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An Appraisal of the Seabed Conditions on the Northwestern Continental Shelf of India

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ABSTRACT

The 300 km wide north western continental shelf off Bombay with structures of hydrocarbon prospects and number of proven oil and gas fields has been the scene of recent development. These developments required extensive seabed surveys for jack-ups, production platforms, pipeline routes, relocation of well heads and post lay surveys of pipelines etc. The surveys during 1976-84 covered an area of 72,600 sq. km on the inner and midshelf between 18° N and 21° N latitudes and comprised of echosounding (12,000 lkms), side scan sonar (7,000 lkms) shallow seismics (11,000 lkms) and seabed samples (252).

The innershelf in the north (the Gulf of Khambhat) is characterised by uneven topography (upto 13 m) chiefly due to NNE - SSW trending sand banks and the intervening channels filled by about 5 m thick clays. The sand banks are superposed by NNE-SSW sand waves (3-4 m high), mega ripples and ripples due to the high energy tidal regime of the Gulf. The sand banks taper off at Lat. 20° 50' N (28 m depth) and further the seabed is covered by clays and marked by even topography. The clay thickness increases towards SSW from 10 m to 20-25 m in water depths from 28-30 m to 50-55 m. Between 28 to 38 m water depths in an area of approximately 2500 sq. km the clays are marked by extensive masking due to gases (about 11.5 percent methane).

The seabed between Bombay and the Bassein offshore area (50-55 m) in the west is marked by even topography and is covered by 20 to 30 m thick acoustically transparent clays. The clays attain the maximum thickness (20-30 m) at about 25 m to 30 m water depth and thin gradually to the west where the underlying relict sands of 10,000 yrs BP out-crop at water depth of 60-65 m. The

transition is marked by NNW-SSE trending sandy ridges (4-5 meters high, 1-2 km wide). The outer midshelf sandy areas are characterised by uneven topography (upto 15 m) chiefly due to relict forms in oolitic, coral and algal limestones and oolites etc and 1 to 2 m high (100 to 200 m wave length) NNE-SSW trending relict sand waves.

INTRODUCTION

The delineation of a structure by geological and geophysical surveys in offshore areas is usually followed by drilling to test the structure and if oil and gas are proved by the development of the structure. Marine geological and geophysical surveys commonly referred to as seabed surveys form an integral part of the development programme and these range from site surveys prior to drilling to surveys for planning the development i.e., location and designing of platforms, pipeline routes and post-constructional surveys i.e., location of well heads and post-lay surveys for pipelines etc. The discovery and subsequent development of the large oil and gas fields on the western Continental Shelf of India at the Bombay High, Bassein and Ratnagiri structures necessitated detailed seabed surveys of large areas. Most of the surveys were carried out by the National Institute of Oceanography on *RV Gaveshani* and even small boats. The surveys involved more than 12,000 line km of echosounding, 7000 line km of side scan sonar, 2000 line km of high resolution ORE multi-frequency seismic profiling, 9000 line km of sparker/boomer profiling followed by seabed sampling by grabs/snapper(171), dredges(5) and coring(76), maximum length (5.4 m).

The Institute as a part of its own R & D programme is already carrying out systematic surveys of the continental margins of India at tracks spaced at 20 km apart and sampling stations at about 5 to

References and illustrations at end of paper

10 km. The surveys carried out for the development of the offshore oil fields not only provided the basic data for the designing and location of offshore platforms and routing of the pipelines but also provided a valuable input for the R & D programmes of the Institute. The synthesis of the data have led to an understanding of the surficial geology and the preparation of a detailed surficial geological map of the Western Continental Shelf off Bombay. The present paper describes the techniques used for the surveys, reviews the work carried out and summarizes the results of the surveys.

