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# Sediment Distribution and Transport Studies of the Inner Shelf Zone off the Central Coast of Kerala, India

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**ABSTRACT**

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Textural parameters of surficial sediments derived from the inner shelf zone off Kerala, between Kuzhipalli and Chawghat, delineate probable sediment transport trends. The onshore-offshore sediment transport study indicated transport trends both in onshore as well as offshore directions in sectors where fluvial action is prevalent. Onshore transport only occurred in the sector devoid of fluvial influence. The alongshore sediment transport study, based on 4 profiles parallel to the coast, showed a strong northerly trend of sediment movement at a depth beyond 20 m isobath and movement in north and south directions in shallower (< 20 m) depths of the shelf. The logical inference drawn from this study is that movement of sediments in shallower portions of the shelf is influenced by the interaction of waves, currents, and fluvial processes. Sediment movement in deeper portions mainly result from wave turbulences.

**ADDITIONAL INDEX WORDS**: *Inner Shelf, surficial sediments, textural parameters, sediment transport, onshore-offshore, alongshore.*

## INTRODUCTION

An important aspect of sedimentology is the study of sediment transport dynamics. This line of research is effectively accomplished using radioactive tracers in the littoral zone (MACHADO and BABA, 1984; SIDDIQUE and SHRIVASTAVA, 1970; RAY and VENKATESH, 1975; RAY *et al.*, 1975). The study of sediment transport in shelf and deep sea environments through the introduction of radioactive tracers is comparatively more complicated. Therefore, inherent characters of sediments like texture, grain shape (MAZZULLO and CRISP, 1985), mineralogy (GRIFFIN *et al.*, 1968), trace element geochemistry (HOLMES, 1982) and isotope geochemistry (SALOMONS *et al.*, 1975) are widely used to trace sediment transport paths. In the present work a simpler and yet reliable technique for predicting sediment transport paths considers the entire population of sediment size distribution. Suggested by McLAREN and BOWELS (1985), this technique helps decipher sediment transportation paths within the innershelf zone off Kerala between Kuzhipalli and Chawghat (Figure 1). In this technique only the moment measures of grain size distribution, namely, mean, sorting and skewness are used in the prediction of probable direction of sediment movement.

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## STUDY AREA

The study area covers about 600 km$^2$ with a length of 50 km and a width of 12 km. The bottom topography of the shelf is regular, with an average slope of 2m/km to the offshore limit of investigation *i.e.* the 25 m isobath. Two rivers, the Periyar and the Keecheri, debouch into this zone at the southern and northern extremes of the study area. The Periyar River, having a length of 244 km, is a major river of Kerala. Draining over high grade metamorphics (charnockitic gneisses and gneisses) in the high lands and midlands, and Pleistocene sediments in the lowland region of Kerala, the Periyar River is the principal sediment supplier to this zone. Compared to the Periyar, the Keecheri River, debouching into the Arabian Sea through the Chetuwai back water system, is a minor river supplying a limited amount of sediment.

The general climate is a tropical monsoon

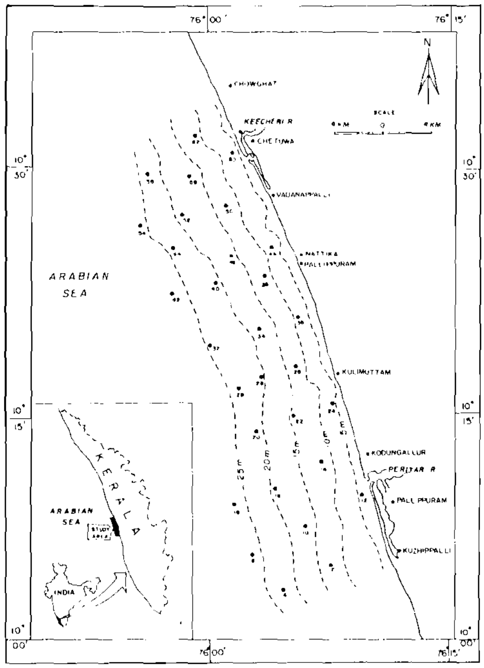


Figure 1. Location map.

type with an average temperature of 30°C and an annual rainfall of about 3000 mm. A summer maximum in precipitation takes place during the southwest monsoon season, between June and September. The general atmospheric circulation shows a seasonal reversal trend. The wind blowing in the northern direction during the pre-monsoon season changes direction from north to west during the peak monsoon season (June-July), with a tremendous increase in speed. Again, the post-monsoonal season (October-November), the wind direction shifts towards the south, with a progressive decrease in speed (ANANTHAKRISHNAN *et al.*, 1979).

