

DEPOSITIONAL ENVIRONMENTS OF COASTAL SEDIMENTS OF CALANGUTE, GOA

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ABSTRACT

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The grain-size statistics and environmental conditions of deposition of the beach and dune sediments from the Calangute region, Goa, have been studied. The results of Student's t test and bivariate plots reveal that there exist distinct differences in grain-size parameters of the sediments from different environments and that these differences are highly significant. The study shows that the variations in mean grain size (Mz), graphic standard deviation (σ_1), graphic skewness (Sk_1), simple sorting measure (So_s) and simple skewness measure (α_s) are significant in identifying the sediments from different environments. Further, the study reveals the usefulness of grain-size parameters not only in differentiating beach and dune sediments, but also in delineating the beach into foreshore and backshore. The differences in grain-size characteristics of the sediments between the environments reflect the transport, erosional and depositional mechanisms (active hydrodynamic processes in the beach foreshore and aerodynamic processes in the backshore and dune environments) prevailing in the area of study.

INTRODUCTION

The importance of grain-size parameters of sediments in sedimentology has been well established (Folk, 1966). They are used often in interpreting the environments of deposition of ancient as well as of Recent sediments (Hails and Hoyt, 1969). There have been many attempts (Mason and Folk, 1958; Friedman, 1961 and 1967) to differentiate the sediments from widely varying environments like beach and dunes; dune, beach and rivers; beach and rivers, etc. based on the grain-size parameters. In contrast to this, however, very few attempts (Sevon, 1966; Greenwood, 1969) have been made so far to utilize the statistical methods in diagnosing the finer differences that may exist within a particular environment of the same physiographic unit viz., foreshore, backshore and dune sediments. In the present paper, the latter is attempted for a strip of beach (Calangute) on the Goa coast, making use of the grain-size characteristics of the sediments collected from different parts

of the environments that are subjected to different transport, erosional and depositional mechanisms.

Earlier the textural characteristics of the same beach foreshore sediments have been reported (Veerayya, 1972), wherein the emphasis was on the seasonal variations, whereas the present study is based on a discrete set of samples collected from the various environments on one occasion.

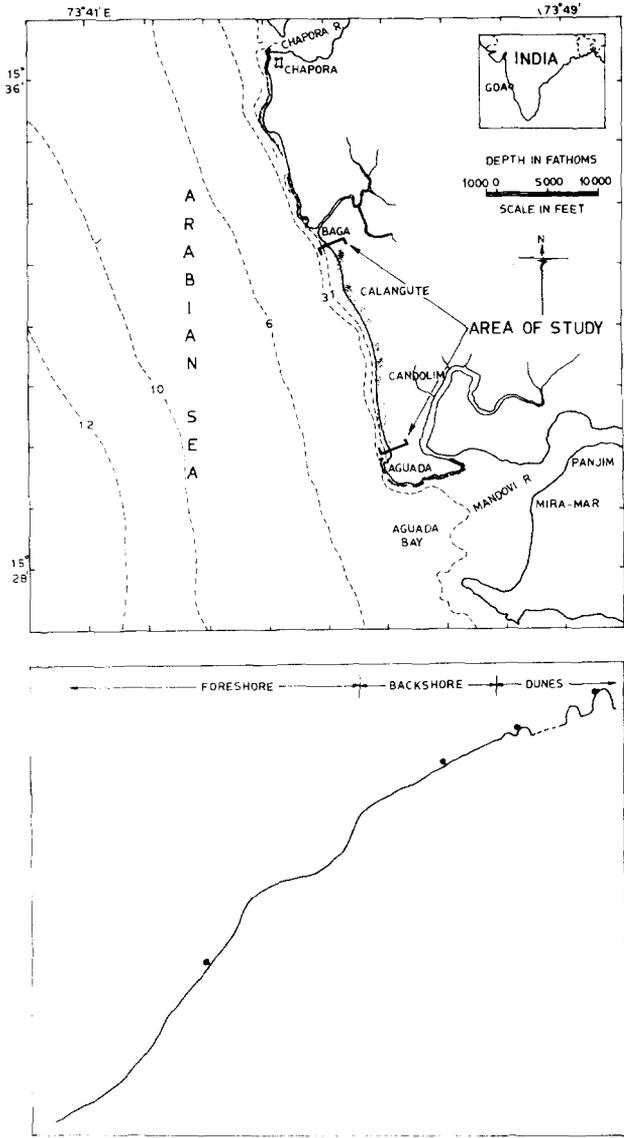


Fig. 1. Location map of the area of study(upper); schematic cross-sectional profile and dots indicate sampling locations(lower).

