

OCEANOGRAPHY IN INDIA

V V R VARADACHARI and V KESAVA DAS
*National Institute of Oceanography
Dona Paula, Goa, 403004*

INTRODUCTION

The awareness in India, of the importance of the ocean, can be traced back to the vedic times. Hindu mythology is full of episodes pertaining to the ocean. Lord Vishnu, the preserver in the Hindu Trinity, is depicted as reclining on Adi Sesha, the Great Serpent, in the midst of the primordial ocean. The legend of Samudra-Manthan has its roots in the Vedas. According to the epic, Ramayana, the Devas and Danavas, the sons of the great saint Kashyapa by Aditi and Diti respectively, decided to churn the ocean, to attain Amrita, the divine nectar. Mount Mandara served as the churning rod and Vasuki, the great serpent king as the rope. There is plenty of evidence derived from Indian literature, art, archaeology etc., to suggest the antiquity of the Indian maritime tradition. A close study of the Lothal dock (Gujarat) reveals that the Harappan Engineers solved the problem of desilting in the dock and the maintenance of constant water level in the channel. Asoka (302 B.C. to 232 B.C.) maintained trade and cultural relations with the kingdoms of Sri Lanka, Syria, Egypt, North Africa, Greece, China, Japan, etc., through

ocean navigation. Herodotus (5th century B.C.) refers to a number of Indian products in Greek markets. Rajaraja, the Chola Emperor, who ascended the throne in the later half of the 10th century A.D., realised the importance of controlling the seas. He led successful expeditions against Sri Lanka. His son Rajendra carried his flag right upto the limits of South East Asia. Naval victory in those days was closely associated with a good knowledge of wind and waves. With the arrival of Vasco da Gama on the west coast, in 1498, and the establishment in India, of the British East India company, in the 16th and 17th centuries, there was considerable increase in the maritime activity on the east and west coasts of India. The tidal observations in the Hoogly were started in 1767. The bathymetric and hydrographic surveys of the Indian coastal waters were begun in 1832, by the Royal Indian Navy. The marine survey department of the Navy was established in 1874 and HMS Investigator I was commissioned in 1881. In 1908 Investigator I was replaced by Investigator II. Systematic collection of oceanographic data in the Indian seas started after Col. R.B.S. Sewell joined HMS Investigator II as surgeon

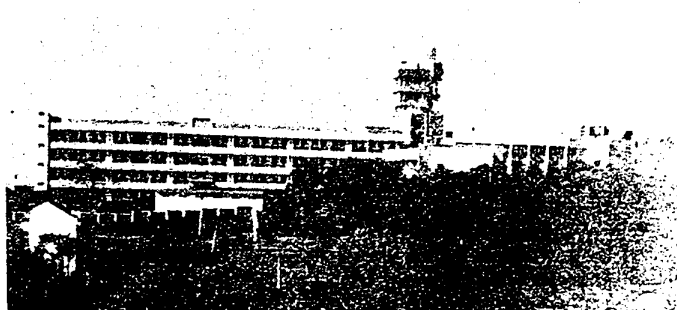


Photo.1 National Institute of Oceanography, Dona Paula. Goa.

-naturalist. These studies were reported in the Memoirs of the Asiatic Society of Bengal (1925-35).

Oceanography in India, received considerable impetus after India became independent. The Central Marine Fisheries Research Institute which was set up in 1947 with its headquarters at Mandapam initiated studies in oceanography in relation to fisheries. Academic courses in oceanography at postgraduate level, were started at the Andhra University, Waltair, in 1948, although some basic studies in Marine Biology and Fisheries were started at the Universities of Bombay and Madras, more than two decades earlier. Systematic cruise programme and research work in oceanography dates back to 1952, when Prof. E.C. LaFond, Head of the Oceanography Section of the U.S. Navy Electronics Laboratory, San Deigo, California, joined the Andhra University as a visiting Professor. During his visits in 1952-53 and 1955-56, several cruises were undertaken off the east coast of India, on board Naval Mine Sweepers, and investigations on various aspects of marine science were carried out at the Andhra University. Most of this work was, however, limited to the shelf and slope waters. These studies were reported in the Andhra University Memoirs in Oceanography Vol. I (1954) and Vol. II (1957) and some scientific journals. During this period, the studies carried out by other organisations in India were, the oceanographic measurements and hydrographic surveys by the new INS Investigator of the Naval Hydrographic Department, the work on tides by the Survey of India, the meteorological and current observations by the merchant vessels, the studies along the west coast of India, by the Indian Naval Physical Laboratory (established in 1952), the Oceanographic Research Wing of the Central Board of Geophysics (established in 1958) and the University of Kerala. The Central board of Geophysics was taken over by CSIR, and the Oceanographic Research Wing which became a part of the National Geophysical Research Institute in 1961, was merged with the Indian Ocean Expedition Directorate (CSIR), in 1963.

International Indian Ocean Expedition (IIOE):- Prior to the 1960's the Indian Ocean was the least known ocean among the world oceans, although some expeditions such as the British

Challenger (1873), the Danish Dana II (1928-1930), the John Murray (1933-34), on board the Egyptian vessel Mahabis, the Swedish Albatross (1947-48) and the Danish Galathea (1950-52) passed through the Indian Ocean and collected valuable information on the surface features of the Indian Ocean. Recognising this fact, the UNESCO and SCOR (Scientific Committee on Oceanic Research) embarked on a great expedition known as the International Indian Ocean Expedition (IIOE) during 1960-65 to study the Indian Ocean, with the participation of 20 countries and 40 oceanographic research vessels. India's venture into oceanographic research in its wider perspective covering all the basic branches such as physical, chemical, biological, geological and geophysical oceanography, had a real start with India's participation in this expedition. The Government of India set up the Indian National Committee on Oceanic Research (INCOR) under the chairmanship of late Dr. D.N. Wadia, in 1960, for planning and coordinating India's programme of IIOE. For implementing the Indian Programme, the Directorate of Indian Ocean Expedition was set up by the CSIR in 1962, with late Dr. N.K. Panikkar as its Director. With the support of UNESCO, the Indian Ocean Biological Centre (IOBC) was established in 1962, at Cochin, for study of zooplankton collected during the IIOE. Four ships from India participated in the Indian programme of IIOE. These were INS Kistna, of the Indian Navy, RV Varuna of the Indo-Norwegian Project, Cochin, RV Conch of the Kerala University and MPV Bangada. Bulk of the data were collected by INS Kistna, which had undertaken about 28 cruises during 1962-65. Several scientists from various organisations in the country participated in the programme.

Establishment of NIO:- A large amount of oceanographic data was collected during the IIOE from different parts of the Indian Ocean which helped in unravelling many features of the Indian Ocean. As a result of this expedition, the country became aware of oceanography and developed a team of trained young scientists by the time the expedition came to an end in December, 1965. And this expedition gave a firm base for the future oceanographic research in India. At the end of the expedition, the Indian National Committee on Oceanographic Research, strongly recommended that it

OCEANOGRAPHY

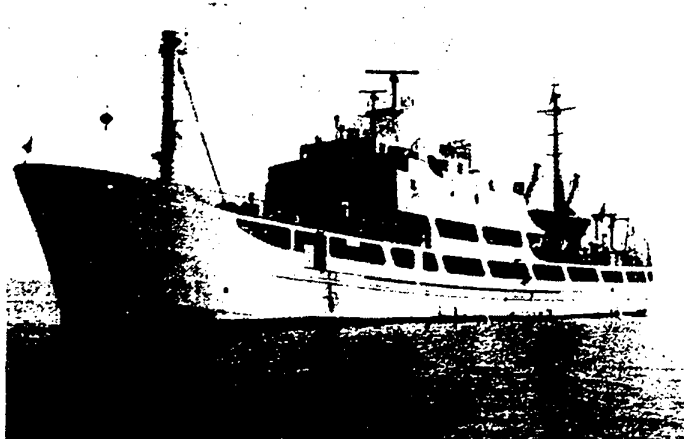


Photo.2 R.V. ⁵GAVESHANI, the first oceanographic vessel of India, commissioned in December, 1975.

would be in the national interest to consolidate the valuable experience gained from India's participation in the IIOE, and that an institute having the status of a national laboratory be established under the umbrella of CSIR. The Government of India agreed to this proposal and thus the National Institute of Oceanography (NIO) was established on 1 January, 1966, as one of the laboratories under CSIR, with its temporary headquarters in New Delhi. NIO took over all the activities of the Directorate of the Indian Ocean Expedition with late Dr.N.K. Panikkar, the father of modern oceanography in India, as its founder director. Over the years, NIO has grown into a sizeable organisation keeping the status of a premier institution dealing with oceanography in the country. It had its headquarters shifted to Goa in 1969. In addition to the headquarters at Goa, it has regional centres at Cochin, Bombay and Waltair. The IOBC, at Cochin was merged with the Regional Centre at Cochin. NIO has several divisions and sections dealing with different disciplines such as Physical Oceanography, Chemical Oceanography including Marine Pollution, Biological Oceanography, Geological and Geophysical Oceanography, Ocean Engineering, Marine Instrumentation, Biofouling, Planning, Data & Information, Publications etc.

Oceanographic research in India, during Dr.S.Z.Qasim's directorship of

NIO (1974-81), received an impetus with the commissioning of the Indian built first multidisciplinary oceanographic research vessel, RV Gaveshani of NIO (CSIR), on 31 December, 1975. This ship has been fitted with modern oceanographic equipment and is also provided with modern navigational and communication systems including the satellite navigation system for accurate position fixing. She has done a commendable job over the years and completed 185 cruises to-date and collected a large volume of data which have contributed a great deal to our knowledge of the seas around India. Prior to the commissioning of RV Gaveshani, an expedition was undertaken on board INS Darshak, in the North Arabian Sea, during 1973-74, and a good amount of oceanographic data was collected.

Department of Ocean Development (DOD):- Another landmark in the history of oceanography in India, was the setting up of the Department of Ocean Development (DOD), under the Government of India, in 1981, thanks to the foresight of the then Prime Minister late Shrimati Indira Gandhi. This has led to a quantum jump in oceanographic activities and allocation of funds for ocean research in India. NIO under the directorship of Dr.V.V.R.Varadachari (1981-85) undertook several major tasks and played a key role in organising annual expeditions to Antarctica,

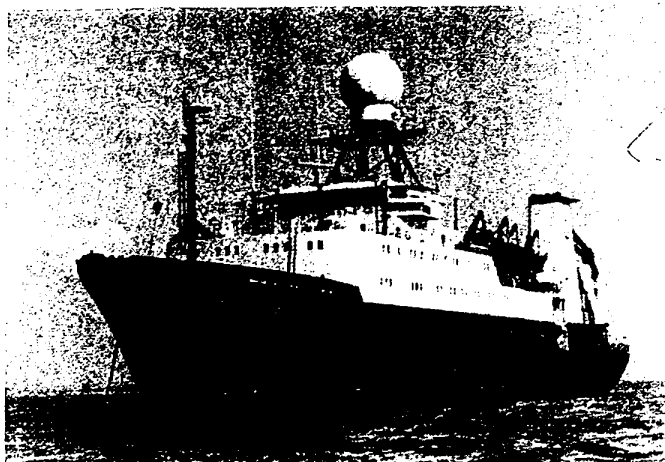


Photo.3 O.R.V. SAGAR KANYA, India's most sophisticated oceanographic vessel, commissioned in June, 1983.

exploration for manganese nodules in the Indian Ocean and development of large scientific and technical manpower, with the active support from Dr.G.S.Sidhu, the then DGSIR, and Dr.S.Z.Qasim, Secretary, DOD. In 1983, DOD acquired from the Federal Republic of Germany, a very sophisticated research vessel ORV Sagar Kanya which has the most modern oceanographic, navigational and communication equipment on board, and has an endurance of 45 days and berths for about 30 scientists. This research vessel has been entrusted to NIO (CSIR) for its scientific management. In 1985, DOD acquired from Denmark, a sophisticated fishery and oceanographic vessel, FORV Sagar Sampada. Being ice-strengthened, the vessel is well suited for India's research on Antarctic krill. The scientific management of this vessel has been entrusted to CMFRI, Cochin.

