

## Textural Characteristics of Calangute Beach Sediments, Goa Coast

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Sediments of Calangute beach (between Baga and Aguada headlands), collected along 5 sections during September 1969-August 1970, have been investigated for their textural characteristics, viz. mean grain size, sorting and skewness along with the beach topographic changes. The study indicates a distinct seasonal variation in these parameters at all the profile sections and the results of Student's *t* test reveal that the variations are highly significant. During the fair weather season, the sediments are in medium to fine sand grade and are moderate to well sorted, with negative to very negatively skewed class, whereas during the monsoon season they are in coarse to medium sand grade (often very coarse sands) in moderate to well sorted and symmetrically skewed class. In general, the sediments of the beach are represented by granule to fine sand size classes. The mean size and sorting values of the sediments tend to increase from the upper to lower foreshore, the increase generally being proportional to the gradient of the beach. The coarsest grain size is encountered at the 'step formation' during the monsoon. The berm is composed of material coarser than the foreshore represented by medium sands during the fair weather season. The breaker zone is composed of medium to fine sands, in moderate to poorly sorted class throughout the study period. The tests of significance for differences in the textural parameters between the stations during the fair weather season indicate that the sediments on the southern side (near Candolim) are coarser and less well sorted than at the other stations on the northern side. The sediments at the northernmost part, i.e. Baga, are finer and very well sorted in nature. However, the variations in textural parameters of the sediments noticed during the fair weather season are absent during the monsoon. These variations have been discussed in relation to the topographic changes, wave climate and the littoral drift.

**B**EACH studies have gained considerable importance in India in view of the presence of economic placer mineral deposits on the one hand and also of the severe erosion experienced in some parts of the west and east coasts of India on the other. As part of the coastal and nearshore oceanography programme of the Institute studies on the sedimentological aspects of Calangute and Colva beaches are undertaken. The present report deals with the investigations on the sediment samples collected during the period 1969-70 from Calangute beach. The principal aim of the investigations is to understand the seasonal variations in the textural characteristics of the sediments of the beach; in relation to beach topography, meteorological and oceanographic factors affecting the changes in the environment. This study subsequently help; in understanding the stability of the beach as the latter constitutes a natural resource of recreational value.

Except for the studies on the (i) geology of Goa by Oertel<sup>1</sup> and Sinha<sup>2</sup>, (ii) geomorphology by D'Souza<sup>3</sup>, and (iii) Foraminifera of Baga beach by Rocha and Ubaldo<sup>4</sup>, no information is available on the distribution, composition and origin of the recent unconsolidated sediments of this beach.

### Description of Area

*Regional setting, physiography and bathymetry* — The coast of Goa trending NNW-SSE more or less in a straight line, facing the Arabian Sea, forms a part of the central west coast of India. It is a coast of submergence and the remarkably straight

alignment has been attributed to the faulting, perhaps in Plio-Pleistocene times<sup>5,6</sup>. Most of the coastline consist; of beautiful sandy beaches separated from one another by rocky headlands and river mouths.

The area of study, known as Calangute beach, is one of the two sandy beaches on the northern part of this coast and is situated between two rock promontories — Baga in the north and Aguada in the south, at a longitude of 73°46'E and latitude of 15°32'N (Fig. 1). On the landward side, the shore is fringed by coastal sand dunes and on the other by the continental shelf. A series of sand dunes parallel the entire backshore of the study area (beach terminology after Shepard<sup>7</sup>) and extend approximately 0.50 km inland and merge with the lateritic soil of the coastal plain. The dunes vary in height from 0.50 to 10 m and their spacing varies from a few metres to 15-20 m along the shoreline. The distribution of unconsolidated sediments along the beach is asymmetrical; the accumulation is much thicker to the south than to the north. The beach at Baga is narrow with a backshore of few metres wide and a moderately steep foreshore, the latter merging with the uniformly sloping offshore topography. A continuous backshore with an average width of 35 to 40 m extends 0.50 km south of Baga up to Station 3, and thereafter up to Station 1 its width varies between 25 and 35 m. In general, the backshore slopes seaward while the region behind the new berm crest slopes landward. The rocky headlands, capped by 30 to 40 m thick laterite, reach an elevation of 75 to 100 m. A

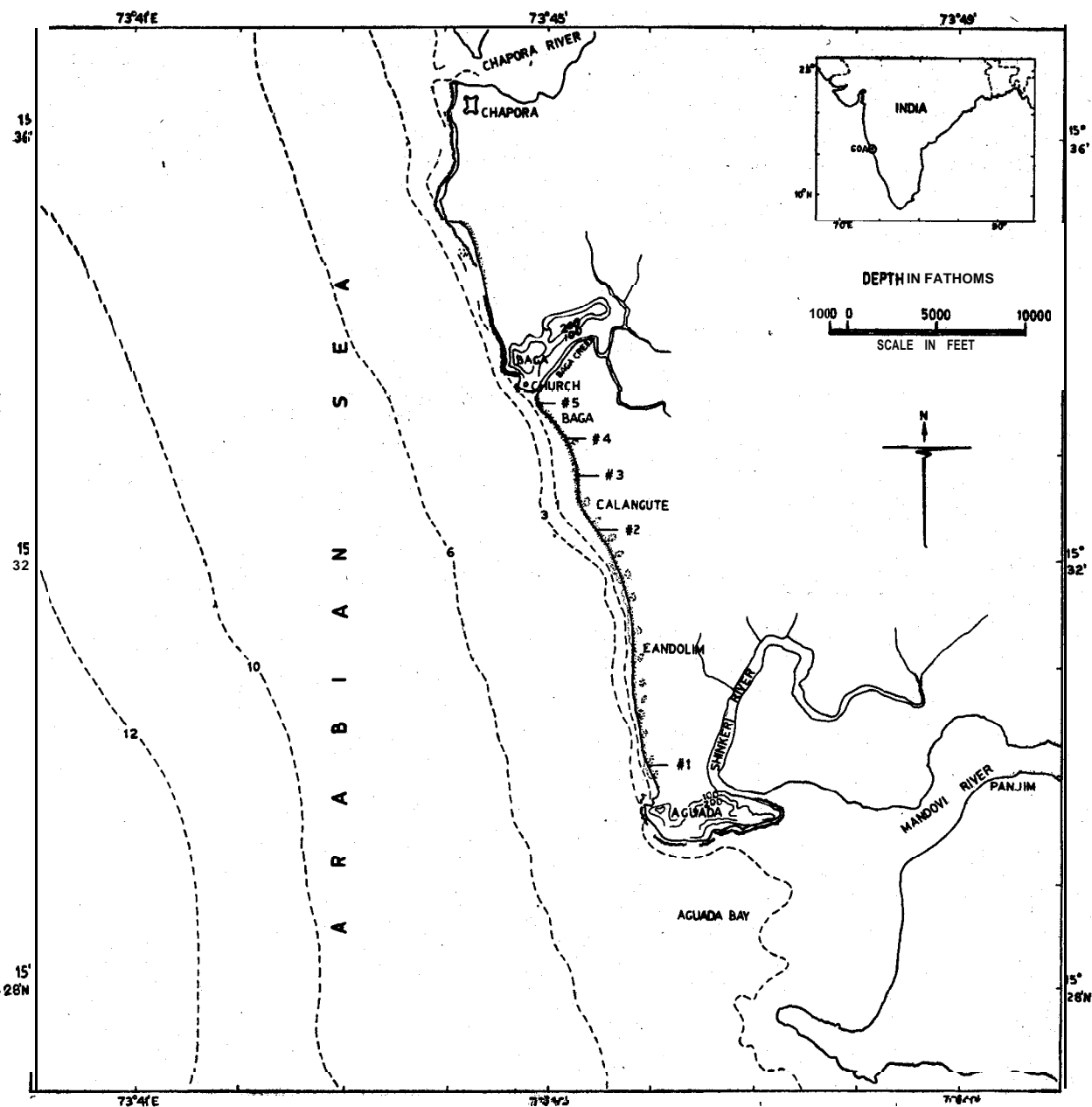


Fig. 1 — Location map of the area of study

few laterite formations crop out at Baga and are exposed during low tide period. The river Mandovi, south of Aguada, the river Chapora, north of Baga and a tidal creek at Baga drain into the Arabian Sea, apart from the small streams from coastal plains, which cut across the beach during the south-west monsoon season. The submarine contours (Fig. 1), as depicted in the Admiralty Chart No. 2022, are approximately parallel to the shoreline. The offshore region in the area of study has an average slope of 1.50 m per km up to 30 fathom contour (shown up to 12 fathoms only).

#### Methods

**Field methods** — Five beach stations were monitored along this strip of coast, during September 1969-August 1970 (Fig. 1). Stations 1 and 5 near Candolim and Baga respectively were established to delineate the influence of the proximity

of the rocky headlands on the beach, the rest of the stations are exposed to the open sea. Samples of sediment were collected along the profile sections at fortnightly intervals during low tide period, from the dunes, backshore, berm and foreshore-breaker zone of the beach, along with the measurement of the beach profiles. The main aim was to study the grain size distribution of the sediments in relation to the topographic changes of the beach, and hence uniform samples from the upper few centimetres of the beach were obtained. Concurrent with sediment sampling, periods, heights and directions of waves, direction and speed of wind, littoral current velocities, foreshore gradients and ground water tables were recorded during each survey.

**Laboratory methods**—Although the samples were collected at fortnightly intervals, 585 samples belonging to one series of collections at monthly intervals were analysed in the present study.

