

Offshore Ilmenite Placers of Ratnagiri, Konkan Coast, Maharashtra, India

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The occurrence of onshore ilmenite placers has been reported as occurring for about 200 km along the Konkan Coast. Surveys in Kalbadevi, Mirya, and Ratnagiri bays (1:10,000,397 samples, and 75 1-km echosounding) indicated the extension of the placers to be about 9 to 12 m in depth and from 2 to 5 km offshore. The sediments in the bays contain 1-91% heavy minerals, including 1-52% ilmenite. The assemblage of heavy minerals (magnetite, ilmenite, augite, diopside, and hornblende) suggests that their derivation is from the Deccan Traps. The maximum precipitation, sediment discharge, and turbulence at sea during the southwest monsoon facilitates the transport, sorting, and concentration of heavy minerals. The entry of a stream into a bay directly or through a swamp or bar leads to overall higher or lower heavy mineral concentrations, and may be of more significance than the input of sediments based on the size of the catchment areas. The distribution of sediments and heavy minerals (magnetic, nonmagnetic fractions, and ilmenite) has been shown in a series of maps. The distribution patterns show that the heavy minerals are concentrated with sands at stream entrances, along the shore, and with silts in the center of the bays or offshore. Because of the arcuate shape of the bays, their northern parts are

subjected to pounding by powerful waves from the west and west-southwest during the monsoon season, leading to concentration in this area. The shape of the bays possibly generates converging or circulatory currents during the monsoon, favoring the deposition of sandy material along the shore and silts rich in heavy minerals in the center or offshore. The distribution of sediments and the concentration of heavy minerals in bays are apparently controlled by the source, the geometry of the bays, and the processes operating in the bays. The ilmenite-rich ($> 5\%$) sediments cover over 15 km^2 , and the inferred reserves to a depth of 1 m are 2 million tons. Considering the number of estuaries and bays still to be surveyed, the offshore reserves may be many times greater, and their quantity compares favorably with the already known onshore reserves.

Titanium is the ninth most abundant element in the earth's crust. Ilmenite (Fe, TiO_3) and rutile (TiO_2) are the most important ores for the metal. Ilmenite deposits occur in rocks as segregation and lodes in gabbros and anorthosites, or as heavy minerals in sands on beaches. Rutile occurs largely as an accessory mineral in rocks and as heavy minerals in beach deposits. The major utilization of titanium (about 95%) is in the form of pigments, while the remaining 5% is in alloys for aerospace industries (Stampfer, 1970). The metal and its alloys are in demand because of their lightness, strength, and resistance to fatigue and corrosion; demand in aerospace industries is likely to increase because of these special qualities. About 85% of the demand for titanium ores is met by ilmenite. Rock deposits commonly containing 17–35% TiO_2 as ilmenite are considered workable, sands containing 4% heavy minerals are being worked in Florida for ilmenite, while even less than 1% rutile in sand can be economically worked (Stampfer, 1970). The offshore heavy mineral placers containing 0.2–0.22% rutile and zircon in Australia are considered as economically workable (Brown, 1971) as these. Beach sand deposits in India and Sri Lanka commonly contain up to 35% TiO_2 as ilmenite and are exploited extensively.

Indian Occurrences

Onshore

Heavy mineral placers, popularly called "black sands," occur on a number of beaches in India, and these contain ilmenite in varying proportions with magnetite, monazite, garnet, sillimanite, kyanite, etc. The well-known occurrences are between Quilon and Cape Comorin in Kerala (Tipper, 1914; Brown and Dey, 1955), the Tinneveli, Ramnad, and Tanjore districts of Tamilnadu (Jacob, 1956), the Visakhapatnam, Yarada, Waltair, and Bhimunipatnam areas of Andhra (Mahadevan and Sriramadas, 1954; Mahadevan and Rao, 1958; Mahadevan and Rao 1960), and some coastal areas of Orissa (Officers of the GSI, 1949). The occurrence of ilmenite on the beaches of Ratnagiri (Konkan Coast) was described by Krishnan and Roy (1945) and Roy (1958).

The reserves of ilmenite and rutile in the beach sands of the Quilon district of Kerala, between Neendakara and Kayankulam, are estimated at 17.5 and 1.3 million tons, respectively (Indian Bureau of Mines, 1974). The Maharashtra Department of Mines and Geology surveyed the ilmenite placers on the beaches of Ratnagiri and estimated the reserve as 4 million tons (Mane and Gawade, 1974). The total reserves of ilmenite in India are estimated to be 132 million tons (Indian Bureau of Mines, 1974). Of these, the beach sands on the Kerala and Tamilnadu coasts are being mined at present. The total production of ilmenite in India (chiefly from beach sands) during 1970 was 76,770 tons (Indian Bureau of Mines, 1974).

Offshore

The heavy mineral placers on the beaches are expected to extend to offshore areas, and some placers may also be associated with the lowered sea level strands during the Pleistocene. Although India has extensive deposits of heavy mineral placers on the beaches, the extension of these placers to offshore areas has not been explored in detail. Chaterji *et al.*, (1968) reviewed the prospects of the extension of heavy mineral placers on the beaches to offshore areas. Rao

