SEDIMENTOLOGY AND MINERALOGY OF THE BEACH STRAND PLAIN AND INNERSHELF SEDIMENTS OF THE NORTHERN KERALA COAST

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CERTIFICATE

This is to certify that this thesis is an authentic record of research work carried out by Shri M. Samsuddin, M.Tech. under my supervision and guidance in the Centre for Earth Science Studies, for the Ph.D. degree under the Faculty of Marine Sciences of the Cochin University of Science & Technology and no part of it has previously formed the basis for the award of any other degree, diploma or associateship in any University.

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PREFACE

Most of the coastal areas are highly fragile, as it is constantly subjected to high physical energy imparted by varying degrees of wave and current activity. In order to properly interpret the transportational and depositional mechanisms of an ancient environment, there is a need for a thorough understanding of the inter-relationship between modern as well as the ancient environments of deposition. Evaluation of the transportational and depositional mechanisms of the strand plain (ancient environment), beach and innershelf (modern environments) sediments are envisaged in this study. This particular study involves a comprehensive approach to understand the process-response in the inter-related environments which is first of its kind on the Kerala coast.

The first chapter introduces the location of the study area, physiography, drainage, climate, geology and coastal geomorphology. The general climate of the Kerala coast are discussed. Geology along with distinct geomorphic features are broadly outlined. The mode of field operations in different environments form part of this chapter.

The second chapter deals with the size and surface textural characteristics of sediments from the three environments. In the first part of the chapter extensive literature survey on size analysis are made starting from the classic contributions of Trask (1932), Krumbein (1936) and Folk and Ward (1957). Methods adopted for the analysis of grain size (wet and dry), surface textures, beach profiling and measurement of oceanographic parameters and computational procedures are outlined. Later part deals with discussion on the mode of deposition of beach, strand plain and innershelf sediments. The granulometry of beach sediments are discussed in two parts viz. foreshore and breaker zone sediments and seasonal textural changes. The textural differences in these environments are studied in the light of dissipation of wave energy under the swash and backwash regimes. The results are corroborated through statistical procedures.

Changes in beach topography, meteorological and oceanographic parameters are studied in the light of seasonal manifestations of inter-relationship between the size parameters. Spatial and temporal changes in the velocity of longshore currents are compared with the sediment transport and those derived from the Z-score statistics. Recognizable characteristics of the grain size parameters are related to different wave energy regimes in different seasons. Along with the detailed size analysis data of strand plain sediments, the study of quartz grain surface textures of beach, strand plain and innershelf are utilized to decipher the depositional/post depositional history of strand plain sediments.

The textural characteristics of the innershelf sediments are evaluated in terms of frequency distribution of the size fraction and sediment type. Multivariate statistical analysis and CM pattern are used to determine the mode of deposition.

The third chapter deals with mineralogy of the strand plain, beach and innershelf sediments. Significant variations of sand mineralogy in different environments are discussed in terms of their relative stability and dispersal. Study of clay minerals form part of this chapter. The relative concentrations of both montmorillonite and kaolinite in the shallower and deeper areas of the innershelf are discussed in terms of their relative grain size and flocculation habits.

In the fourth chapter the results are summarised which ultimately aim at the textural and mineralogical distinction of the three inter-related environments of deposition along the northern Kerala coast.

In connection with the thesis, the following research papers are published.

1. Samsuddin, M., 1986. Textural differentiation of foreshore and breaker zone sediments on the northern Kerala coast, India. Jour. Sed. Geol., 45: 135-145.
2. Samsuddin, M., 1986. Differentiation of beach and strand plain sediments by size analysis. (Abst), VI convention of Indian Assoc. Sedimentol., Dehra Dun, India.
3. Samsuddin, M. and Suchindan, G.K., 1987. Beach erosion and accretion in relation to seasonal longshore current variation in the northern Kerala coast. Jour. Coastal Res., 3: 55-62.
4. Samsuddin, M., 1988. Influence of seasonal changes on the texture of beach sands. Jour. Coastal Res., 5: 57-64.

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CHAPTER I

INTRODUCTION

Sedimentologists have often attempted to understand the response of sedimentological parameters to the different physical processes and their inter-relationship in wide variety of environments like beach, dune, river, innershelf etc. A beach which is the zone of unconsolidated materials is constantly acted upon by waves, currents and tide are considered as a dynamic environment. Depending upon the intensity, nature and duration of the coastal processes, the beaches constantly undergo physical changes that in turn result in different types of sediments. These often reflect the dynamic conditions that were prevalent at the time of deposition.

On the other hand, the strand plain which are linear mounds and depressions that are aligned roughly parallel to the coast is considered ancient environment. These are the remnant of the receding shorelines that indicate the shoreward extension of the wave activity during the regression period. Subsequent to their detachment from the sea these strand plains underwent sub-aerial weathering thus superimposing the inherited characteristics on the sediments. Unlike the beach sediments which are distributed by longshore and/or offshore currents, dispersal of the innershelf sediments are achieved mainly by weak currents. The sediment characteristics are largely dependant on the bottom topography.

These basic differences in the modes of transportation and deposition would thus be reflected in the mineralogical and sedimentological characteristics of the sediments in the above inter-related environments. Eventhough less stable than the interior areas, the beaches and coastal plains are the first to be greatly affected by the impact of growing population. Presently about two thirds of world's population lives within this narrow belt directly landward from the sea. Sandy beaches are particularly unstable as the sand is constantly shifted about by waves, currents and winds. High density of population, pollution from industries and coastal erosion are some of the major problems in the coastal zone. Cumulative losses of beaches during the monsoon period are severe and continuous over the years causing long term and short term changes on the shoreline.

Interaction among winds, waves, currents, tides and sediments are the main factors which control the dynamic shore processes in the littoral zone. Depending upon the rate at which the sediments are supplied to and removed, the shores erode, accrete or remain stable. Excessive erosion or accretion may endanger the functional usefulness of the beach. Great deal of economic importance is attached to the ancient coastal environments where water, oil and gas occur in large quantities in various reservoir sands of beach and dune complexes of ancient barrier island and innershelf sands.

By studying the seasonal fluctuations of the beach profiles, beach changes were monitored by many authors (Armen and Cannel, 1977; Erattupuzha and George, 1980; Christianson and Miller, 1980; Erol, 1983; Pringle, 1981; Raj, 1982; Bird, 1983). Heavy mineral studies were used mainly to understand the provenance history, diagenetic changes, sediment source and sediment transport. (McMaster and Garrison, 1966; Hubert and Neal, 1967; Mallik, 1976; Frores and Shideler, 1978; Leupke, 1980; Mazullo et al., 1984; Peterson et al., 1986).

Since few decades, important contributions were made by sedimentologists on the study of the nature of sediments in modern environments. Present day littoral sediments were studied not only to understand their mode of deposition, but also to recognize ancient beach sediments in the geologic history. Specific studies on statistical properties of the grain size distribution, grain size variation across the beach, degree of roundness, shape of the sediment grains and sedimentary structures etc. were also attempted.

For an effective conservation of the coastal zone, knowledge of the basic processes in modern as well as palaeo-environments is imperative. With this broader perspective in mind, a detailed programme has been worked out to decipher the inter-relationship of the strand plain, beach and innershelf sediments based on the granulometry, surface textures and mineralogy. The objectives of the investigation is to study the following:

i) The textural characteristics of the sediments in the foreshore and breaker zone, where the sediments are deposited under different wave energy conditions.

ii) Characteristics of grain size distribution of the sediments in the light of wave energy and morphological changes of the beach during different seasons along the south-west coast of India.

iii) To evaluate the transportational and depositional mechanism/ history of strand plain sediments.

iv) Study of mode of deposition of the innershelf sediments.

v) Compositional differences of the beach, strand plain and innershelf sediments, so as to understand the processes that control variation in the sand mineralogy.

1.1. LOCATION

The study area in the beach is between Mahe and Talapadi which constitute a narrow belt of land flanked by the Western Ghats and the Arabian Sea in the east and west respectively. The study of strand plain and innershelf sediments are restricted between Azhikkal and Kasargod. The coastline is generally straight, trending NNW-SSE. Bordered by wide strand plains, the coast give way to number of estuaries, rivers, inter-connected canals and highly irregular coast, especially around the promontaries.

1.2. PHYSIOGRAPHY, DRAINAGE & CLIMATE

The region can be longitudinally dissected into highland, midland and lowland. The hilly tract lies mainly on the eastern edge, close to the highly mountainous Western Ghats, the peaks ranging in height from 915 m to 2,061 m. Almost all rivers originate from this region.

The midland region falling between 8 m to 80 m above mean sea level, is a gently sloping land, consisting mainly of laterite flat lands that about at various places along the coast in the form of cliffs. The lowland region lying close to the sea, comprises the coastal plain of barriers, strand plains and flood plains having width between 4-10 km that range in height from 0-15 m above MSL (Nair, 1987).

The narrow width and the rapidly falling landscape from east to west have given rise to twenty west flowing and one east flowing rivers that originate from the high mountains of Western Ghats. While the west flowing rivers drain into the Arabian Sea, Kabhini, the east flowing river, flows through the state of Karnataka and joins the Cauvery river in the east coast. Of the rivers, Chandragiri, Valapatanam, Shiriya, Karingote and Kuppam are perenial, with tidal influences upto 10-20 km inland.

It is because of the seasonal reversal of wind circulation in the Arabian sea, the monsoonal climate is generated along the SW coast of India. The general pattern of wind are shown in Fig. 1.1. The climate of Kerala is broadly grouped under the following seasons (Ananthakrishna et al., 1979) 1) winter month (January-February); 2) hot weather period (March-May); 3) south-west monsoon (June-September) and 4) north-east monsoon (October-November). The winter months are characterised by minimum clouding and rainfall. During this period, the wind blows from north-east. The increasing thunder storm activity during the hot weather period accounts for less than

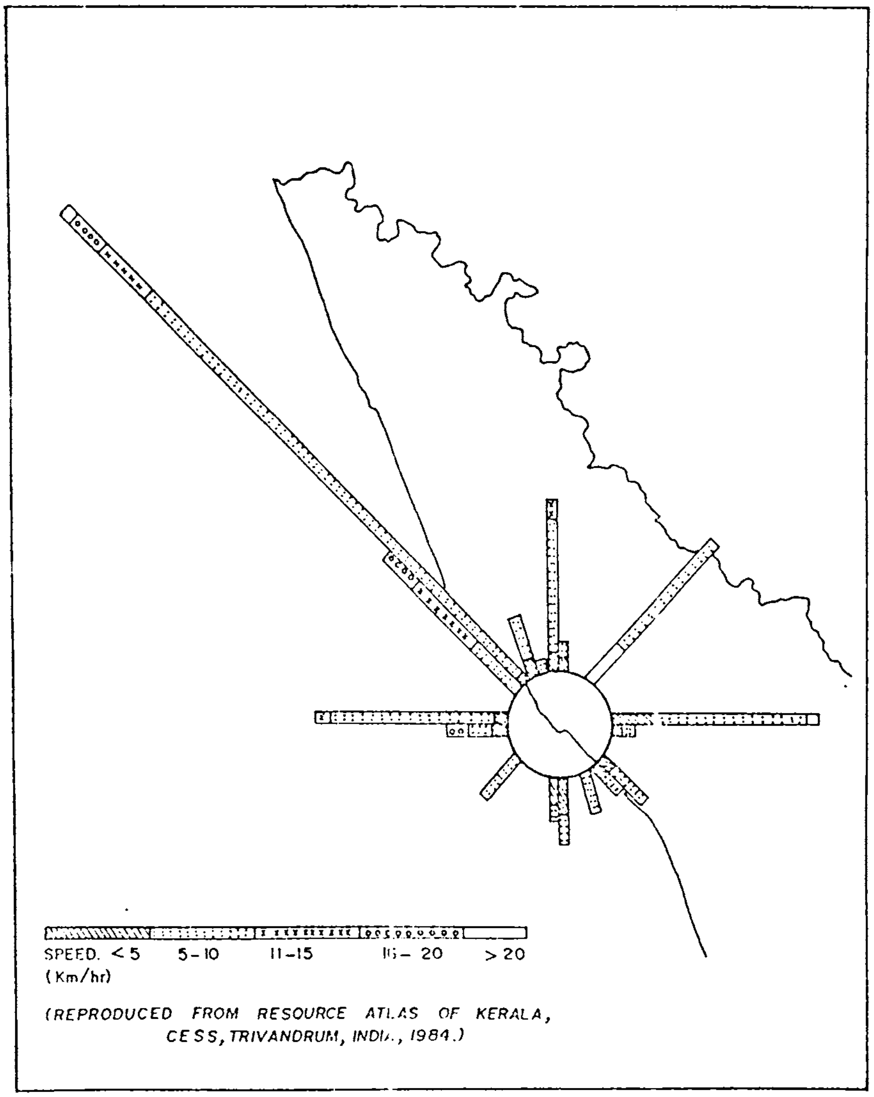


Fig. 1.1. General pattern of wind along the northern Kerala coast.

30 cm of rainfall. The month of May contributes maximum rainfall in the hot weather period. The south- west monsoon, where the wind blows roughly from south-west, is the principal rainfall season. This season accounts for nearly 80% of the annual rainfall in the northern Kerala. In the north-east monsoon, which is the secondary rainfall season, there is a decrease in rainfall from south towards northern Kerala. During this period, the wind blows from north-east.

1.3. GEOLOGY & COASTAL GEOMORPHOLOGY

The region is occupied by the following four major rock formations (GSI, 1976).

1. The **crystalline rocks** of Archaean age are igneous or metamorphic origin which comprise chiefly of charnockites, the khondalite suite of rocks, granites and hornblende gneisses that are traversed by basic dykes. The charnockites, with narrow bands of pyroxene granulites, magnetite-quartz rocks are the widespread group of rocks. The quartz-mica schists, quartz-schists and fuchsite quartzites constitute the narrow belt of Dharwar schists. Pink and grey granites, ortho-gneisses with pegmatites and quartz veins are intrusive into the charnockites and Dharwar schists. Basic dykes of dolerite, gabbro and basalt cut across the crystalline rocks.

2. The Tertiary sediments (of Miocene age) consists chiefly of series of variegated sandstones and clays with lenticular seams of lignite (Warkallai beds). However, occurrences of these formation

in the study area is scanty.

3. The recent to Sub-recent formations confined mostly in low lying areas consists of great thickness of sand with shell fragments, sticky black clays and peat beds. In addition to the Sub-recent marine and estuarine deposits surrounding the backwaters and low lying areas and river alluvium along the major river valleys, there are coastal regions of parallel beach ridges and sandy flats. At places there are raised beaches composed of fine-grained reddish sandy loam commonly known as 'Teris'.

Marine, fluvial, fluvio-marine and aeolian agents appear to influence the disposition of the depositional landforms. On the basis of the environments or agents aiding their formation, five major morpho-stratigraphic surfaces were identified by Nair, (1987). The **Malabar surface** represents very narrow to wide beach with width varying between 40-150 m. The **Punjei surface** represents the sandy barrier or beach ridge situated almost parallel and adjacent to the Malabar surface. This surface appear to represent palaeo-beach which was exposed due to regression of the sea. The **Kadankalli surface** which is formed due to fluvio-marine activity is represented by a tidal flat. It is a low lying marshy land which floods during the high tide. The **Karingote surface** is a fluvial surface, in which are included flood plain, channel bars, point bars and channels of various rivers. The **Payyannur surface** represent old sand barriers or the strand lines that are aligned roughly parallel to the coast. A series of strand lines are noticed around Payyannur, Kunnimangalam, Trikaripur, Vellur, Chandera, Padne, Nileswaram and Pallikkare.

4. Laterite, at places associated with bauxite are found to form low and flat topped ridges and hills. The thickness of the laterite cappings vary from few metres to 50 m.

1.4. FIELD PROGRAMME

The sampling programme is designed to cover all the three physiographic provinces namely, the strand plain, beach and innershelf (Fig. 1.2, 1.3 & 1.4).

Beach sediment samples were collected in the month of November, 1980 from the highwater line, midwater line and plunge point, by piercing few inches of the sediment layer by a PVC pipe from 64 stations over a distance of about 150 km. In addition, sediment samples were collected bi-monthly covering different seasons between January 1980 - October 1982 from the highwater line and plunge point. Along with the sample collection, beach profiles were surveyed and wave parameters like breaker height, wave period and longshore currents were monitored at all locations.

In the month of November, strand plain samples were collected from the beach ridges and swales. The samples are represented by the red sands, yellow sands and white sands.

Detailed surveying and sample collection in the innershelf region was undertaken in the month of October 1984, by employing a

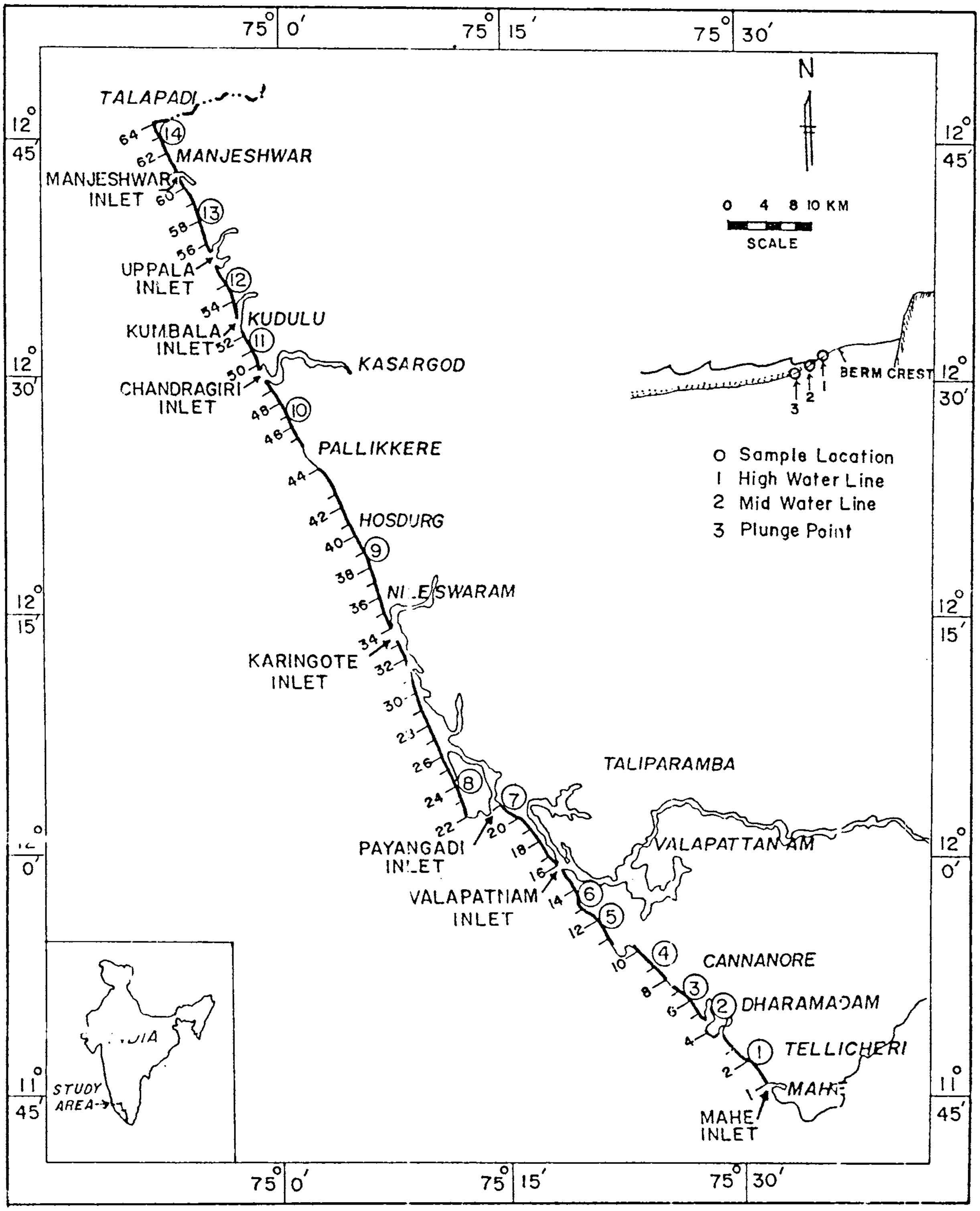


Fig. 1.2. Location map of the study area (beach).

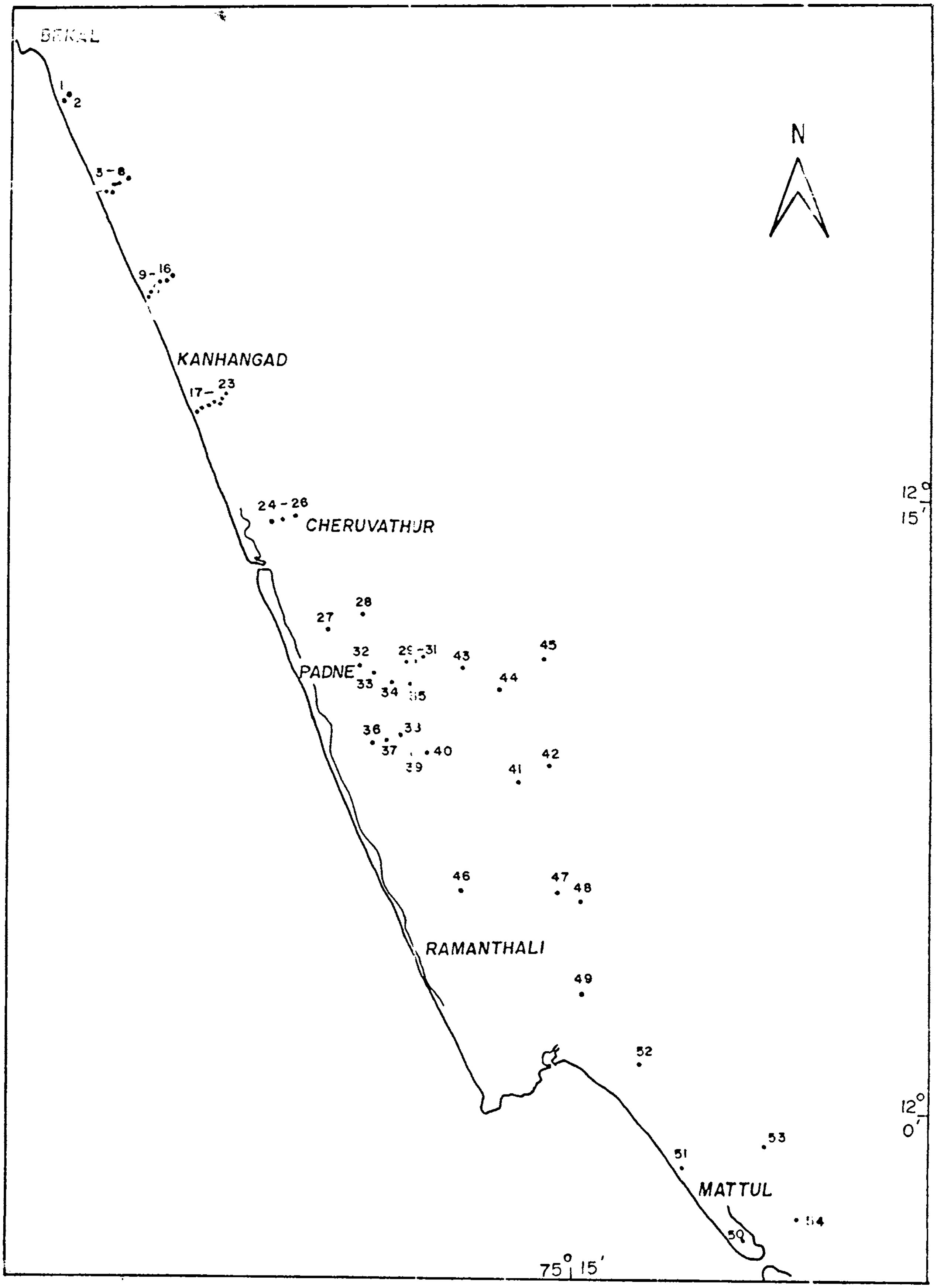


Fig. 1.3. Location map of the study area (strand plain)

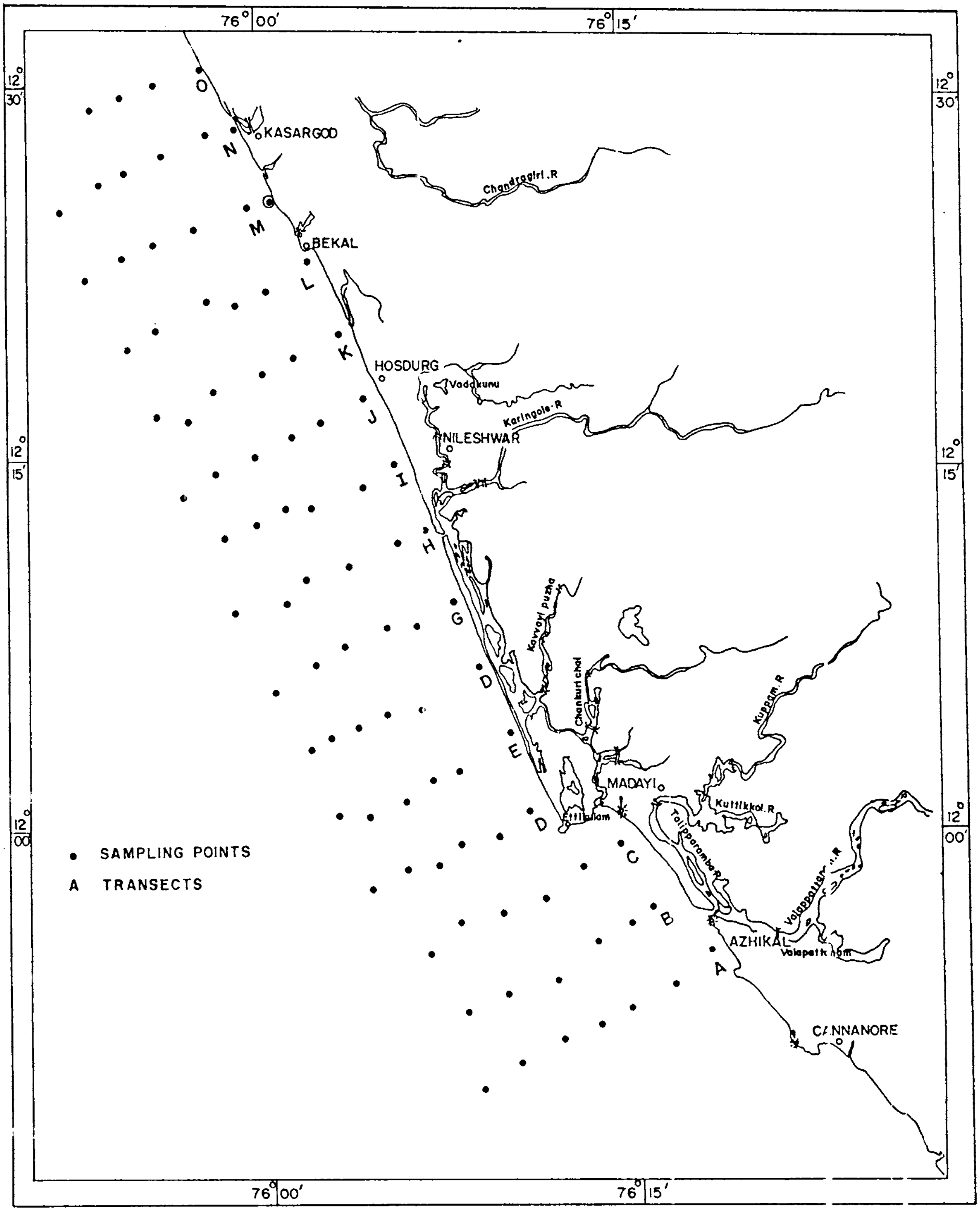


Fig. 1.4. Location map of the study area (innershelf).

large fishing boat with winch and davit facility. During the course of the survey, from 15 tansects spread at 5 km intervals, 90 grab samples which are spaced at a distance of about 2.5 km were collected by employing a van veen grab sampler. In each transect, minimum of 6 samples were collected. Positions were fixed accurately either by plotting the angles from two theodolite base stations or by a sextant.

CHAPTER II

TEXTURAL CHARACTERISTICS

Grain size parameters are related mainly to the formative processes of the clastic sediments, thus characterizing the specific environments of deposition. Various statistical measures were proposed to understand the mode of transportation and the environments of deposition of the sediments. Quartile measures (Trask, 1932; Krumbein, 1938) were found to be inadequate to express the whole distribution, since it incorporates only 50% of the population. The method proposed by Inman (1952) is applicable for nearly normal curves, but fails to reflect the mean size of the bimodal and strongly skewed curves. Folk and Ward (1957) proposed graphic measures by incorporating median of the coarsest third, average size of the finest third and the middle third. Compared to that of McCommon's (1962) method which represent 96% of the population, graphic measures are found to be more popular because of its simplicity and ability to describe the characteristics of the entire population based on simpler statistics.

As the moment measures (Friedman, 1961; 1967 & 1979) incorporates the entire size frequency range of the population, it is considered as a sensitive measure for the environmental discriminations. Significant contributions of Passega (1957, 1964), Favero and Passega (1980) and Visher (1969) were aimed at discerning specific modes of transportation and deposition of the sediments. By plotting coarsest 1 percentile grain size (C) and the median grain size (M) of the distribution on a double log paper, Passega (1957) interpreted distinct patterns and attributed these to different modes of transportation. Log normal sub-populations derived within the total grain size distribution were related to different modes of sediment transport, viz., i) suspension ii) saltation and iii)surface creep or rolling (Visher, 1969).

Duane (1964) and Cronan (1964) effectively discriminated different depositional environments and has noted that in combination with other criteria, skewness can be used as a valuable tool in paleo-environmental interpretations. Significant contributions were made to distinguish the statistical variations of grain size in dune, beach and nearshore sediments (Cadigan, 1961; Fuller, 1961; Giles & Pilkey, 1965; Greenwood, 1969; Johns, 1971; Davis and Fox, 1972 b; Veerayya and Varadachari, 1975; Shideler, 1978; Anwar et al., 1982; Khaláf et al., 1982; El-Ella & Coleman, 1985; Dubois,1972, 1989; Stokes et al., 1989). Nordstorm (1977) has successfully utilized the grain size statistics to distinguish high and moderate energy environments and attributed the differences to wave energy and beach mobility. Based on the moment summation method, Chappel (1967) identified fossil strand lines in the Quaternary deposits. Hodgson and Scott (1970) were able to identify ancient beach sediments by the combination of size analysis and quartz grain surface textures. The study of the grain size characteristics were utilized mainly to distinguish major depositional environments. (Veerayya, 1972; Rao & Rao, 1974; Veerayya and Varadachari, 1975; Chaudhri et al., 1981; Prakash et al., 1984; Ramamoorthy et al., 1986). However little attempts were made to understand significant textural characteristics within an environment, like the foreshore (Bascom, 1951; Miller & Zeigler, 1958; Fox et al., 1966; Friedman & Sanders, 1978; Chaudhiri et al., 1981) and discernable seasonal textural changes of different seasons that are caused due to divergent wave set up. In the present investigation along with the study of transportational and depositional history of the inter-related environments, emphasis has been given to the above aspects.

2.1. METHODS OF STUDY

2.1.1. Size Analysis

Sandy fraction from the beach and strand plain samples were split into 50-60 gm and seived at 0.50 phi interval. As the fractions are quartzose with minor quantities of shell fragments, separate treatment of samples are not warranted (Shideler, 1973). The samples were run on a Ro-Tap seive shaker for 15 minutes using seives range from -0.2 phi to 4.0 phi. The retant on each seive are weighed on a single pan balance to 0.01 gm.

The innershelf sediments, which consists of sand, silt and clay were analysed by the combination of both seiving and pipette method. Stokes law on settling velocity of particles forms the basis for the pipette analysis of sediments (Carver, 1971). Approximately 30 grams of the samples were treated with 10% Hcl and 30% hydrogen peroxide to remove carbonates and organic matter (Van Andel & Postma, 1954). Any coarse shell material that still remained were removed as it was assumed to have been added by organisms and do not represent the transporting medium (McKinney & Friedman, 1970). To a 10 gm of the wet sample, 10 ml of 10% solution of sodium hexa-metaphosphate was added as dispersing agent and kept overnight. The remaining sample was weighed and the moisture content was measured by heating upto 110°C. Weight of the sample taken for the analysis is then corrected for the moisture content. This procedure which is called as the moisture replicate method (Carver, 1971) is most accurate when the sample contains more than 30% of clay.

Before the pipette analysis all materials coarser than 4 Phi were removed from the dispersed sample by wet seiving. The dispersed and seived samples were poured into a graduated cylinder and made upto 1 litre. Samples were withdrawn at specific time intervals (Carver, 1971) for fractions upto 11 Phi. Beyond these, the phi values were extrapolated upto 14 Phi (Folk, 1979).

A FORTRAN computer programme was utilized, which permitted derivation of percentile values and graphic measures (mean, standard deviation, skewness and kurtosis) of Folk & Ward (1957). For each of the grain size parameters, smoothed frequency distribution curves were drawn. Number of scatter plots were drawn to elucidate the differences in the population. Although in theory, the measures are geometrically independant, in actual practice it is usually found that for a given suit of samples the measures are linked by some mathematical relationship (Folk & Ward, 1957).

2.1.2. Q-Mode Factor Analysis

With the introduction of factor analysis (Imbrie, 1963), discrimination of different environments were attempted by applying multivariate statistical methods (Imbrie & Van Andel, 1964; Imbrie & Purdie, 1967; Chambers & Upchurch, 1979). Q-mode factor analysis of unconsolidated sediments are found to be very effective in determining the depositional environments from their grain size distribution characteristics (Klovan, 1966; Solohub & Klovan, 1970). Having applied this technique to the recent sediments of Bartaria Bay, Klovan (1966) concluded that the resulting factors represented different amount and types of energy present at the site of deposition.

Compared to R-mode factor analysis in which the relationship worked out are between variables in the Q-mode factor analysis the inter-relationship between the observations were studied. The analysis which yields an order of arrangement among a suit of samples, indicate the broader relationship between the samples. Q-mode factor analysis of the beach and innershelf sediments were carried out to emphasize their mode of deposition based on geologic factors (Dunteman, 1984).

2.1.3. Beach Profiling and Breaker Parameters

The beach profiles were surveyed with reference to permanent reference marks upto the plunge point seaward upto a few meters beyond the low waterline using dumpy level, metric staff and a tape. The seaward limit of the profile line is arbitrarily fixed by taking into consideration the local wave conditions and maximum wading depth for the surveyors. Vertical changes were measured at every four meters and additional readings were recorded at all significant points with break in slope.

The beach profile data after reduction with reference to the local bench marks were fed to the KELTRON micro-computer for the computation of beach volume changes. The programme has been designed to give the cumulative beach volume changes in erosional or accretional format by superimposing the profiles surveyed in different seasons at the same location (cubic meter/linear meter of beach). This net volume represents the algebraic sum of erosion in one part of the profile line and accretion in another part (Goldsmith et al., 1977).

Breaker height was measured visually. The wave period, was measured as the average time (in seconds) required by eleven successive wave crests to pass an imaginary stationary point. The longshore current velocity and direction were measured using "drift bottles". A suitably buoyant plastic bottle that was deployed close to the area, landward of the breaker zone is allowed to drift for two minutes. The distance travelled by the bottle in two minutes was recorded. The current velocities were represented in meters per second.

2.1.4. Surface Textures

Following the method of Krinsley and Doornkamp (1973) the samples were prepared for the surface textural analysis by SEM. Monocrystalline quartz grains between 200-400 micron diameter from each of the 5 sample were selected. The grains of this particular size are likely to record all of the well known surface features (Krinsley & McCoy, 1977), while grains smaller than this are biased towards recording chemical effects and those larger than 400 micron are biased towards recording abrasion (Margolis, 1968; Krischev & Georgiev, 1981).

Approximately 0.5 gram of each sample were treated for 30 minutes with concentrated hydrochloric acid at 90°C to remove the carbonate particles and washed in distilled water. These samples were then soaked overnight in hydrogen peroxide to remove organic debris and washed again in distilled water. Adhering iron surface coatings were removed by boiling in $Sncl_2$ solution and washed again in distilled water. Fifteen to twenty grains were selected at random from each sub sample and were mounted on 13 mm specimen stubs using double sided adhesive tapes. These stubs were coated with gold in a standard vacuum evaporator before examination. SEM analysis was undertaken at magnifications ranging from 200 to 5000 and examined in the Cambridge Stereoscan S4-10, in the emissive mode.

2.2. RESULTS AND DISCUSSION

2.2.1. Beach Sediments

Eventhough the beaches appear to be relatively permanent, superimposed on this are the changes which result from daily, seasonal and annual variation in intensity and direction of wave attack. These inturn result in apparent seasonal variation in sediment distribution pattern. The textural characteristics of both the foreshore and breaker zone sediments and the seasonal manifestations of the size distribution were studied for the proper evaluation of the transportational and depositional mechanisms of the beach sediments as a whole.

2.2.1.1. Foreshore and breaker zone sediments

This zone in the beach environment is divided into three discrete and gradational units viz., high water line, mid water line and plunge point (Fig. 1.4), wherein the sediments are considered to be transported and deposited under diverse wave energy regimes. Under the influence of the differing wave energy conditions, the textural parameters exhibit distinct differences in the distribution pattern. The percentage distribution of size parameters in these sub-environments are given in table-2.1. To illustrate the comparative variations in percentage abundance of occurrence of parameter values and the significant textural characteristics of the sediments, the corresponding textural measures for the three populations were plotted as frequency distribution curves (Fig. 2.1).

In general, the mean size of beach sands fluctuates between 0.5 phi to 3.0 phi. The plunge point samples are polymodal, constituting coarse to medium grade with significant tail of fines. The polymodality of the plunge point sands, are reflected by the clustering of the mean size of the frequency distribution curves at 1.50 phi, 2.30 phi and 0.60 phi. The samples are moderately sorted to poorly

Table - 2.1

PERCENTAGE DISTRIBUTION OF GRAIN SIZE PARAMETERS IN THE HIGHWATER LINE, MIDWATER LINE AND PLUNGE POINT SEDIMENTS

Size parameters	Plunge point	Midwater line	Highwater line
Mean size (ϕ)			
0.5 - 1.0	26	-	-
1.0 - 1.5	15	23	18
1.5 - 2.0	16	48	41
2.0 - 2.5	29	18	26
2.5 - 3.0	14	11	15
Skewness (ϕ)			
-0.30 to 0.10	41	29	16
-0.10 to 0.10	38	68	77
0.10 to 0.30	21	3	7
Standard deviation			
0.35 - 0.50	-	7	5
0.50 - 1.00	70	87	95
1.00 - 2.00	30	6	-
Kurtosis (ϕ)			
0.67 - 0.90	52	22	12
0.90 - 1.10	33	55	69
1.10 - 1.50	15	23	19

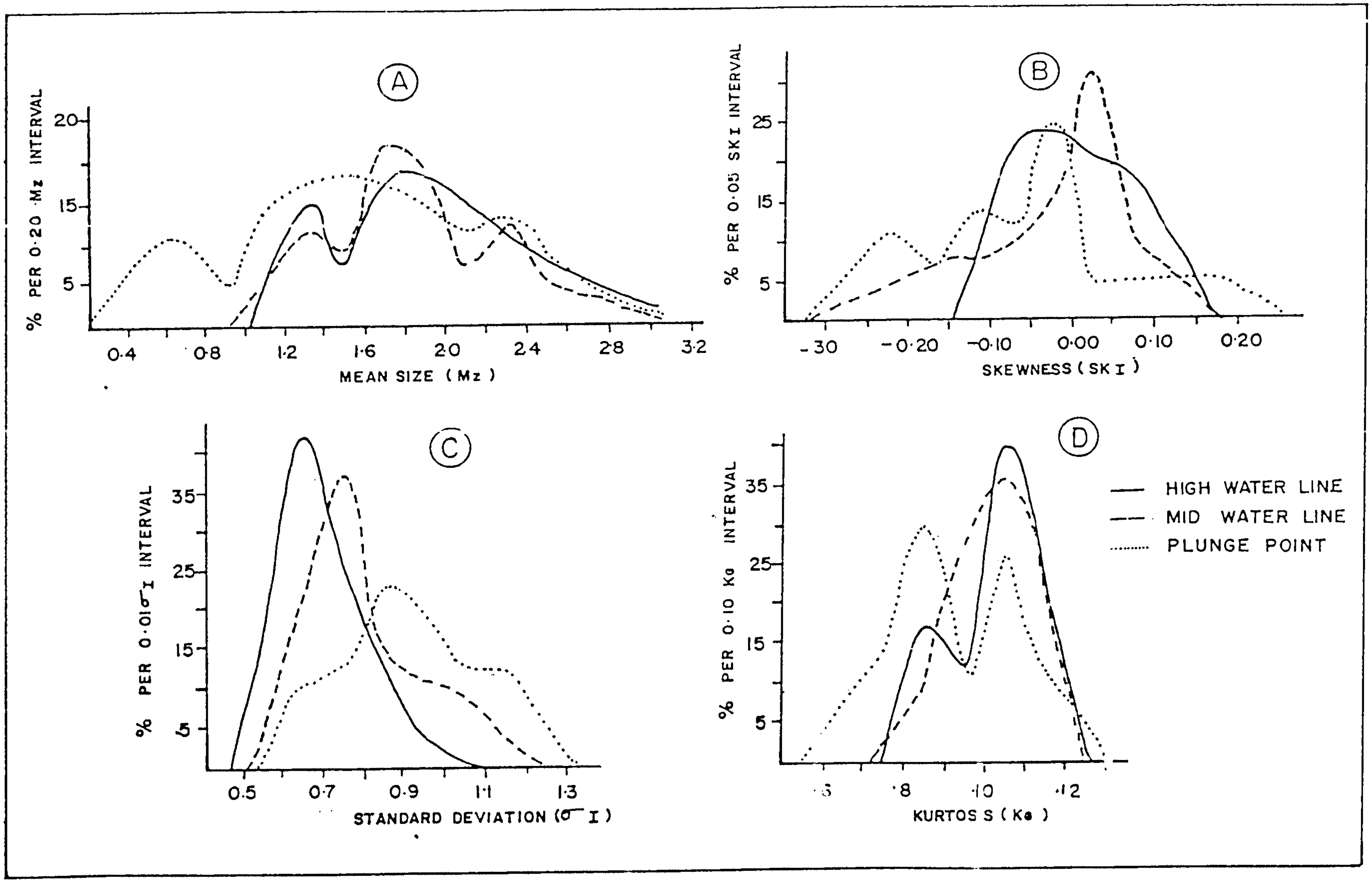


Fig. 2.1. Frequency distribution curves of size parameters of the beach sediments illustrating the percentage occurrence of parameter values.

sorted. Most of the sorting values are clustered around 0.88 and 1.15. The negatively skewed to nearly symmetrical nature of the plunge point samples are inferred by the clustering of the values around -0.03, -0.125 and -0.23. The samples are platykurtic to mesokurtic. The kurtosis values in the frequency distribution curve cluster around 0.80 phi and 1.05 phi.

The high and mid water line samples that are bimodal and show slight overlap, are classified as medium to fine sand. As indicated by a major cluster at 1.7 phi and smaller clusters around 1.3 phi and 2.3 phi, the mid water line samples are considered coarser. The high water line samples that are bimodal, cluster around 1.90 phi and 2.30 phi and incorporate higher proportion of fine sands than both the other units. It is interesting to note the total absence of coarser sands in both mid and high water line samples.

Majority (95%) of the high water line sample are moderately sorted, displaying the best sorting values (average value 0.65) and are nearly symmetrical and mesokurtic. The mid water line samples that are moderately sorted to poorly sorted, nearly symmetrical to negatively skewed and mesokurtic show a tendency to reach the plunge point samples. These samples generally occupy a intermediate position between the high water line and plunge point samples.

The inter-relationship between the size parameters are inferred from the scatter plots (Fig. 2.2). Due to the limited spread of mean size and standard deviation values the scatter plots show no signi-

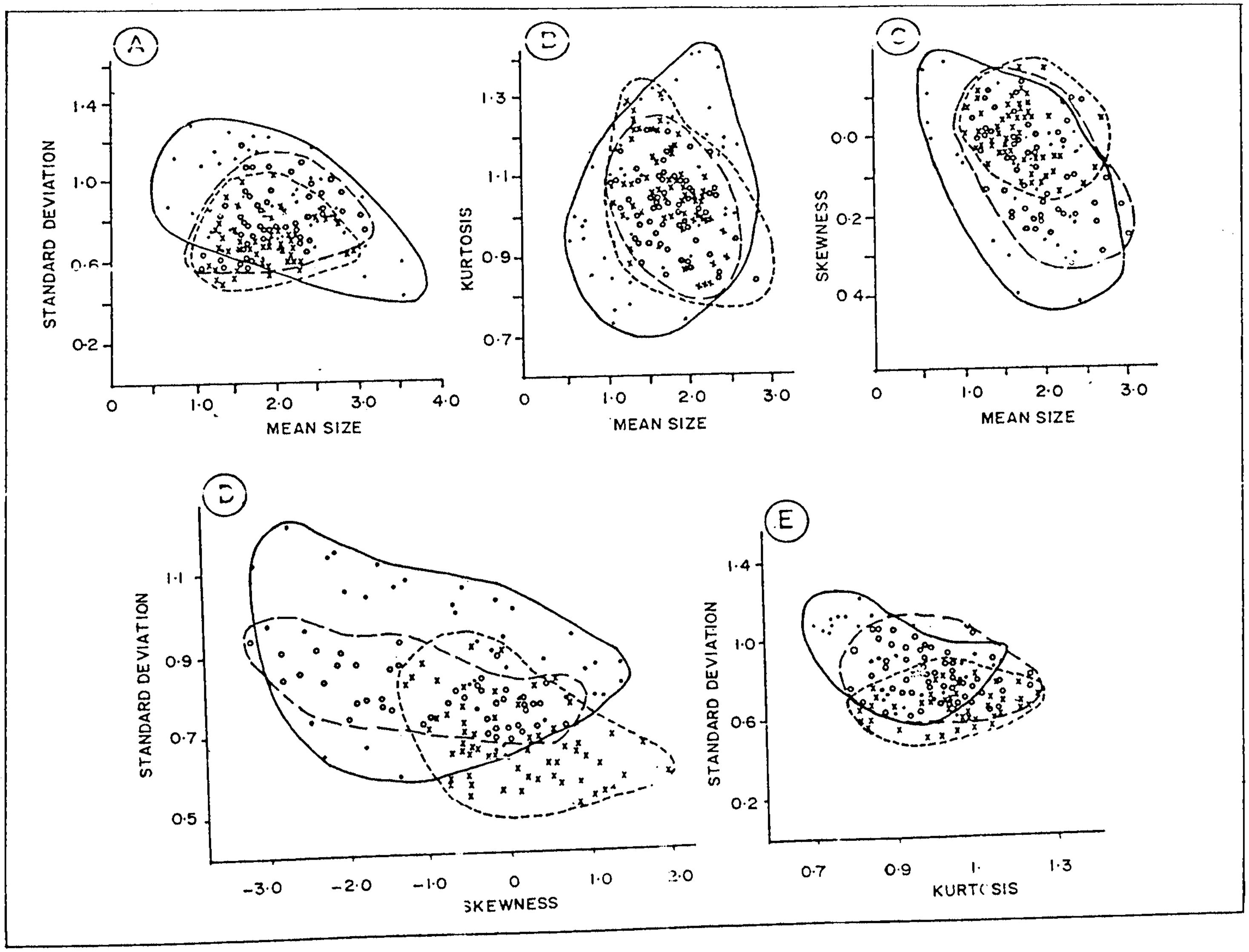


Fig. 2.2. Scatter plo+s of different size parameters of beach sediments.

ficant trends or correlation. The plot of skewness versus standard deviation is significant. Due to their polymodality behaviour, the plunge point samples show wide scattering of the parameter values. The mid water line samples occupy an intermediate position between the high water line and plunge point samples. All the scatter plots maintains the above shape. The following inferences are made from the scatter plots. The high water samples are nearly symmetrical and moderately sorted. The plunge point samples are negatively skewed and poorly sorted. In all the above relationships, the mid water line occupies an intermediate position between the plunge point and the high water line samples.

CM patterns are widely used to attribute the textural relationship of the sediments to the process of transportation. These patterns are generally sharply defined and vary considerably with different depositional agents (Passega, 1957). The CM pattern drawn for each of the three environments (Fig. 2.3) indicate almost similar conditions of transportation. It is inferred that, the beds composed of sand particles are transported by rolling and suspension under conditions of maximum and minimum turbulence. This is generally an area of good sorting, where the pattern is close to the limit C = M. The inference that the plunge point samples are poorly sorted than the high and mid water line samples are noted from the CM diagram too.

Table 2.2 illustrates the eigen values, percent sum of squares and cumulative sum of squares extracted from the principal component

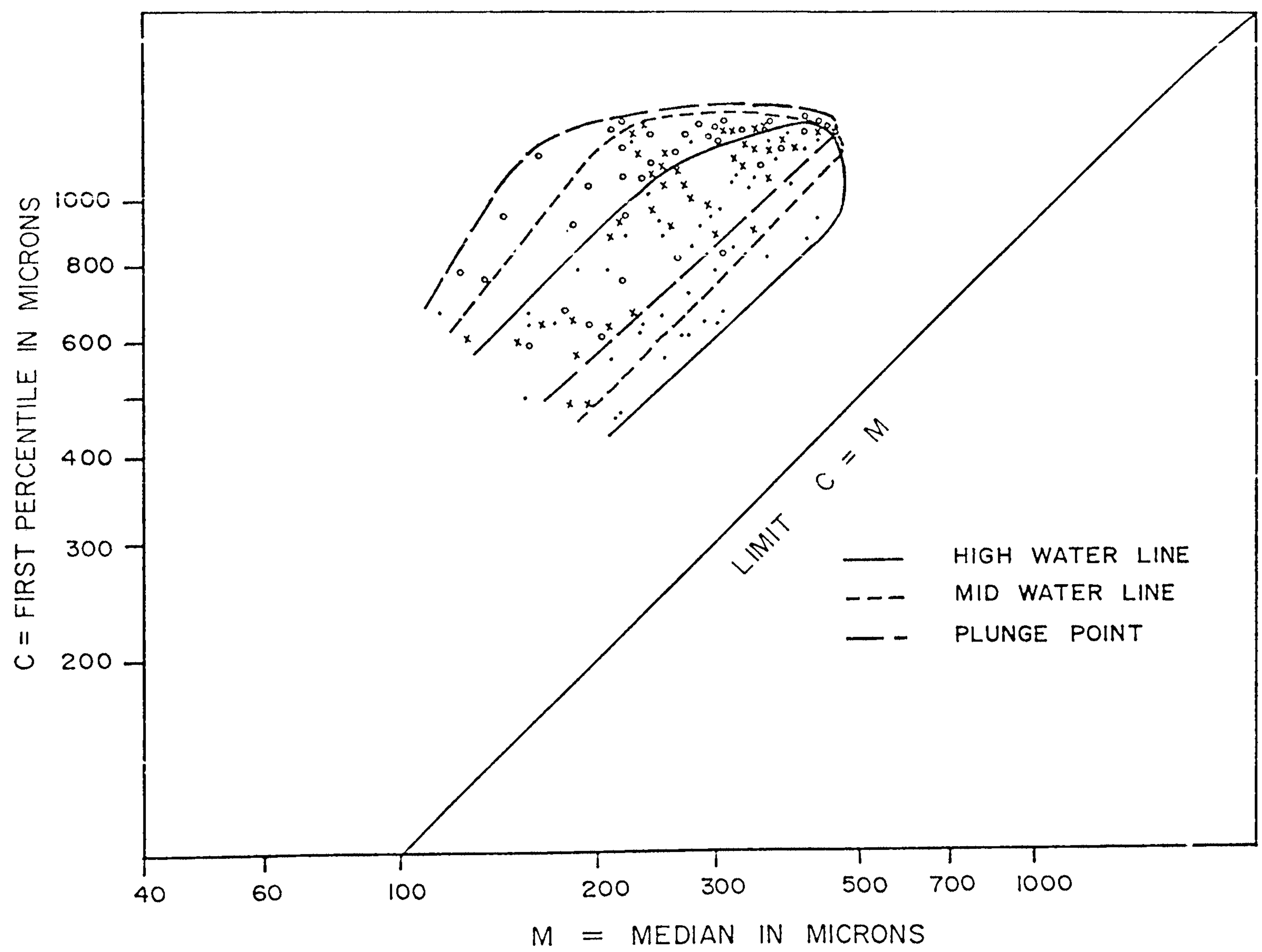


Fig. 2.3. CM diagram of the micro-environments in the beach.

analysis of the n x m matrix. Three factors which account for 94.30% of the variance were retained for the discussion. Table 2.3 illustrate the communality and matrix of factor loadings for the 48 samples of the three factor scores, which have been rotated according to the varimax procedure. The communality, the sum of squared loadings for a specific sample reflects the degree to which the sample vector has been explained by the set of three factor axes. A communality tending towards 1.0 means a perfect explanation for the factor loadings. All samples show very high communality thereby indicating its significance. Normalization of factor components were attained by dividing the squared values of the factor loadings by the corresponding communality. To place each sample in its proper place within the entire spectrum of grain size distribution, the normalized factor components were plotted on a triangular diagram (Fig. 2.4).

The following patterns are recognised from the study of samples from the apices of the diagram:

i) Clustering of plunge point samples around the factor II and the spreading of mid water line and the high water line samples between factor I and III.

ii) Scattering of plunge point samples around the factor I.

iii) Scattering of the mid water line samples more towards the plunge point.

iv) Absence of point in the I - II factor line.