In the laboratory, all the sediment samples were washed free of salt content, oven-dried, representative portions selected by coning and quartering and then subjected to mechanical analysis. Sieving was performed for 15 min on an ILM Labor sieve shaker using  $\frac{1}{4} \phi$  interval Endecotts test sieves. All the fractions were weighed on a Mettler balance. The results were plotted as cumulative frequency curves on arithmetic probability paper the using  $\phi$  scale on the abscissa and cumulative percentage coarser on the ordinate.

The grain size distributions of the sediments were described by evaluating the descriptive statistical parameters, viz. graphic mean ( $M_z$ ), inclusive graphic standard deviation ( $\sigma_1$ ), inclusive graphic skewness ( $S_{ki}$ ) proposed by Folk and Ward\*.

**Results**

Variation of the textural parameters, viz. mean size, standard deviation and skewness, of the sediments along one of the typical profile sections, i.e.

at Station 3, for different months is shown in Figs. 2-4. The monthly distribution of the maximum, mean and minimum values of textural parameters of the foreshore sediments at all the stations, is shown in Figs. 5-7. Frequency distribution curves have been drawn to show the percentage abundance of occurrence of the parameter values for foreshore region at each station separately during the period October-April. Class intervals of  $0.20 \phi$ ,  $0.15 \phi$  and  $0.10 \phi$  for mean size, standard deviation and skewness values respectively have been chosen while drawing the curves. The curves for the individual station and for the combined values of all the stations in respect of each parameter are shown in Figs. 8 to 10. Frequency distribution curves for the monsoon season could not be drawn, since the number of samples, were inadequate.

A close examination of the monthly distribution of the textural parameter values for the different stations (Figs. 5-7) suggests that they exhibit distinct differences in regard to their distribution

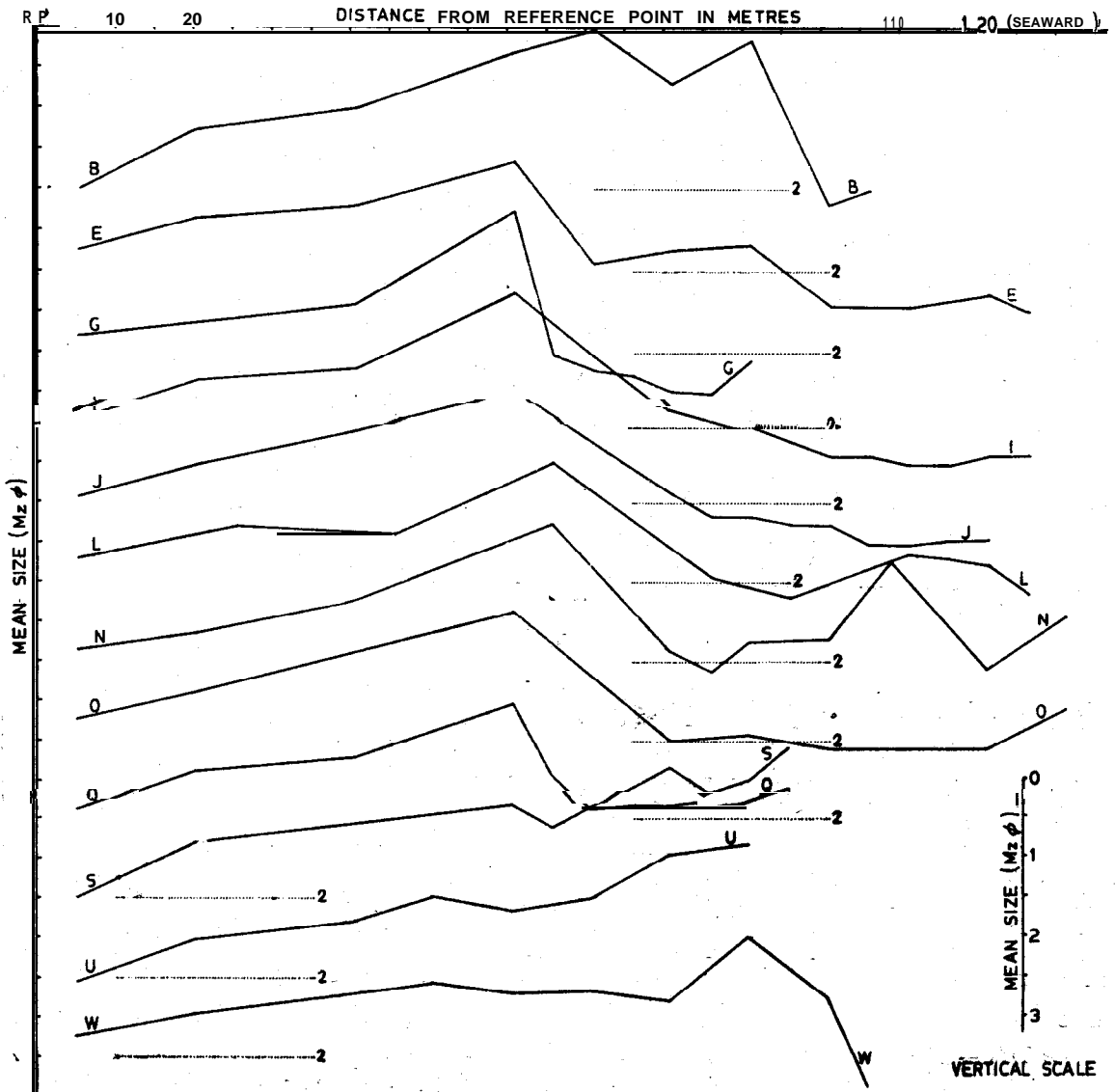


Fig. 2 - Variation in mean grain size ( $M_z \phi$ ) of sediments across the beach at Station 3 for different months [BB - September, EE - October, GG - November, JJ - December, LL - January, NN - April (i), OO - April (ii), QQ - May, SS - June, UU - July and WW - August. September to December 1969 and January to August 1970]

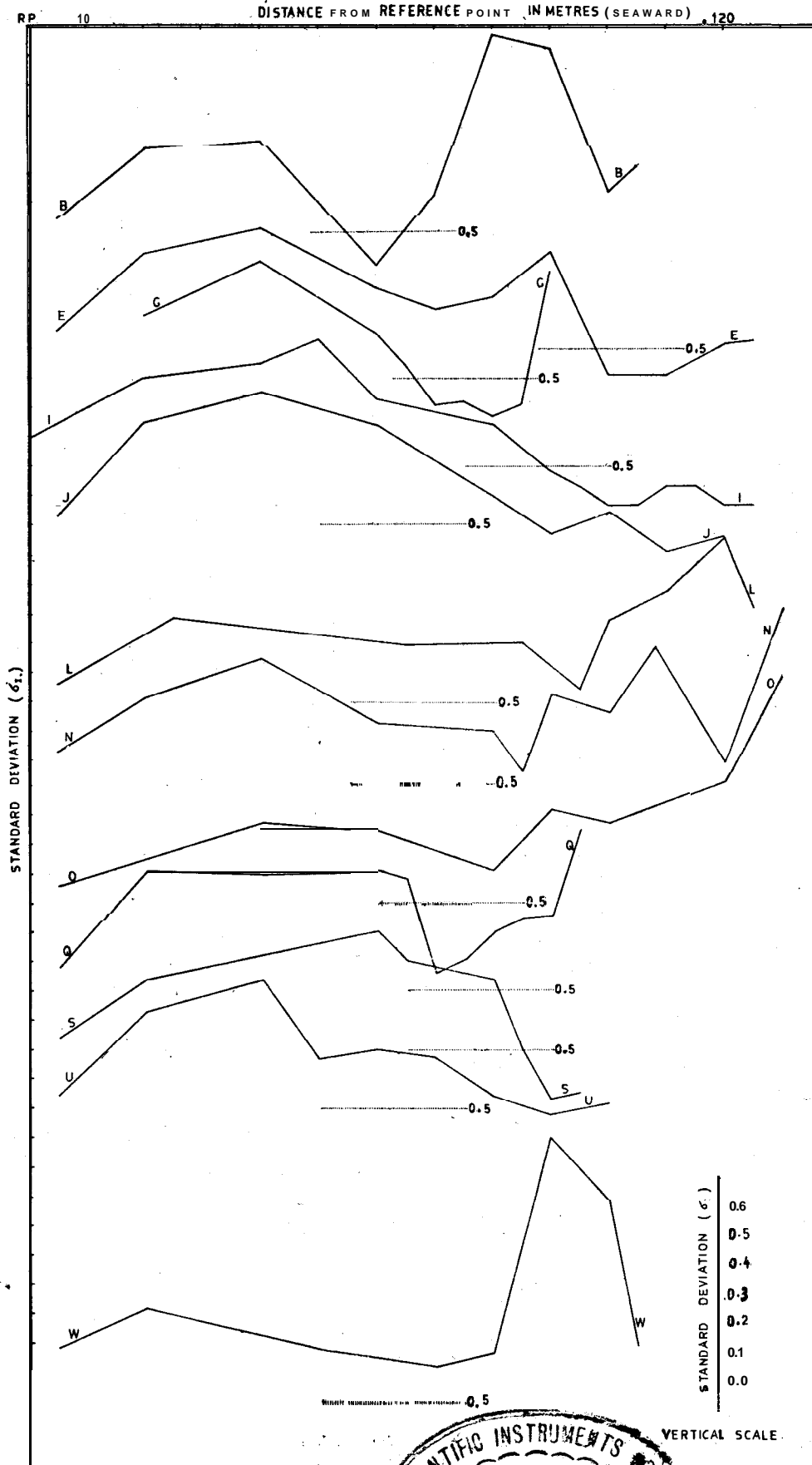
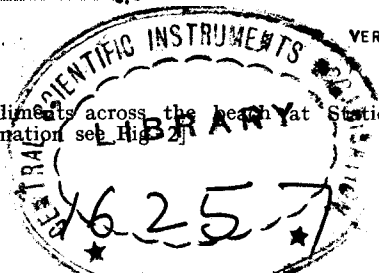