The coastal circulation pattern also shows seasonal reversal trends. The surface current flow from November to January is northwards and, by the end of January, there is sudden reversal in the direction of flow towards the south. This southerly flow is weak until the end of March afterwhich there is a progressive increase in current velocity. During the monsoon season the current attains a maximum speed of 25-40 cm/sec flowing along the coast in a south-south east direction. In the postmonsoon season the current speed diminishes progressively maintaining the southerly flow until October (GOPINATHAN & QASIM, 1974).

The wave regime all along the coast of Kerala is controlled dominantly by the meteorological conditions in the Arabian Sea and the Indian Ocean, with the highest wave activity coinciding with the occurrence of the monsoon. The observed direction of wave approach is dominantly west-southwest during most of the year. Wave periods ranged from 11 sec in the fair weather season to 8.5 sec during the monsoon (BABA *et al.*, 1985). Wave height also shows significant variation seasonally and ranges from 0.5 m to 1.9 m. The tidal influence on this coast is insignificant as the tides are diurnal, with a range of less than 1 meter.

## MATERIALS AND METHODS

Samples were obtained along 11 profiles aligned perpendicular to the coast and parallel to each other at 5 km intervals. Six sampling stations were located on each transect at intervals of 2 km. Sixty three surficial and 11 core samples were collected from depths ranging between 5 m and 25 m. Positions of sampling stations along the transects were determined by the two angle and range method from several established base stations on the shore, using theodolites.

Out of 63 grab samples, 30 selected samples (Figure 1) were subjected to granulometric analysis using a conventional sieve (INGRAM, 1971) and pipette methods (GALEHOUSE, 1971). Sand, silt and clay percentages and the moment statistics of grain size distribution (McBRIDE, 1971) namely, mean, sorting, skewness and kurtosis were computed (Table 1). This basic data was used for the construction of distribution maps, CM diagrams, and for the sediment transport analysis.

## RESULTS

### Sediment Distribution

Sediments were classified on the basis of sand, silt and clay percentages (SHEPARD, 1954). The sediment distribution map (Figure 2) indicates a predominance of clayey silts and silty clays. The clayey silts extend over the inner portion of the shelf adjoining the coastline and estuaries. The silty clays dominate the central and the seaward portion of the inner shelf. Samples derived from stations 44 and 48 contain sand, silt and clay. The percentage of coarse fraction (Figure 3) is higher (> 20%) in the northern portion compared to sediments in the southern region (< 5%). When the area is longitudinally divided the seaward portion is richer in the coarse fraction than the inner portion.

### Areal Variation in Textural Parameters

*Mean Size (Mz).* Variation of mean size of the sediments is shown in Figure 4. The southern end of the shelf is characterized by clayey sediments ranging in mean size from 8.0 to 9.0 $\phi$. Silts, particles between 5.0 $\phi$ and 7.0 $\phi$, are prevalent in the northern part of the area. Coastal sediments away from the Periyar mouth have a mean size range of 6.0 $\phi$ to 7.0 $\phi$, *i.e.* they are dominated by silts. The innershelf

Table 1.

