# Exploring the seas—the National Institute of Oceanography's venture

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The oceans are mankind's last frontier. But apart from the awe and spirit of adventure that surround the oceans and exploration of the oceans, it is becoming increasingly clear that the rapidly dwindling resources on land can be supplemented from the oceans. Fortunately, India has seas on three sides and is bestowed with a very long coastline of about 7500 km. This represents a vast potential of exploitable resources. The new ocean regime has enabled India to possess about 2.01 million square kilometres of sea as its exclusive economic zone (EEZ).

The first major attempt to study the Indian Ocean was the International Indian Ocean Expedition (1962–65). As a consequence of India's participation in this expedition, the National Institute of Oceanography (NIO) was established in 1966 under the umbrella of the Council of Scientific and Industrial Research. To cater to regional needs, NIO has set up three regional centres, at Cochin, Bombay and Visakhapatnam. NIO has emerged as the premier institute for ocean research in India. Its R&D programmes encompass exploration of the seas around India with the objective of understanding the physical, chemical, biological, geological and geophysical processes for the exploitation of living and non-living resources; prediction of monsoon variability; development of techniques and instruments for exploration; and use of the oceans to meet the challenging needs of the country. India now leads the developing countries in the area of ocean research.

## NIO's studies—physical processes

*Nearshore processes*

During the first few years, NIO concentrated mainly on coastal processes. Studies along the Kerala and Goa coasts have thrown considerable light on various aspects of coastal erosion and factors responsible for it. They revealed that the beaches along the Kerala coast are rather unstable compared to the beaches along the Goa coast. Several protective measures have been suggested to protect the coast at specific locations. Studies on nearshore circulation revealed the occurrence of rip currents at several places, and helped in selection and development of beaches for recreation. Sedimentation in harbours and adjacent areas has been studied to find ways to tackle the problem of siltation. Studies on the hydrography of coastal waters and estuaries have revealed various characteristics of these water bodies and their seasonal variability.

*Ocean dynamics*

The north Indian Ocean is unique in its characteristics because it is subjected to the influence of the reversing monsoons. So is the coastal region of India. Annual variations in wind stress, evaporation, precipitation and coastal run-off in the coastal regions produce circulations with characteristics generally not found elsewhere in the world's oceans. Recent studies along the west coast of India, during the south-west monsoon, have revealed an equatorward surface current and a poleward undercurrent at a depth of about 150 m hugging the continental slope. The intensity of the circulation decreases towards the north. Transient motions dominate north of latitude 15° N. In contrast, during the north-east monsoon, the circulation reverses and is marked by a well-defined northward surface flow and southward undercurrent below 200 m. The southernmost section of the west coast of India showed occurrence of upwelling during the south-west monsoon. The intensity of upwelling, the signatures of the surface current, and the undercurrent were found to become weaker progressively from south to north. During the north-east monsoon, the west coast experienced downwelling.

The upwelling indices along the east coast of India indicate that sinking is predominant in the northern zone. The influence of freshwater in the coastal circulation at the sea surface is considerable. Associated with the south-west monsoon circulation, the thermal field in the Bay of Bengal shows a wedge-like structure extending from south-west to north-east Bay. Studies on volume transport across the Bay of Bengal indicate a net northward flow adjoining the east coast of India. This is in consonance with satellite remote-sensed data. The spatial spread of freshwater is seen up to 10° N in the central and up to 6° N in the eastern Bay of Bengal. Its dominance is noticed up to a depth of 10, 75 and 40 m in the northern, eastern and central Bay respectively. Studies on potential vorticity show that the depth of penetration of wind forcing is limited to 300 m in the northern Bay and increases northwards to about 600 m in the central Bay. The region between the Andaman Sea and Madras has very high cyclone heat potential, which aids accelerated growth of atmospheric disturbances during the post-monsoon season.

