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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 (Siddiquie *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 explorated 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&G side scan sonar system.

Sub-bottom profiler :
3.5 kHz ORE sub-bottom profiler,
EG&G Uniboom system, EG&G 24 kj sparker system,
Barringer/Geometrics proton precision magnetometer.

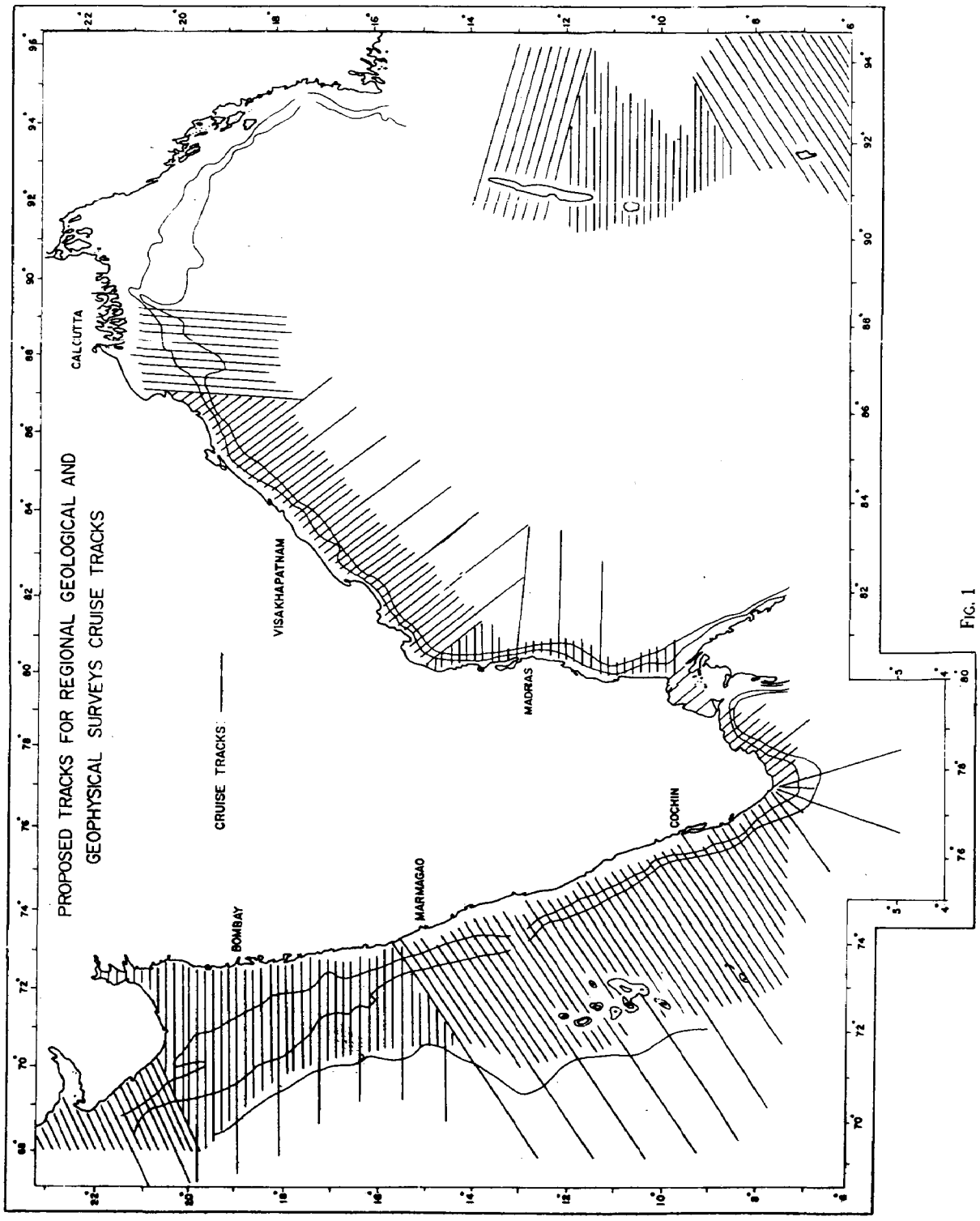
PROPOSED TRACKS FOR REGIONAL GEOLOGICAL AND
GEOPHYSICAL SURVEYS CRUISE TRACKS
CRUISE TRACKS
CALCUTTA
VISAKHAPATNAM
MADRAS
COCHIN
MARMAGAO
BOMBAY

