

# OFFSHORE AND ARCTIC OPERATIONS SYMPOSIUM

87/155  
**ELCE**  
**TENTH ANNUAL ENERGY-SOURCES  
TECHNOLOGY CONFERENCE & EXHIBITION**  
February 15-18, 1987 Loews Anatole Hotel Dallas, TX

## SEABED CONDITIONS FOR OFFSHORE DEVELOPMENT OFF BOMBAY - AN ASSESSMENT

H N Siddiquie, G C Bhattacharya, F Almeida, K H Vora, M V Ramanaiah  
and V Subrahmanyam

National Institute of Oceanography

Dona Paula, Goa 405 004 INDIA

### ABSTRACT

Bombay port handles bulk of India's seaborne trade and the recent discovery of offshore oil and gas fields provided an impetus for industrial development. The industrialisation, urban development (population 8 million) and concern for environment led to considerations for deepening of the harbour, laying of the submarine pipelines for oil and gas or disposal of sewage/effluents and construction of a bridge or subsea tunnel across the harbour. An offshore area of about 65 sq.km. in the harbour and adjacent areas extending from shallow tidal flats to about 14 m isobath was surveyed, with echosounder, side scan sonar and high resolution shallow seismic profiler (followed by seabed sampling) with a Mini-ranger position fixing system. The paper presents an integrated analyses of the data and reviews the geological environment for offshore engineering constructions. The acoustic bedrock is the continuation of the onshore Deccan flood basalts (around 65 million years old) or its derivatives. The bedrock characterised by lithological inhomogeneities, tectonic disturbances and erosion is overlain by recent sediments (maximum 16m thick). The bedrock is observed in the inner harbour and near shore areas and could be traced till about 9 km. seaward in the west. The sediments are mainly the unconsolidated clay locally intercepted by sand bodies. The seabed is largely even but uneven seafloor is observed where stiff clays cover the seabed or rocks outcrop. Ripples on the seafloor indicate mobile sediments. The isopachs of sediments show basement deeps and palaeochannels which can be utilised for deepening of the harbour. The need for transport across the harbour and continual ship movement would require development of a Transharbour transit corridor in the less congested northern part. The bedrock in the northern part of the harbour shows fractures and discontinuities and is not favourable for a tunnel which may be deeper and without sufficient rock roof and with longer approaches. Large rock exposures on the seabed can be considered for piled structures for a bridge. Due to environmental constraints effluents can not be discharged in the harbour and have to be discharged in the open sea to the west. In the west towards offshore the bedrock could be traced as outcrop or subcrop till about 8 km. The intervening areas between outcrops are covered by 4 to 6 m sediments in which effluent pipelines can be layed and buried to safe depth.

## SEABED CONDITIONS FOR OFFSHORE DEVELOPMENT OFF BOMBAY - AN ASSESSMENT

H N Siddiquie, G C Bhattacharya, P Almeida, K H Vora, M V Ramana  
and V Subramanyam

National Institute of Oceanography

Dona Paula, Goa 403 004 INDIA

### ABSTRACT

Bombay port handles bulk of India's seaborne trade and the recent discovery of offshore oil and gas fields provided an impetus for industrial development. The industrialisation, urban development (population 8 million) and concern for environment led to considerations for deepening of the harbour, laying of the submarine pipelines for oil and gas or disposal of sewage/effluents and construction of a bridge or subsea tunnel across the harbour. An offshore area of about 65 sq.km. in the harbour and adjacent areas extending from shallow tidal flats to about 14 m isobath was surveyed, with echosounder, side scan sonar and high resolution shallow seismic profiler (followed by seabed sampling) with a Mini-ranger position fixing system. The paper presents an integrated analyses of the data and reviews the geological environment for offshore engineering constructions. The acoustic bedrock is the continuation of the onshore Deccan flood basalts (around 65 million years old) or its derivatives. The bedrock characterised by lithological inhomogeneities, tectonic disturbances and erosion is overlain by recent sediments (maximum 16m thick). The bedrock is observed in the inner harbour and near shore areas and could be traced till about 9 km. seaward in the west. The sediments are mainly the unconsolidated clay heavily intercepted by sand bodies. The seabed is largely even but uneven seafloor is observed where stiff clays cover the seabed or rocks outcrop. Ripples on the seafloor indicate mobile sediments. The facies of sediments show basement deeps and sub-channels which can be utilised for deepening of the harbour. The need for transport across the harbour and continual ship movement would require development of a Transharbour transit corridor in the congested northern part. The bedrock in the northern part of the harbour shows fractures and discontinuities and is not favourable for a tunnel which may be deeper and without sufficient rock roof and with longer approaches. Large rock exposures on the seabed can be considered for piled structures for

