

## Sediment Depositional Environment in Some Bays in Central West Coast of India

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Sediments in Kalbadevi and Mirya bays are well sorted while those in Ratnagiri bay are poorly sorted. Mean size of the sediments varies among the bays. Sediments in Kalbadevi bay are both positively and negatively skewed while in Mirya bay negatively and Ratnagiri bay positively skewed. Kalbadevi sediments show high kurtosis values while those of Mirya bay show medium values and Ratnagiri bay low values. Bivariate plots between various textural parameters predict mixed environments, viz. for Kalbadevi bay: beach/river/barrier island/lagoon type; Mirya bay: beach to barrier island type and Ratnagiri bay: river to lagoon type. The abnormal values of kurtosis are attributed to such palimpsest environment in these bays. The earlier reported heavy minerals data show a positive correlation with mean grain size in Kalbadevi bay but negative correlation in Ratnagiri bay, whereas they show an unharmonic relationship with sorting. Considering similar hydraulic conditions in all the bays, the existence of variation in the distribution of magnetite and ilmenite has been attributed to either a change in the depositional environment or different amount of input of sediments from a mixed provenance.

The Konkan coast, extending for about 230 km from Dabhol (17°02'N) through Ratnagiri to Vengurla (16°N), is marked by a number of rocky promontories with intervening arcuate bays and estuaries. Occurrence of ilmenite placers on the beaches of these bays and estuaries<sup>1</sup> and their extension to the offshore areas<sup>2</sup> have been reported. In the present investigation sediment texture is studied to understand the environments of sediment deposition and correlate the same with the mineral concentration. Within this region 3 adjacent bays, viz. Kalbadevi, Mirya and Ratnagiri, which are different in their configuration but with common source area of Deccan traps and cliffs, forming headlands, have been selected for the study.

### Materials and Methods

The shore lines of the bays were traversed with Wild T<sub>2</sub> Theodolite to fix markers. The survey tracks were spaced at about 200 m normal to the coast to obtain the best possible coverage of variation in topography and sediments. The positions during the surveys were fixed by sextant angles of shore objects. A seafarer echosounder with a phasing of 10 m adjustable to 60 m was used for depth measurements. Bottom sediment samples were collected as far as possible on uniform spacing by Van Veen grab (area 0.04 m<sup>2</sup>). The surveys were carried out on a scale of 1:10,000 and an area of 17.4 km<sup>2</sup> was covered and 396 samples were collected from the 3 bays.

Sediment samples were washed in the laboratory to remove salt, etc., dried and samples with significant organic matter were treated with 20 volumes of H<sub>2</sub>O<sub>2</sub> before final washing. The dried, coned and quartered

samples were sieved using half phi interval<sup>3</sup> and silt percentage was obtained by pipette analyses. Textural parameters (mean, sorting, skewness and kurtosis) were obtained following moment method using a Fortran IV Programme of Schlee and Webster<sup>4</sup> on an ECIL TDC 316 computer at the Institute. The moment method was preferred as it is found to be superior for describing the natural size frequency distribution<sup>5,6</sup>.

### Results and Discussion

The 3 bays differ in the nature of sediment supply and exposure to monsoon waves (Table 1). Range and average values of textural parameters are given in Table 2.

*Mean-grain size*—The frequency curves (Fig. 1) show bimodal distribution in all 3 bays. The fraction between 3 and 4φ is the primary mode. The secondary mode differs in all the bays, being 1 to 2, 0 to -1 and 1 to -1 φ in Kalbadevi, Mirya and Ratnagiri bays respectively. The change in the primary mode (3 to 4 φ) in all the bays is observed either at the offshore where clay is overlapping the sand or at the river mouth where fresh sediments are introduced in the depositional basins.