TABLE I

Classification of the zones of the depositional environments of Calangute

Environment	Variation in the width of the zone (m)	Classification
Foreshore	35-45	strip of the beach within the tide levels (lowest low water spring and highest high water spring) to the limit of high water swash
Backshore	20-40	that part of the shore lying between the foreshore and the first line of dunes
Aeolian	500	dune field from the first line of dunes adjoining the backshore to the interior
(a) nearby dune	40-50	consists of small dunes (adjoining the backshore) with heights varying between 0.50 and 2.00 m
(b) interior dune	~500	this dune field extends further landward from the nearby dunes and merges with the lateritic soil of the coastal area; the heights of the individual dunes vary from 2 to 10 m

AREA OF STUDY AND DEPOSITIONAL ENVIRONMENTS

The area of study, a sandy beach and the adjoining dune field, is situated between two rocky headlands: Baga ($15^{\circ} 33' 32''\text{N}$, $73^{\circ} 45'\text{E}$) in the north and Aguada ($15^{\circ} 29' 30''\text{N}$, $73^{\circ} 46' 30''\text{E}$) in the south (Fig. 1). A detailed description of its physiography and the offshore bathymetry was given earlier (Veerayya, 1972). The study area has been divided into three discrete but gradational environments of deposition (Shepard, 1973). The classification of the zones of the depositional environments in the area of study (Calangute) is given in Table I.

METHOD OF STUDY

Fifty-three sediment samples were collected from the above-mentioned environments during April, 1972. Samples from the foreshore were collected below the swash line of the high-water mark and approximately at Bascom's reference point (Bascom, 1951) that part of the beach subjected to wave action at the mid-tide stage. The backshore samples were collected from the middle of the zone while the dune samples were taken three-fourths way up the windward side of the first and middle dune. Samples represent the upper

few (4 cm) centimeter column of the depositional environments, after removing the top few layers (lag deposit) of the sediment column as outlined by Mason and Folk (1958). In conjunction with sediment sampling, visual observations of periods, heights and directions of waves, direction and speed of wind and littoral current velocities were made.

The sediment samples were washed (foreshore only), oven dried and then sieved for 15 minutes on a ILM Labor sieve-shaker using $\frac{1}{2} \phi$ interval Ende-cotts test sieves. The retent on each sieve was weighed on a Mettler balance. The graphic measures (Folk and Ward, 1957; Friedman, 1967) were calculated for each sample from the cumulative frequency curve data.

TREATMENT OF THE DATA

For a comparison of the values of textural parameters between the environments, the means and standard deviations of the values were calculated for all the grain-size parameters and they are presented in Table II. Student's *t* test (Griffiths, 1967) was applied to find the statistical significance for the differences in the grain size parameters of the sediments from different environments. The results are given in Table III.

Bivariate plots have been drawn to elucidate the differences which exist

TABLE II

Means and standard deviations of grain-size parameters for foreshore, backshore, nearby dune and interior dune environments of Calangute (values are mean \pm standard deviation)

