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Sedimentological Parameters of Beach Sediments on the East Coast of India

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ABSTRACT

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Study of variations in the sedimentological parameters of 450 representative samples from the east coast of India indicate that the sediments possess a mean grain size in the medium to fine sand class (0.9 to 3.5 phi); have polymodal or bimodal distribution; are well to moderately sorted (standard deviation 0.3 to 1.00 phi); the majority of them are negatively skewed and the sand-to-silt ratio is higher. High input of the source sediments to an area resulting in deposition on the beach: reduces mean size; deteriorates sorting; induces positive skewness; results in higher silt content and positive mean cubed deviation. Variations in the textural parameters of the sediments, therefore, not only depend to a large extent upon the magnitude of geomorphic processes in the surf zone but also on the supply of the sediments.

ADDITIONAL INDEX WORDS: *Beach, beach sediments, geomorphic processes, size parameters, environment of deposition.*

INTRODUCTION

A beach is an accumulation of sediments formed under wave action and its state at any given time reflects various morphodynamic processes operating in the littoral zone, *e.g.* breaker height, shoaling of waves, velocities of shore normal and shore parallel flows at gravity and infragravity frequencies (WRIGHT and SHORT, 1984). The significance of sedimentological studies to decipher the imprint of these geomorphic processes has been appreciated by BASCOM (1951), KING (1951), PASSEGA (1957, 64), FOLK and WARD (1957), SAHU (1962, 82, 84), FRIEDMAN (1961, 67, 79), VISHER (1967) and EMERY (1978).

Regional variations in the sedimentological parameters of the beach sediments along the east coast of India are not well understood due to the paucity of studies. The work of SHRIVASTAVA and RAO (1976) and CHAKRABARTI (1977) covers only two beaches at Gopal Pur and Digga. To determine the regional trend in various sedimentological parameters, studies were conducted at Konarak, Puri, Machillipattanam and Cuddalore beaches (Figure 1), distributed along the east coast of India in an attempt to give a regional picture. The regional variations in the sedimentological parameters have been evaluated in the light of the distinct physiographic setting of these beaches, variable sediment input (ranging from insignificant to extremely high) and the observed littoral current patterns and prevalent wave climate. As the data set of the present work is from heterogeneous beach environments, binary plots between some significant size parameters on the data set have also been obtained to evaluate their usefulness in deciphering the depositional environment of the paleo beach deposits.

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STUDY AREA

The beaches selected for this study are open, directly exposed to the Bay of Bengal and are over 7 km long. Each beach also had a distinct physiographic setting. The beach at Konarak is located between the Prachi, Devi and Kushbhadra Rivers, receives nourishment through longshore currents and has reduced erosion during monsoon seasons of high waves and strong littoral currents (CHAUHAN, 1986). The subaerial beach was 110 m wide with a slope of 3 to 4 degrees. The surf scaling parameter at the beach was, ξ = 23.3 and it was at

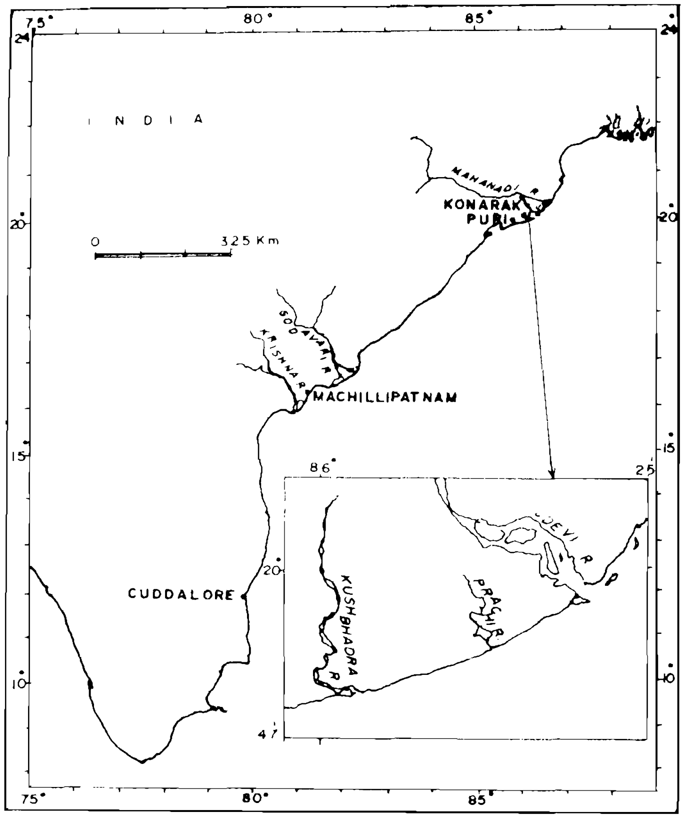

Figure 1. Location map of the study area.

"longshore trough and bar" state (WRIGHT and SHORT, 1984) during the period of observation (December to February).

Puri beach is located south of the Konarak beach and has much less sediment input than the Konarak beach due to its distant location from the river source, *e.g.* rivers Prachi, Devi and Kushbhadra and pattern of the longshore current, and therefore, the sediments of this beach should depict the effects of reduced sediment input. The beach was 95 m wide with 6 degrees beach slope during the period of observations. Surf scaling parameter at this beach indicated a reflective state (ξ = 14).