a bridge. Due to environmental constraints effluents can not be discharged in the harbour and have to be discharged in the open sea to the west. In the west towards offshore the bedrock could be traced as outcrop or subcrop till about 8 km. The intervening areas between outcrops are covered by 4 to 6 m sediments in which effluent pipelines can be laid and buried to safe depth.

### INTRODUCTION

As a result of accelerated petroleum exploration and exploitation, rapid urbanisation and associated development activities during the past one decade, many site investigations have been carried out in the Bombay harbour and adjacent areas. The National Institute of Oceanography (NIO), Goa surveyed about 65 sq. km. of the area covering the harbour and the offshore areas. The area (Fig. 1) extending from shallow tidal flats to about 14 m isobath was traversed with 840 lkm of echosounding, 650 lkm of side scan sonar and 750 lkm of shallow high resolution seismic profiling. In addition, large number of seabed samples were collected using grab, dredge and corer for outcrop control, sediment identification and soil testing. Based on the integration of the collected acoustic profiling data, different types of maps were prepared depicting the surficial and shallow subsurface geological environment of the area under discussion.

A brief inventory of some main geological features, considered useful for pre-design or initial studies is presented in this paper. It is stressed that the requirements for geological input to site studies vary widely, depending upon the nature and purpose of the engineering projects. The information presented may be useful towards an appreciation of the dominant aspects of the geological environment and to anticipate the complexity of the problems to be encountered.

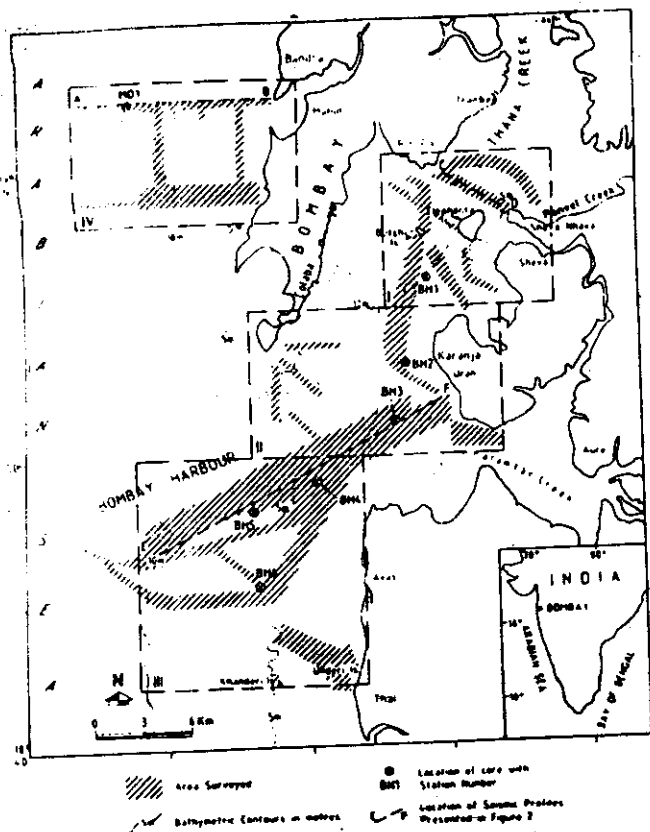


Fig. 1-Map showing the areas of detailed geophysical surveys Off Bombay island and in the harbour.

## EQUIPMENT AND METHODS USED

### Position Fixing

These surveys were mostly carried out using Motorola Miniranger (MRS III) system. However, in some areas sextants with a station pointer have also been used.

