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Use of Shallow Seismic Surveys in the Exploration of Nearshore Placers off Maharashtra Coast, India

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ABSTRACT

Shallow seismic surveys were carried out for 520 km in 3 bays viz., Jaigad, Ambuah and Varwada along the Maharashtra coast in the western part of India. In Total, 53 traverses were run across the shelf perpendicular to the coast upto about 20m water depth.

These surveys were used for the first time in this country by the authors to determine 1) the lateral continuity of the placers below the clay 2) the vertical thickness of placer sand and to use the same for the calculation of the inferred reserves and 3) to understand the nature and structure of the basement which is likely to throw some light upon the important and controversial subject like the evolution of the west coast of India.

From the profiles prepared out of shallow seismic data, five major reflectors in the sandy zone have been recognised. They are sand, sand and murum, murum, altered traps and traps of which the first two have been confirmed by means of, sampling while the rest have been correlated from the borehole log data. The basement has shown a steep plunge below the clay zone and its clear physiographic feature, evolved by the block uplifting which in turn, controlled by E-W fault fractures. In addition, evidence of numerous faults and intrusions associated with fractures and zones of upwarping along with the occurrence of ferro-basalts in Jaigad area converge to point the presence of hot spot in and around the mouth of the Shastri river during the Deccan volcanic activity, and throw modest suggestions on the evolution of the west coast of India.

The continuity of the sand reflector below clay has been traced upto -17 to -18 m where a sudden fall in their level in almost in all the traverses has brought an end to that. The sand isopachs indicate on an average of 4 m thickness which has been, in place of borehole confirmation, directly used to

evaluate the inferred ore reserves of ilmenite-magnetite placers. The continuity of the placer sand below the clay even upto -17m and the 4m thickness of the sand as deduced from the sand isopachs have boosted the inferred reserve potential from 5.27 to nearly 21 million tons.

INTRODUCTION

In the year 1975, National Institute of Oceanography, India, has proved the extension of Off-shore ilmenite placers along the Konkan coast, Maharashtra, situated within the west coast of India (Siddique *et al*)¹. Immediately after that, a systematic detailed off-shore surveys were carried out for 130km long stretch of the innershelf covering 13 bays, along the central Maharashtra coast (Fig.1). The survey includes 1320 grab samples, 66 piston gravity cores, 41 bulk samples, 1889 km echosounding, 895 km shallow seismic profiling and 1228 km magnetics. In the present study the data from three adjacent bays viz. Jaigad, Ambuah, and Varwada situated in the northern extreme of the survey area have been included. The sand samples have been analysed for their placer content and confirmed for their placer enrichment. The concentration of placers has also been evaluated by means of the collection of bulk sediments. Encouraged by the good concentration of ilmenite placer

sediments, it was planned to go ahead with the calculation of reserves. Unlike the surficial deposits on land, it was not possible to calculate the vertical concentration by means of pit samples. As the bore hole sampling was costly, it was felt to carry out shallow seismic surveys to determine the following:

1. the lateral continuity of the placers below the clay,
2. to understand the nature and structure of the basement which is likely to throw some light upon the important and controversial subject like the evolution of the west coast of India, and
3. the vertical thickness of placer sand and to use the same for the calculation of the inferred reserves.

METHODS

Position Fixing: Before commencing the offshore surveys, stations were fixed on the coast by taking positions from the established geodetic stations, locally called as Narvan, Boria and Varvada. The optimum number of additional stations in the area, required for a reliable shore control have been fixed by means of triangulation and intersection methods using wild T₂ Universal Theodolite. The details of the methods of fixing shore markers have already been discussed (Rajamanickam)².

A Motorola Miniranger (MRS III) system, that consist of a range console, transponder, data processor, track plotter and terminal track indicator as peripheral was used for surveys during 1980. The shore stations were installed at the reference points already located by triangulation. The antenna with the space diversity option was fixed on top of the flag mast. The signals on 5570 KHz frequency were transmitted from the boat to shore station and received on 5480 KHz frequency. Based on time delay, the ranges (distances) were calculated and converted into UTM by the data processor

and then plotted on the plotter. The track indicator provided an idea about the deviation of the tracks from the planned tracks and thus helped to steer the boat on the proposed line.

