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Variations in Mean Grain Size as Indicators of Beach Sediment Movement at Puri and Konarak Beaches, Orissa, India

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ABSTRACT

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Over a four year period, between 1979 and 1982, mean size variations were studied under different environmental conditions in 550 sediment samples along and across 10 beach profiles, 5 each at Puri and Konarak beaches along the coast of Orissa, India. The regular monitoring of the mean size along and across the profiles depicts marked variations in the mean size, associated with changes in hydraulic conditions in time and space. The size contours are parallel to the shore in calm conditions when deposition is prevalent on the beach. Onset of erosion is marked by a lack of parallelism and the size contours become convex seawards. The spacing between the size contours also changes with the nature of the movement of the sediments and is reduced during beach erosion. The variations in the mean size in relation to probable source of sediments and change in the nature of the different geomorphic processes are delineated.

INDEX WORDS: *Beach, beach profiles, coastal geomorphology, coastal sediments, mean grain size, onshore deposition, shore erosion.*

INTRODUCTION

Variations in the size parameters of the sediments have been used to decipher the environment of deposition, *e.g.* PASSEGA (1957, 1964), FOLK & WARD (1957), VISHER (1969), and FRIEDMAN (1961, 1967, 1979). The beach is a dynamic accumulation of sediments and the beach profile results from prevailing hydraulic conditions and sediment supply. It is generally the swell type (KOMAR, 1976) under relatively calm conditions when hydraulic conditions are conducive for onshore deposition. It changes to storm type (KOMAR, 1976) under high wave conditions in relation to wave steepness (H_o/L_o). The existence of a longshore current, an important transporting agent in the littoral zone, produced by oblique wave approach, also plays an important role in developing a typical profile. The nature of a beach depends, to a large extent, upon the magnitude and direction of the aforesaid parameters and supply of sediments.

The mean size of the sediments at any given time, therefore, may be used to decipher the imprints of conditions under which they have been deposited. The present work is an attempt to express and discuss the variations in mean size at Puri and Konarak beaches on the east coast of India facing the Bay of Bengal (Figure 1) in relation to variations in magnitude and direction of the dynamic agents and probable source of sediment for the area.

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MATERIALS AND METHODS

Ten profiles, five at each beach, were monitored from February 1979 to June 1982. The samples were collected in February of 1979, 1981 and 1982, April of 1980, September of 1979, 1981 and June of 1982 along and across 5 transect lines, each one km apart. The collection of samples in February was done to observe the pattern of sediment distribution on a swell type profile (KOMAR, 1976) produced by mild waves and weak longshore currents. The collection in April represented mild to rough conditions and those collected in June 1982, immediately after a cyclonic storm with very high

Table 1. *Graphic measure of the sediments[1] at Puri and Konarak beaches in different environmental conditions.*

