

Textural Characteristics of Sediments of Mormugao Bay, Central West Coast of India

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Thirty-three surface sediment samples, collected from Mormugao Bay, are subjected to grain size analysis. Textural characters of the sediments, defined by moment measures, are interpreted as resulting from variable mixing of sand, silt and clay populations derived from different sources. The coarser material, mainly consisting of sands, is well to moderately sorted, positively skewed and leptokurtic, and is confined to the bay marginal high energy areas. The finer material predominantly of silts and clays is poorly to very poorly sorted, negatively skewed, and platykurtic, and is present in the central bay which is a low energy area. There is a patch of coarse material extending from the north-western end of the bay in a NW-SE direction into the bay and this patch indicates that the incoming and outgoing currents follow this path and prevent finer sediments from accumulating and consequently silting up the bay.

AS part of the oceanographic studies oriented towards the Mormugao harbour development programme, undertaken by the Institute, grain size distribution characteristics of the surface sediments from the Mormugao Bay area are studied to understand the trends of sediment transport and silting in the bay.

Mormugao Bay (14 km length and 6.5 km maximum width) extends in a east-west direction from the Western Ghats and opens into the Arabian Sea (Fig. 1). The rocky shoals and reefs extending in a north-south line (across the entrance of the bay) separates the bay from the Arabian Sea. The rock is exposed in the bay all along its northern side except near Dona Paula and Cacra point. In con-

trast, the southern side of the bay is sandy except at Vaddem Bay and Chikkalim point where rock is exposed. A break-water 1714 ft long extending NNE from the shore protects the harbour from the south-west monsoon. About 180 ft within the outer end of this break-water, a mole extends in an easterly direction which gives protection to the berths from the north-east monsoon. River Zuari enters the bay at its eastern end through a constricted passage at Cortalim-Agacaim junction. The bottom topography contours of the bay (as given in Hydrographic Office Chart No. 2022) indicates that the bay is deeper at the western side and gradually becomes shallower towards eastern side.