### Echosounding

Echosounding was carried out mainly with an Atlas Deso-10 dual frequency (30 and 210 KHz) echosounder. Bathymetric charts were prepared after applying tidal corrections. The echograms were also used to identify the areas of even and uneven topography.

### Side Scan Sonar Profiling

An EG&G mark IB Side Scan Sonar with tow fish (Model 272) was used. The Side Scan Sonar records (sonographs) were interpreted on the basis of the tonal variation of the records. These data were used to demarcate the areal distribution of the rock outcrops, their trends and joint patterns, distribution of various sediment types, seabed features including periodic bedforms and dredging mounds.

### Subbottom Profiling

The subbottom profiling was carried out with a Huntex Hydrosound system (mark-2A), with an ED5 Boomer (5 KHz) as the energy source. The northern inner harbour area was surveyed with an ORE subbottom profiler comprising of Transceiver (Model 140) and transducer assembly (Model 132 B).

While determining depths to the reflectors no correction has been applied for the velocity of sound in water or in the sediments. P-wave velocity measured from several core samples collected in the area showed little difference from the speed of the sound in water, hence the factor 1500 m/sec was used to convert the time sections into depth sections.

### Seabed Sampling

Based on the shallow seismic records and sonographs, sites were selected for sampling. The surficial sediment samples were collected by a grab and gravity piston corer, while rock outcrops were dredged. The sampling information was used for outcrop control and to compliment the echosounding, side scan sonar and subbottom profiling data.

## BRIEF DESCRIPTION OF THE GEOLOGICAL ENVIRONMENT

The western side of the Bombay harbour is bordered by the Bombay group of islands whereas in the north and the east lies the mainland. The coastline in the Bombay harbour area is characterised by numerous bays, beaches, cliffs, marine platforms, marshy tidal flats and creeks (1). Several small shoals, islets and few islands are present in the inner harbour. The main rock types exposed on the adjacent onshore areas comprises basalts and associated rocks (Deccan traps, about 65 million years old), interbedded with tuffs (2).

### Surficial and shallow subsurface geology

In the Bombay harbour area recent (3) sediments are deposited over a fractured, weathered and eroded basalt surface. The acoustic basement (lowestmost reflector observed in the seismic records) therefore mainly represents this basaltic bedrock. For the convenience of discussion the Bombay harbour area is divided into four separate blocks (marked as I, II, III and IV in Fig. 1), and the shallow subsurface geology of each block described separately. Line drawings of the representative seismic sections, and lithologs of selected cores are presented in Figures 2 and 3 respectively. Distribution of sediment types alongwith isopachs of sediment is shown in Figure 4.

The northern inner harbour: This area (block I) contains 1) Elephanta and Butcher islands and the channels on either side of the Elephanta island. The river Ulhas from the north through the creek and the river Panvel from the east fall in this area. The water depth varies around dries over the mudflats to a maximum of about 13 metres in the channel between Elephanta island and mainland. Steep seabed and subbottom slopes are noticed to be associated with these channels. Submarine bedrock outcrops occur extensively near the islands and isolated in between Butcher island and Pir Pau, whereas the rest of the nearshore areas are characterised by mudflats. The seismic section shows (Fig. 2) that the bedrock

is mainly in the form of ridge and valley, developed due to differential weathering and erosion. Along some apparently linear zones (Fig. 5) the bedrock is either disturbed or terminated abruptly, possibly reflecting tectonic activity. The partially filled bedrock valleys between Elephanta island and mainland and the same near the Pir Pau are presently in the form of open channels. A buried channel is located between Butcher and Elephanta islands. The undulating relief of the bedrock is reflected in the rapid variation of the overburden thickness which reaches a maximum of about 16 metres. The overburden is usually composed of acoustically transparent clay, of which at least the top 2-3 metres are very soft. Sand bodies are present as the fill in the buried channel. The surficial sediments comprise of mostly the soft clay, but isolated sand ribbons also occur. Near Pir Pau reflectors below the seabed are masked probably by some biogenic material in the sediments.

The southern inner harbour: This area (block II) is bordered by Colaba on the west and Karanja on the east. The water depth varies from less than a metre in the nearshore areas to a maximum of around 11 metres.