	Fair Season								Rough Season							
	Konarak				Puri				Konarak				Puri			
Mean	B	HT	MT	LT	B	HT	LT	LT	B	HT	MT	LT	B	HT	MT	LT
< 1													25			
1 to 1.5	62.5				50				100				75			
1.5 to 2.0	27	54.5			39.5	71.4	16.6			57.1	16.6			28.5		
2.0 to 2.5	10.5	45.5	50	23.1	10.5	21.4	33.3	50		42.9	83.3	66.6		42.8	50	
2.5 to 3.0			50	76.9		7.1	50	50				33.4		28.5	50	60
3.0 to 3.5																40
Inclusive Graphic Standard Deviation																
< 0.35		9	6.6	7.7				10								
0.35 to 0.5	12.5	45.5	76.6	61.5		14.2	63.3	70	44.4	28.5	16.6	22.2	75	28.5		
0.5 to 0.71	87.5	45.5	16.6	30.8	87.5	57.1	36.6	20	63.6	71.4	66.6	77.7	25	57.1	100	100
0.71 to 1.00					12.5	28.5					16.6			14.2		
Inclusive Graphic Skewness																
+1.0 to +0.30	12.5				12.5	7.1										
+0.30 to +0.10	25	45.5	33.3	30.7	37.5	35.7	25		22.2	42.8						
+0.10 to −0.10	50	45.5	66.6	46.1	12.5	35.7	50	30	11.1	28.5	16.6			14.3		22.2
−0.10 to −0.30	12.5	9		23.7	37.5	21.4	25	60	66.6	28.5	33.3	33.3	90	71.4	66.6	55.5
−0.30 to −1.00								10			50	66.6	10	14.3	33.3	22.2
Graphic Kurtosis																
< 0.67	25															
0.67 to 0.90	12.5	27.3	16.6	23.1	37.5	7.1	41.6	90						28.5		
0.90 to 1.11	37.5	27.2	33.3	37.4	25.0	7.1	50.0	10	44.4	28.5			25			
1.11 to 1.50	12.5	45.5	50	38.4	12.5	57.1	8.3		11.1	42.8	16.6		75	28.5	50	66.6
1.50 to 3.00	12.5				25	28.5			44.4	28.5	83.3	100			50	33.3
< 3.0																
Biomodality	32	34	20	69.5	25	20	30	40	40	25	26	20	25	20	33	36
Polymodality	68	64	80	30.5	75	80	70	60	60	75	74	80	75	80	67	64
Silt contents	7.2	8.2	1.2	3.2	.39	.56	.6	.78								

[1] Percentage Frequency Distribution
B = Back Shore
HT = High Tide Level
MT = Mid Tide Level
HT = High Tide Level

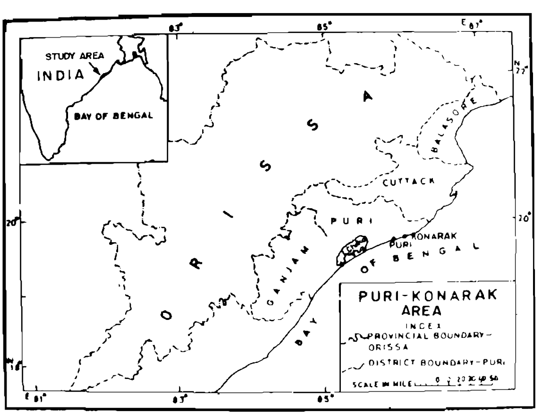

Figure 1. Location map of the study area.

waves and strong longshore currents, represented the pattern in extreme. The samples of September are also from a storm profile, a product of high waves and strong longshore currents associated with the SW monsoon in the area. Constant volume samples were collected during low tide, along and across fixed lines extending from backshore to slightly below low tide level, using a teflon screw-in corer (Length 30 cm, diameter 8 cm). The collected sediments were washed, oven dried at 70 °C reduced to 50 g by the method of coning and quartering, and sieved at 0.25 phi interval using a RO-Tap sieve shaker. A. S. T. M. 20 cm diameter sieves were used applying standard sieving methods (FOLK, 1966). Various size measures were computed on a Norsk Data 520 computer using the