FIG. 1

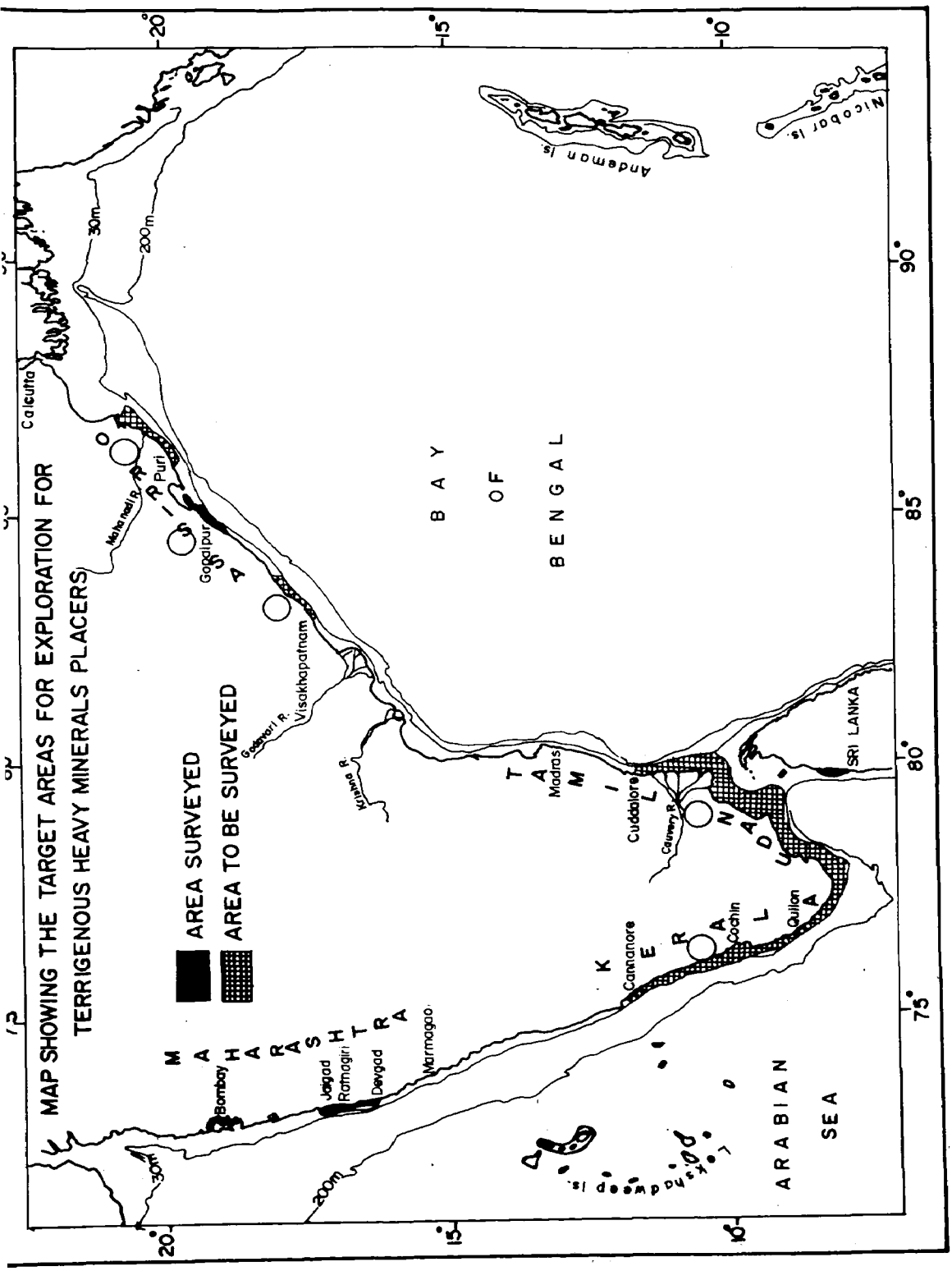
MAP SHOWING THE TARGET AREAS FOR EXPLORATION FOR TERRIGENOUS HEAVY MINERALS PLACERS
AREA SURVEYED
AREA TO BE SURVEYED
BAY OF BENGAL
ARABIAN SEA
MAHARASHTRA
KERALA
TAMIL NADU
Calcutta
Puri
Gopalpur
Visakhapatnam
Madras
Cuddalore
Cannanore
Cochin
Quilon
Bombay
Jaigad
Ratnagiri
Devgad
Varmagao
SRI LANKA
Andaman Is
Nicobar Is
Lakshadweep Is
30m
200m
20°
15°
10°
90°
85°
80°
75°

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).

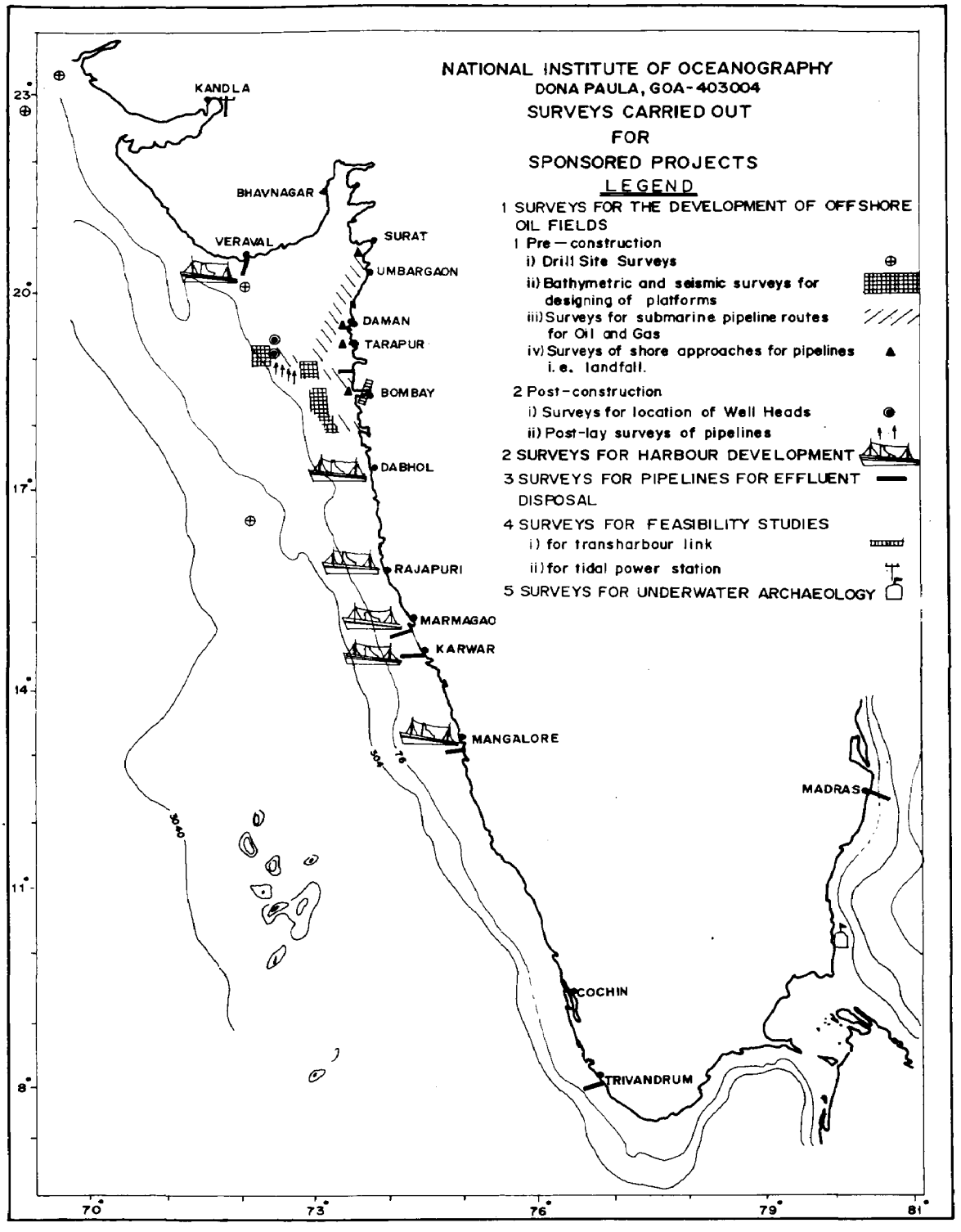
NATIONAL INSTITUTE OF OCEANOGRAPHY
DONA PAULA, GOA-403004
SURVEYS CARRIED OUT
FOR
SPONSORED PROJECTS
LEGEND
1 SURVEYS FOR THE DEVELOPMENT OF OFFSHORE OIL FIELDS
1 Pre—construction
i) Drill Site Surveys
ii) Bathymetric and seismic surveys for designing of platforms
iii) Surveys for submarine pipeline routes for Oil and Gas
iv) Surveys of shore approaches for pipelines i.e. landfall.
2 Post-construction
i) Surveys for location of Well Heads
ii) Post-lay surveys of pipelines
2 SURVEYS FOR HARBOUR DEVELOPMENT
3 SURVEYS FOR PIPELINES FOR EFFLUENT DISPOSAL
4 SURVEYS FOR FEASIBILITY STUDIES
i) for transharbour link
ii) for tidal power station
5 SURVEYS FOR UNDERWATER ARCHAEOLOGY
KANDLA
BHAVNAGAR
VERAVAL
SURAT
UMBARGAON
DAMAN
TARAPUR
BOMBAY
DABHOL
RAJAPURI
MARMAGAO
KARWAR
MANGALORE
COCHIN
TRIVANDRUM
MADRAS
500
1000
23°
20°
17°
14°
11°
8°
70°
73°
76°
79°
81°

