The International Indian Ocean Expedition (1959-1965)

The genesis

The genesis of the International Indian Ocean Expedition (IIOE) may be traced back to 1937, when T. W. Vaughan, in his report on the *International Aspects of Oceanography,* brought to the attention of the oceanographic community, the fact that very little was known about the Indian Ocean and it was time to plan and bridge this big gap in our knowledge. World War II and the subsequent turmoil interfered with such plans for almost two decades. It was only in 1957 that Lloyd Barkner, the American geophysicist who played a leading role in organizing the *International Geophysical Year (IGY)* and who was then President of the International Council of Scientific Unions (ICSU), requested Roger Revelle, Director of the Scripps Institution of Oceanography, to appoint a Special (later, Scientific] Committee on Oceanic Research (SCOR) so that oceanographers could play a major role in the proceedings and plans of the ICSU. Accordingly, Revelle formed a committee consisting of about 15 members; among them were G. E. R. Deacon, Director of the Institute of Oceanographic Sciences (UK), Columbus O'D. Iselin, Director of the Woods Hole Oceanographic Institution (USA), Gunther Boehrecke, Head of the German Hydrographic Office (Federal Republic of

Germany), Lev Zenkevich, a Soviet marine biologist, Maurice Hill, the leader of the Marine Geophysics Group at Cambridge (UK) and N. K. Panikkar, Fisheries Development Advisor to the Government of India.

At the first meeting of the SCOR, held at the Woods Hole Oceanographic Institution (WHOI) 28-3C August 1957, it was decided to plan an international expedition to the Indian Ocean. Roger Revelle, who presided over the meeting, appointed a Working Group under the Chairmanship of Columbus Iselin to prepare a plan for such an expedition. The members of the working group included representatives from Australia, France, Federal Republic of Germany, India, Japan, South Africa, UK, the USSR and the USA. SCOR also appointed Robert Snider as Co-ordinator, whom Revelle called 'a born expeditor'.

SCOR, during its meeting at WHOI, considered three long-range problems seeking a solution by way of the proposed expedition, all of them important for the future of mankind. First, to know the Indian Ocean potential for fishery resources, since most of the countries bordering the Indian Ocean were deficient in proteins in their diet; second, to assess the role of the northern Indian Ocean in effecting the monsoonal changes, which arc vital for agricultural operations in the Indian sub-continent, but which also influence the current patterns, upwelling systems, productivity and the carbon-dioxide cycle; and third, to determine the limits to the use of the oceans for dumping human wastes, including spent nuclear fuels etc. It was also suggested that, during the first two years of the expedition, participating countries should encourage standardization of equipment and methods of analysis and data logging so that the results obtained by different ships would be comparable. SCOR also recommended that, during the third and fourth years of the expedition, as many as 16 ships should simultaneously cruise in the Indian Ocean and make a combined assault on the largest unknown area of the Earth: the deep waters of the Indian Ocean and its sea bed. With SCOR's endorsement of the Expedition, scientists from different countries began to discuss and plan their participation. There were also discordant voices, doubting whether such a large programme was feasible. There were others who very much wanted to study the Arabian Sea in particular for its reversing monsoons, the Somali upwelling and high rates of productivity. Soon there came into being a publication called the *Indian Ocean Bubble* at irregular intervals, and the editor invited freelance discussion on the proposed IIOE. The first issue contained a lengthy letter from Henry Stommel, the renowned oceanographer from WHOI, recommending detailed studies of the Arabian Sea and, to quote, 'The question which we would like to resolve is how much docs the internal density structure of one of these semi-enclosed basins respond to the variations of wind stress. A clear-cut observational answer would be an interesting test of theoretical ideas about the oceanic circulation ...'. Stommel also brought up the Somali current off Somalia and, again to quote, 'according to ship observations, the current flows toward the south during the northeast monsoon and toward the north during the southwest monsoon. It appears to be strong, intense and narrow - ideal for repeated hydrographic sections, season by season. Welander's computations indicated that this ought to be the world's most strongly oscillating current system - the difference in south and north flows amounting to about 61 million cubic metres per second'.

The same issue of the *Babble* contained a letter from another scientist, asking 'Do you think it would be possible tor some of those interested in surveying the Indian Ocean to meet in a bar or other relaxing place, during one of the less enthralling sessions of the Oceanographic Congress in New York next September, 1959?'.

In the second issue of the *Bubble* in February 1959, R.B. Montgomery wrote a letter expressing the hope that the Indian Ocean Programme would be so designed as to aid directly the development of one or more oceanographic research centres in the underdeveloped countries bordering the Indian Ocean. This wish was fully realized in India and Pakistan, where national centres for oceanography were established after the IIOE.

In the third issue of the *Bubble,* which appeared on 10 May 1959, a letter from Martin J. Polak was published in the same vein as above. While endorsing the proposed IIOE programme, he said, 'probably the primary need is to fill in some of the large gaps in the geographical distribution of hydrographic stations ... It seems that it should be possible to combine some of the required reconnaissance surveys with special studies of the circulation patterns. For instance, a seasonal study of the monsoon regimes in the Arabian Sea and the Bay of Bengal would serve a dual purpose: these two areas arc virtually untouched by subsurface thermometers'.

How bad the Indian Ocean situation was can be grasped from a sarcastic postscript added by Montgomery to his letter in the *Bubble*, 'In case anyone should think of a use for them, I have a set of noon temperatures of water, air, and wet bulb made from a passenger vessel from Singapore to Suez in December 1958'.

Stommel made some further comments, stating that he and Fuglister had examined bathythermographic data obtained across the equator in the Atlantic, and saw similar features to those reported for the Cromwell Current in the Pacific Ocean and if such a current exists in the Atlantic Ocean it may also exist in the Indian Ocean, and this was worth investigating. The results of the International Indian Ocean Expedition later showed that the Cromwell Current did exist in the Indian Ocean, as predicted by Stommel.