Other Organisations:- Besides NIO which has been playing a vital role in oceanographic Research in India, a few other institutions and Universities have been carrying out studies on the various aspects of oceanography. They are:
 Andhra University, Waltair,
 Anna Institute of Technology, Madras,
 Annamalai University, Port Novo,
 Berhampur University, Berhampur,
 Bhaba Atomic Research Centre, Bombay,
 Bharati Dasan University, Trichy,

Central Institute of Fisheries Technology, Cochin,
 Central Marine Fisheries Research Institute, Cochin,
 Central Salt and Marine Chemicals Research Institute, Bhavanagar,
 central Water and Power Research Station, Pune,
 Centre for Earth Science Studies, Trivandrum,
 Cochin University of Science & Technology, Cochin,
 Engineers India Ltd., New Delhi,
 Fisheries College, Mangalore,
 Fisheries College, Cochin,
 Fisheries Survey of India, Bombay,
 Geological Survey of India, Calcutta,
 Geodetic and Research Branch of Survey of India, Dehra Dun,
 Goa University, Goa,
 India Meteorological Department, Delhi,
 Indian Institute of Science, Bangalore,
 Indian Institute of Technology, Bombay,
 Indian Institute of Tropical Meteorology, Pune,
 Indian Institute of Technology, Madras,
 Indian Institute of Technology, Delhi,
 Jadavpur University, Calcutta,
 Karnatak University, Dharwad,
 Marathwada University, Aurangabad,
 National Geophysical Research Institute, Hyderabad,
 National Remote Sensing Agency, Hyderabad,
 Naval Physical & Oceanographic Laboratory, Cochin,

OCEANOGRAPHY

Physical Research Laboratory, Ahmedabad,
Rani Durgavati University, Jabalpur,
Shivaji University, Kolhapur,
Space Application Centre, Ahmedabad,
University of Calcutta, Calcutta,
University of Kerala, Trivandrum,

PHYSICAL OCEANOGRAPHY

Perhaps, the first significant research contribution in physical oceanography was the explanation of the colour of the sea by Sir C.V. Raman, in 1921. Dr.E.C. LaFond (USA), who visited the Andhra University during 1952-53 and 1955-'56, initiated active field programmes to study the physical characteristics of the shelf waters, especially the temperature and salinity distributions and their variability, water masses, circulation over the continental shelf, internal waves and the phenomenon of upwelling off the east coast of India. Another important area of research that was taken up relates to shoreline dynamics for understanding the sediment transport processes in the surf zone and the consequent shoreline morphology. Studies on sound velocity distribution and transparency of coastal waters were also initiated. At about the same time, CMFRI had initiated several surveys along the south west coast of India, the Laccadive Sea, and Gulf of Mannar, to study the physical, chemical and biological processes in relation to fisheries. Studies on microseisms, wave characteristics and thermal structure were initiated at the Indian Naval Physical Laboratory, Cochin.

Prior to the IIOE, very little information was available on the response of the Indian Ocean to the reversing wind systems, the structure of the equatorial currents, Somali current, water masses, distribution of temperature, salinity and other parameters, and the air-sea interaction processes. The results of the IIOE brought out significant information on these features for the first time. The horizontal and vertical distributions of temperature, salinity, dissolved oxygen and nutrients in the Indian Ocean were studied during the IIOE. The sources of various water masses in the North Indian Ocean have been identified, their transformation and spreading, broadly studied.

The data collected by the Indian ships during the IIOE, in the Arabian

Sea and the Bay of Bengal led to a better understanding of the coastal dynamics along the coasts of India, a better evaluation of the sinking and upwelling processes, identification of various water masses in the seas around India, and supporting evidence on the existence of an undercurrent in the equatorial region. An important outcome of the IIOE was an increased knowledge of the structure and dynamics of the Indian Summer Monsoon and the understanding that several processes taking place in the Indian Ocean, influence the monsoon.

Coastal Zone Management:- Soon after the IIOE, NIO was established and during the first few years after its inception, physical oceanographic work was mainly concentrated in the coastal and nearshore areas, including the estuaries. Coastal and nearshore oceanographic studies along the Kerala and Goa coasts have thrown considerable light on the processes and factors responsible for the erosion of some of the beaches in those areas and on the phenomenon of formation of mud banks along the Kerala coast. The studies have also revealed that the beaches of the Kerala coast are rather unstable as compared to the beaches of Goa which are fairly stable. Studies on longshore currents along the beaches have revealed the occurrence of rip currents at several points along the beaches. These currents cause danger to the swimmers in the surf zone. Studies on the hydrography of the coastal waters and estuaries brought out the characteristics of these water bodies and their seasonal variability. Studies on sediment transport in harbours and bays along the west coast, have been undertaken to tackle the problem of siltation. Developmental activities, such as harbours, power plants, oil terminals, hotels for tourism, and various industries are fast increasing along the Indian coastline. The most important development has been the offshore oil exploration and production in recent years. All these activities put a lot of pressure on the marine environment in the coastal areas. A fair knowledge of the marine environment is essential for managing the activities in the coastal areas. NIO has been catering to the needs of the industries, ONGC, Ports, State Governments etc., regarding coastal zone management and several investigations under research sponsored by these agencies have been

undertaken by the physical oceanographers. Apart from NIO, the Centre for Earth Science Studies, Cochin and the Universities of Andhra and Cochin have been contributing to the field of nearshore oceanography.

Physical Processes in the North Indian Ocean:- Using the IIOE data, NIO scientists studied the various physical processes taking place in the Indian Ocean, especially the north Indian Ocean. The broad features of the structure and pattern of the circulation at the surface and subsurface layers and the water characteristics of the Indian Ocean are known. However, there have been gaps in our knowledge of the various features in several areas. These gaps are being filled through the data acquisition by the ships RV Gaveshani and ORV Sagar Kanya. Prior to the commissioning of RV Gaveshani, a fairly comprehensive survey of the North Arabian Sea was carried out on board INS Darshak, during 1973-74. This survey collected valuable data and brought out several features of the North Arabian Sea hitherto unknown. The circulation, the thermohaline structure, the micro and fine structure, spreading of Persian Gulf water etc. were studied in detail using the data collected during the Darshak Expedition.

During 1973, an Indo-Soviet collaborative programme called ISMEX-'73, was organised, specifically to study the response of the northwestern Indian Ocean to the monsoon wind system and vice-versa. The studies on thermal structure of the sea revealed that the decrease in the Sea Surface Temperature (SST) was associated with a deepening of the surface layer. India participated in the Monsoon Experiment-1979 (MONEX-79) organised as a part of the First GARP Global Experiment (FGGE) and R.V. Gaveshani collected data in the east central Arabian Sea during the S.W. monsoon of 1979. This area was surveyed repeatedly in 1980 and 1981. The studies led to a better understanding of the Arabian Sea cooling with the advance of the S.W. monsoon. Ocean current shear instability across the thermocline has been recognised as one of the major processes (whereby cold subsurface waters are entrained in the surface layer), which causes the lowering of SST. A significant lowering of SST in the southwestern Arabian Sea, remarkable

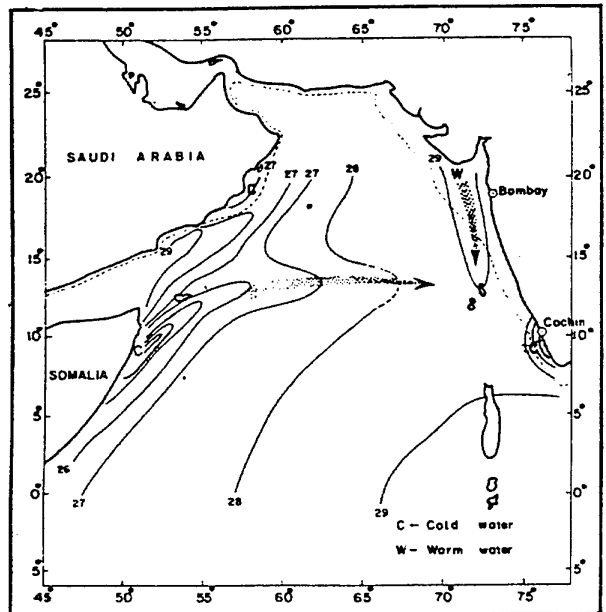


Fig.4 SST ($^{\circ}\text{C}$) distribution in the Arabian Sea during June-July 1973. A tongue of cold water from the Somali coast is seen extending towards the eastern Arabian Sea between 11 and 15 $^{\circ}\text{N}$.

changes in the thermal structure and circulation in the upper 500 m of the northwestern Indian Ocean with the advent of monsoon and a complex vertical structure of horizontal currents with westward jets at 200 m and 800 m depths near the equator are some of the other findings reported by NIO scientists from the monsoon studies. A recent review of the role of oceans on the Indian Summer Monsoon, has discussed the importance of some oceanic features on the monsoon over India.

Ocean Modelling:- Rational exploration of the marine resources call for model studies that will help us in understanding the oceanographic processes in the sea. Ocean modelling is a new field in which a few studies have been initiated at NIO recently. Studies are being carried out to develop prediction models of circulation and thermal structure and biological productivity of the north Indian Ocean and storm surges along the east coast of India. The studies on thermal structure would provide a capability to simulate the

thermal structure of the boundary layer of the ocean, which is very useful for naval operations and may help in the monsoon prediction. Prediction of storm surges will help in disaster warning and operations in the coastal and offshore regions. Surge characteristics along the east coast during different storms have been studied. A numerical model of the wind-driven circulation of the Bay of Bengal has been developed. A numerical mixed layer model has been used to study the temperature variability in the Arabian Sea. A model simulating an oil spill on the sea surface has been developed incorporating variables such as wind, currents, spreading and evaporation. Theoretical studies have been carried out on the scattering of Rossby and Poincare waves from a stochastically rough coastline using a group theoretical argument. An analysis of linear and polygonal arrays has been carried out for wave direction determination with simulated sinusoidal wave trains.

Ocean Remote Sensing:- When the space-time variability of the oceanographic parameters is needed, the conventional methods of collecting data on board ships become inadequate, laborious and time consuming. With the advent of remote sensing techniques via satellites and aircraft, collection of data on surface parameters simultaneously over a large area became possible. Realising the importance of remote sensing applications in oceanography, studies in this area have been initiated at NIO, in collaboration with the Indian Space Research Organisation (ISRO). Some of the activities that are being carried out in this area at NIO are: (i) studies on the use of microwave data (especially from the satellite microwave radiometer on Bhaskara-II) for determination of sea surface winds and wave heights (ii) Study of upwelling along the southwest coast of India and its relation to the productivity of these waters using remote sensing techniques coupled with insitu observations (iii) Study of satellite derived SST variations in the Indian Ocean in relation to the monsoon and (iv) Studies on optical properties of sea water and applications of the results in remote sensing of parameters like chlorophyll concentration, suspended sediment load and water clarity.

Ocean Acoustic Tomography:- The remote sensing techniques have certain limitations. The large attenuation of electromagnetic radiation in water is the major limitation of the techniques to probe the interior of the ocean. In this context Ocean Acoustic Tomography is emerging as a new technique to collect information about the ocean interior on a synoptic scale. Through this technique, it is possible to sample large oceanic areas in a few minutes by suitably installing a network of low frequency sound transmitters and receivers. The sound signals received by the receiver can be analysed and interpreted for deriving information on temperature, salinity, and pressure of the water body through which the signals pass. Reconnaissance surveys have been carried out in the Bay of Bengal and investigations undertaken to study the variability of the sound velocity structures and hydrographic conditions in the Bay of Bengal. Studies in this new area have been initiated at NIO in collaboration with some other organisations (NPOL, NPL, NGRI, IISC, etc.) in the country, to develop the various components and establish an acoustic tomographic system for the northern Indian Ocean.

CHEMICAL OCEANOGRAPHY

During the beginning of the oceanographic era in India, chemical oceanography played a role supplementary to the other disciplines of oceanography, namely, physical, biological and geological. Nutrients and oxygen were the parameters mostly studied. These parameters found their application in the study of water masses, productivity, mineral formation etc. However this trend has gradually changed over the years and chemical oceanography emerged as an independent discipline. Before the 1960's, the studies were confined mostly to coastal waters. During the IOOE, studies were carried out on oxygen, nutrients and other chemical parameters in the North Indian Ocean. In the 70's the area of coverage of chemical oceanography increased significantly. The acquisition of research vessels Gaveshani and Sagar Kanya facilitated regular studies on the various chemical parameters in the Indian waters. The first Indian Antarctic Expedition yielded valuable chemical data on the Southern Indian Ocean. These

studies have been pursued during the subsequent expeditions.

At present, the topics covered under chemical oceanography are major and minor ion chemistry in sea water, chemical behaviour of ions in the various Indian estuaries, aerosol chemistry, chemical properties of various water masses and marine pollution. The most recent studies cover aspects such as speciation of elements in the sea, theoretical studies on seawater, chemical composition and studies on the sediment-seawater interaction. Another significant aspect being covered in recent years is the study of the carbon dioxide system in the North Indian Ocean and the fixation of the excess carbon dioxide generated due to fossil fuel combustion, by marine biota.

