Journal of Coastal Research	8	1	172–182	Fort Lauderdale, Florida	Winter 1992

Laminae and Grain-Size Measures in Beach Sediments, East Coast Beaches, India

O.S. Chauhan

National Institute of Oceanography
Dona Paula, Goa 403 004, India

ABSTRACT

CHAUHAN, O.S., 1992. Laminae and grain-size measures in beach sediments, east coast beaches, India. *Journal of Coastal Research*, 8(1), 172–182. Fort Lauderdale (Florida). ISSN 0749-0208.

The studies of size parameters in 1.8 mm slices in 36 4-cm long cores from different physiographic units of 4 beaches along the east coast of India, having beach states from "reflective" to "dissipative", suggest significant variations in these parameters. Individual layers have wider ranges of mean sizes, variable sorting, skewness and kurtosis values. These variations are pronounced and are observed in fine grained dark laminae as well as interlaminae space. These results suggest variations in micro-layer structure of beach sediments at berm/backshore, foreshore and offshore regions.

The sediments from the 0.5, 1.0, 1.5, and 2.0-cm layers as well as from the full core show effects of mixing of the individual micro-layers. The degree of correlation, relative to the 1.8 mm layer, decreases with increase in the depth of sampling. Amongst all the measures, statistical correlation was found to be poorest for sorting index and skewness measures.

INDEX WORDS: *Beach laminae, beach sand, size parameters, depth of sampling, statistical correlation.*

INTRODUCTION

The nature of a beach, to a large extent, depends upon the interaction between prevailing hydraulic conditions and sediments in the littoral zone. The zone of interaction begins at the wave base and extends shoreward across the nearshore–surf zone to the upper limit of swash action. The level of wave energy (which controls the depth of the wave base and limit of swash action) and sediment size (which influences the sediment transport and beach gradient) are two prime factors that determine the extent and nature of sediment dynamics in the littoral zone. Research covering different aspects of morphodynamic processes in the littoral zone has produced a large body of literature that documents the significance of size frequency distribution (SFD) in deciphering the imprints of morphodynamic processes in this zone (Bascom, 1964; Folk and Ward, 1957; Passega, 1964; Visher, 1969; Friedman, 1979; Sahu, 1984; Chauhan *et al.*, 1988; Chauhan, 1990). Most of these studies are based on variations in lognormality of SFD which are then interpreted in terms of genetic processes. In common practice, a few cm of the upper surfaces of a beach are collected and the size distribution is derived from a sample amounting to about 50 g or more for sieving and 20 g or more for pipette analyses. In most instances standard procedures of progressive splitting by coning and quartering methods are used to obtain this desired amount. The behaviour of the size frequency distribution arising from such samples are then analysed using different methods, *e.g.*, moment, phi, graphic, multivariate analysis, and variations in the different size parameters or eigen-vectors or subdivision of cumulative frequency curve on a probability paper are then used to interprete the genetic processes and environments of deposition (Folk and Ward, 1957; Visher, 1969; Friedman, 1979; Sahu, 1984; Murty *et al.*, 1986).

Grain size studies are also applied to understand organism–sediment relationships in the soft substrate ecology of beach and near-shore environments. The studies of Janson (1971), Johnson (1971), Meadow and Campbell (1972), Fenchel *et al.* (1975), Henning *et al.* (1982) and Fleming and Fricke (1983) have addressed their work to establish a correlation between an individual organism, or even whole faunal assemblages and the physical nature of the substrata. A major constraint in quantitative soft substrate ecology is the requirement of representative sample size (Elliot, 1972) and this normally varies from several 1,000 cm^3 to less than 100 cm^3 for macro-fauna and micro-fauna studies.

91018 received 27 February; accepted in revision 25 June 1991.

Table 1. *Characteristics and prevalent wave climate of the beaches of study area (modified from Chauhan* et al., *1988; Chauhan, 1990).*

Location	Characteristics of the Beach	Beach State	Prevalent Wave Parameters: Fair Season H	T	Dir	Transitional H	T	Dir	Rough Season H	T	Dir	Tidal Range
Konarak	Open, receives sediments through fluvial sources	Longshore trough and bar (ϵ = 23.3)	1	5–6	0–60 (30 for >80%)	1–3	5–8	va. (30–300)	2–4	8–12	180–210 (210 for >80%)	0.4–2.99
Puri	Open, receives sediments through fluvial source in fair season only	Reflective (ϵ = 14)	1	5–6	0–60 (30 for >80%)	1–3	5–8	va. (30–300)	2–4	8–12	180–210 (210 for >80%)	0.4–2.99
Machilli-pattanam	Open, tremendous sediment input through fluvial sources	Dissipative (ϵ = 30)	1–2	6	30–60	1–4	5–10	va. (30–210)	2.5–4.5	7–12	180–270 (240 for >70%)	0.17–1.97
Cuddalore	Open, no fluvial source	Highly reflective (ϵ = 10)	1–2	6	60–90 (60 for >60%)	1–4	5–8	va. (60–210)	2.5–4.0	8–12	180–270 (210 for >60%)	0.12–1.35

H = wave height (H_0) in m
T = wave period (T_0) in sec
Dir = dir of wave approach
va. means variable
Tidal range in m

