

## **EXPLORATION OF THE CONTINENTAL MARGINS OF INDIA**

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### **ABSTRACT**

In mid 1970's the Institute prepared a plan for systematic regional geological and geophysical surveys of the continental margins of India. This involved over 75,000 km of underway (bathymetric, side scan sonar, magnetic, gravity and seismic) surveys on tracks about 20 km apart, and collection of about 1500 seabed samples at about 10 to 20 km spacing. It was anticipated that the entire programme would require 22 ship's months. This programme received considerable impetus from sponsored surveys of other organizations, chiefly the oil industry, ports and harbours as well as industries disposing of their effluents in the marine environment. By now the entire western continental shelf and a large part of the continental slope have been covered by about 68,314 km bathymetric surveys, 12,720 km side scan sonar surveys, 46,222 km magnetic surveys, 27,200 km seismic surveys (including 5,489 km multichannel seismic), and 9,065 km gravity surveys. Approximately 1500 seabed samples have been collected. These surveys, besides providing basic information on the morphology, sediments, and geochemistry of the sediments of the western continental margin of India, have also led to the estimation of resources of offshore ilmenite placers and low grade phosphorite deposits. The data collected are proposed to be depicted in a series of maps showing the morphology, sediments and geochemistry of sediments.

### **INTRODUCTION**

The Indian Ocean is largely bordered by developing countries. Little data on its physical, biological and chemical oceanography, marine geology and geophysics or on living and non-living resources were available until the International Indian Ocean Expedition. The Expedition (IIOE) indeed enhanced the knowledge of the Indian Ocean in general but, being a large international regional effort, it paid little attention to the continental margins of the countries bordering the Indian Ocean. Many countries at that time, and even now, do not have the capability to carry out surveys on their own.

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The available data on the continental margins of the Indian Ocean at the end of the IIOE in 1967-1968 were meagre and comprised a few samples collected from the continental margins of India, mainly off the main ports of Bombay, Cochin, Madras and Calcutta. By and large the area remained unexplored.

## PLANNING FOR GEOLOGICAL EXPLORATION

The continental margins of India cover an area of more than 2 million sq.km, which is approximately two thirds of the land area of the country.

The planning for the geological exploration of the continental margin proposed systematic collection of scientific data for two basic objectives. First, to provide information about the surficial geology, geological structure, tectonics, and also the history of the continental margins and second, to obtain data about its surficial mineral resources, terrigenous, biogenous and chemogenous. The initial phase necessarily had to be for reconnaissance. Therefore, the tracks were planned at a spacing of about 20 km with sampling stations at about 10-20 km. While planning this programme, not only spacing was considered. Initially, a sediment distribution map of the area was prepared, based on notations on hydrographic maps, samples collected and geomorphic features already known in the area (SIDDIQUE *et al.*, 1977). It was estimated that the coverage of the continental margin at this spacing would require approximately 22 ship's months (Table 1).

## INPUTS REQUIRED

The execution of such a programme required three basic components, i.e. manpower, equipment, and suitably equipped vessels, both small and large. After the data collection plan had been defined, attention was equally paid to quality control of the data, their acquisition, storage, processing and interpretation.

The undertaking of such a large programme also required trained manpower. The programme was originally launched in 1976 with a group of 14 geologists, 2 geophysicists and 8 instrument technicians : gradually, with training being imparted on smaller boats, the group was able to expand and presently consists of 102 persons, including 46 geologists, 9 geophysicists, 16 instrumentation engineers, 6 mechanical engineers and 13 marine surveyors.

The basic programme was drawn up for the geological and geophysical surveys of the entire continental margins, but since the Institute is a multidisciplinary organization, there were competing demands for collection of data from other disciplines, such as physical, chemical and biological oceanography. Therefore, it would not always have been practical to collect the data as per the requirements of the geologists and geophysicists alone. An analysis also indicated that the areal spacing for collection of physical, chemical and biological data (time variable data) was not only wider, but also required seasonal operations. Time variable and non time variable data collection could therefore not be combined.

TABLE 1

*Estimated quantum of work for the regional Programme of Exploration of the continental margins of India*

Sr No.	Region and tracks	Time required in between tracks	Cruising time (h) (10 km/h)	Sampling time within 1000 m (1 h/sample)	Sampling time within 3000 m but beyond 1000 m (2 h/sample)	Total No. of hours	Total time required for the cruise		
							months	days	hours
1.	Andaman, 88 tracks	176	1396	417	892	2881	4	—	1
2.	East coast, 92 tracks	184	2360	593	1966	5003	6	28	11
3.	West coast, 130 tracks (including Lakshadweep)	260	3813	1736	2008	7817	10	21	13
Total : 310 tracks		620	7569	2746	4766	15701	22	2	1

Say 22 months

The target areas for the surveys were identified in two parts, those requiring general regional geological and geophysical surveys (Fig. 1) and those requiring surveys for resources. Those requiring surveys for resources were the areas covered by terrigenous and biogenous sediments in the shallow coastal areas off the Maharashtra, Kerala, Tamilnadu and Orissa coasts (Fig. 2) where deposits of terrigenous heavy mineral placers, i.e. monazite, ilmenite, zircon, garnet and sillimanite, etc., were reported. As these deposits could be explored with smaller vessels, the equipment (echosounder, side scan sonar, seismic profilers, magnetometer, grab samplers and corers, etc.) was temporarily mounted on fishing trawlers. Surveys were carried out using short range position fixing system, i.e. Mini-Ranger or sextant. For regional geological and geophysical work larger vessels, mainly RV *Gaveshani* (length 68.33 m, breadth 12.19 m) and more recently ORV *Sagar Kanya* (length 100.3 m, breadth 16.39 m, GRT 4209 mt) have been used. The vessels are equipped with geological and geophysical equipment as follows :

**RV Gaveshani***Position fixing systems :*

SATNAV

Omega, Decca Navigator and Mini-Ranger.

*Echosounding :*

Simrad EKS 12, narrow beam precision depth recorder,

Simrad EQ and Kelvin Hughes MS-45 echosounders.

