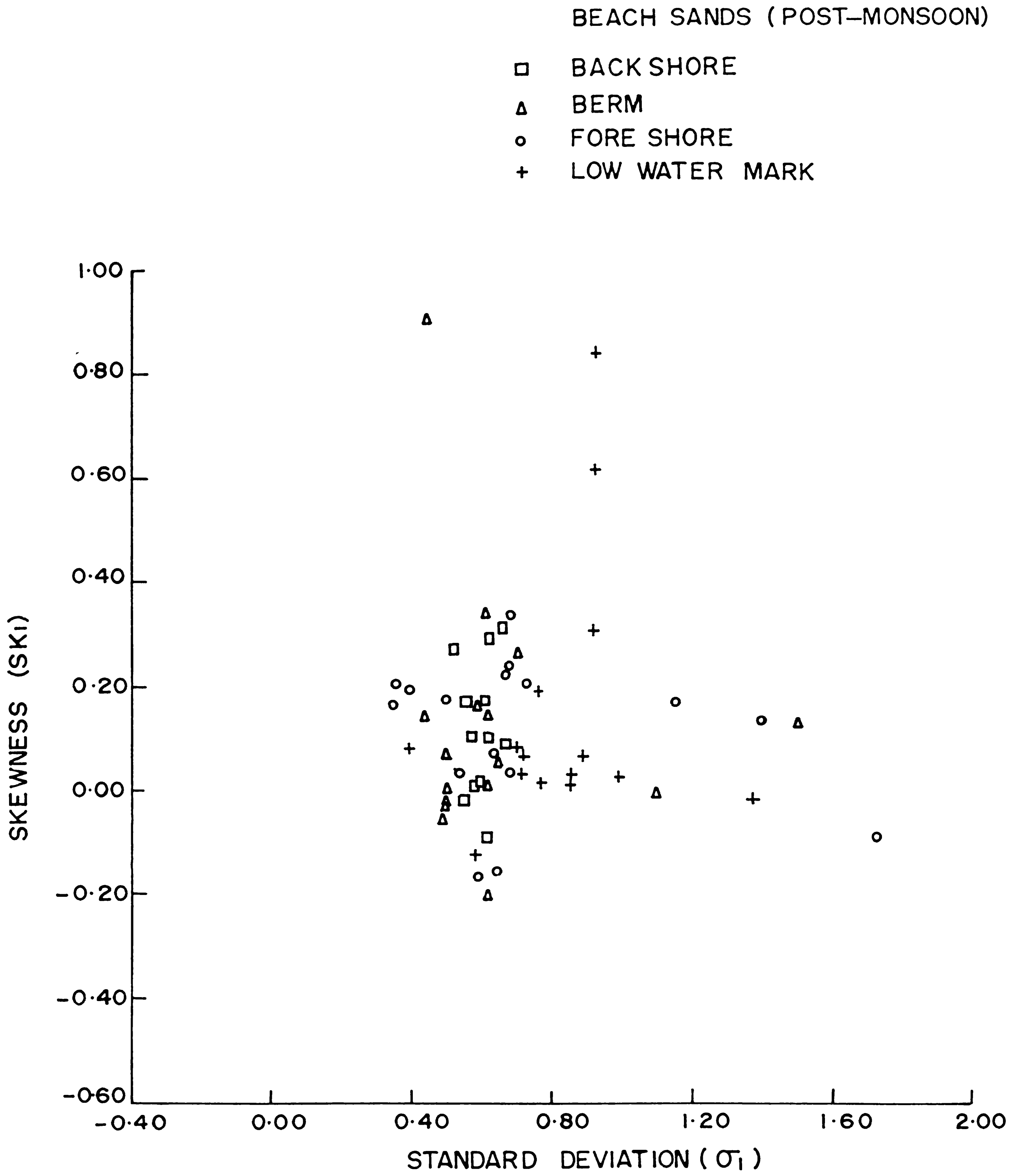


FIG. 4·43 STANDARD DEVIATION σ_1 (Vs) SKEWNESS (SK_1)

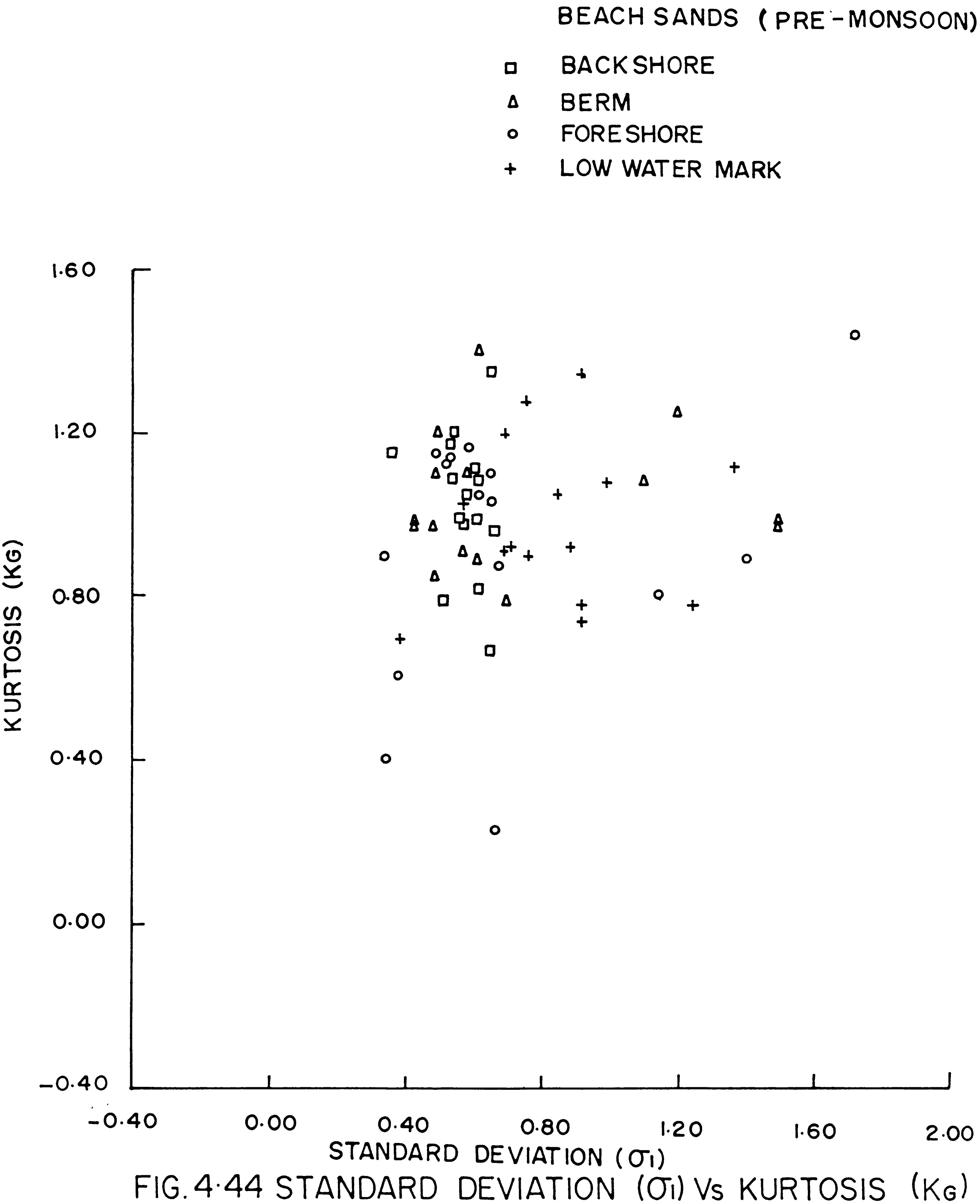


FIG. 4·44 STANDARD DEVIATION (σI) Vs KURTOSIS (KG)

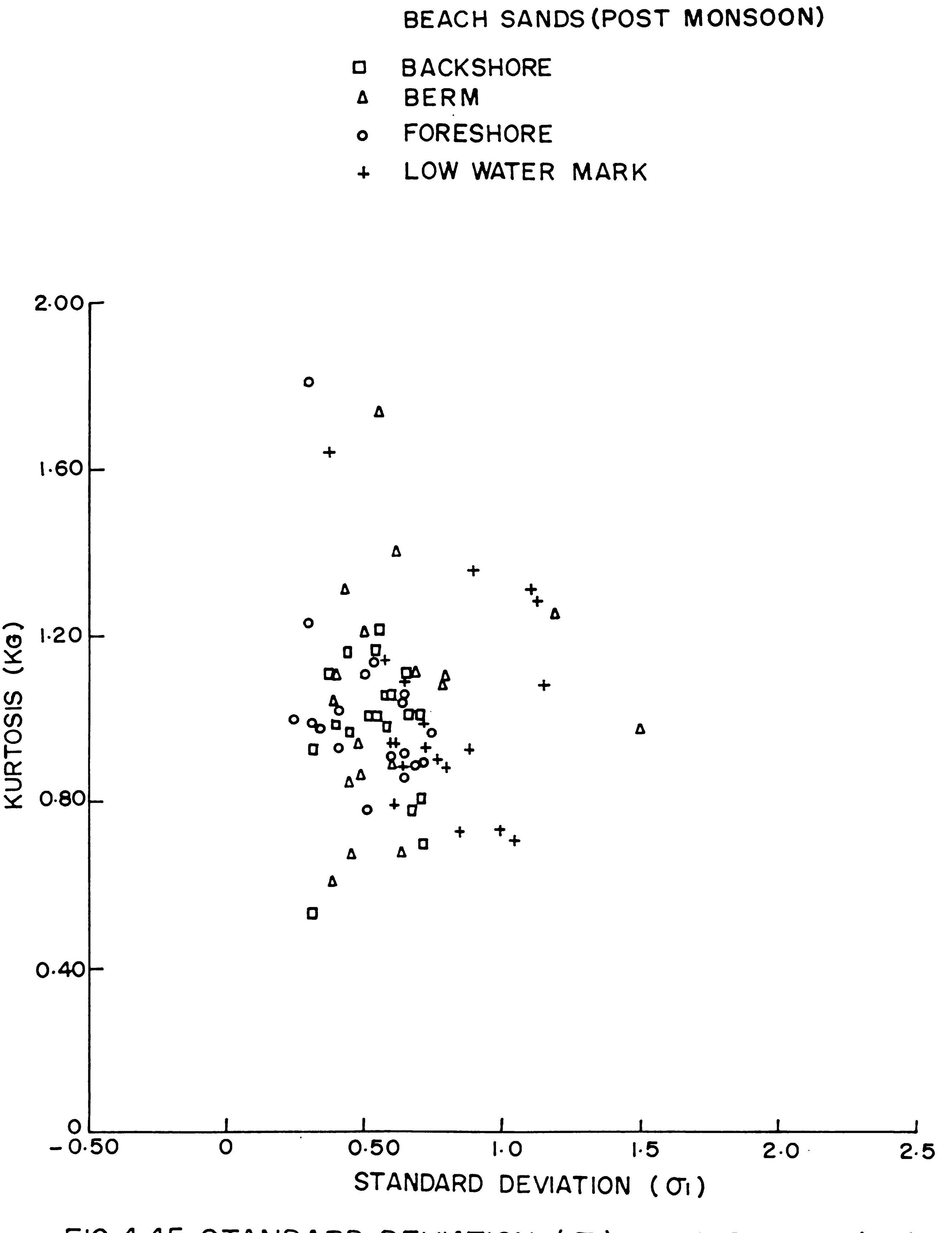


FIG. 4·45 STANDARD DEVIATION (σI) Vs KURTOSIS (KG)

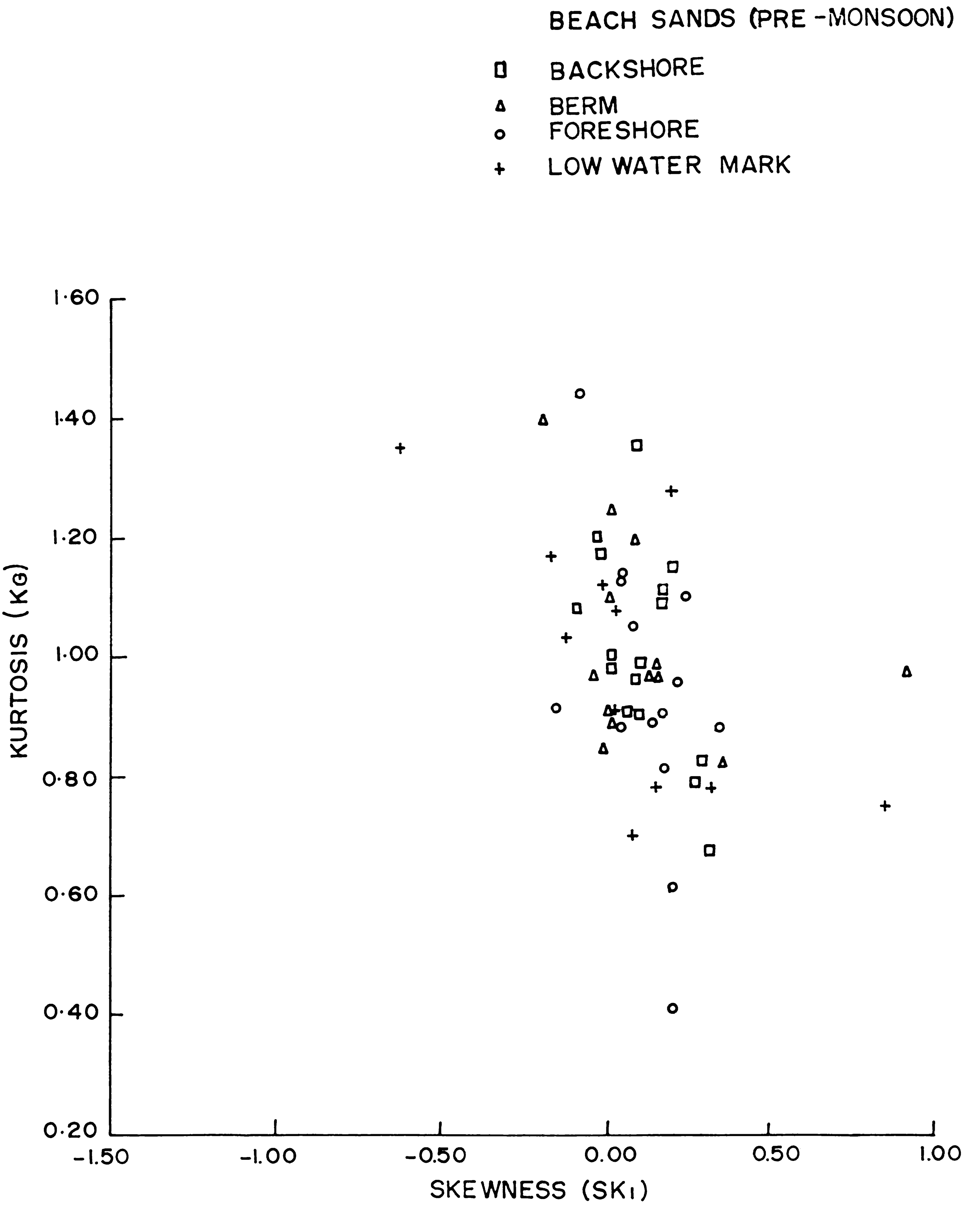


FIG. 4·46 SKEWNESS (SKI) Vs KURTOSIS (KG)

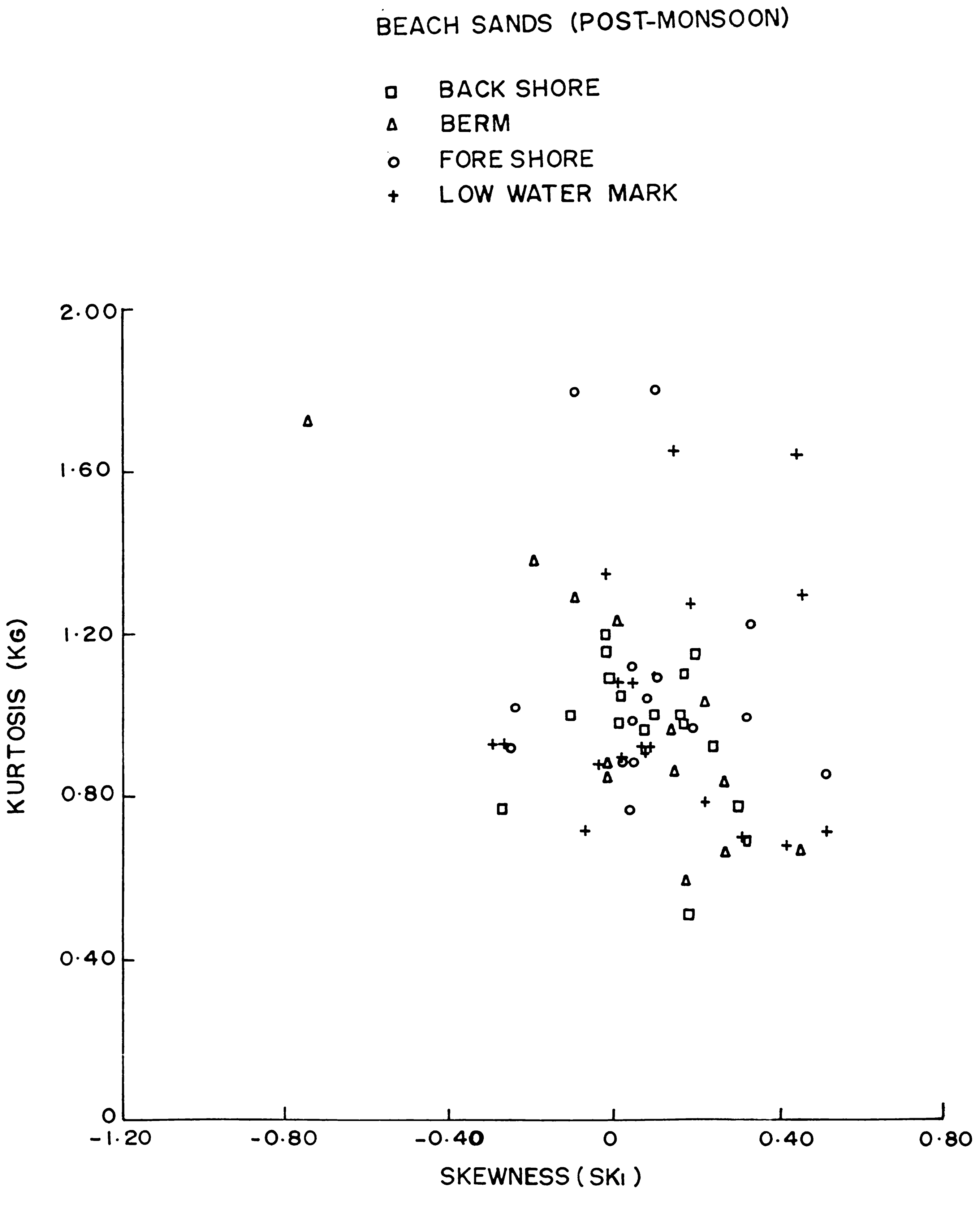
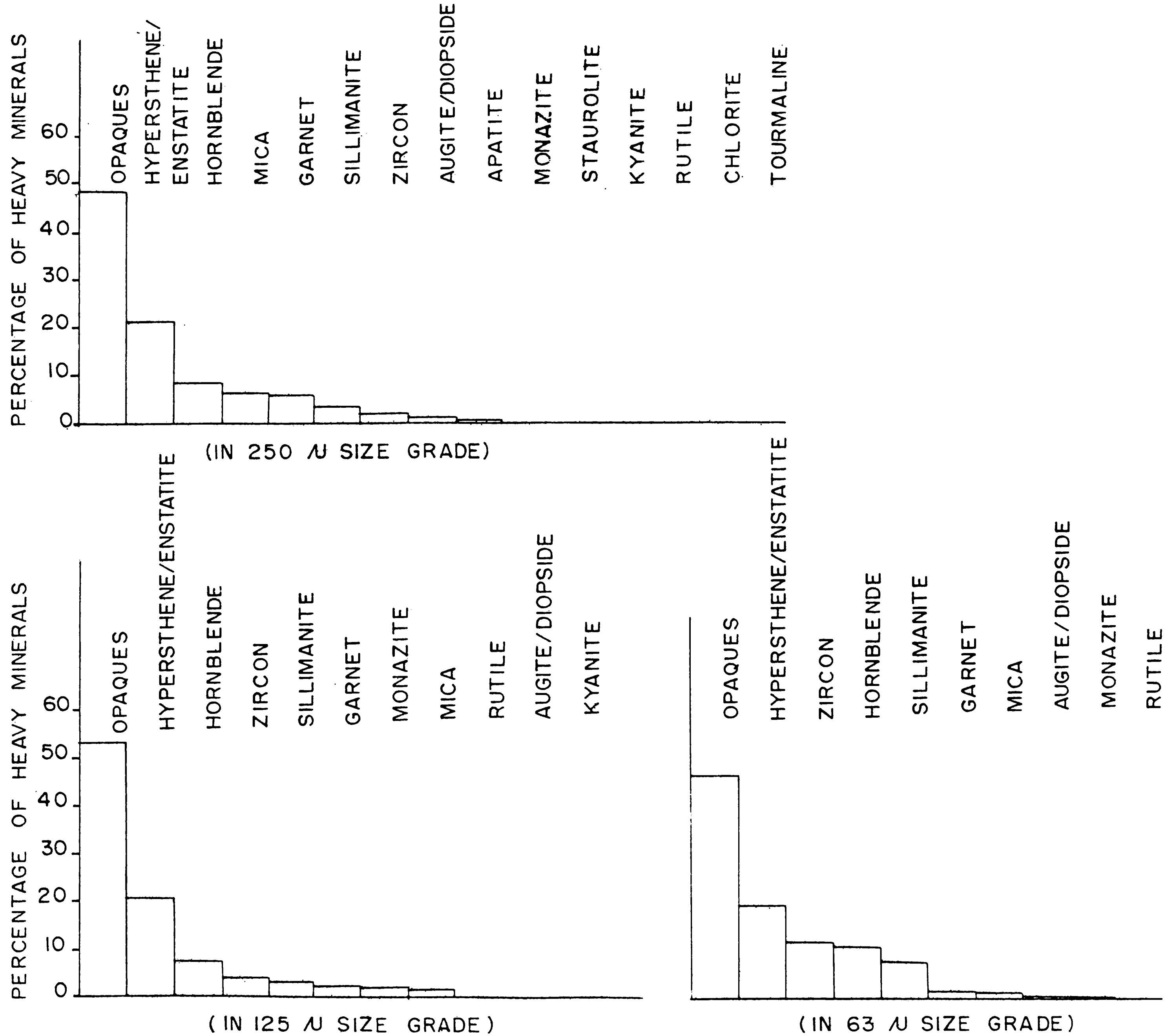


FIG.4·47 SKEWNESS SKI Vs KURTOSIS (KG)



FIG· 5·1 DISTRIBUTION OF HEAVY MINERALS IN PAMBA AR SEDIMENTS

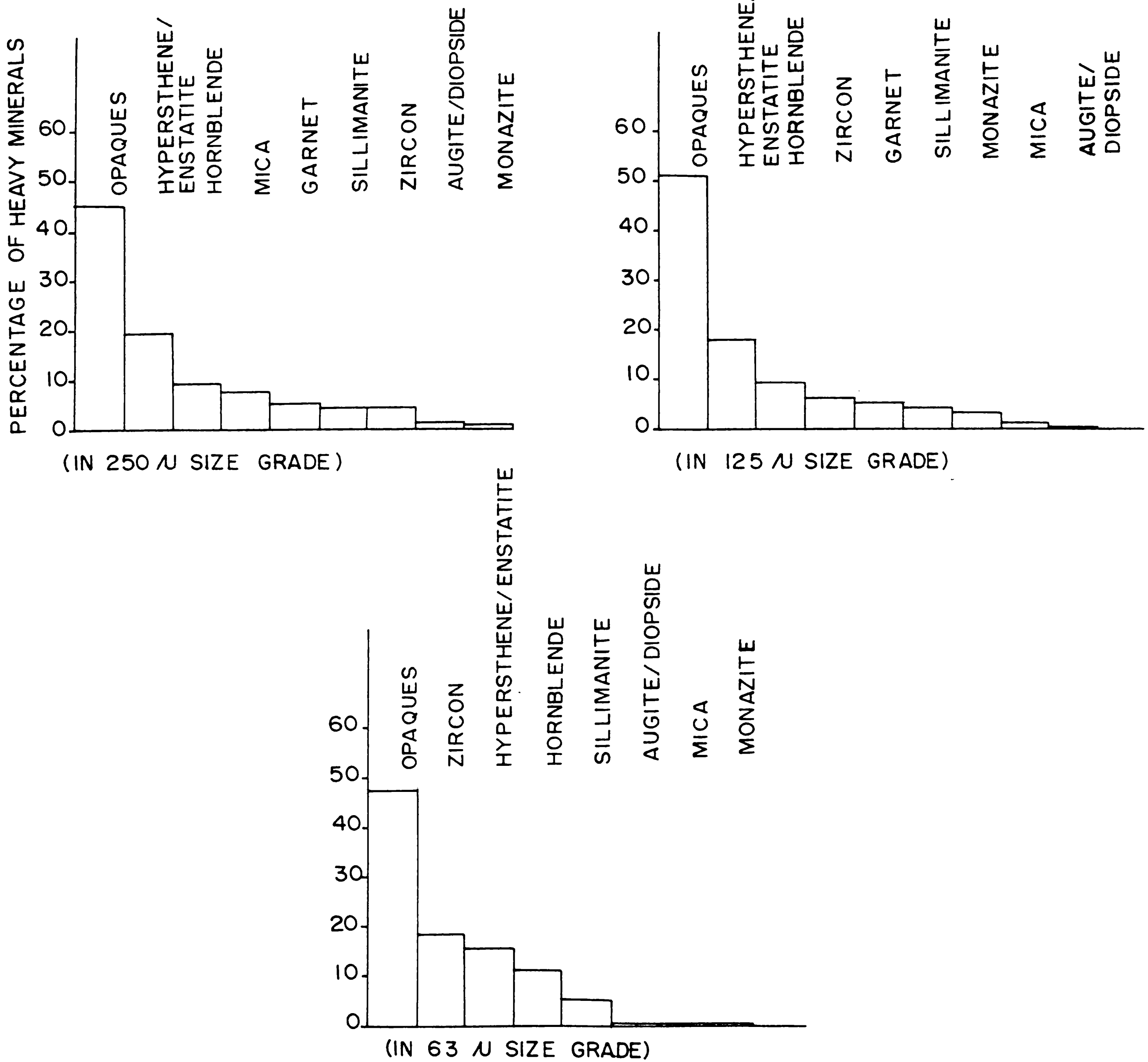
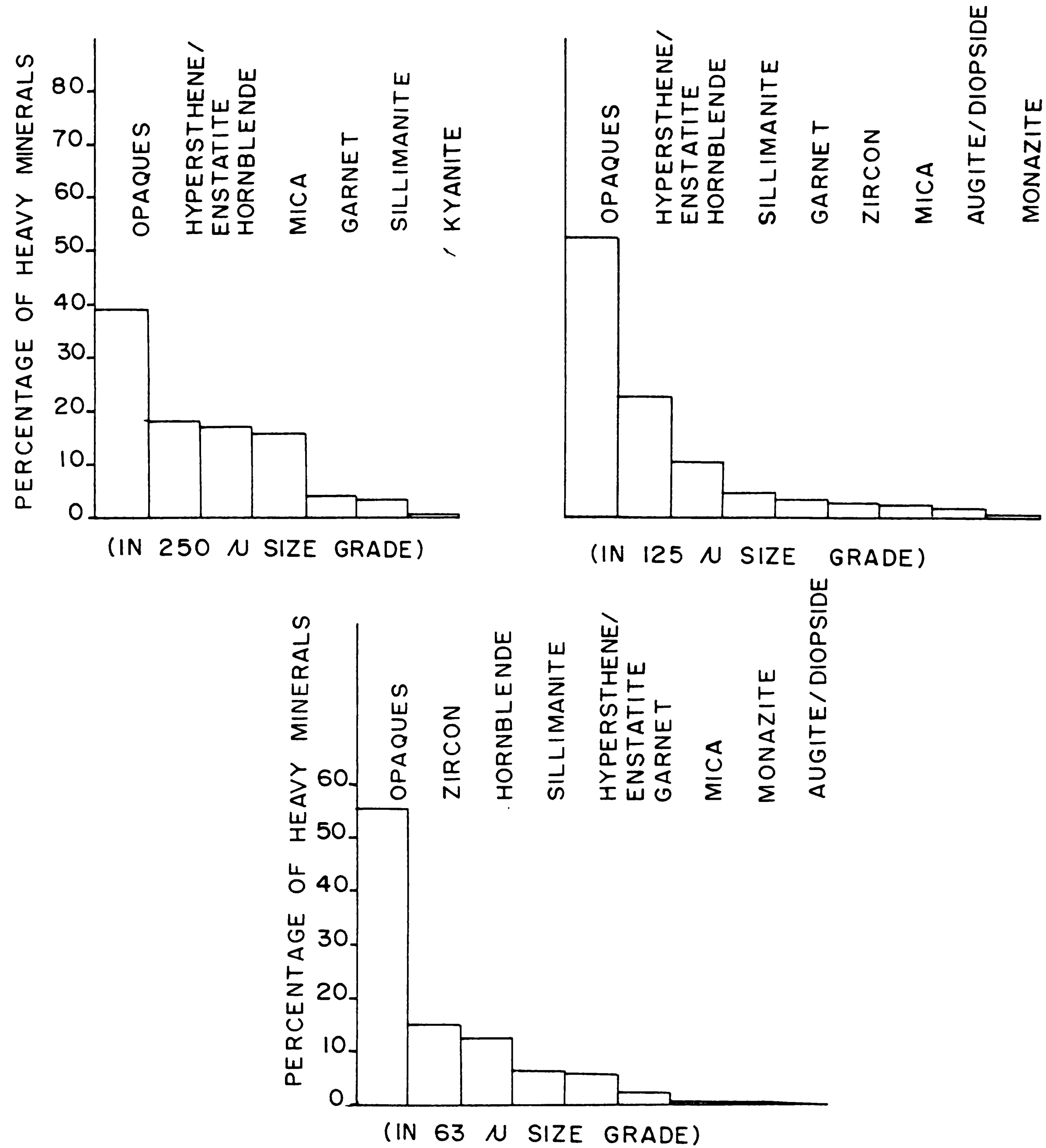


FIG. 5·2 DISTRIBUTION OF HEAVY MINERALS IN MANIMALA AR SEDIMENTS



FIG· 5·3 DISTRIBUTION OF HEAVY MINERALS IN MINACHIL AR SEDIMENTS.