Echosounding: An Atlas Deso-10 Dual Frequency (30 KHz and 210 KHz) Echosounder with 230 mm wide dry paper recording type was used for the surveys. The low frequency of 30 KHz provided the subbottom penetration, whereas the high frequency 210 KHz provided a good resolution. The echosounder was calibrated and adjusted by lowering a bar to a set depth beneath the transducers and adjusting the motor speed to give a correct depth. The index error was corrected by adjusting the transmission mark and speed error was eliminated by adjusting the motor governor. The bar check was always carried out before commencement of the sounding and at the end of the days work. Survey tracks were drawn perpendicular to the coast. To delineate the depth contours accurately, a few cross lines were run parallel to the coast. The surveys were carried out on fishing trawler, about 15 m long, and tracks were spaced at about 200 m interval normal to the coast in order to obtain the best possible coverage of variation in topography and sediments. The soundings were reduced to datum from the predicted tide values of Jaigad, supplied by the Captain of Ports of Maharashtra State. These tide values were fed in computer and the necessary tidal deductions were made in the soundings in the suitable fix and time.

Shallow Seismic Profiling: In order to find out the thickness of sand, continuous shallow seismic profiling was done using, first, Huntac Hydrosonde and then EG & G Spark Array. Huntac Hydrosonde 2A system consists of a boomer source, the transmitter energy storage unit, the hydrophone array and receiver, the latter being the combination of signal processor, graphic

recorder (10 cm wide paper) and keying programmer. The boomer KO 5 source can be fired at an energy level 1000 joules once every two seconds. In the present survey, only an energy level of about 100 to 300 joules was used.

In the following stages of the survey, EG & G Spark Array system was used for obtaining the sand thickness through seismic profiling. EG & G spark array consists three electrode spark array (Model 267-A), power supply (Model 232-A), triggered capacitor bank (Model 231-A), Krohn-hite band pass filter (Model 3700), Key gate programmer (Model 1100) and EPC 3200 recorder with 49 cm dry electro-sensitive paper and single element hydrophone (Model 262J). Spark array is towed by its rugged four conductor ceoprene covered cable. Electrical energy is discharged into the positive electrodes through the conductor salt water and to the surrounding frame to produce the explosively formed bubble. The acceleration of the bubble growth generates the positive acoustic pulse of high intensity. The energy is in the range of 80 to 120 Hz, while the maximum energy per electrode is 3000 watt seconds.

In 1979, 148 km of seismic survey, using Huntac hydrosonda 2A system, was completed but since its acoustic pulses could not pass through the placer sand to reach the basement, operations were repeated using EG & G shallow seismic profiling system and more clear and better resolution between clay and sand similar to double frequency echosounder was obtained. In 1980, 370 line kilometer (1km) of seismic surveys using EG & G system were carried out over the investigated area. The lines were run across the shelf, perpendicular to the coast up to about -20 m and an interval of about 400 m between the lines off Jaigad river mouth and of about 1000 m in other areas was maintained. In the surveyed areas

about 53 survey traverses (Fig. 2&3) were undertaken. The seismic data were processed in the laboratory and the profiles prepared. The depth of the first reflector was always verified with the echosounder for confirmation because of its better resolution. The profiles of all the traverses were prepared on a horizontal scale of 1 cm = 100 m and vertical scale of 1 cm = 5 m. Representative profiles in the bays are shown in Figure.4.

Results and Discussion

THE REFLECTORS:

From these profiles five major reflectors have been recognised. Of these, lithology of surface reflectors was confirmed by on the spot examination of the grab samples. The second reflector was identified by the piston-gravity corer sampling. The rest of the reflectors were correlated with the borehole-log data obtained in Mirya bay, a little north of the investigated area by taking traverse adjacent to the boreholes. (Siddiquie et al).³ These reflectors from the surface downwards have been equated to sand, sand and murum, murum, altered trap and basement trap but in the offshore zones beyond 9-11m water depth, the surface reflector is identified as recent clay above the sand.

Seaward continuity of the near-shore surface reflector, indicated by the echosounder (Fig.5) and seismic records (Fig.6), was further confirmed by collecting systematic closely-spaced samples from sand-clay interface together with the last samples from greater depth obtained by using piston-gravity corer. Presence of onshore sands in several localities, surveyed by the author in detail, is confirmed below offshore clay zones by the respective collected core samples. Among the reflectors, the third and the fourth reflectors that of sand and murum and murum are found to be discontinuous in many profiles and

the junctions between them are not easily decipherable, possibly due to the high porosity of the medium causing the dissipation of energy. The fourth or fifth reflector related to the altered traps could not be recorded in certain profiles. It might have remained unrecorded owing to the instruments limited resolution, to record hard rock thickness of about a meter.