*Side scan sonar :*

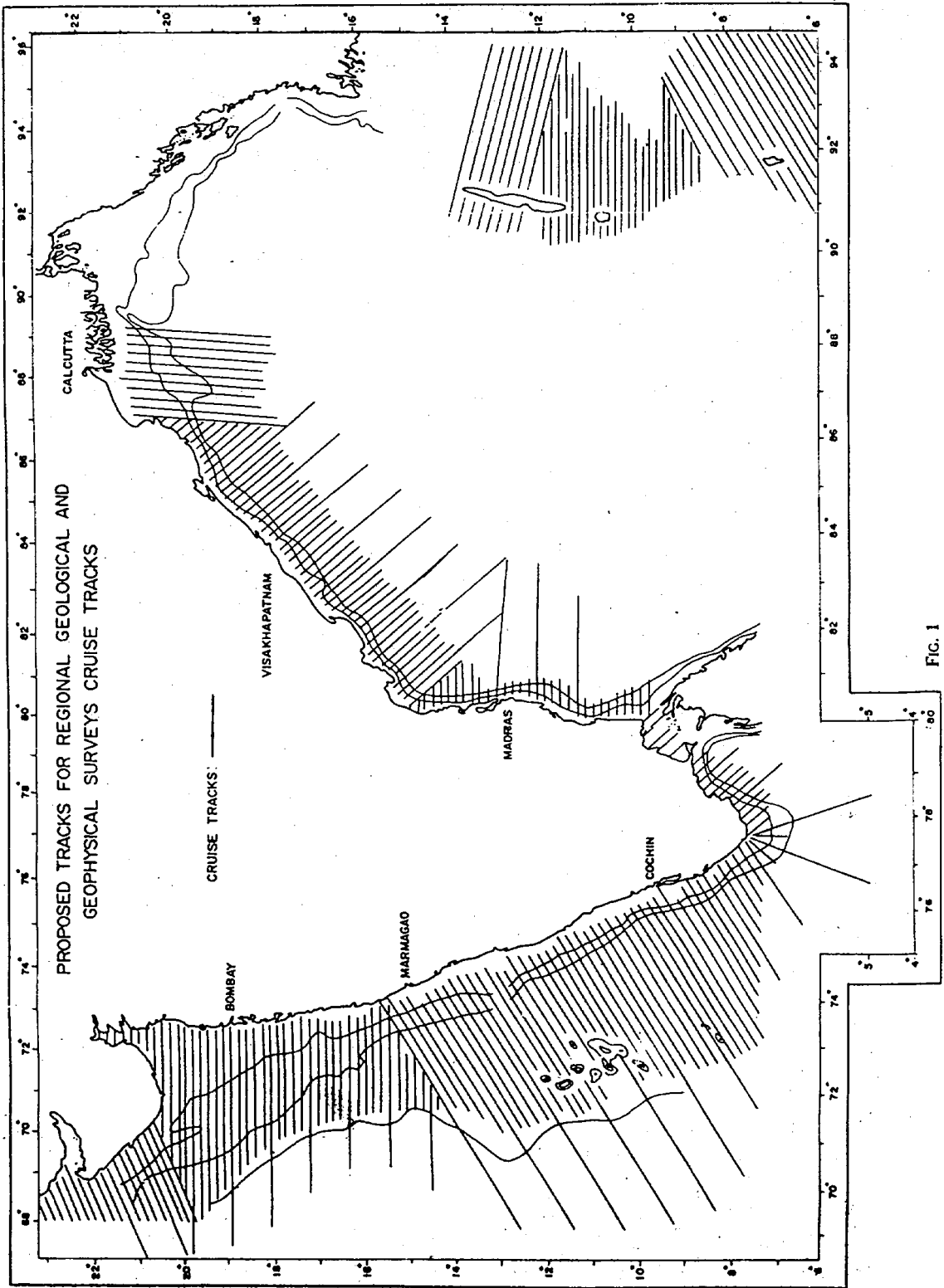
EG&amp;G side scan sonar system.

*Sub-bottom profiler :*

3.5 kHz ORE sub-bottom profiler,

EG&amp;G Uniboom system, EG&amp;G 24 kj sparker system,

Barringer/Geometrics proton precision magnetometer.



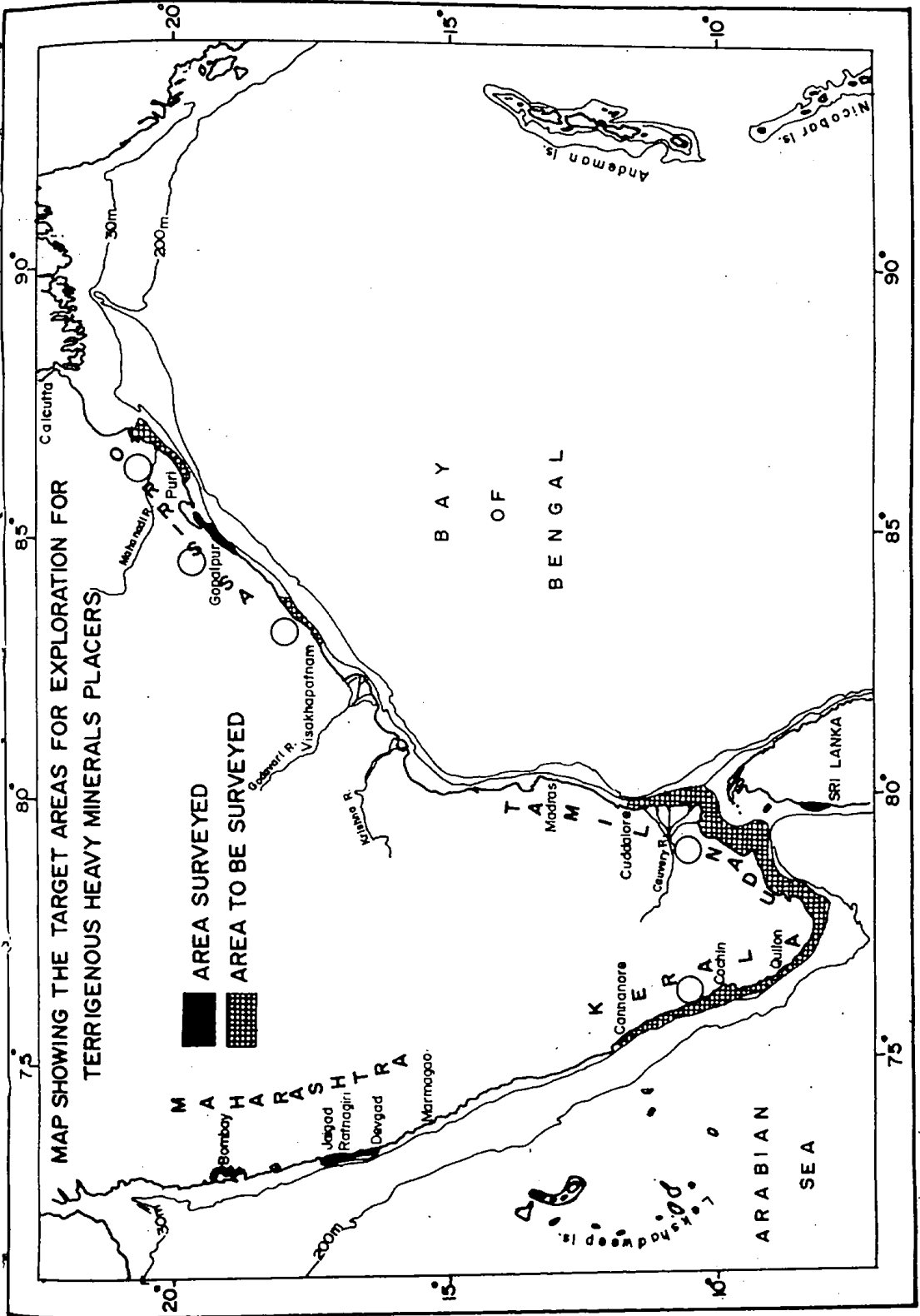


FIG. 2

*Sampling gear :*

Deep sea grabs, free fall grabs, free fall corer, piston corer and dredges, etc.