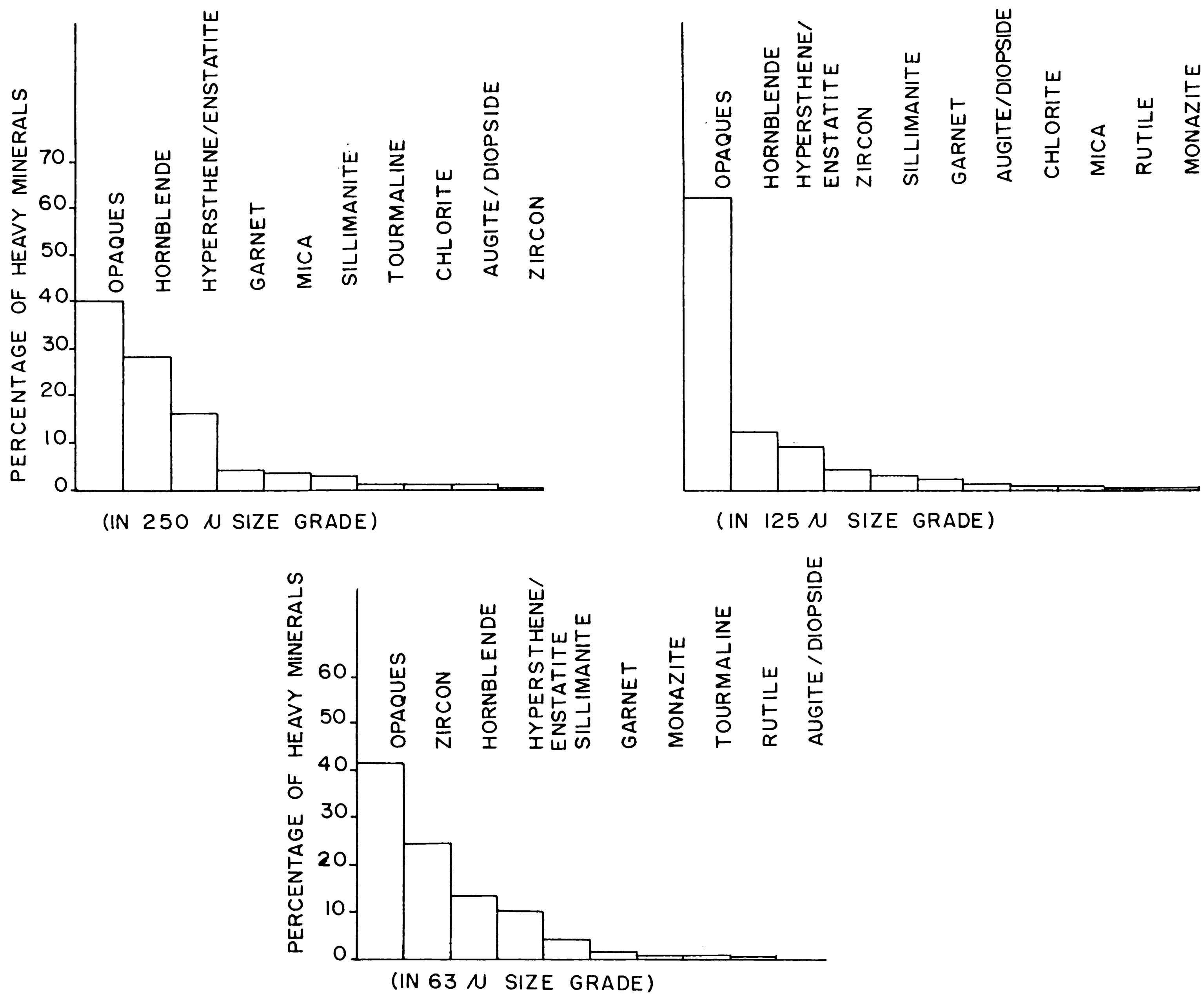


FIG · 5·4 DISTRIBUTION OF HEAVY MINERALS IN MUVATTUPUZHA SEDIMENTS.

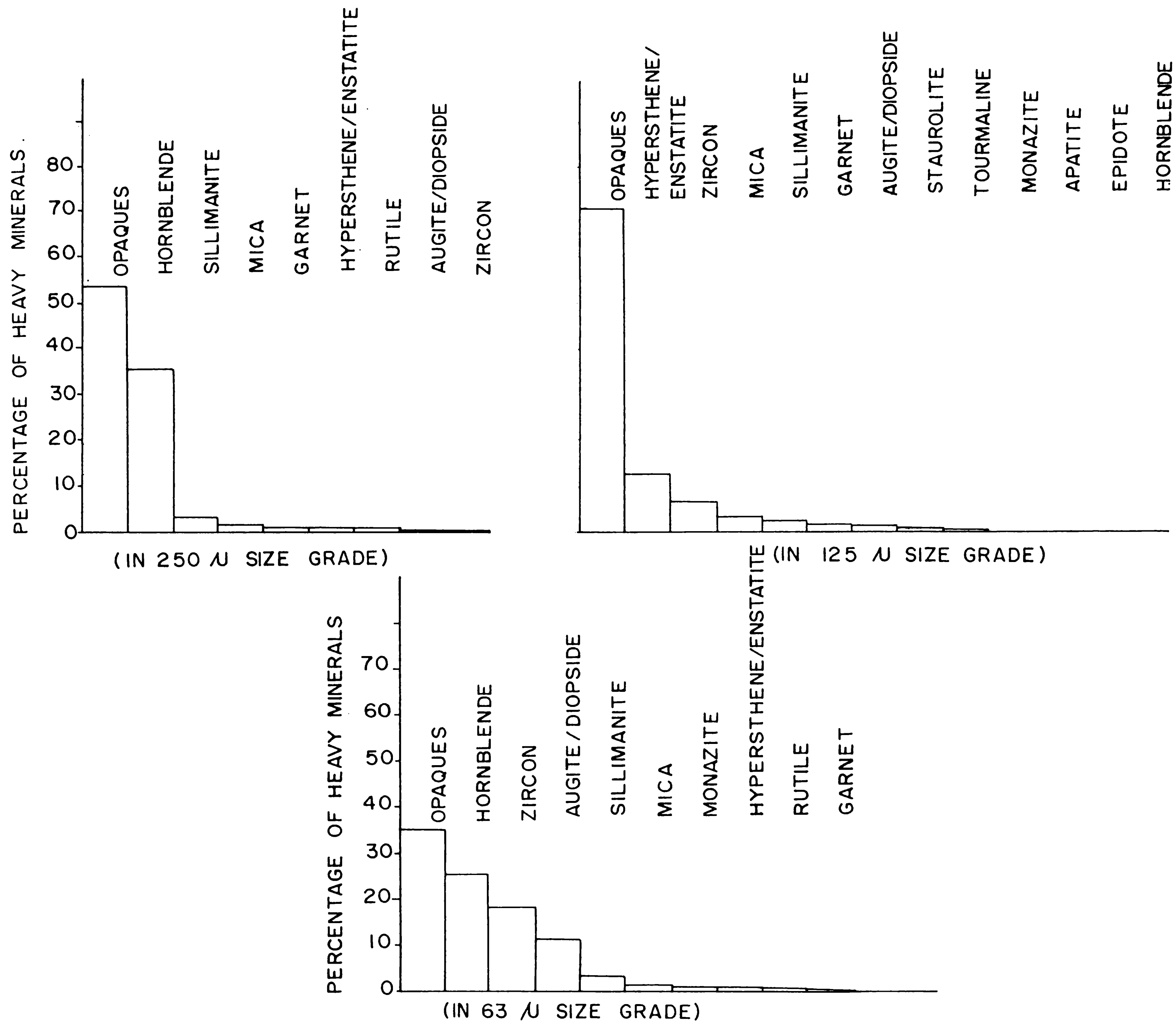


FIG.5·5 DISTRIBUTION OF HEAVY MINERALS IN PERIYAR SEDIMENTS.

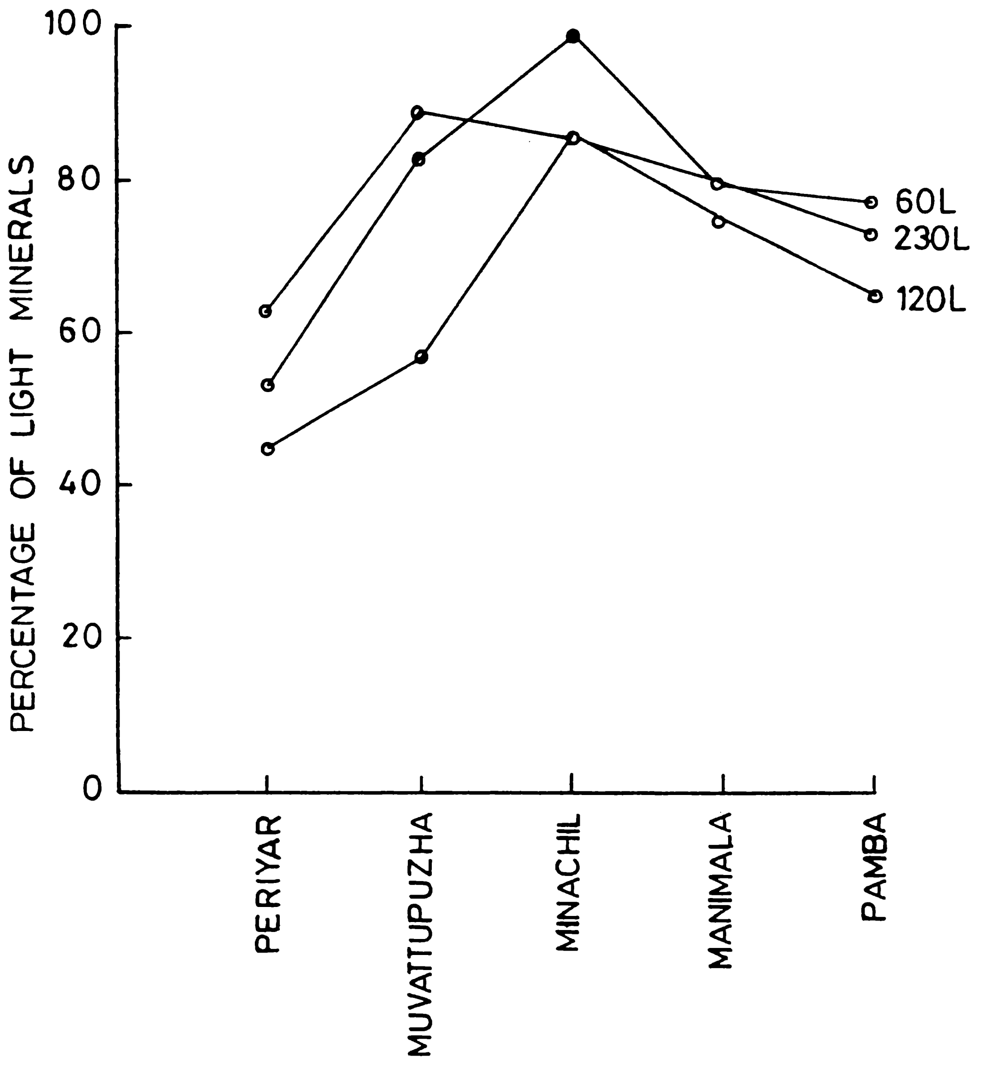


FIG. 5·6 AVERAGE LIGHT MINERALS IN RIVER SEDIMENTS

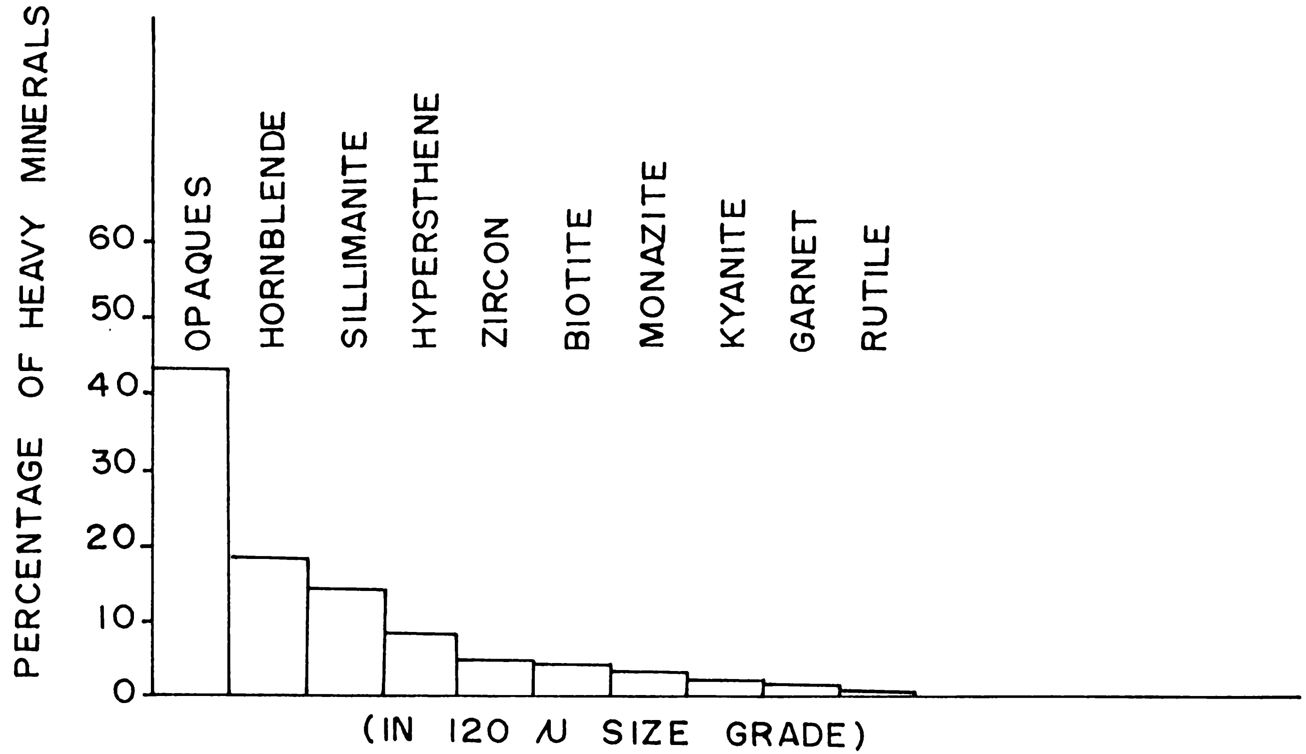


FIG. 5·7 HEAVY MINERAL DISTRIBUTION IN THE INNERSHELF SEDIMENTS IN 125 μ SIZE GRADE

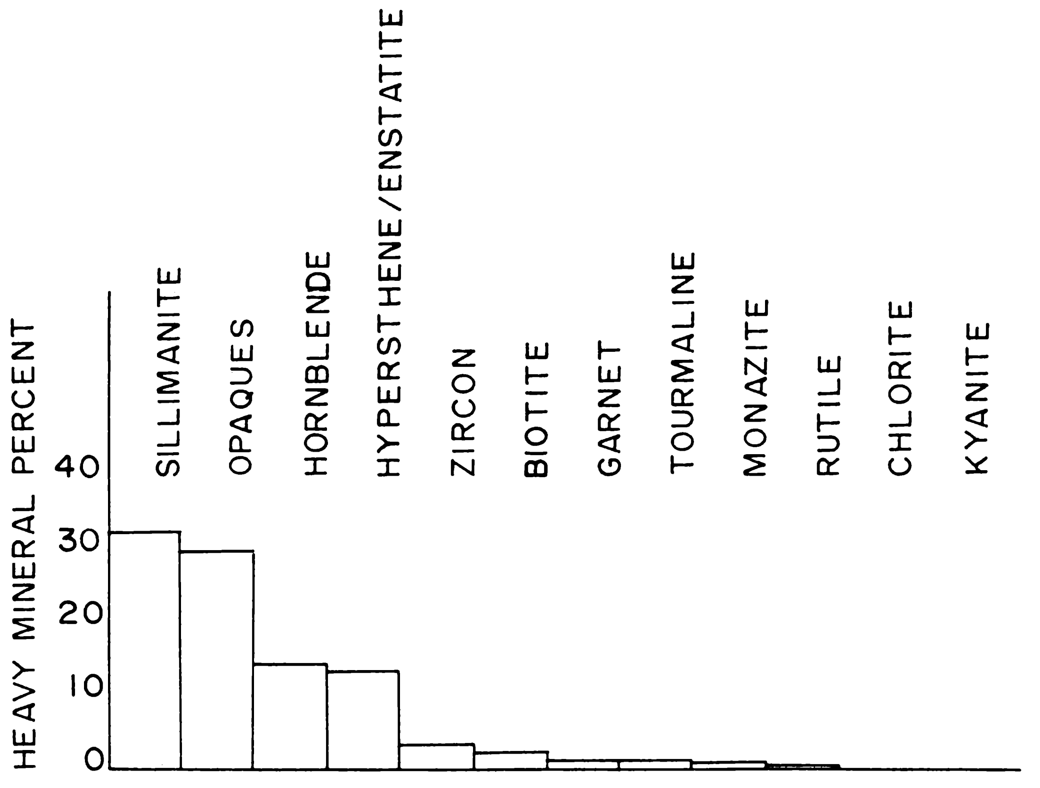


FIG.5·8 AVERAGE HEAVY MINERAL DISTRIBUTION IN THE VEMBANAD LAKE SEDIMENTS (IN 125 μ SIZE GRADE)

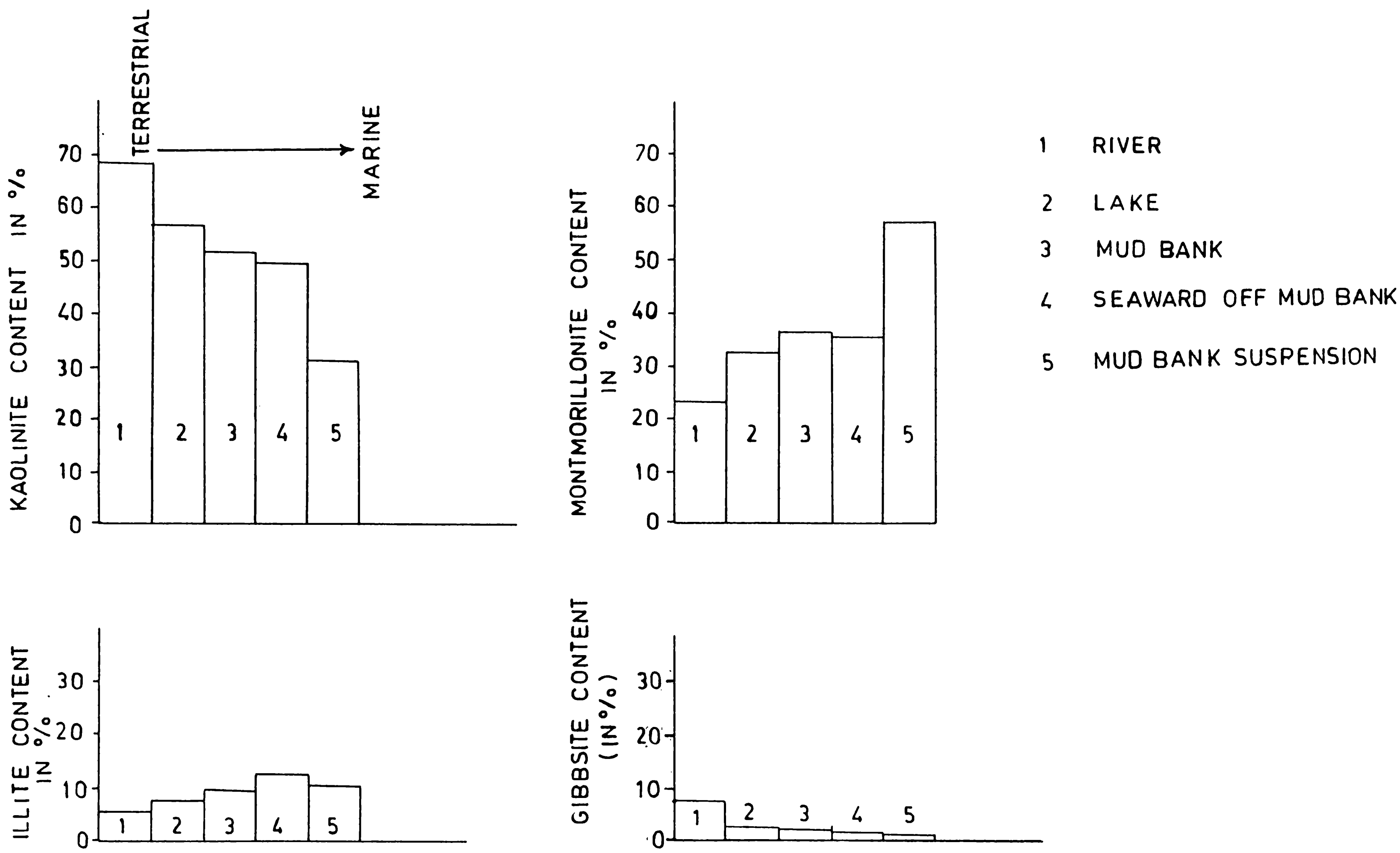


FIG. 5·9 CLAY MINERAL DISTRIBUTION IN THE DIFFERENT ENVIRONMENTS

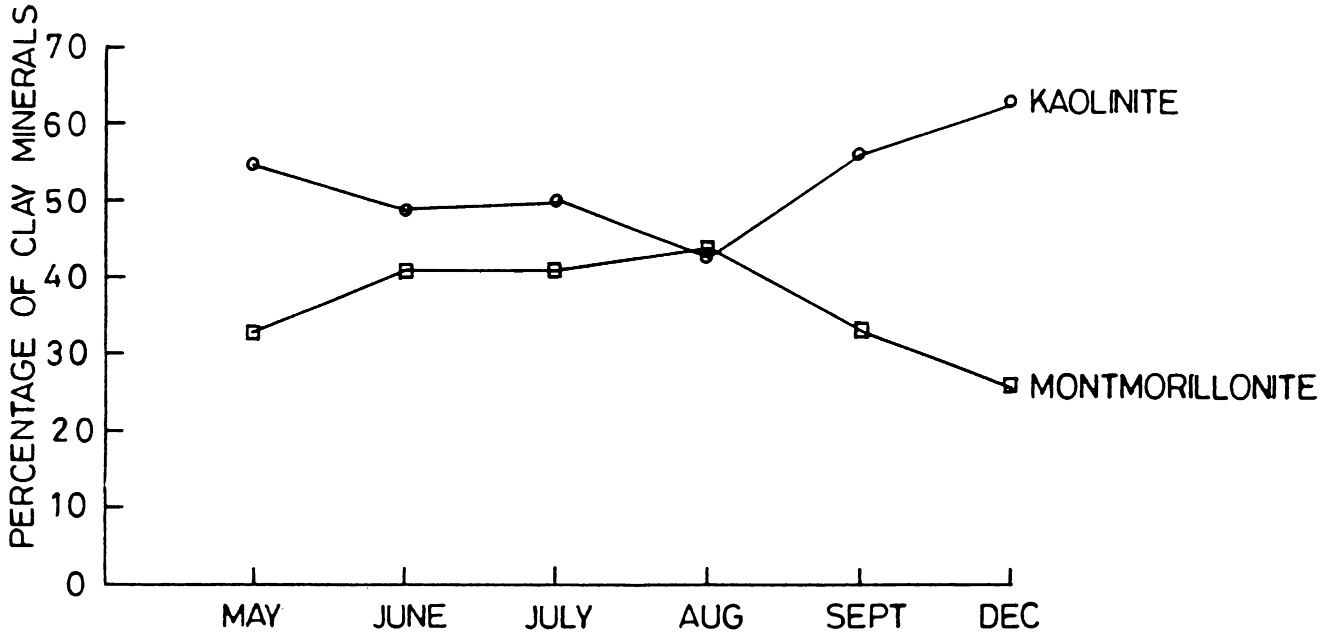


FIG. 5·10 TEMPORAL VARIATION OF CLAY MINERALS IN THE MUD BANK SEDIMENTS

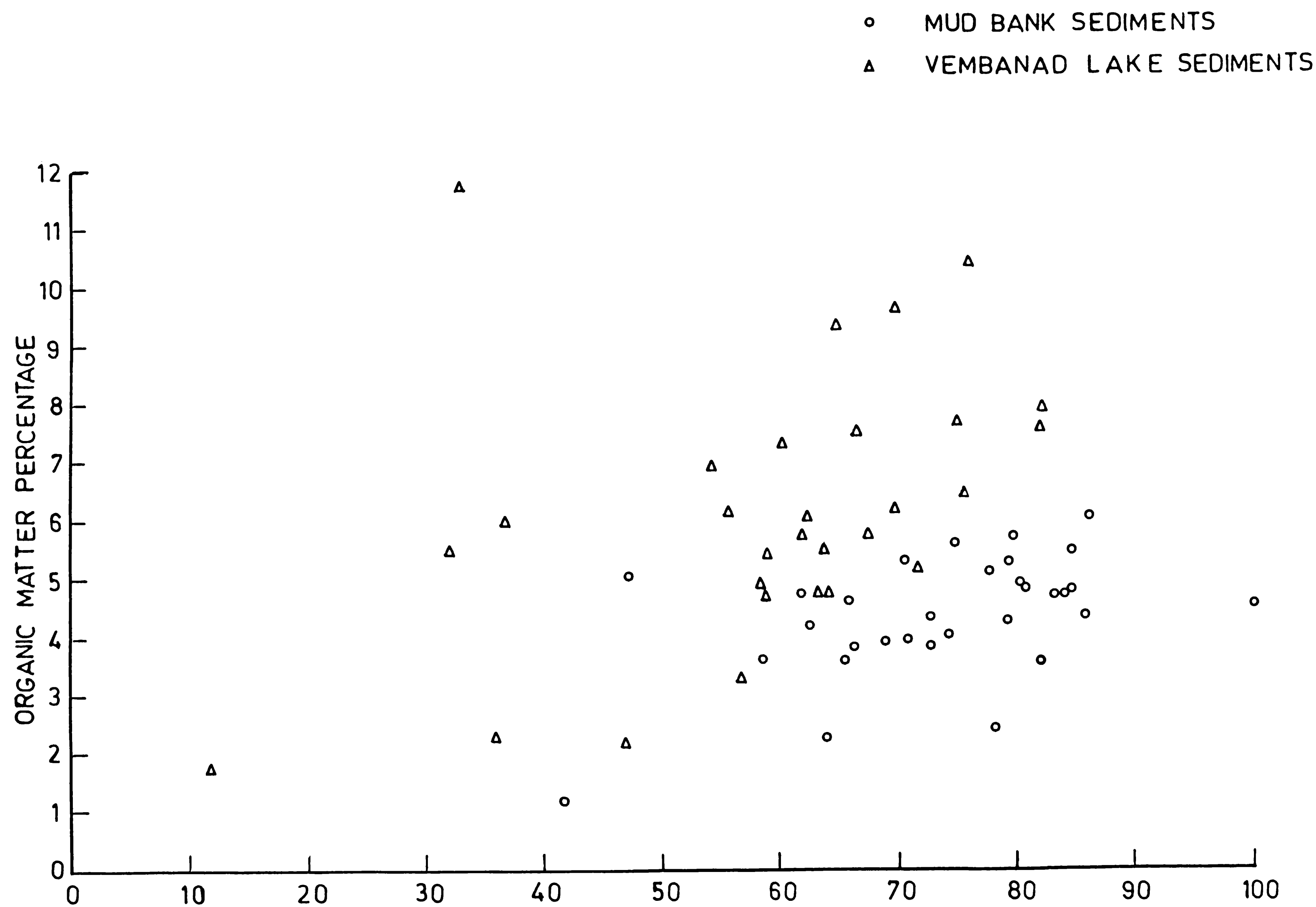
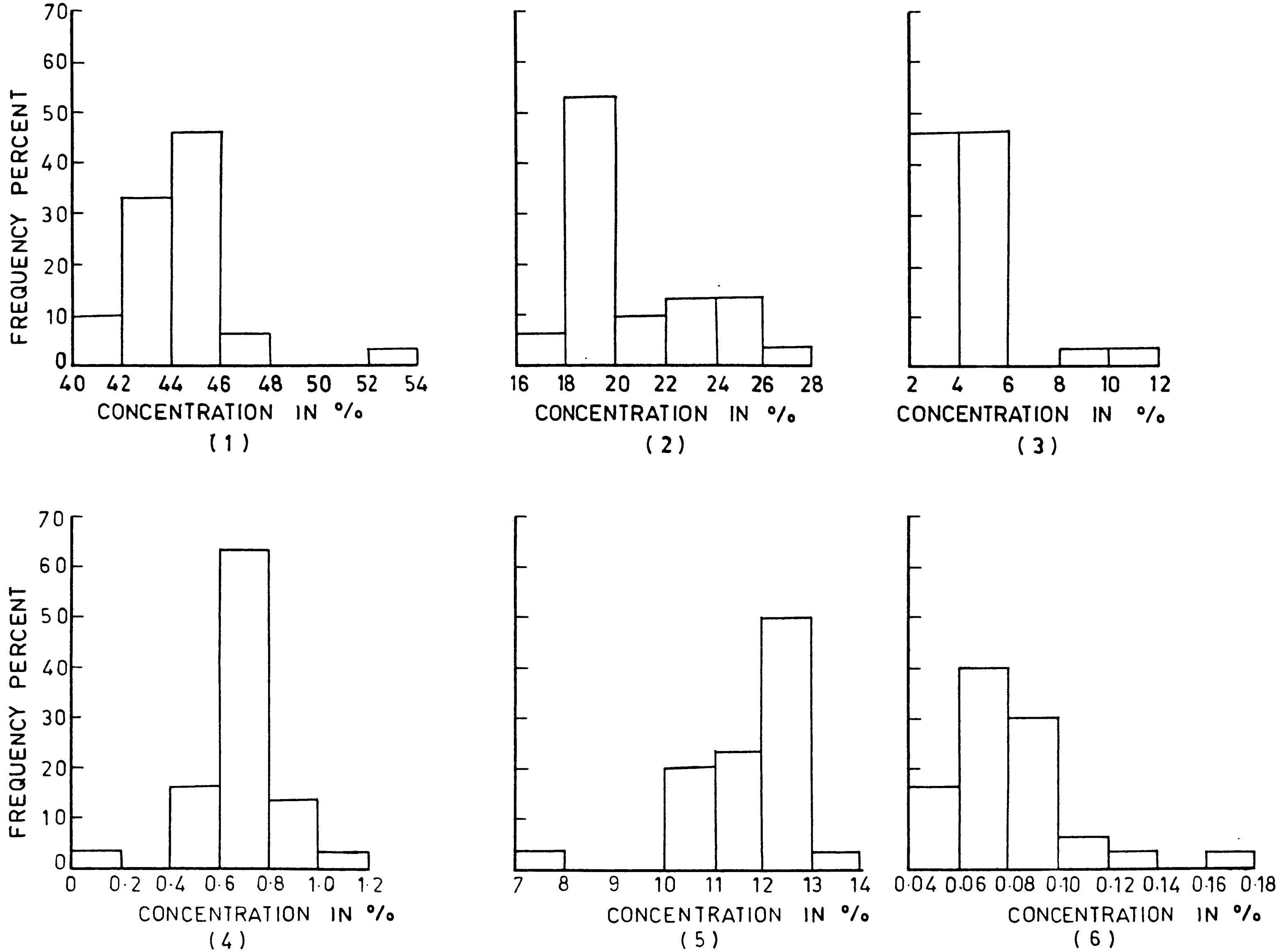
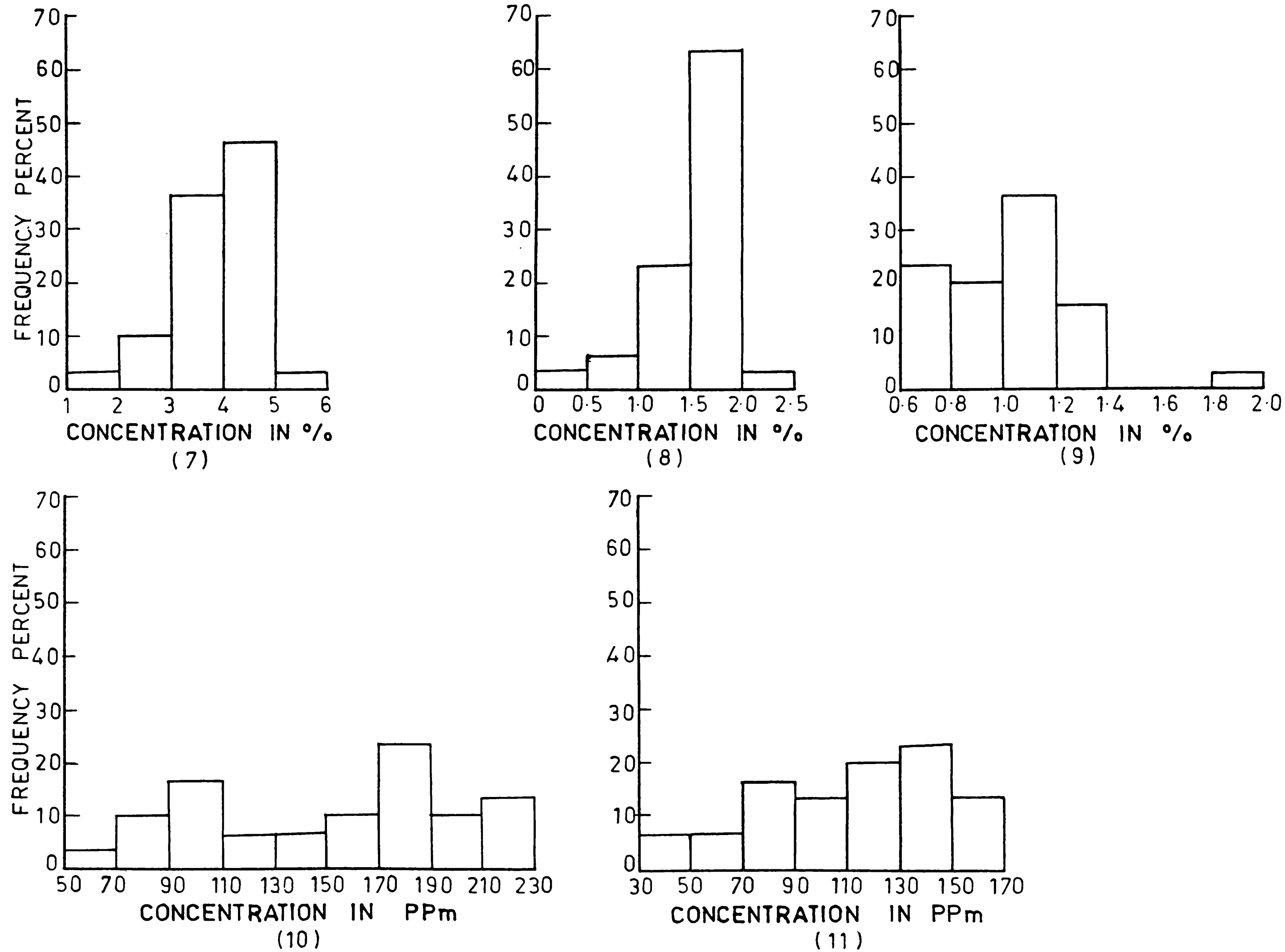