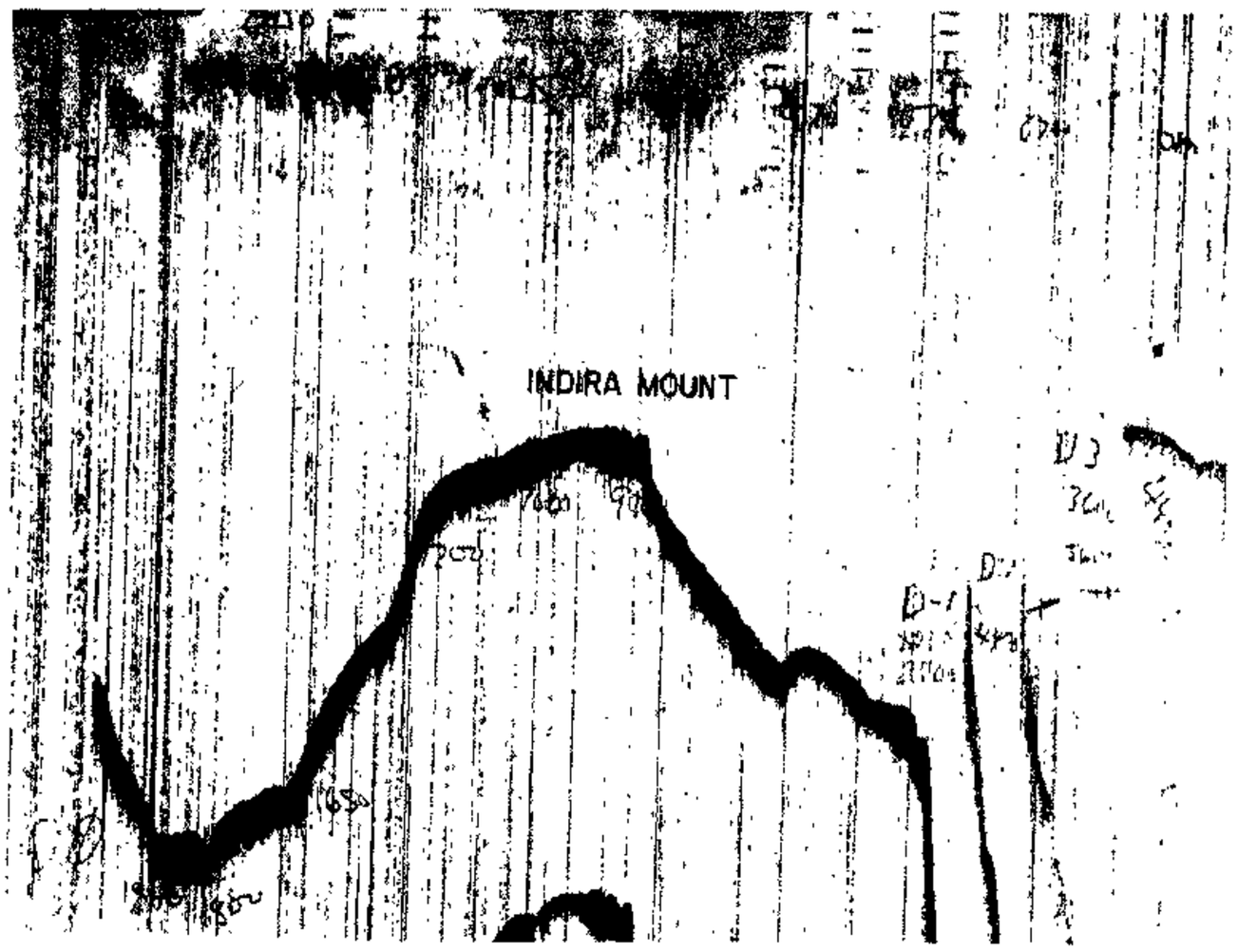
*Air–sea interaction*

A few experiments have been conducted during the last two decades to study the monsoon and its variability. Many scientists have attempted to find predictors for the monsoon in the oceans. Some of these studies indicate that the sea surface temperature (SST) variations noticed in the Arabian Sea can be taken as one of the parameters linked with monsoon variability. However, all the variability could not be assigned to variation in SST. Studies using satellite-derived data on SST variability over the north Indian Ocean for two contrasting monsoons reveal that large negative anomalies off the Somali and Arabian coasts are associated with good monsoon rainfall over India. Another study indicates significant positive correlation between the extent of coverage of warm pool in the Bay of Bengal during May and

the rainfall over India during the following summer. Pre-monsoon SST anomalies in the eastern Arabian Sea are found to be related to summer monsoon rainfall intensity along the west coast of India. Abnormally warm waters during the pre-monsoon season are associated with poor monsoon, and vice versa. A study of SST variations in the Indo-Pacific region shows that summer rainfall over India has been above normal whenever waters of SST higher than 29°C were nearer to the Indian subcontinent; rainfall was less whenever the position of the warm waters shifted to the east. It has been found that evaporation from the Arabian Sea during the south-west monsoon is nearly the same irrespective of whether monsoon is good or bad. Studies of heat content variations in the northern Arabian Sea during a monsoon break period in 1986 show that the surface warming, on an average, is almost accounted by the net energy exchange at the sea surface during a weak spell of summer monsoon. The studies also indicate that energy exchange in the eastern Arabian Sea influences coastal rainfall pattern within a season.