Grain-size parameters	Environment			
	foreshore (<i>n</i> * = 12)	backshore (<i>n</i> = 19)	nearby dune (<i>n</i> = 13)	interior dune (<i>n</i> = 9)
Mean grain size (<i>Mz</i> ϕ)	2.03875 ± 0.16900	1.25594 ± 0.08889	1.55400 ± 0.11050	1.98733 ± 0.11210
Standard Deviation ($\sigma_1 \phi$)	0.56153 ± 0.11490	0.78493 ± 0.09537	0.59574 ± 0.06957	0.46916 ± 0.07285
Skewness (<i>Sk</i> ₁)	-0.29061 ± 0.09654	+0.04998 ± 0.11280	+0.03828 ± 0.09958	-0.17560 ± 0.12140
Kurtosis (<i>K_G'</i>)	0.51025 ± 0.03715	0.48378 ± 0.02118	0.46655 ± 0.02159	0.48421 ± 0.02646
Simple sorting measure (<i>So</i> _s)	0.91875 ± 0.16570	1.26368 ± 0.15380	0.95384 ± 0.10820	0.76144 ± 0.11880
Simple skewness measure (α_s)	-0.61583 ± 0.25310	-0.06473 ± 0.37340	+0.01615 ± 0.20430	-0.30666 ± 0.20700

**n* = number of samples.

TABLE III

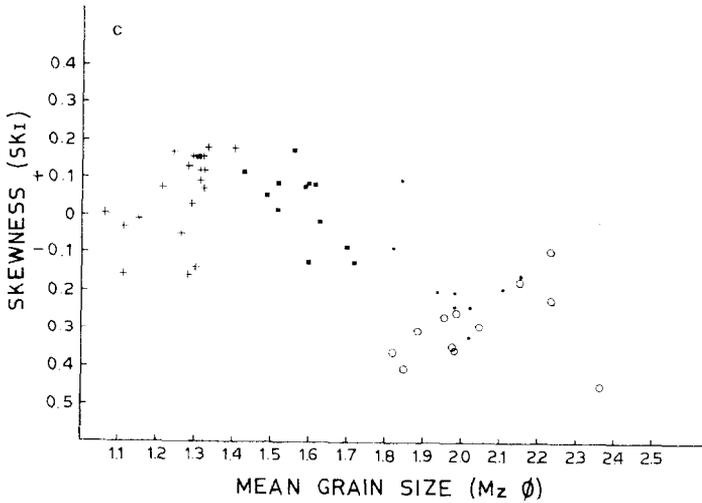
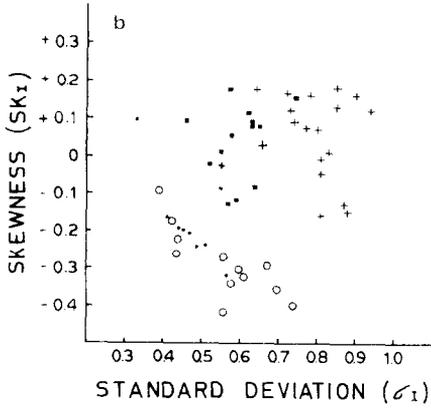
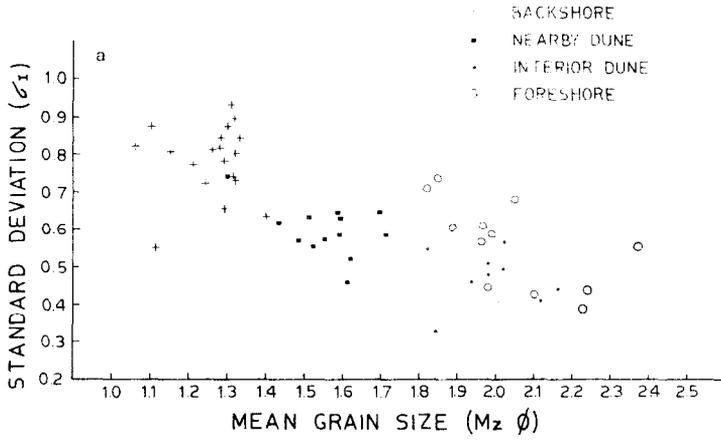
Values of Student's t and their significance for the difference in the grain-size parameters of the sediments between the different environments of Calangute

	Environment					
	foreshore vs. backshore (df = 29)	foreshore vs. nearby dune (df = 23)	foreshore vs. interior dune (df = 19)	backshore vs. nearby dune (df = 30)	backshore vs. interior dune (df = 26)	nearby dune vs. interior dune (df = 20)
Mean grain size ($Mz \phi$)	16.900**	8.553**	0.800 ns	8.441**	18.700**	8.995**
Standard deviation ($\sigma_I \phi$)	5.869**	0.908 ns	2.108 ns	6.115**	8.766**	4.120**
Skewness (Sk_I)	8.638**	8.373**	2.422*	0.302 ns	4.827**	4.535**
Kurtosis (K_G')	2.534*	3.633*	1.786 ns	2.242*	0.467 ns	1.722 ns
Simple sorting measure (Sto_s)	9.183**	0.613 ns	2.336*	6.267**	8.622**	3.941**
Simple skewness measure (α_s)	4.490**	6.889**	2.986*	0.708 ns	1.805 ns	3.617**

* Significant at 5% level ($p < 0.05$).