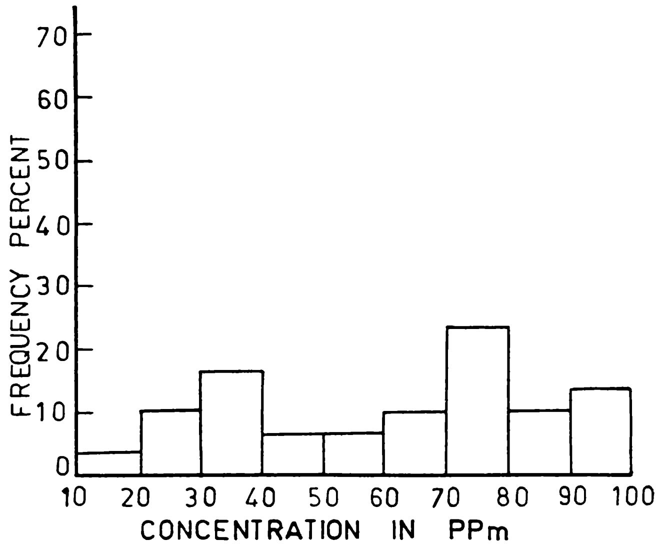
FIG. 6·1 CLAY PERCENTAGE Vs ORGANIC MATTER PERCENTAGE

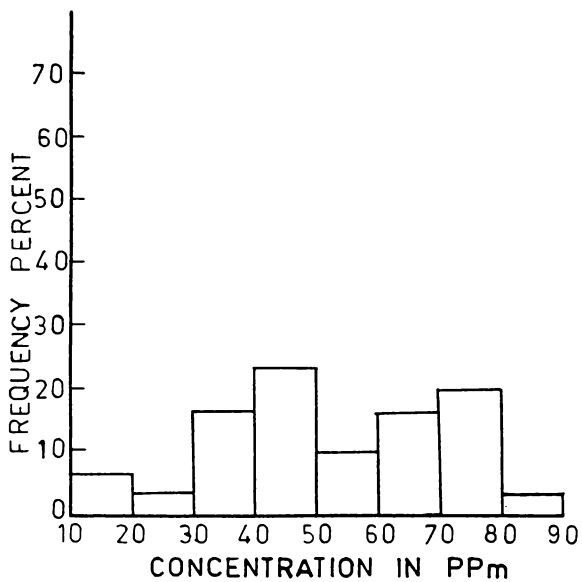


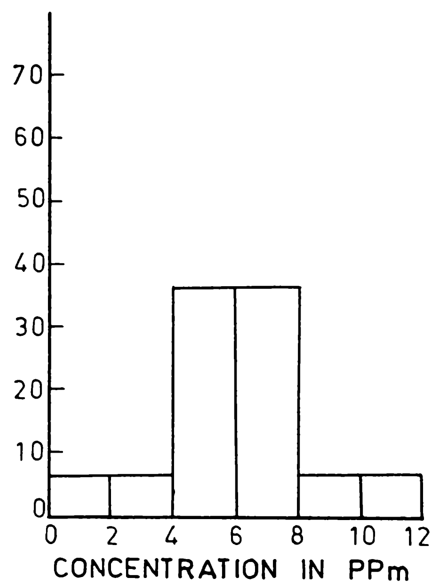
1. SILICA 2. ALUMINA 3. MAGNESIUM 4. PHOSPHOROUS 5. TOTAL IRON 6. MANGANESE 7. SODIUM 8. POTASSIUM 9. TITANIUM 10. COPPER 11. NICKEL 12. COBALT 13. ZINC 14. ORGANIC MATTER 15. CALCIUM CARBONATE.

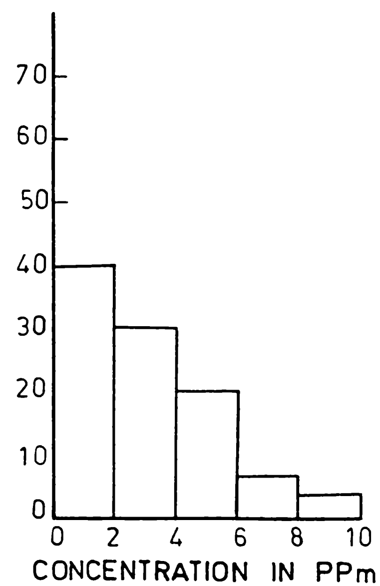
FIG. 6·2 FREQUENCY DISTRIBUTION OF CHEMICAL CONSTITUENTS IN THE VEMBANAD LAKE SEDIMENTS


FREQUENCY PERCENT
0
10
20
30
40
50
60
70
1 2 3 4 5 6
CONCENTRATION IN %
(7)
0 0·5 1·0 1·5 2·0 2·5
CONCENTRATION IN %
(8)
0·6 0·8 1·0 1·2 1·4 1·6 1·8 2·0
CONCENTRATION IN %
(9)
50 70 90 110 130 150 170 190 210 230
CONCENTRATION IN PPm
(10)
30 50 70 90 110 130 150 170
CONCENTRATION IN PPm
(11)


FREQUENCY PERCENT
70
60
50
40
30
20
10
0
10 20 30 40 50 60 70 80 90 100
CONCENTRATION IN PPm
(12)


FREQUENCY PERCENT
70
60
50
40
30
20
10
0
10 20 30 40 50 60 70 80 90
CONCENTRATION IN PPm
(13)


70
60
50
40
30
20
10
0
0 2 4 6 8 10 12
CONCENTRATION IN PPm
(14)


70
60
50
40
30
20
10
0
0 2 4 6 8 10
CONCENTRATION IN PPm
(15)

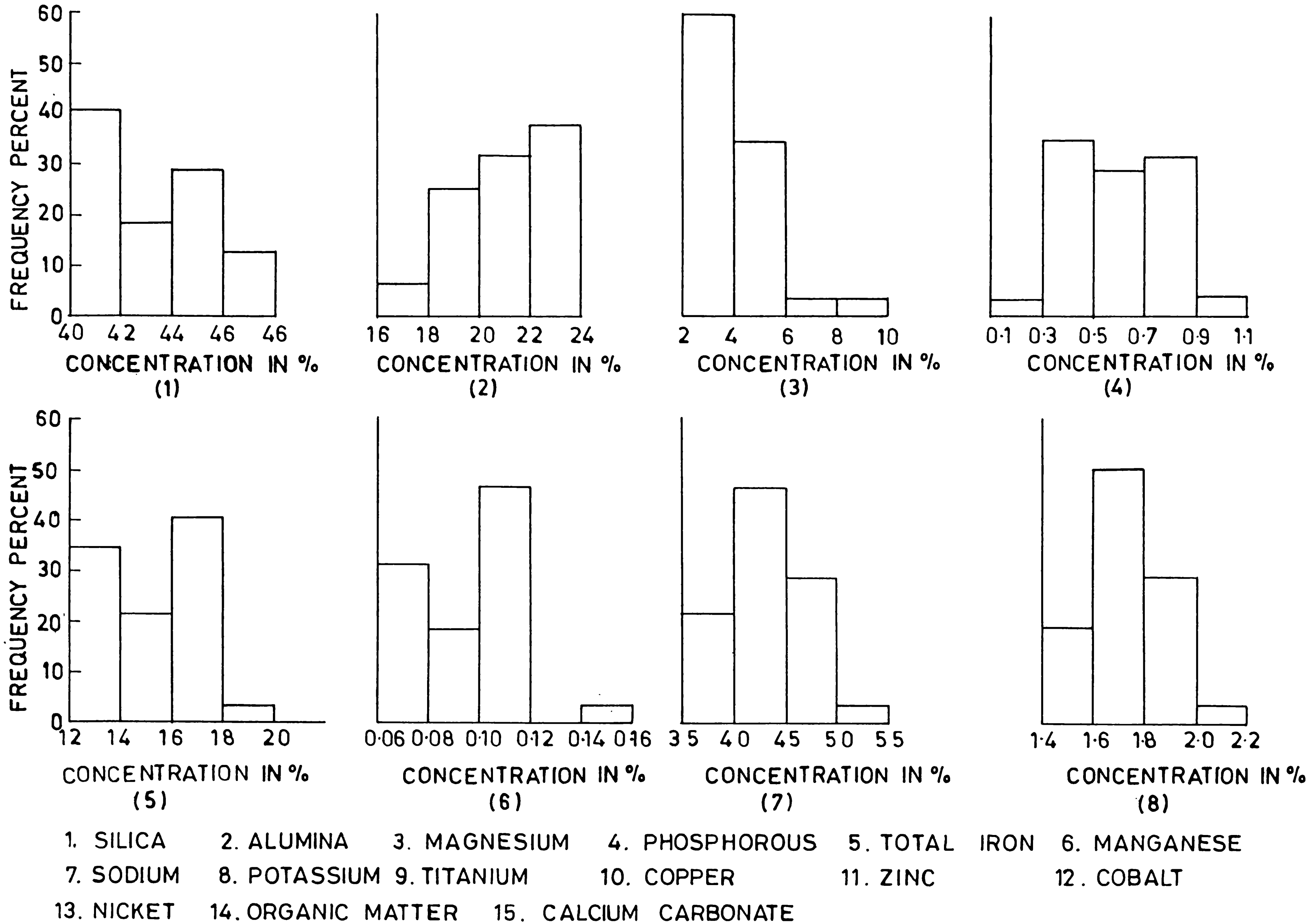
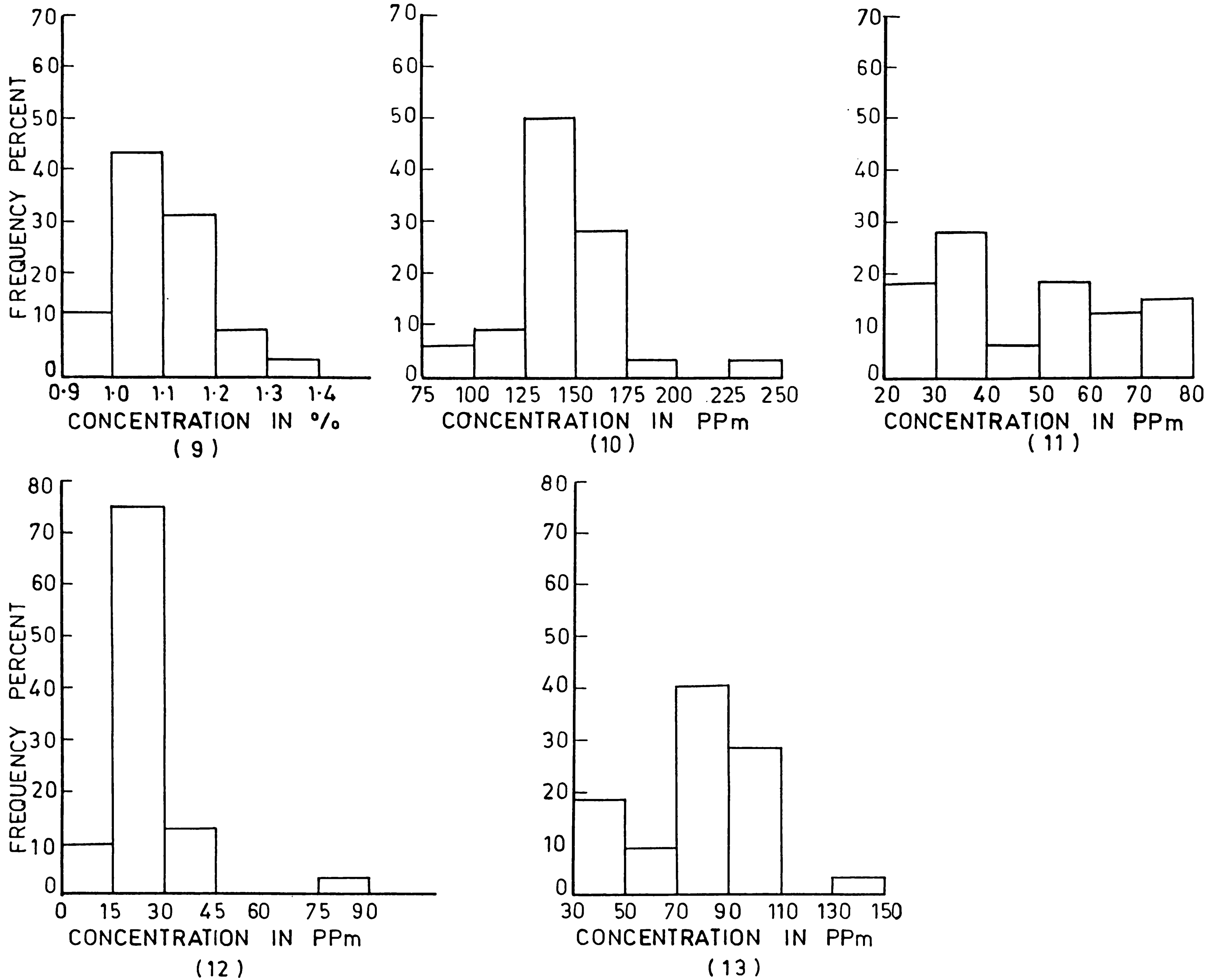
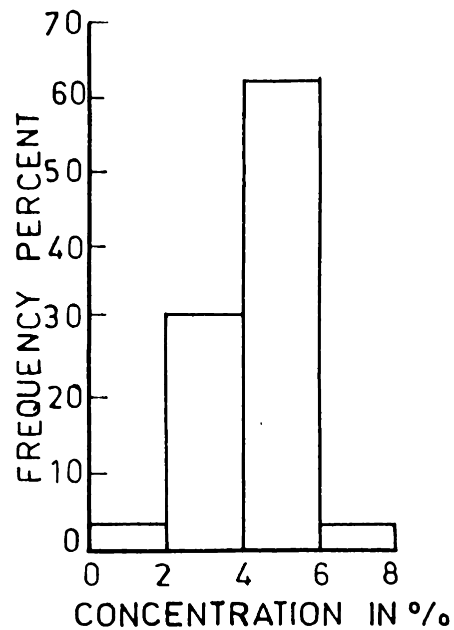
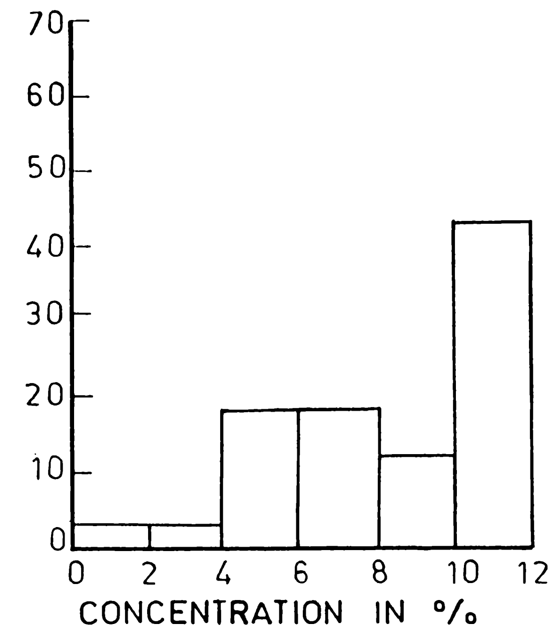


FIG. 6·3 FREQUENCY DISTRIBUTION OF CHEMICAL CONSTITUENTS IN THE MUD BANK SEDIMENTS


FREQUENCY PERCENT
CONCENTRATION IN %
(9)
CONCENTRATION IN PPm
(10)
CONCENTRATION IN PPm
(11)
CONCENTRATION IN PPm
(12)
CONCENTRATION IN PPm
(13)


FREQUENCY PERCENT
70
60
50
40
30
20
10
0
0 2 4 6 8
CONCENTRATION IN %

(14)


70
60
50
40
30
20
10
0
0 2 4 6 8 10 12
CONCENTRATION IN %

(15)

