Mary Sears

R E P O R T

OF THE

COMMITTEE ON OCEANOGRAPHY

OF THE

NATIONAL ACADEMY OF SCIENCES

Report of the Committee on Oceanography of the National Academy of Sciences.

Foreword.

On April 27, 1927, it was voted by the Academy "That the President of the Academy be requested to appoint a Committee on Oceanography from the Sections of the Academy concerned to consider the share of the United States of America in a world-wide program of Oceanographic Research and report to the Academy."

The President of the Academy, Professor A. A. Michelson, accordingly appointed Messrs. William Bowie, E. G. Conklin, B. M. Duggar, John C. Merriam, T. Wayland Vaughan and Frank R. Lillie (Chairman) as members of the Committee.

The Committee has consulted persons engaged in various phases of oceanographic research from all parts of America, and secured the services of one distinguished European explorer and oceanographer, H. U. Sverdrup, for consultation during a period of a month in America; it has engaged as its Secretary the Curator of Oceanography at Harvard University, Dr. Henry B. Bigelow, who devoted all of his time for several months to investigations on the status of oceanography throughout the world, and to the preparation of the accompanying report. One of the members of the Committee, T. Wayland Vaughan, has collected data for the Committee in the Dutch East Indies, Siam and Indo-China, and has also placed at the service of the Committee his extensive knowledge of the oceanography of the Pacific. The other members of the Committee have contributed their experience and knowledge. The reports of the various oceanographic stations and organizations of the world are available in printed form, and have been freely consulted; moreover, each of the more important stations and organizations is known by personal contacts to at least one member of the Committee or to its Secretary.

The Committee, therefore, feels that no good purpose would be served by a more prolonged formal examination of existing conditions. It therefore begs to submit to the Academy the accompanying report, together with the recommendations based upon it, contained in Chapter VII.

Many persons have assisted in the preparation of this report, either in consultation, or by revision of parts of the manuscript. The directors of the principal Sea Side Laboratories in Europe as well as in America, have freely contributed information as to the organization of their institutions, as have the administrative officers of all the governmental establishments mentioned in the report. To all of the collaborators we offer our hearty thanks.

We wish in particular to express our gratitude for special assistance in the preparation of the several chapters of the report; to Messrs. L. B. Becking, C. F. Brooks, L. J. Collet, W. J. Crozier, R. A. Daly, Haldane Gee, L. J. Henderson, A. G. Huntsman, Alfred Redfield, H. U. Sverdrup, W. H. Twenhofel and R. deC. Ward.

Frank R. Lillie,

Chairman.

Report on the scope, problems and economic importance of oceanography, on the present situation in America, and on the handicaps to development, with suggested remedies.

By

Henry B. Bigelow

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Chapter I.

SCOPE AND PRESENT PROBLEMS OF OCEANOGRAPHY

I. DEFINITION AND GENERAL SCOPE

Oceanography has been aptly defined as the study of the world below the surface of the sea: it should include the contact zone between sea and atmosphere. According to present-day acceptance it has to do with all the characteristics of the bottom and margins of the sea, of the sea water, and of the inhabitants of the latter. It is thus widely inclusive, combining Geophysics, Geochemistry and Biology. Inclusiveness is, of course, characteristic of any "young" science, and modern Oceanography is in its youth. But in this case it is not so much youth that is responsible for the fact that these several subsciences are still grouped together, but rather the realization that the Physics and Chemistry and Biology of the sea water are not only important *per se*, but that in most of the basic problems of the sea all three of these subdivisions have a part. And with every advance in our knowledge of the sea making this interdependence more and more apparent, it is not likely that we shall soon see any general abandonment of this concept of Oceanography as a mother science, the branches of which, though necessarily attacked by different disciplines, are intertwined too closely to be torn apart. Every oceanic biologist should, therefore, be grounded in the principles of Geophysics and Geochemistry; every chemical or physical oceanographer in some of the oceanic aspects of Biology.