Basement and sub-surface structures: With a view to obtain relief of the basement, different basement depths observed in the seismic profiles, at 15 m and 10 m water depths, are plotted in Figure.7, with latitudes of respective lines shown in abscissa. The last reflector, normally the fifth in the clayey zone and the fourth in the sandy zone, is found to indicate the characters of the basement reflector. If deeper reflectors are not marked highly irregular in nature, invariably accompanied with multiples and not followed by the other deeper reflector, is considered as basement reflector. Fig.7 shows a variation from 5 m to 41 m in the basement depth. The boreholes in the bays end in the coast indicate the presence of the trap rocks right from 5 m level to a few km. Contrary to deep basements, presence of altered traps is not observed in the shallow basements.

Coupled with the structural disturbance, that the basement has undergone prolonged erosion is indicated by its highly undulatory surface. Deepest basement in the investigated area is observed in the Jaigad bay river mouth and Figure.7 brings out a similar kind of patterns both in 10 m and 15 m which indicate that they align along E-W direction, developing the adjacent area into blocks. The basement plot displays a step-like rise from Jaigad to Ambuah and Ambuah to Varuada. Such physiographic feature might have been due to block uplifting controlled by the E-W fault fractures in two stages of which Varuada might

have been the youngest. The block movements are supported by the presence of beach rocks in Varuada back-shore. In addition to the difference caused by the uplifting, the continued erosion of the river channels from time immemorial might have contributed to the development of valley-like depressions in the basement all along easterly trending zones of weakness. Similarly there is development of deep valley in the basement and its formation may be attributed to the old river channel off Kachera by which a deep V-shaped valley is continuously being formed even in the present day shelf. This is in agreement with the observation of Babu⁴, who has considered the secondary E-W lineaments, developed due to the major denudational patterns and the river courses.

The seismic data indicates the presence of a large number of dykes mostly in the northern part of Jaigad bay. Figure. 8 shows a dyke intrusion upto the second reflector, whereas the Figure.9 depicts a series of minor intrusions. Dome type (Fig.10) of intrusions even upto the clay zones have also been observed. From Jaigad to Ambuah bays, out of a number of observed minor faults a sinistral en-echelon, simple down-fault with a throw to the west of nearly 20 m and another with an upthrow of 11 m are shown in Figures.8,11, and 12, respectively. But, such structural deformations are not recorded in the Varuada bay, possibly due to the absence of the dykes. In general, minor structural anomalies are not, however, recorded in the seismic surveys but they are deduced from the magnetic anomalies whose structural interpretations have been given in an earlier paper of the author (Siddiquie *et al*⁷, and Rajamanickam *et al*⁸,) which also contains a comprehensive structural deformations indicated by the geophysical surveys have been found to be in agreement with the postulates of the earlier workers.

Dessai and Peshwa⁹ from the study of land-net pictures have recorded two sets of prominent lineations, roughly trending ENW and ENE. Ramanna¹⁰ from the magnetic studies of Jaigad bay has supported the extension of these lineaments in the off-shore and has located one such feature traversing the Jaigad bay. Das and Ray¹¹ have reported the presence of N-S fracture pattern in the Ratnagiri Deccan traps and the streams of the area are found to follow these parallel fractures. Siddique *et al*⁷ have attributed the steep gradients observed in the magnetic intensity maps in the north of Jaigad to NNW trending dykes, fractures and the lineaments in Jaigad bay and north-westerly features in Varwada bay, which are the extension of the lineaments recorded by Dessai and Peshwa⁹ on land.

Off-shore seismic surveys carried out by the author have provided the following observations: (1) a sudden increase from 2 to 6 m in the thickness of clay at 10-18 m water-depth about 5-7 km from the coast; (2) a steep plunge in the basement underneath the clay zones, and (3) a complete offset of the different formations.

The above observations strongly indicate the possible presence of a group of N-S faults. Should these faults continued further northwards, they can be connected to the Panvel flexure zone, identified off Bombay for nearly 100 km in length. Similar faults have also been postulated by Babu⁴ for the Neogene sedimentation around Ratnagiri basin on land. Glennie¹² on the basis of geophysical studies has postulated an upwarping of the crust along the west coast of India by means of such faults. Existence of such fault fractures although between 7 to 20 km instead of the author's observation of 5 to 7 km from the shore, has been surmised by different workers (Glennie,¹² Guha *et al*,¹³

Auden,¹⁷ and Guha and Padale,¹⁵). Most of them have felt that they are nothing but the extension of the Panvel flexure along the strike.