Machillipattanam beach is located between the distributaries of two major rivers, Krishna and Godavari, which together have a combined discharge of 122 x $10^9 m^3$ per year and yield a tremendous input of river sediments to the beach. The width of the beach was about 150 m and it was at a "dissipative state" ($\xi > 30$) with a low beach slope of 2 to 3 degrees.

Cuddalore beach which does not have any river source provides a site to study the sedimentological parameters of a beach with insignificant fluvial sediment input. The beach was 95 m wide and beach slope was 5.6 degrees during the period of observation. The beach was at "highly reflective state" (ξ = about 10).

MATERIALS AND METHODS

In all, 450 sediment samples (135 each from Konarak and Puri and 90 each from Machillipattanam and Cuddalore) were collected during the mild wave season (December to February) from the upper 5 cm of the beach surface using a teflon screw-in corer (Length 30 cm, diameter 8 cm), along and across 6 transects extending from berm/backshore to slightly below low tide

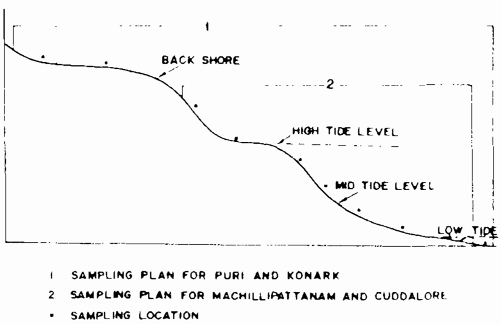

Figure 2. Sampling plan along a profile.

(Figure 2). The profiles were taken at 1 km intervals along the beach. As the studies are aimed at comparing the gross textural properties of the sediments, no attempt is made to present the results in an individual sample.

The collected sediments were washed, oven dried at 70°C and 100 g was obtained by coning and quartering. Mechanical analysis was carried out by sieving at 0.25 phi interval using a Ro-Tap sieve shaker and A.S.T.M. 20 cm diameter sieves (mesh No 6 to 350) for 15 min.

The various moment measures were computed on a Norsk Data 520 computer based on the formulae of FRIEDMAN (1979). The results of the sedimentological parameters on each beach, in different physiographic units, *i.e.* berm/backshore, low, mid and high tide level (Figure 2) were obtained and presented.

Binary plots were obtained between (i) < 62 μm fraction and moment standard deviation (ii) < 62 μm fraction and moment skewness (iii) < 62 μm fraction and first percentile (iv) < 62 μm fraction and simple skewness measure (v) moment mean and moment skewness (vi) moment standard deviation and moment skewness (vii) moment standard deviation and mean cubed deviation and (viii) cubed standard deviation and mean cubed deviation.

The physiography of each beach is based on the Indian Naval Hydrographic charts 352, 355 and 357. The wave parameters for each beach have been obtained from the daily reports published by the India Meteorological Department. Details of the profile measurements and determination of "H_o", "H_b", "T_o" and littoral current patterns for the study area have been described by CHAUHAN (1986), CHAUHAN and CHAUBEY (1988) and CHAUHAN *et al.* (1988).

Wave refraction patterns for all the beaches have been obtained following numerical method (HARRISION and WILSON, 1964) for the T_o = 6, 8, 10, and 12 sec, on the ND 520 computer. Common assumptions as detailed in the *Shore Protection Manual* (1977) have been adopted. The wave directions for these studies for each beach have been determined based on past 10 years of wave data (as given in the daily reports of India Meteorological Department), and the orientation of each beach. The variations in the refraction function (at 2 m depth) which provided the information regarding wave energy distribution along the coast together with the direction functions have been used to construct the littoral current patterns and to mark the area of wave energy concentration along each coast.

RESULTS AND DISCUSSION

During the course of the present work, at all the beaches undertaken for this study, the prevalent waves were mild (H_o = 1 to H_o = 1 − 1.5m and T_o = 5 − 6s) and they were generally from the NE to NNE direction (Table 1). Figure 3 depicts the littoral current patterns for each beach as observed during the course of sample collection, *i.e.* during December to February. The narrow continental shelf off the east coast of India, in general, leads to an oblique wave approach to the coast. Based on the results of wave refraction studies, the littoral current patterns and the area of the concentration of wave energy for T_o-6, 8, 10 and 12 sec and probable wave approaches, for each beach, are obtained and presented in the Figure 4. The nature of the beach and the rate of the accretion or the erosion at all the beaches, obtained through beach profile monitoring at 6 transects, between February 1978 to 1982, are presented in the Table 2.

The gross textural parameters of the beach sediments in the study area vary within a wide range (Table 3). The observed changes, in different moment size measures along these east coast beaches are presented below.

