"The International Indian Ocean Expedition"

by

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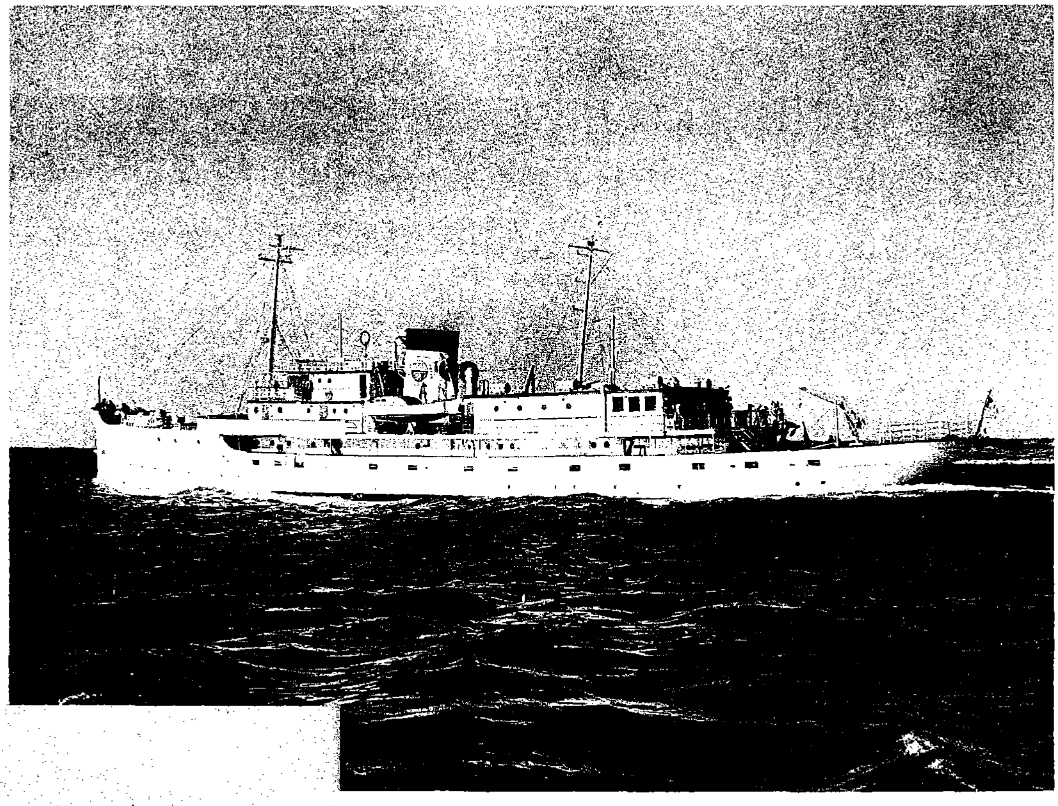
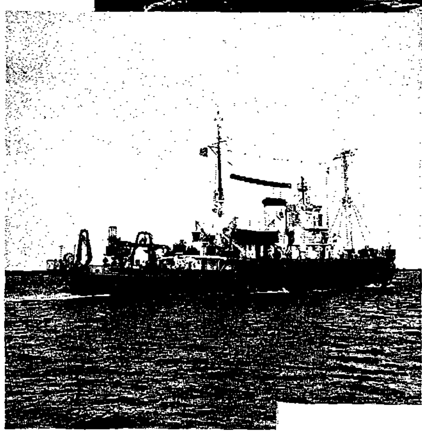


ANTON BRUUN



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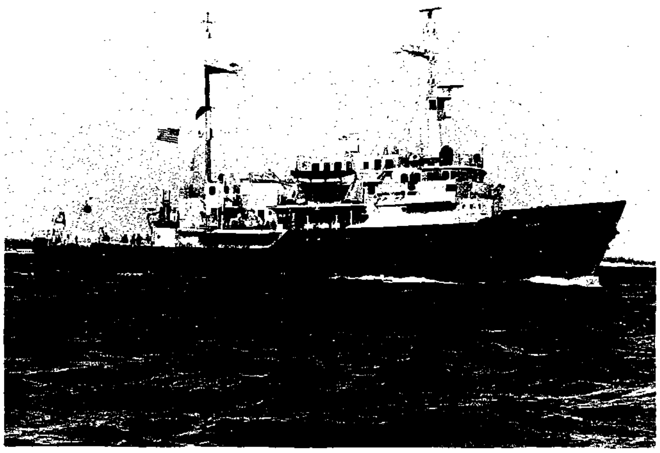