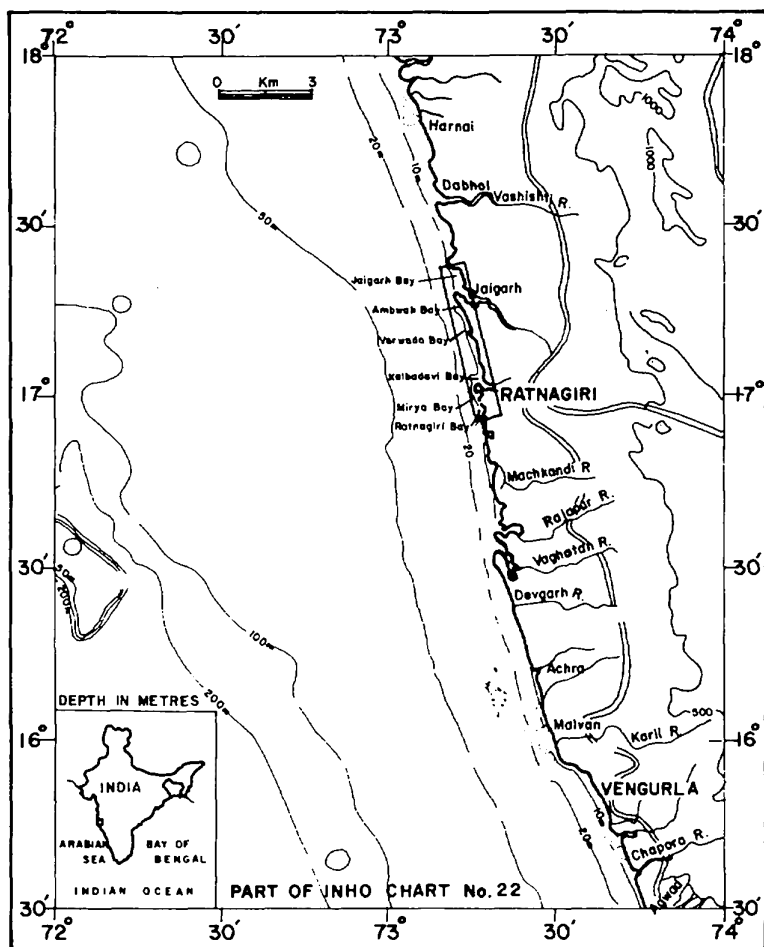


Figure 1. Map showing the area surveyed in detail for offshore heavy mineral placers.

(1968) explored the extension of heavy mineral placers in the offshore areas of Kerala. The occurrence of ilmenite placers is known along the beaches of the Konkan Coast from Dabol to Vengurla, a distance of about 200 km (Krishnan and Roy, 1945; Roy, 1958). The extension of these placers to offshore areas has not been surveyed, and their mode of occurrence and formation are not known. The authors, therefore, selected the area shown in Figure 1 for a preliminary survey of offshore ilmenite placers. Siddiquie and Rajamanickam (1979) in their review of the surficial mineral deposits on the continental shelf of India described briefly the preliminary results of the surveys for heavy mineral placers off Ratnagiri. Siddiquie, *et al.* (1975) and Siddiquie and Rajamanickam (1979).

Exploration Off the Konkan Coast

The Coast

The coast in this area is marked by a number of arcuate bays with rocky promontories and cliffs of Deccan Plateau basalts.

The three bays surveyed (Kalbadevi, Mirya, and Ratnagiri), though broadly similar in their geometry, differ in the nature of sediment sources. Kalbadevi Bay has two streams entering at its northern (catchment area 50 km²) and southern ends (catchment area 100 km²). While the northern stream enters more or less straight into the bay, the southern one enters through a mangrove swamp, and its seaward end is blocked by a barrier which appears to have grown progressively southward. Ratnagiri Bay has only a single stream (catchment area 540 km²) entering in the north through a mangrove swamp. Mirya Bay, on the other hand, has no source of sediment supply, and the sand in the bay is apparently relict. The stream to the east of the barrier perhaps used to flow into the bay, but the growth of the barrier joining the two headlands on the north and south has diverted the streams northward to Kalbadevi Bay.

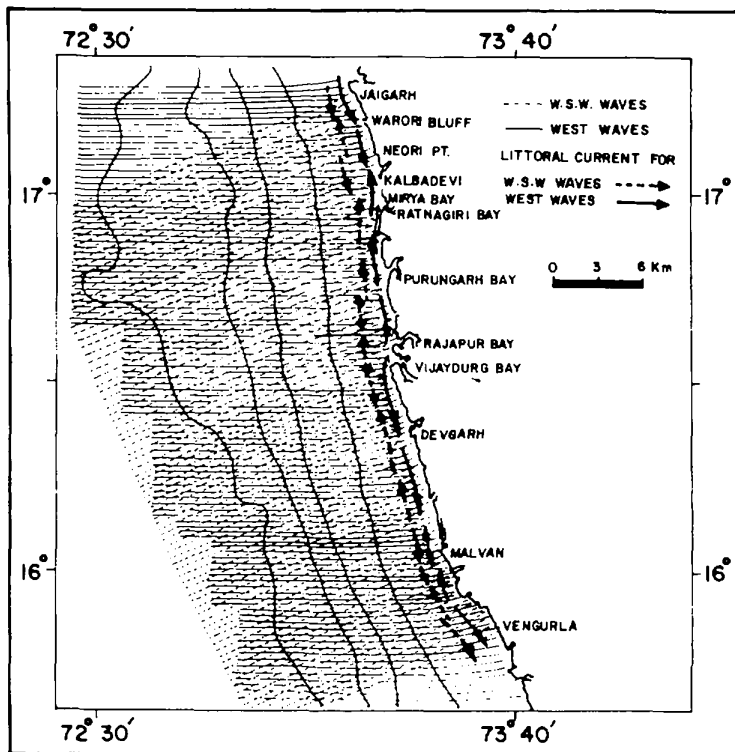


Figure 2. Wave refraction for deep water waves (10 sec period) from the west-southwest and west in the region from Vengurla to Jaigarh (after Reddy, 1976).

The tidal range in the area varies from 1 to 2 m. The area receives precipitation on the order of 2,500–3,000 mm, which is confined to the season of the southwest monsoon during June to September. This season is also the period of maximum turbulence in the sea. Studies by Reddy (1976) indicated that the predominant direction of waves is from the southwest, west-southwest, west, and west-northwest directions, with periods ranging from 5 to 14 seconds. For waves from the southwest, the tendency of sediment transport

is mostly northerly, and for waves from west-southwest and west the sediment transport is not likely to be in one direction. For the waves from west-northwest, the sediment transport tendency is generally toward the south. For west-southwest and west waves, there are several places where convergence and divergence of littoral currents take place. The sediment transport is likely to be directed into several bays present in this area (Figure 2). Preliminary surveys indicated that the sands are mostly confined to the bays, and the promontories are devoid of sands.