II. DIVISIONS OF OCEANOGRAPHY

In practice Oceanography naturally falls into three chief divisions: (a) the geological; (b) the physical-chemical; (c) the biological. Up to recently these three disciplines were handled jointly. But with improved technical methods, and greater refinement, it has become more effective to examine them separately, and then to combine the results in an attempt to understand the natural economy of the sea. Thus, students of the sea tend to fall into the three groups just mentioned.

A rational order of presentation is to consider first the shape, and composition of the basins that hold the oceans, i.e., submarine geology; next the physical character and chemical composition of the waters that fill these basins (Physics and Chemistry of sea water), and third the nature and activities of the animals and plants that inhabit the waters (Life in the Sea).

A. SUBMARINE GEOLOGY

This subject covers the shapes of the oceanic slopes and floors, and the materials of which the sea bottom is composed, the changes these undergo in the process of deposition, and such chemical and physical features of the sea water as affect these changes, directly

or indirectly. In practice it is convenient to divide this general field into (1) Submarine Topography, (2) Sedimentation, and (3) Submarine Dynamics.

1. Submarine Topography

Knowledge of the topography of the basins that enclose the oceans is the rational introduction to the science of Oceanography, because this is the factor that determines the extent, shapes, and depths of the oceans, which in turn largely control the whole gamut of thermal, circulatory and biological phenomena in the sea. This knowledge is equally needed by the geologist for (as often stated), all advances in the specific field of submarine geology must be founded thereon, while it is equally basic to our understanding of some of the most pressing problems of general geology, for we see here the modes and results of the earth's deformations in past ages.

In connection with the leading question concerning the strength of the earth's crust, for example, much more sounding is needed in such submarine hollows as the Tonga, Kermadec, and Porto Rico deeps, which bid fair to indicate the actual strength of the crust, and the degree of stability of mountains and plateaux. In the same way, an exact knowledge of the topography of the bottom would establish the possibility of great rock-slides on the steeper submarine slopes - a problem recently raised by puzzling rock formations in the Alps, Appalachians, and other mountain chains. "The bearing of submarine mapping and its geologic interpretation on the discovery of regions of submarine volcanoes, and areas of earthquake displacements must," to quote from Doctor David White's statement to the U. S. Naval Conference on Oceanography, 1926, "be obvious to all." Fuller knowledge of the shape of the bottom should, as he has emphasized, disclose the locations where many of the great earthquakes originate; they should also disclose the centers of submarine vulcanism where islands may now be building up or the reverse.

Better information on the depth, especially as regards drowned valleys, etc., would also afford data for deducing the minor changes of position of shorelines, and for estimating the amount of material removed from the land surfaces by the various processes of erosion. In this connection we need to know how deep wave-base is, and how effective waves and currents actually are, as scouring forces (Page 32). Until we know more about the exact depths we can not hope to understand the origin and history of the thousands of oceanic islands, or the remarkable events that led to the formation of such islands as the Hawaiian, or Samoan.

The Coral Reef problem - a hardy-perennial controversy - is also as much a question of submarine geology as of biology, or more, because of the fact that the up-growth of these peculiar lime formations depends on a complex interaction of physical and chemical factors, in which temperature, salinity, currents, the absolute depth risings or sinkings of the bottom, and possible changes of sea level, all play a part.

In considering the origin of any given reef, as well as in the general reef problem, the submarine topography of the island or

continental slope in question is of first importance. Still more is this essential as a basis for weighing the validity of the assumed shifts in sea level that are integral in the glacial-control theory of coral reef formation. The relation to the coral reef problems of submarine volcanoes is equally evident. Pendulum measurements of the gravity, for some distance out at sea, are also needed to combine with the geologic data above sea level as evidence whether the region in question be one of recent subsidence, of emergence, or stationary; i.e., as a test of the crustal stability of the coral reef regions, especially of the West-Tropical Pacific.