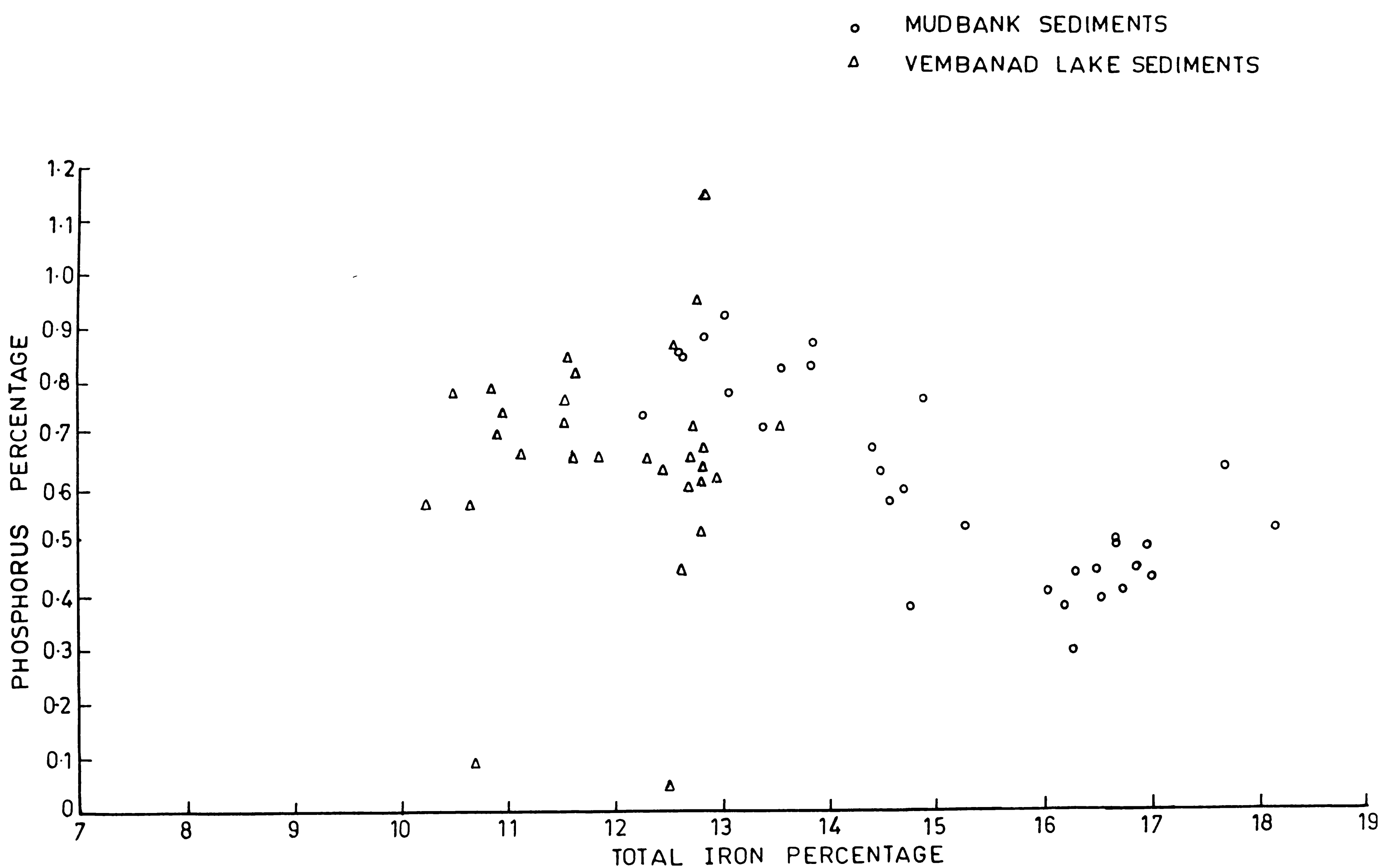


FIG. 6·4 TOTAL IRON PERCENTAGE Vs PHOSPHORUS PERCENTAGE

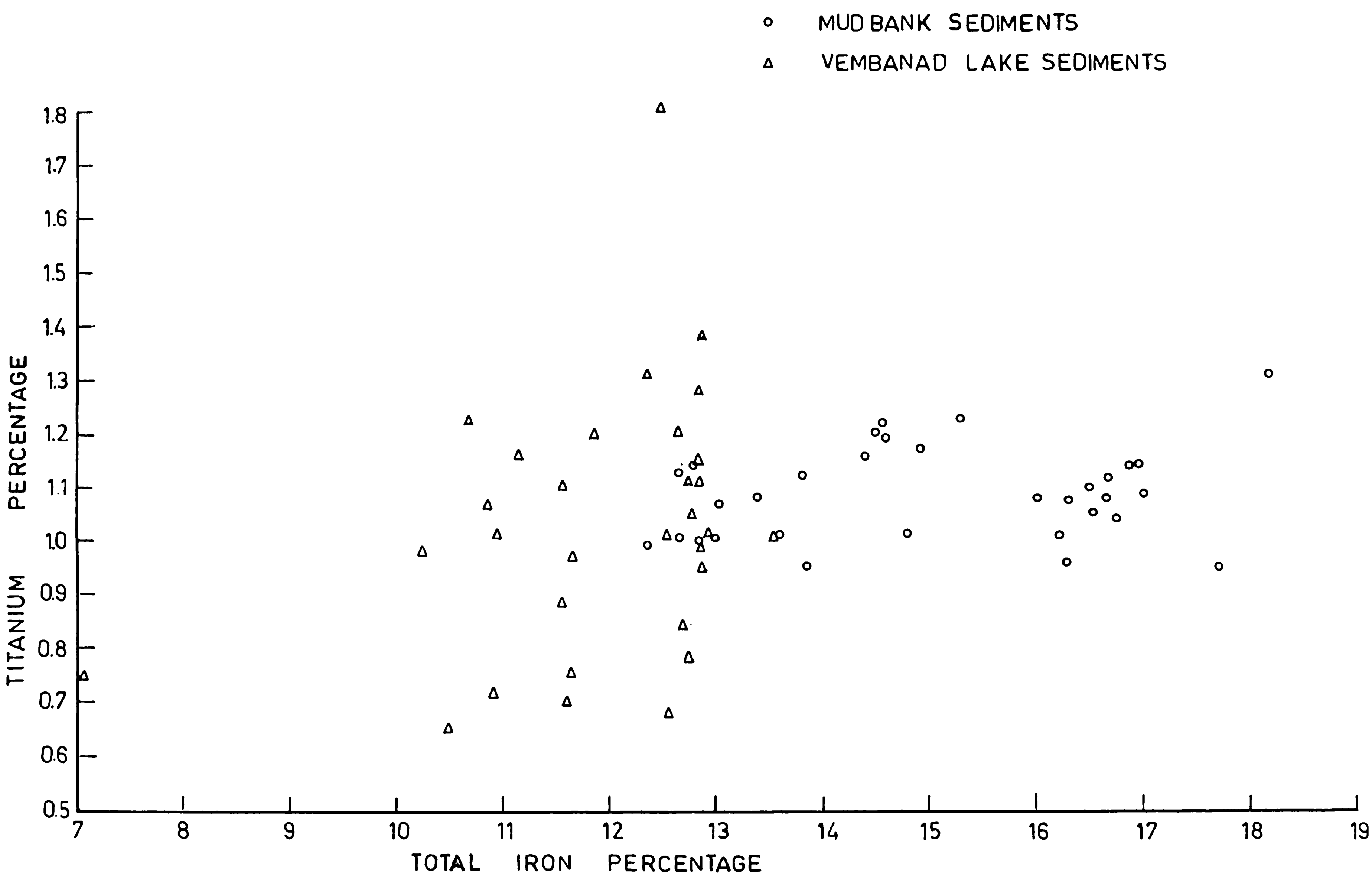


FIG.6·5 TOTAL IRON PERCENTAGE Vs TITANIUM PERCENTAGE

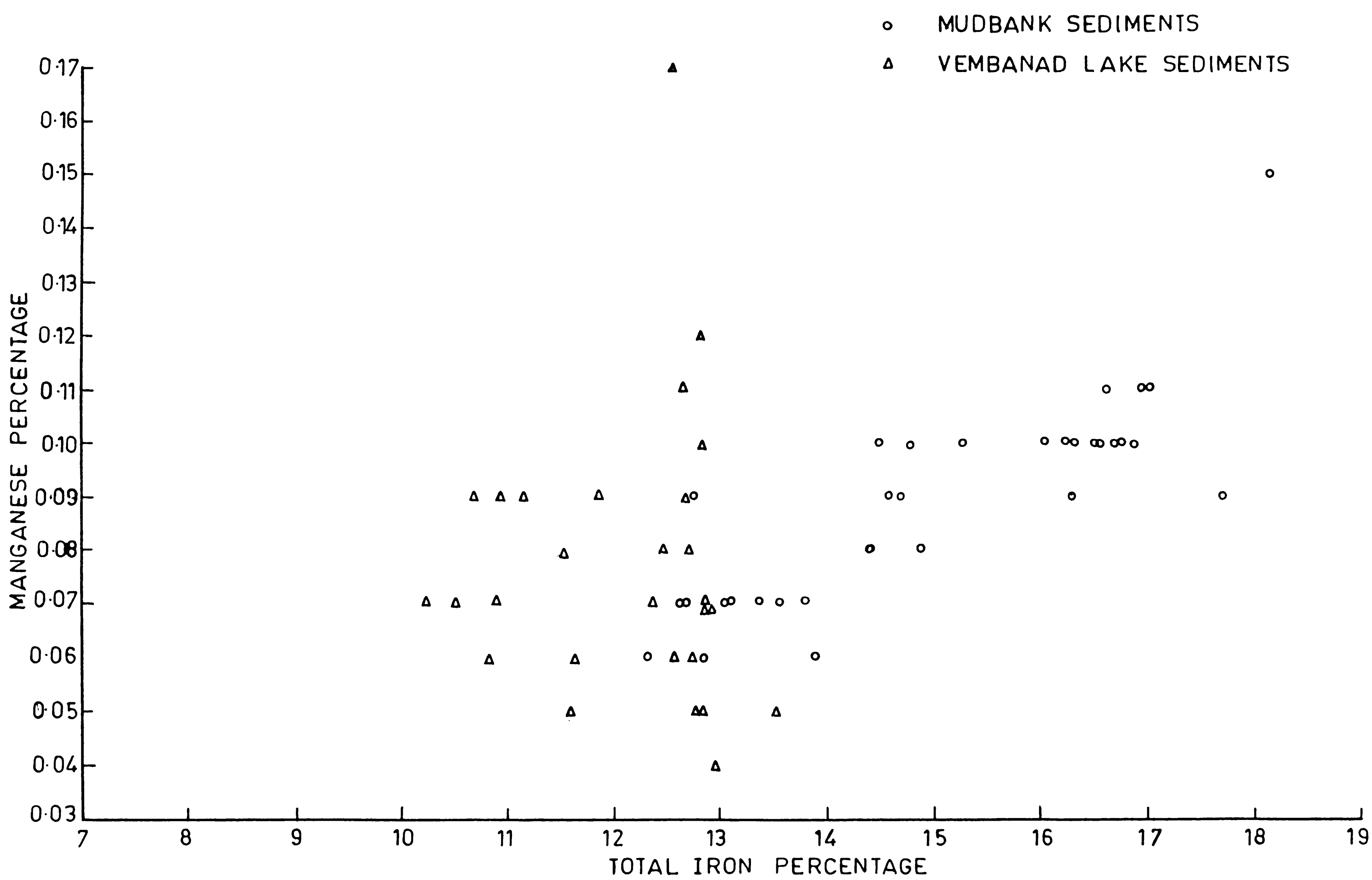


FIG. 6·6 TOTAL IRON PERCENTAGE Vs MANGANESE PERCENTAGE

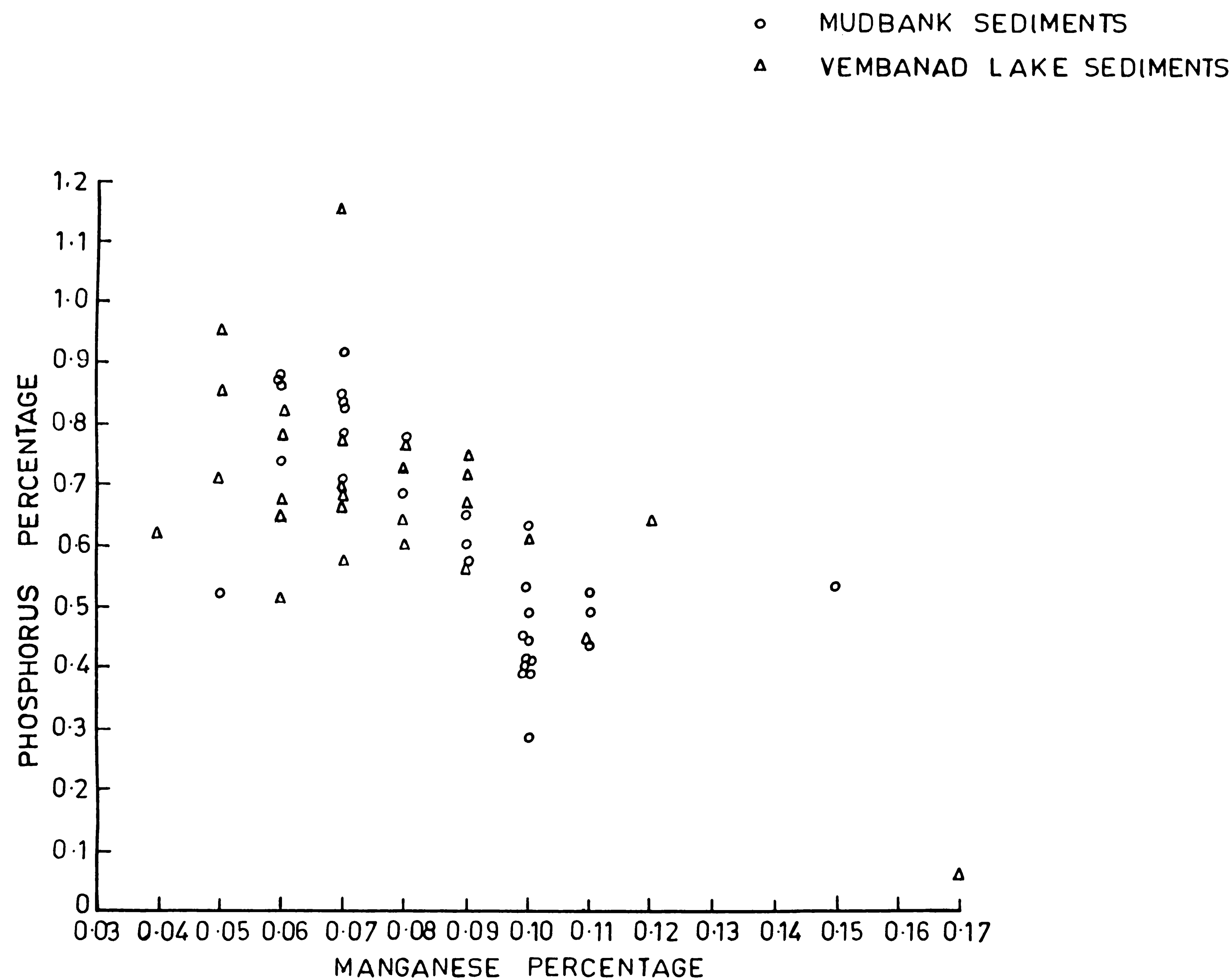


FIG. 6·7 MANGANESE PERCENTAGE Vs PHOSPHORUS PERCENTAGE

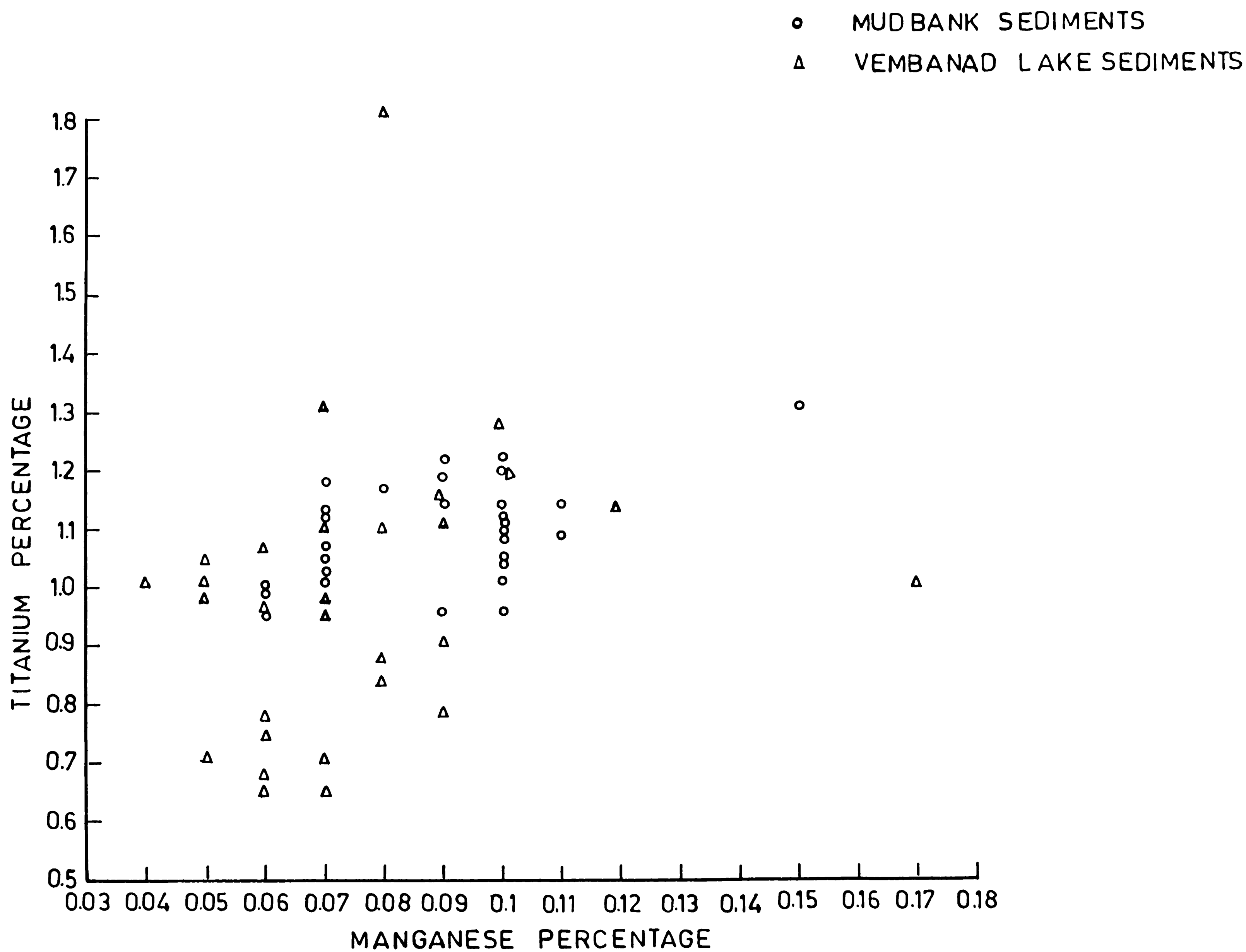


FIG. 6·8 MANGANESE PERCENTAGE Vs TITANIUM PERCENTAGE

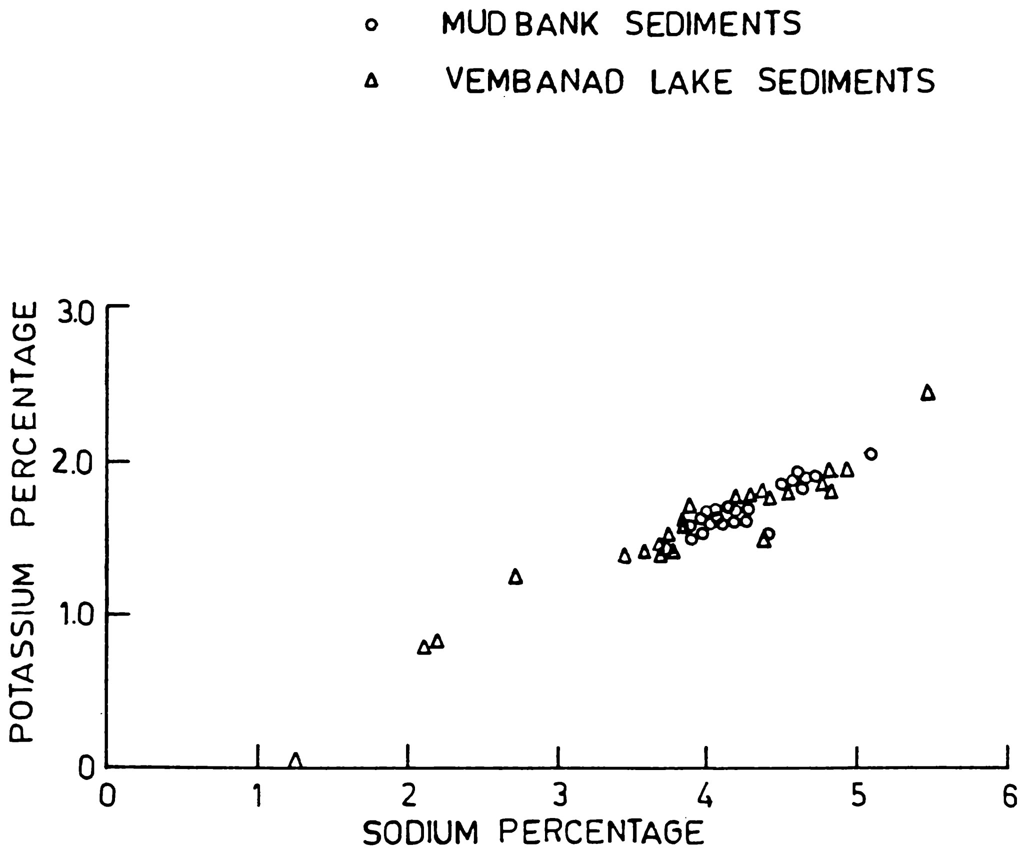


FIG. 6·9 SODIUM PERCENTAGE Vs POTASSIUM PERCENTAGE

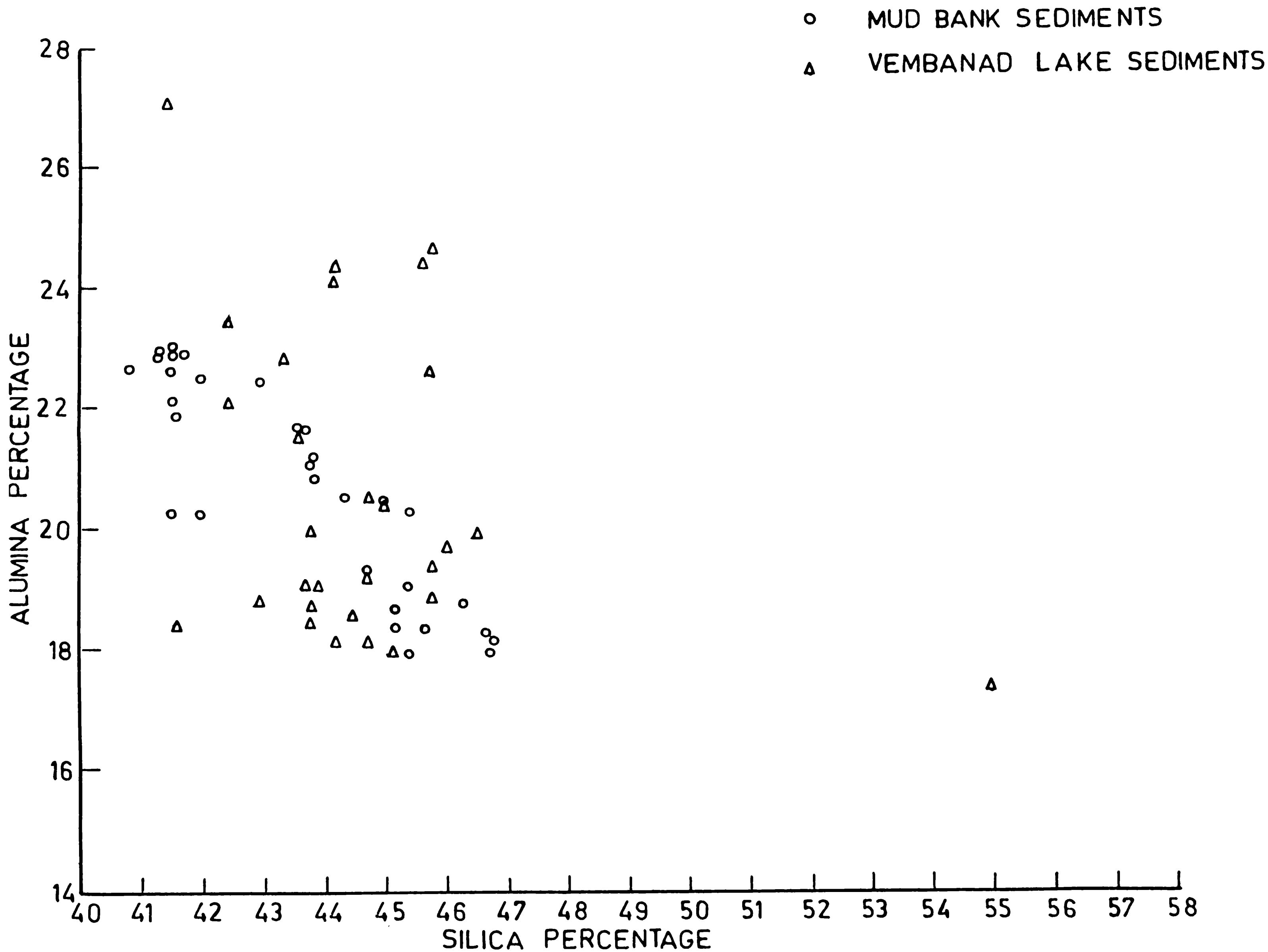


FIG.6·10 SILICA PERCENTAGE Vs ALUMINA PERCENTAGE

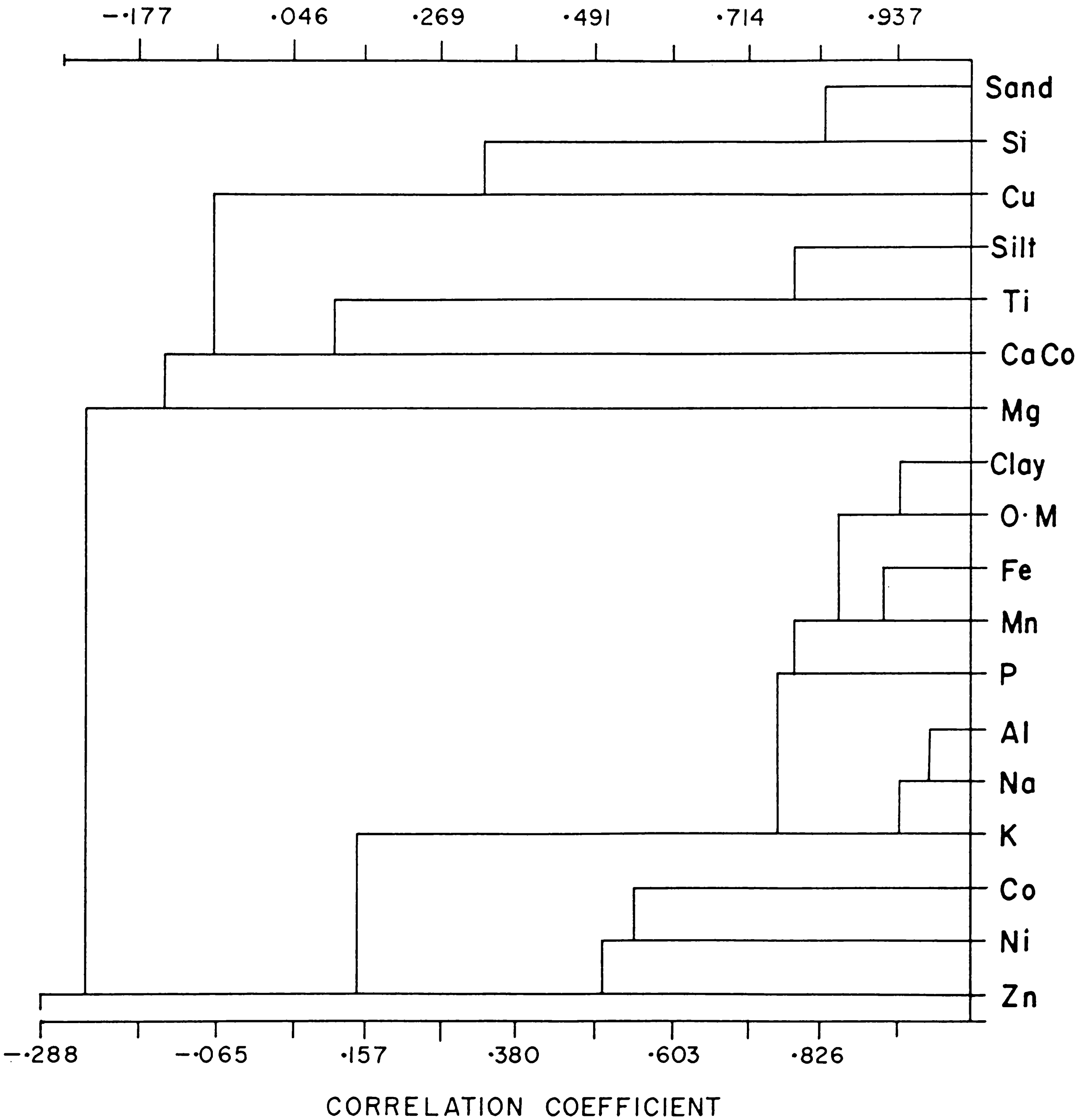


FIG_6_11. DENDROGRAM SHOWING BULK SEDIMENT (MUD BANK) GEOCHEMISTRY

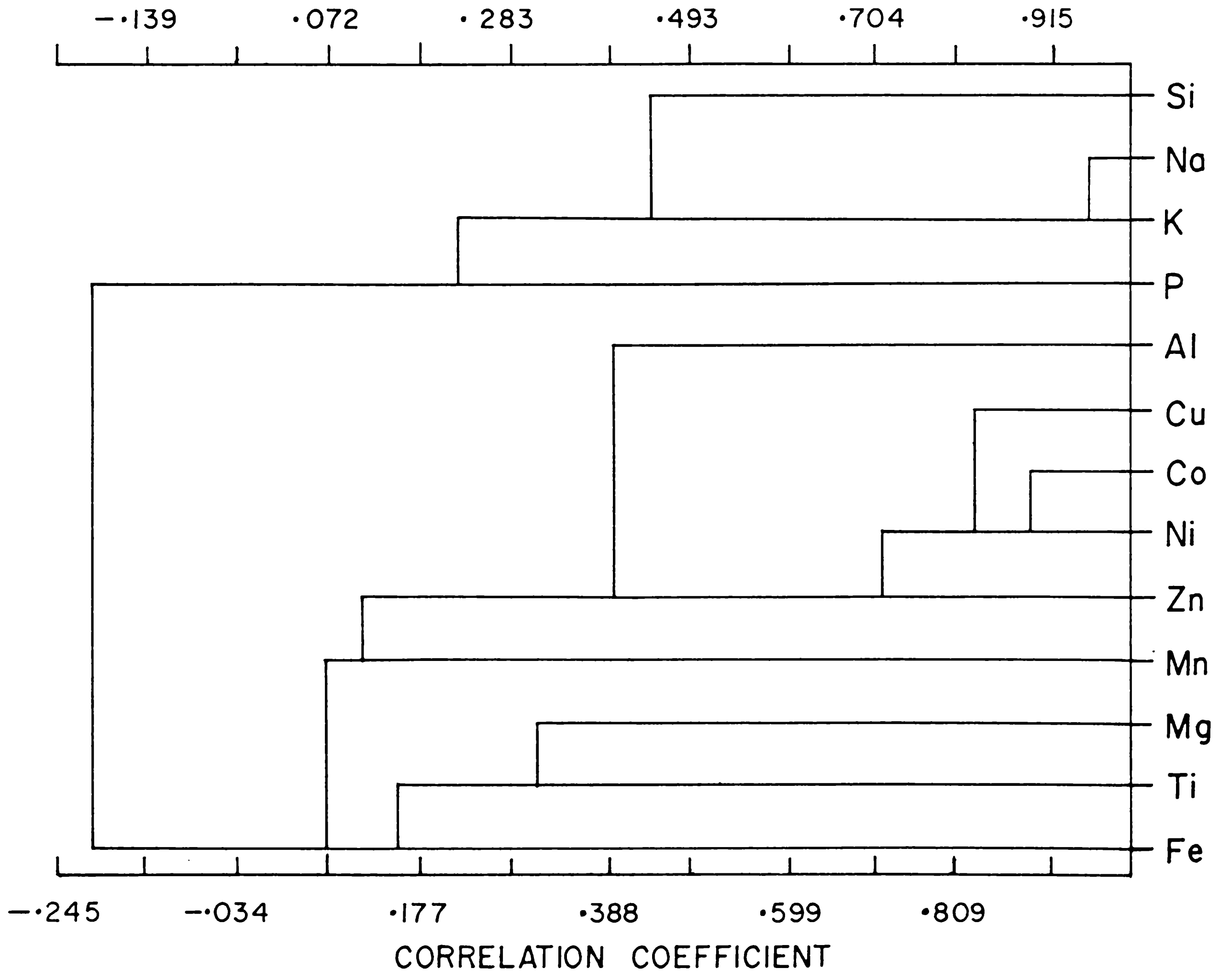


FIG_6_12.DENDROGRAM SHOWING VEMBANAD LAKE SEDIMENT GEOCHEMISTRY

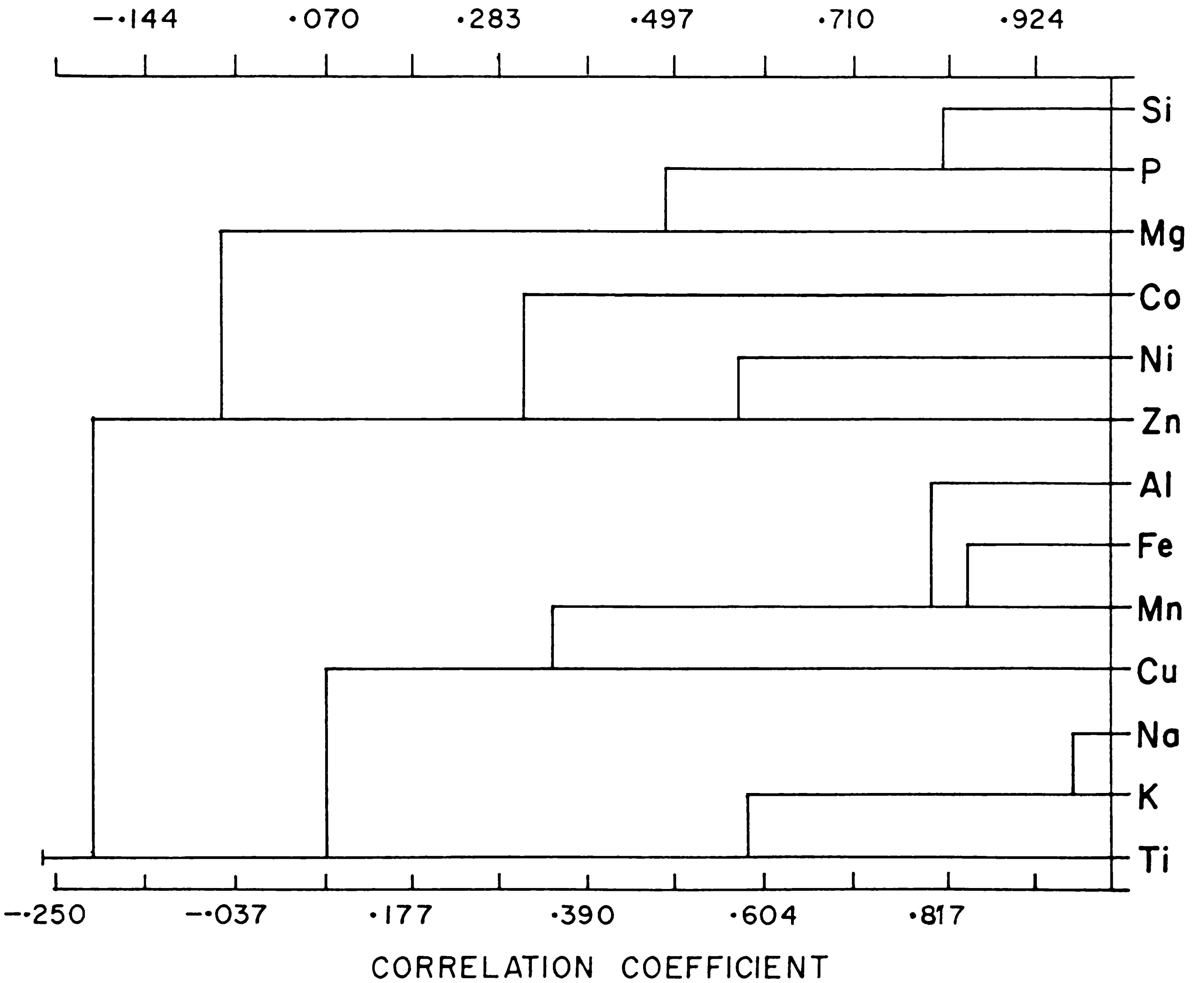
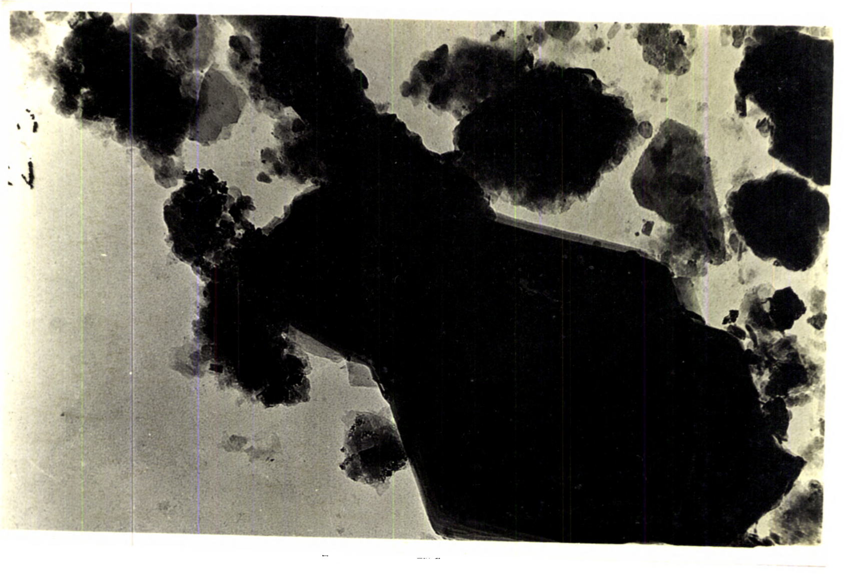