Further support came from George Wust, Head of the Institute of Marine Science at the University of Kiel, Federal Republic of Germany, who submitted a plan for the survey of the Indian Ocean to SCOR. In the history of oceanography, Wiist is well remembered for his classical work on board the German Research Vessel *Meteor* which criss-crossed the Atlantic Ocean 14 times, from 20°N to the ice edge of the Antarctic Ocean. He suggested that the Indian Ocean be investigated from about 30°N south to the Antarctic on a grid basis, stations to be occupied at 8° intervals. His plan was appended to the IIOE prospectus prepared and issued by SCOR for wide circulation and comment. The prospectus was prepared by about 4C scientists invited by SCOR, representing different disciplines in oceanography, and was finalized by a group of 3 eminent scientists, namely, Roger Revelle, of the United States, George Deacon, of the United Kingdom, and Anton Bruun, of Denmark, who had been the leader of the second Danish *Galathea* Deep-Sea Expedition of 1950-52 and then the first Chairman of the Intergovernmental Oceanographic Commission (IOC) of UNESCO. Recalling those days, Behrman (1981), in his excellent book on the IIOE, quotes Revelle as remembering 'that July and August of 1960 were the most difficult months in my scientific life. After the subcommittee met in July, George Deacon, Anton Bruun and I had to put together their reports, synthesizing them into a coherent document... Nobody had studied the Indian Ocean. This was to be an exploration in the old-fashioned sense. There were so many scientific problems and the Indian Ocean was so far away from all our institutions that no one felt that his territory was being usurped... The Indian Ocean expedition was a pioneering effort in international oceanographic planning. It was like the International Geophysical Year, but on a much bigger scale. We learned how difficult the task was. We had to accommodate conflicting interests, for this was a political operation in which people had to be persuaded'.

In a letter to the fourth issue of the *Indian Ocean Bubble* in July 1959, LaFond wrote:

'I have been interested in the various discussions of the proposed oceanographic studies for the Indian Ocean appearing in the Indian Ocean Bubble. To me, the problem is not what to do, but rather, who in the Indian Ocean Region can be rounded up to do it? Everyone should be reminded that this is the Indian Ocean, and not the Woods Hole or Scripps ocean.

To spread the gospel and attain any lasting results, the work has to be carried on partly by the scientists of the Indian Ocean area. This does not mean just coming along for a ride, but actually give a major share in planning, analysis, and reporting. Most Asian students will be enthusiastic about the work if given the opportunity to collect data for thesis material. This opportunity and encouragement should be the primary goal for the expedition.

All plans dealing with the expedition and their execution will progress very slowly in Asia due to lack of authority and the complex restrictions on travel, money exchange, imports, immigration, and numerous other necessities of the program. Thus, planning with Indian Ocean scientists for participation should start early to avoid some of the inevitable delays.

Unfortunately, it is not possible to deal directly with students. It is necessary to go down through the chain of command. The most promising approach would be to contact high-level people, such as heads of scientific organizations, naval laboratories, fisheries, or universities, explaining the proposed program. Eventually, through these contacts, it may be possible to assemble some good Indian Ocean scientists and get them started in oceanographic research in their ocean.'

It was important, therefore, to involve developing countries, so that the expedition would not appear to be what Revelle called 'A club of rich countries that wanted to do oceanography'. Here, help came from the late N. K. Panikkar, an Indian scientist on SCOR, whom Revelle remembers as 'very sensible and very enthusiastic'.

Shortly after the plan for the IIOE was unfolded in the prospectus issued by SCOR at its meeting in

Helsinki in August 1960, Robert Snider left on a mission round the world to meet and persuade all countries interested in the expedition to contribute, plan and execute the programme. In this task he got full support from the members of SCOR national committees in various countries. He particularly made it a point to meet 'political activators' and influential members of the governments and local parliaments. He also carried with him colourful charts showing the proposed cruise tracks of the IIOE and, more importantly, an IIOE emblem the use of which on letterheads and packages would facilitate customs clearance of scientific equipment, exempting them from payment of duties, etc., for all countries participating in the International Indian Ocean Expedition. In India, he approached Homi Bhaba, the eminent nuclear scientist, who in turn obtained the support of Jawaharlal Nehru, the then Prime Minister of India. The American participation in the IIOE had already been endorsed by President Eisenhower and later by President Kennedy.

In all these activities, SCOR, being a nongovernmental group, had a fairly free hand to co-ordinate the expedition programme till the end of 1962, at which time, the newly formed IOC of UNESCO assumed co-ordinating responsibilities from Snider and SCOR. At the Woods Hole meeting of SCOR in August 1957, an estimate of the cost of the International Indian Ocean Expedition was projected (Table 1.6).

Nobody seemed to have paid much attention to these cost estimates, for the simple reason that there was just no money for such a major venture, either through UNESCO or any other country. In a way, this was for the best, because individual countries had to fend for themselves to obtain the necessary funds from their own governmental agencies. Recognizing the importance of the Expedition, and the fact that economic conditions were improving worldwide, many countries found funds and support from their governments for their participation in the IIOE.

At the Helsinki meeting of SCOR in August 1960, plans for the IIOE and general guidelines were issued. The SCOR working groups on the Indian Ocean gave some directions to the scientific programmes. The panel for physical oceanography, meteorology and chemistry recommended some areas for intense study: the Arabian Sea in summer and winter and the waters northwest of Australia; the Red Sea and the Persian Gulf for their heat budget and, similarly, the southern part of the Bay of Bengal. Emphasis was laid on correlating weather charts with oceanographic conditions wherever possible.

In chemistry, it was urged that all participating ships undertake a minimum common programme, such as the collection and analysis of water samples from standard depths for estimating dissolved oxygen and nutrients at each station. The panel on geology requested that all ships carry precision echosounders and continuously run them to record the water depth and to share such information with all other participating ships. Geomagnetic and gravimetric studies were also planned. In the biology programme, it was recommended that plankton samples be collected at all stations using an Indian Ocean Standard Net, designed by Currie, and make a vertical haul from 200m depth to the surface. Also, phytoplankton samples and productivity measurements should be taken wherever possible, and more particularly along the meridians 62°, 78° and 95° in the north-south direction. Another recommendation was to establish a sorting centre for zooplankton in India, where all the zooplankton samples could be sorted group-wise and then distributed to specialists. All the participating ships were requested to send the plankton samples to the proposed sorting centre.