** Significant at 1% level ($p < 0.01$).

ns = Not significant at 5% level ($p > 0.05$); df = degrees of freedom.



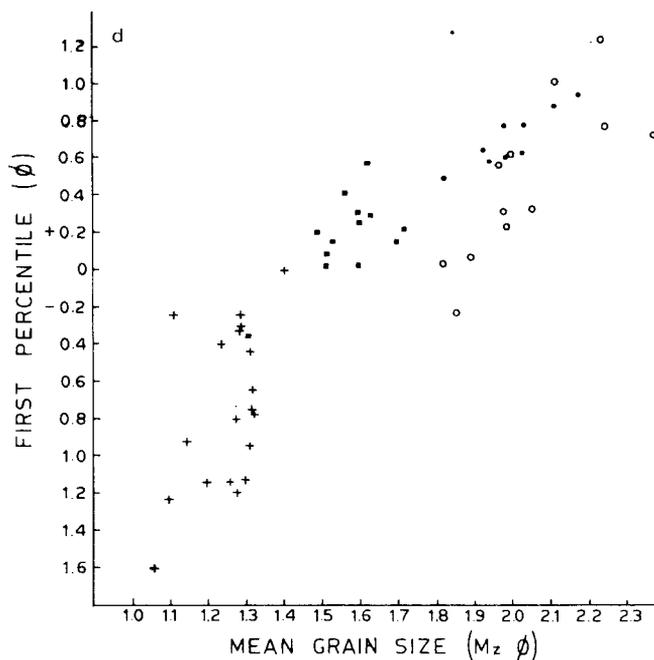


Fig. 2a. Scatter plot of mean grain size ($Mz \phi$) versus standard deviation (σ_1) values of the sediments. b. Scatter plot of standard deviation (σ_1) versus skewness (Sk_1) values of the sediments. For explanation, see Fig. 2a. c. Scatter plot of mean grain size ($Mz \phi$) versus skewness (Sk_1) values of the sediments. For explanation, see Fig. 2a. d. Scatter plot of first percentile values (ϕ_1) versus mean grain size ($Mz \phi$) values of the sediments. For explanation, see Fig. 2a.

between the parameter values from different environments and these are shown in Figs. 2a–2d.

RESULTS

Table II reveals that the sediments of the foreshore have their mean grain size in the medium- to fine-sand class, well to moderately sorted and are negative (–0.10 to –0.30) to very negatively (–0.30 to –1.00) skewed (verbal classification and the limits therein in respect of graphic standard deviation or sorting and graphic skewness are after Folk and Ward, 1957 while the classification in case of simple sorting and simple skewness is after Friedman, 1967). The backshore sediments are coarser, represented by the medium sand class, moderately sorted with nearly symmetrical distribution. Nearby dune sediments are in the medium sand class, well to moderately sorted and nearly symmetrical, whereas the sediments of the interior dunes are in the medium to fine sand class, well sorted and in nearly symmetrical to negatively skewed class. The simple sorting and simple skewness parameter values

indicate that the sediments of the backshore are less well sorted and less negatively skewed than that of the foreshore; interior dune sediments are well sorted but more negatively skewed than either the backshore or nearby dune sediments; the foreshore sediments are very negatively skewed. The trends in the average values of these parameters, in general, correspond fairly to those of graphic standard deviation and graphic skewness.