This matter of depth, and of the local variations in crustal stability, is of great interest to the palaeontologist, and to the zoogeographer, as well as to the dynamic geologist, for its bearing on possible former land connections which have been postulated to explain the distribution of terrestrial animals and plants, as at present existing; equally to account for the continental separations by which the different floral and faunal areas (once continuous) are now isolated from one another. Changes in the depths of epicontinental seas, and in the degree to which the great oceans have been in free communication with one another in the past, equally concern the marine biologist as factors controlling the dispersal routes of many marine organisms, and as affecting the ocean currents that transport animal and plant species.

The changes in the ocean currents that must necessarily follow any considerable alteration in the level of the sea floor, or in the shapes of the land masses, also concern the meteorologist, because of their influence on the evolution of climates. Of interest in this connection is the question what configuration of the old northern oceans was reflected by the mild climate of the polar regions in Eocene-Miocene times; a mildness made evident by the discovery in the Arctic of fossil remains of animals and plants belonging to groups that can now only live much farther south.

Until very recently sounding in deep water (carried on with wire) was a laborious and time-consuming process; to take a sounding in 2000 fathoms, for instance, required at least an hour after the ship had been stopped. From this it has naturally followed that our present knowledge of the shape of the sea floor is inversely proportional to the depth of the water, and to the distance from land; the less frequented, too, any part of the sea, the less we know about its depth.

Naturally, information is most extensive for shoal waters near land. In fact, as pointed out elsewhere (Page 84), our charts of the more frequented coasts leave little to be desired from the navigator's standpoint. But the various investigators who have attempted geologic interpretation of the configuration of the sea bottom, especially near land, have constantly faced the obstacle that perhaps no existing charts of the American coast line are wholly satisfactory, except for one covering a limited area off California prepared within the past year through the cooperative effort of the Coast and Geodetic Survey and of the Scripps Institution. The same, (with local exceptions) is also true for European waters, while the

situation is even more unsatisfactory for the less frequented parts of the world. Existing soundings, to quote a specific example, do not allow satisfactory mapping of the shape of the bottom of the Gulf of Maine, a region made physiographically interesting for the glacial geologist by its submarine troughs and banks. Even within the past year one of the main channels leading into one of its larger tributaries (Passamaquoddy Bay) has been found considerably deeper than had previously been supposed.

A multiplication of soundings in depths greater than 100 fathoms is absolutely necessary if the geologist is to discover what becomes of the geologic structures as they plunge into the sea; and it is obvious that much of our philosophy regarding mountain ranges is dependent on their submarine continuations. We might call attention especially to the inadequacy of existing soundings to show the fault scarps believed to exist along the northern slope of South America, or to outline the under-sea contours of the Caribbean volcanic arcs and of the outer Bahamas.

The difficulty is not one of inaccuracy of observation,--on the contray, the soundings taken by all the important maritime nations have long been extremely exact - but of their comparative scarcity everywhere outside the 50-fathom contour. We must remember that while the soundings marked on the chart may seem frequent enough, in reality they may be many miles apart. Furthermore, as they have been taken with the needs of navigation constantly in mind, it often happens that just those regions where the geologist needs the closest survey have been the most neglected, while the approaches to harbors, etc., that have been the most carefully sounded, may be the least interesting stretches of bottom, scientifically considered.

The case is far worse for the ocean basins, where we owe practically all our knowledge of the depth, away from the slopes of the continents, to the occasional deep-sea exploring expeditions, to the surveys made along routes thought suitable for submarine cables, and to scattering data from other sources. Of these three sources of information, cable surveys alone, and a few lines recently surveyed with sonic depth-finders, have yielded data at all comparable, in closeness, with the surveys that have been made of shoal waters. The result has been that our knowledge of the sea floor is still of a very generalized sort. And the contour lines laid down on the bathymetric charts of the oceans are equally generalized, located on the assumption that submarine slopes are as a rule so gentle that if soundings are taken every couple of hundred miles they will probably reveal the existence of any important ridges or troughs. But recent soundings by the "Meteor", by the U. S. Navy, and those now being carried out by the "Carnegie" prove that this assumption is not as sound as was formerly supposed.