In addition to NIO, scientists at PRL, Ahmedabad, have also been working on the chemistry of seawater and sediments using radio active methods. Other organisations like CMFRI, Universities of Cochin, Andhra, Annamalai, Kerala, etc. have also been contributing significantly to the studies in chemical oceanography.

Fertility of the Seas around India:-

The availability of living and non-living resources in the sea, largely depend upon different cycles of chemical constituents present in the sea water and sediments. The inorganic substances required by plants, called plant nutrients, constitute the raw materials out of which the plants, with the aid of sunlight build up organic components. NIO has carried out studies in the seas around India to evaluate the distribution of the nutrients, and their variability and to demarcate the areas of potential fertility. Besides, studies on trace metals and their interrelationship with other physico-chemical parameters and studies on the cycles of phosphorous, nitrogen compounds and some biologically active trace metals in the estuarine, inshore and offshore waters along the coasts of India, are also being carried out.

Studies have revealed that a thick oxygen minimum layer from 300 to 1000 m is present in the North Indian Ocean, especially in the Arabian Sea. About 35% of the available nitrate-nitrogen in the depth range of 75-1200 m, in the Arabian

Sea, appears to be depleted due to denitrification. The mean residence time of the water mass in the depth interval of denitrification in the Arabian sea has been found to be in the range of 13 to 54 years. The distribution of nitrate is characterised by large spatial and temporal variations. The thick oxygen-deficient layer in the Arabian Sea and Bay of Bengal has a labile character. The turnover time of this water mass between 600 and 1000 m depth has been calculated as around 4 years. These results have immense significance in marine pollution mechanism indicating the possibility of intermediate water turning completely anoxic either due to pollution or due to climatic changes which may have a serious impact on the ecosystem.

Marine Pollution Studies:- Studies on the protection of the marine environment and monitoring of marine pollutants in the seas around India were initiated in 1975 at the National Institute of Oceanography. Since then a lot of work has been carried out in ascertaining the health of the seas around India. The need for such an investigation had arisen because of the vast potential of marine living resources being confined to the coastal areas of India and the effect that any indigenous or man-made changes could have on these resources. India has a coastline of about 6000 km. Nearly 170 million people of India or roughly about 25% of the total population, live in the coastal areas and depend directly or indirectly on the coastal marine resources and in turn generate and add to the sea to the tune of 3.7 km³ of sewage in these areas annually. The industrial wastes, both coastal and inland, going into the coastal waters have been estimated to be about 0.37 km³ and the solid wastes generated by coastal population, about 2.5 million tonnes, annually. In addition to this about 20,000 and 30,000 tonnes of pesticides and detergents, respectively, are added to the sea every year. The rivers bring in additional quantities of wastes to the coastal waters. Apart from this, the Arabian Sea and the southern Bay of Bengal are important sea routes for most of the oil moving from the Gulf to the far east as well as to the West and thus vulnerable to oil discharges either accidentally or on account of routine shipping activities. In 1983, 291 and 222 million tonnes of oil and

OCEANOGRAPHY

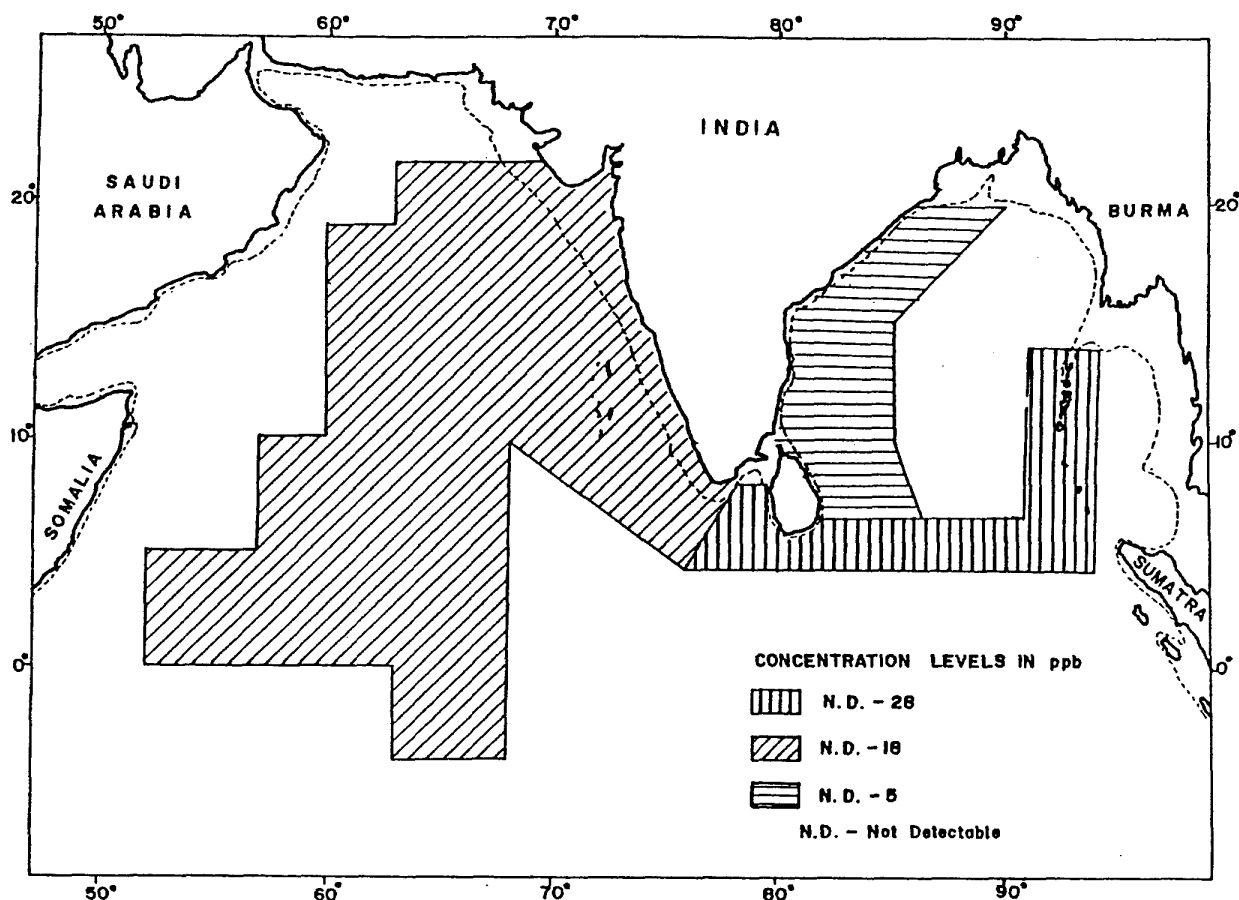


Fig.5 Dissolved petroleum residues in the Indian Ocean.

its products respectively, were transported across these two tanker routes. Such enormous additions to these waters endanger the marine living resources of these areas. Several investigations were undertaken in recent years to study and establish the effects of these additions and to suggest remedial measures. These are: (i) Dissolved and dispersed petroleum hydrocarbons in various segments of marine environment, their fate and effects, (ii) Toxic and non-toxic heavy metals in various segments of the marine environment, their fate and effects, (iii) Pesticides, their occurrence in various segments of the marine environment and their fate and effects, (iv) Investigations carried out at the request of sponsoring public and private sector organisations on matters

pertaining to the disposal of industrial and domestic effluents, collection of baseline data, and testing of their products with respect to their environmental safety.

NIO has played a pioneering role in studies on "oil pollution" and has identified the sources and determined levels of petroleum hydrocarbons in the marine environment and more specifically along the oil tanker routes. Apart from the levels of dissolved/ dispersed hydrocarbons in these areas, the presence and distribution of tarry lumps on the sea surface and on the beaches along the coast were also monitored regularly. The data obtained so far suggests levels of petroleum hydrocarbons in the Arabian Sea and along the oil tanker routes, higher than

on the east coast and the Bay of Bengal. Similarly the deposition of tarry lumps on the beaches of the west coast is much higher than on the east coast beaches. NIO evolved a prediction model for the movement of an oil spill originating from the Bombay High region based on the current pattern and wind for different periods of the year and carried out investigations, for ONGC, in combating and successfully dealing with an accidental blow out in the sea off Bombay in collaboration with the Coast Guard. Apart from this, several dispersants were experimentally tested for their efficiency in removing oil and for their environmental safety.

Another field of investigation where NIO has been actively involved is the heavy metal pollution whereby all segments of the marine environment have been investigated for the presence of toxic and non-toxic metals. These investigations cover almost all the areas of the Arabian Sea and the Bay of Bengal including portions of the equatorial region of the northern Indian Ocean. The levels of toxic metals such as mercury, cadmium and lead in marine organisms as possible sources of metals being transferred to human beings, indicate that there is no cause for anxiety as the levels of these toxic metals in edible portions of fish and other marine products are very much below the maximum levels for fish products, specified by WHO, for human consumption. However, the presence of certain elements is noticed in coastal waters and sediments which calls for a regulated monitoring programme to be initiated. Analysis of some zooplankton samples for certain chlorinated pesticides such as DDT etc., have shown high levels.

Several projects carried out for the sponsoring agencies such as the Central Water Pollution Board, ONGC, Regional Water Pollution Boards, Municipal Bodies, Private and Public sector industries, relate to problems associated with the disposal of industrial and domestic effluents in the sea, environmental characteristics of certain estuarine and coastal areas and assessment of the effects on the coastal environment.

Organic Chemicals from the Sea:- The utilisation of the vast marine resources

as raw material for potent and safe drugs and pharmaceuticals, is of recent origin. In order to tap these resources, a research project was initiated at NIO, in 1978, in collaboration with the Central Drug Research Institute, Lucknow.

Several marine organisms have been screened over a wide spectrum of biological activity and some of them have exhibited promising results, the most remarkable activity being the antifertility activity exhibited by some corals and seaweed species. Other activities observed are antiviral, CNS stimulant, hypotensive, spasmogenic, spasmolytic, diuretic, analgesic and toxic. Based on the preliminary screening results, some of the organisms have been taken up for detailed chemical investigations. These include a) antifertility activity: Porites sp., Accantophora specifera, Gelidiella acerosa, Padina tetrastrumatica, b) highly toxic: Gemmaria sp., c) potent diuretic activity: Hypnea musciformis, d) highly potent analgesic activity: Acanthus illicifolius and e) antiviral activity: Codium elongatum. The chemical investigations of the above organisms led to the isolation of several types of steroids, fatty acids and their esters, diterpenes and halocompounds. These studies have shown that four species of marine algae which exhibit antifertility activity may also contain prostaglandins (the substances which are known to play a major role in controlling the biological reproduction). These findings when confirmed will open up new replenishable sources of prostaglandins for commercial exploitation.

Studies have also led to isolation of good quantities of steroids from corals and seaweeds which may serve as commercial sources of steroids and useful hormones. Studies on the brown seaweed Hypnea musciformis, found along the Goa coast, have shown that it is a good source of carrageenan, a sulphated polysaccharide of commercial importance. Antiinflammatory tests have indicated that the carrageenan isolated from the Indian seaweed is comparable with the imported variety.

GEOLOGICAL AND GEOPHYSICAL OCEANOGRAPHY

Although some bathymetric surveys of the Indian coastal waters were begun in 1832, systematic marine geological

OCEANOGRAPHY

research in India started only in the 1950's, at the Andhra University. The studies include variations in the topography of the Bay of Bengal, especially the continental shelf, the Ganges submarine canyon, the nature of sediments of the shelf, river deltas and beaches, the concentration and distribution of heavy mineral sands, annual cycles of beach erosion and the littoral drifts of sand on the east coast. India's participation in IIOE gave an impetus to marine geology in the country, and several submarine canyons were charted along the east coast of India. Sediment characteristics and some geochemical studies at selected locations along the coast were studied during this period by the scientists of the IIOE Directorate, Geological Survey of India, BARC, TIFR etc. The establishment of a full fledged geological oceanography division in the late sixties led to a comprehensive programme of study of geology, geophysics, geochemistry, palaeoclimatology and the mineral potential of the seas around India. In 1981, when a team of scientists with Dr.S.Z.Qasim, the then Director of NIO as chief scientist on board RV Gaveshani, scooped some manganese nodules from the Arabian sea, a new era began in the exploration of minerals from the Indian ocean. And now, India has a high status among the countries of the world who ventured exploration of the deep sea minerals. The work carried out in the country in marine geology, geophysics and geochemistry during the last three decades brought out some significant results.