Hora¹⁶ has remarked from the study of fish remains in the Western Ghats that the final phase of the Deccan trap volcanism most probably occurred in more recent times than the Tertiary or even in the Quaternary. Such periodical eruptions might have acted as a driving force for the block movements and the upheaval of the coastline might have taken place stage by stage. Das and Ray¹⁷ have identified a number of faults, fractures, and dykes from ERTS imageries. The intrusions marked in the present study even upto the clay zone are in agreement with the views that volcanic activities continued even after Tertiary and the picture of the basement depicting two blocks of Ambuah and Varwada, is fully endorsing the postulated view of Hora.

Tipnis and Shrivastava¹⁸ have proposed the north Konkan area as the possible eruptive centres due to the presence of many dykes and fractures centering around this area. Auden¹⁹ has stated that the places of concentrated dykes with zones of upwarping are the main foci of eruptions. Agashe and Gupte²⁰ have felt that presence of dykes with varying widths of 5 to 200 m mark the centers of pouring out magmas. Evidence of numerous faults and intrusions associated with fractures, zones of upwarping, varying widths, and other linear patterns, marked by the occurrence of ferrobasalts in Jaigad area converge to point out the presence of hot-spot in and around the mouth of the Shastri river during the Deccan trap volcanic activity.

The Sand Thickness: Continuity of the placer-sand, i.e., the first reflector at 9 m water depth on near shore areas has

been proved by the geophysical surveys and sampling data. The appearance of the second reflector in the sandy zone and the third reflector in the clayey zone is treated as the closing boundary of the black-sand. The continuity of the placer sand reflectors very well defined below the clay up to 17 to 18 m water-depth or to a point where there is an abrupt change in the profile of the reflector so as to produce an offset with simultaneous increase of the clay thickness from 2 to 6 m. This abnormal characteristics encountered in the recorded data is considered to be of a fault. The continuity of the black sand for all practical purposes is inferred by the author only up to this point. The difference between the first and second reflectors in the sand covered zone and the second and third reflectors in the clay covered zone is attributed to the vertical thickness of the placer sand. This thickness of sand in the near shore is in agreement with the borehole information.

Irregular nature of the basement has shown many eroded channels in the form sand lenses to give rise to a sandy layer as much as 8 m thick. The sand thickness along the lines was calculated and isopach maps prepared. These maps show the sand thickness varying from 1 to 8 m (Figs. 13 & 14). It can be seen from the figure that there is a thicker sand layer in Jaigad and northern Ambuar bay, contrary to thinner zones of such layers in the southern Ambuar and Varuada bay. This perceptible variation in the sand layers in the offshore areas is considered either converting the depositional basin shallow, due to the uplifting of the southern part or lack of supply unlike Jaigad where there is a high influx of sediments by the Shastri river. It can be due to one or the combined influence of both. Even with the appreciable discharges of the Shastri river, its mouth

has very thin sandy layer, perhaps due to either the presence of hard rocky bottom, made up of the Intrusives, whose presence is common feature of the area or, the extension of Narvan promontory extending flat right up to the bank of the channel or inability of the sediment waves, the latter producing wave convergence resulting in strong littoral drift, that is supplemented by the absence of fine fraction in the sediments of this area (Rajamanickam et al.)² Throughout the bays and the offshore areas are noted pockets of thick sand accumulations owing to the various forms of eroded channel (Fig. 15) and sand-bank (Fig. 16) caused by the basic dykes frequently occurring at places. The average vertical thickness of sand layers comes out 4 m as determined from the values obtained through centimeter grid on the isopachs of the original map in the scale of 1 : 10,000.

Reserves: By field experimentation it has been found that one cubic meter sand weighs 1.22 tons. Since for this study a very rough estimate, that too, based on surface sampling has been made, reserves are classified only as 'inferred'. Table I gives ilmenite concentration by percent in the three bays. Taking the mean of the ilmenite concentration of each area, and multiplying the same with the respective volume calculated for one meter depths, the total ilmenite reserves are found to be nearly 5.27 million tons.