| Station Number | Sand % | Silt % | Clay % | Mean Mz | Median Md | Sorting $\sigma$ | Skewness $Sk_1$ | Kurtosis $K_G$ |
|---|---|---|---|---|---|---|---|---|
| 2 | 3.81 | 44.48 | 51.71 | 8.84 | 9.03 | 3.29 | − 0.05 | 0.15 |
| 4 | 1.18 | 37.54 | 61.28 | 9.32 | 9.70 | 3.23 | − 0.21 | 0.23 |
| 8 | 16.03 | 30.17 | 53.80 | 8.36 | 8.40 | 3.70 | − 0.10 | 0.25 |
| 10 | 1.07 | 67.15 | 31.78 | 6.90 | 5.45 | 2.90 | 0.93 | 0.46 |
| 12 | 0.95 | 62.72 | 36.33 | 7.16 | 5.95 | 2.96 | 0.78 | 0.47 |
| 14 | 4.13 | 62.68 | 33.19 | 6.45 | 5.20 | 2.35 | 0.76 | 0.17 |
| 16 | 11.06 | 51.84 | 37.10 | 7.19 | 6.37 | 2.88 | 0.74 | 0.53 |
| 18 | 6.81 | 64.48 | 28.71 | 6.85 | 6.30 | 2.87 | 0.79 | 0.43 |
| 20 | 1.82 | 64.01 | 34.17 | 7.20 | 6.50 | 2.78 | 0.81 | 0.65 |
| 22 | 7.83 | 33.98 | 58.19 | 9.01 | 10.13 | 3.39 | − 0.27 | 0.22 |
| 24 | 15.94 | 62.51 | 21.55 | 6.22 | 4.95 | 2.81 | 1.11 | 0.82 |
| 26 | 10.06 | 56.39 | 33.55 | 6.69 | 5.00 | 2.92 | 0.78 | 0.48 |
| 28 | 2.69 | 50.25 | 47.06 | 8.50 | 7.75 | 3.35 | 0.15 | 0.18 |
| 29 | 12.58 | 31.35 | 56.07 | 8.56 | 9.45 | 3.63 | − 0.16 | 0.22 |
| 32 | 8.25 | 28.52 | 63.23 | 9.01 | 10.17 | 3.25 | − 0.34 | 0.24 |
| 34 | 3.32 | 26.83 | 69.85 | 9.57 | 10.06 | 2.64 | − 0.52 | 0.64 |
| 36 | 4.01 | 29.72 | 66.27 | 9.01 | 9.50 | 3.03 | − 0.23 | 0.30 |
| 38 | 1.09 | 52.13 | 46.78 | 8.34 | 7.75 | 2.94 | 0.34 | 0.30 |
| 40 | 1.42 | 46.82 | 51.76 | 8.45 | 8.14 | 3.02 | 0.24 | 0.23 |
| 42 | 7.33 | 52.51 | 40.16 | 7.94 | 7.56 | 3.28 | 0.30 | 0.26 |
| 44 | 35.79 | 38.82 | 25.39 | 5.99 | 5.28 | 3.25 | 0.87 | 0.59 |
| 46 | 6.79 | 62.88 | 30.33 | 7.20 | 6.25 | 3.10 | 0.78 | 0.33 |
| 48 | 26.66 | 52.76 | 20.58 | 5.72 | 4.95 | 2.27 | 0.46 | 0.49 |
| 50 | 7.28 | 57.48 | 35.24 | 7.47 | 6.82 | 2.99 | 0.56 | 0.41 |
| 52 | 1.93 | 41.51 | 56.56 | 8.20 | 8.50 | 2.81 | 0.20 | 0.41 |
| 54 | 14.46 | 26.66 | 58.88 | 7.83 | 9.04 | 2.63 | − 0.69 | 0.26 |
| 56 | 4.25 | 46.49 | 49.26 | 7.69 | 7.98 | 2.89 | − 0.10 | 0.42 |
| 58 | 2.53 | 57.14 | 40.33 | 7.38 | 6.92 | 2.64 | 0.66 | 0.57 |
| 60 | 32.45 | 45.55 | 22.00 | 5.75 | 4.88 | 2.51 | 0.82 | 0.22 |
| 62 | 31.93 | 54.87 | 45.13 | 5.38 | 4.63 | 2.36 | 1.16 | 0.79 |

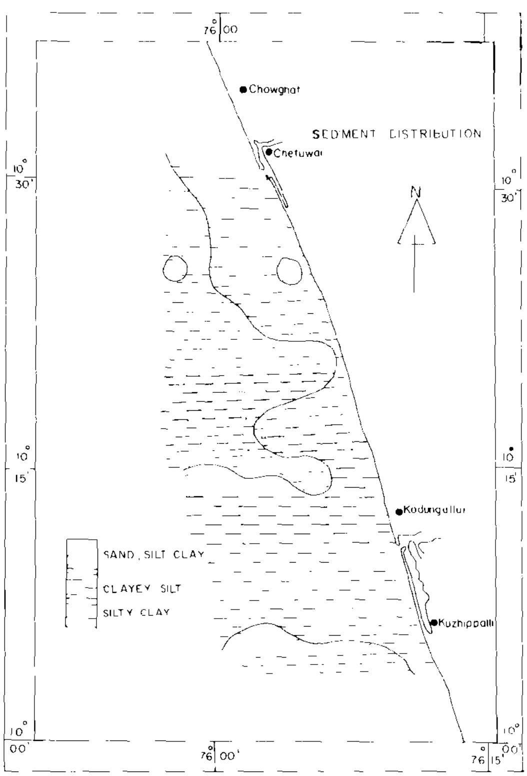


Figure 2. Sediment distribution map.