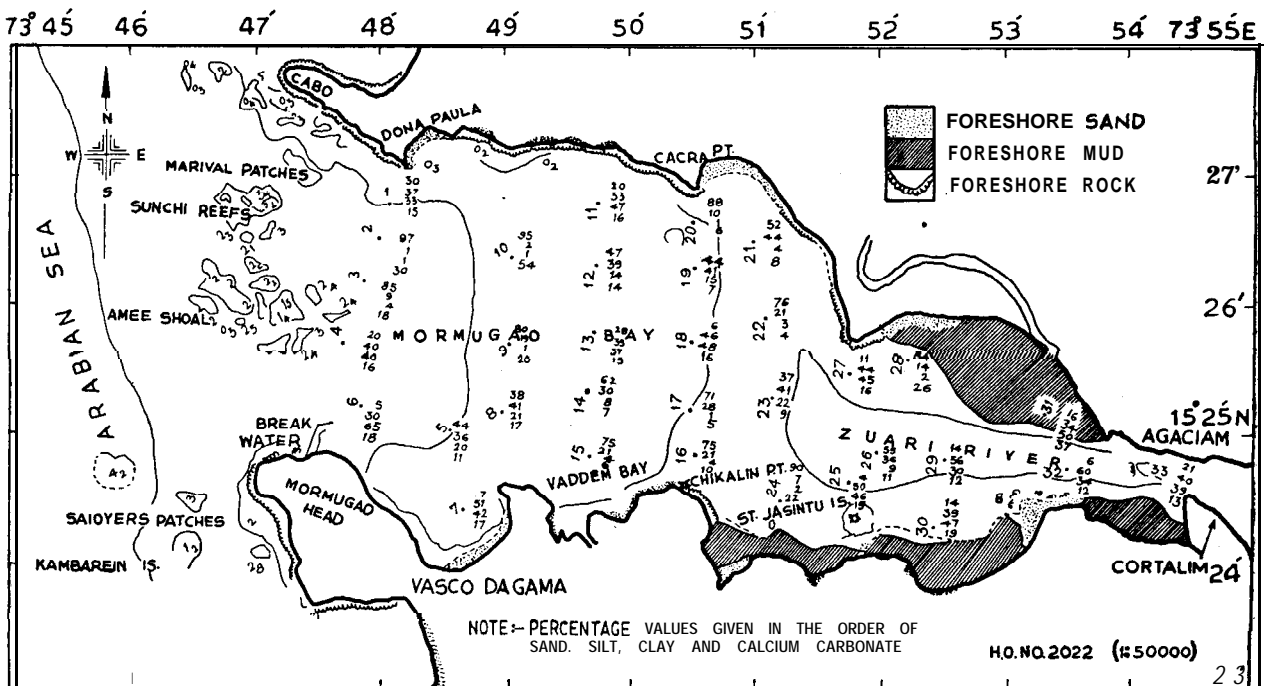


Fig. 1 — Station location and topographic contours of the Mormugao Bay

Methods

In all 33 surface sediment samples were collected using the Van-Veen grab in October and December 1972. Station positions were fixed by sextant with reference to the prominent shore features. Sediment samples collected were in general composed of brown sands, greyish silts and clays.

After preliminary preparation, each sediment sample was initially washed through a ASTM 230 mesh sieve. The coarser, material retained on the sieve was dried and separated into different 'size grades by shaking it through a nest' of sieves. The finer material that passed through the sieve was analysed by the pipette method¹. The two analyses were combined into a single one. The sediments were then classified into gravel, sand, silt and clay following Shepard². Calcium carbonate content was also determined as the difference in weight of the fixed amount of dry sample before and after digesting with dilute hydrochloric acid.

Results

Frequency Distribution and Interrelationships of Statistical Parameters

Statistical parameters are estimated and their distribution properties are studied for making a qualitative comparison of the sedimentary environments. The mean size ($M_z\phi$), standard deviation (a), skewness (Sk) and kurtosis (K_G) are determined graphically by reading selected percentiles of the cumulative curves as suggested by Folk and Ward³. The values thus obtained are given in Table 1. Frequency distribution and their interrelationships are described below.

Mean size - Mean size value mostly varies between 3ϕ and 8ϕ (Fig. 2a). However, it is less than 1.2ϕ for 3 samples corresponding to the minor peak of frequency distribution curve in which gravel and coarse sands associated with shells are present. The two clusters occurring with ϕ values ranging between 2.5 and 4.5 and 6.5 and 8.0 corresponding to fine sands and silty clays respectively reveal the bimodal distribution of the sediments.

Standard deviation - Standard deviation values range from 0.35 to 2.95 (Fig. 2b). This shows a bimodal distribution with two clusters occurring between 0.3 and 0.7 and 2.0 and 2.5. These represent well to moderately sorted sands, poor to very poorly sorted silty clays respectively.

Skewness - The sediments have bimodal distribution of skewness values with a larger clustering about +0.2 to +0.45 and the smaller clustering about -0.2 to +0.1 (Fig. 2c). The first group corresponds to sediments with higher percentage of sands as well as those samples in which nearly equal percentages of sand, silt and clay occur. The second group corresponds to those with higher percentage of silt and clay.

Kurtosis - Mormugao bay sediments show a non-normal distribution of kurtosis values (Fig. 2d) with clustering between 0.6 and 1.0 (leptokurtic) and the second smaller cluster with kurtosis values between 1.2 and 1.4 (platykurtic). The large cluster of values corresponds to coarser sediments and the small cluster to finer sediments.

Mean size versus standard deviation - Mean size versus standard deviation (sorting) shows (Fig. 3a) only one limb of the broadened M as suggested by

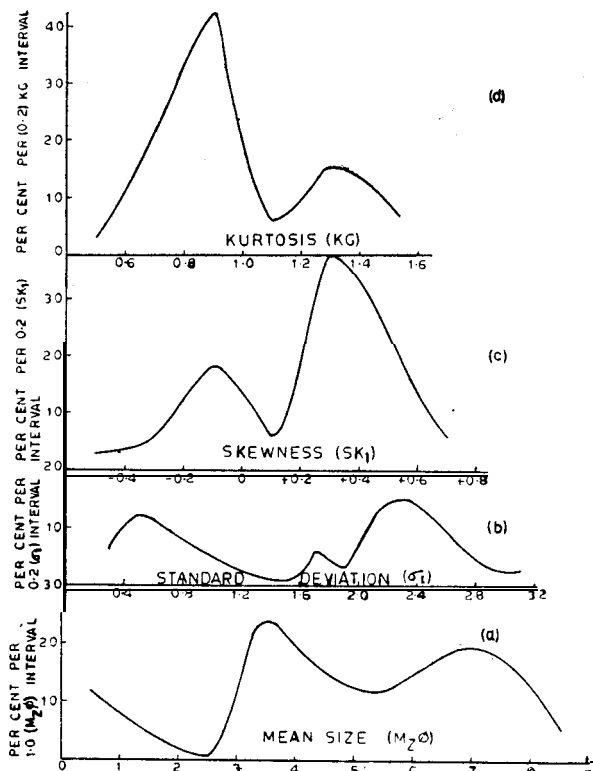


Fig. 2 — Frequency distribution curves [a, mean size; b, standard deviation; c, skewness; and d, kurtosis]