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

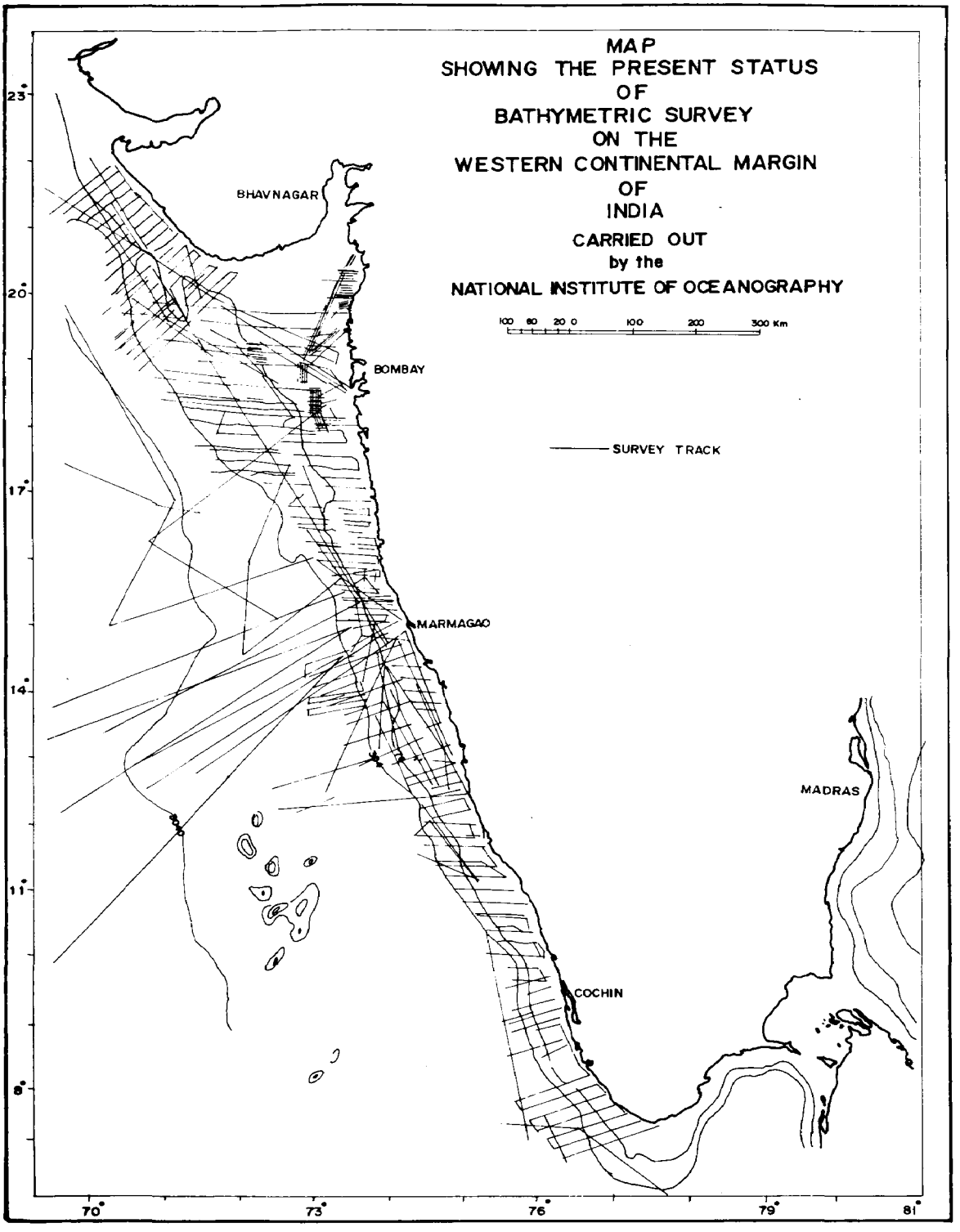
MAP
SHOWING THE PRESENT STATUS
OF
BATHYMETRIC SURVEY
ON THE
WESTERN CONTINENTAL MARGIN
OF
INDIA
CARRIED OUT
by the
NATIONAL INSTITUTE OF OCEANOGRAPHY
100 60 20 0 100 200 300 Km
SURVEY TRACK
BHAVNAGAR
BOMBAY
MARMAGAO
COCHIN
MADRAS
23°
20°
17°
14°
11°
8°
70°
73°
76°
79°
81°

