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Detrital Mica Grains As An Indicator of Hydrodynamic Condition for Depositional And Non-Depositional Environments :

A Case Study of a Part of West Coast of India

(From Karwar To Coondapoor)

A Dissertation submitted to the Jawaharlal Nehru University in partial fulfilment of the requirement for the Degree of

MASTER OF PHILOSOPHY

by

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CERTIFICATE

Certified that the work embodied in this dissertation entitled "Detrital mica grains as an indicator of hydrodynamic condition for depositional and non-depositional environments: A case study of a part of West coast of India (from Karwar to Coondapoor)", has been carried out in the School of Environmental Sciences, Jawaharlal Nehru University, New Delhi. The work is original and has not been submitted in part or in full for any other degree or diploma in this or in any other University.

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Surendra Nath Pandey

CONTENTS

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CHAPTER I

INTRODUCTION

Oceanographers divide sediments of the ocean floor into those carried from the continents by currents, Pelagic sediments include wind blown dust, organic skeletal particles and chemical precipitates from the oceans themselves such as zeolites and manganese nodules.

The oceans are thousands of times wider than they are deep, but the ratio of width to depth is much smaller than the theoretical ratio of horizontal speed to vertical speed for fine particles. In deep water organic particles from the surface are carried horizontally by currents many times faster than they ought to settle downwards the sea floor likewise wind blow dust that settle on sea should be spread far and wide by currents before it sinks to the sea bed. The properties of the fine particles making more than half of the seabed ought therefore, to be the same throughout the deep oceans of the world, though they are not.

Some parts of the sea-floor comprise clay minerals as well as other parts may comprise wind blown quartz dust. This makes it clear that in terms of properties of its particles, the ocean floor is not homogeneous. Why is it so? The answer is that there must be a very rapid flux of material between the water and the sea-bed. Also the distribution of energy on the various parts of oceans is not uniform. This inhomogeneity in energy condition prevailing in ocean waters is due to various physical factors like depth, wind, water current etc.

Sedimentologists on the basis of energy condition prevalent in oceans, classify sedimentary environments into two broad types :

1. Depositional or low energy environment;

2. Non-depositional, or high-energy environment.

The main aim of present work is to delineate these two types of environment in coastal regimes of west-coast between Karwar and Coondapoor. To delineate these two types of regimes, two different methods were adopted.

The first method comprises the conventional grain size analysis because for many years sedimentary petrographers have attempted to use grain size analysis to determine sedimentary environments. A survey of the extensive literature on this subject illustrates the steady progress that has been made towards this goal. Many workers have attempted to relate grain-size distribution to the depositional processes responsible for their formation. Extensive textural studies of both modern and ancient sands have provided the basis for a genetic interpretation of sand texture. Analysis is based on recognising subpopulations within individual log-normal subpopulation. Each log-normal subpopulation may be related to a different mode of sediment transport and depositions, thus providing a measure of their importance in the genesis of a sand unit. The number, amount, size range, mixing and sorting of these populations vary systematically in relation to provenance, sedimentay processes and sedimentary dynamics.

My present area of study is the coastal tract between Karwar and Coondapoor which comprises a variety of coastal environments like beaches, dunes, bays, bars, etc. Grain size analysis was carried out for the samples from the varying coastal environments. For the same type of information from the corresponding off-shore region, work done by Hashimi et al. (1978) and Nair et al (1978) was found to be very much helpful. Their work covers almost every aspect of sedimentological analysis of continental shelf sediments belonging to this region. A striking feature of the shelf sediments of this region is the presence of a narrow band confined to less than 50 metre water depth and within a distance of 25 to 35 km. from the coast of clayey silt. Nair et al. (1978) in their paper have put forward a possible mechanism of deposition of fine sediments by flocculation during Monsoon due to salinity contrast in the estuarine waters.

In total 30 on-shore samples were processed and size analysis was carried out using standard sieves technique. Sediments less than 63 μ that is, from silt to clay size were put into one group. A computer programme was run for further treatment of the data and various statistical parameters were then computed for these parameters like mean, sorting and skewness of grain-size frequency distributions which follow trends that identify the direction of transport and the sedimentary processes of winnowing, selective deposition and total deposition.

The second approach to the problem of delineation of depositional and non-depositional regimes is on the basis of the work carried out by Doyle et al. (1967) in the Atlantic continental margin off the southern United States. On the basis of close correlation between mica content and gross energy levels they have delineated the depositional and non-depositional regimes in their study area mentioned above. Sand size mica, because of its platy nature, would be expected to be the hydraulic equivalent of smaller particles of other minerals hence as a result of transportation and depositional characteristics of mica, its distribution in sediments can serve to be a very useful tool for the determination of environmental energy condition, although this may depict a short term response. Hence the relative abundance or lack of mica in a sediment can prove to be a useful tool for the delineation of depositional and non-depositional regimes, respectively.

CHAPTER II

PREVIOUS WORK

Geologists for many years have been interested in extracting informations from the grain size analysis of sands regarding environmental conditions of deposition, erosion and transport (Udden 1914; Wentworth 1929; Otto 1939; Keller 1945; Deoglas 1946; Inman and Chamberlain 1955; Chaien 1958; Sindowoski 1958, Fuller 1961; Viser 1965; Friedman 1967; Moiola 1968). Since then sedimentologists have published conflicting opinions on the environmental sensitivity of textural parameters (mean diameter, standard deviation; skewness, kurtosis, etc.), calculated from the grain size analyses of modern beach, rivers, eolian sands. One of the most significant paper on textural parameters was by Doeglas (1946). He concluded that the grain size distribution follows an arithmatic probability law. Two major contributions by Doeglas (1946) were that: (1) grain size distributions are mixtures of two or more component distribution of populations; (2) These distributions were produced by varying transport conditions. Works by Pettijohn (1949) indicated a polymodal nature of grain size distribution, and that deficiencies occurred in the coarse sand-fine granule size and in the coarse silt size. These modes and deficiencies were attributed to provenance and to the hydraulics of stream transport, but little environmental significance was placed on the observations.

One of the most significant papers relating sedimentation dynamics to texture was published by Inman (1949). He recognized that there are three fundamental modes of transport - surface creep, saltation, and suspension and he utilized the existing knowledge concerning fluid mechanics to analyze the modes of transport of sedimentary particles. Mason and Folk (1958) concluded that a plot of skewness vs. kurtosis was effective in discrimination among beach, coastal dune and eolian flat sands from Mustang Island, Texas.

Shapes of grain size distribution curves of sediments from both modern and ancient environment were described by Sindowosky (1958). He referred the pioneer studies by Doeglas (1946) but deviated from that work in the sense that he used log-probability plots of the grain size information.

Work by Passega and others (1957, 1968) has led to the development of C/M plots. By using a number of samples it is possible to distinguish suspension, traction, graded suspension and other sedimentary processes. Analyses of many samples by use of C/M plots when combined with other methods of textural analysis should add additional insight into the genesis of individual sand units.

Friedman (1961) in his important contribution to the textural characteristics as criteria for recognising the depositional environments had concluded that a plot of the mean grain size against skewness results in complete separation of fields representing dune-sands and beach-sands. He also stated that the sign of skewness is not affected by the mineralogy of the samples. Folks and Robles (1964) studied several aspects of pure carbonate beach sands of Isla Perez, Yucatan and concluded that the effect of sedimentation processes on the sediment parameters are essentially the same as observed elsewhere on the non-carbonate material.