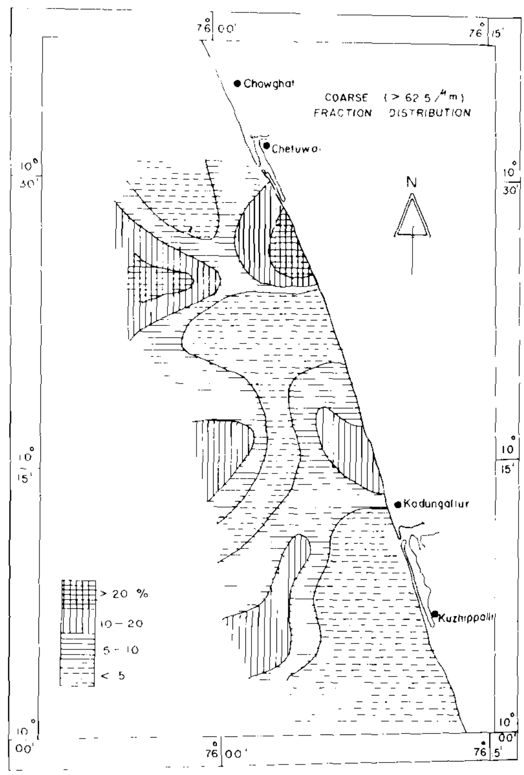


Figure 3. Coarse fraction distribution map.

between Kullimuttam and Pallipuram along the central portion of the coast is devoid of riverine influence and is characterized by a high proportion of clay (mean size range of 8.0 $\phi$ to 9.0 $\phi$).

*Sorting ($\sigma$).* In general, sorting is very poor in the study area and ranges between 2.0 $\phi$ and 4.0 $\phi$. The map showing the variation of sorting (Figure 5) closely resembles the sediment distribution map (Figure 2). Portions of the inner shelf lying close to the shore and away from river mouths exhibit better sorting (< 3.0 $\phi$), that is when compared to sediments seaward of the shelf (> 3.0 $\phi$).

*Skewness ($Sk_1$).* Skewness in this paper refers to grainsize distributions on a phi scale. Thus, positive skewness indicates an abundance of coarse grains and negative skewness, an abundance of fine grains. The variation of skewness is shown in Figure 6. Northern and southern sectors of the shelf exhibit positive skewness. Between these two zones skewness progressively approaches a negative value. Offshore skewness values are almost constant off the Periyar mouth but off Chetuva, skewness approaches negative values beyond the 15 m isobath.

*Kurtosis ($K_G$).* Almost all samples show a lepto/platykurtic tendency, with kurtosis values ranging between 0.15 to 0.53. Samples from stations 30 and 34 exhibit a mesokurtic tendency whereas those from stations 24 and 62 show a platy/leptokurtic tendency.

## C. M. Diagrams

CM patterns are one of the best and easiest means of determining the hydrodynamic conditions of deposition from textural data (PASSEGA, 1957). The CM pattern for the study area (Figure 7) exhibits a distribution parallel to the M axis which indicates deposition by uniform bottom suspension (PASSEGA *et al.*, 1967). However, when observed closely, the majority of the samples derived from the shallower portion of the shelf (about 10 m isobath)

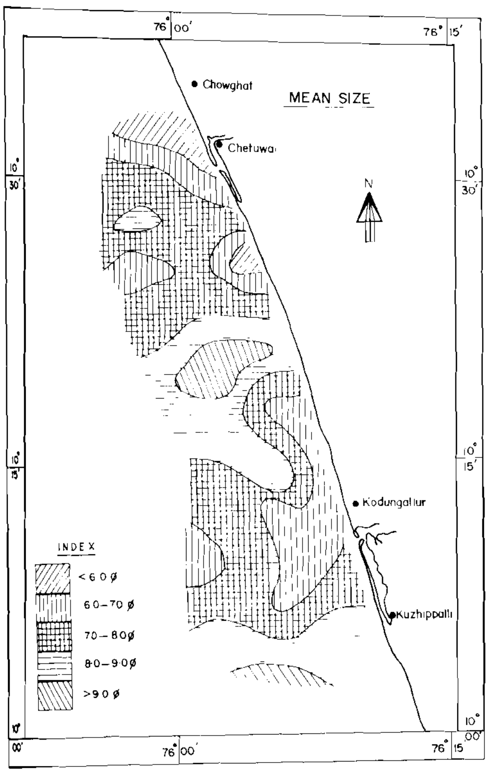


Figure 4. Mean size map.