FIG. 4

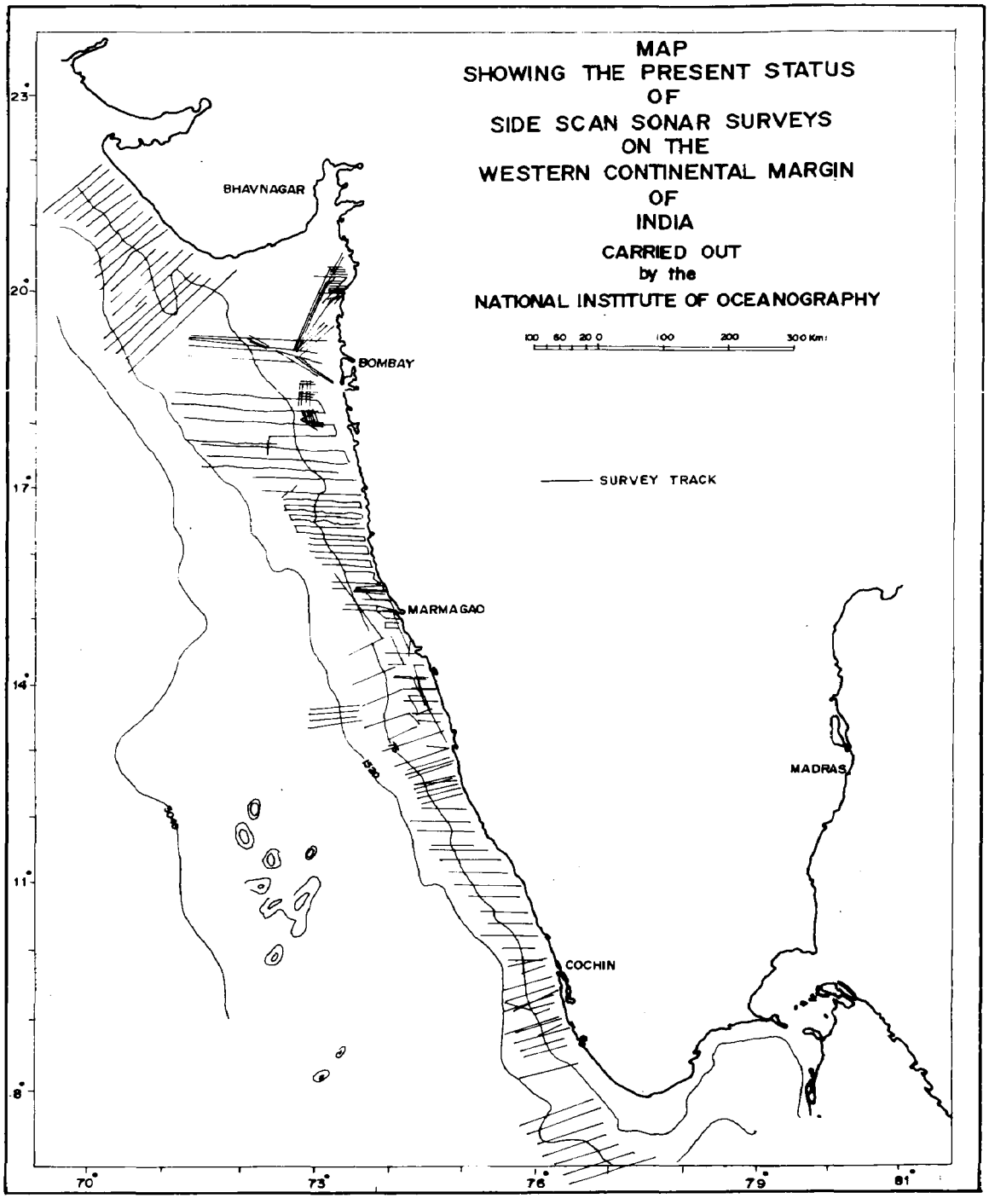
MAP
SHOWING THE PRESENT STATUS
OF
SIDE SCAN SONAR SURVEYS
ON THE
WESTERN CONTINENTAL MARGIN
OF
INDIA
CARRIED OUT
by the
NATIONAL INSTITUTE OF OCEANOGRAPHY
100 60 20 0 100 200 300 Km
SURVEY TRACK
BHAVNAGAR
BOMBAY
MARMAGAO
COCHIN
MADRAS
23°
20°
17°
14°
11°
8°
70°
73°
76°
79°
81°

FIG. 5

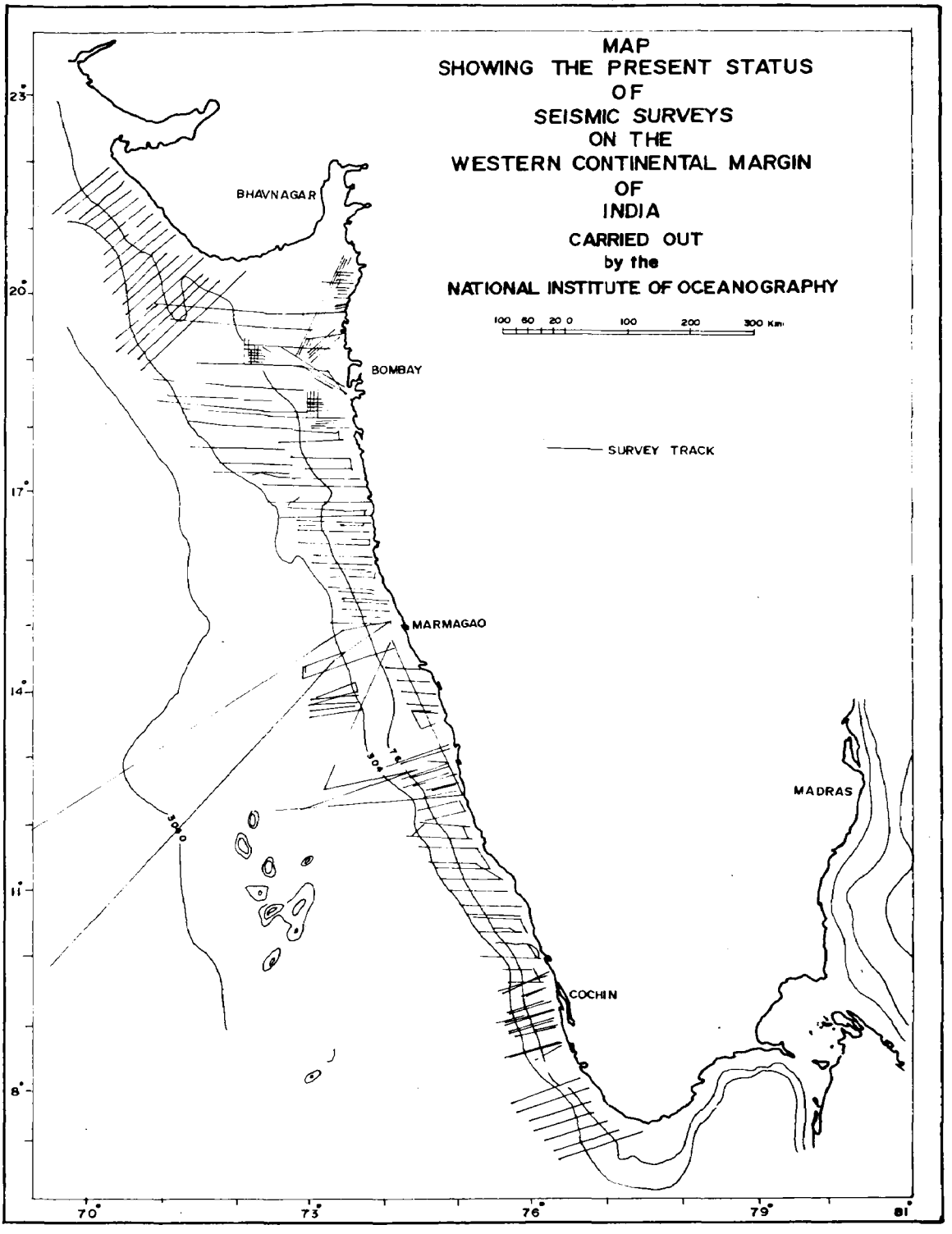
MAP
SHOWING THE PRESENT STATUS
OF
SEISMIC SURVEYS
ON THE
WESTERN CONTINENTAL MARGIN
OF
INDIA
CARRIED OUT
by the
NATIONAL INSTITUTE OF OCEANOGRAPHY
100 60 20 0 100 200 300 Km
SURVEY TRACK
BHAVNAGAR
BOMBAY
MARMAGAO
COCHIN
MADRAS
300
23°
20°
17°
14°
11°
8°
70°
73°
76°
79°
81°