It is inferred from the results of factor analysis that sediments of the micro-environment are deposited under different physical

Table - 2.2

EIGEN VALUES, PERCENT SUM OF SQUARES AND CUMULATIVE PERCENT SUM OF SQUARES EXTRACTED FROM THE PRINCIPAL COMPONENT ANALYSIS OF THE BEACH SEDIMENTS

Eigen value	Percent sum of squares	Cumulative sum of squares
34.343	71.549	71.549
07.269	15.144	86.692
03.762	07.837	94.530
01.289	02.686	97.216
00.482	01.004	98.220
00.429	00.892	99.111
00.195	00.407	99.518
00.166	00.346	99.864
00.065	00.136	100.000

Table - 2.3

COMMUNALITY AND VARIMAX FACTOR MATRIX WITH ROTATED FACTORS
DRAWN FOR THE BEACH SEDIMENTS

Communality (1)	Factor I (2)	Factor II (3)	Factor III (4)
0.972	0.706	0.246	-0.642
0.866	0.729	0.040	-0.577
0.817	0.891	0.097	0.119
0.972	0.940	0.075	-0.289
0.838	0.000	0.615	-0.678
0.985	0.469	0.252	-0.838
0.958	0.202	0.252	-0.924
0.984	0.694	0.438	-0.557
0.979	0.736	0.344	-0.565
0.918	0.921	0.088	-0.247
0.975	0.791	0.143	-0.574
0.919	0.062	0.524	-0.801
0.978	0.479	0.467	-0.729
0.948	0.146	0.389	-0.880
0.965	0.461	0.457	-0.737
0.993	0.883	0.121	-0.445
0.985	0.820	0.206	-0.520
0.917	0.944	0.139	-0.086
0.976	0.338	0.300	-0.879
0.958	0.609	0.172	-0.747
0.919	0.567	0.116	-0.764
0.944	0.454	0.169	-0.842
0.991	0.757	0.390	-0.516
0.949	0.947	0.137	-0.170
0.963	0.428	0.741	-0.481

Table 2.3 contd.

(1)	(2)	(3)	(4)
0.833	0.849	0.129	-0.309
0.956	0.585	0.366	-0.692
0.884	0.026	0.892	-0.295
0.957	0.206	0.924	-0.245
0.986	0.207	0.574	-0.784
0.957	0.467	0.694	-0.507
0.966	0.939	0.167	-0.239
0.972	0.556	0.702	-0.413
0.941	0.895	0.213	-0.317
0.989	0.138	0.875	-0.452
0.927	0.041	0.951	-0.144
0.866	0.039	0.930	0.000
0.947	0.039	0.870	-0.434
0.932	0.393	0.880	-0.059

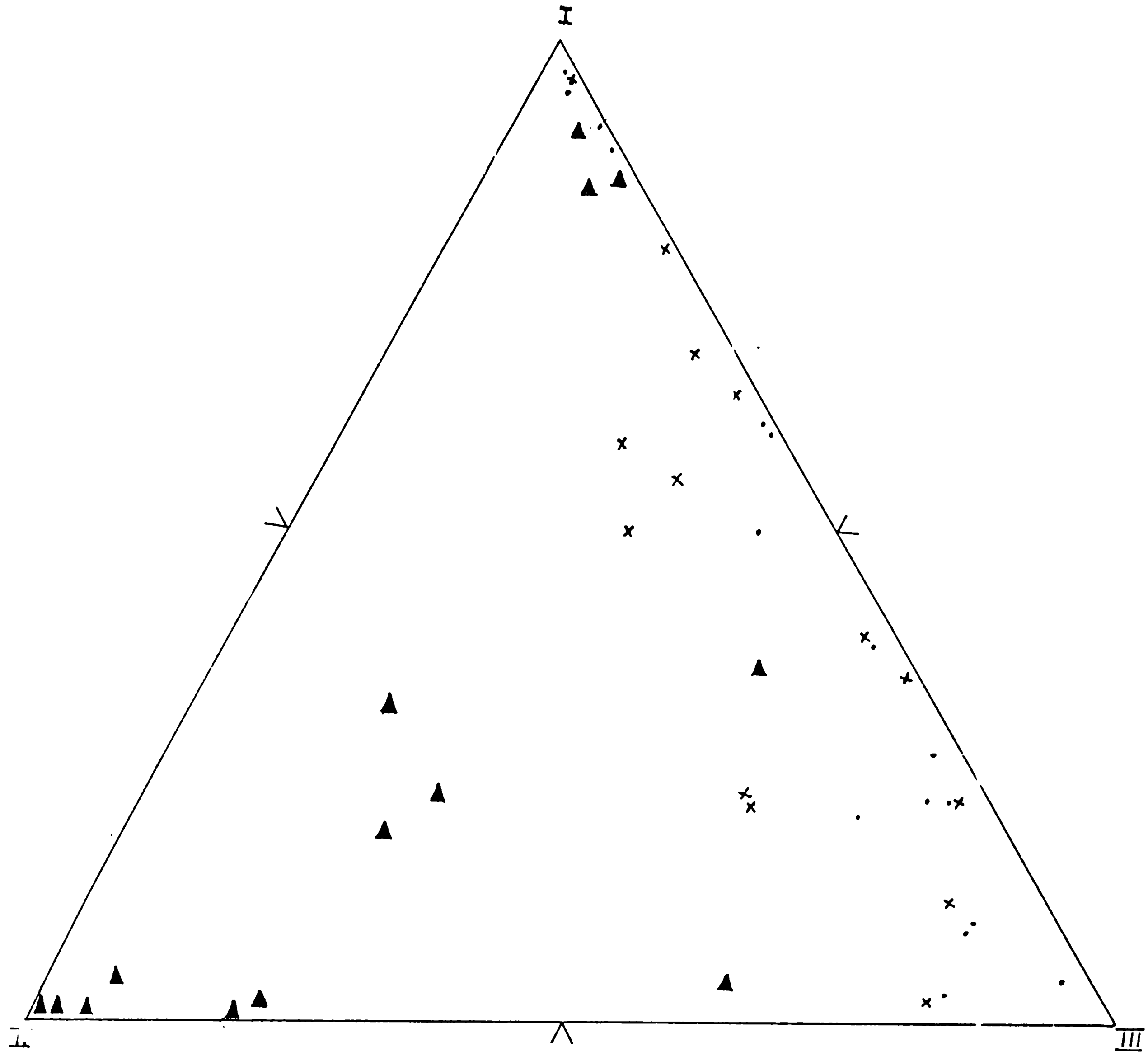


Fig. 2.4. Ternary diagram illustrating the plot of normalized factor components drawn for beach sediments.

Table - 2.4

GRAIN SIZE PARAMETERS OF THE HIGHWATER LINE, MIDWATER LINE AND PLUNGE POINT SAMPLES

S.No.	Size Parameters					
	1st %	50th %	Mean size	Standard deviation	Skewness	Kurtosis
(1)	(2)	(3)	(4)	(5)	(6)	(7)
<u>Highwater line samples</u>						
01/A	0.94	2.73	2.76	0.78	0.01	0.86
02/A	-0.47	-0.87	1.10	1.22	0.31	0.86
04/A	1.55	3.56	3.32	0.63	-0.55	0.80
05/A	2.11	3.67	3.58	0.39	-0.48	1.68
06/A	1.41	2.21	3.20	0.55	-0.10	1.07
07/A	0.14	1.94	2.14	0.91	0.22	0.63
08/A	-0.42	-1.73	1.69	1.01	0.07	0.98
09/A	-0.42	1.41	1.41	0.92	-0.01	1.03
10/A	-0.23	2.42	2.27	1.01	-0.26	0.70
11/A	1.02	2.30	2.29	0.60	0.02	0.86
12/A	0.61	1.90	1.93	0.53	0.08	1.06
13/A	0.52	2.75	2.77	0.78	-0.06	1.15
14/A	1.55	2.85	2.93	0.67	0.09	0.86
15/A	0.75	2.03	2.12	0.60	0.19	1.04
16/A	1.04	2.24	2.25	0.59	0.03	0.83
17/A	0.86	2.26	2.24	0.58	-0.10	0.83
18/A	0.56	1.83	1.87	0.56	0.11	1.15
19/A	0.50	1.90	1.91	0.68	-0.01	1.04
20/A	0.17	1.72	1.75	0.63	0.05	1.09
21/A	1.54	2.88	2.95	0.65	0.09	0.82
22/A	-0.10	1.52	1.56	0.88	0.13	1.33
23/A	-0.31	2.09	1.15	0.58	0.08	0.97

Table 2.4 contd.

1	2	3	4	5	6	7
24/A	0.02	1.26	1.27	0.55	0.10	0.92
25/A	-0.31	1.48	1.47	0.78	0.00	1.00
26/A	-0.25	1.39	1.35	0.66	-0.07	1.22
27/A	0.53	1.76	1.77	0.60	0.05	1.16
28/A	0.10	1.72	1.81	0.70	0.12	1.00
29/A	-0.16	1.70	1.71	0.70	0.02	1.05
30/A	-0.27	1.95	1.92	0.82	-0.06	1.06
31/A	-0.17	1.40	1.39	0.65	-0.02	1.22
32/A	-0.11	2.15	2.07	0.85	-0.12	1.04
33/A	-0.20	1.60	1.56	0.66	-0.04	1.06
34/A	0.60	2.14	2.17	0.63	0.04	1.04
35/A	-0.22	1.65	1.65	0.67	-0.04	1.31
36/A	0.04	1.87	1.93	0.70	0.05	1.01
37/A	1.05	2.29	2.28	0.57	-0.01	0.84
38/A	-0.15	1.61	1.62	0.65	-0.00	1.24
39/A	0.58	2.22	2.20	0.59	-0.10	0.83
40/A	0.56	2.14	2.16	0.71	0.05	1.05
41/A	0.01	1.74	1.79	0.68	0.08	1.08
42/A	-0.37	1.89	1.88	0.83	-0.13	1.11
43/A	0.04	2.18	2.09	0.88	-0.11	1.04
44/A	0.59	2.72	2.70	0.84	-0.09	0.98
45/A	0.34	1.39	1.53	0.60	0.36	1.22
46/A	-0.30	1.48	1.49	0.78	0.07	1.10
47/A	-0.13	1.54	1.56	0.70	0.03	1.15
48/A	-0.30	1.06	1.08	0.50	0.02	1.03
49/A	-0.43	1.31	1.31	0.81	-0.02	1.03
50/A	0.25	1.87	1.88	0.59	0.04	1.02
51/A	-0.15	1.61	1.60	0.66	0.00	1.14
52/A	-0.02	2.06	2.03	0.75	-0.09	1.05
53/A	0.04	1.85	1.83	0.67	-0.06	1.18
54/A	0.09	2.05	2.06	0.66	-0.05	0.90

Table 2.4 contd.

1	2	3	4	5	6	7
55/A	-0.39	1.27	1.23	0.75	-0.02	1.12
56/A	-0.03	2.03	2.05	0.68	-0.06	-0.98
57/A	-0.00	1.98	1.94	0.72	-0.10	0.87
59/A	0.00	2.26	2.21	0.71	-0.17	1.00
60/A	0.31	1.74	1.80	0.60	0.18	1.09
61/A	0.52	1.75	1.75	0.62	0.00	1.17
62/A	-0.35	1.31	1.31	0.67	0.02	1.08
63/A	-0.36	1.37	1.33	0.72	-0.06	1.26
64/A	0.04	2.17	2.15	0.70	-0.12	1.00
<u>Midwater line Samples</u>						
01/B	0.53	2.51	2.44	0.99	-0.10	0.91
02/B	0.49	-0.36	0.71	1.08	0.49	0.87
04/B	1.53	3.62	3.34	0.65	0.63	0.90
05/B	2.08	3.70	3.69	0.30	-0.32	1.74
06/B	0.80	3.23	3.19	0.41	-0.18	1.61
08/B	-0.45	1.68	1.58	1.09	-0.14	0.96
09/B	-0.45	2.14	1.88	1.20	-0.27	0.99
11/B	0.62	2.26	2.28	0.69	0.10	1.00
12/B	-0.43	1.75	1.65	0.97	-0.19	0.99
13/B	-0.13	2.80	2.68	1.02	-0.24	0.96
14/B	1.01	2.52	2.42	0.70	-0.20	0.83
15/B	0.08	1.47	1.65	0.73	0.28	1.12
16/B	0.99	2.43	2.37	0.65	-0.11	0.85
17/B	0.16	1.91	1.95	0.74	0.01	0.80
18/B	0.08	1.65	1.70	0.63	0.12	1.22
19/B	-0.22	0.23	1.60	0.83	0.08	1.03
20/B	-0.36	1.50	1.53	0.86	0.04	0.94
21/B	0.65	2.79	2.83	0.77	0.01	0.80
22/B	-0.43	1.37	1.35	0.97	-0.02	0.94
23/B	-0.35	1.11	1.15	0.59	0.05	1.03

Table 2.4 contd.

1	2	3	4	5	6	7
24/B	-0.32	1.13	1.13	0.67	0.05	1.18
25/B	-0.31	1.48	1.47	0.78	0.00	1.00
26/B	-0.41	1.27	1.35	0.84	0.12	1.01
27/B	-0.44	0.98	1.00	0.69	0.00	1.10
28/B	-0.38	1.38	1.36	0.76	0.00	1.13
29/B	-0.44	1.37	1.39	0.91	0.00	0.99
30/B	-0.28	1.69	1.65	0.80	-0.06	0.94
31/B	-0.44	1.77	1.63	1.09	-0.20	0.78
32/B	-0.34	1.92	1.82	0.79	-0.18	1.11
33/B	-0.36	2.11	1.97	0.96	-0.21	1.08
34/B	0.52	2.13	2.12	0.78	0.01	1.03
35/B	-0.05	1.82	1.84	0.72	-0.04	1.11
36/B	-0.15	1.97	1.94	0.87	-0.04	0.98
37/B	0.58	2.31	2.28	0.71	-0.02	1.08
38/B	0.09	1.62	1.63	0.58	-0.00	1.11
39/B	0.53	2.62	2.57	0.84	-0.13	1.26
40/B	0.56	2.75	2.77	0.84	-0.07	0.99
41/B	-0.38	1.62	1.58	0.89	-0.04	1.04
42/B	-0.41	1.77	1.71	0.93	-0.15	1.04
43/B	-0.29	2.59	2.34	1.08	-0.32	1.16
44/B	8.66	3.15	3.07	0.74	-0.25	0.93
45/B	-0.33	1.35	1.33	0.75	0.02	1.23
46/B	0.00	1.84	1.85	0.76	0.03	1.10
47/B	-0.27	1.70	1.72	0.74	-0.01	1.18
48/B	-0.02	1.34	1.33	0.60	0.03	0.91
49/B	-0.43	1.30	1.26	0.85	-0.04	1.03
50/B	-0.26	2.00	1.90	0.90	-0.12	0.89
51/B	-0.02	1.70	1.68	0.63	-0.02	1.13
52/B	-0.32	2.42	2.20	1.04	-0.28	1.10

Table 2.4 contd.

1	2	3	4	5	6	7
53/B	-0.01	1.92	1.95	0.69	-0.03	1.05
54/B	-0.42	2.19	1.95	1.07	-0.31	1.09
55/B	-0.33	1.59	1.58	0.76	-0.02	1.06
56/B	-0.31	2.02	2.00	0.78	-0.16	1.08
58/B	-0.24	2.08	0.07	0.74	-0.15	0.95
59/B	-0.24	2.33	2.25	0.79	-0.19	1.17
60/B	0.12	2.33	2.24	0.76	-0.16	0.91
61/B	0.53	2.18	2.19	0.68	0.00	1.02
62/B	0.05	1.64	1.66	0.69	0.06	1.07
63/B	-0.27	1.60	1.67	0.78	0.06	1.10
64/B	-0.43	1.80	1.73	1.06	-0.11	0.93
Plunge Point Samples						
01/C	-0.28	3.64	3.16	0.99	-0.78	1.84
02/C	-0.48	-0.54	0.99	1.28	0.46	0.60
04/C	0.61	3.45	3.05	0.90	-0.61	0.72
05/C	1.95	3.70	3.63	0.39	-0.48	2.04
06/C	0.64	3.68	3.51	0.57	-0.63	2.73
07/C	-0.40	-1.76	1.77	0.87	-0.08	1.16
08/C	0.06	2.54	2.55	0.89	-0.04	1.09
09/C	-0.39	1.91	1.96	0.87	-0.01	1.32
11/C	0.22	1.94	2.01	0.70	0.15	0.88
12/C	-0.48	1.10	1.14	1.14	0.08	0.80
13/C	-0.47	2.26	1.94	1.56	-0.25	0.64
14/C	0.50	2.53	2.38	0.81	-0.25	0.77
15/C	-0.31	1.74	1.71	0.79	-0.11	1.14
16/C	1.11	2.60	2.66	0.80	0.10	0.79
17/C	-0.34	1.52	1.60	0.95	0.07	0.83
18/C	0.63	2.34	0.40	0.80	0.11	1.00
19/C	-0.28	2.11	2.00	1.02	-0.07	0.88

Table 2.4 contd.

1	2	3	4	5	6	7
20/C	-0.30	2.34	2.17	0.91	-0.25	1.11
21/C	0.92	3.13	3.05	0.51	-0.30	1.37
22/C	-0.47	0.76	0.78	0.83	0.13	1.03
24/C	-0.46	1.08	1.01	0.84	-0.05	1.01
25/C	-0.48	0.83	0.95	1.07	0.20	0.80
26/C	-0.48	0.50	0.81	1.12	0.42	0.76
27/C	-0.48	0.69	0.72	0.87	0.13	0.89
28/C	-0.43	1.17	1.17	0.71	-0.05	1.01
29/C	-0.47	1.22	1.13	1.07	-0.06	0.05
30/C	0.45	3.02	3.07	0.65	-0.01	0.86
31/C	-0.21	0.26	2.22	0.68	-0.18	0.97
32/C	0.50	2.54	2.54	0.93	-0.05	0.92
33/C	0.67	2.73	2.78	0.73	0.03	0.98
34/C	-0.14	2.44	2.42	0.91	-0.08	1.09
35/C	-0.47	1.46	1.32	1.08	-0.14	0.74
36/C	-0.47	1.31	1.28	1.14	-0.02	0.69
37/C	0.89	2.55	2.44	0.66	-0.23	0.93
38/C	-0.48	0.61	0.68	0.90	0.20	0.85
39/C	0.04	2.26	2.11	0.93	-0.17	1.03
40/C	0.80	2.60	2.55	0.60	-0.14	1.02
41/C	-0.44	1.64	1.62	1.08	-0.01	1.20
42/C	-0.46	2.13	1.73	1.22	-0.41	0.84
43/C	-0.37	2.56	2.25	0.95	-0.50	1.18
44/C	-0.31	2.69	2.49	0.84	0.44	1.39
45/C	-0.48	0.62	0.69	0.92	0.21	0.87
46/C	-0.45	1.33	1.33	0.94	-0.01	1.00
47/C	-0.49	0.08	0.35	0.80	0.54	0.89
48/C	-0.47	0.70	0.68	0.75	0.04	0.88
49/C	-0.48	0.66	0.58	0.63	-0.13	0.91
50/C	-0.45	1.61	1.52	1.10	-0.13	0.72

Table 2.4 contd.

1	2	3	4	5	6	7
51/C	-0.49	-0.09	0.20	0.73	0.65	1.03
52/C	-0.45	1.90	1.77	1.14	0.16	0.86
53/C	-0.19	2.13	2.04	0.88	-0.14	1.07
54/C	-0.46	1.90	1.64	1.14	-0.31	0.78
55/C	-0.49	-0.04	0.26	0.74	0.61	0.89
56/C	-0.48	1.73	1.45	1.24	-0.27	0.59
58/C	-0.42	2.27	2.10	1.03	-0.27	1.33
59/C	-0.40	2.59	2.46	0.99	-0.30	1.66
60/C	-0.37	2.55	2.43	1.16	-0.22	1.01
61/C	0.59	2.44	2.40	0.77	-0.84	1.11
62/C	-0.48	0.56	0.52	0.67	-0.02	0.84
63/C	-0.49	0.08	0.26	0.66	0.44	0.83
64/C	-0.49	0.74	1.03	1.29	0.33	0.63

conditions. The three factors that are found to control the depositional agents can be identified in terms of their energy of deposition. The factor II can be considered as a coarse end member deposited under high energy and turbulent wave conditions. Factor I and III are the finer end members with lesser wave energy and involve greater mixing of sediments.

The remarkable variation in the textural characteristics of the foreshore and breaker zone sediments leads to genetically and texturally distinct populations with typical sorting and size patterns. The sediments exhibit a progressive decrease in mean size i.e. increase in grain size towards the plunge point. These differences in the size distribution may be due to variations in the wave energy reaching the point of sampling and the extent of its turbulence. Although no complete statistical data on wave energy are available for this area, it is inferred that the plunge point is the area of maximum turbulence and that is associated with high wave energy conditions. This zone is of prime importance in forming the final sediment pattern in the beach environment.

Approaching the breaker zone, the wave height decreases initially, then increases upto the point of breaking, where maximum wave height occurs. The turbulent and internal motion of a breaking wave is capable of keeping large amount of particles in suspension by way of increase in velocity of water particles (Iverson, 1951). Because of this, relatively large proportion of sediments are kept in suspension near the plunge point of the breaker, as compared to the regions on either side. Due to this turbulent wave conditions, wide range of particles ranging from fine to coarse sands (polymodal) are deposited in the plunge point keeping majority of the finer particles in suspension. Such process makes the plunge point samples poorly sorted. The platykurtic nature of the plunge point samples indicate the poorer sorting of the central part of the distribution curve than the tails (Folk & Ward, 1957; Cadigan, 1961). The poly-modality of the plunge point sands are thought to be partially been inherited from the characteristics of the incoming sediments and could be attributed to the net vertical movement at the base of the turbulent breaker, with secondary sorting action of the materials that are thrown into suspension (Miller & Zeigler, 1958).

Along with the sediment load derived from the lower foreshore, the suspended materials are transported by rolling by the breaking waves. When these sediments are carried up the slope, the swash transforms from a turbulent flow in the plunge point to laminar flow in the mid water line, then slow down to a halt in the high water line. During this process, majority of the remaining coarser materials are deposited in the mid water line. The remaining sediments that are mainly finer materials are transported upslope upto the high water line. This progressive winnowal action leads to decrease in the grain size from the plunge point to high water line. In addition, this process leads to greater mixing of the high and mid water line samples. The bimodal distribution of the mid water line samples could be ascribed to the entrapment of fines during the retreat of backwash. The water that has not percolated into the sediment flows straight back again, thus sorting the sediments down the slope (Friedman & Sanders, 1978).

According to Friedman (1961), the mode and energy of the transporting medium are reflected in the grain size distribution of the sediments. More poorly sorted and very negatively skewed nature of the plunge point sands may be attributed to its high energy conditions. Upslope from the plunge point, better sorting and the nearly symmetrical distribution of the sediments reflect the low energy conditions of the mid water line and high water line samples. The near-symmetrical nature of the curve results from the presence of fine tails entrapped in the coarse mode that are derived from the vertical sorting action of the waves and partly by the material carried by the backwash. The better sorting of the high water line and mid water line samples could be attributed to the panning action of the continued laminar sheet flow in the foreshore zone and prolonged winnowing action of the waves.

2.2.1.2. **Seasonal textural changes**

Because of its dynamic nature, the beaches that undergo seasonal fluctuations affect its configuration and in turn influence the changes in sediment distribution pattern (Komar, 1976). The seasonal reversal of wind circulation is closely linked with the onset of the monsoon along the west coast of India. Coastal erosion, a recurring hazard which occur especially during the south-west monsoon season (June-September) causes great concern to the local public. Alarming impact of erosion on the socio-economic spheres has incited the researchers to account for the processes that impart instability to the coast. Previous studies pertaining to the inter-relationship between wave refraction, shoaling and the ultimate effects of waves on the transportation of sediments are numerous (Nair et al., 1973; Reddy & Varadachari, 1973; Udaya Varma, 1977; Murthy and Varadachari, 1980; Shenoi, et al., 1981; Hameed et al., 1984. Sediment dynamics and beach volume changes along the Kerala coast were documented by Prakash et al., 1984; Samsuddin, 1986, 1988; Mallik et al., 1987; Samsuddin & Suchindan, 1987 and Suchindan et al., 1987.

However knowledge on the dispersion of sediments in the light of seasonal fluctuation of the beaches are sparse. Sedimentologists interpreted processes based on the assumptions that a set of sediment samples can be considered to be in textural equilibrium with the dynamics of the environment. In addition, several techniques were proposed to deduce the movement of sediment in different dynamic environments. Methods such as radioactive and fluorescent tracer techniques (Ingle, 1966), construction of polynomial trend surface maps (Booth, 1973), grain shape (Mazullo & Crisp, 1985), mineralogy (Griffin et al., 1968), trace element geochemistry (Holmes, 1982), isotope geochemistry (Solomons et al., 1975), silt-clay ratio (Shideler, 1978) and down-stream variation in grain size (McLaren & Bowles, 1985) were extensively used to trace the transport directions. In the present study, the effectiveness of the method proposed by McLaren and Bowles (1985), which takes into account a model of progressive changes of the moment measure statistics in the sediments along the transport direction is tested in a wave dominated environment.

In order to understand the inter-relationship between the textural characteristics of sediments and the stability of the beaches, sediment samples were collected from the high water line and plunge point during different seasons. As the climate of Kerala is monsoon dominated, its responses to the sediment dispersion are discussed season-wise viz., Pre-monsoon (January-April) monsoon (May-August) and post-monsoon (September-December). With respect to the geographic disposition of the promontary at Ezhimala, the study area is divided into two distinct sectors, viz., southern side (21 profiles) and northern side (43 profiles).

From the long-term study of waves at Tellichery, a predominant breaker direction of 200°-220° with respect to north was described by Harish (1988). A wide fluctuation between 180°-240° N was noticed during fair weather seasons (November-April) whereas during the rough season (May-October), it was almost consistent between 210°- 220°N. Depending upon the location, the breaker direction are found to vary between 210°-300°N in the south-west coast (Baba, 1988). The breakers were mostly plunging or surging and occasional spillers.

2.2.1.2.1. **Breaker period:** Breaker period vary between 10 seconds to 16 seconds throughout the year. Average periods calculated for different months show that in both sectors the waves break at higher frequency during south-west monsoon (Fig. 2.5a). Both pre-monsoon and post-monsoon display lesser frequency of waves. In both years a cyclic increase in wave period is apparent from pre-monsoon to monsoon. This trend is almost similar for both the sectors.

2.2.1.2.2. **Breaker height:** Breaker height (average) plotted for both the sectors (Fig. 2.5b) shows an increase in height from pre-monsoon to the south-west monsoon. These changes in the breaker height is cyclic. Following the monsoon, the sudden decrease in height towards the post-monsoon is followed by an increase in the monsoon period in the subsequent year (July 1982). Irrespective of the seasons there is a notable decrease in breaker height along the southern sector as compared to that of the north throughout the study period.

2.2.1.2.3. **Longshore current and transport of material:** Temporal and spatial variation of the wave induced longshore current are significant in the study area. Depending upon the flow direction of the longshore currents, the beach materials are transported either in southerly or northerly directions. The movement of material along shore is one of the most important processes, that is responsible for many instances of coastal erosion and accretion (King, 1972). Measurement of longshore current velocities shows that reversal in current direction occur just before the onset of monsoon. However, current flowing towards north and south are prominant during the fair weather and monsoon season respectively. Based on the monthly changes

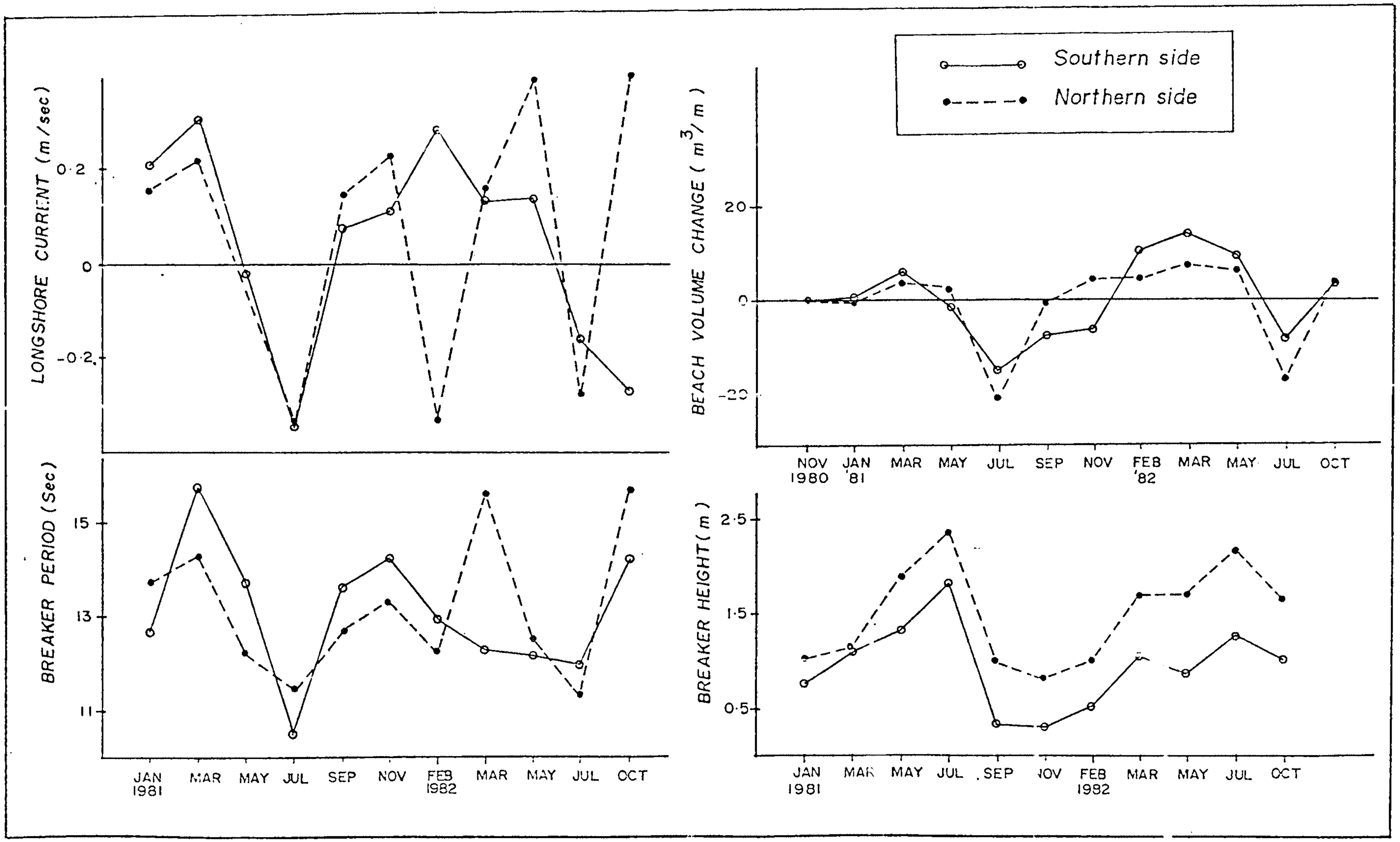


Fig. 2.5. Average variation of (a) breaker period; (b) breaker height; (c) longshore current and (d) beach volume changes.

in the longshore current pattern (Fig. 2.6), three distinct phases of longshore current activity are inferred in the first year of observation, viz. (i) northerly current dominated depositional phase. The depositional phase is further divided into pre-monsoon (January-April) and post-monsoon (September-December) phase (ii) with the introduction of the prominant southerly reversal of the current, the transitional phase (May) induces perceptible erosion and (iii) an erosional phase (June-July) characterized by a regional southerly current.

Eventhough the erosional and depositional phases are persistant, the transitional phase is more or less absent in the subsequent year. The absence of transitional phase could be due to the inordinate delay of the SW monsoon during 1982 along the Kerala coast. Generally the monsoonal wave climate sets in the Kerala coast by the month of May (Ananthakrishna et al., 1977), inducing reversal of the longshore current direction. The unusual delay of the SW monsoon in 1982 could be the reason why the transitional phase went unrecorded. During May 1982, the observed current is towards north. It is quite interesting to note that under this changed flow set up, majority of the beaches show an accretionary trend. A reversal in the flow direction towards south occur in February 1982. Such a reversal could be due to the change in the direction of waves approaching from west to WNW.

In the depositional phase, the longshore current is feeble and directed towards north. A progressive increase in current velocity occur from November through March. The low velocity northerly current

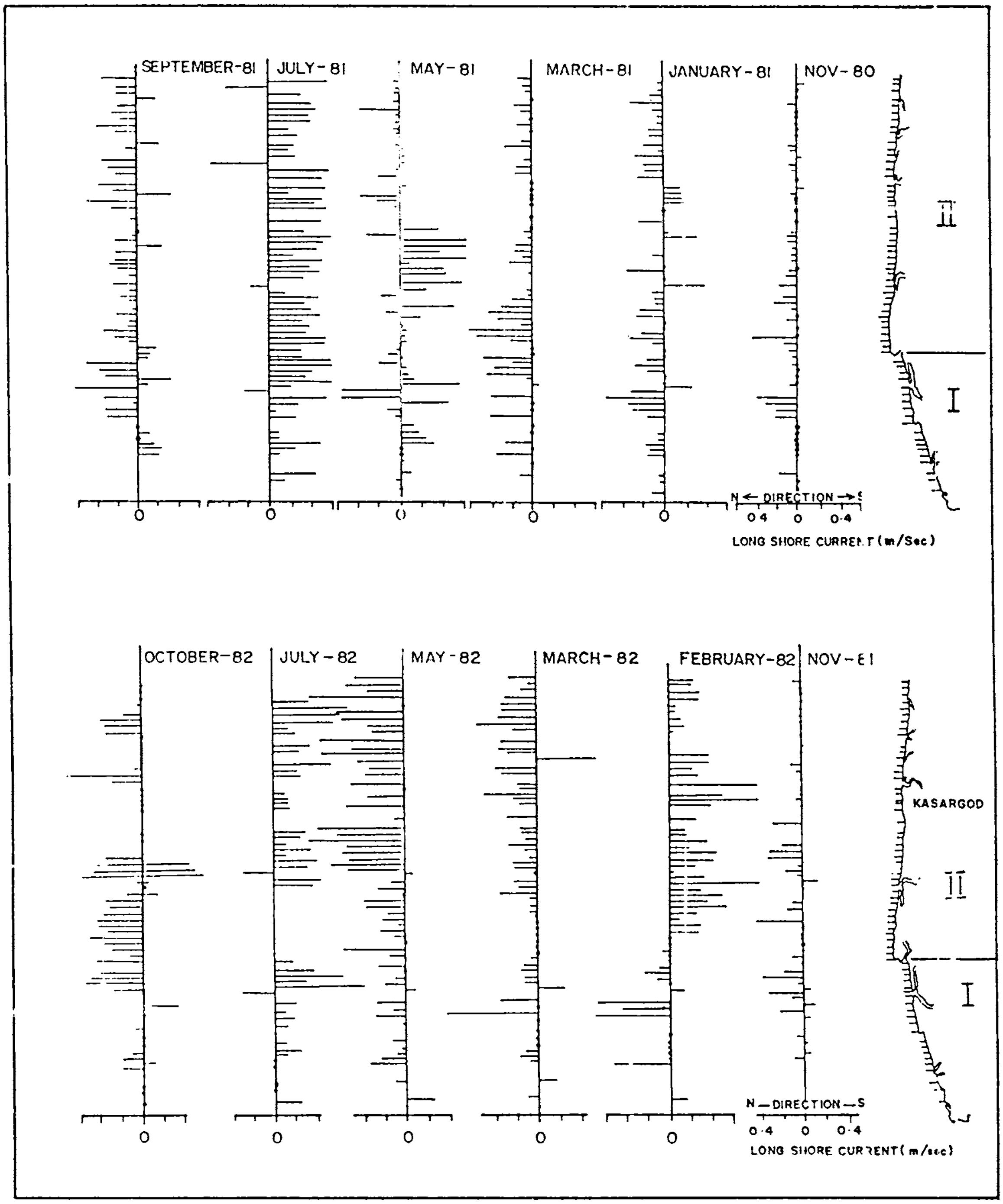


Fig. 2.6. Spatial and temporal variation of longshore current pattern.

of November (0.2 m/sec) which increases steadily through January attains higher velocity (0.4 m/sec) by the month of March. Under the influence of the long period swell waves and northerly longshore currents the beaches show an accretionary trend in the pre-monsoon season. The rate of accretion gradually increases from January to March (Fig. 2.5 d).

A scatter plot representing 12 profiles (between stations 22-33) is drawn to relate the erosional and accretional behaviour of the beaches and the variation in the longshore current in different seasons. Figure 2.7 shows that majority of the data points related to southerly longshore currents fall in the field of erosion; whereas the majority of the data points related to northerly lonshore currents fall in the field of accretion. Reverse relations also occur locally, but in such cases the erosion or accretion is found to be of lesser magnitude. The frequency distribution diagram of the intensity of the longshore currents (1981) are given in figure 2.8.

Changes in the wind direction mark the onset of SW monsoon in the month of May. These changes in wave orientation result in reversal of the longshore current direction in most part of the coast. The strong SW monsoon winds of July drives short period and steep waves onshore. Coupled with the high velocity southerly longshore current, this sort of wave climate makes the beach environment a higher energy domain that ultimately causing widespread erosion in the monsoon.

However with the offset of monsoon winds and under the influ-

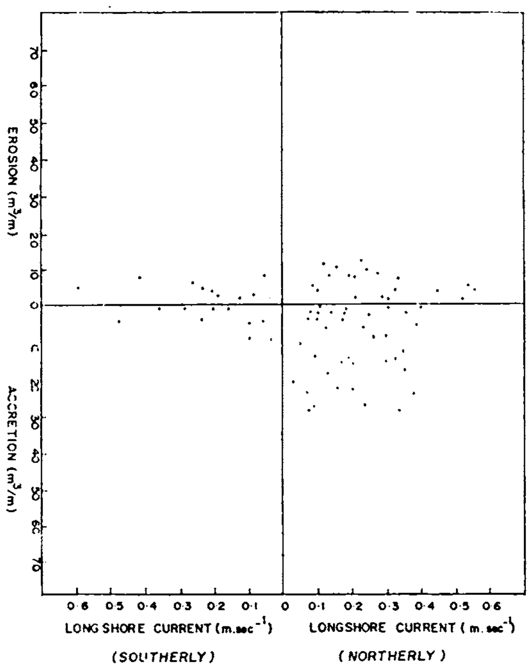


Fig. 2.7. Scatter plot showing the relationship between the speed and direction of longshore current with erosion and accretion.

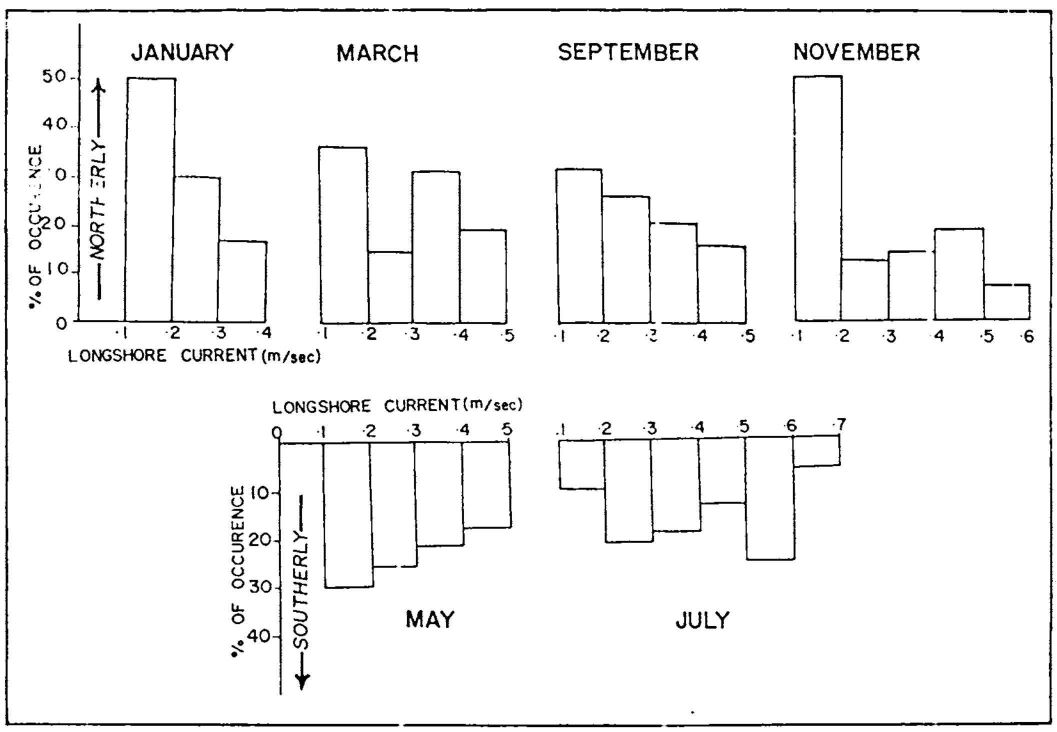


Fig. 2.8. Frequency distribution diagram of the intensity of the longshore currents in different months.

ence of long period swell waves and strong northerly longshore currents, the beaches are again transformed into an accretionary state. The longshore current show decrease in velocity from the initial stages of post-monsoon to the later stages of the post-monsoon. The slackened rate of accretion in the subsequent months are found to be influenced by the low velocity of the longshore currents.

Numerous examples can be cited to establish the role of promontaries and the river outlets in acting as a trap for the movement of materials along the coast. This observation can very well be explained by considering the depositional and erosional behaviour of the beaches under the differing patterns of longshore current in their vicinity. In the month of May, when the longshore current is northerly, the stations north of the river outlets and promontaries show an erosive trend. The coastal features which protrude out to the sea, would act as a barrier to the northerly moving sediments, causing deposition of coarse grained sediments in the updrift side, thus making the downdrift side sediment starving. Similarly the flow of the water through the river outlets may also act as a barrier to the sediment transport, by the interception of the northerly/southerly moving sediments. Similarly during the monsoon, the southerly longshore transport of sediments are intercepted by these coastal features (promontaries and river outlets) thus resulting accretion in the updrift side and erosion in the downdrift side. Examples of such features acting as barriers to the littoral drift of sediments are given in the table 2.5.

Table -2.5

EXAMPLES OF COASTAL FEATURES ACTING AS
BARRIERS TO LITTORAL DRIFT OF SEDIMENTS

Profile Location	Month of Observation	Longshore Current Direction	Volume Change (m^3/m)
Profile - 11 north of Cannanore headland	May	northerly	-42.64
	July	southerly	+33.48
Profile - 22 north of Ezhimala headland	May	northerly	-29.44
	July	southerly	+40.16
Profile - 1 north of Mahe river outlet	May	northerly	-24.62
	July	southerly	+35.64
Profile - 50 north of Chandragiri river outlet	May	northerly	-02.44
	July	southerly	+15.22
Profile - 54 north of Kumbla river outlet	May	northerly	-00.32
	July	southerly	+13.78
Profile - 56 north of Uppala river outlet	May	northerly	-00.68
	July	southerly	+9.98

+ = Accretion

- = erosion

2.2.1.2.4. **Beach volume changes:** Cumulative beach volume changes normalized to the November 1980 profiles are represented in figure-2.5 d. The overall beach volume changes upto October, 1982 is around 4 cubic metre/linear meter of accretion of beach. The erosion is well defined in the monsoon profiles. The erosion is relatively vigourous in the northern side. In general, the beaches accrete in pre-monsoon and post-monsoon season and erode during SW monsoon season. The post-monsoon season records maximum accreted phase with respect to November (1980) profile. The pre-monsoon profiles show progressive increase in accretion rate from January to March. Approaching the monsoon, the trend is erosion. With cessation of the monsoon, the rebuilding of beach taken place at a faster rate in the initial stages of post-monsoon. In the similar way the process of erosion/accretion continues in the subsequent year. The overall cumulative beach volume changes in the study area are illustrated in fig. 2.9.

2.2.1.2.5 **Size characteristics:** Sediment samples were collected along the beach during pre-monsoon, monsoon and post-monsoon seasons from 64 stations. Out of this, 25 samples were selected for the study. A FORTRAN programme was utilized, which permitted derivation of three grain size moment measures (mean, standard deviation and skewness). Because of their relative sensitivity, the moment measures serve a basis for the comparative textural study (Shideler, 1973).

The differences in seasonal beach responses can be directly related to the energy of waves and frequency of the ocean swell. Com-

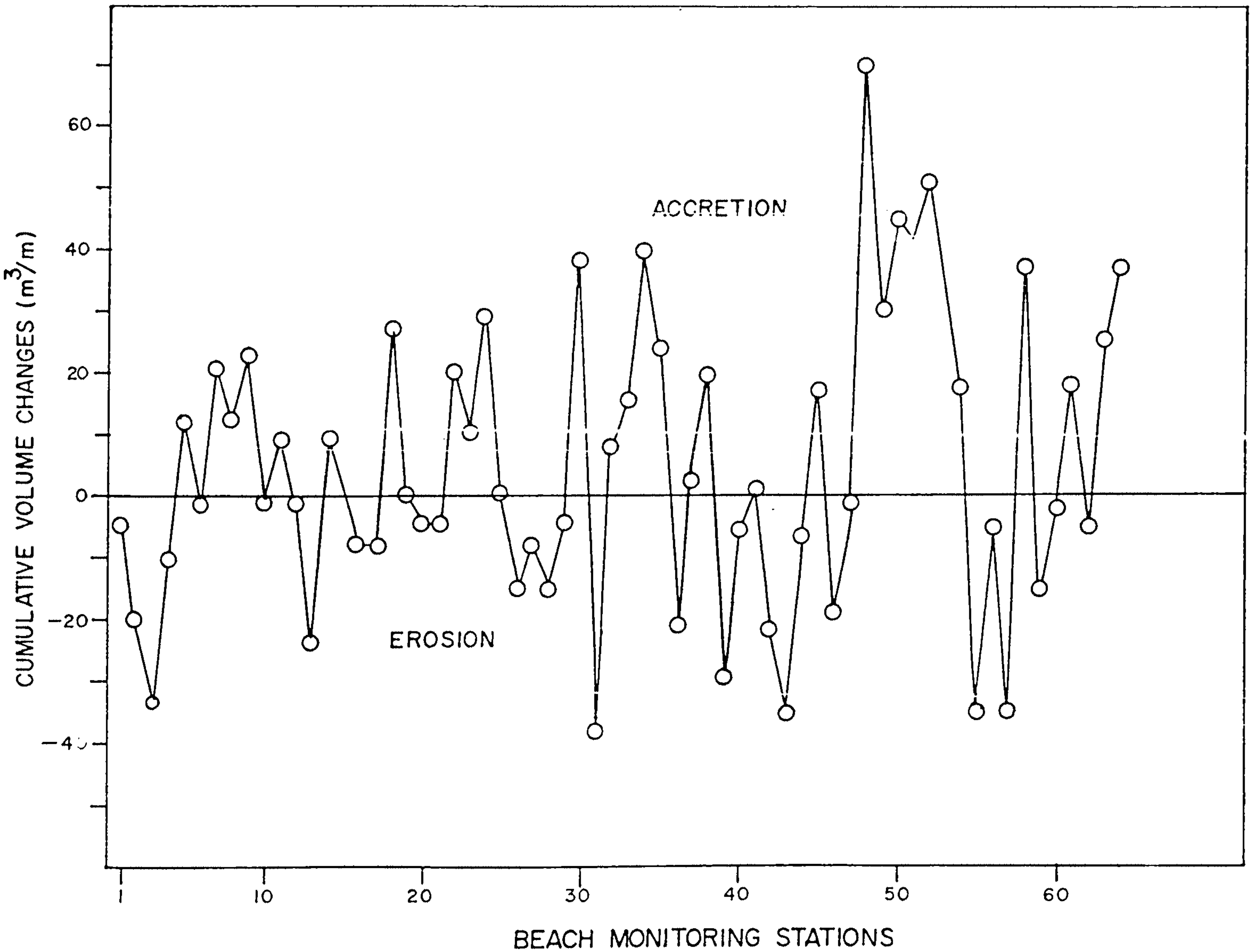


Fig. 2.9. Cumulative beach volume changes during the period between 1980-1982.

parative size analysis indicate statistically significant textural differences between the three distinct populations. It was assumed that the differences in wave regimes during different seasons would impart recognizable characteristics in the grain size distribution of the sediments. Comparisons were made by constructing histograms that are illustrative of the relative frequency distribution of moment measures. The comparative histograms were evaluated in terms of the central tendency, dispersion and symmetry. They are illustrated in figures 2.11 and 2.12 and their associated statistics are presented in the tables 2.6 a and 2.6 b.

In the southern and northern sectors, comparative histograms of mean size (Fig. 2.10 & 2.11) illustrate the progressive increase in grain size from pre-monsoon to monsoon and a subsequent decrease in grain size towards post-monsoon. The pre-monsoon and post-monsoon sands are fine grained, whereas the sands of the monsoon are medium grained. Cessation of monsoon climate can be indirectly inferred from the occurrence of finer sands in the post-monsoon. The plot of mean size shows that there are three distinct populations that can be related to different seasonal changes. The coarsening of sand from pre-monsoon to monsoon and subsequent decrease in the post-monsoon can be explained if the wave energy level differences of the seasons are taken into consideration. In the pre-monsoon, the beach is flatter and formed of fine grained sediments. These beaches, a product of long period swell waves indicate a low energy level. The monsoon

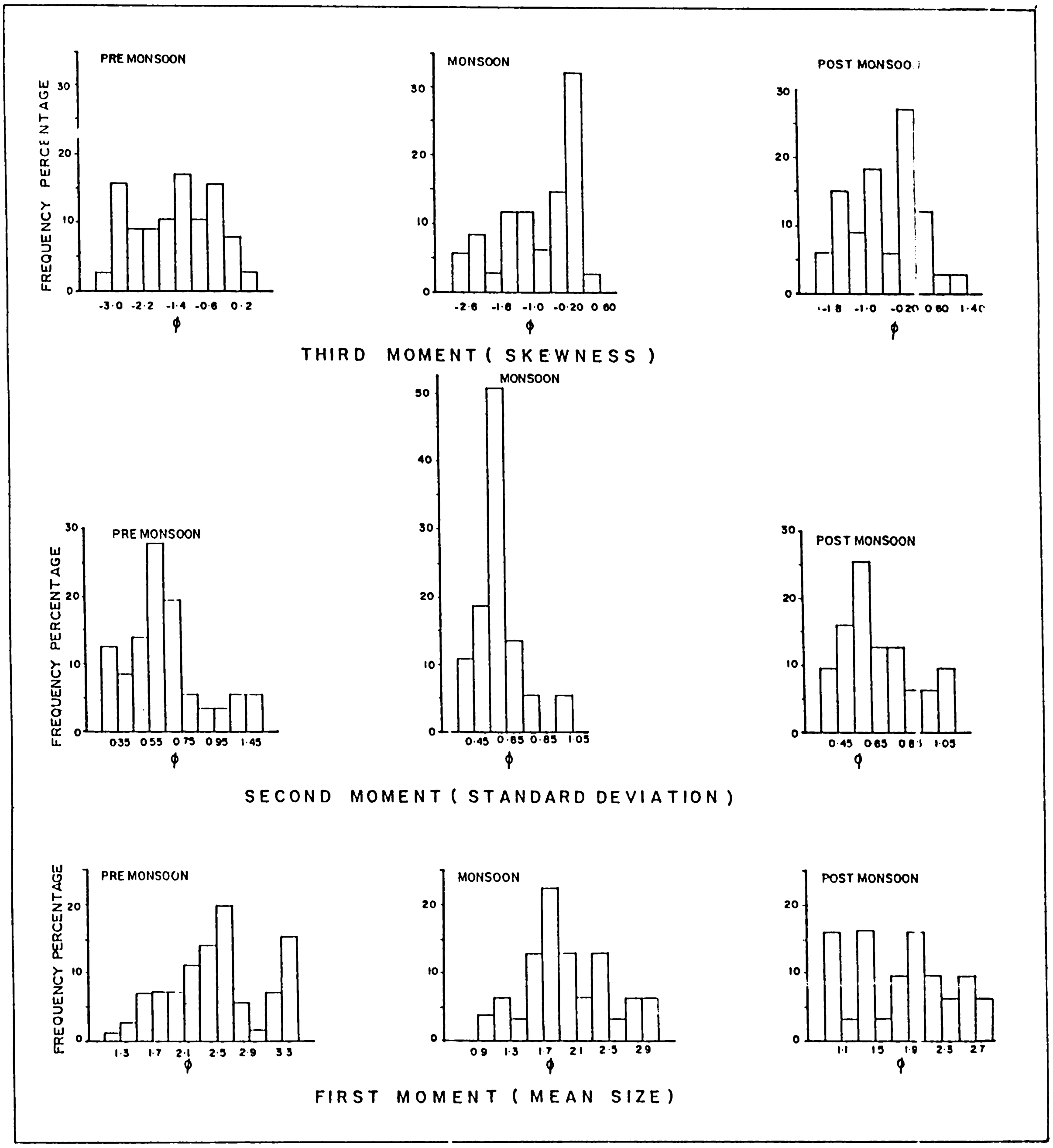


Fig. 2.10. Comparative histograms of mean size, standard deviation and skewness of beach sediments in the southern sector in the pre-monsoon, monsoon and post-monsoon seasons.