The central part of Kalbadevi bay (Fig. 2) shows finer sediments surrounded by coarse ones suggesting a low energy zone in the center. This may be due to coarse material, brought by the rivers, being deposited at their mouths, the north and south, while the finer material is carried further and deposited in the center. A general decrease in the grain size is observed from the shore in the E to W in Mirya bay (Fig. 2), while in Ratnagiri bay, the size of the sediments decreases gradually seawards. This perhaps, indicates a normal

Table 1—Characteristic Features of Kalbadevi, Mirya and Ratnagiri Bays

	Kalbadevi	Mirya	Ratnagiri
Location	17°05':17°02'N 73°15':73°18'E	16°59'20":17°02'N 73°15':73°17'40"E	16°57':16°59'20"N 73°16':73°18'E
Area	7.5 km <sup>2</sup>	6.5 km <sup>2</sup>	7.3 km <sup>2</sup>
River and its catchment	one in the north (50 km <sup>2</sup> ) one in the south (100 km <sup>2</sup> )	no	one in the north (540 km <sup>2</sup> )
Promontories and cliffs	only southern side	both southern and northern side	only northern side
Nature of beach	straight, sandy with earlier dunes	arcuate, sandy with limited dunes	irregular, sandy and rocky
Wind	open and exposed to wind	closed and protected from wind	semi-closed and partly protected from wind
Bathymetry	marked E-W trending depression in the center southern part bar and barriers present	insignificant E-W trending depression in the center NE-SW trending shoal in the northern part present	no such depression bar present in the southern part

Common features: Depth—10-13 m. Rainfall—2500-3500 mm. Tide—1 to 2 m. Waves and period—WSW, W, WNW & SW directions with 5-14 sec. Direction of sediment movement—Northerly for SW waves and WNW waves move the sediment southerly while multi-directional for all other waves mentioned above.

Table 2—Textural Parameters of Sediments from Different Bays

(Range values are given with average in parenthesis)

Textural parameter	Kalbadevi (n-135)	Mirya (n-97)	Ratnagiri (n-84)
Mean (Mz), $\phi$	1.28-4.19 (3.32)	2.39-4.89 (3.45)	0.98-6.45 (3.95)
Standard deviation ( $\sigma$ ), $\phi$	0.39-2.59 (0.74)	0.50-1.54 (0.83)	0.58-2.57 (1.18)
Skewness (SK <sub>d</sub> )	-1-1 (0.11)	-1-1 (0.19)	-0.5-1 (0.61)
Kurtosis (K <sub>d</sub> )	1.28-27.58 (9.76)	0.17-14.79 (7.27)	0.13-17.17 (4.82)

sediment dispersion without interference from other factors.

*Standard deviation (sorting)*—The standard deviation in the 3 bays does not show any significant variation among them. According to Folk<sup>3</sup> the sediments in Kalbadevi and Mirya bays are moderate to well sorted whereas in Ratnagiri bay poorly to moderately sorted (0.58-2.5  $\phi$ ). In Kalbadevi bay sorting and mean size (Figs 2 and 3) is negatively correlated ( $r = -0.33$ ).

The well sorted sediments in the northern part of the Kalbadevi bay are bordered by moderately and well to poorly sorted sediments. In the southern part, the sediments are mainly poorly sorted which may be due to the coarse nature of sediments. The convergent and circulatory currents facilitate the mixing of coarser and finer sediments brought by the rivers in the north, south and in the center of the bay. Strong positive skewness and high kurtosis also indicate mixing of 2 unequal fractions.

The sediments of Mirya bay are well sorted and as in Kalbadevi, do not show any correlation with the mean size and sorting (Figs 2 and 3). The sorting in the bay is uniform except at the periphery where the offshore finer sediments overlap the sandy sediments. This may be due to a uniform level and insignificant fresh sediment input which is also evidenced by negative correlation of  $\sigma_1$  and SK<sub>1</sub> and positive correlation of Mz and depth ( $r = -0.4075$  and  $0.3943$  respectively).

Distribution of sorting and mean size, with the positive correlation ( $r = 0.5588$ ) for Ratnagiri bay, shows a similar pattern unlike in Kalbadevi and Mirya bays. The poor sorting of the sediments may be due to a wide fluctuation in energy level or mixing of populations. The sediments in the Ratnagiri bay are finer and poorly sorted towards the south. This is also supplemented by positive correlation of Mz and  $\sigma_1$  with the depth range ( $r = 0.3612$  and  $0.5216$  respectively). In general, the sorting deteriorates as one moves from Kalbadevi bay to Ratnagiri bay.