Mean Size

The sediments of the beaches of the east coast of India, in general, fall in the medium to fine

Table 1. *Wave parameters for the east coast of India. The data are based on published daily weather reports of India Meteorological Department (average based on past 10 year data). Data also includes wave rider records taken in 20 m water depth, 12 to 15 km offshore, for a period of 6 months for Puri and Konarak beaches.*

	Prevalent wave parameters								
	Fair weather (Dec. to Feb.)			Transitional (March, April and Sept. to Nov.)			Rough weather (May to Sept.)		
Location	H (m)	T (sec)	Dir. (degrees)	H (m)	T (sec)	Dir (degrees)	H (m)	T (sec)	Dir. (degrees)
Konarak	1	5-6	0-60 (30 for > 80%)	1-3	5-8	Variable (30-300)	2-4	7-12	180-240 (210-240 for > 80%)
Puri	1	5-6	0-60 (30 for > 80%)	1-3	5-8	Variable (30-300)	2-4	7-12	180-240 (210-240 for > 80%)
Machillipattanan	1-2	6	30-60	1-4	5-10	Variable (30-210)	2.5-4.5	7-12	180-270 (240 for > 70%)
Cuddalore	1-2	6	60-90 (60 for > 60%)	1-4	5-8	Variable (80-210)	2.5-4	8-12	180-270 (210 for > 60%)

Table 2. *Sediment budget at the selected beaches of East Coast of India. Data are average of sediment exchange recorded at 6 transects, one line apart on each beach, between 1978 to 1983.*

Location	Average Volume Eroded from Swell To Storm Profile in One Cycle (m^2 m)	Average Volume Deposited from Storm to Swell Profile in One Cycle (m^2)	Sediment Movement per Year per Profile (m^2)	Sediment Budget Between 1973-82 (m^2)	Nature of The Beach
Konarak	70.5	111.4	− (13-28)	57.8	Accretionary
Puri	65.9	81.9	− (10-16)	49.2	Accretionary
Machillipattanam	58.6	118.9	− (28-60)	107.8	Accretionary
Cuddalore	78.1	73.5	− (5-11)	(28.9)	Eroding

*(+) Sediment Deposited. ( ) Sediment Eroded.

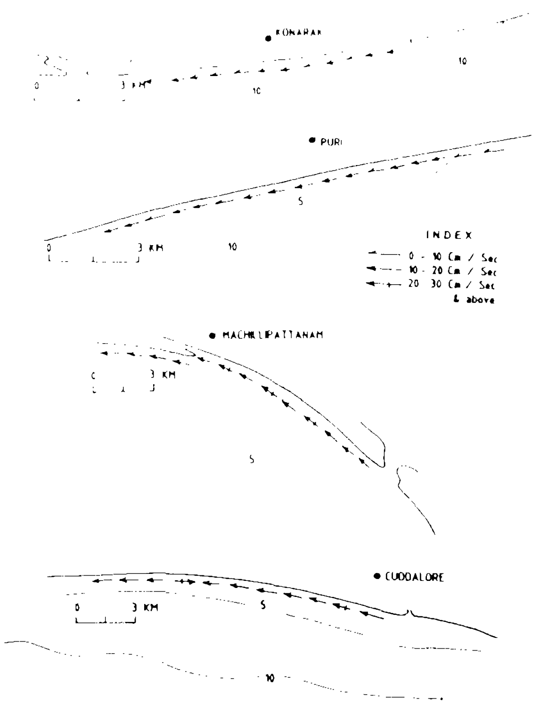

Figure 3. Observed current patterns (based on float movements) at the beaches of the study area during December to February.

sand range (Table 3). The sediments of the Machillipattanam beach are the finest (mean size 2 to 4 phi) with the sediments at Cuddalore the coarsest. At Puri beach, sediments at the low tide region are marginally coarser than the sediments of Konarak. The sediments of Puri, Konarak and Cuddalore are mostly polymodal. The sediments at Machillipattanam beach are predominantly bimodal (Table 3).

Mean grain size of the beach, to a large extent, depends upon three major factors, *i.e.* nature of the source sediment, wave energy level and general offshore slope (KOMAR, 1976). CHAUHAN *et al.* (1988), in order to determine the mean grain size variations on a sandy beach as a result of change in wave energy level, monitored mean grain size in Puri and Konarak for over 4 years. They have reported that during low energy conditions (H_o = 1m, T_o = 5 sec) the mean grain size was smaller than in the rough weather (H_o − 2.5m, T_o > 8 sec). The influence of sediment supply and wave energy on the mean grain size of the