The beach system, as mentioned earlier, is highly dynamic and constantly responds to short and longterm fluctuations in energy level. Based on surf scaling parameters $\epsilon = aw^2/g \tan^2 B$, where a = wave amplitude near the break point, $w = 2\pi/T$, T = wave period, g is acceleration due to gravity and B is the beach slope (SHORT 1979a,b) and the criterion of WRIGHT and SHORT (1984), beaches are classifed as reflective or dissipative (with four more intermediate stages). The terms are largely synonymous with winter and summer profiles (BASCOM, 1964; KOMAR, 1976). Each morphodynamic stage in these classifications is characterised by internal sedimentary structures, summaries of which are given in FLEMING and FRICKE (1983:Figure 3a–c). This conjecture, together with the studies of SANDERS (1965), CLIFTON (1969), HUNTER *et al.* (1979), EMERY (1978) and GRACE *et al.* (1978) suggest vertical variations in size-frequency distribution in the beach sediments. Determination of SFD in the sediments of the microstructure (laminae and interlaminae space) in beach sediments (EMERY, 1978; GRACE *et al.*, 1978; FLEMING and FRICKE, 1983) has established that the SFD or size measures observed in individual laminae or in interlaminae space, have wide variations. These studies have demonstrated that differences in mean size and sorting occur not only between different laminae, but size grading occurs even within an individual lamina. These studies are significant as they demonstrate that grading in the size measures in the laminae or intra-laminae appears to be the rule rather than the exception. Hence, SFD obtained in the homogenised few cm surfaces of a beach may not yield an accurate picture of the prevailing morphodynamic state of a beach, particularly when grain size is considered an important parameter

Table 2. *Details of the position of cores from the beaches of the study area.*

Core Number	Locality	*Location of* the Core	Length (cm) of the Core
1	Konarak	Backshore	4
2	Konarak	Upper foreshore	3
3	Konarak	Middle foreshore	3
4	Konarak	Offshore	4
5	Konarak	Backshore	4
6	Konarak	Upper foreshore	3.2
7	Konarak	Middle foreshore	3.5
8	Konarak	Lower foreshore	3.5
9	Konarak	Offshore bar	2.9
10	Puri	Backshore	3.9
11	Puri	Upper foreshore	3.2
12	Puri	Middle foreshore	3
13	Puri	Lower foreshore	3
14	Puri	Middle foreshore	3.4
15	Puri	Upper foreshore	3.8
16	Puri	Upper foreshore	3.4
17	Puri	Middle foreshore	2.8
18	Puri	Offshore	3.2
19	Machillipattanam	Backshore	3.2
20	Machillipattanam	Upper foreshore	3.6
21	Machillipattanam	Middle foreshore	2.8
22	Machillipattanam	Lower foreshore	3.4
23	Machillipattanam	Upper foreshore	3.4
24	Machillipattanam	Upper foreshore	2.8
25	Machillipattanam	Middle foreshore	3.4
26	Machillipattanam	Lower foreshore	2.8
27	Machillipattanam	Offshore	4
29	Cuddalore	Backshore	3
30	Cuddalore	Upper foreshore	3.6
31	Cuddalore	Middle foreshore	2.8
32	Cuddalore	Upper foreshore	2.8
33	Cuddalore	Upper foreshore	2.4
34	Cuddalore	Middle foreshore	3.6
35	Cuddalore	Lower foreshore	2.8
36	Cuddalore	Offshore	3.2

Table 3. *Comparison of the results of size parameters in the reconstituted and undivided cores of the beaches of the study area.*

Name of the Parameters	Coefficient of Correlation (r) between Undivided and Reconstituted Sample	Probability (p) of r Being Accidental
Mean size	0.99	0.01
Standard deviation	0.94	0.01
Skewness	0.96	0.01
Kurtosis	0.98	0.01

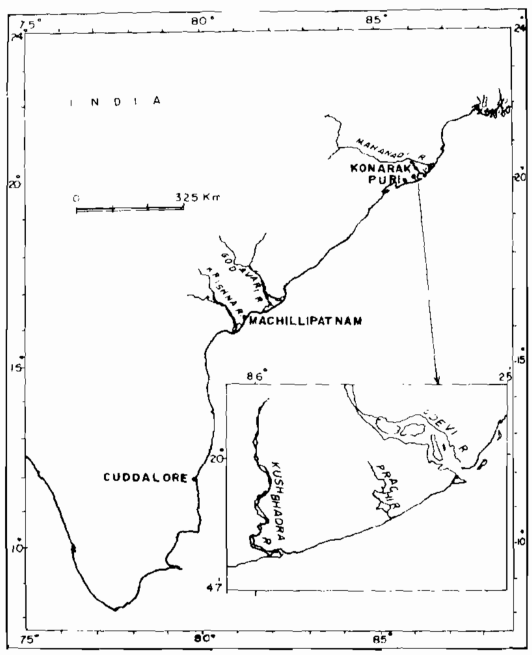

Figure 1. Location of the beaches studied.

that determines the morphodynamic state of a beach according to the criteria of WRIGHT and SHORT (1984) by the relations $r = H_b/TW_s$, where H_b is breaker height, T is period of the wave and W_s is sediments fall velocity. The studies addressing themselves to the genetic processes of sediment dynamics or to the beach or nearshore habitat involving SFD as a prerequisite, require a suitable modification in the methodology of beach sediment sampling because if the basic methodology is not accurate, no amount of specialized and sophisticated treatment of this data can satisfactorily nullify the errors of poor sampling. However, difficulties in collection of an individual lamina in the field and analysis of these sediments (varying from a few grains to a few grams) by conventional methods to obtain precise SFD has led most sedimentologists to ignore the problem and to adhere to the usual practice of beach sampling, *i.e.*, collection of a few cm in homogenised surfaces of a beach.