*Skewness*—The sediments in the central part of the Kalbadevi bay are mostly negatively skewed but in the nearshore and offshore positively skewed which may be due to probable admixture of sands in the nearshore and clays in the offshore (Fig. 4). In Mirya bay the sediments are mostly negatively skewed except in the central part which may be related to coarser sediments present on the topographic high, while offshore samples tend to zero because of the admixture of the finer population. In Ratnagiri bay the sediments are mostly positively skewed except in the southern part where there is very little input of river sediments. This

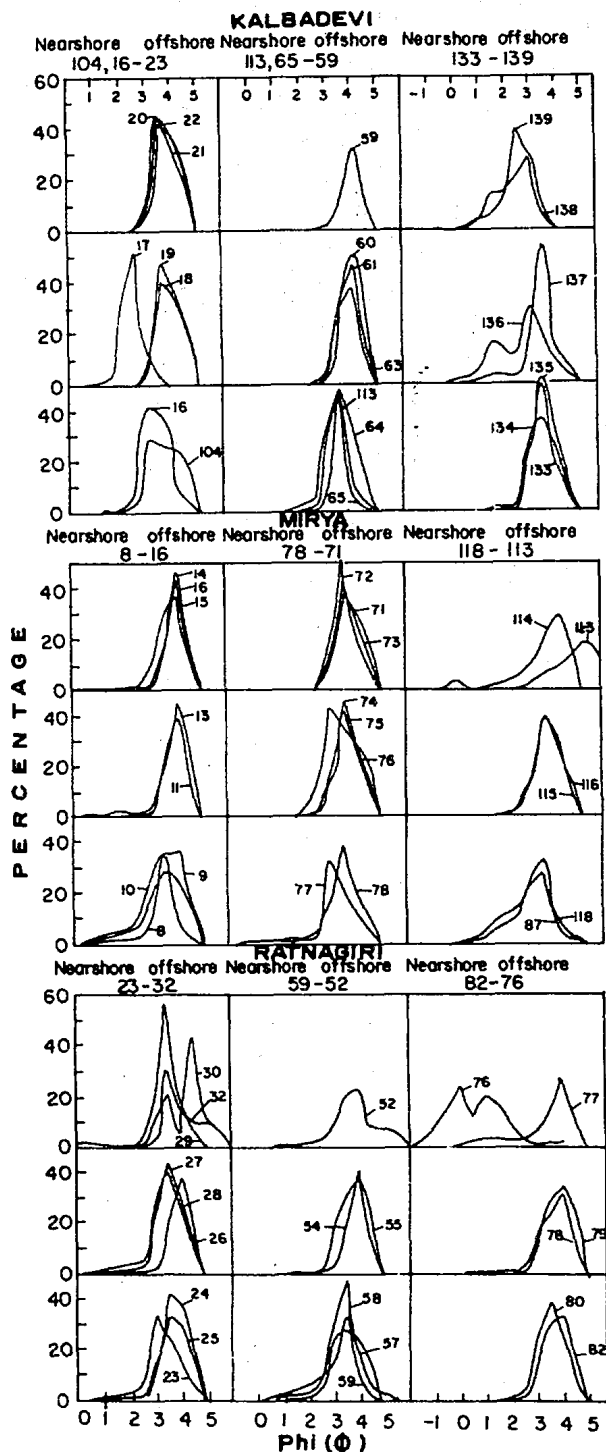


Fig. 1—Representative frequency grain size distribution curves for Kalbadevi, Mirya and Ratnagiri bays

anomaly of negative skewness in the south may probably be due to the presence of fine sediments of unimodal nature.

**Kurtosis**—Mean values of kurtosis for Kalbadevi are high while for Mirya bay moderate and Ratnagiri bay low. The kurtosis values are high in the central part

of Kalbadevi bay (Fig. 5). The variation in these values from the center to the nearshore or offshore is directly related to the grain size. Kurtosis values in Mirya bay do not vary significantly except in the center of the bay which may be attributed to the least chance of mixing of another population. The seaward decrease of kurtosis in Ratnagiri bay may be explained due to gradual change in sediments from sandy to clay.

**Depositional environment**—Above discussed statistical parameters have been utilized in the bivariant plots and computed to get correlation coefficients between each other. The results of bivariant plots in predicting the environment are shown in Table 3 and amount of perfection in interrelationship between any 2 parameters is shown in Table 4.