Another very important programme endorsed and executed by SCOR and UNESCO related to the intercalibration of equipment and standardization of analytical procedures. Accordingly, three such tests were conducted, the first of which was organized in September 1960, at Honolulu, on board the Australian ship *Gascoyne*, the Soviet vessel *Vityaz* and at the laboratories of the University of Hawaii. The second test was held off Freemantle, Australia, again on board the *Vityaz*. And finally, a third series of chemical tests was organized on board the British ship *Discovery* in 1964. Against this background, an exciting drama to unfold the scientific secrets was played on the vast stage of the Indian Ocean. In view of its strategic location, India played a significant role in the overall operations and co-ordination of the IIOE, as well as being an active participant.

The Indian response to the IIOE

A person in the right place at the right time was N. K. Panikkar in India. As already mentioned earlier in this chapter, Panikkar held a very influential position as Fisheries Development Advisor in the Ministry of Food and Agriculture, in Delhi. He also represented India on SCOR. Besides, Panikkar knew, perhaps

Table 1.6 IIOE participants, ship time, estimated cost (in US$) etc.

1. **Countries participating:**

   (a) Ship-operating countries: Australia, France, Germany (Fed. Rep.). India, Indonesia, Japan, Pakistan, Portugal, Republic of South Africa, Thailand, USSR, UK, USA.

   (t>) Other participants: Burma, Ceylon, China, Pthiopia, Israel, Italy, Malagasy Republic, Federation of Malaya, Mauritius, Sudan.

   Number of ship-months: 323 (approximately)

   Distribution: Australia (37), France (20), Germany (Fed. Rep) ((>), India (24), Indonesia (3), Japan (2C), Pakistan (18), Portugal (3), Republic of South Africa (13), Thailand (2), USSR (20), UK (35) and the USA **(119).**

2. **Area of study:** Indian Ocean including adjacent seas.

3. **Period of study:** 1959 to 1963, peak at 1962, 1963 and 1964.

4. **Object of study:** Complete survey of the Indian Ocean, including descriptive physical, chemical, biological oceanography, marine geologv, geophysics and meteorology.

5. **Co-ordinator:** The Secretary, IOC

6. **Principal sponsors:** UNESCO, SCOR and IOC

7. **Other interested organizations:** International Meteorological Centres, Indian Ocean Biological Centre, FAO, WMO.

8. **Estimated costs** (US$):

(a) Cost of approximately 16 ships each operating in the Indian Ocean for 8 months	2,400,000
(b) Training of 25 scientists from Indian Ocean area, each for one year @ $3,000 per head	75,300
(c) Special equipment for each ship @' $24,000 per ship	384,000
(d) Salaries of the scientists working on ships (100 people for 1 year)	550,000
(e) Working up the scientific results (100 people for 1 year)	600,000
(I) Publication of results	30,000
(g) TOTAL COST	4,039,030
Less estimated contribution from normal operating costs and salaries	2,000,000
Estimated extraordinary cost	2,039,000

From UNESCO (1963)

better than anyone in India, the marine research capabilities that the country could muster for taking part in the IIOE. Having participated in the SCOR-UNESCO meetings in Paris and Helsinki in 1960, Panikkar decided to act and, on his advice, the Government in Delhi appointed an Indian National Committee on Oceanic Research (1NCOR) with the following terms of reference:

1. to draw up a co-ordinated plan for India's participation in the IIOE;
2. to advise on the allocation of a programme between governmental departments, research organizations, universities and other institutions;
3. to consider and approve detailed plans for research in the several scientific disciplines related to India's participation and to recommend financial grants;
4. to further and co-ordinate research programmes;
5. to advise the Government generally on all matters connected with India's participation in the Expedition.

In the light of these terms of reference, INCOR, besides being responsible for India's participation in the IIOE, also became the focus for all developments and research projects connected with oceanographic research in the country. The Committee and its working groups included almost all the important scientists representing various Indian institutions concerned with different branches of oceanography. The results of the Committee's deliberations led directly to the establishment of an Indian Ocean Expedition Directorate as a department of the Council of Scientific and Industrial Research, and to the allocation of sufficient funds and staff to ensure the full participation of India in this Expedition. The subsequent establishment of the International Meteorological Centre at Colaba (Bombay) and the Indian Ocean Biological Centre at Cochin is well known to marine scientists the world over.

The Expedition sought to explore in detail the oceanography of the Indian Ocean and to make the area as well known as the Atlantic and the Pacific. It was also fashionable for all who ever spoke on the programme of IIOE to draw attention to the enormous population increase of India and neighbouring countries and the inadequacy of food and protein supply for the undernourished people and to plead fervently for the exploration and exploitation of the food resources of the sea. If the speaker was a marine meteorologist, he would say how interesting are the reversing monsoons and how unpredictable or unreliable they are for Indian agriculturists. A geophysicist would stress the possibility of locating oil resources in the shelf areas off India. In this way, all sought to justify the many cruises, ships and nations participating in the joint enterprise of the IIOE. India's response to the call of the IIOE, as that of other countries in the region, was positive.

India's exploitation of fishery resources has been growing every year and it was reasonable to expect that, given more vessels and men, it should be possible to double the gross tonnage of fish landed on India's coasts. The most interesting aspect of the problem, however, was the fact that 67-75% of marine fish landed annually in India came from the west coast. This was pointed out by Panikkar and Jayaraman (1956) at the 8th Pacific Science Congress, and the picture remains the same even today. The reason for the apparent scarcity of fishery resources off the east coast of India and the rest of the Bay of Bengal should be urgently investigated and considered quite separately from the problem of whether we are fully exploiting the available fishery resources off the west coast. Although, in recent years, mechanization of fishing vessels has increased, the fact remains that fishing is done mostly in nearshore waters while the vast shelf off the west coast remains totally unexploited. For example, off the Bombay and Gujarat coasts, the shelf extends out for nearly 200 miles and, but for a few vessels of the deep-sea section of the Food and Agriculture Ministry, no large-scale commercial trawlers are commissioned to fish these vast areas. Regular mapping of coastal areas rich in fishery resources was one of India's immediate requirements.