METHODS

Position Fixing:

The surveys carried out for the development of offshore oil and gas fields on the western shelf ranged from reconnaissance to detailed and in some areas, the survey tracks were spaced at about 500 m to even 50 m. The position fixing used for the various surveys are described in increasing order of accuracy.

i) Sextant angles of shore objects: The method was used largely for reconnaissance in nearshore areas for the shore approaches of the pipeline route to Bombay and Gujarat. This was useful for identification of areas for later detailed surveys by an accurate navigation system.

ii) Decca Navigator: The Continental Shelf off Bombay is covered by a Decca Navigator Chain with shore stations at Savarkundla, Billimora, Veraval and Dhangdhra. The system was installed for general navigation and therefore, its accuracy is not high. The accuracy in the area of survey is about ± 230 m during daylight hours, but at night a wide variation in position is observed due to lane drift/wandering. The chain was used initially for reconnaissance surveys and for cross-check.

iii) Satellite Navigation System: A Canadian Marconi CMA 722 Satellite Navigation System was used for position fixing of some drill sites and in combination with Decca Navigator for reconnaissance surveys. However, where navigation on predetermined tracks is required, systems such as Decca or Satellite Navigator not suitable because of the lack of accuracy and non-availability of continuous position fixes.

iv) Shoran: The Oil & Natural Gas Commission operated a Shoran Chain on the western continental shelf off Bombay. The base stations at Manori, Daman, Erangal, Hazira, Korlai Fort were used for covering the area from Bombay High to Bombay, Bassein to Gujarat and Bassein to Direction Bank. The system does not have the ambiguities associated with other navigation systems and provides a day and night

coverage to a distance of 150 to 200 miles in good weather. The vessel was guided on the preplanned survey tracks with preplots. The system provided an accuracy of ± 50 m and was used for accurate surveys on closely spaced tracks. These included the surveys for location and designing of platforms on Bombay High, Bassein and Direction Bank, pipeline route from Bombay High to Bombay and Bassein to Gujarat etc.

v) Mini Ranger : The Motorola Mini-ranger provides position fixing upto a distance of 75 km (depending on the heights of base stations) and the accuracy is ± 3 m. The system was used for surveys of the shore approaches of the pipeline route at Bombay and subsequently for the northern end of the pipeline route to Gujarat. The system was preferred because of the mobility and the accuracy provided.

Echosounding :

A knowledge of the depths is a basic requirement for any operations at sea and the nature of topography provides a clue to the nature of the seabed i.e., rocky, sandy or clay covered. RV Gaveshani is equipped with a Kelvin and Huges MS 45 (30 KHz, paper width 21.7 cms) which were used during the surveys. For surveys on small boats an Atlas Deso 10 Echosounder was also used. The lower frequency in the echosounders provided a subbottom penetration especially in clay covered areas down to 10-12 m. This was useful for identifying the strata on the seabed, contact between different sediments and rocks, mapping of facies estimating the thickness of clays, identification of acoustic masking in clays and pipelines buried in clays. The depth of penetration with this frequency also indicated that the clays on the shelf are soft which was confirmed later by the length of core obtained with a small weight and soil tests.

Side Scan Sonar :

An EG & G Mark 1B Side Scan Sonar with Tow Fish (Model 272) was used for seabed surveys both from RV Gaveshani and small boats. The side scan sonar records of the seabed were used for identifying and demarcating the areas covered by rocks and sediments i.e., sands and clay (pipeline routes from Bassein to Gujarat, Bombay Floating Light to Karanja and shore approaches of the pipeline route to Gujarat) the latter is of considerable value for planning structures on the seabed.

The side scan sonar has also been useful for relocating well heads by identifying the spud marks of a jack up where the recallable marker buoy was lost due to stormy weather or failed to respond due to malfunctioning of electronics. The side scan sonar coupled with high resolution seismic profiling was used for post-lay surveys of the pipelines

to demarcate the exposed pipelines.

Shallow seismic profiling:

The shallow seismic profiling was initially carried out with Hunttec Sparker/Boomer system and subsequently by ORE Profiler and EG & G Sparker/Boomer system.

ORE Profiling:

An ORE Mud penetrator system with either a hull mounted or over the side mounted transducers was used for high resolution profiling. The system operates on a frequency between 1 to 12 KHz with various combinations of band width and pulse length and provided penetration down to about 35 m. This was useful for mapping the surficial distribution of sediments as also for post-lay surveys of the pipelines to estimate their depths of burial.

Hunttec sparker and boomer:

The single tip sparker provided limited penetration and therefore, the boomer (5 KHz) was invariably used.

EG & G Sparker:

An EG & G Sparker was usually operated at about 1-4.5 KHz and this provided a penetration down to 140-150 m.