Field

In view of the reported onshore occurrences, it was decided to survey at first the three bays at Ratnagiri, Kalbadevi, and Mirya. In the first phase of the program, it was decided to map the distribution of sediments, as heavy minerals are likely to be concentrated in coarser sediments, i.e., sands and silts, to estimate the heavy mineral content and particularly the ilmenite content. The first phase of the survey, therefore, comprised echosounding, magnetics, and bottom sampling. This was followed by the second phase, with shallow seismic profiling and sampling by vibro corers, etc.

Since large-scale navigational charts of the offshore areas were not available, the shoreline was traversed with a theodolite to fix the shore markers. While traversing the shoreline, the information about the nature of the coast and the nature of distribution of heavy mineral placers was also recorded. The surveys were carried out on a fishing trawler (about 15 m long), and the tracks were spaced about 200 m normal to the coast in order to obtain the best possible coverage of variation in topography and sediments, etc. Bottom samples were collected at a spacing of about 200 m as far as possible to ensure a uniform spacing over the area surveyed (Figure 3).

A Seafarer echosounder with a range of 60 m and phasing of 10 m was used during the surveys. As usual, a bar check was carried out before the commencement of the surveys, and the depths recorded were corrected for tides. The bottom samples were collected by a Van Veen grab with a scoop area of about 0.04 m². The

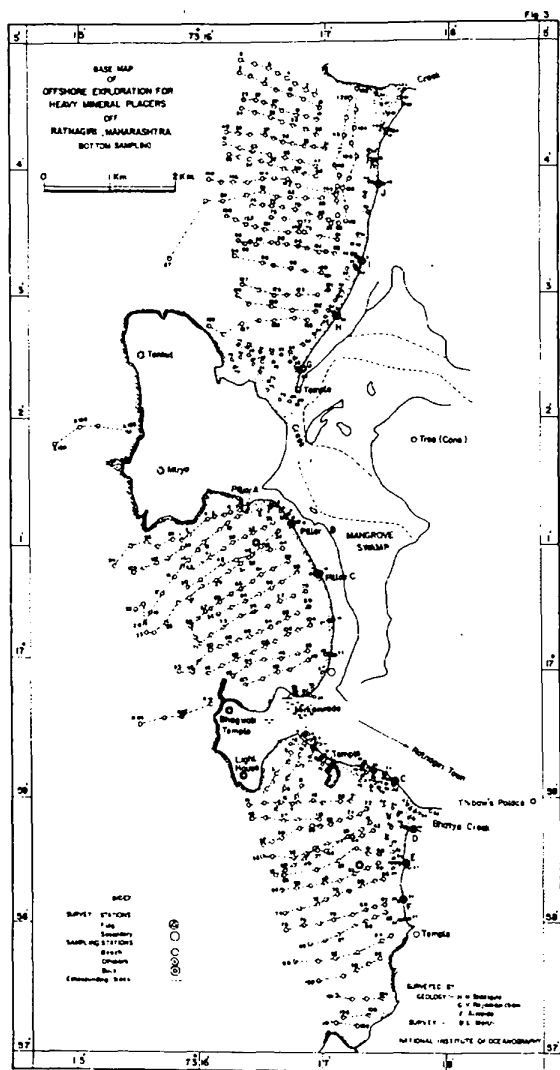


Figure 3. Base map of offshore exploration for heavy mineral placers off Ratnagiri, Maharashtra.

surveys were carried out on a scale of 1:10,000, and an area of 7.4 km² was covered in Kalbadevi (155 samples and 28 1-km echosounding), 6.5 km² in Mirya (123 samples and 25 1-km echosounding), and 7.3 km² in Ratnagiri Bay (119 samples and 22 1-km echosounding). In addition to the surface samples, lithological logs of boreholes drilled in Mirya Bay for the construction of the harbor were also examined.

Laboratory

The sediment samples were washed in the laboratory to remove salt, etc., dried, and sieved to standard mesh sizes so as to separate them into sand, silt, and clay fractions. The sand and silt fractions were separated into heavy and light minerals using bromoform (specific gravity 2.89). The heavy mineral fractions were further separated on a Cook's Magnetic Separator into magnetic and non-magnetic fractions. The initial magnetic separation was carried out at the lowest magnetic intensity and on a vertical feed, so as to separate magnetite. Subsequently, the nonmagnetic fraction was separated on an inclined feed on the magnetic separator into ilmenite and other minerals, i.e., hornblende, augite, and diopside, etc. Selected samples of heavy minerals were mounted in Canada Balsam and examined under the microscope to differentiate and identify the various minerals. The initial sand and silt samples and the various separated fractions were weighed, and the results have been expressed as weighed percentages in the tables and depicted on the maps.

Results of Exploration

Bathymetry

The depths in the three bays surveyed range down to 10 to 13 m (Figure 4). The central part of Kalbadevi Bay is marked by an E-W-trending depression, which may indicate an old channel or a recent sedimentary feature. In the southern part of the bay, near the entrance of the stream, some bars and barriers occur, which

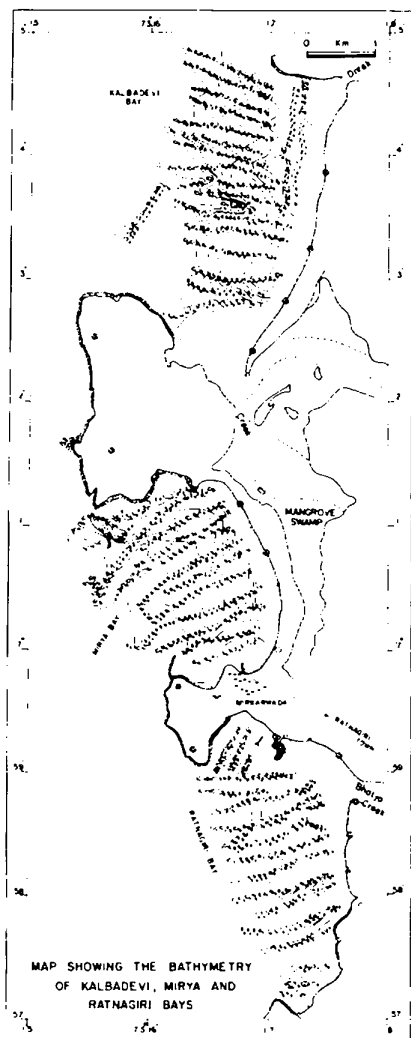


Figure 4. Map showing the bathymetry of Kalbadevi, Mirya, and Ratnagiri bays (depths reduced to observed tides at Ratnagiri).