**ORV Sagar Kanya***Position fixing system :*

Integrated navigation system, with inputs from Satellite Navigator, Omega, Decca, gyro compass with Doppler log.

*Echosounding :*

3-frequency narrow beam echosounder (MP 24 Master), deep sea echosounder (MP 36 Master) and shallow water echosounder (LAZ 72 AT).

*Side scan sonar :*

EG&G seafloor mapping system (SMS 969).

*Seabed photography :*

Sub-sea system TV camera with pan and tilt unit, photo sledge, X-radiography unit.

*Geophysics :*

Proton magnetometer, marine gravimeter, DFSV 24 channel digital seismic system.

*Sampling gear :*

Deep sea grabs, free fall grabs with or without cameras, free fall corer, box corer, dredges and rock core drill.

**Small boat**

Mini-Ranger and sextant position fixing system.

Atlas Deso-10 and Simrad shallow water echosounders.

EG&G image processing side scan sonar.

EG&G side scan sonar.

ORE sub-bottom profiler.

EG&G Uniboom system.

EG&G 1 kj sparker system.

Proton precision magnetometers.

Sampling gear : 2 m long corer, grabs and snappers.

**INPUTS FROM OTHER SOURCES**

The initial development of capabilities at the Institute received impetus from broadly different sources. The initiation of the programme for a reconnaissance of the continental margin at the Institute coincided with the discovery of a major oil field on the western continental margin of India (Bombay High) and the development of many ports on both the west and east coasts. Subsequently, the need for environmental awareness led to seabed surveys to monitor effluent and sewage outfalls of the major urban centres on the west coast. The initial efforts were further strengthened by these surveys, which were a substantial contribution to the Institute by the Oil and Natural Gas Commission, the ports of Bombay, Mangalore, Ratnagiri, Tuticorin, Cochin, Madras and Karwar, and the industries, etc. (Fig. 3).

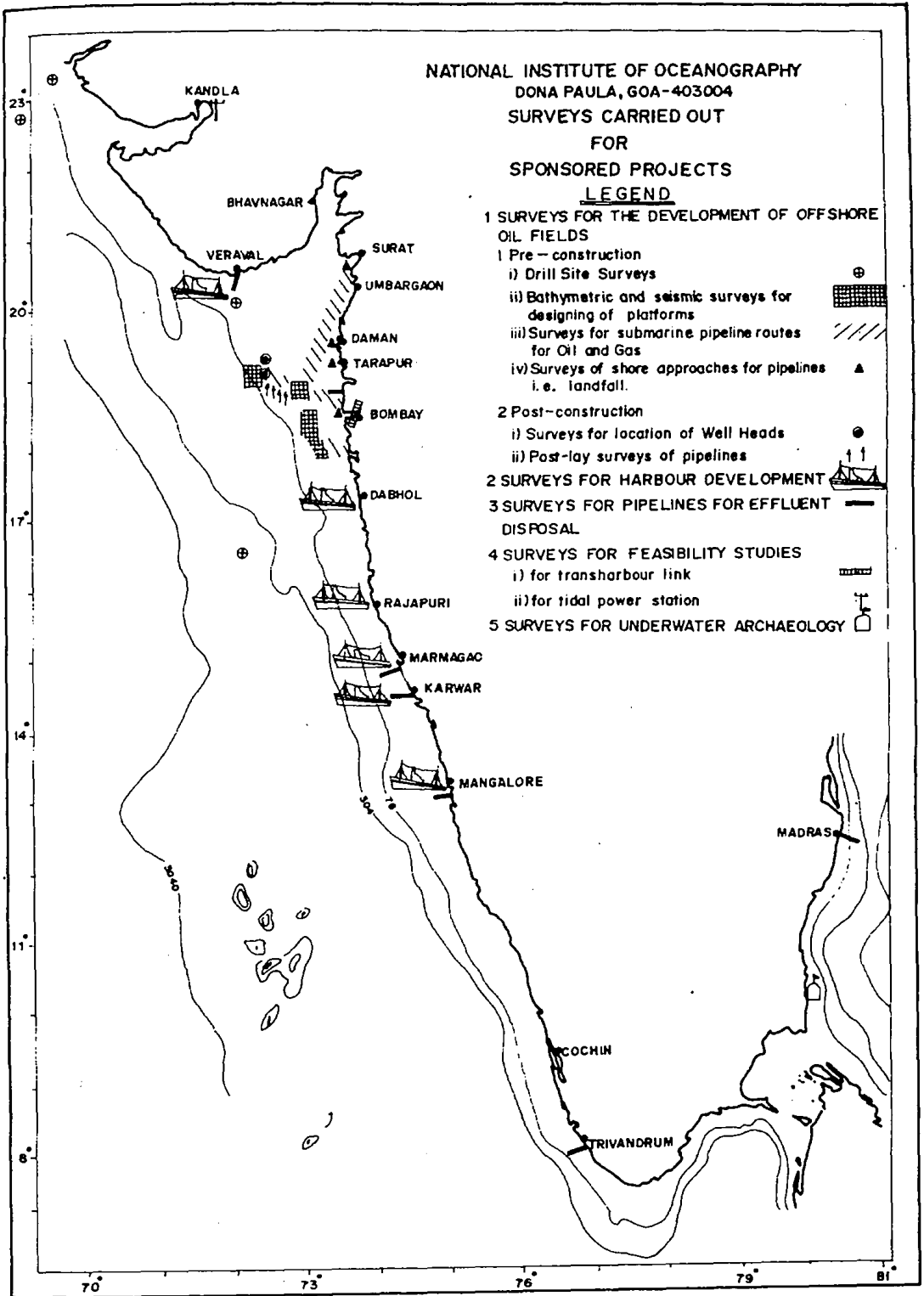


FIG. 3

Besides inputs from national sources, substantial assistance concerning equipment and training of personnel was also received under CIDA (Canada) and NORAD (Norway) assistance programmes and, more recently, the ORV *Sagar Kanya* under the FRG programme.

## RESULTS

### Quantum of work carried out

The work carried out has generated a good picture of the surficial geology and geophysics of the continental margins of India, especially the western margin. The accompanying maps (Fig. 4 to 9) show that almost the entire western continental shelf of India has by now been surveyed at a 20 km line spacing for depths, side scan sonar imagery, high resolution shallow seismic profiles, magnetic anomalies and, in some areas, for gravity, multichannel seismic profiles (Table 2), and seabed sampling as well.