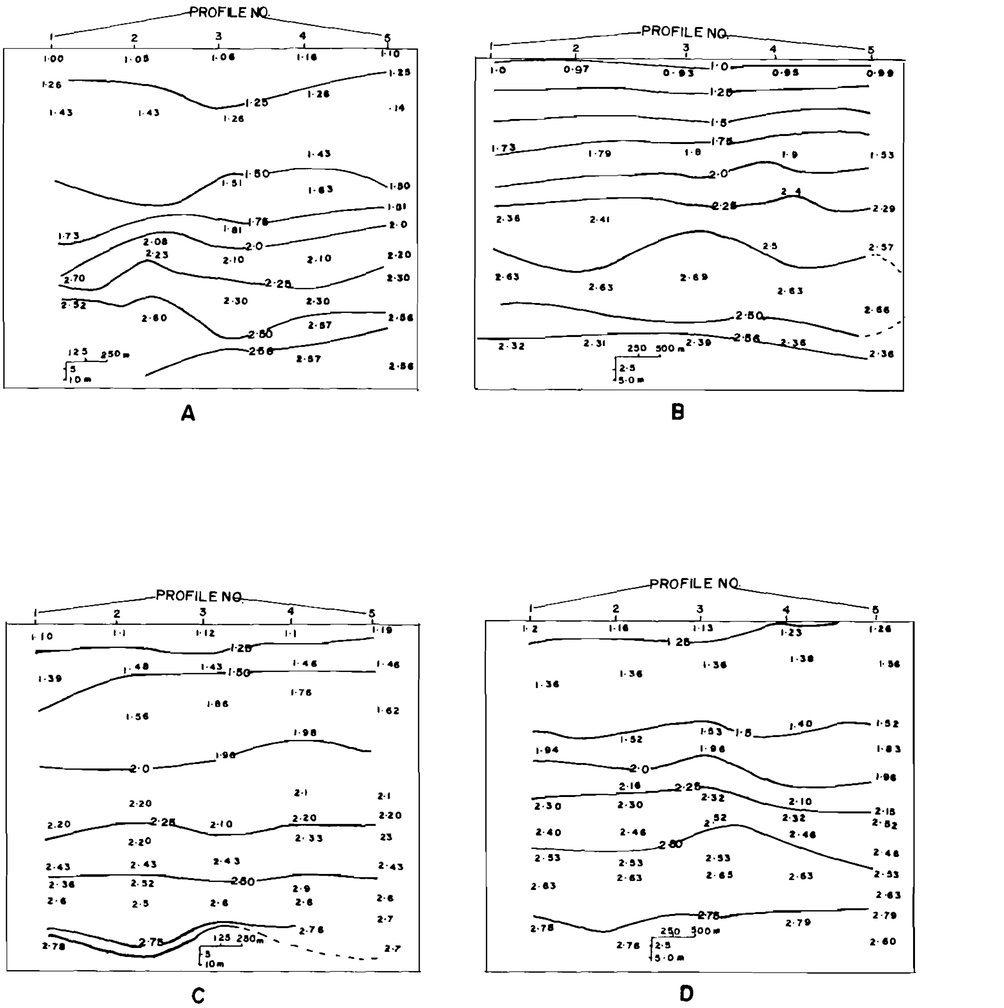

Figure 2. Spatial distribution of mean size at Puri: (a) in February 1979, (b) in September 1979, (c) in April 1980 and (d) in February 1981.

formulae of FOLK & WARD (1957). Due to high correlation between moment and graphic mean (SEVON, 1968; HASHIMI, 1981, CHAUHAN and CHAUBEY, 1986), only the graphic mean was used following the formula of FOLK and WARD (1957).

The littoral current patterns were obtained in February 1981, 1982, September 1981, and June 1982 following the methods of VEERAYYA *et al.* (1981). The wave parameters were obtained from daily weather reports published by the Indian Meteorological Department. The data are statistically analysed and presented.

RESULTS AND DISCUSSION

The study shows wide variations in the mean size in time and space which is due to the change in the environment of deposition. The observed changes are reported in what follows.

At Puri, it is observed that the sediments in general fall in the sand grade (0.90 to 2.84 phi). The observed size is coarser at the backshore and becomes progressively finer towards offshore in the inshore region. The sediments are generally well to moderately sorted, negatively skewed and mesokurtic (Table 1). The varia-