ATLANTIS II

"The International Indian Ocean Expedition"

Oceanography is the interdisciplinary scientific study of the oceans and all the phenomena, all the constituents, and all the living things contained within the oceans. It is a part of the sciences dealing with our earth and has developed, like all science, from a descriptive phase gradually into a phase in which there is a greater application of exact sciences. Although, it should be remembered that today oceanography is still in a comparatively early stage of its development into an exact science. Like all other sciences, its facts are obtained by observation. Initially these observations were of phenomena and conditions in the immediate neighborhood of continental coasts and islands. For many centuries, the conditions in the open sea were indefinite and uncertain and, as the studies progressed, it was inevitable that the new and spectacular were much more interesting than the normal everyday phenomena. As knowledge increased, men ceased to be content to recognize conditions and changes immediately around them; they sought more and more an insight into the natural phenomena occurring all over the earth and penetrated out into the vast stretches of the seas. There they gradually developed a conception of the oceans. Bold voyages of seamen gradually clarified the ideas about the earth and the confirmation of its spherical shape showed that the oceans were finite in size.

With the expansion of trade and commerce across the seas, our knowledge of surface conditions of the oceans grew considerably through the study of ships' logs and journals. In 1853, at an international conference in Brussels an American naval officer, Matthew Fontaine Maury, suggested that there should be an agreement on the form and content of these journals. This marked the beginning of extensive international cooperation in oceanography which continues today in an ever-growing and increasingly important way. Records of temperature, salinity, surface currents and tides were beginning to be compiled in hydrographic offices throughout the world.

However, journals of merchant ships, which were interested only in the fastest crossings between continents, were not sufficient to give a broad comprehension of oceanic phenomena. Remote parts of the ocean were not studied and, too often, phenomena occurring in these areas were important for a correct scientific assessment and comprehension of worldwide phenomena. Furthermore, a knowledge of conditions at the surface was wholly inadequate to an understanding of the large dynamic fluid systems of the oceans and the atmosphere.

It was only within the past century that studies of the oceans have been placed on a systematic and scientific basis. With the work of Matthew Fontaine Maury in this country, and with the CHALLENGER expedition from England in the 1870's, scientists began systematic collections of data and extensive oceanographic expeditions which have led to the studies we call oceanography today.

The great deep-sea expeditions at the end of the last century and the beginning of this century laid the foundations of modern oceanography. Over the years the character of these expeditions has undergone many changes. At first, they investigated only a section through the ocean along the route of the ship. It was not until the expedition into the Atlantic Ocean by the German Research Vessel METEOR in the 1920's that oceanographers had sufficient information to develop a three-dimensional conception of ocean phenomena through the systematic survey of a whole ocean basin. The results of the METEOR cruises were not equalled until the North and South Atlantic Oceans were again studied in great detail during the International Geophysical Year in 1956, '57 and '58.

Tonight, I want to tell you about another great oceanographic expedition; one which has been done in the tradition of the past great expeditions, but with all the tools available to modern oceanography. This is the International Indian Ocean Expedition, which constitutes the cooperative efforts of some 27 nations which have committed over 40 oceanographic research vessels to more than 70 cruises in the Indian Ocean over the past four years. It has been supported in this country by the National Science Foundation, the Navy, the Weather Bureau, the Bureau of Commercial Fisheries and the Coast and Geodetic Survey. Officially, the International Indian Ocean Expedition is being completed during the current year but it will be many years before all the data have been thoroughly analyzed and evaluated.

I have chosen to talk about this expedition for three reasons. First, it is typical of the type of oceanography currently being done at sea. Second, it represents the greatest effort in international cooperation ever undertaken in marine science. And, third, because I personally have had an opportunity to participate in a small way in this work.