The results of bivariant plots (Table 3) indicate that Ratnagiri sediments have a dominance of riverine origin. This is attributable to the major influence of Bhatia river sedimentation.

Friedman<sup>7</sup> attributed positive skewness to dune sand and negative skewness to beach sands. Bivariant plots show a predominant beach environment in Mirya bay. This is also supported by the prevalence of negatively skewed sediments. Kalbadevi sediments have a combination of beach, dune (barrier island) and river environments. The influence of different environments is suggested because of the mixed skewed sediments and a good correlation of heavy minerals with mean grain size.

Results of skewness when compared with the study of winnowing caused by waves and tides by Duane<sup>8</sup>, Kalbadevi sediments indicate moderate winnowing because of mixed skewness. Mirya bay sediments suggest strong winnowing action due to predominant negative skewness and Ratnagiri sediments match well of Duane's sheltered lagoon environment of poor winnowing because of predominant positive skewness. Table 3 also suggests another type of environment to Kalbadevi bay as barrier island and lagoon-salt marsh type, Mirya bay as barrier island type and Ratnagiri bay lagoon-salt marsh type.

High values of kurtosis in Kalbadevi bay may be due to transport and mixing of sand, from one environment to another place of moderate energy probably a new lagoonal or barrier island type of environment. Less variation of kurtosis in sediments of Mirya bay may be attributed to a limited admixture or minimum changes from old beach environment to new barrier island type of environment. The sediments in Ratnagiri also show such a mixing of an old high energy river environment to probably a new lagoonal environment, an area of moderate energy. From the study of kurtosis, Folk and Ward<sup>9</sup> attributed high and low values of kurtosis to a mixed population, one maintaining yet, the old environment characteristics.

