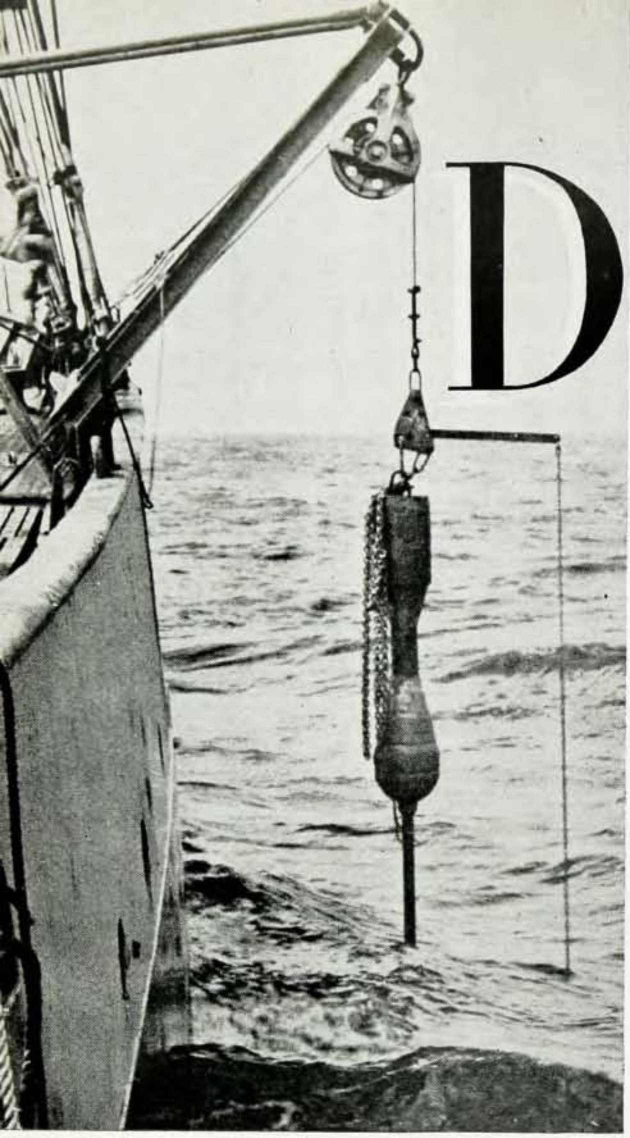

DOWN TO THE SEA

by ***Columbus O'D. Iselin***

Salt-water physicists, and those land-locked too, are bringing modern instrumentation to bear on studies of the ocean.

Physical oceanography has been, until recently, the most unsuccessful of the geophysical sciences in enlisting the aid of physicists. Laboratory-trained, they have preferred to remain in their laboratories rather than set up their instruments in as unfavorable an environment as a small vessel. This has been exasperating to that small group of scientists having a burning desire to understand the physical aspects of the earth and its surrounding atmosphere.

In oceanography the break came during World War II, when it was found that in many and unexpected ways the environment can become the limiting factor in the use of complicated military devices. And thus in many different ways the earth scientists and the physicists found themselves drawn together to achieve highly practical goals. Having gotten to know each other in war, successful collaboration on more basic problems is being continued in peace, often with the financial encouragement of the Government.

The Government has a special interest in the earth sciences, not only for military reasons, but also because nature in so many ways affects the lives of the people. In the case of meteorology this is very obvious. The importance of oceanography to the Government, though less evident at first glance, has many more ramifications, especially when the term is so broadly defined as to include all the scientific problems of the parts of the earth covered by salt water. Science does not stop at the beach.

Oceanography

Beyond the beach, in most investigations, science must take to ships. But a very practical difficulty pops up: scientists as a rule are not notably seaworthy. In this respect, physicists have a particularly low score. To secure the aid of a few physicists in oceanography, it has been necessary to test a considerable number of reluctant candidates. It must be admitted that oceanographers have taken an unkind delight in watching the sufferings of highly competent, laboratory-trained scientists when they first try to go to sea. Fortunately for oceanography, a few have been found with sufficiently strong stomachs.