The value of cooperative international oceanographic work was clearly demonstrated during the International Geophysical Year. The idea of an international program of studies in the Indian Ocean, consisting of cooperative synoptic observations, was proposed by SCOR, the Scientific Committee on Oceanic Research of the International Council of Scientific Unions. The Indian Ocean was chosen for this major effort because it was an ocean about which very little was known. True, commerce had been traversing its stormy surfaces and man had been fishing its banks and shelves for many centuries. There had even been a number of expeditions which passed through its waters, making such observations as opportunity provided, but there had never been a systematic study of this vast region of the world. Even though it is a part of the world which supported the earliest civilizations, we had learned little about the natural phenomena that occur there. The charts and sailing directions are some of the most primitive in the entire world. The surrounding countries, which are just now beginning to develop a competence in oceanic research, had lacked the ability to do more than limited surveys in waters immediately adjacent to their coasts. Also, this is a hungry part of the world. Despite an acute protein deficiency, no adequate survey of the food resources of the Indian Ocean had been made, or more importantly, of the factors which control the distribution and abundance of life in these waters. The nations of Asia and Africa which border the Indian Ocean were anxious for assistance and for a better understanding of the environment in which they live. They believed that fuller knowledge of the resources of the Indian Ocean could provide a basis for the solution of some of their problems. The areas around the Indian Ocean represent areas of greatest extremes in drought and rainfall and the largest seasonal swings from rainy seasons to hot, dry dusty days.

Some idea of the extent of the total effort involved in the International Indian Ocean Expedition can be seen from this chart; this does not represent all of the cruises planned for the expedition, but does display the principal cruises of the key nations involved in the expedition. These include Australia, France, Germany, India, Indonesia, Japan, Pakistan, Portugal, South Africa, Thailand, Russia, the United Kingdom and the United States. The seasons of the year and the scientific disciplines which represent the major mission of a given cruise are shown in different colors. This chart may give you the impression that there has been one large traffic jam of research ships in the Indian Ocean. I should point out that since the expedition has been spread over a number of years and since it is quite a large ocean, it is a rare occasion, indeed, when two scientific ships have met.

I shall make no pretense of giving you an over-all assessment of this great expedition. The work is too recent and some of it, as you shall see, is still underway. I will talk principally about the participation of my own laboratory, the Woods Hole Oceanographic Institution, in this expedition. Consequently, I will only talk about the work of three of these research ships.

The responsibility for the participation of the United States in this international expedition was assumed by the National Academy of Sciences'

Committee on Oceanography, which in turn established a number of working groups in different scientific disciplines. The working group in biology recommended that a major oceanographic vessel be especially equipped for biological oceanography. Under the sponsorship of the National Science Foundation, the former Presidential yacht, WILLIAMSBURG, was converted to a research vessel and re-named the ANTON BRUUN in honor of the famous Norwegian oceanographer. Under the chairmanship of Dr. John H. Ryther of our Institution, shown here on the right listening to Madame Pandit welcome the ANTON BRUUN to India, the National Committee planned and carried out nine extensive cruises during the past two years. The work of this nation-wide program encompassed an intensive biological survey in the Bay of Bengal and in the western Indian Ocean from the continent south to 40° South latitude. About 150 scientists were selected from over 300 applicants to take part in these cruises; these scientists have been predominantly American, but the groups have included participants from 12 other countries. In this work, as in all other aspects of the expedition, the scientific leaders from countries bordering the Indian Ocean have been consulted and arrangements have been made for taking guest scientists from these countries along on the cruises. A principal leader in this planning has been Dr. Panikkar, the Indian representative to SCOR. The ANTON BRUUN was converted from a plush Presidential yacht to a working research vessel, in accordance with plans developed at our Institution in Woods Hole and with funds provided from the National Science Foundation. Comfortable quarters for 27 scientists were arranged and excellent laboratories for chemical and biological work were provided. The ship was equipped to permit all types of biological oceanographic research from microbiology in the laboratory to sampling and experimentation with larger pelagic fishes. For the first time, the taxonomist and the ecologist were able to make a systematic study of the deep-sea biota, both benthic and planktonic. Major objectives of the cruises of the ANTON BRUUN were to study the physical-chemical properties of the Indian Ocean and to relate these to the primary productivity and plankton biology of the region. Many types of fishing were used to assess the fisheries resources, both along the continental shelves and in the deeper portions of the western basin. Here we see the otter boards which serve as paravanes for large trawl nets going over the side of the ship. Another technique which was used was that of long-lining; the complex system of lines needed for this are partly shown on the fantail of the ANTON BRUUN in this slide. This is a system developed extensively by the Japanese for commercial fishing in the Pacific in which a surface line extending for miles in length across the ocean has dangling from it short lengths of line which are terminated in baited hooks. In some instances, the surface line may be 5, 6 or 7 miles long. The beginning end of the line has a sea anchor attached to it to keep the line taut and the following end is finally floated on a small buoy. After putting out the entire system of line, the ship goes to the forward end to begin reaping the harvest. Since this method sweeps out a broad section of ocean, it is particularly useful in evaluating something of the statistics of fish populations.