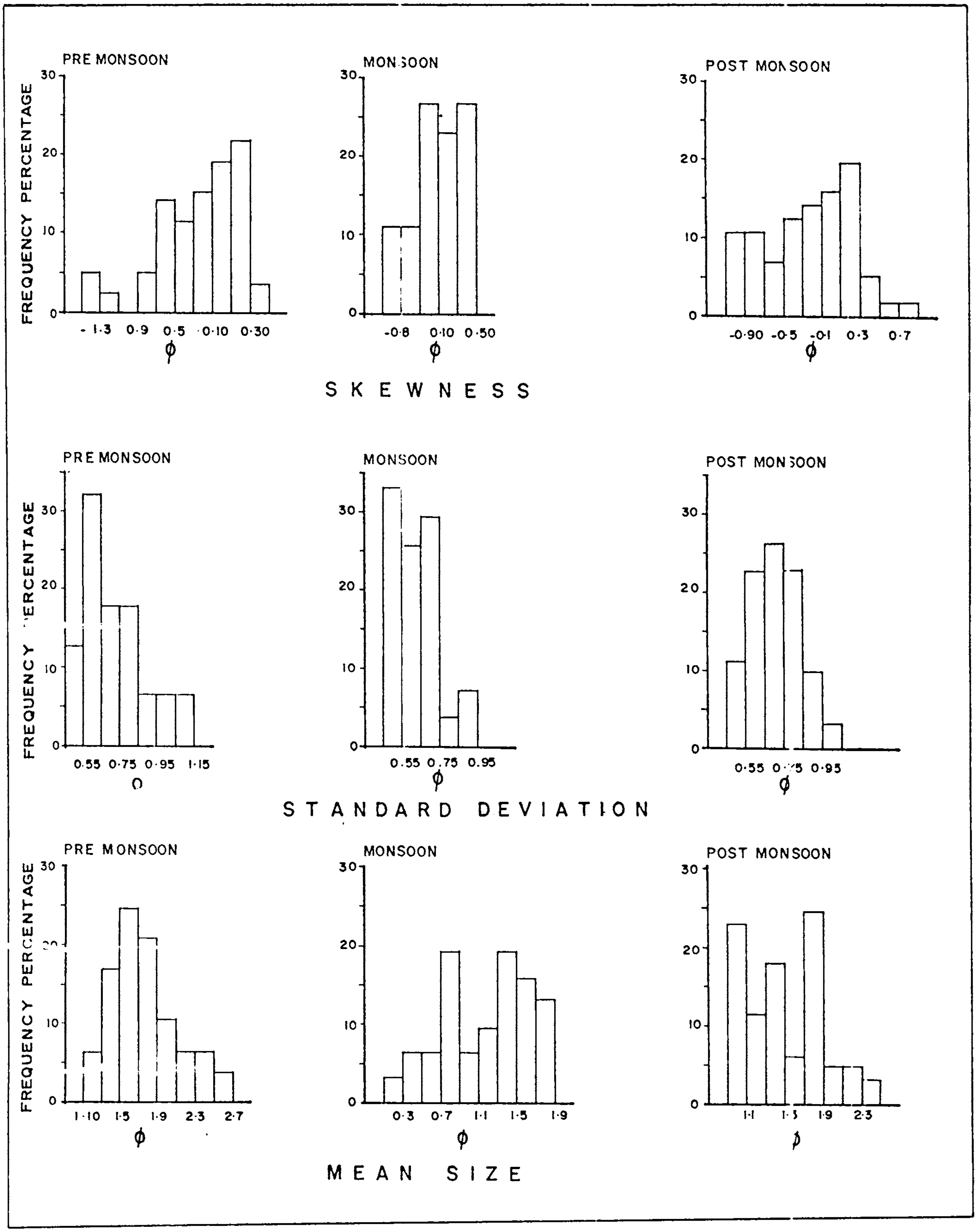


Fig. 2.11. Comparative histograms of mean size, standard deviation and skewness of beach sediments in the northern sector in the pre-monsoon, monsoon and post-monsoon seasons.

season is characterized by a steeper foreshore with short period and higher waves. The high energy character of the monsoon profile is reflected by the occurrence of coarser sands. The steeper foreshore of the monsoon which auguments the back wash, removes the finer sands in suspension leaving behind the coarser material in the beach face. The effect of long period and low energy waves are illustrated by the occurrence of finer sands in the post-monsoon. This wave climate rebuilds the beach in the post-monsoon and appear to have close resemblance to the pre-monsoon sediments. In general the northern sector samples are coarser than that of the southern sector.

The generalization that mean size is a function of amount of wave energy imparted to the sediment hold true for comparison in different seasons. Giles & Pilkey (1965), Gorsline (1966) and King (1972) also noted that the grain size increases as the wave energy increases along a coastline.

The standard deviation (Figs. 2. 10 & 2.11) and skewness show perceptible changes in different seasons. In general, the sands of all seasons are moderately sorted. The monsoonal sands depict comparatively a better sorting than the other seasons. These changes are more pronounced in the northern sector. On comparison, the northern sector samples are found to be better sorted. With the cessation of monsoon, the sorting is again found to be poorer. Folk (1967) noted that there seems to be little differences in sorting between beaches with gentle wave action as those of with vigorous surf. The

Table - 2.6 (b)

SUMMARY OF VARIATION MONTHLY IN BREAKER AND SIZE PARAMETERS AND RATES OF ACCRETION/EROSION IN THE SOUTHERN SIDE

Months of observation	Breaker period (sec)	Breaker height (m)	Long shore current (m/sec)	Fore shore slope (o)	Beach width (m)	Mean size HWL	Mean size PP	Standard deviation HWL	Standard deviation PP	Skewness HWL	Skewness PP	Erosion/ Accre-tion
January 1981	12.65	0.75	0.20	3.97	71.90	2.49	2.33	0.82	0.77	-0.94	-0.33	+0.75
March 1981	15.70	1.10	0.30	3.95	85.00	2.60	2.55	0.54	0.75	-1.24	-1.42	+5.98
May 1981	13.70	1.25	-0.02	4.47	75.00	2.58	2.38	0.58	-0.73	-0.67	-0.77	-1.39
July 1981	10.50	0.80	-0.35	4.18	66.45	2.15	1.93	0.62	0.76	-0.66	-0.41	-15.15
September 1981	13.60	0.30	0.08	4.13	71.89	2.22	1.67	0.65	0.76	-0.47	-0.23	-7.50
November 1981	14.20	0.28	0.11	3.56	83.21	1.81	1.77	0.81	0.82	-0.16	-0.18	-6.17
February 1982	12.90	0.50	0.28	2.55	85.40	2.71	2.74	0.65	0.66	-1.47	-1.68	+10.44
March 1982	12.20	1.00	0.13	2.08	93.40	2.46	2.87	0.80	0.75	-1.13	-2.04	+14.31
May 1982	12.10	0.85	0.14	3.99	72.60	2.29	2.50	0.64	0.76	-0.83	-1.08	+9.30
July 1982	12.00	1.25	-0.16	4.74	66.10	2.15	2.26	0.57	0.72	-0.50	-0.62	-8.40
October 1982	14.10	1.00	-0.27	3.89	72.53	2.19	2.22	0.76	0.82	-0.72	-1.19	+3.14

HWL - highwater line; PP - plunge point; Longshore current : Positive sign indicate northerly current; negative sign indicate southerly current; Erosion/accretion : positive represent accretion ; negative represent erosion.

Table - 2.6 (a)

SUMMARY OF AVERAGE MONTHLY VARIATION IN BREAKER AND SIZE PARAMETERS AND RATES OF ACCRETION/EROSION IN THE NORTHERN SIDE

Months of observation	Breaker period (sec)	Breaker height (m)	Long shore current (m/sec)	Fore shore slope (o)	Beach width (m)	Mean size		Standard deviation		Skewness		Erosion/ Accretion
						HWL	PP	HWL	PP	HWL	PP	
January 1981	13.7	1.00	0.15	7.30	72.50	1.75	1.72	0.64	0.91	+0.07	-0.25	-0.36
March 1981	14.3	1.15	0.22	5.70	84.14	1.90	1.62	0.63	0.86	-0.01	-0.40	+3.53
May 1981	12.2	1.85	0.02	5.35	82.67	1.97	1.76	0.59	0.35	+0.04	-0.24	-2.33
July 1981	11.5	2.35	-0.34	7.84	64.28	1.32	1.12	0.66	0.79	+0.16	-0.00	-20.86
September 1981	12.7	1.00	0.14	6.75	75.46	1.63	1.76	0.68	0.85	-0.17	-0.61	-0.34
November 1981	13.3	0.80	0.23	6.55	66.30	1.51	0.98	0.71	0.83	-0.02	-0.04	+4.34
February 1982	12.3	1.00	-0.33	5.10	71.22	1.78	1.77	0.77	0.84	-0.04	-0.37	+4.61
March 1982	15.6	1.70	0.16	5.24	72.00	1.91	1.74	0.80	0.96	-0.30	-0.75	+7.33
May 1982	12.5	1.70	0.39	4.47	93.18	1.90	1.76	0.74	0.97	-0.20	-0.66	+6.39
July 1982	11.4	2.15	-0.28	9.10	51.55	1.57	0.78	0.66	0.80	+0.29	+0.31	-17.08
October 1982	15.7	1.65	0.40	7.13	69.52	1.66	1.33	0.76	0.92	-0.39	-0.31	+4.04

HWL - highwater line; PP - plunge point; Longshore current; Positive indicate northerly current; negative indicate southerly current; Erosion/accretion: Positive represent accretion; negative represent erosion.

skewness values show perceptible changes in different seasons. The erosive phase are less negatively skewed than the other seasons (Fig. 2.10 & 2.11).

2.2.1.2.6. **Correlation matrix**

Average monthly variation of the wave and size parameters were correlated to understand the inter-relationship between the variables and to assess their responses to erosion and accretion. High negative and positive loadings (> ± 0.50) were considered to work out the meachanism of beach stability. The correlation matrix of different sedimentological and physical parameters for the southern and northern sectors are given in table 2.7 a and 2.7 b. From the significant positive and negative correlations, the response of the coastline and beach material to the physical processes were inferred.

Breaker period shows a positive correlation with longshore current, sorting of the sediments in the plunge point and erosion/ accretion. It is inferred that under the influence of the swell wave conditions and lesser frequency of waves in the pre-monsoon and post-monsoon seasons, the northerly longshore current velocity generally increases and the beaches are accreted. Further, these lesser frequent waves show negative correlation with skewness both in the plunge point and high water line (HWL). The swell waves that transport wide range of particles ranging between finer to coarser sands to the beach environment would make the population a negatively skewed distribution.

Table - 2.7 (a)

MATRIX OF CORRELATION (NORTHERN SIDE)

Parameters	Breaker period	Breaker height	Long shore current	Fore shore slope	Beach width	Mean size (HWL)	Mean size (PP)	Sort-ing (HWL)	Sort-ing (PP)	Skew-ness (HWL)	Skew-ness (PP)	Erosion/ Accretion
Breaker period	1.00											
Breaker height	-.29	1.00										
Longshore current	0.69	-.36	1.00									
Foreshore slope	-.25	0.31	-.37	1.00								
Beach width	0.18	-.24	0.56	-.83	1.00							
Mean size (HWL)	0.35	-.11	0.39	-.75	0.71	1.00						
Mean size (PP)	0.27	-.35	0.30	-.76	0.78	0.75	1.00					
Sorting (HWL)	0.46	-.12	0.21	-.33	-.05	0.05	0.11	1.00				
Sorting (PP)	0.66	-.20	0.60	-.38	0.37	0.37	0.39	0.66	1.00			
Skewness (HWL)	-.76	0.25	-.72	0.54	-.45	-.37	-.48	-.68	-.71	1.00		
Skewness (PP)	-.50	-.04	-.34	0.68	-.51	-.63	-.43	-.43	-.58	0.44	1.00	
Erosion/ Accretion	0.62	-.63	0.69	-.80	0.65	0.72	0.66	0.41	0.55	-.74	-.55	1.00

HWL - Highwater line; FP - Plunge point.

Table - 2.7 (b)

MATRI . OF CORRELATION (SOUTHERN SIDE)

Parameters	Breaker period	Breaker height	Long shore current	Fore shore slope	Beach width	Mean size (HWL)	Mean size (PP)	Sort-ing (HWL)	Sort ing (PP)	Skew-ness (HWL)	Skew-ness (PP)	Erosion/ Accretion
Breaker period	1.00											
Breaker height	-.04	1.00										
Longshore current	0.45	-.28	1.00									
Foreshore slope	0.30	0.29	-.46	1.00								
Beach width	0.40	-.14	0.65	-.85	1.00							
Mean size (HWL)	-.20	0.18	0.16	-.72	0.64	1.00						
Mean size (PP)	0.00	0.52	0.40	-.55	0.54	0.52	1.00					
Sorting (HWL)	-.03	-.42	0.08	-.50	0.30	0.39	-.04	1.00				
Sorting (PP)	0.24	-.16	-.32	0.21	-.14	-.06	-.49	0.53	1.00			
Skewness (HWL)	-.05	-.22	-.51	0.57	-.51	-.32	-.84	0.13	0.60	1.00		
Skewness (PP)	-0.10	-.36	-.33	0.70	-.69	-.62	-.90	0.04	0.40	0.80	1.00	
Erosion/ Accretion	0.25	0.16	0.62	-.69	0.71	0.52	0.86	0.19	-.25	-.74	-.86	1.00

HWL - Highwater line; PP - plunge point.

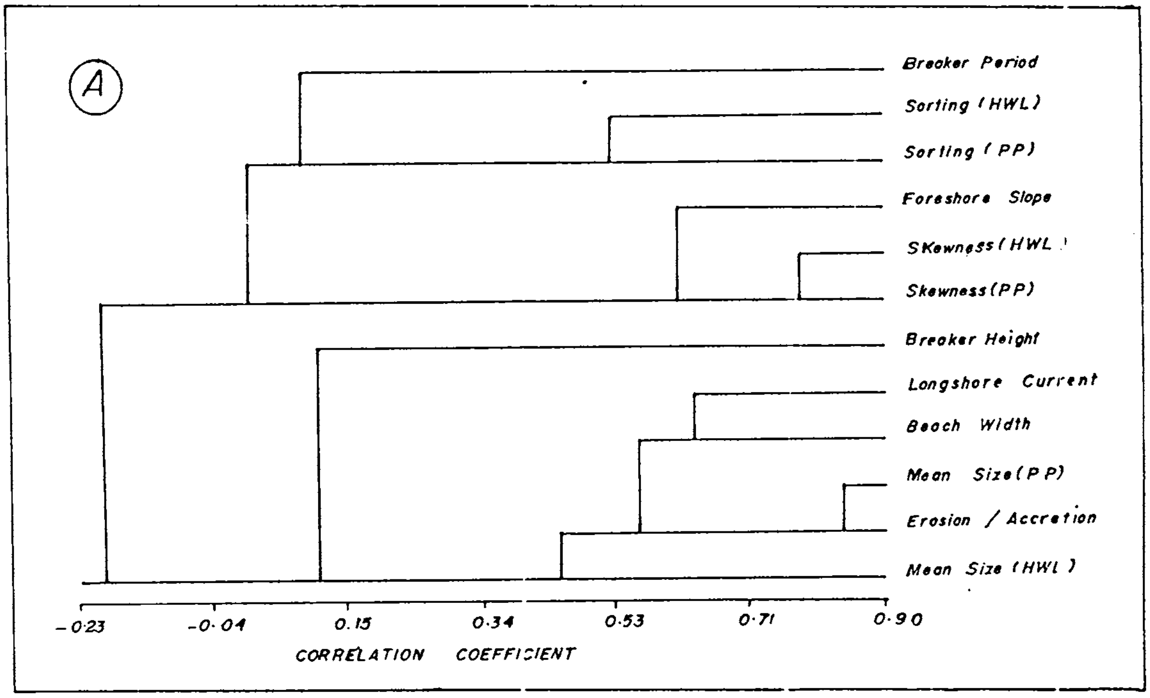
As naturally expected, high breakers are the ultimate cause of erosion on the beaches. The longshore current shows a positive correlation with beach width, sorting and skewness. The northerly and southerly longshore currents are generally represented by positive and negative sign respectively. When the northerly longshore current increases in intensity, the beaches are generally wider and show an increase in the accretion rate. This inturn imparts a negative skewness to the poorly sorted sediments.

The foreshore slope shows a negative correlation with beach width and mean size of the plunge point and high water line samples and a positive correlation with skewness. It denotes that during the eroding season, when the beach width is reduced the grain size becomes coarser and the foreshore steeper. However with an increase in foreshore slope the sediment becomes less negatively skewed.

In general, the high water line sediments are finer than that of the plunge point. However, during accretionary state, fineness of the high water line sediments increases. The negatively skewed and better sorted nature of the plunge point sediments may be attributed to the littoral processes, where the finer sediments are removed in suspension from the plunge point and transported and deposited to in the high water line by the action of the swash.

On the contrary, the net effect of the littoral processes during the erosive phase is removal of the sediments from the beach environment. By comparing the moment measure statistics, it can be inferred that during the erosive and depositional phase the removal/deposition of sediments are triggered by the nature of the foreshore, owing to its modification by the infiltration capacity of the swash. By virtue of the lesser energy and lesser gradient of foreshore, the momentum transfer mechanism of the backwash is reduced to a minimum in the pre-monsoon and post-monsoon seasons. This imparts a less effective infiltration which is ineffective in removing the sediments from the high water line. Coupled with the increase in water table height, the high precipitation and recharge causes the saturation of the landward side of the beach in the monsoon. Because of the oversaturation and higher gradient of the upper foreshore, the infiltration of swash is reduced to minimum. The overflow of water along the steeper foreshore augments the momentum of the backwash velocity. In such cases, the water saturated foreshore and backshore sediments are easily erodable owing to the gravity creep on a steeper surface.

To characterize different parameters into definite groupings dendrograms were drawn for the southern and northern sectors (Fig. 2.12). The clustering indicate that in response to the northerly longshore currents the beaches show an accretionary trend. This inturn influences the beach topography by illustrating a wide beach with fine grained sediments. The skewness (high water line and plunge point) and foreshore slope has indirect correlation with accretion. The accreted zones are characterized by a lesser gradient of foreshore and negatively skewed sediments. The eroded zones are characterized by higher gradient of foreshore and less negatively skewed sediments.



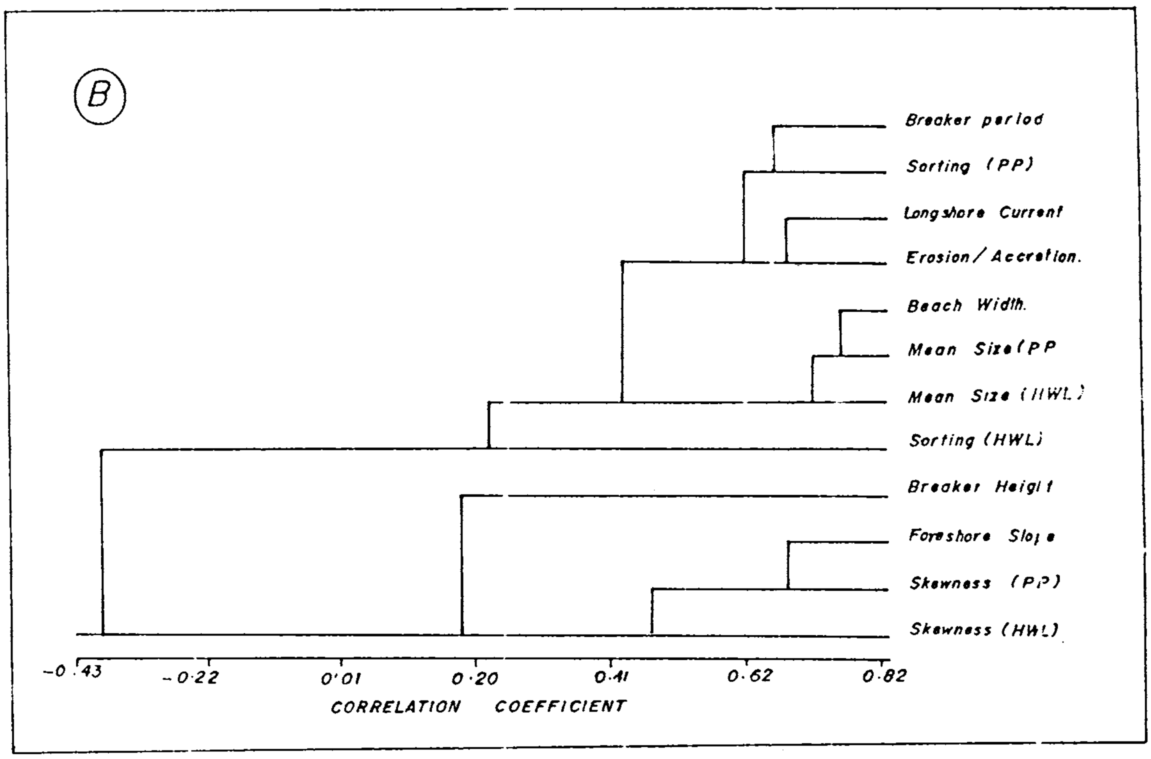


Fig. 2.12. Dendrogram illustrating the inter-relationship among the size and wave parameters in the (a) southern sector and (b) northern sector.

In the northern sector, the loading of some of the variables show slight deviation from that of the southern sector. Whereas the longshore currents, mean size, skewness and beach width show sympathetic relationships in both the sectors.

The marginal differences in the process - response of the southern and northern sectors can be attributed to its geomorphic settings. The Ezhimala promontary acts as a barrier to the sediments that are transported along the shore. Wave divergence at the promontary (Reddy and Varadachari, 1973), makes the southern sector a low energy area thus favouring the deposition of the fine sands. This makes the northern part adjoining the headland a coarse grained beach with the accumulation of lag deposits. In the northern sector with numerous small rivers draining into the sea, the influx of sediments are considerable in all the seasons especially during monsoon.

Scrutinizing the above trends in the sediment distribution in different seasons, it is inferred that the beaches behave in a seasonal manner in response to the changes in wave energy. In Sandy Hook beaches, Nordstorm (1977) considered energy and mobility as critical factors in determining whether the beach has behaved in a seasonal or cyclic manner. Energy referred to wave energy and mobility to the inputs of sediments into the system by any source (wind, wave and current) with resulting changes in foreshore, grain size and other response variables. The three season sands can thus be classified as follows:

Table - 2.8 (a)

MOMENT MEASURE DATA FOR BEACH SEDIMENTS FROM MAHE - PAYANGADI COAST (SOUTHERN SIDE) COLLECTED DURING 1981

Sl.No.	Mean size	Standard deviation	Skewness	Mean size	Standard deviation	Skewness
	January					
	High Water Line			Plunge Point		
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	2.42	0.68	-0.94	3.15	0.46	-2.39
2.	2.43	0.64	-1.24	2.62	1.25	-1.74
3	3.39	0.64	-2.46	3.22	0.70	-2.49
4	3.31	0.39	-2.17	-	-	-2.40
5	3.26	0.45	-2.43	2.25	0.78	-2.27
6	2.15	1.37	-1.10	1.81	0.73	-2.52
7	2.50	0.73	-1.07	3.07	0.44	-
8	1.49	0.89	-0.13	2.61	0.78	0.03
9	2.73	0.56	-1.35	2.87	0.58	-2.61
10	2.75	0.52	-1.58	2.60	0.59	-1.84
	March					
1	2.04	1.01	-0.46	3.19	0.61	-2.39
2	1.72	1.31	-0.55	2.62	1.46	-1.74
3	3.33	0.63	-2.83	3.22	0.65	-2.49
4	3.30	0.43	-2.59	-	0.61	-2.40
5	2.32	0.96	-1.19	2.25	0.91	-2.27
6	2.33	0.99	-0.91	1.81	0.52	-2.52
7	2.57	0.77	-0.72	3.07	-	-
8	2.80	0.55	-1.00	2.61	0.82	0.03
9	2.02	0.80	-0.25	2.87	0.73	-2.61
10	1.85	0.75	0.12	2.60	0.82	-1.84

Table 2.8 (a) contd.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
			May			
1	2.56	0.56	-0.99	2.45	1.03	-1.21
2	1.30	0.66	-0.35	2.65	0.74	-1.26
3	3.08	0.54	-1.81	3.17	0.85	-2.18
4	3.26	0.30	-3.95	3.27	0.40	-4.07
5	-	0.00	-	2.20	1.15	-1.63
6	1.42	0.36	-0.09	1.42	0.86	-0.09
7	2.89	0.45	-1.06	2.85	0.51	-1.37
8	1.85	0.70	0.60	2.15	0.77	0.09
9	1.91	0.68	0.11	2.74	0.66	-0.90
10	2.26	0.76	-0.50	2.19	0.62	-0.20
			July			
1	-	-	-	2.57	0.86	-1.94
2	0.19	0.60	1.20	-	-	-
3	3.09	0.44	-2.52	2.94	0.62	-1.35
4	3.21	0.43	-2.64	2.85	0.69	-1.36
5	2.58	0.58	-1.27	1.32	0.78	0.70
6	2.26	0.70	-0.57	2.15	0.88	-0.49
7	2.88	0.39	-2.20	2.63	0.55	-0.57
8	1.95	0.65	0.50	2.13	0.68	-0.11
9	1.79	0.50	0.36	1.77	0.64	0.27
10	1.80	0.60	0.42	1.99	0.73	-0.31

Table 2.8 (a) contd.

September

1	2.59	0.77	1.21	2.70	0.5[illegible]	-1.78
2	0.53	1.16	1.30	0.27	1.5[illegible]	1.16
3	2.63	0.93	1.14	3.00	0.78	-2.08
4	2.93	0.37	1.93	-	-	-
5	2.72	0.57	1.51	2.84	0.71	-1.83
6	1.32	0.98	0.07	2.31	0.79	-1.20
7	2.64	0.54	-1.34	2.78	0.6[illegible]	-1.41
8	-	-	-	-	-	-
9	-	-	-	-	-	-
10	-	-	-	-	-	-

Table - 2.8 (b)

MOMENT MEASURE DATA FOR BEACH SEDIMENTS FROM ETTIKULAM - TALAPADY COAST (NORTHERN SIDE) COLLECTED DURING 1981

	Highwater Line			Plunge Point		
Sl.No. (1)	Mean size (2)	Standard deviation (3)	Skewness (4)	Mean size (5)	Standard deviation (6)	Skewness (7)
January						
1	1.74	0.66	-0.10	1.22	0.79	0.44
2	1.63	0.63	0.04	1.44	1.21	0.28
3	2.05	0.58	0.04	2.48	0.60	-0.59
4	2.37	0.69	-0.17	2.71	0.84	-0.52
5	1.53	0.69	-0.02	1.31	0.90	0.18
6	2.17	0.62	-0.42	2.47	0.86	-1.39
7	1.49	0.64	0.09	1.09	0.91	0.27
8	1.96	0.62	0.22	1.99	0.71	-0.34
9	1.97	0.63	0.38	1.83	1.00	-0.18
10	1.64	0.56	0.08	1.84	1.19	-0.27
11	1.68	0.61	0.41	1.83	0.74	-0.26
12	1.81	0.67	0.33	2.05	0.89	-0.30
13	1.18	0.77	0.02	2.07	1.18	-0.62
March						
1	1.31	0.64	0.23	0.91	0.89	0.42
2	2.20	0.58	0.09	2.53	0.69	-0.61
3	2.23	0.63	0.01	1.95	1.07	-0.27
4	2.11	0.60	0.22	-	-	-
5	2.59	0.58	-1.11	1.94	1.08	-0.51
6	1.59	0.66	-0.22	1.75	0.99	-0.45

Table 2.8 (b) contd.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
7	1.74	0.66	-0.14	1.15	1.01	0.00
8	1.98	0.62	-0.06	2.23	0.75	-1.34
9	1.55	0.85	0.12	2.13	1.12	-1.09
10	2.43	0.55	-0.79	1.85	1.24	-0.70
11	1.46	0.57	0.15	1.80	0.65	-0.13
12	1.60	0.56	0.32	1.31	0.80	-0.15
13	-	-	-	1.55	0.91	-0.41
			May			
1	-	-	-	0.94	0.86	-0.02
2	-	-	-	2.13	0.80	-0.82
3	2.39	0.59	-0.17	2.65	0.65	-1.31
4	2.22	0.53	-0.14	2.12	0.66	-0.25
5	2.57	0.47	-0.06	2.40	0.57	-0.45
6	-	-	-	1.84	0.70	0.22
7	1.57	0.70	0.14	0.94	0.99	0.12
8	1.73	0.67	0.02	2.03	0.56	-0.17
9	2.05	0.58	-0.32	-	-	-
10	1.96	0.65	0.34	-	-	-
11	-	-	-	1.84	0.56	0.39
12	-	-	-	1.26	0.34	0.02
13	1.29	0.52	0.53	1.16	1.09	0.40
			July			
1	0.63	0.71	0.08	0.90	0.51	0.00
2	1.46	0.56	0.79	1.74	0.59	0.72
3	2.15	0.65	-0.15	0.97	0.56	-0.13
4	1.46	0.69	0.46	1.82	0.56	0.41

Table 2.8 (b) contd.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
5	0.61	0.94	0.11	1.48	0.65	0.35
6	0.84	0.31	0.41	0.52	1.04	0.28
7	1.17	0.95	-0.10	-	-	-
8	2.14	0.80	-1.42	1.79	0.73	-0.38
9	-	-	-	1.37	0.70	-0.39
10	-	-	-	-	-	-
11	0.52	0.87	-0.36	1.60	0.54	0.45
12	0.25	0.92	0.18	0.97	0.65	0.24
13	-	-	-	-	-	-
			September			
1	-	-	-	-	-	-
2	1.21	0.57	0.22	1.01	0.76	0.02
3	2.51	0.63	-1.38	1.67	1.03	-0.62
4	1.59	0.63	0.10	1.76	0.85	-0.89
5	1.83	0.73	-0.24	1.94	0.91	-0.96
6	-	-	-	2.40	0.74	-1.84
7	1.59	0.64	-0.07	1.87	0.79	-0.66
8	1.89	0.87	-0.65	2.50	0.54	-0.70
9	1.41	0.69	0.18	1.10	1.09	-0.42
10	1.71	0.62	0.24	1.92	0.76	-0.33
11	1.08	0.83	-0.36	1.83	0.97	-0.11
12	1.48	0.62	0.29	1.31	0.86	-0.25
13	-	-	-	-	-	-
			November			
1	1.80	0.52	0.30	1.23	0.45	0.96
2	1.53	0.65	0.27	1.14	0.79	0.27
3	1.42	0.86	-0.02	1.12	0.94	0.16

Table 2.8 (b) contd.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
4	1.17	0.74	0.05	1.21	0.34	-0.02
5	1.41	0.66	0.07	2.18	0.63	-0.73
6	-	-	-	-	-	-
7	1.06	0.84	0.47	1.16	0.34	0.19
8	1.90	0.80	-0.69	1.85	0.32	-0.62
9	1.82	0.55	-0.05	1.04	0.30	0.07
10	1.52	0.58	-0.04	1.82	0.35	0.31
11	1.48	0.70	-0.40	1.28	0.69	0.35
12	1.04	0.74	0.42	1.48	1.00	0.15
13	2.24	0.67	-0.31	1.55	0.91	-0.09

Table -2.8 (c)

MOMENT MEASURE DATA FOR BEACH SEDIMENTS FROM MAHE-PAYANGADI COAST (SOUTHERN SIDE) COLLECTED DURING 1982

			February			
	Highwater Line			Plunge Point		
S.No.	Mean size	Standard deviation	Skewness	Mean size	Standard deviation	Skewness
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	2.42	0.68	-0.94	3.15	0.46	-2.90
2	2.43	0.64	-1.24	2.62	1.25	-2.13
3	3.39	0.64	-2.46	3.22	0.70	-2.01
4	3.31	0.39	-2.17	-	-	-
5	3.26	0.45	-2.43	2.25	0.78	-0.82
6	2.15	1.37	-1.10	1.81	0.73	-0.03
7	2.50	0.73	-1.07	3.07	0.44	-1.60
8	1.49	0.89	-0.13	2.61	0.78	-1.09
9	2.75	0.56	-1.35	2.87	0.58	-2.71
10	2.75	0.52	-1.58	2.60	0.59	-1.76
			March			
1	2.04	1.01	-0.46	3.19	0.61	-2.39
2	1.72	1.31	-0.55	2.55	1.46	-1.76
3	3.33	0.63	-2.88	3.38	0.65	-2.49
4	3.30	0.43	-2.59	3.19	0.61	-2.40
5	2.32	0.96	-1.19	2.73	0.91	-2.27
6	2.33	0.99	-0.91	3.04	0.52	-2.52
7	2.57	0.77	-0.72	-	-	-
8	2.80	0.55	-1.00	2.09	0.82	0.03
9	2.02	0.80	-0.25	2.83	0.73	-2.61
10	1.85	0.75	0.12	2.61	0.82	-1.84

Table 2.8 (c) contd.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
			May			
1	2.56	0.66	-0.99	2.45	1.03	-1.21
2	1.30	0.66	-0.35	2.65	0.74	-1.26
3	3.08	0.54	-1.81	3.17	0.85	-2.18
4	3.26	0.30	-3.95	3.27	0.40	-4.07
5	-	-	-0.09	2.20	1.15	-1.63
6	1.42	0.86	-1.06	1.42	0.85	-0.09
7	2.89	0.45	0.60	2.85	0.56	-1.37
8	1.85	0.70	0.11	2.15	0.77	0.09
9	1.91	0.68	-0.50	2.74	0.65	-0.90
10	2.26	0.76	-0.56	2.19	0.62	-0.20
			July			
1	-	0.60	1.20	2.57	0.85	-1.94
2	0.19	0.44	2.52	-	-	-
3	3.09	0.43	-2.24	2.94	0.62	-1.35
4	3.21	0.58	-1.27	2.85	0.69	-1.36
5	2.58	0.70	0.57	1.32	0.73	0.70
6	2.26	0.39	-2.20	2.15	0.88	-0.49
7	2.88	0.65	0.50	2.63	0.55	-0.59
8	1.95	0.56	0.36	2.13	0.68	-0.11
9	1.79	0.60	0.42	1.77	0.64	-0.27
10	1.86	-	-	1.99	0.73	-0.31
			October			
1	2.55	0.77	-2.21	2.70	0.51	-1.78
2	0.53	1.16	1.30	0.27	1.51	1.16
3	2.63	0.93	-1.14	3.00	0.78	-2.08

Table 2.8 (c) contd.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
4	2.93	0.37	-1.93	-	-	-
5	2.72	0.57	-1.51	2.84	0.71	-1.83
6	1.32	0.98	0.07	2.31	0.79	-1.20
7	2.64	0.54	-1.34	2.78	0.61	-1.40

Table - 2.8 (d)

MOMENT MEASURE DATA FOR BEACH SEDIMENTS FROM PAYANGADI - TALAPADY COAST (NORTHERN SIDE) COLLECTED DURING 1982

	Highwater Line			Plunge Point		
Sl.No.	Mean size	Standard deviation	Skewness	Mean size	Standard deviation	Skewness
(1)	(2)	(3)	(4)	(5)	(6)	(7)
February						
1	2.86	0.82	-1.48	1.68	0.76	0.16
2	1.62	0.85	-0.03	1.88	0.85	-0.24
3	1.68	1.34	-0.65	1.87	0.77	-0.14
4	1.72	0.74	0.26	2.21	0.79	-0.87
5	1.88	0.73	-0.35	2.30	0.66	-0.62
6	1.87	0.64	0.17	1.46	0.94	-0.21
7	1.83	0.75	-0.07	1.30	1.06	-0.18
8	1.69	0.69	0.32	0.72	1.00	-0.07
9	1.79	0.74	0.06	2.53	0.60	-1.18
10	1.41	0.87	-0.05	2.43	0.77	-1.41
11	1.59	0.58	0.35	0.93	0.97	0.17
12	1.58	0.65	0.27	1.96	0.59	-0.10
13	1.64	0.70	0.26	1.17	0.95	-0.14
14	1.73	0.69	0.70	1.71	1.04	-0.32
March						
1	2.12	0.82	-0.40	2.01	0.71	0.10
2	2.60	0.62	-2.62	1.62	0.88	0.15
3	2.23	1.12	-1.37	1.83	-0.82	-0.12
4	2.10	0.96	-0.77	1.64	0.79	0.40
5	2.28	0.81	-0.93	2.30	0.62	-0.44
6	2.12	1.20	-1.34	1.86	0.99	-0.50

Table 2.8 (d) contd.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
7	1.08	1.01	-0.34	1.66	0.87	-0.19
8	2.22	0.97	-1.37	1.87	0.90	-0.57
9	1.93	0.94	-0.38	3.05	0.50	-1.53
10	2.21	0.77	-0.77	2.26	0.64	-0.45
11	0.73	1.11	0.36	1.45	0.89	-0.20
12	1.93	0.81	-0.25	2.13	0.83	-0.39
13	0.04	1.28	0.42	1.62	0.74	-0.13
14	-	-	-	1.49	1.05	-0.27
			May			
1	1.18	0.93	-0.27	2.53	1.06	-1.69
2	1.81	0.74	0.12	2.15	0.90	-1.04
3	1.98	1.01	-0.99	2.52	0.80	-1.19
4	2.01	0.69	-0.27	2.05	0.89	-0.94
5	2.41	0.69	-0.63	1.59	1.12	-0.16
6	1.81	0.77	0.12	1.90	0.81	0.11
7	1.97	0.77	-0.05	2.42	1.02	-1.40
8	1.18	0.93	0.01	0.53	0.99	0.02
9	2.42	0.62	-0.97	1.83	1.02	-0.73
10	2.26	0.70	-0.64	2.03	0.86	-0.44
11	1.94	0.63	0.32	1.80	0.88	-0.25
12	2.22	0.60	-0.32	2.01	0.82	-0.27
13	1.62	0.69	0.54	1.87	0.96	-0.37
14	1.75	0.85	-0.33	1.50	1.40	-0.84
			July			
1	1.13	0.51	0.51	0.70	0.70	0.26
5	1.46	0.71	0.30	0.84	0.88	0.56
6	1.25	0.52	0.54	0.54	0.80	-0.46

Table 2.8 (d) contd.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
7	1.82	0.76	0.08	1.46	0.74	0.47
8	1.55	0.79	0.04	0.72	0.79	-0.04
9	2.02	0.52	0.01	0.62	0.75	2.15
10	1.62	0.60	0.37	0.58	0.90	0.03
11	1.79	0.78	0.05	1.21	0.87	0.26
12	1.75	0.75	0.33	0.72	0.77	-0.45
13	1.27	0.56	0.69	0.47	0.75	0.34
			October			
1	1.03	0.72	0.34	0.49	0.91	0.75
2	1.34	0.63	0.52	0.68	0.89	0.09
3	0.94	0.80	0.16	1.05	0.93	0.13
4	1.24	0.83	0.15	2.51	0.54	-1.52
5	2.01	0.77	-0.67	2.13	0.86	-0.93
6	1.12	0.85	0.20	0.47	1.06	-0.07
7	2.13	0.75	-0.83	1.02	0.96	-0.22
8	1.70	0.83	-0.10	0.65	1.24	0.33
9	2.39	0.65	-0.92	2.22	0.65	-0.45
10	1.82	0.87	-0.49	0.65	1.14	-0.12
11	1.87	0.95	-0.83	2.81	0.62	-1.80
12	1.96	0.75	-0.50	1.21	0.72	-0.01
13	1.13	0.46	-2.00	0.67	1.15	-0.12
14	1.98	0.74	-0.45	1.51	1.16	0.46

1. Pre-monsoon : Low energy : High mobility
2. Monsoon : High energy : Very low mobility
3. Post-monsoon : Low energy : High mobility

In Sandy Hook beaches the differences in grain size distribution are attributed largely to its provenance, where Nordstorm (1977) has noted that the high energy beaches have higher proportions of fines than the low energy beaches. Contrary to this observation, along the northern Kerala coast the decrease in energy in post-monsoon and pre-monsoon resulted in a fine grained beach with a flatter foreshore. On the other hand in the monsoon season with greater energy available for the dispersal of sediments, the beach is steeper and coarser. A low degree relationship between grain size and wave energy on beach foreshore was also noted by Engström (1974). A decrease in beach mobility indicate a limited input of sediments to the system. The low mobility of the sediments in the monsoon seasons is reflected by the occurrence of moderately well sorted and coarser sediments. This observation is not in agreement with Nordstorm, who noted that 'higher wave heights and longer waves periods result in a flatter foreshore which in turn result in a poorly sorted finer sediments. Lower wave height and period result in steeper foreshore slope and low beach mobility result in larger grain size and better sorted sediments'.

2.2.1.2.7. **Sediment transport**

Possible transport directions were inferred using the method of McLaren & Bowles (1985). According to McLaren & Bowles (1985), when any two samples are compared with respect to their moment grain size parameters, viz., mean size, sorting and skewness, eight relationships exists. In reality, only two of the eight possible relationships can be considered based on the 'hydraulic sorting' of the sediment. They are, along the transport direction, the sediment becomes progressively (i) finer, better sorted and more negatively skewed (mentioned as Case B in the model) and (ii) coarser, better sorted and more positively skewed (mentioned as Case C in the model).

Transport directions derived from the moment measures based on 'Z' score indicate a complex dispersal pattern with differing energy regimes in both the sectors at the plunge point and high water line. Table 2.9 a - d gives the summary of pairs producing the transport trends and Fig. 2.13 a & b demonstrates the sediment transport trends worked out for both sectors at the plunge point and high water line during 1981 and 1982. Except for higher energy (case-C) northward flow in the northern sector during January and in the southern sector during November, significant case-C trend does not exist in 1981. Differences in the transport pattern in the south and north sectors are evident from the figure.

In most of the cases the trends at highwater line and plunge point are not similar in the northern side. During the peak monsoon (July), the transport direction is insignificant at the high water line, whereas in the plunge point it shows a southerly direction.

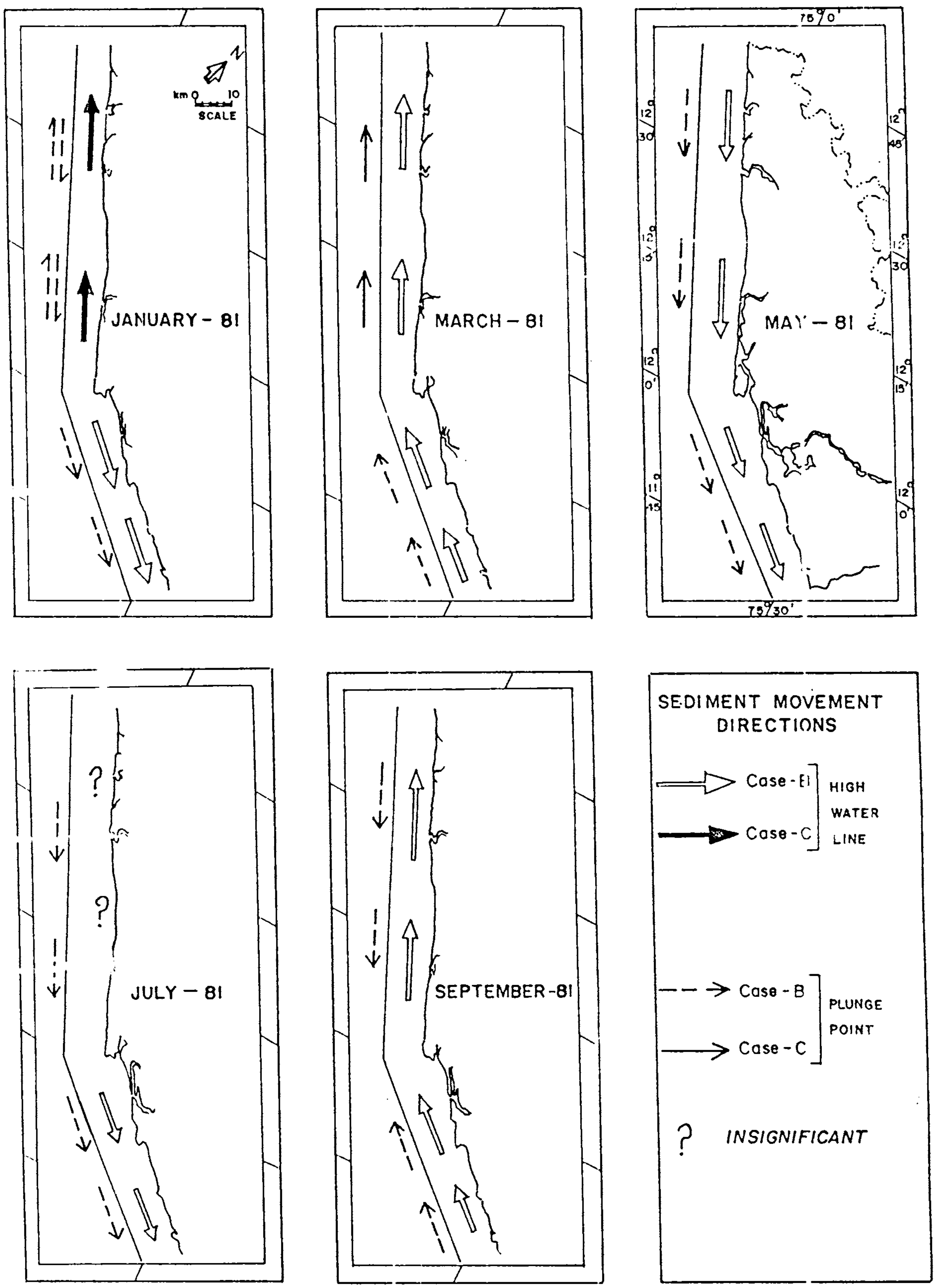


Fig. 2.13 a. Sediment transport patterns (1981) deduced from the grain size analysis.

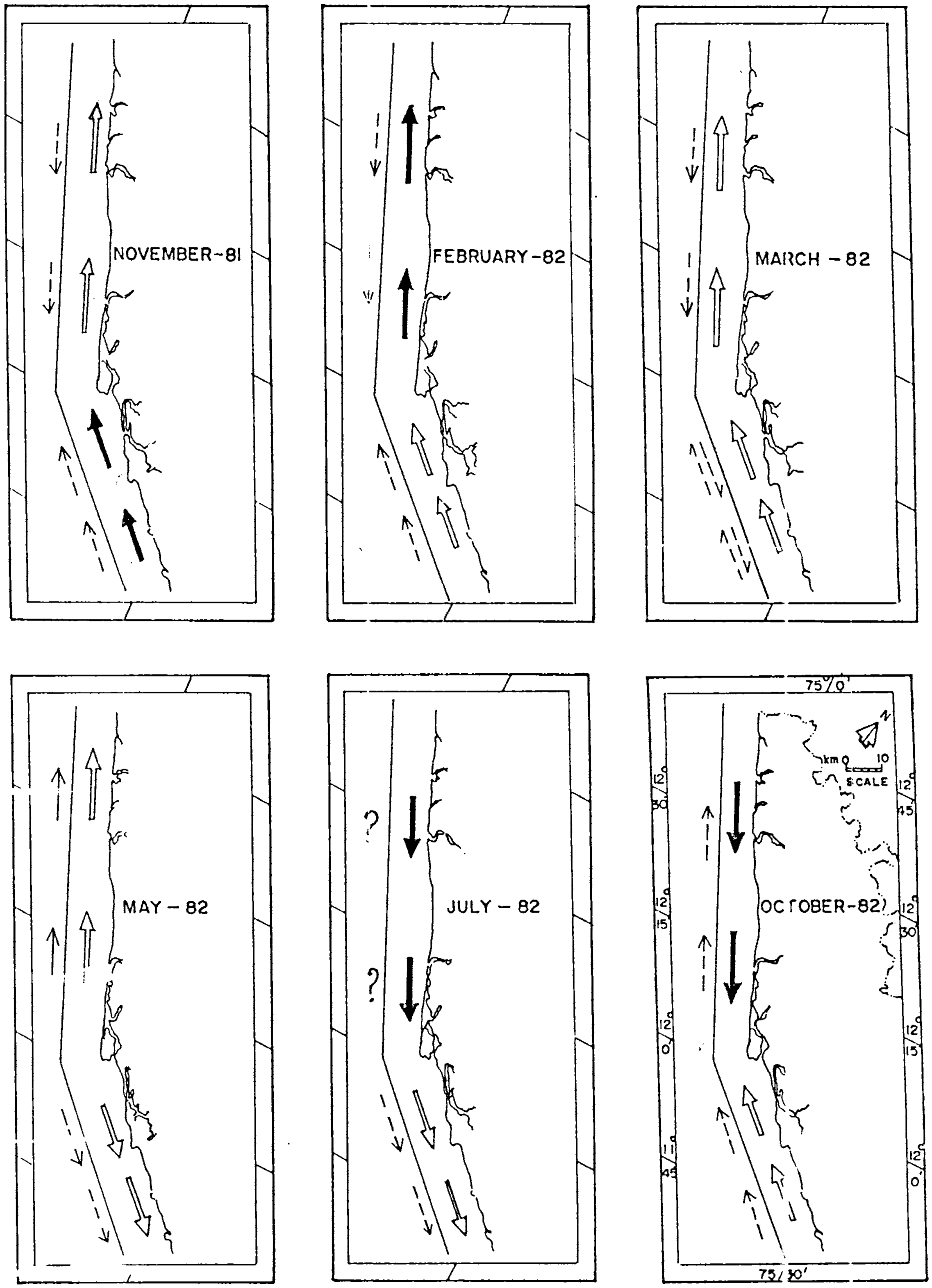


Fig. 2.13 b. Sediment transport patterns (1982) deduced from the grain size analysis.

Table - 2.9 (e)

SUMMARY OF NUMBER OF PAIRS PRODUCING THE TRANSPORT TRENDS IN THE HIGH WATER LINE AND PLUNGE POINT OF THE SOUTHERN SIDE DURING 1981

Case		Highwater Line						Plunge Point					
		North trend			South trend			North trend			South trend		
		N	X	Z	N	X	Z	N	X	Z	N	X	Z
January	B	45	12	2.87"	45	16	4.67"	45	8	1.07	45	15	4.22"
	C	45	7	0.62	45	3	-1.18	45	6	0.17	45	8	1.07
March	B	28	9	3.14"	28	7	2.00"	36	15	5.30"	36	13	4.29"
	C	28	6	1.43	28	-	-	36	1	-1.77	36	-	-
May	B	36	4	-0.25	36	16	5.81"	45	14	3.77"	45	17	5.12"
	C	36	7	1.26	36	1	-1.77	45	2	-1.64	45	5	-0.28
July	B	36	6	0.76	36	13	4.29"	36	6	0.76	36	14	3.77"
	C	36	3	-0.76	36	5	0.25	36	6	0.76	36	5	0.25
September	B	36	14	4.80"	36	10	2.78"	28	11	4.29"	28	8	2.57"
	C	36	6	0.76	36	3	-0.76	28	1	1.43	28	1	-1.43
November	B	15	4	1.66	15	4	1.66	28	13	5.45"	28	6	1.43
	C	15	5	2.44"	15	1	-0.69	28	3	-0.29	28	3	-0.29

N = total number of possible unidirectional pairs which is equal to n^2-n/2

X = observed number of pairs representing a particular case in a particular direction.

n = number of samples in a sequence.

Z = X-Np/ Npq = 1.645 (0.05 level of confidence) or 2.33 (0.01 level of confidence).
where p = 0.125 and q = 0.875.

Table – 2.9 (b)

SUMMARY OF NUMBER OF PAIRS PRODUCING TRANSPORT TRENDS IN THE HIGH WATER LINE AND PLUNGE POINT OF THE NORTHERN SIDE DURING 1981.

Case		Highwater Line						Plunge Point					
		North trend			South trend			North trend			South trend		
		N	X	Z	N	X	Z	N	X	Z	N	X	Z
January	B	78	5	-1.63	78	13	1.11	78	20	3.51"	78	21	3.85"
	C	78	17	2.48"	78	5	-1.63	78	5	-1.63	78	12.	0.77
March	B	66	16	2.88"	66	12	1.39	66	11	1.02	66	12	1.39
	C	66	15	2.51"	66	4	-1.58	66	18	3.62"	66	14	2.14"
May	B	28	3	-0.29	28	11	4.29"	55	10	1.27	55	16	3.72"
	C	28	7	2.00"	28	-	-	55	11	1.68	55	2	-1.99
July	B	45	4	-0.73	45	2	-1.64	45	4	-0.73	45	10	1.97'
	C	45	4	-0.73	45	6	0.17	45	2	-1.64	45	6	0.17
September	B	45	-	-	45	7	0.62	55	11	1.68	55	21	5.76"
	C	45	12	2.87"	45	11	2.42"	55	5	0.77	55	7	0.05
November	B	55	20	5.36"	55	8	0.46	55	12	2.09	55	20	5.36"
	C	55	8	0.46	55	8	0.46	55	10	1.28	55	9	0.87

N = total number of possible unidirectional pairs.

X = observed number of pairs representing a particular case in a particular direction.

Z = 'Z' score.