Next, we may consider the mineral resources of the sea. India lacks natural deposits of fertilizer salts and rich deposits of fossil fuel. One of the ingenious suggestions was that the possibility of extracting nutrient salts, such as phosphates and nitrates, from the vast quantities of marine sediments dumped by the great river systems into the Bay of Bengal and the Arabian Sea should be considered. The possible accumulation of oil under the shelf (offshore areas), particularly off Cambay, was also considered suitable for investigation, particularly since the nearby area of Ankaleswar had yielded exploitable deposits of gas and oil.

Again, the mapping of coastal currents and the bathymetry of nearshore areas, and their importance for coastal navigation, defence, harbour construetion, and so on, cannot be minimized. With the increase in industries and the number of nuclear reactors, the question of pollution and waste disposal takes on added significance. Our knowledge of coastal bathymetry and bottom topography was inadequate and the physical oceanography of the coastal waters was almost unknown. The use of modern instruments was essential.

Finally, there was the study of the monsoons. Two problems were involved: first, how does the reversal of the monsoons affect the oceanic circulation in the northern Indian Ocean, and secondly, how may the onset and intensity of the southwest monsoon be predicted. This second problem was of great agricultural importance since most of the *ryots* (farmers) in India depend on monsoon rains for the cultivation of summer crops *(kharif).*

These were some of the problems in which India was interested at the time of launching of the IIOE (Rao, 1967). Quite rightly, therefore, the planners of the Indian Programme concentrated their efforts in these directions and constrained their cruises and observations so as to obtain substantial information on the coastal areas in the Arabian Sea and the Bay of Bengal. With the inauguration of the 1st Scientific Cruise of INS *Kistna* on 9 October 1962, by Professor Hymayun Kabir, Minister for Scientific Research and Cultural Affairs, the Indian Programme of Work during the IIOE was officially launched. Besides INS *Kistna,* the Indian Programme included scientific cruises by RV *Varuna,* of the Indo-Norwegian project, RV *Conch,* of the University of Kerala, and FV *Bangada,* an exploratory fishing vessel of the Ministry of Food and Agriculture, Government of India. All the cruise tracks and programme of work were co-ordinated so that a complete coverage of important coastal areas in the Bay of Bengal and the Arabian Sea was effected.

The participation and programme of the INS *Kistna* in the IIOE are unique in many respects. The Indian Navy should be congratulated for placing the frigate at the disposal of the Indian National Committee on Ocean Research solely for oceanographical work. This was a most welcome development for the future of ocean sciences in India since, by this gesture of co-operation, the Indian Navy's full support of IIOE was assured.

Commencing in October 1962, INS *Kistna* completed 28 scientific cruises and, had it not been for the unfortunate Indo-Pakistan conflict in the middle of 1965, she would have successfully accomplished the rest of the cruises planned for the autumn of 1965. The vast amount of data collected by INS *Kistna* were later analysed at the data and planning division of the National Institute of Oceanography.

Meanwhile, the International Meteorological Centre (IMC) at Colaba, Bombay, functioned from 1 January 1962, with Prof. C. S. Ramage of the University of Hawaii as Director. This Centre was financed by the Council of Scientific and Industrial Research and was manned by the Indian Meteorological Department. The United Nations Special Fund provided an IBM 1620 electronic computer for data processing. The US National Science Foundation gave liberal assistance in the form of equipment and other services. The extended Indian Ocean chart in use at IMC covers the whole of the Indian Ocean plus adjacent areas. Reception of about 75 daily radio teletype broadcasts from Canberra, Nairobi, Singapore and Pretoria provided the bulk of the southern hemisphere coverage. Data exchanged with Tokyo and Moscow and some 40 radio teletype/carrier-wave broadcasts received from Karachi, Aden, Colombo, Jakarta and Saigon, supplemented by collections at the meteorological communication centre, formed the coverage of the northern hemisphere. Ships' reports obtained over radio teletype circuits from Mauritius by the Indian Navy added to the coverage oi the southern Indian Ocean. On a typical day the total coverage amounted to: Surface reports - 1155; Ships - 384; Upper air - 429. Aircraft reported from long-distance international flights on three or four air routes.

At the IMC, synoptic charts were prepared for two principal times - 00 and 12 hours Greenwich Mean Time - for surface and standard isobaric levels; namely, 50, 100, 200, 300, 500 and 700mb. Back plotting was also done after reception of additional information/data from other centres. During the IIOE, perhaps the most important observations on the monsoons were carried out by specially instrumented research aircraft of the US Weather Bureau Research Flight Facility and by the Woods Hole Oceanographic Institution. In addition, an automatic weather station was anchored in the Bay of Bengal half-way between Madras and the Andamans in April 1964 but this was soon lost. An Automatic Picture Transmission (APT) receiving equipment on loan from the US National Science Foundation was installed at IMC in December 1963, and this picked up pictures of cloud cover from *Tiros* VII and *Nimbus* meteorological satellites during their orbits over the Indian subcontinent. It is too early to say that the IMC has solved the problem of the development of the monsoon or is able to predict the arrival of the monsoon accurately, but it has accumulated a vast quantity of information and the preliminary analysis of the data has improved our knowledge of the circulation pattern of the monsoon winds. In fact, for the first time, meteorologists in India were able to get data from over the oceans for their studies and have come to realize that the weather pattern of the Indian sub-continent is greatly influenced by conditions in the sea.