It is interesting to note that some of the richest areas of the world exist in the Indian Ocean. In spite of this, the methods of fishing have changed little since the time of Christ.

All life in the ocean, just as on the land, depends upon the photosynthetic process by which the chlorophyl of the green plants fix carbon by the manufacture of carbohydrates from CO_2 and H_2O. In the ocean, photosynthesis occurs principally in tiny one-celled plants called phytoplankton located in the sunlit area near the water surface. These small plants as well as tiny floating animals - the zooplankton - are collected at regular intervals by dragging a fine net through the water while the ship is underway. In addition, samples of water are collected by means of the Van Dorn bottle at depths down through the sunlit areas and below to about 200 meters. These samples permit a measurement of the total phytoplankton in the water, as well as measurements of chlorophyl and chlorophyl a. These measurements provide our best basis for estimating the food resources and total biological productivity of the oceans.

The area of the Arabian Sea along the Saudi Arabian coast showed the highest productivity ever observed in the oceans. Here we find that as much as 6 grams of carbon was converted from carbon dioxide to plant carbohydrates under each square meter of ocean per day. This would average out to something more than 2 kilograms of carbon per square meter being fixed over the period of a year. This is a hundred times greater than in some other portions of the Indian Ocean and approximately 20 times larger than the average for the oceans as a whole. This high productivity results, at least in part, from the fact that there is a great upwelling of bottom water along this coast. The strong monsoon winds blow the surface water away from the shore along this coast, and this results in the flow of bottom water to the surface. On this slide, we have shown the constant temperature lines for the water out some distance from the Arabian coast. Here, we can see that the surface water has moved up from a depth of about 150 meters offshore into the surface along the shore. This is strikingly evident when bathing in this water, which is cooler than the water 200 miles offshore by five to eight degrees. I suspect this cool, comfortable water must be greatly appreciated by the people living in these hot desert climates.

In the life cycle occurring in the ocean, with death and decay, material falls gradually to the ocean floor, and this material can be brought to the surface only through such an upwelling process. This is the way the ocean has of refertilizing itself--returning the nutrients to the sunlit area where they can once again be useful in the food chain of the ocean. Thus, the upwelling of bottom water along the Arabian coast brings nutrients back to the surface. Note the enrichment of phosphates and oxygen shown on the lower two graphs. This results in a very rich area indeed which has been exploited only in a minor way so far.

Turning from the biological work, I would like to describe briefly the work of a very different character which will illustrate the great variety of work which has been done as a part of this whole expedition. Geophysical investigations of the northern Somali basin and of the Seychelles-Mauritius ridge were carried out by a group from Woods Hole on board our Research Vessel CHAIN during this past spring. Since the purpose of the cruise of the CHAIN was primarily to study the bottom characteristics and the sub-bottom features of the western portion of the Indian Ocean, we have shown a cruise track drawn on a portion of the topographic chart prepared by Professor Heezen of Columbia University. The complete chart is posted for your closer inspection. We went from the mouth of the Red Sea, down across the Somali basin to the Seychelles Island. Then we made seven crossings of the Seychelles-Mauritius ridge and returned northward after putting in at Mauritius. While underway, continuous measurements of water depth were made by means of a precision Fathometer. Also, continuous measurements of free air gravity anomalies were made by means of a La Coste-Romberg gravimeter, and continuous measurements of total field magnetic anomalies were taken while underway by means of a proton resonance magnetometer.

Just as it is possible to measure water depth by bouncing echoes off the bottom, it is also possible to determine something about the structure of the earth beneath the bottom by the echoes reflected from sub-bottom features using a more intensive sound source. For this purpose, we used a high-energy 100,000 joule spark discharge under water to give a continuous record of the deeper sub-sea floor structure. Note the rock layer made apparent by this technique on the slide. Bottom samples were obtained by coring and by use of the rock dredge, and underwater photographs contributed significantly to the findings. The method of developing a strip photo of the bottom through a mosaic of single snapshots, which had been developed so extensively during the THRESHER hunt, was used very successfully along the Seychelles-Mauritius ridge and is illustrated in this picture. The mosaic shows quite clearly that a considerable area of the bottom consists of an outcrop of nearly horizontally layered rocks which, in view of the material found in the rock dredges, was considered to be limestone. The ripple marks, shown here, clearly indicate a bottom current at this depth of about 3200 meters.