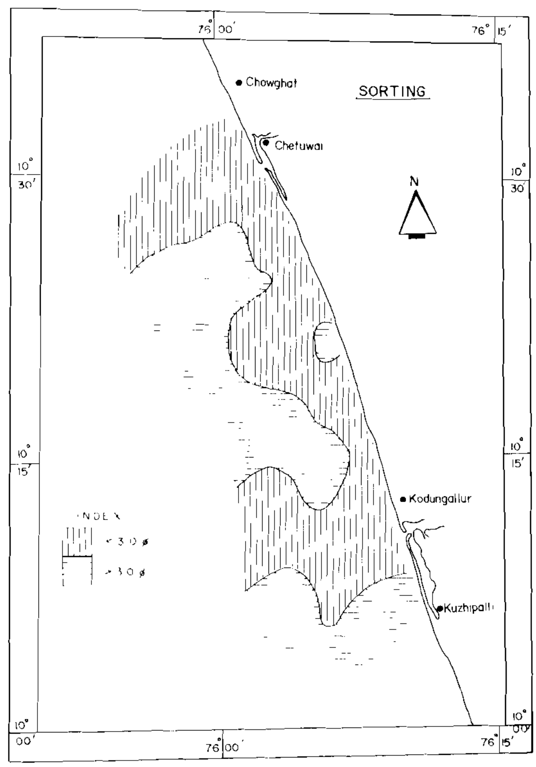


Figure 5. Map showing sediment sorting.

fall in Zone VI of Passega thus indicating deposition by graded suspension. This may be due to presence of both silt and clay sized particles in subequal proportions. On the contrary, the samples derived from the shelf beyond the 10 m isobath exhibiting a distribution pattern parallel to the M axis of the diagram, within a median range of 1 to 10 μ and C values between 60 μ and 200 μ, is suggestive of deposition by uniform bottom suspension and to some extent by pelagic suspension (PASSEGA, 1964). This is attributed to the very high percentage of clay in these sediments which tends to get suspended uniformly throughout when disturbed by marine processes.

## Sediment Transport Studies

The sediment transport analysis was conducted by comparing grain-size moment statistics of a selected sample station (assumed source) with other stations (probable deposits) in order to identify possible relationships existing between the two. After finding the relationship of all the deposits with respect to the assumed source-I, another sampling station was considered as an assumed source. In this manner, all the sampling points which were under consideration were assumed as sources and compared with the other deposits.

In the original model (McLAREN and BOWELS, 1985) the probable deposit is said to be related to the assumed source only when the grain size characteristic of the deposit is either finer, better sorted and more negatively skewed or coarser, better sorted and more positively skewed. Only these two combinations out of the possible eight combinations (F), (B), ( + ); (F), (P), ( + ); (C), (B), ( − ); (C), (P), ( − ); (F), (P), ( − ); (F), (B), ( − ); (C), (B), ( + ); (C), (P), ( + ) were found to suggest preferred direction of transport.

Low energy transportation (Case B) is indicated when the sediment distribution of subsequent deposits show a finer, better sorted and more negatively skewed tendency than the

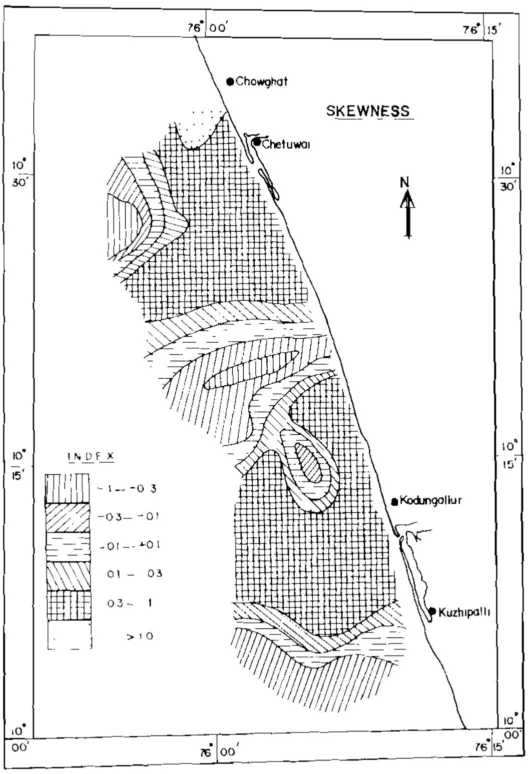

Figure 6. Skewness map.