Onshore rocks continue as submarine outcrop near Colaba and extend till about 2 Km towards inner harbour and about 4 Km towards south. This offshore dipping bedrock surface have a relief of the order of 10 metres. The bedrock is overlain by the acoustically transparent clay (maximum thickness about 6 metres).

Near Karanja the onshore rocks continue offshore till about 12 Km either as submarine outcrop or as subcrop below a thin cover of clay. The bedrock has characteristic high relief and is expressed as valleys and ridges. The bedrock valleys are filled mainly with acoustically transparent clay (maximum thickness about 16 metres). From the trend of the approach and the depositional pattern, a buried channel is inferred to be present near Karanja (Fig. 5). Near the Dharamtar Creek the acoustic basement surface is conspicuously flat and covered with a uniform 2-3 metres clay. This reflector perhaps represents either a relict beach or a patch of sandy or shelly deposit. Large patches of well defined ripple marks (4) are present on the seafloor on some areas particularly near the rock outcrops.

The outer harbour: This area (block III) is bordered by the coastal areas in the east and open sea on the west. The water depth varies from dries nearshore to a maximum of about 12 metres towards the western end of the surveyed portion. Most of the nearshore area is dotted with patches of submarine rock outcrops of varying sizes, of which the Thal shoal is the largest. The bedrock outcrops in the Thal shoal area have unevenness of the order of 3-4 metres. The seafloor gradient over the shoal is very steep and ranges between 1:750 to 1:50. The relief in this area occurs only as thin veneer or patches on the bedrock. West of Thal shoal, the bedrock deepens rapidly and could not be traced further. The overburden thickness gradually increases to a maximum of about 12 metres towards the western limit of the block. The acoustic basement west of Thal shoal is an angular unconformity surface. This unconformity surface is overlain by series of faintly stratified layers which onlap

against the bedrock as they approach shore. The top most sediment layer is composed of acoustically transparent clay of more or less uniform thickness of about 2-3 metres. The sonographs indicate the presence of extensive areas of ripple marks close to the rock outcrops. Off Thal a narrow shallow channel like feature caused by scouring was reported (5) to be present on the flat clay covered seabottom.

The Mahim offshore area: This area (block IV) represents a typical geological situation from the shore towards open sea off the Bombay island. The bedrock continues westwards either as extensive outcrop or as subcrop beneath thin sediment cover and outcrops even upto 9 Km away from the shoreline. A subsurface lineament was identified (Fig. 5) about 10 Km west of the coast. Along this lineament the gradually westward dipping bedrock surface shows an abrupt increase in its slope. At places some faint reflectors could be seen below the acoustic basement and therefore it is inferred that there the acoustic basement represents the dense consolidated or cemented overburden or weathered basalts. Shorewards of 10 metres isobath the overburden thickness is less than 2 metres except for some pockets where more sediments are noticed. Seaward of 10 metres isobath the bedrock deepens rapidly and the sediment cover increases to a maximum of about 12 metres towards the western limit of the block.

#### SALIENT GEOLOGICAL FEATURES AND CONCLUSIONS

Some of the significant submarine geological features which require consideration for any offshore engineering studies in the Bombay harbour area are summarised below:

##### Bedrock surface

The bedrock surface has an overall relief and significant microrelief. Bedrock occurs either as outcrop or subcrop under a thin cover of clay over large areas. The northern inner harbour area contains few linear zones where the bedrock surface is either highly fractured or bounded by sharp discontinuities. Some of these zones coincide with the reported (6) onshore fracture lineaments, which possibly suggest tectonically weak zones in this region. Deepening of the inner harbour may be necessary for enhancing navigability or accommodating large draught vessels, while the less congested northern harbour can be considered as a feasible location for construction of transharbour tunnel, or bridge. These outcrops or the shallow subcrops can be the foundation sites for piled structures, such as a bridge, but may pose problems where dredging, trenching or burial is concerned. The overall relief of the bedrock may be disadvantageous for subsea bored tunnels, which possibly have to be bored deeper and the approach may have to be longer to maintain suitable gradient and required solid rock roof. The presence of weak zones also have to be taken into account for construction of any tunnel.