Table - 2.9 (c)

SUMMARY OF NUMBER OF PAIRS PRODUCING THE TRANSPORT TRENDS IN THE HIGH WATER LINE AND PLUNGE POINT OF THE SOUTHERN SIDE DURING 1982

Case		Highwater Line						Plunge Point					
		North trend			South trend			North trend			South trend		
		N	X	Z	N	X	Z	N	X	Z	N	X	Z
February	B	55	25	7.40"	55	17	4.13"	45	12	2.87"	45	11.	2.42"
	C	55	8	0.46	55	1	-2.40	45	9	1.52	45	7	-2.08
March	B	55	21	5.77"	55	15	3.32"	45	12	2.87"	45	13	3.32"
	C	55	11	1.68	55	-	-	45	7	0.62	45	1	-2.08
May	B	45	14	3.77"	45	19	6.02"	55	12	2.09	55	16	3.72"
	C	45	3	-1.18	45	3	-1.18	55	15	3.32"	55	1	2.40"
July	B	45	8	1.07	45	21	6.93"	45	7	0.62	45	14	3.77"
	C	45	6	0.17	45	3	-1.18	45	13	3.32"	45	5	-0.28
October	B	21	12	6.17"	21	8	3.54"	15	5	2.44"	15	4	1.66
	C	21	-	-	21	-	-	15	3	0.88	15	2	0.10

N = total number of possible unidirectional pairs.

X = observed number of pairs representing a particular case in a particular direction.

Z = 'Z' score.

Table – 2.9 (d)

SUMMARY OF NUMBER OF PAIRS PRODUCING TRANSPORT TRENDS IN THE HIGH WATER LINE AND PLUNGE POINT OF THE NORTHERN SIDE DURING 1982

Case		Highwater Line						Plunge Point					
		North trend			South trend			North trend			South trend		
		N	X	Z	N	X	Z	N	X	Z	N	X	Z
February	B	91	4	-2.34	91	11	-0.12	91	23	3.69"	91	30.	5.91"
	C	91	38	8.45"	91	6	-1.71	91	8	-1.07	91	11	-0.12
March	B	91	23	3.69"	91	19	2.42"	78	10	0.09	78	37	9.33"
	C	91	8	-1.07	91	12	0.20	78	16	2.14'	78	4	-1.97
May	B	91	28	5.27"	91	15	1.15	91	12	0.20	91	5	-2.02
	C	91	17	1.79'	91	5	-2.02	91	28	5.28"	91	8	-1.07
July	B	82	3	-1.18	82	2	-1.63	45	3	-1.18	45	4	-0.73
	C	82	12	2.87"	82	18	5.57"	45	8	1.07	45	5	-0.28
October	B	91	26	4.64"	91	10	-0.44	91	29	5.60"	91	26	4.64"
	C	91	3	-2.66	91	28	5.28"	91	1	-3.29	91	17	1.79

N = total number of possible unidirectional pairs.

X = observed number of pairs representing a particular case in a particular direction.

Z = 'Z' score.

The same cyclicity is not observed in 1982. Contrary to measured trends, the sediment pathways in the northern sector is erratic that give rise to numerous combinations. The irregular behaviour of the transport pathways would have been influenced by the deposition of the beach sediment from multiple sources such as numerous rivers and by the erosion of coastal cliffs. This is significant in the monsoon season, where enormous amount of sediments are transported through the rivers that drain into the sea. This may cause intermittent interception of the sediments, thus resulting in highly irregular trends in both high water line and plunge point.

On the southern side the high water line and plunge point trends coincide with each other and demonstrate relatively better correlation with the measured longshore currents. Other than a southward flow in January and a strong case C trend in November, in general the monsoon season is characterised by a southward flow. The pre-monsoon and post-monsoon season shows a northerly transport. Eventhough the longshore currents are northerly, the beaches are eroding during November (1981). The rate at which it erodes increases in the northerly direction. It is evident from the earlier discussions that the erosion is achieved by the removal of fine tails of the population by the winnowing action of the waves. More the erosion, more the fines are removed. This process makes the lag deposit coarser, better sorted and less negatively skewed in the transport direction, thus artificially creating a strong case-C trend in November (1981). With certain exceptions, the same cyclicity is observed in 1982.

By taking into consideration the highly irregular behaviour of the transport pathways in the northern sector, it is emphasized that the model of McLaren and Bowles (1985) can be applied only to geomorphically distinct environments without multiple sources like the one in the southern sector. In the littoral environment of northern sector, with numerous rivers debouching into the sea, the model of sediment transport pathways cannot be applied. The patterns would be biased, owing to irregular supply of varying grades of sands through different rivers.

2.2.2. Strand Plain Sediments

A typical strand plain is formed of numerous beach ridges and swales that are aligned roughly parallel to the coast. The aerial photographs and LANDSAT imageries demonstrate the occurrence of swarms of beach ridges, isolated dunes and hills of Quaternary age that are characteristic of strand plains along the Azhikkal-Kanhangad coast. Beach ridges are defined by Stapor (1982) as linear round shaped ridges that are aligned roughly parallel to the coast. Carter (1986) considered the ridges to be formed around the high water mark of spring tide through the migration and coalescence of swash bars. Sediments stored in the longshore bar are moved alongshore causing the bar elongation. Normally, this sediment starved remnant welds progressively into the beach face in the direction of dominant process of gradient.

Detailed size analysis of the strand plain sediments indicate unique distribution characteristics that can be considered typical to this particular environment. In order to compare the range of values of the size parameters, the size data are reproduced as frequency distribution diagrams. Table 2.10 shows the percentage occurrence of various grades of size parameters.

2.2.2.1. Size characteristics

Mean size of the strand plain sediments fluctuates between 1.27 phi to 2.19 phi and are considerably coarser than the normal beach sediments. Clustering of the mean size values indicate that the sediments are dominant of coarser sands. The uni-modality of the sediments are indicated by the clustering of major population around 1.3 phi and 1.7 phi (Fig. 2.14). The standard deviation (sorting) values that fluctuate between 0.5 to 0.9 indicate that strand plain sediments are well sorted to moderately well sorted. This sort of sorting is not expected in beach sediments. Skewness values range between -0.08 to 0.10 indicating that the sediments are nearly symmetrical. Folk & Ward (1957) has noted that, with the addition of coarser mode to the population consisting mainly of fine sands, the sediments become nearly symmetrical in distribution. With subsequent addition, it becomes positively skewed. Similarly, selective removal of fines from the population, without any external addition may also make a lag deposit a symmetrically distributed population. The CM diagram (Fig. 2.15) reveals that the strand plain sediments are transported

Table - 2.10

PERCENTAGE DISTRIBUTION OF GRAIN SIZE PARAMETERS IN THE STRAND PLAIN SEDIMENTS

Mean size			Standard deviation		
0.5 - 1.0	-	22.22	0.50 - 0.60	-	12.96
1.0 - 1.5	-	53.70	0.60 - 0.70	-	40.74
1.5 - 2.0	-	18.52	0.70 - 0.80	-	31.48
2.0 - 2.5	-	05.56	0.80 - 0.90	-	14.81

Skewness			Kurtosis		
-0.15 to -0.10	-	03.70	0.80 - 1.90	-	07.41
-0.10 to -0.05	-	07.41	0.90 - 1.00	-	20.37
-0.05 to 0.00	-	14.81	1.00 - 1.10	-	46.30
0.00 to 0.05	-	31.48	1.10 - 1.20	-	20.37
0.05 to 0.10	-	18.52	1.20 - 1.30	-	05.56
0.10 to 0.15	-	24.07			

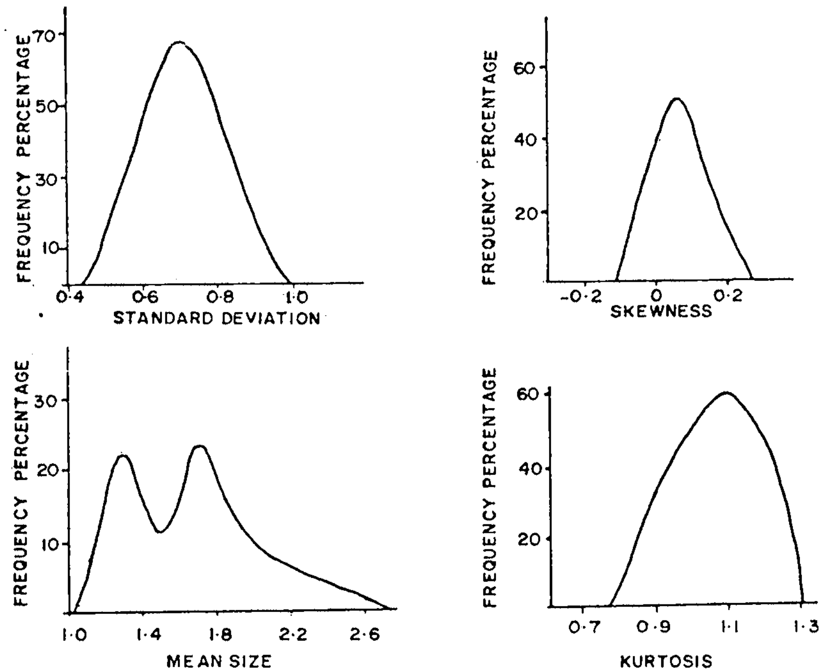


Fig. 2.14. Frequency distribution curves of size parameters of the strand plain sediments.

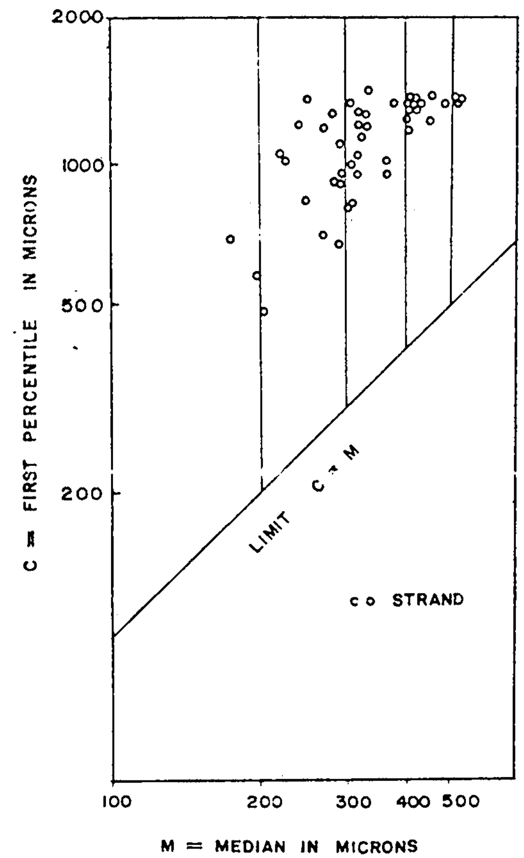


Fig. 2.15. C M diagram of strand plain sediments.

mainly by rolling and suspension. The points nearer to the C = M limit indicate a better sorted nature.

The scatter plots drawn between different size parameters show definite demarcation of beach and strand plain sediments (Fig. 2.16). The scatter plot between mean size and standard deviation shows that the strand plain samples are coarser and better sorted than the beach sediments. The plot between the mean size and skewness shows that the beach sediments which are finer are negatively skewed. The strand plain sediments are nearly symmetrical and coarser than the beach sediments. Similarly, other scatter plots also show better demarcation of beach and strand plain sediments.

2.2.2.2. **Surface textures**

Statistical analysis of the granulometric data indicated a mixed nature for the strand plain sediments. The quartz grains were examined by scanning electron microscopy (SEM) to analyse if there were any characteristic surface features that can be systematically related to the depositional/post-depositional history of the strand plain sediments. Since decades, sedimentologists have understood that the present is the key to the past. The knowledge of the present day processes would be imperative for a better understanding of the transportational and depositional history of a palaeo-environment like that of the strand plain. In order to have a comparative picture of the depositional pattern, along with the strand plain, SEM of beach and innershelf sands were also undertaken.

CM - chatter marks
LS - linear steps
VP - V shaped pits
LG - linear or curved grooves
UP - upturned plates
DC - dish shaped cavities
SG - silica globules
SP - silica plasterings
EO - euhedral outgrowths

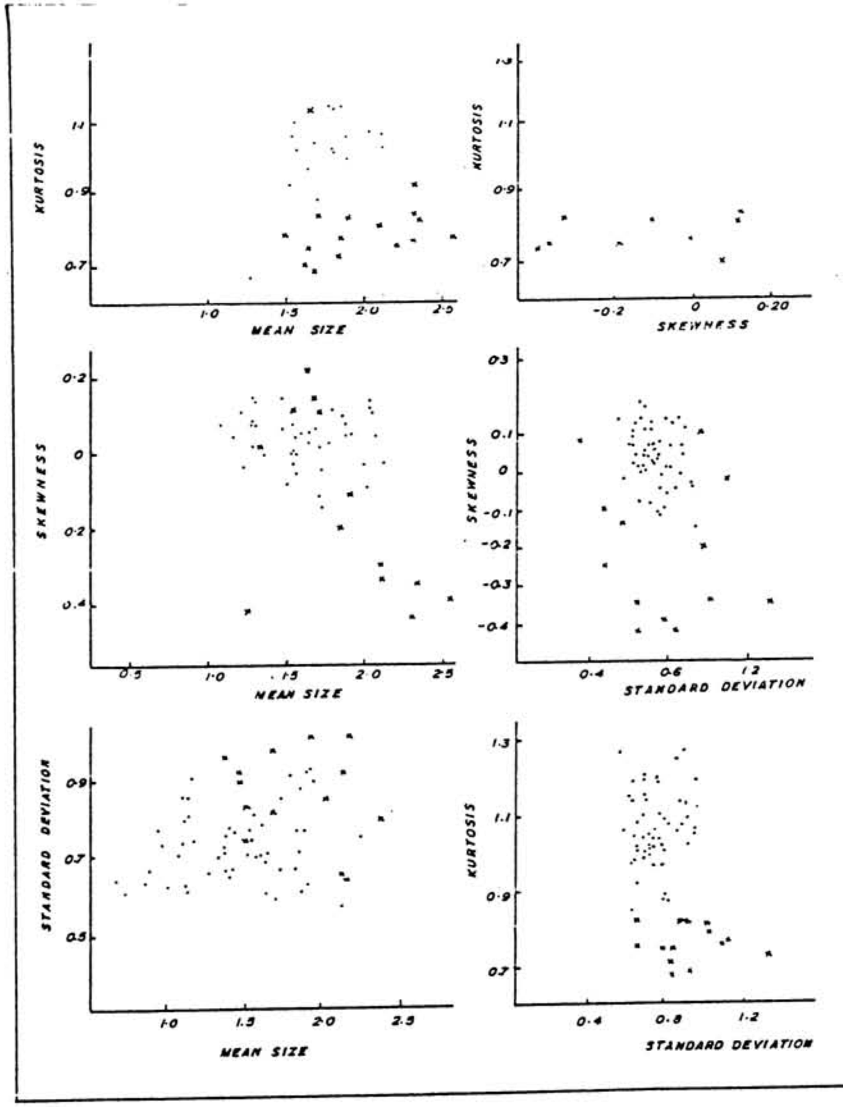


Fig. 2.16. Scatter plots of different size parameters showing the demarcation of beach and strand plain sediments.

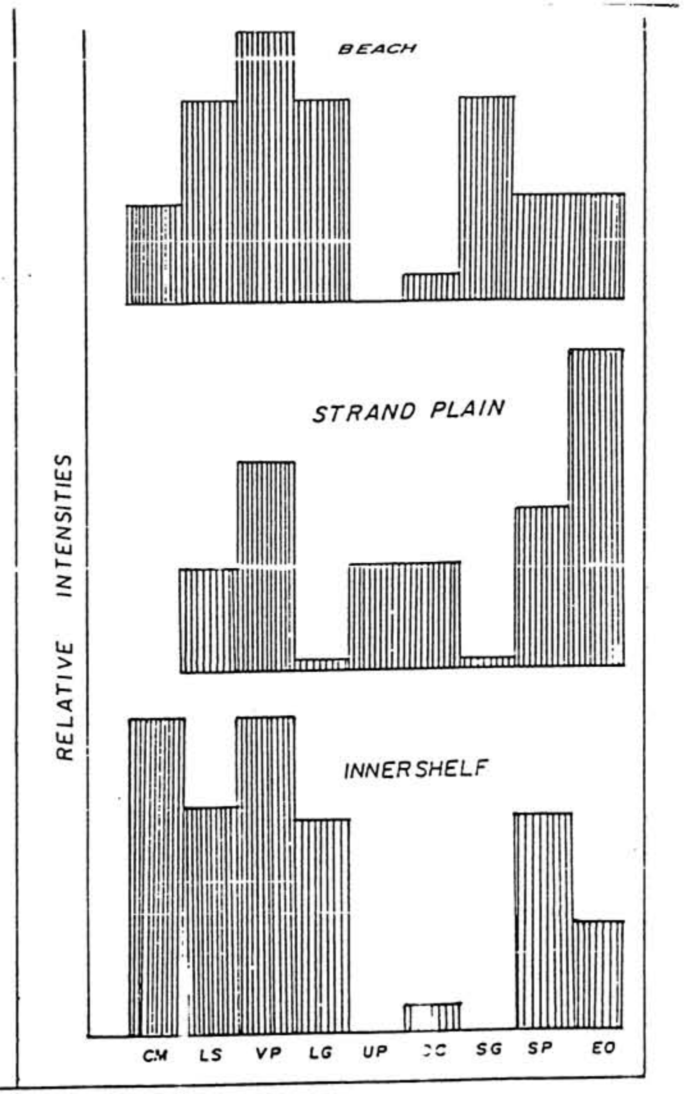


Fig. 2.17. Histogram showing relative abundance of the surface textures in different environments.

SEM techniques have been extensively used to study the surface textures of detrital minerals in particular to those of recent quartz grains. The different chemical and mechanical processes that affect the quartz sand grains are regarded as important indicators of depositional environments through which the sediments have passed (Blackwelder & Pilkey, 1972; Krinsley & Doornkamp, 1973; Krinsley et al., 1976; Strass, 1978; Georgiev & Stoffers, 1980; Bull et al., 1980; Bull, 1981). Identification of the sources, genesis and diagenetic changes of various detrital sediments were made easier with SEM techniques (Tankard & Krinsley, 1975; Krinsley et. al., 1976; Ly, 1981). The development of quasi-quantified approach to SEM analysis (Margolis, 1968; Margolis & Kellner, 1969; Carter, 1984) has clearly shown that no single surface texture or feature can be used to identify the past environmental history of a deposit, but it is the combination of these features that enable the determination.

During examination of the samples under SEM, different surface features were identified and recorded. The abundance of each of the surface features were noted by making a numerical record of visual estimate of the percentage of grain surface covered by the feature (Carter, 1984). Absent (0): 10% coverage (1): 10-50% coverage (2): 50% coverage (3). This is converted to a histogram of relative intensity of features (Fig. 2.17) and chronologic sequences of transportational, depositional and diagenetic processes were inferred.

In general, mechanical processes dominate the surface features of the sand grains from the beach and innershelf. Apart from the features of mechanical processes, those result from precipitation and the dissolution are widely imprinted in the strand plain grains. The beach grains show low degree of angularity (Plate I). The degree of rounding are probably related to beach energy (Gravenor, 1985). The innershelf grains are angular (Plate II). The fairly well rounded appearence (plate III) indicate a possibility of aeolian transport of strand plain sands at some time in their history.

Mechanical features like 'V' shaped pits, dish shaped concavities (with irregular edges) and chatter marks are common in beach and innershelf grains. Beach grains with surface features such as linear steps and dish shaped cavities with irregular edges are common (Plate IV). Regular 'V' shaped pits with linear scratches (Plate V) with a density of 2-3 V's/square micron suggest a sub-aqueous transport under high energy collisions (Krinsley and Doornkamp, 1973), their density and abundance related to the duration and intensity of subaqueous agitations. Similarly the innershelf grains also display high density of 'V' shaped pits (Plate VI). These are the result of mechanical action.

Elongated post-depositional cracks with linear grooves and impact pits with traces of euhedral silica recrystallization are seen in beach grains (Plate VII). Three generations of surface textures can be inferred from the beach grain (Plate VIII). The 'V' shaped pits on smooth surface of the grain indicate the first stage of mechanical action. Superimpósed on this are the linear grooves which are cut across by the later impact pits. The dish shaped concavities with irregular edges (Plate IX) are characteristic of beach grain. Recrystallization textures, which takes the form of silica globules (Plate X) are generally considered as deposited due to periodic evaporation of inter-granular water (Ribault, 1975; Davis, 1979) in the beach environment.

The chatter marks which are not the common surface texture from the sub-aqueous tropical environments are well preserved in the innershelf and beach grain in the study area. The chatter marked grains were mainly reported in garnets from glacial environments and are considered as an unique feature developed due to glacial grinding (Folk, 1975; Gravenor, et al., 1977; Gravenor 1982, 1985; Orr & Folk, 1983). Similar crescentic marks were also reported on detrital quartz grains from glacial environments (Bull, 1977; Rocha Campos & Krauspenhar, 1978). Subsequently Bull et al., (1980) found chatter marks on garnets from Sierra Leone and Cape Comerin (India) which are unlikely to have been developed by glacial grinding. Karpovich (1971) has reported chatter marks from dune sands.

The chatter marks that are reported from many parts of the world are either restricted mainly to the garnets or quartz grains from glacial environments or are in garnets from the beaches which are unlikely to have been developed by glacial grinding (Krinsley & Funnel, 1965; Doornkamp & Krinsley, 1971). But there are no frequent reports of chatter marks on quartz grains from the innershelf environments that have no record of glacial action. In the innershelf and beach environment off the northern Kerala coast, the chatter marks are very well preserved and are abundant in the quartz grains (Plate XI-XV). Bull (1978) proposed that the chatter marks can be developed in the quartz particles in response to meachanical abrasion that are caused by glancing blow across the face of a grain. The main contention for the mechanical abrasion theory is the existence of the chatter mark trails in association with other mechanical features like the 'V' shaped pits. Gravenor (1979) observed that chatter marked trails could be produced by any slip stick motion, if sufficient pressure is applied to break or severely strain the mineral surface. Hence the chatter marks can no longer be considered as an unique feature of garnet and quartz grain from glacial environments or on garnets from other environments. This can be developed on the quartz grain by mechanical abrasion in a sub-aqueous environment also. In addition to the chatter marks, the innershelf grains show evidences of crypto-crystalline sugary coating of silica which tend to obscure the original surface textures (Plate XVI). Linear grooves and 'V' pits (Plate XVII) that are similar in nature to the beach grain are also found in the innershelf grains.

Most of the strand plain grains show many of the textural features of both sub-aqueous and aeolian action such as 'V' pits (Plate XVIII) and dish shaped concavities with regular than curved edges (Plate XIX). The upturned plates, marked with secondary silica precipitation which rather subdue the relief are well preserved in the strand plain grains (Plate XX). The upturned plates that are observed in the strand plain are considered as a characteristic feature of the aeolian action (Krinsley & Doornkamp, 1973). Evidences of crypto-crystalline sugary silica coating and euhedral quartz overgrowths on the surfaces of the grain are seen in the strand plain (Plate XXI). The outgrowth formation had been related to the crystal structures (Karpovich, 1971) and different stages of diagenetic history of the sediment (Marzolf, 1976; Ribault, 1975; Preston, 1977). The widespread occurrence of recrystallization phenomenon in the strand plain grain would have been formed in response to their location in the zones of weathering, where they are exposed to rain water, organic action and probably fairly rapid changes in p^H and temperature (Hey, et al., 1971). Recrystallization of euhedral grain on the smooth surfaces and in cavities of the quartz grain in the strand plain grain would indicate a over saturated silica environment, which is diagenetically related (Carter, 1984). Pitman's (1972) genetic model of overgrowth development are comparable in the strand plain grains. The overgrowth starts as numerous incipient crystals (Plate XXII) that eventually develop into overgrowths with well defined rhombhohedral crystal faces. Only the first stage of incipient crystal overgrowth are preserved in the beach grain.

Quartz grains from the strand plain examined under high magnification exhibit distinct history of different stages of superposition of surface textures. High concentration of 'V' pits on the surfaces of the strand plain grain (Plate XXII) may be a product of pre-depositional imprint from the sub-aqueous environment under high energy conditions. The dish shaped concavities and upturned plates which are the post depositional features indicate subsequent modification of the grains under the impact of aerodynamics.

From the combined results of granulometry and SEM studies, it is inferred that the strand plain sediments are the resultant response of marine and aeolian activity. The results indicate that the strand plain sediments would be a product of the wave activity in the initial stages its deposition. The waves built up longshore bars by the interception of the backwash, thus making a sediment population consisting of mixture of all grades of sand. These are considered to be the regions of high turbulence and consists of poly-modal sand (Samsuddin, 1986). Subsequent to the formation of these bars, these would have emerged as beach ridges during the regression quite possibly during the Quaternary period (Curray et al., 1969). There are ample evidences from the SW coast of India for conceiving the idea of emergence of coast during the Quaternary period. From the occurrences of peat sequences and shell deposits in the sediments from the low lying areas, an initial subsidence and subsequent transgression of sea around 8000-6000 YBP and a regression around 5000-3000 YBP in the west coast of India had been reported by Rajendran et al., (1989). These emergent strand lines are also considered to be a product of Quaternary sea level changes in other part of India (Ahmed, 1962; Gupta, 1977; Sudesh Kumar and Rao, 1982; Suktankar, 1986; Nair, 1987).

It is inferred that subsequent to their emergence, these beach ridges are exposed to subaerial weathering, thus effecting winnowal of the fine sands from the population leaving behind the coarser materials as lag deposits. Such process is inferred from the occurrences of dominant coarser sand with nearly symmetrical and better sorted distribution of the strand plain sediments. The wind action might have caused the impregnation of surface textures that are characteristic of aeolian action.

Bagnold (1954) has noted that the onshore winds with a threshold velocity of 14 kms/hr are capable of transporting substantial amount of sediment inland resulting in the formation of coastal dune fields. The winds stronger than 22 km/hr are effective in blowing grains greater than 1 mm in diameter. Earlier records (Resource Atlas of Kerala, 1984) of wind show that wind blowing at velocity between 10-15 km/hr which at times with high velocity (20 kms/hr) blow onshore during the monsoon. With this velocity it is quite possible to winnow away the finer sands from the strand plain leaving behind the coarser material. Occurrences of isolated patches of dune fields in the study area further corroborates this hypothesis.

2.2.3. Innershelf Sediments

The innershelf zone are usually composed of clayey silt to silty sand (Reineck and Singh, 1973). This zone is characterized by maximum number of species and high amount of bioturbation struc-

Table – 2.11

GRAIN SIZE PARAMETERS OF THE STRAND PLAIN SEDIMENTS

Sample No.	Size Parameters					
	1 %	50%	Mean size	Standard deviation	Skewness	Kurtosis
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Strndp/01	0.10	2.14	2.10	0.92	-0.03	1.05
Strndp/02	0.16	1.76	1.77	0.70	0.03	1.01
Strndp/03	-0.26	1.27	1.27	0.62	0.02	0.97
Strndp/04	-0.16	1.27	1.29	0.60	0.08	0.96
Strndp/05	-0.08	1.75	1.80	0.78	0.08	1.00
Strndp/06	-0.37	1.25	1.31	0.80	0.14	1.07
Strndp/07	-0.43	0.88	0.90	0.60	0.03	1.18
Strndp/08	-0.38	1.37	1.35	0.73	-0.02	1.16
Strndp/09	0.20	1.87	1.91	0.66	0.05	0.98
Strndp/10	-0.34	1.26	1.28	0.73	0.09	1.03
Strndp/11	-0.26	1.14	1.19	0.62	0.11	1.04
Strndp/12	-0.22	1.56	1.56	0.72	0.04	1.05
Strndp/13	0.16	1.76	1.77	0.70	0.03	1.01
Strndp/14	0.82	2.32	2.30	0.56	-0.01	1.06
Strndp/15	0.04	1.66	1.69	0.71	0.07	1.03
Strndp/16	-0.14	1.28	1.32	0.79	0.02	0.86
Strndp/17	0.11	1.73	1.73	0.77	0.02	0.87
Strndp/18	-0.38	0.97	1.06	0.63	0.19	1.07
Strndp/19	-0.03	1.63	1.65	0.76	0.06	0.96
Strndp/20	-0.44	0.91	0.84	0.63	-0.08	1.00
Strndp/21	0.57	1.77	1.81	0.60	0.10	1.13
Strndp/22	0.55	2.48	2.42	0.74	-0.10	1.19
Strndp/23	0.34	1.74	1.79	0.68	0.12	1.14
Strndp/24	0.23	2.16	2.13	0.88	-0.01	1.00
Strndp/25	-0.32	1.57	1.55	0.75	-0.03	1.09

Table 2.11 contd.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Strndp/26	-0.38	1.20	1.33	0.88	0.24	1.12
Strndp/27	-0.39	1.23	1.24	0.70	0.03	1.04
Strndp/28	-0.44	1.10	1.15	0.83	0.05	1.09
Strndp/29	0.53	1.84	1.87	0.58	0.08	1.14
Strndp/30	0.50	1.55	1.53	0.64	0.00	0.91
Strndp/31	-0.25	1.62	1.58	0.77	-0.05	1.01
Strndp/32	-0.21	1.87	1.89	0.85	0.05	1.05
Strndp/33	0.51	1.59	1.60	0.71	0.08	0.97
Strndp/34	-0.38	1.04	1.13	0.66	0.18	1.09
Strndp/35	0.09	1.63	1.62	0.66	0.01	1.08
Strndp/36	-0.35	1.66	1.66	0.84	-0.00	1.13
Strndp/37	-0.38	1.24	1.25	0.70	0.02	1.05
Strndp/38	0.11	1.44	1.48	0.53	0.15	1.26
Strndp/39	0.01	1.42	1.39	0.65	0.02	1.03
Strndp/40	-0.38	1.29	1.32	0.85	0.07	1.05
Strndp/41	-0.40	1.71	1.73	0.82	-0.04	1.24
Strndp/42	-0.17	1.59	1.53	0.69	-0.08	1.31
Strndp/43	-0.35	1.75	1.71	0.74	-0.11	1.09
Strndp/44	0.27	1.68	1.69	0.66	0.05	1.14
Strndp/45	0.57	2.01	2.10	0.60	0.11	0.84
Strndp/46	-0.23	1.98	2.06	0.70	0.14	1.19
Strndp/47	0.62	2.11	2.15	0.62	0.05	1.01
Strndp/48	0.35	2.02	2.08	0.87	0.12	1.08
Strndp/49	0.52	2.09	2.05	0.76	-0.09	0.08
Strndp/50	1.04	2.30	2.32	0.25	0.15	0.99
Strndp/51	1.28	2.80	2.86	0.68	0.06	0.98
Strndp/52	1.52	2.68	2.76	0.69	0.12	1.00
Strndp/53	-0.43	1.98	1.98	0.91	-0.14	1.18
Strndp/54	0.54	2.13	2.19	0.76	0.14	1.08

tures. A broad account of the continental shelf sediments in the west coast of India were made by many workers (Hashimi et al., 1978; Kolla et al., 1981; Knedler et al., 1983; Machado & Vasudevan, 1980). But detailed account of sediments on the transition zone is lacking, which is more important from the developmental point of view of the coastal zone. The textural characteristics of the innershelf sediments were evaluated in terms of the frequency distribution of the size fraction, sediment type, CM pattern and Q-mode factor analysis.

To classify the sediments, Sheperd's (1953) three end member triangle was used. The geographic distribution of the sand, silt and clay grade are illustrated in figs. 2.18 & 2.19. The predominant portion having widest distribution is the silty clay which is followed by intermediate patches of clayey silt. In the vicinity of major rivers like Valapatnam and Karingote, the gradation from sand, silty sand and sand-silt-clay are well preserved. The isopleth map shows a progressive fining of sediments with depth. As Miller and Zeigler (1958) has noted this feature is a common phenomenon in the open inner-shelf where waves resort the dispersal of sediments. Tongues of iso-pleth map point north-west, by which a northward dispersion of sediment can be inferred. Isopleth map of sand (Fig. 2.18) illustrate abundance of coarser sands in the innershelf area south of the Ezhimala promon-tary that cover 40% of sand, which at some places reach even upto 80%. Majority of the northern side sediments comprise 5-10% of sand. Invariably the deeper parts of the innershelf have insignificant quan-tity of sand (less than 5%). In the southern sector clay and silt

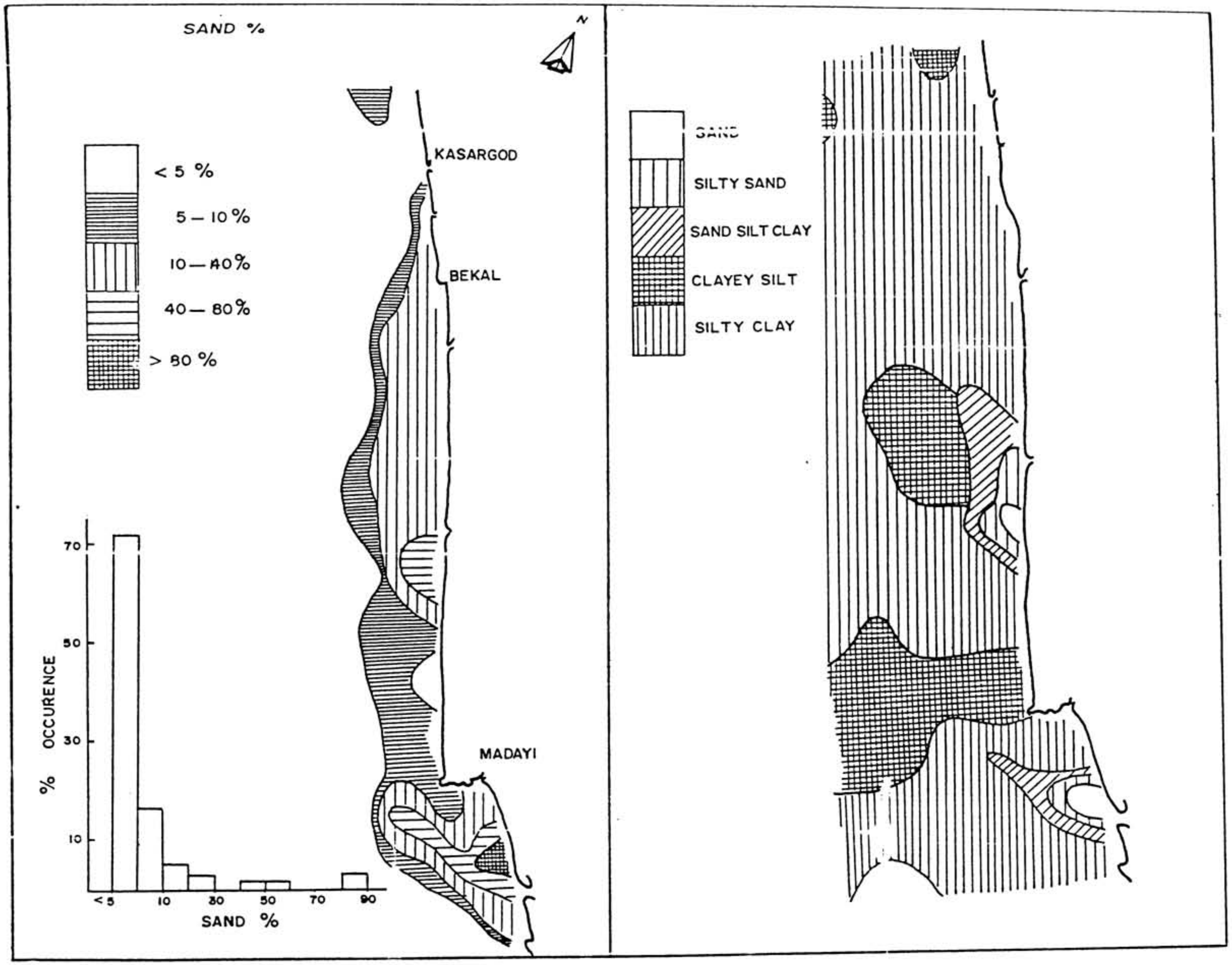


Fig. 2.18. Isopleth map of sand and sand-silt-clay percentages in the innershelf sediments.

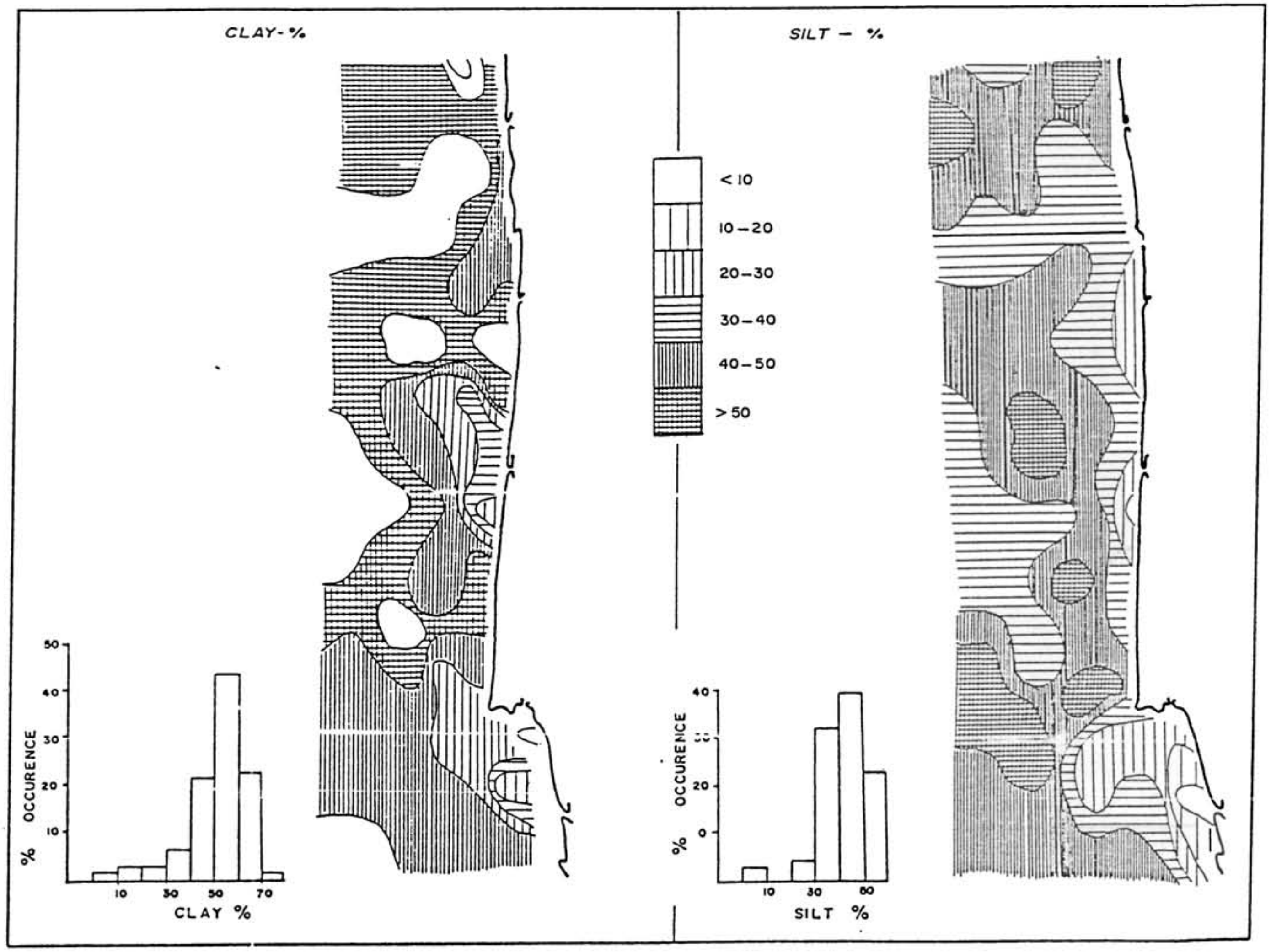


Fig. 2.19. Isopleth map of clay and silt percentage in the innershelf sediments.

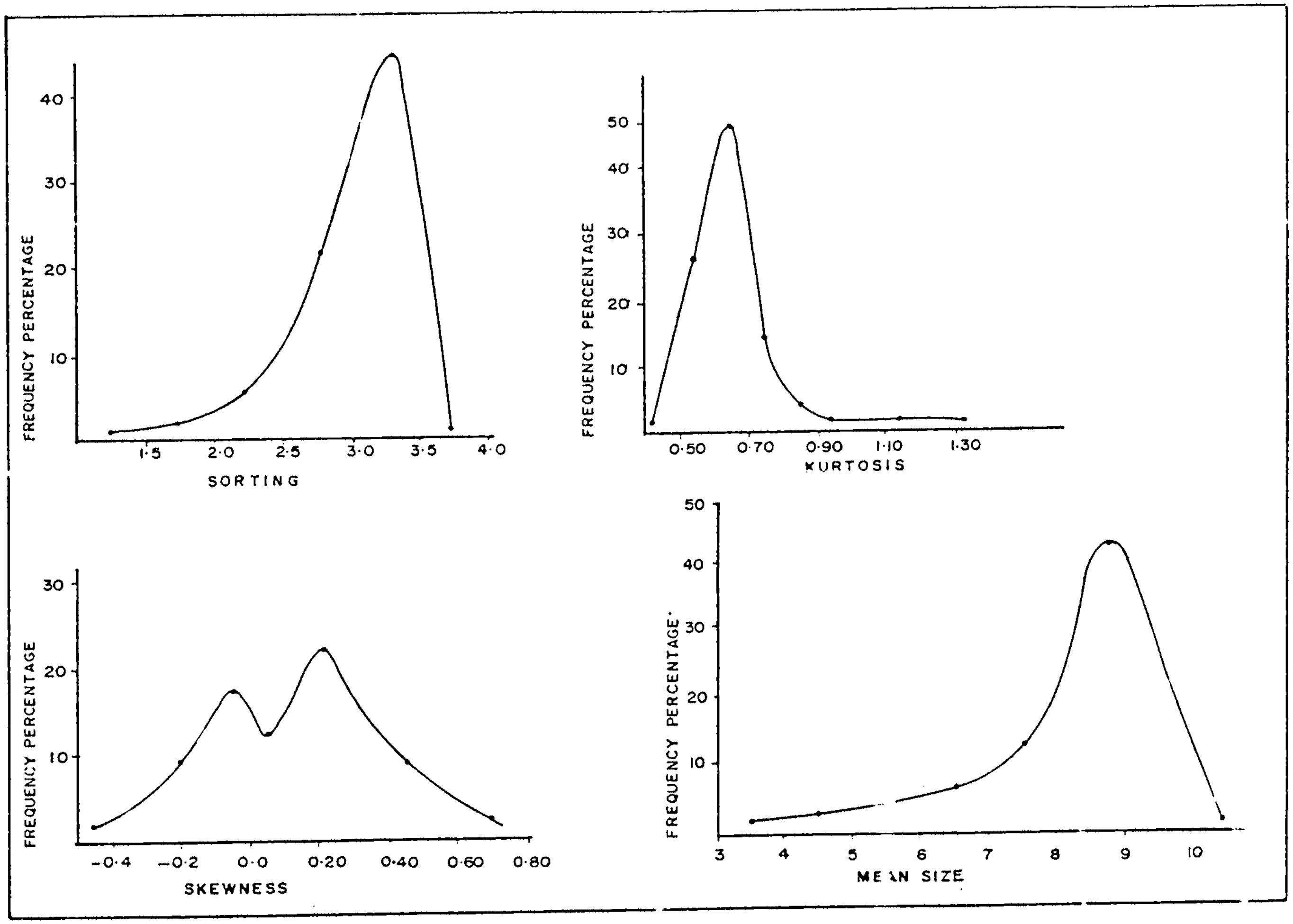


Fig. 2.20. Frequency distribution curves of size parameters of the innershelf sediments showing the percentage occurence of parameter values.

mode are subsidiary. From the sand, silt and clay percentage distribution map, a northerly sediment dispersal is inferred.

The isopleth map of the silt and clay percentages presented in fig. 2.19 illustrate that the silt content in the range of 30-60% are more dominant and cover approximately 90% of the total silt percentages. Similar to the distribution of sand, the coarse silt are the dominant fraction in the shallower areas, which become finer seaward in both sectors.

In conjunction with sand and silt percentages, the clay content exhibit a similar trend in both the sectors. Coarse clay with greater than 50% clay content is predominant in the northern sector. Bordering the river outlets, the clay content considerably decreases especially against the Valapatnam and Karingote inlet. Nearly 1/3 of the area in the southern sector has a clay content between 10-30%.

2.2.3.1. **Areal variation of size distribution**

Isopleth map of the mean size is illustrated in fig. 2.21. Mean size of the sediment range from 5 phi to 9 phi with an average value of 8.3 phi. In general, the sediments fall predominantly in very fine silt to coarse clay grade. Geographically greatest variation occur in the vicinity of river outlets, where coarser sands are concentrated. The sediments of the southern sector exhibit a distinct trend of decreasing grain size, both as water depth increases and towards the Ezhimala promontary. Very fine sand to fine silt dominate the shallow water areas, whereas coarse and medium clay dominate the deeper areas. However, this relationship does not fully apply to the sediment in the northern sector. There, excepting in the vicinity of major river outlets coarse to medium clay are the main constituent in both shallow and deep waters.

Sorting values are indicative of mean energy conditions of the depositional environments (Sherwood & Nelson, 1979). Phi deviations are utilized as an index of turbulence and variation in the velocity of water currents that transport the sediments (Wigley, 1961). The sorting variability of sediments in terms of standard deviation are illsutrated by an isoplth map (Fig. 2.21). Standard deviation values range from a minimum of 1.18 to a maximum of 3.59. By taking into consideration the verbal limits of Folk & Ward (1957), the sediments are classified as either poorly sorted or very poorly sorted.

The very poorly sorted sediments comprises most of the southern and northern sectors and are the most common in the study area. A regional comparison however exists with the mean size map. In the vicinity of river outlets like Valapatanam and Karingote, where fine sand and silt dominate the sediments are better sorted. The regional trend is a general seaward worsening of the standard deviation values. Such a trend suggest that sediment sorting is significantly influenced by the regional variation in hydraulic regime (Shideler, 1978). Wigley (1961) had inferred that the 'poorly sorted sediments, those possessing wide range of particle sizes indicate a variable or turbulent current

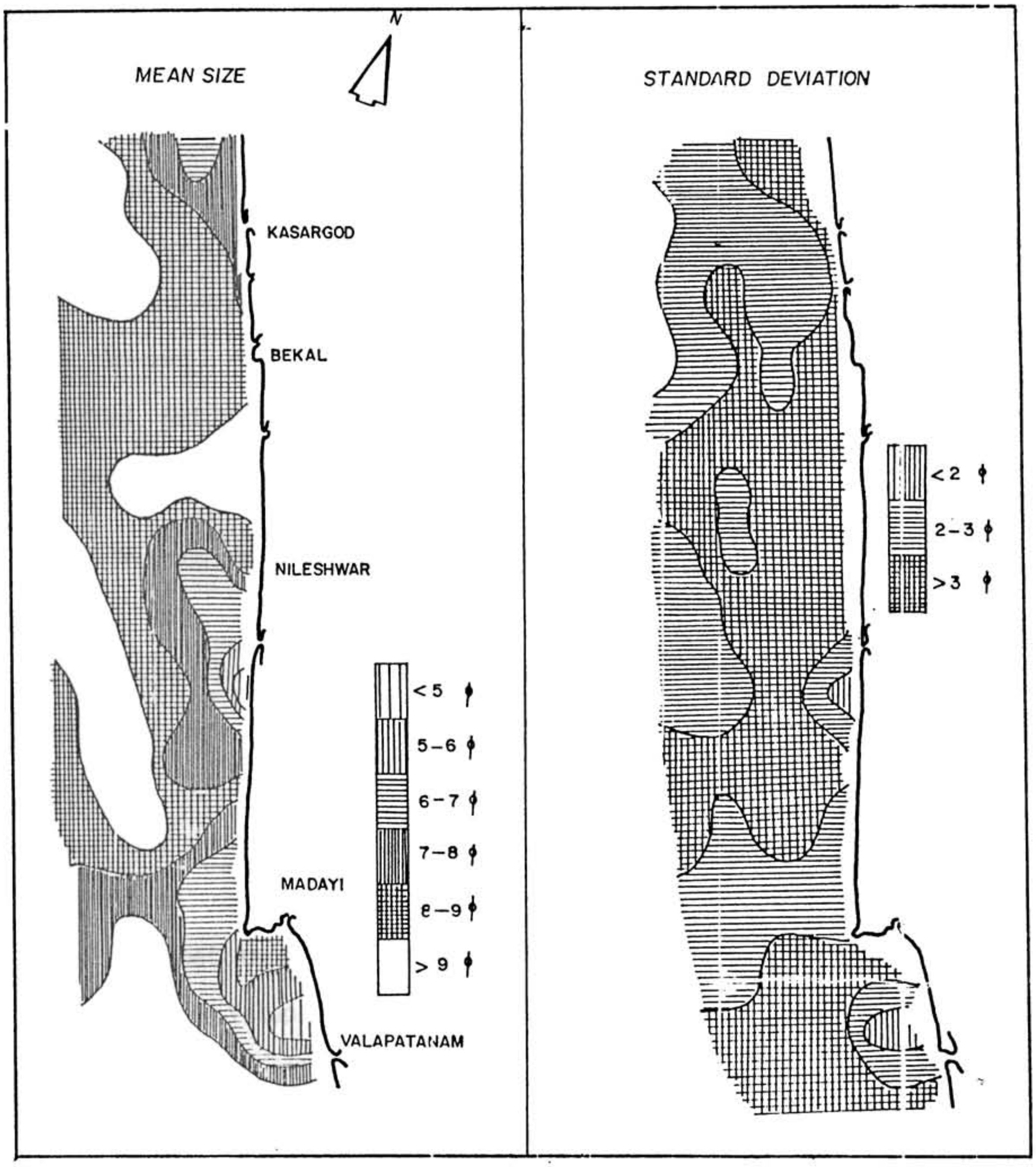


Fig. 2.21. Isopleth map of mean size and standard deviation of the innershelf sediments.

during deposition and well sorted sediments are considered to be an indication of smooth and stable currents'.

The regional variability of skewness values are illustrated by an isopleth map (Fig. 2.22). Skewness is the measure of assymmetry of the grain size distribution of the sediments and can be a sensitive indicator of sub-population mixing (Folk & Ward, 1957; Mason & Folk, 1958; Spencer, 1963). As noted by Friedman (1967) and Cronan (1972), polymodal sediments can show variable skewness values depending upon the specific proportions of the component sub-populations.

The sediments range between very positively skewed to negatively skewed. Majority of the sediments are positively skewed to very positively skewed. Near symmetrical sediments are moderately distributed. Negatively skewed sediments are the least abundant, being confined mainly to the northern sector near Bekal and Kasargod. The skewness values show perfect correlation with the mean size and sorting pattern. When the sediments are coarser, they tend to become more positively skewed and better sorted. In the vicinity of the river outlets like Karingote and Valapatnam, where the sediments are coarser, they are positively skewed and better sorted.

The regional variability of kurtosis values are illustrated by an isopleth map (Fig. 2.22). Kurtosis is the measure of peakedness of the grain size distribution and is a sensitive and valuable measure of normality of the distribution (Folk & Ward, 1957). The sediments range between very platykurtic to extremely leptokurtic. Majority

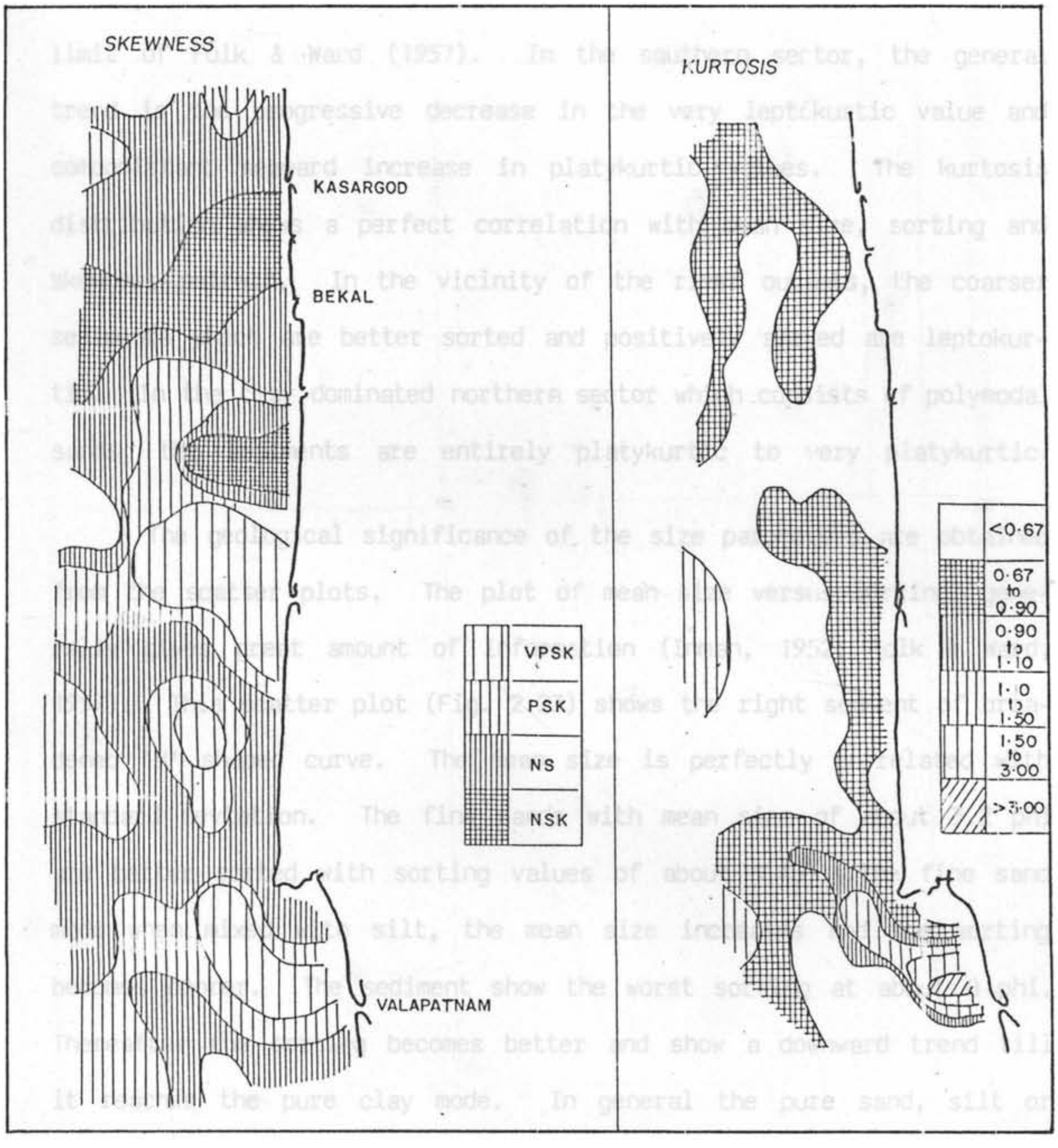


Fig. 2.22. Isopleth map of skewness and kurtosis of the innershelf sediments.

of the sediments in the northern sector are very platykurtic to platy kurtic, while the southern sector sediments cover the entire verbal limit of Folk & Ward (1957). In the southern sector, the general trend is the progressive decrease in the very leptokurtic value and comcomittant seaward increase in platykurtic values. The kurtosis distribution shows a perfect correlation with mean size, sorting and skewness pattern. In the vicinity of the river outlets, the coarser sediments which are better sorted and positively skewed are leptokurtic. In the clay dominated northern sector which consists of polymodal sands, the sediments are entirely platykurtic to very platykurtic.