The North Atlantic is, naturally, the best known ocean bathymetrically. There is no reason to suppose that even such detailed examination as is now possible with sonic methods will seriously alter the existing picture of it. Even in the North Atlantic, however, we still lack detailed knowledge about the important deeps north of Porto Rico, and in the Caribbean. We have recently learned that the representation on the charts, of the slopes of the Grand

Banks off Newfoundland was far from satisfactory, and it was only last year that the bottom contour of Davis Strait was adequately surveyed.

South Atlantic topography is made especially interesting by the longitudinal furrows in the east and west sides, along which bottom water from the Antarctic drifts northward. The recent work of the "Meteor" was the first to yield an approximately correct picture of these troughs and of the intervening ridge. The unexpected irregularities which her sonic soundings brought to light on her several profiles of the South Atlantic show the need of lines run much closer together in latitude than has yet been attempted.

It is when we turn to the Pacific, however, that we most clearly appreciate the vast amount of sounding that still remains to be done. In this ocean it is only directly along the cable routes from California to Hawaii and to Alaska; in the general vicinity of Japan; along one profile from America to Australia; one from Hawaii to the East Indies, and on the lines run within the past year by the Carnegie (details not yet available) that the contours have been even approximately developed for the open basin. Elsewhere we see areas, greater in extent than most European principalities, marked only by soundings far apart along the lines of the few deep-sea expeditions, or scattered here and there. Thus, an area off lower California, fully twice as large as the Republic of Mexico still remains unmarked by a single sounding. Another terra incognita extending northward from the foot of the Hawaiian slope nearly to the Aleutian Chain, and westward to the Japan deep, i.e., 2/3 of the way across the Pacific, (larger than the whole of continental United States) is crossed from east to west by only one line of soundings, along which the individual measurements of depths are hundreds of miles apart.

The case is as bad in the high latitudes of the South Pacific and Antarctic, with an area of nearly 2,000,000 sq. miles to the southeast of Chile in which (up to 1927) only eight soundings had ever been taken. To the southward of the Jeffrey trough, south of Australia, and right down to the Antarctic edge, we again find only odd soundings, while other vast blanks still remain to be explored in the southern part of the Indian Ocean.

A major problem in this connection is whether the floor of the Pacific is systematically furrowed on a grand scale, as suggested by at least one bathymetric map, and how it compares with the floors of the Atlantic, the Indian, and the Arctic Oceans in this respect.

About six thousand soundings had been taken in the different oceans in depths greater than 1000 fathoms, up to 1912, an average of only one sounding for every 23,000 square miles for all the oceans combined; one sounding for every 7,000 square miles for the Atlantic. And while a considerable number of deep soundings have since been obtained, notably in the South Atlantic by the "Meteor," and in the Northern Pacific by United States and Japanese vessels, the average area for each deep sounding, the oceans over, still roughly equals half the area of the state of Pennsylvania, or more than the area of Denmark. It may be of interest to note, in passing, that the most recent pilot charts of the U. S. Hydrographic Office list no less than 127 shoals in the Atlantic, 68 in the Indian Ocean, and 221 in the

Pacific Ocean the position or the existence of which is still doubtful.

Mapping the topography of the regions that have as yet been only plumbed here and there, added to more detailed examination of other parts of the ocean, will bring to light many ridges, troughs, escarpments, and other irregularities of the bottom such as have actually been revealed by the Panama-Australian profile just mentioned, by the Meteor's traverses of the South Atlantic, and by those of the Carnegie in the southeastern Pacific.

Now we have at hand a new tool for the purpose, in the recently developed method of sounding by timing the echo sent back by the bottom, by which any ship equipped with the necessary gear can take almost continuous soundings in any depth of water throughout her voyages, and while running full speed. There is no longer any doubt as to the accuracy of the method, and it has been tried often enough to prove its entire practicability. We may, therefore, look forward to a very rapid development of our knowledge of the shapes of the ocean basins along all the commercial routes, and on the routes followed by naval ships. All that is needed is to arouse interest, and to procure the funds necessary for equipping ships with the sonic gear. Here it is the task of the oceanographer to accumulate and tabulate the data, for the geologist to interpret it in terms of the earth's history.