source sediment distribution and/or the preceding deposit. A coarser, better sorted and more positively skewed trend of the grain size distribution of the deposits, in comparison to the assumed source, is indicative of high energy transportation (Case C).

Another important aspect which should be

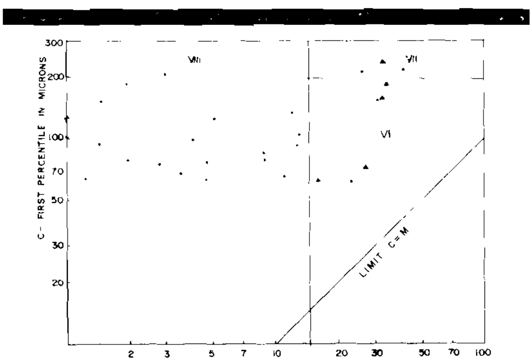

Figure 7. C. M. Diagram. ▲ represent samples within 10 m isobath.

considered while conducting the exercise is the direction of transport. Only two opposite directions such as north-south and offshore-onshore were considered. The results of this analysis were then grouped into the respective classes as shown in Table 2. This result was then subjected to Z score one-tailed test (SPEIGEL, 1961) to find the probability of preferred direction of transport.

The hypothesis that transport occurs in a preferred direction is accepted only when

$$z = \frac{z - NP}{\sqrt{Npq}} \geq 1.645 \text{ (0.05 level of significance)}$$

or

$$Z \geq 2.33 \text{ (0.01 level of significance)}$$

N is the total number of possible unidirectional pairs

N $= \frac{n^2 - n}{2}$ where n = number of samples in a sequence;

x = observed number of pairs suggesting transport;

p = 0.125 = ⅛th probability of occurrence of either case B or case C kind of transportation;

q = 1.0 − p = 0.875 i.e. probability of transportation not occurring.

The Z scores for the study area is given in Table 2.

The probable onshore-offshore transport occurring within the study area as represented by the Z scores for the southern, central and northern sectors, are shown in Figure 8. This study indicated the prevalence of a high energy transport regime (Case C) in both offshore and onshore directions in Sector A, *i.e.*, the sector under the influence of the Periyar River. Sector B, which is devoid of fluvial influences, exhibited a high energy transport regime (Case C) only in the onshore direction. Sector C, under the influence of the Keecheri river showed a high energy transport regime (Case C) in the onshore direction and a low-energy regime (Case B) in the offshore direction.

The probable directions of sediment transport occurring parallel to the depth contours were also investigated along 4 profiles (Figure 9). The zone lying within the 15 m isobath exhibits transport trends in both northern and southern directions in the higher energy regime (Case

Table 2.

| | Southern Sector | | Central Sector | | Northern Sector | |
|---|---|---|---|---|---|---|
| | Onshore | Offshore | Onshore | Offshore | Onshore | Offshore |
| Case B | F N = 28 | N = 28 | N = 91 | N = 91 | N = 28 | N = 28 |
| | B x = 1 | x = 3 | x = 16 | x = 10 | x = 3 | x = 7 |
| | −Z = 1.43 | Z = 0.29 | Z = 1.46 | Z = 0.44 | Z = −0.29 | Z = 2.00[(] |
| Case C | C N = 28 | N = 28 | N = 91 | N = 91 | N = 28 | N = 28 |
| | B x = 9 | x = 10 | x = 45 | x = 16 | x = 14 | x = 3 |
| | + Z = 3.14* | Z = 3.71* | Z = 10.64* | Z = 1.46 | Z = 6.00* | Z = −0.29 |