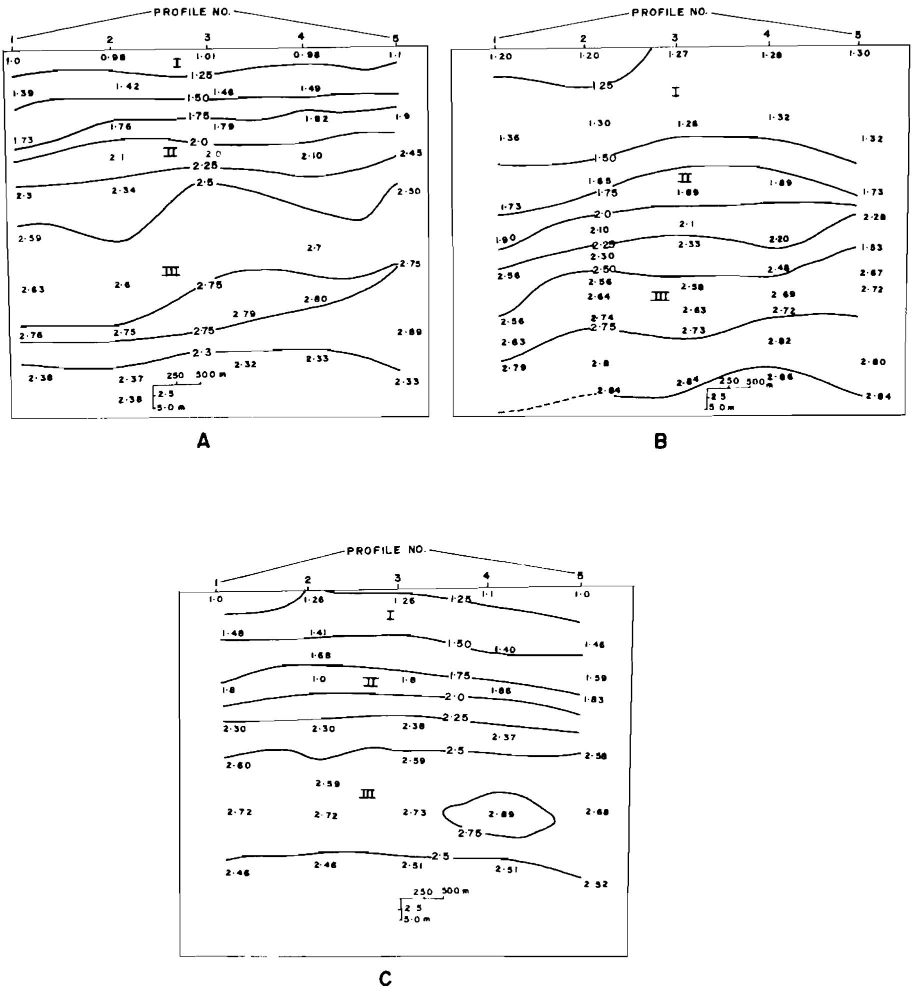

Figure 3. Spatial distribution of mean size at Puri: (a) in September 1981, (b) in February 1982, and (c) in June 1982.

tions in the mean size across the beach from profile 1 to 5 in time and space is presented in Figures 2 and 3.

On the basis of the spatial distribution of the mean size at Puri beach in time and space, (Figures 2 and 3) it is observed that mean size becomes finer and finer towards profile 5 in February 1979, 1981, 1982, and April 1980, *i.e.* in fair weather seasons.

The mean size also becomes finer between February 1979 to 1982. It was 1 to 2.66 phi in 1979 and 1.20 to 2.84 phi in 1982. The observations also indicate that the mean size of the sediments increased during monsoon in September 1979, 1981, and June 1982 compared to February 1979, 1981, 1982, and April 1980.

The various graphic measures of Konarak beach are presented in Table 2. Lateral variations in mean grain size during the period of observation are presented in Figures 4 and 5. The spatial distribution of the sediments at Konarak shows that the sediments of profile 5 are finer than those of profile 1. The Konarak sediments are finer than at Puri. The mean size at Konarak beach also gets coarser in the monsoon seasons, *i.e.* in September 1979, 1981, and in June 1982. The sediments become finer from 1.35 to 2.74 in February 1979 to 1.40 to 2.80 phi

Table 2. *Wave height parameters for the study area.*

Period	Wave height in m						
	1.0	1.5	2.0	2.5	3.0	3.5	4.0
December 1978—February 1979	65.00%	25.00%	10.00%	—	—	—	—
July 1979—September 1979	23.80%	—	14.28%	38.09%	28.80%	—	—
February 1980—April 1980	88.85%	—	11.11%	—	—	—	—
December 1980—February 1981	66.66%	25.26%	8.33%	—	—	—	—
July 1981—September 1981	15.00%	15.00%	30.00%	25.00%	10.00%	—	5.00%
December 1981—February 1982	62.90%	25.00%	12.25%	—	—	—	—
May 1982—June 1982	10.00%	10.00%	40.00%	20.00%	—	—	20.00%

Table 2. Chauhan et al 1986

in February 1982. However, the sediments in April 1980 were the finest.