In further continuation of the work of EMERY (1978), GRACE *et al.* (1978) and FLEMING and FRICKE (1983), the present study evaluates variations in grain size measures in laminae and interlaminae in the sediments collected from the different physiographic units of beaches having "reflective" to "dissipative" states (SHORT, 1984;

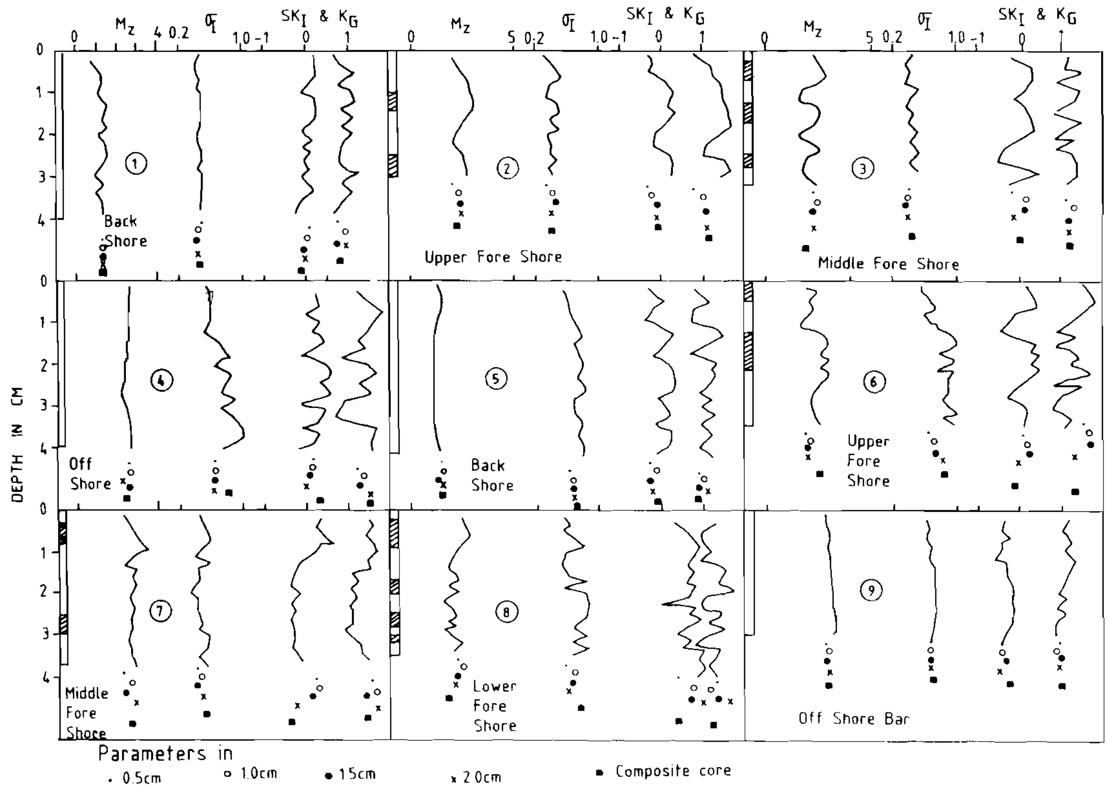

Figure 2. Observed variations in mean size, sorting index, skewness and kurtosis measures (in phi units) in layer 1 in core numbers 1–9. The parameters in layers 2–6 are also depicted by different symbols. The shaded portion in the left corner of the sets indicates the existence and characteristics of dark colour laminae in the cores. Location of the core on the physiographic units of the beaches are also known in each unit.

WRIGHT and SHORT 1984). The results are derived from the variations in size measures in 1.8 mm thick slices in small cores (≃ 4 cm), collected from four beaches (Puri, Konarak, Machillipattanam and Cuddalore), all located on the east coast of India and representing different beach states (Table 1). The size measures in homogenised 0.5, 1.0, 1.5, and 2.0 cm portions and in full core are also obtained and these results are correlated with the parameters obtained in the top most 1.8 mm slice and the effect of mixing of laminae and interlaminae portions in a core has been evaluated. These results have further been used to arrive at a meaningful compromise between an ideal and a viable rapid method for beach sampling.

METHODOLOGY

A specially designed piston-controlled teflon screw-in corer (length 30 cm, dia. 8 cm) was used to retrieve sediments. The corer is so designed that the piston is controlled precisely through the movement of a piston rod, screwed through the threaded portion at the close end of the core barrel, provides a 1.8 mm-thick slice (weight about 8 g). The corer was gently pushed about 4 cm in the sediments and gently retrieved to avoid any disturbance. The beaches chosen for this study are open, exposed to the Bay of Bengal, over 7 km long and represent wide varieties of wave climate and beach states (Table 1). The cores were collected from 5 beach transects one km apart, extending from backshore/berm to the offshore region. The details of location of the cores on a beach profile are presented in Table 2. As laminae are expected to be mostly confined to the foreshore region (EMERY, 1978), most of the cores were collected from this region.

Individual slices were separated in the field. The sampling was repeated at each station to obtain sediments of the top 0.5, 1.0, 1.5 and 2 cm