TABLE 2

*Quantum of work carried out (in km, except sampling in numbers)*

	Echosounding	Side scan sonar	Shallow seismic	Magnetics	Multi-channel seismics	Gravity	Sampling stations
For regional R and D programme	68314	12720	21603	46222	5489	9065	1500
For sponsored projects							
i) Oil industry	12942	7205	11847	—	—	—	276
ii) Ports	1003	606	884	—	—	—	200
iii) Effluent disposal	527	357	396	—	—	—	92
iv) Others	720	608	593	—	—	—	125

The data provide a base for the preparation of geomorphological maps which are further substantiated by data collected during extensive side scan sonar surveys. The side scan sonar data have been used to identify not only features which were recorded as topographic highs and lows, but also mobile features on the seabed such as sand waves, mega ripples, ripples, etc. These data have been further substantiated by shallow high resolution profiling by either a sparker/boomer or a multi-frequency mud penetrator. These indicate the type of sediments. It has thus been possible to demarcate the thickness of layers in areas covered by clay and to identify other areas with sediment cover and exposed rocks on the continental shelf. The records of shallow seismic profiling show both erosional and depositional features on the shelf. Concurrently, magnetic surveys were carried out. The data in some areas were substantiated by deep seismic surveys, i.e. high powered sparker and multichannel seismics and gravity.

There were two types of data to be collected during the surveys : underway data and on station data. The underway data comprised echosounding, side scan sonar, seismic profiling, magnetics and gravity. The on station data comprised collection of