Seabed sampling:

The locations for seabed samples were selected after an examination of the underway records to confirm the strata observed and to collect samples for sedimentological studies and geotechnical tests.

Grabs and dredges:

The surficial sediment samples were collected by a modified Peterson Grab with a scoop area of about 900 sq.cm. The locations where rocks were suspected to outcrop on the seabed were sampled by a pipe or a chainbag dredge.

Corer:

Core samples were collected by a piston gravity corer with acrylic liners (inner dia 50 mm) weight upto 365 kg and a free fall ranging from 1 to 3.5 m. The core recovery depended on the nature of seabed sediments and a maximum core of 5.4 m was collected in the area.

REGIONAL SURFICIAL GEOLOGY

The map (Fig.1) shows the distribution of various sediment types and the isopachs of clays on the continental shelf. For the convenience of discussion the areas are divided into inner and mid shelf.

Inner shelf of Bombay:

The innershelf encompasses the shallow areas extending from Umbhrat to Bombay and the depth ranges from 2-3 m in the east to 55-60 m in the west. The distribution of sediments in the area off Daman, the north and to the south, off Tarapur and off Bombay are markedly different (Fig.2).

1) Off Daman: The area situated at the southern end of the Gulf of Khambat is affected by its high tidal range (more than 9 m) and strong tidal currents. The rivers and creeks provide abundant sediment supply for the gulf and the adjacent shelf. These high currents conditions inhibit deposition of fine or even coarse sediments in some parts and as a result sandbanks are formed in some areas along the direction of the current and rocks and cemented sands etc. are exposed near the coast. Due to abundant sand supply and strong currents, sandwaves and ripples are formed on the sand banks.

The northern most area surveyed and the areas near the shore between Umbhrat and Daman are covered by thin (3-5 m) acoustically transparent clays which do not extend to the west. A study of the underway records, cores and the logs of bore holes shows that the youngest sediments in the areas are apparently the olive gray, dark gray and brownish clays. The clays are underlain by gravel in the north and silty sandy clays in south. The reflector underlying the clays in the west is uneven with a relative relief of 2 to 3 m in the north and 1 to 2 m in south. The limited subbottom penetration within the area covered with sand is perhaps due to the hard and compact underlying sediments.

The seabed off Daman is marked by a wide NNE-SSW trending sandy area (Fig.3 E). The area is marked by uneven topography due to sand banks and sand waves and pinnacles due to rocks/coral exposures (Fig. 3 C, 4 G and 4 H). The NNE-SSW trending sandbanks rise to a height of 6-13 m extend over 34 kms and widen as much as 6 kms in north. Further south of the banks, the thickness of the acoustically transparent clay increases replacing the sand out crops. The sediments are underlain by southwest dipping stratified reflectors at depths of 5, 7 and 10 m.

II) Off Tarapur: In contrast to the area off Daman the seabed off Tarapur does not show sand. The thickness of the acoustically transparent clays increases gradually towards south to a maximum of 20 m (section D-D', Fig.2) overlying the sands and sandstones within which stratified layers dipping southwest were noted. The clays cover the seabed upto Bassein field in the south west, but in large areas extensive acoustic masking is seen in echograms (Fig.3 D) and shallow seismic records (Fig. 4 L). Siddiquie *et al* (1980 and 1981 A) reported occurrences of these maskings below the seabed at depths of 5 to 10 m. The sediments with acoustic

masking extend upto 50 to 70 kms towards northeast from the Bassein field and cover an area of approximately 2500 sq. km.

III) Off Bombay: At about 60-65 m depth two NNE-SSW ridges (5m high and 1-2 kms wide) mark the limit of the inner shelf. From the approaches to Bombay harbour (depth 20 m) except in the shallow areas of the harbour where ripples have been formed due to wave action and currents (Almeida and Bhattacharya 1980; Bhattacharya et al, 1981) till these ridges the seabed is even and is carpeted by thick (about 20-25 m) acoustically transparent clays which gradually thin westwards to less than 10 m. Within the clays and underlying the clays (at depth of about 30 m) number of reflectors are seen. These mark coarser sediment or contrasting lithologies.