Fig. 3 - Variation in standard deviation ( $\sigma_t$ ) of the sediments across the beach at Station 3 for different months [For explanation see Fig. 2]



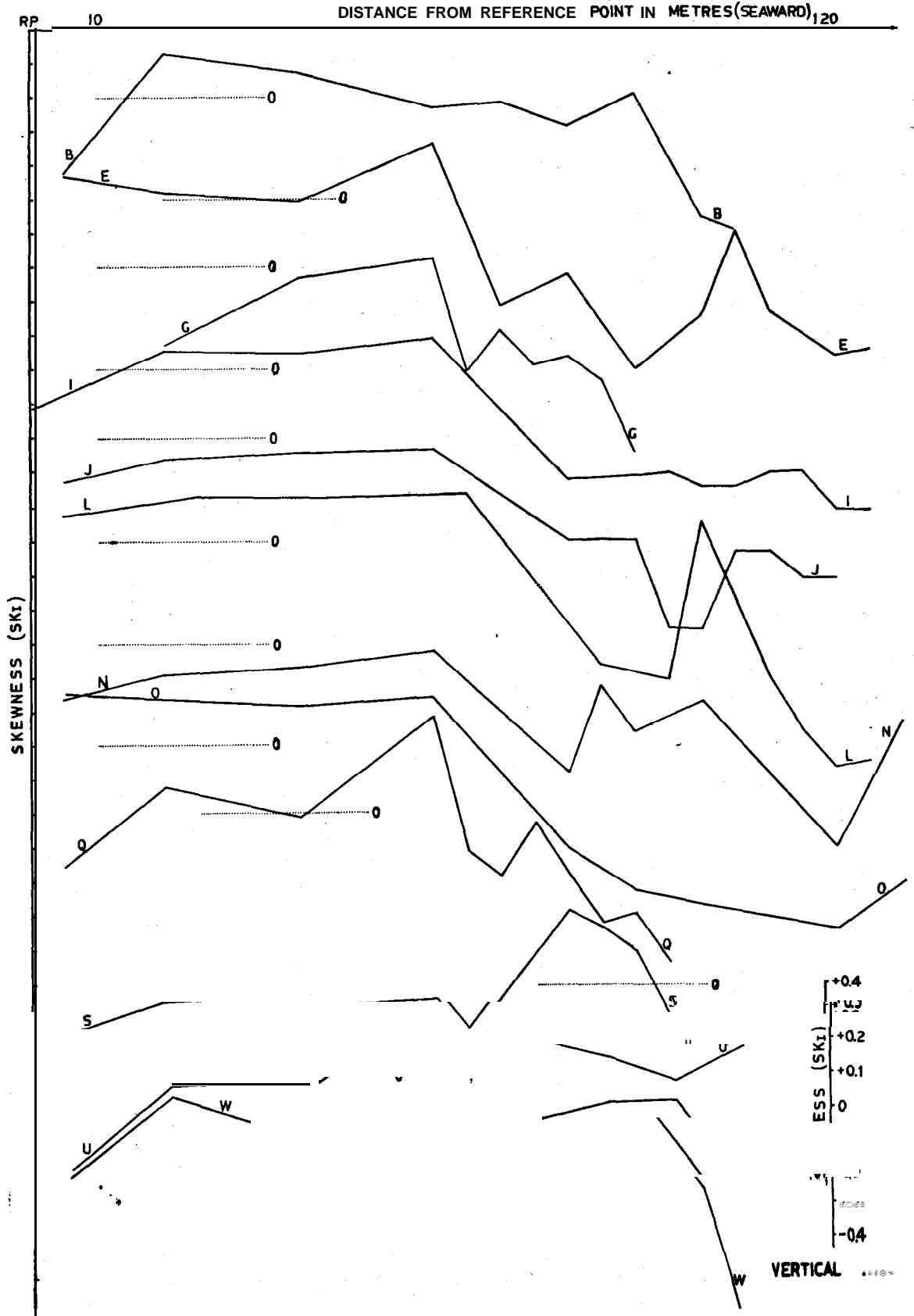


Fig. 4 — Variation in skewness (Ski) of the sediments across the beach at Station 3 for different months [For explanation see Fig. 2]

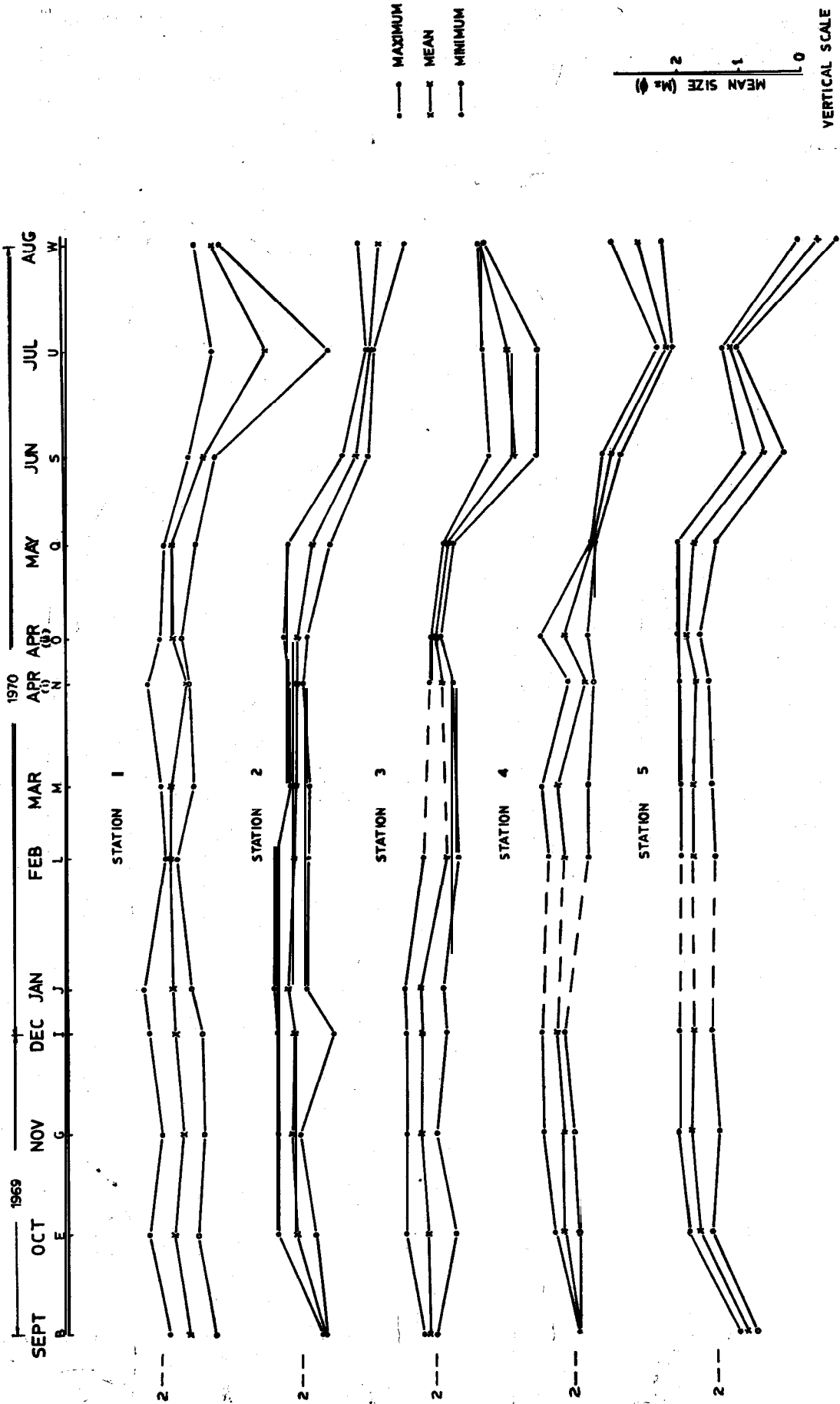


Fig. 5 — Monthly distribution of the maximum, mean and minimum values of mean grain size ( $Mz \phi$ ) of the foreshore sediments at all stations