The patterns of the spatial distribution of the mean size of the sediments at Puri and Konarak (Figures 2 to 4) show that size contours are generally parallel or convex to the shore in the fair weather season, *i.e.* in Februarv 1979, 1981, 1982, and April 1980.

Under these conditions the size contours are widely spaced. The picture modifies as conditions change from calm to rough seas. Mean size increases and spacing between the contours is reduced. Size contours loose their parallelism and become convex towards offshore in the foreshore and inshore regions. Closing of the contours is also observed. The occurrence of a coarser sediment band is observed in the inshore region having mean sizes of 2.36 2.33, and 2.51 phi at Puri and 2.33, 2.40 and 2.55 phi at Konarak in September 1979, 1981, and June 1982, respectively.

On the basis of the above observations, the following types of variations are identified at Puri and Konarak: (i) lateral variation in mean size along the beaches; (ii) variation in mean size between Puri and Konarak in one season; (iii) variation in the mean size due to change in hydraulic conditions from nonmonsoon to monsoon; and (iv) total variations in mean size during the entire period of observation.

As the mean size of sediments reflects the intensity of transporting media and supply of sediments, the above variations may be used to construct a meaningful tool to interpret the probable sediment dynamics and the source of the sediments to the area in the following manner. During the fair weather season wave height "H_o" is generally 1 m with wave period "T_o" 5 to 6 sec (Table 2 and 3). Due to resultant wave steepness (H_o/L_o) the sediment movement is onshore. The wave approach is from a northeasterly direction during nonmonsoon months, and therefore does not greatly influence the coast because of its NNE-SSW orientation. The longshore current patterns (Figure 5) indicate weak SW (0-20 cm/sec) currents. These parameters collectively favour deposition on the beach profile (KOMAR, 1976; CHAUHAN, 1986); the same environment of deposition prevails at both beaches. This sediment deposition nourishes the beaches with fine sediments, resulting in the reduction of mean size. The lateral variation in mean size during a given season is mainly due to variation in the intensity of sediment supply. As shown in Figure 6, longshore current velocities range from 0 to 20 cm per sec in the area during February 1981 and 1982. These currents are from the northeast and they pick up some of the sediments discharged by rivers Daya, Devi and Prachi, all having a high sediment load. Konarak beach receives more sediments because it is located closer to these rivers (and NE of Puri) whereas Puri beach receives much less. Evidently this fluvial component becomes progressively less from NE to SW. Thus profile 1 at Puri (at the southernmost end) receives lesser sediments than profile 5 at Konarak (northenmost end) which is closest to the source. The fineness of the sediments at profile 5 at Puri is also noticeable, for the same reasons. The higher deposition at Konarak beach is further