Briefly, it was found that the northern portion of the Somali basin is a deep sedimentary basin partially enclosed to the east by a submarine ridge, which had previously been believed to be but a few isolated sea mounts, and to the south by partially buried abyssal hills. The Seychelles-Mauritius ridge is composed of two sections; the northern section consists of the horizontally stratified rocks seen in the photograph, whereas the southern section appears to be volcanic in nature. The fact that much of the Seychelles Island is made up of granite, which is commonly found on the continents and not on marine islands, raises the question, again, of whether or not this island chain was once a part of a continental land mass and brings to the fore the interesting question of continental drift.

But these features of the ocean basin will not change with seasons or be effected by the shift of the monsoon winds. And it is primarily of winds and currents that I would talk about this evening.

To illustrate this I would like to tell you about the work on board the Woods Hole research vessel ATLANTIS II. This is the work which I know best since I participated in it and was on board during the final legs of this cruise of ATLANTIS II in the Indian Ocean about a year ago. This is a new ship which has been the queen of our fleet in Woods Hole for the past two years. It was designed and planned by our own staff and built with funds provided by a grant from the National Science Foundation. It is one of the few research ships in the United States which has been designed uniquely for oceanography. Here are a few views of the ship which show some of its special features. From the bulbous bow where one can observe life beneath the sea surface through five heavily glassed portholes-to the top of the enclosed crow's next; from the spacious bridge with its delightful bay windows to the even more spacious laboratories, this ship has been carefully designed for the work it has to do. There are four large laboratories on board at deck levels - one above the other, with easy access one to another through connecting stairways and equipment elevators. Even though large when compared to laboratories on any of our other ships, they are still crowded with scientific equipment when the ship is ready to sail. The comfortable staterooms provide each of the 25 scientists on board a place for desk work as well as a place to sleep. The Martin Pollack Memorial Library is a special feature on this ship which has been enjoyed by all scientists and crew members alike. It contains a large selection of scientific books as well as fiction for entertainment during long days at sea.

The sailing of ATLANTIS II for the Indian Ocean had been somewhat delayed by the unhappy but necessary job of hunting for the lost submarine THRESHER. So it was with a great rush that she left Woods Hole early in July so as not to miss the southwest monsoon season in the Indian Ocean. The monsoons come and go with great regularity and, as you will see, this was a very important element in our planning. One of our advisors who knows this part of the world well, but had not been aware of our plans said to me "but why are you going now? This is the worst possible time in the Indian Ocean." Fortunately we accomplished our purpose of arriving during the monsoons and we did not miss the rough weather. In fact, this proved to be an excellent test of our anti-rolling tanks and large stabilizing bilge keels. The ship rode out the storms beautifully and whereas it was not always pleasant - and she did not always cruise between stations at top speed - not a single hydrogrographic station was missed or even delayed because of the weather. This in part was due to the high maneuverability built into the ship both from the twin screws which propel her and from the special bow thruster which permits maintaining our heading while hove to on stations.

In addition to the several reasons I have already cited for the Indian Ocean studies, there is a very special reason why this ocean is of unique interest to us in Woods Hole. For more than three decades a main theme of our work in Woods Hole has been the study of the currents of the world. The Gulf Stream which we almost consider our own private river (although in recent years the Russians could well dispute this) has been investigated repeatedly. As you all know, the greatest rivers in the world are in the oceans. For example, the flow of the Gulf Stream which is approximately 80 million cubic meters of water each second represents a volume which is equal to some 5,000 Mississippi Rivers.

There are many complex reasons for the great currents of the world, not all of which are fully understood. The differential heating at the poles and the equator produces thermal and density gradients which produce dense bottom water at the poles and an upwelling at the equator. The earth's rotation causes currents to flow generally in a clockwise direction in the northern hemisphere and counterclockwise in the southern. The great steady wind systems, such as the westerlies and the trade winds drive large masses of water before them. In the Indian Ocean the situation is unique. For almost four months in the summer the monsoon winds blow strongly out of the southwest. From the hot dry lands of the African continent across the northwestern sector of the Indian Ocean across the Arabian Sea and then over India these winds often result in extensive and disastrous rains during the rainy season. With the approach of the winter and after a lull, the winds reverse and blow strong out of the northeast from India across the ocean to Africa during the months of December through March.