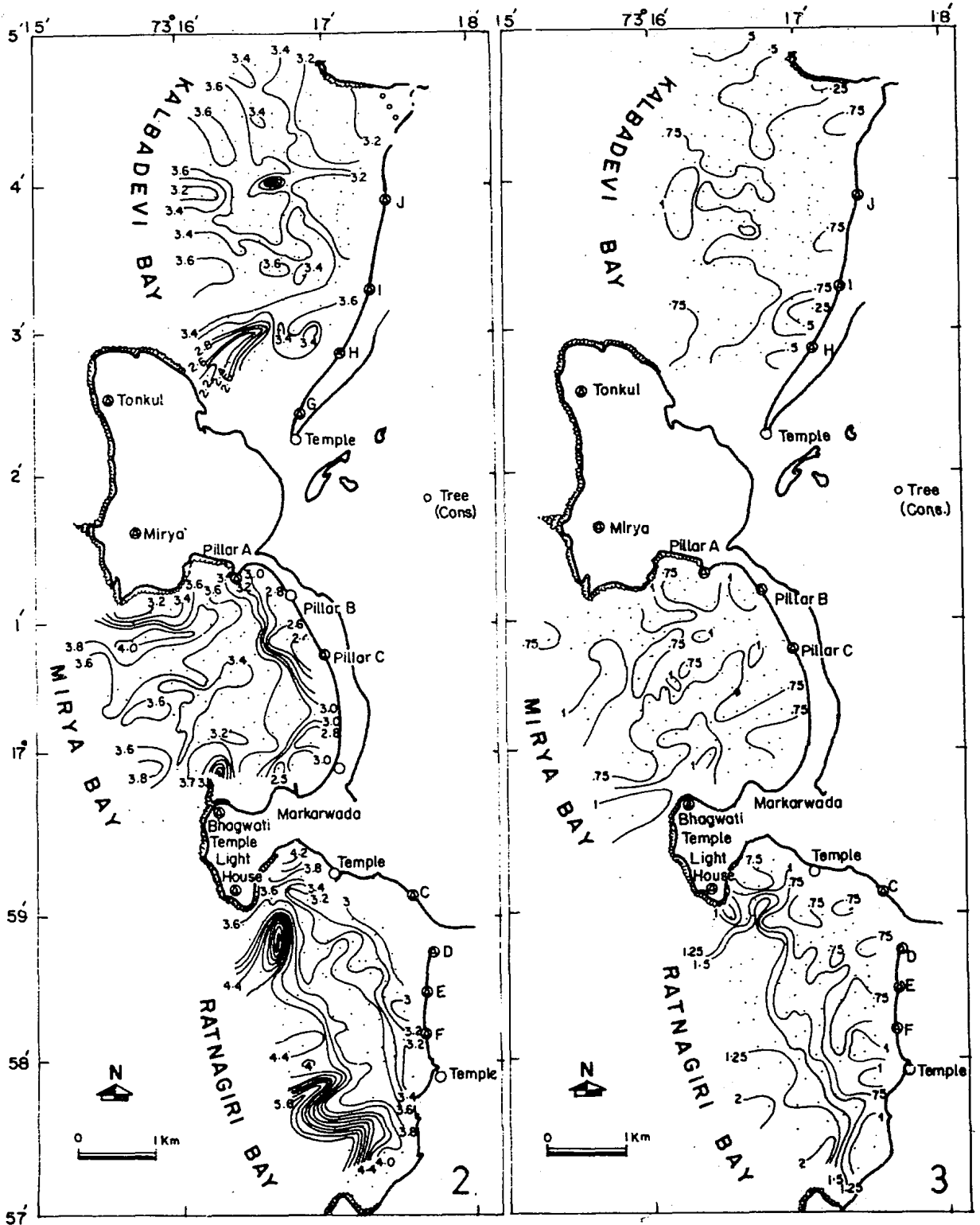


Fig. 2—Mean grain size ( $M_z$ ) of sediments from Kalbadevi, Mirya and Ratnagiri bays (contour interval  $0.2 \phi$ )

Fig. 3—Standard deviation ( $\sigma$ ) of sediments from Kalbadevi, Mirya and Ratnagiri bays (contour intervals  $0.25 \phi$ )