FIG_6_13. DENDROGRAM SHOWING MUD BANK SEDIMENTS GEOCHEMISTRY

PLATE - 1

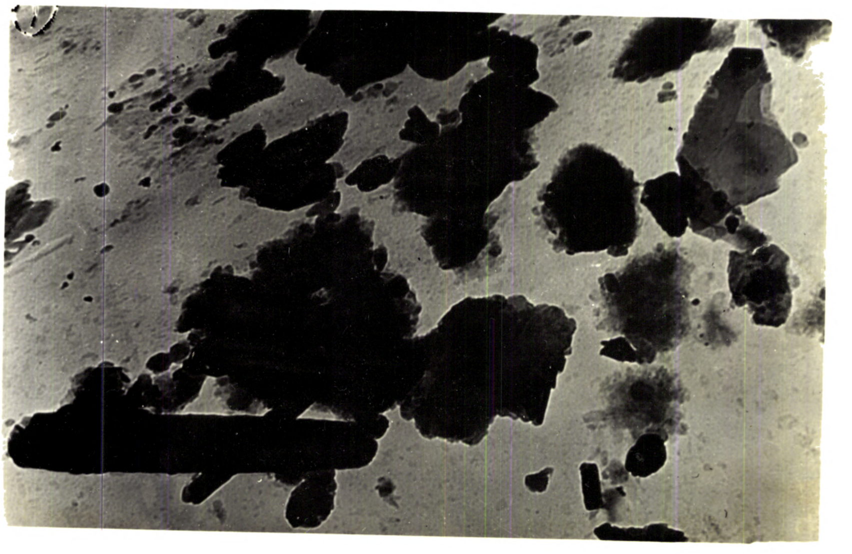


A. KAOLINITE (VEMBANAD LAKE)

B. KAOLINITE (MUD BANK)

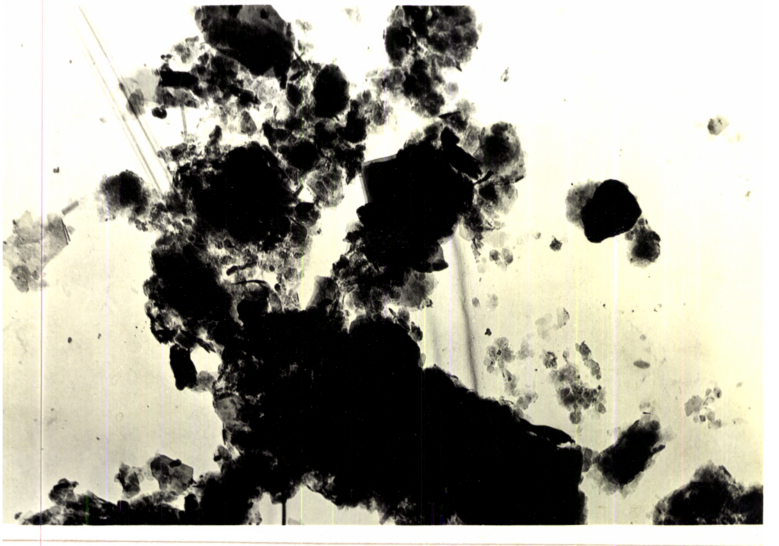
PLATE - 2

A. ILLITE (VEMBANAD LAKE)



B. ILLITE (MUD BANK)

PLATE - 3



A. MONTMORILLONITE (MUD BANK)

LIST OF TABLES

Table - 4.1

GRAIN-SIZE PARAMETERS OF RIVER SEDIMENTS

PAMBA AR

Sl. No.	Sample No.	Mean	Median	Standard Deviation	Skewness	Kurtosis	One percentile (in micron)	Median (in micron)
1	2	3	4	5	6	7	8	9
1.	0C	9.20	9.25	3.55	0.28	0.75	4.0	1.65
2.	2C	8.60	7.80	1.84	0.34	0.83	14.0	4.40
3.	4C	9.73	10.85	3.21	-0.38	0.67	64.0	<1
4.	6C	9.73	10.00	1.86	-0.18	1.32	68.0	1.0
5.	8C	10.47	10.85	2.92	-0.23	0.69	69.0	<1
6.	10C	9.96	10.50	2.90	-0.28	0.58	44.0	<1
7.	12C	9.90	10.80	0.69	-0.42	0.72	60.0	<1
8.	14C	9.75	9.90	2.92	-0.13	0.91	66.0	1.1
9.	16C	8.78	8.60	3.15	0.098	0.70	7.9	2.55
10.	18C	10.50	11.00	2.79	-0.32	0.80	11.0	<1
11.	20C	9.33	9.70	3.03	-0.16	0.75	4.5	1.10
12.	22C	10.72	11.10	2.29	-0.49	1.00	22.0	<1
13.	24C	1.77	1.90	0.73	-0.23	0.94	1100.0	270.0
14.	26C	1.63	1.75	1.11	0.046	0.83	900.0	300.0
15	28C	1.71	1.70	0.43	-0.018	0.82	760.0	310.0
16.	30C	1.92	2.20	0.99	-0.21	1.08	800.0	220.0
17.	35C	2.27	2.33	1.03	-0.16	0.85	1400.0	200.0

Table 4.1 contd.

1	2	3	4	5	6	7	8	9
18.	40C	2.02	2.20	0.81	-0.31	1.21	1250.0	220.0
19.	45C	1.92	2.20	0.99	-0.21	1.076	7800.0	220.0
20.	50C	1.05	1.33	1.31	0.098	1.11	5600.0	410.0
21.	55C	1.68	1.80	1.08	0.035	1.15	1950.0	315.0
22.	60C	1.43	1.55	0.80	0.125	1.75	2400.0	340.0
23.	70C	-1.12	-0.95	1.15	0.41	1.11	7000.0	1900.0
24.	80C	-0.67	-0.80	1.14	0.16	1.33	1950.0	315.0
25.	90C	0.33	0.33	0.80	-0.05	0.67	3700.0	750.0
26.	100C	0.008	-0.28	1.47	0.26	1.057	6600.0	1250.0
27.	110C	0.33	0.10	1.41	0.077	2.50	7400.0	940.0
28.	120C	0.67	0.85	1.04	-0.84	0.90	4700.0	520.0
29.	130C	-0.20	-0.15	0.96	-0.065	0.62	7400.0	1100.0
30.	140C	0.15	-0.15	1.40	0.27	0.79	5000.0	1100.0
31.	150C	-0.21	-0.38	1.89	0.165	0.86	7200.0	1300.0
32.	160C	-0.85	-0.85	1.10	0.12	1.48	7000.0	1800.0
33.	170C	-0.23	-0.28	1.66	0.074	0.78	7000.0	1250.0
34.	171C	2.47	2.50	0.59	-0.10	0.96	580.0	180.0
35.	172C	1.64	1.70	0.51	0.17	1.03	800.0	310.0
36.	173C	0.87	1.20	1.32	-0.37	1.27	5400.0	570.0
37.	174C	0.17	-0.15	1.12	0.36	0.71	3400.0	110.0
38.	0R	1.77	1.90	0.73	-0.23	0.95	1100.0	270.0
39.	2L	1.63	1.75	1.11	0.046	0.82	1900.0	300.0
40.	4R	1.71	1.70	0.43	-0.018	0.87	760.0	310.0

Table 4.1 contd.

1	2	3	4	5	6	7	8	9
41.	6L	0.91	1.20	1.09	0.29	0.98	3400.0	440.0
42.	8R	0.78	0.85	0.95	-0.11	1.05	3700.0	550.0
43.	10R	0.017	-0.15	1.11	0.38	0.83	4500.0	1100.0
44.	12L	1.62	1.65	0.95	0.38	1.19	3300.0	320.0
45.	14R	-0.033	-0.20	1.51	.0.12	1.05	6400.0	1150.0
46.	16R	0.13	-0.40	1.98	-0.028	0.72	7200.0	1350.0
47.	22R	1.73	1.75	1.07	-0.064	0.91	780.0	300.0
48.	30R	0.18	0.025	1.55	0.041	0.78	6400.0	990.0

Table 4.1 contd.

MANIMALA AR

Sl. No.	Sample No.	Mean	Median	Standard Deviation	Skewness	Kurtosis	One percentile (in micron)	Median (in micron)
1.	175C	1.43	1.55	0.80	0.13	1.75	1500.0	345.0
2.	176C	0.23	0.50	1.79	0.22	0.94	4800.0	700.0
3.	177C	-0.033	-0.28	1.12	0.40	0.94	5800.0	1250.0
4.	178C	0.41	0.12	1.03	0.19	0.91	4250.0	900.0
5.	179C	0.82	-1.05	1.44	0.23	0.68	7250.0	2100.0
6.	180C	-0.59	-0.8	1.10	0.27	1.99	5500.0	1750.0

Table 4.1 contd.

MINACHIL AR

Sl. No.	Sample No.	Mean	Median	Standard Deviation	Skewness	Kurtosis	One percentile (in micron)	Median (in micron)
1	2	3	4	5	6	7	8	9
1.	0C	9.80	9.1	3.22	-0.028	0.70	4.0	1.82
2.	2C	2.40	2.15	0.80	0.25	0.98	500.0	230.0
3.	4C	1.85	1.60	1.10	0.40	0.88	670.0	330.0
4.	6C	2.43	2.50	0.45	0.18	0.67	400.0	175.0
5.	8C	0.18	0.15	1.47	-0.012	0.90	1600.0	900.0
6.	10C	-0.18	-0.12	1.50	-0.40	0.89	2400.0	1100.0
7.	12C	2.74	2.80	0.47	-0.30	2.14	700.0	255.0
8.	14C	0.22	-0.11	1.45	-0.37	0.74	2000.0	1100.0
9.	16C	0.55	0.52	1.15	0.03	0.82	800.0	500.0
10.	18C	1.13	1.50	1.60	-0.42	1.02	600.0	445.0
11.	20C	0.20	0.00	1.46	0.22	0.79	1500.0	1000.0
12.	22C	0.30	0.15	1.45	-0.25	0.78	1200.0	900.0
13.	24C	0.20	0.50	1.60	-0.16	1.23	900.0	500.0
14.	26C	0.10	0.00	1.40	0.08	1.31	1400.0	1000.0
15.	28C	0.15	0.12	1.25	0.05	1.11	1200.0	910.0
15.	30C	-0.15	-0.20	0.85	-0.013	1.42	3500.0	1150.0
17.	35C	0.45	0.45	1.048	0.14	1.23	1850.0	860.0
18.	40C	-0.90	-0.95	1.37	0.59	0.81	7000.0	1900.0
19.	45C	0.04	-0.125	0.97	0.28	0.88	2400.0	1100.0

Table 4.1 contd.

1	2	3	4	5	6	7	8	9
20.	50C	-0.33	-0.57	0.74	0.61	1.19	2450.0	1600.0
21.	55C	0.63	0.75	1.20	-0.04	0.73	2400.0	600.0
22.	60C	0.28	0.15	1.06	0.14	0.68	2350.0	900.0
23.	65C	0.68	0.60	1.01	0.13	1.00	2150.0	525.0
24.	66C	-0.025	-0.60	1.06	0.61	0.74	2500.0	1525.0
25.	70C	-0.017	-0.60	1.17	0.67	0.95	2500.0	1525.0
26.	75C	1.60	1.75	1.04	0.24	0.81	1800.0	300.0
27.	76C	-0.35	-0.90	1.94	0.57	0.57	6200.0	1870.0
28.	0R	1.02	1.10	0.86	-0.12	1.12	5200.0	450.0
29.	2L	1.13	1.00	1.49	0.11	1.0	4600.0	500.0
30.	4R	2.43	2.50	0.45	0.18	0.67	400.0	175.0
31.	6L	0.18	0.15	1.47	-0.012	0.90	6000.0	900.0
32.	8R	2.74	2.80	0.47	-0.30	2.14	2700.0	255.0
33.	10L	0.27	0.15	1.20	0.10	0.99	5400.0	900.0
34.	12R	1.13	1.50	1.60	-0.42	1.02	5600.0	445.0
35.	14L	0.20	0.0	1.46	0.22	0.79	3500.0	1000.0
36.	16R	0.20	0.50	1.60	-0.16	1.23	5800.0	700.0
37.	18L	0.10	0.00	1.40	0.08	1.31	6600.0	1000.0
38.	20R	-0.15	-0.20	0.85	-0.03	1.42	3500.0	1150.0
39.	22L	0.22	0.00	1.41	0.23	0.77	3500.0	1000.0
40.	24R	0.33	0.25	1.18	0.02	0.88	5600.0	940.0
41.	26L	-0.11	-0.38	1.41	0.30	0.90	3800.0	1300.0
42.	28R	-0.97	-1.20	1.32	0.77	1.04	6600.0	2300.0

Table 4.1 contd.

1	2	3	4	5	6	7	8	9
43.	30L	0.43	-0.10	1.72	0.37	0.60	3400.0	1050.0
44.	35R	0.066	-0.30	1.38	0.37	0.94	3500.0	1225.0
45.	40L	0.08	-0.25	1.46	0.34	0.88	3500.0	1750.0
46.	45R	0.94	0.85	0.64	0.25	0.83	1250.0	640.0

Table 4.1 contd.

MUVATTUPUZHA AR

Sl. No.	Location	Mean	Median	Standard Deviation	Skewness	Kurtosis	One percentile (in micron)	Median (in micron)
1	2	3	4	5	6	7	8	9
1.	0C	8.20	8.35	3.40	0.27	0.77	7.5	3.8
2.	2C	9.38	9.40	2.92	0.10	0.70	400.0	205.0
3.	4C	2.21	2.13	0.53	0.20	0.80	1000.0	230.0
4.	6C	0.73	0.63	0.90	0.14	0.93	2000.0	540.0
5.	8C	1.27	1.6	2.18	-0.27	0.90	1400.0	340.0
6.	10C	3.00	2.95	0.48	0.06	1.52	400.0	130.0
7.	12C	1.58	1.70	0.80	-0.24	1.58	900.0	310.0
8.	14C	1.40	1.60	1.17	-0.26	1.02	750.0	330.
9.	16C	2.65	2.65	0.74	-0.18	1.98	800.0	160.[illegible]
10.	18C	0.77	0.90	1.28	-0.19	1.05	1400.0	540.0
11.	20C	0.87	0.85	0.77	-0.06	0.89	1800.0	600.0
12.	22C	0.60	0.70	1.39	-0.05	0.93	1600.0	620.0
13.	24C	0.48	0.40	0.87	0.19	1.20	900.0	765.0
14.	26C	2.16	2.00	0.67	0.11	1.12	1000.0	250.0
15.	28C	2.33	2.85	1.34	-0.49	1.11	480.0	265.0
16.	30C	-0.35	-0.40	1.77	0.12	0.69	2000.0	325.0
17.	35C	-0.71	-0.85	1.44	0.25	1.01	6600.0	1700.0
18.	40C	-0.10	-0.125	0.99	0.007	1.43	5800.0	1100.0
19.	45C	-0.15	-0.60	1.33	0.41	1.00	6600.0	1500.0

Table 4.1 contd.

1	2	3	4	5	6	7	8	9
20.	50C	-1.15	-1.75	1.35	0.60	0.70	7000.0	3400.0
21.	55C	-0.71	-1.50	1.83	0.58	0.67	7200.0	2800.0
22.	60C	-0.25	-0.30	1.79	0.21	0.57	7200.0	1225.0
23.	65C	0.48	0.40	0.87	0.19	1.20	2500.0	770.0
24.	70C	-0.35	-0.30	1.37	-0.002	1.01	6800.0	1225.0
25.	75C	-0.35	-0.70	1.73	0.28	0.67	6800.0	1650.0
26.	80C	-1.10	-1.10	1.12	0.13	1.02	6800.0	2125.0
27.	90C	-0.03	-0.10	1.88	0.07	0.68	6900.0	2000.0
28.	100C	-0.92	-0.90	1.16	0.095	0.97	6600.0	1875.0
29.	110C	-0.88	-0.90	1.07	0.16	0.93	6800.0	1875.0
30.	120C	-1.05	-1.075	1.25	0.16	0.96	7000.0	2075.0
31.	0L	0.68	0.95	1.59	-0.37	0.89	6000.0	520.0
32.	2R	0.77	0.90	1.28	-0.19	1.05	5400.0	540.0
33.	4L	0.87	0.85	0.77	-0.06	0.89	2000.0	600.0
34.	6R	0.60	0.70	1.39	-0.05	1.43	4600.0	620.0
35.	8L	0.73	0.63	0.90	0.14	0.93	2000.0	640.0
36.	10R	2.16	2.00	0.67	0.11	1.12	1950.0	250.0
37.	12L	1.27	1.60	2.18	-0.27	0.90	5800.0	330.0
38.	14R	-0.83	0.78	1.06	-0.058	0.85	6200.0	600.0
39.	16L	-0.38	-0.33	1.38	0.01	1.07	6400.0	1275.0
40.	18R	2.21	2.13	0.53	0.20	0.80	1000.0	230.0
41.	20L	-0.35	-0.40	1.77	0.12	0.69	6900.0	1325.0

Table 4.1 contd.

1	2	3	4	5	6	7	8	9
42.	22R	1.58	1.70	0.80	-0.24	1.58	1900.0	310.0
43.	24L	1.40	1.60	1.17	-0.26	1.02	2750.0	330.0
44.	26R	2.33	2.85	1.34	-0.49	1.11	1350.0	265.0
45.	28L	2.08	1.90	0.59	0.26	0.86	780.0	270.0
46.	30R	3.00	2.95	0.48	0.06	1.52	400.0	130.0

Table 4.1 contd.

PERIYAR

Sl. No.	Location	Mean	Median	Standard Deviation	Skewness	Kurtosis	One percentile (in micron)	Median (in micron)
1.	0C	7.55	7.35	2.90	0.17	0.61	nd	nd
2.	2C	9.77	9.40	2.51	0.13	0.79	"	"
3.	4C	9.97	11.00	3.15	0.40	1.00	"	"
4.	6C	1.60	1.70	0.85	0.29	2.74	"	"
5.	8C	2.65	2.65	0.74	-0.18	1.98	"	"
6.	10C	3.00	2.90	0.50	0.06	1.40	"	"
7.	12C	2.55	2.85	1.30	-0.50	1.10	"	"
8.	14C	0.33	0.16	1.16	0.09	1.05	"	"
9.	16C	0.01	-0.15	1.20	0.17	1.10	"	"
10.	18C	0.30	0.15	1.15	0.14	1.05	"	"
11.	20C	0.64	0.50	1.55	-0.07	0.80	"	"
12.	22C	0.40	0.30	1.25	-0.05	0.77	"	"
13.	24C	1.58	1.70	0.80	-0.24	1.58	"	"
14.	26C	-0.88	-0.90	1.15	-0.17	0.85	"	"
15.	28C	0.80	1.00	1.15	-0.17	0.70	"	"
16.	30C	-1.10	-1.00	1.25	0.15	1.05	"	"

Table - 4.2 a

SAND-SILT-CLAY PERCENTAGES WITH GRAIN-SIZE PARAMETERS OF VEMBANAD LAKE (PRE-MONSOON) SEDIMENTS

Sl. No.	Sample No.	Sand	Silt	Clay	Mean	Median	Standard Deviation	Skewness	Kurtosis	One per-centile (in micron)	Median (in mi-cron)
1	2	3	4	5	6	7	8	9	10	11	12
					(a) Northern Zone						
1.	61	6.70	20.65	72.65	9.50	9.50	3.40	0.27	0.77	5.50	1.30
2.	62	9.50	19.90	70.60	9.80	8.60	4.00	-0.38	0.62	4.00	2.50
3.	63	19.16	22.24	58.60	9.10	8.80	4.54	-0.39	0.65	4.20	2.20
4.	64	2.42	29.93	67.65	9.42	9.39	3.01	0.19	0.74	4.00	1.45
5.	65	3.50	19.10	77.40	8.85	8.95	3.10	0.32	0.50	5.00	2.00
6.	66	6.10	17.05	76.85	9.35	9.20	3.35	0.28	0.80	4.50	1.70
7.	67	3.50	19.50	77.00	9.00	9.20	3.20	-0.039	0.73	3.80	1.70
8.	68	2.85	20.50	76.65	9.90	9.50	2.80	0.19	0.67	4.20	1.35
9.	69	2.50	22.47	75.03	9.60	9.75	3.05	0.19	0.79	4.00	1.15
10.	70	3.24	36.01	60.75	10.10	6.05	3.30	0.28	0.80	4.00	2.40
11.	71	5.51	12.69	81.80	2.70	4.00	3.05	0.19	0.76	450.00	63.00
12.	72	8.85	17.80	73.35	9.20	9.05	3.05	0.17	0.67	6.00	1.90
13.	73	26.70	10.55	62.75	9.70	9.20	3.45	0.19	0.78	3.40	1.70
14.	74	12.60	36.25	51.15	8.10	8.35	3.45	0.15	0.70	71.50	3.10
15.	75	7.35	15.46	77.19	9.75	9.10	3.17	0.21	0.80	6.50	1.80
16.	76	5.80	20.60	74.60	9.40	9.15	3.10	0.17	0.68	4.80	1.75

Table 4.2 a contd.

1	2	3	4	5	6	7	8	9	10	11	12
17.	77	6.10	37.40	56.50	8.90	8.55	2.45	0.40	0.55	12.50	2.65
18.	78	8.82	15.74	75.44	9.30	9.05	3.16	0.28	0.66	4.50	1.90
19.	79	7.70	12.82	79.48	9.60	9.25	3.28	0.17	0.70	2.75	1.65
20.	80	50.50	40.98	8.52	4.20	4.20	2.15	0.42	0.90	160.00	54.00
						(b) Estuarine Zone					
21.	81	6.89	15.22	77.89	9.5	9.25	3.47	-0.015	0.59	4.80	1.65
22.	82	7.77	12.55	79.68	9.8	9.62	2.89	0.18	0.72	4.20	1.28
23.	83	8.89	13.54	77.57	9.75	9.40	3.12	0.21	0.75	6.50	1.48
24.	84	11.44	12.76	75.80	9.66	9.32	3.02	0.32	0.65	5.50	1.40
25.	85	20.50	20.75	58.75	8.80	8.20	4.20	-0.035	0.58	12.80	3.40
26.	86	9.50	16.35	74.15	9.66	9.44	3.31	-0.021	0.66	4.00	1.45
27.	87	2.42	29.93	67.65	9.45	9.20	3.01	0.22	0.78	4.00	1.60
28.	88	5.55	11.72	82.73	10.55	10.12	3.66	-0.11	0.61	2.20	1.00
29.	89	7.80	16.55	75.65	9.74	9.25	3.14	0.26	0.70	2.80	1.65
30.	90	7.44	14.55	78.04	10.40	10.11	3.42	0.19	0.72	2.00	1.00
31.	91	5.27	18.22	76.54	10.15	9.88	3.11	0.24	0.74	2.90	1.10
32.	92	6.66	14.88	78.46	10.33	10.02	3.0	0.27	0.75	2.40	1.00
33.	93	6.03	28.17	65.83	10.45	9.90	3.04	0.22	0.69	2.80	1.25
						(c) Central Zone					
34.	94	9.50	16.3	74.15	9.85	8.60	4.20	-0.35	0.65	4.00	2.55

Table 4.2 a contd.

1	2	3	4	5	6	7	8	9	10	11	12
35.	95	11.26	56.89	31.85	6.90	7.80	3.37	0.20	0.80	16.50	4.45
36.	96	40.85	20.00	39.15	5.10	6.50	3.93	-0.22	0.66	14.50	11.00
37.	97	8.31	30.80	60.89	9.40	9.25	3.05	0.19	0.75	4.50	1.65
38.	98	38.25	15.85	45.90	5.00	5.50	3.21	-0.03	0.71	58.00	22.00
39.	99	28.75	18.64	52.51	3.35	4.00	3.35	0.18	0.01	185.00	62.00
40.	100	3.15	20.65	75.60	9.80	9.40	4.05	-0.31	0.68	4.00	1.48
41.	101	30.95	25.50	43.65	6.25	6.50	3.25	0.15	0.78	60.00	11.00
42.	102	34.25	15.55	50.20	5.80	6.10	3.10	0.22	0.68	31.00	14.50
43.	103	6.25	20.70	73.05	9.80	9.50	2.89	0.015	0.65	4.00	1.35
44.	104	3.40	20.85	75.75	9.90	9.90	2.80	-0.01	0.09	4.5	1.02
45.	105	2.85	35.70	61.45	9.00	8.80	3.10	0.15	0.72	4.50	2.20
46.	106	3.50	22.40	74.10	9.50	9.50	3.75	-0.03	0.85	4.00	1.37
47.	107	68.25	20.55	11.20	2.82	3.74	2.20	0.44	0.89	230.00	74.00
48.	108	40.38	20.57	39.05	4.95	6.69	3.65	0.15	0.80	160.00	9.60
49.	109	87.35	6.35	6.30	2.68	2.73	1.62	0.50	0.98	195.60	150.00
50.	110	89.46	5.49	5.05	3.50	2.60	1.52	0.46	0.95	381.00	165.00
51.	111	87.58	6.37	6.05	2.64	2.68	1.39	0.55	0.98	198.00	160.00
52.	112	69.40	8.50	22.10	3.25	5.10	3.75	0.21	0.72	640.00	30.00
53.	113	54.64	11.81	33.55	6.50	6.05	2.90	0.31	0.66	52.00	15.00
54.	114	11.43	35.77	52.80	8.10	8.30	3.53	0.22	0.77	7.00	3.15
55.	115	10.50	30.80	58.70	8.20	8.35	3.40	0.27	0.77	6.20	3.10
56.	116	1.55	28.50	69.95	8.30	8.35	3.50	-0.035	0.91	4.50	3.00

Table 4.2 a contd.

1	2	3	4	5	6	7	8	9	10	11	12
						(d) South Zone					
57.	117	8.85	15.50	75.65	9.50	9.35	3.70	-0.02	0.71	4.0	1.60
58.	118	10.65	20.25	60.10	9.10	9.05	2.95	0.30	0.65	4.20	1.80
59.	119	8.20	21.50	70.30	9.80	9.10	3.22	-0.03	0.70	4.0	1.82
60.	120	0.63	20.02	79.38	9.15	9.10	3.15	-0.16	0.68	4.0	1.82
61.	121	5.78	11.98	82.24	8.85	8.85	3.45	-0.03	0.82	5.50	2.15
62.	122	2.20	25.19	72.61	8.10	8.20	2.80	0.19	0.69	7.00	3.40
63.	123	0.82	25.78	73.40	7.40	7.30	2.85	0.23	0.66	12.50	6.40
64.	124	5.50	24.70	69.80	8.80	8.80	2.90	0.20	0.72	9.00	2.20
65.	125	9.50	36.10	54.40	8.10	8.15	3.35	0.25	0.75	7.00	3.50
66.	126	0.65	20.05	79.30	9.00	9.05	3.05	-0.03	0.62	4.50	1.80
67.	127	1.52	18.20	80.28	8.95	8.98	3.42	0.20	0.80	5.00	2.00
68.	128	3.80	18.80	77.40	8.80	8.95	3.20	0.28	0.78	5.20	2.00
69.	129	40.45	30.87	28.68	6.80	6.50	2.70	0.32	0.65	24.00	11.00
70.	130	2.50	20.50	77.00	9.20	9.25	3.55	0.28	0.75	4.00	1.65

Table - 4.2 b

SAND-SILT-CLAY PERCENTAGES WITH GRAIN-SIZE PARAMETERS OF VEMBANAD LAKE (POST-MONSOON) SEDIMENTS

Sl. No.	Sample No.	Sand	Silt	Clay	Mean	Median	Standard Deviation	Skewness	Kurtosis	One per-centile (in micron)	Median (in mic-ron)
1	2	3	4	5	6	7	8	9	10	11	12
						Northern Zone					
1.	1	9.71	35.90	54.40	8.10	8.35	3.43	0.28	0.77	4.50	3.10
2.	2	6.46	38.9	54.83	8.05	8.40	3.25	0.28	0.81	5.20	3.10
3.	3	6.50	25.74	67.70	9.00	9.00	3.85	-0.37	0.64	2.10	1.75
4.	4	0.03	25.02	74.98	9.05	9.05	3.10	-0.17	0.81	2.40	1.80
5.	5	35.32	10.68	54.00	5.75	5.80	2.45	0.02	0.75	25.00	17.00
6.	6	2.28	22.13	75.60	9.80	9.05	3.22	-0.04	0.73	2.30	1.80
7.	7	1.15	31.00	67.85	6.80	6.80	2.95	-0.38	0.77	19.00	9.00
8.	8	5.78	11.97	82.25	8.90	8.95	3.55	-0.04	0.91	3.00	2.00
9.	9	9.30	27.78	62.92	7.10	7.15	3.85	0.19	0.68	13.50	7.00
10.	10	22.68	47.20	30.12	5.85	5.80	3.10	0.32	0.55	27.00	18.00
11.	11	7.38	29.87	62.75	7.40	7.40	2.85	0.18	0.62	16.00	5.90
12.	12	7.46	28.68	63.85	6.85	6.80	2.60	0.32	0.82	17.00	9.00
13.	13	7.45	28.65	63.80	7.20	7.15	2.95	0.28	0.71	14.00	7.00
14.	14	7.30	28.88	63.75	7.85	7.80	3.05	0.19	0.77	14.00	4.50
15.	15	9.20	26.78	63.91	7.50	7.55	2.92	0.17	0.72	11.00	5.40

Table 4.2 b contd.