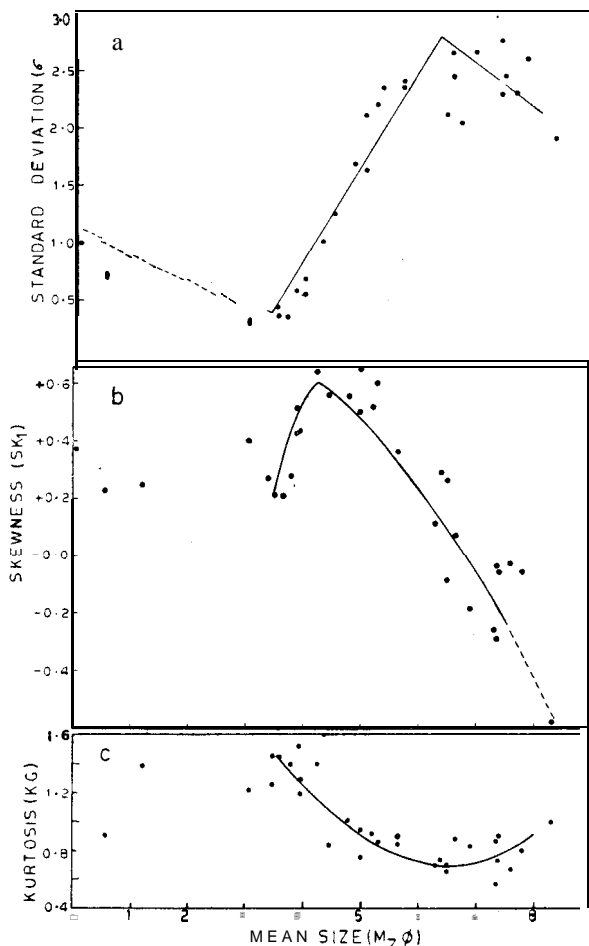


Fig. 3 - Scatter plot of mean size versus (a) standard deviation, (b) skewness and (c) kurtosis

Folk and Ward³ which covers the range from fine sands to coarse silts. The downward hook of the limb corresponds to the fewer samples in which the clay portion is fairly high. The three samples containing gravel are not well connected with the main limb. This may be due to the absence of samples ranging from gravel to sands. The minima or best sorting (0.35ϕ) coincides with the prominent sand mode (80 to 90%) with Mz values 3.30ϕ . As the sand population decreases and silt population increases the sorting becomes poorer. The maxima of the curve corresponding to poorest sorting (2.75ϕ) occur for those samples consisting of mixtures of sand, silt and clay with Mz values around 6.5ϕ . As the clay percentage increases and the sand population decreases the sorting improves and the curve shows a downward trend.

Mean size versus skewness - Scatter plot of mean size versus skewness (Fig. 3b) represents the half portion (positive side) of the sine curve suggested by Folk and Ward³. In most of the samples the second mode is of the order of 10% or even more and as such none of the samples are symmetrically skewed. Skewness values of the order of +0.2 to 0.45 occur for the samples in which the gravel plus sand or silt plus clay is more than 80%. As the sand mode decreases and silt mode increases the samples are more positively skewed and the maximum positive values occur for the samples in which the sand and other finer modes are nearly in equal proportion. Addition of clay mode further decreases the skewness values and the negative skewness occur for the sediments with predominant silt and clay populations.

Mean size versus kurtosis - Scatter plot of kurtosis versus mean size (Fig. 3c) follows the theoretical trend as suggested by Folk and Ward³. The presence of second mode deteriorates the sorting in the tails for the samples mainly consisting of sands, while sorting in the central part remains good. Hence the curve becomes strongly leptokurtic with kurtosis values considerably higher than 1. As the sand content decreases and the silt and clay content increases the samples become platykurtic with KG values around 0.6. As the clay content further increases, the kurtosis values also increases and the curve shows a slightly upward trend.