| | Within 10 m Isobath | | Beyond 10 m upto 15 m | | Beyond 15 m upto 20 m | | Beyond 20 m isobath | |
|---|---|---|---|---|---|---|---|---|
| | North | South | North | South | North | South | North | South |
| Case B | F N = 45 | N = 45 | N = 55 | N = 55 | N = 36 | N = 36 | N = 45 | N = 45 |
| | B x = 1 | x = 4 | x = 8 | x = 7 | x = 11 | x = 4 | x = 7 | x = 9 |
| | −Z = −2.08 | Z = −0.73 | Z = 0.46 | Z = 0.05 | Z = 3.28* | Z = −0.25 | Z = 0.62 | Z = 1.52 |
| Case C | C N = 45 | N = 45 | N = 55 | N = 55 | N = 36 | N = 36 | N = 45 | N = 45 |
| | B x = 19 | x = 11 | x = 24 | x = 13 | x = 7 | x = 9 | x = 14 | x = 7 |
| | + Z = 6.02* | Z = 2.42* | Z = 6.99* | Z = 2.50* | Z = 1.26 | Z = 2.27[(] | Z = 3.77* | Z = 0.62 |

*0.01 level of significance; [(] 0.05 level of significance.

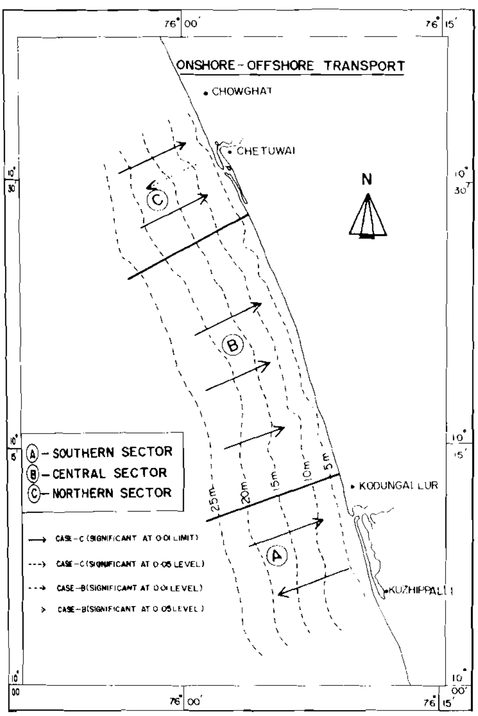


Figure 8. Figure showing the onshore-offshore sediment transport.

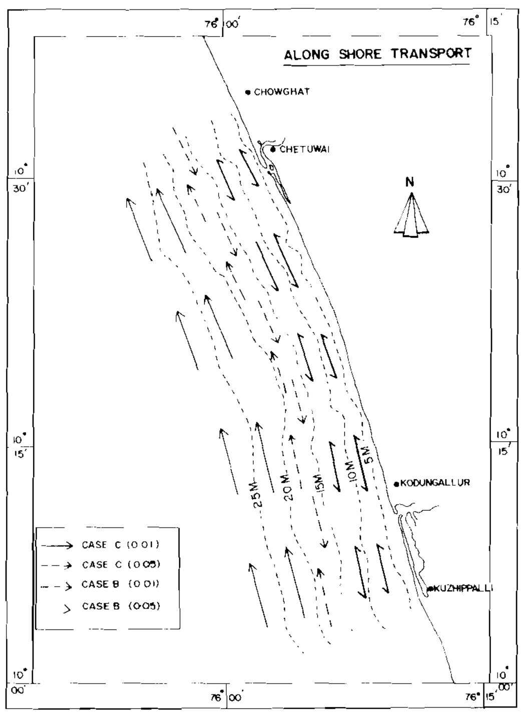


Figure 9. Figure showing alongshore sediment transport.

C). Between the 15 and 20 m isobaths, the transportation is again in both directions but here the southerly transport is of higher energy regime (Case C) and the northerly transport is of lower energy regime (Case B). Though, this southerly transport is of higher energy regime, it is significant only at 0.05 level of confidence.

Beyond the 20 m isobath the study indicated the predominance of a northerly trend.

## DISCUSSION

The results of the analyses indicate the dominance of poorly sorted sediments of silt and clay grade in the study area. The poor sorting of the sediments may be indicative of the inefficiency of the fluvio-marine processes in separating the sediments into different size classes (HASHIMI *et al.*, 1978).