Mid shelf off Bombay: Further west of the sandy ridges the clays thin out and fill only shallow depressions and the underlying sands are exposed. The ridges probably acts as barriers for sediments from the east. The sand covered areas are characterised by periodic bedforms. The sandwaves are oriented NNW-SSE and 1-2 m high with wavelength of 100-200 m. The samples collected from the crest of the sand waves revealed holocene relict, oolitic sands (10,000 yrs. B.P.) and that from the trough finer sediments. The fluorescent tracer studies before and after monsoons did not reveal sediment movement. The periodic bedforms are not seen further towards the north perhaps due to increased clay cover (Fig. 4 K).

Further west of these features, the Bombay High field was surveyed on a grid of a km. Profiles A-A' and B-B' (Fig.2) depict the changes in the bathylithology from north to south. Extensive areas in the north are covered with acoustically transparent clays (upto 7 m thick) concealing the underlying uneven topography and depicting an even topography in the area (Fig.3 B). In contrast, the southern area is marked by uneven topography and covered with sand (Fig. 3 A). A series of NE-SW trending highs and lows of the order of 10-15 m are observed at the western end of the area. Below the surficial sands lithified beds at depths of 3-7, 9-15, and 20-25 m in the south west (section B-B' Fig. 2) are interpreted as cemented calcareous sands and limestones (Fig.4 J). Similar unevenness is also seen in the east in profile A-A' (Fig.2). The lack of deeper penetration in seismic records in the north may also be due to the compact sediments at depths.

SURFICIAL GEOLOGY OF THE AREA AND RELEVANCE TO OFFSHORE ENGINEERING PROBLEMS :

The prominent features/changes in the morphology of the seabed and substrata in response to varied processes in space and time in the area and its relevance to offshore engineering problems are discussed. The features include sedimentary bedforms, sand ridges, buried channels, acoustic masking due to gases, rock exposures, pinnacles and ridges. Similar features have been observed along the other continental shelves of the world and in some cases these have been studied in detail for their origin, extent and their bearing to offshore structures.

1. Periodic bed forms: Sand waves, mega ripples and ripples are seen in the area. The bed forms represent areas of instability and may create problems with shallow footing, jack up drill rigs and buried pipelines. The sand waves on the midshelf off Bombay (east of Bombay High) (Fig.3 F) are not covered by recent sediments and are perhaps not always mobile. They may be mobile during severe storms and certain types of construction especially pipelines across such zones needs caution as mobile strata may expose the pipelines. The sand wave fields are not large and can be avoided by routing the pipelines or structures to the north where these are covered by recent clays.

Sand waves are also seen in the north off Daman in the Gulf of Khambhat, and in comparison to the sand waves of the mid shelf off Bombay, these sand waves are mobile towards the south and have high relief, 3-4 m (Vora et al 1980). Apart from the problem of trenching and burial for laying pipelines in such areas the problems of their migrations and magnitude of scouring due to high tidal energy etc. need to be examined in detail.

2. Sand banks and ridges: The features include accumulations of sands as banks along the channels with a relative relief of more than about 5 m. Laying of pipelines across such banks (and across the currents) may pose problems due to the difference in pressure gradient and spanning and bending of pipelines. Therefore while routing pipelines such features could be avoided, however, the intervening clay filled channels may be explored as they provide finer sediments suitable for burial. The sandy ridges are noticed on the mid shelf off Bombay and sand banks off Daman in the Gulf of Khambhat.

3. Buried Channels: NW-SE trending buried channels covered by acoustically transparent clays are observed off Daman in water depths of about 20 m (Fig. 4 I). The channels are symmetrical the slopes of their flanks gentle and the channels are 1 to 2 km wide with a maximum depth of 8-10 m. The

channels perhaps represent earlier drainage pattern developed during lowered sea levels.

The gentle slope of the flanks and the fine infill may be of interest to the design engineer. Since the channels are filled with fine surficial sediments they could be utilised for routing pipelines but crossing such features may pose problems.