Seismic record shows that the thickness of the sand, though ranging up to 9 m, averages 4 m. Assuming the presence of placers for a minimum of 4 m depth, the ilmenite reserves in the surveyed area, are expected to be of the order of 21.08 Mt. The computations include only the sampling area, that is, the sand covered zone. Although the continuity of the sand below the clay is confirmed, the area

beyond sandy zone is not included in the reserve estimation for want of detailed heavy mineral data. With the surveyed area of about 36 km² the inferred reserves are likely to be of 21.08 Mt and if proportionately the total area of about 216 km² is considered for the reserve estimation, the reserve will be several fold than the above figures. Siddiquie et al³ have estimated 2 Mt. of inferred reserves for one meter sand in Ratnagiri, Mirya, and Kalbadevi, located south of the study area. The ilmenite quantity in this area is within the limit of economically workable concentration. The cumulative estimates including the beach placers (Mane and Gawade)²² and other adjacent bays, will be much more to support a titanium industry in this relatively backward area.

CONCLUSIONS

1. The surveys indicate the continuity of the nearshore surface reflector (sand) below clay even upto 17 m water depth.
2. The shallow seismic profiles display lot of minor intrusives and faults associated with fractures, zones of upwarping, in varying widths and other linear patterns, the presence of hot spot in and around the mouth of the Shastri river during the Deccan trap volcanic activity. This is also supplemented by the occurrence of ferro-basalts in Jaigad area.
3. Preparation of sand isopachs shows the presence of an average 4 m thick sand sediments in the investigated bays.
4. Considering the surveyed sandy sediment distribution area combined with the average sand thickness, the reserve of ilmenite placer is inferred within these studied bays to be of 21 million tons.

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TABLE I. ILMENITE RESERVES IN THE INVESTIGATED AREA

Ilmenite Concentra- tion(in per cent)	Jaigad bay	Ambwah bay	Varvada bay	Total area	Inferred reserves(Mt)	
					1m thick	4m thick
35	----	0.40	1.40	1.80	0.84	3.36
25-35	2.01	1.23	1.98	5.22	1.75	7.00
15-25	4.27	0.96	0.93	6.16	1.50	6.90
15	8.50	3.61	0.80	12.91	1.18	4.72
Total	14.78	6.30	8.11	28.09	5.27	21.08

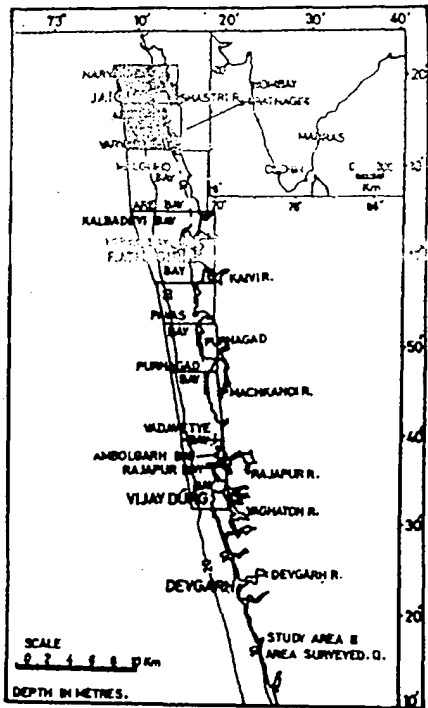


Fig. 1—Locality map.

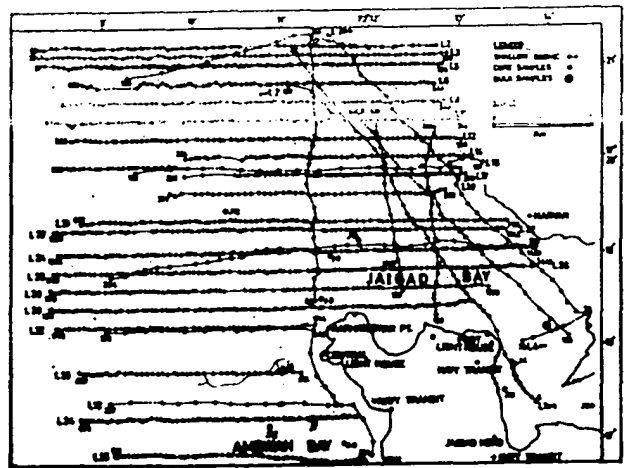


Fig. 2—Shallow seismic survey traverses in the northern part of the study area.