2. Submarine Sedimentation

Study of the marine sediments has three chief objects: (a) it throws light on the cycle of matter within the sea, (b) a knowledge of the sediments now being laid down under the sea is prerequisite for interpretation of sedimentary rocks on land; and (c) better knowledge of the nature of the sediments, and of the rate at which they are now being laid down, will clarify our ideas as to the permanence of the ocean basins.

To the geologist a study of sediments and of sedimentation is essential, because the development of stratigraphy depends upon a knowledge of the environment of deposition; and this development is necessary for a correct understanding of the sequence of events in the earth's history. Furthermore, sedimentary rocks that were originally laid down under water now cover some 75% of the surface of the lands. It is also probable that areas overlayed by igneus rocks are in many places underlayed by sedimentary. In fact, there are probably no large parts of the continental areas that were not under salt water at some time in the geologic past. Sedimentary rocks also contain a majority of our mineral resources. They are, thus, the most important element in the earth's outer shell as they affect man's undertakings. If we can safely reconstruct the ecological relationships of the fossil remains they enclose from analogy with their closest living relatives in the modern seas, the study of sediments will tell us much about the climates of the past; will also give clues to the character of the earth's atmosphere, and to the chemistry and physics of the sea bottom, during past ages.

The task of the sedimentary geologist, therefore, includes, not

only an examination of the composition, texture, chemistry, etc., of existing sediments, but also the restoration, from these characters, and from the factors in the environment that compel the deposition of one kind of sediment and not of another, of the conditions as to depth of water, temperature, activity of circulation, distance from land, topography of bottom, etc., under which the old sediments accumulated. For this he needs to know which classes of sediments are so sensitive to environmental factors that they are deposited only under special combination of these, and which classes are either less sensitive or are limited by only a single factor, e.g., temperature: the rocks derived from the first group have a limited, those from the second a much more general distribution. The organic sediments may be expected to prove especially instructive in this connection because certain of them seem so closely bound to particular environments that when their requirements are once comprehended it will be possible to translate the old organic sediments into terms of the physical and chemical conditions under which they were laid down. Since sediments of different sorts are laid down in sequence, changing as the environment changes (e.g., if the sea floor rises or sinks), study of the old sediments should also give us the sequences of such changes in the old seas.

It is, therefore, no exaggeration to name the study of modern submarine sediments (as has been done) a geologic necessity, for only by this means can geologists hope to understand how the different classes of sediments, now solidified into rock, were actually accumulated; and still more important, what chemical changes they have undergone on the floor of the sea, since that time. Neither the study of modern sediments alone, nor of their ancient prototypes now represented by the sandstones, chalks, and limestones can tell the whole story: the two must be examined hand in hand. Systematic dredging and laboratory studies of the material so far gathered from the bottom of the sea are likely to throw a flood of light on such outstanding problems as the origin of the various kinds of limestone, dolomites, petroleum deposits (Page 11), and of the valuable deposits of potash and other salts.

The transformations that chemical changes in the impregnating water may have caused in the limy sediments on the floor of the ocean deserve particular attention, because we know that while the old sedimentary limestone and shale rocks were laid down under water, and under conditions comparable to those existing today, they differ greatly from the muds and oozes that are now being deposited. In this connection new studies on the hardening (diagenesis) of marine sediments are urgently needed to explain the origin of the old stratified rocks of the earth's crust. The formation of phosphatic concretions and of glauconite, also needs study, for its bearing on the origin of phosphate and potash rocks.