Thus, nature has provided a classical textbook type of experiment for us to use in an attempt to answer more specifically the effect of the winds in driving ocean currents. Indeed it was the possibility of just this investigation that triggered the entire Indian Ocean Expedition. Then with the development of extensive plans for biology and geophysics and many other disciplines, this almost seemed forgotten; for of all the ships participating in the Expedition only ATLANTIS II and DISCOVERY from England have undertaken extensive work related to the study of wind-driven currents.

But how do we measure currents out in the deep ocean with no reference points for markers. The first observation of ocean currents was obtained from the drifting of floating objects, such as logs and debris. On our own West Coast it is not uncommon to find glass balls which Japanese fishermen use as floats for their nets. This indicates that in the Pacific there are currents flowing from west to east. The fact that there were currents flowing across the northern top of the world was first evidenced by the recovery in 1884 off southwest Greenland of equipment and documents from the barque Jeanette which was crushed in the ice just northeast of the New Siberian Islands some three years earlier. Today we still make use of drifting objects - the drift bottle shown here has been systematically used since the early 1800's as an indication of surface currents. Through the cooperation of Coast Guard weather ships and lightships we still set out over 20,000 drift bottles each year from our laboratory in Woods Hole and recover about 10% of them. An improved version of the drift bottle is shown by this plastic flower which is more colorful and thus more easily seen along the shore. The plastic flower exists in two forms - one which floats just beneath the surface of the water and another which will drift along the bottom by having a small weight added to it to compensate for its buoyancy. In either case, we attach a card with a serial number to the drifting object and ask the finder to return this card to us indicating the time and location of the finding. Thus knowing the launch point of each bottle we have two points of reference on the path of the current - the point from which the bottle was launched and the end point at which it was recovered. We know nothing about the intermediate path between these points from these observations and can only make an estimate of minimum velocity because we do not know how long the drifter has been on the beach before it was picked up.

A more modern version of the drift bottle consists of a surface buoy which contains a radio receiver and transmitter. This buoy when set out on the surface of the ocean floats with the current can be tracked by ship or airplane. The radio receiver turns on a homing beacon when triggered by the search craft thus permitting the location of the buoy to be determined at regular intervals. The obvious advantage is that we are now able to obtain information about the course of the current which is not available from the old fashioned drift bottle method.

Deeper currents may be measured by use of an underwater drogue. The drogue sketched here was made from a surplus Army cargo parachute, which was 64 ft. in diameter. This large surface produces so much drag in the water that the drag of the supporting surface buoy and connecting cable is completely negligible. At the surface the buoy supporting the drogue can be tracked by the ship again by means of a radio link. Here we see a buoy moving along the surface at some 3 knots being propelled by a strong underwater current. This was dramatic evidence of a current deep below the surface since it was going in a direction opposite to the surface current in which the ship was drifting.

The most extensive knowledge of world currents has been from information obtained on hydrographic stations. The basic information required is a measure of water density which can be calculated by measuring the temperature and salinity of the water. If the complete distribution of density throughout a region is known, currents can be calculated by using classical hydrodynamics. The collection of water samples from deep within the ocean is accomplished by means of the Nansen bottle while the ship is hove to on station. At each hydrographic station, after the ship has been brought into the wind and is motionless in the water, 20 to 30 samples of ocean water will be obtained at depth intervals of 100-200 meters from the surface to the bottom of the ocean. To do this Nansen bottles are attached at measured intervals to a 5/16 inch stainless steel wire from the winch shown on this slide. Here you can see the oceanographer attaching the Nansen bottle to the wire and on the deck above you see the starboard wing of ATLANTIS II where the deck officer has complete control of the ship. At this point, and at four other points on the ship a single man can control the engines, the rudder and the bow thruster without assistance from the engineers in the engine room or the helmsman on the bridge. Since we are lowering objects all the way to the bottom of the ocean several miles deep, it is important for the officer in charge to maneuver the ship so as to keep this wire vertical, which he can readily do from this vantage point where he can see the wire going into the water.