Placer Deposits:- The country's coastline is gifted with the presence of minerals and beach placer deposits such as ilmenite, monozite, magnetite, etc. As a part of the programme of study on the extension of these deposits into the offshore areas, extensive surveys were carried out along the Konkan coast. It has been established that sands rich in heavy minerals extend to a distance of 2-5 km offshore to a water depth of 10-13 m. In the area surveyed off Ratnagiri, the sands containing heavy minerals cover an area of about 96 sq km with an average ilmenite concentration of 10% and the ilmenite resources have been estimated to be of the order of 12.5 million tonnes in the upper 1 m layer. But the seismic profiles show

2-10 m thick sand layers which extend to a water depth of 20 m over a large area promising larger reserves.

Regional Geological Studies:- The bathymetric and high resolution seismic reflection profiles covering the shelf and slope region from Dwaraka to Cochin revealed interesting features. The continental shelf break occurs between 90 and 145 m water depth. The inner shelf is largely characterised by even and gently sloping topography and carpeted by recent clays. The even topography extends upto 130 m water depth in the shelf off Mangrol-Dwaraka, while it is confined to 50 m depth in the far south. Seismic reflection profiles show 10 to 40 m thick acoustically transparent sediments on the inner shelf. The thickness of these surficial sediments decreases offshore and the underlying relict sands are exposed on the outer shelf. The continental shelf off Bombay is marked by a prominent ridge while off Mangrol-Dwaraka, it is characterised by rugged topography and steep gradients. Ancient coastlines, palaeochannels and submarine terraces have been recognised in this shelf region. These are the possible sites of deposition of placer minerals during the geological past.

Sedimentology:- Sedimentological maps have been prepared for the west coast of India. Such maps are pre-requisites for offshore mineral exploration and sea bed engineering projects. Some important features are: (i) the inner shelf region is covered by fine grained terrigenous silty clays and clayey silts and (ii) the outer shelf upto the shelf edge is carpeted by coarse sands which are found to be relict in nature.

Sedimentological studies in the Gulf of Kutch have resulted in the discovery of the phenomenon of the 'dynamic barrier' associated with the strong currents off the gulf and the fact that the sediment input to the gulf is from the open sea. The implication of these results is that these processes play a decisive role in favouring the Gulf of Kutch for tidal power generation. Palaeoclimatic studies based on the nature, age and composition of the western shelf sediments have provided an evidence that the climate about 10,000 years ago in the peninsular India, was semi-arid and that the change over from semi-arid to the present moist condition

was geologically 'sudden' and associated with a low sea level, about 90 m below the present sea level.

Geophysical Studies:- Geophysical studies on the western shelf and slope have been carried out to understand the magnetic and gravity signatures of the Arabian sea and the subsurface formations. About 50,000 lkm of magnetics and 19,000 lkm of gravity and 5,500 lkm of multichannel seismic data were collected. Magnetic data revealed the following features: The WNW-ESE trending faults off Saurashtra, represent the northern boundary fault of the Narmada rift graben. The depth of the basement varies from 1 to 5 km. Positive and negative anomalies off Bombay revealed areas of late Cretaceous/early tertiary fissure eruptions and Pre-Cambrian granitic gneisses respectively. The studies indicate that the sediment thickness is 1.4 to 5 km on the continental shelf off Bombay and the continental type crust of this area bounded by faults subsided into the Arabian sea due to basement faulting as a consequence of sea floor spreading in the west and subsequent sedimentation. A high frequency anomalous zone exists off Konkan, indicating extensions of basalts/ submerged promontories. Off Devgarh and Goa, low frequency anomalous zones are encountered indicating probable fissure eruptions/tectonic activity. Off Karwar, a NNW-SSE trending basement ridge composed of basaltic/ charnockite type rock, seems to lie parallel to the shelf edge. Deeper and shallow basalts are reported off Udipi and basalts are likely to be at 4 km depth off Mangalore and Malpe.

Gravity survey conducted between Devgarh and Karwar has revealed that the midshelf is characterised by the horst structures flanked by the grabens on both sides. The outershelf is characterised by a predominantly high gravity zone. Multichannel seismic data has revealed that the acoustic basement in the shelf margin basin widens and deepens towards the south along the west coast and is overlain by about 2 km thick sedimentary sequence. The Laccadive ridge system is characterised by a generally raised acoustic basement mantled by transparent sediments and its morphology is governed at some places by steep scraps and at others by volcanic

intrusives. The studies indicate that the basement underneath the shelf margin basin is a crust of continental type. Studies carried out over the north-eastern flank of Mount Error in the northwestern Indian ocean have revealed a weakly magnetised igneous basement of continental origin situated at shallow depths.

Geochemical Studies:- Geochemical studies along the west coast of India have been carried out to understand the distribution and the process of incorporation of the various major and trace elements into the sediments and to demarcate the possible areas for future exploration. Maps depicting the distribution of CaCO_3 , Al, Fe, Ti, P_2O_5 , Mn, Ni, Cu, Zn etc have been prepared for the west coast of India. Some of the salient features are: (i) The distribution pattern of CaCO_3 suggests that there had been a major difference in the sedimentation pattern during the Holocene period in the regions north and south of Mangalore. The northern region received very little detrital material compared to the southern region. (ii) Elevated levels of organic carbon (upto 12%) mostly of planktonic origin in the sediments of the slope regions between Bombay and Quilon, presence of reducing conditions and occurrence of thick sediments suggest that these sediments can act as source beds for petroleum. (iii) High concentrations of phosphate in the sediments of the outershelf and slope regions between Bombay and Quilon, indicate need for detailed exploration for phosphate deposits in these regions. All the elements, in the sediment have both lithogenous and non-lithogenous components.

In the field of geochemistry, PRL, Ahmedabad, has also been contributing substantially.

Exploration for Manganese Nodules :-

Though the country exports at present a substantial quantity of manganese, the resources are insufficient to meet the growing demand. Also, a large part of the demand for copper and almost the entire requirements of nickel and cobalt are met from imports. The imports are expected to grow further. In view of the future requirements and the longterm international implications, the project on polymetallic nodules was given a top priority. The nodules cover a large area

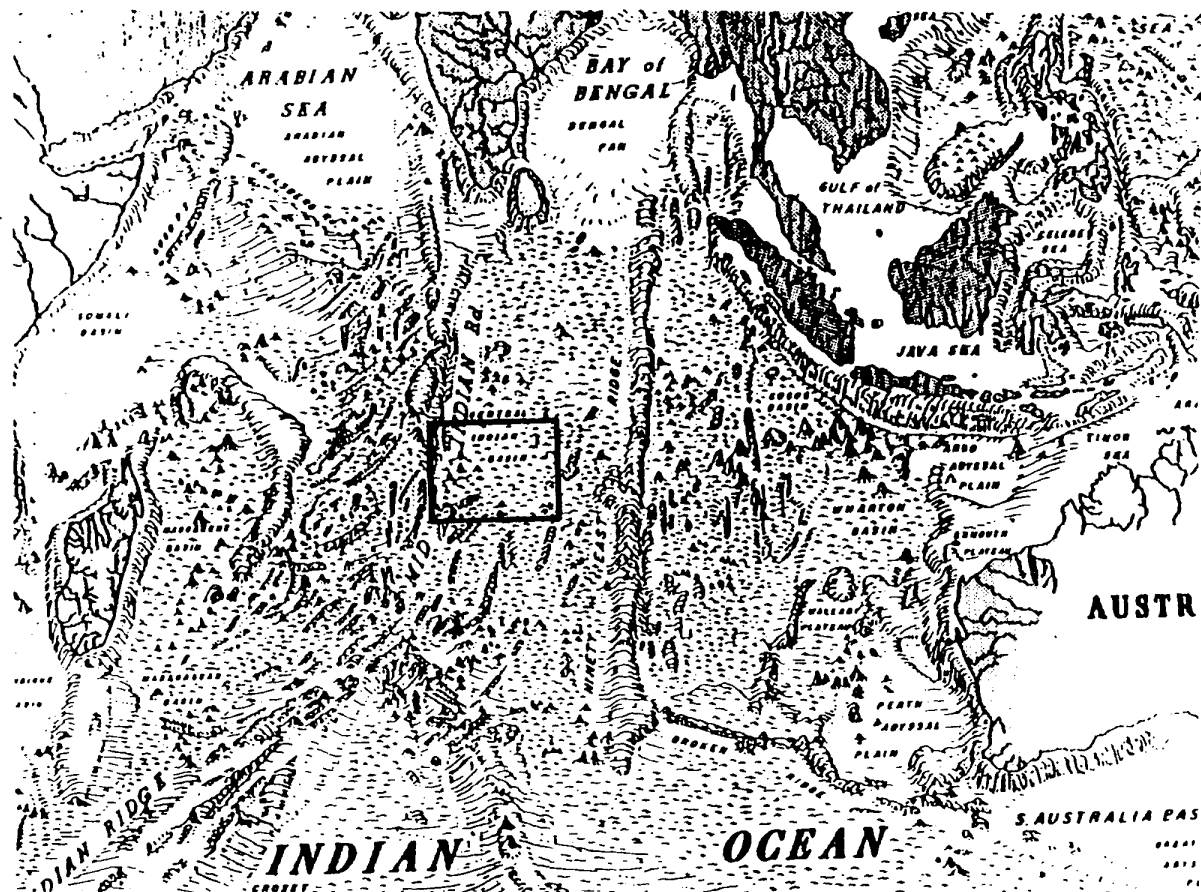


Fig.6 India's Application Area for Polymetallic Nodules in the Indian Ocean.

of sea-bed over 5 km deep in the world oceans, spread over an area of about 46 million sq km. The total resources are estimated at 1.7 to 3 trillion tonnes. The area covered by the nodules in the Indian ocean is about 10 to 15 million sq km and the resources are estimated at over a billion tonnes. The nodules contain enough quantities of manganese, nickel, copper and cobalt to be economically attractive.

India became the first developing country to collect polymetallic nodules from the sea-bed in January 1981, when NIO scientists achieved this feat on a cruise on RV *Gaveshani*, an event which had a profound impact, both in India and abroad. The success of the first cruise generated considerable enthusiasm and the programme was accelerated. This led

to the recognition of India as a 'Pioneer Investor' at the Law of the Sea Conference in April, 1982, where India was the only developing country among the 8 countries and consortia to be accorded this status. As Pioneer Investor, India had to demarcate its 'Application Area'.

The work on polymetallic nodules involved subjects ranging from exploration to mining and metallurgy, cutting across diverse disciplines. The CSIR, therefore, planned from the very initial stages, to utilise its chain of laboratories (NIO, Regional Research Laboratory, Bhubaneswar, National Metallurgical Laboratory, National Geophysical Research Institute etc.) and the infrastructure developed over the last three decades. In order to

accelerate the surveys and meet the stipulated time targets, besides RV Gaveshani, and ORV Sagar Kanya, three additional vessels with necessary equipment for surveys were chartered from the international market, by the Department of Ocean Development, Govt. of India, who amply funded the survey. These vessels carried out a number of cruises and surveyed an area of over 4 lakh sq km in the central Indian Ocean, about 2,000 km away from Cape Camorin. The area surveyed is almost equal to the land area of the country.

Within the short time available before the target date, not only has the project been able to demarcate the Application Area of 300,000 sq km in the central Indian Ocean basin (Fig.6), but has also identified the metallurgical routes and RRL-Bhubaneswar produced the first samples of pure metals, although in small quantities- a task which has taken some of the developed countries a much longer time. The total estimated quantity of the nodules in the areas surveyed, is 1335 million tonnes. The metal content (Cu+Ni+Co) is about 21.84 million tonnes.

Now, India has become the first country in the world to get registration as a 'Pioneer Investor' at the U.N. Preparatory Commission for the International Sea-Bed Authority and certain rights for exploitation of the nodules from the pioneer area of 150,000 sq. km in the central Indian Ocean. This recognition for India was possible mainly due to the dedicated work of a team of scientists of NIO under the leadership of late Dr.H.N.Siddiquie, Head of the Geology Division (1973-85) and Director, NIO (1985-86) and due to the firm support extended for the extensive survey of polymetallic nodules in the Indian Ocean, by CSIR, DOD, and the Prime Minister of India.