The Indian Ocean Biological Centre (1962-66)

The establishment of the Indian Ocean Biological Centre (IOBC) at Ernakulam (Cochin) marks a very important milestone in the history of marine biology in India. The Centre was established by the Council of Scientific and Industrial Research in co-operation with UNESCO. The main considerations which led to the selection of India for the location of the Centre were:

- geographical location of India at whose ports many of the ships participating in the expedition were likely to call;
- the very considerable interest in biological and taxonomic studies in India at scientific and university institutions;
- the availability of a large number of trained biologists who could take on the work;
- the advantage of a centre of this type in South Asia which would stimulate marine biological studies in the Asian region.

The principal functions of the Centre were:

- maintenance of a named reference collection of Indian Ocean material and duplication of it for laboratories throughout the world;
- sorting zooplankton samples taken by standard methods
- examination of the sorted standard material or sending it to specialists throughout the world;
- sorting of zooplankton samples at the request and expense of participating laboratories;
- training.

The development of this Centre in India has provided a unique opportunity for the training of biologists from India and other countries in the region.

The US IIOE programme in biology

Woods Hole is a picturesque village located on Cape Cod in the State of Massachusetts in the United States. Geomorphologically, Cape Cod is like a hooked finger projecting from the northeast American coast and appears to beckon people from other countries, which is a fact if one looks at the number ot foreign visitors during the summer months at the famous Woods Hole Oceanographic Institution (WHOI) and the Marine Biological Laboratory (MBL). As already indicated, it was at WHOI that a decision to plan the IIOE was made in August 1957 by a group of eminent oceanographers who met under the chairmanship of Roger Revelle.

The US National Committee acquired the Presidential Yacht *Williamsburg* for conversion into an oceanographic vessel (the ship was 243 feet (73m) long and displaced 1700 tons) and was renamed the *Anton Bruun,* after the famous Danish scientist who led the second *Galathea* Deep-Sea Expedition round the world in 1950-52. Also, as the first Chairman of the Intergovernmental Oceanographic Commission of UNESCO, at that time, he influenced the UN bodies concerned and the Member States to support the proposed International Indian Ocean Expedition. The National Science Foundation named John Ryther, a renowned scientist at WHOI, as Director, and Edward Chin, as Associate Director, of the US Programme in Biology in the IIOE and gave them a free hand to organize the *Anton Bruun* cruises in the Indian Ocean.

Ryther had a good understanding of the problems in biology the Expedition was seeking to solve. Behrman (1981) quotes Ryther's writing in 1963 that 'for the systematics, the Indian Ocean represents a world of which only tantalizing glimpses have been obtained. A few fortunate individuals have taken part in expeditions to some of the more remote, exotic island groups (the Seychelles, Maldives, Laccadives, Comores and Chagos) and have brought back a wealth of new material. Just enough is known of the flora and fauna of these areas to whet the appetite of the taxonomist with the desire to make a thorough and exhaustive study of the entire region ...

For the ecologist, there are reports of many fascinating phenomena of unknown nature and origin. Vast fish mortalities in the central Arabian Sea are perhaps produced by the overturn of water from mid-depths reportedly devoid of oxygen and laden with hydrogen sulphide. The central Bay of Bengal may at times have similar properties. Are these anoxic layers related to the biological productivity of the overlying surface waters? Do they reflect stagnation implying lack of vertical or horizontal circulation for long periods of time? Notorious outbreaks of discolored water, sometimes also producing mass mortalities of marine life, are frequently reported along the coasts of India and Africa. Are these "blooms" of dinoflagellates similar to the causative agent of the Florida red tide? Are they the result of fertilization of the coastal waters from upwelling processes...? Huge meadows of blue-green algae extending for many hundreds of square miles are known to occur in the Arabian Sea. What makes these plants grow in this particular region? Where do they get their nutrients? How does their presence affect other forms oi marine life? These are just a few of the problems, probably unique in the Indian Ocean, which will require a combination of physical, chemical and biological information to answer.'

The *Anton Bruun* had a crew of 30 and accommodation for 28 scientists. Of these, 8 staff scientists were responsible tor the basic programmes such as casting oi water bottles, BT lowerings, plankton collections, primary-production determinations, meteorological observations, depth soundings, etc. In early 1962, Ryther held a planning conference in New York and, because of his previous work in the Bay of Bengal and good contacts with Indian scientists, asked Eugene Lal'ond to head the first cruise of the *Anton Bruun* and to develop a programme for the Bay of Bengal and Andaman Sea areas. Since the Andhra University oceanographers had established the time and space variables on the western side of the Bay of Bengal, LaFond wanted to establish the same variables on the opposite side of the Bay. For example, when upwelling occurs off Waltair, would upwelling exist on the other side or would we find sinking? Would the immense dilution due to river discharges extend as far down the east side as it does in the west? There were other questions dealing with the monsoon circulation gyres, such as: are the currents in the Bay one large eddy or are they broken up into smaller gyres? To answer these questions, a pattern of stations was laid out along a track criss-crossing the Andaman Sea, and the eastern, northern and western parts of the Bay of Bengal.

Prior to the beginning of the cruise, Panikkar asked the LaFonds to visit Indian marine science centres, give lectures, explain the IIOE programme and, especially, the objective of the US Programme in Biology and the *Anton Bruun* cruises (Table 1.7). A number of Indian scientists were invited to participate in the cruises. The LaFonds visited and lectured at:

- Bombay Academy of Sciences, in Bombay
- Taraporevala Marine Biological Research Station, in Bombay
- Osmania University, in Hyderabad
- Andhra University, in Waltair
- Navy Physical Laboratory, in Cochin
- Oceanographic Research Wing of National Geophysical Research Institute, in Cochin
- Maharaja's College, in Ernakulam
- Kerala University, in Trivandrum
- Central Marine Fisheries Research Institute, in Mandapam
- Annamalai University, in Chidambaram
- Maharaja Sayajirao University, in Baroda
- Gujarat University, in Ahmedabad
- Physical Research Laboratory, in Ahmedabad
- Delhi University, in New Delhi

These lectures and discussions informed the Indian scientific community of the oceanographic programmes about to take place in the Indian Ocean, and the members of this community were invited to participate in the scientific cruises.