Probably another and more important deterrent to physicists has been that the tools and the facilities of oceanography seemed so hopelessly primitive. For many years oceanographers tried to get along with little more than a bucket, a net, and a thermometer. It was not that they did not know that more elaborate instruments existed, it was simply that they could seldom afford them. Until recently, it was rare indeed even to find a supply of AC current on an oceanographic vessel. But Government money became available to oceanography as a result of the war, and the vessels and laboratories are now relatively well supplied with the basic tools and instruments. Moreover, oceanographers have acquired the use of a number of elaborate devices originally developed for and by the Navy. Today our research vessels contain enough bulky electronics equipment to satisfy all but the most sophisticated physicist.

The central problem in oceanography is to understand the circulation of the ocean. This is not only an interesting study in its own right, but without such knowledge most other scientific problems in the sea cannot be advanced beyond a rather primitive stage. The currents, of course, profoundly affect the distribution of life in the sea and the distribution of nutrients on which this life depends. Gradual or sudden changes in the circulation of the waters can have important biological consequences. What are the causes of such changes and how can they be predicted? It is the answer to these two main questions that is sought.

Dissolved in the sea are most of the nutrient chemicals that have washed off the land since the beginning of time. Because animals and plants tend to sink when they die, these nutrients tend to collect below the depth to which light can penetrate. For the surface layer of the sea to be productive, some mechanism must exist to return the deeper waters to the surface. In this respect the winter storms serve somewhat the function of a plow. They restore the fertility of the surface layer, but they are also greatly aided by the slow, gradual circulation of the sea as a whole.

The currents in the ocean derive most of their energy from the winds. The effects of land drainage, of heating and cooling, and of evaporation and precipitation all play a part; but it is the steady winds of the trade-wind latitudes that drive the major ocean currents. In turn the ocean acts as a regulator of climate. We ordinarily think of meteorology as a land-based science. But the oceans cover nearly three-quarters of the earth's surface and water has a tremendous capacity for heat, compared to the atmosphere. Thus in all probability the problem of forecasting climatic trends, and the problem of understanding the decay and development of storms, is intimately bound up with physical oceanography.

The sediments on the bottom of the ocean also are influenced by the currents, by the climate, and by the strong winds. In the deep ocean, remote from the land, the sediments accumulate relatively slowly

and remain undisturbed for long periods of time. Thus from cores of the bottom sediments much of the past history of the earth can probably be worked out. Oceanographers have only recently learned how to collect long cores of bottom material in deep water. The study of these samples has not only been most stimulating to submarine geology, but it is also beginning to present the student of ocean circulation with a whole new series of problems. What was the distribution of temperature in the ocean in the past and how did the general pattern of the currents differ from that prevailing today?

To date, model studies have not been particularly helpful to our understanding of ocean circulation. The effects of the earth's rotation are all important to the character of these currents, and the horizontal dimensions of the sea are huge relative to its depth. Progress has mainly depended on theoretical studies and on indirect observations of the water movements. Direct observations with mechanical current meters in deep water are impractical. In studying the permanent currents, most oceanographers have relied in the past on gaining a measure of the internal distribution of density in the sea. The primary data are observations of temperature and salinity, usually made at right angles to the expected flow of the water. From these the cross-current pressure gradient can be computed and compared with the available theory. The great weakness of such studies has been the lack of any reliable surface-current data. All we have had were rather crude compilations of average currents derived from ships' logs. Fortunately, with the help of modern radio navigational techniques, this is beginning to change.