The geological significance of the size parameters are obtained from the scatter plots. The plot of mean size versus sorting, generally gives great amount of information (Inman, 1952; Folk & Ward, 1957). This scatter plot (Fig. 2.23) shows the right segment of broadened 'M' shaped curve. The mean size is perfectly correlated with standard deviation. The fine sands with mean size of about 3.2 phi are better sorted with sorting values of about 1.40. The fine sand mode when mixed with silt, the mean size increases and the sorting becomes poorer. The sediment show the worst sorting at about 8 phi. Thereafter the sorting becomes better and show a downward trend till it reaches the pure clay mode. In general the pure sand, silt or clay mode shows better sorting values. Subsequent addition of finer sediments makes the population poorly sorted.

The plot of mean size versus skewness also shows a similar

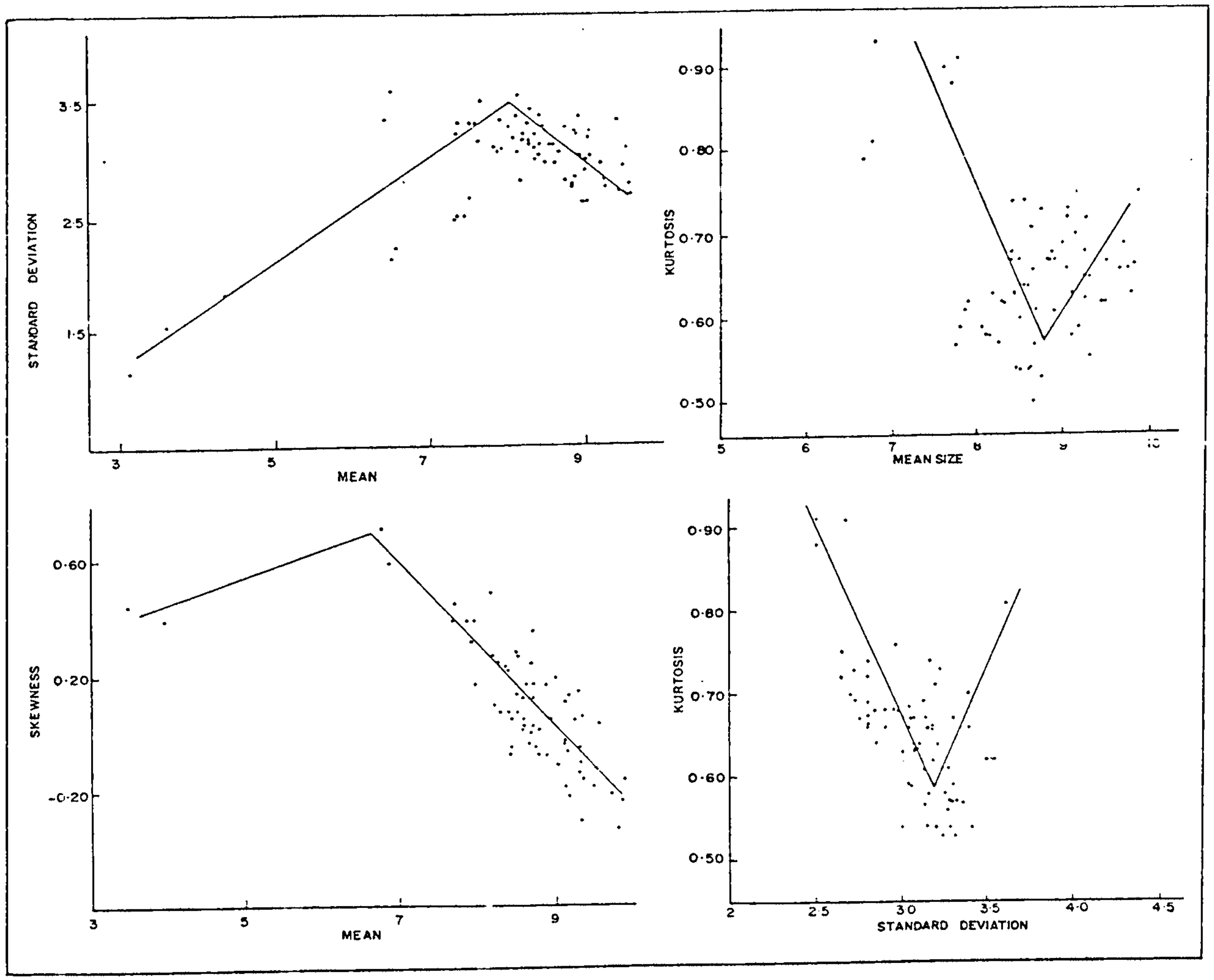


Fig 2.23. Scatter plots of different size parameters of the innershelf sediments.

inverted 'V' trend like that of the former one. The fine sands with mean size of 3.2 phi are positively skewed with skewness of about 0.40 phi. With the addition of silt mode, the population becomes more positively skewed until it reaches 7 phi. Subsequent addition of clay mode makes the skewness values to sweep through the near symmetry and become more and more negatively skewed. No characteristics trends were discerned from the plots between standard deviation versus kurtosis and mean size versus kurtosis.

The CM diagram drawn for the innershelf sediments are given in figure 2.24. By the disposition of the points, it is infered that the sediments are transported mainly by pelagic suspension and partly by uniform suspension. Poorer sorting of the sediments are indicative of the absence of swift bottom currents.

2.2.3.2. **Factor analysis**

The range of values, percent sum of squares and cumulative sum of squares are extracted from the principal component analysis of n x m matrix (Tables 2.12 & 2.13). The analysis used percentage of samples retained in each phi units and identified three factors which account for 89 percent of the variance. Communality and the matrix of factor loadings for the 81 samples have been rotated according to the varimax procedure. All the samples indicate high communality, thereby indicating its reliability. Normalization of factor components were obtained by dividing the squared values of the factor

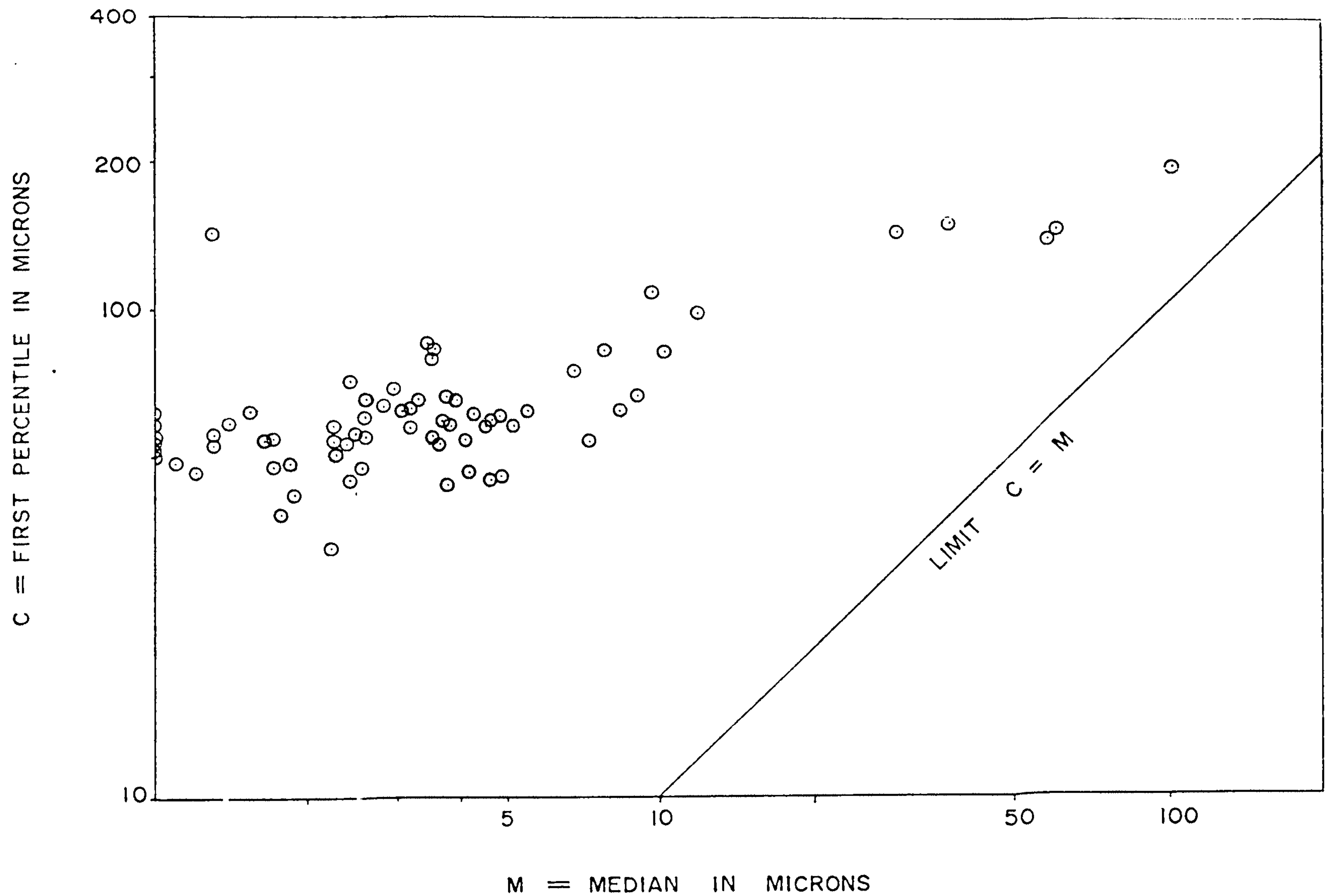


Fig. 2.24. CM diagram of the innershelf sediments.

Table - 2.12

EIGEN VALUES, PERCENT SUM OF SQUARES AND CUMULATIVE PERCENT SUM OF SQUARES EXTRACTED FROM THE PRINCIPAL COMPONENT ANALYSIS OF THE INNERSHELF SEDIMENTS

1	2	3
60.895	75.180	57.180
7.042	8.694	83.874
4.057	5.009	88.883
2.383	2.942	91.825
1.853	2.288	94.113
1.264	1.560	95.673
1.073	1.325	96.998
0.829	1.023	98.021
0.792	0.978	98.999
0.547	0.676	99.674
0.240	0.296	99.970
0.023	0.028	99.998
0.001	0.002	100.000

Column 1 = eigen velues; column 2 = percent of trace; column 3 = cumulative percent of trace.

Table - 2.13

COMMUNALITY AND VARIMAX FACTOR MATRIX WITH ROTATED FACTORS DRAWN FOR THE INNERSHELF SEDIMENTS

Communality (1)	Factor I (2)	Factor II (3)	Factor III (4)
0.949	0.333	0.65	0.009
0.922	0.349	0.588	0.064
0.928	0.302	0.647	0.051
0.833	0.291	0.701	0.009
0.933	0.340	0.592	0.069
0.634	0.911	0.068	0.020
0.920	0.152	0.821	0.26
0.951	0.709	0.259	0.032
0.717	0.926	0.057	0.017
0.908	0.719	0.207	0.073
0.888	0.630	0.284	0.086
0.851	0.798	0.189	0.014
0.988	0.921	0.073	0.005
0.855	0.839	0.159	0.002
0.815	0.641	0.356	0.003
0.926	0.753	0.203	0.045
0.835	0.951	0.034	0.015
0.910	0.645	0.281	0.074
0.891	0.441	0.487	0.072
0.840	0.846	0.109	0.045
0.981	0.510	0.456	0.034
0.900	0.820	0.180	-
0.931	0.901	0.097	0.002
0.973	0.926	0.068	0.006
0.857	0.552	0.440	0.009
0.961	0.854	0.125	0.020
0.948	0.789	0.191	0.020

Table 2.13 contd.

(1)	(2)	(3)	(4)
0.953	0.769	0.203	0.028
0.899	0.485	0.461	0.055
0.937	0.676	0.301	0.022
0.847	0.894	0.100	0.006
0.932	0.445	0.470	0.084
0.803	0.000	0.002	0.998
0.971	0.124	0.706	0.170
0.926	0.644	0.075	0.281
0.864	0.019	0.042	0.939
0.865	0.071	0.879	0.050
0.886	0.040	0.892	0.067
0.776	0.111	0.886	0.002
0.680	0.000	0.002	0.998
0.919	0.559	0.332	0.109
0.972	0.141	0.216	0.642
0.941	0.249	0.571	0.180
0.932	0.727	0.171	0.103
0.945	0.078	0.213	0.708
0.877	0.575	0.123	0.304
0.972	0.733	0.102	0.165
0.901	0.462	0.178	0.360
0.937	0.676	0.301	0.022
0.937	0.000	0.285	0.714
0.929	0.223	0.705	0.072
0.866	0.257	0.722	0.017
0.885	0.210	0.656	0.134
0.868	0.085	0.915	0.000
0.834	0.087	0.912	0.000
0.806	0.507	0.405	0.088
0.932	0.380	0.481	0.140
0.950	0.879	0.121	0.000

Table 2.13 contd.

(1)	(2)	(3)	(4)
0.897	0.637	0.336	0.026
0.918	0.209	0.508	0.282
0.918	0.502	0.439	0.059
0.903	0.844	0.113	0.042
0.915	0.803	0.191	0.006
0.905	0.808	0.192	0.000
0.555	0.729	0.219	0.052
0.778	0.829	0.171	0.000
0.967	0.212	0.596	0.000
0.936	0.745	0.213	0.040
0.929	0.911	0.072	0.017
0.964	0.556	0.397	0.097
0.987	0.801	0.162	0.036
0.974	0.770	0.204	0.026
0.946	0.860	0.115	0.024
0.823	0.920	0.067	0.013
0.923	0.452	0.504	0.043
0.933	0.882	0.114	0.003
0.756	0.744	0.249	0.007
0.034	0.291	0.468	0.240
0.820	0.464	0.503	0.033
0.907	0.330	0.579	0.095
0.718	0.000	0.119	0.881

loadings by the corresponding communality (Klovan, 1970).

The plot of factor loadings and the normalized factor components (Fig. 2.25) illustrate that the deposition of the innershelf sediments are influenced principally by three factors namely, the low energy (factor I), medium energy (factor II) and high energy (factor III). The factor I is dominated by size grades in the range of 9 phi to 14 phi which constitute mainly the silty clay sediments. The population contains about equal proportions of all sizes, a feature that indicate the polymodality of the innershelf sediments. The factor II that associated with the size grade between 4 phi to 8 phi are principally clustered around 4 phi to 8 phi and 8 phi to 9 phi and are essentially a silty population. This can be considered as the medium energy category. Factor III, which is the least frequent type, represent the high energy hydraulic regime and is associated with the size grade between 3 phi to 4 phi. This is the coarse end member. This factor which is associated with the coarser sediments are confined to the shore and are tentatively has been correlated with the surf energy where there is high turbulence (Klovan, 1966). The high energy of waves causes the winnowal of finer material from the mixture of sand leaving behind the coarser and better sorted sediments. The finer materials are transported and winnowed offshore by the nearshore currents. The selective removal or concentration of certain grades result in the depth controlled progressive fining of sediments.

The plot of aerial distribution of the factor scores (Fig.

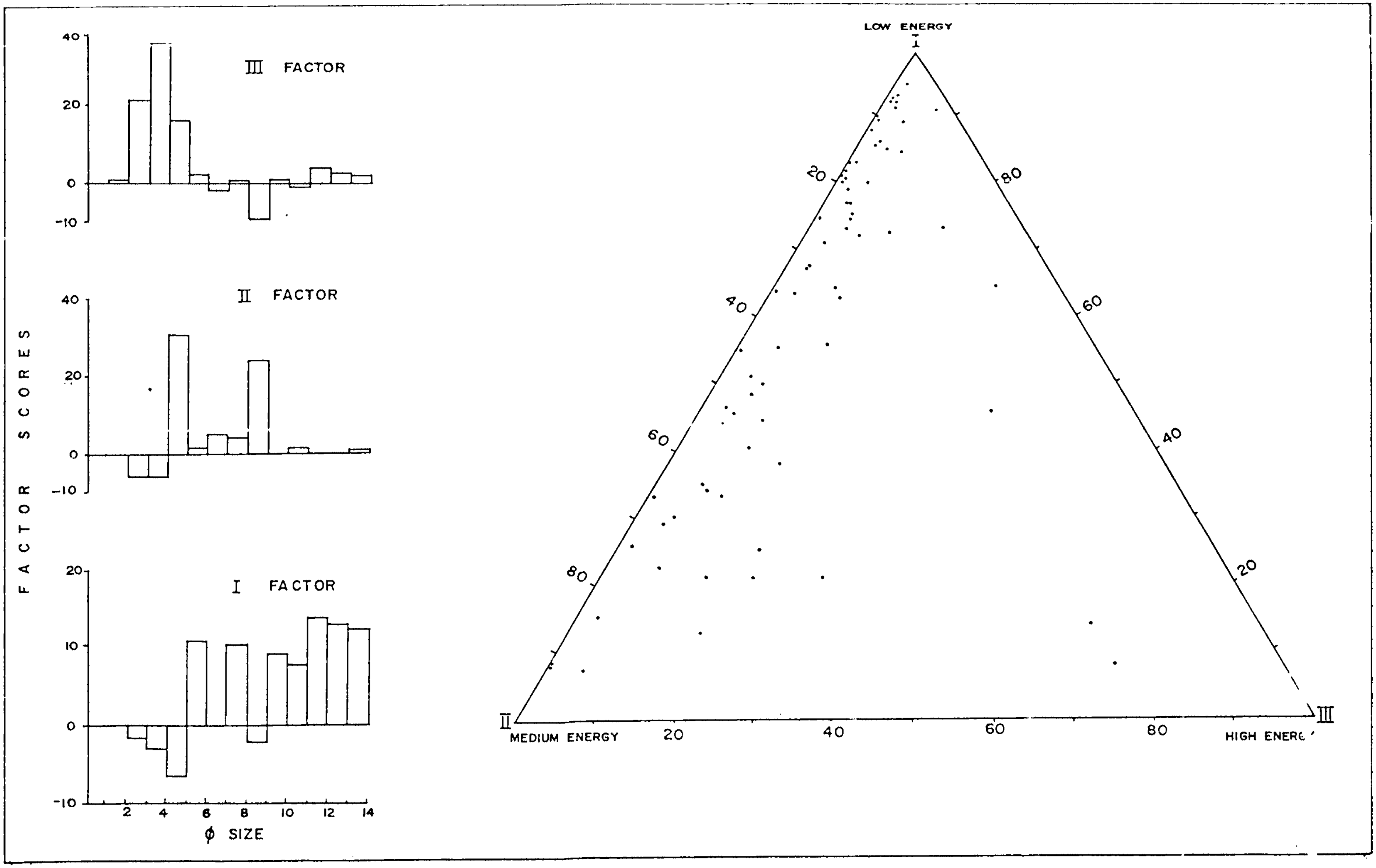


Fig. 2.25. Factor scores and the ternary diagram illustrating the normalized factor components drawn for the innershelf sediments.

2.26) indicate the depth control of the energy regimes. The high energy, factor (factor III) are concentrated in the innershelf area nearer to the river outlets, from where it thin out offshore. This phenomenon is very well preserved along the Valapatnam, Karingote and Bekal outlets. Factor II, which is related to medium energy dominated environment occur in the intermediate areas. The Factor I, which is related to low energy dominated environment signify the deeper areas.

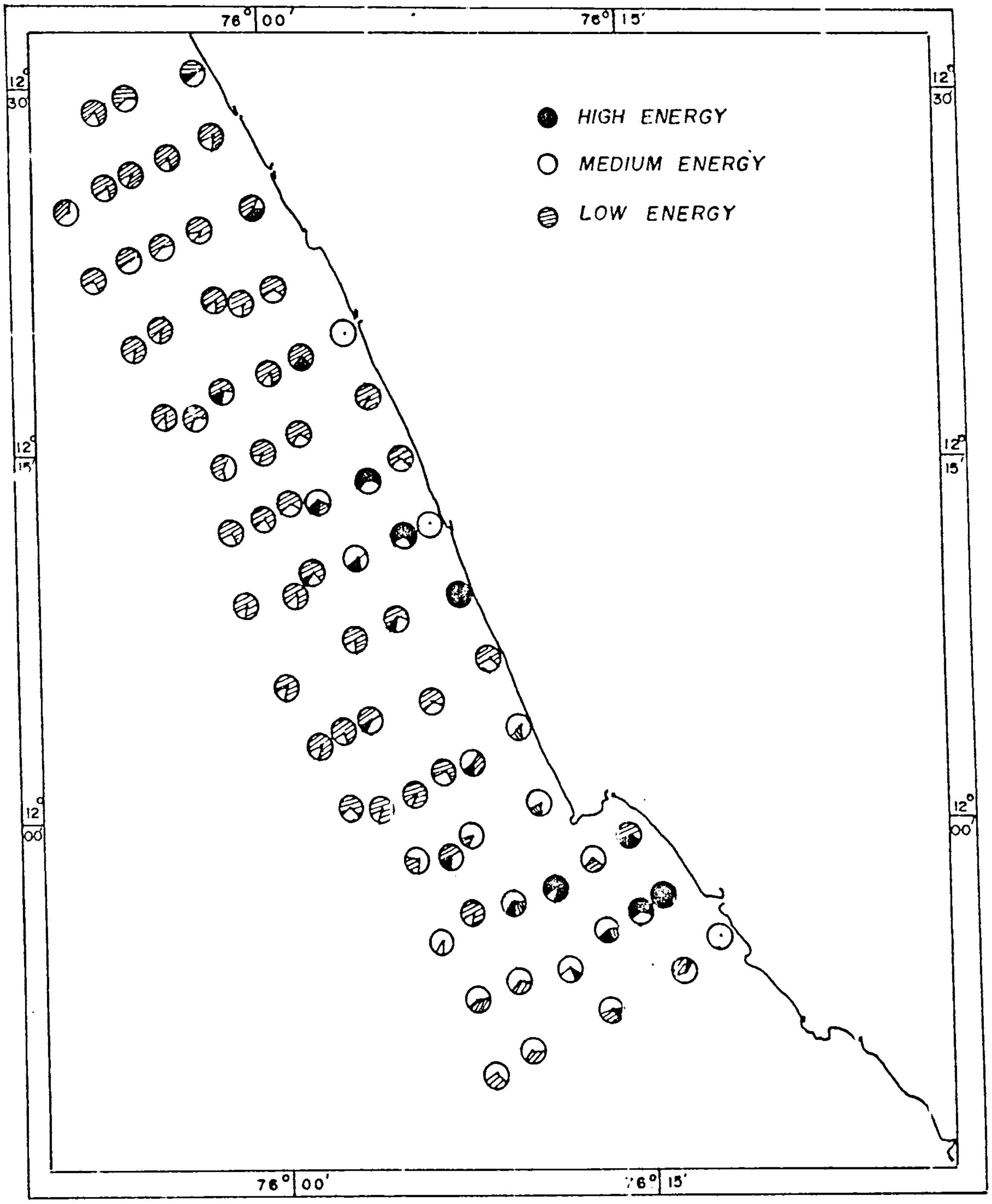


Fig. 2.26. Aerial distribution of factor scores of different energy regimes in the innershelf.

Table - 2.14

SIZE PARAMETERS AND SAND-SILT-CLAY PERCENTAGES OF THE INNERSHELF SEDIMENTS OF AZHIKKAL-KASARGOD

Sample No.	I st %	PHI median	Mean size	Standard deviation	Skewness	Kurtosis	Sand	Silt	Clay	Description
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
A1	4.40	9.20	9.10	3.21	-0.05	0.71	-	-	-	-
A2	3.80	8.70	8.60	3.14	-0.02	0.58	1.85	41.95	56.22	Silty clay
A3	4.20	9.20	8.97	3.27	-0.10	0.52	0.32	39.96	59.72	Silty clay
A4	4.10	8.05	8.42	3.17	0.15	0.63	0.30	42.52	57.18	Silty clay
A5	3.92	8.60	8.51	3.31	0.02	0.67	2.7	41.69	55.61	Silty clay
A6	4.05	7.70	8.25	3.29	0.24	0.57	0.74	52.38	46.88	Clayey silt
A7	4.01	7.50	8.10	3.07	0.28	0.58	0.68	54.90	44.42	Clayey silt
B1	2.39	3.30	3.36	1.18	0.44	2.92	85.00	9.35	5.65	Sand
B2	2.85	4.12	4.60	1.84	0.68	3.70	43.99	40.97	15.04	Silty sand
B3	4.00	6.90	7.85	3.17	0.40	0.61	7.08	52.89	40.03	Clayey silt
B4	4.00	8.30	8.45	3.21	0.09	0.54	0.31	46.48	53.21	Silty clay
B5	4.00	8.30	8.37	3.05	0.06	0.67	0.48	42.47	57.04	Silty clay
B6	4.23	8.12	8.43	3.16	0.15	0.54	0.27	46.25	53.48	Silty clay
C1	3.12	8.53	8.36	3.54	-0.04	0.62	15.68	31.87	52.45	Silty clay
C2	3.98	8.48	8.53	3.17	0.04	0.74	1.78	36.32	61.90	Silty clay
C3	2.80	4.06	6.01	3.29	0.80	1.36	52.28	26.36	21.35	Sand silt clay
C4	3.92	8.00	8.55	3.42	0.18	0.54	2.09	48.00	49.91	Silty clay

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
C5	4.48	7.77	8.40	12.81	0.30	0.68	0.19	56.54	43.27	Clayey silt
C6	4.03	7.88	7.59	2.51	-0.01	0.91	0.82	49.90	49.28	Cdayey silt
D1	3.58	7.00	6.74	2.15	-0.06	0.69	8.93	50.75	40.32	Clayey silt
D2	3.73	7.21	6.81	2.25	-0.04	0.93	5.64	58.63	35.73	Clayey silt
D3	4.08	8.07	7.74	2.67	-0.01	0.91	0.79	47.48	51.73	Silty clay
D4	4.21	7.10	8.35	3.36	-0.06	0.93	0.45	57.41	42.14	Clayey silt
D5	4.21	8.15	7.68	2.51	-0.08	0.88	0.24	54.75	45.01	Clayey silt
E1	3.92	8.06	7.54	2.49	-0.13	1.12	4.37	36.91	58.72	Silty clay
E2	3.58	8.15	8.80	3.12	0.18	0.61	5.37	44.07	50.56	Silty clay
E3	4.00	9.35	9.27	3.20	-0.08	0.64	2.61	33.71	63.68	Silty clay
E4	4.72	9.13	4.49	2.77	0.05	0.67	0.08	36.77	63.15	Silty clay
E5	4.40	7.67	8.60	3.01	0.37	0.54	0.29	50.04	49.67	Clayey silt
E6	4.30	8.30	8.65	3.12	0.14	0.57	0.31	46.79	52.90	Silty clay
F1	2.78	9.60	9.14	3.38	-0.20	0.70	5.84	35.12	59.04	Silty clay
F2	3.46	6.40	7.59	3.31	0.46	0.53	8.75	54.16	37.09	Clayey silt
F3	4.20	10.08	9.29	3.26	-0.29	0.56	0.58	44.94	54.48	Silty clay
F4	4.20	8.15	8.65	3.36	0.18	0.50	0.33	44.01	55.66	Silty clay
F5	4.48	8.70	9.17	3.04	0.06	0.59	0.10	35.79	64.11	Silty clay
F6	4.28	10.90	9.66	3.34	0.19	0.66	0.39	37.98	61.63	Silty clay
G1	1.48	3.77	3.83	1.58	0.39	5.50	79.32	9.87	10.81	Sand
G3	3.66	8.15	8.33	3.18	0.09	0.62	4.34	44.42	51.24	Silty clay
G4	4.36	9.08	9.06	2.80	-0.02	0.66	0.35	39.01	60.64	Silty clay
G5	4.42	9.70	9.47	2.82	-0.11	0.64	0.39	35.22	64.39	Silty clay

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
G6	4.30	8.80	8.99	2.82	0.09	0.69	0.50	38.36	61.14	Silty clay
H2	2.80	5.09	6.73	3.59	0.60	0.81	28.36	39.01	32.63	Sand silt clay
H3	3.20	6.70	7.74	3.32	0.40	0.57	7.83	50.59	41.58	Clayey silt
H4	3.90	6.80	8.06	3.10	0.50	0.59	1.15	51.19	47.66	Clayey silt
H5	4.40	8.70	9.10	2.84	0.15	0.64	0.62	40.15	59.23	Silty clay
H6	4.94	8.82	9.06	2.76	0.12	0.73	0.57	38.51	60.92	Silty clay
I1	3.12	8.54	8.61	3.26	0.01	0.54	9.61	35.94	54.45	Silty clay
I2	2.74	4.77	6.64	3.34	0.72	0.79	31.12	43.02	25.86	Sand silt clay
I3	3.63	6.60	7.57	3.22	0.40	0.73	7.89	54.04	38.07	Clayey silt
I4	4.10	7.80	8.43	2.83	0.28	0.34	0.83	51.84	47.33	Clayey silt
I5	4.21	7.93	8.60	3.09	0.26	0.64	0.39	50.12	49.49	Clayey silt
I6	4.38	9.66	9.45	2.98	-0.17	0.62	0.32	40.58	59.10	Silty clay
J1	3.10	10.83	10.29	2.48	-0.30	0.53	1.94	27.81	70.25	Silty clay
J3	4.23	9.57	9.08	3.24	-0.17	0.58	2.22	34.57	63.21	Silty clay
J4	4.30	10.22	9.73	2.93	0.25	0.66	0.43	30.71	68.86	Silty clay
J5	4.22	8.80	8.73	3.25	0.03	0.53	0.28	44.27	55.45	Silty clay
K1	-	-	-	-	-	-	18.51	29.95	51.54	Silty clay
K2	-	7.86	8.14	3.25	0.11	0.57	15.52	38.24	46.23	Silty clay
K3	3.95	8.25	8.92	3.05	0.21	0.67	2.09	47.22	50.69	Silty clay
K4	3.55	8.20	8.50	3.16	0.13	0.60	1.22	45.00	53.78	Silty clay
K5	3.90	8.44	8.52	3.13	0.06	0.69	1.23	43.41	55.36	Silty clay
K6	4.08	9.48	9.24	2.99	-0.12	0.63	0.79	40.28	58.93	Silty clay

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
L2	-	8.80	8.69	3.28	-0.04	0.61	8.42	40.29	51.29	Silty clay
L3	4.12	8.80	9.21	2.63	0.16	0.75	0.89	37.69	61.42	Silty clay
L4	4.16	9.58	9.31	3.04	-0.14	0.64	0.60	35.56	63.84	Silty clay
L5	4.19	10.00	9.68	2.73	-0.19	0.69	0.70	30.76	68.54	Silty clay
L6	4.10	10.50	9.77	3.08	-0.32	0.73	0.32	33.38	66.26	S)lty c,ay
M1	-	7.40	7.88	3.48	0.18	0.62	14.50	42.95	42.55	Clayey silt
M2	4.02	10.00	9.84	2.70	-0.15	0.75	0.52	35.41	64.07	Silty clay
M3	4.19	10.20	9.81	2.78	-0.22	0.66	0.71	32.26	67.03	Silty clay
M4	4.17	8.66	8.62	3.12	0.01	0.66	0.44	43.21	56.35	Silty clay
M5	4.06	8.62	8.73	2.97	-0.06	0.76	0.79	40.82	58.39	Silty clay
M6	-	-	-	-	-	-	0.37	42.69	56.94	Silty clay
N2	-	-	-	-	-	-	0.59	43.11	56.30	Silty clay
M3	4.20	9.25	9.24	2.91	-0.04	0.68	0.42	40.23	59.35	Silty clay
N4	4.58	9.07	9.27	2.64	0.07	0.72	0.13	39.87	60.00	Silty clay
N5	4.20	8.73	8.87	2.96	0.06	0.68	0.46	46.43	53.12	Silty clay
N6	4.10	7.60	8.17	3.08	0.26	0.63	0.57	56.45	42.92	Clayey silt
O1	-	9.00	8.83	3.11	-0.06	0.67	2.55	41.88	56.27	Silty clay
O2	-	6.95	7.80	3.30	0.33	0.59	6.88	56.03	37.09	Clayey silt
O3	4.15	8.60	8.64	3.03	0.04	0.66	0.57	45.00	54.43	Silty clay
O4	-	9.05	9.06	2.80	-0.01	0.72	2.64	39.48	57.88	Silty clay
O5	-	-	-	-	-	-	0.26	39.64	60.10	Silty clay

CHAPTER III

MINERALOGY OF THE SEDIMENTS

The minerals with specific gravity greater than 2.89 are considered as heavy minerals (Howell, 1957). These are commonly a significant constituent of all terrigenous sediments or sedimentary rocks, especially in mature sands that lack rock fragments or light mineral grain (Carver, 1971). During diagenesis, some of these may preferentially undergo dissolution either by weathering or intra-stratal solution. In such cases the interpretation of provenance based on the remaining heavy minerals would sometimes be erroneous. Intra-stratal solution may completely destroy minerals such as pyroxene or hornblende that otherwise serve as important provenance indicators.

Heavy mineral studies were widely applied to solve many of the intricate problems in the field of sedimentology and has been a topic of intense research with wide application in many fields. With Van Andel (1959, 1960) and Van Andel & Poole's (1960) work on sources and dispersion of the Holocene sediments, the heavy mineral studies gained momentum which ultimately led the identification of variety of processes which produce diversity in heavy mineral suite. With the hydraulic equivalence theory proposed by Rubey (1933), later adopted by Rittenhouse (1943) and Pamerancblum (1966), Hand (1967) was able to discriminate aeolian and beach sands.

Kulm & Byrne (1966) used relative abundance of heavy minerals to differentiate among the marine, fluviatile and marine-fluviatile realms of deposition. White & Willams (1967) found that differences in settling velocities in quartz and tourmaline revealed differences in rates of traction to suspension and sedimentation.

The major application of heavy mineral studies is in the deciphe-rence of provenance, dispersal and stability of the minerals (Briggs, 1961; Scheidegger et al., 1971; Frores & Shideler, 1978; Morton, 1979, 1984, 1985; Barrie, 1980; Duyverman, 1981; Ly, 1981; Leupke & Clifton, 1983; Al-Bakri et al., 1984; Darby, 1984; Valloni, 1985; Peterson et al., 1986). Nickel (1973), Simpson (1976) and Morton (1979) high-lighted the effect of intra-stratal solution, overgrowth, solution and etching on selected heavy minerals in the provenance and correla-tion studies. Based on the percentage occurence of opaque minerals, Leupke (1980) was able to distinguish between source and sorting effect of beach sand mineralogy in the south-western Oregon. Gravenor & Gostin (1979) examined the heavy minerals from the upper palaeozoic tillites and attributed the loss of heavy minerals to the action of alkaline intra-stratal solution. Clemens & Komar (1987) demonstrated that the relict beach sands of the Oregon coast reflect an along-coast mixing of mineralogy from four sources during lowered sea-level. Statteger (1986) and Hurst & Morton (1988) showed that the lithologic variation of heavy mineral population can be used in modelling of lithologic end members from river sand and also for reservoir modelling and provenance studies. The surface micro-textures of the heavy mine-rals were used in identifying the transportational and depositional history of the population (Lin et al., 1974; Mallik, 1986). Swift et al., (1971) studied the heavy minerals in order to understand the hydraulic fractionation of mineral suits. Heavy mineral occurrences in many parts of the western coast of India have also been studied to understand the provenance and the basic processes of concentration of beach placer deposits into limited pockets (Kidwai, 1971; Kidwai, et al., 1981; Mallik et al., 1987).

Recently Morton (1985, 1987) Hurst & Morton (1988) showed that electron microprobe analysis of a single and diagenetically stable heavy mineral having wide range of composition are useful in solving problems of provenance and for correlation studies in the reservoirs. Komar & Wang (1984) have shown that heavy mineral enrichment in the backshore of the central Oregon coast are maintained on the beach as a whole according to equivalence of their settling velocities and locally segregated by entrainment processes.

The aim of the present work is to study the response of heavy mineral suite in the Palaeo and dynamic environments in the light of their mineral abundance.

3.1. METHODOLOGY

3.1.1. **Mineral Seperation**

The separation of heavy minerals is accomplished by mass seperation method of Carver (1971) which is based on the gravity based settling of the sample in a brominated hydrocarbon liquid (bromoform). The clay and silt fraction from the beach, strand plain and innershelf sediments were removed by wet seiving. The sand fraction was washed thoroughly to remove wood fragments and soluble salts and treated with dilute HCl to remove carbonates. Tri-bromoethane (bromoform), a heavy liquid with specific gravity of 2.9 was used in the mineral separation procedures.

After assembling the glasswares needed for the analysis, the holding funnel is partly filled with bromoform and the first sediment sample is poured into the heavy liquid. The sample is stirred periodically, until heavy minerals can longer be observed to settle into the stem of the holding funnel. The accumulated heavy minerals are dropped from the stem of the holding funnel by opening a clamp on the tubing. The heavy minerals thus collected were washed several times by directing a stream of xylene from the squeeze bottle.

3.1.2. Grain Mount & Modal Analysis

Canada balsam (n = 1.54) is used as the resin in grain mounting. A piece of solid canada balsam is placed on top of a slide and heated until it becomes fluid and spreads to the desired thickness and area. Grain mounts were prepared by sprinkling the heavy minerals uniformly on the slide. A cover glass is pressed gently down the slide and is allowed to cool. After scraping the extruded portions of the canada balsam, the slide is cleaned with xylene and soap solution.

A polarising microscope attached with a automatic point counter unit (ELTINOR-4 Carl Zeíss) is used in the modal analysis. The number percentage of heavy minerals were determined by counting nearly 300 grains on each of the 37 slides.

3.1.3. X-ray Diffraction

Calcium carbonate and organic matter were removed from the sediment by heating in 6% hydrochloric acid and 30% solution of hydrogen peroxide. Clay fraction (less than 2 micron) were separated from the bulk sediment by standard sedimentation techniques. The aliquotes were pipetted on glass slides and dried at room temperature (Gibbs, 1965). In the oriented clay aggregates thus obtained, the flake shapes or basal cleavage planes of the layer silicates lie flat on the substrate and enhance the diffraction peaks that are caused by inter-planar spacings parallel to the flake surfaces (Hathaway, 1972). The slides were scanned from 2° to 30° on a Philip's X-ray diffractometer using Ni-filtered Cukα radiation. Machine setting of 40 KV, 20 ma and goniometer speed of 2° 2θ/minute were used. Standard tests were carried out for confirmation of expandable clay minerals by placing the glass slide with ethylene glycol in atmospheric temperature for 24 hrs. Confirmation tests were also carried out by heating the slide upto 450° and scanning the same from 2° to 15° (Caroll, 1970; Thorez, 1973). Relative proportions of the clay minerals were determined by measuring the area of their principal reflections by a polar planimeter. The percentage of clay minerals were determined by weighted peak area method of Biscaye (1965), which is achieved by multiplying the principal peak areas of kaolinite (7 A°), illite (10 A°)and montmorillonite (14 A°) by the integers 2, 4 and 1 respectively.

3.2. RESULTS AND DISCUSSION

3.2.1. Heavy Minerals

Petrographic analysis of heavy minerals provided the basic framework for establishing the mineralogical identities. Opaques, hornblende and garnet are the principal components in the heavy mineral suit. Other than the above, the percentage of rutile and ilmenite vary between 3-8% by weight in the strand plain sediments. In the beach and innershelf, these minerals are present in insignificant quantity i.e. mainly less than 3%. Hypersthene which is totally absent in the strand plain sediments are present in the beach and innershelf sediments, their percentage even going upto 10%. Other minerals which are present in insignificant quantities are epidote, sillimanite, monazite and clino-pyroxene.

Opaque minerals include magnetite and ilmenite. Hornblende are mainly green in colour with different shades of pleochroism and inclined extinction. Grains with brown shades are also present but in little quantities. Garnets are mainly colourless, irregular with sharp edges and light pink to pink in colour. Solution features like impact pits and etch features are mainly observed in the strand plain grains. Garnets are of almandine and spessartite variety. Sillimanite forms as elongate, short and colourless grains with prismatic habits.

Zircon are euhedral and elongated. Monazite are light yellow in colour with characteristic interference colours.

In the strand plain sediments, the opaques vary between 58%-86% by weight. The percentage of opaques progressively reduces towards the beach and innershelf. The magnetite and ilmenite are together grouped as opaque minerals, as it is quite difficult to identify these minerals in the grain mount. Unlike the opaques, the hornblende with differing pleochroic haloes of green shows a reversing trend of concentration towards the strand plain. Brown varieties of hornblende are not uncommon. Similarly when compared with the beach and innershelf sediments most of the strand plain sediments have higher proportions of almandine and spessartite variety of garnet. Of these, the innershelf sediments show the least abundance.

Eventhough the heavy mineral content of the beach, strand plain and innershelf are identical, the relative percentages of mineral assemblages show significant variation. The relative abundance of individual heavy minerals from different environments are pictorically represented to have a overall picture of the nature of heavy mineral distribution. The areal variation of the heavy mineral assemblages in the strand plain, beach and innershelf sediments are shown in the figs. 3.1 a, b and c and their corresponding statistics in table 3.1. Using the innershelf sediments as a central group, variations imposed on the strand plain sands and processes of selective entrainment of heavies in beach sand are studied. Eventhough opaques constitute an integral part of the heavy mineral distribution, it occur in differ-

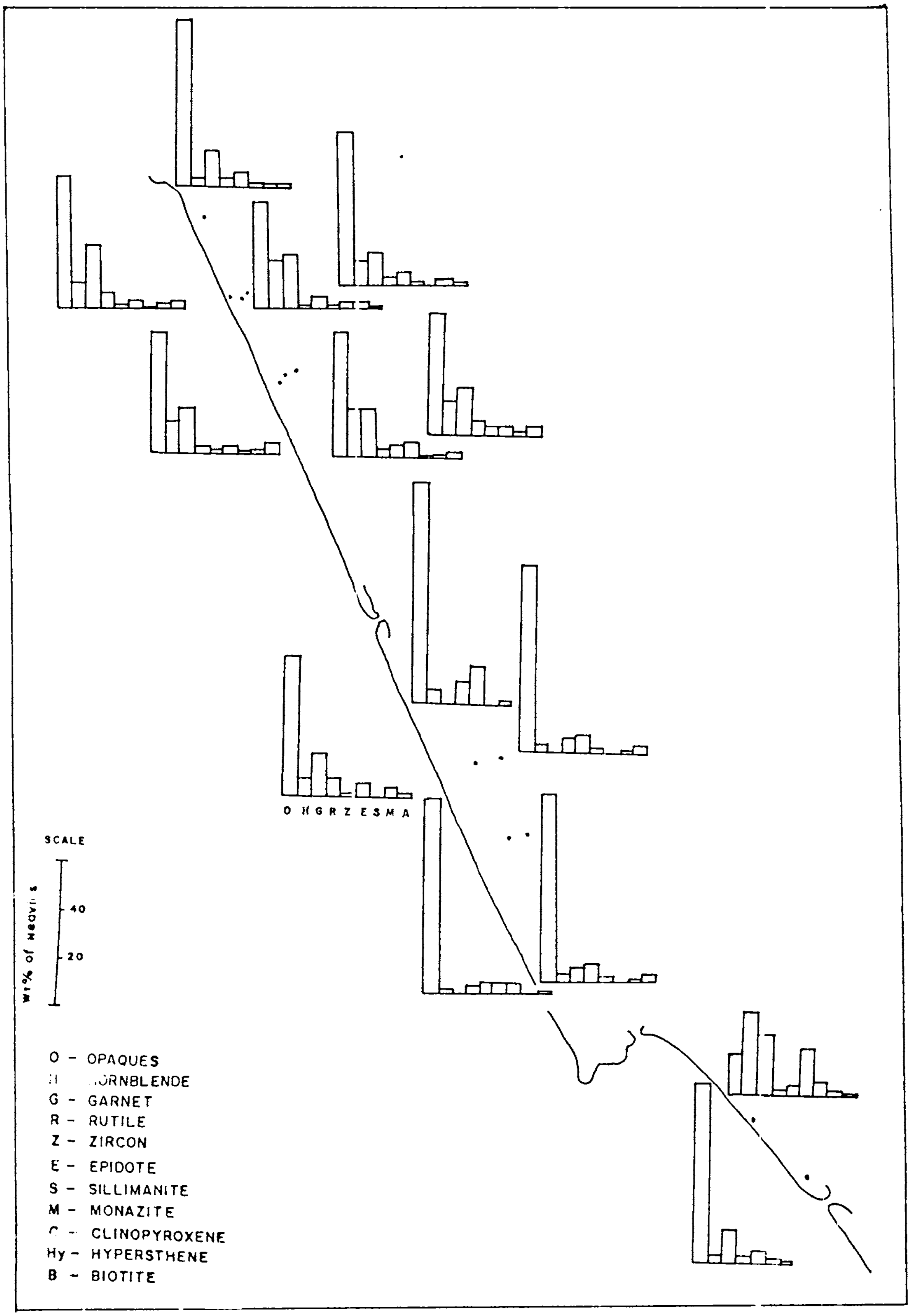


Fig. 3.1a. Relative proportion of heavy minerals in the strand plain sediments.

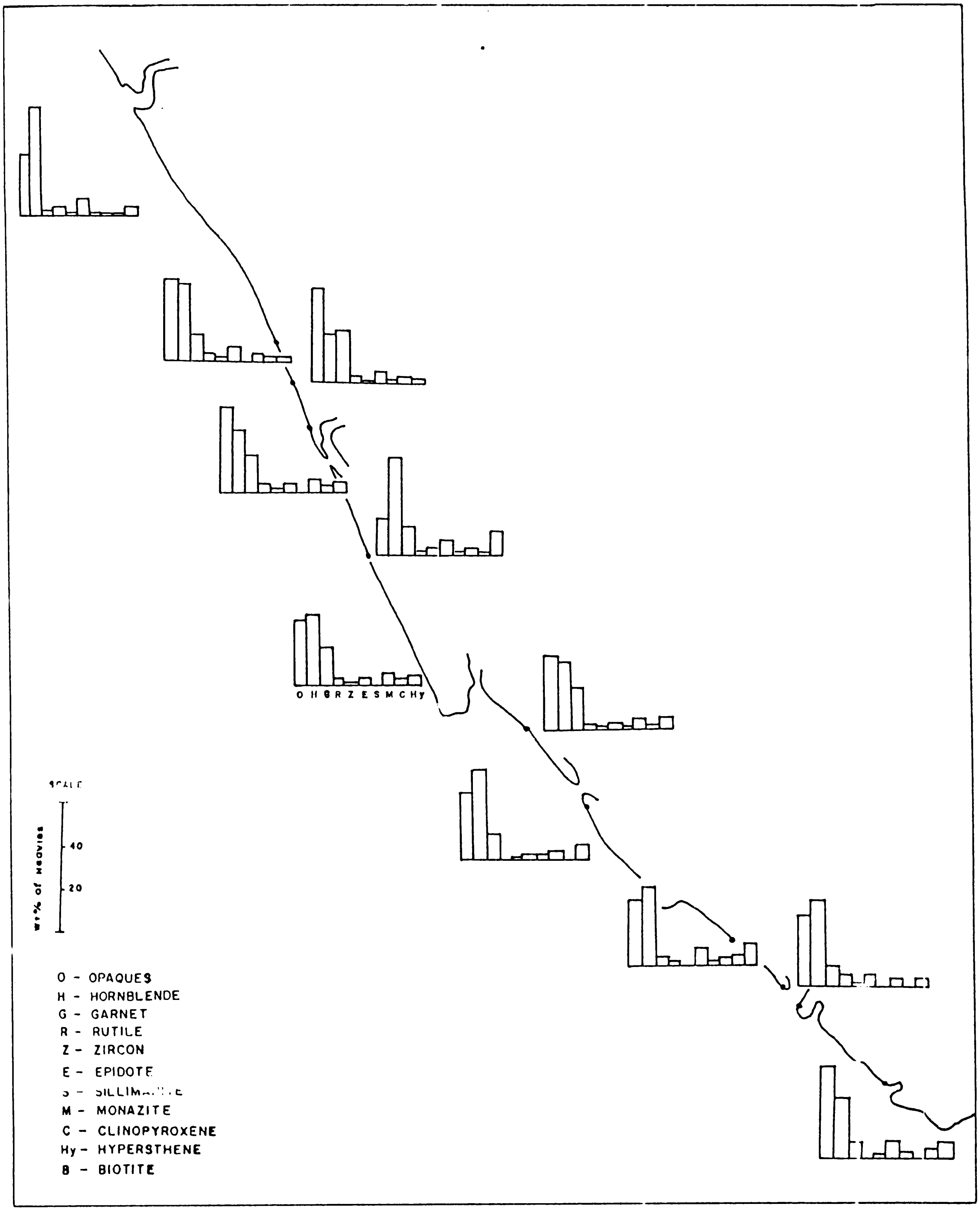


Fig. 3.1b. Relative proportion of heavy minerals in the beach sediments.

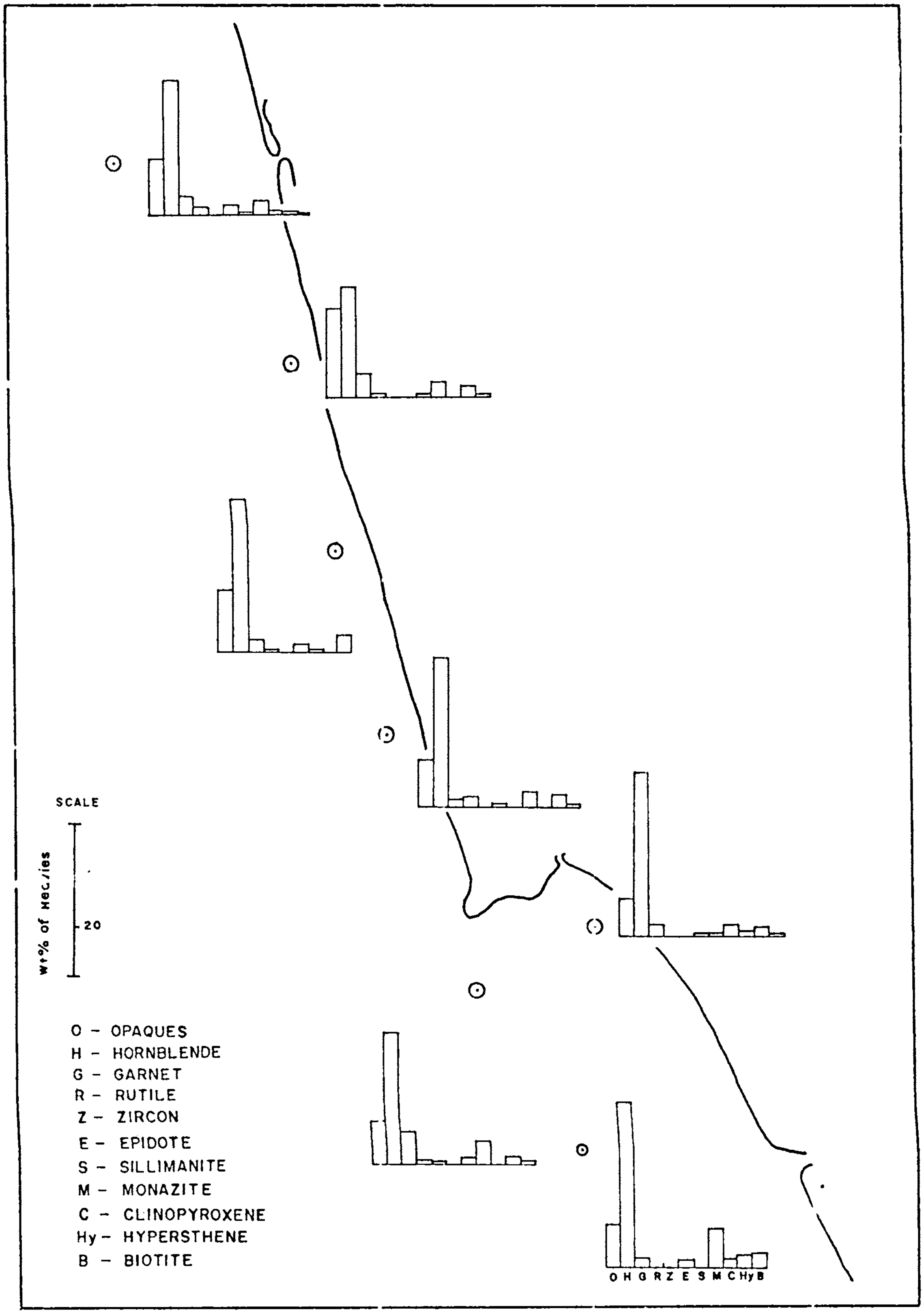


Fig. 3.1c. Relative proportion of heavy minerals in the innershelf sediments.