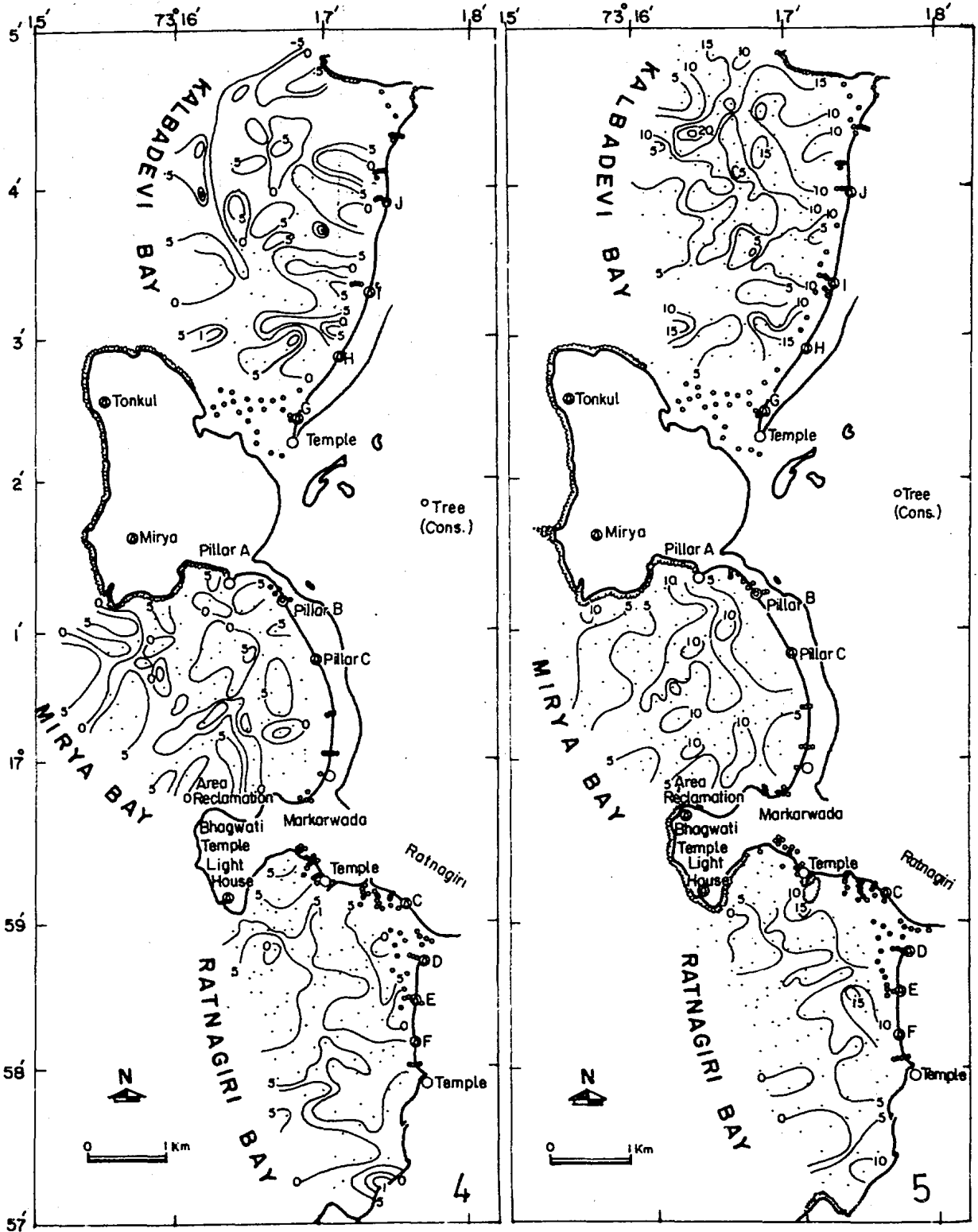


Fig. 4—Skewness ( $SK$ ) of sediments from Kalbadevi, Mirya and Ratnagiri bays (contour interval 0.5)

Fig. 5—Kurtosis ( $K_c$ ) of sediments from Kalbadevi, Mirya and Ratnagiri bays (contour interval 5)

Table 3—Predicted Dominant Environment of Deposition Using Different Techniques

Ref. No.	Kalbadevi	Mirya	Ratnagiri
		Mz/σ <sub>1</sub>	
10	Moderate energy high mobility	Moderate energy high mobility	High energy low mobility
5	Dune	Dune and river	River
19	Beach and river	Beach	River
20	Barrier island and lagoon-salt marsh facies	Barrier island and lagoon-salt marsh facies	Lagoon-salt marsh facies
		Mz/SK <sub>1</sub>	
20	Barrier island and lagoon-salt marsh facies	Lagoon-salt marsh facies	Lagoon-salt marsh facies
		SK <sub>G</sub> /K <sub>G</sub>	
20	Barrier island	Barrier island	Lagoon-salt marsh facies
5	Beach	Beach	River
		SK <sub>G</sub> /σ <sub>1</sub>	
20	Barrier island and lagoon-salt marsh facies	Barrier island	Lagoon-salt marsh facies
21	Central lagoon and lagoonal margins	Central lagoon and lagoonal margins	Lagoonal margins
6	Beach and river	Beach	River
19	River and beach	Beach and river	River

Barrier island includes dune, littoral, shallow neritic and offshore channel deposits.

Lagoon-salt marsh facies include estuaries and tidal channel sediments.

Table 4—Pearson Product Moment Correlation Coefficients for Grain Size Parameters

Variables	Kalbadevi (n-135)	Mirya (n-97)	Ratnagiri (n-84)
Depth/Mz	0.3201*	0.3943*	0.3612*
Depth/σ <sub>1</sub>	0.2709 <sup>f</sup>	0.0391	0.5216*
Mz/σ <sub>1</sub>	-0.3319*	-0.0717	0.5588*
Mz/SK <sub>1</sub>	0.0562	-0.0042	-0.2754 <sup>f</sup>
Mz/K <sub>G</sub>	0.3383*	0.2277	-0.5763*
SK <sub>G</sub> /σ <sub>1</sub>	-0.1956	-0.4075*	-0.2973 <sup>f</sup>
K <sub>G</sub> /σ <sub>1</sub>	-0.6986*	-0.6561*	-0.8167*
K <sub>G</sub> /SK <sub>1</sub>	0.0193	0.1329	0.2608 <sup>f</sup>
Mz/Heavy mineral	0.4238*	0.1493	-0.2536 <sup>f</sup>
σ <sub>1</sub> /Heavy mineral	-0.1585	0.0109	-0.2329 <sup>f</sup>

Significant at P = \*0.001 and <sup>f</sup>0.01.