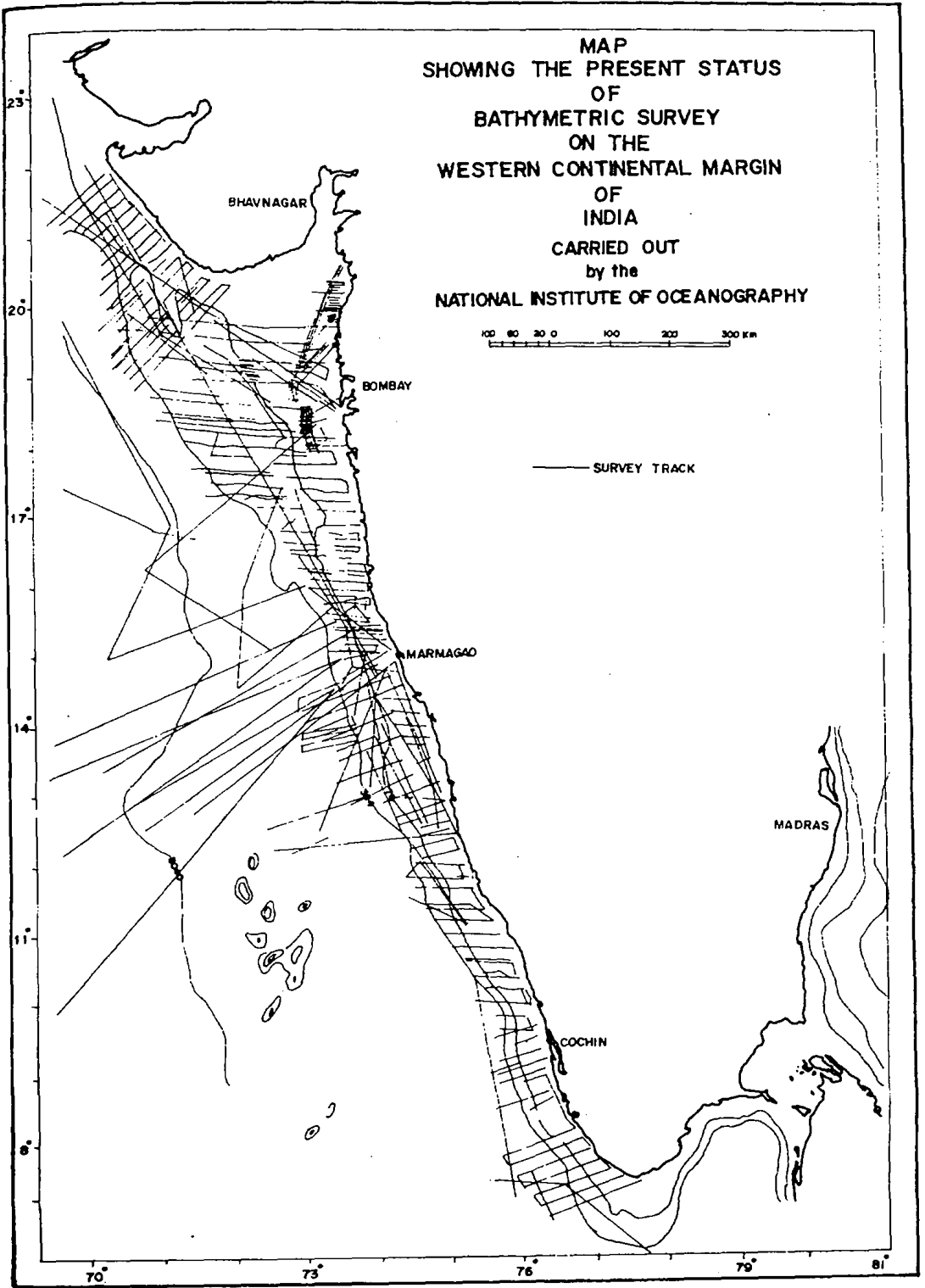


FIG. 4

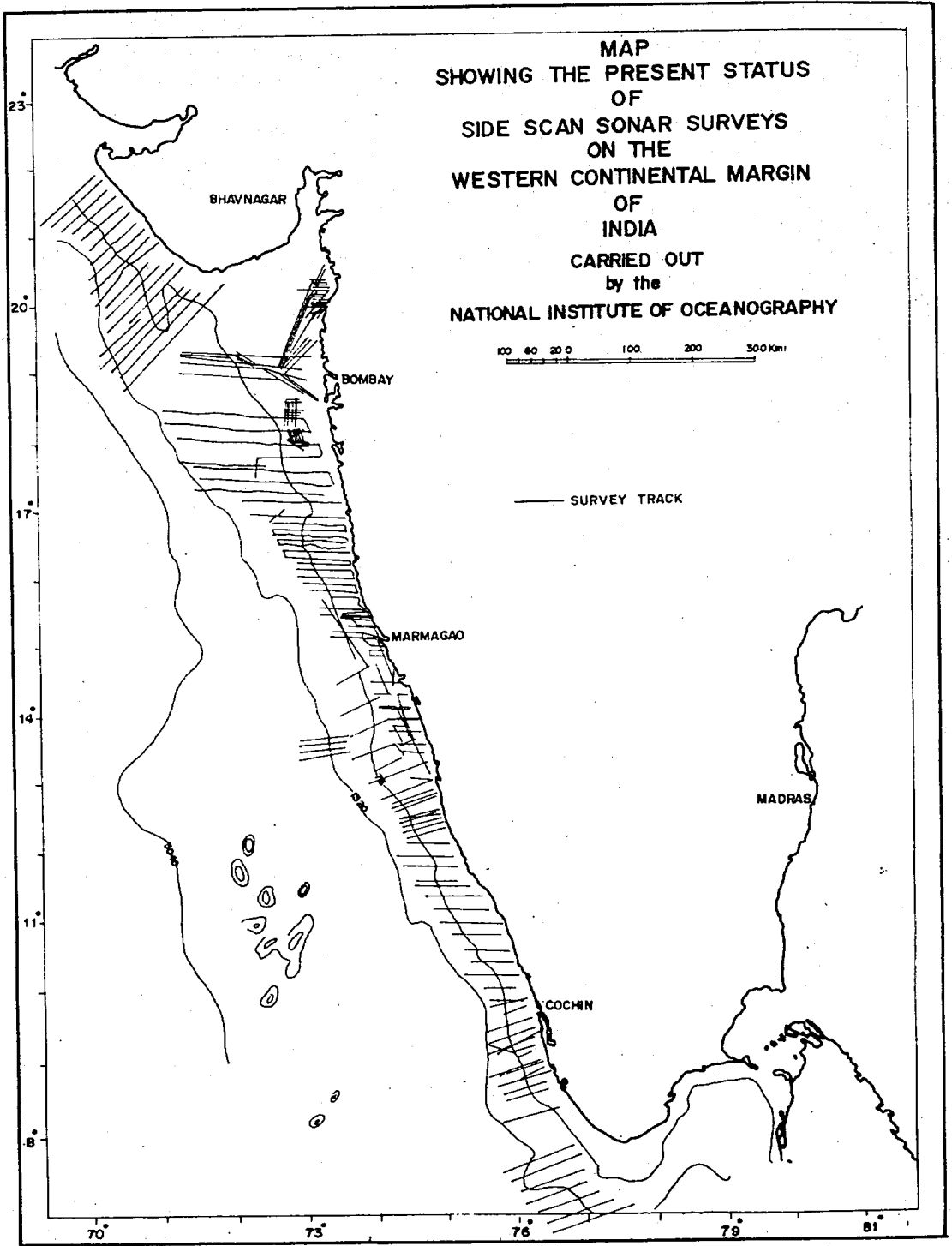


FIG. 5