Tracking Currents

Once out of sight of land, the first problem of an oceanographer is to know where he is. Many of the navigational problems of the past have now been solved by Loran, a system of radio pulses from fixed stations on shore that allows a ship to fix its position by triangulation. Although the distribution of Loran stations is dictated by the needs of air traffic and commercial shipping, at least over very considerable areas of the North Atlantic, it is now possible for oceanographers to obtain frequent, accurate fixes.

The accuracy of an individual Loran reading, though a great improvement over celestial navigation from small vessels, is subject to various errors which combine to make an uncertainty of half a mile or more, depending on where one is. However, it is possible to determine more reliably how the ship is moving relative to the Loran stations. In observing the direction and velocity of the surface currents, two different methods may be employed with great success. The receiver may be left turned on and the course of the vessel adjusted at frequent intervals to keep the time interval of the received signals constant; or the course can be kept constant and frequent fixes recorded. In either case, the difference between the dead reckoning positions and the course as determined by Loran is due to the currents. When relatively strong currents are encountered by a slow ship, they are easily determined this way with useful accuracy. As a result an oceanographic vessel can now follow a current by tacking in and out of it and thus determine its course as well as the horizontal changes in velocity. Such studies of the large-scale pattern of circulation in the ocean have been greatly facilitated by the bathythermograph, an instrument which records temperatures as a function of depth down to several hundred meters from a vessel proceeding at normal speed. All of this is of great interest to oceanographers, who until now have had to be satisfied with indirect and crude means of studying currents.

The use of Loran to date along the course of the Gulf Stream has shown that the current is considerably narrower and swifter than had been supposed. Larger meanders in the current have been found in the sector off New England and powerful eddies have been observed to form on either side. The bathythermograph has disclosed in a very satisfactory manner the smaller-scale temperature structure associated with these currents.

Sea Floor

Having gained a means of navigating with considerable assurance, the scientific usefulness of recording sonic sounding machines has been greatly increased. It is now practical for a single vessel to work out the shape of the larger, deeply submerged structures such as sea mounts and canyons. Within the area where Loran can be used, combining soundings made by different vessels can be expected to reveal the bottom topography in useful detail from the geological standpoint. Before long we can hope that the bottom topography of the oceans will be known with something approaching the accuracy obtained on land.

The areas thus far investigated show that much of the bottom of the ocean is surprisingly rough, that many flat-topped sea mounts exist, and that terraces and cliffs are common along submerged slopes. As a case in point, within the last few months, a sea mount has been located about halfway between Cape Cod and Bermuda in an area which had been comparatively well sounded by the old-fashioned wire technique.

It has been known for some time that on the continental shelf the sonic sounder sometimes records reflections from below the bottom. Soft mud is relatively transparent to high-frequency sound so that over pockets in the Gulf of Maine, for example, weak echoes are obtained from the surface of the mud and stronger ones from the firmer bottom under the mud. Thicknesses of as much as 60 feet have frequently been recorded with standard sounding equipment.

Recently, with much more sensitive equipment, corresponding observations have been obtained in the main ocean basins, where in contrast with the Gulf of Maine the bottom has not recently been scoured by glaciers. Using a small explosion as the sound source, reflections have been obtained from the bottom itself and from considerable distances below the bottom. These observations show that over much of the basin of the western North Atlantic several thousand feet of unconsolidate material has accumulated.

Much to the astonishment of oceanographers, the geophysicists who have gone to sea have been able to proceed almost as though the water were not there at all. (The same techniques of refraction and reflection shooting that have been used so successfully on land in oil geology can be worked at sea with surprising ease.) True, they load the research vessel with explosives and fill her laboratory space with electronics equipment, but so far nobody has been hurt. And gradually the shape and character of the real bottom of the ocean is being revealed.

Sea Crops

During the last war, great advances were made in underwater acoustics. The transmission of sound in sea water is influenced by the distribution of its physical properties, by reflections from the boundaries of the water, and by scattering from within the water mass. As these and other factors become more clearly understood, sound can be used as an effective tool in oceanography. In Norway a standard echo sounding machine is being used successfully to locate shoals of codfish. In France with the additional help of echo ranging equipment, the distribution and habits of several of the more plentiful species of fish are being studied. The use of sound in biological oceanography is still in its infancy, but much can be expected of it in the near future.