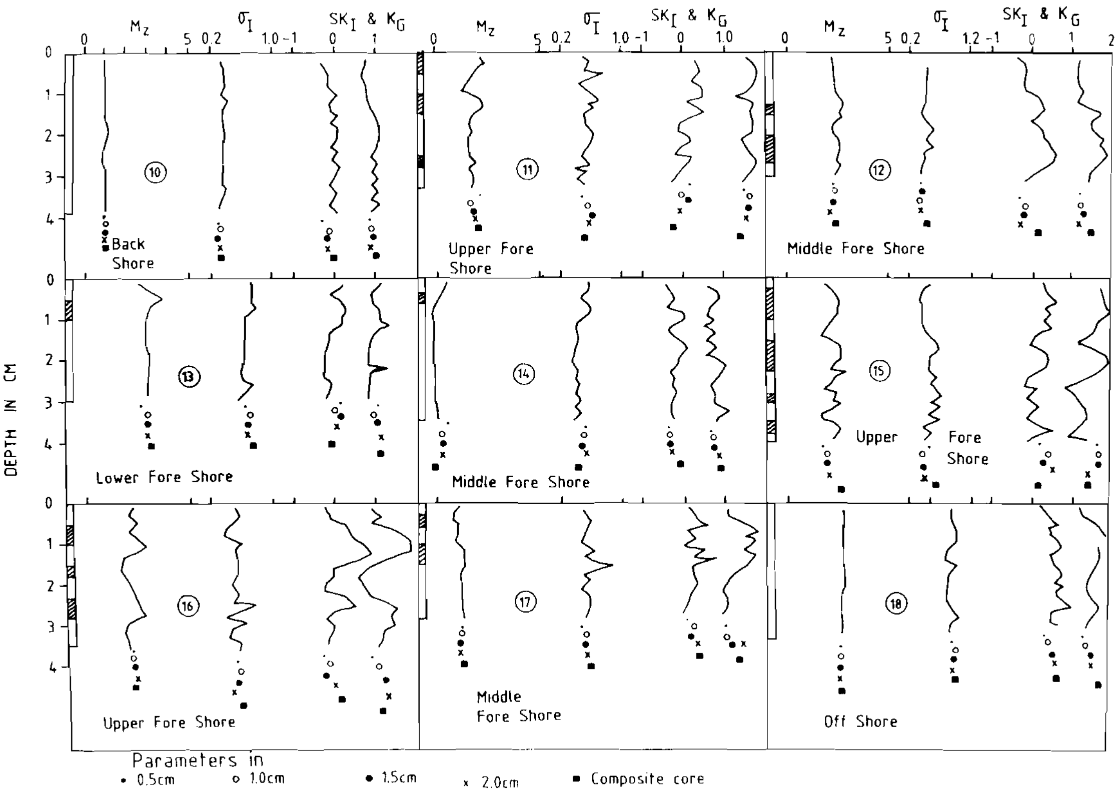

Figure 3. Same as Figure 2, but for cores 10–18.

portions and of the full core. For the sake of convenience the top 1.8 mm of the core has been designated as layer 1, top 0.5 cm as layer 2, 1.0 cm as layer 3, 1.5 cm as layer 4, 2 cm as layer 5 and the composite core as layer 6. To estimate the possible effects of mixing of slices or sampling error, sampling was repeated at 8 locations and samples of layers 1–6 were obtained by mixing and homogenising all the slices in the desired portion. The size measures in undivided and reconstituted cores were obtained and statistically compared. The values of different size measures in the unconstituted and reconstituted core were found to be significantly correlatable (Table 3).

The collected sediments were washed salt free and oven dried at 70°C. Because of the small amount of the sediments, and to obtain size frequency distributions comparable with other prevalent methods (*e.g.*, pipette or sieve analysis or deployment of a sedimentation balance) analyses were carried out on a Coulter Analyser. The results of BEHRENS (1978) have demonstrated that the size distribution obtained on the Coulter Analyser are highly correlated with distribution from the conventional method, *i.e.*, pipette analysis (r = 0.99, 0.92, 0.98, and 0.98 for mean size, standard deviation, skewness and kurtosis, respectively, for the results obtained on these measures). As the reported correlation between moment and graphic measures is very high (SEVON, 1968; HASHIMI, 1981; CHAUHAN and CHAUBEY, 1989), the graphic measures have been computed on a Norsk Data 570 computer, based on the formulae of FOLK and WARD (1957). In all, over 1,000 analyses were computed.

The results in individual slices of 1.8 mm and in layers 2–6 were computed and presented. The results obtained in the layer 1, reflecting the sedimentological parameters under the then prevalent hydraulic conditions, have been correlated with the results in layers 2–6. Correlation coefficient (r), probability (p) of r being accidental for every correlation, equations of regression for X and Y variables and mean of X and Y variables

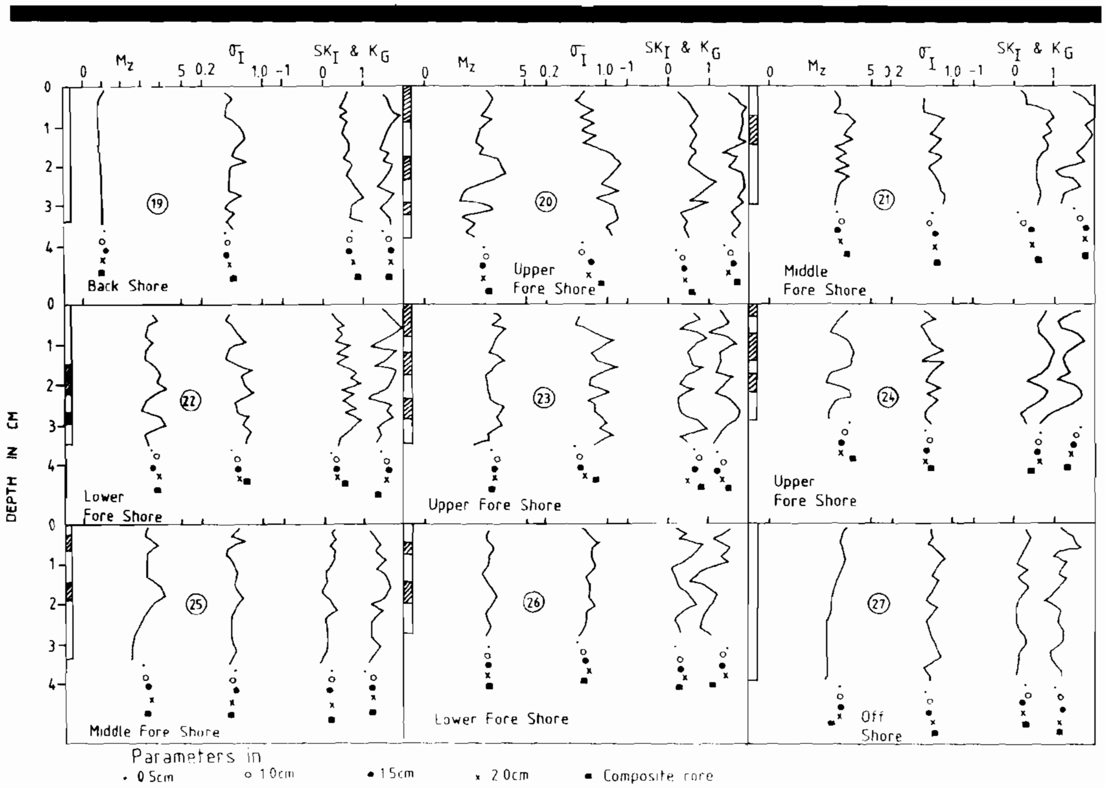

Figure 4. Same as Figure 2, but for cores 19–27.