Folk (1967) has also shown how the sorting and skewness co-efficients permit a rapid differentiation between beach and reef sands. Mathur and Verma (1976) have concluded by the preliminary study of calcareous sands of Saurashtra that the mineralogy of sands does not effect the tendency of dune sands to be positively skewed and beach sands to be negatively skewed. On the other hand, there are workers like Shepard and Young (1961), Schlee and others (1964), Gees (1965) and Sevon (1966), who on the basis of their work, refused to accept that textural parameters are environmentally sensitive and in their opinion the differentiation between modern beach and coastal dune sands and between beach and river sands cannot be done on the basis of textural parameters alone.

Thus, we observe that there are two contrastingly different schools of thoughts regarding the use of textural parameters for environmental interpretation. Athough we cannot outrightly discard the view that textural parameters are not environmentally sensitive, but one of the major problems in the analysis of grain size distribution is that the same sedimentary processes occur within a number of environments and the consequent textural responses are similar. Now that there are many physical criteria available to identify specific depositional environment the textural studies do not need to stand alone, but can provide a separate line of evidence to aid in interpreting clastic deposits of unknown origin.

A very interesting approach but quite different from those of earlier studies, to the problem of environment interpretation was taken by Doyle et al. (1967) while studying the Atlantic continental margin off the southern United States. On the basis of the close correlation between mica content and gross energy level they have delineated the depositional and non-depositional regimes in the study area mentioned above. Sand size mica, because of its platy nature, would be expected to be the hydraulic equivalent of smaller particles of other minerals hence as a result of transportation and depositional characteristics of mica, its areal distribution in sediments has short-terms response to environmental energy condition.

Therefore, its relative abundance or lack in a sediment can serve as an excellent tool for the delineation of depositional and non-depositional regimes. They succeeded in delineating depositional and non-depositional regimes off the coast of Atlantic Southern United States. To quote them "Investigations have demonstrated that the mica content of modern continental shelf sediments can be used to rapidly and accurately outline depositional and non-depositional regimes of fine sediments over large areas".

THEORETICAL BACKGROUND

Robert Folk (1974) in his book "Petrology of Sedimentary Rocks" has written at length about the grain size analysis technique and its use in environmental interpretation. He has compiled all the techniques for grain-size analysis and discussed in detail the various statistical parameters and its use in the determination of associated environments. Here is a brief discussion on various statistical parameters and their computation.

There are two basic methods of obtaining statistical parameters. The first and most commonly used one involves plotting the cumulative curve of the sample and reading the diameter represented by various cumulative percentages (as what grain size value corresponds to 30% mark of the sediment meaning 30% of the material is coarser than that diameter). The second method, called the method of moments includes computation of statistical parameters using complex formulae with the help of a calculator. Both the methods have advantages and disadvantages associated with them. It was difficult for me to avoid the temptation of following the Graphic method in my present work which involves less computation, and gives better visual information for interpretation. Among the various measures of averages size of the sediment only graphic - mean was calculated as other two have limtations, for example median can not be used in case of bimodal sediments, and above all graphic Mean is suposed to be the best graphic measure for determining overall size.

For the measure of uniformity both simple graphic standard deviation and inclusive graphic standard deviation were calculated. Similarly simple graphic skewness and inclusive graphic skewness as well as simple graphic kurtosis and inclusive graphic kurtosis were calculated. The difference between these two types lies in the fact that the former type covers ony 68% of the curve whereas the latter covers 90% of the curve and hence yields better results. Folk (1974) also discussed the limitation for the use of these parameters. As for example, the interpretation based only on the basis of mean size must not always be correct. To quote him "The significance of mean grain size is not yet well known to make any positive statements; volumes of data on recent sediments must be be collected before we can say anything really meaningful". So, the general notion that fining is always away from the source is not true. Detailed studies of many individual environments by various workers have shown that sometimes just the reverse is found to be true. This is because grain size depends largely on the current strength of the local environment together with size of the available particles and not on distance.

Another parameter which is used for environmental interpretation is sorting. Although this method is also not properly understood but usually it depends on at least three major factors:

[1] Size range of the material supplied to the environment,

[2] Types of deposition "bean spreading, city dumps etc.,

[3] Water current characteristics: Currents of relatively constant strength whether low or high

will give better sorting than current which fluctuate rapidly from almost slack to violent. Also very weak currents do not sort grain well, neither do very strong currents. There is an optimum current velocity or degree of turbulence which produce best sorting. For best sorting the current must be of intermediate strength and also be of constant strength.

[4] Time: rate of supply of detritus compared with efficiency of the sorting agents.

Skewness and Kurtosis are other parameters which tell us how closely the grain-size distribution approaches the normal Guassian probability curve, and the more extreme the values the more non-normal the size curve. It has been found that single source sediments tend to have fairly normal curves, while sediments from multiple sources (e.g., mixtures of beach sand and lagoonal clays, etc.) show pronounced skewness and kurtosis. Bimodal sediments exhibit extreme kurtosis values, although the pure end-members of such mixtures have normal curves. Sediment consisting dominantly of one end member with only a small amount of other end member are extremely leptokurtic and skewed, the sign of the skewness depends on which end member dominates, sediments consisting of subequal amounts of the two end-members are extremely platykurtic (Folk and Ward, 1957). Plot of skewness against kurtosis is a promising clue to environmental differentiation.

CHAPTER III

GEOLOGY AND GEOMORPHOLOGY OF THE AREA

The continental shelf between Karwar to Coondapoor is bordered by Western Ghats. The average gradient of the whole shelf region of the W-Coast is about 9.4 cm/km (6') and the average width of shelf is 80 km. But near Karwar (the continental shelf steepense near the shore so that 9 m (5 fathom) contour is occasionaly at the shore near promontaries and cliff. The 18 m (10 fathom) contour, however, is at an average distance of about 3.2 km (2 miles), the gradient of the shelf nearer the shore goes upto 14'. Ahmed (1972) has classified the continental shelf along the western coast to be of fault origin.

The deposits on the continental shelf area are mostly those supplied from the Subaerial erosion of inland areas and from coastal erosion. Frequent occurrence of finer sediments near shore is reported by Hashimi et al. (1978) and Nair et al. (1978).

Continental Shelf Topography and Shelf Break

The continental shelf in the study area has an average width of 80 km. The mud covered inner shelf to a depth of 40-50 km is generally smooth and featureless. Beyond 50 m numerous small scale (maximum relief of 5 m), prominences and undulations appear (Fig. 1A). Off Karwar, some of these prominences at 70 m depth are seen as continuous features extending for about 60 km and they may be algal ridges. Other prominences occur as isolated pinnacles 6 m in height in a water depth of 111 m. A prominent scarp with the height of 4 m is seen at 98 m off Bhatkal (Fig. 1C).

The shelf break takes various forms. One definition is that the shelf edge (shelf break) is the point of the first major change in gradient at the outer most edge of the continental shelf. According to Wear et al. (1974) the most common is the sharp break type where the change in gradient is abrupt. A gradual shelf break is one which is arcuate and generally broader than the abrupt type. The gentle break type is one, in which the change in gradients is only slight.