These variations in grain-size statistics of the sediments across the area of study encompassing all the environments, indicate that distinct differences exist among the depositional environments. Table III indicates the values of Student's *t* test obtained and the statistical significance. The values of mean grain size, graphic skewness, graphic standard deviation, simple sorting and simple skewness measures indicate a strong differentiating power between foreshore, backshore and dune sediments. Though the sediments from both backshore and nearby dunes are in the medium sand class (Table II), the environments differ significantly from each other with respect to mean grain size and graphic standard deviation values, and the differences are highly significant (Table III). The differences in simple sorting values of the sediments are highly significant in all the combinations except between foreshore and nearby dune. The variations in graphic standard deviation values between foreshore and interior dunes are not significant while, on the other hand, simple sorting values showed significant differences. Simple skewness parameter values between foreshore and interior dune are not significant, whereas graphic skewness showed significant variations.

Further, recent investigations (Folk and Ward, 1957; Friedman, 1961) indicated that a scatter diagram drawn between two of the statistical parameters is useful in distinguishing the sediments from different depositional environments. In the present study, graphic measures (Folk and Ward, 1957) of the sediments have been compared on four scatter plots.

An examination of the bivariate plots of the parameter values shown in Figs 2a–2d reveals that the values in respect of these sedimentary environments fall in different fields on the scatter diagrams, with minor departures.

Fig. 2a shows that interior dune and foreshore sediments having their mean grain size in the medium to fine sand range exhibit considerable degrees of overlapping. In spite of this, the dune sediments have lower numerical values for graphic standard deviation. The range of graphic skewness values for these different depositional environments allows for a distinct separation of the environments (Fig. 2b). The overlapping of graphic skewness values between foreshore and interior dune sediments, is probably due to a considerable spread in skewness values of the foreshore sediments. Except for this mixed pattern, the differences in graphic skewness values between the environments are highly significant and these differences have, in fact, revealed the greatest significance next to mean grain-size values (Table III). The distribution between simple sorting measure ($S_{0.5}$) and simple skewness measure (α_s) values of the sediments also indicated fairly identical spread to that noticed in Fig. 2b. Fig. 2c shows that there is no marked

variation between skewness values of the backshore and nearby dune sediments, although their mean grain-size values differ significantly (Table III). The *t* test results show that significant differences exist between some of the environments in respect of graphic kurtosis values (Table III).

In Fig. 2d, first-percentile (Passegga, 1957) values are plotted against mean grain-size values. This diagram further confirms a clear distinction in the distribution of the sediment parameter values from zone to zone. However, there is an overlap of values in respect of interior dunes and the foreshore.

DISCUSSION

The variations in grain-size parameters of the sediments from the beach foreshore, backshore, nearby and interior dunes (Table II) and the distinct differences (Table III) reflect different depositional processes operating in the area of study. The sediments of the foreshore are under the influence of swash-backwash phenomena, giving rise to good sorting and negative skewness. The sediments from the backshore and dune environments, are under the influence of wind action. The backshore sediments are composed of several grades of material, ranging from granule to very coarse sand. Bagnold (1954) points out that winds having velocities greater than the threshold velocity (9 mph or 7.82 knots) are capable of initiating transport of sand-size sediment and moving it over considerable distances and that the winds must be stronger than 14.50 mph (12.60 knots) to move grains greater than 1.00 mm in diameter. Folk (1971) mentions that normal surface winds can move particles no larger than 2 or 3 mm but larger grains upto a few cms can be moved "sporadically" by rare gusts. Field observations show that the prevailing as well as dominant winds with velocities of 20 knots and at times gusty winds with high velocities (30 knots) blow onshore during the monsoon season (Veerayya, 1972). It seems possible that very coarse to coarse sand material (<2.0 to 0.5 mm) which becomes deposited at the upper limit of the swash of monsoon high waves is being transported, occasionally, landward onto the backshore by the strong winds which prevail in this region during the non-monsoon months also, i.e., October to May. This particular type of transport of material from the exposed parts of the upper foreshore (as the greater part of the beach foreshore becomes exposed to intense insolation and wind action due to considerable tidal ranges) onto the backshore and dunes, was observed on many occasions. The transport of material from the beach foreshore to the landward side of it was also observed at Mira Mar (Fig. 1), which resulted in deposition of the material on the nearby road. Further, the concentration of coarse-grain-size material composed of quartz sand, rock fragments, shells and shell fragments beyond the upper foreshore upto the first line of dunes, as well as into the troughs of these dunes, has been recorded. Thus, the mixing of bed load and saltation load gives rise to poor sorting of the backshore sediments. Besides, the incorporation of a part of fine-size material into the backshore by onshore winds from

the exposed parts of the foreshore and the berm crest as suspended load, contributed to positive skewness.