4. Acoustic masking: Acoustic masking due to gases within the sediments is observed in a large part of the area. The acoustically masked sediments can be grouped in two categories, one of limited extent (e.g. inner shelf off Bombay coast) and the other of very wide extent, at times occurring over a stretch of 50 km. In echograms and seismic records acoustic masking is recognised by cloudiness. Cores of sediment from these acoustically masked area were found to contain 10% (by volume) of pores or gas bubbles (Siddiquie *et al* 1981 B). The gas is mostly methane (around 11.5%) though some higher hydro carbon also occur. The gas is perhaps largely derived from degradation of organic material at shallower depth or seepages from deeper fractures in the oil/gas bearing structures. Such gas charged sediments may influence offshore constructions in different ways, the laying of pipelines may not pose problem but while planning large gravity structures, settlement and bearing capacity of the sediments may be taken into consideration at the design stage itself. If the gas is from deeper areas, the possibility of hazards like blow out may also be examined.

5. Rocks: Rocks are exposed on the sea bed in large areas in the nearshore between Daman and Tarapur (Fig. 3 C and 4 G). These are the offshore extensions of basalts exposed along the coast. The depressions within these rocky areas are filled with thin sediments. Rocks may provide good foundation for structures at the times, but these may add to difficulties for burial of pipelines and cables.

6. Pinnacles: Rugged topographic areas, exposed and buried pinnacles are found on the mid shelf off Bombay and the inner shelf off Daman (Fig. 3 A). The exposed and buried pinnacles in the SW on the Bombay High are due to ancient carbonate build up rocks while these in the NE off Daman are extension of basalts from land.

Some of the pinnacles have relative relief of upto 15 m they could pose problems in routing pipelines especially because of the steep gradients but the hard strata may provide stable foundation. The high energy regime (Tide > 9 m, currents < 6 knots) in the Gulf of Khambhat area coupled with high sediment load has given rise to the sand banks and periodic bed forms and at places exposed the bed rocks.

CONCLUSIONS

1. The north western continental shelf off Bombay is marked by uneven topography at the mouth of the Gulf of Khambhat along with the coast from Umbharat to Tarapur and the mid and outer shelf off Bombay. The inner shelf extending from Bombay (depth about 20 m) marked by even topography.
2. The uneven topography at the mouth of the Gulf of Khambhat and along the coast from Umbharat to Tarapur is due to sand banks, periodic bed forms and rock exposures. The uneven topography on the mid and outer shelf is due to periodic bed forms and exposures of calcareous rocks.
3. The area of even topography is largely covered by clays and thickness increases from 10 m off Bombay, Tarapur, Daman to the Bassein area. Within the clay covered region a large area (about 2500 sq. km) shows acoustic masking due to gases. The clay thickness decreases towards the mid shelf where the underlying relict oolitic sands are exposed.

The relict sands contain a number of reflectors which may be due to variations in lithology and degree of compactness.