##### Open and buried channels

Open channels in the Bombay harbour area are easily seen in the hydrographic charts. Several buried channels could be mapped in the course of present study. Presence of more buried channels can not be ruled out. The open channels either overlie the buried ones or are of recent origin, deepened mainly by dredging. Buried channels represent the former subaerially developed

drainage system. These are mostly infilled with acoustically transparent clay and at places by intervening lens shaped bodies of sand or other coarse grained material. Foundations on these buried channels could undergo differential settling. Therefore accurate mapping of these features and proper identification of the infill materials is necessary. However these thick sediment filled channels may be ideal routes for submarine pipelines or cables and also can be utilised for deepening the harbour.

#### Sediment cover over the bedrock

The sediment overburden in the area is mainly composed of clay, however coarse grained materials also occur. The top 2-3 metres of acoustically transparent clay is very soft, but the sand and stiff clay deposits are relatively hard. Table.1 gives details about some of the geotechnical properties of the clays from the core samples (7). The clay cover-ages may be suitable for trenching and easy burial of submarine pipelines, or cables.

#### Mobile seafloor sediments

**Sand ripples:** Identification of ripple marks indicate the presence of zones of unstable seafloor in the Bombay harbour area. This type of features may cause problems with the structures with shallow burial.

**Scouring of the sea floor:** Seafloor scouring is observed along a narrow zone off Thal. This phenomenon is attributed to intensification of bottom currents due to funneling during its passage between two islands (5). Offshore structures such as pipelines built across this type of features are likely to be affected. Similar situation can be expected to exist near other closely spaced islands or submerged rock outcrops.

#### ACKNOWLEDGEMENTS

The results presented in this paper are based on the studies carried out by the Institute for several offshore construction projects. The authors are grateful for the financial support provided by (1) Indian Natural Gas Commission, (2) Bombay Municipal Corporation, (3) Rashtriya Chemicals and Fertilizers Ltd. and (4) The Government of Maharashtra.

#### REFERENCES:

- (1). Subrahmanyam, V.: "Geomorphology of the Deccan Volcanic Provinces". Geol. Soc. India., Memoir 4, 1981.
- (2). Sukheshwala, R.N., and Poldervart.: "Deccan Basalts of the Bombay Area, India". Bull. Geol. Soc. Amer., 69, 1958, 1475-1494.
- (3). Hishini, N.H., Sankaranarayana Gupta, M.V.S., Kidwai, R.M., and Nair, R.R.: "Sediment and Sedimentary Processes on the Continental Shelf off Bombay". Mahasagar, Bull. Natl. Inst. of Ocean., 11, 3 & 4, 1978, 155-161.
- (4). Almeida, F., and Bhattacharya, G.C.: "Ripples on the Seabed in the Bombay Harbour Area". Indian Jour. Mar. Sci., 9, 8, 1980, 212-214.
- (5). Subrahmanyam, V and Bhattacharya, G.C.: "Shallow Seafloor Channel - an indication of

Current Scouring off Thal, Maharashtra." Bull. Soc. for Offshore Engineering and Underwater Technology of India., 5 & 6., 1984, 18-21.

- (6). Das, S.R., and Ray, A.K.: "Fracture pattern, Hot springs and Lineaments of West Coast". Geol. Soc. India., 125th year News letter, 1976.
- (7). Siddiquie, H.N., Almeida, F., and Bhattacharya, G.C.: Unpublished Data of Natl. Inst. of Ocean., 1977.
- (8). Power, K.B.: "Lineament fabric and dyke pattern in the western part of the Deccan Volcanic Province." In: Deccan Volcanism., Geol. Soc. India, ed., by K.V. Subba Rao and R.N. Sukheshwala., 1981., 45-57.