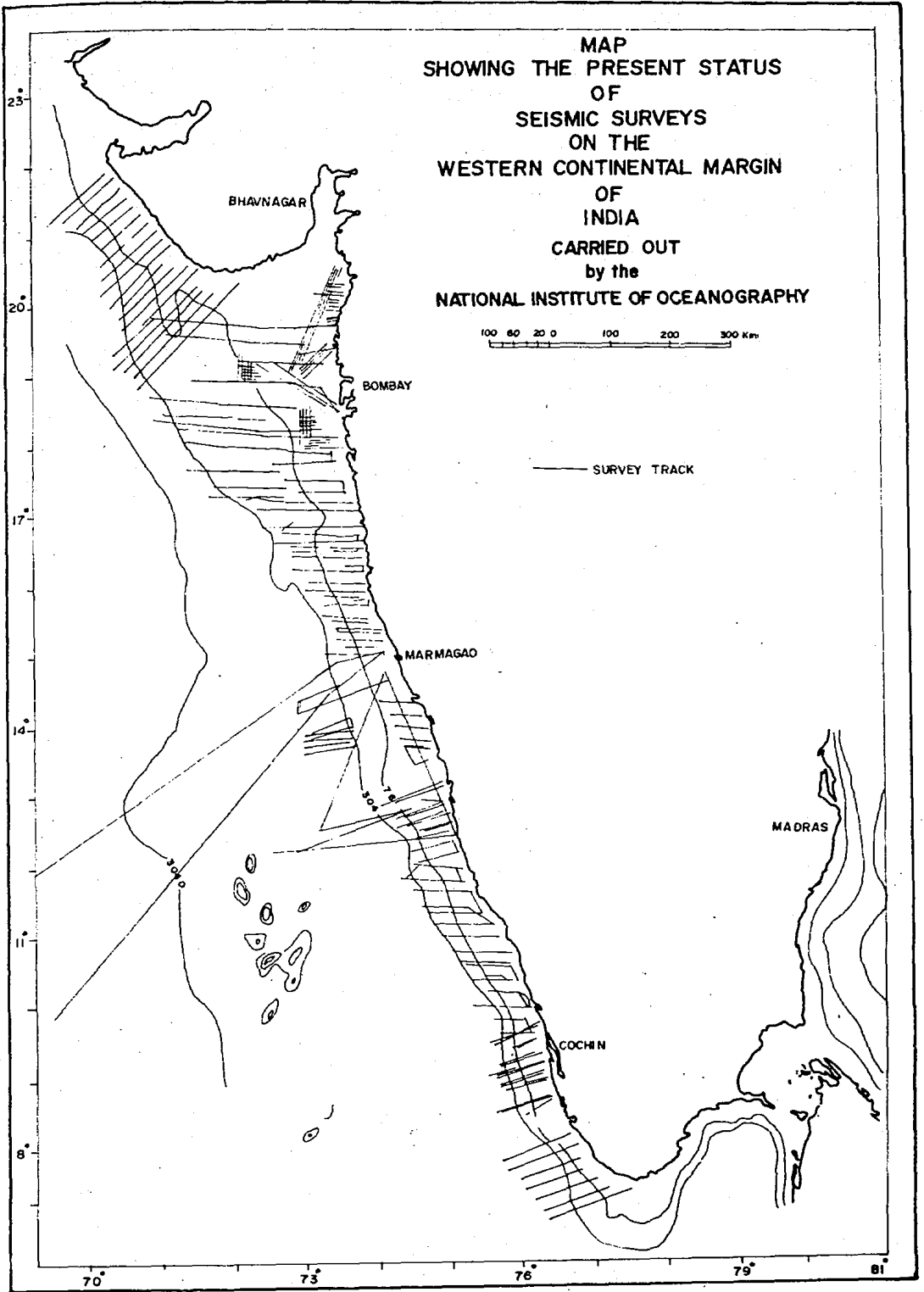


FIG. 6

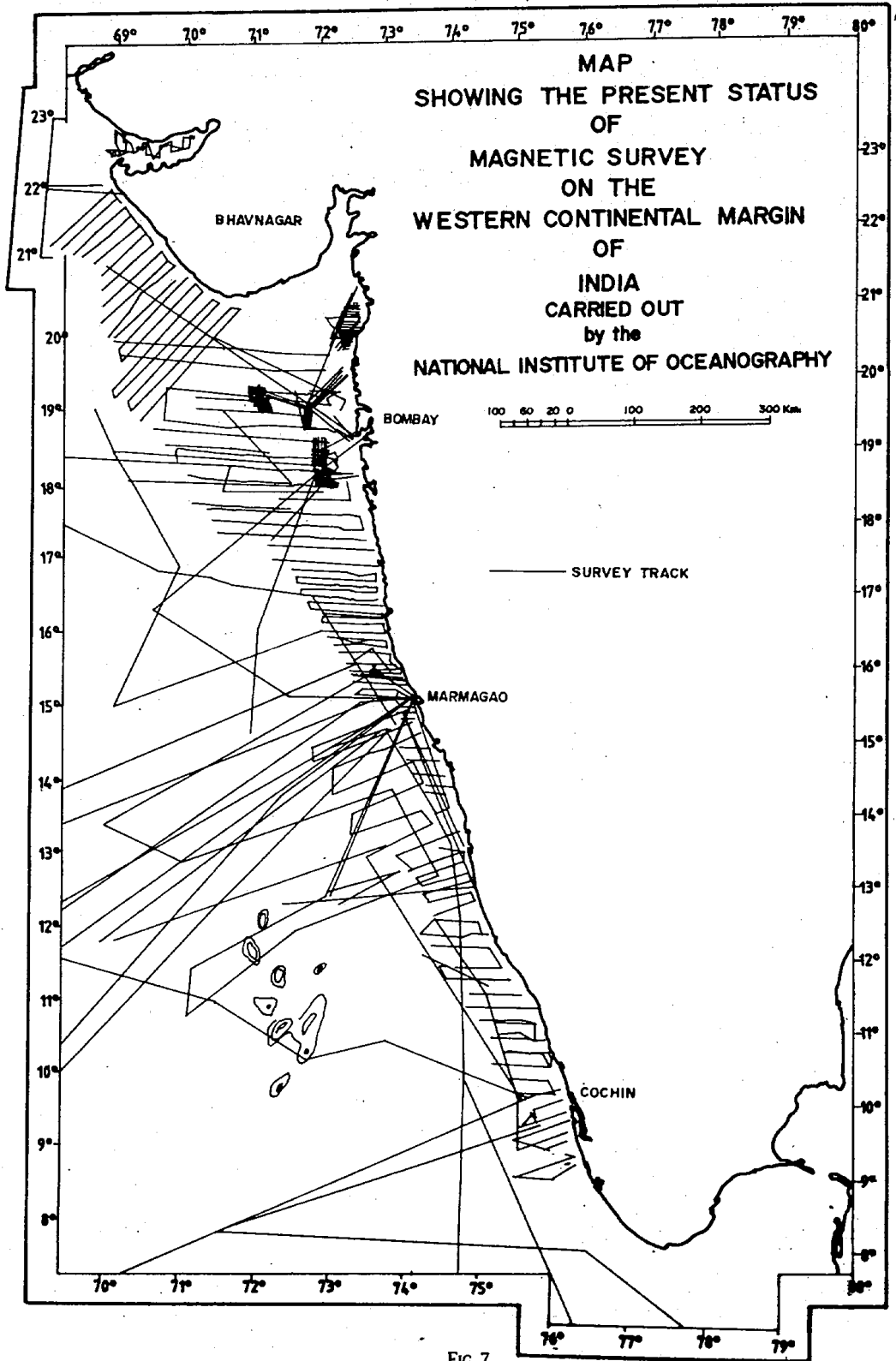
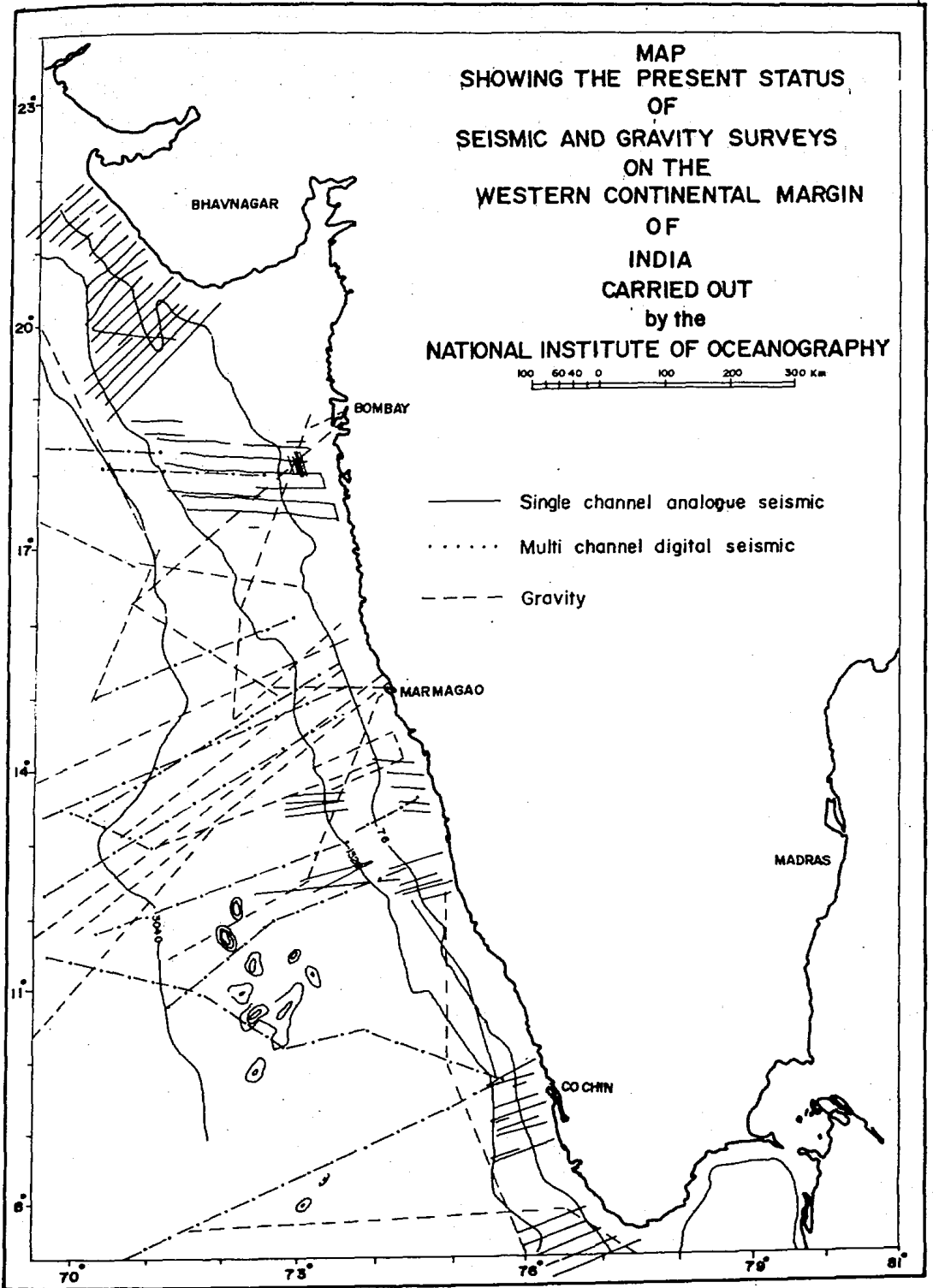