The *Anton Bruun* arrived in Bombay in early March 1963 after occupying a series of stations in the Arabian Sea. She soon refueled and departed on 12 March on the first of 9 cruises (see Table 1.7) with all scientific billets filled.

Table 1.7 *Anton Bruun* cruises in the Indian Ocean during the IIOE

Cruise No.	Dates	Area covered
A	2/24/63-3/04/63	Gulf of Aden to Bombay-
1	3/12/63-5/10/63	Bay of Bengal
2	5/22/63-7/23/63	Along 70° E and 80°E
3	8/08/63-9/20/63	Along 60°E
4	9/25/63-12/10/63	Western Arabian Sea
5	1/26/64-5/04/64	Along 55°E
6	5/16/64-7/16/64	Along 65°E
7	7/29/64-9/10/64	East African coast
8	9/25/64-11/09/64	East African coast
9	11/18/64-12/28/64	Somalia and Red Sea

The initial programme consisted of taking underway BT observations from Bombay across the southern Bay of Bengal to the Andaman Sea. In the Andaman Sea, the ship stopped for full-fledged oceanographic stations. The normal procedure in occupying a station was to make the following measurements and collections:

- hydrographic cast using Nansen bottles;
- 200m haul with the IIOE plankton net;
- phytoplankton trawl;
- deep-water fish trawl;
- vertical series of water samples for primary production;
- meteorological observations;
- bathythermograph lowering to 900 feet (275m);
- coring and dredging of the sea floor;

The Indian scientists for the first leg were:

C. Poornachandra Rao (meteorologist), International Meteorological Centre, Bombay
S.P. Anand (chemist), Indian Research and Development Centre, New Delhi
K. Balasubrahmanyan (marine biologist), Annamalai University, Marine Biological Station, Porto Novo
V. Chalapati Rao (marine biologist), Andhra University, Waltair
R. Varadarajulu (meteorologist), Andhra University, Waltair

Others who joined the first *Anton Bruun* cruise on one or more later legs were:

P. W. Backar (photographer), Ministry of Information and Broadcasting, Bombay
P. Chandramohan (marine biologist), Andhra University, Waltair
C. M. Gupta (marine geologist), University of Baroda, Baroda
R. M. Kidwai (marine geologist), Andhra University, Waltair
G. R. Lakshmana Rao (physical oceanographer), Andhra University
G. H. Madhusudana Rao (marine geologist), Andhra University
K. V. Nair (marine planktonologist), Indian Ocean Biological Centre, Ernakulam
N. K. Panikkar (marine fisheries biologist), Council of Scientific and Industrial Research, New Delhi
B. Ramareddi (meteorologist), Andhra University, Waltair
M. Sakthivel (marine planktonologist), Indian Ocean Biological Centre, Ernakulam
V. N. Sankaranarayan (marine chemist), Indian Ocean Biological Centre, Ernakulam
T. S. S. Rao (marine biologist), Scientific Liaison Office, Bombay
R. V. Unnithan (marine biologist), Indian Ocean Biological Centre, Ernakulam
V. V. R. Varadachari (physical oceanographcr and marine meteorologist), Andhra University, Waltair
S. Varma (photographer), Ministry of Information and Broadcasting, Madras
A. B. Wagh (marine planktonologist), Institute of Science, Bombay
P. K. Das (physical oceanographer), National Geophysical Research Institute, Cochin
K. Krishnamurty (marine zoologist), Annamalai University, Marine Biological Station, Porto Novo

In addition to the Indian oceanographers and the eight staff scientists, there were two Thai scientists:

Thumnoon Supanich (marine biologist), Chulalongkorn University, Bangkok
Mahn Bhovichitra (fisheries biologist), Chulalongkorn University, Bangkok

Needless to say, enormous quantities of oceanographic data were obtained from the network of stations throughout the Andaman Sea and Bay of Bengal.

In this connection, it may be stated that very little information was available on the responses of other countries in the Indian Ocean area, once the IIOE was over. One could infer from later publications, that Pakistan and some Gulf States had established marine research institutions. For its part, India went ahead to advance marine research in a big way.

The benefits of the IIOE to India

The IIOE achieved for itself the distinction of being one of the best examples of co-operation between many nations from East and West. Indian scientists visited many neighbouring countries and the Indian ship INS *Kistna* visited Singapore. India played host to scientists from many nations, resulting in deep and abiding friendships. Many of the participating foreign research ships, as the RV *Anton Bruun*, RV *Argo* and RV *Horizon* (USA), the RV *Vityaz* (USSR) and the RRS *Discovery* (UK) provided facilities for ship-board training and research for many Indian scientists.

The expedition also provided opportunities for organizing seminars in which many young scientists from different parts of the country and senior scientists from abroad participated. An All-India Seminar on Marine Science was held in Waltair, 26-27 April 1963, sponsored by the Andhra University, Waltair, the Indian National Committee on Ocean Research, the US Programme in Biology and the US Information Service, to present results from the first *Anton Bruun* cruise. It was well attended and was a great success. At the time of the visit of RV *Horizon* and RV *Argo* to Cochin and then again at Calcutta during the visit of the US Coast and Geodetic Survey Ship *Pioneer*, seminars were arranged at which visiting scientists and their Indian counterparts participated in discussions. In July 1965, an International Symposium on the Meteorological Results of IIOE was held in Bombay and this was attended by a large number of foreign and Indian participants.

As a finale to all this activity, a training programme was organized at the postgraduate level to train junior scientists in the practice of oceanography as a multi-disciplinary science, during January-March 1966 at Bombay. This was jointly sponsored by UNESCO and CSIR (Council of Scientific and Industrial Research). Twenty-five trainees were recruited from among the applications submitted by India and adjacent Asian countries to UNESCO. The break-down figures for the trainees were: India 20, Thailand 2, Singapore 1, Ceylon 1, and Malaysia 1.