## Regional geology

NIO has carried out detailed surveys and has collected bathymetric, shallow-seismic, side-scan sonar and magnetic data to study the regional geology of the continental margin. Geomorphological, sedimentological and geochemical studies have also been carried out along the western continental shelf. Bathymetric and seismic profiles of the shelf and slope between Dwarka and Cochin have been prepared. The data reveal that the continental shelf break occurs between 90 and 145 m depth. The inner shelf is largely carpeted by recent sediments. The rugged topography of the outer shelf appears to be a relict of a lowered-sea-level period. An even topography extends between 50 (Kasargod) and 139 m (Dwarka) depth. The continental shelf is floored with three distinct sedimentary types and the boundaries between these are gradational. The inner shelf is marked by acoustically transparent sediments of 10–40 m thickness. In places, the continental slope is characterized by sediment slumping, subsurface faults, contended reflectors and facies changes. Ancient coastlines, palaeochannels and submarine terraces have been identified in the shelf region. It is likely that these were sites of deposition of placer minerals in the geological past. Palaeoclimatic studies based on the nature, age and composition of the western shelf sediments have provided inferences that the climate about 10,000 years ago in peninsular India was semi-arid and that the changeover from semi-arid to the present moist condition was geologically 'sudden' and associated with low sea level, about 90 m below the present sea level.




Echogram of a deep-sea mount discovered in the Indian Ocean.

*Structure and tectonics*

NIO has collected underwater geophysical data covering almost the entire western continental margin and part of the eastern continental margin. Studies carried out so far have given interesting information regarding the offshore continuation of structural trends, and extension of the Deccan Traps and basement features. Magnetic studies indicate a regional E–W-trending or ENE–WSW-trending fault across the margin off Saurashtra coast and subsidence of the axial part of the Gulf of Kutch. These studies also indicate that the tertiary sediments, reaching a maximum thickness of 8 km, overlie a Deccan Trap-type magnetic basement that was block-faulted. This area can be considered as an important future target area for hydrocarbon exploration. Offshore extension of onshore amphibolites and/or intrusions up to 50 m depth off Bhatkal, on the south-west coast, is also found. High-resolution seismic reflection profiles collected in the nearshore areas off Bombay were used for the first time to infer palaeoclimate and the results indicate that there was no major climatic change in the last 600–700 years, but before this the monsoon had been periodically more vigorous. Studies on high-precision gravity data collected in the Bombay High and adjoining areas indicate the presence of a prominent gravity low coinciding with the western flank of the Bombay High structure, India's major offshore oilfield. On the east coast, the magnetic anomaly map of the Krishna–Godavari basin shows a linear trend parallel to the coast. Another NW–SE trend is delineated by the map north of Amalapuram, extending from nearly 200 to 2500 m depth, suggesting a structural lineament from the coast to the sea.

*Geochemistry*

Geochemical studies have been carried out to understand the distribution and processes of incorporation of the various major and trace elements into the sediment and to demarcate areas for future exploration. Based on these studies distribution maps for $CaCO_3$, organic C, Al, Fe, Ti, $P_2O_5$, Mn, Ni, Cu, Zn, etc. have been prepared. Sands

with high carbonate content occur in the outer-shelf region between Gulf of Cambay and Coondapur and off Cape Comorin. High concentrations of phosphate in the sediments are found in the outer-shelf and slope regions. It has been found that the nearshore region acts as a sink for most of the elements and that removal of elements like Ni, Cu and Zn is in association with Fe–Mn hydroxides. In contrast, in the slope regions some of the elements (Zn, Ni, Cu) are associated with organic carbon.

## Chemical processes

A knowledge of the different chemical constituents and of their cycles in seawater and sediments is very important in understanding and evaluating living and nonliving oceanic resources. NIO's studies on the fertility of the seas indicate high concentration of nutrients along the south-west and north-east coasts of India during the south-west monsoon. In general, organic carbon is higher in the coastal regions than farther offshore. Work on the consequences of the oxygen-deficient condition in the Arabian Sea has led to estimates of denitrification in the region. The true levels of oxygen within the oxygen-depleted layers have been established. Chemical modelling is an area of recent beginning. These studies indicate substantial short-term variability in the reducing conditions, but the timescale and the factors controlling these changes remain unknown. A regeneration model has been developed to estimate additional fluxes and removal constraints of trace metals in seawater. Studies on chromium speciations based on thermodynamic models reveal that chromate and uranyl phosphate are the most stable species in seawater. A predictive model to estimate the abundance and residence times of various oxidation states of some elements hitherto unknown in the marine environment has also been developed.