for each pair were obtained on the ND 570 computer based on the formulae of KENNY and KEEPING (1964) and GRIFFITHS (1967).

RESULTS

The observed variations in various size measures in layers 1–6 in all 36 cores are presented in Figures 2–5. Details of coefficients of correlation, regression equations and lines of regression obtained for different measures are shown in Figures 6–9. The details of variations in each measure are as follows.

Mean Size

Remarkable variations exist in the values of mean size of the 1.8 mm slices. The degree of variation is very pronounced in dark fine grained as well as interlaminae space of all the cores collected from the foreshore region. No apparent trend in the mean size values has been observed in the beaches with different beach states. The sediments of the offshore region, however, show coarsening trends downward (Figures 3–5, cores 18, 27, 36).

The degree of linear correlation in the values of mean size in different layers, in general, is good. Among different pairs, however, this correlation deteriorates with an increase in the depth of sampling and is the poorest for layer 1 versus 6 (Figure 6).

Sorting Index

The value of sorting index in all the slices of layer 1 show marked variations in almost all the cores. The dark fine grained laminae present at the beach surfaces at Machillipattanam and Cuddalore (Figures 4 and 5, cores 20, 23, 24, 31–34) in the foreshore have significant variations. The value of sorting index in an individual slice often is much more than in the layers 2–6 (Figures 2–5).

The degree of linear correlation among different layers is moderate and becomes poorer with

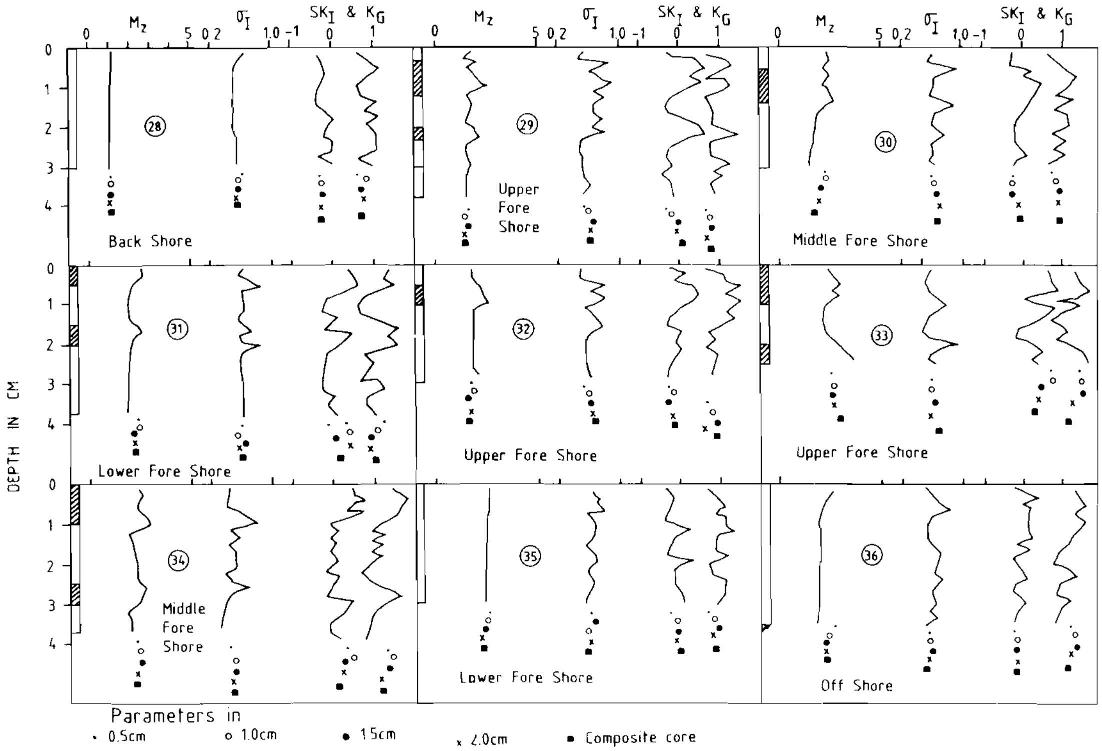

Figure 5. Same as Figure 2, but for cores 28–36.