While the training programme marked the end of IIOE activities, it also saw the birth of the National Institute of Oceanography (NIO) of India. The Indian Government approved the establishment of this institute as one of the national laboratories under the CSIR and appointed Dr. N.K. Panikkar, Director of the Indian Programme under the IIOE, as Director of the new institute. All the activities started under the Indian Programme of the IIOE, including the Indian Ocean Biological Centre, have now been merged into the National Institute of Oceanography.

Table 1.8 Principal atlases resulting from the International Indian Ocean Expedition

- *International Indian Ocean Expedition Plankton Atlas.* Panikkar, N.K., editor (1968-1973).
  - 1(1): Maps on total zooplankton biomass in the Arabian Sea and the Bay of Bengal (1968).
  - 1(2): Maps on total zooplankton biomass in the Indian Ocean (1968).
  - 2(1): Distribution of copepod and decapod larvae in the Indian Ocean (1970).
  - 2(2): Distribution ot fish eggs and larvae in the Indian Ocean (1970).
  - 3(1): Distribution of Crustacea (Cladocera, O.stracoda, Cirripedia, Mysidacea, Cumacca, Isopoda, Amphipoda, Kuphausiacea, Stomatopoda) and Insecta (Halobatida) in the Indian Ocean (1972).
  - 3(2): Distribution ot planktonic inollusca of the Indian Ocean (1972).
  - 4(1 &2): Distribution of Platyhelminthes, Tomopteridae and other pelagic Polychatta, Trochophores and Sipunculida ot the Indian Ocean (1973). Distribution of Actinotrocha, brachiopod larvae, Chaetognatha, Copelata, Pyrosoma, salps and doliotids and Amphioxus of the Indian Ocean (1973).
  - 5(1 &2): Indian Ocean Biological Centre, National Institute of Oceanography, Council of Scientific and Industrial Research, New Delhi.

- *Oceanographic Atlas of the International Indian Ocean Expedition.* Wyrtki, K. (1971). National Science Foundation, Washington DC, USA.

- *Meteorological Atlas of the International Indian Ocean Expedition.* National Science Foundation, Washington DC, USA.
  Ramage, C.S., F.R. Miller and C. Jcfferics (1972). *The surface climate of 1963 and 1964.*
  Ramagc, C.S. and C.V.R. Raman (1972). *Upper Air.*

- *Geological-geophysical Atlas of the Indian Ocean.* Udintsev, G. B., editor (1975). Academy of Sciences, Moscow.

- *Phytoplankton Production Atlas of the International Indian Ocean Expedition.* Krey, J. and B. Babenard (1976). Institut fur Meereskunde, Kiel.

The main results of the IIOE

The IIOE ended officially in 1965. More than 4C oceanographic research vessels belonging to 13 countries surveyed the Indian Ocean and collected useful data in almost all disciplines in the marine sciences, except perhaps in fishery research and marine microbiology. The scientists' work begins when the expedition ends and sometimes it takes several years for the results to be published. Since the completion of the expedition proper, hundreds of papers have been published and some of them reprinted and included in the 8 volumes of collected reprints of the International Indian Ocean Expedition published by UNESCO. This apart, a set of atlases was published which is unique for the Indian Ocean (Table 1.8).

The introduction of computers for data logging and analysis made a world of difference in the handling ot large amounts of data collected during the various cruises. Many countries established national oceanographic data centres for storage and dissemination of information. Two World Data Centres were also created, one in Washington, DC, and another in Moscow. Moreover, sorting centres for handling fauna and flora, including plankton, came into existence in Cochin (Indian Ocean Biological Centre), in Tunis (The Mediterranean Sorting Centre), and the National Oceanographic Data Centre at the Smithsonian Institution in Washington, DC. Some time later, a sorting centre was also started in Mexico. For biology specialists, the sorting centres were of immense help, since the drudgery ot mechanical sorting of animals and plants was done elsewhere, so that the biologists could concentrate on their specialized work.

Perhaps the most important thing was that oceanography became an eligible science for support and funding by the governments, particularly those of developing countries, and the interest shown in the IIOE by developed countries by their extended participation in an area so remote from their home, triggered a kind of paradigm for the developing countries. The benefits to coastal countries in the Indian Ocean region include the training of their scientists aboard research vessels of the developed countries, as the *Discovery* (UK), the *Meteor* (Germany), the *Atlantis* and the *Anton Bruun* (USA). This apart, oceanographic and marine biological research institutes were either newly started or the existing ones were strengthened. The oceanographic institutes established at Karachi, Pakistan, and Goa, India, the marine stations at Pukhet in Thailand and Nosy-be in Madagascar, and the East African Marine Fisheries Research Institute in Zanzibar are some of the examples. What was even more important was the mingling of scientists with different backgrounds, both in scientific status and culture, for the common cause of Indian Ocean exploration; they got to know each other and continued their contacts for many more years after the Expedition.

From the technical point of view, the six years of the IIOE (1959-65) marked a watershed in the state of the art in oceanographic instrumentation. Some of the new research vessels built and commissioned for survey during the expedition had better winches and echo-sounders and far more accurate navigational instruments; a satellite navigation system was available to the *Atlantis* II of the Woods Hole Oceanographic Institution. Narrow-beam precision echo-sounders, magnetometers and gravimeters were also made available on most of the oceanographic vessels.

Going through the literature and the excellent atlases to assess the results is a long but exciting task. Many interesting findings are briefly mentioned in the following account.