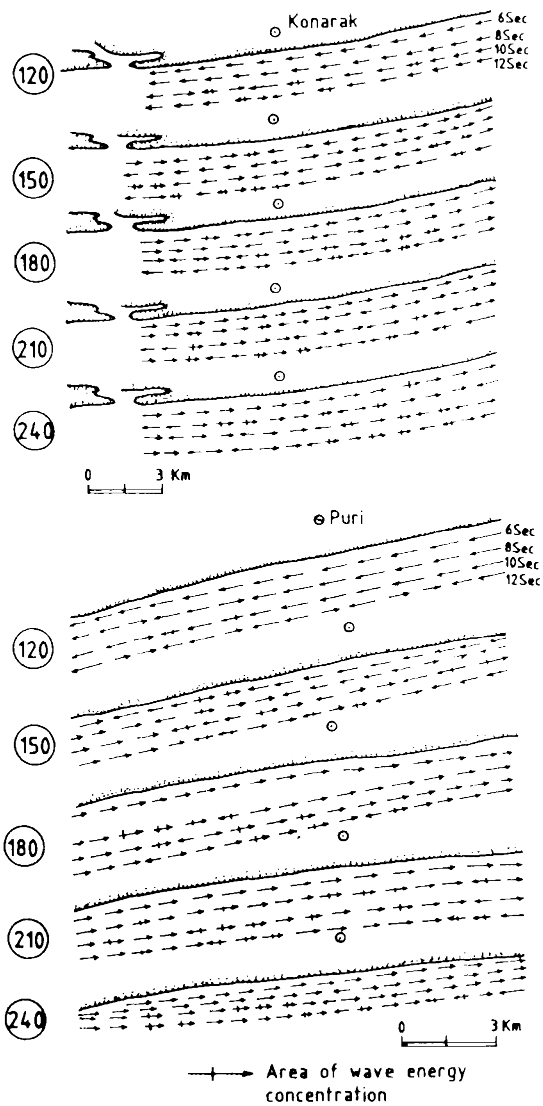

Figure 4. Patterns of the littoral currents and area of wave energy concentrations obtained for the beaches of the study area for To-6, 8, 10 and 12 sec from the refraction functions and direction functions (direction of the wave approach is shown within circles on each set).

beach sediments is further evaluated in the present study. The majority of the sediments in the foreshore region of the Konarak beach are finer than those of Puri, despite the similarity in the prevailing hydrodynamic regimes (Table 1). The variations in the size therefore, seem to be influenced by the intensity of the fluvial com-

Table 3. *Textural data for the selected beach sediments of the East Coast of India. Data are based on mamani measures obtained in 100 g sleved samples. Total number of samples analyzed were 450.*

	Konarak				Puri				Macculli-pattanam			Cuddalore		
	B	HT	MT	LT	B	HT	MT	LT	B/HT	MT	LT	B/HT	MT	LT
Mean														
1.0 to 1.5	60	9			50									
1.5 to 2.0	40	73			50	44						67	45	31
2.0 to 3.6		18	50	40		39	33	30	28	10	10	33	55	69
2.5 to 3.0			50	60		17	67	70	72	60	60			
3.0 to 3.5										30	30			
3.5 to 4.0														
STANDARD DEVIATION														
< 0.35				10			11	10				30	10	
0.35 to 0.50	30	9	80	70	10	22	78	80	21	20	15	60	70	67
0.50 to 0.70	70	64	12	10	80	61	11	10	65	60	60	10	20	33
0.71 to 1.00		23		10	20	17			14	20	25			
1.00 to 2.00														
SKEWNESS														
+ 1.00 to + 0.30		9		10	10				16	11	22			
+ 0.30 to + 0.10		36	50	60	70	30		33	50	59	61	20	18	25
+ 0.10 to − 0.10	70	54	50	20	10	30	67	34	34	29	17	53	35	37
− 0.10 to − 0.80	30			10	10	40	33	33				27	47	38
MEAN CUBED DEVIATION														
+ 0.0 to + 0.1	40	64	68	70	60	67	67	60	40	41	31	38	39	33
+ 0.1 to + 0.2		9	20	20	10				10	17	12			15
+ 0.2 to + 0.5									10		12			6
+ 0.0 to − 0.5	60	13	17	10	30	11	33	40	40	41	45	54	67	46
− 0.5 to − 0.1		9				22						8	4	
BIMODALITY	32	34	20	69.5	25	20	30	40	80	65	60	25	20	33
POLYMODALITY	68	64	80	30.5	75	80	70	60	20	35	40	75	80	67
SILT CONTENTS	.72	.82	1.2	3.2	.39	.56	0.6	.78	3.05	7.8	5.6	—	—	—

B = Bachshore, MT = Mid Tide Level, HT = High Tide Level, LT = Low Tide Level ponent. Konarak beach, due to its location closer to the river source and favourable NE longshore currents, has finer mean grain size (CHAUHAN, 1986). The sediment supply to Puri beach is reduced (Table 2), due to weak NE currents (0.1 to 0.2 ms $^{-1}$, Figure 3) which are incapable of transporting the sediments of the river source to the distant Puri beach.

The higher polymodality of the sediments at Puri and Konarak beach stems from the source sediments contributed by the Prachi, Devi and Kushbhadra Rivers. These sediments are eroded from the alluvium constituted of the sediments mainly reworked by these rivers, comprising the different modes.

The finest sediments at Machillipattanam beach reflect high input of the sediments to the beach because of its location between the rivers Godavari and Krishna. Both the rivers have very high sediment load (Total Suspended Matter 1840 and 1158 ppm or 187 and 14.4 million tonnes a year for Godavari and Krishna respectively, SUBRAMANIAM, 1987) and part of this discharge finds its way to Machillipattanam beach through favourable littoral currents commonly 0.1 to 0.40 ms $^{-1}$ from NE during fair season (Figure 3) and 0.2 to 0.7 ms $^{-1}$ from the SW during the rough season (Figure 4). The high input of the sediments to this area favours higher accumulation of fine sediments along this beach (Table 2).