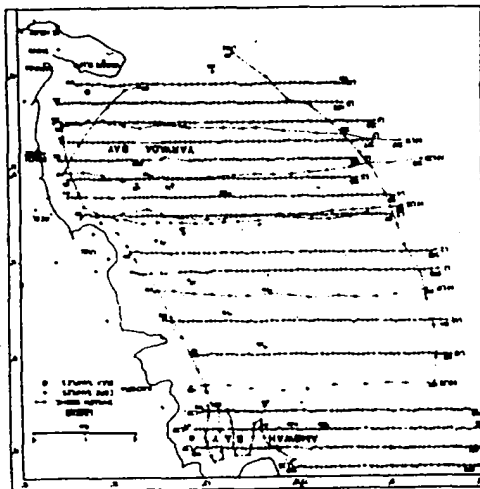


Fig. 3—Shallow seismic survey traverses in the southern part of the study area.

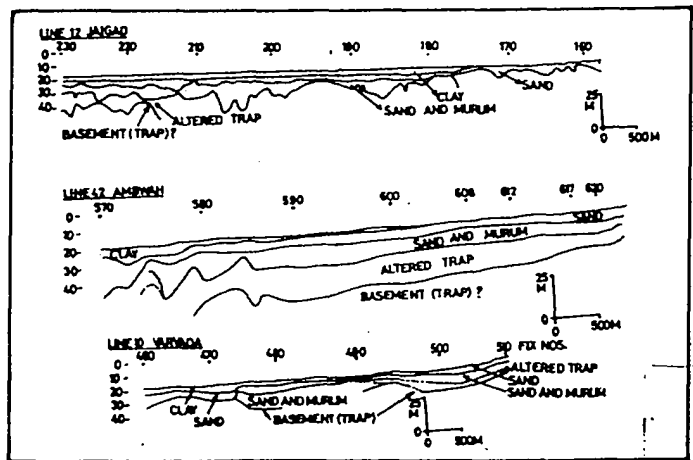


Fig. 4—Representative interpreted shallow seismic profiles.

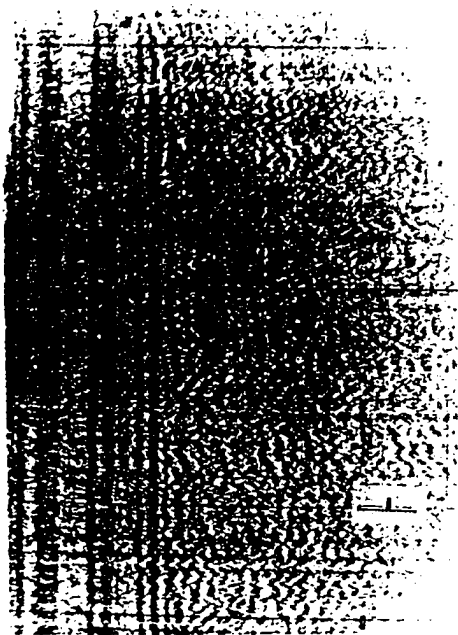


Fig. 6--Continuity of surface sand reflector below the clay in the shallow seismic record.

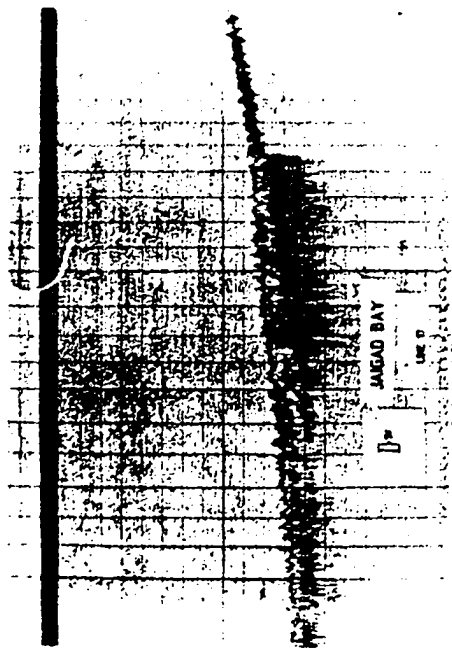


Fig. 5--Continuity of surface sand reflector below the clay from the sounding record.