1	2	3	4	5	6	7	8	9	10	11	12
						Estuarine Zone					
16.	16	5.50	24.70	69.83	8.82	8.80	2.95	0.21	0.74	3.30	2.20
17.	17	1.52	18.23	81.77	8.95	8.98	3.42	0.20	0.79	2.50	1.95
18.	18	2.21	26.19	71.60	8.55	8.22	2.95	0.20	0.69	5.50	3.30
19.	19	1.62	39.58	58.80	6.15	6.22	2.45	0.22	0.65	21.00	13.70
20.	20	2.80	34.90	62.30	7.00	7.05	2.68	0.22	0.64	14.00	7.60
21.	21	3.50	34.49	62.00	7.00	7.10	2.75	0.22	0.60	12.00	7.25
22.	22	0.82	27.78	71.40	7.45	7.32	2.81	0.23	0.62	11.00	6.20
23.	23	4.84	36.51	58.65	6.18	6.25	2.70	0.29	0.67	22.00	13.00
24.	24	2.80	34.90	62.30	7.00	7.05	2.82	0.22	0.70	19.00	7.45
25.	25	1.62	39.58	58.80	7.35	7.40	2.90	0.21	0.72	18.00	5.90
26.	26	2.20	26.19	71.60	7.40	7.37	2.88	0.22	0.64	14.00	6.00
27.	27	1.04	43.29	55.70	6.30	6.36	2.42	0.26	0.52	17.80	12.50
						Central Zone					
28.	28	45.30	15.05	39.65	4.95	6.50	2.52	0.28	0.58	49.00	11.00
29.	29	50.22	20.34	29.50	4.44	4.20	2.20	0.42	0.92	62.00	54.00
30.	30	29.63	20.18	50.19	5.50	5.45	2.85	0.29	0.75	56.00	23.00
31.	31	44.37	11.25	44.38	5.00	4.95	2.15	0.39	0.66	34.00	7.00
32.	32	61.90	28.10	10.00	3.21	3.12	2.10	0.42	0.35	140.00	115.00
33.	33	11.50	15.65	72.85	4.10	4.10	2.20	0.40	0.48	160.00	58.00

Table 4.2 b contd.

1	2	3	4	5	6	7	8	9	10	11	12
34.	34	50.15	45.30	4.55	3.75	3.60	2.45	0.41	0.40	86.00	82.00
35.	35	68.32	20.14	11.54	2.56	2.43	2.05	0.46	0.31	230.00	180.00
36.	36	53.16	30.22	16.52	3.82	3.80	2.22	0.48	0.39	182.00	71.00
37.	37	9.87	31.11	59.02	5.55	5.55	2.82	0.32	0.60	50.00	21.50
38.	38	24.60	43.40	32.00	4.76	4.82	2.25	0.29	0.51	43.00	36.00
39.	39	82.10	16.60	1.30	2.00	2.05	2.13	0.44	0.38	420.00	245.00
40.	40	10.60	59.13	30.30	4.95	4.85	2.10	0.29	0.51	60.00	35.00
41.	41	43.25	50.50	6.25	3.10	3.08	2.07	0.33	0.47	154.50	120.00
42.	42	40.25	50.50	9.20	3.43	3.28	1.95	0.40	0.58	192.60	150.00
43.	43	9.50	54.30	36.20	5.10	5.18	2.15	0.35	0.60	130.50	27.50
						Southern Zone					
44.	44	2.83	30.62	66.55	7.72	7.68	2.88	0.18	0.77	12.00	5.00
45.	45	1.14	32.15	66.71	7.75	7.75	2.95	0.19	0.70	14.00	4.60
46.	46	2.15	31.14	66.72	7.50	7.40	2.65	0.16	0.69	8.00	6.20
47.	47	14.32	35.40	50.18	6.45	6.35	2.20	0.30	0.72	25.00	12.50
48.	48	6.05	24.35	69.60	7.85	7.70	2.75	0.18	0.70	17.00	4.80
49.	49	9.80	36.20	54.00	5.82	5.78	2.95	0.32	0.72	62.00	18.00
50.	50	17.30	45.80	36.90	5.22	5.15	2.67	0.30	0.61	130.00	29.00
51.	51	12.85	22.50	64.50	6.82	6.70	2.64	0.30	0.45	24.00	9.80
52.	52	15.10	30.60	54.30	5.85	5.80	2.71	0.33	0.58	29.00	18.00
53.	53	8.20	31.35	60.45	6.70	6.75	2.78	0.26	0.62	27.00	9.20

Table 4.2 b contd.

1	2	3	4	5	6	7	8	9	10	11	12
54.	54	18.20	41.15	40.65	5.12	5.15	2.22	0.27	0.55	133.40	28.00
55.	55	2.46	21.54	76.00	8.44	8.30	3.05	0.19	0.62	6.50	3.15
56.	56	8.28	30.32	61.40	7.55	7.38	2.85	0.19	0.65	15.60	6.20
57.	57	7.44	35.66	56.90	6.45	6.40	2.43	0.22	0.68	31.00	12.00
58.	58	9.50	34.60	55.90	6.20	6.15	2.25	0.21	0.66	27.00	14.00
59.	59	15.40	40.20	44.40	5.90	5.80	2.40	0.20	0.55	27.00	18.00
60.	60	7.85	36.00	56.85	7.55	7.35	2.90	0.17	0.61	11.50	6.20

Table - 4.3 a

SAND-SILT-CLAY PERCENTAGES WITH GRAIN-SIZE PARAMETERS (IN ϕ VALUES) OF NARAKKAL MUD BANK DURING THE YEAR 1985

Sl. No.	Sample No.	Sand	Silt	Clay	Mean	Median	Standard Deviation	Skewness	Kurtosis
1	2	3	4	5	6	7	8	9	10
					MAY				
1.	01N/M	14.85	39.20	45.95	8.53	8.95	3.67	-0.13	0.63
2.	02N/M	5.54	31.71	62.75	8.88	8.35	3.10	-0.28	0.76
3.	03N/M	0.85	30.58	68.57	9.75	10.30	2.81	-0.25	0.92
4.	04N/M	1.65	25.55	72.80	10.18	10.60	2.65	-0.20	0.69
5.	05N/M	0.96	28.19	70.86	9.80	10.65	2.95	-0.27	0.88
6.	06N/M	0.87	29.48	69.65	9.95	10.40	2.89	-0.25	0.98
7.	07N/M	1.50	25.50	73.00	10.12	10.85	3.71	-0.42	1.05
8.	08N/M	9.71	29.90	60.40	9.72	10.40	3.54	-0.36	0.75
9.	09N/M	1.15	20.80	78.05	11.08	11.08	3.80	-0.47	1.26
10.	10N/M	8.80	21.20	70.00	9.85	10.55	3.62	-0.37	0.97
					JUNE				
1.	01N/Ju	5.84	26.87	67.30	9.08	9.00	2.97	0.03	1.55
2.	02N/Ju	12.05	15.00	72.95	10.00	10.20	2.56	-0.09	-0.69
3.	03N/Ju	9.54	25.51	64.95	10.00	10.00	2.56	-0.06	0.81

Table 4.3 a contd.

1	2	3	4	5	6	7	8	9	10
4.	04N/Ju	0.86	23.25	75.89	10.23	10.50	2.60	-0.18	0.89
5.	05N/Ju	0.58	13.55	85.87	10.25	10.50	2.62	-0.29	0.82
6.	06N/Ju	0.26	10.05	89.70	10.00	10.00	2.58	-0.06	0.78
7.	07N/Ju	9.87	12.30	77.80	9.88	9.50	2.54	0.12	0.52
8.	08N/Ju	4.53	24.64	70.81	9.83	10.70	3.03	-0.33	0.94
9.	09N/Ju	1.49	25.91	72.60	9.55	9.80	2.96	-0.14	0.78
10.	10N/Ju	4.27	14.07	81.67	10.72	11.00	2.45	-0.22	0.81
					JULY				
1.	01N/Jl	4.80	25.14	70.06	10.10	9.70	2.60	-0.17	0.85
2.	01N/Jl	2.01	16.18	81.80	10.30	10.40	2.45	-0.15	1.05
3.	03N/Jl	9.81	15.40	74.79	10.00	10.20	2.60	-0.07	0.80
4.	04N/Jl	4.80	13.10	82.10	8.50	9.02	2.95	-0.03	0.78
5.	05N/Jl	2.78	13.72	83.50	8.70	9.05	3.20	-0.02	0.75
6.	06N/Jl	0.35	14.50	85.15	11.20	11.25	2.35	-0.17	0.98
7.	07N/Jl	0.52	12.00	87.48	11.10	11.20	2.20	-0.15	0.87
8.	08N/Jl	1.50	13.01	85.00	10.22	10.35	2.30	-0.05	1.19
9.	09N/Jl	2.15	25.15	72.70	9.80	10.60	2.85	-0.19	0.65
10.	10N/Jl	9.50	25.50	65.00	10.20	9.50	2.60	-0.16	0.80
					AUGUST				
1.	01N/A	0.90	30.56	69.55	5.83	7.50	2.01	-0.101	1.96

Table 4.3 a contd.

1	2	3	4	5	6	7	8	9	10
2.	02N/A	4.32	16.00	79.68	9.82	10.00	2.69	-0.11	0.78
3.	03N/A	2.55	12.70	84.75	10.03	10.20	2.63	-0.13	0.78
4.	04N/A	6.15	12.35	81.50	10.10	10.25	2.61	-0.129	0.78
5.	05N/A	0.57	15.38	86.06	10.06	10.20	2.55	-0.10	0.84
6.	06N/A	0.78	11.27	87.95	10.02	10.10	2.35	-0.06	0.88
7.	07N/A	0.59	9.51	89.90	10.35	10.30	2.33	-0.06	0.89
8.	08N/A	9.89	27.35	62.76	9.24	9.50	3.33	-0.27	0.99
9.	09N/A	0.86	15.82	84.18	9.66	10.00	2.77	-0.16	0.81
10.	10N/A	9.59	14.05	76.07	9.59	10.00	2.85	-0.18	0.78
					SEPTEMBER				
1.	01N/S	5.66	36.64	57.70	8.87	8.35	2.69	0.26	1.62
2.	02N/S	0.24	37.08	62.90	8.79	8.00	2.85	0.29	1.69
3.	03N/S	0.22	24.77	75.02	10.20	10.50	2.72	-0.21	0.65
4.	04N/S	0.30	11.40	88.30	10.83	10.90	2.25	0.06	0.87
5.	05N/S	0.66	11.88	87.46	10.25	10.50	2.62	-0.18	0.89
6.	06N/S	0.95	18.83	80.23	11.00	10.20	2.59	-0.32	0.75
7.	07N/S	0.57	10.51	88.93	10.80	11.00	2.35	-0.16	0.90
8.	08N/S	7.24	25.46	67.31	9.21	9.40	2.97	-0.08	0.89
9.	09N/S	0.26	13.00	86.75	10.13	10.41	2.69	-0.23	0.58
10.	10N/S	0.16	25.53	74.31	8.74	8.50	2.81	-0.00	1.45

Table 4.3 a contd.

1	2	3	4	5	6	7	8	9	10
					DECEMBER				
1.	01N/D	23.50	30.7	45.8	6.85	7.20	3.55	-0.02	0.80
2.	02N/D	13.57	31.41	55.02	8.80	9.05	3.20	-0.07	0.83
3.	03N/D	9.20	13.65	77.15	9.62	9.10	2.57	0.22	0.98
4.	04N/D	22.50	14.90	62.66	10.48	11.20	2.74	-0.37	0.93
5.	05N/D	11.49	12.11	76.40	10.68	11.00	2.37	-0.23	0.86
6.	06N/D	17.90	5.80	76.30	10.70	10.60	2.25	-0.06	1.03
7.	07N/D	9.23	12.50	78.27	9.59	8.95	2.63	0.20	1.00
8.	08N/D	4.70	38.20	57.10	8.68	9.19	3.25	-0.28	0.64
9.	09N/D	14.19	50.03	55.78	9.39	10.20	3.35	-0.30	0.61
10.	10N/D	5.46	34.40	60.14	8.86	8.95	3.24	-0.08	0.86

Table - 4.3 b

SAND-SILT-CLAY PERCENTAGES WITH GRAIN-SIZE PARAMETERS OF THE SHELF SEDIMENTS SEAWARD OF NARAKKAL MUD BANK DURING THE YEAR 1986

Sl. No.	Sample No.	Sand	Silt	Clay	Mean	Median	Standard Deviation	Skewness	Kurtosis
1	2	3	4	5	6	7	8	9	10
					JULY				
1.	12N/Ju	9.90	25.25	64.85	8.69	8.00	2.57	0.39	2.40
2.	14N/Ju	9.13	30.95	59.92	7.77	7.50	2.01	0.10	1.96
3.	16N/Ju	4.87	36.13	59.00	8.44	7.80	2.68	0.36	0.74
4.	18N/Ju	9.65	21.45	68.90	9.15	8.40	2.66	0.31	2.66
5.	20N/Ju	8.74	27.35	63.91	9.24	9.50	3.33	-0.27	0.99
6.	22N/Ju	9.30	23.90	66.80	8.82	8.00	2.81	0.33	0.94
7.	24N/Ju	9.52	21.58	68.90	8.55	8.05	2.45	0.36	2.20
8.	26N/Ju	8.93	33.26	57.81	7.58	7.50	2.10	0.15	1.85
9.	28N/Ju	14.85	39.20	45.95	8.53	8.95	3.67	-0.14	0.63
10.	30N/Ju	5.70	43.25	51.05	9.75	9.04	2.90	0.10	0.69
					AUGUST				
1.	12N/A	15.40	39.20	46.95	7.65	8.50	3.85	0.28	0.65
2.	14N/A	3.39	49.10	47.42	9.05	8.55	3.38	-0.01	0.95
3.	16N/A	6.85	47.50	45.65	7.80	8.20	3.72	0.10	0.75

Table 4.3 b contd.

1	2	3	4	5	6	7	8	9	10
4.	18N/A	3.34	41.56	55.10	6.75	7.60	3.45	0.45	0.65
5.	20N/A	14.12	37.56	48.32	8.15	8.45	3.45	0.15	0.65
6.	22N/A	20.50	44.90	52.60	6.95	7.30	3.65	0.02	0.80
7.	24N/A	20.50	38.70	40.80	8.35	8.35	3.20	0.05	0.82
8.	26N/A	2.40	41.70	55.90	9.80	9.05	2.95	0.10	0.69
9.	28N/A	28.50	37.70	33.80	4.60	6.35	3.60	0.48	1.65
10.	30N/A	25.28	52.52	22.20	4.55	5.55	2.58	0.43	0.48

Table - 4.4 a

SAND-SILT-CLAY PERCENTAGES WITH GRAIN SIZE PARAMETERS OF PURAKKAD MUD BANK SEDIMENTS

Sl. No.	Sample No.	Sand	Silt	Clay	Mean	Median	Standard Deviation	Skewness	Kurtosis
1	2	3	4	5	6	7	8	9	10
					MAY				
1.	01P/M	12.10	30.21	57.69	9.50	9.50	3.41	-0.35	0.72
2.	02P/M	2.30	20.65	77.05	10.58	10.00	3.75	0.38	1.10
3.	03P/M	14.70	30.50	54.80	9.65	9.75	3.20	-0.34	0.91
4.	04P/M	12.20	35.20	52.60	9.45	9.45	3.60	-0.40	0.98
5.	05P/M	8.60	32.80	58.60	9.55	9.50	3.50	-0.32	0.80
6.	06P/M	7.20	31.40	61.40	9.60	9.85	3.70	-0.36	0.74
7.	07P/M	7.80	33.60	58.60	9.72	9.75	3.55	-0.32	0.75
8.	08P/M	8.10	22.50	69.40	9.85	9.85	3.62	-0.37	0.96
					JUNE				
9.	01P/Ju	12.71	20.30	66.99	10.10	10.40	2.55	-0.09	0.70
10.	02P/Ju	2.40	12.80	84.80	10.65	11.10	2.45	-0.22	0.82
11.	03P/Ju	2.20	20.40	77.40	9.82	10.25	2.65	-0.11	0.78
12.	04P/Ju	0.98	10.00	89.02	10.35	10.30	2.35	-0.06	0.90
13.	05P/Ju	4.78	20.75	76.67	10.00	10.20	2.60	-0.07	0.80
14.	06P/Ju	6.82	21.45	71.73	10.15	9.85	2.58	-0.17	0.87

Table 4.4 a contd.

1	2	3	4	5	6	7	8	9	10
15.	07P/Ju	0.82	15.00	84.18	10.25	10.50	2.62	-0.29	0.82
16.	08P/Ju	0.91	18.25	80.84	9.75	10.15	2.68	-0.12	0.84
					JULY				
17.	01P/Jl	4.28	12.80	82.92	8.50	9.02	3.20	-0.02	0.76
18.	02P/Jl	0.98	18.80	80.22	11.25	10.31	2.56	-0.32	0.72
19.	03P/Jl	0.44	11.72	87.84	11.25	11.18	2.18	-0.17	1.01
20.	04P/Jl	0.80	8.75	90.45	10.35	10.30	2.35	-0.06	0.90
21.	05P/Jl	2.20	18.21	79.59	10.03	10.20	2.63	-0.13	0.78
22.	06P/Jl	0.70	9.30	90.00	10.35	10.22	2.30	-0.06	0.88
23.	07P/Jl	0.10	5.50	94.40	11.40	11.50	2.58	-0.06	0.78
24.	08P/Jl	0.88	12.70	86.42	10.25	10.50	2.62	-0.30	0.82
					AUGUST				
25.	01P/A	0.81	8.51	90.68	9.80	10.10	2.52	-0.05	0.70
26.	02P/A	0.92	19.62	79.46	10.08	11.00	3.80	-0.47	1.27
27.	03P/A	2.72	18.10	79.18	10.30	10.40	2.45	-0.15	1.05
28.	04P/A	0.78	14.65	84.57	10.22	10.35	2.30	-0.05	1.20
29.	05P/A	2.10	20.05	77.85	10.15	10.40	2.55	-0.07	1.05
30.	06P/A	2.40	14.65	82.95	10.05	10.20	2.50	-0.18	1.10

Table 4.4 a contd.

1	2	3	4	5	6	7	8	9	10
31.	07P/A	0.72	12.75	86.52	11.15	11.25	2.35	-0.17	0.98
32.	08P/A	0.15	21.86	78.00	10.20	10.50	2.75	-0.21	0.65
				SEPTEMBER					
33.	01P/S	8.08	22.24	69.68	10.20	9.50	2.65	-0.16	0.80
34.	02P/S	3.02	16.97	80.01	10.35	10.30	2.45	-0.25	1.05
35.	03P/S	2.85	17.88	79.27	9.82	10.00	2.69	-0.11	0.78
36.	04P/S	2.50	16.85	80.65	9.70	9.95	3.20	0.02	0.75
37.	05P/S	6.78	24.31	68.91	9.21	9.00	2.97	0.07	0.90
38.	06P/S	3.22	18.76	78.02	10.75	10.80	2.60	-0.33	0.72
39.	07P/S	1.80	10.75	87.45	10.22	10.32	2.41	-0.05	1.17
40.	08P/S	3.75	22.31	73.94	10.20	9.65	2.61	-0.17	0.80
				DECEMBER					
41.	01P/D	4.40	32.80	62.80	8.68	9.19	3.25	0.28	0.76
42.	02P/D	9.30	36.20	54.70	8.15	8.65	3.82	0.28	0.65
43.	03P/D	4.30	24.80	70.90	9.82	10.00	2.69	-0.11	0.8
44.	04P/D	6.80	29.70	63.50	9.35	9.50	3.35	-0.27	0.99
45.	05P/D	4.10	35.60	60.30	9.75	10.30	2.81	-0.25	0.92
46.	06P/D	4.53	28.22	67.25	9.80	9.95	2.60	-0.16	0.80
47.	07P/D	1.48	27.12	70.70	10.10	10.50	2.85	-0.19	0.65
48.	08P/D	6.55	27.30	66.15	10.10	9.70	2.60	-0.17	0.85

Table 4.4 b

SAND-SILT-CLAY PERCENTAGES WITH GRAIN-SIZE PARAMETERS OF THE SHELF SEDIMENTS SEAWARD OF PURAKKAD MUD BANK DURING THE YEAR 1986

Sl.	Sample No.	Sand	Silt	Clay	Mean	Median	Standard Deviation	Skewness	Krutosis
1	2	3	4	5	6	7	8	9	10
					JULY				
1.	11P/J1	4.40	32.80	62.80	9.78	9.40	3.10	-0.08	0.78
2.	13P/J1	9.30	36.00	54.70	7.60	8.52	3.80	0.28	0.65
3.	15P/J1	4.30	24.80	70.90	9.90	9.75	2.54	-0.08	0.55
4.	18P/J1	6.80	29.70	63.50	11.02	10.18	2.99	0.37	0.65
5.	21P/J1	25.85	46.01	28.44	6.50	6.75	3.65	0.54	1.25
6.	23P/J1	11.88	40.70	47.72	8.15	8.45	3.45	0.15	0.68
7.	25P/J1	3.10	34.93	61.97	8.70	9.20	3.25	0.28	0.76
8.	28P/J1	3.80	30.20	66.00	10.20	9.85	2.85	0.17	0.80
					AUGUST				
9.	11P/A	3.78	26.30	69.92	8.50	7.85	2.68	0.33	0.75
10.	13P/A	10.32	23.69	65.99	9.15	8.80	2.75	0.35	1.75
11.	15P/A	14.75	30.20	55.05	8.20	8.55	3.45	0.15	0.85
12.	18P/A	44.13	19.14	36.73	5.75	6.10	3.56	0.51	1.70
13.	21P/A	30.60	38.90	30.50	4.59	6.32	3.62	0.53	1.59

Table 4.4 b contd.

1	2	3	4	5	6	7	8	9	10
14.	23P/A	32.71	30.04	37.25	5.20	6.35	3.55	0.52	1.70
15.	25P/A	7.90	26.84	65.26	8.69	8.00	2.57	0.39	2.00
16.	28P/A	9.10	32.70	58.20	7.58	7.50	2.01	0.15	1.85

Table - 4.5

SAND-SILT-CLAY PERCENTAGES WITH GRAIN SIZE PARAMETERS OF NARAKKAL MUD BANK SEDIMENTS DURING THE YEAR 1986

Sl. No.	Sample No.	Sand	Silt	Clay	Mean	Median	Standard Deviation	Skewness	Kurtosis
1	2	3	4	5	6	7	8	9	10
					JULY				
1.	01N/J12	7.85	57.25	34.90	6.60	7.50	3.40	0.42	0.62
2.	02N/J12	5.77	45.23	49.00	5.80	5.60	2.70	0.31	0.55
3.	03N/J12	12.66	24.14	64.20	6.70	6.95	3.10	0.33	0.61
4.	04N/J12	9.40	30.80	59.80	6.20	6.10	2.75	0.27	0.69
5.	05N/J12	14.85	42.00	43.15	6.70	7.20	3.45	-0.15	0.58
6.	06N/J12	1.48	27.12	70.70	7.20	7.50	2.10	-0.22	0.70
7.	07N/J12	12.80	34.65	52.55	5.50	5.75	3.70	0.32	0.85
8.	08N/J12	9.71	35.89	54.40	7.70	7.50	2.00	0.10	1.20
9.	09N/J12	14.30	40.70	45.00	7.55	7.50	2.10	0.15	1.60
10.	10N/J12	6.65	25.50	67.85	6.50	6.25	1.72	-0.08	1.44
					AUGUST				
1.	01N/A2	5.76	44.44	49.80	6.90	7.15	3.72	0.32	0.60
2.	02N/A2	4.84	36.50	58.65	6.70	6.85	3.50	0.22	0.80

Table 4.5 contd.

1	2	3	4	5	6	7	8	9	10
3.	03N/A2	10.54	39.76	49.70	5.85	6.30	2.88	-0.03	0.55
4.	04N/A2	1.02	42.55	56.00	5.70	5.90	3.15	-0.10	0.62
5.	05N/A2	1.58	45.92	52.50	3.78	4.25	2.12	0.41	0.51
6.	06N/A2	1.50	35.00	63.00	6.78	6.32	2.70	0.20	0.59
7.	07N/A2	1.60	39.20	59.00	7.30	7.70	3.15	-0.15	0.70
8.	08N/A2	2.25	42.75	55.00	5.64	5.35	2.90	0.18	0.65
9.	09N/A2	2.78	35.00	62.30	4.45	4.50	2.26	0.45	0.49
10.	10N/A2	1.50	35.00	61.00	5.90	5.25	3.10	0.19	0.62

Table - 4.6 a

TEXTURAL PARAMETERS OF BEACH SAND (PRE-MONSOON)

Sl.No.	Month	Mean	Median	Standard Deviation	Skewness	Kurtosis	One percentile (in micron)	Median in (in micron)
1	2	3	4	5	6	7	8	9
				Narakkal				
1.	April	A 2.85	2.90	0.44	0.08	0.96	540	135
2.		B 2.55	2.55	0.43	-0.10	1.31	480	170
3.		C 2.10	2.16	0.29	0.33	1.23	430	230
4.		D 2.52	2.65	0.57	-0.40	1.14	1350	160
5.	May	A 1.70	1.80	0.67	-0.27	0.78	600	280
6.		B 2.30	2.55	0.40	+0.25	0.94	520	240
7.		C 2.40	2.55	0.40	-0.25	0.92	500	170
8.		D 2.10	2.25	0.60	-0.29	0.93	710	210
				Malipuram				
9.	April	A 2.20	2.15	0.37	0.17	1.10	850	230
10.		B 2.30	2.25	0.39	0.16	0.11	520	210
11.		C 2.00	2.20	0.33	0.18	0.97	1025	220
12.		D 2.10	2.20	0.61	-0.26	0.93	770	220

Table 4.6 a contd.

1	2	3		4	5	6	7	8	9
					Malipuram				
13.	May	A	2.00	2.15	0.39	0.17	0.98	690	230
14.		B	2.05	2.00	0.38	0.18	0.61	600	250
15.		C	2.00	2.00	0.29	-0.09	1.80	500	250
16.		D	2.05	2.00	0.37	0.44	1.64	760	250
					Puthuvypu				
17.	April	A	2.75	2.45	0.71	0.32	0.69	460	195
18.		B	2.50	2.20	0.637	0.45	0.68	1100	220
19.		C	2.80	2.80	0.404	-0.09	1.01	400	145
20.		D	2.32	2.30	0.99	0.51	0.72	542	205
21.	May	A	2.70	2.55	0.67	0.30	0.77	425	170
22.		B	3.01	3.20	0.55	-0.74	1.74	440	110
23.		C	7.70	7.50	2.00	0.10	1.80	34	6
24.		D	7.58	7.50	2.10	0.15	1.65	42	6
					Fort Cochin				
25.	April	A	2.35	2.35	0.55	-0.02	1.20	580	200
26.		B	2.20	2.20	0.78	0.00	1.05	630	220
27.		C	2.45	2.45	0.50	-0.01	1.10	490	195
28.		D	1.10	1.05	1.15	0.03	1.08	1075	480

Table 4.6 a contd.

1	2	3	4	5	6	7	8	9
29.	May	A 2.70	2.25	0.55	0.16	1.00	700	210
30.		B 2.4	2.20	1.50	0.14	0.98	520	220
31.		C 2.40	2.40	0.63	0.08	1.05	420	190
32.		D 2.10	2.25	0.77	0.02	0.90	1150	210
				Beach Road				
33.	April	A 2.10	2.20	0.58	0.015	1.05	1200	220
34.		B 1.75	1.95	0.62	-0.20	1.40	760	260
35.		C 1.68	1.55	0.74	0.20	0.96	1900	340
36.		D 1.38	1.35	1.12	0.19	1.28	1700	400
37.	May	A 2.38	2.35	0.54	-0.02	1.16	700	195
38.		B 1.85	1.80	0.62	0.12	0.19	710	290
39.		C 1.60	1.75	0.65	0.05	0.85	1000	300
40.		D 1.59	1.60	0.70	0.03	0.83	1200	330
				Kannamaly				
41.	April	A 1.60	1.65	0.50	-0.10	1.00	1800	320
42.		B 1.80	1.85	0.50	-0.02	1.20	940	280
43.		C 1.95	2.05	0.65	-0.24	1.03	1700	240
44.		D 1.50	1.60	0.85	-0.07	0.72	1200	320

Table 4.6 a contd.

1	2		3	4	5	6	7	8	9
45.	May	A	1.70	1.70	0.59	0.02	1.05	830	310
46.		B	1.50	1.50	0.50	0.01	1.10	1500	350
47.		C	2.30	2.35	0.68	0.04	0.88	860	200
48.		D	1.42	0.95	0.90	-0.02	1.35	1200	520
					Chellanam				
49.	April	A	1.20	1.30	0.70	0.06	0.80	780	410
50.		B	1.40	1.70	0.48	-0.01	0.87	1300	310
51.		C	1.68	1.75	0.64	0.08	0.91	640	300
52.		D	1.20	1.20	0.80	-0.03	0.88	920	435
53.	May	A	1.80	1.70	0.58	0.01	0.98	4300	310
54.		B	1.62	1.55	1.20	0.01	1.25	2100	340
55.		C	1.65	1.65	0.53	0.04	1.13	2600	320
56.		D	1.30	1.30	0.72	0.07	0.92	5000	410
					Taikal				
57.	April	A	0.65	0.72	0.31	0.18	0.52	960	600
58.		B	0.72	0.78	0.45	0.27	0.68	580	580
59.		C	1.55	1.65	0.68	0.10	1.10	440	320
60.		D	1.50	1.48	0.86	0.01	0.92	530	345
61.	May	A	1.70	1.60	0.66	0.10	1.00	400	330
62.		B	1.77	1.72	0.70	0.15	0.88	640	310

Table 4.6 a contd.

1	2		3	4	5	6	7	8	9
63.		C	0.72	0.66	0.71	0.32	0.99	1000	640
64.		D	0.56	0.60	1.10	0.45	1.30	700	750
					Alleppey				
65.	April	A	1.60	1.60	0.70	0.10	1.00	740	330
66.		B	1.82	1.79	0.80	0.18	1.10	450	290
67.		C	1.62	1.75	0.64	0.05	0.88	570	300
68.		D	1.44	1.53	0.61	0.22	0.79	1000	345
69.	May	A	1.84	1.87	0.65	-0.02	1.10	335	280
70.		B	1.90	1.85	0.60	-0.01	0.90	480	280
71.		C	2.20	2.05	0.51	0.04	0.77	810	240
72.		D	1.40	1.25	1.05	0.31	0.70	1200	425
					Purakkad				
73.	April	A	2.10	2.25	0.44	0.20	1.15	360	210
74.		B	2.40	2.20	0.38	0.22	1.05	400	220
75.		C	1.80	2.00	0.31	0.17	0.98	620	250
76.		D	1.85	1.77	0.64	1.00	1.08	740	295
77.	May	A	2.20	2.35	0.31	0.24	0.92	1200	195
78.		B	2.10	2.05	0.44	0.27	0.85	1050	240
79.		C	2.44	2.35	0.24	0.04	0.99	580	200
80.		D	2.95	1.77	0.63	0.41	0.68	410	300

Table - 4.6 b

TEXTURAL PARAMETERS OF BEACH SAND (POST-MONSOON)

Sl.No.	Month		Mean	Median	Standard Deviation	Skewness	Kurtosis	One percentile (in micron)	Median in (in micron)
1	2		3	4	5	6	7	8	9
					Narakkal				
1.	September	A	2.35	2.20	0.55	-0.02	1.20	510	220
2.		B	2.20	2.20	0.50	0.18	1.08	472	220
3.		C	2.45	2.40	0.50	0.18	1.15	425	185
4.		D	1.10	1.05	0.85	0.03	1.05	780	480
5.	October	A	1.80	1.70	0.58	0.01	0.98	720	310
6.		B	1.75	1.95	0.62	-0.20	1.40	600	260
7.		C	1.95	2.05	0.66	-0.24	1.10	1654	240
8.		D	1.30	1.30	0.72	0.07	0.92	1100	410
					Malipuram				
9.	September	A	2.40	2.55	0.62	0.29	0.82	400	170
10.		B	2.30	2.35	0.68	0.04	0.88	320	230
11.		C	4.55	4.10	2.15	0.18	0.81	-	-
12.		D	6.25	6.50	1.25	0.15	0.78	250	110

Table 4.6 b contd.