Table – 3.1

PERCENTAGE VARIATION OF HEAVY MINERALS IN THE STRAND PLAIN, BEACH AND INNERSHELF SEDIMENTS

Opaques	Horn- blende	Garnet	Rutile	Zircon	Epidote	Silli- manite	Mona- zite	Clino- Pyroxene	Hyper- sthene
Strand Plain									
58.82	05.98	10.56	05.63	4.93	0.70	0.69	-	-	-
49.27	13.41	19.53	05.25	3.21	3.50	1.46	3.21	-	1.17
73.61	07.64	-	10.07	4.86	1.04	2.78	-	-	-
49.81	18.51	19.06	02.72	3.11	3.81	0.78	1.17	1.95	-
48.85	13.46	18.46	03.85	1.93	3.08	0.77	1.54	4.23	-
71.57	08.53	-	10.15	6.09	-	0.59	-	4.06	-
54.50	10.90	26.07	06.54	1.91	3.27	1.63	2.18	3.00	-
43.40	19.44	21.88	01.74	5.21	1.74	2.43	2.43	1.74	-
62.01	09.74	13.31	03.57	5.84	1.95	0.32	1.95	1.30	-
67.39	02.99	14.40	03.53	5.98	1.36	1.36	1.36	0.56	-
80.00	00.58	00.58	03.48	8.41	1.16	2.61	2.03	1.16	-
86.07	01.60	-	04.34	7.08	-	0.68	-	0.23	-
17.36	34.37	24.65	02.08	3.82	9.37	5.56	2.08	0.69	-
74.13	03.43	11.67	00.52	4.73	1.89	1.26	0.32	-	-
76.78	00.75	-	08.99	6.37	1.12	2.25	-	3.75	-
82.78	01.32	-	02.65	3.97	3.97	3.97	-	1.32	-

Opaques	Horn-blende	Garnet	Rutile	Zircon	Epidote	Silli-manite	Mona-zite	Cli-pyro-xene	Hyper-sthene	Biotite
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
76.97	03.09	00.57	05.90	7.30	1.97	0.28	1.12	2.81	-	-
57.62	7.44	16.73	6.69	1.12	4.83	-	3.72	1.86	-	-
Beach										
28.37	50.15	02.29	3.44	1.15	7.74	0.86	1.15	1.15	3.72	-
42.86	21.62	22.71	2.56	1.10	4.40	1.47	2.20	1.10	-	-
38.31	28.03	17.34	2.42	1.21	4.44	1.21	1.61	1.21	4.44	-
17.77	45.04	12.81	1.65	0.41	7.44	1.24	2.07	0.83	10.74	-
29.46	32.44	17.26	3.27	1.19	3.87	0.30	5.95	2.38	3.87	-
34.24	30.51	18.31	2.03	1.02	2.37	0.68	4.75	0.68	5.42	-
31.02	37.50	04.16	1.39	-	8.33	1.85	2.31	2.78	10.65	-
33.35	39.09	09.77	5.21	0.98	4.23	-	3.26	0.33	3.58	-
42.74	27.39	07.13	0.27	1.10	8.22	-	0.55	4.93	7.67	-
31.12	42.66	11.88	0.35	0.70	1.40	1.05	3.15	0.70	6.99	-
37.60	34.29	10.89	2.86	0.95	6.19	0.48	2.86	1.90	1.90	-
Innershelf										
35.67	39.95	4.77	3.27	1.51	2.01	1.26	8.54	0.75	2.26	-
13.96	59.94	5.71	1.79	-	3.57	1.14	7.79	-	7.14	-
21.79	51.96	07.53	2.79	-	4.19	1.12	05.87	1.96	1.68	1.12

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
17.84	51.67	12.26	1.49	1.12	-	2.60	08.92	-	2.97	1.12
14.62	61.49	05.07	-	0.60	1.49	1.49	04.48	2.09	3.88	1.48
34.32	42.01	09.17	1.78	0.30	0.30	0.89	05.62	0.59	4.14	0.89
19.41	59.31	03.72	3.99	0.27	0.80	0.53	06.12	-	4.52	1.33
16.89	64.21	03.51	0.35	-	2.46	0.35	14.74	2.81	4.21	5.26

ent proportions in different environments. The nature and concentration of different heavy minerals from beach, strand plain and innershelf are shown in plates XXVI- XXXIII.

Percentage abundance of heavy mineral suit in different environments were correlated to understand the inter-relationships between different mineral assemblages. Table 3.2 gives the correlation matrix that summate the relationship between the heavy minerals. Dendrograms (Fig. 3.2) were drawn to assess the mineral groupings. Significant positive and negative loadings were observed among these parameters. A correlation coefficient greater than 0.30 were considered to work out the stability of the minerals in different environments as it is found significant at 0.01 percent confidence level (Thomas et al., 1972).

The opaques in the strand plain show high degree of negative correlation with hornblende and epidote, whereas it shows a positive correlation with rutile and zircon. These relationship may be an indirect expression of the preferential solution of the less stable minerals such as horrblende and epidote. In this process, minerals such as rutile and zircon which are relatively stable and that are not affected by the solution activity are concentrated in the lag deposits. On the other hand the antipathetic relationship between opaques and hornblende in the beach and innershelf sediments may be due to addition of the latter relative to opaques, a phenomenon which is related to specific gravity controlled transportation.

Table - 3.2

CORRELATION COEFFICIENT MATRIX OF THE STRAND PLAIN, BEACH AND INNERSHELF SEDIMENTS

	Opaques	Horn-blende	Garnet	Rutile	Zircon	Epidote	Silli-manite	Mona-zite	Pyro-xene	Hypers-thene
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Strand plain										
Opaques	1.000									
Hornblende	-.941	1.000								
Garnet	-.863	.729	1.000							
Rutile	.335	-.325	-.446	1.000						
Zircon	.567	-.450	-.688	.056	1.000					
Epidote	-.733	.729	.601	-.393	-.584	1.000				
Sillimanite	-.300	.411	.064	-.248	.013	.540	1.000			
Monazite	-.571	.429	.682	-.284	-.444	.503	-.051	1.000		
Pyroxene	.009	.003	-.030	.337	-.127	-.053	-.223	-.003	1.000	
Hypersthene	-.196	.126	.220	.025	-.194	.115	-.030	.402	-.275	1.000

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Beach										
Opaques	1.000									
Hornblende	-.795	1.000								
Garnet	.260	-.661	1.000							
Rutile	-.066	.121	.059	1.000						
Zircon	.494	-.380	.384	.371	1.000					
Epidote	-.193	.287	-.678	-.094	-.395	1.000				
Sillimanite	-.204	.056	.091	-.324	-.584	.035	1.000			
Monazite	-.079	-.242	.597	.301	.242	-.731	-.108	1.000		
Clinopyroxene	.291	-.240	-.388	-.422	-.098	.627	-.275	-.407	1.000	
Hypersthene	-.553	.397	-.444	-.583	-.762	.368	.279	-.229	.276	1.000

	Opaques	Horn-blende	Garnet	Rutile	Zircon	Epidote	Silli-manite	Mona-zite	Clino-pyroxene	Hyper-sthene	Biotite
Innershelf											
Opaques	1.000										
Hornblende	-.927	1.000									
Garnet	.136	-.424	1.000								
Rutile	.443	-.410	-.086	1.000							
Zircon	.452	-.620	.263	.160	1.000						
Epidote	-.237	.326	-.390	.041	-.469	1.000					
Sillimanite	-.107	-.249	.762	-.173	.608	-.318	1.000				
Monazite	-.146	.238	-.206	-.286	-.045	.121	-.213	1.000			
Clinopyroxene	-.170	.386	-.377	-.552	-.302	.405	-.346	.336	1.000		
Hypersthene	-.445	.434	-.266	-.209	-.468	.057	-.272	.070	-.324	1.000	
Biotite	-.336	.548	-.320	-.509	-.388	.024	-.428	.723	.708	-.017	1.000

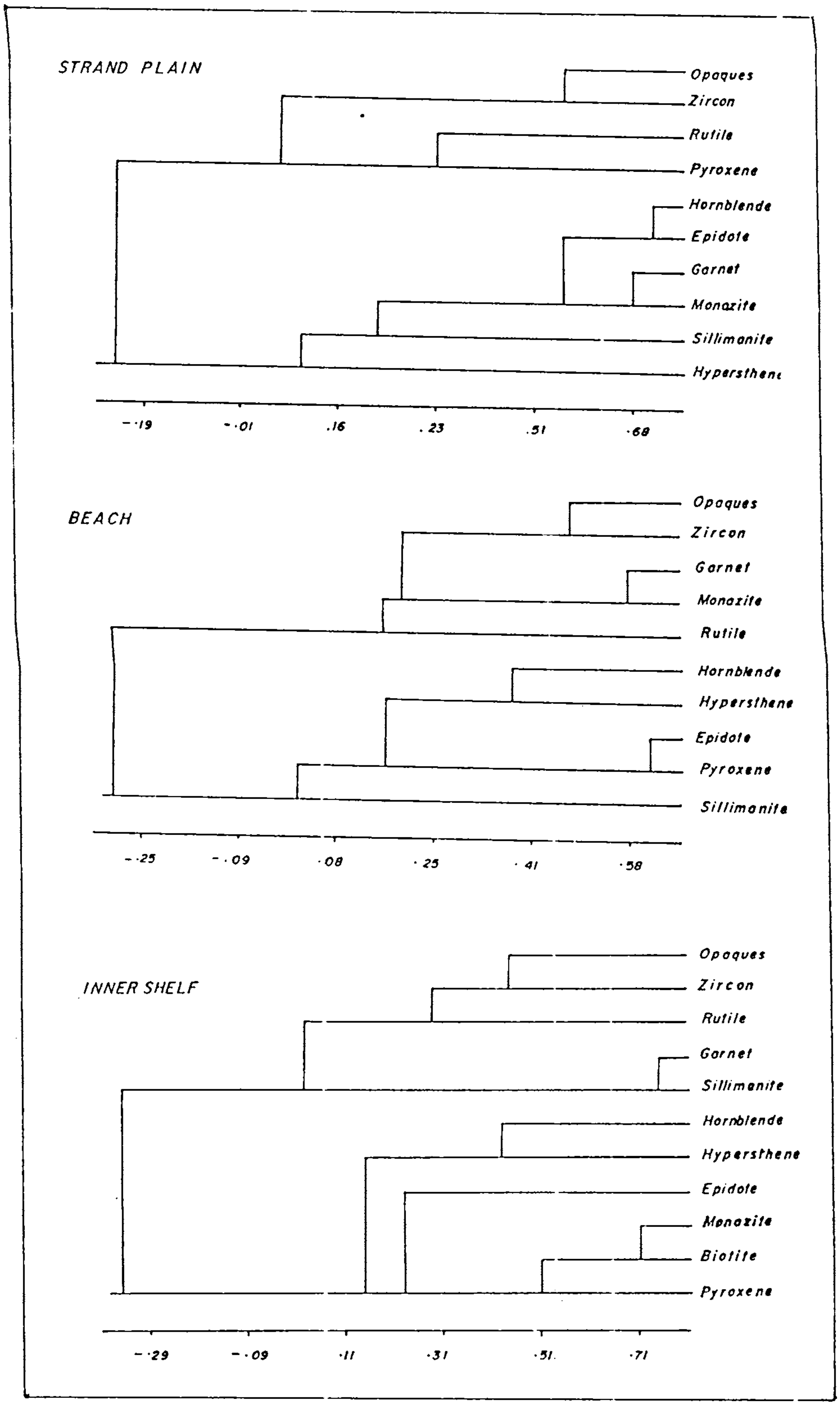


Fig. 3.2. Dendrogram illustrating the relationship between the heavy minerals in different environments of deposition.

High velocity longshore or onshore currents in the littoral zone transport minerals with different shape, size and specific gravity towards the shore by simultaneous suspension and bottom drag. These minerals are transported onshore by the internal turbulence of the breakers. During the process of transportation, some of these minerals would be deposited in the bottom of waves, finally transporting the remaining minerals onshore. These minerals are carried up the beach upto the swash limit. While retreating, the lighter heavies such as hornblende and hypersthene are transported back to the offshore by the weaker backswash leaving behind the denser opaques. During the course of the offshore transportation, these minerals may get deposited by the friction caused by the interaction of the incoming and retreating waves, thus creating a state of abundance of hornblende over opaque.

Together with the depletion of hornblende, this process effects concentration of more opaque minerals than the hornblende in the beach. Percentage of magnetite in beach sand is in large, a part of function of sorting processes (Leupke, 1980). Komar & Wang (1984) also found that the light minerals are preferentially entrained and transported offshore relative to heavy minerals. The onshore transport condition during fair weather season marks the return of light minerals and available heavy minerals from the offshore.

In addition to this process, being lighter than magnetite (Sp. gr. 5.2) and ilmenite (sp. gr. 4.7), majority of hornblende grains (sp. gr. 3.27) are liable to be transported farther and deposited in the open shelf where favourable conditions prevail. This sort of density based sorting could be reason why the innershelf sediments abound in hornblende than the opaques. Sallenger (1979) and Komar & Wang (1984) also attributed the abundance of ferro-magnesian minerals in the open shelf to the differential settling of heavy minerals, a process that is controlled by the variable physical properties of the minerals.

The statistical significance of the mineral variability was evaluated by means of Q-mode factor analysis of the strand plain, beach and innershelf sediments. Q-mode factor analysis exemplify groupings of minerals within the assemblages and it is used to reduce the number of variables that describe each sample. The table 3.3 shows the eigen values, communality and factor scores worked out individually and collectively for different environments. Analysis of raw data of the mineral composition in the strand plain show high communality and yielded two factors which account for 99% of the variance (Fig. 3.3). Factor I consists almost entirely of stable minerals such as opaques rutile and zircon. The factor II consists of almost equal proportions of relatively unstable minerals such as hornblende and garnet. The beach and innershelf areas incorporate a single factor distribution (Fig. 3.3). The Factor I in beach consists of opaques and garnet, the earlier with greater factor loadings. In the innershelf sediments, hornblende and opaques show significant positive and negative loadings respectively.

Table - 3.3

EIGEN VALUES, COMMUNALITY AND FACTOR SCORES OF HEAVY MINERAL ASSEMBLAGES FOR INDIVIDUAL AND COMBINED ENVIRONMENTS OF DEPOSITION

Strand Plain

Eigen values	Percent of trace	Cumulative percent of trace
16.577	92.207	92.207
1.240	6.886	99.094
0.109	0.606	99.699
0.023	0.130	99.830

Communality	Factor I	Factor II
.998	.881	.471
.994	.735	.674
.985	.924	.363
.998	.703	.709
.994	.742	.666
.982	.920	.369
.974	.727	.668
.994	.629	.774
.998	.849	.526
.991	.884	.458
.996	.941	.308
.997	.951	.305
.971	.087	.981
.995	.902	.426
.996	.950	.304
.992	.946	.312
.996	.942	.329
.986	.824	.555

Communality and rotated factor matix.

Table 3.3 contd.

Factor I	Factor II
80.192	-4.547
-9.586	32.756
-8.043	34.597
5.963	0.269
5.653	0.252
-1.606	7.311
0.054	2.987
-0.330	3.075
1.289	1.089
-0.037	0.193
0.000	0.000

Varimax factor scores.

Beach

Eigen values	Percent of trace	Cumulative percent of trace
10.354	94.129	94.129
0.451	4.103	98.232
0.130	1.178	99.410

Table 3.3 contd.

Communality	Factor I	Factor II
.984	.468	-.874
.993	.917	-.390
.995	.834	-.547
.970	.428	-.887
.980	.730	-.669
.989	.788	-.607
.975	.590	-.791
.992	.663	-.744
.947	.790	-.568
.991	.617	-.781
.992	.746	-.659

Communality and rotated factor matrix.

Factor I	Factor II
44.964	-3.481
-1.539	-53.227
22.998	5.300
1.554	-1.828
1.325	0.029
0.051	-7.330
0.377	-0.827
3.504	-0.849
1.629	-0.588
-2.677	-10.531
0.000	0.000

Varimax factor scores.

Table 3.3 contd.

Innershelf

Eigen values	Percent of trace	Cumulative percent of trace
7.681	96.010	96.010
0.265	3.317	99.327
0.023	0.283	99.610
0.017	0.213	99.823
0.006	0.071	99.894
0.004	0.054	99.948
0.003	0.036	99.984
0.001	0.016	100.000

Communality	Factor I	Factor II
.996	.516	-.854
.996	.858	-.509
.995	.772	-.631
.935	.788	-.603
.996	.858	-.509
.997	.550	-.833
.995	.812	-.579
.986	.843	-.525

Communality and rotated factor matrix.

Table 3.3 contd.

Factor I	Factor II
-12.092	-48.955
68.223	-4.807
2.472	-7.336
-.512	-3.682
-.627	-1.497
2.707	0.281
0.845	-.856
7.355	-3.545
1.604	0.285
5.229	0.123
3.203	1.592

Varimax factor scores.

Strand plain Innershelf and Beach

Eigen values	Percent sum of squares	Cumulative percent sum of squares
29.077	78.586	78.586
6.901	18.652	97.238
0.750	2.026	99.264
0.116	0.314	99.578
0.056	0.152	99.730
0.031	0.085	99.815
0.029	0.077	99.892
0.019	0.052	99.944
0.012	0.033	99.977
0.006	0.016	99.993
0.003	0.007	100.000

Table 3.3 contd.

Communality	Factor I	Factor II	Factor III
.998	.957	.264	-.107
.998	.862	.417	-.283
.995	.961	.257	.065
.998	.831	.488	-.262
.996	.866	.417	-.269
.994	.957	.270	.069
.997	.864	.352	-.355
.994	.776	.527	.338
.998	.937	.319	-.137
.998	.965	.215	-.145
.997	.983	.168	.051
.998	.982	.175	.062
.975	.279	.823	-.468
.998	.971	.214	-.093
.997	.982	.169	.059
.995	.980	.177	.055
.999	.978	.200	.054
.993	.926	.302	-.211
.987	.345	.931	.041
.998	.747	.563	-.352
.995	.666	.699	-.250
.978	.208	.952	-.166
.996	.515	.810	-.274
.994	.592	.754	-.276
.969	.483	.857	.001
.996	.515	.850	-.096
.970	.719	.670	-.056
.992	.441	.885	-.121
.996	.610	.779	-.125
.992	.530	.843	.002

Table 3.3 contd.

Communality	Factor I	Factor II	Factor III
.999	.067	.997	-.010
.995	.216	.973	-.043
.988	.171	.971	-.129
.994	.072	.994	.003
.995	.492	.865	-.069
.995	.155	.985	.030
.981	.089	.986	.030

Communality and rotated factor matrix.

Factor I	Factor II	Factor III
72.473	5.043	40.912
-8.909	56.834	15.939
3.609	3.836	-51.740
5.477	0.648	3.559
5.497	-0.945	2.983
0.928	3.440	-4.316
0.966	0.805	-1.374
-.804	6.327	1.092
1.560	0.924	0.879
-1.018	5.957	3.658
-0.326	1.099	1.526

Varimax factor scores.

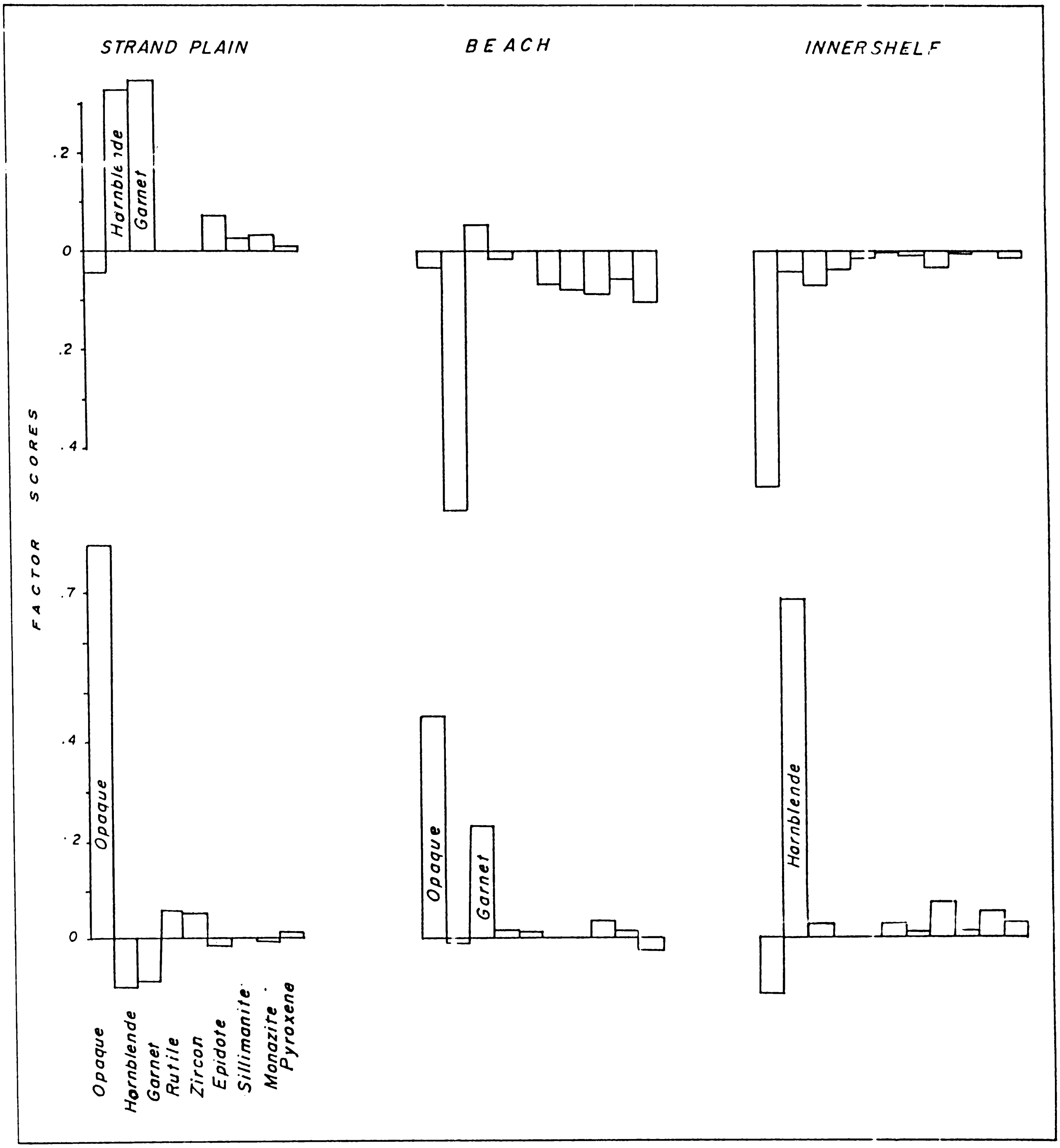


Fig. 3.3. Individual composition of three factors obtained from the analysis of heavy minerals from the strand plain, beach and innershelf sediments.

Comparative factor analysis of heavy mineral assemblages from all the environments yielded very significant results (Fig. 3.4). The factor I which is that of the strand plain, show dominant positive loadings for opaques and less significant positive loadings for garnet, rutile and zircon. The negative loading for the hornblende is significant. Factor II, (innershelf) consists pre-dominantly of hornblende. The loadings pertaining to all other minerals are insignificant and are distributed almost in equal proportions. Factor III (beach) consists mainly of opaques and hornblende with insignificant quantities of other minerals.

The relative proportions of opaques and hornblende in the three environments can be explained in terms of the differential settling and relative stability of the heavy minerals. A stability series has been identified by Pettijohn (1975) which is based orthe persistance of heavy minerals through time. The ratio of frequency occurrence of heavy minerals in recent sediments and average frequency of occurrence in ancient sediments were taken as a measure of the survival ability of each species (Table 3.4). Stability order of common rock forming minerals from the weathering profiles also show a close resemblance to the order of persistance of the heavy minerals. The differences which do occur may be due to the differences between the soil and subterranean environment. It was also emphasized that occurrence of more number of mineral species in comparatively younger deposits, is an indication of its residence time in any particular environment.

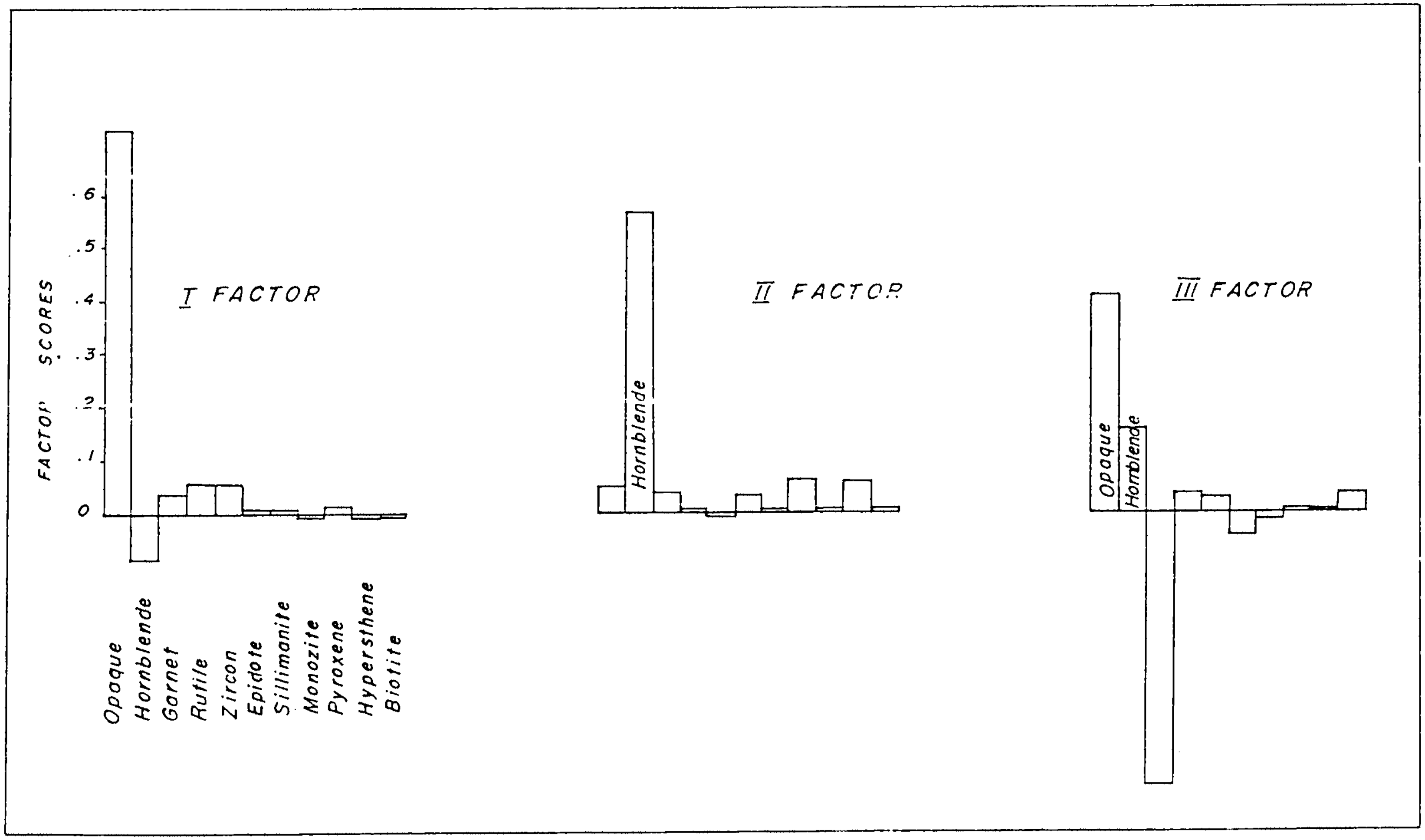


Fig. 3.4. Composition of three factors obtained from the analysis of heavy minerals of the sediments from three environments.

Table - 3.4

ORDER OF PERSISTANCE OF DETRITAL MINERALS
(After Pettijohn, 1975)

-3	Anatase	6	Apatite	14	Topaz
-2	Muscovite	7	Ilmenite	15	Sphene
-1	Rutile	8	Magnetite	16	Zoisite
1	Zircon	9	Staurolite	17	Augite
2	Tourmaline	10	Kyanite	18	Sillimanite
3	Monazite	11	Epidote	19	Hypersthene
4	Garnet	12	Hornblende	20	Diopside
5	Biotite	13	Andalusite	21	Actinolite
				22	Olivine

Soils of sub-terranean environments also have a similar stability series. In such areas the stability zones owe their existence and character to selective removal of less stable species in deeper zones by intra-stratal solution (Blatt & Sutherland, 1969; Pettijohn, 1975). In the strand plain, the relative dominance of the stable minerals such as opaques (ilmenite and magnetite), rutile and zircon over the less stable minerals would probably indicate of some sort of solution activity, that can remove chemically less stable heavy minerals by dissolution, thus leaving behind more stable and durable minerals in the deposit. The effect of solution can be inferred by studying the nature of occurrence of some mineral grains. The garnets show ample evidences for the solution activity such as the formation of mamillary patterns.

The mamillary patterns (Gravenor & Levitt, 1981) found on the surfaces of the detrital garnets has attracted the attention of many geologists for the past 80 years. These facetted surfaces are remarkably symmetrical and resemble elongated, overlapping and rectangular or rhombohedral building blocks (Plates XXIII-XXV). These surface patterns were described by the use of a number of terms including facets (Bramlette, 1929) intricate wedge markings (Rahmani, 1973), hillocks (Simpson, 1976) and rectangular etch pattern (Gravenor, 1979). As pointed out by Simpson (1976), opinion is split between those who believe that the facets are caused by chemical etching and those who believe that they originate from growth on a pre-existing nucleus. The etch patterns were developed by immersion of garnet in acid and alkaline solution (Bramlette, 1929). McMullen (1959) produced facetted surfaces by the immersion of crushed spessartite in Nacl for several days. Simpson (1976) placed crushed garnet in 40% HF acid and noted the appearences of pitted grains.

Howie et al., (1980) suggested that facetted surfaces on detrital garnets are the result of overgrowth from intra-stratal solution. Gravenor & Gostin (1979) suggested that such facetted surfaces without any traces of modification of the grains, are produced due to etching activity. In the strand plain sediments evidences of nucleus could not be seen on the facetted garnet grains when viewed under binocular microscope. Upon immersion in HF acids of different concentrations for different periods, garnets showed mamillated surfaces that are identical to those found on natural garnets (Gravenor & Levitt, 1981). This observation prompted Gravenor & Levitt (1981) to conclude that 'the chemical homogenity of surface patterns on the garnets are not developed from the growth over a pre-existing nucleus. The absence of variation in chemical composition on the edges of garnets within a single sample indicate that the surface pattern on the detrital garnets are the result of etching'. On examination under the binocular microscope it is found that crusts of what may be iron oxide was situated on the recesses or flat portions in many of the strand plain grains.

Most of the strand plain sediments are either red coloured or yellow coloured. Colour of coastal dune sediments are apparently dependent on several variables, such as availability of iron in humid oxidizing conditions (Swift & Boehmer, 1972), thickness of iron oxide coatings (Norris, 1969), degree of iron oxide hydration (Soileau and McCracken, 1967) and time (Norris, 1969). Redness can only a general guide to sediment age, though progressively older deposits may be distinctly redder (Norris, 1969). Disintegration and solution of epidote, amphibole and ortho-pyroxenes are considered as the likely sources of iron in the coastal sands (Setlow, 1979). However, some of the irons was probably derived from minerals in the bleached soil zone. As Norris (1969) mentioned, the solution of iron bearing heavy minerals is the probable source of iron oxide stain in the strand plain sands.

3.2.2. Clay Minerals

Clay is essentially a weathering product of disintegration and chemical decomposition of igneous rocks and some types of metamorphic rocks and are related to pedological processes. In marine environment, clay is principally a detrital component but it may be subsequently modified by the environment and may undergo partial to complete chemical transformation and take a more stable phase (Grim, 1968). The laboratory evidences are sufficient to emphasize the relative depletion of montmorillonite to kaolinite and kaolinite to illite or chlorite.

The potential usefulness of clay mineral studies in understanding several marine depositional processes has been amply demonstrated. The sources, dispersal pathways, transport mechanism and depositional sites of fine grained particles in the oceans were elucidated using clay mineral distribution (Biscaye, 1965; Gorubonova, 1966; Griffin et al., 1968; Keller, 1970; Naidu & Mowatt, 1974; Gibbs, 1977; Moriarthy, 1977; Kalin, 1980; Kolla et. al., 1981; Maldonado & Stanley, 1981; Liyanange, 1986). Naidu et al., (1982) emphasized the importance of repositary of clays discharged into the ocean in the light of Quaternary marine transgressive and regressive history. In the west coast of India, the clay mineral assemblages were used to decipher the dispersal pattern by some of the authors (Nair, et al., 1982; Rao, et al., 1983; Rao & Nagendranath, 1988) and has been mainly restricted to deeper areas. In the present study, depth controlled dispersal behaviour of the clay minerals in the shallower portions of the innershelf of the northern Kerala coast is studied.

In the order of abundance, the marine clay minerals such as montmorillonite, kaolinite, illite and gibbsite are recognized in the innershelf zone of northern Kerala (Table 3.5). The principal reflection (001) of montmorillonite is identified approximately at 14 A° (that has expanded to 17 A° 001 peak upon glycolation), that of kaolinite at 7.15 A° (001) and 3.57 A° (002) and of illite and gibbsite at 10 A° and 4.90 A° respectively (Figs. 3.5).

Regional variation of clay mineral assemblages were plotted to understand the depth control of the dispersal pattern (Figs. 3.6 to 3.8). The relative proportions of the clay minerals were estimated from the peak areas of the basal reflection from the untreated sample. Relative percentages of montmorillonite is low in the shallower parts, from where it shows a gradual increase in abundance towards the deeper areas (Fig. 3.6). The percentage of montmorillonite vary between 40% in the shallower areas and to 70% in the deeper areas. The percentage of kaolinite are 35% and 25% in the deeper and shallower areas respectively (Fig. 3.6). Due to the lesser abundances of gibbsite and illite, their depth controlled variations are insignificant. Illite and gibbsite vary between 0%-7% and 0%-4% respectively.

The clay mineral occurences in the innershelf can be related to the energy conditions and the property of individual mineral constituents. Differential flocculation (Whitehouse et. al., 1960) and

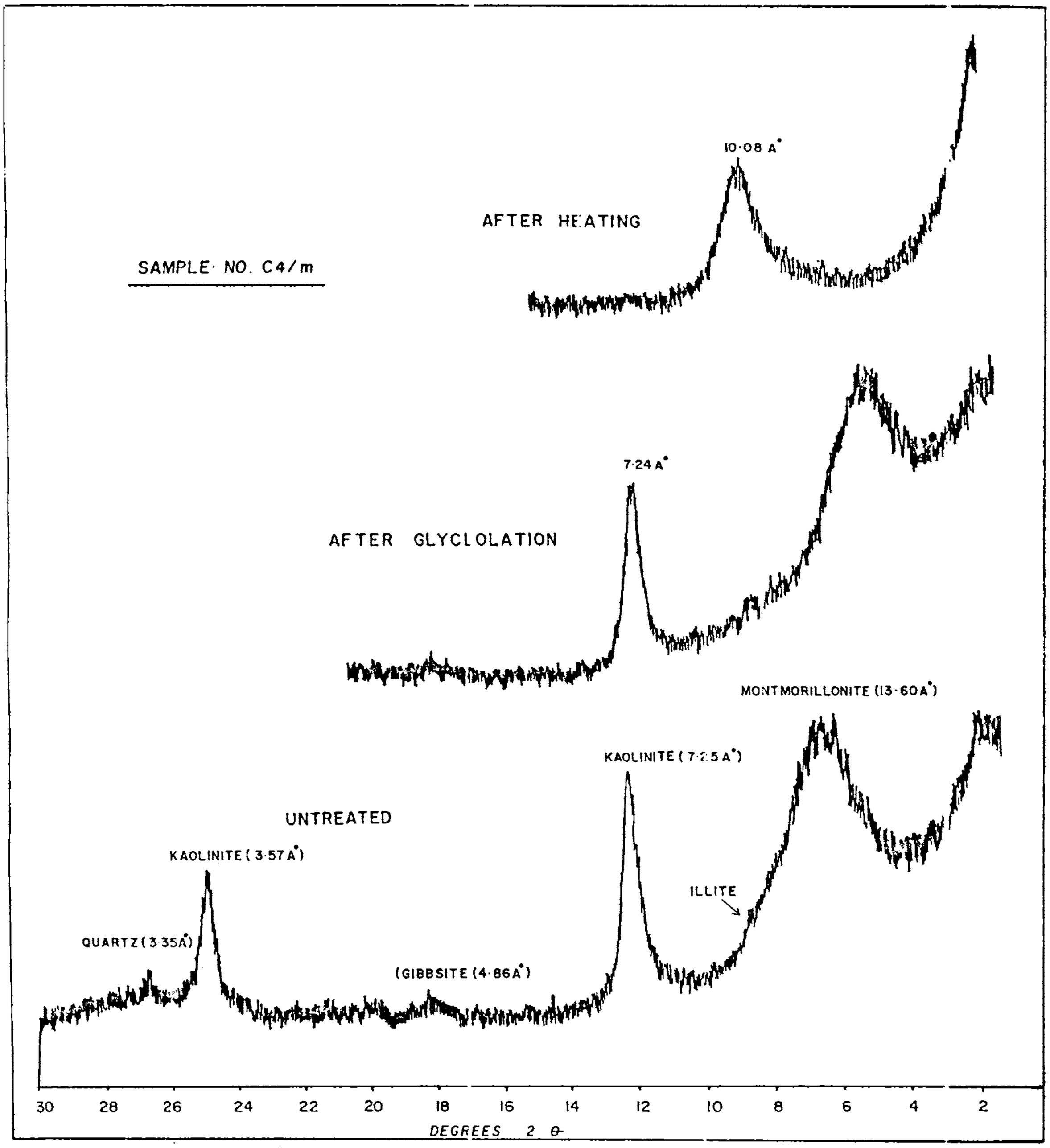


Fig. 3.5. Diffractogram of the clay mineral assemblages.

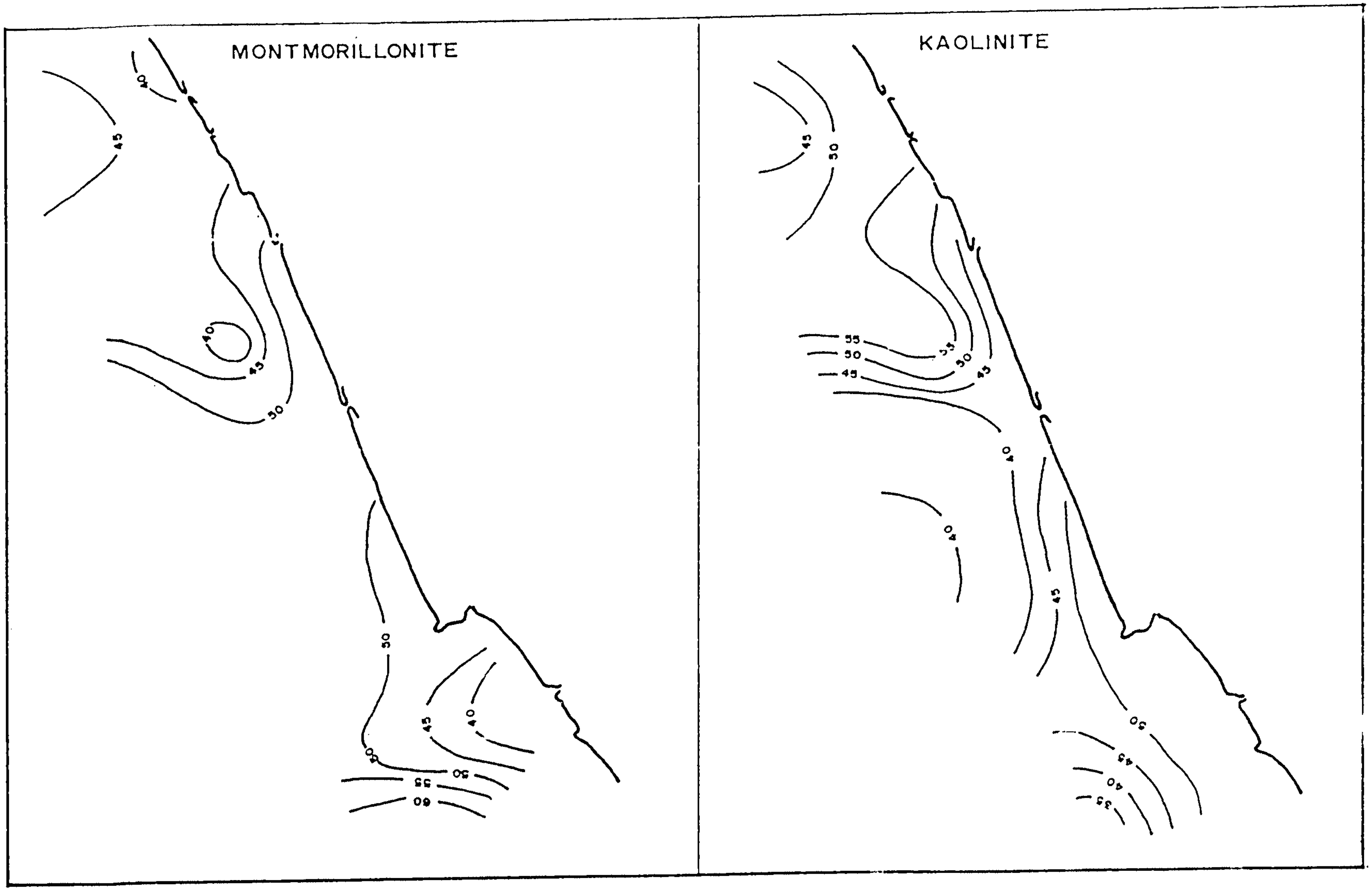


Fig. 3.6. Aerial variation of montmorillonite and Kaolinite in the innershelf sediments.

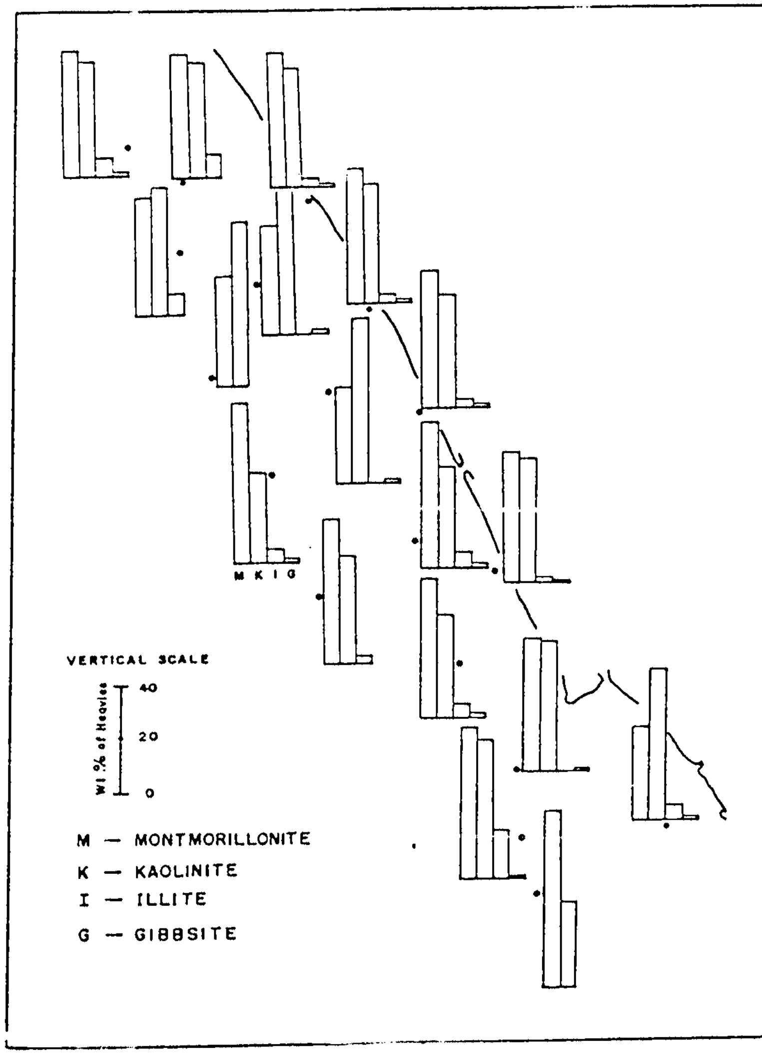


Fig. 3.7. Relative percentages of montmorillonite and kaolinite in the innershelf sediments.

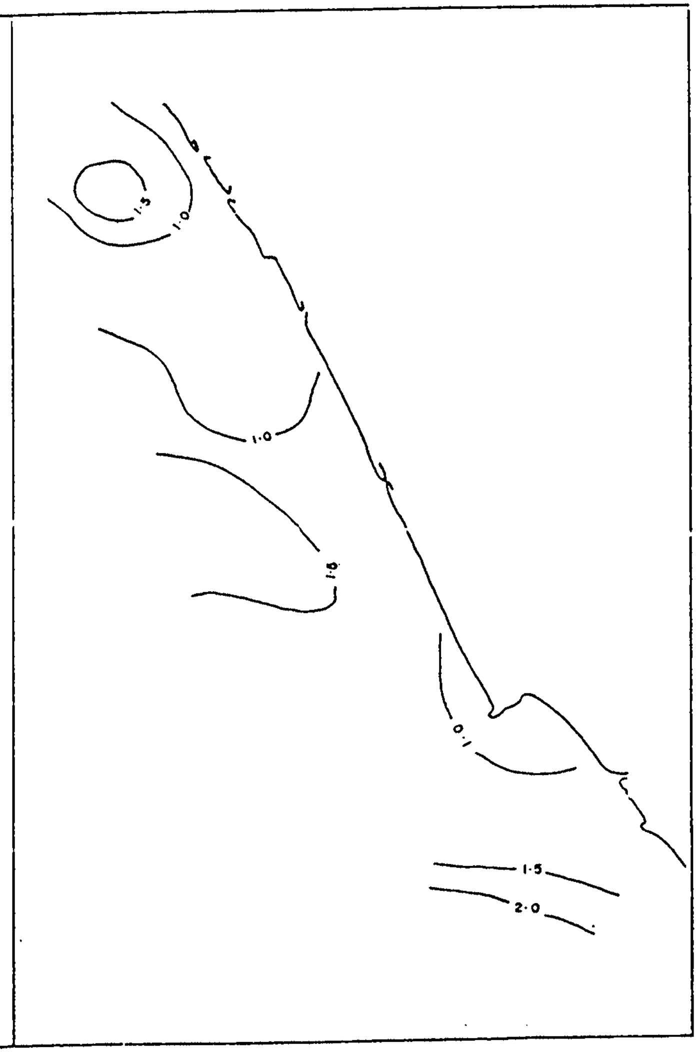


Fig. 3.8. Aerial variation of the ratio of montmorillonite and kaolinite in the innershelf sediments.

Table - 3.5

SEMI-QUANTITATIVE AMOUNT (%) OF CLAY MINERALS IN THE INNERSHELF SEDIMENTS

Sample No.	montmorillonite (M)	kaolinite (K)	illite	gibbsite	M/K*
O5	47.64	43.53	7.06	1.76	1.09
O1	37.86	53.40	7.76	0.97	0.71
N4	47.05	44.12	8.82	-	1.07
M5	44.15	48.05	7.79	-	0.92
M1	42.73	56.43	-	0.85	0.76
L4	42.60	55.62	-	1.78	0.77
K6	40.63	59.37	-	-	0.68
K1	51.29	45.02	2.95	0.74	1.11
J3	36.50	61.53	-	1.92	1.14
I6	60.53	33.72	4.60	1.15	1.80
I1	52.38	42.86	3.81	0.95	1.22
G6	55.17	41.38	3.45	-	1.33
G3	55.07	37.68	5.80	1.45	1.46
F1	50.02	47.14	2.10	0.79	1.01
E3	53.23	38.85	5.76	2.16	1.37
C4	50.32	49.04	-	0.64	1.03
B5	47.22	42.59	8.33	1.85	1.11
A2	35.75	56.98	5.59	1.68	0.63
A6	65.37	31.08	-	-	2.17

* montmorillonite/kaolinite ratio.

size segregation (Gibbs; 1977) play an important role in the occurrence of high percentages of kaolinite in the shallower areas and to their decrease in the seaward direction. Montmorillonite being fine grained and because of its tendency to remain in suspension for longer duration they are preferentially settled in low energy environments. Higher concentration of kaolinite in the shallower areas may be due to its early flocculation in response to the saline conditions (Whitehouse, et. al., 1960). Kaolinite being a low altitude clay mineral (Biscaye, 1965) is more abundant in the innershelf areas (Milney and Early, 1958; Griffin, et. al., 1968).

Rao et al., (1983) attributed detrital origin to the clay minerals. Montmorillonite is considered to be the detrital end products of weathering of variety of rock types such as volcanic materials, igneous, pyroclastic rocks and soil on land (Aoki and Oinuma, 1978). Kaolinite is derived from the intense leaching of Ca^{21}, Mg^{21}, K^{1} and Na^{1} etc from the granitic rocks due to high rainfall and warm temperature (Aoki and Oinuma, 1978). Gibbsite which is of continental in origin is considered to be formed part of the residual laterite and owe its derivation to aluminous laterites and bauxites. Gibbsite forms either directly from parent rock or indirectly from kaolinite by the desilicification processes brought out by ground water (Millot, 1970).

Other than clay minerals quartz is present in insignificant quantity as a non-clay mineral. Kolla et al. (1981) considered that the occurrences of quartz along with the clay minerals reflect the latters terrigenous origin and that it is derived from the Pre-Cambrian granulite gneisses and other metamorphic rocks.

CHAPTER IV

SUMMARY AND CONCLUSIONS

The textural characteristics of the sediments in the strand plain, beach and innershelf vary considerably and give rise to unique distribution typical to each environments. For evolving a comprehensive picture of the process, comparative histograms of graphic parameters were drawn for each of the environment (Figs. 4.1 & 4.2).

Majority of the strand plain sediments, which cluster around 1.10 phi and 1.90 phi are mainly the medium to coarse grade. It is quite interesting to note the total absence of fine 'tail', in the strand plain sediments which the beach sediment retains. On the other hand, the beach sediments encompass the complete range of the sand grade, starting from coarse to very fine sand. The innershelf sediments are polymodal and cover the size ranges from silt to clay grade. Majority of the population which cluster around 7.4 phi to 9.4 phi are in the silty clay grade. Other than against major river outlets, no sandy patches occur in the innershelf area.

Comparative histogram of standard deviation illustrate that the strand plain sediments are better sorted than the beach and innershelf sediments. The strand plain sands are clustered around 0.40 and 0.80 whereas the beach sands cluster around 0.70 and 0.90. Majority of the innershelf sediments are spread around 2.5 and 3.3 and illustrate very poorly sorted grade. The sediment dispersion beyond the breaker zone are essentially controlled by current, rather than

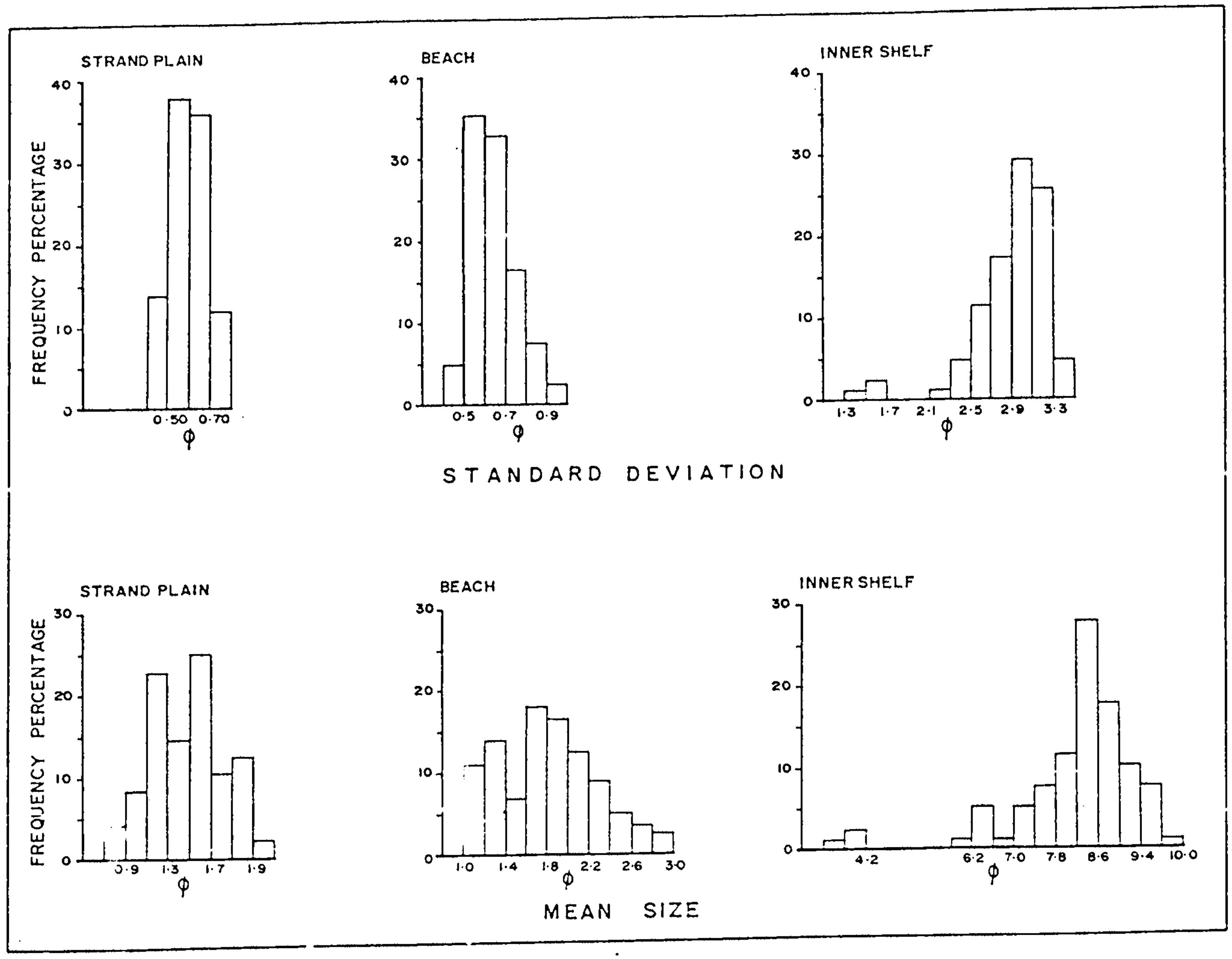


Fig. 4.1. Comparative histograms of mean size and standard deviation of strand plain, beach and inner shelf sediments.