FIG. 6

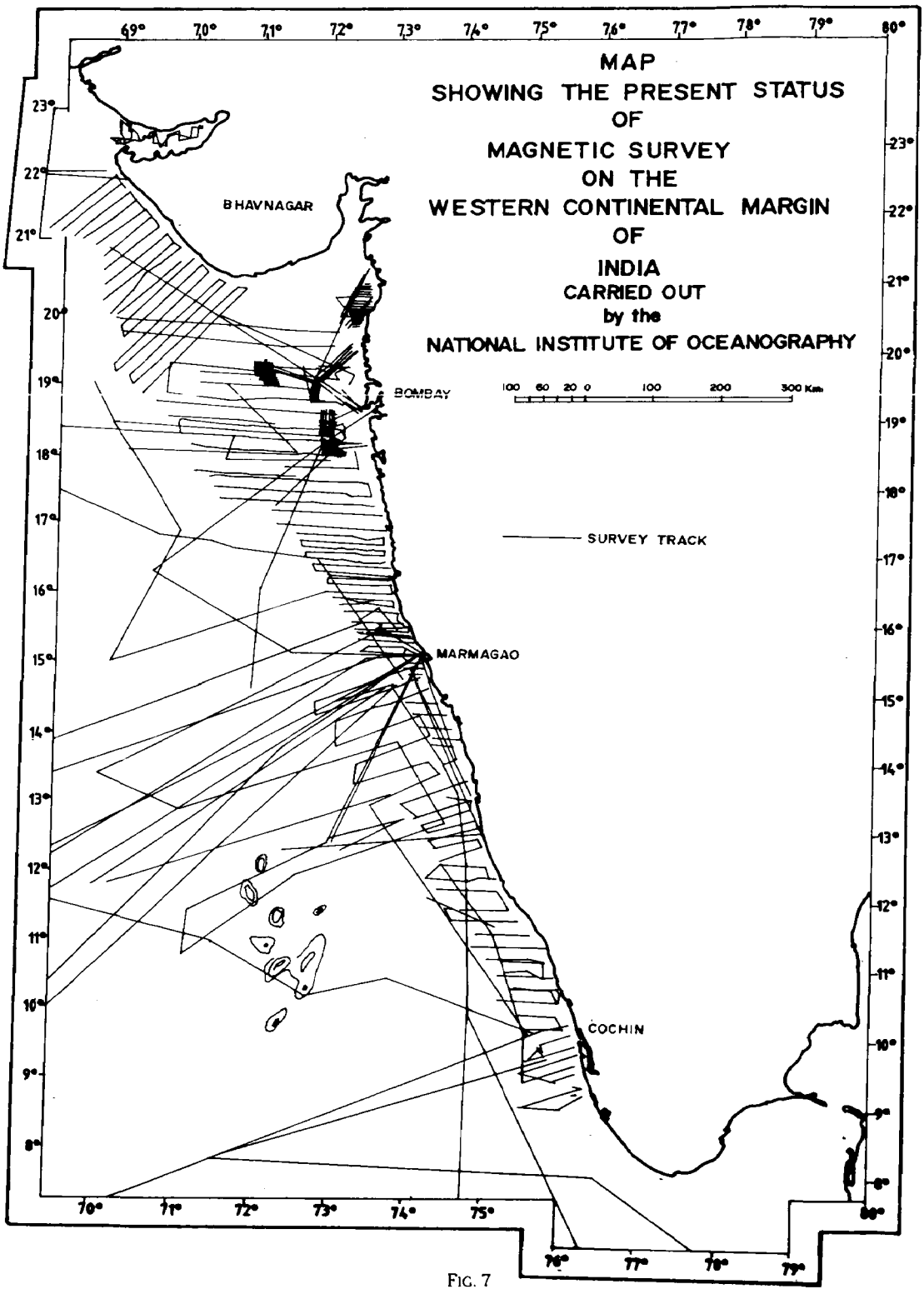
MAP
SHOWING THE PRESENT STATUS
OF
MAGNETIC SURVEY
ON THE
WESTERN CONTINENTAL MARGIN
OF
INDIA
CARRIED OUT
by the
NATIONAL INSTITUTE OF OCEANOGRAPHY
BHAVNAGAR
BOMBAY
MARMAGAO
COCHIN
100 60 20 0 100 200 300 Km
SURVEY TRACK