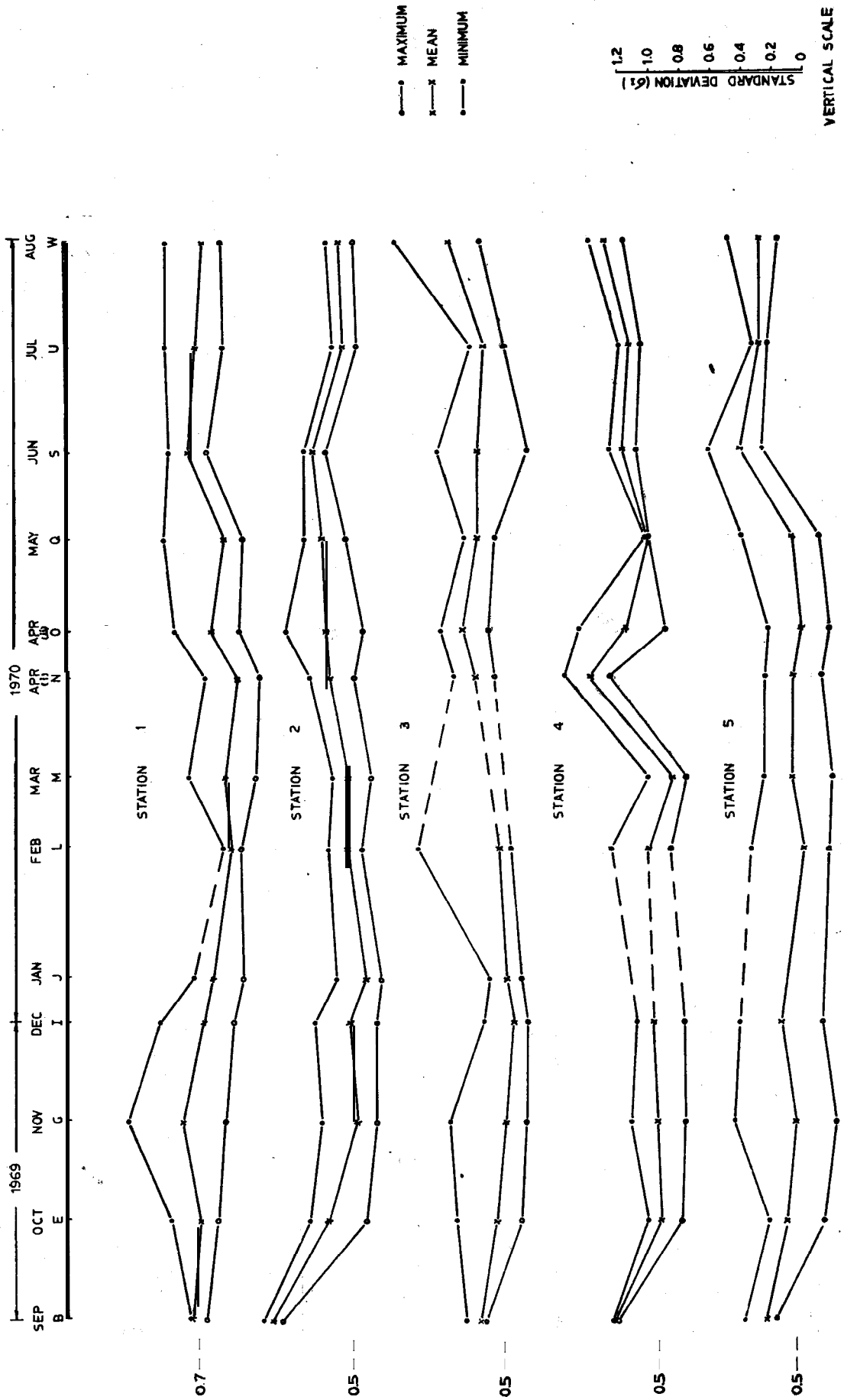


Fig. 6 — Monthly distribution of the maximum, mean and minimum values of standard deviation ( $\sigma_1$ ) of the foreshore sediments at all stations

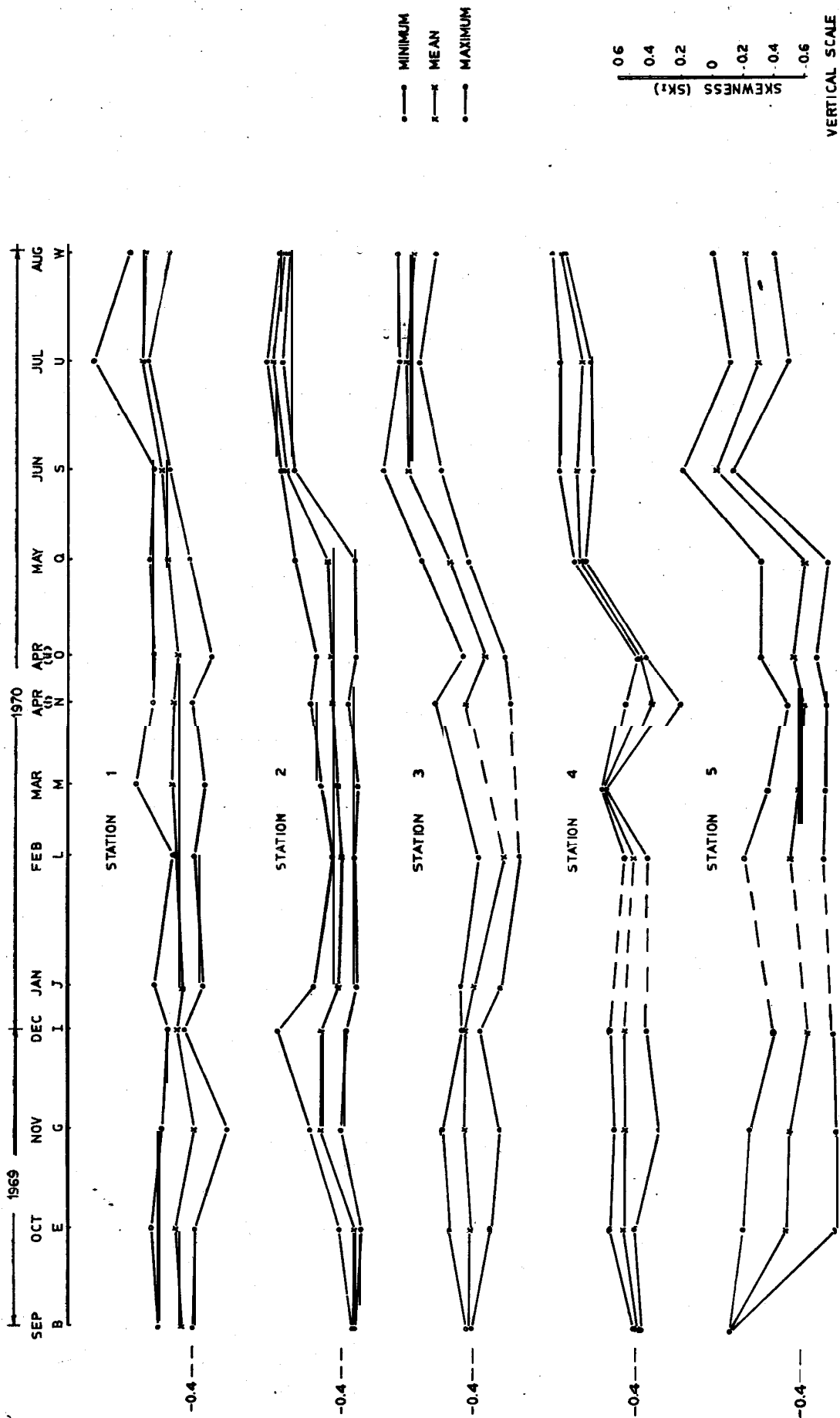


Fig. 7 — Monthly distribution of the maximum, mean and minimum values of skewness (Ski) of the foreshore sediments at all stations



pattern during the fair weather season (October to April) and monsoon season (June to August) with May and September as transition periods between the seasons.

As such, for a comparison of the values between the seasons, all the individual values in respect of one parameter in the fair weather season were combined and the same was done for the data for the monsoon season. The mean and standard deviation for values in the two seasons were calculated for the three grain size parameters and are presented in Table 1 for each of the stations.

Tests of significance for the differences between the two seasons for the same station and between the stations during the same season have been carried out by Student's *t* test<sup>9</sup> and the results presented in Tables 2 and 3.

**Variations in Textural Parameters**

The variations in the textural parameters of the sediments are briefly described below.

**Graphic mean (Mz)** - The mean grain size across the beach showed an increasing trend from the upper to lower foreshore during the period of study (Fig. 2). However, the inconsistencies present, at times, in this trend were due to the variation in beach slopes. The sediments of the backshore were observed to be coarser than those of the foreshore

(except during the monsoon season). The breaker zone in contrast to the foreshore is represented by a mixture of granule to fine sand class material during all the surveys. The mean grain size of the adjoining dunes was in medium to fine sand grade.

As indicated in Fig. 5, the average values of mean size from October to March and for a part of April fell in fine sand grade, while from the end of April they showed an increase and were in coarse to medium sands and often very coarse sand also was encountered. The *t* test results show that the differences in mean size between the two seasons (Table 2) are highly significant at all the stations ( $P < 0.001$ ) thus indicating a distinct seasonal variation.