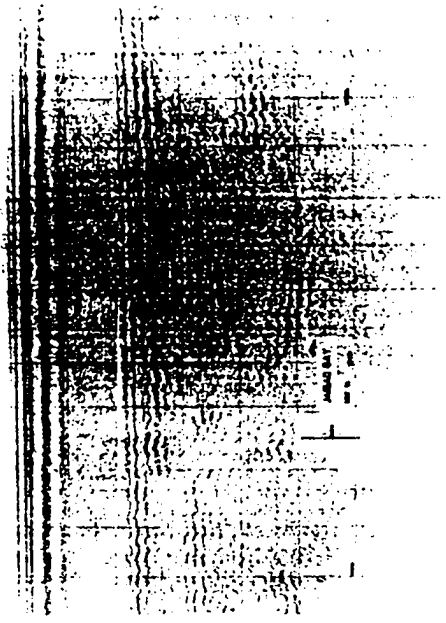


Fig. 8--En-echelon fault and intrusion in Jagad Bay as revealed in shallow seismic record.

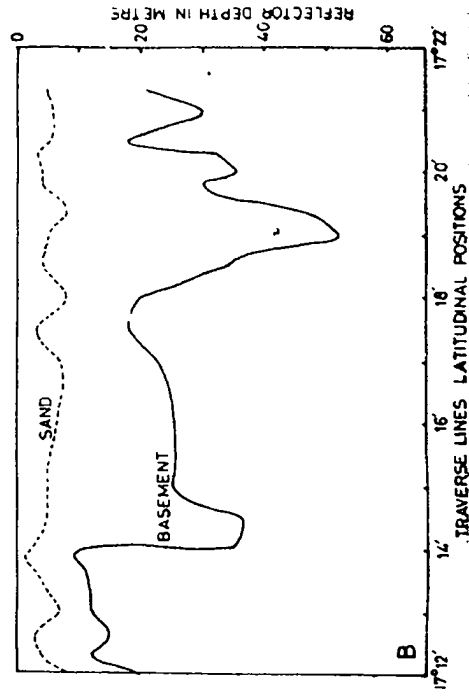


Fig. 7--Basement depths observed in seismic profiles.

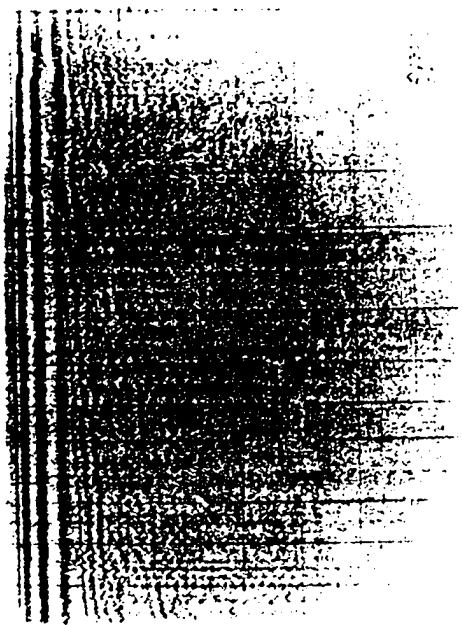


Fig. 10—Domal type of intrusion even up to second reflector in Varwada Bay.

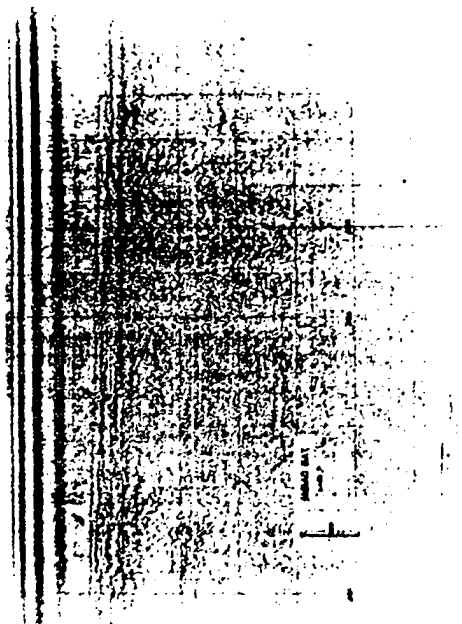


Fig. 9—Series of intrusions in Jaigad Bay's shallow seismic record.

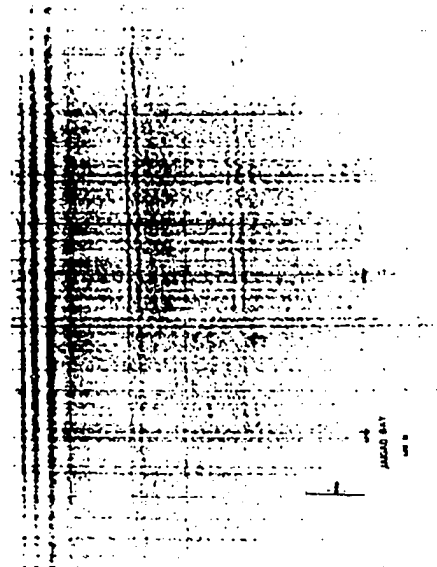


Fig. 12—An upthrow fault in Jaigad Bay.