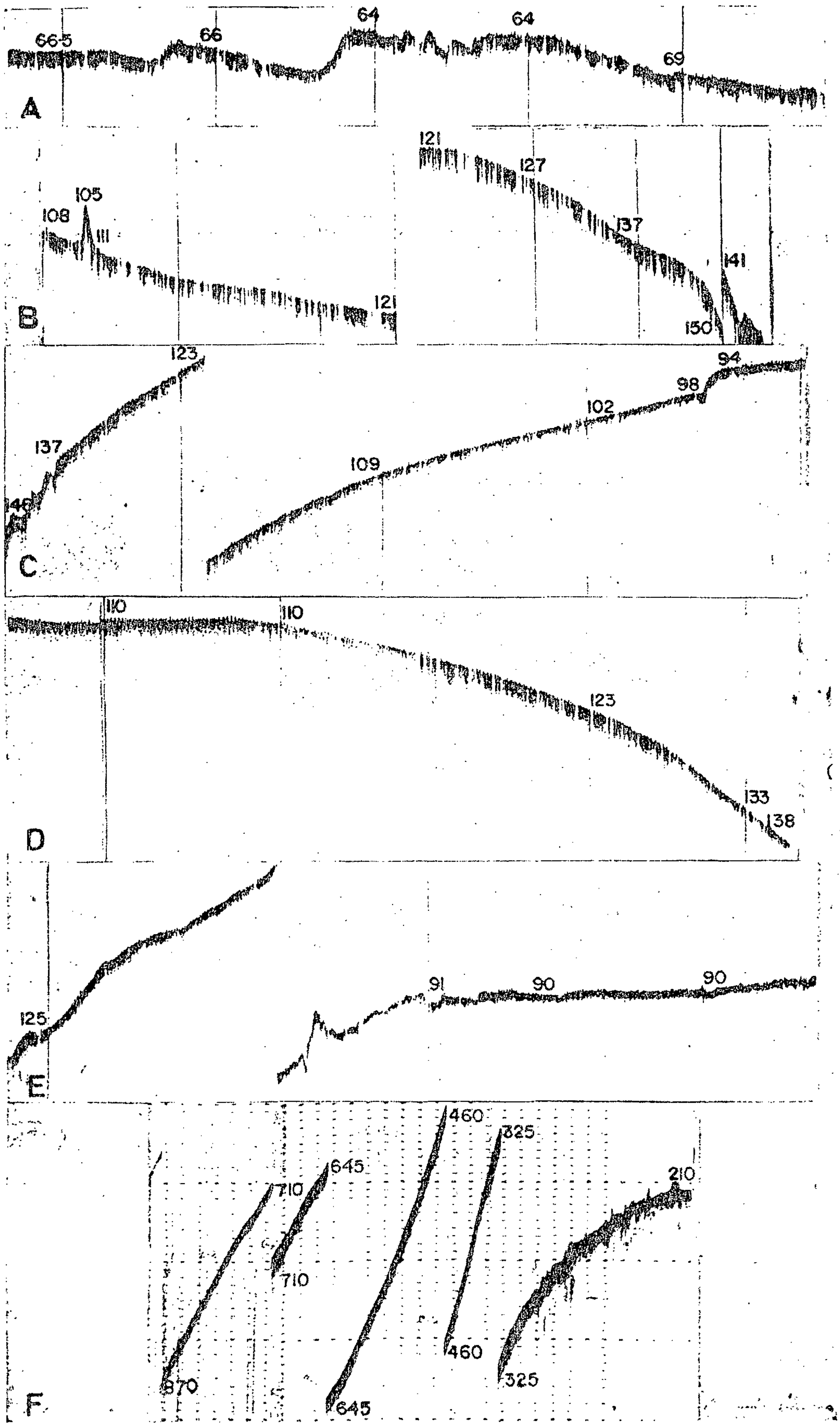


Fig. 1, - Bottom profiles, depth in metres

(AFTER NAIR et al., 19 6

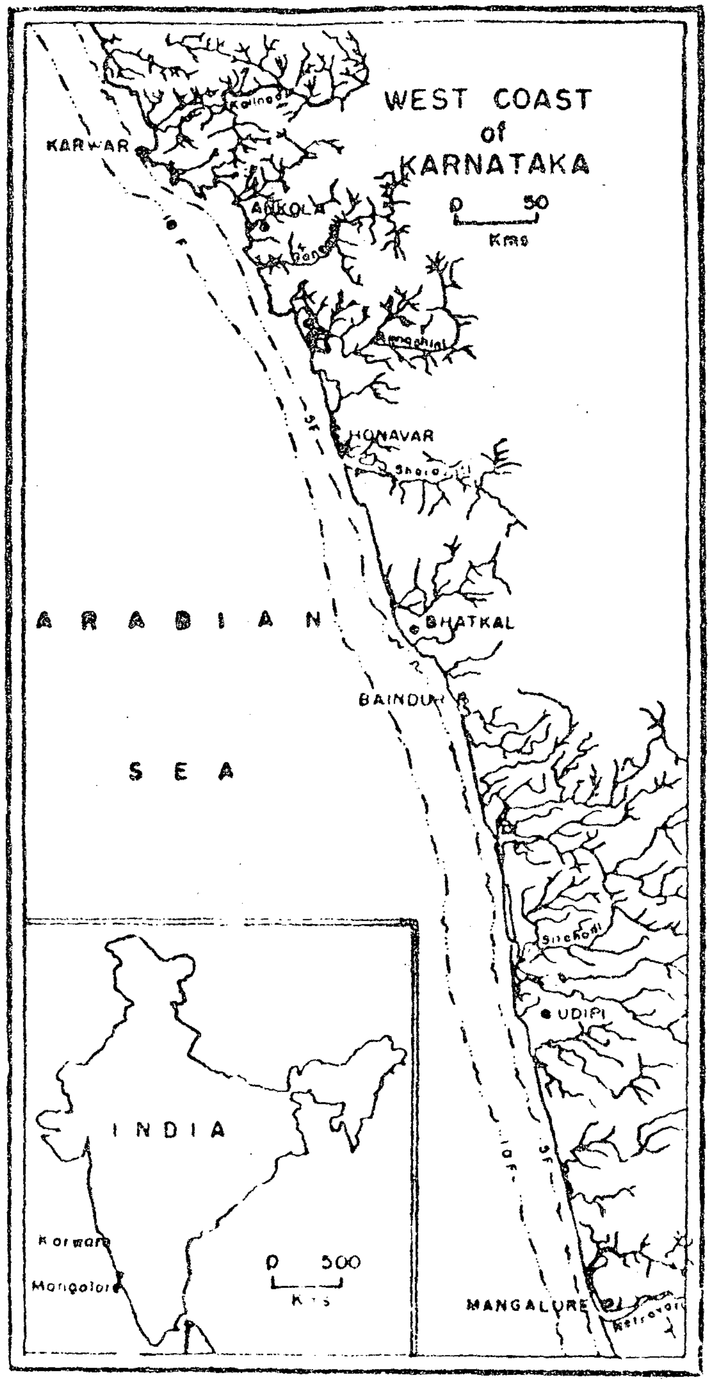
There is yet another type where terraces are present at the shelf break.

The shelf breaks between Vengurla and Mangalore belong to the gentle break type (Nair et al. 1978). Since the change in gradient is gradual the depth of the shelf break varies between 90 and 120 m. Fig. 1C is an example of a shelf break with a terrace. The first change in gradient is abrupt and takes place at 94 m and seaward of 98 m, the change in gradient is gradual upto 137 m. The first change in gradient in the seaward edge of the 90 m terrace. This terrace may be the southward extension of the 50 fathom flat which is very prominent on the outer continental shelf off Bombay (Nair, 1971).

Beyond the shelf edge the sea floor falls sharply to 1000 m. Many topographic prominences and terraces are present between 210 m and 275 m and from 278 m and 1000 m the upper continental slope has smooth topography (Fig. 1F).

Physical Features of the Coast

The west coast from Coondapoor to Karwar is dominated by a number of estuaries. There is a considerable mixing of marine and fresh water at the mouths of rivers which flow in this region. Important among them are Chakrondi near Coondapoor, Venktapore rivers estuary north off Bhatkal, Sharavati river estuary near Honnavar; Aganashini river estuary near Ankola and Kalinadi river estuary near Karwar (Fig. 2). The shore line from Coondapoor to Karwar is generally straight. The straightness of the shoreline is due to the development of the bars. There are scores of tiny rocky and fairly dissected islands and submarine banks in the neighbourhood off Coondapoor, Bhatkal and Karwar, for example Piegeon islands near Bhatkal, Oyester rocks near Karwar etc. The height of some of these islands is over 80 m. The origin of these islands should be viewed along with several physical aspects in the region. They include a highly rugged terrain behind the coast. There are stretches of cliffs, sometimes as high as about 170 m above the sea.