The significant variations in some of the grain-size parameters between backshore and nearby dunes, backshore and interior dunes, and nearby dunes and interior dunes reflect the selective transport capacity of the prevailing wind system. However, the lack of significant variations in skewness of the backshore and nearby dune sediments (Table III) shows the more or less identical phenomena of transport of fine size material which influences the tails of the cumulative curve.

As the process of transport of sediments from the beach upper foreshore to the landward region continues, coarser sized material is left behind on the backshore and mostly the fine grain size material is transported as saltation load (largely) and suspension load forming the dunes.

The interior dune sediments, unlike those of nearby dunes, are fine grained, well sorted and negatively skewed. In general, the size of the dune sediments is in the range of 1.44–2.10 ϕ i.e., fairly well within the classification of Folk (1971) in respect of aeolian deposits (1.50–4.00 ϕ), but coarser than the limits (2–3 ϕ) proposed by Udden (in Folk, 1968). Further, the average mean grain size of the dune sediments in the area of study is slightly larger than that of the corresponding beach foreshore sediments which is in contrast to the principle that the dunes should be composed of material finer than that of the material met within the corresponding foreshore.

This kind of distribution has been reported elsewhere also (Bigarella et al., 1969). The possibilities for this distribution are: (a) the erosion of the dunes due to catastrophic events like storms and cyclones; (b) the erosion of the dunes due to strong offshore winds; and (c) the transport of material inland by onshore winds. From the position of the dunes, the first possibility can be precluded. The offshore winds associated with land breezes do not, in general, exceed 5 knots and blow in the night and in the morning hours and the onshore winds associated with sea breezes start around noon with speeds reaching a maximum of 10 knots. Hence, the erosion due to offshore winds is negligible. The onshore winds, besides favouring the dune building (accretion) processes also transport fine-grained material further landward, leaving behind the coarser particles. Several rows of dunes exist along this part of the coast. The sediment samples collected at random from these dunes on previous occasions (during 1969–1970) have also indicated similar results. The negative skewness of the interior dune sediments, reflects the presence of coarse grain-size material as coarse tails with fine mode on the frequency curve. The significant variations observed in skewness, simple skewness and simple sorting parameters of these sediments, however, enable the identification of the dune sediments from those of the corresponding beach foreshore sediments.

CONCLUSIONS

(1) The sediments of the foreshore, backshore, nearby dune and interior dune environments of Calangute, Goa, show distinct differences in their

mean grain size, graphic standard deviation, graphic skewness, simple sorting and simple skewness parameters. The sediments of the foreshore are in the medium to fine sand class, well to moderately sorted and negative to very negatively skewed. The sediments of the backshore are in the medium sand class, moderately sorted with nearly symmetrical distribution. Nearby dune sediments are in the medium sand class, well to moderately well sorted and nearly symmetrical, while the sediments of the interior dunes are in the medium to fine sand class, well sorted and nearly symmetrical to negatively skewed.

In general, the average mean grain size of the dune sediments is slightly greater than that of the corresponding beach foreshore sediments.

(2) The trends in the average values of simple sorting measure and simple skewness measure, in general, correspond to those of graphic standard deviation and graphic skewness.

(3) The variations in simple sorting values between foreshore and interior dunes are significant, whereas in respect of graphic standard deviation, they are not.

(4) The distributions of (a) mean grain size versus graphic standard deviation, graphic skewness and first percentile, (b) graphic standard deviation versus graphic skewness, and (c) simple sorting versus simple skewness values of the sediments indicate clear zonations, enabling the identification of the sediments from different environments.

(5) The differences in grain-size parameters of the sediments between the environments reflect the transport, erosional and depositional processes that are operative in the area of study.

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