Since it is desired to lower the string of Nansen bottles attached to the wire so that the lowermost bottle takes a sample of water close to the bottom of the ocean, we have placed a noisemaker called a "pinger" at the end of the wire. This is a little instrument which emits a ping periodically. From the sound of the ping as it comes back to the ship both by a direct path and by bouncing off the bottom you can tell quite precisely how far the end of the wire is away from the bottom. As you can see in this record of the pinger approaching the bottom, the recorded underwater sound signals provide the operator with the capability of maneuvering the lowermost bottle to within a few feet of the ocean bottom which may be three or four miles beneath the ship. While being lowered the Nansen bottle is open at both ends, thus it is flushed thoroughly by ocean water during its descent. After it is in position in depth, a copper cylinder slides down the wire tripping the top bottle by releasing a catch at the top of the bottle which permits the bottle to turn upside down. It is then held on the wire only by the bottom attachment. In overturning two valves, one at the top and one at the bottom of the bottle are closed trapping a sample of water inside. When the bottle turns upside down two thermometers on the outside of the bottle have their columns of mercury interrupted fixing precisely the amount of mercury retained in the bulbs. One of these thermometers is protected from the great pressures of the ocean by being encased in steel. This thermometer reads the true temperature of the water. The other thermometer is open to the sea and thus reacts both to the sea temperature and to the pressure. The difference between the two readings permits us to calculate the depth at which the water sample was obtained. In the laboratory about half a liter of water is drawn off from the bottles for analyses of salinity, oxygen, phosphates, nitrates, and occasionally nitrites, ammonia and silicates.

All told over 200 hydrographic stations were completed between the time ATLANTIS II sailed through the Suez Canal and when she arrived at the tip of the Cape of Good Hope. The locations of these stations are shown by the dots on this slide. Over 5,000 samples of Indian Ocean water were thus obtained for analysis.

There are a number of other ways by which ocean currents can be observed directly or inferred from other measurements. Since the flow is often from warm regions of the world to cold or vice versa, the measurement of water temperature is a good way to delineate the edges of the stream. To illustrate this, think again about the Gulf Stream which flows along our eastern continental shelf. It begins along the Florida coast flowing northward up along Cape Hatteras and then northeast out along the Grand Banks turning eastward south of Newfoundland. Since this great volume of water comes from warmer waters into cold it is very easy to determine the boundary of this current by simply measuring the temperature of the water. A record of the temperature of the water from the surface down to 300 meters is obtained every hour on our ships by means of an instrument called a bathythermograph or BT. The plotting of the constant temperature lines called isotherms readily shows the sharpness of the shear and the extent of the current system. As the Gulf Stream flows into the colder northern waters sharp temperature changes as much as 10° may be observed over very short distances.

Obviously it would be highly desirable to measure currents directly rather than to infer them from such indirect measurements. Here we see a meter designed for measuring ocean currents. At the top of the meter, we see a vane which will indicate the direction of the current and at the bottom of the meter a Savonius rotor which indicates the magnitude of the current. In order to make an absolute measurement of currents with such an instrument, it is necessary to have a reference point against which the motion of the total regime can be referred. If this is not possible, two instruments one above another can be used to determine the horizontal shear in the water. In the use of this instrument on ATLANTIS II, the information was recorded directly on the ship by means of electrical cables connecting the ship with the instrument in the water. Another use is to package a recorder with the velocity meter and to suspend them under buoys such as the one shown here in the deep ocean by means of a mooring running to a bottom anchor.

In any such direct measurement of current, the most difficult part of the measurement is the determination of a reference point. Sufficiently accurate measurements of ship's drift over a short period are most difficult. For example, while off Zulu land one day I decided we would attempt to make a direct measurement of current using visual and radar highlights on the shore. After bringing the current meter back on board having been on station for about an hour we found we had measured a current of about 1/2 a knot plus or minus 1 knot since the ship had an uncertainty in position of about 1 mile during the measurement. This may sound completely foolish and is certainly a very poor measurement indeed, but realizing that no estimates of currents had been made previously in this part of the world it did permit us to set some limitations upon the magnitude of the current.