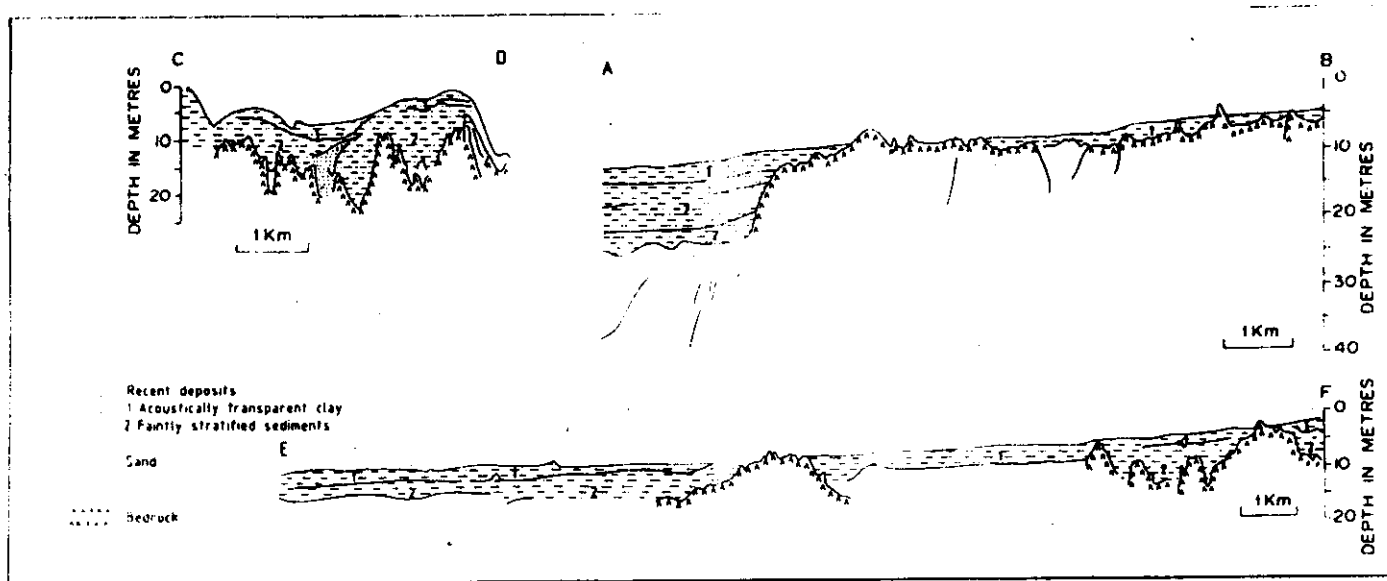
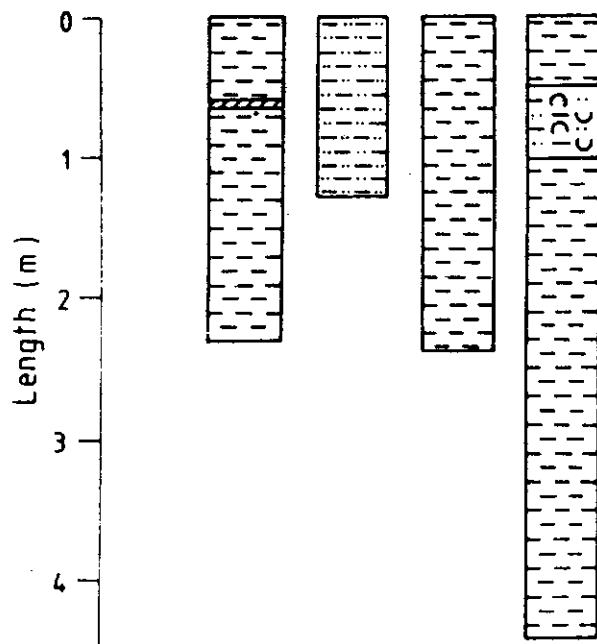


Fig.2 - Seismic sections from the Bombay harbour with interpreted lithological sequences. Locations of the profiles is shown in Figure.1.

Sample Number      MO1      BH5      BH3      BH1

Water Depth (m)      10.8      9.0      4.6      10.8



- Olive Gray Clay
- Silty Clay with Shells
- Olive Gray Clayey Silt
- Shell Fragments

Fig.3-Selected core locations from the Bombay harbour area showing various lithological units.

Table 1: Geotechnical properties of surficial clay from the Bombay harbour area.