(After, Lonnappa, V. V. et al, 1979)

Fig. 2-Estuaries and drainage system westcoast of Karnataka.

There are numerous promontories and typically crenulated coast. Rias are quite frequent. There is a complete absence of the so-called coastal plain in several areas of the stretch under reference. The offshore submarine topography is relatively steep. These features leave little doubt about regional submergence which has brought about these islands. Yet it is also clear that subsequent to submergence, emergence has taken place. This is suggested by the straightness of the shore, the occurrence of the sea-beach near the shore, off-shore bars, bayheads, beaches, long spits, lagoons, etc.

Geomorphologically the coast is classified into three categories (Lonnappa et al., 1979): (1) Emergent straight shore near Mangalore; (2) Stable Coast off Bhatkal; (3) Crenulated shore north of Mangalore particularly near and around Karwar, where the rocky shore is made of rugged hills, islands with cliffs, notches and promontaries alternating with rias and estuaries (Fig. 2).

Geological Setting

Along the coast from Mangalore to Karwar, the rocky cliffs and islands are made up of Pre-camb. crystalline gneisses and schists. In Mangalore harbour area, the boreholes have struck the crystalline gneisses and hornblend biotite schist. The depth of boreholes range from 25 to 40 m. It is inferred from the bore hole data, that the deposition has taken place right on the undulating gneissic and schistose terrain.

The Precambrian crystalline rocks are capped by the laterites and unconsolidated recent alluvial material which forms an interland between the Ghats and the sea-coast. This alluvial cover on the banks of the streams and the estuaries is noticed. In some places the alluvium is associated with fresh molluscan shells. The deltaic structure is frequently seen along the coastal plain. But in and around Karwar the island topography presents a much contrast to that of Mangalore. Here the land between the shore and the Ghat is made up of clays and sands, containing a large number of recent molluscan and microfaunal shells.

Geological Action

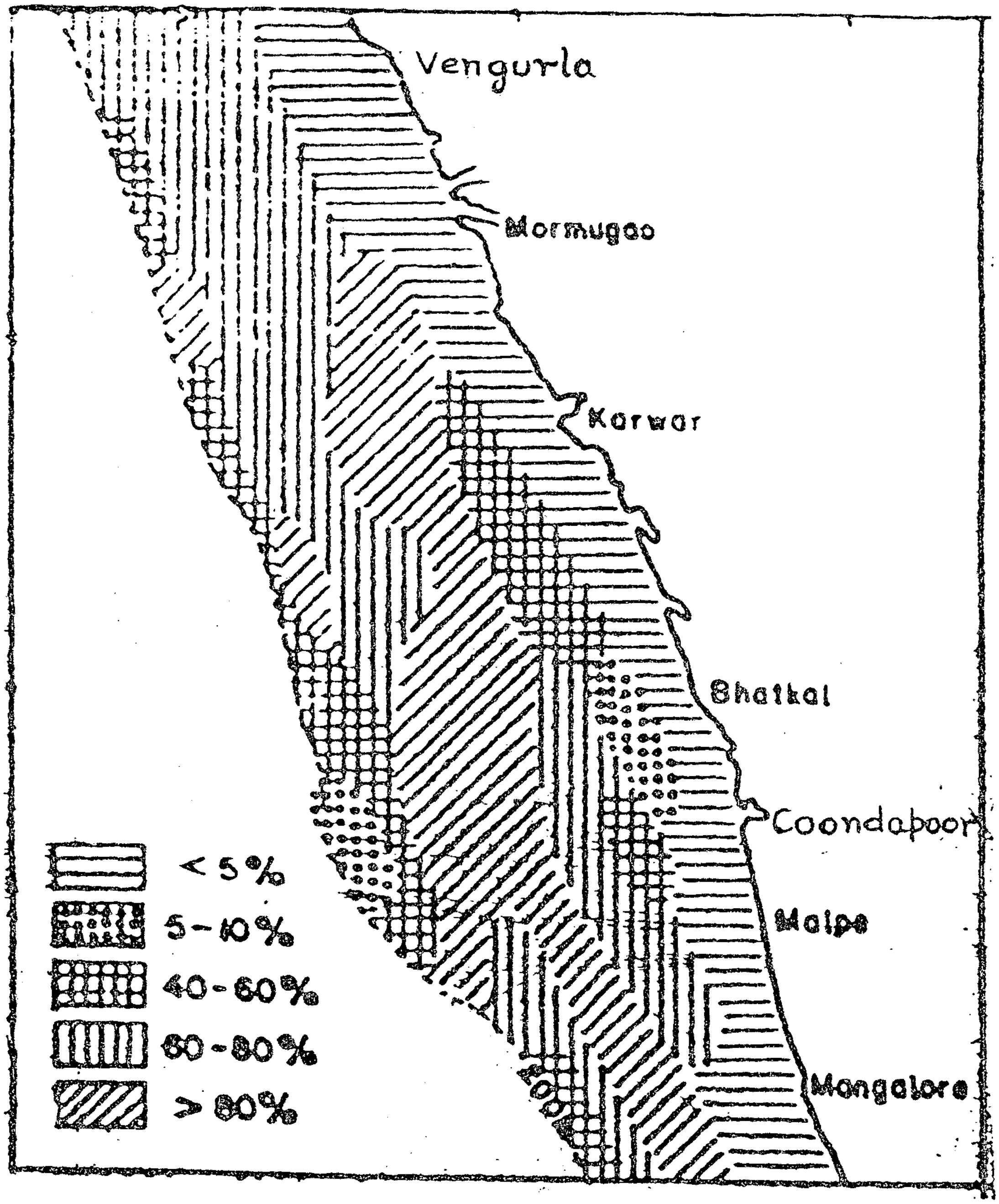
South-west monsoon is generally active from June to October and strikes the coast orthogonally. The monsoon circulation plays an important role in shaping the present day shore features. Powerful waves generated by the strong monsoon winds against the rocky coast cause considerable erosion. This is primarily responsible for the formation of the shore features like cliffs islands, embayments, notches, promontories, sand beaches, bars, spits, mud flats and sand barriers. The wind direction is favourable for the formation of off-shore bars. The spits and mudflats might have formed due to the interaction between landward rushing tidal-waters and seaward rushing flood waters of the streams. The occurrence of sand dunes appears to be related to areas of thick soil cover. The sedimentation along the west coast from Mangalore to Karwar is controlled by the geomorphological features, especially by the nature of coastline and estuaries. The deposition of the sediments is caused chiefly by the inflowing rivers. The coastline serves as the junction plain between the subaerial and marine processes of erosion and deposition.

Regarding the age of the sediments of the coast from Mangalore to Karwar, Lonnappa et al. (1979) on the basis of faunal evidences have suggested Pliestocene-Recent age.

Sediment Type Offshore

On the basis of abundance of coarse fraction (> 62 μ) inferred from the grain-size analysis. Hashimi et al. (1978) have classified the sediments of the continental shelf region between Mangalore to Vengurla, into 5 classes. Those with less than 5% of coarse fraction belong to the inner shelf region.

Those with 5-10% of coarse fraction lies between the inner shelf and outer shelf and is found particularly off Bhatkal upto Coondapoor. This type of sediment is also observed at the margin of the outer shelf off Coondapoor.