1	2	3		4	5	6	7	8	9
13.	October	A	2.30	2.25	0.37	0.19	1.15	430	210
14.		B	2.45	2.25	0.44	0.15	0.97	420	210
15.		C	2.18	2.20	0.35	0.17	0.90	460	220
16.		D	2.05	1.90	0.39	0.08	0.70	620	270
					Puthuvypu				
17.	September	A	2.55	2.60	0.52	0.27	0.79	460	165
18.		B	3.05	2.95	0.61	0.35	0.82	180	130
19.		C	6.50	6.25	1.72	-0.08	1.44	30	13
20.		D	5.70	5.85	1.37	-0.01	1.12		
21.	October	A	2.70	2.60	0.66	0.31	0.68	800	165
22.		B	2.20	2.35	0.70	0.27	0.79	460	200
23.		C	2.90	2.75	0.39	0.20	0.61	290	150
24.		D	2.18	2.25	0.92	0.31	0.78	420	210
					Fort Cochin				
25.	September	A	2.75	2.25	0.61	0.17	1.11	495	210
26.		B	2.40	2.35	1.50	0.14	0.97	600	200
27.		C	2.25	2.10	1.41	0.14	0.89	410	235
28.		D	1.82	1.85	0.58	-0.12	1.03	1500	300

Table 4.6 b contd.

1	2		3	4	5	6	7	8	9
29.	October	A	2.37	2.35	0.54	-0.02	1.17	594	200
30.		B	2.28	2.20	0.58	0.01	0.91	425	220
31.		C	1.68	1.55	0.73	0.21	0.96	1200	340
32.		D	0.55	0.60	0.99	0.03	1.08	2350	500
					Beach Road				
33.	September	A	1.85	1.80	0.67	0.09	0.96	1125	290
34.		B	1.98	1.95	0.65	0.062	0.91	530	260
35.		C	1.62	1.60	0.35	0.21	0.41	1850	380
36.		D	1.40	1.40	0.70	0.08	1.20	1000	420
37.	October	A	1.87	1.85	0.66	0.09	1.35	1500	280
38.		B	1.75	1.70	0.62	0.15	0.99	644	310
39.		C	1.68	1.55	0.73	0.21	0.96	1250	340
40.		D	1.38	1.30	0.76	0.19	1.28	1075	410
					Kannamaly				
41.	September	A	1.65	1.60	0.57	0.10	0.99	1800	330
42.		B	1.83	1.85	0.49	-0.04	0.97	940	300
43.		C	1.95	2.05	0.67	0.24	1.03	1650	240
44.		D	1.50	1.60	0.89	0.06	0.92	2600	330

Table 4.6 b contd.

1	2		3	4	5	6	7	8	9
45.	October	A	2.07	2.20	0.62	-0.09	1.08	515	220
46.		B	1.45	1.70	0.50	-0.01	0.85	725	310
47.		C	2.30	2.35	0.59	-0.17	1.17	725	230
48.		D	1.42	0.75	0.92	0.84	0.75	2600	575
					Chellanam				
49.	September	A	1.80	1.80	0.57	0.013	1.00	610	290
50.		B	1.62	1.55	0.44	0.90	0.98	1800	340
51.		C	1.66	1.65	0.54	0.04	1.14	1650	320
52.		D	1.33	1.30	0.72	0.07	0.92	785	410
53.	October	A	1.72	1.75	0.62	-0.09	1.08	540	300
54.		B	1.05	1.00	0.59	0.17	1.10	1175	500
55.		C	1.68	1.75	0.61	-0.15	0.91	780	300
56.		D	1.42	0.75	0.92	0.84	0.75	2500	580
					Taikal				
57.	September	A	1.70	1.70	0.59	0.02	1.05	570	310
58.		B	1.50	1.50	0.50	0.01	1.10	1500	345
59.		C	2.30	2.35	0.68	0.04	0.88	250	230
60.		D	1.42	0.95	0.92	-0.62	1.35	-	-

Table 4.6 b contd.

1	2		3	4	5	6	7	8	9
61.	October	A	1.45	1.40	0.62	0.10	0.99	970	380
60.		B	1.40	1.45	0.50	+0.08	1.20	750	380
63.		C	1.95	2.05	0.66	-0.23	1.03	500	240
64.		D	1.50	1.60	0.85	0.02	1.05	750	330
					Alleppey				
65.	September	A	1.80	1.70	0.58	0.01	0.98	520	310
66.		B	1.80	1.85	0.50	-0.01	1.20	940	280
67.		C	1.95	1.95	0.53	0.04	1.13	1100	260
68.		D	1.30	1.30	0.72	0.06	0.92	5000	410
69.	October	A	1.80	1.70	0.65	0.01	0.98	4100	310
70.		B	1.62	1.65	1.20	0.01	1.25	2200	340
71.		C	1.65	1.65	0.53	0.04	1.13	1550	320
72.		D	1.30	1.30	0.72	0.07	0.92	1100	410
					Purakkad				
73.	September	A	2.70	2.25	0.55	0.17	1.09	390	225
74.		B	2.40	2.20	1.50	0.14	0.98	270	220
75.		C	2.40	2.40	0.63	0.08	1.05	240	190
76.		D	2.10	2.25	0.77	0.02	0.90	460	225
77.	October	A	2.38	2.30	0.54	-0.02	1.17	508	200
78.		B	1.85	1.80	0.62	0.02	0.89	900	390

Table 4.6 b contd.

1	2	3	4	5	6	7	8	9
79.	C	2.30	2.35	0.68	0.34	0.88	320	230
80.	D	1.59	1.60	0.70	0.03	0.91	1300	550

A - Backshore.

B - Berm.

C - Foreshore.

D - Low Water Mark.

Table - 5.1

HEAVY MINERAL DISTRIBUTION IN THE PERIYAR SEDIMENTS

(+ 250 Microns)

Sl.No.	Name of the Mineral	Sampling Locations						Average
		2C	8C	14C	20C	26C	30C	
1.	Opaques	54.40	48.06	52.07	55.15	59.52	54.18	53.90
2.	Garnet	1.53	2.99	1.01	2.88	1.60	1.16	1.86
3.	Hornblende	34.92	39.77	38.87	32.34	33.40	34.30	35.60
4.	Hypersthene/Enstatite	2.51	2.53	1.02	1.70	1.30	1.44	1.75
5.	Augite/Diopside	-	0.14	0.91	-	0.94	1.02	0.50
6.	Mica	2.99	2.54	1.10	0.80	2.30	1.97	1.95
7.	Sillimanite	2.31	2.97	4.82	4.60	0.14	4.12	3.16
8.	Zircon	1.03	0.40	0.04	0.53	0.33	0.15	0.41
9.	Monazite	-	-	-	-	-	-	-
10.	Rutile	0.32	0.60	0.16	2.00	0.47	1.66	0.87
11.	Staurolite	-	-	-	-	-	-	-
12.	Epidote	-	-	-	-	-	-	-
13.	Tourmaline	-	-	-	-	-	-	-
14.	Apatite	-	-	-	-	-	-	-

Table 5.1 contd.

HEAVY MINERAL DISTRIBUTION IN THE PERIYAR RIVER SEDIMENTS

(+ 125 Microns)

Sl.No.	Name of the Mineral	Sampling Locations						Average
		2C	8C	14C	20C	26C	30C	
1.	Opaques	67.75	65.87	72.60	72.13	70.30	72.44	70.18
2.	Garnet	2.02	1.70	1.32	1.68	1.61	1.57	1.65
3.	Hornblende	-	0.25	0.12	0.10	-	-	0.078
4.	Hypersthene/Enstatite	10.95	16.76	12.05	12.94	10.15	12.51	12.56
5.	Augite/Diopside	0.78	1.90	1.40	0.98	1.47	1.51	1.34
6.	Mica	3.60	2.94	2.35	2.64	2.89	3.76	3.03
7.	Sillimanite	1.56	3.70	2.40	1.98	2.54	2.10	2.38
8.	Zircon	6.08	4.21	7.15	6.81	6.40	5.89	6.09
9.	Monazite	1.80	0.60	0.44	0.30	-	0.22	0.56
10.	Rutile	-	-	-	-	-	-	-
11.	Staurolite	2.01	0.41	0.17	0.44	3.75	-	1.13
12.	Epidote	0.73	0.05	-	-	-	-	0.13
13.	Tourmaline	2.49	0.22	-	-	0.89	-	0.60
14.	Apatite	0.23	1.39	-	-	-	-	0.27

Table 5.1 contd.

HEAVY MINERAL DISTRIBUTION IN THE PERIYAR RIVER SEDIMENTS

(+ 63 Microns)

Sl. No.	Name of the Mineral	Sampling Locations						Average
		2C	8C	14C	20C	26C	30C	
1.	Opaques	35.40	38.75	32.18	34.55	38.55	32.65	35.34
2.	Garnet	0.70	0.20	0.22	0.38	0.30	0.32	0.35
3.	Hornblende	26.32	26.18	29.90	22.22	21.97	27.87	25.74
4.	Hypersthene/Enstatite	2.18	1.08	0.40	0.68	0.96	1.56	1.14
5.	Augite/Diopside	12.10	9.78	7.10	17.23	10.31	13.58	11.68
6.	Mica	1.52	1.12	1.78	0.66	1.58	1.20	1.31
7.	Sillimanite	4.82	2.85	2.80	2.14	3.31	3.10	3.17
8.	Zircon	15.00	17.63	23.10	19.18	20.82	18.15	18.98
9.	Monazite	0.96	1.70	1.30	1.60	1.30	0.76	1.27
10.	Rutile	1.00	0.71	1.22	1.36	0.90	0.81	1.00
11.	Staurolite	-	-	-	-	-	-	-
12.	Epidote	-	-	-	-	-	-	-
13.	Tourmaline	-	-	-	-	-	-	-
14.	Apatite	-	-	-	-	-	-	-

Table 5.1 contd.

HEAVY MINERAL DISTRIBUTION IN THE MUVATTUPUZHA SEDIMENTS

(+ 250 Microns)

Sl.No.	Name of the Mineral	Sampling Locations						Average
		2C	10C	20C	30C	40C	60C	
1.	Opaques	38.20	41.49	41.34	41.47	39.20	39.95	40.28
2.	Garnet	2.15	3.82	3.70	4.76	3.77	4.12	3.72
3.	Hornblende	28.72	27.20	29.30	25.25	27.90	31.26	28.27
4.	Augite/Diopside	1.71	1.96	1.28	1.76	1.80	1.15	1.61
5.	Hypersthene/Enstatite	16.30	14.43	13.78	16.70	17.37	14.62	15.53
6.	Mica	5.41	4.82	3.95	3.64	3.50	3.22	4.09
7.	Sillimanite	4.91	3.82	3.15	3.20	3.19	2.55	3.47
8.	Chlorite	1.36	1.22	1.35	1.40	1.28	1.31	1.32
9.	Tourmaline	0.92	0.98	1.87	1.61	1.70	1.62	1.45
10.	Zircon	0.32	0.26	0.28	0.21	0.29	0.20	0.26
11.	Monazite	-	-	-	-	-	-	-
12.	Rutile	-	-	-	-	-	-	-

Table 5.1 contd.

HEAVY MINERAL DISTRIBUTION IN THE MUVATTUPUZHA SEDIMENTS

(+ 125 Microns)

Sl.No.	Name of the Mineral	Sampling Locations						Average
		2C	10C	20C	30C	40C	60C	
1.	Opaque	58.05	57.91	62.33	64.82	63.82	63.91	61.81
2.	Garnet	1.06	1.20	2.17	3.22	2.70	3.10	2.24
3.	Hornblende	16.90	12.70	11.74	10.90	12.72	12.44	12.90
4.	Augite/Diopside	1.04	1.02	0.90	1.70	1.98	2.00	1.44
5.	Hypersthene/Enstatite	9.08	11.58	10.70	7.86	7.11	8.15	9.08
6.	Mica	2.29	1.84	1.20	0.90	0.72	0.80	1.29
7.	Sillimanite	4.62	4.70	3.26	2.78	3.15	3.20	3.62
8.	Chlorite	1.74	1.80	1.40	1.74	0.60	1.15	1.41
9.	Tourmaline	-	-	-	-		-	-
10.	Zircon	3.91	5.87	5.21	4.77	5.78	3.92	4.91
11.	Monazite	0.63	0.94	0.32	0.71	0.56	0.62	0.63
12.	Rutile	0.68	0.44	0.77	0.61	0.86	0.71	0.68

Table 5.1 contd.

HEAVY MINERAL DISTRIBUTION IN THE MUVATTUPUZHA SEDIMENTS

(+ 63 Microns)

Sl.No.	Name of the Mineral	Sampling Locations						Average
		2C	10C	20C	30C	40C	60C	
1.	Opaques	37.76	45.67	44.30	39.20	40.40	43.18	41.75
2.	Garnet	1.88	1.29	1.87	1.66	1.78	1.60	1.68
3.	Hornblende	14.10	14.72	12.40	13.70	12.84	10.90	13.11
4.	Augite/Diopside	0.62	0.75	0.22	1.06	0.41	0.70	0.63
5.	Hypersthene/Enstatite	11.73	11.81	10.68	11.24	10.15	8.76	10.73
6.	Mica	-	-	-	-	-	-	-
7.	Sillimanite	6.78	4.71	4.95	4.24	4.60	3.92	4.87
8.	Chlorite	-	-	-	-	-	-	-
9.	Tourmaline	0.83	0.71	0.39	0.62	0.77	0.71	0.67
10.	Zircon	24.86	18.54	23.72	26.81	27.33	28.62	24.98
11.	Monazite	0.90	1.10	0.88	0.76	1.02	0.87	0.92
12.	Rutile	0.54	0.70	0.60	0.71	0.70	0.72	0.66

Table 5.1 contd.

HEAVY MINERAL DISTRIBUTION IN THE MINACHIL AR SEDIMENTS

(+ 250 Microns)

Sl.No.	Name of the Mineral	Sampling Locations						Average
		2C	10C	20C	30C	40C	60C	
1.	Opaques	34.34	34.20	41.66	43.36	41.02	43.20	39.63
2.	Garnet	2.24	3.81	2.60	3.90	6.89	7.20	4.44
3.	Hornblende	19.64	19.79	16.37	18.21	16.84	13.91	17.46
4.	Augite/Diopside	-	-	-	-	-	-	-
5.	Hypersthene/Enstatite	20.39	21.23	18.28	16.65	17.23	16.56	18.39
6.	Mica	17.31	15.52	17.20	14.55	15.25	16.11	15.99
7.	Sillimanite	4.88	4.45	2.59	2.78	2.10	1.86	3.11
8.	Kyanite	1.20	1.00	1.30	0.55	0.67	1.16	0.98
9.	Zircon	-	-	-	-	-	-	-
10.	Monazite	-	-	-	-	-	-	-

Table 5.1 contd.

HEAVY MINERAL DISTRIBUTION IN THE MINACHIL AR SEDIMENTS

(+ 125 Microns)

Sl.No.	Name of the Mineral	Sampling Locations						Average
		2C	10C	20C	30C	40C	60C	
1.	Opaques	46.10	44.32	48.60	58.20	56.79	58.59	52.1
2.	Garnet	2.48	2.80	2.90	3.42	4.60	3.65	3.31
3.	Hornblende	11.66	12.85	12.87	9.28	8.46	7.89	10.50
4.	Augite/Diopside	-	2.39	1.96	1.02	1.27	4.00	1.77
5.	Hypersthene/Enstatite	24.33	23.89	22.70	20.69	22.17	20.38	22.36
6.	Mica	3.76	3.82	2.39	2.27	1.61	1.65	2.58
7.	Sillimanite	6.92	4.35	5.67	3.44	3.78	2.70	4.48
8.	Kyanite	-	-	-	-	-	-	-
9.	Zircon	4.21	5.31	2.80	1.60	1.20	0.90	2.67
10.	Monazite	0.54	0.27	0.13	0.08	0.12	0.24	0.23

Table 5.1 contd.

HEAVY MINERAL DISTRIBUTION IN THE MINACHIL AR SEDIMENTS

(+ 63 Microns)

Sl.No.	Name of the Mineral	Sampling Locations						Average
		2C	10C	20C	30C	40C	60C	
1.	Opaques	49.66	53.87	57.45	56.30	58.60	54.70	55.93
2.	Garnet	0.90	0.88	2.80	3.15	3.45	3.96	2.52
3.	Hornblende	14.55	14.15	13.44	12.20	11.20	10.90	12.74
4.	Augite/Diopside	-	-	-	1.00	0.32	0.94	0.38
5.	Hypersthene/Enstatite	7.91	6.62	5.18	5.65	5.70	4.82	5.98
6.	Mica	0.13	0.68	-	1.67	1.50	0.62	0.77
7.	Sillimanite	8.10	7.71	6.90	5.59	4.39	4.20	6.15
8.	Kyanite	-	-	-	-	-	-	-
9.	Zircon	18.00	15.54	13.73	14.00	14.62	14.73	15.10
10.	Monazite	0.75	0.55	0.50	0.44	0.22	0.12	0.43

Table 5.1 contd.

HEAVY MINERAL DISTRIBUTION IN THE MANIMALA AR SEDIMENTS
(+ 250 Microns)

Sl.No.	Name of the Mineral	Sampling Locations				Average
		175C	177C	179C	180C	
1.	Opaques	40.55	44.69	49.54	47.81	45.65
2.	Garnet	3.93	3.98	8.43	8.54	6.22
3.	Hornblende	11.27	9.44	8.86	8.90	9.62
4.	Augite/Diopside	0.58	0.50	2.32	1.80	1.30
5.	Hypersthene/Enstatite	22.78	21.06	16.85	17.80	19.62
6.	Mica	8.81	8.55	5.59	7.62	7.64
7.	Sillimanite	5.05	5.41	3.58	3.89	4.48
8.	Zircon	5.81	4.89	4.15	3.05	4.48
9.	Monazite	1.22	1.48	0.68	0.59	0.99

Table 5.1 contd.

HEAVY MINERAL DISTRIBUTION IN THE MANIMALA AR SEDIMENTS

(+ 125 Microns)

Sl.No.	Name of the Mineral	Sampling Locations				Average
		175C	177C	179C	180C	
1.	Opaques	46.90	51.42	52.96	53.49	51.19
2.	Garnet	2.19	3.15	6.97	7.94	5.06
3.	Hornblende	9.64	8.89	8.96	8.92	9.10
4.	Augite/Diopside	0.10	0.14	0.93	0.31	0.37
5.	Hypersthene/Enstatite	20.47	18.67	16.90	16.55	18.15
6.	Mica	2.64	1.78	1.20	0.98	1.65
7.	Sillimanite	4.50	4.04	3.86	3.80	4.05
8.	Zircon	9.14	7.79	5.82	4.89	6.91
9.	Monazite	4.42	4.12	2.40	3.12	3.52

Table 5.1 contd.

HEAVY MINERAL DISTRIBUTION IN THE MANIMALA AR SEDIMENTS
(+ 63 Microns)

Sl.No.	Name of the Mineral	Sampling Locations				Average
		175C	177C	179C	180C	
1.	Opaques	41.30	43.20	50.96	53.14	47.14
2.	Garnet	-	-	-	-	-
3.	Hornblende	12.68	12.00	9.54	10.74	11.24
4.	Augite/Diopside	0.80	0.72	0.80	1.49	0.95
5.	Hypersthene/Enstatite	16.46	17.11	15.75	12.47	15.45
6.	Mica	1.10	0.89	0.68	0.89	0.89
7.	Sillimanite	6.78	6.11	4.60	3.62	5.28
8.	Zircon	20.18	19.22	16.98	16.91	18.32
9.	Monazite	0.70	0.75	0.69	0.72	0.72

Table 5.1 contd.

HEAVY MINERAL DISTRIBUTION IN THE PAMBA AR SEDIMENTS

(+ 250 Microns)

Sl.No.	Name of the Mineral	Sampling Locations						Average
		2C	10C	20C	40C	60C	100C	
1.	Opaque	42.40	45.25	47.50	46.93	53.23	54.60	48.32
2.	Garnet	2.25	4.40	4.10	7.85	9.15	8.22	6.00
3.	Hornblende	11.60	9.77	8.28	7.65	6.15	5.40	8.14
4.	Augite/Diopside	0.50	1.10	1.55	1.60	0.95	1.12	1.14
5.	Hypersthene/Enstatite	23.25	22.70	22.90	21.82	19.10	18.33	21.35
6.	Mica	8.30	6.45	7.20	6.40	4.38	5.00	6.29
7.	Sillimanite	4.64	4.05	3.41	2.77	2.30	2.18	3.23
8.	Kyanite	0.70	0.72	0.32	0.34	0.18	0.19	0.41
9.	Apatite	0.82	0.80	1.05	1.07	1.08	1.04	0.98
10.	Zircon	2.85	2.54	2.11	1.40	1.72	1.39	2.00
11.	Monazite	1.08	0.94	0.80	0.80	0.60	0.89	0.85
12.	Rutile	0.49	0.32	0.14	0.17	0.10	0.15	0.23
13.	Tourmaline	0.18	0.19	0.20	0.12	0.14	0.20	0.17
14.	Chlorite	0.18	0.16	0.20	0.21	0.24	0.22	0.20
15.	Staurolite	0.76	0.61	0.24	0.87	0.67	1.07	0.70

Table 5.1 contd.

HEAVY MINERAL DISTRIBUTION IN THE PAMBA AR SEDIMENTS

(+ 125 Microns)

Sl.No.	Name of the Mineral	Sampling Locations						Average
		2C	10C	20C	40C	60C	100C	
1.	Opaque	45.04	47.56	50.98	56.55	58.80	63.16	53.68
2.	Garnet	1.77	2.15	2.65	3.90	4.30	4.08	3.14
3.	Hornblende	9.24	7.96	7.79	8.49	7.72	6.71	7.99
4.	Augite/Diopside	0.39	0.39	0.83	-	0.20	0.21	0.34
5.	Hypersthene/Enstatite	26.50	24.50	21.96	19.60	17.76	15.66	21.00
6.	Mica	3.06	2.80	2.11	2.28	2.12	2.41	2.46
7.	Sillimanite	5.08	4.98	3.88	3.15	3.02	2.45	3.76
8.	Kyanite	0.11	0.28	0.46	-	-	0.30	0.19
9.	Apatite	-	-	-	-		-	-
10.	Zircon	4.50	4.98	5.12	3.68	3.98	2.65	4.15
11.	Monazite	3.32	3.52	3.18	2.15	1.70	2.18	2.68
12.	Rutile	0.99	0.88	1.04	0.20	0.40	0.19	0.62
13.	Tourmaline	-	-	-	-	-	-	-
14.	Chlorite	-	-	-	-	-	-	-
15.	Staurolite	-	-	-	-	-	-	-

Table 5.1 contd.

HEAVY MINERAL DISTRIBUTION IN THE PAMBA AR SEDIMENTS

(+ 63 Microns)

Sl.No.	Name of the Mineral	Sampling Locations						Average
		2C	10C	20C	40C	60C	100C	
1.	Opaque	40.15	42.54	44.79	49.90	50.88	49.99	46.37
2.	Garnet	-	0.68	1.89	2.36	2.54	2.48	1.66
3.	Hornblende	12.06	11.09	10.50	9.44	11.09	11.46	10.94
4.	Augite/Diopside	0.11	0.34	0.33	-	-	1.92	0.45
5.	Hypersthene/Enstatite	22.69	21.44	20.17	17.77	18.60	19.15	19.90
6.	Mica	1.12	1.08	0.92	0.81	0.71	1.36	1.00
7.	Sillimanite	9.15	8.55	8.28	6.88	5.84	6.90	7.60
8.	Kyanite	-	-	-	-	-	-	-
9.	Apatite	-	-	-	-	-	-	-
10.	Zircon	13.64	13.50	12.51	12.48	9.91	6.55	11.43
11.	Monazite	0.88	0.56	0.50	0.22	0.20	0.11	0.41
12.	Rutile	0.20	0.22	0.11	0.14	0.23	0.12	0.17
13.	Tourmaline	-	-	-	-	-	-	-
14.	Chlorite	-	-	-	-	-	-	-
15.	Staurolite	-	-	-	-	-	-	-

Table - 5.2

AVERAGE LIGHT MINERAL PERCENTAGES IN THE VARIOUS RIVER SEDIMENTS OF CENTRAL KERALA

Sl.No.	Name of the rivers	Minerals present				
		Quartz	K-felspar	Soda lime felspar	Quartz / Total felspar	K-felspar / sodalime felspar
1.	Periyar	90.47	6.92	2.61	9.49	2.65
2.	Muvattupuzha	95.30	3.50	1.20	20.28	2.98
3.	Minachil ar	92.80	4.60	2.60	12.89	1.77
4.	Manimala ar	84.95	9.65	5.40	5.64	1.79
5.	Pamba ar	92.54	5.37	2.09	12.40	2.60

Table - 5.3

DISTRIBUTION OF HEAVY MINERALS IN THE VEMBANAD LAKE SEDIMENTS

Sl.No.	Minerals present	Average percentage of heavy minerals in the Vambanad Lake					
		Periyar zone	Estuarine zone	Muvattupuzha zone	Minachil zone	Pamba zone	Average %
1.	Opaques	30.14	22.56	36.05	30.22	27.02	29.20
2.	Sillimanite	28.86	33.44	38.28	32.53	30.12	32.65
3.	Hornblende	17.61	18.22	7.40	13.82	14.24	14.26
4.	Hypersthene	13.62	17.60	5.50	14.20	18.22	13.23
5.	Zircon	6.24	1.63	4.08	2.71	2.09	3.35
6.	Monazite	1.49	-	1.06	1.70	1.20	1.09
7.	Garnet	1.49	-	1.21	1.99	2.00	1.34
8.	Mica	2.45	4.00	2.16	2.40	1.81	2.56
9.	Tourmaline	-	1.95	2.72	-	1.89	1.31
10.	Rutile	1.10	0.60	0.45	0.25	1.11	0.70
11.	Chlorite	-	-	0.87	-	0.20	0.21
12.	Kyanite	-	-	0.22	0.18	0.10	0.10

Table - 5.4 a

AVERAGE HEAVY MINERAL DISTRIBUTION IN THE BEACH SANDS DURING PRE-MONSOON SEASON

Sl.No.	Locations	Horn-blende	Opaques	Hyper-sthene/ Enstatite	Silli-manite	Zir-cone	Kya-nite	Rutile	Mica	Garnet	Mona-zite
1.	Narakkal	59.55	12.50	4.50	3.13	3.13	1.40	1.85	7.90	5.15	0.98
2.	Malipuram	58.70	13.15	4.10	3.94	2.78	0.55	0.55	10.46	5.68	0.10
3.	Puthuvypu	54.98	15.18	3.21	3.21	4.10	0.83	1.07	12.00	4.87	0.55
4.	Fort Cochin	50.39	19.28	15.30	3.52	2.10	2.30	0.98	-	5.15	0.98
5.	Beach Road	40.77	22.36	10.34	4.30	3.58	1.14	1.15	10.58	5.68	0.10
6.	Kannamaly	47.19	18.75	6.68	3.90	2.15	1.05	1.20	14.55	3.75	0.78
7.	Chellanam	40.98	20.50	13.88	6.70	4.16	0.15	0.45	5.59	7.58	0.01
8.	Taikal	42.14	19.90	15.17	5.54	5.50	0.10	0.15	4.96	6.47	0.07
9.	Alleppey	40.94	22.15	13.00	3.84	7.70	0.11	2.18	6.87	3.20	0.01
10.	Purakkad	37.95	18.77	12.60	6.45	8.80	0.18	2.25	8.17	4.78	0.05
	Average	47.36	18.25	9.88	4.45	4.40	0.78	1.18	8.11	5.23	0.36

Table - 5.4 b

AVERAGE HEAVY MINERAL DISTRIBUTION IN THE BEACH SANDS DURING POST-MONSOON SEASON

Sl.No.	Locations	Horn-blende	Opaques	Hyper-sthene/ Enstatite	Silli-manite	Zir-cone	Kya-nite	Rutile	Mica	Garnet	Mona-zite
1.	Narakkal	51.79	7.49	16.04	8.02	3.15	2.14	1.87	2.44	6.95	0.110
2.	Malipuram	57.19	8.24	15.29	3.52	3.65	2.05	0.67	1.15	8.24	0.001
3.	Puthuvypu	36.02	18.26	17.81	6.13	1.78	0.01	0.89	7.77	11.24	0.104
4.	Fort Cochin	58.32	13.79	12.62	0.05	4.72	1.14	1.28	3.48	4.60	-
5.	Beach Road	42.81	15.10	14.01	7.20	8.71	-	0.22	0.97	10.98	-
6.	Kannamaly	56.52	6.52	13.05	3.62	4.85	0.07	0.61	2.45	12.31	0.004
7.	Chellanam	55.14	12.60	11.69	1.58	8.76	-	4.31	2.90	3.01	0.014
8.	Taikal	61.44	9.05	12.04	4.19	2.88	-	3.11	3.66	3.62	0.005
9.	Alleppey	50.73	15.76	15.87	4.70	3.46	-	3.44	4.22	1.80	0.020
10.	Purakkad	35.47	17.70	22.59	2.88	1.77	0.40	1.50	7.89	8.65	1.150
	Average	50.54	12.45	15.10	4.19	4.37	0.58	1.79	3.69	7.14	0.140

Table - 5.5 a

AVERAGE LIGHT MINERAL CONCENTRATION IN THE CENTRAL KERALA BEACH SANDS DURING PRE-MONSOON

Sl.No.	Location	Minerals present				
		Quartz	K-felspar	Sodalime felspar	Quartz / total felspar	K-felspar / sodalime felspar
1.	Narakkal	97.60	1.98	0.42	40.66	4.71
2.	Malipuram	98.70	1.20	0.10	75.92	12.00
3.	Puthuvypu	97.88	1.20	0.98	44.90	1.22
4.	Fort Cochin	99.22	0.78	-	127.21	-
5.	Beach Road	99.15	0.70	0.15	116.65	4.67
6.	Kannamaly	98.72	1.12	0.13	78.98	8.85
7.	Chellanam	98.15	1.06	0.79	53.05	1.34
8.	Taikal	99.02	0.88	0.10	101.04	8.80
9.	Alleppey	97.65	1.89	0.46	41.55	4.10
10.	Purakkad	98.78	0.66	0.56	80.97	1.18
	Average	98.48	1.15	0.37	76.09	4.69

Table - 5.5 b

AVERAGE LIGHT MINERAL CONCENTRATION IN THE CENTRAL KERALA BEACH SANDS DURING POST-MONSOON

Sl.No.	Location	Minerals present				
		Quartz	K-felspar	Sodalime felspar	Quartz / total felspar	K-felspar / sodalime felspar
1.	Narakkal	96.22	2.18	1.60	25.46	1.36
2.	Malipuram	92.77	4.21	3.02	21.93	1.39
3.	Puthuvypu	93.77	4.81	1.22	18.68	21.86
4.	Fort Cochin	89.15	9.87	0.98	8.22	10.07
5.	Beach Road	92.99	3.58	3.43	13.27	1.04
6.	Kannamaly	72.18	22.15	5.67	2.59	2.19
7.	Chellanam	96.68	2.85	0.47	29.12	6.06
8.	Taikal	77.22	20.77	2.01	3.39	10.33
9.	Alleppey	89.11	8.15	2.74	8.18	3.81
10.	Purakkad	98.15	1.78	0.07	53.05	25.42
	Average	89.82	8.04	2.12	18.39	8.35

Table - 5.6

CLAY MINERAL COMPOSITIONS (IN %) IN THE SEDIMENTS OF DIFFERENT ENVIRONMENTS (XRD RESULTS)

Sl.No.	Location	Sample No.	Kaolinite	Montomor-illonite	Illite	Gibbsite	M/K
1	2	3	4	5	6	7	8
1.	Pamba ar	2C	69.74	22.56	2.22	5.47	0.32
2.	Minachil ar	2C	59.56	30.22	6.45	3.77	0.51
3.	Muvattupuzha	2C	61.55	22.71	5.66	10.08	0.37
4.	Periyar	2C	64.88	18.55	7.31	9.26	0.29
	Average		63.93	23.51	5.41	7.14	0.37
5.	Vembanad Lake	5	67.12	18.49	8.90	5.48	0.28
6.	Vembanad Lake	18	50.08	38.10	9.60	2.22	0.76
7.	Vembanad Lake	35	56.34	34.21	6.43	3.01	0.61
8.	Vembanad Lake	44	50.22	38.52	8.63	2.61	0.77
9.	Vembanad Lake	54	57.69	34.29	6.41	1.60	0.59
	Average		56.29	32.72	7.99	2.98	0.60
10.	Narakkal Mud bank	08N/M	54.55	32.58	11.40	1.47	0.60
11.	Narakkal Mud bank	08N/Ju	48.08	40.10	7.69	4.13	0.83
12.	Narakkal Mud bank	06N/Jl	49.80	40.22	6.75	3.23	0.81
13.	Narakkal Mud bank	06N/Jl	45.42	42.55	9.78	2.25	0.94

Table 5.6 contd.