In order to improve our ability to navigate and, in particular, to dead-reckon the position of the ship while making such measurements we have developed a new method of navigation. This system makes use of the high power, low-frequency radio stations which the United States Navy has built for world-wide communication. These radio stations transmit at frequencies ranging from 14 to 20 kilocycles. The frequency of the station is very precisely controlled by atomic clocks. By putting a very precise clock and a special radio receiver which can be phase-locked on to the received signal on board the ship, a method of navigation from any known fixed point on earth becomes possible. The clock on board consists of an oscillator which is able to keep time to better one part in (10^{10}), which represents a variation of about 1 second in three hundred years. The procedure is to zero in on two or more such radio stations while in port and then to measure the difference in travel time of the radio signal from the radio to the ship while the ship is underway. The change in travel time for each mile of distance between the ship and the station is about 6 microseconds. Hence, if we can measure time to a microsecond, we have an accuracy of navigation to 1/6 mile. This was the kind of accuracy observed near home, but not at a distance of 8 to 10 thousand miles from the stations while we were in the southern part of the Indian Ocean. In the next slide we see an example of a record taken while the ship was underway. In this instance, we were listening to radio stations in Ruggby, England, and in the Panama Canal zone. As the ship proceeded further away from the radio station, the record shows the increase of travel time by the diagonal line across the chart. Each time the ship moved 16 miles further from the station, the record makes a full swing across the chart paper. The almost horizontal portion of the record shows the slow drift of the ship while on station. Stations available for this world-wide navigation system are located in Maine, in Annapolis, Maryland, Colorado, state of Washington and in Hawaii. Each system of precise navigation has its own peculiarities and difficulties. In this system the path of the radio signal varies from night to day because of the expansion of the ionosphere at night. This diurnal effect produces a slow drift of the record starting at sunrise or sunset at the radio station and continuing until sunrise or sunset at the ship. So far the system has been most useful for the determination of ship's drift while on station. We have just installed a radio receiver on ATLANTIS II permitting us to make use of the Navy's satellite navigation system and hope this will solve much of our navigation problem.

To show you how an oceanographer looks at the ocean, I have photographed two examples of the worksheets as they were plotted on board ATLANTIS II. These are vertical sections of the ocean with depth plotted vertically and distance horizontally. First, a plot of the constant temperature lines called isotherms from the Somali coast eastward along the 10° N latitude. Close to the shore at the left, the isotherms climb steeply showing an upwelling of deeper water and a current flowing to the north. Further to the east, we see evidence of a current flowing to the south. In fact the complete analysis of the data from all the hydrographic stations indicates that there is a northward current flowing along the coast, with a southern countercurrent about 300 miles off the coast. Alternating bands of north flowing and south flowing currents recur at varying intervals across the entire extent of the northwestern Indian Ocean. Here we see an indication of the mass transport of water in these bands. The Somali current flowing close along the shore to the north is a major current having about 1/3 the volume of flow that is in the Gulf Stream. It is a broad current about 150 miles across and as deep as 1,000 meters so that it does not appear to be solely a wind-driven current. Incidentally the current direction to the northeast along the coast was opposite the direction for currents shown on the pilot charts, and we may find that it reverses itself in the winter monsson season. The next section shows this current even more sharply in depth. This is a plot of the oxygen content in the same section of water, again a vertical section cut through the ocean.

Since we were trying to relate the current systems to the monsoon winds, it was of obvious importance to make extensive meteorological observations during the period when the currents were being measured. Before sending out ATLANTIS II we had surveyed the wind system quite extensively by means of our research aircraft. We were surprised to find that the monsoon winds extended only about 1,000 meters above the sea service. This is a very shallow wind system especially for such strong winds and what we appear to have can be described essentially as a giant sea breeze. Even though the cloud cover was heavy all through this part of the ocean during the monsoon season, the rain over the ocean was almost negligible. We went prepared to measure rainfall and the rain gauges seldom had enough water in them to permit a measurement. At the same time there were heavy rains all over India to such an extent that the waters of the Bay of Bengal were measurably less salty than other waters.

Even though we had mapped out the extent of the monsoon wind system using our flying laboratory before ATLANTIS II arrived, it was still essential to make extensive meteorological observations from the ship. Weather balloons carrying a radiosonde were sent up daily. During the ascent of the balloon to about 100,000 feet where it would burst, temperature, pressure and humidity were radioed back to the ship. On good days when the position of the ship was sufficiently well known, the stratification of wind could be measured by observing the path of the ascent of the balloon. Many other types of meteorological observations were made including radiation and evaporation studies which should tell us something about the energy exchange between the air and the water. On the top deck, we carried a cloud camera which took a complete horizon-to-horizon picture of the clouds in the sky during the daylight hours every couple of minutes. This is a view of our home port used as a calibration picture before leaving. It shows a complete 360° view of the sky from the Woods Hole dock. Our laboratory buildings are shown in unusual perspective at the bottom of the picture.

But studying the Indian Ocean currents during the summer monsoon is obviously only half the story. This is the reason that one week ago today ATLANTIS II left Woods Hole again for the Indian Ocean where similar measurements will be made during the winter monsoon season. After six months in the Indian Ocean she will continue on to Australia, the Philippines and Japan; then home by way of the Pacific and the Panama Canal. By that time we hope to know a great deal about the Indian Ocean and have a better understanding of the environment of the peoples who live in this part of the world.

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