(AFTER , Hashimi et al., 1978)

FIG - 3, Aerial distribution of Coarse fraction (> 62 μm)

This 5 to 10% coarse fraction sediment off BhatKal-Coondapoor has on its both sides north and south, 40 to 60% coarse fraction sediment at the boundary of inner and outer continental shelf which extends parallel to the coast from Karwar upto Coondapoor and further south. This type of sediment is also found at the margin of the continental shelf. The 60-80% coarse fraction sediment is found throughout the boundary of inner and outer continental shelf parallel to the coast line and at the outer continental shelf. But in general the outer continental shelf is characterised by the presence of sediments having greater than 80% of this coarse fraction (Fig. 3).

THE MAJOR CURRENT SYSTEM OF ARABIAN SEA

The current system of Indian ocean is mainly subdivided into two parts which is based on the strongly influenced factors like monsoon and the change with seasons along with a number of local factors like density structure of the water and current bearing local nature (Fig. 4). Mainly, the currents in the

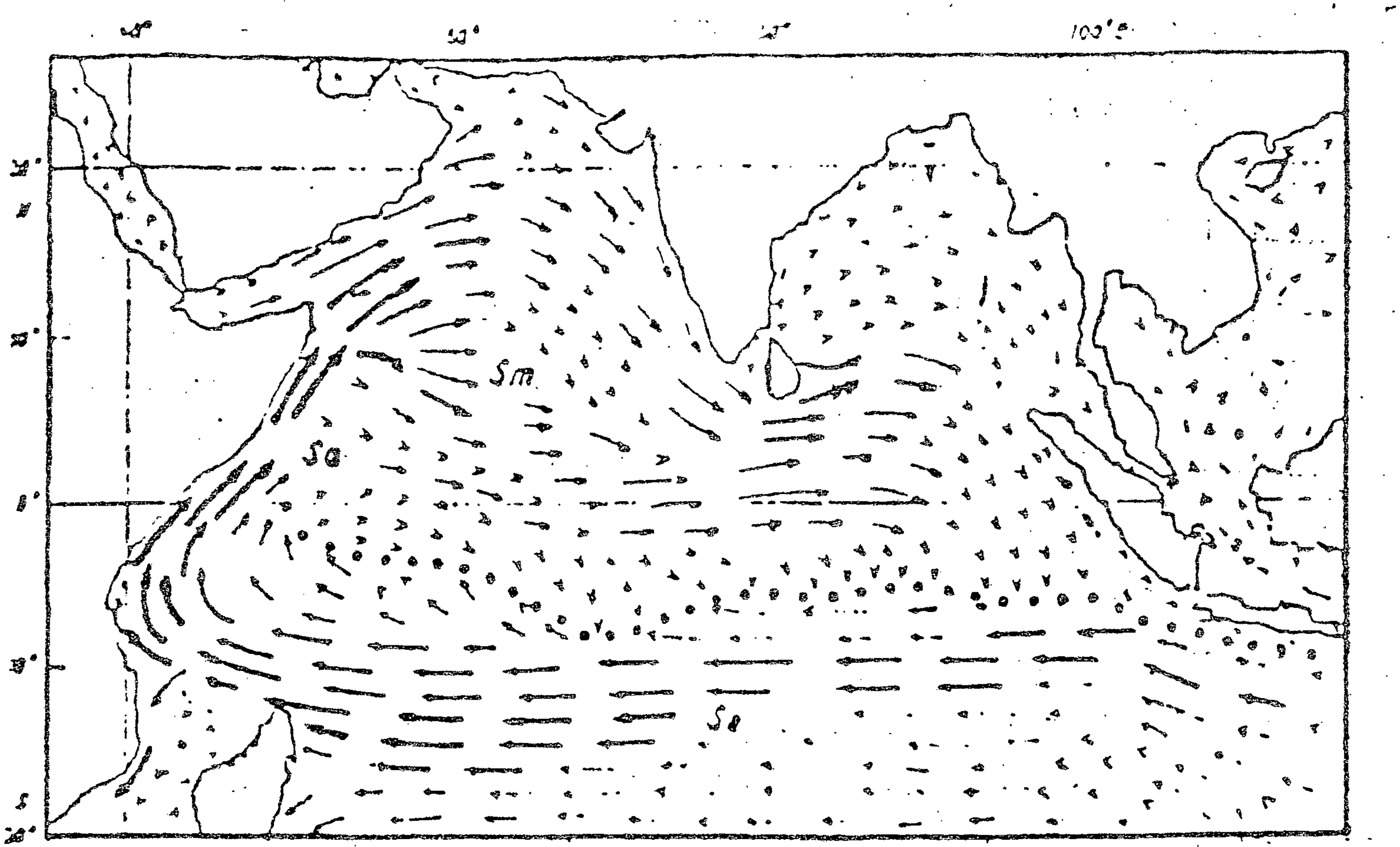


FIG-4. , Currents at the sea surface in the Indian Ocean in northern summer. So: Somali Current; Sm: Southwest Monsoon Current; Se: South Equatorial Current (according to G. Schott, 1943). Strength and persistence of the current is indicated by the thickness and length (respectively) of the arrow.

northern part which are highly influenced by the monsoons and the change with seasons are known to be as south-west and north-east monsoon drift in summer and winter, respectively.

The current pattern of south hemisphere are large anticyclonic gyre and are subject to greater annual variation which are similar to the gyre in the south Pacific and Atlantic oceans. The southern most leg of the gyre is the westward drift between 38^{o} s to 50^{o} s. This current is bounded by the subtropical convergence and by the subpolar convergence. The velocity of the current depends upon the wind of the region and it varies seasonally and regionally. In the southern summer, the current turns north before reaching Australia and is joined by a current flowing south of Australia from Pacific. In winter, the current joins southward flow along the west coast of Australia and continues towards the Pacific off the Australian south coast. The eastern leg of gyre is the west Australian current which flows northward only in the summer and it becomes weak in winter. The northern leg of gyre is the south Equatorial current which continues from the west Australian current at the Tropic of Capricorn due to the effect of the south east trades. The eastern part of the current reaches its greatest velocity during the southern winter when the westward flow north of Australia from the Pacific ocean reinforces. In the southern summer, when the flow becomes eastward, the northern boundary of south Equatorial current is at about 9^{o} s between 100^{O} and 80^{o} E.

The current splits in several branches before reaching Madagascar. One branch flows northwards around island and then turns westward. It splits again into two branches off cape Delgado. One branch turns north and the other turns south flowing through Mozambique channel and is known as Mozambique current. The Agulhas current is formed with continuation of Mozambique current and the southern branch of the south Equatorial current south of Mauritius. This current extends from the coast upto less than 100 kms. In this case cold water is found in shore and the sea surface rises towards the offshore. To the south of South

Africa, a greater part of the current bends sharply to the south and then to the east. Owing to reversal of direction and breaking up of currents numerous eddies develop off South Africa.

The surface current vary greatly to the north of latitude 10^{o} s from winter to summer. The southern boundary changes from $3-4^{o}$ N in November to $2-3^{o}$ S in February and turns to the north again in March. The northern boundary runs north of the equator in November and shifts to the southernmost latitudes to $2-3^{o}$ S in February. Later it moves again to the north and disappears. During the south-west Monsoon from April to October, the north equatorial current disappears and is replaced by the southwest monsoon drift which flows eastward south of India. Its branches flow clockwise in the Arabian sea and the Bay of Bengal following the coast lines. Water of south equatorial current crosses the equator and strong upwelling takes place off the Somali coast, causing the vast area of low surface temperature.

Study of subsurface currents in the Indian ocean north of 10° S by "Vityaz" cruise (Jan-April 1960) shows that the current is almost similar to the climatological surface current chart for the northern winter. At 200 m the currents south of 5° N are reverse to 15 m and they are eastward below the north and south equatorial currents and westward below the counter current coast of 70° E longitude. Direct current measurements by the same shows that the current system did not compound yet to that for winter monsoon in spite of the fact that the winds were already north-westerly.