FIG. 7

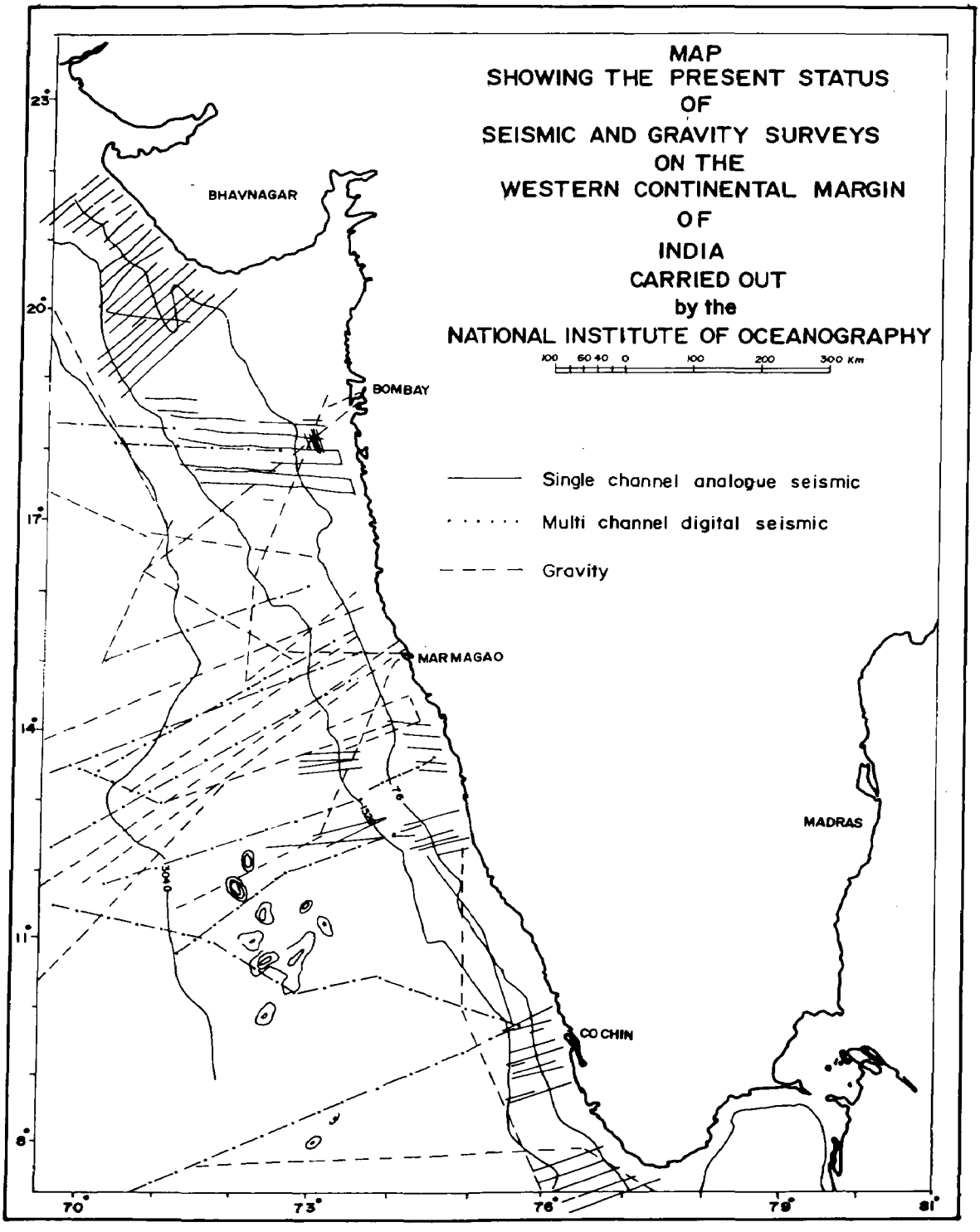
MAP
SHOWING THE PRESENT STATUS
OF
SEISMIC AND GRAVITY SURVEYS
ON THE
WESTERN CONTINENTAL MARGIN
OF
INDIA
CARRIED OUT
by the
NATIONAL INSTITUTE OF OCEANOGRAPHY
100 60 40 0 100 200 300 Km
Single channel analogue seismic
Multi channel digital seismic
Gravity
BHAVNAGAR
BOMBAY
MARMAGAO
MADRAS
COCHIN
3040
23°
20°
17°
14°
11°
8°
70°
73°
76°
79°
81°

FIG. 8

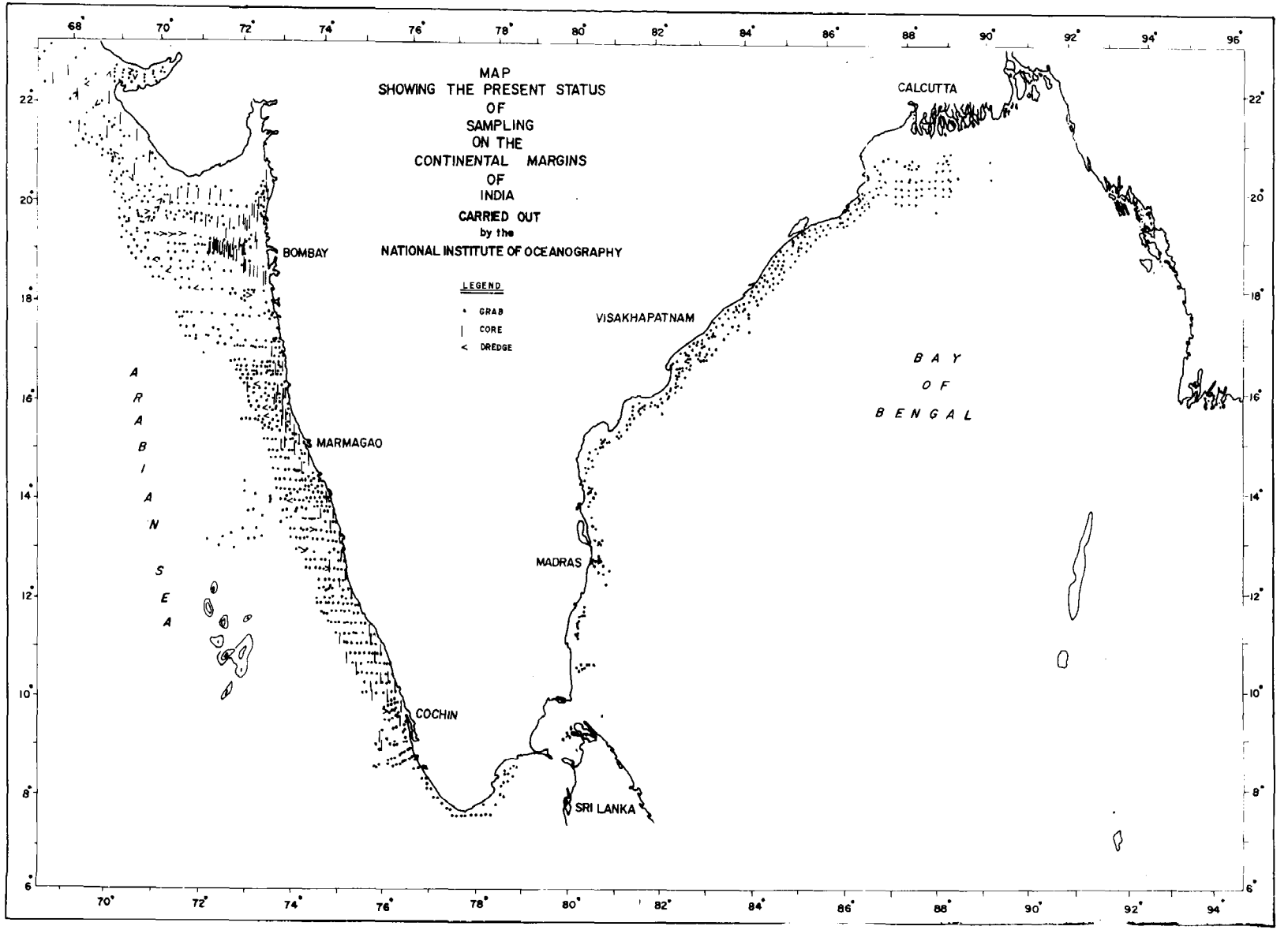
MAP
SHOWING THE PRESENT STATUS
OF
SAMPLING
ON THE
CONTINENTAL MARGINS
OF
INDIA
CARRIED OUT
by the
NATIONAL INSTITUTE OF OCEANOGRAPHY
LEGEND
GRAB
CORE
DREDGE
BOMBAY
MARMAGAO
COCHIN
MADRAS
VISAKHAPATNAM
CALCUTTA
SRI LANKA
ARABIAN SEA
BAY OF BENGAL

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-

nental shelf off the west coast of India. Warmer climate and low terrestial 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. *Virgulinella 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 (1276), 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).