There is an apparent variation in mean size from station to station during the fair weather season. The frequency distribution curves (Fig. 8) show that the maximum percentage of Mz values at Baga (Station 5) occur between 2.00 and 2.60  $\phi$ , with peak percentage between 2.40 and 2.60  $\phi$  indicating the abundance of finer end of fine sand class. At Station 4, south of Baga, the sediments are composed of medium to fine sands with clustering of Mz values around 1.60 to 1.80  $\phi$  and 2.20 to 2.40  $\phi$ . Fig. 8 reveals that the Mz values at Station 3 further south are predominantly medium and to

TABLE 1 — MEAN AND STANDARD DEVIATIONS OF GRAIN SIZE PARAMETERS (MEAN SIZE, STANDARD DEVIATION, SKEWNESS) DURING FAIR WEATHER SEASON AND MONSOON SEASON FOR ALL THE STATIONS

(Values are mean  $\pm$  SD)

Grain size parameters	Stations				
	1	2	3	4	5
	Fair weather season				
No. of samples (n)	52	34	37	31	59
Mean size (Mz $\phi$ )	1.7501 $\pm$ 0.4683	2.1025 $\pm$ 0.1432	$\pm$ 0.2838 0.5968	2.1127 $\pm$ 0.2708	2.3177 $\pm$ 0.1905
St. deviation ( $\sigma_1$ )	0.6000 $\pm$ 0.1803	0.5638 $\pm$ 0.1600	$\pm$ 0.1911	0.5912 $\pm$ 0.1980	0.5258 $\pm$ 0.1814
Skewness (Ski)	-0.2950 $\pm$ 0.1144	-0.3368 $\pm$ 0.1194	-0.3700 $\pm$ 0.1251	-0.3533 $\pm$ 0.1120	-0.3476 $\pm$ 0.1592
	Monsoon season				
No. of samples (n)	12	11	14	10	11
Mean size (Mz $\phi$ )	0.7306 $\pm$ 0.6990	0.6928 $\pm$ 0.3808	0.7090 $\pm$ 0.3572	0.9522 $\pm$ 0.4401	0.7838 $\pm$ 0.6446
St. deviation ( $\sigma_1$ )	0.7351 $\pm$ 0.0588	0.6125 $\pm$ 0.1102	0.7350 $\pm$ 0.2816	0.7111 $\pm$ 0.1187	0.7843 $\pm$ 0.1581
Skewness (Ski)	-0.0705 $\pm$ 0.1644	-0.0137 $\pm$ 0.2160	0.0516 $\pm$ 0.1093	0.0185 $\pm$ 0.0899	0.0683 $\pm$ 0.0014

TABLE 2 — VALUES OF STUDENT'S *t* TEST AND THEIR SIGNIFICANCE FOR THE DIFFERENCES IN GRAIN SIZE PARAMETERS BETWEEN FAIR WEATHER SEASON AND MONSOON SEASON AT EACH STATION

Grain size parameters	Stations				
	1	2	3	4	5
	D F: 62				
		43	49	39	68
Mean size (Mz $\phi$ )	6.155*	18.260*	13.020*	10.040*	15.390;
St. deviation ( $\sigma_1$ )	2.550†	0.938†	2.013†	1.803†	4.416*
Skewness (Ski)	5.622*	6.308*	11.140*	9.521*	7.628*

\*  $P < 0.01$ . †  $P < 0.05$ . ‡ Not significant.

TABLE 3 - VALUES OF STUDENT'S *t* TEST AND THEIR SIGNIFICANCE FOR THE DIFFERENCES IN GRAIN SIZE PARAMETERS (i) BETWEEN STATIONS DURING THE FAIR WEATHER SEASON AND (ii) BETWEEN STATIONS DURING MONSOON SEASON

Grain size parameters	Stations									
	1 v/s 2	2 v/s 3	3 v/s 4	4 v/s 5	1 v/s 3	1 v/s 4	1 v/s 5	2 v/s 4	2 v/s 5	3 v/s 5
	Between stations during fair weather season									
DF:	84	69	66	88	87	81	109	63	91	94
Mean size (Mz $\phi$ )	4.248*	0.928†	0.892†	4.175*	3.493*	3.931*	8.547*	0.192†	5.715*	5.483*
St. deviation ( $\sigma_1$ )	0.952†	0.787†	0.119†	1.575†	0.079†	0.207†	2.156:	0.617†	1.012†	1.828†
Skewness (Ski)	1.627†	1.210†	0.643†	0.168†	3.004*	2.260†	1.972†	0.224†	0.344†	0.791†
	Between stations during monsoon season									
DF:	24	23	22	19	24	20	21	19	20	23
Mean Size (Mz $\phi$ )	0.159†	0.109†	1.494†	0.692†	0.102†	0.868†	0.188†	1.448†	0.403†	0.369†
St. deviation ( $\sigma_1$ )	3.371*	1.358†	0.252†	1.190†	0.008†	0.618†	1.005†	1.974†	2.954*	0.518†
Skewness (Ski)	0.713†	0.987†	0.785†	0.719†	2.258:	1.526†	1.818†	0.434†	0.921 †	0.265†

•  $P < 0.01$ . †Not significant. ‡ $P < 0.05$ .

a lesser extent fine sands and shows the presence of a greater percentage of medium sand. At Station 2 further south, the percentage of Mz values is clustered around 2.0 to 2.20  $\phi$  and indicates a greater percentage of fine sand size material than at the previous two stations. In contrast to the above, the sediments at Station 1 are predominantly composed of finer division of medium sand class with minor percentage of Mz values in fine sand class, thus indicating the existence of coarser size material at the extreme southern end than at the other stations towards north. When grouped together, the values clustered around 2.0 to 2.50  $\phi$ , indicating the percentage abundance of fine sand during the fair weather season.

There is a significant difference between the means of Mz values at Station 1 and those at other stations during October-April. The sediments at Station 5 are relatively finer than at the other stations, the differences in means being highly significant (Table 3):

However, the variations in mean size along the beach, found during October-April, were absent in the monsoon season (Table 3).

**Inclusive graphic standard deviation ( $\sigma$ )** — The sorting values (Fig. 3) show an increasing trend from upper to lower foreshore corresponding to an increase in the mean size. The backshore is composed of moderately sorted sediments while sediments of poor sorting were encountered at the breaker zone. The dunes are represented by moderately to well sorted sediments.

Besides mean size, the standard deviation values indicate a clear-cut seasonal variation (Fig. 6). The values increase from the end of April through August broadly corresponding to the distinct change in mean size. They tend to decrease from September through October to March and later the increasing trend is noticed. The lowest standard deviation values representing very well sorted class were encountered during October to April, while the sediments in monsoon were dominantly well to moderately sorted in nature. The differences in standard deviation values between the seasons

mentioned above were significant in all the stations except at Station 2 where they were not significant and at Station 4 they were significant at 10% level only (Table 2).

The means of standard deviation values broadly indicate variation along the beach similar to that seen in the mean size during fair weather season (Table 1). These variations have been brought out clearly by the frequency distribution curves (Fig. 9). At Station 5 the values show a bimodal distribution with clustering around very well and moderately well sorted classes. This grouping approximately represents the finer and coarser subdivisions of fine sand class. South of Station 5, i.e. at Station 4, the sediments are well to moderately sorted in nature, dominated by moderately well sorted class. Beyond this station towards south and up to Station 1, the sorting values come under well to poorly sorted class, majority of them being in well to moderately sorted classes. Though this is the general pattern from Station 4 to Station 1, the sorting values at Station 2 in particular are distributed in well to moderately sorted classes. The poorly sorted class has less percentage of representation throughout the foreshore during the above period. When the standard deviation values of the foreshore are grouped together, the distribution is peaked around 0.50 to 0.65  $\phi$ , thus showing the dominance of well to moderately sorted sediments. However, a tail corresponding to poor sorting of some of the sediments is also evident from Fig. 9.

**Inclusive graphic skewness (Ski)** — The skewness values of the foreshore sediments showed an increasing trend towards low water line corresponding to an increase in mean grain size. The backshore sediments are positively skewed or nearly symmetrical throughout the study period.

Monthly distribution of the average values of skewness also indicates a distinct seasonal variation at each of the stations (Fig. 7). The values apparently decrease from May-July and later on show an increasing trend from August onwards. The study reveals that the sediments have negative