It has been observed, for example, that over wide areas of the ocean by day weak echoes are returned from a layer two or three hundred fathoms beneath the surface. At night this so-called scattering layer is much more diffuse and much nearer the surface. A regular diurnal migration is involved, the layer reforming and moving down at sunrise and returning to near the surface after dark. It is believed that the controlling organisms are certain species of shrimp, but it is not known for certain whether the shrimp scatter the sound or whether the echoes are returned by larger animals feeding on the shrimp. Here may be found a vast population of animals which has been eluding the rather inefficient nets of the marine biologists. Few commercial fisherman, of course, have yet tried to develop fisheries at any such depths, so that it is quite possible that there remains a huge supply of food in the ocean which is sufficiently concentrated, at least by day, so that it could be caught economically. Obviously, this possibility should be quickly and thoroughly investigated.

It is generally agreed that on an annual basis an acre of sea water is about as productive in plant material as an acre of land. But except in certain limited situations, the sea produces a three-dimensional crop which is too diluted with salt water to harvest at a reasonable price. If additional means could be found to draw on the food resources of the sea—for example, if the recently discovered acoustical scattering layer at mid-depths represents a sufficient concentration of protein—the food problem of the world would be greatly alleviated. When it comes to fishing, man is still in the bow-and-arrow stage. Oceanographers have in the past done little to improve this situation. Here is a real challenge which it is to be hoped they will soon meet.

Paper Work

One more modern trend in oceanography seems worth mentioning here, for much help from physics will clearly be required. Having equipped his vessel with recording instruments of various types, the quantity of raw data which is accumulated each day at sea presents a very serious problem. The oceanographic vessel has become much more efficient, but still in most cases the observations must be processed by hand at the end of the voyage.

It is clear that if we are ever to be able to describe the ocean at all accurately, the problems of dealing with very large numbers of observations will have to be alleviated. The ideal oceanographic instrument must not only take in continuous information, but it must present this information in a convenient form and, if possible, automatically carry out the first steps in the analysis. Great strides in this direction have recently been made in England. The wave recorder, a bottom-mounted pressure-actuated instrument from which a cable leads to the shore, furnishes a record which can be fed into a wave period analyzer so that in a short time, and with a minimum of labor, the periods of the various wave trains combining to disturb the sea surface can be known. Such instrumentation has greatly facilitated the development of improved methods of forecasting the waves generated by distant storms and in turn has provided means of locating the storms by observing the swell.

It must be admitted, however, that the physicists who developed these most convenient and informative devices did not have to go to sea. A good wave recorder for the open ocean still awaits development.

There is a serious danger that in a brief summary of this kind the reader will gain the impression that much more is known about the physics of the sea than is actually the case. It is easy for an oceanographer to make the mistake of discussing some of the things he knows and of ignoring the things he does not know. Chief among these at the present time is the problem of wind currents.

As has already been stressed, the major ocean currents result from the winds blowing over the whole surface of the ocean. The effect of the local, variable wind has received little study in comparison with the accumulated effect of all winds. How long does it take the wind to set up a current? In what direction will this flow in relation to the wind? How rapidly will this current deepen if the wind remains steady? How long will it take the current to die down after the wind has stopped? Such simple questions are only very imperfectly understood today. We lack means of observing weak currents or of observing currents simultaneously at a number of different depths. An ideal instrument would be one which provided a velocity-depth profile. In meteorology the combination of radar and a pilot-balloon carrying a reflector has more or less solved this problem. The corresponding instrument in oceanography will have to measure much weaker movements and will have to overcome the fundamental difficulty of an oceanographer—he has no fixed platform to work from.

Photos by Woods Hole Oceanographic Institution