The erosion at Cuddalore (Table 2) resulting in the depletion of fine sediments, which are not replenished due to insignificant input of sediments, appears to be the reason for the coarseness of the sediments.

Standard Deviation

The sediments at Konarak, Puri and Cuddalore are generally well sorted, whereas the sediments at Machillipattanam are generally moderately sorted. The values of moment and graphic standard deviation show similarity due to high correlation between them ($r = 0.86$, $p = 0.01$) (SEVON, 1968; CHAUHAN and CHAUBEY, 1988).

Among the different physiographic sub-units at each beach, the sediments of Konarak and Puri from the berm and high tide zone have poorer sorting, which appears to be the result of the mixing of the fine sediments from the dune belt or partially induced by the presence of shelly material. Entrapment of swash deposited fine sediments, leads to the poorer sorting at the high tide level.

The poor sorting of Machillipattanam sediments may be ascribed to the finer size of the sediments. The influence of size on the sorting has been established by GRIFFITHS (1951), INMAN and CHAMBERLIN (1955), and FOLK and WARD (1957). They have observed that medium to fine sand is better sorted than very fine sediments. The poorer sorting may be, in part, because the sediments at Machillipattanam beach are part of the sediments discharged by the rivers Krishna and Godavari, and still retain remanent characters of an antecedent environment.

Skewness

In the present work, between moment and inclusive graphic skewness, the value of moment skewness which is 4.35 Sk_I (FOLK and WARD, 1957) and considered more representative (KOLDJIK, 1968) has been taken for discussion. As each physiographic unit at all four beaches shows variations in the values of the skewness, the results of each sub-unit are discussed separately.

At Konarak berm, 70% of the sediment samples have symmetrical and 30% have negatively skewed distributions. The negative skewness of some of the berm sediments is due to the presence of coarser shelly material which is left behind after high wave energy conditions (H_o = 2 to 4 m and T_o = 8 to 10 sec, during monsoon). The sediments at other physiographic sub-units of this beach are generally positively skewed.

The majority of the Puri berm sediments (80 per cent) are positively skewed. The sediments at other physiographic sub-units are negatively skewed. The positive skewness of the berm sediments results from the contribution of fine aeolian sediments, transported from the foredunes by offshore winds (CHAUHAN, 1986).

The sediments for all physiographic sub-units of the Machillipattanam beach are, in general, positively skewed. The sediments at Cuddalore, show symmetrical distribution at the backshore whereas in the remaining units they have deviation towards negatively skewed distributions.

The variation in the symmetry of the distribution reflects the prevailing environment of deposition at different areas. The excess of coarser tail (negatively skewed distribution) depicts the depletion of the fine sediments and suggests the dominance of the erosional processes. The positively skewed distribution (having more of the fine sediments), indicates a depositional tendency (DUANE, 1964). The sediments at Konarak and Machillipattanam beach have positively skewed distribution indicating high supply of fine fluvial sediments. At Puri and Cuddalore beaches, where erosional processes are dominant, sediments are generally negatively skewed indicating selective winnowing of the fine sediments.

Binary plots between moment standard deviation and moment skewness (Figure 5A), moment standard deviation and mean cubed deviation (Figure 5B), cubed standard deviation and mean cubed deviation (Figure 6), and moment mean and skewness (Figure 7) have been suggested to differentiate beach, river and dune environments (FRIEDMAN, 1961, 1967, 1979) and CHAKRABARTY (1982). The sediments of the beaches of the east coast of India, in general, occupy the area demarcated for the beaches. However, at the beaches where the supply of the fine sediments is high, as reflected by the positive values of mean cubed deviation and skewness, the spread of data over other domains has been observed. The poor sorting of the sediments resulting due to mixing of fine sediments further adds to it, and hence, these plots do not have a good fit for the data set of these beaches.

Sand and Silt Ratio

The sand:silt ratio is environmentally sensitive and has been considered as a useful criterion to distinguish the different depositional environments, *i.e.*, beach, river and dune by SHEPARD (1964), FRIEDMAN (1967, 1979), and ASSEEZ (1972). This ratio shows wide variation along the beaches of the study area. The sediments of Machillipattanam have the highest amount of silt, which is present only in a few samples at Konarak, and fewer samples at Puri (Table 3). At Cuddalore sediments are devoid of silt. The higher content of silt at the Machillipattanam beach is a result of high supply of fine fluvial sediments through favourable littoral currents (Figure 3 and 5).