The importance of the problem of iron in the deep-sea sediments is obvious when we remember that most of the iron ores of today were almost certainly laid down under the sea over a wide range of geologic periods. To quote from Doctor David White's report to the Naval Conference of 1926 "We do not know how they were deposited in such enormous amounts, and in their present relations to other minerals and rocks. What were the water, the biologic, the bottom,

and the terrestrial conditions which led to the origin of these great deposits?" Are deposits of this sort being laid down today? What, if anything, have bacteria to do with the segregation of iron? How does the common association of iron with manganese in modern deep-sea deposits bear on this problem of iron? How sound are the chemical reactions that have been proposed to account for the deposition of either of these minerals, and what conclusion must we draw, as to the depths of the Paleozoic seas, from the fact that today it is only in deep water that the bottom sediments contain a considerable percentage of either of these metals?

Similar problems also arise in connection with the rarer metals, the metamorphic limestones, silicious deposits, etc. With silica constantly contributed by the rivers to the sea, and with no back loss either to the atmosphere, or to the land (except in regions of elevation) it is obvious that the silica of the earth is now tending to accumulate on the sea floor. The geologist is, therefore, as deeply interested, as is the biologist, in the factors that cause such accumulation of silica to take place most rapidly in cold water, and at great depths, as signboards to the conditions under which accumulations of silica occurred in the old seas.

Analysis of the depths at which coarse sediments are now accumulating, and of the role played in this connection by the scouring action of waves, tides, and currents as a governing factor, is instructive from the geologic point of view because the conglomerates and breccies that were formed in the old seas have their equivalent in the gravels and sands that are being deposited around the shores of the oceans today. In like manner, a study of the blue muds around the continental shoals and on the shelves is important because of the probability that many of the shales laid down under the seas of old were deposited in the same way. We think especially of the genesis of the Paleozoic black shales of vast extent, as to whose origin there are nearly as many theories as students. Modern deposits on the submarine slopes of the oceanic islands, also bear on the sedimentary effects of landslides as pointed on Page 2 . On the steep slopes into the abyss, special watch should be kept for rock masses that have broken away from the shelf and slipped down the slope.

The regional distribution of the different types of oceanic sediments, when we learn the correct interpretation, will throw light on the problem of the permanence of the basins. Is it safe to assume that where a basin is now floored with red clay (the most typical abyssal sediment), it has continued deep for geologic ages past, and that the presence of the teeth of sharks, and earbones of whales of species long since extinct that our dredges often bring up from red clay bottom, means that not enough sediment has sifted down, since Tertiary times, to bury them deeper than the instruments scrape? Or may this old stratum have been repeatedly covered by lime ooze and as repeatedly freed from the latter by the solvent action of the water, with successive uplifts and sinkings of the sea floor?

We commonly think of the terrigenous detritus around the continents as accumulating faster than do any of the oceanic oozes. How, then, are we to interpret the fact that glacial pebbles have often been dredged, and over a wide range of depths? Is the depth to which

these stones are buried a measure of the thickness of deposition since Glacial times?

The failure of sediments to accumulate, even in deep water, in regions where the scouring action of currents or waves is strong (e.g., the Pourtales Plateau off Florida and the Wyville Thompson ridge in the North Eastern Atlantic) is also geologically suggestive. Can the fact that Devonian strata have been found lying direct upon Cambrian in certain places, with nothing between, long a geologic puzzle, be credited to similar local scourings in the Paleozoic Sea?

The presence of glacial pebbles, even boulders, embedded in the bottom on the off-shore banks, in regions such as have been found far out from the land at various localities on both sides of the North Atlantic, where their presence can not be credited to transport by floating ice under present conditions, emphasizes the importance of relicts of this sort as evidence of the distances to which the ice sheets of the last glacial period extended out beyond the edges of the modern continents. The information so far gathered on this point is only enough to whet our appetite for more. And the discovery of shoal-water shells in dredgings from considerable depths marks the importance of submarine evidence of the sort in relation to the possible existence of former land bridges or other areas of subsidence.