Direct current measurements in four meridional sections across the equator shows that the eastward flow in the middle of the thermocline similar to the Pacific equatorial under current. Measurements showed that the under current seemed to be associated with the eastward presence gradient even though the pressure gradient at the surface is westward.

CHAPTER IV

FIELD AND LABORATORY METHODS

Sample Collection : ON-SHORE

For samples collection, extensive field work was carried out during the month of August and September. Over 60 samples were collected from beaches, river confluences, bays, dunes along the western coastal margin of India from Karwar to Coondapoor. At each station first few centimeters of the sediments were scooped and put into polythene bags. The location of each station was marked on the map. The description of the samples were noted down in the field diary. The selection of stations after taking into consideration the accessibility of the region, was done in such a manner that various types of coastal environment like beach, dune, coast, river confluence etc. could be covered.

Out of these 60 samples, 30 representative samples were taken for grain size and mica content analysis, the location of which are shown in the Fig. 5.

OFF-SHORE SAMPLES

21 Off-shore samples obtained from the sample archives of the National Institute of Oceanography, were also taken for mica-content and grain size analysis. These off-shore samples belong to the continental shelf region off-Karnataka coast between Karwar to Coondapoor. These are from various depths, the maximum depth being 76 m. Locations of these off-shore sampling stations are given in Fig. 5.

METHODOLOGY

Both on-shore and off-shore samples were washed and then in total 52 samples were processed for mica content and grain size analysis.

On-Shore Samples

WAshing and Drying: Each sample was washed repeatedly with distilled water (separately) to remove

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the salt content. The washed samples were then transferred to crucibles and dried in an electric oven under low temperature (40 °C to 50 °C) range to avoid caking and a few lumps that were present in the material were broken down by fingers with little pressure so that the individual grains are not broken down to smaller pieces.

Mica Content Analysis: About 100 grams from each washed and dried samples were taken and put at the top screen of the nest of screens built with the coarsest screen on the top. A pan was put at the bottom of the nest of screens before pouring the sample and a lid was put on the top before transferring the nest into the Ro-tap mechanical shaker. After 15 minutes of shaking 125 μ to 250 μ (fine sand) fraction was separated and put in plastic bottle, marking the sample no. on it. This way from each sample 125 to 250 μ size fraction was separated. This particular size fraction was choosen because it often contains more mica relative to other size fractions and mica in it is hydraulically equivalent to less than sand-size sediment.

Calcium carbonate was removed from each sample by treating it with 10% dilute HCl (Carver, 1971). Each sample was placed in a 250 ml beaker and 25 ml distilled water was added and stirred. Dilute (10%) HCl was added slowly until effervescence stopped. Then the beaker was heated to 80 ^{o}C to 90 ^{o}C and more dil. HCl was added until no effervescence stage reached. Then the acid was decanted and repeated washing was done with the help of filter paper and funnel. The sample was then transferred to crucible and dried in an electric oven at about 50 ^{o}C. The acid insoluble residue was then dispersed with the help of finger and mortar. A representative portion of acid insoluble residue was sprinkled evenly upon a 48 unit or 98 unit (depending upon the fineness of the grain) micro-palaeontology slide. For the samples which were found to contain finer grains 98 unit micropalaeontology slides were used.

The entire slide was microscopically scanned for mica and the number of mica grains recorded without making any distinction between biotite and muscovite since both are hydraulically similar. For insoluble grains, counting in any four randomly choosen squares was done by standard point counting technique using mechanical stage and point counter. The average of all the four count was taken for each sample and multiplied by either 48 or 98 depending upon the type of the slide used and an approximate total no. of grains in the slide was obtained. This way, it was possible to count between 2,000 to 4,000 grains rapidly with reproducibility viable with the needs of the investigation. All results are expressed as mica grains per 10,000 grains of insoluble residue. In all the samples studied mica usually comprises less than 1% of the sediment.

Grain Size Analysis: For grain size analysis the washed samples were dried in an electric oven at 60 ^{o}C and a few lumps that were present in the sediment were broken down by putting little pressure so that the individual grains are not broken down to smaller pieces. A representative amount (100 gms) of weight of dried sediment from each sample were taken by coning and quartering method. A nest of clean screens comprising 25μ, 63 μ, 125 μ, 250 μ upto 500 μ was built with the coarsest screen on the top. A lid was put on the top and a pan at the bottom of the nest of sieves. Dry sediment was poured on to the top screen in the nest and the nest was placed in to Ro-Tap mechanical shaker and shaked for 15 minutes. Each sieve was emptied on to a large sheet of paper. The removal of sediment was helped by striking the rim of the sieve with a wooden rod along the general direction of the diagonals of the wire nest and brushing the bottom of the sieve with a sieve brush.

Each size fraction was weighed accurately into four decimal point in grams on AE50 electronic balance.

This analysis yielded results in terms of weights between sieve sizes from which weight percent frequencies for each class was computed. The cumulative weight frequencies were then calculated for further treatment of the data.

The various statistical parameters of the grain size data were calculated with the help of graphical method.

Graphical Method:

Cumulative weight percentages in Phi unit wee first calculated which were plotted against Phi diameter on the Arithmatic probability paper. The Ist, 5th, 16th, 25th, 50th, 75th, 84th and 95th percentiles were read off to the nearest 0.01 Phi. The following formulae were used to compute the graphical measurement in Phi notations.

$$\text{Mean - (Mz)} = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3}$$

$$\text{Standard Deviation} = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_{5}}{6.6}$$

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

$$\text{Kurtosis} = \frac{\phi_{95} - \phi_{25}}{2.44\,(\phi_{75} - \phi_{25})}$$

Off-Shore Samples:

For mica grain analysis of the off-shore sediments 125 to 250 µ size fraction was separated from washed and dried samples by standard sieve analysis using Ro-Tap mechanical shaker.

Calcium carbonate was removed by dilute acid treatment. The acid insoluble residues was then washed with distilled water and dried in an electric oven at 60 °C. Dispersal of the grains in the dried samples was done by putting little pressure in case of sediment containing no coagulated particles. For sampls which were found to contain coagulated particles the ultrasonic probe method was used to disperse the finer particles which were coagulated. The same point counting technique was adopted which was carried out for on-shore samples, to determine the mica content.

Mica content is expressed as mica grains per 10,000 grains of insoluble residue.

CHAPTER V

RESULTS AND DISCUSSION

Grain Size Characteristics of On-Shore Samples

The graphical method was adopted to calculate various grain size parameters. The Phi values calculated from cumulative frequency curves is given in Table 1 for each sample. Different statistical parameters were calculated from cumulative curve for which a computer programme was run. The results thus obtained are listed in Table 2 , a discussion of which is given below.

The graphic mean (Mz) values vary from 3.317 to 0.667 in Phi units, i.e. size ranges from very fine sand to coarse sand but most of the sample fall in the category of medium to fine sand (1.0 to 3.0).