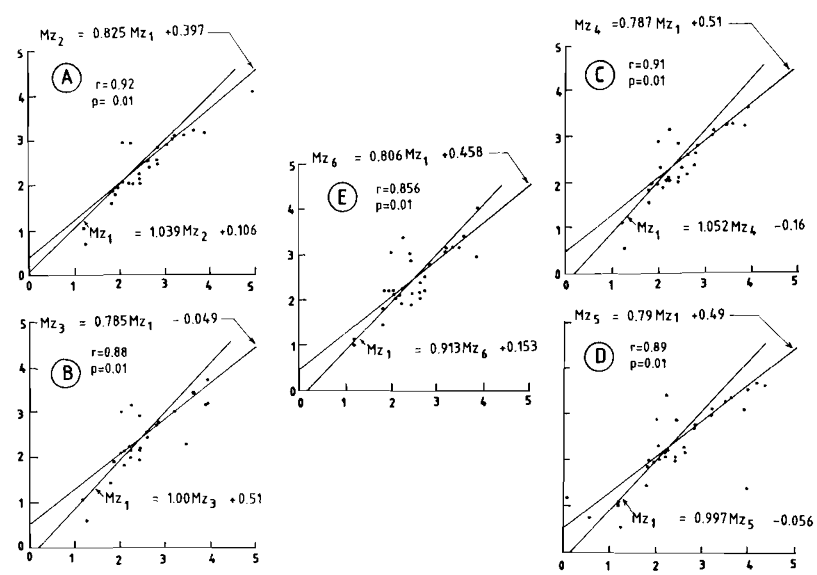

Figure 6. Coefficients of correlation (r), probability of correlation being accidental (p), regression equations and lines and X versus Y plots for mean size for layer 1 versus 2 (A), for layer 1 versus 3 (B), for layer 1 versus 4 (C), for layer 1 versus 5 (D) and for layer 1 versus 6 (E).

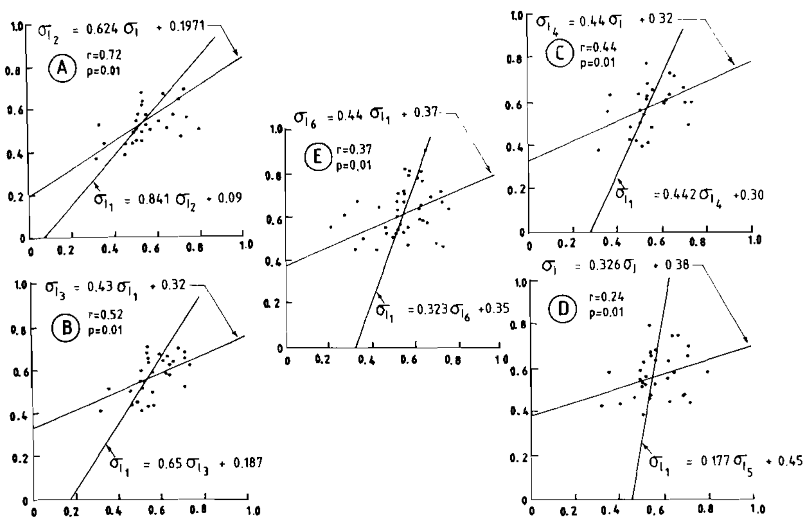

Figure 7. Same as Figure 6, but shows standard deviation.

increasing depth of sampling (r = 0.24 for layer 1 versus 5, Figure 7).

Skewness

Pronounced variations have been observed in the values of skewness in layer 1 slices. Individual slices have much wider range of skewness values compared to layers 2–6. The variations are observed in almost all the cores irrespective of their location along every beach. Presence of dark fine grained laminae, as observed in almost all the cores from the foreshore, at different depths, have maximum variations. These variations are observed within fine grained laminae as well as interlaminae space.

The coefficient of correlation obtained for different layers for skewness measures (Figure 8) ranges from fair (r = 0.82 for layers 1 and 2) to poor (r = 0.48 for layers 1 and 6). The values of X and Y variables computed from the equations of regression show wide deviations. These deviations are maximum for layers 1 versus 6.

Kurtosis

Kurtosis measures also have fluctuations in the values in layer 1 slices implying that the individual slices have much wider ranges of kurtosis than the composite cores. Among the cores from the different physiographic units of the beaches, the sediments of offshore and backshore areas have the least variation. The variations in the values of kurtosis measures within individual lamina and interlamina spaces (Figures 2–5, cores 3, 6, 11, 12, 15, 21–24 and 30–34) have a very wide range, varying from platykurtic to leptokurtic.

The degree of correlation among different layers for kurtosis measure is generally good (Figure 9). The lines of regression among different layers show a similarity. The degree of correlation among different layers decreases with mixing of microlayers, yet it is much better than in standard deviation and skewness.

DISCUSSION

The variations in the values of various size measures with depth clearly implies that the beach sediments are composed of micro-layers. The variation in the values of mean size in the individual layers of layer 1 in time and space at the beaches having variable beach states further confirm the existence and fine layers at irregular intervals. These variations in the laminae and interlaminae space lead to the inference that visible expression of laminae on a vertical surface representing differences in grain size is complex, and identification of individual laminae on a vertical surface is not a true demarcation of a single sedimentation unit. Thus, the boundary between laminae seems to have very little expression in terms of mean grain size.

The contrast in the values of sorting index, skewness and kurtosis further amplifies the mi-

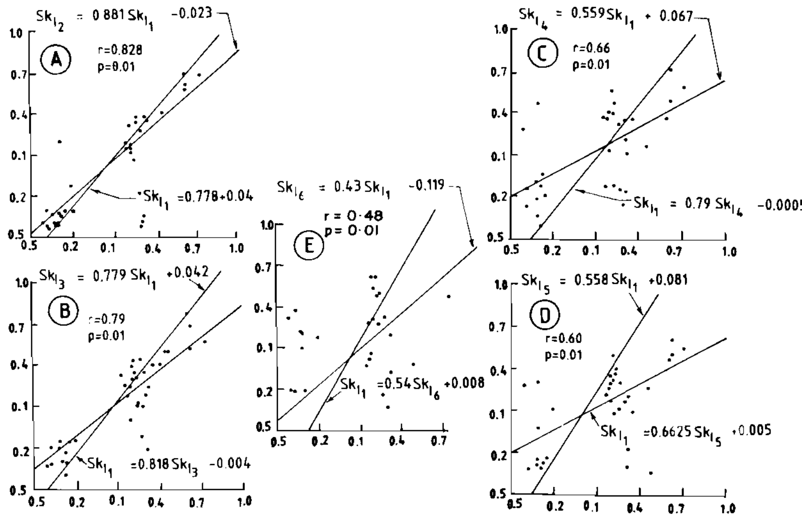

Figure 8. Same as Figure 6, but shows skewness measures.