BIOLOGICAL OCEANOGRAPHY

The beginning of marine biological research can be traced back to 1871 when an officer of the Indian Museum, Dr.J. Wood Mason was sent to Andamans to explore the fauna and flora of the region. He was perhaps the first person to carry out biological oceanographic work in deeper waters of the Andaman sea on board S.S. Undaunted. As mentioned earlier Marine Survey of India was

established soon after. This was the time (1873) H.M.S. Challenger sailed on her voyage through the world oceans. Perhaps, stimulated by the success of H.M.S. Challenger and under the persuasion of the Royal Asiatic Society of Bengal, the Govt. of India appointed Dr.J. Armstrong as surgeon - naturalist in 1875, to carry out work in Indian waters, similar to that carried out by the Challenger. At the request of the Govt. of India, the Admiralty agreed to give some of the equipment used on board Challenger for their use on Investigator I. These largely included biological collections, although occasionally observations on sea water temperature and bottom deposits were also made. Due to the first world war, the work was temporarily suspended from 1914 to 1921. However, the surveys carried out, under the leadership of Col.R.B.S Sewell, a surgeon-naturalist, in the Arabian sea, Bay of Bengal, Andaman and Lacadive seas revealed a wealth of knowledge on marine plants and animals in these waters off the Indian coast, which were described in the publications of the Royal Asiatic Society of Bengal.

After India attained independence, the need for maximum utilization of the living resources in the seas around India was realised. CMFRI was established in 1947 to carry out the work related to fish and fisheries. Thus began a systematic approach towards marine biological research in India. In the later years, a few more institutes namely Central Institute of Fisheries Technology, Cochin, Central Institute of Fisheries Operatives (renamed as Central Institute of Nautical Engineering and Training, (CIFNET)), Central Institute of Fisheries Education, Bombay, Fisheries survey of India, etc., were established for the development of marine fisheries research in India. The contributions of these institutions and the Universities of Annamalai, Andhra, Cochin, Karnatak, Kerala etc., in the fields of biological oceanography, fisheries and aquaculture are commendable.

Biological oceanographic studies received an impetus when the Indian Ocean Biological Centre started functioning for sorting out the zooplankton samples collected during the IIOE. This centre later became a part of NIO. The work carried out at this centre

was commendable and for the first time distribution of different species of zooplankton in the Indian ocean were studied and the results published in the form of Atlases. This centre combined with the group working on International Biological Programme later became the Biological Oceanography Division. The horizon of biological oceanography which mainly dealt with the distribution of organisms in time and space, and their ecological interactions with each other in the food chain and with the environment, has been extended to include experimental biochemistry, physiography, microbiology, marine plants and aquaculture, by 1970.

Primary Productivity Studies:- In an ecosystem a vast array of microscopic plants viz. phytoplankton, constitute the primary producers, which are the first link in the food chain. Studies on primary producers are undertaken to evaluate the capacity of an ecosystem to build at the expense of external energy, both radiant and chemical, and primary organic compounds of high chemical potential for further transformation and flow to higher levels. The fertility and productivity potential of different ecosystems like estuaries, backwaters, neritic and oceanic regions have been studied at NIO in order to assess the potential fishing grounds. Also this information is required for systematic marine farming, fish breeding, culture and similar activities in the marine environment.

Of the total Exclusive Economic Zone of about 2 million sq km, the studies on primary production have so far been carried out over 50% of the area. These studies have revealed that certain areas such as the southwest coast, followed by the central and northwest coasts of India are highly productive. Northern Bay of Bengal is relatively more productive than the rest of the east coast. Both the Andaman and Laccadive regions are found to be less productive than the west coast of India. In general, the coastal waters are more productive than the oceanic regions because the availability of the nutrients is more in the coastal waters.

Investigations on the estuaries and backwaters have shown that the Mandovi-Zuari estuarine complex is more productive than the Cochin backwaters of

the west coast and the Vellar - Coleron estuary on the east coast of India. Some studies have been carried out on the occurrence of 'Red Tide' phenomenon on the west coast of India. 'Red Tide' is formed due to the bloom of certain phytoplankton, especially dino-flagellates. Certain 'Red Tide' forming algae are highly toxic and cause large scale fish mortality.

Secondary Production:- Zooplankton play an important role in the energy transfer at secondary level. They feed on phytoplankton and in turn form the major food item for the fish, particularly the fish larvae. The main energy pathways in the open ocean are phytoplankton > zooplankton > fish. Hence, plankton rich places indicate better fishery potential, especially the pelagic fishery. The zooplankton standing stocks are the index of ocean fertility. The investigations carried out by NIO during the last few years show that the west coast of India is more productive than the east coast. The southwest coast of India is a region of high zooplankton production owing to replenishment of nutrients in the surface layers through strong upwelling. The studies indicate that the north and northeastern Arabian sea is also a region of high zooplankton production. Along the east coast of India, the zooplankton production shows an increase towards the south. The south western region of the Bay of Bengal supports high zooplankton standing stocks.

Studies on the breeding periodicity of commercially important species of prawns have also been carried out on the basis of occurrence of their larvae in zooplankton. The peak breeding periods of different species in the coastal waters of Goa are, January - February and April - May.

Benthic Studies:- Benthos include all the bottom and nearbottom dwelling organisms, both plants and animals, including different biotopes extending from high tide mark to the deepest parts of the ocean. Studies on benthos of the Indian ocean are of recent origin and are carried out by NIO, and the results obtained are used for the assessment of exportable fishery resources, development of sea farming, protection of marine environment etc.



Photo.7 Mussel culture on ropes - a technique developed by N.I.O.

Quantitative studies on the benthos showed that the annual mean biomass productions in the Arabian sea, Andaman sea, Bay of Bengal and the Lakshadweep sea are 7.6, 7.3, 5.5 and 0.7 g/m² respectively. The continental shelf produces maximum biomass and the production decreases with increasing depth. Maximum production has been observed along the south west coast of India. Northwest Arabian sea and the northern Bay of Bengal are also areas of high benthic production. Studies on deep sea benthos in the central Indian ocean indicate that in spite of great depths, the production is uniformly high with vast potential for organisms with bioactive substances.

The potential demersal fishery resources from the continental shelf of India, based on the benthic production, is estimated to be 1.8 millions tonnes/year as against the exploited catch of 0.4 million tonnes/year.

Aquaculture:- Aquaculture or sea farming, of commercially important marine organisms, has been recognised as a way to generate more sea food resources and to guarantee steady supply of sea foods. It is estimated that India has a potential area of 1.711 million hectares of nearshore land area suitable for commercial aquaculture. However, only less than 30,000 hectares are being currently used for traditional sea

farming practices. Several commercially important species of shrimps, lobsters, crabs, fishes, oysters, mussels, clams and sea weeds are ideal candidates for sea farming. Some studies conducted on the techno-economic feasibility have provided encouraging results.

Sea farming of green mussels, on ropes suspended from raft, a technology developed by NIO, yields 2-3 crops/year and a profit of 181%. This technology has been demonstrated to fishermen in Goa. One of the major bottlenecks in the development of shrimp culture is the scarcity of seeds. At the same time, large quantities of shrimp seeds/ juveniles are destroyed by certain groups of fishermen engaged in the capture of juvenile prawns, for their sustenance. A technology developed at NIO is available for helping in retrieving the juvenile catch alive so that they could be utilised as seed for shrimp culture. Applying modern scientific principles of ecology and aquaculture, NIO has developed an improved technology of traditional paddyfield prawn culture in Kerala. A technique developed for short-term high density farming of prawns helps in having two harvests a year instead of a single harvest in the traditional manner. The improved technique has enhanced not only the quality of prawns but also the annual yield (1000-1750 kg/ha as against 600-800 kg/ha by

traditional methods). A technoeconomically feasible method for the commercial scale production of a brineshrimp, *Artemia* (a feed organism), has been developed at NIO

Marine Microbiological Studies:- This is a branch of marine science which deals with microscopic organisms such as bacteria, yeast, fungi, microflagellates, blue-green algae and allied microbes which are widely distributed in the sea and significantly contributing to the biological and geochemical aspects. This area of study has been promoted to a realistic scale only in the late 70's. The following are some of the significant results of the work carried out at NIO. (i) The occurrence and distribution of pathogenic bacteria in the nearshore and offshore areas have been studied. This has far reaching effects on the future prospects of aquaculture and export of marine fish products. (ii) Several metal tolerating/concentrating bacteria from the sea have been isolated. These strains, may be used for microbial leaching of minerals, ores or bioconcentration of metals from industrial effluents. (iii) A number of nitrogen fixing and phosphate solubilising bacteria have been isolated from marine environment, which could be effectively used as "biofertilizers" for saline agricultural lands. (iv) Several pathogens of sea weeds, algae and diatoms have been isolated and identified. These pathogens are important not only in the natural ecosystem affecting the standing crop but also in the aquaculture system. (v) Several true marine fungi from Indian seas have been brought under pure culture in the laboratory for the first time. Some fungal parasites were recorded from various species of algae from the tropical waters.

Sea Weeds and Mangroves:- Marine algae form one of the most economically important plant resources which are being used in several countries for food, feed, fertilizer, drugs and industrial products like agar, alginates, carrageenan etc. From the sea weed survey carried out along the Indian coast, it has been estimated that the inter tidal area alone can be harvested to yield about 100,000 tonnes/year. Although in India, marine algae are not widely used as in Japan, the species in Indian waters have been found to contain proteins, carbohydrates, trace metals

etc. Some of the species have been proved to have bioactive compounds which can be used for producing drugs. The methodologies for sea weed cultivation are being standardised at NIO, and the cultivation of some species has been initiated along the Indian coast.

Mangroves which grow mostly in brackish waters constitute a typical tropical ecosystem. About 700,000 ha along the Indian coast are covered by mangrove forests. NIO has been actively working on the various aspects of the mangroves. The mangrove swamps are highly productive areas because of the presence of detritus and they can be used for aquaculture purposes. These are the best spawning, breeding and nursery grounds for several organisms.

Marine Biofouling:- The increase in offshore activity necessitated detailed studies on biodeterioration of materials in the marine environment, although work in this field has been going on at various places in India for the last few decades. Some of the institutions which have been working in this field are, the Naval Chemical and Metallurgical Laboratory (NCML), Bombay, Centres of Wood Preservations Scheme of the Forest Research Institute, Dehradun, the Central Institute of Fisheries Technology, Cochin, etc.

A programme for studies on deterioration of materials in estuarine, nearshore and offshore environments has been undertaken at NIO, since 1980. Studies on coastal ships and barges have indicated that the operational cost of the vessels due to marine growth or fouling increases by 25% within 6 to 8 months. Biofouling studies conducted on ORV Sagar Kanya have shown that the fuel consumption has increased by 35%, speed has been reduced by 6 knots and the ship time has been increased by 4 hrs/300 nautical miles, within a period of about one year, due to the fouling on the hull.

MARINE INSTRUMENTATION

In the past, almost all the instruments used for oceanographic research in India used to be imported from developed countries. There were problems of import and difficulties in servicing and maintenance due to the nonavailability of spare parts. Therefore, it became imperative to initiate indigenous design and

development of oceanographic instruments in the country. With this in view, a marine instrumentation group was formed at NIO in the 70's. Now a full fledged division has been functioning at NIO and efforts are underway to attain self sufficiency in this field as far as possible. Several instruments have been developed indigenously, processes released and patents filed.

Some of the patents filed are: (i) Current controlled inductive transducer and associated electronic circuit, (ii) Digital transmission meter for the measurement of turbidity of a fluid, (iii) Mechanical adapter to improve the efficiency of a water sampler (iv) Digital dampometer used in the measurement of logarithmic decrement and (v) Improved rotating cup anemometer. Some of the processes released are: (i) Tide and wave telemetry, (ii) Rotor induction current meter, (iii) Tide and wave recorder and (iv) In situ temperature and salinity meter.

Some of the instruments developed recently, at NIO, are: (i) Current meter model 1, (ii) Current meter model 2, (iii) Wave and tide recording instrument, (iv) Tide recording instrument (micro processor based), (v) Weather station for Antarctica, (vi) Ocean data buoy, (vii) Shallow water echo sounder, (viii) Bathy thermograph and (ix) Wave digitizer.

Besides developing various oceanographic instruments, the Marine Instrumentation Division of NIO plays a key role in the servicing and maintenance of the various sophisticated instruments on board RV Gaveshani and ORV Sagar Kanya and in maintaining a smooth communication with the Indian team at Antarctica and with the research vessels during their cruises.

Apart from NIO, NPOL, Cochin, has been playing a pioneering role in the country, in the design and development of instruments for ocean research.