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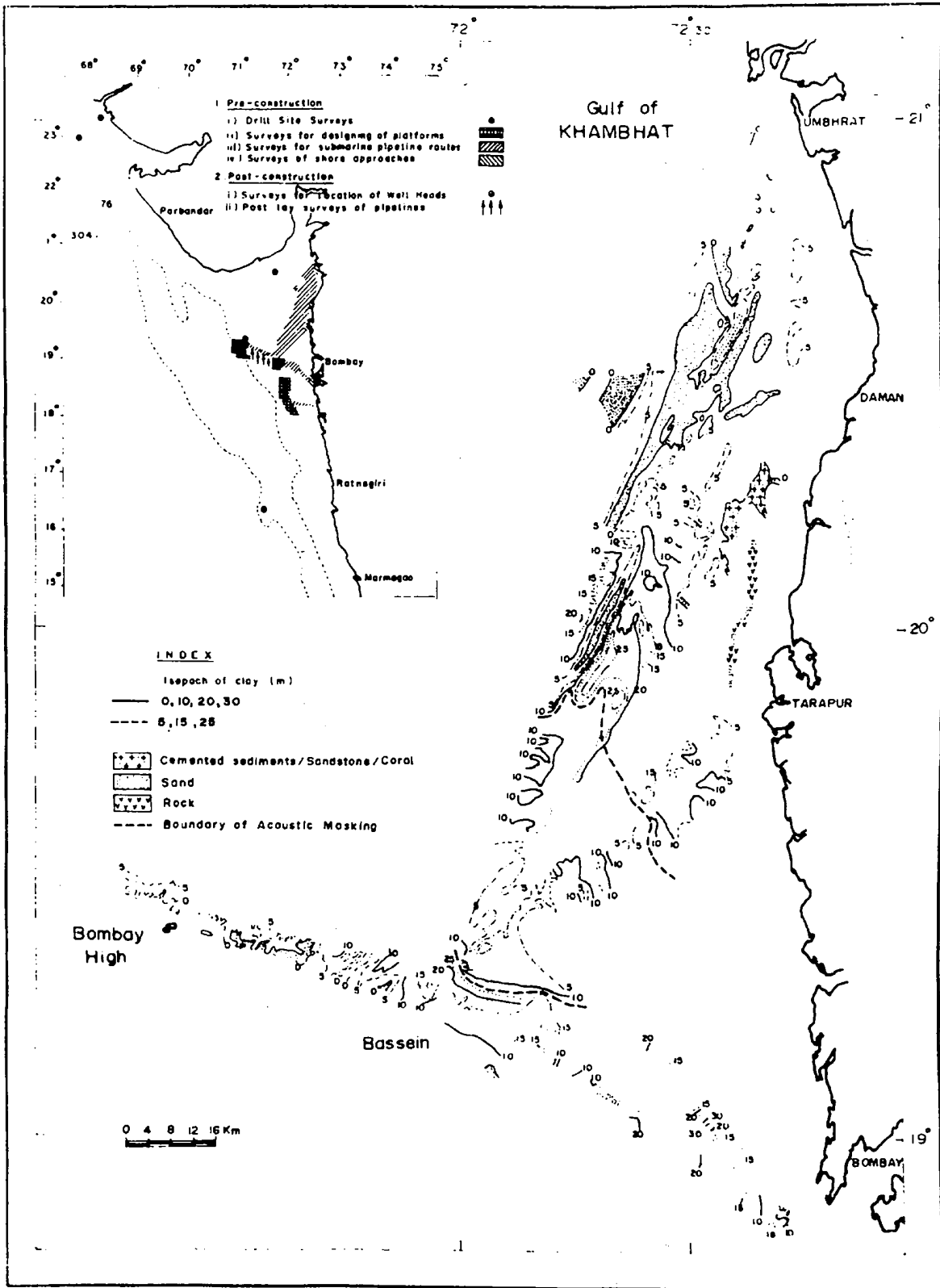


Fig. 1—Map showing the surficial geology of a part of the northwestern continental shelf of India.