Skewness versus kurtosis - Scatter plot of skewness versus kurtosis (Fig. 4) is divided into four zones, a, b, c and d, following Thomas *et al.*⁴. In zone 'a' the samples are leptokurtic with positive skewness denoting the prominent sand mode population; zones 'b' and 'c' are platykurtic and represent the progressive mixing; the predominant modal type is denoted by the sign of the skewness. Zone 'b' is positive with dominance of coarser material and zone 'c' is negative with dominance

of finer material. No sample falls in zone 'd' since more of the samples consists more than 50% clay with exception of one sample wherein the clay percentage is about 65% and still fall in zone 'c'.

Regional Distribution

Sand predominates in the inshore regions (Fig. 5a). Along northern side the sand population is 60 to 90%. On the southern side the sand population is 70 to 90% in the central portion and it is less than 10% in western and eastern portions. The sand population gradually decreases from the inshore regions to central bay. Around stations 2, 3 and 9 the sand plus gravel contours reveal a tongue-like feature which suggests the flow of coarser material into the bay from a NW to SE direction.

Silt percentage contours (Fig. 5b) in general represent a pattern similar to that of sand plus gravel percentage contours. The silt content is around 10% in the north-western portion of the bay whereas it is of the order of 40% in the harbour area. The silt content increases from the inshore regions into the central bay. It is of the order of 60% along the axis of river Zuari in the eastern bay.

Clay population (Fig. 5c) is almost absent along the northern margin of the bay except at isolated 'pockets'. In the southern side the clay population predominates in the harbour area and along the axis of river Zuari in the eastern bay. In the central bay the clay population is about 45% which is almost the same as that of silt.

Regional distribution of the mean grain size values (Fig. 5d) shows good confirmity with the regional distribution of sands and silts. Coarse size material along the bay margins, the finer size material in the harbour area, central bay and eastern bay and the tongue like feature of the coarse material at the bay mouth that have been indicated by the sand, silt and clay percentage contours are also well defined.

In the nearshore area where the sands predominate, the standard deviation values are fairly less, representing well to moderately sorted sediments. From the nearshore to the central bay the sediments are characterized with higher values of standard deviation which represents the progressive mixing of sands, silts and clays. In the central bay, eastern bay and harbour area these are poorly to very poorly sorted with still higher values of standard deviation. The patch of coarse material at the bay mouth as indicated by the regional contours of sands and silts is also well indicated with the lower values of standard deviation.

Skewness values are negative for the sediments with very fine silts and clays and positive for the sands and coarse silts. Lack of symmetry in size distribution is due to the presence of silts which induces a positive skewing of sand population and negative skewing of clay population. The skewness values are nearly zero for those sediments mainly consisting of silts and clays as well as those consisting of equal proportions of silts and clays with little amount of coarse material.

Kurtosis values indicate all the sedimentary environment patterns that are represented by the regional distribution of sands, silts and mean size. Sediments consisting mainly of coarse material are