REFERENCES

ALMEIDA, F. and BHATTACHARYA, G.C. (1980) : Ripples on the seabed in the Bombay Harbour Area, Indian Journal of Marine Sciences, 9(3):212-214.

GUPTHA, M.V.S. (1973) : A preliminary note on the foraminiferal assemblage from the sediments of Kavaratti Atoll (Laccadives), Current Science, 42 (22), 781-782.

HASHIMI, N.H., GUPTHA, M.V.S., KIDWAY, R.M. and NAIR, R.R. (1978a) : Sediments and sedimentary processes on the continental shelf off Bombay, Mahasagar — Bulletin of the National Institute of Oceanography, 11 (3 and 4), 155-161.

HASHIMI, N.H., KIDWAY, R.M. and NAIR, R.R. (1978b) : Grain size and coarse fraction studies of the sediments between Vengurla and Mangalore on the Western Continental Shelf of India. Indian Journal of Marine Sciences, 7(4), 231-238.

HASHIMI, N.H., KIDWAY, R.M. and NAIR, R.R. (1981) : Comparative study of the topography and sediments of the western and eastern continental shelves around Cape Comorin. Indian Journal of Marine Sciences, 10(1), 45-50.

HASHIMI, N.H. and NAIR, R.R. (1986) : Climatic aridity over India 11,000 years ago; evidence from feldspar distribution in shelf sediments. Palaeogeography, Palaeoclimatology, Palaeoecology, 53, 309-320.

HASHIMI, N.H., NAIR, R.R. and KIDWAY, R.M. (1978c) : Sediment of the Gulf of Kutch — A high energy tide dominated environment. Indian Journal of Marine Sciences, 7(1), 1-7.

HASHIMI, N.H., NAIR, R.R., KIDWAY, R.M. and PURNACHANDRA RAO, V. (1982) : Carbonate mineralogy and faunal relationship in tropical shallow water marine sediments : Cape Comorin, India. Sedimentary Geology, 32, 89-98.

KAMESWARA RAO, K. (1970a) : Foraminifera of the Gulf of Cambay. Journal of the National History Society, 66 (3), 584-596.

KAMESWARA RAO, K. (1970b) : Foraminifera of the Gulf of Cambay. Journal of the Natural History Society, 67(2), 259-273.

KAMESWARA RAO, K. (1971) : On some foraminifera from the NE part of the Arabian Sea. Proceedings of the Indian Academy of Sciences, 73, 155-178.

KAMESWARA RAO, K. (1972) : Planktonic foraminifera in sediment samples from the Eastern Arabian Sea. Indian Journal of Marine Sciences, 1, 1-7.

KAMESWARA RAO, K. (1973) : Quantitative distribution of planktonic foraminifera in the SW coast of India. Indian Journal of Marine Sciences, 2, 54-61.

KAMESWARA RAO, K. and RAO, T.S.S. (1979) : Studies on pollution ecology of foraminifera of the Trivandrum Coast. Indian Journal of Marine Sciences, 8, 31-35.

KIDWAY, R.M. (1971) : Grain size distribution and mineralogy of Miramar Beach. Journal of the Geological Society of India, 12, 395-398.

KIDWAY, R.M. and ALMEIDA, F. (1974) : Sediment distribution of the western continental margin of India (northern part). Initial Rep. and Data File, INS *Darshak* 1973-74 Oceanographic Expedition, 74/1, 243-248.

MASCARENHAS, A., PAROPKARI, A.L. and MURTY, P.S.N. (1985) : Geochemistry of sediments of the eastern continental shelf of India. Mahasagar — Bulletin of the National Institute of Oceanography, 18(1), 1-25.

NAIR, R.R. (1971) : The continental shelf, Souvenier, Seminar on Scientific Technological and Legal Aspects of the Indian Continental Shelf, *and* Journal of the Indian Geophysical Union, 13-16.

NAIR, R.R. (1972) : Outer shelf carbonate pinnacles and troughs on the western continental shelf of India. Journal of the Indian Geophysical Union, 10 (1-4), 135-140.

NAIR, R.R. (1975) : Nature and origin of small scale topographic prominence on the western continental shelf of India. Indian Journal of Marine Sciences, 4(1), 25-29.

NAIR, R.R. and HASHIMI, N.H. (1980) : Holocene climate inferences from the sediments of the western Indian continental shelf. Proceedings of the Indian Academy of Sciences (E&P Sciences), 89(3), 299-315.

NAIR, R.R. and HASHIMI, N.H. (1981) : Mineralogy of the carbonate sediments. Western Continental Shelf of India. Marine Geology 41, 309-319.

NAIR, R.R., HASHIMI, N.H., KIDWAY, R.M., GUPTHA, M.V.S., PAROPKARI, A.L., AMBRE, N.V., MURALINATH, A.S., MASCARENHAS, A. and D.COSTA, G.P. (1978) : Topography and sediments of the western continental shelf of India — Vengurla to Mangalore. Indian Journal of Marine Science, 7(4), 224-230.

NAIR, R.R., HASHIMI, N.H. and PURNACHANDRA RAO, V. (1982a) : Distribution and dispersal of clay minerals on the western continental shelf of India. Marine Geology, 50(1 and 2), M1-M9.

NAIR, R.R., HASHIMI, N.H. and PURNACHANDRA RAO, V. (1982b) : On the possibility of high velocity tidal streams as dynamic barriers to longshore sediments transport evidence from the continental shelf off the Gulf of Kutch, India. Marine Geology, 47, 77-86.

NAIR, R.R. and QASIM, S.Z. (1978) : Occurrence of a bank with living coral off the south west coast of India. Indian Journal of Marine Science, 7(1), 55-58.