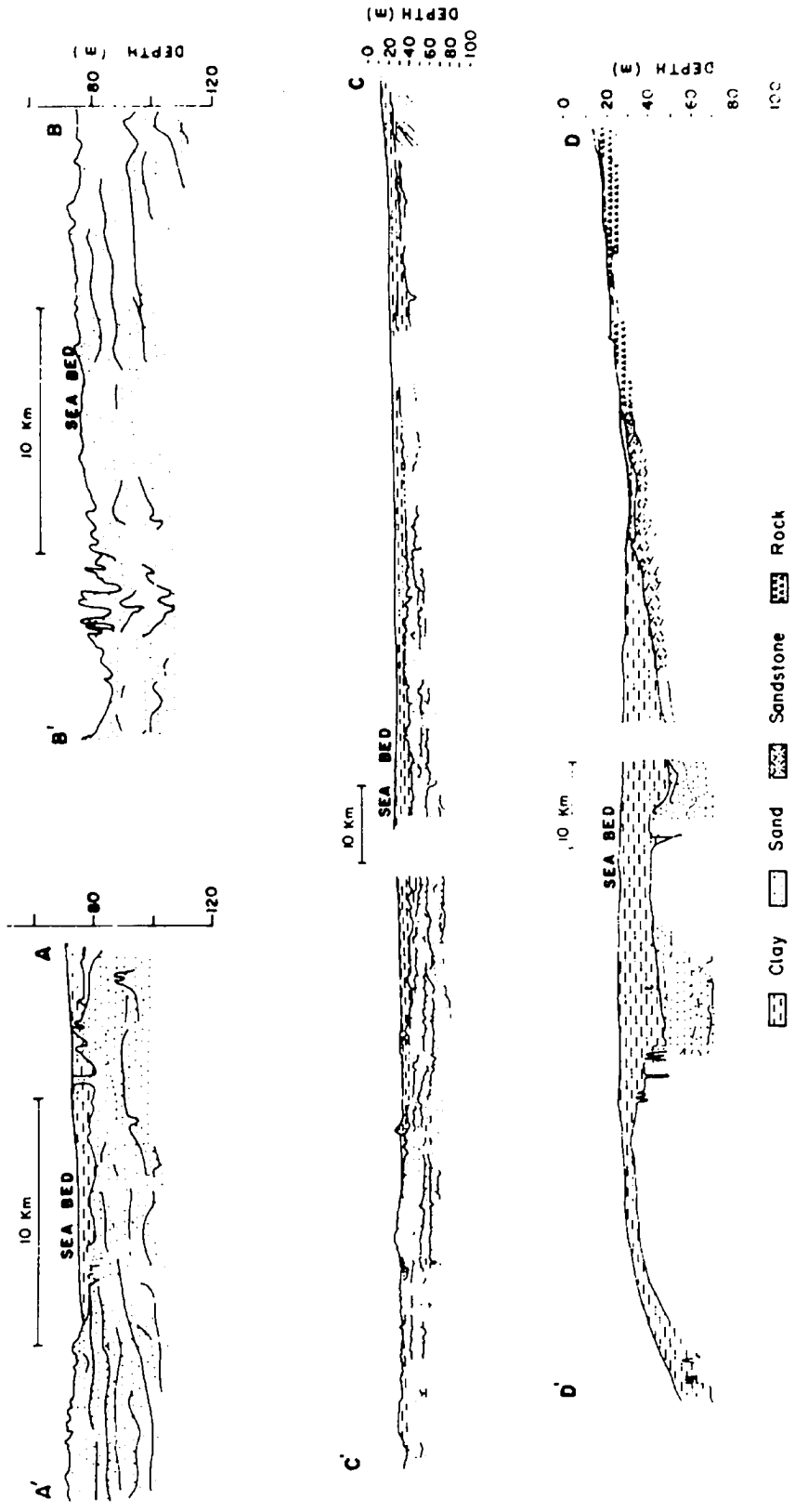


Fig. 2—Line drawings of selected shallow seismic profile on the continental shelf off Bombay (A-A' and B-B' Bombay High, C-C' Bombay High to Bombay, and D-D' Bassein to Damam).

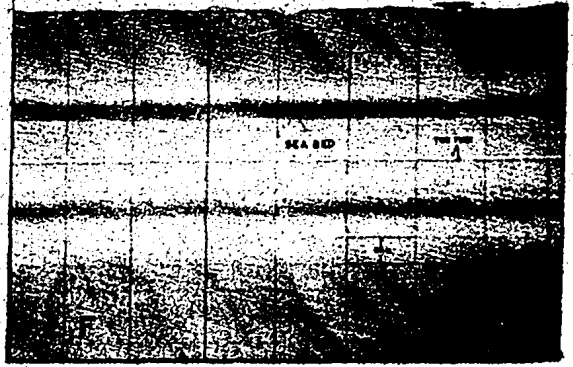
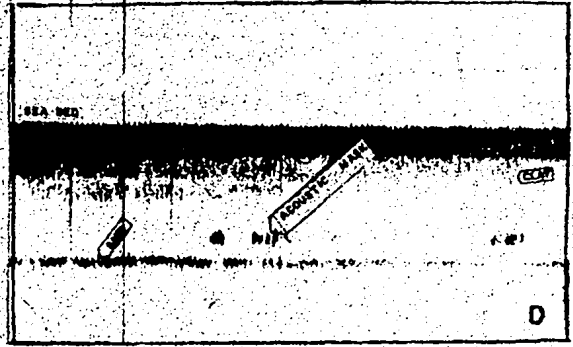
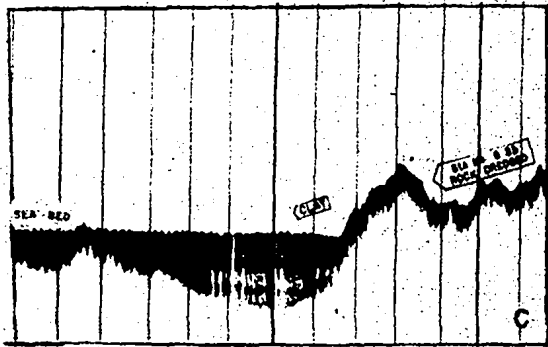
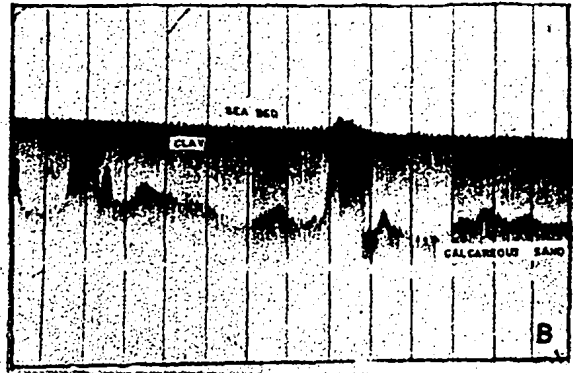
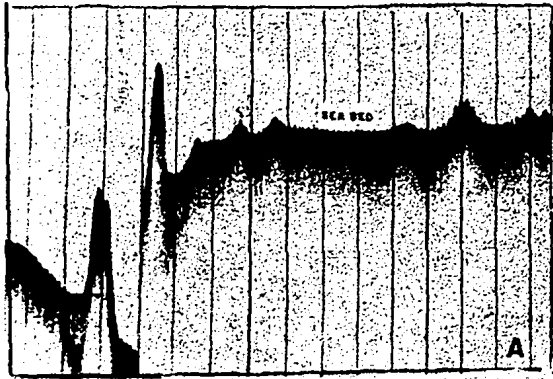