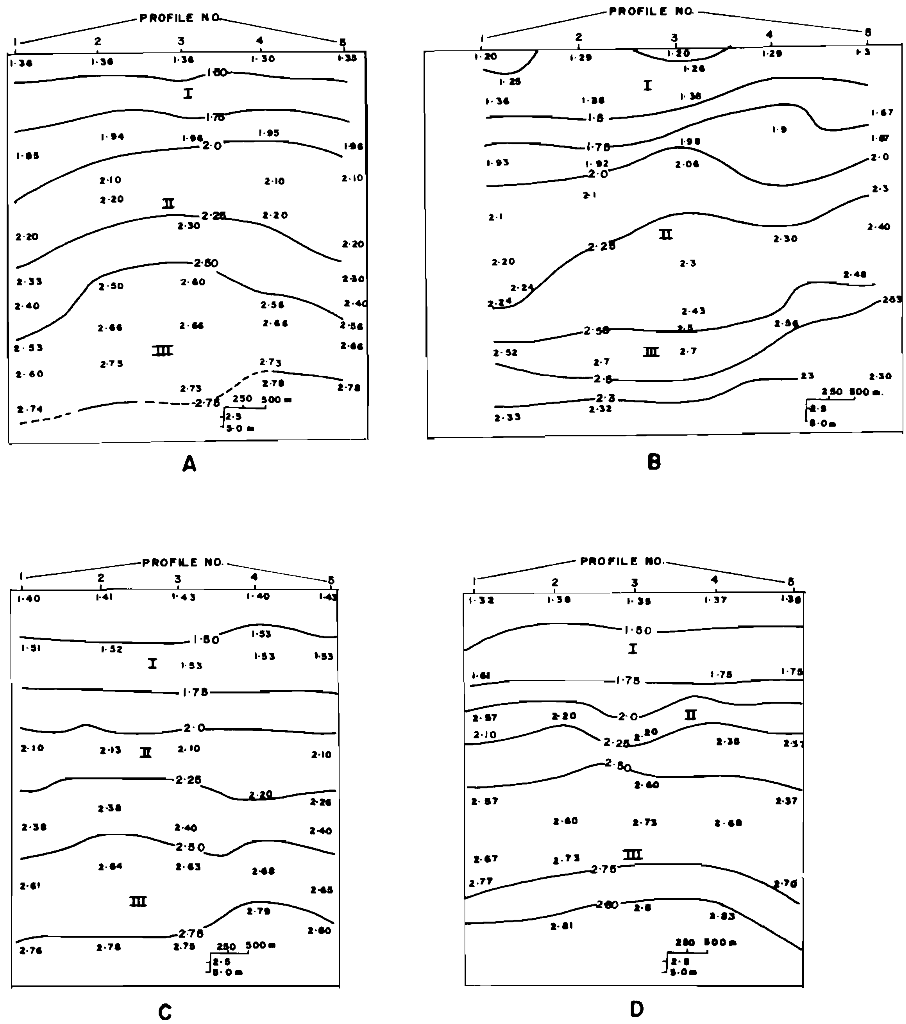

Figure 4. Spatial distribution of mean size at Konarak: (a) in February 1979, (b) in September 1979, (c) in April 1980, and (d) in February 1981.

illustrated by skewness values which are positive compared to Puri and are characteristic of a depositional environment (DUANE, 1964).

During the monsoon, *i.e.* in September 1979, 1981, and June 1982 the scenario changes. The waves are higher, having wave height "H_o" from 2.5 to 4 m with wave period "T_o" 8 to 12 sec (Tables 2 and 3). The resultant wave steepness is favourable for offshore movement of sediments and therefore beaches erode. The wave energy density $E = \rho g H^2/8$ is higher because of higher wave height and waves are capable of carrying more sediment. Further, the longshore current patterns also change.

Currents from the southwest during the monsoon season, are stronger [20 to 40 cm/sec (Figure 6)] enhancing coastal erosion. The net result is removal of fine sediments from beaches, *i.e.* increase of mean grain size. Erosion also reduces the spacing between the size contours. The convexity of the contours reflects the offshore movement of the sediments. Clos-