TABLE no.1

PHI VALUES CALCULATED FROM CUMULATIVE CURVES

SAMPLE NO.	PHI 1	PHI 5	PHI 16	PHI 25	PHI 50	PHI 75	PHI 84	PHI 95
16G	0.75	1.50	2.10	2.25	2.60	2.80	2.90	3.00
5 Ba	0.15	0.60	1.00	1.15	1.50	1.90	2.00	2.65
24 Bh	0.30	0.75	1.05	1.20	1.60	1.90	2.15	2.80
98Bh	0.10	0.30	0.70	0.85	1.50	2.20	2.40	2.80
10Bh	1.90	2.15	2.30	2.50	2.90	3.40	3.50	4.50
22CT	0.30	0.00	0.10	0.25	0.50	1.00	1.40	2.00
25 CT	2.00	2.05	2.25	2.40	2.75	2.85	3.00	3.65
21CT	2.00	2.35	2.75	2.95	3.20	3.50	4.00	5.50
12Bh	2.05	2.15	2.35	2.50	2.85	3.30	3.65	4.00
8Ba	1.05	1.50	1.90	2.10	2.30	2.50	2.65	3.00
17G	0.10	0.50	1.20	1.55	2.10	2.50	2.60	2.80
26By	2.05	2.10	2.20	2.25	2.45	2.75	2.95	3.55
18CT	1.10	1.70	2.10	2.20	2.40	2.60	2.70	2.80
27 By	0.80	1.10	1.40	1.60	2.00	2.15	2.35	2.85
30By	1.05	1.50	2.10	2.25	2.40	2.65	2.80	3.50
29By	0.25	0.70	1.25	1.70	2.25	2.65	2.75	2.95
2c	0.75	0.10	0.30	0.40	0.90	1.60	1.90	2.75
23c	0.10	0.40	0.85	1.00	1.40	1.85	2.00	2.75
3C	0.14	0.70	1.20	1.65	2.25	2.65	2.75	3.00
11C	2.00	2.25	2.55	2.75	3.10	3.50	3.65	4.00
14C	0.05	0.20	0.55	0.85	1.35	1.90	2.25	2.80
19G	1.10	2.00	2.30	2.45	2.65	2.90	3.15	5.50
7c	0.25	0.55	1.10	1.35	1.90	2.40	2.60	2.90
4c	0.90	0.65	0.00	0.25	0.95	1.95	2.45	3.25

Table II

Sample no.	Graphic mean	Inclusive Graphic Standard Division	Inclusive Graphic skewness	Inclusive Graphic Kurtosis	Simple skewness	Simple sorting	< 62 μ Silt + clay (%)
1c	x	x	x	x	x	x	x
2c	1.033	0.802	0.484	0.905	1.325	1.050	0.2
3c	2.067	0.736	-0.505	0.943	1.150	-0.80	0.4
4c	1.133	1.203	0.281	0.940	1.950	0.700	0.65
5Ba	1.500	0.561	0.137	1.120	1.025	0.250	0.25
6Ba	x	x	x	x	x	x	x
7c	1.867	0.731	-0.170	0.917	1.175	-0.350	0.12
8Ba	2.283	0.415	-0.136	1.537	0.750	-0.100	0.24
9Bh	1.533	0.804	0.060	0.759	1.250	0.100	0.00
10Bh	2.90	0.656	0.387	1.070	1.175	0.850	7.89
11c	3.10	0.540	0.027	0.956	0.875	0.50	4.16
12Bh	2.95	0.605	0.346	0.948	0.925	0.450	4.79
13c	x	x	x	x	x	x	x
14c	1.383	0.819	0.147	1.015	1.300	0.300	0.0
15Bh	x	x	x	x	x	x	x
16G	2.533	0.427	-0.647	1.118	0.750	-0.700	1.22
17G	1.967	0.698	-0.531	0.992	1.150	-0.900	0.00
18c	2.40	0.317	-0.307	1.127	0.550	-0.300	0.03
19G	2.70	0.743	2.092	3.188	1.750	2.200	3.07
20e	x	x	x	x	x	x	x
21ct	3.317	0.790	1.220	2.347	1.575	1.450	2.62
22ct	0.667	0.628	0.739	1.093	1.00	1.00	0.11

Contd...

23c	1.417	0.644	0.190	1.133	1.175	0.350	0.04
24Bh	1.60	0.586	0.205	1.20	1.025	0.350	0.01
25ct	2.667	0.430	0.015	1.457	0.800	0.200	0.89
26By	2.533	0.407	0.781	1.189	0.725	0.750	0.46
27By	1.917	0.503	-0.169	1.304	0.875	-0.050	0.00
28By	x	x	x	x	x	x	
29By	2.083	0.716	-0.533	0.971	1.125	-0.850	0.06
30By	2.433	0.478	0.276	2.049	1.00	0.200	0.37

c- River confluence;

Ba - Bar;

Bh - Beach;

G - Gulf;

E - Estuary;

ct - open coast;

By - Bay.

Inclusive Graphic Standard Deviation:

The values of inclusive graphic standard deviation varies between 1.203 Øto 0.317 Ø, meaning that the sample represents a wide range of sorting measure, varying between well sorted to very poorly sorted. The sample from bars, bays and gulf have a clustering of standard deviation values between 0.4 to 0.7 Ø indicating that they are relatively better sorted than the samples from beach, open coast and river confluence. The poor sorting of beach indicates that during monsoon there is a considerable mixing of different size ranges.

Inclusive Graphic Skewness:

The inclusive graphic skewness values ranges between 2.092 to -0.136 covering the entire range from strongly fine skewed to strongly coarse skewed. Out of the 24 samples analysed only 8 samples show negative skewness. But a comparison between beach, confluence, bar, bay and gulf samples on the basis of skewness seems to be impossible on the basis of the values obtained and no generalization could be done as far as the interpretation for accumulation of fine or winnowing of sediments is concerned.

Inclusive Graphic Kurtosis:

The inclusive graphic kurtosis values range between 3.188 to 0.905 Ø indicating that the samples range from extremely leptokurtic to mesokurtic. None of the samples has a truely platykurtic value, i.e., below 0.9 Ø. Most of the beach and open coast samples exhibit a mesokurtic value.

MICA CONTENT ANALYSIS

The distribution of fine sand size mica grains is shown on the map (Fig. 5). The station-wise values are given in Table 3. The aerial distribution of mica in both off-shore and on-shore sediments is such that certain inferences can be drawn with the help of figure no. 5.

TABLE III-A

OFF-SHORE SAMPLES

Station No.	Depth	Mica grains per 10,000 grains of insoluble residue
2	67	5
4	56	8
6	49	35
8	36	Nil
12	20	Nil
14	30	7
16	39	x
18	47	12
20	50	5
22	60	2
24	58	Nil
26	48	13
28	46	15
30	42	21
32	33	Nil
34	24	Nil
36	17	Nil
38	27	Nil

40	38	18
42	43	x
44	49	23

TABLE III-B

ON-SHORE SAMPLES

Sample No.	Location	Mica grain per 10,000 grains of I-residue
1c	River Confluence at Coondapoor	36
2c	River Confluence north of Coondapoor	40
3c	Kuluru river confluence at Gangali	20
4c	Yadamani river confluence	15
5Ba	Bar sample at Yadamani	5
6Ba	Bar sample at south of Baindur.	7
7c	Baindur river confluence	8
8Ba	Baindur offshore bar	6
9Bh	Bhatkal Beach sample	Nil
10Bh	Shirali Beach	Nil
11c	Shirali river confluence	30
12Bh	Murdeshwar beach	Nil
13c	Manki river confluence	30
14c	Saravati River Confluence	8
15Bh	Honawar beach	Nil
16g	Tadri gulf	42
17g	Tadri gulf (nothwest of Tadri gulf)	38

(contd...

18ct.	Straight open coast (north of Gokarn)	10
19g.	Gulf Sample near Gokarn	7
20e.	Gangavali estuary	2
21ct.	Ankola open coast	Nil
22ct	Ankola closed coast.	Nil
23c	Belekeri river confluence	25
24Bh	Belekeri beach	Nil
25Ct	Aligadde coastal area	Nil
26By	Binge Bay	16
27By	Baitkal Bay	2
28By	Karwar Bay (southern part)	30
29By	Karwar Bay (intertidal area)	2
30By	Karwar Bay (northern part)	25

c- confluence; g- gulf; ct- coast; Ba- Bar;

By- bay; Bh- beach.