NIGAM, R. (1984) : Ecological response of living benthonic foraminifera in a tidal environment — Gulf of Khambhat (India), Marine Geology, 58(3/4), 415-425.

NIGAM, R. (1986a) : Foraminiferal assemblages and their use as indicators of sediment movement — A study in the shelf off Navapur, West Coast of India. Continental Shelf Research, 5(4), 421-430.

NIGAM, R. (1986b) : Dimorphic forms of recent foraminifera : an additional tool in palaeoclimatic studies. Palaeogeography, Palaeoclimatology, Palaeoecology, 53(2-4), 239-244.

NIGAM, R. and RAO, A.S. (in press) : Prolocules size in recent benthic foraminifera : implications for palaeoclimatic studies. Estuarine, Coast and Shelf Sciences.

NIGAM, R. and SARUPRIA, J.S. (1981) : Cluster analysis and ecology of living benthonic foraminiferids from inner shelf off Ratnagiri, West Coast, India. Journal of the Geological Society of India, 22(4), 175-180.

NIGAM, R. and SETTY, M.G.A.P. (1980) : Paleogene reworked foraminifera in the recent sediments off Daman, Western India. Proceedings of the 3rd Indian Geological Congress, Poona, 273-280.

NIGAM, R. and SETTY, M.G.A.P. (1982) : Ecological regime and distribution of *Virgulinella* sp, in the inner shore sediments of western India. Palaeogeography, Palaeoclimatology, Palaeoecology, 38, 57-61.

NIGAM, R., SETTY, M.G.A.P. and AMBRE, N.V. (1979) : A check list of benthic foraminiferids from the inner shelf of Dabhol-Vengurla region. Arabian Sea. Journal of the Geological Society of India, 20, 244-247.

NIGAM, R. and THIEDE, J. (1984) : Recent foraminifera from the inner shelf of the central west coast. A reappraisal using factor analysis. Proceedings of the Indian Academy of Science (Earth and Planetary Sciences), 92(2), 121-128.

PAROPKARI, A.L., RAO, Ch. M., and MURTY, P.S.N. (1985) : Environmental controls on the distribution of organic matter in recent sediments of the western continental margin of India, International Congress on Petroleum Geochemistry and Explorations in the Afro-Asian Region, Dehra Dun, India. (Abs).

PURNACHANDRA RAO, V., NAIR, R.R. and HASHIMI, N.H. (1983) : Clay mineral distribution on the Kerala continental shelf and slope. Journal of Geological Society of India, 24(10), 540-546.

RAO, Ch. M., PAROPKARI, A.L. and MURTY, P.S.N. (1986) : Distribution of phosphate in the unconsolidated sediments of the western continental margin of India. Accepted in Sediments Down Under, 12th International Sedimentological Congress, 24-30 August, 1986, Canberra, Australia.

SETTY, M.G.A.P. (1972) : Holocene planktonic foraminifera from the shelf sediments off Kerala Coast. Journal of the Geological Society of India, 13(2), 131-138.

SETTY, M.G.A.P. (1974a) : Holocene benthic foraminifera from the shelf sediment of Kerala coast. Bulletin of Earth Science, 3(1), 21-28.

SETTY, M.G.A.P. (1974b) : *Globigerina pachyderma* (Ehrenberg) in the outer shelf slope sediments of the northern Indian Ocean. Proceedings of the 4th Indian Colloquium on Micropalaeontology and Stratigraphy, 21-26.

SETTY, M.G.A.P. (1976) : The relative sensitivity of benthonic foraminifera in the polluted marine environment of Cola Bay, Goa. Proceedings of the 6th Indian Colloquium on Micropalaeontology and Stratigraphy, 225-234.

SETTY, M.G.A.P. (1979) : Role of foraminifera in oceanographic events. Journal of Science and Industrial Research, 58(7), 380-399.

SETTY, M.G.A.P. and GUPTHA, M.V.S. (1972) : Recent planktonic foraminifera from sediments of Karwar and Mangalore. Proceedings of the Indian National Science Academy, 38(5 and 6)A, 148-160.

SETTY, M.G.A.P. and NIGAM, R. (1980) : Microenvironmental and anomalous benthic foraminiferal distribution within the neritic regime of the Dabhol-Vengurla sector of the Arabian Sea. Rivista Italiana de Paleontologia e Stratigrafia, 86(2), 417-428.

SETTY, M.G.A.P. and NIGAM, R. (1982) : Foraminiferal assemblages and organic carbon relationship in benthic marine ecosystem of the western Indian continental shelf. Indian Journal of Marine Sciences, 11(3), 225-232.

SIDDIQUIE, H.N. (1973) : Coral reefs and atolls of Laccadive Islands. 2nd International Symposium, Coral Reef, Australia.

SIDDIQUIE, H.N., GUJAR, A.R., HASHIMI, N.H. and VALSANGKAR, A.B. (1984) : Superficial mineral resources of the Indian Ocean. Deep Sea Research, Part A 31, (6 to 8 A), 763-812.

SIDDIQUIE, H.N. and RAJAMANICKAM, G.V. (1974) : The geomorphology of the western continental margin of India. Initial Report and Data Files, INS *Darshak* 1973-74, Oceanographic Expeditions, 74/1, 228-233.

SIDDIQUIE, H.N. and RAJAMANICKAM, G.V. (1979) : Surficial mineral deposits of the Continental Shelf of India. Proceedings of the International Seminar on the Offshore Resources, Orléans, France. BRGM documents, 7, 233-258.

SIDDIQUIE, H.N., RAJAMANICKAM, G.V. and ALMEIDA, F. (1979) : Offshore ilmenite placers of Ratnagiri, Konkan Coast, Maharashtra, India, Marine Mining, 2(1), 91-118.

SIDDIQUIE, H.N., SHRIVASTAVA, P.C., MALLICK, T.K., RAY, I. and VENKATESH, K.V. (1977) : Bottom sediment map of the sea bordering India. Geological Survey of India, Bangalore.

VEERAYYA, M. (1972) : Textural characteristics of Calangute Beach sediments, Goa coast. Indian Journal of Marine Sciences, 1(1), 28-44.

VEERAYYA, M. and VARADACHARI, V.V.R. (1975) : Depositional environments of coastal sediments of Calangute, Goa. Sedimentary Geology, 14(1), 63-74.

VORA, K.H., GUJAR, A.R. and KARISIDDAIAH, S.M. (1980) : Sandwaves of the Gulf of Khambhat. Indian Journal of Marine Sciences, 9, 90-93.

WAGLE, B.G. (1979) : Geomorphology of the Gulf of Kutch. Indian Journal of Marine Sciences, 8(1 and 2), 123-126.