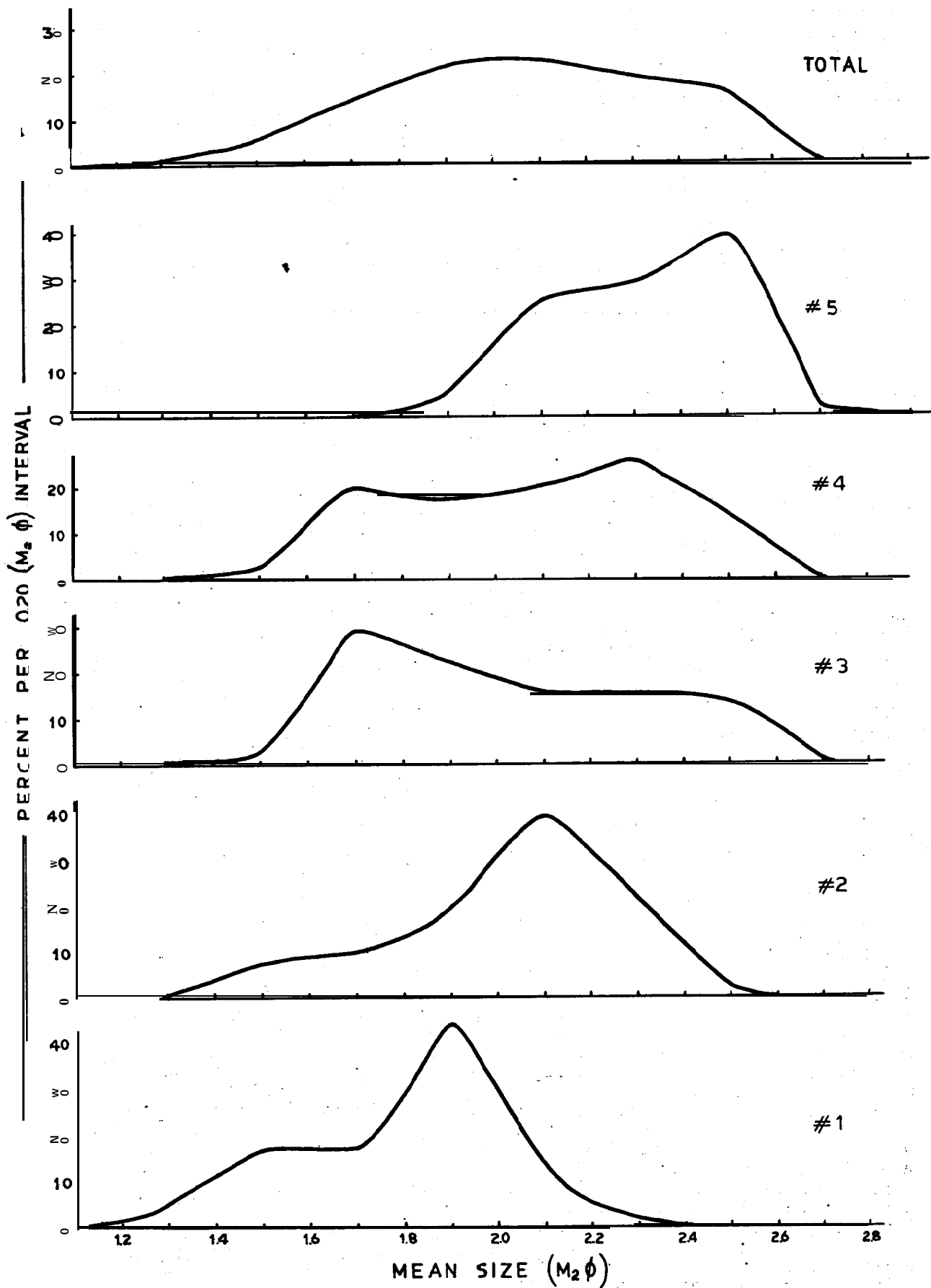


Fig. 8 — Frequency distribution curves for mean grain size ( $M_z \phi$ ) values of the foreshore sediments during the fair weather season (1969-70)

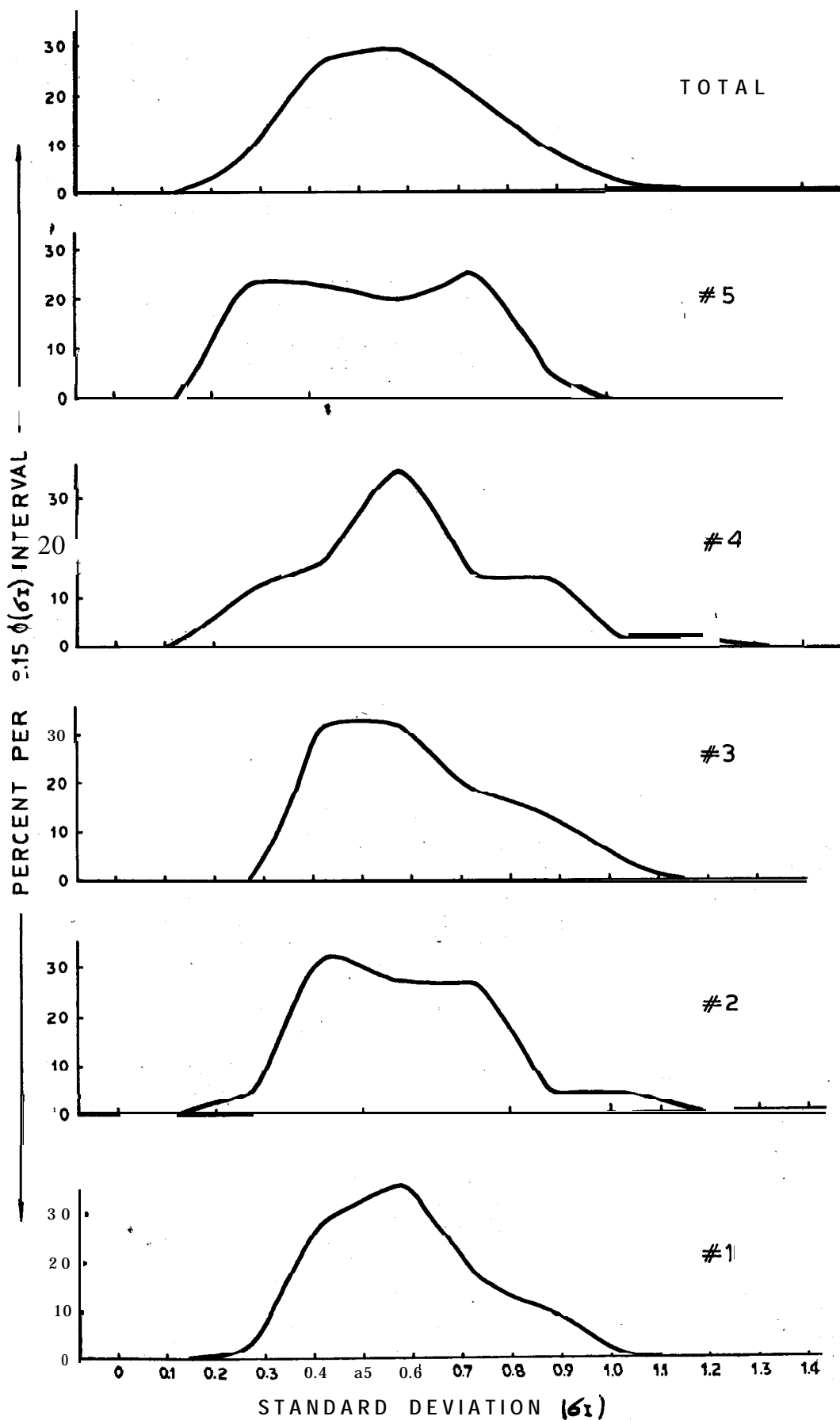


Fig. 9 — Frequency distribution curves for standard deviation ( $\sigma_1$ ) values of the foreshore sediments during the fair weather season (1969-70)

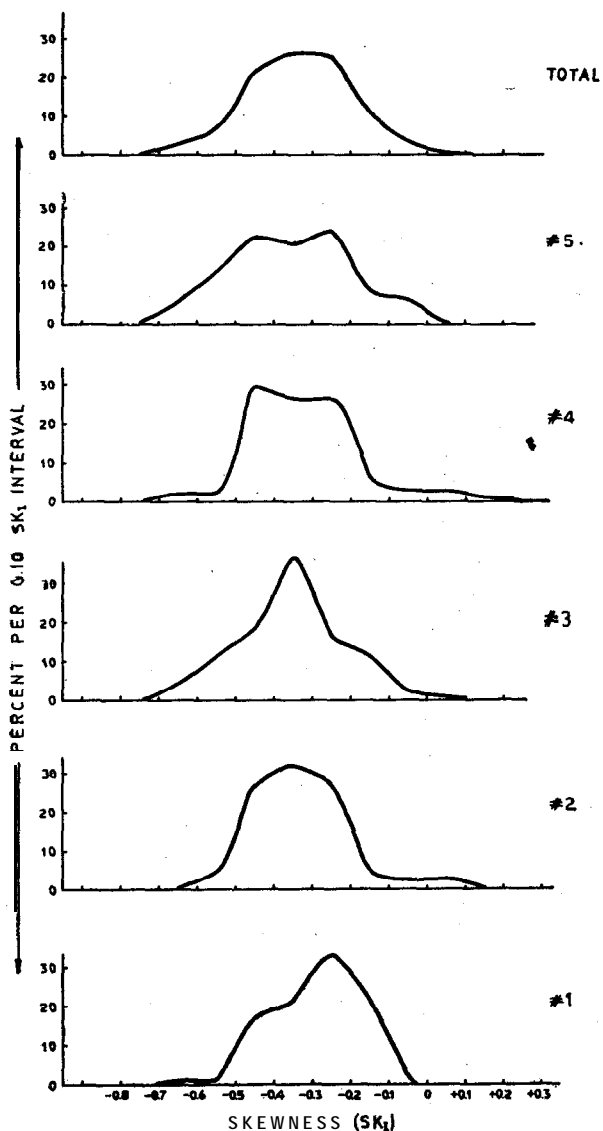


Fig. 10 — Frequency distribution curves for skewness ( $S_{ki}$ ) values of the foreshore sediments during the fair weather season (1969-70)

to very negative skewness and negative to positive skewness during fair weather and monsoon seasons respectively. However, in the latter season they are symmetrically distributed within the negative to positive skewness classes.

Frequency distribution curves (Fig. 10) indicate that at Station 5 the values are clustered around two classes, viz. negative to very negative skewness. This clustering shows a bimodality and a similar phenomenon was observed in the case of standard deviation values at this station. The nearly symmetrical distribution class also has about 6% of the values at this station. South of Station 5, up to Station 1, the skewness values have approximately a range from 0.00 to -0.65  $S_{ki}$ , thus representing the nearly symmetrical to very negatively skewed distribution. The occurrence of peak percentage of values does show an **apparent variation from station to station**, viz. at Stations 3 and 2 the values are concentrated around **-0.30 to -0.40** while at Station 1 they are between **-0.20 and -0.30**. The values are approximately distributed in a sym-

metrical pattern at Station 3 and a minor percentage of values at Stations 2 and 1 represent a tail towards lesser skewness values. When grouped together the values were clustered around -0.20 to -0.60  $S_{ki}$  showing negative to very negative skewed class.