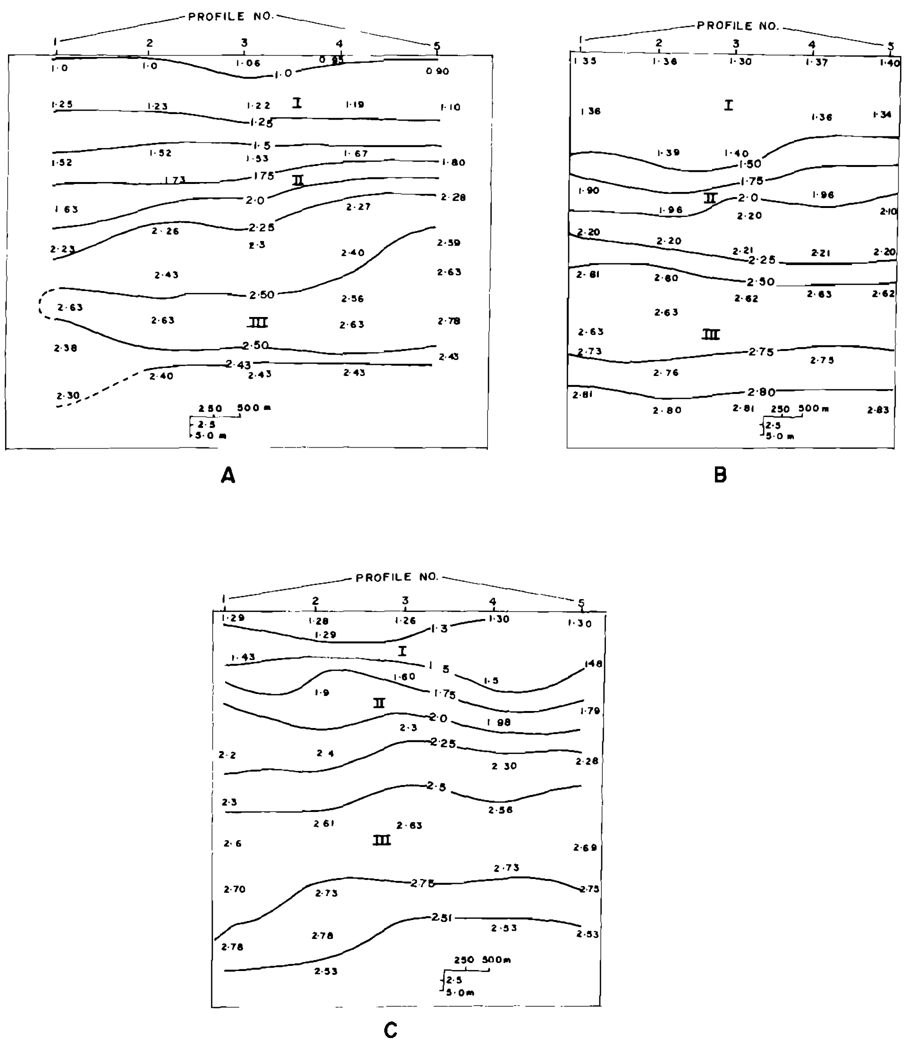

Figure 5. Saptial distribution of mean size at Konarak; (a) in September 1982, (b) in February 1982, and (c) in June 1982.

ing of contours and occurrence of the coarser sediment band represent the formation of bars in the inshore region, a characteristic storm type profile (KOMAR, 1976).

CONCLUSION

The following conclusions may be drawn from the present study. Variation in mean grain size on a beach may be used to determine the probable dynamics of beach sediments. Deposition is marked by a decrease in mean size and parallelism of size contours. Coastal erosion increases the mean size and the offshore component is marked by convexity of size contours towards offshore. The spacing between size contours is wider in a depositional environment. Sediment supply and longshore current patterns play a dominant role in determining the nature of a beach.

Both Konarak and Puri beaches show a net reduction in mean size from 1979 to 1982, in keeping with the accretionary nature of these beaches. However, at Konarak beach, the deposition is higher due to a more favourable location near a source of fluvial sediments.