## Marine pollution

Studies on various aspects of marine pollution in the seas around India have been carried out at NIO. It was found that the dissolved/dispersed petroleum hydrocarbon in the northern Arabian Sea (2.43 to 20.68 $\mu$g/l) had both beneficial and detrimental effects on phytoplankton biomass in different well-marked areas. Within the EEZ along the west coast of India, dissolved petroleum hydrocarbon levels appear to be rather consistent (1 to 26 $\mu$g/l) in the depth range of 0 to 20 m. The Bombay High oilfield region maintains nearly the same level of background petroleum hydrocarbon concentration in water in spite of the continuous offshore drilling and increasing oil production. Data collected over the north Indian Ocean in the last decade indicate an apparent reduction in oil pollution due to reduction in oil transport in this area. Studies on the effect of dissolved petroleum on phytoplankton indicate that, depending on their nature, the hydrocarbon components cause either enhancement or inhibition of phytoplankton communities. In regions close to oil tanker routes, growth is severely inhibited. The level of hydrocarbons in the Arabian Sea appears to be higher than that in the Bay of Bengal. Studies on residues of organochlorine pesticides in surficial coastal sediments around India show that concentrations on the east coast are more than those on the west coast. Data on levels of toxic metals in marine organisms in the Arabian Sea and Bay of Bengal in general indicate that there is no cause for anxiety as the levels in edible portions of the organisms are below the maximum levels specified by WHO as safe for human consumption. However, some 'hot spot' areas have been identified off Bombay, the coastal strip from Mangalore to Calicut, and the Hooghly river mouth, and these spots merit a close watch, though there seems to be no apparent risk at present. In general, except for the petroleum residues, the extent of pollution in Indian waters is not yet alarming.

## Biodeterioration of materials

Deterioration of materials in the sea due to biofouling and corrosion has attracted attention because of increased offshore activities such as oil production. NIO began studies in this field in 1980. Studies along the west coast of India reveal that microfouling biomass is higher in the shelf waters than that in the slope waters. Studies on biofouling of offshore platforms at Bombay High show that settling of fouling organisms occurs throughout the year at all depths and the biomass is higher in the upper layers. Methods to evaluate microfouling have been developed. The involvement of suspended matter and particulate organic carbon of seawater in microfouling was reported for the first time. A new approach to characterize microfouling material based on sugar monomer ratios has been suggested. Observations on the corrosion of reinforcement in concrete under varying stresses in marine environment indicate increase of corrosion with increased stress. In a laboratory experiment, it was found that a thick microalgal mat could reduce the corrosion rate of mild steel initially. At greater depths the extent of corrosion of mild steel and brass increased, but in the case of stainless steel and aluminium, corrosion decreased.

## Living resources

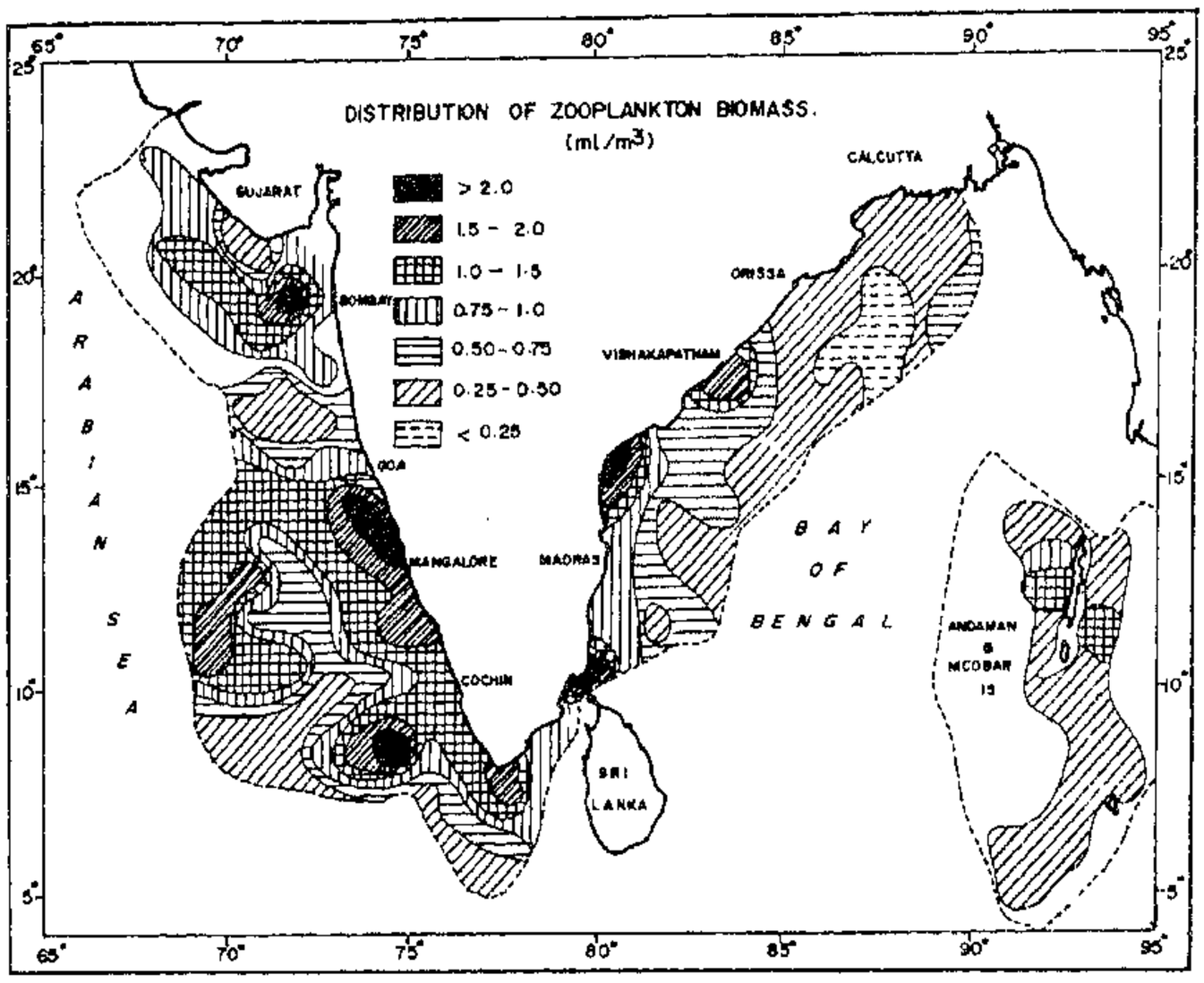
India's annual seafood harvest is about 1.5 million tonnes, which constitutes only about 2% of the world fish catch. With increasing demand for protein, it is estimated that India will need 11.4 million tonnes of fish by the year 2000. Meeting this demand is a challenging task. In this context, NIO's task is to identify and demarcate productive areas through studies on primary, secondary and benthic production in the Indian seas, and to develop sea-farming.