FIG. 7



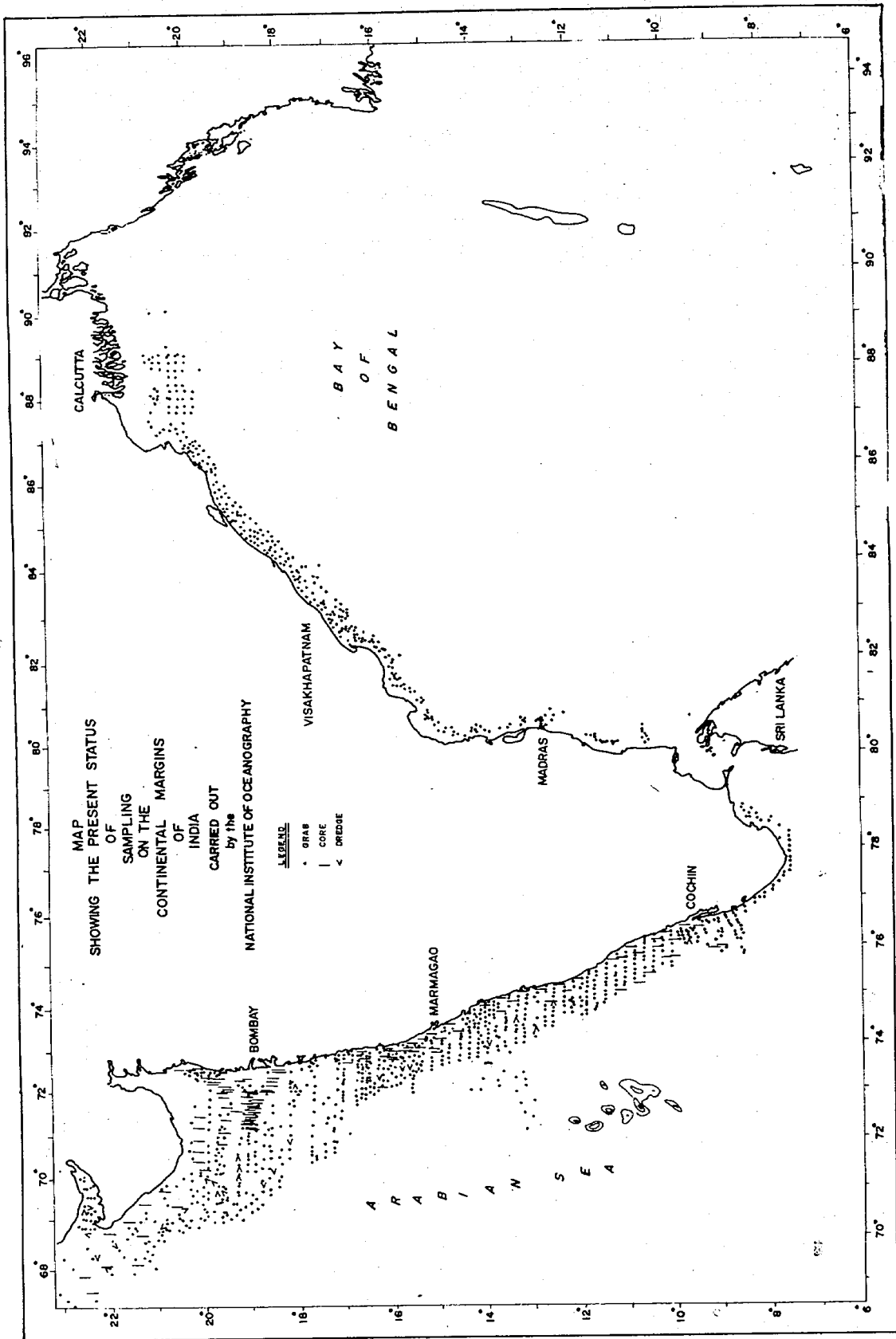


FIG. 9

samples by grabs, snappers, dredges and corers. The on station data were not only collected at the predetermined spacings of 10-20 km, but also when the underway data indicated certain interesting features like ridges, depressions, rock outcrops or mobile features. The data are being used in preparing accurate surficial geological maps of the continental shelf. Based on the results of the initial planning for the continental shelf, the planning is now being extended to the continental slope and will eventually cover the entire Exclusive Economic Zone of the country (Fig. 1). The large volume of data collected (Table 2) has led to the following scientific contributions.

### Geomorphology

NAIR (1972, 1975) noted small scale irregularities on the outer western shelf and concluded that these are algal and oolitic ridges formed during Holocene. SIDDIQUIE and RAJAMANICKAM (1974) indicated that, on the western shelf, the shelf break occurs between 120-145 m. They identified three types of topography, i.e. smooth (practically no variations), uneven (about 5 m) and rough (up to 20 m). They inferred that smooth topography on the Saurashtra shelf and the inner shelf off Bombay is due to the deposition of recent sediments while the outer shelf rugged topography appears to be a relict of the lowered sea level period. Similar studies were carried out for the Gulf of Kachchh (WAGLE, 1979). NAIR *et al.* (1978), while studying the topography of the area between Vengurla and Mangalore, found, beyond 50 m depth, numerous small scale (< 5 m relief) prominences and undulations. NAIR and QASIM (1978) reported two mount-shaped features on the outer shelf off Malpe, which are 14 and 38 m high. The latter is capped by living hermatypic corals and has been named Gaveshani Bank. VORA *et al.* (1980), ALMEIDA and BHATTACHARYA (1980) and HASHIMI *et al.* (1981) have reported sand waves in the Gulf of Khambhat, ripples in the Bombay Harbour area and periodic bed forms (ripples/waves) from the area between Cape Comorin to Tuticorin in the Gulf of Mannar, respectively. SIDDIQUIE (1973) described the geomorphology of the Laccadive Islands and reported that the first break in the profile of the seaward reef occurs at about 4-8 m water depth followed by a number of terraces at 7-12, 15, 21-36 (prominent) and 43-47 m.

### Sediments

*Beach* : KIDWAY (1971) brought out textural differences between dune and beach sands of Miramar. VEERAYYA (1972), VEERAYYA and VARADACHARI (1975), from the studies of beach and dune sands at Calangute, indicated seasonal variations in the statistical parameters at all sections.

*Shelf and deep sea* : Based on the samples and data collected during the cruises of INS *Darshak*, and RV *Gaveshani*, reports on sediment distribution are available for different parts of the shelf. NAIR (1971), KIDWAY and ALMEIDA (1974), HASHIMI *et al.* (1978a), HASHIMI *et al.* (1978b), HASHIMI *et al.* (1978c), NAIR *et al.* (1978) and NAIR and HASHIMI (1980) have summarised these details and reported that the continental shelf is floored with three distinct sedimentary facies and the boundaries between these are gradational. The first two facies of sand and mud are of recent period while the outer shelf relict carbonate sand facies (8,000 - 11,000 years) are of late Pleistocene period formed at the time of lowered sea level. Evidence of lowered sea levels is the presence of ooids, grapestones and shallow water foraminifera in the deeper waters of the conti-

mental shelf off the west coast of India. Warmer climate and low terrestrial run off was inferred by NAIR and HASHIMI (1980), based on the study of the carbonate sediments and the size of the quartz grains, and by HASHIMI and NAIR (1986) based on the distribution of feldspars in the shelf sediments.