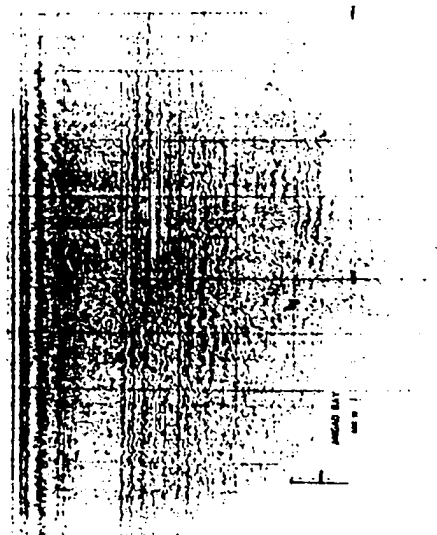


Fig. 11—A simple down fault in Jaigad Bay.

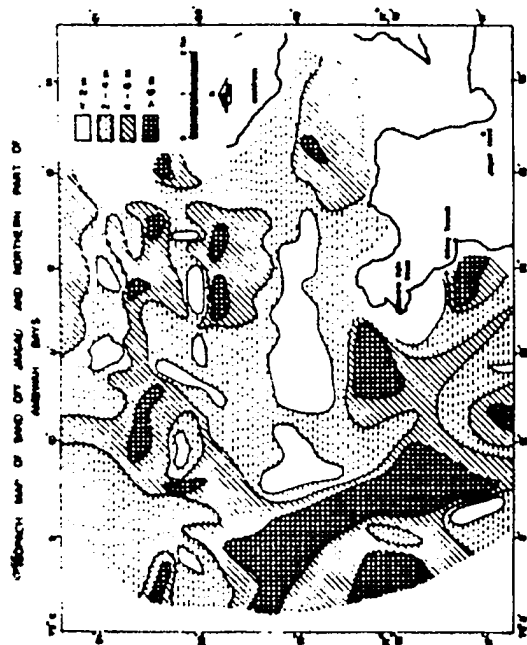


Fig. 13—Isopach map of sand reflector in the northern half of the investigated area.

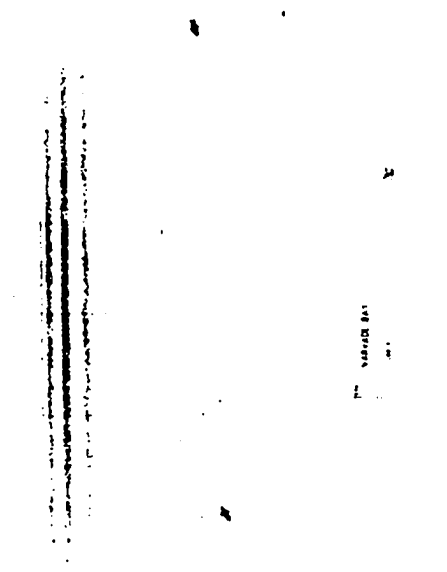


Fig. 15—Feature of an eroded channel in Varwada Bay.

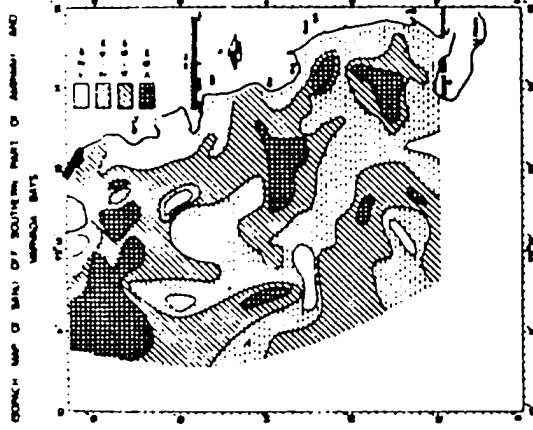


Fig. 14—Isopach map of sand reflector in the southern half of the study area.



Fig. 16—Sand accumulation due to a sand bank.