1	2	3	4	5	6	7	8
14.	Narakkal Mud bank	08N/A	42.75	43.67	12.88	0.70	1.02
15.	Narakkal Mud bank	08N/S	55.48	32.30	9.22	3.00	0.58
16.	Narakkal Mud bank	08N/D	62.40	25.55	9.30	2.75	0.41
	Average		51.21	36.71	9.57	2.5	0.74
17.*	Narakkal Mud bank	28N/Jl	48.22	38.32	10.30	3.16	0.79
18.*	Narakkal Mud bank	28N/A	50.95	33.35	15.35	0.35	0.65
	Average		49.59	35.84	12.83	1.76	0.72
19.**	Narakkal Mud bank	06N/Jl	31.40	52.46	15.40	0.74	1.67
20.**	Narakkal Mud bank	08N/Jl	30.52	62.50	5.44	1.54	2.05
	Average		30.96	57.48	10.42	1.14	1.86

* Peripheral mud bank sediment.

** Suspended sediment.

Table - 6.1

ORGANIC MATTER AND CALCIUM CARBONATE IN THE VEMBANAD LAKE (POST-MONSOON) SEDIMENTS

Sl.No.	Sample No.	North Zone		Sl.No.	Sample No.	Estuarine Zone	
		Organic matter (%)	Calcium carbonate (%)			Organic matter (%)	Calcium carbonate (%)
1	2	3	4	1	2	3	4
1.	1	6.95	6.25	16.	16	6.21	3.00
2.	2	5.83	1.25	17.	17	7.93	1.75
3.	3	5.83	1.50	18.	18	5.81	6.50
4.	4	7.69	0.50	19.	19	4.75	5.00
5.	5	6.25	0.50	20.	20	6.13	6.25
6.	6	6.54	1.50	21.	21	5.75	4.50
7.	7	5.99	2.00	22.	22	6.05	8.00
8.	8	7.61	3.50	23.	23	4.95	9.00
9.	9	7.12	2.75	24.	24	5.02	7.00
10.	10	10.20	3.50	25.	25	4.89	6.25
11.	11	6.07	2.75	26.	26	5.25	4.50
12.	12	4.86	3.75	27.	27	6.12	3.25
13.	13	4.82	3.00				
14.	14	5.52	3.25				
15.	15	7.20	4.25				

Table 6.1 contd.

Central Zone				Southern Zone			
1	2	3	4	1	2	3	4
28.	28	6.32	1.75	44.	44	7.44	1.50
29.	29	3.48	1.25	45.	45	8.25	2.03
30.	30	5.56	5.25	46.	46	7.52	1.50
31.	31	6.72	3.00	47	47	5.42	0.90
32.	32	2.19	1.25	48.	48	9.66	1.00
33.	33	11.73	0.75	49.	49	2.19	1.25
34.	34	2.82	0.75	50.	50	2.02	1.15
35.	35	1.72	5.00	51.	51	9.31	0.50
36	36	2.10	1.75	52.	52	5.42	2.50
37.	37	5.42	1.25	53.	53	7.28	4.25
38.	38	5.50	1.25	54.	54	1.70	1.25
39.	39	1.70	0.13	55.	55	10.44	3.25
40.	40	2.02	5.60	56.	56	6.55	1.00
41.	41	3.08	4.90	57.	57	6.72	3.40
42.	42	1.70	1.25	58.	58	6.12	5.25
43.	43	2.31	2.75	59.	59	2.67	1.50
				60.	60	3.18	6.25

Table - 6.2

DISTRIBUTION OF ORGANIC MATTER AND CALCIUM CARBONATE IN THE MUD BANK SEDIMENTS

Sl.No.	Sample No.	Organic matter (%)	Calcium carbonate (%)	Sl.No.	Sample No.	Organic matter (%)	Calcium carbonate (%)
1	2	3	4	1	2	3	4
			Narakkal Mud Bank Sediments				
1.	01N/M	3.73	6.00	22.	08N/A	5.50	4.10
2.	02N/M	2.45	7.75	23.	10N/A	4.70	8.38
3.	03N/M	2.76	10.50	24.	01N/S	4.20	6.50
4.	04N/M	3.66	10.75	25.	02N/S	4.15	8.00
5.	05N/M	3.98	4.00	26.	04N/S	4.40	8.88
6.	08N/M	3.90	4.50	27.	06N/S	4.55	7.50
7.	09N/M	3.40	7.00	28.	08N/S	4.50	5.50
8.	10N/M	3.70	6.00	29.	10N/S	4.25	4.90
9.	02N.Ju	3.88	6.00	30.	02N/D	4.21	3.25
10.	04N/Ju	4.35	11.75	31.	03N/D	4.74	4.50
11.	05N/Ju	4.35	11.75	32.	04N/D	3.84	5.50
12.	08N/Ju	4.70	11.75	33.	06N/D	2.22	4.25
13.	09N/Ju	4.75	7.00	34.	08N/D	4.05	7.00
14.	02N/Jl	4.35	11.75	35.	10N/D	3.64	5.75
15.	03N/Jl	4.70	9.13	36.	18N/Jl	4.70	9.15
16.	05N/Jl	4.75	7.00	37.	28N/Jl	4.65	10.75
17.	08N/Jl	5.60	6.50	38.	18N/A	3.56	10.80
18.	10N/Jl	5.30	10.50	39.	28N/A	3.62	11.50
19.	02N/A	4.75	4.55	40.*	08N/Jl	4.56	1.25
20.	03N/A	5.55	11.85	41.**	08N/Jl	1.22	3.40
21.	05N/A	6.01	9.68				

Table 6.2 contd.

1	2	3	4	1	2	3	4
			Purakkad Mud Bank Sediments				
42.	01P/M	4.72	4.30	66.	01P/A	4.83	nd
43.	12P/M	4.94	9.30	67.	02P/A	5.32	9.10
44.	03P/M	4.25	7.00	68.	03P/A	6.15	11.75
45.	04P/M	4.83	10.00	69.	04P/A	5.81	9.70
46.	05P/M	4.93	9.40	70.	05P/A	5.11	7.12
47.	06P/M	5.93	8.40	71.	06P/A	5.83	8.20
48.	07P/M	5.26	6.70	72.	07P/A	5.36	8.13
49.	08P/M	5.78	nd	73.	08P/A	5.05	8.38
50.	01P/Ju	3.48	nd	74.	01P/S	3.72	7.88
51.	02P/Ju	4.63	5.20	75.	02P/S	3.75	5.38
52.	03P/Ju	4.83	nd	76.	03P/S	4.05	5.25
53.	04P/Ju	4.78	7.70	77.	04P/S	3.86	nd
54.	05P/Ju	4.04	8.20	78.	05P/S	3.75	6.10
55.	06P/Ju	5.21	nd	79.	06P/S	3.82	6.90
56.	07P/Ju	5.31	7.70	80.	07P/S	3.56	7.75
57.	08P/Ju	4.87	9.30	81.	08P/S	3.81	6.10
58.	01P/Jl	4.73	12.50	82.	01P/D	2.10	4.00
59.	02P/Jl	4.95	nd	83.	02P/D	3.72	9.00
60.	03P/Jl	5.14	11.75	84.	03P/D	3.75	9.00
61.	04P/Jl	6.15	9.75	85.	04P/D	4.05	4.00
62.	05P/Jl	5.72	10.13	86.	05P/D	3.86	5.00
63.	06P/Jl	5.52	nd	87.	06P/D	3.75	6.50
64.	07P/Jl	5.21	nd	88.	07P/D	3.82	5.75
65.	08P/Jl	5.35	9.38	89.	08P/D	3.56	nd

Table - 6.3

ELEMENTAL CONCENTRATION IN MUD BANK SEDIMENTS (BULK SEDIMENTS)

Sl.No.	Sample No.	Organic matter^{+}	$CaCo_3^{+}$	Si^{+}	Al^{+}	Mg^{+}	P^{+}	Fe^{+}	Mn^{+}	Na^{+}	K^{+}	Ti^{+}	Cu^{*}	Co^{*}	Ni^{*}	Zn^{*}
1.	02N/M	4.45	3.88	44.52	20.51	4.85	0.65	11.70	0.070	4.10	1.84	1.05	152	14	35	20
2.	05N/Ju	3.90	2.25	44.70	19.31	3.70	0.72	11.67	0.068	3.88	1.60	1.10	149	14	32	31
3.	02N/Jl	4.94	11.63	44.67	19.27	3.92	0.70	11.80	0.072	3.84	1.58	1.12	149	15	81	27
4.	05N/Jl	2.45	8.75	54.89	17.30	2.80	0.60	7.15	0.054	3.41	1.49	1.35	150	31	60	25
5.	02N/A	4.35	5.25	45.31	20.78	3.15	0.70	10.86	0.062	4.18	1.88	0.99	229	27	91	37
6.	05N/A	5.04	9.50	40.90	22.42	3.91	0.84	13.15	0.08	4.49	1.99	0.78	150	16	73	22
7.	02N/S	4.35	5.88	43.66	18.49	3.88	0.68	11.56	0.070	3.70	1.48	0.88	154	22	62	78
8.	05N/D	5.70	3.50	40.78	21.95	3.48	0.78	12.56	0.075	4.42	1.98	0.71	146	30	93	74
9.	05P/M	4.90	9.75	41.36	20.71	3.22	0.75	12.40	0.070	4.14	1.84	0.88	126	29	93	73
10.	05P/Ju	5.50	4.10	40.15	21.26	3.10	0.80	12.61	0.070	4.25	1.90	0.90	149	29	75	52
11.	05P/Jl	3.70	8.38	40.30	19.05	3.21	0.60	11.51	0.065	3.77	1.68	0.98	107	22	95	63
12.	05P/A	5.80	7.88	39.89	23.45	2.84	0.80	13.48	0.080	4.75	2.03	0.67	149	27	83	55
	Average	55.08	80.75	43.43	20.38	3.505	0.72	11.70	0.700	4.08	1.77	0.95	150.83	23	72.75	46.42

+ = in percentage.

* = in ppm.

Table - 6.4 a

ELEMENTAL CONCENTRATION IN THE VEMBANAD LAKE SEDIMENTS (IN CLAY FRACTION)

Sl.No.	Sample No.	Organic matters$^+$	$CaCo_3^+$	Si^+	Al^+	Mg^+	P^+	Fe^+	Mn^+	Na^+	K^+	Ti^+	Cu^*	Co^*	Ni^*	Zn^*
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1.	1	6.95	6.25	41.44	27.07	2.07	0.05	12.55	0.17	1.25	0.05	1.01	77	30	78	37
2.	3	5.83	1.50	45.73	19.31	4.78	0.72	12.75	0.09	4.93	1.97	1.11	55	31	71	41
3.	5	6.25	0.50	41.55	18.45	3.86	0.64	12.83	0.12	4.78	1.91	1.15	64	37	101	44
4.	7	5.99	2.00	43.75	18.76	4.10	0.66	11.65	0.06	4.43	1.77	0.75	78	44	114	39
5.	9	7.12	2.75	44.50	18.55	3.15	0.62	12.95	0.04	4.80	1.90	1.01	64	22	57	16
6.	11	6.07	2.75	44.70	18.15	3.90	0.52	12.84	0.05	4.30	1.70	0.99	68	28	63	30
7.	16	6.21	3.00	45.17	17.92	10.91	0.86	12.56	0.06	4.40	1.51	0.68	69	44	75	27
8.	17	7.93	1.75	42.41	22.06	3.18	0.66	12.35	0.07	3.88	1.70	1.31	94	52	87	34
9.	18	5.81	6.50	54.90	17.38	2.89	0.51	7.07	0.06	5.48	2.23	0.75	88	71	98	37
10.	20	6.13	6.25	43.62	21.54	3.39	0.61	12.85	0.10	4.40	1.76	1.28	102	64	112	46
11.	22	6.05	8.00	44.91	20.44	3.59	0.57	10.69	0.09	4.65	1.89	1.22	124	58	140	52
12.	25	4.89	6.25	44.77	20.51	3.74	0.67	11.15	0.09	4.78	1.89	1.16	141	77	128	48
13.	28	6.32	1.75	44.20	18.15	3.43	0.45	12.65	0.11	3.70	1.44	1.20	89	36	71	41
14.	30	5.56	5.25	43.76	19.49	9.58	0.64	12.50	0.08	3.98	1.59	1.81	76	74	110	64
15.	32	2.19	1.25	43.65	19.05	4.55	0.74	10.95	0.09	4.25	1.70	1.01	62	78	121	71
16.	33	11.73	0.75	42.85	18.72	4.70	0.72	11.55	0.08	3.75	1.45	1.10	99	66	105	70
17.	35	1.72	5.00	41.55	18.35	5.05	0.70	10.92	0.07	3.82	1.51	0.71	51	19	39	18
18.	36	2.10	1.75	46.05	19.75	4.80	0.77	11.55	0.08	3.75	1.50	0.88	144	82	132	79

Table 6.4 a contd.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
19.	39	1.70	0.13	43.85	19.00	4.85	0.82	11.65	0.06	4.50	1.80	0.97	152	74	149	64
20.	43	2.31	2.75	46.50	19.92	5.50	0.78	10.50	0.07	3.58	1.43	0.65	178	89	131	58
21.	44	7.44	1.50	45.80	24.65	5.85	0.67	12.75	0.06	4.14	1.67	0.78	137	61	127	46
22.	47	5.42	0.90	45.65	24.48	5.40	0.85	11.60	0.05	4.10	1.64	0.70	189	97	144	67
23.	48	9.66	1.00	44.70	19.15	4.35	1.15	12.88	0.07	3.45	1.38	1.11	176	94	162	54
24.	51	9.31	0.50	43.75	18.45	4.77	0.79	10.85	0.06	3.68	1.44	1.07	97	39	97	61
25.	52	5.42	2.50	45.80	18.88	3.86	0.95	12.80	0.05	3.88	1.55	1.05	54	27	49	48
26.	53	7.28	4.25	44.15	24.15	4.78	0.68	12.88	0.07	4.18	1.67	0.95	161	71	140	74
27.	54	1.70	1.25	45.70	22.65	3.25	0.71	13.55	0.05	3.70	1.48	1.01	217	93	148	71
28.	56	10.44	3.25	42.45	23.41	5.40	0.66	11.85	0.09	2.08	0.79	1.20	202	88	167	85
29.	57	6.72	3.40	43.34	22.85	3.90	0.58	10.25	0.07	2.20	0.84	0.98	179	77	151	79
30.	60.	3.18	6.25	44.20	24.35	3.80	0.60	12.70	0.08	2.68	1.22	0.84	171	90	167	68

+ = in percentage.

* = in ppm.

Table - 6.4 b

ELEMENTAL CONCENTRATION IN MUD BANKS (IN CLAY FRACTION)

Sl.No.	Sample No.	Organic matters$^+$	$CaCo_3$$^+$	Si^+	Al^+	Mg^+	P^+	Fe^+	Mn^+	Na^+	K^+	Ti^+	Cu^*	Co^*	Ni^*	Zn^*
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1.	02N/M	2.45	7:75	46.73	17.93	7.42	0.74	12.38	0.06	4.11	1.64	0.99	152	14	35	20
2.	05N/M	3.98	4.00	43.80	21.20	3.94	0.60	14.71	0.09	4.50	1.82	1.19	143	25	38	35
3.	08N/M	3.90	4.50	41.54	21.86	4.03	0.52	16.65	0.11	4.10	1.58	1.08	149	14	32	31
4.	02N/Ju	3.88	6.00	41.50	23.02	3.39	0.41	16.03	0.10	4.70	1.84	1.08	182	18	37	31
5.	03N/Ju	4.35	11.75	41.23	22.86	3.56	0.45	16.89	0.10	4.23	1.65	1.14	149	15	81	27
6.	02N/Jl	4.35	11.75	43.78	20.84	4.32	0.68	14.42	0.08	4.36	1.72	1.16	148	12	65	38
7.	05N/Jl	4.75	7.00	43.66	21.69	3.38	0.53	15.29	0.10	4.62	1.84	1.23	149	19	78	29
8.	08N/Jl	5.60	6.50	41.29	22.94	3.79	0.38	16.23	0.10	4.18	1.67	1.01	150	31	60	25
9.	10N/Jl	5.30	10.50	44.91	20.44	3.59	0.57	14.58	0.09	4.83	1.89	1.22	150	16	73	22
10.	18N/Jl	4.70	9.15	41.45	22.52	3.66	0.43	17.01	0.11	4.00	1.61	1.09	143	25	86	33
11.	28N/Jl	4.65	10.75	40.78	22.65	3.81	0.49	16.97	0.11	4.15	1.62	1.14	229	27	91	37
12.	02N/A	4.75	4.55	42.94	22.42	3.64	0.38	14.80	0.10	3.93	1.53	1.01	126	29	93	73
13.	05N/A	6.01	9.68	41.96	22.55	3.30	0.45	16.50	0.10	4.18	1.64	1.10	146	30	93	74
14.	08N/A	5.50	4.10	41.46	22.67	4.05	0.39	16.54	0.10	4.10	1.64	1.05	135	30	94	55
15.	18N/A	3.56	10.80	41.51	22.13	3.81	0.49	16.68	0.10	3.95	1.54	1.12	154	25	92	49
16.	28N/A	3.62	11.50	43.74	21.02	3.88	0.63	14.50	0.10	4.68	1.83	1.20	149	25	75	52
17.	02N/Jl2	4.01	10.80	44.29	20.53	4.85	0.71	13.37	0.07	4.68	1.83	1.08	150	24	86	54
18.	05N/Jl2	4.10	10.80	45.41	20.30	4.03	0.60	12.78	0.09	5.08	2.03	1.14	147	22	93	71

Table 6.4 b contd.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
19.	02N/A2	4.30	11.50	45.38	17.91	9.58	0.87	13.87	0.06	3.78	1.43	0.95	152	24	94	73
20.	02P/M	4.63	6.50	44.61	19.31	3.84	0.77	14.91	0.08	4.28	1.67	1.17	147	25	77	52
21.	05P/M	4.04	10.25	45.06	18.35	5.69	0.92	13.03	0.07	4.23	1.65	1.01	113	38	95	68
22.	08P/M	4.87	11.63	45.66	18.32	5.14	0.88	12.85	0.06	4.03	1.61	1.00	149	15	81	27
23.	02P/J1	4.95	9.13	46.62	18.27	4.19	0.85	12.66	0.07	4.65	1.86	1.03	156	27	85	31
24.	05P/J1	5.72	10.75	41.48	22.95	3.45	0.44	16.32	0.10	4.00	1.61	1.08	150	19	82	60
25.	15P/J1	3.56	10.75	45.31	19.05	3.78	0.83	13.80	0.07	4.40	1.78	1.12	149	27	83	55
26.	25P/J1	3.62	9.13	41.96	20.23	4.72	0.64	17.73	0.09	3.95	1.57	0.96	107	22	95	63
27.	02P/A	5.32	5.38	46.24	18.74	3.90	0.78	13.06	0.07	4.20	1.69	1.07	83	25	38	31
28.	05P/A	5.11	6.13	46.80	18.16	4.13	0.85	12.61	0.07	4.63	1.85	1.13	109	25	132	54
29.	15P/A	3.82	8.83	41.27	22.68	3.71	0.41	16.75	0.10	3.90	1.55	1.04	150	19	82	60
30.	25P/A	2.28	11.50	43.66	21.69	3.38	0.53	18.17	0.15	4.60	1.84	1.31	137	22	64	48
31.	08N/J1*S	1.22	3.40	41.68	22.90	3.84	0.28	16.29	0.10	4.10	1.64	0.96	145	75	70	70
32.	08N/J1*C	4.56	1.25	45.15	18.68	4.28	0.82	13.58	0.07	4.30	1.72	1.05	83	25	38	31

+ = in percentage; * = in ppm.

*S = Suspended sediment from the mud bank area.

*C = Core sample collected from the mud bank region.

Table - 6.5

CORRELATION MATRIX BETWEEN TEXTURE AND CHEMICAL ELEMENTS IN THE BULK SEDIMENTS

Sl.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1.	+																	
2.	0.255	+																
3.	-0.656	-0.897	+															
4.	-0.658	-0.840	0.954	+														
5.	0.173	0.028	-0.095	-0.028	+													
6.	0.832	0.562	-0.827	-0.802	0.089	+												
7.	-0.495	-0.899	0.931	0.853	-0.097	-0.708	+											
8.	-0.46	0.079	0.138	0.079	-0.196	-0.083	-0.043	+										
9.	-0.440	-0.875	0.880	0.829	-0.064	-0.618	0.836	-0.074	+									
10.	-0.86	-0.674	0.920	0.887	-0.085	-0.943	0.793	0.228	0.752	+								
11.	-0.925	0.556	0.848	0.818	-0.067	-0.860	0.751	0.271	0.706	0.924	+							
12.	-0.501	-0.899	0.933	0.858	-0.121	-0.707	0.999	-0.038	0.838	0.799	0.755	+						
13.	-0.356	-0.875	0.852	0.747	-0.138	-0.625	0.956	-0.081	0.729	0.66	0.612	0.946	+					
14.	0.196	0.786	-0.689	-0.696	-0.198	0.266	-0.645	-0.101	-0.791	-0.489	-0.461	-0.664	-0.526	+				
15.	0.437	-0.338	0.059	0.002	-0.278	0.273	0.120	-0.021	0.090	-0.163	-0.318	0.142	0.146	-0.360	+			
16.	0.475	-0.233	-0.029	0.069	0.005	0.078	0.106	-0.796	0.081	-0.229	-0.255	0.099	0.216	-0.136	0.083	+		
17.	0.017	-0.409	0.328	0.376	0.458	-0.409	0.330	-0.556	0.227	0.244	0.186	0.316	0.381	0.018	-0.027	0.572	+	
18.	-0.272	-0.144	0.220	0.334	-0.085	-0.493	0.114	-0.337	0.127	0.316	0.311	0.124	0.084	-0.109	-0.311	0.535	0.531	+

1. Sand; 2. Silt; 3. Clay; 4. Organic matter; 5. $CaCo_3$; 6. Si; 7. Al; 8. Mg; 9. P; 10. Total Fe; 11. Mn; 12. Na; 13. K; 14. Ti; 15. Cu; 16. Co; 17. Ni; 18. Zn.

Table - 6.6

CORRELATION MATRIX BETWEEN CHEMICAL ELEMENTS OF VEMBANAD LAKE (CLAY) SEDIMENTS

Sl.No.	1	2	3	4	5	6	7	8	9	10	11	12	13
1.	+												
2.	-0.237	+											
3.	-0.096	-0.017	+										
4.	0.090	-0.324	0.260	+									
5.	-0.554	0.254	0.020	0.117	+								
6.	-0.394	0.302	-0.176	-0.579	0.095	+							
7.	0.460	-0.614	0.017	0.324	-0.163	-0.409	+						
8.	0.456	-0.581	0.087	-0.387	-0.170	-0.484	0.974	+					
9.	-0.331	-0.047	0.334	-0.075	0.293	0.319	-0.032	-0.004	+				
10.	0.086	0.540	0.127	0.210	-0.014	-0.171	-0.370	-0.269	-0.151	+			
11.	0.235	0.357	0.298	0.313	-0.189	-0.131	-0.177	-0.077	-0.024	0.835	+		
12.	0.014	0.457	0.229	0.218	-0.090	-0.280	-0.256	-0.154	-0.002	0.866	0.898	+	
13.	-0.052	0.367	0.396	0.188	-0.074	0.014	-0.380	-0.382	-0.142	0.693	0.766	0.786	+

1. Silicon; 2. Alumina; 3. Magnessium; 4. Phosphorus; 5. Total Iron; 6. Manganeze; 7. Sodium; 8. Potassium; 9. Titanium; 10. Copper; 11. Cobalt; 12. Nickel; 13. Zinc.

Table - 6.7

CORRELATION MATRIX BETWEEN CHEMICAL ELEMENTS OF MUD BANK (CLAY) SEDIMENTS

Sl.No.	1	2	3	4	5	6	7	8	9	10	11	12	13
1.	+												
2.	-0.921	+											
3.	0.430	-0.604	+										
4.	0.810	-0.927	0.536	+									
5.	-0.894	0.814	-0.434	-0.740	+								
6.	-0.714	0.806	-0.591	-0.757	0.843	+							
7.	0.398	-0.144	-0.316	0.104	-0.352	0.015	+						
8.	0.407	-0.144	-0.363	0.107	-0.353	0.019	0.983	+					
9.	0.010	0.196	-0.514	-0.141	0.173	0.474	0.605	0.593	+				
10.	-0.391	0.410	-0.049	-0.347	0.282	0.290	0.063	0.008	0.186	+			
11.	-0.144	0.149	-0.068	-0.198	0.081	0.070	-0.142	-0.109	-0.331	0.090	+		
12.	0.001	-0.040	0.027	0.075	-0.002	-0.052	-0.061	-0.074	-0.051	0.044	0.161	+	
13.	-0.097	0.061	0.129	-0.018	0.073	0.042	-0.200	-0.214	-0.238	-0.142	0.455	0.58	+

1. Silicon; 2. Alumina; 3. Magnessium; 4. Phosphorus; 5. Total Iron; 6. Manganese; 7. Sodium; 8. Potassium; 9. Titanium; 10. Copper; 11. Cobalt; 12. Nickel; 13. Zinc.

Table - 7.1

GEOLOGY OF THE STUDY AREA

Rivers	Catchment area (Km^2)	Rock types in the catchment areas	Characteristic minerals present in the river sediments
Periyar	5398	Charnockites, laterites, gneisses, granites and dykes	Opaques, hornblende, hypersthene, mica, garnet, sillimanite, augite/diopside, rutile and monazite.
Muvattupuzha	2004	Charnockites, gneisses, laterites, dykes and tertiary sediments	Opaques, hypersthene, hornblende, mica, zircon, sillimanite, garnet, augite/diopside and monazite.
Minachil	1272	Charnockites, khondalites, gneisses, laterites, dykes and tertiary sediments	Opaques, hypersthene, hornblende, zircon, sillimanite, garnet, micas, monazite and augite/diopside.
Manimala	847	Charnockites, laterites, gneisses, tertiary and quarternary sediments and dykes (dolerite)	Opaques, hypersthene, hornblende, zircon, sillimanite, garnet, micas, monazite and augite/diopside.
Pamba	2235	Charnockites, laterites, gneisses, tertiary and quarternary sediments and dykes	Opaques, hypersthene, hornblende, zircon, sillimanite, garnet, micas, monazite, augite/diopside and rutile.