The mean size and sediment distribution maps (Figure 4 & 2) show that the shallower portion of the shelf adjoining the coast and portions near the confluence of rivers are dominated by silts with very low percentages of sand. The deeper portions of the shelf have a very high proportion of clay (> 60%). This may be due to the filtering action of estuaries which trap and hold most of the coarser fraction brought in by the fluvial system, releasing only clay and silt-sized fractions to the open sea (HASHIMI *et al.*, 1981) which are later subjected to marine processes. The marine agencies acting on these sediments tend to winnow the clay-sized particles which are deposited in the deeper portions of the shelf, thus increasing the silt content in sediments on shallow portions of the shelf.

The distribution of the coarse fraction (> 62.5 μ) (Figure 3) show the higher percentage of sand in the offshore zone beyond the 20 m isobath and two prominent patches of sand concentration immediately south of the Keecheri outlet (> 20 %) and immediately north of the Periyar outlet (10–20%) in the inner portions of the shelf. The presence of a continuous sand ribbon at a depth of 25 m isobath all along the coast of Kerala (HASHIMI, *et al.*, 1981) leads us to suggest that they are relict sands which may have been deposited during a lower stand of sea level. Only a detailed study of their surface micromorphology and a comparison of their heavy mineral assemblages with the coarse fraction of present day fluvial deposits would clarify their exact mode of origin and provenance.

Although estuaries retain most of the coarse sediments some may have passed to the open sea and later dispersed by littoral currents in shallow portions of the shelf. Sand patches adjoining the estuaries on the innershelf might have resulted from this mechanism. The littoral current pattern (REDDY & VARADACHARY, 1973) also substantiates the possibility of sand accumulation by the abovementioned mechanism.

The onshore-offshore sediment transport study (Figure 8) indicates the movement of sediments in both onshore and offshore directions in sectors were fluvial action is prevalent (Sectors A and C). Only onshore transport occurs in sector B where a fluvial influence is absent. This observation suggests that the factors responsible for onshore transport are marine processes and the factors influencing offshore sediment transport are fluvial processes. Further, the presence of offshore transport in a high energy regime (Case C), off the Periyar mouth, and in a low energy regime (Case B), off the Keecheri mouth, suggests the relatively higher competency of the Periyar River in offshore transport of sediments, that is, compared to the Keecheri River. This fact is also supported by variability in skewness, which shows a dominantly positive value on the shelf off the Periyar, even beyond 15 m isobath, in contrast to the negatively trending values off the Keecheri.

The alongshore sediment transport study, parallel to the depth contours (Figure 9), indicated a transport trend in both northern and southern directions to a depth of 20 m, and a dominant northerly trend beyond the 20 m isobath. A possible reason for the behavior of sediment transport in this manner may be that in the shallower portions the southerly directed surface currents (GOPINATHAN and QASIM, 1974) are interacting with the bottom and in turn move sediments in that direction. Sediments are also moved northwards by north-northwest oriented waves (BABA, *et al.*, 1985). As the basin depth increases, these surface currents may loose contact with the bottom and therefore the sediment transport trends reflect only the influence of waves which effectively transport them in a northerly direction.

## CONCLUSION

The results of this study lead us to infer that sedimentation and sediment mobility in the shallower portions of the shelf (within the 20 m isobath) is relatively complicated and exhibits the combined action of river, surface currents and waves. In contrast, the seaward portion of the shelf (having a depth of more than 20 m) shows an apparent decrease in the influence of surface currents and the riverine processes in distributing sediments, and reflect the dominance of wave action in the transport and deposition of sediments.

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□ RESUMEN □

Los parámetros de textura de los sedimentos superficiales procedentes de la plataforma interior en la zona de Kerala, entre Kuzhipalli y Chawghat, marcan la tendencia del transporte de éstos. Los estudios de transporte de sedimentos onshore/offshore indican tendencias de transporte tanto onshore como offshore en los sectores donde prevalece la influencia fluvial y colamente transporte onshore en los sectores libres de al influencia fluvial.

Los estudios de transporte longitudinal, basados en 4 perfiles paralelos a la costa, muestran una fuerte tendencia norte del movimiento de sedimentos por debajo de los 20 m y en dirección norte y sur en profundidades reducidas (20m). La consecuencia lógica axtraida de estos estudios es que el movimiento de los sedimentos en la zona de profundidades reducidas de la plataforma está influenciada por acción de las olas, corrientes y procesos fluviales. El movimiento de sedimentos en zonas mś profundas se debe principalmente a la turbulencia de las olas.—*Department f Water Sciences, University of Cantabria, Santandez, Spain.*