Based on this suggestion, Kalbadevi, Mirya and Ratnagiri bays may be adjudged to maintain sediments of mixed population, an old beach, river or barrier island or lagoon-salt marsh type of environment because of large variation found in the kurtosis values. Similar observations have also been recorded in the northern part of Konkan coast off Shastri river<sup>10</sup>.

Sorting of sediments when compared with the studies of Channon and Hamilton<sup>11</sup>, in Kalbadevi bay shows dominance of wave induced currents over the tidal currents because of the presence of negative correlation of mean and standard deviation and better sorting in the sediments. Mirya bay shows possible influence of both tidal and wave cut currents because of mixed sorting values. In Ratnagiri bay mean size decreases towards the shore, and mean and standard deviation show positive correlation, but the sorting is poor and so it is attributed to the influence of tidal currents in the redistribution of Bhatia sediments.

Nordstrom<sup>12</sup> has related the variation in kurtosis to the variation in wave energy. Such variations observed in these bays may also be considered to the difference in the mode of wave energy acting in the depositional basins, in causing variations in the redistribution of the sediments.

Heavy mineral variation: Distribution of heavy mineral concentrations in these bays has been earlier reported by Siddiquie *et al.*<sup>16</sup>. Among the heavy minerals (Table 5), magnetite and ilmenite are found to be predominant. They have almost similar stability<sup>13</sup>. Magnetite and ilmenite show very close similarity in hydraulic properties (ilmenite-4.72 and magnetite-4.92 sp. g). Earlier workers<sup>1,14-16</sup> have suggested a common source of Deccan trap to these sediments. Reddy<sup>17</sup> attributes similar type of wave actions in those bays as well as no significant change in tides. These minerals are expected to have a similar type of weathering in the provenance because of the proximity of the source. Under microscopic examination these grains show angular to sub-angular nature of shape in all the bays which rules out any long transportation. It is interesting to note the differences in the distribution of these 2 minerals within the neighbouring bays though they have many common causative factors.

Considering the various factors referred earlier the variations in heavy mineral compositions are expected to be in close similarity. Instead, ilmenite is found to be concentrated in decreasing order from Kalbadevi to Mirya and then to Ratnagiri bay. The textural parameters fail to suggest any direct relationships with

Table 5—Range and Average (in parenthesis) of Heavy Mineral Concentration (%) in the Bays

	Kalbadevi	Mirya	Ratnagiri
Total heavy mineral	7-91 (39)	5-72 (46)	1-78 (40)
Magnetite	1-38 (12)	3-48 (24)	0.4-59 (32)
Ilmenite	3-52 (28)	1-35 (23)	1-22 (16)

(Modified after Siddiquie *et al.*<sup>16</sup>)

the heavy mineral variation and grain size. Table 4 shows the independent behaviour of different bays in the heavy mineral variation with the mean and sorting.

The large differences in the kurtosis values suggest the presence of palimpsest environment within the bays. Such changes in the depositional environments derived from the studies of textural parameters might have influenced in introducing a variation in the distribution of magnetite and ilmenite. Variations in the winnowing observed from the values of skewness are also likely to cause possible variation in the mineral concentration. The geographical disposition of the southern river in the Kalbadevi bay is suggestive of the possible change in its course from Mirya bay to Kalbadevi bay. The supply of sediment from 2 rivers to Kalbadevi bay is found to be close by as well as less in amount, while supply of Bhatia river to Ratnagiri bay is distinct in bringing large amount of sediments with the large catchment. Present day Mirya bay is cut off from the direct supply of river sediments. So, there is a clear difference in the input of sediments for the 3 bays under study. Fermor<sup>18</sup> has pointed out 2 distinct magma types based on character of iron ores as magnetite rich and ilmenite rich in the Deccan flows. In addition to the differences in the environments and input of sediments with minor role of differences in the input of sediments with minor role of differences in the waves and winnowing, the presence of magnetite and ilmenite rich basaltic rocks in the catchment area might have caused the probable variation in the distribution of magnetite and ilmenite in Kalbadevi to Ratnagiri bay.

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