*Primary production*

About 50% of the EEZ of India has been studied in the last few years to evaluate primary production. These studies have revealed that certain areas, such as the south-west coast, followed by the central and the north-west coasts, are highly productive. Northern Bay of Bengal is relatively more productive than the rest of the east coast. The Andaman and Lakshadweep regions are less productive than the west coast of India.

*Secondary production*

Zooplankton-rich regions indicate better fishery potential, especially pelagic fishery. NIO's studies indicate that the west coast of India is more productive than the east coast. The south-west coast of India is a region of high zooplankton production owing to replenishment of nutrients in the surface layers through




Distribution of zooplankton biomass in the EEZ of India.

strong upwelling. Pockets of high production have been observed off Bombay, Cochin and the coast between Goa and Mangalore. The north and southeastern Arabian Sea are also regions of high production. Along the east coast of India, secondary production increases towards the south, with pockets of high production between Visakhapatnam and Madras. The western region of the Bay of Bengal supports high standing stock of zooplankton. Fish eggs and larvae are abundant off Ratnagiri, Konkan, Cochin and Quilon on the west coast and in the northeastern region of the Bay of Bengal.

*Benthos*

Studies on benthos (plants and animals on the seabed) of the Indian Ocean are of recent origin and are useful for assessing exploitable demersal fishery potential and development of sea-farming. The studies indicate that the continental shelf produces the maximum biomass and production decreases with depth. North-west Arabian Sea and the northern Bay of Bengal are also areas of high benthic production. The potential demersal fishery from the continental shelf of India is estimated to be 1.8 million tonnes per year as against the exploited catch of 0.4 million tonnes per year. Long-term studies in the Mandovi–Zuari estuarine system of Goa revealed 70% reduction in clam production and 50% in benthic biomass due to pollution from mining rejects.

*Seaweeds*

Marine algae form one of the most economically important plant resources. The seaweed resource survey along the Indian coast indicates that the intertidal area alone can give a yield of about 100,000 tonnes per year. Although in India marine algae are not widely used as food as in Japan, the species in Indian waters are rich in protein and carbohydrate. Techniques for seaweed cultivation are being standardized at NIO and the cultivation of some species has been initiated along the Indian coast.

*Mangroves*

Mangroves grow mostly in brackish water and form a typical ecosystem. Mangrove swamps are highly productive areas and can be used for aquaculture because these are the best spawning, breeding and nursery grounds for several organisms. NIO has been carrying out a mangrove resource survey along the Indian coast and propagating techniques for cultivation and conservation of mangroves. Coastal vegetation along the central west coast has been mapped using remote-sensing techniques.