Table 1
The range of sand, silt, and heavy mineral fractions in the heavy mineral sands from the offshore area of Ratnagiri.

			% Heavy		% Non-	
	% Sand	% Silt	Minerals	% Magnetic	magnetic	% Ilmenite
Kalbadevi						
Bay	43-99	1-42	7-91	1-38	5-60	3-52
Mirya Bay	12-99	1-37	5-72	3-48	1-51	1-35
Ratnagiri						
Bay	8-99	2-69	1-78	0.4-59	0.6-50	1-22

may influence the distribution of sediments and heavy minerals. The northern part of Mirya Bay is marked by a NE-SW-trending shoal, while a depression is seen in the center. In Ratnagiri Bay relatively shallower areas are seen in the southern part, although the major source of sediment supply, i.e., Bhatya Creek, is in the north.

Sediment Distribution

The three bays surveyed are largely covered by sands, silty sands, and sandy silts (Table 1; Figures 5, 6). Toward the west the sands and silts are covered by clays, and dual-frequency echosounder records (210 and 30 kHz) indicate that the sands may continue seaward to the west below the clays. In Kalbadevi Bay, sand is concentrated along the shore, particularly near the stream entrances in the north and south. The center of the bay is marked by a lower concentration, but a small patch of higher concentration is located in the northern offshore area. In Mirya Bay, sand is concentrated along the shore particularly in the east and south, while an isolated patch is seen at the northeastern end. Some patches of concentration are also seen in the north near the headland and offshore, and these coincide with the shoals and rock outcrops in some cases. The distribution of sand in Mirya Bay is puzzling, as at present no stream discharges in this bay. The stream now flowing to the east of the bar perhaps flowed into the bay sometime in the past and supplied the sediments. The growth of the bar and its connection

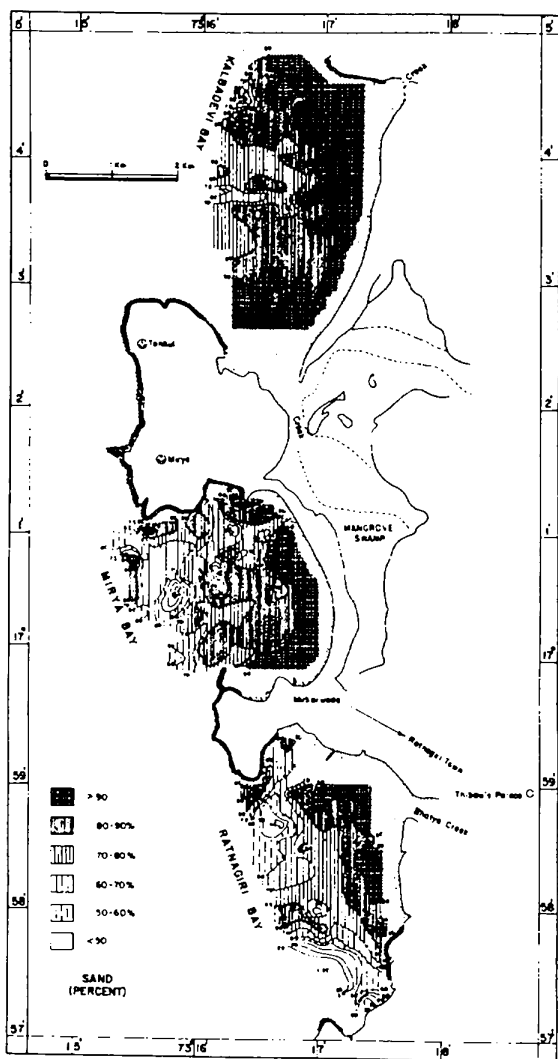


Figure 5. Map showing the distribution of sand.

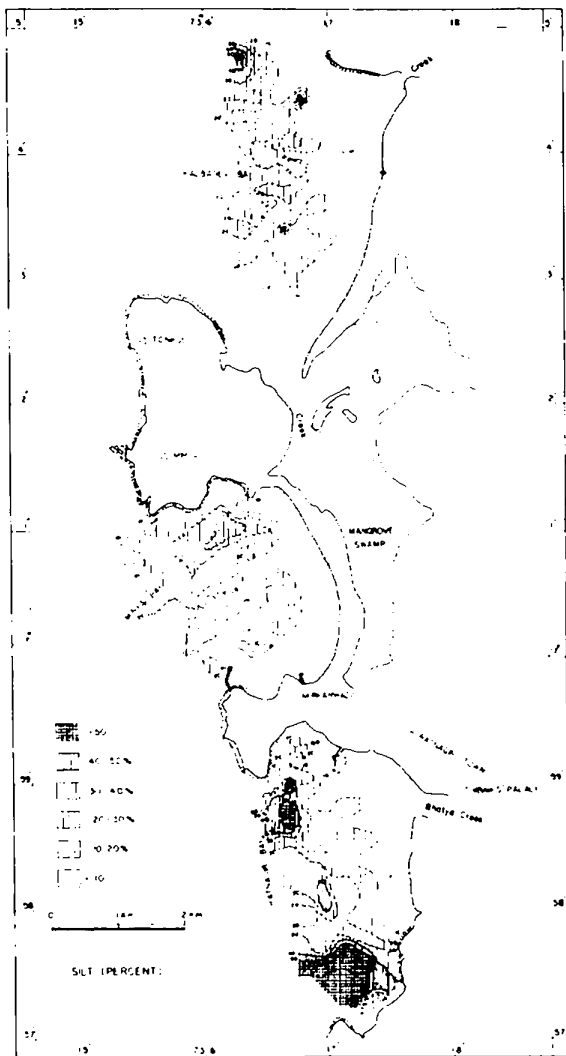


Figure 6. Map showing the distribution of silt.

with the headlands in the north and south blocked its entry to the bay and diverted it to the north to Kalbadevi. The sediments in this bay, therefore, may be relict sediments, or perhaps another, though remote, possibility could be that they were brought into this bay by converging currents from the adjacent areas. In Ratnagiri Bay, sand is concentrated along the northeastern shore near the stream entrance. The widening of the distribution to the north perhaps indicates a northward sediment drift. Some sand bodies are located in the north near the headland and in the central part of the bay.