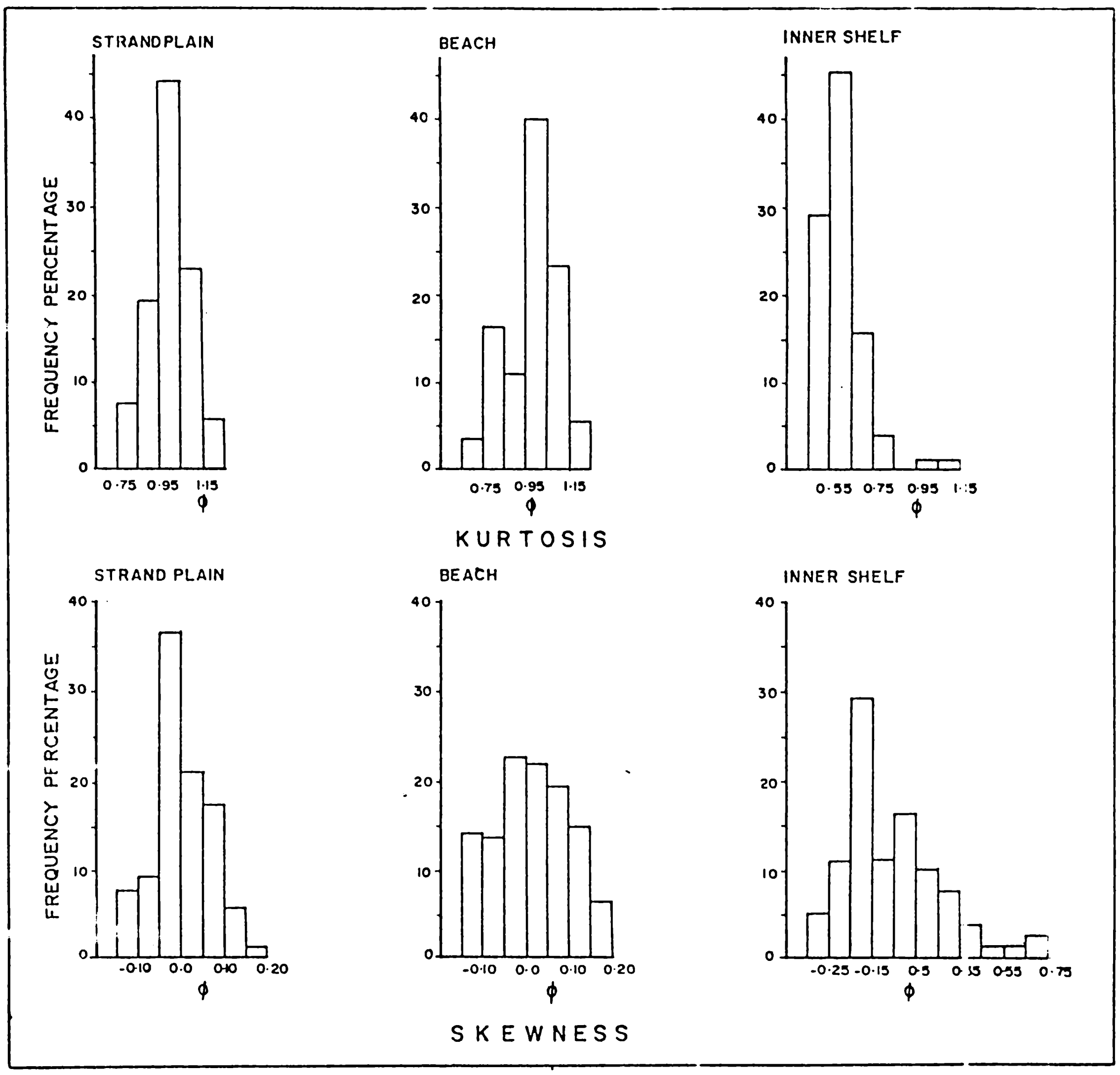


Fig. 4.2. Comparative histograms of skewness and kurtosis of strand plain, beach and innershelf sediments.

the turbulent wave energy (Wigley, 1961). Because of its lesser energy, as the currents are unable to sort out or disperse the sediments properly, the population tend to become very poorly sorted grade. On the other hand, the better sorted nature of the strand plain sediments could have been achieved by the selective removal of the fine sands from the population by the winnowal action of winds.

Comparative histograms of skewness indicate a near symmetrical distribution for the strand plain sediments, where the values are spread between 0.10 phi to 0.10 phi. The beach sediments are more negatively skewed than the strand plain sediments. As the innershelf sediments encompass the entire size range in the mud category they become negatively skewed to positively skewed. Folk and Ward (1957) has noted that a curve of a pure sand size is essentially nearly symmetrical in nature. With subsequent addition of fine sand, the population becomes negativedy skewed and further positively skewed. In a smiliar way, a population with either a pure clay or silt mode may also become nearly symmetrical in nature. Subsequent addition of finer or coarser fraction render the population more negatively skewed or positively skewed. The kurtosis value indicates insignificant changes in both beach and strand plain sediments whereas the innershelf sediments are platykurtic by its very nature.

The CM patterns (fig. 4.3) drawn for each of the three environments occur in different fields of Passega (1957). From the comparison of the CM patterns, it is inferred that the strand plain sediments

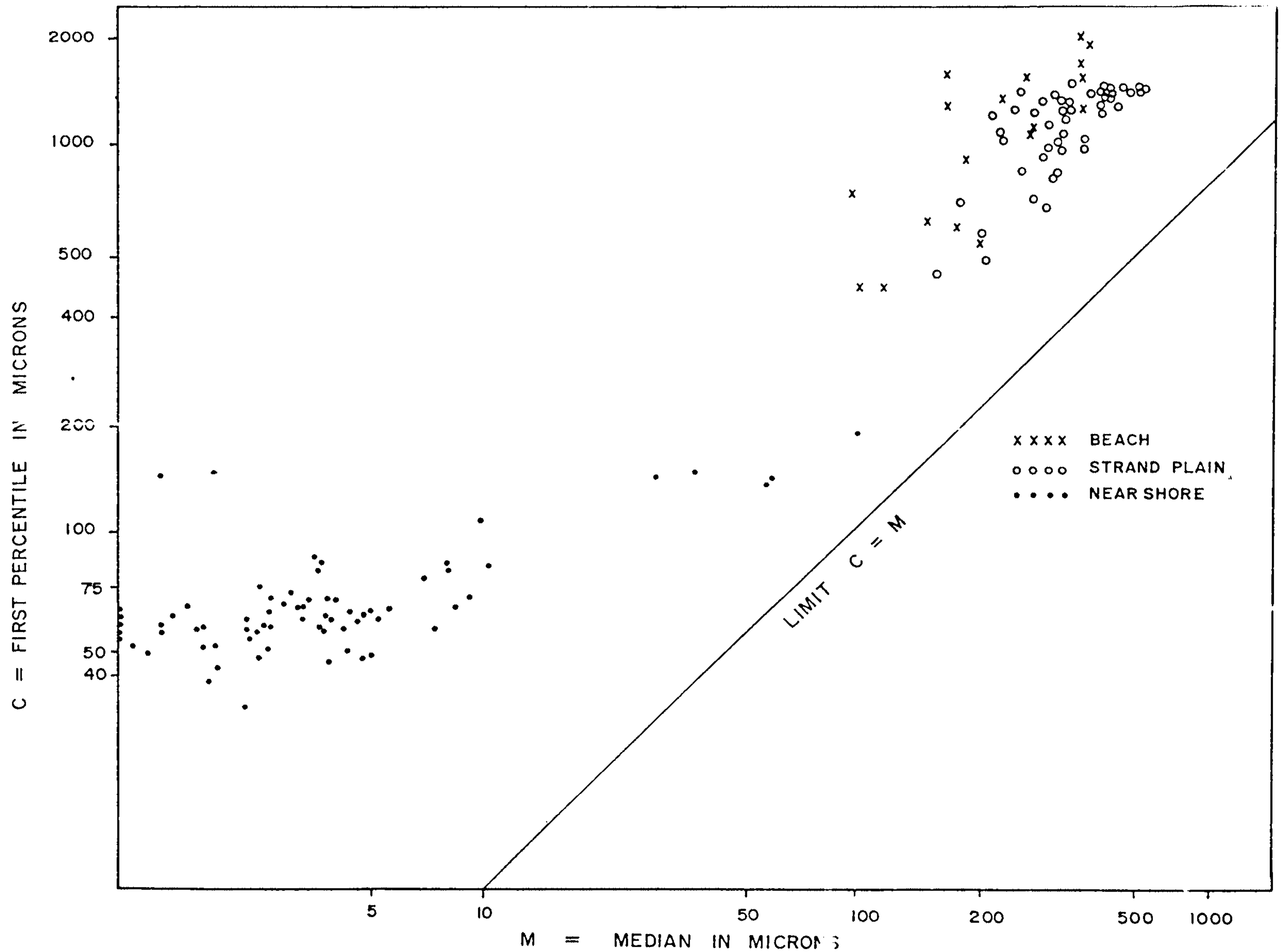


Fig. 4.3. CM diagram of strand plain, beach and innershelf sediments.

are transported mainly by rolling and the beach sediments by both bottom suspension and rolling. The gradational changes from rolling to bottom suspension are well represented in the beach and strand plain sediments. Passega has considered the sediments to be better sorted, when the points are nearer to the limit C = M. By its disposition it is inferred that the strand plain sediments are better sorted than that of the beach. The transportational mechanism of the inner-shelf sediments vary considerably from other two environments. It occupies a position farther in the finer side of the pelagic suspension area as demarcated by Passega.

The foreshore and breaker zone of the beach can be gradationally divided into high water line, mid water line and plunge point, where the sediments undergo different transportational and depositional mechanisms. The beach sediments in the above 'micro-environment' illustrate significant differences in the size characteristics, thereby reflecting the variation in amount of wave energy imparted to the sediments. The plunge point samples are coarser, polymodal, moderately to poorly sorted, negatively skewed to nearly symmetrical and platykurtic. The high water line samples are bimodal, medium to fine sand grade, moderately sorted, nearly symmetrical to negatively skewed and mesokurtic. The mid water line samples occupy a intermediate position between the other two. Because of its high turbulent conditions, the sediments in the plunge point are deposited without proper sorting. Hence the plunge point becomes poorly sorted and platykurtic. Such sediments which are not deposited in the plunge point, are carried upslope upto the maximum reach of the waves and deposited along the course of its transportation. This process (progressive winnowal action of the waves) makes the sediments finer and better sorted towards the high water line.

Beach topography and sediments show perfect correlation with the oceanographic parameters. The longshore current in the littoral zone are found to vary alternately in both southerly and northerly directions. In general, the fair weather season (both pre-monsoon and post-monsoon) is dominated by a northerly current, where the net effect is accretion. On the other hand, high velocity southerly current sweeps the beach zone in the monsoon, inducing widespread erosion. Needless to say the monsoon season is dominated by high breakers and more frequent waves. Because of the high wave energy the fine sands are winnowed away leaving behind the coarser, better sorted and less negatively skewed sediments as a lag deposit. A better correlation exist between the breaker parameters, size parameters and erosion/accretion phenomenon.

The erosional and accretional behaviour of the beaches can be properly understood if the swash and backwash mechanisms are taken into consideration. The infiltration capacity of the swash is considerably higher in the shallower premonsoon and postmonsoon profiles. Because of its high percolation, the backwash is ineffective to remove the sediments from the foreshore. In the monsoon the steeper foreshore with its high precipitation rate renders the beach foreshore oversaturated with water, thus reducing the infiltration of the swash and backwash. In such cases the water saturated foreshore are easily erodable owing to the gravity creep on the steeper surface.

From the textural studies (both size and surface textures) it can be assumed that the strand plain sediments are the resultant response of combined influences exerted by the beach and aeolian regime, the variable degree of surface texture production originating from its residence time in different environments. From the granulometric and surface textural studies, it is inferred that the strand plain sediments would have been cut off from the beach during the regressive processes, quite possibly during the Quaternary period. Subsequent to their deposition, the fine sands would have been winnowed away from the population leaving behind the coarser, better sorted and nearly symmetrical sand as a lag deposit.

As far as the sediment distribution patterns in the beaches are concerned, the Ezhimala headland which protrude out to the sea divide the study area into two halves, with distinct size characteristics in both the sectors. The beach sands are found to be coarser and finer in the north and south sectors respectively. Perversive to the nature of the beach sediments, the innershelf area south of the promontary is sandy consisting of sand to sand-silt-clay grade. One the other hand in the northern sector silty clay is the main constituent of the sediment. This can be explained if the wave refraction phenomenon around the headland and the river are taken into consideration. The primary impact of wave refraction is to concentrate the wave energy on the headland and river outlets, where the wave heights are several time as large as in the adjacent embayment. Because of the higher energy, the coarser sediments are deposited in and around the headland, by winnowing the finer sediments towards the low energy area on either side of the headland. The sediment which reaches the divergent zone are further distributed onto the shore. By the inter-action of incoming waves and the water flow from the river outlets, the waves are refracted, inducing deposition of the coarser sediments in its vicinity, which in turn become finer farther from the river outlets. The seaward side of the headland would necessarily be an environment dominated by low energy, as the sedimentation in such cases are influenced by the current activity.

To assess the statistical significance of the textural characteristics of the sediments, Q-mode factor analysis were undertaken. The normalized factor components (Klovan, 1966) represented in figure 4.4, illustrate the arrangement of three factor in different corners of the ternary diagram. It is quite interesting to note the mixed nature of the strand plain and beach sediments, which are spread between I and III factor. The innershelf sediments (factor-III) are altogether a separate entity. In association with CM diagram it is summarized that the strand plain (factor I) sediments are transported mainly by rolling and beach sediments (factor-III) by rolling and suspension. The innershelf sediments (factor-II) are transported by pelagic suspension and partly by uniform suspension.

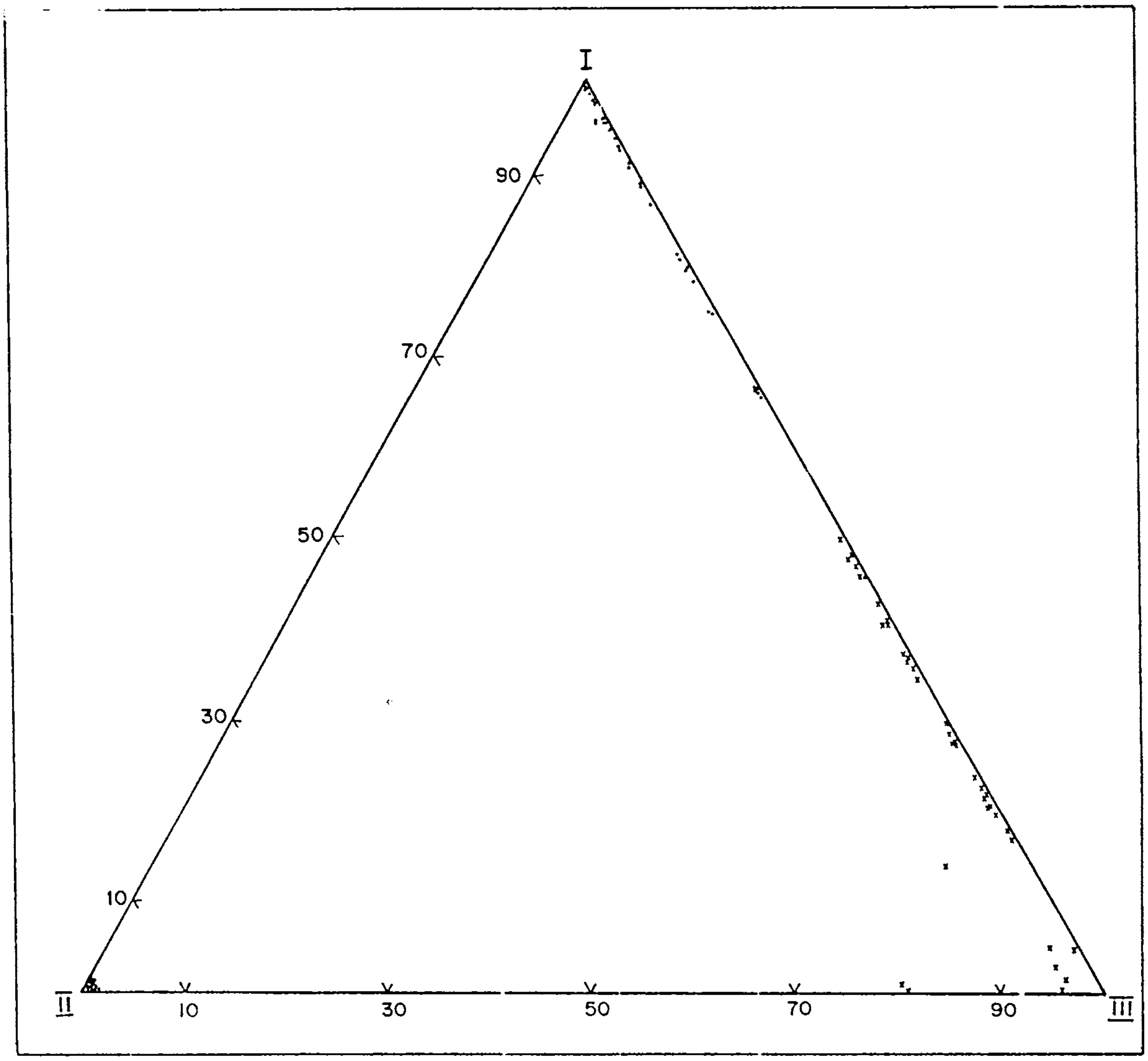


Fig. 4.4. Ternary diagram illustrating the plot of normalized factor components for the strand plain, beach and innershelf sediments.

The heavy mineral suits of the strand plain, beach and innershelf sediments consist of opaques, hornblende, garnet, ilmenite, zircon, hypersthene, rutile, epidote and sillimanite, that are concentrated in varying proportions. The strand plain sediments consists mainly of opaques with little quantities of hornblende, garnet, zircon and rutile. The beach sediments contain sub-equal proportions of opaque and hornblende with little garnet. The innershelf sediments are composed dominantly of hornblende with opaques forming less than 20% of the population.

Percentage abundance of heavy minerals in different environments were correlated to understand their inter-relationship with the concentration mechanisms of the minerals. The high negative correlation of opaque with hornblende and epidote may indicate the preferential solution of less stable minerals in the strand plain sediments. On the other hand, opaques show a positive correlation with the more stable minerals such as zircon and rutile. The antipathetic relationship of opaques with hornblende in the innershelf and beach may be a phenomenon that is effected by the specific gravity controlled selective littoral transport of the heavy minerals. Q-mode factor analysis forms the basis of demarcation for the basic differences in the mineral assemblages.

Diverse theories had been put forward concerning the formation of the mamillary features on the surfaces of garnet grains. Garnets occur as irregular, sharp edged grains with many impact pits and etch features. Absence of any indication of a nucleus on the garnet grain and thick iron oxide coatings on the surfaces of many of the grains may authentically indicate the formation of these mamillary structures by solution activity. The very persistance of stable minerals such as opaques, rutile and zircon and relative depletion of less stable minerals such as hornblende, epidote and pyroxene may indicate the effect of some sort of solution activity that remove chemically less stable minerals leaving behind the more stable minerals in the deposit.

In the order of abundance montmorillonite, kaolinite, illite and gibbsite are the dominant clay minerals found in the innershelf area of the northern Kerala coast. The percentage of montmorillonite vary between 40% in the shallower part to 60% in the deeper areas. On the other hand, kaolinite shows lesser abundance in deeper areas than the shallower portions. Montmorillonite being fine grained and because of its tendency to remain in suspension for longer duration, they are preferentially settled in low energy environments. Differential flocculation in response to saline water conditions and size segregation contribute to the occurrence of high percentages of kaolinite in the shallower areas and to their seaward decrease. Kaolinite is formed from the intense leaching of certain elements in the granitic rocks. Gibbsite is considered to be formed part of the residual laterite and owe its derivation to aluminous laterites and bauxites. Montmorillonite is considered as detrital end product of weathering of variety of rock types and from soil on land. Presence of quartz along with the clay minerals indicate the latters detrital origin.

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APPENDIX

Computer Programmes

1. Computation of graphic measures of Folk and Ward (1957).
2. Moment measures of Friedman (1961).
3. Q-mode factor analysis (modified after Davis, 1973).
4. Cluster analysis (modified after Davis, 1973).

Computer Program No. 1

```
C     sediment size parameters: mean size,standard deviation
C     skewness and kurtosis
      character title*9
      character*6 FN1,FN2
      dimension b(15),a(9),x(14),xp(14),c(15),[illegible],vb(8)
      write(*,800)
800   format('give input file name in six letters:')
      read(*,801)FN1
801   format(a6)
      write(*,802)
802   format('give output file name in six letters:')
      read(*,801)FN2
      open(5,file=FN1,status='old',form='formatted')
      open(7,file=FN2,status='new',form='formatted')
      ns=0
      xj=-2.0
      n=14
      nn=n+1
      np=0
      do 5 j=1,nn
      xj=xj+0.5
      b(j)=xj
  5   continue
      vb(1)=1
      vb(2)=5
      vb(3)=16
      vb(4)=25
      vb(5)=50
      vb(6)=75
      vb(7)=84
      vb(8)=95
 10   ns=ns+1
      write (7,61)
 61   format(1x,'sample no',19x,'percentiles',23x,size
    + parameters')
      write (7,09)
 09   format(81(1h-))
      write (7,1)
  1   format(13x,'1st',2x,'5th',3x,'16th',2x,'25th7,2x',
    + '50th',2x,'75th',2x,'84th',2x,'95th',3x,'mz',4x,'
    + sd',4x,'sk',4x,'kg')
      write (7,1)
 11   format(81(1h-))
 02   read(5,08,end=04)title
 08   format(8x,a9)
      read(5,15,end=04)(x(i),i=1,n)
 15   format(7f7.4,/,7f7.4)
      s=0
      do 20 j=1,n
 20   s=s+x(j)
```

```
      do 25 j=1,n
25    xp(j)=x(j)/s*100
      c(1)=0
      do 30 j=2,nn
30    c(j)=c(j-1)+xp(j-1)
      do 45 jk=1,8
      y=vb(jk)
      do 35 j=2,nn
      if(y.lt.c(j))go to 40
35    continue
      stop 333
40    d=c(j)-c(j-1)
      v(jk)=(b(j-1)+ds/d*0.5)1.0
45    continue
      mz=((v(3)+v(5)+v(7))/3)
      sd=(v(7)-v(3))/4+(v(8)-v(2))/6.6
      sk1=(v(7)+v(3)-2*v(5))/(2*(v(7)-v(3)))
      sk2=(v(8)+v(2)-2*v(5))/(2*(v(8)-v(2)))
      sk=sk1+sk2
      kg=(v(8)-v(2))/(2.44*(v(6)-v(4)))
      write(7,03) title,(v(jk),jk=1,8),mz,sd,sk,kg
03    format((/,1x,a9,8(1x,f5.2),4(1x,f5.2)))
      go to 02
      stop
      end
```

```
       dimension phi(100),y(100)
       character*80 FN1,FN2
       write(*,3000)
3000      format (' give input file name: '$)
       read(*,3100)FN1
3100      format(2A80)
       write(*,3200)
3200      format (' give output file name: '$)
       read(*,3100)FN2
       open (7,file=FN1,status='old')
       open (8,file=FN2,status='new')
       read(*,n)
       read (3.*,end=99)  (phi(i),i=1,n)
99       do 20 i=1,n
       y(i)=1000.0*(2**(-phi(i)))
20       continue
       write (4,1000)(y(i),i=1,n)
1000      format(10(1x,f7.2))
       stop
       end
```

```
         dimension x(50,50),fscore(50,50)
         dimension a1(50,50),a2(50,50),a3(50,50)
        character*80 FN1,FN2
         md=50
         nd=50
         mm=50
        write(*,3000)
3000        format ('GIVE INPUT FILE NAME: '$)
        read(*,3100)FN1
3100        format(2A80)
        write(*,3200)
3200        format ('GIVE OUTPUT FILE NAME: '$)
        read (*,3100)FN2
        open (7,file=FN1,status='old')
        open (8,file=FN2,status='new')
1        read (*,1000) itran,isim,l
         if (itran .le. 0) stop
         call readm(x,n,m,nd,md)
         call printm(x,n,m,nd,md)
c        write (8,2001)
         if (isim .ne. 1) go to 2
         call stand(x,n,m,nd,md)
         call printm(x,n,m,nd,md)
c        write (8,2008)
2        if (itran .ne. 2) go to 3
         mt=m
         if (n .gt. m) mt=n
         do 110 i=1,mt
         do 110 j=i,mt
         xs=x(i,j)
         x(i,j)=x(j,i)
         x(j,i)=xs
110      continue
         mt=m
         m=n
         n=mt
3        if (isim .eq. 1) call rcoef(x,n,m,nd,md,a1,mm)
         if (isim .eq. 2) call ctheta(x,n,m,nd,md,a1,mm)
         call printm(a1,m,m,mm,mm)
         write (8,2002)
         if (isim .ne. 1) go to 4
         do 111 i=1,m
         do 111 j=1,m
         a3(i,j)=a1(i,j)
111      continue
4        call eigenj(a1,a2,m,mm)
         sume=0.0
         do 100 i=1,m
         a1(i,1)=a1(i,i)
         sume=sume+a1(i,1)
100      continue
```

```
      sumee=0.0
      do 101 i=1.m
      a1(i,2)=a1(i,1)*100.0/sume
      sumee=sumee+a1(i,1)
      a1(i,3)=sumee*100.0/sume
101   continue
      call printm(a1,m,3,mm,mm)
      write (8,2003)
      call printm(a2,m,m,mm,mm)
      write (8,2004)
      do 102 i=1,m
      do 102 j=1,l
      a2(i,j)=a2(i,j)*sqrt(a1(j,1))
102   continue
      call printm(a2,m,m,mm,mm)
      write (8,2005)
      if (isim .ne. 1) go to 5
      do 112 i=1,m
      do 112 j=i,m
      det= 0.0
      do 113 k=1,l
      det=det+a2(i,k)*a2(j,k)
113   continue
      a1(i,j)=det
      a1(j,i)=det
112   continue
      call printm(a1,m,m,mm,mm)
c     write (8,2010)
      call subm(a3,a1,a3,m,m,mm,mm)
      call printm(a3,m,m,mm,mm)
c     write (8,2011)
5     do 103 i=1,l
      do 103 j=i,l
      det=0.0
      do 104 k=1,m
      det=det+a2(k,i)*a2(k,j)
104   continue
      a3(i,j)=det
      a3(j,i)=det
103   continue
      call minv(a3,a1,l,mm,det)
      call mmult(a2,a1,a3,m,l,l,mm,mm,mm,mm,mm,mm)
      call mmult(x,a3,fscore,n,m,l,nd,md,mm,mm,nd,md)
      call printm(fscore,n,l,nd,md)
      write (8,2007)
      call varmax(a2,m,l,mm)
      call printm(a2,m,l,mm,mm)
      write (8,2006)
      do 105 i=1,l
      do 105 j=i,l
      det=0.0
      do 106 k=1,m
      det=det+a2(k,i)*a2(k,j)
```

```
106     continue
        a3(i,j)=det
        a3(j,i)=det
105     continue
        call minv(a3,a1,l,mm,det)
        call mmult(a2,a1,a3,m,l,l,mm,mm,mm,mm,mm,mm)
        call mmult(x,a3,fscore,n,m,l,nd,md,mm,mm,nd,md)
        call printm(fscore,n,l,nd,md)
        write (8,2009)
        go to 1
1000    format (3i3)
2001    format (4x,'input data matrix -',1x,
     1   'columns = variables, rows = observations')
2002    format (4x,'similarity matrix')
2003    format (4x,'column 1 =eigenvalues,',2x,
     1  'column 2 =percent of trace',/,
     2   5x,'column 3 =cumulative percent of trace')
2004    format (4x,'principal axis matrix -',1x,
     1   'columns = eigenvectors, rows = variables')
2005    format (4x,'factor loadings -',1x,
     1   'columns = factors, rows = variables')
2006    format (4x,'rotated factor matrix -',1x,
     1   'columns = factors, rows = variables')
2007    format (4x,'factor scores -',1x,
     1   'columns = factors, rows = observations')
2008    format (4x,'standardized input data matrix -',1x,
     1   'columns = variables. rows = observations')
2009    format (4x,'varimax factor scores -',1x,
     1   'columns = factors, rows = observations')
2010    format (4x,'reproduced correlation matrix')
2011    format (4x,'residual correlation matrix')
        end
        subroutine readm(a,n,m,n1,m1)
        dimension a(n1,m1)
        read(*,1000) n,m
        do 100 i=1,n
        read(7,*) (a(i,j),j=1,m)
100     continue
        return
1000    format(2i3)
        end
        subroutine printm(a,n,m,n1,m1)
        dimension a(n1,m1)
        do 100 ib=1,m,10
        ie=ib+9
        if (ie-m) 2,2,1
1       ie=m
2       write(8,2000) (i,i=ib,ie)
        do 101 j=1,n
        write(8,2001) j,(a(j,k),k=ib,ie)
101     continue
100     continue
        return
```

```
2000    format(1x,8i9)
2001    format(i5,8f9.3/8f9.3)
        end
        subroutine subm(a,b,c,n,m,n1,m1)
        dimension a(n1,m1),b(n1,m1),c(n1,m1)
        do 100 i=1,n
        do 101 j=1,m
        c(i,j)=a(i,j)-b(i,j)
  101   continue
  100   continue
        return
        end
        subroutine mmult(a,b,c,l,n,m,na,ma,nb,mb,nc,mc)
        dimension a(na,ma),b(nb,mb),c(nc,mc)
        do 100 i=1,l
        do 101 j=1,m
        c(i,j)=0.0
        do 102 k=1,n
        c(i,j)=c(i,j)+a(i,k)*b(k,j)
 102    continue
 101    continue
 100    continue
        return
        end
        subroutine minv(a,b,n,n1,det)
        dimension a(n1,n1),b(n1,n1)
        do 100 i=1,n
        do 101 j=1,n
        b(i,j)=0.0
  101   continue
        b(i,i)=1.0
  100   continue
        det=1.0
        do 102 i=1,n
        div=a(i,i)
        det=det*div
        do 103 j=1,n
        a(i,j)=a(i,j)/div
        b(i,j)=b(i,j)/div
  103   continue
        do 104 j=1,n
        if (i-j) 1,104,1
    1   ratio=a(j,i)
        do 105 k=1,n
        a(j,k)=a(j,k)-ratio*a(i,k)
        b(j,k)=b(j,k)-ratio*b(i,k)
  105   continue
  104   continue
  102   continue
        return
        end
        subroutine stand(x,n,m,n1,m1)
        dimension x(n1,m1)
```

```
      do 100 i=1,m
      sx=0.0
      sxx=0.0
      do 101 j=1,n
      sx=sx+x(j,i)
      sxx=sxx+x(j,i)**2
 101  continue
      xm=sx/float(n)
      sd=sqrt((sxx-sx*sx/float(n))/float(n-1))
      do 102 j=1,n
      x(j,i)=(x(j,i)-xm)/sd
 102  continue
 100  continue
      return
      end
      subroutine rcoef(x,n,m,n1,m1,a,m2)
      dimension x(n1,m1),a(m2,m2)
      an=n
      do 100 i=1,m
      do 100 j=i,m
      sx1=0.0
      sx2=0.0
      sx1x1=0.0
      sx2x2=0.0
      sx1x2=0.0
      do 101 k=1,n
      sx1=sx1+x(k,i)
      sx2=sx2+x(k,j)
      sx1x1=sx1x1+x(k,i)**2
      sx2x2=sx2x2+x(k,j)**2
      sx1x2=sx1x2+x(k,i)*x(k,j)
101   continue
      r=(sx1x2-sx1*sx2/an)/
     1 sqrt((sx1x1-sx1*sx1/an)*(sx2x2-sx2*sx2/an))
      a(i,j)=r
      a(j,i)=r
100   continue
      return
      end
      subroutine ctheta(x,n,m,n1,m1,a,m2)
      dimension x(n1,m1),a(m2,m2)
      do 100 i=1,m
      do 100 j=i,m
      sx1x1=0.0
      sx2x2=0.0
      sx1x2=0.0
      do 101 k=1,n
      sx1x1=sx1x1+x(k,i)**2
      sx2x2=sx2x2+x(k,j)**2
      sx1x2=sx1x2+x(k,i)*x(k,j)
101   continue
      a(i,j)=sx1x2/sqrt(sx1x1*sx2x2)
      a(j,i)=a(i,j)
```

```
100     continue
        return
        end
        subroutine eigenj(a,b,n,nl)
        dimension a(nl,nl),b(nl,nl)
        anorm=0.0
        do 100 i=1,n
        do 101 j=1,n
        if (i-j) 2,1,2
  1     b(i,j)=1.0
        go to 101
  2     b(i,j)=0.0
        anorm=anorm+a(i,j)*a(i,j)
 101    continue
 100    continue
        anorm=sqrt(anorm)
        fnorm=anorm*1.0e-09/float(n)
        thr=anorm
  23    thr=thr/float(n)
  3     ind=0
        do 102 i=2,n
        il=i-1
        do 103 j=1,il
        if (abs(a(j,i))-thr) 103,4,4
  4     ind=1
        al=-a(j,i)
        am=(a(j,j)-a(i,i))/2.0
        ao=al/sqrt(al*al+am*am)
        if (am) 5,6,6
  5     ao=-ao
  6     sinx=ao/sqrt(2.0*(1.0+sqrt(1.0-ao*ao)))
        sinx2=sinx*sinx
        cosx=sqrt(1.0-sinx2)
        cosx2=cosx*cosx
        do 104 k=1,n
        if (k-j) 12,10,12
12       if (k-i) 13,10,13
13       at=a(k,j)
        a(k,j)=at*cosx-a(k,i)*sinx
        a(k,i)=at*sinx+a(k,i)*cosx
  10    bt=b(k,j)
        b(k,j)=bt*cosx-b(k,i)*sinx
        b(k,i)=bt*sinx+b(k,i)*cosx
 104    continue
        xt=2.0*a(j,i)*sinx*cosx
        at=a(j,j)
        bt=a(i,i)
        a(j,j)=at*cosx2+bt*sinx2-xt
        a(i,i)=at*sinx2+bt*cosx2+xt
        a(j,i)=(at-bt)*sinx*cosx+a(j,i)*(cosx2-sinx2)
        a(i,j)=a(j,i)
        do 105 k=1,n
        a(j,k)=a(k,j)
```

```
      a(i,k)=a(k,i)
  105 continue
  103 continue
  102 continue
      if (ind) 20,20,3
   20 if (thr-fnorm) 25,25,23
   25 do 110 i=2,n
      j=i
   29 if (a(j-1,j-1)-a(j,j)) 30,110,110
   30 at=a(j-1,j-1)
      a(j-1,j-1)=a(j,j)
      a(j,j)=at
      do 111 k=1,n
      at=b(k,j-1)
      b(k,j-1)=b(k,j)
      b(k,j)=at
  111 continue
      j=j-1
      if (j-1) 110,110,29
  110 continue
      return
      end
      subroutine varmax(f,m,l,ml)
      dimension f(ml,ml),h(100)
      write (8,2001)
      sqrt2=1.0/sqrt(2.0)
      xm=m
      ll=l-1
      nit=-1
      ncm=0
      do 100 i=1,m
      sumh=0.0
      do 101 j=1,l
      sumh=sumh+f(i,j)**2
  101 continue
      h(i)=sumh
      do 102 j=1,l
      f(i,j)=f(i,j)/sqrt(sumh)
  102 continue
  100 continue
    1 tvf=0.0
      do 103 i=1,l
      sf1=0.0
      sf2=0.0
      do 104 j=1,m
      sf1=sf1+f(j,i)**2
      sf2=sf2+f(j,i)**4
  104 continue
      tvf=tvf+(xm*sf2-sf1*sf1)/(xm*xm)
  103 continue
      if (nit .lt. 0) go to 2
      if (abs(tvf-tvi) .gt. 0.000001) go to 2
      ncm=ncm+1
```

```
      if (ncm .ge. 5) go to 50
2     nit=nit+1
      tvi=tvf
      write (8,2002) nit,tvf
      do 105 i=1,l1
      l2=i+1
      do 106 j=l2,l
      a=0.0
      b=0.0
      c=0.0
      d=0.0
      do 107 k=1,m
      x=f(k,i)
      y=f(k,j)
      u=(x+y)*(x-y)
      v=2.0*x*y
      a=a+u
      b=b+v
      c=c+(u+v)*(u-v)
      d=d+2.0*u*v
107   continue
      xn=d-(2.0*a*b)/xm
      xo=c-(a*a-b*b)/xm
      xr=sqrt(xn*xn+xo*xo)
      if (xr .le. 0.001) go to 106
      cos4t=xo/xr
      cos2t=sqrt((1.0+cos4t)/2.0)
      cos1t=sqrt((1.0+cos2t)/2.0)
      sin1t=sqrt(1.0-cos1t*cos1t)
      if (sin1t .le. 0.001) go to 106
      if (xn .lt. 0.0) sin1t=-sin1t
      do 108 k=1,m
      x=f(k,i)
      y=f(k,j)
      f(k,i)=x*cos1t+y*sin1t
      f(k,j)=y*cos1t-x*sin1t
108   continue
106   continue
105   continue
      go to 1
 50   write (8,2004)
      write (8,2001)
      do 110 i=1,m
      sumh=0.0
      do 111 j=1,l
      f(i,j)=f(i,j)*sqrt(h(i))
      sumh=sumh+f(i,j)**2
111   continue
      d=h(i)-sumh
      write (8,2003) i,h(i),sumh,d
110   continue
      write (8,2005)
```

```
        return
2001    format (1h1)
2002    format (10x,i5,3x,f9.3)
 2003   format (1x,i5,3f9.3)
2004    format (4x,'number of varimax iterations',1x,
     1   'and variance at each step')
2005    format (4x,'column 1 = initial communality',2x,
     1   'column 2 = communality after rotation',/,
     2   5x,'column 3 = difference')
        end
```

Computer Program No. 4

```
        dimension x( 60, 60),ipair(2, 60),xlev( 60),a( 60, 60)
        character*80 FN1,FN2
          md=60
               nd=60
        mm=60
        write(*,3000)
3000    format(' give input file name: '$)
        read(*,3100)FN1
3100    format(2A80)
        write(*,3200)
3200    format(' give output file name: '$)
        read(*,3100)FN2
        open(7,file=FN1,status='OLD')
        open(8,file=FN2,status='NEW')
1       read(*,1000) itype,isim
        if (itype .le. 0) stop
        if (itype .ne. 3) go to 2
        call readm(a,n,m,mm,mm)
        go to 4
2       call readm(x,n,m,nd,md)
        call printm(x,n,m,nd,md)
c       write (8,2001)
        if (itype .ne. 2) go to 3
        mt=m
        if (n .gt. m) mt=n
        do 110 i=1,mt
        do 110 j=i,mt
        xs=x(i,j)
        x(i,j)=x(j,i)
        x(j,i)=xs
110     continue
        mt=m
        m=n
        n=mt
3       if (isim .eq. 1) call rcoef(x,n,m,nd,md,a,mm)
        if (isim .eq. 2) call dist (x,n,m,nd,md,a,mm)
4       call printm(a,m,m,mm,mm)
c       write (8,2002)
        call wpga(a,m,mm,ipair,xlev,isim)
        call dendro(ipair,xlev,m,mm,isim)
        go to 1
1000       format (2i3)
2001    format (4x,'input data matrix-',1x,'columns=variables',
     1  'rows=observations')
2002    format (4x,'similarity matrix')
        end
        subroutine readm(a,n,m,n1,m1)
        dimension a(n1,m1)
       read(*,1000) n,m
        do 100 i=1,n
       read(7,*) (a(i,j),j=1,m)
100     continue
        return
```

```
1000       format(2i3)
        end
        subroutine printm(a,n,m,n1,m1)
        dimension a(n1,m1)
        do 100 ib=1,m,10
        ie=ib+9
        if(ie-m) 2,2,1
1       ie=m
2       write(8,2000) (i,i=ib,ie)
        do 101 j=1,n
        write(8,2001) j,(a(j,k),k=ib,ie)
101     continue
100     continue
        return
2000    format(1x,10i6)
2001    format(i5,10f6.3/10f6.3)
        end
        subroutine rcoef(x,n,m,n1,m1,a,m2)
        dimension x(n1,m1),a(m2,m2)
        an=n
        do 100 i=1,m
        do 100 j=i,m
        sx1=0.0
        sx2=0.0
        sx1x1=0.0
        sx2x2=0.0
        sx1x2=0.0
        do 101 k=1,n
        sx1=sx1+x(k,i)
        sx2=sx2+x(k,j)
        sx1x1=sx1x1+x(k,i)**2
        sx2x2=sx2x2+x(k,j)**2
        sx1x2=sx1x2+x(k,i)*x(k,j)
101     continue
        r=(sx1x2-sx1*sx2/an)/sqrt((sx1x1-sx1*sx1/an)*(sx2x2
     1  -sx2*sx2/an))
        a(i,j)=r
        a(j,i)=r
100     continue
        return
        end
        subroutine dist(x,n,m,n1,m1,a,m2)
        dimension x(n1,m1),a(m2,m2)
        an=n
        do 100 i=1,m
        do 100 j=i,m
        distx=0.0
        do 101 k=1,n
        distx=distx+(x(k,i)-x(k,j))**2
101     continue
        a(i,j)=sqrt(distx/an)
        a(j,i)=a(i,j)
100     continue
```

```
      return
      end
      subroutine wpga(x,m,ml,ipair,xlev,isim)
      dimension x(ml,ml),ipair(2,ml),xlev(ml)
      dimension il(100),i2(100),xsim(100)
      do 110 i=1,m
      il(i)=i
110   continue
      xxxx=-9.0e+35
      if (isim .ne. 1) xxxx=+9.0e+35
      m3=m-1
      ic=0
1     do 100 i=1,m
      if (il(i) .le. 0) go to 100
      ix=0
      xx=xxxx
      do 101 j=1,m
      if (i .eq. j) go to 101
      if (il(j) .le. 0) go to 101
      go to (11,12),isim
11    if (x(j,i)-xx) 101,101,13
12    if (x(j,i)-xx) 13,101,101
13    xx=x(j,i)
      ix=j
101   continue
      i2(i)=ix
      xsim(i)=xx
100   continue
      do 102 i=1,m3
      if (il(i) .le. 0) go to 102
      j=i2(i)
      if (il(j) .le. 0) go to 102
      if (j .le. i) go to 102
      if (il(j) .eq. i) go to 14
      if (abs(xsim(i)-xsim(j)) .gt. 0.00001) go to 102
14    ic=ic+1
      ipair(1,ic)=i
      ipair(2,ic)=j
      xlev(ic)=xsim(i)
c     write(8,2002) i,j,xsim(i)
      il(i)=j
      il(j)=0
      do 103 k=1,m
      x(k,i)=(x(k,i)+x(k,j))/2.0
103   continue
102   continue
      do 105 i=1,m3
      if (il(i) .le. 0) go to 105
      if (il(i) .eq. i) go to 105
      j=il(i)
      do 106 k=1,m
      if(il(k) .le. 0) go to 106
      x(i,k)=(x(i,k)+x(j,k))/2.0
```

```
106     continue
        il(i)=i
105     continue
        if (ic .lt. m3) go to 1
        write (8,2003)
        return
2002    format (6x,2i5,f8.3)
2003  format(/4x,'columns 1 and 2 -  observations combined into'
     1  'clusters',/,5x,'column 3 - similarity level clustering')
      end
        subroutine dendro(ipair,xlev,m,ml,isim)
            character iblnk,ici,icp,icm,iout(61)
        dimension ipair(2,ml),xlev(ml)
        dimension i1(100),i2(100)
        dimension xx(13)
          data iblnk,ici,icp,icm/' ','i','.','-'/
        m2=m-1
        do 100 i=1,m
        i1(i)=0
        i2(i)=0
100     continue
        do 101 i=1,m2
        j=i-1
11      if (j .le. 0) go to 12
        if (ipair(1,i) .eq. ipair(1,j)) go to 13
        j=j-1
        go to 11
12      i2(i)=1
        go to 15
13      k=i1(j)
        if (k .eq. 0) go to 14
        j=k
        go to 13
14      i1(j)=i
15      do 102 j=1,i
        k=j
        if (ipair(2,i) .eq. ipair(1,j)) go to 16
102     continue
        go to 101
16      i2(k)=0
        i1(i)=k
101     continue
        do 103 i=1,m2
        js=i
        if (i2(i) .ne. 0) go to 20
103     continue
        stop
20      node=ipair(1,js)
        xmin=xlev(1)
        xmax=xmin
        do 104 i=1,m2
        if (xlev(i) .lt. xmin) xmin=xlev(i)
        if (xlev(i) .gt. xmax) xmax=xlev(i)
```

```
104     continue
        dx=(xmax-xmin)/25.0
        xmin=xmin-dx
        xmax=xmax+dx
        dx=(xmax-xmin)/60.0
        if (isim .ne. 2) go to 21
        dx=-dx
        xmin=xmax
21      do 105 i=1,61
        iout(i)=iblnk
105     continue
        x=xmin
        do 106 i=1,13
        xx(i)=x
        x=x+dx*5.0
106     continue
        write (8,2000)
        write(8,2001) (xx(i),i=2,12,2)
        write(8,2002) (xx(i),i=1,13,2)
        write(8,2003)
22      x=xmin
        if (js .ne. 0) x=xlev(js)
        is=ifix((x-xmin)/dx)+1
        do 110 i=is,61
        iout(i)=icm
110     continue
        iout(is)=icp
        if (js .ne. 0) write(8,2004) iout,node,x
        if (js .eq. 0) write(8,2004) iout,node
        if (js .eq. 0) go to 31
        do 111 i=is,61
        iout(i)=iblnk
111     continue
        iout(is)=ici
        write (*,2004) (iout(i),i=1,is)
        node=ipair(2,js)
        js=il(js)
        go to 22
31      write (8,2003)
        write (8,2002) (xx(i),i=1,13,2)
        write (8,2001) (xx(i),i=2,12,2)
        write (8,2005)
        return
2000    format (1h1)
2001    format (6x,6f10.4)
2002    format (1x,7f10.4)
2003    format (6x,'+',12('----+'))
 2004   format (6x,61a1,1x,i3,f10.4)
2005    format (4x,'dendrogram -',1x,'values along x-axis are
     1 similarities',/)
        end
```

SEM PHOTOGRAPHS

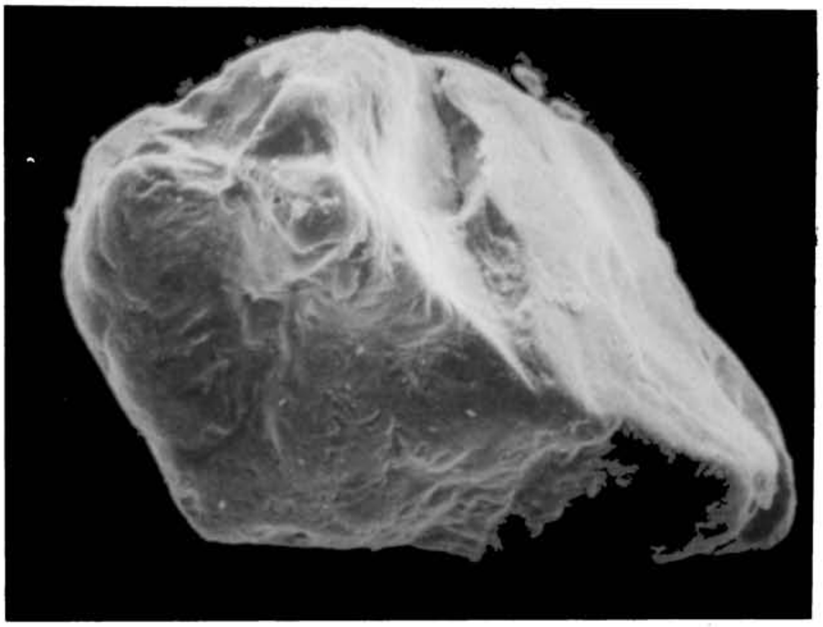


Plate I Sub angular grain from the beach (scale bar 50 um)

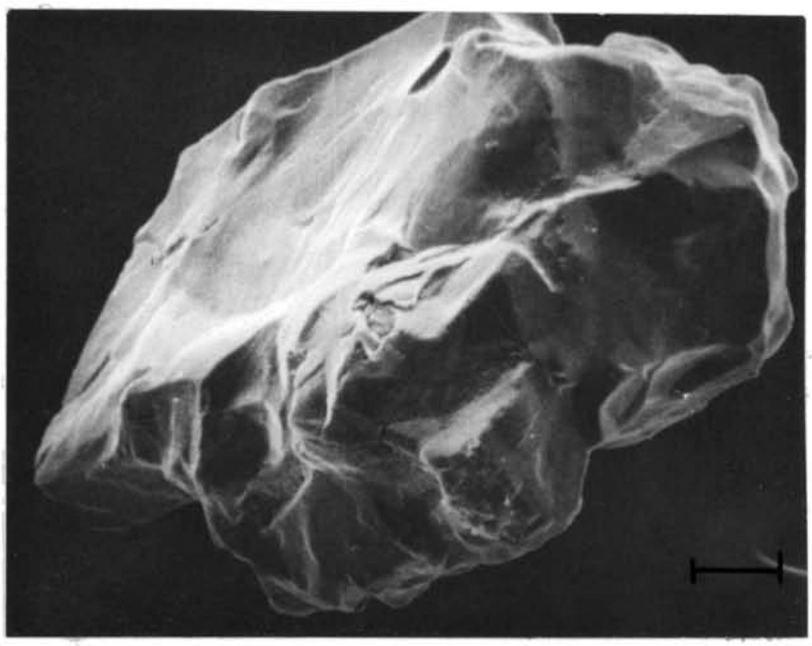


Plate II A quartz grain from the innershelf showing the characteristic angular edges (scale bar 50 um)

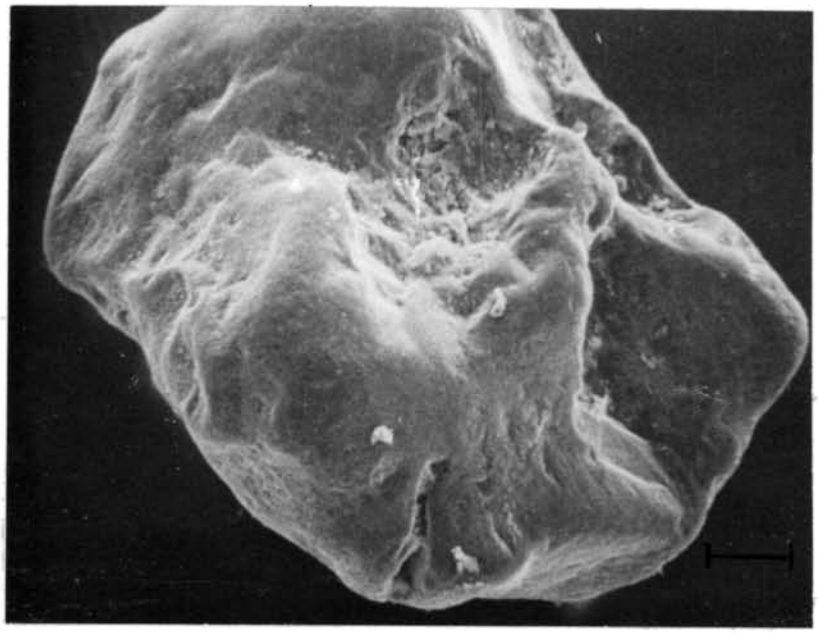


Plate III A well rounded grain from the strand plain showing angular edged dish shaped cavities indicating wind action. Note the 'V' shaped pits that are suggestive of transport under sub-aqueous conditions (scale bar 50 um)