*Sea-farming*

Sea-farming of commercially important organisms has been recognized as a way to generate more seafood. A technique for the culture of green mussels on ropes on floating rafts developed at NIO can give a yield of 480 tonnes per hectare per year with the possibility of three harvests in a year and profit of about 180% on capital investment. This technique has been demonstrated to fishermen and potential fish farmers at the instance of the Government of Goa. Applying modern concepts of ecology and aquaculture, NIO has developed a technique to improve the traditional paddy-cum-prawn culture in Kerala to give a high annual yield. NIO also has a technology for retrieving juvenile shrimp catch alive so that it can be utilized as seed for shrimp farming. A technique for the commercial culture of Artemia, used as food in aquaculture, has been perfected and is being commercialized by a private firm in Jamnagar. A breakthrough has been achieved in the controlled breeding and hatching of young ones of horse-shoe crab Trachypleus gigas, which provides a substance used to detect bacterial endotoxin.

*Bioactive substances*

Utilization of the vast marine resources as raw material for potent and safe drugs and pharmaceuticals is of recent origin. Several marine organisms have been screened for a wide spectrum of biological activities and some of them have shown promising results. This work has been carried out under an Indo-US collaborative programme, and the Central Drug Research Institute, Lucknow, is also involved. Corals, seaweeds and other organisms that produce substances with antifertility, antiviral, CNS-stimulant, hypotensive, spasmogenic, spasmolytic diuretic, analgesic, toxic, antimicrobial and other activities are known. Chemical investigation of some of the organisms led to the isolation of several types of steroids, fatty acids and their esters, halocompounds, lactones, alcohols and their esters, etc. Chemicals indicating analgesic, spermicidal, oxytoxic and hypotensive activities in a mangrove plant, a seaweed and a soft coral have been isolated and characterized, and are being synthesized in the laboratory. The synthetic chemical with spermicidal acti-

vity is in the process of confirmatory tests.

## Non-living resources

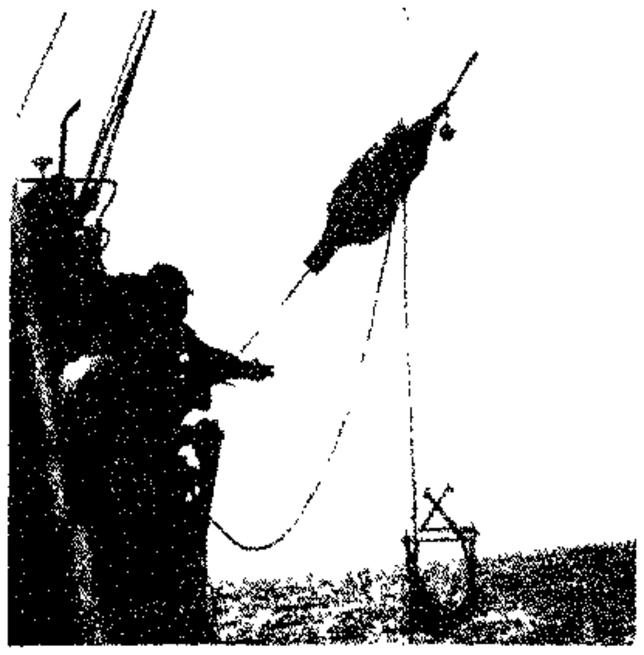
The oceans hold a promise for the future as regards the vast mineral and hydrocarbon potential they hold. At NIO, several programmes have been going on to detect and assess the mineral deposits in the seas around India.

*Placer mineral deposits*

Mineral beach placers such as ilmenite, monazite and magnetite occur along the Indian coast. The monazite sands of Kerala coast are the best known and are being exploited. NIO has undertaken studies to assess the extension of the placer deposits offshore. Investigations along the Konkan coast indicate that heavy-mineral-rich sands extend to a distance of 2–5 km offshore to a water depth of 10–13 m and cover an area of about 96 $km^2$ of the seabed. In the area surveyed reserves are estimated to be about 12.5 million tonnes. The seismic profiles show that the thickness of ilmenite-bearing sand layers ranges from 2 to 10 m and the deposits extend to a water depth of 20 m over an area of 436 $km^2$.

*Polymetallic nodules*

A national programme on exploration for polymetallic nodules was launched in 1982 with support from the Department of Ocean Development, Government of India. Detailed survey has been carried out over 441,000 $km^2$ in the central Indian Ocean. The total estimated quantity of the nodules in the areas surveyed is about 1335 million tonnes. An application area of 300,000 $km^2$ in the central Indian Ocean was demarcated and India filed a claim with the International Sea-Bed Authority under the United Nations. Now India has become the first country in the world to receive registration as a 'Pioneer Investor' at the UN Preparatory Commission for the International Sea-Bed Authority. A pioneer area of 150,000 $km^2$ in the central Indian Ocean has been allotted to India for developing a mining site. At present, close-grid surveys are being carried out to select a pilot mine site and to study environmental aspects to arrive at a design of



Boomerang grab used for collection of nodules being hauled up.

parameters for a mining system and gain some knowledge about the possible ecological impact of mining.