As expected, the distribution of silt is opposite to that of sand. In Kalbadevi Bay, the silt is concentrated in the center of the bay. In Mirya Bay, the concentration is seen in the northern and central part of the bay, while in Ratnagiri Bay, the concentration is in the south and to the northwest in the offshore waters.

Heavy Minerals

The distribution of heavy minerals in Kalbadevi Bay shows their concentration to be in the north at the stream entrance, while in the south at the stream entrance the concentration is low (Table 1; Figure 7). Apparently the bars at the stream entrance in the south favored the deposition of heavy minerals in the stream channel rather than their being transported and deposited in the bay. The highest concentration of heavy minerals in the central part of the bay coincides with that of silt. The heavy minerals may be concentrated largely in the finer silt, and this may be related to the circulation in the bay. In Mirya Bay, the concentration in the north and on the shoal is perhaps related to the distribution of both sand and silt. However, the concentrations in other parts of the bay are related to the distribution of silt. In Ratnagiri Bay, the higher concentration of sand at the stream entrance largely reflects the source. The concentrations offshore are perhaps related to the distributions of sand and silt. High silt concentrations in the south, unlike in the other two bays, are not associated with heavy mineral concentration.

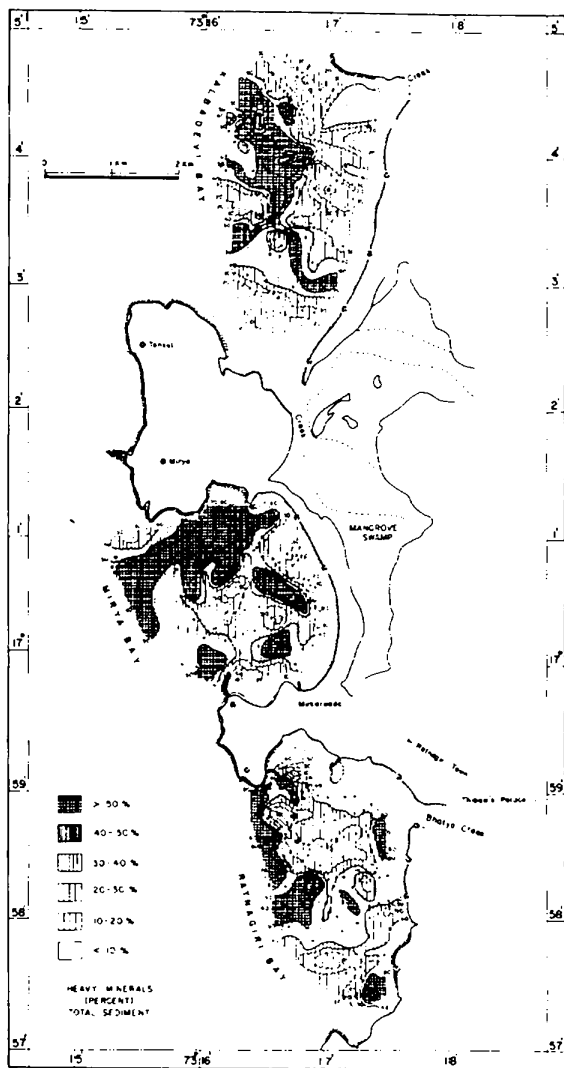


Figure 7. Map showing the distribution of heavy minerals in sediments.

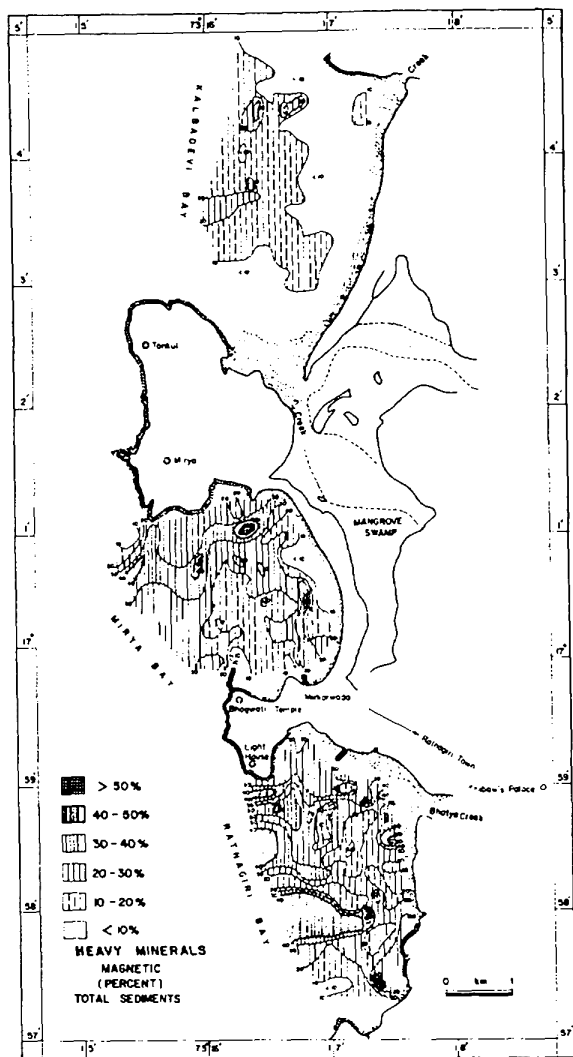


Figure 8. Map showing the distribution of heavy minerals, magnetic fraction.