OCEAN ENGINEERING

In view of the rapidly increasing offshore activities in India, there is need for development of capabilities, indigenous knowhow and expertise in the field of ocean engineering including geotechnical engineering. An ocean

engineering group was formed at NIO, in 1976, to develop expertise in this field. Significant contributions were made by the ocean engineering division in the development of oil fields in the offshore areas. NIO has been playing a pioneering role in the collection, analysis and interpretation of time series data on waves, currents and winds for engineering applications, for organisations like ONGC, Engineers India Ltd., etc. Capabilities for the design, deployment and retrieval techniques for the instrumented moorings in shallow and deep waters, have been developed and successfully used. Marine geotechnical engineering studies along the Bombay High oil and gas pipe lines were undertaken by NIO scientists and several studies in connection with the design, construction and burial of submarine pipe lines were carried out for certain industries situated on the west coast of India.

Some of the current activities in ocean engineering are: (i) development of a wave hindcasting model for the east and west coasts of India, (ii) computer aided fluid-structure interaction studies on certain specific problems related to offshore platforms, pipelines and anchored moorings, (iii) studies on the engineering behaviour of materials and corrosion, and its prevention in the marine environment, (iv) development of mathematical models for shallow seas to study the wave transformation, sediment transport, diffusion, dispersion etc., with a view to develop engineering solutions to ocean problems and (v) soil-structure interaction studies for evolving design criteria.

Apart from NIO, ocean engineering studies are carried out in other institutions like IIT, Madras, IIT, Bombay, Regional Engineering College, Suratkal, etc. An important programme for extraction of energy from the sea has been undertaken at IIT, Madras, where an academic course at postgraduate level in ocean engineering has been conducted and a well developed department exists. This department has been working on the development of wave energy and ocean thermal energy conversion with funding from DOD, Govt. of India. The Central Water and Power Research Station (CWPRS), Pune, has also been working on problems of development of harbours and ports, coastal protection designs, tidal

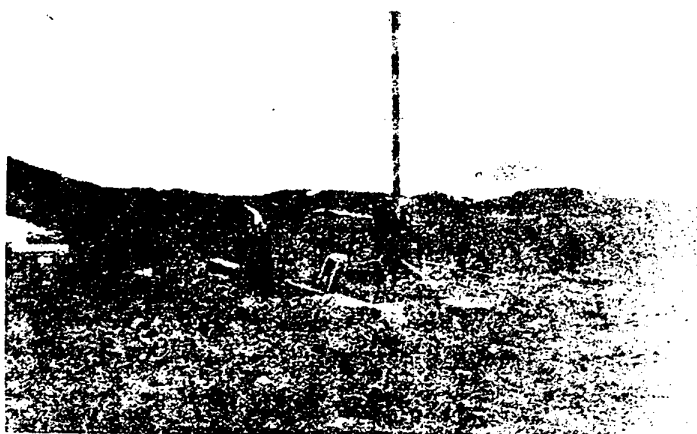


Photo.8 Weather Station (designed by N.I.O.) set up at Dakshin Gangotri during India's First Expedition to Antarctica (1981-82).

power plants etc. CWPRS has been associated with the project of tidal power plant in the Gulf of Kutch.

ocean and its influence on the monsoon systems, (ii) studies on the circumpolar current in the Indian ocean sector and

ANTARCTIC RESEARCH

The first Indian Scientific Expedition to Antarctica was organised within a record time of three months in 1981, with CSIR as the lead organisation and with NIO as the coordinating laboratory. The landing of the expedition team led by Dr.S.Z, Qasim, the then secretary to Govt. of India, DOEn, at Antarctica, on 9 January, 1982, was a landmark in the Indian oceanography. During the expedition an unmanned station named 'Dakshin Gangotri', was established at Antarctica and during the subsequent expeditions a permanent station was set up at Antarctica, where Indian scientists could stay throughout the year for conducting studies. Several scientists from NIO and the other CSIR laboratories, universities, IIT's, and organisations like NPOL, IMD, PRL, BARC, etc., participated in the expeditions and a few scientists stayed at Antarctica throughout the winter and undertook studies.

Some of the oceanographic components of Antarctic research are (i) studies on the interaction between ice, water and atmosphere in the Antarctic

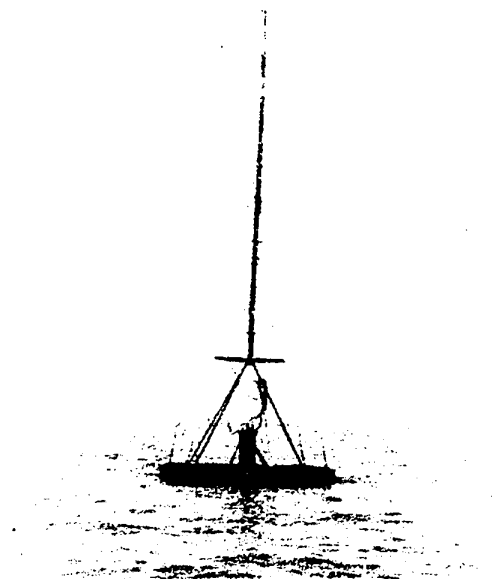


Photo.9 Ocean Data buoy designed and developed at N.I.O.

the zonal characteristics of the major frontal systems, (iii) investigations on the distribution and cycles of micro nutrients in relation to biological productivity and effect of pack ice on air-sea exchange of gases and on the calcium and carbon cycles, (iv) studies to establish the source levels of chemical constituents in the waters originating in the southern ocean, etc.

MARINE ARCHAEOLOGY

Marine archaeological studies in India were initiated under the leadership of Dr.S.R. Rao, a leading archaeologist in India, for the first time at NIO. Now this project is funded by the Department of Science and Technology, Government of India. Marine archaeology has as its objectives, the reconstruction of the history of shipping, maritime trade and cultural migration, by exploring and excavating submerged ports and wrecks of historical and cultural significance. Each wreck site acts as a chronological scale on the sea floor and the nature and rate of subsequent accumulation of sediment can be ascertained with the help of datable archaeological finds.

The marine archaeological unit at NIO, has collected a wealth of information of ancient ship wrecks in Indian waters from different archives. The investigations carried out in the nearshore waters at Dwaraka, Gujarat, have revealed that the destruction of temples and submergence of the town occurred around 14th century BC and that the net rise in sea level since then is about 5 m. The excavations of the ancient brick wharf in the Rajbandar Port, at the foot of the Elephanta Caves have revealed that it was raised in height by more than 1 m in 500 years. The survey carried out off Kaveripatnam, has indicated the presence of ancient remains of the city on the sea floor.

SUPPORT TO INDUSTRIES AND OTHER AGENCIES

Marine activities are increasing fast and more and more efforts are put in to tackle the problems concerning these activities. In this regard, NIO's assistance has been increasingly sought by several agencies and coastal oceanography is becoming more and more application oriented. Several sponsored projects and consultancy services worth several crores of rupees have been taken

up by NIO to cater to the needs of various agencies. Some of the important services rendered by NIO covered vital fields such as development of oil fields, offshore construction projects such as submarine pipe lines, harbours and ports, waste disposal, development and protection of coastal zones, development of tourism and recreation, and design and development of marine instruments to suit the requirements of public and private sector undertakings. These have not only saved huge amount of foreign exchange but developed self reliance and competence to take up the various tasks connected with the sea with indigeneous capability.

TECHNICAL ASSISTANCE TO OTHER COUNTRIES

Assistance to Sri Lanka:- NIO has undertaken intensive surveys in Sri Lanka waters in 1983, to study the chemical, biological and pollution aspects. A few Sri Lankan scientists were given training on board RV Gaveshani as well as at NIO, on oceanographic data collection, processing and analysis, under the Indian Technical Economic Co-operation programme. NIO has deputed two scientists to Sri Lanka, to help in developing aquaculture techniques for commercially important marine and brackish water fishes and shrimps and for surveying the distribution of brine shrimp Artemia in the coastal areas and identifying suitable sites for their large scale culture.

Assistance to Seychelles:- At the request of the Govt. of Seychelles, received through the Govt. of India, NIO conducted surveys in the Exclusive Economic Zone (EEZ) of Seychelles, in March, 1984. The surveys resulted in finding manganese nodules in the EEZ of Seychelles. NIO scientists also carried out nearshore surveys including bathymetric surveys and seabed sampling in the Victoria Harbour, Seychelles, to study the siltation problems and geomorphological studies of the beaches and coasts to evaluate the erosion problems. Biologists located immense resources of seaweeds on the islands of Mahe, Praslin and La Digue. The work was highly appreciated by the Govt. of Seychelles and it was hailed as a good example of south-south cooperation.

Assistance to Kenya:- NIO conducted an oceanographic study on board ORV Sagar

OCEANOGRAPHY

Kanya, in the sea off Kenya, in August, 1983. This was organised as a joint programme between NIO and Kenya Fisheries Research Institute (KMFI). Two Kenyan scientists participated in the programme and they were given training on board ORV Sagar Kanya in collection techniques.

TRAINING AND DEVELOPMENT OF MANPOWER

Courses in Marine Science at graduate and post graduate levels have been offered in several universities and institutions in India for more than four decades. The earliest universities to start training and research in Marine Zoology, were the Universities of Madras and Bombay in the late 1920's. In 1938, The University of Travancore (Presently the University of Kerala) created a chair for Marine Biology and Fisheries. Andhra University was the first to start a teaching course in Oceanography and Meteorology at M.Sc level, in 1948.

Later, the University of Kerala started a course in Marine Biology and General Oceanography in the early sixties, and another course in Oceanography in the mid sixties, at M.Sc level, at the Dept. of Marine Biology and Oceanography, at Cochin. Now, this department is under the Cochin University of Science and Technology. The Annamalai University, Port Novo, set up a Dept. of Marine Biology in 1962, which later became the Centre for Advanced Studies in Marine Biology, and it offers M.Sc course in Marine Biology. In the mid seventies, Berhampur University started M.Sc course in Oceanography and Marine Biology. In 1975, the Karnatak University introduced M.Sc course in Marine Biology, at the Marine Biological Station at Karwar. In 1983, the Calcutta University started M.Sc course in Marine Biology. Latest in the series, is the M.Sc course in Marine Sciences, started at the Goa University, in 1985.

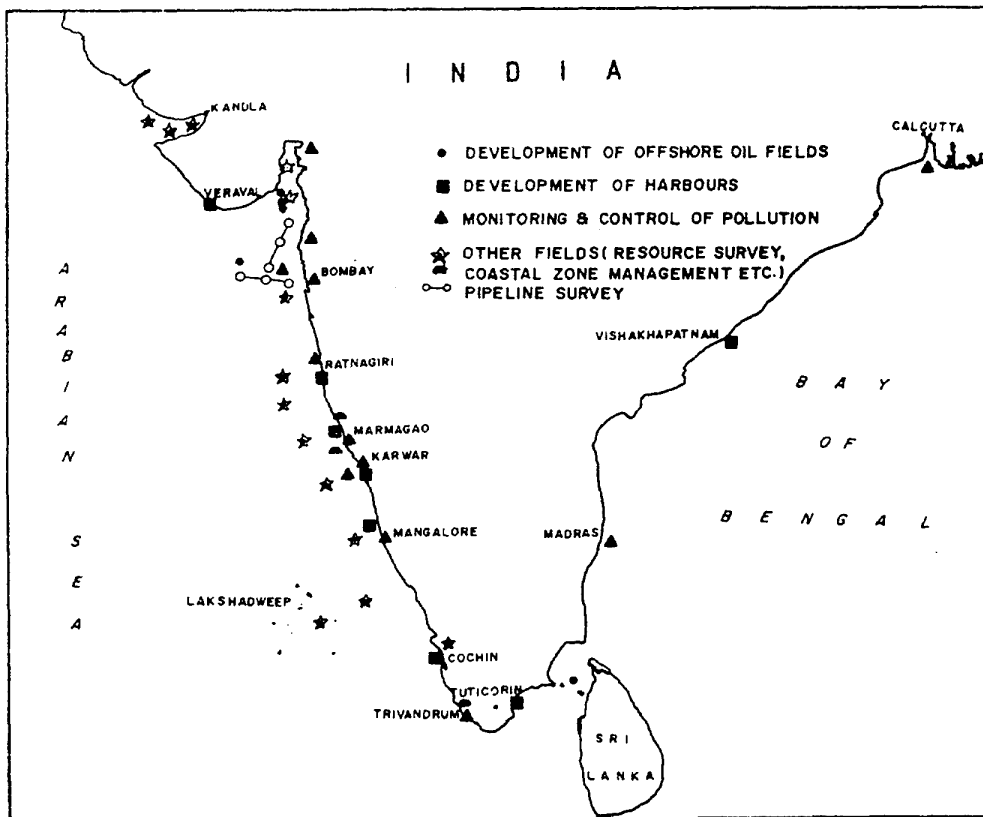


Fig.10 Major sponsored projects undertaken by N.I.O.