cro-layer structure of beach sediments, which sometimes is not well reflected in mean size. The marked variations in all of these parameters in all the cores, particularly from the backshore and offshore region further support the postulation of GRACE *et al.* (1978) that each microlayer may not have a phi normal distribution, and sedimentary structures and size frequency distributions are more closely linked than generally considered. These observations lead one to reconsider and reevaluate the influence of mixing of these microlayers in normal sediment sampling methods. The results of the present work, which are limited in the sense that they compare and correlate the various size measures of the topmost layer with different fractions of the core, clearly show the influence of homogenising of these micro-layers. Apparent reduction in the degree of linear correlation among layer 1 versus 2–6 for different measures (Figures 6–9) clearly reflects the effects of mixing of micro-layers having variable mean size. To arrive at a viable rapid method for the mean size study, based on the statistical correlation among different layers (r is good down to layer 1 versus 4 only), the depth of sampling should be restricted to 1.5 cm.

Larger variations in the values of sorting index in the individual layers of layer 1 than in the homogenized layers 2–6, account for the reduced correlation with increase in the depth of sampling, and variations in the regression lines for different pairs. The relative reduction in the degree of linear correlation between layers 1–5 and between 1–6 clearly reflects this point. The lines of regression of X and Y and *vice-versa,* and values of sorting index obtained using regression equations in layers 1 and 4, 1 versus 5 and 1 versus 6 further highlights these inferences.

The influence of combining the micro layers is found to be very pronounced for skewness measure and is reflected by the poor correlation between layer 1 versus 6 ($r = 0.48$, Figure 8). The larger variations in the values of this measure in the individual slice (positive for fine grained and negative for coarse grained) explain this point.

The mixing of different micro-layers was found to have fewer effects on the kurtosis measure. The degree of correlation, like other measures, decreases with the depth of sampling. However, the degree of this correlation remains good down to 1.5 cm depth.

CONCLUSIONS

The results of the present study demarcated the existence of vertical variations in the different size parameters within all the cores. These variations are very pronounced for sorting index and skewness measures and provide further evidences for the micro-layer structure of beach sediments and the need for the review of the existing methodology for the beach sampling.

For mean grain size, the correlation among dif-

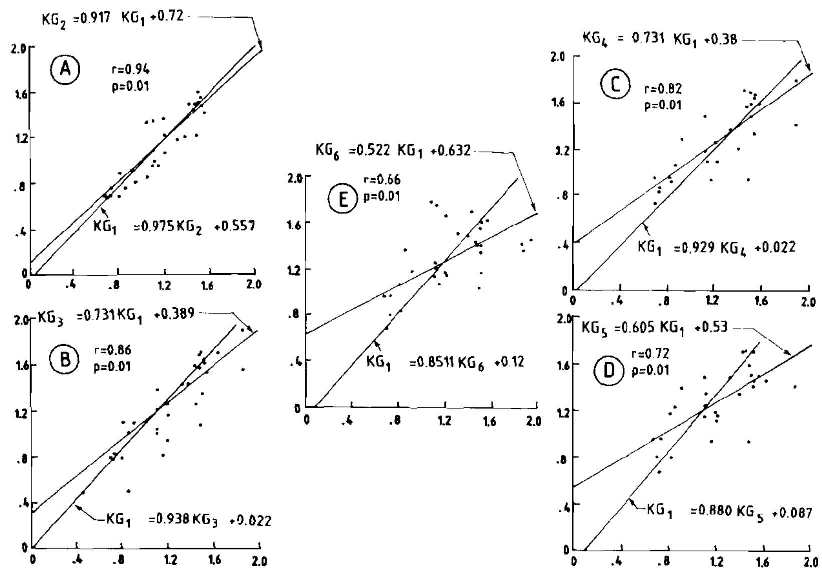

Figure 9. Same as Figure 6, but shows kurtosis measure.

ferent layers is generally good up to layer 4 (1.5 cm), and hence, studies concerned with the determination of mean grain size should sample the top 1.5 cm of the beach surface.

The values of standard deviation were found to have maximum variations with depth due to laminae mixing. The value of the coefficients of correlation (r) for different layers decreases with increasing depth of sampling. Better correlation between layer 1 versus 2 implies that the depth of sampling should be restricted to 0.5 cm for the study concerning sediment sorting.

For skewness, the degree of correlation among layer 1 versus 2–6 depicts the influence of combining the layers having variable skewness values. Moderate correlation exists only up to 1 cm depth.

The kurtosis values in different layers have good to fairly good correlation. The correlation among the values of kurtosis in different layers remains good up to layer 4 (1.5 cm).

The foregoing results lead to the conclusion that for determination of sedimentological parameters in the micro-layered beach sediments, special attention needs to be paid to the methodology and the plan of the beach sediment sampling. In the absence of a specialized sampling device, a sampling depth down to 1.5 cm for mean size and kurtosis, and 1 cm for sorting index and skewness should be adequate.

ACKNOWLEDGEMENTS

The author is thankful to the Director, National Institute of Oceanography (Dona Paula, Goa) for providing the facilities. Thanks are also due to Mr. R.R. Nair for comments on the manuscript. The author expresses his gratitude to Dr. R.A.S. Kushwaha for his help in size analysis. Thanks are also due to Dr. Charles W. Finkl and an anonymous referee for the improvements to the manuscript.

LITERATURE CITED

BASCOM, W.M., 1964. *Waves and Beaches.* New York: Doubleday, 267p.