Magnetic Minerals

The pattern of distribution of magnetic minerals largely follows the distribution of heavy minerals, which in turn is related to the pattern for silt and partially sand (Table 1; Figure 8). In Kalbadevi Bay, the stream entrance in the north and the central part of the bay are marked by concentrations, while there is no concentration at the mouth of the stream in the south. At the stream entrance the concentration is largely of sand, while the other concentrations follow the pattern of the silt. In Mirya Bay, the magnetic minerals are concentrated in a belt extending from northeast to southwest, and in the center of the bay the concentrations largely follow the pattern for heavy minerals and silt within the bay and sand offshore. In Ratnagiri Bay, the concentration is seen at the river mouth and in the offshore areas. Both the concentrations match with those of sand and heavy minerals, excepting one in the offshore area where it matches with that of the silt. The sediments in Ratnagiri Bay show a comparatively higher magnetite content, and this may be related to predominance of magnetite in the Deccan Plateau basalts in the source area of this bay.

Nonmagnetic Minerals

The distribution of nonmagnetic minerals generally follows that of silt and heavy minerals (Table 1; Figure 9). In Kalbadevi Bay the concentrations are seen in the north at the stream entrance, in the center of the bay, and offshore. In Mirya Bay the distribution is patchy, but the concentration largely occurs in the southeastern part of the bay and in the offshore areas. In Ratnagiri Bay the overall concentration is low, but some patches of concentration are seen in the northeast and in the offshore area.

The distribution of nonmagnetic minerals indicates their highest concentration in Kalbadevi Bay, followed by Mirya Bay, while Ratnagiri Bay appears to be the poorest. The distribution is quite the converse of that for magnetic minerals. A comparison of the pattern for magnetic and nonmagnetic minerals at the stream en-

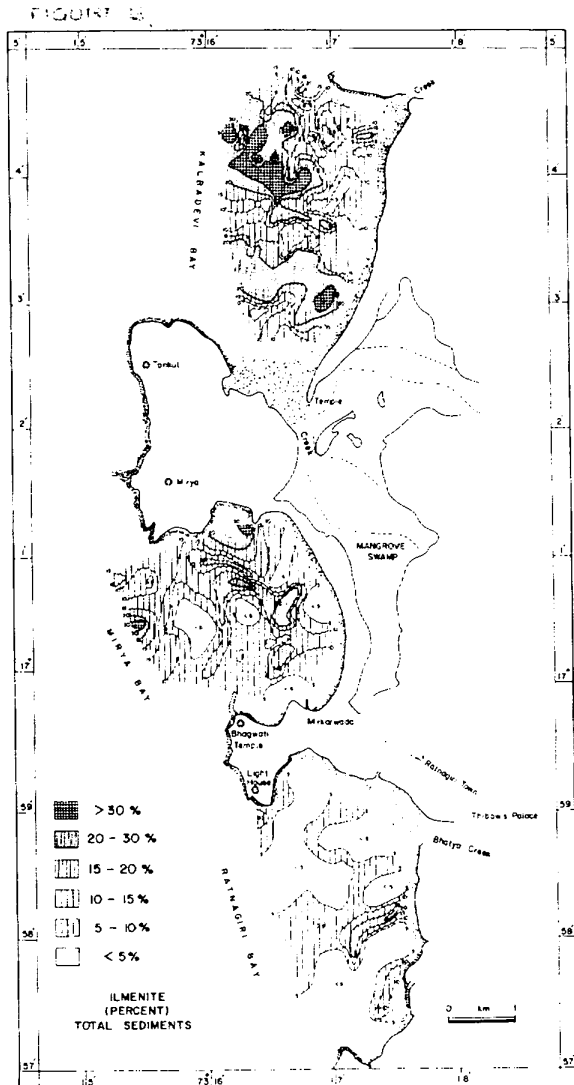


Figure 10. Map showing the distribution of ilmenite.

trances indicates that in the case of nonmagnetic minerals the concentration is generally in the north, while concentration of magnetic minerals is to the south. This factor may be related to the lower specific gravity of nonmagnetic minerals, and consequently, their farther transport in the direction of drift to the north.

Ilmenite

The distribution of ilmenite generally follows the pattern shown by silt and heavy minerals (Table 1; Figure 10). Its distribution in Kalbadevi Bay indicates concentration in the central part of the bay and also offshore. However, this differs from the pattern shown by the heavy minerals, because at the northern stream entrance the area of concentration is considerably reduced and is shifted to the south. In Mirya Bay, the concentration occurs in the northern and central parts of the bay and in the offshore areas. In Ratnagiri Bay the concentration of ilmenite is very low, the pattern does not exhibit any significant correlation with the distributions of other minerals, excepting that in some cases the lows in the heavy minerals coincide with the lows for ilmenite.

Source and Formation of Offshore Placers

The heavy mineral assemblage—ilmenite, magnetite, hornblende, diopside, augite with rare zircon, and kyanite—suggests derivation from an igneous, chiefly basaltic, terrain. Their proximity to the Deccan Traps indicates that the mineral assemblage and ilmenite placers have been derived from the Deccan Traps. The Deccan Traps, on an average, contain 1.76–3.29% TiO_2 , mostly as ilmenite or titanomagnetite (Krishnan, 1968). The weathering and alternation of basalt lead to progressive removal of unstable minerals and enrichment in more stable magnetite and ilmenite.

The Konkan Coast receives sediments from the numerous small streams draining the Western Ghats covered by extensive Deccan Traps. These streams bring large quantities of sediments derived from the Deccan Traps. The weathering and alteration of basalt

and the transport of residue over a distance progressively eliminates the unstable minerals, i.e., feldspar and olivine, and enriches the residue in amphiboles, pyroxenes, magnetite, and ilmenite. The period of maximum precipitation and maximum discharge of sediments (southwest monsoon—June to September) coincides with the maximum turbulence at sea and, therefore, probably favors the transport of sediments and sorting and concentration of heavy minerals.