Geology and geophysics: The major discoveries relate to the complexity of the mid-Indian Ocean ridges and the famous triple junction, like an inverted Y, found south of the Seychelles, where the southern end of the Carlsberg Ridge (sometimes called the Mid-Indian Ocean Ridge) meets the Southwest Indian Ocean Ridge and the Southeast Indian Ocean Ridge which extend eventually into the mid-Atlantic Ridge and the South Australian Ridge, respectively. Until comparatively recently, geologists had no clear proof of the theory of continental drift first proposed by Wegener in 1910. However, in 1959, coinciding with the IIOE, Ewing, with Heezen and Tharp, published a paper describing a mid-ocean ridge running continuously in all the three major oceans for a total distance of 60,000km, 30-400 km wide and rising to 3000-5000m above the ocean floor. The significance of these long ridges was realized when several ships all made successful and successive cruises to study the geological and geophysical aspects of the mid-Indian Ocean ridges. They were: the USSR's *Vityaz* in 1960-62 and 1964-65, the UK's HMS *Owen* and *Dalrymple* in 1961 and 1963, and the RRS *Discovery* in 1963, the USA's RV *Argo* and RV *Horizon* in 1960-64, as well as the RV *Vema*, RV *Chain*, the

Conrad and the *Pioneer,* and Germany's *Meteor.* The results indicated that these ridges are the site of basaltic upwelling and sea-floor spreading to form the new ocean floors. This phenomenon is now called plate tectonics. Also discovered was the 90°-East Ridge in the eastern part of the Indian Ocean. This straight ridge rises out of the Bay of Bengal sediments, about 1000km north of the equator and extends in a straight line for 4000 km to the south; its crests lie 1800-3000 m below the ocean's surface. This ridge is unconnected with other ridges and is aseismic; its origin is an enigma.

The hot holes in the Red Sea were another surprising discovery of the IIOE. Although the *Dana* and the *Atlantis* had reported finding some unusually warm waters in the bottom of the Red Sea during their cruises in 1947 and 1958, little did they expect that what they had passed over was really a rich mineral source at the bottom of the sea. To quote Swallow in one of the issues of *Oceanus:* 'We were expecting something unusual on Discovery Station 5580 on September 11, 1964. It was near 21°N in the middle of the Red Sea, very close to the place where both the *Atlantis* in 1958 and the *Atlantis* II in 1963 had found abnormally hot salty water near the bottom. We had anchored a radar buoy in water about 2200 metres deep, and were putting down a closely-spaced cast of water bottles. Approaching the bottom, the one-second pinger on the wire below the bottles had gone out of step and then re-synchronized itself with the echo-sounder - a sure sign (with that particular pinger) that it had gone through a sudden change of temperature. But even then we found it hard to believe the thermometers when the bottles came up. All quite normal, around 22° C. to within 200 metres of the bottom, then 26° C then both thermometers went off scale (over 35° C), then again both protected thermometers went off scale but the unprotected [thermometer] showing 58° C. And so on. We did a second dip using only 60° unprotected thermometers on the deeper bottles - the only means we had of measuring the high temperature of the bottom water, which we found after correction to be about 44.3°C. This was far in excess of the 25.8°C found previously and which in itself had seemed abnormally high'.

Then the salinity turned out to be equally surprising. When water was being drawn from bottles that had been near the bottom, it seemed to run out more slowly than usual, and salinity at these holes was estimated to be extremely high, measuring about 270 parts per thousand, while the normal salinity of the Red Sea water varies between 38-40 parts per thousand. The origin of these warm-water and high-salinity holes was traced to the great rift valley which originates in East Africa and extends through the Red Sea and Gulf of Aden, since all this is an area of intense sea-floor spreading and the birth of an embryonic ocean. The overlain sediments in these hot holes were estimated to contain a high percentage of iron, manganese, zinc and copper. A Sudanese-Saudi joint commission, in collaboration with Germany, was looking for the possibility of exploiting these sediments for these metals.

Physical oceanography and meteorology: The scientists were astounded to see the see-saw game played by the monsoon winds with the surface currents. During the strong southwest monsoon season, the Somali current was raging towards the north and then northeast near 8°- 10°N. The current was strong, up to 7 knots (~3.6m/s), and its inner edge was close to the Somali shore, where the temperature of the surface waters was sometimes I6°C or less when the rest of the Arabian Sea was at nearly 30°C. It was also noticed that a strong set of the Somali current preceded the onset of the southwest monsoon along the west coast of India by almost a month, thereby indicating a possible relationship between the two events. Meteorologists and physical oceanographers now descended on the East African coast with many ships to study and unravel the Somali events vis-a-vis the Indian monsoons.

Biology and chemistry: The biologists were quite anxious to learn what sustainable yield of fish the Indian Ocean could provide and what were the productivity estimates and their translation into biological resources. Here again, the ship surveys covered upwelling regions and reported highest productivity rates in the Arabian Sea and off the northwest coast oi Australia. However, no new fishing grounds were discovered, but the biological surveys indicated areas for further detailed study. As a result, the Food and Agricultural Organization of the United Nations (FAO) constituted an Indian Ocean Fisheries Commission to help assess the fishery potential of the Indian Ocean.

At first sight, the massive Somali upwelling area appeared to promise rich fishing grounds, as is the case with other boundary currents elsewhere, as the Benguela, Peru and California currents, but it would appear that the high productivity recorded off the

Somali and Saudi Arabian coasts failed to reach massive production at the tertiary level: in practice, fish. Why? Perhaps we need to plan and execute another IIOE soon, to answer this question.

The chemical oceanographers did not have much to say about the nutrient distribution in the Indian Ocean, as compared to other oceans. A chemical front was recognized around 10°-20°S through which an increase in the nutrient content of the waters took place as one proceeded towards the northern Indian Ocean. Another important feature noticed was the existence of an oxygen-deficient layer (between 200 and 800m depth), in the Bay of Bengal and Arabian Sea, for which a convincing explanation is still to be found. In some places in the Arabian Sea, even the presence of hydrogen sulphide was recorded. It would appear that the development and persistence of an oxygen-minimum layer in large parts of the Bay of Bengal and the Arabian Sea is a curse on the northern Indian Ocean's productivity.

Conclusion

The IIOE - International Indian Ocean Expedition (1959-1965) - marks a watershed in the pursuit of knowledge of the Indian Ocean. The main results, briefly described above, further attracted the attention of scientists the world over to begin more detailed studies of selected areas, such as the Somali current, the mid-Indian Ocean ridges, the effects of monsoonal winds on surface currents, the productivity of the upwelling areas, geochemistry and geophysics etc. Some of these phenomena and processes are described in the following chapters.

The following three chapters deal with the environmental setting of the Indian Ocean: the origin and structural geology; the hydrography; and the nutrients.