Sample number →	BH1	BH2	BH3	BH4	BH5	BH6
Specific gravity (%)	2.62	2.69	2.65	2.69	2.67	2.64
Natural moisture content (%)	114.15	86.20	110.13	85.10	126.90	91.70
Liquid limit (%)	85.00	64.20	98.40	65.00	99.60	89.00
Plasticity index (%)	35.60	31.94	43.50	26.30	48.52	44.02
Sensitivity	3.30	3.10	2.20	3.60	2.80	2.20

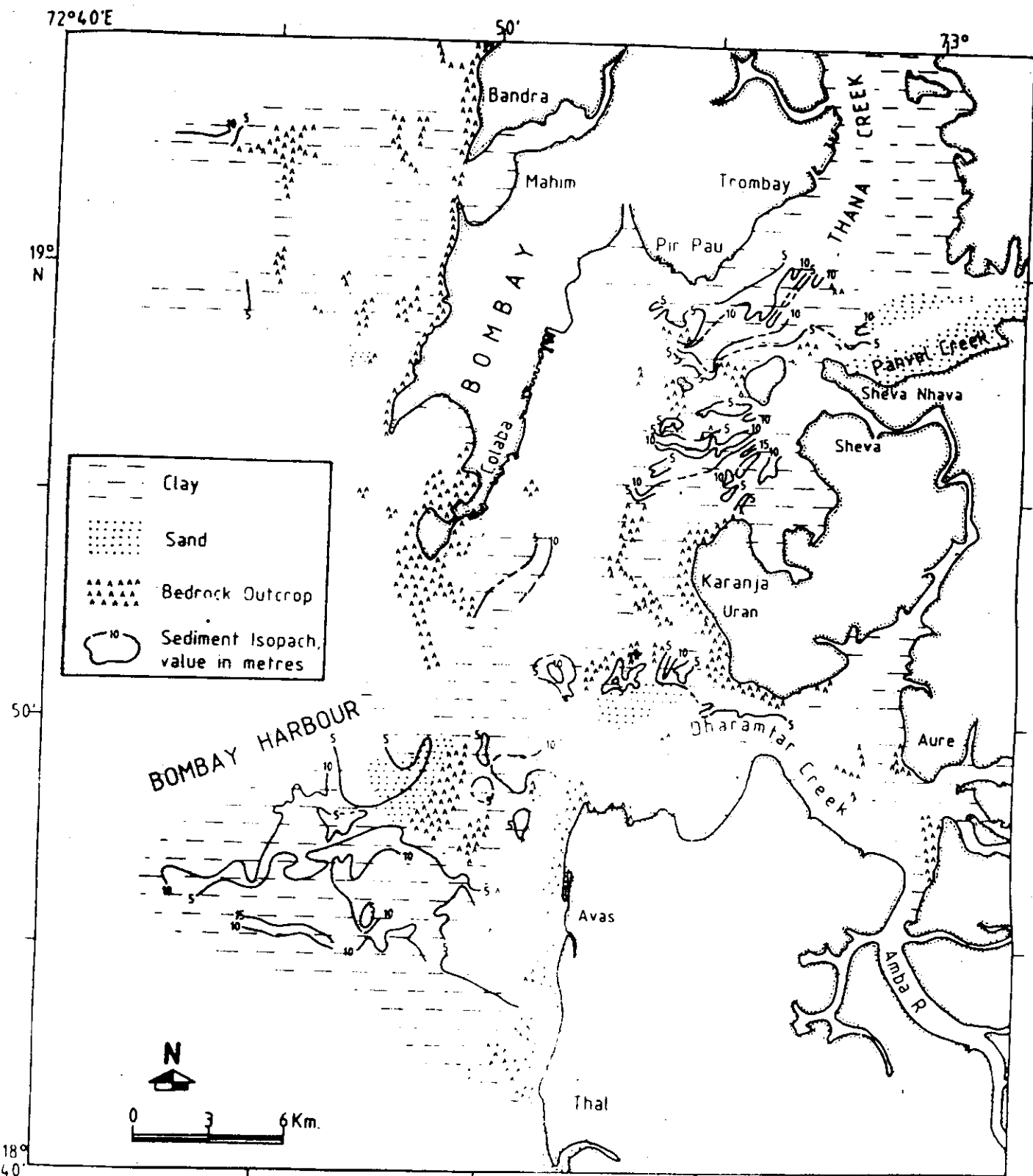
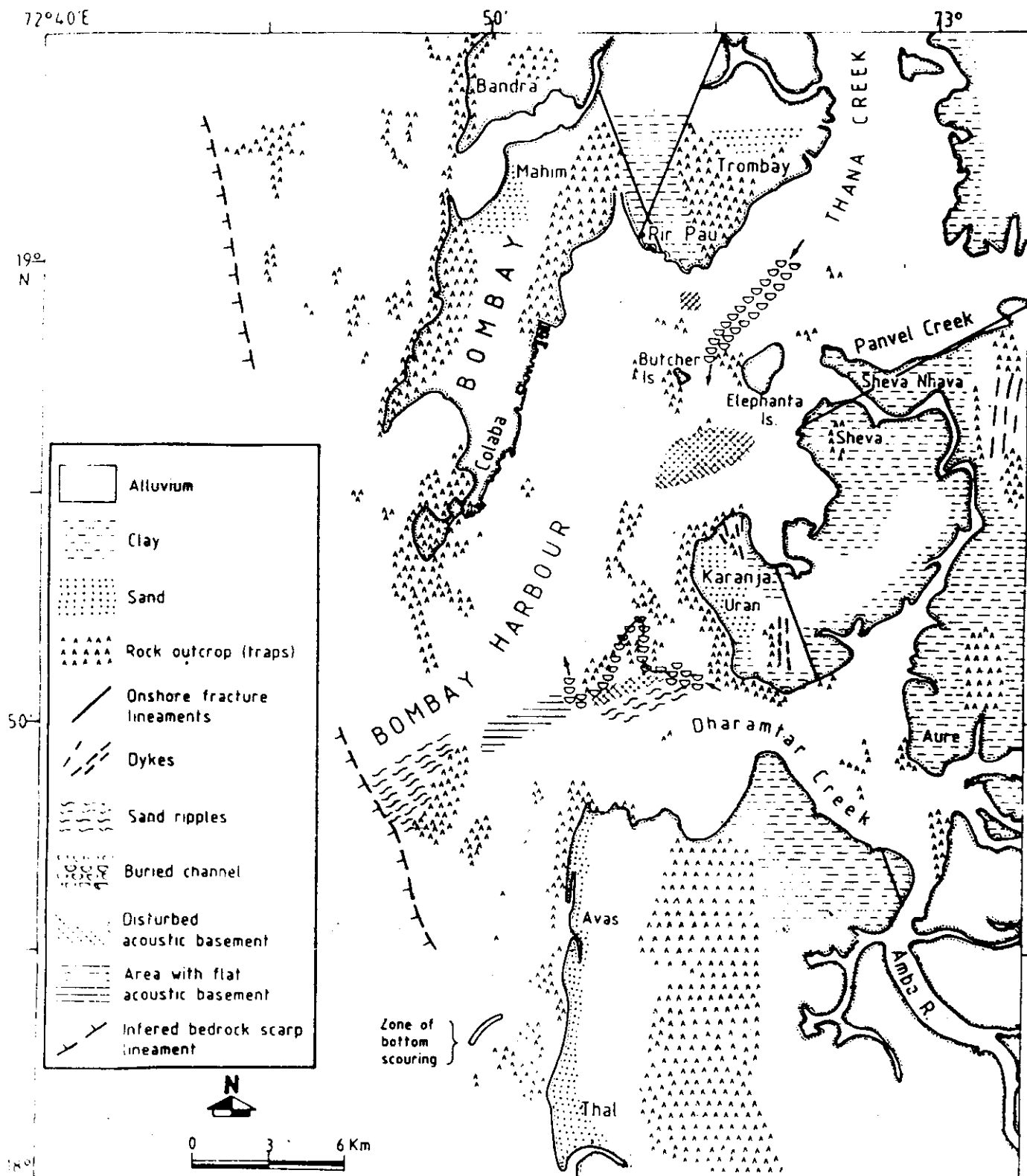


Fig.4 - Map showing distribution of surficial sediments alongwith the sediment isopachs



and showing the main lineaments of the land and main fracture lineaments after earlier workers. (#6-8-)

charged in the open sea to the west. In the west