#### Variations in Beach Topographic Features

It was found that the changes in sediment characteristics mentioned above were associated with corresponding variations in width and elevation of the beach (backshore and foreshore regions) from time to time. In order to get a relatively better picture of the variations in sediment characteristics, a few of the beach profiles are described and discussed below.

The monthly profiles for Station 3 shown in Fig. 11 reveal that the beach can be delineated into backshore and foreshore. In general, most of the erosion took place during the months of May, June, July and in the first half of August with a reduction in the berm widths, and a corresponding increase in mean grain size (i.e. lesser  $\phi$  values) and less well sorting of the sediments (Figs. 5 and 6). Another feature of importance was the formation of 'step' just at the lower foreshore during monsoon season.

In contrast to the rapid changes and large variations in the foreshore topography during the monsoon season, the recovery of the beach sediments needed longer period after the monsoon season. A maximum build up of 1.7 to 2.0 m at Stations 2 and 5 while a build up of the order of 1 m at Station 1 and of a lesser order at Station 4 was recorded during fair weather season. This build up was accompanied by a decrease in mean grain size as well as in sorting values (Figs. 5 and 6).

#### Discussion

The above seasonal changes in sediment parameters as well as in dimensions of the beach are possibly due to the corresponding changes in oceanographic conditions. It is known that winds, waves and tides are the important factors responsible for the movement of the material on the beach and the resultant form of the beach profile<sup>10</sup>. Among these, the force of wind-generated surface waves is the primary oceanographic factor affecting the changes in the beach. Although no complete statistical wave data are available for this strip of coast, the wave heights and periods observed during the surveys and the compiled swell wave statistics for the area<sup>11</sup> are in good agreement. The predominant directions from which severe waves were experienced are between west and south-west (during SW monsoon season) generated by west and south-west winds, the wave periods ranging from 5 to 14 sec, and waves approaching from west and WNW directions leach the shoreline during the rest of the year.

These seasonal changes in textural characteristics of the sediments as well as in dimensions of the foreshore reflect the changes in oceanographic conditions as outlined by Trask<sup>12</sup>. The coarser grain size in conjunction with the erosional features during May to August is due to the high and steep waves associated with the south-west monsoon. Field observations show that the prevailing as well as dominant winds with velocities of 18-20 knots

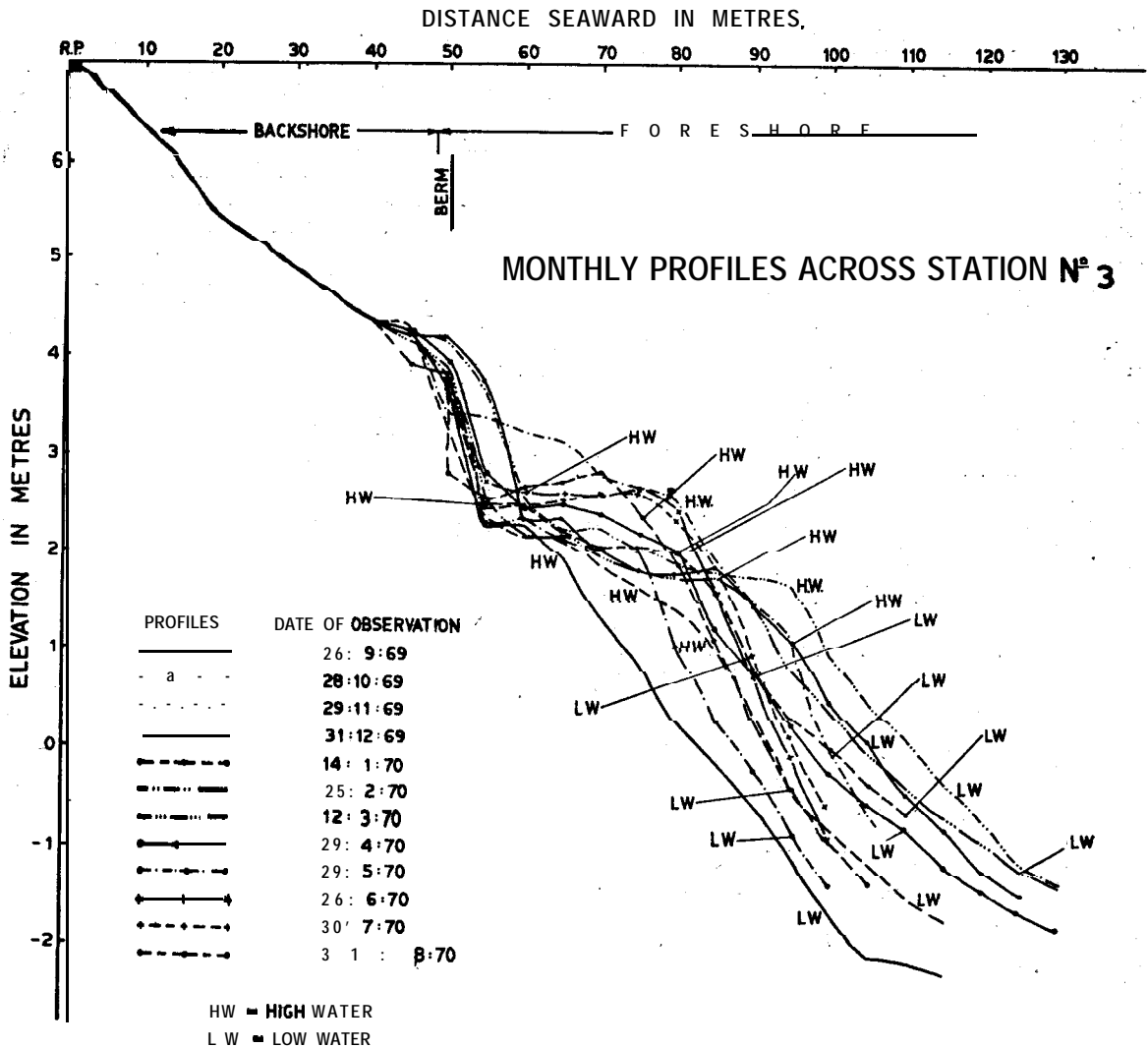


Fig. 11 — Monthly beach profiles for Station 3

and at times gusty winds with high velocities of about 28-30 knots blow onshore during the monsoon season. These prevailing onshore winds cause shoreward transport of surface water and compensatory offshore flow at depth<sup>13</sup>. Breaker heights were of the order of 2.50 to 3.50 m at Stations 1 and 2, and slightly less in height beyond Station 2 up to Station 4, while 1.00 to 1.50 m breakers were observed at Station 5 during the SW monsoon season. The turbulent swash of these breakers would keep the fine sediments of the beach in suspension. However, prior to the prevalence of severe monsoon conditions, the concentrated wave action on the beach developed a vertical scarp just below the new berm edge. The development of this scarp gave rise to steep slopes of the order of 15 to 17° at the upper foreshore which decreased to 3 to 4° towards lower foreshore. The return flow of water in the form of backwash, aided by the steep slopes, transports the sediment seaward, thus giving rise to coarser grain size on the foreshore. This feature in the month of May at Station 3 may be observed from Fig. 2. In this process the berm is cut back and it further undergoes reduction in width as soon as the monsoon intensifies. The

result of this is an accumulation of sediment below the low water line (and also outside the breakers) at the expense of the beach in the form of an offshore bar. Further, a part of the suspended sediment is being carried offshore by the rip currents prevailing in this region during the monsoon season.

Although the variations in sediment parameters during January-February (another period of erosion) were not very pronounced, the corresponding changes in elevations of the foreshore, in general, were relatively noteworthy. These can be attributed to the changes in wave regime in this part of the year. Except for these minor changes, which may be of local nature, the beach has undergone accretion till April aided by the relatively long-period swell waves. These swell waves cause net shoreward transport. In this process, the bottom sediment is moved shoreward and it thus re-enters the littoral zone<sup>13</sup>. Further, these low frequency waves break in such a way that the swash is more effective than the backwash, thus moving the material up the beach<sup>10</sup> and replenishing the beach material. Hence, the sediments are represented by fine sand size class in majority of the cases during this period. The monsoon high waves, while aiding the cut at

the seaward side of the berm during spring tides, push back some of the material landward, thereby building up the berm from that end. The sediment which was pushed back thus contributes to a further build up of the berm or double berm. Subsequently as the SW monsoon conditions recede, the berms start building up and grow seaward during neap tide conditions and the sediment is pushed back by the succeeding spring tide swashes<sup>14</sup> and this feature was observed during the tidal cycle observations on this beach, the details of which will be described separately elsewhere. The material deposited in this way on the landward side sloping part of the new berm was left out as lag deposit. This washover material was generally composed of shells, shell fragments, well-rounded rock and quartz pebbles of granule to pebble size class. This may be one of the reasons for the coarser mean size of the new berm than that of the foreshore and backshore of the beach (Fig. 2). This washover material is present at all the stations, except at Station 5 and is one of the characteristic features of this beach. If similar sediments were preserved in the stratigraphic columns of the ancient beaches, they would aid in the identification and delineation of regions of high wave activities along the past shorelines and the results of this study corroborate the statement that 'washover material present interpretative problems of paleoenvironments'<sup>15,16</sup>. Thus the unique presentation of wide range of size of material, i.e. represented by granule (often pebble size) to fine sand classes, represents a special case<sup>17</sup>. Besides this feature, fragments of tax of about 5 to 15 mm and of lesser dimensions were concentrated at swash marks and also at the upper limits of swashes of the monsoon high waves. A similar feature was observed on the Mediterranean beaches of Israel<sup>18</sup>. The detailed investigations about the nature and origin of the tar material in the area of study may, perhaps, reveal some interesting results.