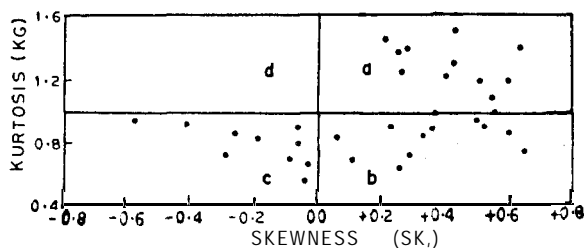


Fig. 4 — Scatter plot of skewness versus kurtosis

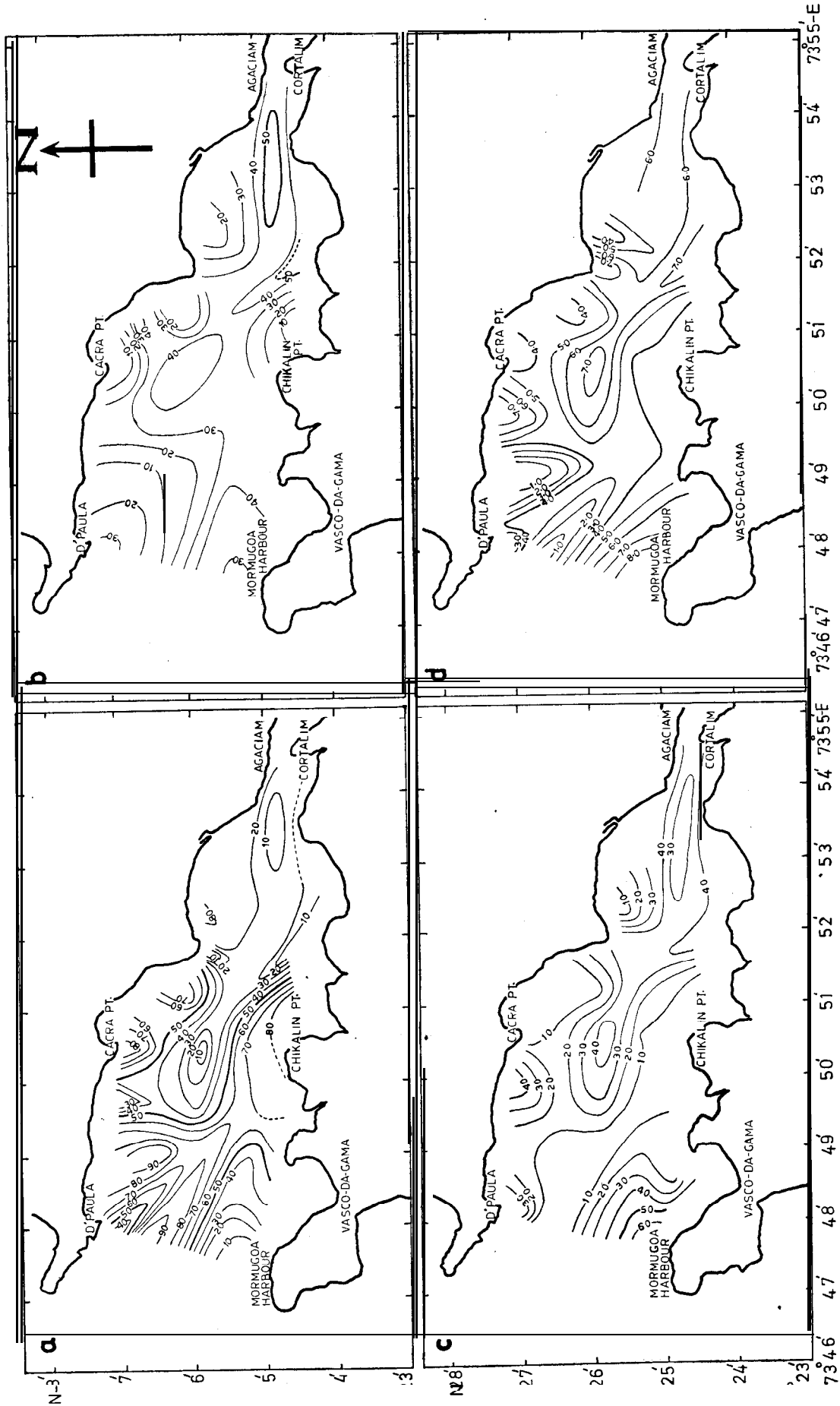


Fig. 5 — Regional distribution of (a) gravel plus sand, (b) silt, (c) clay percentage, and (d) mean size ($Mz\phi$)

all leptokurtic with kurtosis values much higher than 1 and of fine material are all platykurtic with kurtosis values less than 1.

Discussion

From the textural characteristics of the bay sediments the bay may be divided into four sedimentary environments : (i) marginal high-energy areas of bay with sands, (ii) bay mouth with coarse sands, (iii) eastern bay with silts and clays, and (iv) central bay with fine silts and clays.

The sediments along the northern and southern margins are predominantly sands. These are well to moderately sorted and positively skewed. Gradual decrease in mean size and increase in standard deviation (σ) from the coast line into the offshore region can be due to the progressive variation in the mixing of sand and clay end member populations. The transport and mixing of the sediments in this area is believed to have been brought by the wave action whose energy level decreases as the depth to the bottom increases. The presence of silts among coarse material in this region induces positive skewing of sands.

The regional distribution of sands, silts and mean size indicates a patch of coarse material extending into the bay from bay mouth in a NW-SE direction. This patch indicates the path of currents prevailing in this area. Strong currents along this trend winnow the fine material and carry it away leaving the residual deposit enriched in coarse material. Earlier Reddy⁵ reported that the sediments accumulate within the bay area as the littoral currents are directed into the bay both from its northern and southern sides for all wave directions. It has been further stated that the maximum wave heights are found near Dona Paula and Cabo regions. From above observations it may be inferred that the patch of coarse material which extends into the bay from its north-western end owes its origin to the transportation of coarser material from the Cabo and Dona Paula regions. The topographic data (collected separately and not reported here) do not indicate any surface relief in this area. This indicates that even though the currents in this region are favourable for the flow of sediments into the bay there is no substantial build up of sediments. The tidal currents observed in this area have indicated that the flood and ebb currents are of the same magnitude of the order of 1.08 knots. Therefore, the tidal currents do not favour for the accumulation of the sediments because whatever the material brought by them can be taken away as both the currents are of equal magnitude. Topographic data also suggest that the transport and supply of sediments into the bay by littoral currents⁵ are also very less. One of the possible reasons for this effect may be that these currents might have been weakened by the shoals and reefs present at the bay mouth.