The growth rates of nodules in the central Indian Ocean are in the range of 1–3 mm per million years. The nodules contain records of significant changes in climate over a span of 200,000 years. It appears that nodule formation in the explored area started later than 24 million years ago. The topography of the area was found to influence the abundance, chemistry and morphology of the nodules. Nodules from seamount summits, slopes and regions of rugged topography have high to sporadic abundance, smooth surfaces, low oxide/nucleus ratio and low Mn/Fe, Ni and Cu in contrast to those from plain regions of the seabed.

*Oilfield development*

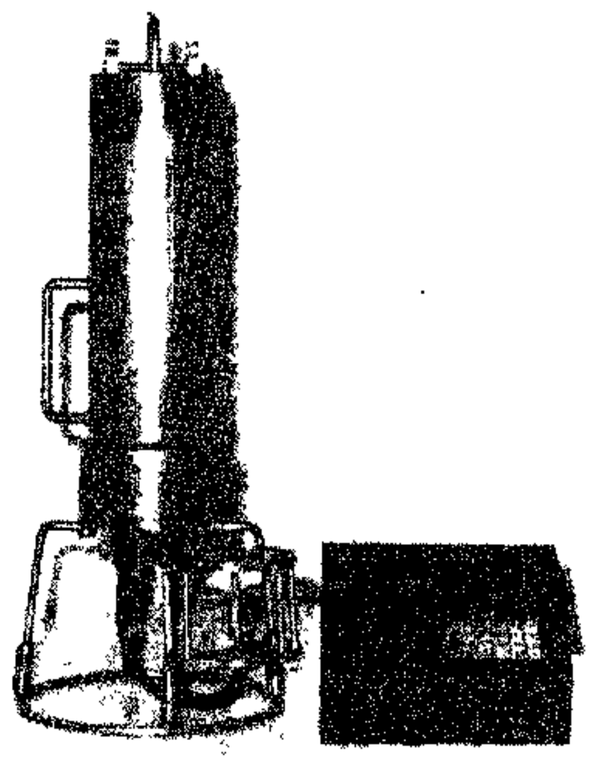
About 60% of the world's oil production is from the EEZ of the coastal nations. Offshore oil accounts for about 75% of India's production. NIO has been undertaking several projects for the Oil and Natural Gas Commission (ONGC) in developing oilfields along the west coast of India. Studies were carried out to understand the environment of the oilfields at several locations. Results from these studies have been utilized by ONGC in the design and construction of offshore platforms. Surveys were carried out for laying submarine pipelines in the Bombay High region and for the location of single buoy mooring terminal and connecting pipeline off Hazira. Water quality studies were also carried out for water injection in the Heera oilfield.

## Ocean engineering

The extension of engineering works to offshore areas necessitated development of expertise in this field. NIO initiated work in ocean engineering in 1976. Collection of long-term time-series data required for evaluation of design parameters for coastal and offshore engineering works was a problem because of difficulties with instrumented moorings. Now NIO has developed mooring techniques for both shallow and deep sea and has successfully deployed and retrieved moorings. Computer software was developed to analyse the stresses in deep-sea moorings during deployment and under *in situ* conditions. Numerical models for determining wave transformation from deep water to shallow water till wave breaking and for computing longshore sediment transport were developed. Work on development of a data base on directional waves, essential for estimating structural behaviour at sea and for evaluating coastal engineering problems, has been initiated. Software has also been developed to retrieve and analyse the raw data on heave/pitch/roll time series to obtain directional wave spectra. Estimation of 100-year wave height has been made based on directional wave data collected off Karwar. Marine geotechnical studies have been carried out in connection with the construction and burial of submarine pipelines for ONGC and other agencies.

## Development of instruments

Most of the equipment and instruments for oceanographic research are imported. NIO has been carrying out design and development of instruments with a view to indigenize them. These instruments are used by NIO as well as other agencies. Some of the instruments developed are: tide and wave recorder, depth recorder, current meters, microprocessor-based tide gauge, electronic bathythermograph and weather station. The weather station installed in Antarctica by the first Indian Antarctic expedition was developed at NIO. Recently, NIO released technical know-how for large-scale production of its direct-reading current meter, wave recorder and electronic bathythermograph to the National Research and Development Council (NRDC).



NIO's electronic bathythermograph.