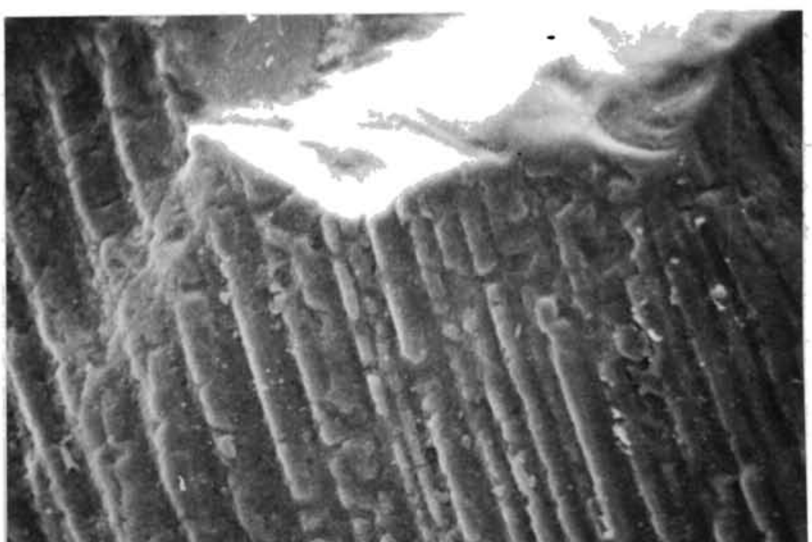
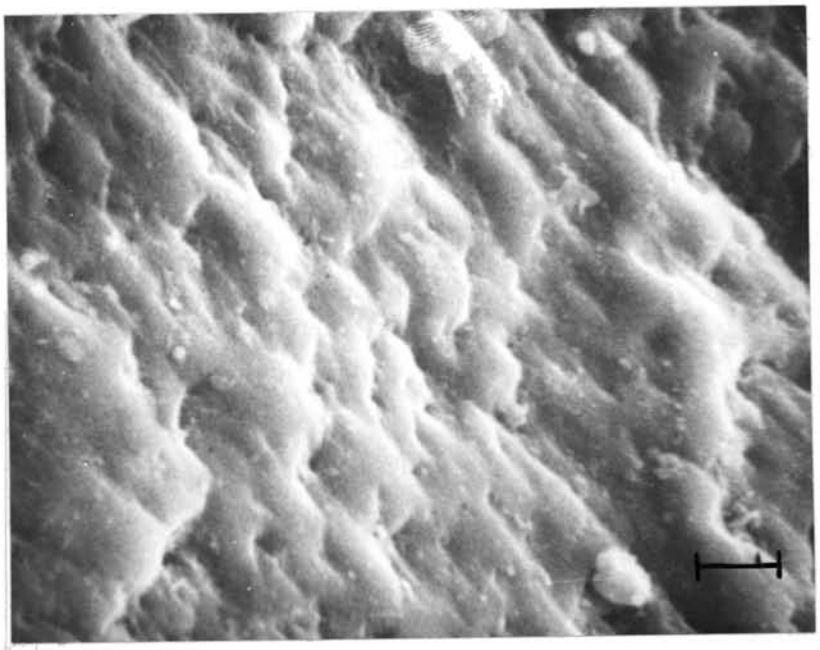


Plate IV Linear steps and dish shaped cavities with irregular edges, a characteristic feature of the beach grain (scale bar 20 um)



Scale V Straight or slightly curved linear scratches and 'V' shaped pattern from a beach grain, the characteristic textures produced by transport under sub-aqueous conditions. (scale bar 5um)

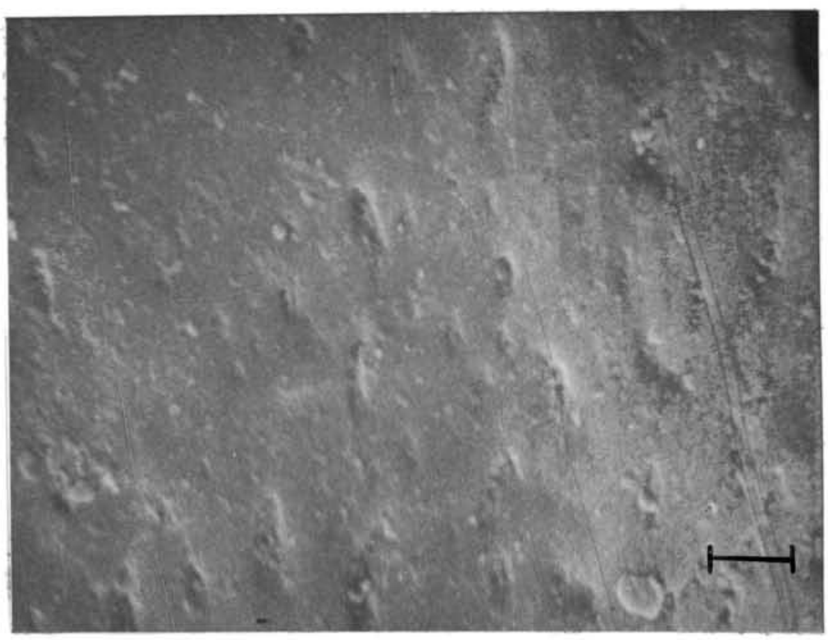


Plate VI 'V' shaped pits from the innershelf grain (scale bar 5um)

Plate VII Earlier fractures (a) on the beach grain that found to abut against the latter irregular, elongated pits. Sheltered angular blocks (c) in the pit are formed probably due to impact. Note the development of new crystal faces (d) on the bottom of the grain (scale bar 5 um)

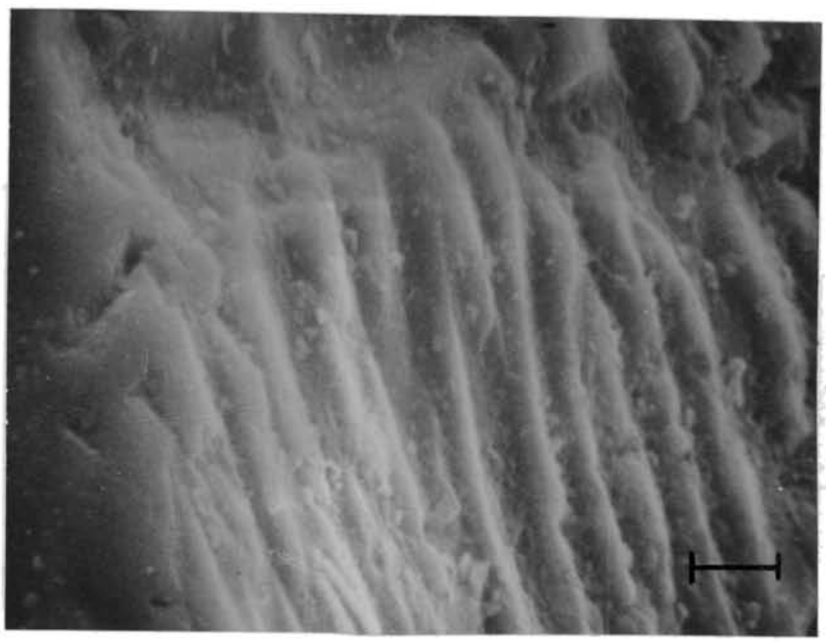


Plate VIII 'V' shaped pattern (a) on the smooth surface of the beach grain and the later dish shaped cavities with irregular edges (b). Note the intensive deposition of sugary coatings of silica in the cavity and on the surface of the grain (c) and growth of incipient crystal faces (d) (scale bar 5um)

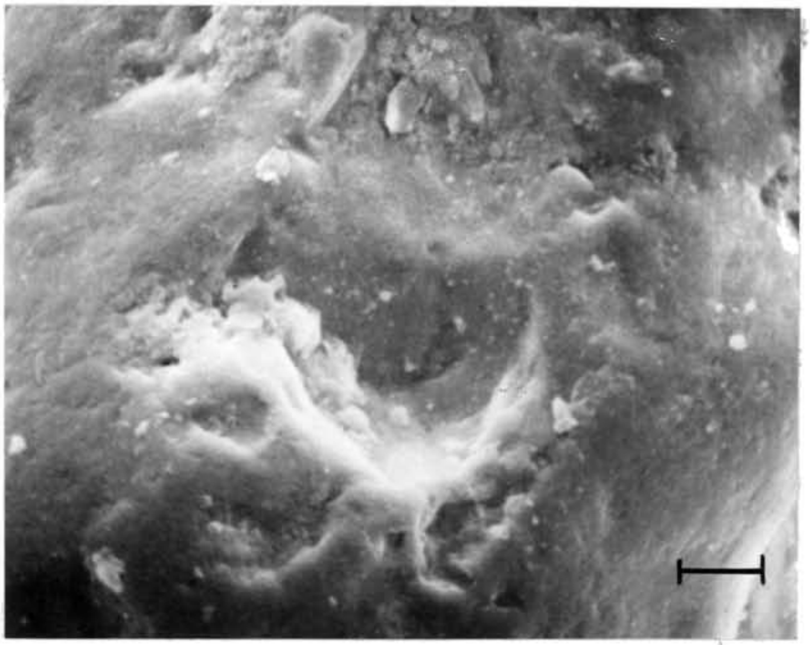


Plate IX A beach grain showing dish shaped concavities with irregular edges (scale bar 10 µm)

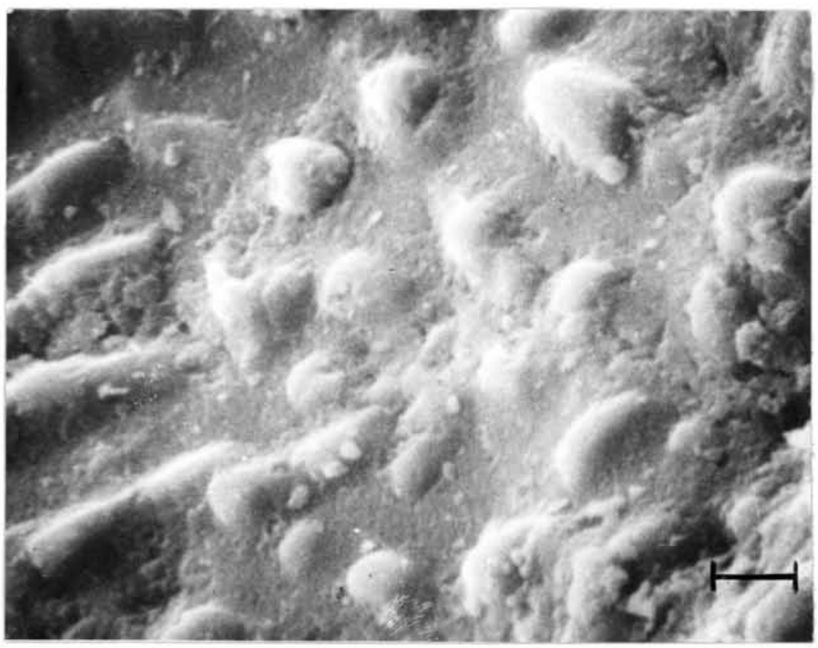


Plate X Superposition of three generations of surface textures on the beach grain. Earlier 'V' pits (a) on the smooth surface of the grain are found to occur with later straight or slightly curved linear grooves (b) The third stage is the formation of widespread silica globules (scale bar 5µm)

Plate XI Chatter marks (?) on the surfaces of the beach grain. Note the deposition of silica in the form of surface cappings (scale bar 5 μm)

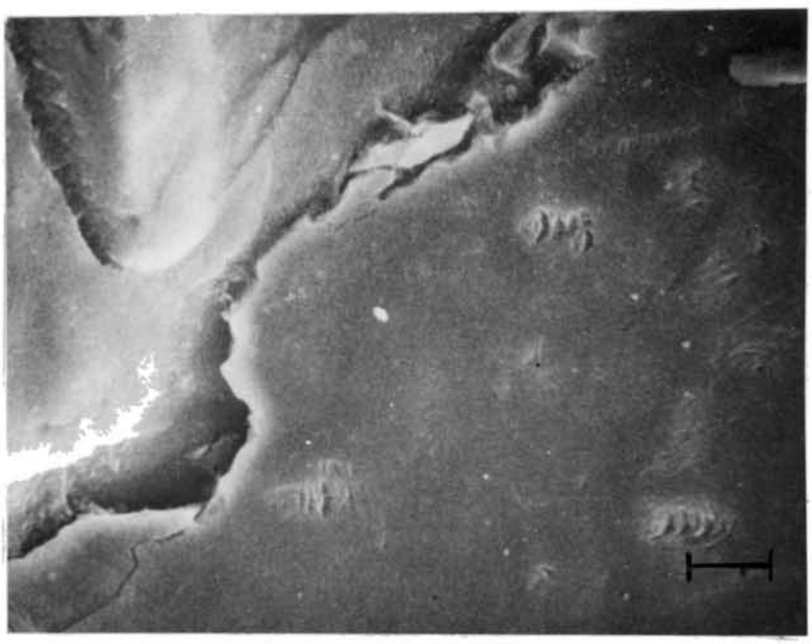


Plate XII Development of chatter marks on the surfaces of the inner-shelf grain. Note the euhedral crystal growths in the bottom portion of the grain (scale bar 10 μm)

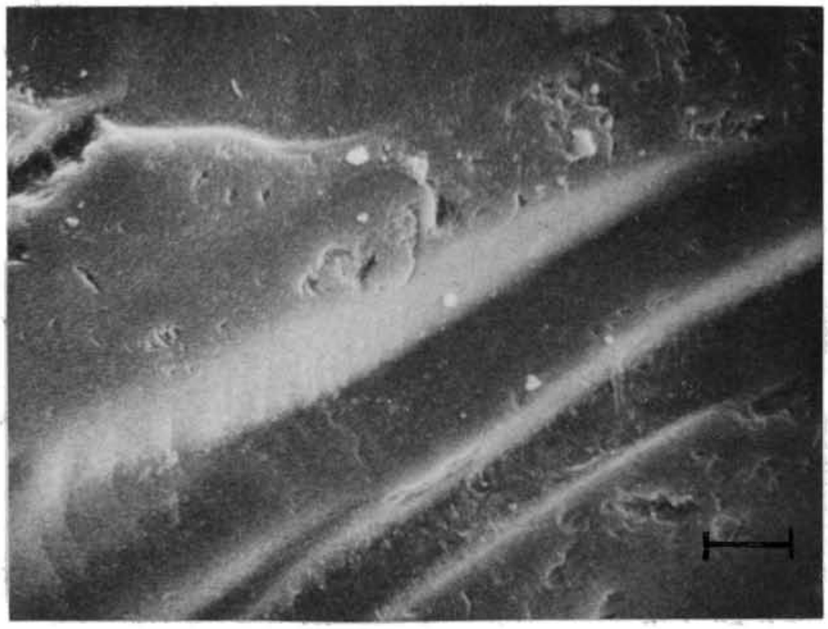


Plate XIII Close up of the chatter marked innershelf grain under higher magnification (scale bar 10 um)

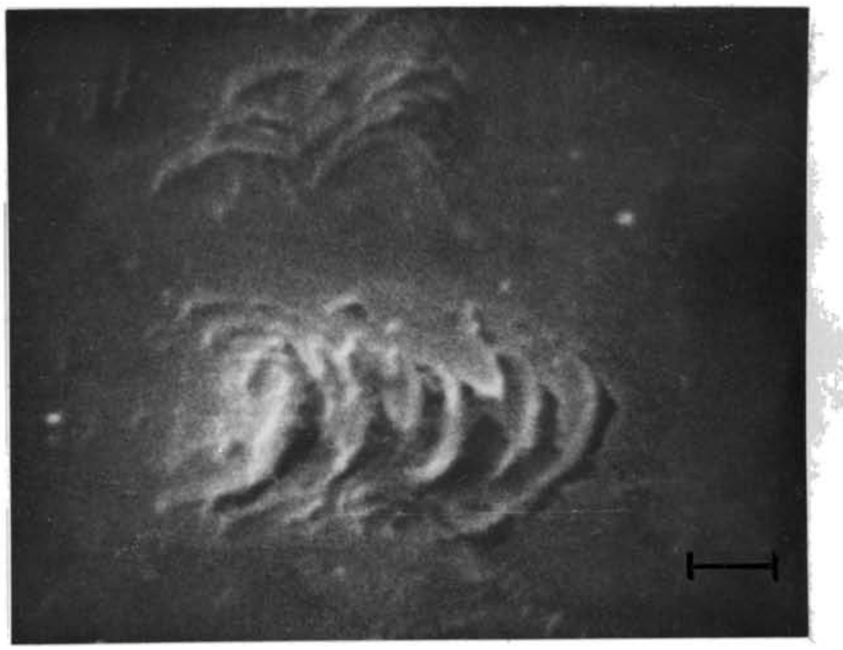


Plate XIV Close up of the chatter marked innershelf grain under higher magnification (scale bar 2 um)

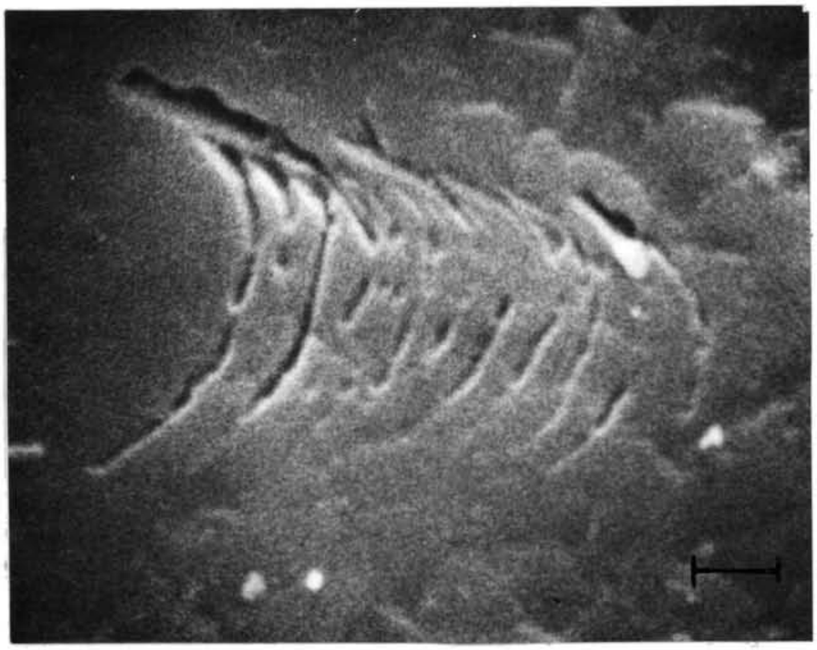


Plate XV Close up of the chatter marked innershelf grain under higher magnification (scale bar 2 μm)

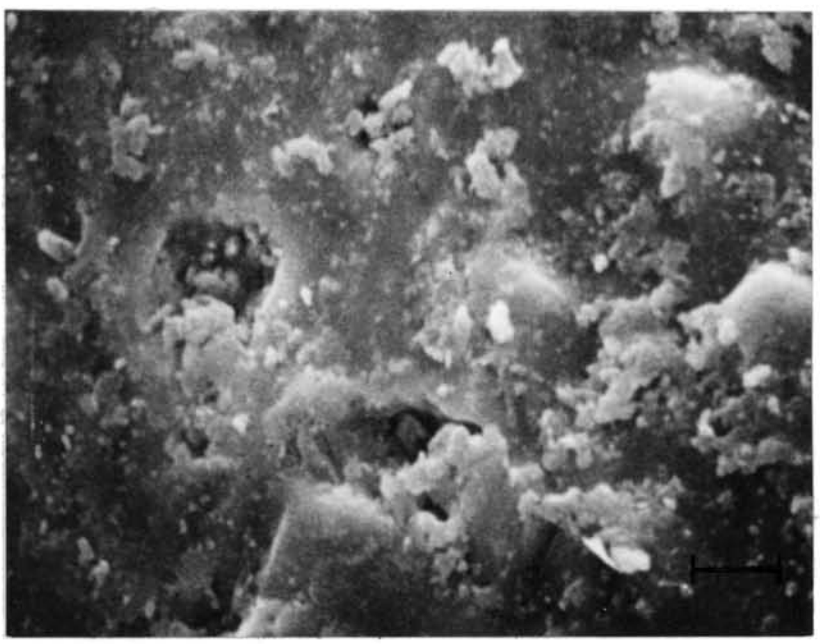


Plate XVI Extensive surface cappings of silica on the surfaces of the innershelf grain, which tend to obscure the original surface textures (scale bar 5 μm)

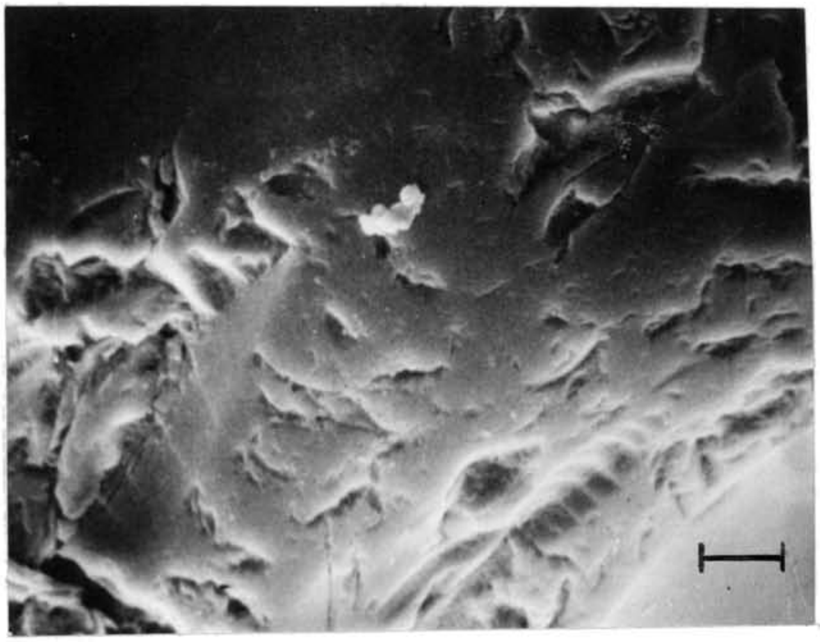


Plate XVII A grain from the innershelf showing 'V' shaped patterns, irregular cavities and linear steps characteristic of transport under sub-aqueous conditions (scale bar 10 um)

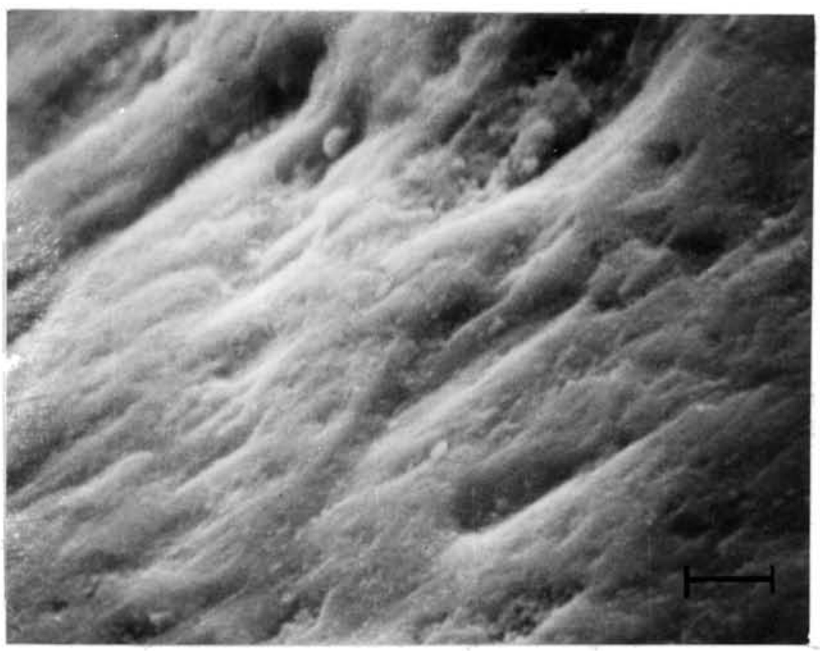


Plate XVIII 'V' shaped pattern in the strand plain grain largely modified by solution. Development of upturned plate evident. Note the dish shaped cavities with regular edges, characteristic of wind action (scale bar 5 um)

Plate XIX A typical grain from the strand plain showing well rounded behaviour and dish shaped cavities with regular edges, a characteristic surface texture produced due to wind action (scale bar 20 um)

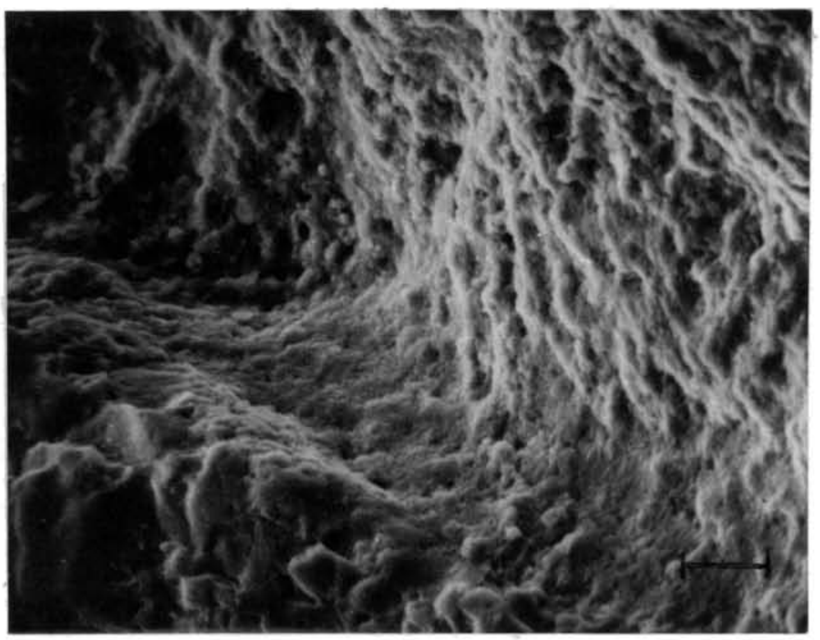


Plate XX Intensive recrystallization of silica on the surfaces of the upturned plates, a characteristic feature produced due to wind action (scale bar 20 um)

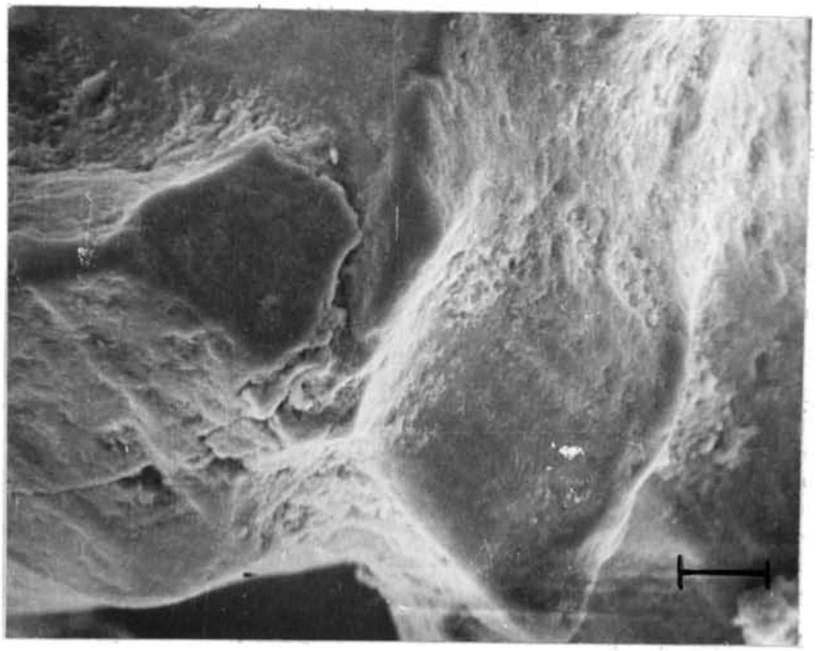


Plate XXI A quartz grain from strand plain showing development of euhedral crystal faces formed due to re-crystallization of silica, thus producing incipient crystal outgrowths (scale bar 20 um)

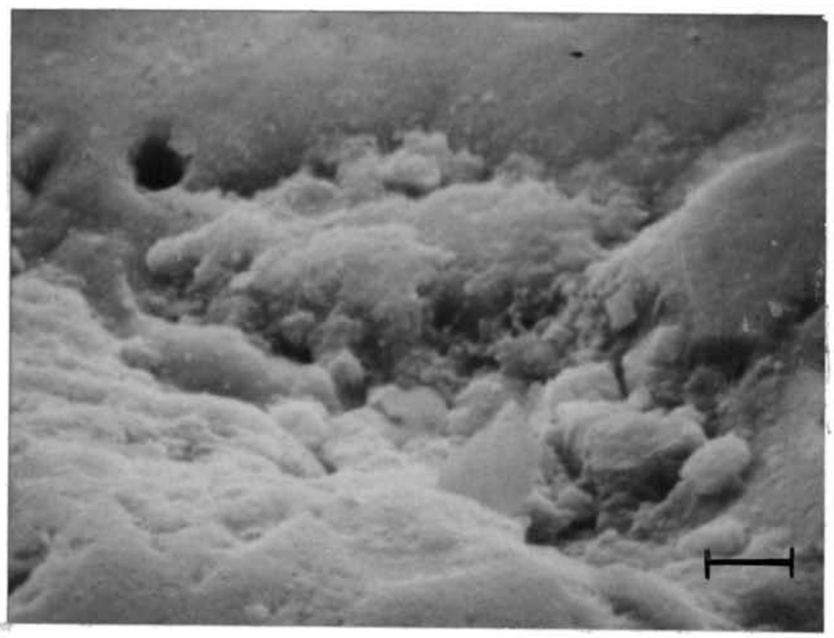


Plate XXII 'V' shaped pits on the surface of the strand plain grain, indicative of beach action. Note the dish shaped cavities and recrystallization of euhedral silica outgrowths, which starts as numerous incipient crystal faces (scale bar 5 um)

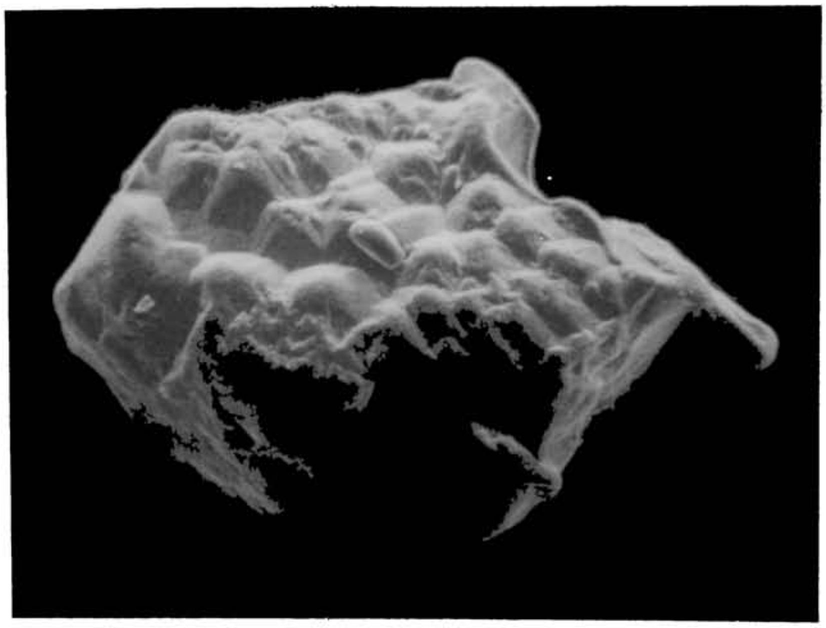


Plate XXIII A garnet grain illustrating the mamillary features that are indicative of solution activity in the strand plain (scale bar 100 um)

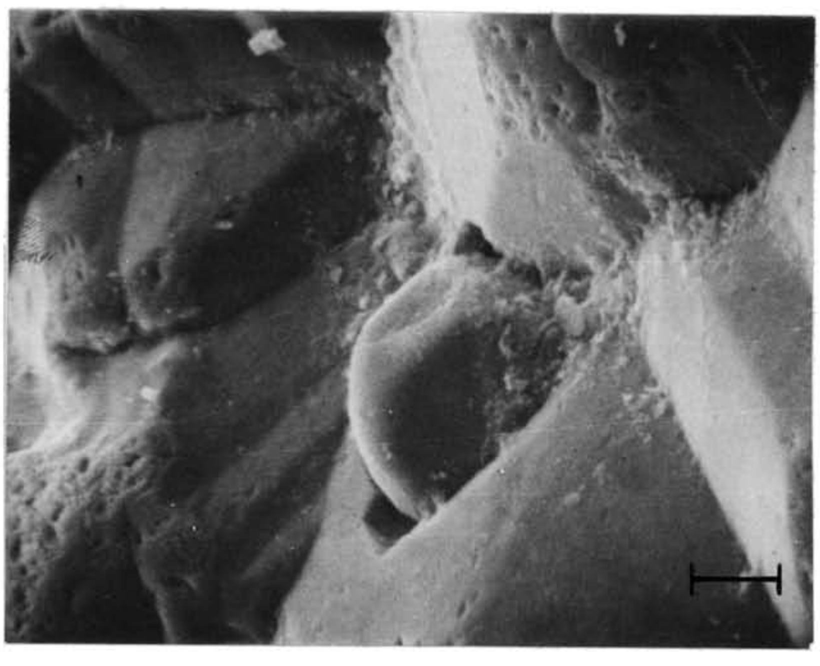


Plate XXIV Close up of the grain showing the mamillary feature. Note the crystallization of euhedral quartz grain in the cavity (scale bar 10 um)

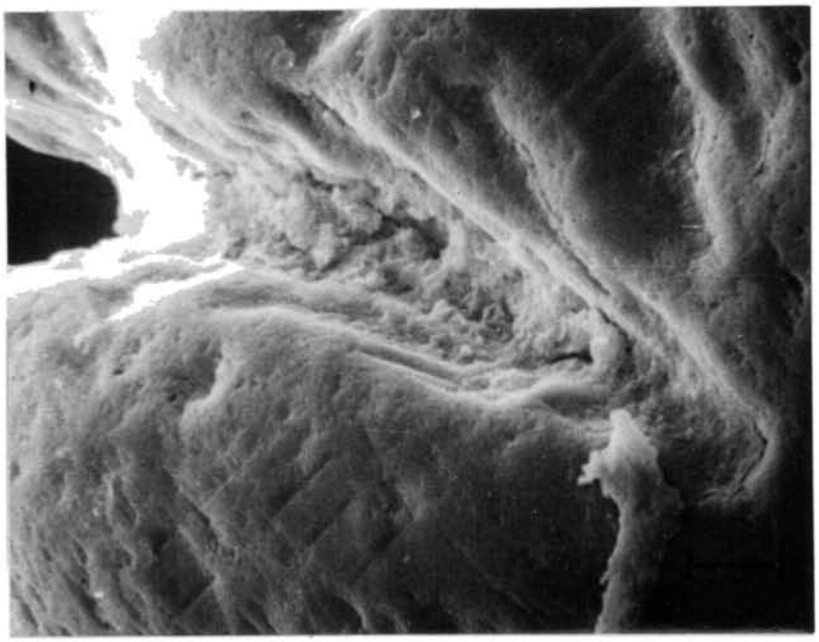


Plate XXV Arc shaped linear furrows in the garnet grain from the strand plain which may be developed due to grinding and collision (scale bar 10 µm)

PHOTOMICROGRAPHS

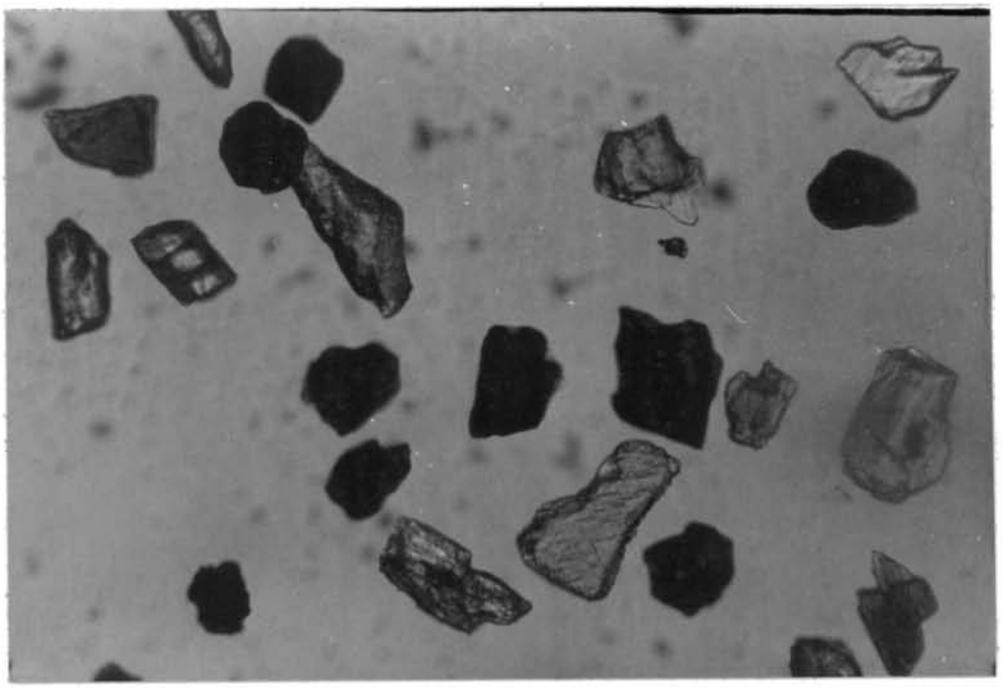


Plate XXVI Heavy mineral assemblages in the beach sands.

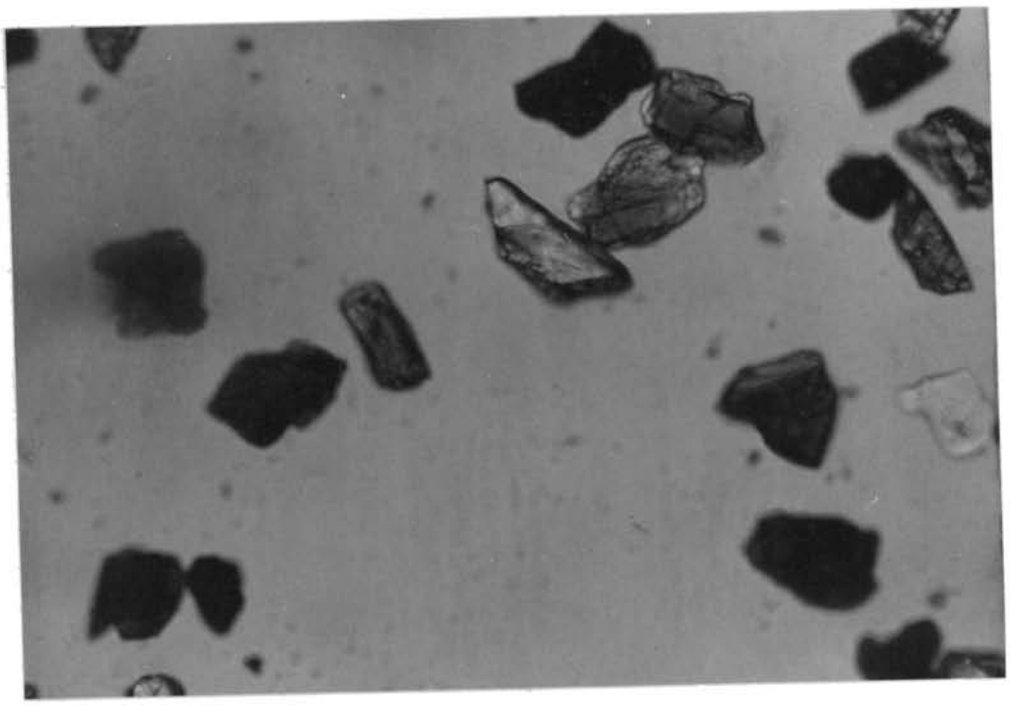


Plate XXVII Relative abundance of opaques and hornblende in the beach sands.

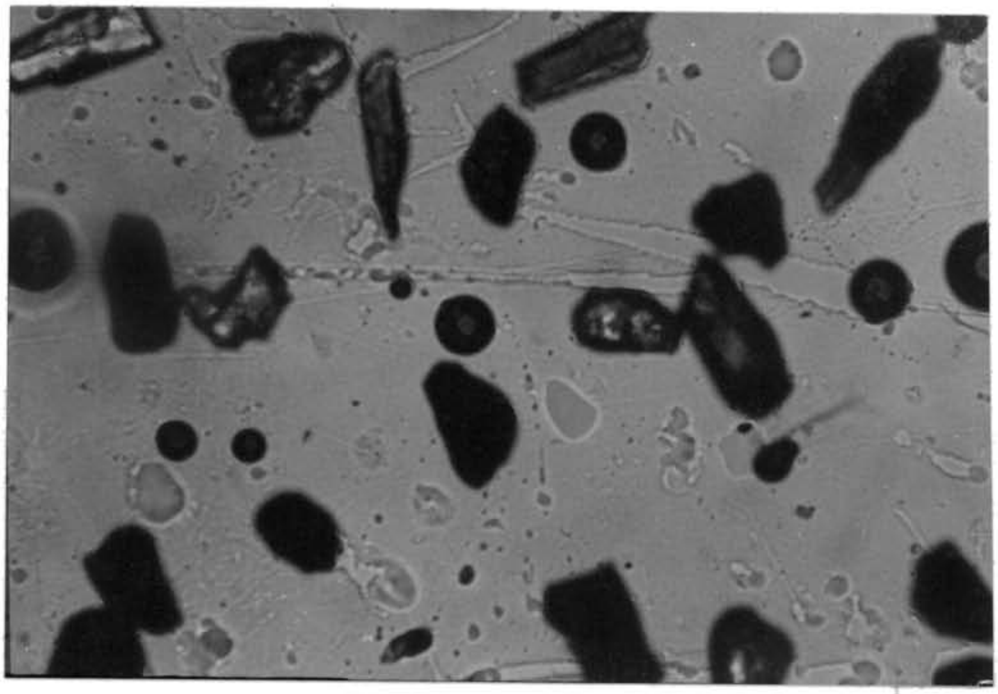


Plate XXVIII Heavy mineral assemblages in the strand plain sands.

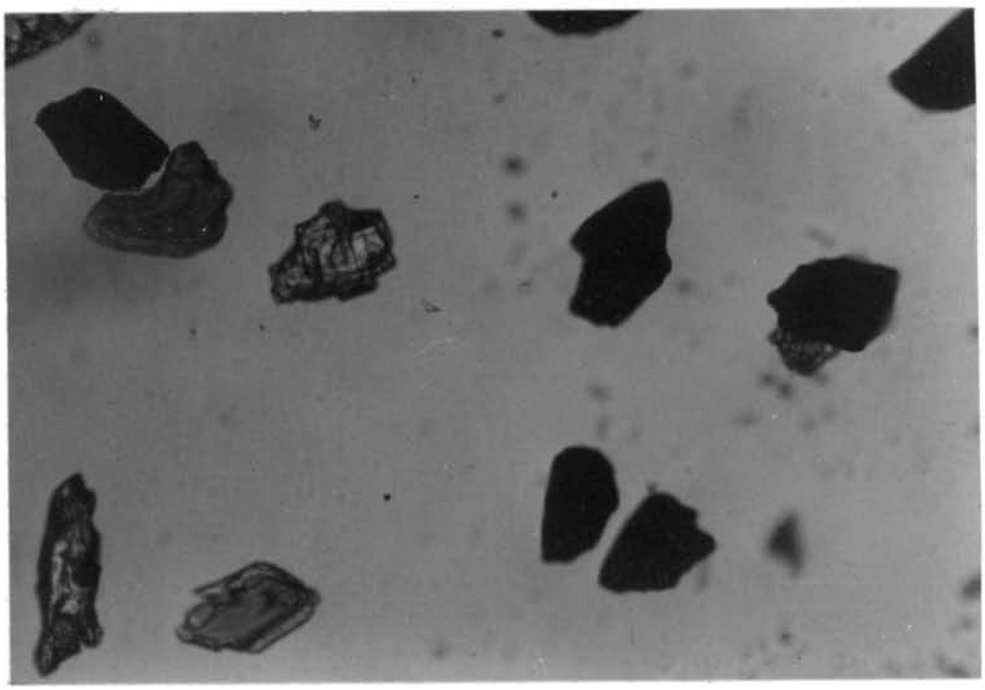


Plate XXIX Relative abundance of opaques and hornblende in the strand plain sands.

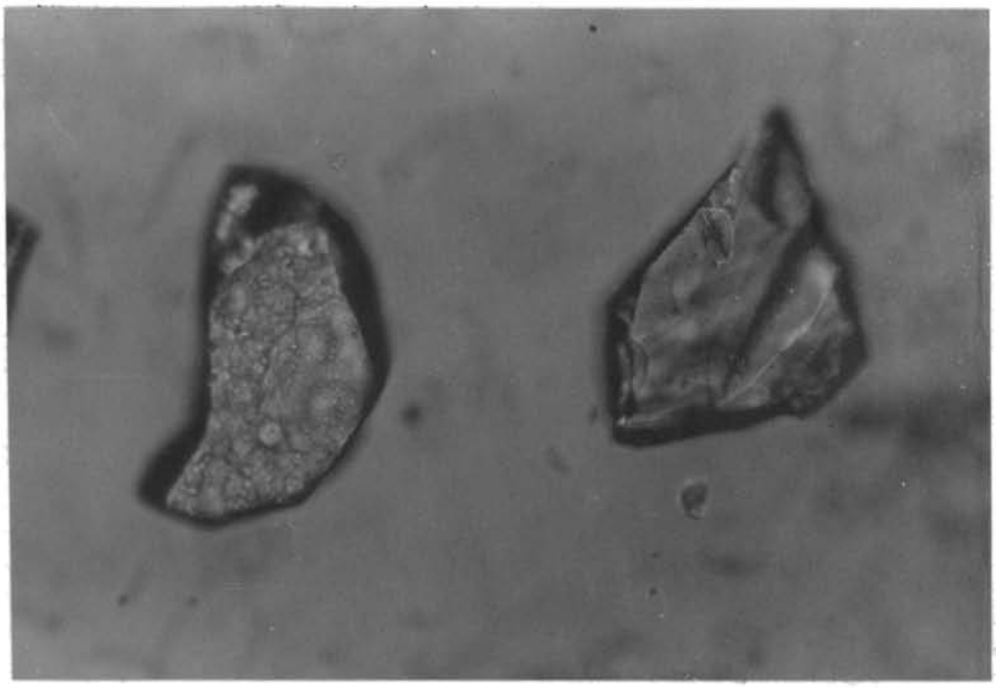


Plate XXX   Garnet grain from the strand plain showing mamillary patterns.

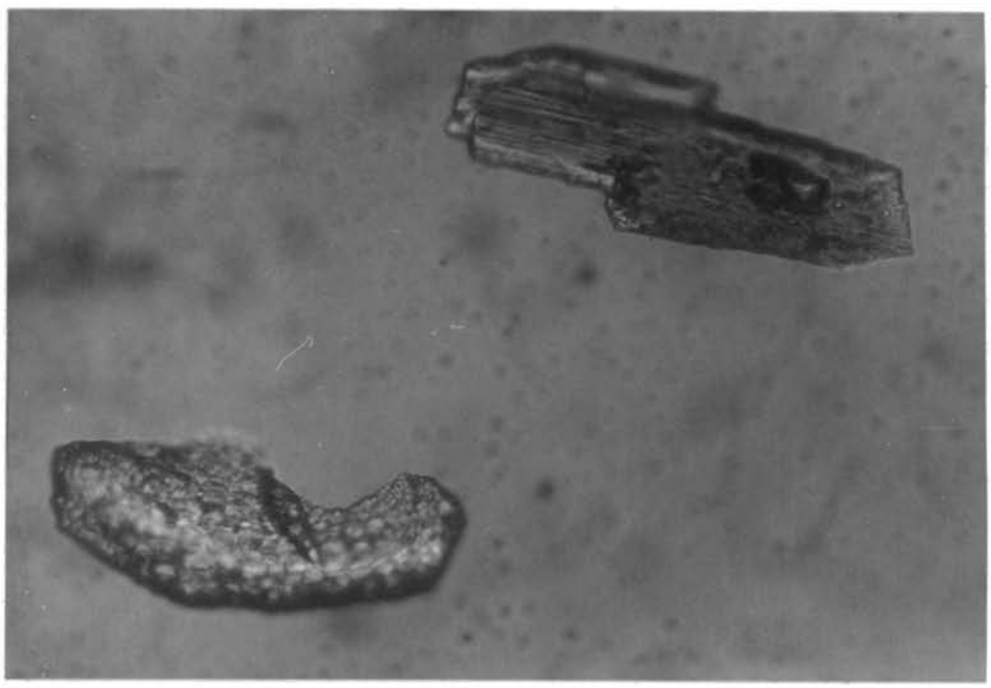


Plate XXXI   Garnet grain from the strand plain showing mamillary patterns.

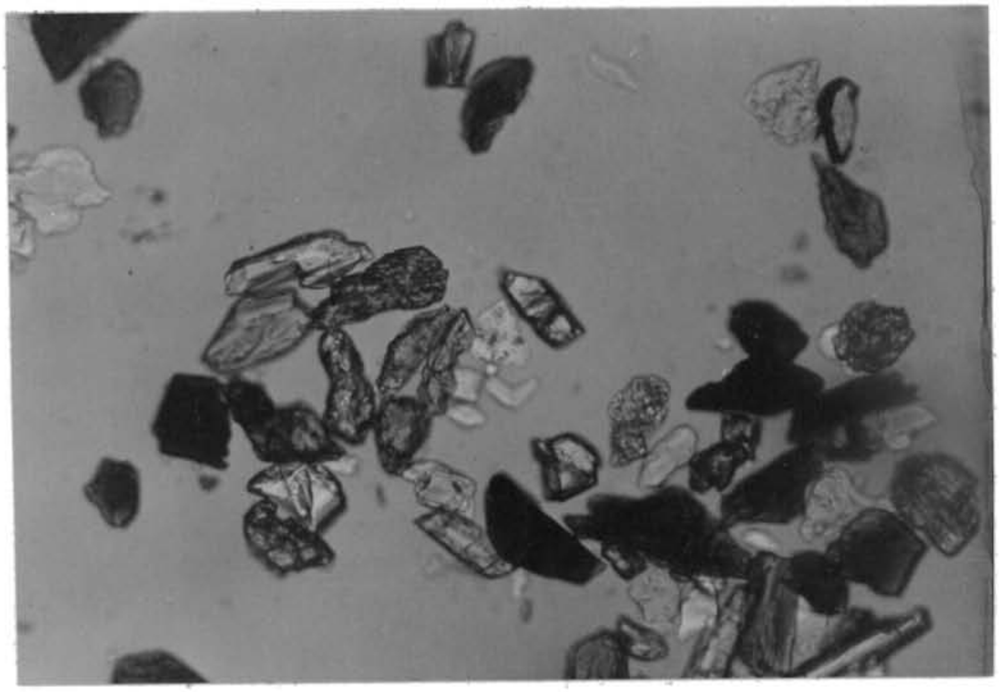


Plate XXXII Heavy mineral assemblages in the innershelf sands.

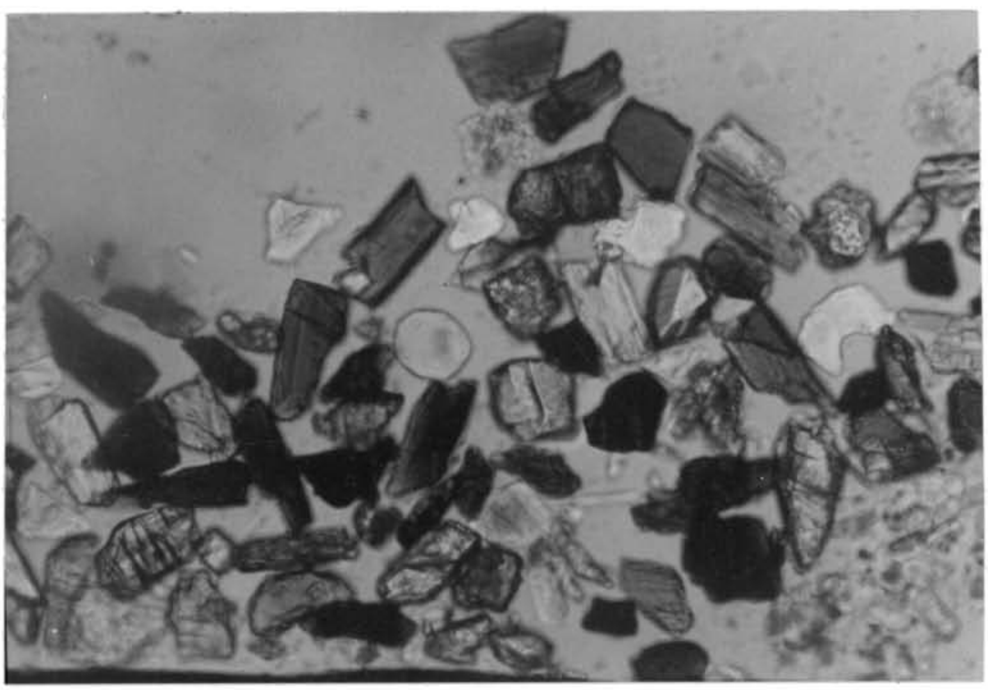


Plate XXXIII Relative abundance of opaques and hornblende in the innershelf sands.