In the eastern bay the sediments are mainly clays associated with fine silts. They are poorly to very poorly sorted and are negatively skewed. The eastern bay is mainly effected by the material brought by the river Zuari that enters into the eastern bay through a narrow constriction at Agacaim and Cortalim junction. The 1 fm contour line clearly indicates the main axis of the river flow into this bay. The finer material content is more

TABLE 1 — GRAIN SIZE DATA OF SEDIMENTS OF MORMUGAO BAY

Station No.	Depth In	$M_z(\phi)$	Standard deviation (σ)	Skewness (S_k)	Kurtosis (K_G)
1	6.8	5.63	2.39	0.36	0.90
2	7.0	0.53	0.74	0.23	0.91
3	8.1	1.20	1.15	0.25	1.38
4	10.0	6.50	2.48	0.26	0.66
5	8.0	5.30	2.35	0.60	0.87
6	10.0	8.30	1.90	-0.58	0.95
7	4.0	7.37	2.31	-0.29	0.74
8	5.5	5.20	2.20	0.52	0.92
9	6.9	3.47	0.48	0.27	1.26
10	6.5	0.03	1.00	0.37	1.00
11	5.7	7.33	3.10	-0.04	0.58
12	5.7	5.00	2.11	0.50	0.95
13	5.7	6.30	2.81	0.11	0.70
14	5.3	4.26	1.00	0.64	1.40
15	4.1	3.93	0.63	0.43	1.51
16	3.3	3.80	0.58	0.46	1.40
17	3.3	3.93	0.67	0.51	1.20
18	4.0	7.80	2.60	-0.06	0.81
19	4.2	5.00	1.62	0.65	0.76
20	3.0	3.50	0.35	0.21	1.45
21	3.2	4.43	1.26	0.56	0.84
22	3.0	3.93	0.54	0.43	1.30
23	3.0	5.63	2.35	0.33	0.85
24	3.0	3.10	0.35	0.40	1.23
25	3.1	7.60	2.31	-0.03	0.68
26	2.0	4.80	1.68	0.55	1.10
27	4.5	7.40	2.45	-0.06	0.91
28	1.0	3.63	0.42	0.21	1.45
29	4.0	6.63	2.03	0.07	0.88
30	5.9	6.90	2.65	-0.19	0.84
31	1.2	7.33	2.77	-0.26	0.87
32	5.9	6.40	2.11	0.09	0.74
33	5.5	6.50	2.60	-0.09	0.71

in the eastern bay and it gradually decreases towards the central bay. This may be due to the phenomena that most of the finer material brought by river Zuari when it meets the salt water in the upper bay gets flocculated and settles down. Tidal observations near Agacaim-Cortalim junction have recorded the ebb currents of the order of 3 knots and the flood current is nearly 1.5 knots during the spring tide. The ebb currents being much stronger than the flood current it also contributes significantly for the transportation of the material from east to west.

The sediments in the central bay mainly consists of silts and clays characterized by higher values of mean size, and standard deviation. The silts and clays together are of the order of 95% whereas sands are only about 4 to 5%. Calcium carbonate content is nearly 16% in this area (Table 1) and it is about 5 to 10% in the neighbouring area. The amount of suspended load shows relatively higher percentage in the central bay both during ebb and flood currents. However, the suspended material is significantly high (70 to 90 mg/litre) during the ebb currents. The flow of finer material into the central bay from the eastern bay and the closed nature revealed by regional contours for silts and clays suggest that the material, being transported by river Zuari, is deposited mainly by the silting of the suspended load.

Zones 'a' to 'c' (Fig. 4) indicate a condition of progressive decline in energy from the nearshore area of higher energy condition to the central bay of lower energy condition. The coarser population,

mainly sands and coarse silts, corresponds to higher energy regime and occurs predominantly along the margins of the bay. The sediments with higher percentage of clays and fine silts, corresponding to the lower energy regime, occur mostly in the central and eastern bay.

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