OCEANOGRAPHY

Some of the Agricultural Universities in coastal states have also been offering courses in Marine Science oriented towards Fisheries, at graduate and postgraduate levels. These are the Konkan Krishi Vidya Peeth, Ratnagiri, and the fisheries colleges at Tutucorin, Cochin and Mangalore.

Apart from these, some of the IIT's and engineering colleges have also been involved in teaching and research on some aspects of Oceanography, especially related to Ocean Engineering and Technology. The IIT, Bombay, offers a course leading to post graduate diploma in Dock and Harbour Engineering, and IIT, Madras, offers M.Tech course in Ocean Engineering.

In 1982, NIO undertook a programme of development of large manpower of marine scientists, at junior level. A batch of 41 trainee scientists possessing a minimum qualification of M.Sc, in the different disciplines of marine science or basic sciences related to oceanography, were recruited on an all India basis, after an entrance test, and given extensive training for about 6 months. They were absorbed in NIO, in a regular cadre, through selection after completion of the training. A separate Training Division exists at NIO now, to cater to the various training needs of the Institute.

CONCLUSION

Oceanography, the collective entity of all the basic sciences applied to the oceans, is still considered to be a young science in India even though lot of work has been done during the last three decades. Considerable infrastructure facilities and manpower have been built up at the various institutions in the country, and now, India can claim to have capability for undertaking major tasks in oceanographic work. However, what has been achieved so far, is meagre compared to what needs to be achieved. With the emergence of a new ocean regime, India has about two million sq km of Exclusive Economic Zone (EEZ), covering an area extending upto 200 nautical miles from the shoreline. Intensive exploration of this zone is required for its optimum utilisation and management of its living and non living resources. CSIR has, therefore, identified studies in the EEZ, as a

thrust area in oceanography, for the seventh plan period, and the programmes are being planned in this direction.

Although considerable work has been carried out in physical oceanography, since the IIOE, there are several gaps in our understanding of the seas around India. We have not made much headway in the prediction of the marine environment which is essential in view of the increasing activities in the offshore areas, directed towards the exploitation of living and non living resources of the sea. Our endeavour in future may have to be focussed on an understanding of the variability of the ocean processes on different time and space scales and on using this knowledge for future prediction of the processes. Data on time scales of hours to years will be needed for effective weather forecasting and understanding climatic variability. In this context, it is essential that India plays a vital role in the Tropical Ocean and Global Atmosphere (TOGA) programme and the World Ocean Circulation Experiment (WOCE), pertaining to the Indian Ocean to understand better and to predict the vagaries of the monsoon. Development of modern measurement techniques such as remote sensing from satellites etc., and continuous monitoring of ocean features using instrumented anchored buoys, drifting buoys, acoustic tomography etc., play an important role in achieving this goal.

Our knowledge of the biological productivity in the EEZ is good but not quite adequate for developing strategies for the exploitation, development and conservation of living resources. This is mainly because of the variability occurring on different time and space scales. Currently, thrust has been given for an extensive study of the EEZ. Aquaculture techniques have to be improved and new techniques evolved for cultivation of commercially important organisms. Hence, a frontier area for development in the near future would be marine biotechnology, an extension to marine science, of advances made in the field of biotechnology. This can significantly contribute to the areas of mariculture or sea farming, marine pharmaceuticals and bioproducts, marine biofouling and marine pollution control. Currently, attention is being paid in this direction, at NIO.

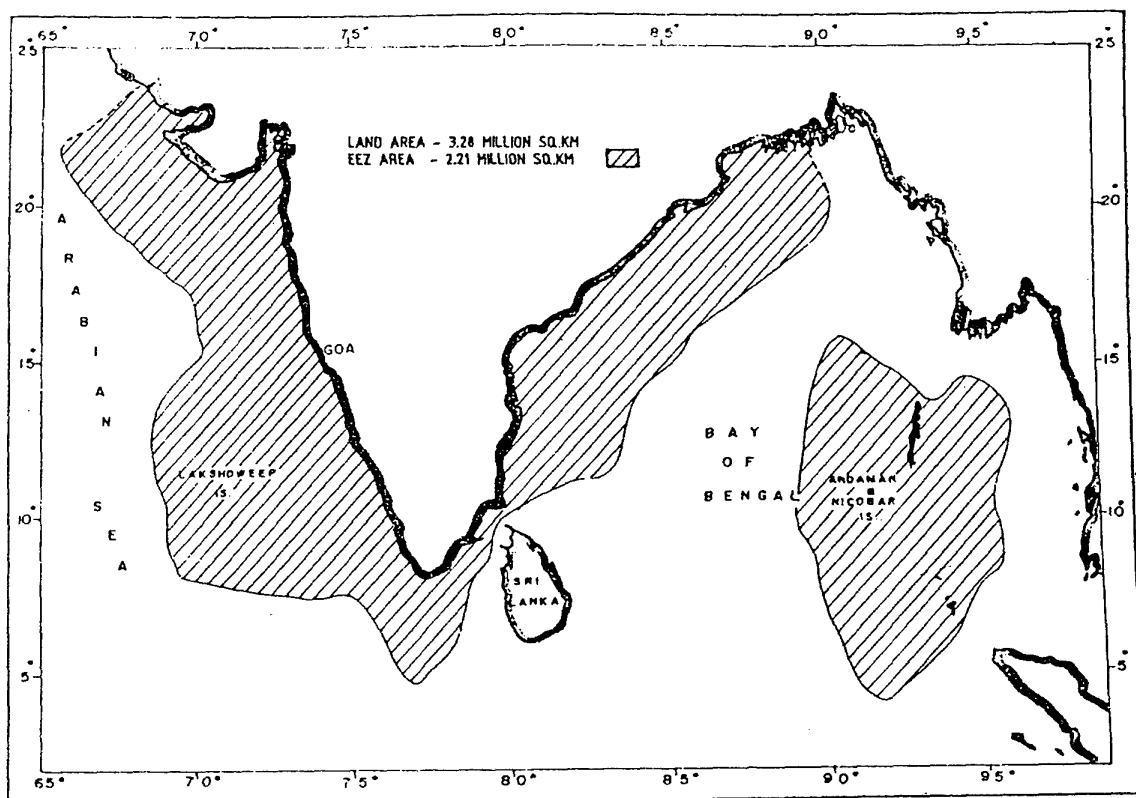


Fig.11 Exclusive Economic Zone of India.

The chemical processes involved in the transfer of matter from one region to another in the sea, are not yet clearly understood. Coastal problems involving a build up of pollutants and their possible uses as chemical tracers, chemistry of the surface microlayer, chemical processes occurring at the interfaces of sea and land, sea and air, and sea water and bottom sediments, and organic chemicals from the sea, are some of the areas in chemical oceanography which need attention in the near future.

The exploration and exploitation of minerals such as manganese nodules, sulphides, ilmenite, monozite, and phosphate deposits, from the sea floor, warrant fundamental studies in marine geology and geophysics. An important aspect which needs immediate attention is a study on the impact of exploitation of these minerals, on the environment.

Sea is a storehouse of energy from sources such as tides, waves, thermal

and salinity gradients, biomass etc. Technology for extraction of these energy sources is still in the experimental stages and needs further development to make it a reality. Indigenous design and development of marine instruments including calibration and testing facilities, is another area that needs further attention.

In general, India, in the coming years and decades, should move towards self-reliance in undertaking the various challenging tasks of exploration and exploitation of the sea and its resources and also provide expertise to the various developing countries of the Indian Ocean region which may need India's support.

ACKNOWLEDGEMENT

The authors wish to express their thanks to Dr. B. N. Desai, Director, NIO, for the facilities provided during the preparation of this report.

OCEANOGRAPHY

SELECTED REFERENCES

- Alagarwami, K. Contributions in Marine Sciences, Dr.S.Z. Qasim sastyabdapurti felicitation volume, NIO, Goa, 1987, 37-49.
- Anand, S.P. and R. Jayaraman. Indian J. Mar. Sci. 1 (1972), 79-84.
- Antony, M.K. et al. Estu.Coast. Shelf Sci., 21(1985), 823-834.
- Baba, M. and C.M. Harish. Indian J. Mari. Sci., 14(1985), 1-8.
- Bahulayan, N. and V.V.R.Varadachari. Ibid, 15 (1986), 8-12.
- Behrman, D. Assault on the largest unknown - the International Indian Ocean Expedition 1959-65, Unesco, Paris, 1981.
- Bhattathiri, P.M.A. and V.P. Devassy. Indian J.Mar.Sci.,10(1981),243-245.
- Chandramohan, D. et al. Geomicrobiology Journal, 5 (1987), 17-31.
- Das, P.K. Mathematical aspects of Non-linear Studies in Ocean Sciences, D.K.Sinha (ed), South Asian Publishers, New Delhi, 1986,54-71.
- Dave, M.J. and V.D. Chauhan, Indian J. Mar. Sci. 14 (1985),46-47.
- Desa, E. Growing Focus on Antarctica, R.C.Sharma (ed), Rajesh Publications, New Delhi, 1985, 79-85.
- Desai, B.N. Mahasagar - Bull. natn. Inst. Oceanogr. 6, (1973), 128-132.
- Desai, B.N. et al. Ibid, 16(1983), 281-291.
- Desai, P.S. Ibid, 18(1985),199-202.
- Dutt, S. and Y.T. Varma. Ibid, 16(1983) 81-86.
- Dwivedi, S.N. Ibid, 6 (1973), 112-119.
- Dwivedi, S.N. et al. Ibid, 7 (1974), 91-94.
- Ganapati, P.N. and A.V. Raman, Indian J. Mar. Sci. 5 (1976), 134-135.
- Ganguly, A.K. Mahasagar - Bull. natn. Inst. Oceanogr., 6 (1973), 47-48.
- George, M.J. Ibid. 6 (1973), 133-139.
- Gopalan, U.K. et al. Proc. first natn. Sympo. Shrimp Farming, Bombay, (1980), 175-186.
- Gopinathan, C.K. and D.P.Rao. Mahasagar, 18 (1985), 281-292.
- Goswami, S.C. et al. Ibid, 10 (1977), 129-138.
- Gupta, H.K. Contributions in Marine Sciences, Dr. S.Z. Qasim Sastyabdapurti felicitation volume, NIO, Goa, 1987, 447-456.
- Harkantra, S.N. et al. Indian J. Mar. Sci. 9 (1980), 106-110.
- Hashimi, N.H. J. Inst. Maths. Geol, 13 (1981) 291-301.
- Jain, A.K. Mahasagar - Bull. natn. Inst. Oceanogr., 11 (1978), 1-10.
- James, P.S.B.R. and M. Badsudeen. Indian J. Mar. Sci. 4 (1975), 50-59.
- Jayaraman, R. Mahasagar - Bull. natn. Inst. Oceanogr. 3 (1970), 28-30.
- Josanto, V. and R.V. Sarma. Ibid, 18 (1985), 333-345.
- Joshi, L.U. and Qasim, S.Z. Ibid, 18 (1985), 145-152.
- Karande, A.A. Indian J. Mar. Sci., 7 (1978), 39-43
- Kesava Das, V. Mahasagar, Bull. Natn. Inst. Oceanogr. 12 (1979), 59-63.
- Kesava Das, V. and D.V. Rama Raju Ibid, 19 (1986), 113-118.
- Kesava Das, V. et al. Indian J. Mar. Sci., 9 (1980), 148-155.
- Krishnankutty, M. Mahasagar, 18 (1985), 219-229.
- Kurup, P.G. and V.V.R. Varadachari. Indian J. Mar. Sci. 4 (1975), 21-24.
- Kurup, P.G. and A. Pylee. Mahasagar - Bull. natn. Inst. Oceanogr. 9 (1976), 191-206.
- LaFond, E.C., Proc. Indian Acad. Sci. 46B(1957), 1-46.
- LaFond, E.C. Indian J. Mar. Sci., 1(1972),66-73.
- Lakshmana Rao, G.R. et al. Mahasagar, Bull. Natn. Inst. Oceanogr. 18 (1985), 381-385.
- Lal, D. and S. Krishnaswami. Ibid, 6 (1973), 59-66.
- Lal, D. and B.L.K. Somayajulu. Tectonophys.,105 (1984), 383.
- Lingaraja, T. et al. Indian J. Mar. Sci. 5 (1976), 218-221.
- Lokabharathi, P.A. et al. Ibid, 15(1986), 96-98.
- Madhavan, C. Def. Sci. J., 33 (1983), 323-330.
- Malhotra, A.K. et al. Mahasagar - Bull. natn. Inst. Oceanogr.,9 (1976), 221-226.
- Mehta, A.J. et al. Ibid, 16 (1983), 95-108.
- Murty, A.V.S. Ibid, 18 (1985), 293-298.
- Murty, C.S. et al. Indian J. Mar. Sci. 9 (1980), 77-81.
- Murty, C.S. and M. Veerayya. Mahasagar - Bull. natn. Inst. Oceanogr., 18 (1985), 163-172.
- Murty, P.S.N. et al. Ibid, 16 (1983), 9-30.
- Murty, P.S.N. et al. Ibid, 18 (1985), 187-197.
- Murty, T.S. and M.I. El-Sabh. Ibid, 18 (1985), 99-127.
- Nafday, A.M. Ibid, 8 (1975), 1-8.
- Nagabhushanam and U.H. Mane. Indian J. Mar.Sci. 4 (1975), 86-92.
- Naik, C.G. et al, Curr. Sci. 53 (1984) 1150-1151.
- Nair, K.V.K. et al. Indian J. Mar. Sci.