Fig. 3—Typical echo-sounding and side-scan sonar records.

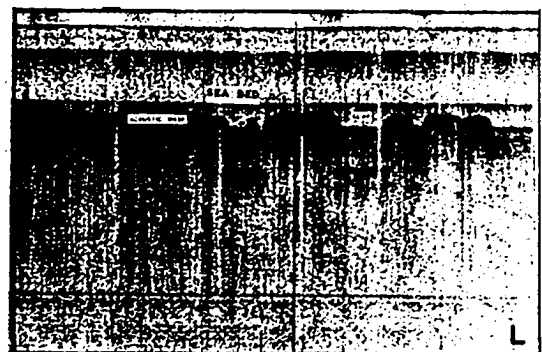
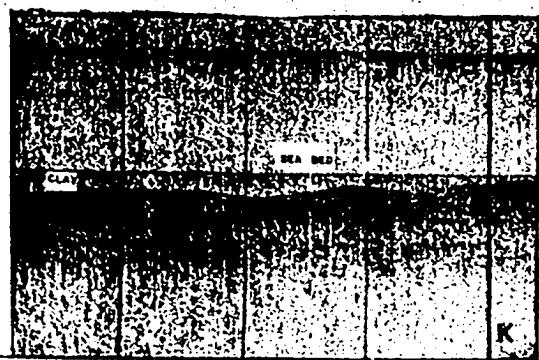
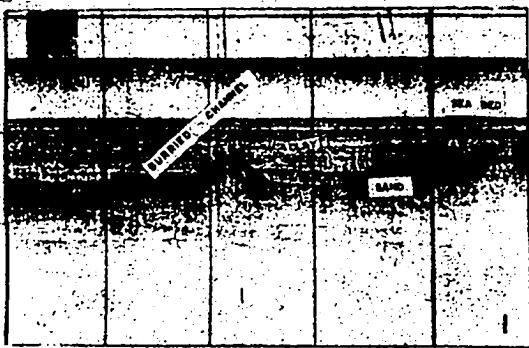
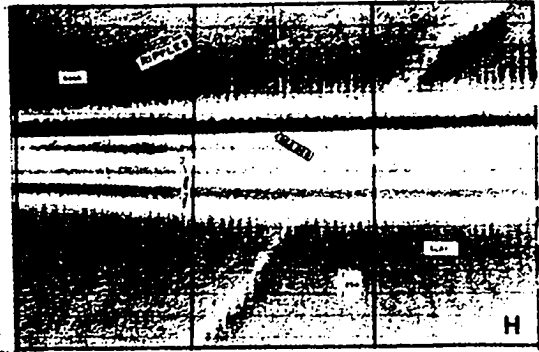


Fig. 4—Typical side-scan sonar and shallow seismic records.