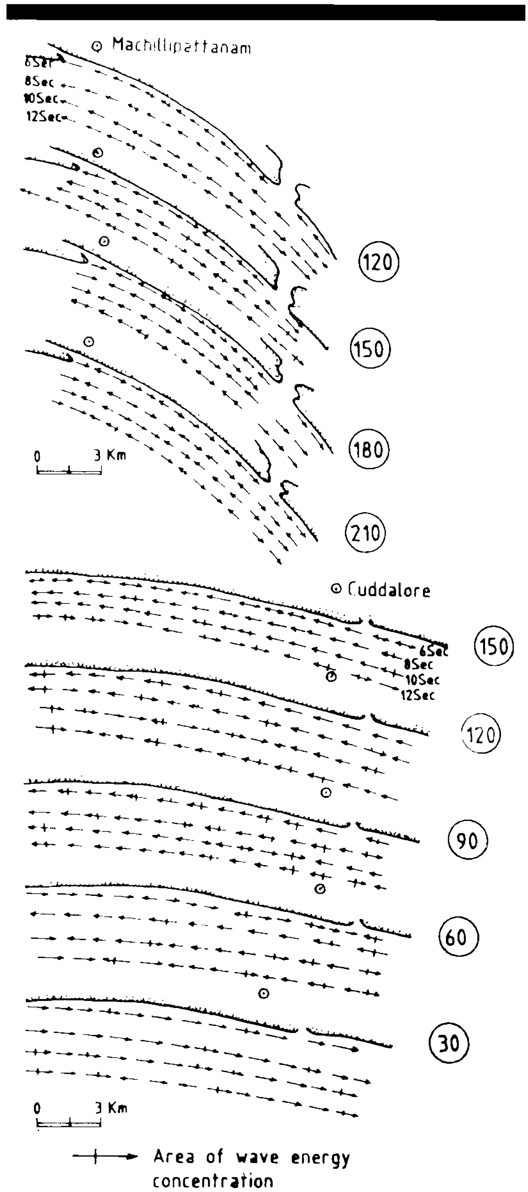

Figure 5. Binary plot between moment standard deviation and moment skewness (A), and between moment standard deviation and mean cubed deviation (B) (demarcation of the fields for beach, river and dune is shown based on FRIEDMAN, 1979).

Binary plots between < 62 μm fraction and moment skewness (Figure 8A), < 62 μm fraction and moment standard deviation (Figure 8B), < 62 μm fraction and first percentile (Figure 9A) and < 62 μm fraction and simple skew-

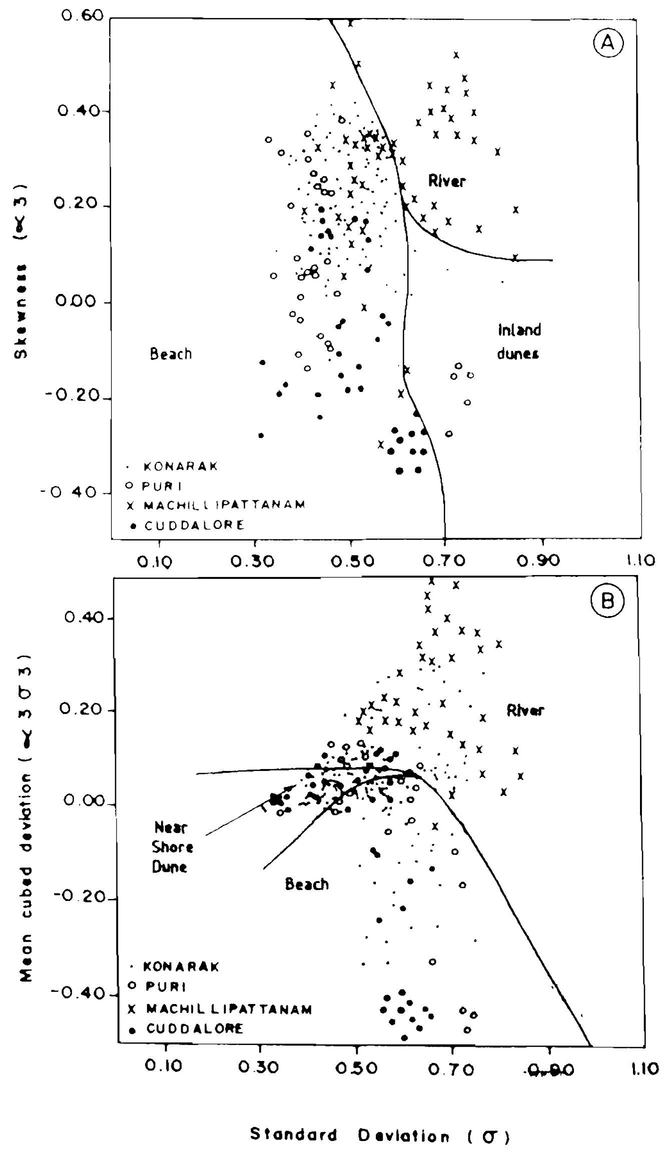

Figure 6. Binary plot between cubed standard deviation and mean cubed deviation (demarcation of the fields, in the plots for beach, river and dune, is based on FRIEDMAN, 1979).

ness measure (Figure 9B) have been used to demarcate beach and river environments by FRIEDMAN (1967, 1979) and CHAKRABARTY (1982). The sediments of the beaches of the present study, to some extent, fall in the area designated for the beach sediments. The sediments of the beaches which are under the influence of fluvial source are, however, spread over river domain and thereby reduce the applicability of these plots.