The mineralogy of the carbonate sediments and limestones of the western continental shelf was studied by X-ray diffraction by NAIR and HASHIMI (1981). They concluded that the aragonite is the dominant carbonate (99% maximum), followed by low-magnesium calcite (77% maximum) and high-magnesium calcite (29% maximum).  $MgCO_3$  in high-magnesium calcite ranges from 5 to 21% (maximum in the limestones). HASHIMI *et al.* (1982) concluded after the study of the carbonates on the eastern and western shelves around Cape Comorin that, in the sediments where benthic foraminifera are abundant, high magnesium calcite is also high, whereas the aragonite is high in the mollusc dominant areas. NAIR *et al.* (1982a) studied the clay minerals of the western shelf and they demarcated four zones : (i) the montmorillonite-kaolinite-illite-chlorite province off the Gulf of Kachchh; (ii) the montmorillonite rich zone off the Gulf of Khambhat; (iii) a transitional zone on the central part of the shelf; (iv) a relatively montmorillonite-poor gibbsite province on the south western part of the shelf. The clay minerals of shelf and slope of Kerala were also studied by PURNACHANDRA RAO *et al.* (1983).

In the Gulf of Kachchh, coarse fraction component studies, carbonate mineralogy and clay mineralogy show that the high velocity tidal stream at the mouth of the Gulf acts as 'Dynamic Barrier', inhibiting sediment transport across the mouth of the Gulf (HASHIMI *et al.* 1978c, NAIR *et al.* 1982b).

### Micropaleontology

In marine faunal studies, foraminiferal studies have a very dominant role. They extend from the beaches to the deeper part of the oceans.

KAMESWARA RAO (1970a, 1970b and 1971) noted similarities in the foraminiferal assemblage of the Gulf of Cambay and the north eastern part of the Arabian Sea. SETTY (1972, 1974a) reported twenty-two species of planktic and thirty two species of benthic foraminifera from the shelf of Kerala. GUPTHA (1973) reported a mixture of relict foraminiferal fauna on the outer shelf of Cochin. SETTY and GUPTHA (1972) identified *Globigerina pachyderma* in sediments off Karwar and Mangalore, which they inferred as an indication of the influx of Antarctic cold waters. Subsequently, SETTY (1974b) discussed in detail the occurrence of the different forms of this species in the north Indian Ocean. KAMESWARA RAO (1972, 1973) compared the fauna of the Bay of Bengal and the Arabian Sea and noted the diversity of species in the Arabian Sea which may be attributed to increase in salinity.

Microenvironment and anomalous benthic faunal distribution and geology were inferred in the study of 27 samples from Dabhol-Vengurla sector of the Arabian Sea made by NIGAM *et al.* (1979), SETTY (1979), SETTY and NIGAM (1980). NIGAM and SARUPRIYA (1981) divided the area into two biotopes which correspond to freshwater influence from Shastri-Vaishithi rivers and organic carbon content. Despite the anomalous distribution of the fauna, a meaningful pattern was obtained by NIGAM and THIEDE (1983) by factor analysis, which showed four major assemblages. *Virgulinitella pertusa*, an important species during Miocene and Pliocene time, was encountered in recent marine sediments



off the west coast. Its ecology, distribution and relationship with various environmental parameters were studied by NIGAM and SETTY (1982). Moreover, SETTY (1976), KAMESWARA RAO and RAO (1979), SETTY and NIGAM (1982) have used foraminifera as pollution indicators.

Study of foraminifera from the shelf region off Daman and Bombay area (NIGAM and SETTY, 1980; NIGAM, 1984 and 1986a) showed that the substrate near the eastern bank is mobile, which does not allow benthic foraminifera to be attached to substrata and flourish. Differences in distribution of living and dead benthic foraminifera were used to prepare a new method to decipher net sediment transport direction, and foraminiferal data off Navapur were used to test this method (NIGAM, 1986a). Based on the difference in dimorphic forms of foraminifera, NIGAM (1986b) proposed that the higher ratio of microspheric/megalospheric forms indicates warmer climate. NIGAM and RAO (in press) further modified the technique and suggested that lower mean proloculus size in benthic foraminifera indicated low temperature and salinity. This technique can be utilized to study palaeomonsoon.

### Geochemistry

The geochemical investigations of both major and trace elements of surficial sediments of the western (550 samples) and eastern (113 samples) continental margins revealed the following :

*Western Continental Margin* : Elevated levels of organic carbon (up to 12%), mostly of planktonic origin, in the sediments of the slope region between Bombay and Quilon, presence of reducing conditions, and occurrence of thick sediments suggest that these sediments could be the future source beds for petroleum (PAROPKARI *et al.* 1985). High concentrations of phosphate (up to 6.5%  $P_2O_5$  on carbonate free basis) are found to be associated with the sediments of the outer shelf/slope region. High phosphate in the near bottom as well as in the interstitial waters, high organic carbon content (with which phosphate has a genetic relationship), the reducing conditions, and the presence of carbonate substrate form a favourable environment for phosphatization along the outer shelf/slope region (RAO *et al.* 1986).

*Eastern Continental Shelf* : The bulk and partition geochemistry of several elements (Al, Fe, Ti, Mn, Zn and Cu) shows that the contributions made by the lithogenous components to the concentrations in the bulk samples are highest for Al and Ti, followed next in order by Fe, lowest in respect of Mn, while the values for other elements lie in between the Al and Ti on the one hand and Mn on the other. Similarity in the metal/Al ratios of the shelf region and those of the sediments of the adjacent river systems suggests that Fe, Mn hydroxides along with metal contents are transported through the estuaries without any modification and deposited in the shelf region (MASCARENHAS *et al.* 1985).

### Mineral Resources

The results of the surveys in Kalbadevi, Mirya and Ratnagiri bays on the Konkan Coast, reported by SIDDIQUIE *et al.* (1979), indicate the extension of heavy mineral placers to a depth of 9 to 12 m extending to 2 to 5 km offshore. The sediments in the bays contain up to 91% heavy minerals which include ilmenite up to 64%. They

concluded on the basis of heavy mineral assemblage that the heavy minerals have been derived from the Deccan Trap. The ilmenite rich (> 5%) sediments cover over 15 sq. km and the inferred reserves to a depth of 1 m are of the order of 2 million tons. The results of the surveys for mineral resources have been summarised by SIDDIQUIE and RAJAMANICKAM (1979) and SIDDIQUIE *et al.* (1984).

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