- 12 (1983), 11-16.
- Nair, R.R. et al. Indian J. Mar. Sci. 7 (1978), 224-230.
- Nair, R.R. Mahasagar - Bull. natn. Inst. Oceanogr., 18 (1985), 273-279.
- Nair, N.B. et al. Contributions in Marine Sciences, Dr.S.Z.Qasim sastyabdapurti felicitation volume, NIO, Goa, 1987, 269- 289.
- Nair, N.B. et al. Indian J. Mar. Sci. 12 (1983), 143-150.
- Nair, R.N. et al. Ibid, 14(1985), 9-14.
- Nair, V.R. et al. Ibid, 10(1981), 270-273.
- Nandi, S. and A. Choudhary. Mahasagar - Bull. natn. Inst. Oceanogr. 16 (1983), 409-414.
- Naqvi, S.W.A. and Qasim, S.Z. Indian J. Mar. Sci., 12 (1983), 21-26.
- Palaniappan, R. and K. Krishnamurthy. Ibid, 14(1985), 113-114.
- Pandya, J.A. Ibid, 5(1976), 249-250.
- Pandya, P.C. et al. Mahasagar - Bull. natn. Inst. Oceanogr. 13 (1980), 91-98.
- Panikkar, N.K. and R. Jayaraman. Proc. Eighth Pacific Sci. Congr. IIIA (1956), 111-122.
- Panikkar, N.K. Mahasagar - Bull. natn. Inst. Oceanogr., 6 (1973), 39-42.
- Pant, A. Indian J. Mar. Sci., 7(1978), 39-43.
- Parekh, K.S. et al. Indian J. Mar. Sci., 13 (1984), 45-46.
- Parulekar, A.H. and S.G. Motondkar. Contributions in Marine Sciences, Dr. S.Z. Qasim sastyabdapurti felicitation volume, 1987, 51-60
- Premchand, K. and C.M. Harish. Mahasagar - Bull. natn. Inst. Oceanogr. 18 (1985), 299-305.
- Qasim, S.Z. Indian J. Mar. Sci. 6 (1977), 122-137.
- Qasim, S.Z. Deep Sea Res. 29 (1982), 1041-1068.
- Qasim, S.Z. IOC Workshop Report No. 32, Supplement, 1982, 91-115.
- Qasim, S.Z. and T.W. Kurishy. Proc. Indian Acad. Sci. (Animal and Plant Sci.) Suppl. 1986, 1-17.
- Raju, V.S. and Ravindran, M. Dr. S.Z. Qasim sastyabdapurti felicitation volume, NIO, Goa, 1987, 199-209.
- Radhakrishna, K. Indian J. Mar. Sci. 7 (1978), 58-59.
- Raman, Sir C.V. Nature 108 (1921), 367.
- Raman, Sir C.V. Proc. Roy Soc. Lond. A 101 (1922), 64-80.
- Ramana, M.V. Geo-Mar. Letters, 6 (1986), 1-15.
- Rama Raju, V.S. et al. Indian J. Mar. Sci., 8 (1979), 78-84.
- Ramesh Babu, V. et al. Mahasagar - Bull. natn. Inst. Oceanogr., 16(1983), 1-8.
- Ramesh Kumar, M.R. et al. Proc. Indian Acad. Sci. (Earth & Planet Sci.) 95 (1986), 435-446.
- Rao, C.V.K.P. Indian J. Mar. Sci. 14 (1985), 202-205.
- Rao, D.P. and J.S. Sastry. Mahasagar - Bull. natn. Inst. Oceanogr. 14 (1981), 1-16.
- Rao, K.V. et al. Indian J. Mar. Sci. 4 (1975), 189-197.
- Rao, K.K. Ibid, 1 (1972), 1-7.
- Rao, K.P. Mahasagar - Bull. natn. Inst. Oceanogr. 7 (1974), 1-14.
- Rao, L.V.G. et al. Monsoon Dynamics, M.J. Lighthill and R.P. Pearce (eds), Cambridge Univ. Press, 1981, 453-463.
- Rao, S.R. Indian J. Mar. Sci. 16 (1987), 22-30.
- Rao, T.C.S. et al. Mahasagar - Bull. natn. Inst. Oceanogr. 18 (1985), 257-264.
- Rao, T.S.S. Oceanogr. Mar. Biol. Ann. Rev. 5 (1967), 111-118.
- Rao, T.S.S. and A.H. Parulekar. Mahasagar - Bull. natn. Inst. Oceanogr. 18 (1985), 249-255.
- Rao, T.S.S. and Madhu Pratap. Unesco Technical Papers in Marine Science, 49 (1986), 212-214.
- Rao, T.S.S. et al (eds). Contributions in Marine Sciences- Dr.S.Z.Qasim sastyabdapurti felicitation volume, NIO, Goa, 1987, 472pp.
- Rao, V.P. Mar. Geol. 74 (1987), 151-157.
- Ray, I. and K.V. Venkatesh. Indian J. Mar. Sci. 4 (1975), 93-95.
- Reddy, B.S.R. et al. Ibid, 14 (1985), 210-216.
- Reddy, C.V.G. and V.N. Sukaranarayanan. Ibid, 1 (1972), 57-60.
- Reddy, H.R.V. and V. Hariharan. Ibid, 14 (1985), 163-164.
- Reddy, M.P.M. Ibid, 5(1976), 152-162.
- Roonwal, G.S. and G.H. Friedrich. Indian J. Mar. Sci. 10 (1981), 57-60.
- Royan, J.P. et al. Ibid, 7(1978), 116-119.
- Saha, K.R. Mahasagar - Bull. natn. Inst. Oceanogr. 6 (1973), 43-46.
- Sankaranarayanan, V.N. et al. Indian J. Mar. Sci. 12 (1983), 181-182.
- Sarin, M.M. et al. Mahasagar - Bull. natn. Inst. Oceanogr. 18 (1985), 129-143.
- Sarkar, A and Rajkumar. Proc. Ind. Acad. Sci. (Earth and Planet Sci.) 94 (1985), 249-260.
- Sarkar, S.K. et al. Indian J. Mar. Sci., 14 (1985), 98-101.
- Sarma, V.V.J. et al. Mahasagar - Bull. natn. Inst. Oceanogr. 18 (1985), 377-380.

OCEANOGRAPHY

- Sastry, A.V.R. et al. Indian J. Mar. Sci. 10 (1981), 369-370.
- Sastry, J.S. and R.D. D'Souza Indian J. Met. Geophys, 22 (1971) 23.
- Sastry, J.S. and V. Ramesh Babu. Proc. Indian Acad. Sci. (Earth & Planet Sci.) 94 (1984), 117-128.
- Satyanarayana, D. et al. Indian J. Mar. Sci. 14 (1985), 147-150.
- Sears, M. and Daniel M. (eds). Oceanography, the Past, Springer Verlag, New York, 1980, 812 pp.
- Sen Gupta, R. and T.W. Kurishy. Mar. Poll. Bull. 12 (1981), 295-301.
- Sen Gupta, R. and S.W.A. Naqvi. Deep Sea Res. 31 (1984), 671-706.
- Setty, M.G.A.P. Mahasagar - Bull. natn. Inst. Oceanogr. 13 (1980), 111-116.
- Sewell, R.B.S. Memoirs of Asiatic Society of Bengal 9 (1925), 27-50.
- Sewell, R.B.S., Ibid, 9 (1929), 207-423.
- Sharma, G.S. Indian J. Mar. Sci. 7 (1978), 209-218.
- Sharma, P. and B.L.K. Somayajulu. Contribution in Marine Sciences, Dr. S.Z. Qasim sastyabdapurti felicitation volume, 1987, 355-390.
- Shetye, S.R. J. Mar. Res. 44 (1986), 521-542.
- Siddiquie, H.N. and N.H. Hashmi, Scientific Report of the First Antarctic Expedition to Antarctica, Department of Ocean Development, New Delhi, 1983, 114-122.
- Siddiquie, H.N. et al. Deep Sea Res. 31 (1984), 763-812.
- Solimabi and R.S. Topgi. Indian J. Mar. Sci. 7 (1978), 203-204.
- Somayajulu, B.L.K. and M.S. Srinivasan. Indian Lithosphere, K.S. Valdiya (ed) INSA, New Delhi, 1986, 124-133.
- Somayajulu, Y.K. et al. Indian J. Mar. Sci. 9 (1980), 141-147.
- Srinivasan, D. Mahasagar - Bull. natn. Inst. Oceanogr. 18 (1985), 91-97.
- Srivastava, P.S. Ibid, 8 (1975), 133-150.
- Subbaramayya, I. and M. Subba Rao. Ibid, 18 (1985), 179-185.
- Subramanyan, V.J. Geol. Soc. India, 29 (1987), 256-263.
- Unesco. Ocean Science for the year 2000. IOC, Unesco, 1984, 95 pp.
- Unnithan, R.V. et al. Indian J. Mar. Sci., 10 (1981), 371-372.
- Untawale, A.G. Contributions in Marine Sciences, Dr. S.Z. Qasim sastyabdapurti felicitation volume, NIO, Goa, 1987, 85-104.
- Udaya Varma, P. and V.V.R. Varadachari. Proc. Indian Acad. Sci. 85A (1977), 191-198.
- Vannucci, M. and V. Santhakumari. Indian J. Mar. Sci. 1 (1972), 119-124.
- Varadachari, V.V.R. Proc. Mahadevan Volume, Osmania University Press, Hyderabad, 1961, 159-162.
- Varadachari, V.V.R. and G.S. Sharma. J. Indian Geophys. Un. (1967), 61-73.
- Varadachari, V.V.R. et al. Bull. natn. Inst. Sci., India, 38 (1968), 338-343.
- Varadachari, V.V.R. et al. Ibid, 38 (1968), 457-462.
- Varadachari, V.V.R. et al. Contributions in Marine Sciences - Dr. S.Z. Qasim sastyabdapurti felicitation volume, NIO, Goa, 1987, 141-174.
- Varadarajulu, R. et al. Mahasagar - Bull. natn. Inst. Oceanogr. 18 (1985), 265-272.
- Varkey, M.J. and V. Kesava Das. Indian J. Mar. Sci. 5 (1976), 147-151.
- Varma, K.K. and Rao, L.V.G. Indian J. Mar. Sci. 7 (1978), 79-83.
- Veerayya, M. and V.V.R. Varadachari. Sediment. Geol., 14 (1975), 63-74.
- Venkateswara Rao, M. et al. Indian J. Mar. Sci., 13, 3 (1984), 128-130.
- Venkateswaran, K. and R. Natarajan. Ibid, 12 (1983), 21-232.
- Vijayaraghavan, S. et al. Indian J. Mar. Sci. 7 (1978), 195-196.
- Viswambharan, N.K. et al., Proc. Indian Acad. Sci. (Engg. Sci.), Sadhana, 9 (1986), 281-297.
- Wagh, A.B. and S.S. Sawant. Mahasagar - Bull. natn. Inst. Oceanogr. 15 (1982), 189-192.
- Zingde, M.D. and B.N. Desai. Contributions in Marine Sciences - Dr. S.Z. Qasim sastyabdapurti felicitation volume, NIO, Goa, 1987, 245-267.
- Zingde, M.D. et al. Mahasagar - Bull. natn. Inst. Oceanogr. 18 (1985), 307-321.