The first and the foremost is where-ever coastal rivers are draining into the ocean, sediments are found to have relatively higher values of fine sand size mica grains than the beach and dune sediments (e.g., station nos. 1C, 2C, 25C, 62C, 2G, 9G, 6BY, 35BY etc. where C stands for river confluence, G shown for gulf and BY stands for bay). Although the amount of mica content is less than 1 per cent by number of the total sediment in 125 to 250 μ size fraction, still it is evident that rivers are supplying large volumes of sediments during monsoon seasons, the whole of which the coastal hydraulic regime is unable to transport away from these areas atleast locally. Hence this high mica content patches around river confluences suggests that atleast in these areas of a limited extent, sediments carried by rivers exceed the marine transport capability during monsoon. But the absence of mica grains in beaches and straight open coastline confirms the prevalence of high energy conditions, and associated high marine transport ability, which is the sum total of tidal wave, wind and longshore transport.

By taking into account the aerial distribution of mica in both shelf sediments and on-shore sediments, some generalization can be made. Nearshore sediments of the inner shelf (<35 m) are in general devoid of fine sand size mica grains. The 125 to 250 micron fraction which was microscopically scanned for counting mica grains was found to contain upto 98% of perfect spherules, which are considered to be comprised of agglomerated silt and clay particles. Hashimi et al. (1978) in the classification of surface sediments of western coast has also reported that the inner shelf sediments are mostly mud, and coarse fraction (> 62 μ) are less than 5% by weight.

Nair et al. (1978) have proposed the possible mechanism for the deposition of fine particles in nearshore regions, which otherwise could be transported away from those shallower parts. In their opinion as a result of sharp contrast in salinity between the estuarine waters and the open ocean waters, especially during the monsoon season, fine particles (silts and clay) suddenly undergo a process of agglomeration.

As a result of agglomeration process deposition of the bulk of fine sediment takes place within 25 to 35 km from the coast. Considering the geologic formation present along the west coast and observation of Doyle et al. (1967), terrestial sediments of any depositional regime should contain relatively high percent of mica, but this aerial distribution of mica in the inner shelf between Karwar to Coondapoor does not present such a simple picture. Instead, the situation seems to be much more complex than what was presumed.

The nearshore part of the innershelf region comprises sediments which are almost devoid of mica grains of fine sand size extending approximately upto 35 m depth and run almost parallel to the coast. Adjacent to this, there is a zone upto 50 m depth, i.e., upto the margin of the inner shelf which contains more than 10 grains of fine sand size mica grains per 10,000 grains of insoluble residue. Beyond this mica abundant zone, there is again a zone of less than 10 mica grains per 10,000 grains and which is the inner part of the outer shelf regime.

In the absence of samples from the entire outer shelf and from continental slope, no information could be obtained for the distribution of mica in these regions. Thus, the areas under study is reduced upto inner part of the outer shelf region. To delineate the depositional regime from that of non-depositional one, a boundary at 10 mica grains per 10,000 grains of insoluble residue was fixed on the basis of highest value obtained from the straight open coast sediments which should normally represent a high energy condition locally.

On the aforesaid basis of delineation, roughly three different zones can be distinguished.

A narrow band parallel to the coast upto the depth of 35 m roughly and extending upto 8 km away from the coast on an average, which has less than 10 mica grains of fine sand size per 10,000 grains of insoluble residue.

Zone beyond 35 m depth upto the margin of inner shelf (50 m depth), which contains more than 10 mica grains, the maximum being 35 grains.

A zone beyond the inner shelf comprising the outer shelf and the continental slope regions. Since a very limited number of samples from this zone are available and the same confined to the inner part of the outer shelf, nothing with certainty could be said about energy condition prevailing in it. But the inner part of the outer shelf adjacent to inner shelf contains again less than 10 grains of mica per 10,000 grains of insoluble residue. Hence, it can be said that there is atleast a very thin band adjacent to the inner shelf which at present is an area of non-deposition.

A question arises, however, if the entire inner-shelf regime is a zone of deposition as reported by Hashimi et al. (1978) and Nair et al. (1978) then why do we get a thin band of sediments in the nearshore regions of inner shelf which is almost devoid of mica grain in the fine sand size fraction?

To find the solution to this problem the following points could be kept in mind :

Firstly, the deposition of fines which is taking place in the no mica zones by means of flocculation may not be a type of deposition that is usually found in the natural systems where silt and clay particle settle owing to the prevalence of low energy condition.

Secondly, a depositional zone marked by the high value of mica content adjacent to this inner most zone of no mica indicates that whatever be the energy condition in the nearshore part of the inner shelf, this zone of high mica is marked by relatively diminished energy level so as to let the fines to settle down. Hence, transporting agencies working on both sides of it (Zone 2; Fig. 5) ceases to operate here.

Lastly, the mica grains of fine sand size are hydraulically equivalent to less than fine sand size grains of silts and clays and not to the flocculated spherules of silt and clays of increased size and weight. Also mica does not go into flocculation.

On the basis of the above mentioned observations, one possible explanation that can be put forward is - The deposition taking place in the nearshore band of inner shelf (Zone 1; Fig. 5) is only due to agglomeration (which enhances the speed of settling). However, under normal conditions when no agglomeration is taking place, the energy condition in the area (Zone 1; Fig. 5) is such that all the silt and clay particle would be winnowed away from this zone and would be deposited in the depositional zone (Zone 2; Fig. 5) marked by the high mica content.

Whatever samples from the outer shelf that could be analysed for mica grains indicate that inner part of the outer shelf is an area of relatively non-deposition as inferred by the values of fine sand size mica grains which were less than 10 grains per 10,000 grains of insoluble residue. This zone (Zone 3; Fig. 5) is characterized by the presence of coarse sand (> 62 μ) which is more than 80% as reported by Hashimi et al. (1978). These sands may be relict in nature. During periods of lowered Pliestocene sea level rivers would have discharged their sediment load further seaward from their present day mouths. The subsequent Holocene trend of rising sea level would result in progressive displacement of the shore line to the coast and in this process dispersed of sediments may result which may account for the presence of coarse sand at the outer shelf as advocated by Nair et al. (1978).

Work done on differential transport of fall-equivalent sand grains in Lake Ontario (N.Y.) region by Trask et al. (1985), also seems to support the explanation given for the absence of mica in the zone 1 (Fig. 5) which is dominated by agglomerated silt and clay spherules. They on the basis of their work, have tried to differentiate between hydraulic equivalence and fall-equivalence, and have reported that the heavy minerals are less transportable than the fall-equivalence lights. If the fall-equivalent relationships between these agglomerated spherules and mica grains can be determined in the laboratory, another line of thinking could emerge to solve the problem. The time constraint at present, does not permit me for carrying out such experiments but in future work can also be done on this line. But one aspect which is clear is that the implied departure of transport equivalence from fall-equivalence in fact relate to difficulty of entrainment, as proposed by Hand (1967). Grains having equal fall velocities were presumed to travel similar distances during each brief transport episode. But a heavy mineral grain because of its smaller size, has a geometric disadvantage that makes it less entrainable and less transportable in terms of the overall transport process. Similarly, even if we assume that the mica grains of fine sand size are fall-equivalent of the agglomerated silt and clay spherules, the degree of entrainability will differ depending upon the size and shape characteristics of both types of grains and also on the nature of packing and the adhesive forces in operation. Still mica grains would remain hydraulically more sensitive and more entrainable than the agglomerated spherules of silt and clay. This in a way support the absence of mica in Zone I (Fig. 5), dominated by agglomerated spherules of silt and clay.

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