## Emerging techniques

*Remote sensing*

An ocean remote-sensing centre has been set up at NIO to develop remote-sensing techniques for ocean studies. Sea surface temperature (SST), wind and wave-height data obtained through the *Bhaskara II* satellite have been validated by *in situ* observations. SST data for the north Indian Ocean have been derived from satellite data. Mangrove resources evaluation and coastal geomorphological studies have been carried out using remote-sensing techniques. A theoretical model has been developed to evaluate sensitivity of the remote-sensing technique to changes in the spectral quality of incoming solar radiation and changes in the vertical distribution pattern of chlorophyll concentration in vegetation. A new method of land-sea delineation in visible channels using the principal component transformation technique, and a new algorithm for remote sensing of sea surface winds have been developed. Water vapour flux divergence over the Arabian Sea during the 1987 summer monsoon was studied using *INSAT-1B* data.

*Ocean acoustic tomography*

This is a technique to collect information about the ocean interior on a synoptic scale. If the concept of this technique becomes a reality, it will be possible to sample large oceanic areas in a few minutes by suitably installing a network of sound transmitters and receivers. Recently NIO initiated a programme in this field. The acoustic characteristics of the Bay of Bengal have been studied and found to vary with depth. The forward problem of determining the source–receiver configuration has been largely completed. Starting from the hydrographic data, procedures for the computation of the reference profiles, ray path geometry, Eigen rays, arrival times, intensity loss of sound signals, and travel times from source to receiver have been perfected through software development. The results of the attempts made to reconstruct the reference sound speed profile derived from oceanographic data sets using singular value decomposition technique under natural generalized inverse methods yielded acceptable limits of variance.

*Modelling*

Rational use of the sea calls for model studies that lead to prediction of conditions in the marine environment. NIO is developing prediction models of circulation, thermal structure and biological productivity of the north Indian Ocean and of storm surges along the east coast. Some of these have been developed and used: a numerical model of wind-driven circulation in the Bay of Bengal; a numerical mixed-layer model to study temperature variability in the Arabian Sea; a three-dimensional model of circulation in the Arabian Sea with 31 layers in the vertical and taking into consideration the actual bottom topography; a model simulating an oil spill on the sea surface; a one-dimensional model of marine atmospheric boundary layer that can predict the vertical structure of waves, temperature and moisture, which has been tested for a region in the Arabian Sea; a numerical model to study wave-induced circulation in nearshore areas, which has been applied to small stretches along the Goa coast and has produced results comparable to the observed features; and a theoretical model to study the reflection of Rossby and Poincare waves from continental edges, which predicts the presence of new roughness-generated trapped waves in both cases.

## Antarctic oceanography

NIO has been associated with all the Indian scientific expeditions to Antarctica. The first expedition was coordinated mainly by NIO. Studies carried out during these expeditions have provided valuable information. Traces of dissolved petroleum hydrocarbon were detected in surface waters of the southernmost regions of the Indian Ocean. The hydrographic regime from Dronning Maud Land to 30°S shows the presence of distinct water masses. Intense vertical mixing was observed in the upper 300 m of the sub-Antarctic region. Geophysical studies made over the Astrid Ridge and Dronning Maud Land showed its crest trending N–E in the south, and veering to NNW–SSE and changing to NNE–SSW towards the north. The seismic profiles of the Ridge show a top transparent or layered sediments underlain by a prominent reflector and the acoustic basement. Phytoplankton productivity and biomass have been found to be variable in Antarctic waters but rich in coastal regions. The physical structure of the water column, near-freezing temperature at the ice edge, and heavy grazing and rapid sinking are significant factors controlling phytoplankton production in the southern ocean. Marine mammals were found to be concentrated in the region between 60° and 70°S and density varied from 16 to 246 animals per 100 $km^2$. Abundance was related to the richness of prey organisms, i.e. krill. Annual variability in krill biomass in the southern ocean is related to production in the microbial food-webs and a relationship between water masses and nutrient anomalies.

## Support to national development and international cooperation

The capabilities and expertise developed at NIO have been gainfully uitilized to provide support to industries and other agencies in tackling problems connected with the seas. So far, NIO has undertaken 270 contract research projects and earned revenue of over Rs 300 million. The main areas in which the institute has been undertaking contract research projects are coastal zone management, development of oilfields and harbours, pollution monitoring and control, industrial and domestic waste disposal, resource surveys, biodeterioration in the marine environment, and development of marine instruments. Till date, NIO remains the only organization

in India whose scientists and technicians have been associated with almost all the seabed surveys carried out along the Indian coast. The major beneficiaries of NIO's technical expertise are ONGC, NTPC, NPC, Indian Navy, port trusts, central and state government departments, private industries, public sector undertakings, water pollution boards, etc. The services rendered to these agencies have led to considerable saving of valuable foreign exchange.

NIO has provided technical assistance to Sri Lanka, the Seychelles, Kenya, Mauritius and Caribbean countries, at the request of the respective governments, in exploring the resources and environment of their EEZs. The assistance provided includes training of scientists from these countries in collection, analysis, processing and interpretation of oceanographic data on board research vessels as well as at NIO.

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