Besides the general increase in the mean size from the upper to lower foreshore the study also indicated maximum grain size material at the 'step formation' during June to August corresponding to high wave energies as predicted under the model proposed by Miller and Zeigler<sup>19</sup>. In general, the mean size increases corresponding to an increase in the foreshore gradient. The presence of coarse size material at the lower foreshore is due to the fact that it receives more energy than the upper foreshore. However, at times the upper foreshore was also represented by coarse size material and this is the result of the winnowing away of fine material by wave action and wind. Breaker zone is the other region where coarser size material was encountered. This phenomenon was due to the active hydrodynamic processes in this zone which keep the fine particles continually in suspension<sup>20,21</sup>.

The relatively good sorting of the sediments during fair weather season indicates the dominance of one size class, i.e. fine sand; whereas the poor sorting in monsoon is due to the presence of a combination of several grades dominated by coarse to medium sands. However, the transition periods are characterized by high sorting values, because of the presence of coarse and fine sands which contribute to high deviation values. Subsequently

as the monsoon conditions recede, the finer sediments are being brought back on to the beach and the mean size shows decreasing trend, thus giving rise to lesser standard deviation values. The significant differences in these values between the two extreme stations (Stations 1 and 5) are due to the fact that the sediments at Station 5 are dominated by fine sands whereas at the other end they are mainly composed of coarse to medium sands, and to a lesser extent the fine sands present give rise to a better sorting at Station 5 and a less well sorting at Station 1.

In general, the sorting values increase from the berm crest to seaward side of it on the foreshore. This increase is due to the corresponding increase in the size of the sediments (Fig. 3). In contrast to the very well to moderately sorted sediments of the foreshore (fair weather season), the breaker zone is characterized by poorly sorted sediments. This poor sorting is due to the presence of wide range of material sizes present<sup>22</sup>. The winnowing action of waves transports the fine material from the beach face and subsequently a part of it would be deposited below the low water line. The poor sorting is the result of mixing of this fine material with the coarse material already present in this region. Similar phenomenon was observed by Inman and Chamberlain<sup>23</sup> in the surf zone off La Jolla, California, USA.

Most of the time the sediments are having their mean diameters in medium to fine sand grades and also in coarse to very coarse sand grades, i.e. they are beyond the best sorted range of Inman<sup>24</sup> and are hence less well sorted in nature. The frequency curves for the individual samples show that they are represented by more than one population, i.e. from granule to fine sand grade, and exhibit, at times, a tendency towards bimodality. The mixing of these populations led to decrease of level of sorting<sup>25</sup> while the sediments with dominantly one population becoming well sorted. Although it has been stated in the literature that certain size fractions are relatively scarce among terrigenous sediments, the sediments of this beach are composed of granule to coarse sand material fairly in good percentage (particularly in the monsoon season). The dominance of this size of material in the area of study may reflect the dominance of this size material in the source area<sup>26</sup>. Hence, the degree of sorting is dependent not only upon the effects of wave energy reaching the coast, but also upon the source from which the sediments were derived<sup>27</sup>.

However, plots of sorting versus mean size for the foreshore sediments (Fig. 12) indicate broadly a sinusoidal pattern as noticed by Folk and Wards and further reveal that the best sorted sediments coincide on the graph with the lower deflections on the sinusoidal trend. It also shows that an increase in standard deviation occurs from fine to medium sand sizes as reported by McKinney and Friedman<sup>28</sup>. This shows that the measures of size distribution are somewhat interdependent and that a physical relationship exist: between the mean diameter and the standard deviation for most water-transported sediments<sup>24,28</sup>.

Of the three measures of size distribution under consideration, the skewness parameter has shown significant seasonal variations<sup>20</sup> next to mean size

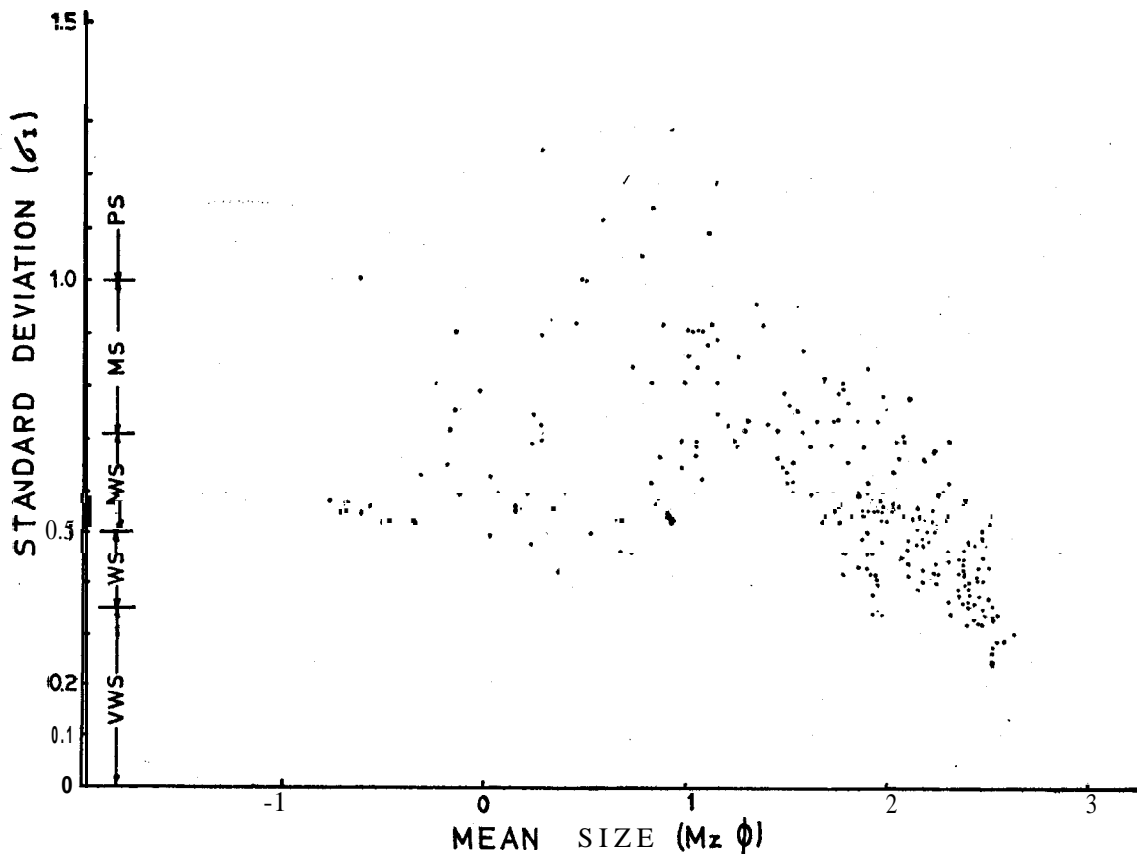


Fig. 12—Scatter plot of mean grain size ( $M_z \phi$ ) versus standard deviation ( $\sigma_1$ ) of the foreshore sediments [VWS — very well sorted, WS — well sorted, MWS — moderately well sorted, MS — moderately sorted, and PS — poorly sorted]

(Table 2). As mentioned earlier all the foreshore samples, during the fair weather season, are negatively skewed and this negative skewness is due to the presence of line size material in greater percentage with a coarse tail thereby skewing the frequency curve to the coarser side. The positive skewness or the nearly symmetrical distribution of the foreshore sediments during monsoon season may be due to the subtraction of fine size material leaving behind the coarse mode with fine tails (relative to the coarse sizes). The positive skewness or nearly symmetrical nature of the backshore and the dune sediments: would result from the incorporation of fines by onshore winds from the exposed parts of the foreshore and berm crest.

Apart from winds, waves and tides, the direction and amount of littoral drift and the configuration of the shoreline are also important in determining the distribution of sediments of the beach<sup>29</sup>. This is due to the reason that waves breaking at an angle with the shoreline set up a longshore/cr littoral current which may reach a velocity of several knots and, which is capable of carrying large amounts of sediments<sup>30</sup>. Since the shoreline under investigation trends approximately in NNW-SSE direction, the longshore drift would be in either of these directions, depending upon the prevailing direction of onshore wave travel due to sea and swell. The longshore current velocities determined by observing float movements varied from a few centimetres to about 80 cm/sec. During the monsoon season they were directed towards north and in

the rest of the year they were partly north, and also in offshore-onshore directions, and at times south.

The observed variations in mean size along the beach from Station 1 to Station 5 during fair weather season revealed that the mean size decreases in that direction. The sorting values also showed a similar pattern. It is surmised that these differences would arise due to the prevailing northerly littoral currents. Further it has been observed during the surveys that on the southern part of the beach the waves break closer to the shoreline, while on the northern side they break a little away from the shoreline. This may also be partly responsible for the general decrease in the mean size from south to north. This indicates that the change in mean grain size along the beach reflects the changes in the nearshore energy environment<sup>31</sup>.

However, lack of significant variations in textural parameters of the sediments along the beach during the monsoon season may indicate the intensity of oceanographic conditions prevailing over the area during this season.

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