BEHRENS, E.W., 1978. Further comparison of grain size distribution determined by electronic particle counting and pipette techniques. *Journal Sedimentary Petrology,* 48, 1213–1218.

CHAUHAN, O.S., 1990. Sedimentological parameters of beach sediments on the East Coast of India. *Journal Coastal Research,* 6, 573–585.

CHAUHAN, O.S. and CHAUBEY, A.K., 1989. Comparative studies of the moment, graphic and phi measures on the sand of the East Coast beaches, India. *Sedimentary Geology,* 65, 183–189.

CHAUHAN, O.S.; VERMA, V.K., and PRASAD, C., 1988. Variations in mean grain size as an indicator of beach sediment movement at Puri and Konarak, Orissa, India. *Journal Coastal Research,* 4, 27–33.

CLIFTON, H.E., 1969. Beach lamination, nature and origin. *Marine Geology,* 7, 553–559.

ELLIOT, J.H., 1972. Some methods for the statistical analysis of samples of benthic invertebrates. *FBA Scientific Publication 25,* 207p.

EMERY, K.O., 1978. Grain size in laminae of beach sand. *Journal Sedimentary Petrology,* 48, 1203–1212.

FENCHEL, T.; KOFOED, L.H., and LAPPALAINEN, A., 1975. Particle size selection of dispose feeder the amphiphode *Corophium volutator* and the prosobranch *Hydrobia ulval. Marine Biology,* 30, 119–128.

FLEMING, J.H. and FRICKE, A.H. 1983. Beach and nearshore habitat as a function of internal geometry, primary sedimentary structures and grain size. *In:* MALACHLAN, A. and ERASMUS, A. (eds.), *Sandy Beaches as Ecosystem,* pp. 115–132.

FOLK, R.L. and WARD, R.C., 1957. Brazos river bar: A study in the significance of grain size parameters. *Journal Sedimentary Petrology,* 29, 3–36.

FRIEDMAN, G.M., 1979. Difference in size distribution of population of particles among the sand of various origin: address of the retiring president of the International Association of Sedimentologists. *Sedimentology,* 26, 3–32.

GRACE, J.T.; GROTHAUS, B.T., and EHLRICH, R., 1978. Size frequency distribution taken from within sand laminae. *Journal Sedimentary Petrology,* 48, 1193–1202.

GRIFFITHS, J.C. 1967. *Scientific Methods in Analysis of Sediments.* New York: McGraw-Hill, 507p.

HASHIMI, N.H. 1981. Comparative study of moment and graphic size measures of the sediments of the western continental shelf of India. *Mathmetical Geology,* 13, 291–301.

HENNING, H.K.; ERICKE, A.H.; GREENWOOD, P.J., and EAGLE, G.A., 1982. Relationship between meio-faunal population densities and physicochemical properties of unpolluted beaches. *Environment Monitoring & Associates,* 1, 337–344.

HUNTER, R.E.; CLIFTON, H.E., and PHILLIPS, R.L., 1979. Depositional processes, sedimentary structures and predicted vertical sequence in barred nearshore systems of the Southern Oregon Coast. *Journal Sedimentary Petrology,* 49, 711–727.

JANSON, B.O., 1971. The "unwelt" of the interstitial fauna. *In:* HULING, N.C. (ed.), Proceedings of the 1st International Conference on Meio fauna. *Smithsonian Contribution Zoology,* 76, 129–140.

JOHNSON, R.G., 1971. Animal sediment relationships in a shallow water benthic community. *Marine Geology,* 11, 93–104.

KENNY, J.F. and KEEPING, E.S., 1964. *Mathematics of Statistics (part one).* Princeton, New Jersey: Van Nostrand, 348p.

KOMAR, P.D., 1976. *Beach Processes and Sedimentation.* Englewood Cliffs, New Jersey: Prentice Hall, 429p.

MEADOW, P.S. and CAMPBELL, J.I., 1972. Habitat selection by aquatic invertebrates. *Advances Marine Biology,* 10, 271–382.

MURTY, T.V.R.; VEERAYYA, M., and MURTY, C.S., 1986. Sediment size distribution of the beach and nearshore environs along the Central West Coast of India: An analysis using EOF. *Journal Geophysical Research,* 91, 8523–8536.

PASSEGA, R. 1964. Grain size representation by CM patterns as a geological tool. *Journal of Sedimentary Petrology,* 34, 830–847.

SAHU, B.K., 1984. Multigroup linear discrimination of modern river, beach and dune sand using axial ratio as well as roundness sample statistics. *Indian Journal Earth Science,* 1, 50–59.

SANDERS, J.E., 1965. Primary sedimentary structures formed by turbidity currents and related sedimentation mechanics. *In:* MIDDLETON, G.V. (ed.), Primary Sedimentary Structures and their Hydrodynamic Interpolation. *Society Economic Paleontologist Mineralogical Special Publication No. 12,* pp. 192–219.

SHORT, A.D., 1979a. Wave power and beach stage: A global model. *Proceedings 16th CEC (Hamburg),* pp. 1145–1162.

SHORT, A.D., 1979b. Three dimensional beach stage model. *Journal Geology,* 87, 553–571.

SHORT, A.D., 1984. Beach and nearshore facies: Southeast Australia. *Marine Geology,* 60, 261–284.

SEVON, W.D., 1968. First and second degree regression correlation of the size analysis statistical parameters of Trask, Inman, Folk and Ward and Friedman. *Journal Sedimentary Petrology,* 38, 238–246.

VISHER, G.S., 1969. Grain size distribution and depositional process. *Journal Sedimentary Petrology,* 39, 1074–1106.

WRIGHT, L.D. and SHORT, A.D., 1984. Morphodynamic variability of surf zone and beaches: A synthesis. *Marine Geology,* 56, 93–118.