A study of the heavy mineral concentrations indicates that though Ratnagiri Bay receives drainage from an area of 540 km² and Kalbadevi Bay from 50 km² (northern stream) and 100 km² (southern stream), the concentrations of heavy minerals including ilmenite are relatively higher in Kalbadevi Bay. Even in Kalbadevi Bay the southern stream drains a larger area than the northern one, but the concentrations of heavy minerals are lower at the entrance of the southern stream. This may be explained because the passage of the southern stream through mangrove swamps and the occurrence of bars at the stream entrance would probably favor the deposition of heavy minerals *prior* to the entry of the river into the sea. On the other hand, the northern stream, though smaller, directly enters into the sea. Similarly, the stream in the Ratnagiri Bay area passes through a low-lying swampy area, possibly leading to the deposition of a significant proportion of heavy minerals before their entry into the bay. The other factor leading to their concentration in the north could be the result of some of the processes operating in the bay, the effect of which will be discussed later.

The study of the heavy mineral distribution indicates that the concentration of nonmagnetic minerals (pyroxene and amphiboles, etc.) and ilmenite is highest in Kalbadevi, while magnetite is comparatively lower, and the reverse is seen in Ratnagiri Bay. Such an association is apparently a good guide for the search for ilmenite concentrations in offshore areas and may be attributed to their differences in the source areas. The pattern of mineral distribution indicates that at the entrance of the streams to the bays, a large portion of heavy minerals, associated with sands, is deposited due to a sudden decrease in velocity. The shift of concentration of nonmagnetic minerals to the north and magnetic minerals to the south

of the stream mouth may be due to the transport of the comparatively lighter, nonmagnetic minerals in the direction of the drift, i.e., to the north.

Higher concentrations of heavy minerals and ilmenite also occur in the central or offshore areas of the bays. These concentrations appear to be related to the pattern of silt distribution rather than sand, indicating thereby that most of the heavy minerals are concentrated in silty sand and sandy silt.

The sources, i.e., streams, have been responsible for bringing the sediments into the bays. Once the sediments are brought into the bays, they are subjected to various processes operating in these bays. The period of maximum precipitation and maximum discharge of sediments (southwest monsoon—June to September) coincides with the maximum turbulence, and therefore favors the transport of sediments, sorting, and concentration of heavy minerals. Because of the arcuate shapes of the bays, the northeastern parts of the bays would be exposed to large waves from the southwest and west during the monsoon season, and this would lead to better sorting and a greater concentration of minerals in the north. This would also explain the higher mineral concentration in the north in the Kalbadevi, Mirya, and to some extent, Ratnagiri bays. Converging and diverging littoral currents produced by the west-southwest waves during the monsoon in the area have already been reported by Reddy (1976). The arcuate shape of the bays also favors the generation of a converging, or circulatory, current pattern in the bays. This may lead to the deposition of finer sediments rich in heavy minerals in the central part of the bay or farther offshore.

The general distribution of sediments in the area and the concentration of heavy minerals is apparently controlled by three factors: (1) the sources (the source rocks, streams and their entry), (2) the geometry of the bays (arcuate shapes), and (3) the processes (waves and currents) operating in the bays.

Reserves and Economic Potential

The surveys so far carried out indicate that heavy mineral sands are spread over an area of 23 km² in the three bays: Kalbadevi,

Table 2
TiO₂ content of heavy mineral sands from the offshore areas of Ratnagiri.
Analyst: G.V. Rajamanickam.

<i>Locality</i>	<i>Sample No.</i>	<i>TiO₂ in % Non-magnetic fraction</i>		<i>Ilmenite Concentrate</i>
		<i>Sand</i>	<i>Silt</i>	
Kalbadevi Bay	25	23.24	52.43	57.79
	142	26.88	50.10	
Mirya Bay	18			52.99
	11	26.77	51.99	
	42	18.50	35.32	
	108	33.68	46.88	
Ratnagiri Bay	56			42.24
	22	41.39	42.51	
	111	25.12	33.82	
	64	29.90	24.00	

Table 3
Approximate area covered by different concentrations of ilmenite in the offshore heavy mineral sands of Ratnagiri and the inferred reserves to a depth of one meter.

<i>Ilmenite Concentration (in %)</i>	<i>Kalbadevi Bay Sq. km.</i>	<i>Mirya Bay Sq. km.</i>	<i>Ratnagiri Bay Sq. km.</i>	<i>Total Sq. km.</i>	<i>Inferred Reserves (Million tons)</i>
> 30	0.54	0.08	—	0.62	0.24
20–30	1.85	0.62	0.08	2.55	0.66
10–20	2.31	2.47	0.54	5.32	0.70
5–10	2.16	2.31	2.16	6.63	0.43
<5	0.54	1.00	4.47	6.01	—
Total	7.40	6.48	7.25	21.13	2.03