Mean Cubed Deviation

The value of mean cubed deviation reflects absence or abundance of the fine sediments and has been used by FRIEDMAN (1967, 1979) to

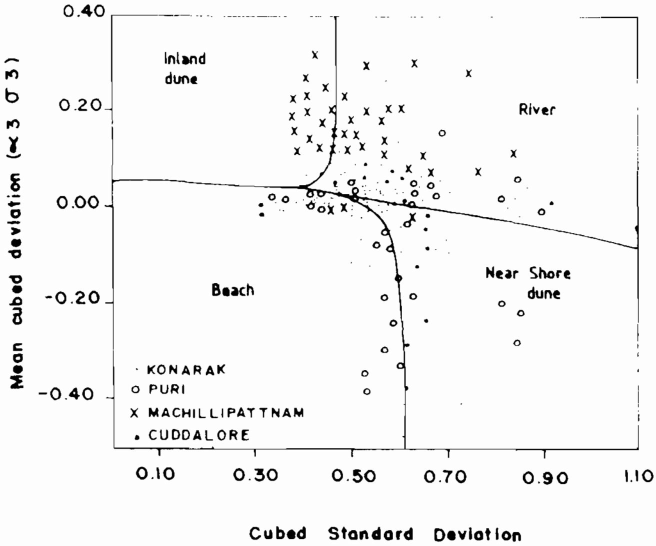

Figure 7. Binary plot between moment mean and moment skewness (demarcation line for beach and river is based on FRIEDMAN, 1967, 1979).

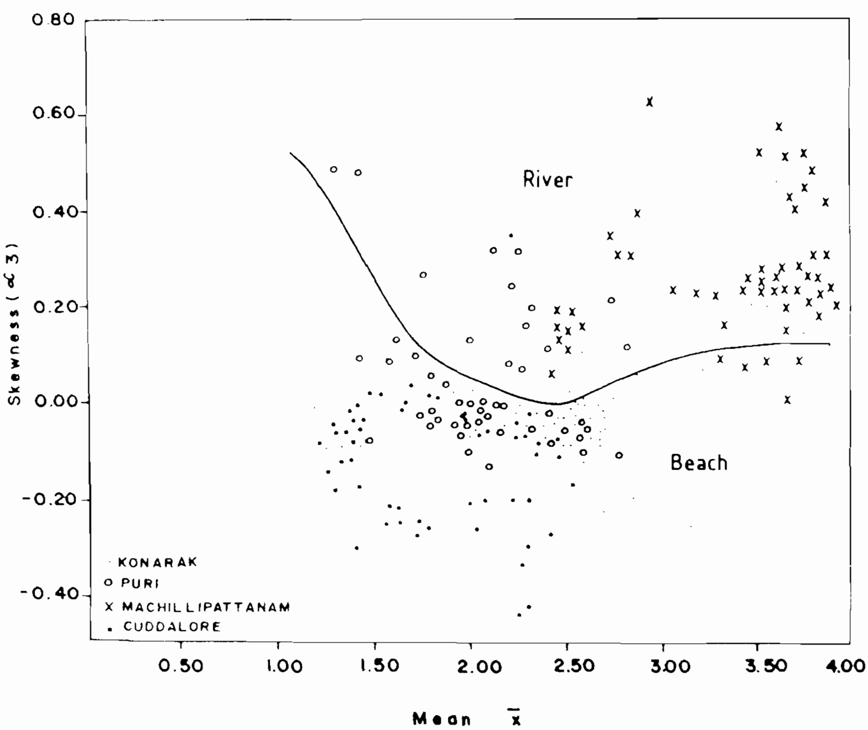

Figure 8. Binary plot between < 62 μm fraction and moment skewness (A), and between < 62 μm fraction and moment standard deviation (B) (demarcation line for beach and river domains is based on FRIEDMAN, 1976).