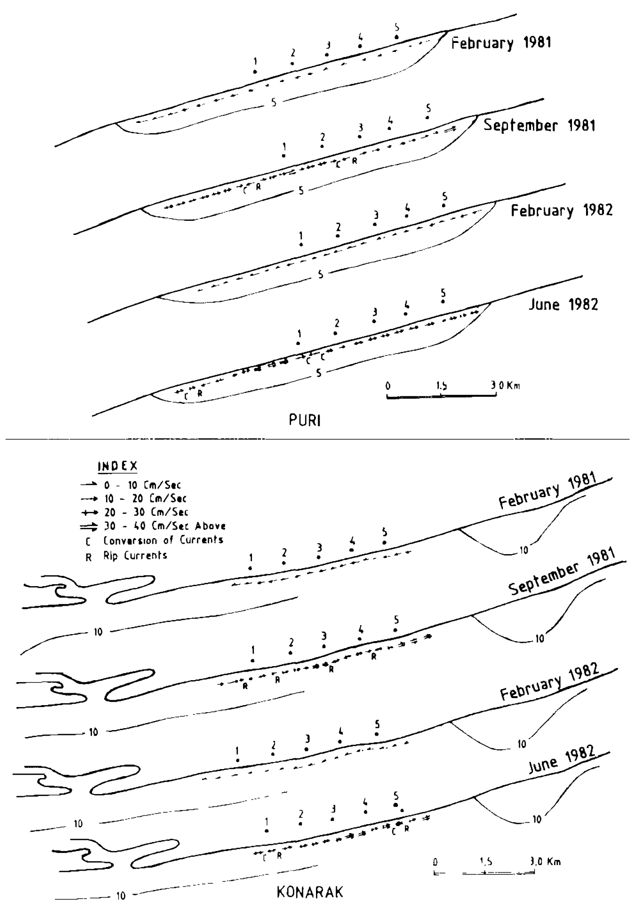

Figure 6. Patterns of littoral currents at Puri and Konarak beaches.

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Table 3. *Wave period and wave length parameters for the study area.*

Period	Wave period	5	6	7	8	9	10	11	12
	Wave length	39.00	56.16	76.44	99.84	126.36	156.00	188.76	224.64
December 1978—February 1979		46.15%	23.07%	23.07%	7.60%	—	—	—	—
July 1979—September 1979		15.00%	5.00%	15.00%	60.00%	5.00%	—	—	—
February 1980—April 1980		87.50%	—	12.50%	—	—	—	—	—
December 1980—February 1981		90.9%	—	—	—	9.09%	—	—	—
July 1981—September 1981		16.60%	11.10%	38.88%	27.70%	5.55%	—	—	—
December 1981—February 1982		75.00%	25.00%	—	—	—	—	—	—
May 1982—June 1982		11.10%	11.10%	—	—	—	33.3%	—	44.4%

Table 3 Chauhan et al (1986).

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□ RÉSUMÉ □

Etudie les variations de la taille moyenne de 550 sédiments prélevés entre 1979 et 1982 selon 5 profiles de chacun des deux sites. De larges variations sont observées, qui sont en rapport avec les changements de conditions hydrauliques dans le temps et dans l'espace. Les lignes d'égale taille moyanne sont parallèles à la plage par temps calme, lorsque le dèpôt predomine. Après les phases d'érosion, les lignes, au lieu d'être parallèles deviennent convexes vers la mer. L'espacement entre ces isolignes change aussi avec la nature du mouvement des sédiments: il est réduit quand il y a érosion de la plage (rapprochement des isolignes). Souligne les variations de la taille moyenne du sediment par rapport à la source sédimentaire, et les modifications des processus géomorphologiques.—Catherine Bressolier, EPHE, UA 910 CNRS, Montrouge, France

□ ZUSAMMENFASSUNG □

Mittlere Grössenveränderungen von 550 Sedimentprobe unter verschiedenen Umweltumstände wurden von 1979 bis 1982 betrachtet; die Probe stammten aus 10 Strandprofile (5 von Puri-Strand und 5 von Konarak-Strand; die beiden Strande sind auf der Orissa-Küste zu finden sein). Die regelmässige Überwachung der mittleren Grösse entland und quer über die Profile zeigt merkwürdige Veränderungen davon; die sind an Ändenrungen der Hydraulik angeschlossen. Die Umrisslinie der Grösse sind parallel zum Strand, wenn Umstände ruhig sind und Ablagerung vorherrschend ist. Die Verschwundung des Parallelismus zeigt das Ankommen der Auswaschung; die Umrisslinie werden auch konvex zum Meere hin. Der Zwischenraum der Umrisslinie ändern mit den verschiedenen Bewegungen der Sedimente; er wird unter Auswaschungsumstände abgenommen und eine Beschränkung der Linie wird auch beachtet. Veränderungen der mittlerem Grösse in Beziehung auf wahrscheinlichen Sedimentquelle und Änderungen der geomorphologischen Prozesse werden entworfen.—Stephen A. Murdock, Charlottesville, Virginia, USA