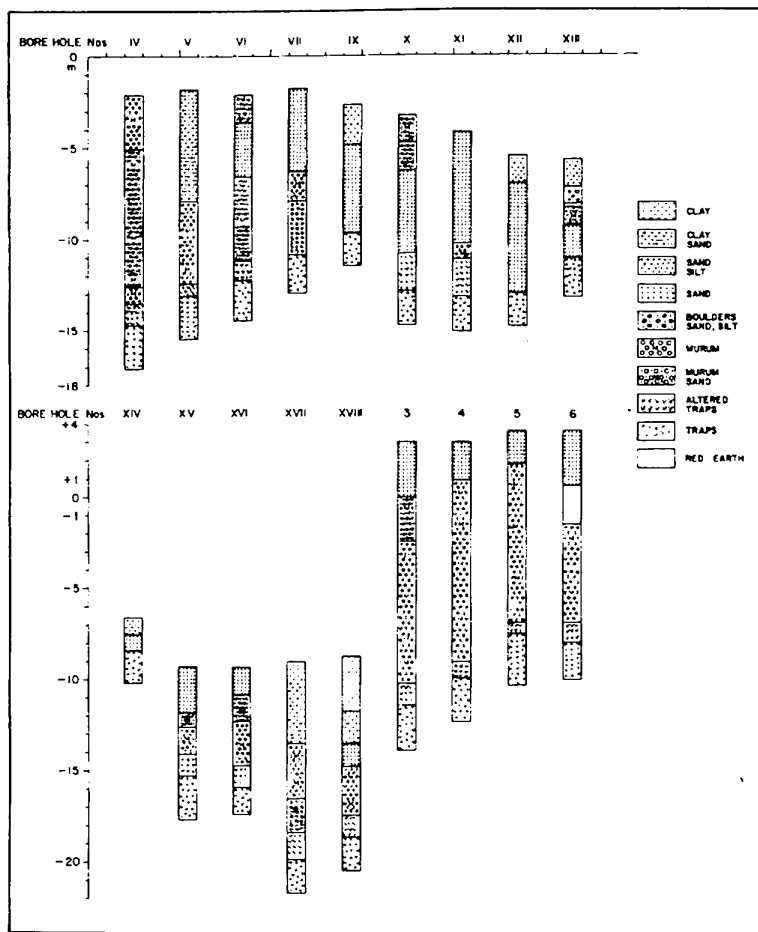


Figure 11. Lithological logs of the boreholes drilled in Mirya Bay (kindly provided by the Port Officer, Ratnagiri).

Mirya, and Ratnagiri. The concentration of ilmenite ranges from about 1–52% in the total sediments, and large areas are covered with over 5–30% ilmenite (Tables 1, 2, 3). The TiO_2 content of the

ilmenite concentrates ranges from 46 to 57% (Table 2). The concentrations and chemical analyses compare favorably with both onshore and offshore placers mined or explored elsewhere. The analyses of the bulk samples carried out at the Regional Research Laboratory, Bhubaneswar, (Dr. P.K. Jena, personal communication), have indicated that samples contain about 25–46% of mostly ilmenite with titanomagnetite and hematite. A leaching test on ilmenite in one of the samples indicated that the ilmenite is amenable for recovering titanium as synthetic rutile

Since the first phase of the work involved only surficial sampling, and as no drilling has been carried out, the reserves cannot be categorized as “indicated,” or “proved.” However, the information from the boreholes drilled in Mirya Bay (Figure 11) has indicated that the sands extend down to a depth of about 3 m. Therefore, on a very conservative estimate and if the sands extend to a depth of even about one meter, the inferred reserves of ilmenite in the three bays surveyed would be of the order of about 2 million tons. In estimating the reserves, a cubic meter of sand has been taken to weigh about 1.3 tons, which is based on an average weight of a number of 100 cc samples of sand from these bays. Of the several bays and estuaries on the Konkan Coast, only three have been surveyed so far in detail. Therefore, the total offshore reserves of ilmenite off the Konkan Coast in other bays still not surveyed may be many times greater. The present surveys indicate that higher concentration is associated with silts in offshore areas, but beyond depths of 10 m the silts are covered by clays. Undoubtedly the ilmenite sands extend offshore below the clays, and this may add substantially to the potential reserves. The onshore reserves of ilmenite in the beach sands of Konkan have been estimated at 4 million tons (Mane and Gawade, 1974). It is, therefore, interesting to note that the offshore reserves of ilmenite in the Konkan area may even be more than the onshore reserves. While undoubtedly mining for offshore and onshore deposits will have to be carried out by different techniques, the method of processing and beneficiation will be similar. It is, therefore, suggested that an integrated plan for mining and beneficiation of these ilmenite deposits, both onshore and offshore, may provide for a large reserve.

Conclusions

(1) Detailed exploration of three bays (Kalbadevi, Mirya, and Ratnagiri) along the Konkan Coast indicated that the ilmenite placers extend to about 9 to 12-m depth and 2 to 5 km offshore, beyond which these are covered by clays. The sediments in the bays consist of sand (8–99%) and silts (1–69%). The heavy minerals range from 1–91% and ilmenite from 1–52%.

(2) The heavy mineral assemblage (magnetite, ilmenite, augite, diopside, and hornblende) and their proximity to the Western Ghats suggest that the sediments have been derived from the Deccan Traps. The maximum precipitation and sediment discharge during the southwest monsoon (June to September) coincides with the turbulence at sea, facilitating transport, sorting, and concentration of heavy minerals. The distribution of sand, silt, and heavy minerals (magnetic, nonmagnetic fractions, and ilmenite) shows that the heavy minerals are concentrated with sand at stream entrances and with silts and silty sands in the center of the bays or offshore. Higher concentrations of heavy minerals, as well as ilmenite, do not appear to be related to larger sediment input and catchment areas, but to the entry of the stream directly into a bay (higher concentration) or through a swamp or bar (lower concentration). Higher concentrations of nonmagnetic minerals are associated with ilmenite, while lower concentrations are associated with magnetite, which may be used as guide for the exploration. The differences may be attributed to areas and processes operating in the bays.

(3) Because of the arcuate shape of the bays, the northern parts are subjected to west-southwest and west monsoon waves, favoring sorting and concentrations of heavy minerals in the north. The arcuate shape also leads to the generation of converging or circulatory currents in the bays during the monsoon season. Thus, the sandy material is deposited along the shore, and the silts rich in heavy minerals are deposited in the center of the bay or in the offshore areas.

(4) The general distribution of sediments in the area and the concentration of heavy minerals are apparently controlled by three factors: (1) the sources (source rocks, streams and their entry), (2) the geometry of the bays (arcuate shapes), and (3) the processes (waves and currents) operating in the bays.

(5) The sediments with over 5% ilmenite cover an area of 15 km² and are based on a probable extension up to a depth of 1 m: the inferred reserves are estimated to be about 2 million tons. Considering the large

number of estuaries and bays still to be surveyed along the Konkan Coast, the total offshore reserves may be many times more and compare favorably with the known onshore reserves of about 4 million tons.

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