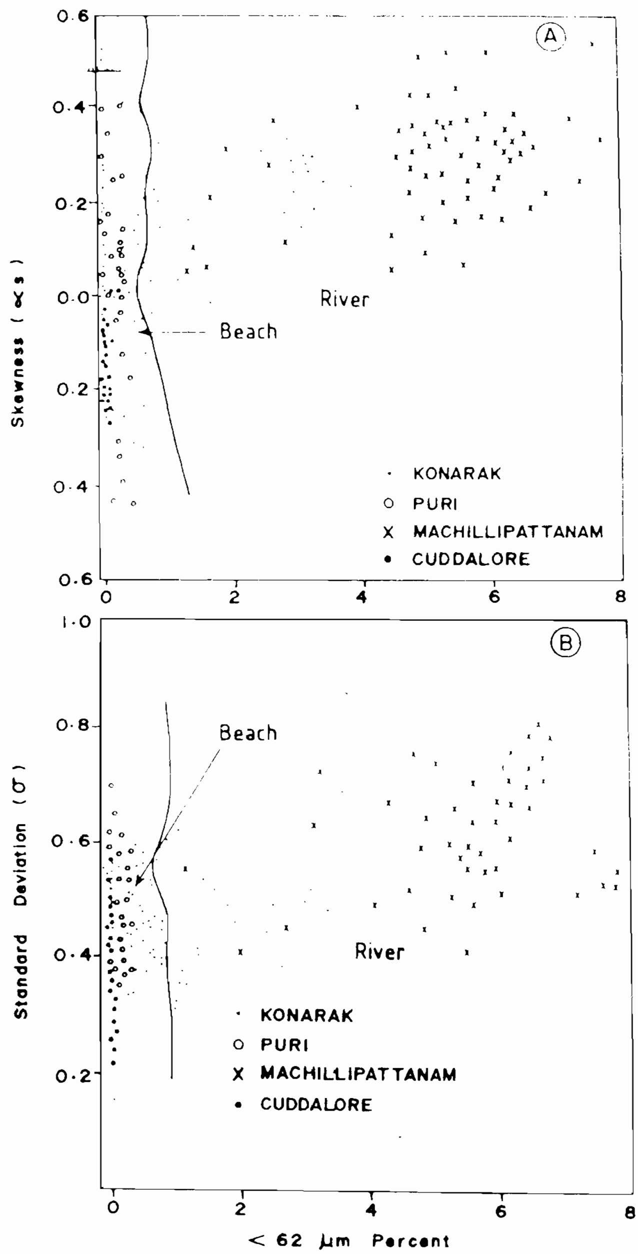

Figure 9. Binary plot between < 62 µm fraction and first percentile (A), and between < 62 µm fraction and simple skewness (B) (demarcation line for beach and river domains is based on FRIEDMAN, 1967, 1979).

differentiate river (positive mean cubed deviation), foredunes (slightly positive values) and beach sediments (negative values). In the present study the variations in the values of the mean cubed deviation are found to be related to the sediment supply. The high supply of sediment to Machillipattanam and to a lesser extent to Konarak yields positive values. At

Puri and Cuddalore beaches, the paucity of the fine sediments due to insignificant fluvial input, is reflected by the negative to marginally positive values of mean cubed deviation (Table 3).

CONCLUSIONS

The results of the present study lead to the following conclusions:

(1) The size of the beach sediments from the east coast of India varies from medium sand to fine sand.

(2) The sediments are generally well sorted. The sorting of the sediments deteriorates with reduction in grain size due to the addition of the different modes of the sediments.

(3) Skewness of the majority of the sediments is negative (excess of coarse fraction), indicative of dominance of erosional processes, whereas deposition is marked by positive skewness (excess of fine sediments).

(4) Sand-silt ratio of the beach sediments is high, except where, the sediment input by rivers is significant.

(5) Mean cubed deviation of the sediments in the present study are negative or slightly positive, except at the places where, the beach sediments are influenced by river sediments.

(6) Different binary plots, used to distinguish the beach environment, show deviations in the cases where the deposition at the beach is higher, and may be used only with due caution.

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ZUSAMMENFASSUNG

Untersuchungen der Schwankungen sedimentologischer Parameter von 450 repräsentativen Sedimentproben der indischen Ostküste zeigen folgende Ergebnisse: Die Sedimente haben mittlere Korndurchmesser im Fein- bis Mittelsandbereich, die Kornverteilungskurve ist polymodal oder bimodal, die Körnung gut bis normal sortiert, die Kornverteilung zeigt eine negative Schiefe und das Sand-Schluff-Verhältnis ist hoch. In die Küstengebiet von außerhalb eingetragene Sedimente lagern sich vorwiegend am Strand ab und verändern dort die sedimentologischen Parameter. Der mittlere Korndurchmesser nimmt ab, die Sortierung wird schlechter, die Schiefe der Kornverteilung nimmt zu und der Schluffanteil steigt. Die beobachteten Veränderungen sind auch auf Vorgänge in der Brecherzone zurückzuführen.—*Reinhard Dieckmann, WSA Bremerhaven, West German (FRG).*

RÉSUMÉ

L'étude de la variation des paramètres sédimentologiques de 450 échantillons représentatifs de la côte Est de l'Inde indique que les sédiments ont un grain moyen à fin (0,9 à 3,5 phi), ont une distribution polymodale ou bimodale, sont bien à modérément triés (écart-type compris entre 0,3 et 1 phi); la majorité d'entre eux ont une asymétrie négative et le rapport sable/silt est élevé. Un apport élevé de la source sédimentaire à une zone se traduisant par un dépôt, a pour conséquence la diminution du grain moyen, la détérioration du triage, avec une asymétrie positive, une plus forte teneur en silts et un écart moyen cubique positif. Aussi, à grande échelle, les variations des paramètres texturaux des sédiments ne dépendent pas seulement de l'ordre de grandeur des processus d'actions dynamiques de la zone de déferlement, mais aussi des apports sédimentaries.—*Catherine Bressolier (EPHE, Montrouge, France).*

RESUMEN

El estudio de las variaciones en los parámetros sedimentológicos de 450 muestras representatives de la costa Este de la India indica que los sedimentos poseen un tamaño medio de grano hacia el medio de la clase de arena fina (phi de 0.9 a 3.5); tienen una ditribución polimodal o bimodal; están entre bien y moderadamente graduados (varianza entre 0.3 y 1.00 phi); la mayor parte tiene un sesgo negativo y la relación arena-limos es más alta.

El aumento del transporte de sedimentos en un área induce en la sedimentación sobre la playa, reduce el tamaño medio, deteriora la distribución, induce un sesgo positivo, produce un mayor contenido de limos y una desviación no solamente dependen, por tanto, de la gran extensión de los procesos geomorfológicos en la zona de rotura, sino también del suministro de sedimentos.—*Department of Water Sciences, University of Cantabria, Santander, Spain.*