So much information has already been gathered from the numerous bottom samples collected by the various deep-sea expeditions, that further exploration is not likely to seriously alter our general conception of the general character of the bottoms of the ocean basins, at depths greater than, say, 500 fathoms; either as to the structural or chemical composition of the several classes of deep-sea sediments, or as to their regional distribution. It is true that our present charts are largely based on the assumption that within certain ranges of depth, and at certain distances out from the submarine slopes, the mud or ooze that superficially clothes the sea floor is so uniform that data from points as widely scattered as most of the deep-sea soundings have been do in truth suffice for the intervening stretches. But the relationship that the type of bottom bears to the depth, to the distance from land, and to the plankton of the overlying waters, is so direct that this assumption is generally justified, except where more detailed soundings reveal unexpected shoals or troughs dissecting the abyssal plain.

This uniformity depends on the rule that the sediments of the ocean basins are what is known as "oceanic" in origin, consisting of the shells of pelagic plants and animals that rain down from above under the regions where the plankton is abundant, of the skeletons of bottom dwellers, or of the so-called "red clay" that accumulates with almost unbelievable slowness from the disintegration of the pumice from volcanic eruptions, from cosmic dust, and from the precipitation of manganese and other less common minerals out of the sea water. Much is yet to be done, however, even in the ocean abyss, to fill in the extensive blanks that still mar our charts, especially for the Pacific and for the Indian, while work recently done shows that important modification of mapping of Antarctic deposits is needed.

The question whether any of the existing sedimentary rocks were laid down at great depths is still to be answered. An especially momentous problem, for our understanding of geosynclinal rocks, and hence of the world's mountain chains, relates to the conditions under which radiolarian-bearing sediments were deposited. New work on the radio-activity of deep-sea sediments would add much needed data on the origin and distribution of radio-activity in the earth, hence of its internal heat.

When we turn to the coastal waters, and to the shelves of the continents, where all sorts of debris from the land entirely overshadow the local shell-builders, geologists need a much more detailed knowledge of the sediments than it has yet been possible to attain. In part, the wide regional variations in this zone are associated with differences in the nature of the source rocks on land from which much of the material comes; this applied equally in the past. But regional differences in the turbulence of the water, and in the scouring action of tides and currents are also important in this connection, because they govern the degree of coarseness or fineness of the detritus that can be held in suspension, thus sorting the sand or mud regionally as it is laid down.

This whole field is of great interest to the paleontologist, whose best clue to the conditions of depth, etc., under which ancient aquatic animals lived is the nature of the rocks in which their remains are found.

In shoal water, to meet the needs of the geologist a large number of samples of the sediment must be taken close together, (many more per hundred square miles than would suffice in the abyss) and the samples should be taken throughout the entire depth range of the region in question; they must then be subjected to detailed analysis in the laboratory. Though this last requirement may seem self-evident, it has been met for very few localities, because our present knowledge of shoal water sediments is based chiefly on the data given on the navigational charts, which in turn, are drawn from wholly inadequate samples or (as when the bottom is described as "hard") simply from the failure of the sounding lead to bring back any sample at all. Geologically speaking, "hard" or "rocky" is a meaningless term, unless we know whether it was some rock fragment that the lead struck, perhaps brought from afar by glacial action ages ago, or solid ledge in situ; or unless at least a fragment of the material be obtained. To quote a specific example, the nature of the bottom as noted on the charts of the Gulf of Maine (one of the better sounded seas), is of very little service to the geologist, and even when samples were collected and analysed from 200 stations there, for this very purpose, it proved that serious gaps still remained.

The obvious importance of accumulations of calcium carbonate, in shoal water, in the formation of sedimentary rocks have, it is true, stimulated intensive examination of several shoal areas in tropical and sub-tropical regions; of the reefs of Murray Island, Australia, for instance; of restricted localities around Samoa; and of the Floridian and Bahaman Banks. Much attention has also been directed, of late, to the precipitation of calcium carbonate from the sea water in the Tropics, whether by bacterial or by direct

chemical action (Page 41). Similar studies of sedimentation in restricted areas are also in progress in more northern seas; the Bay of Fundy, for example, off the coast of California, and around Great Britain among others. But these isolated projects must be greatly multiplied, and extended out to the mud line at the edges of the continents, before we can hope even to sketch in the very complex mosaic picture presented by the deposition of shoal water sediments.

Thus, judged even as a descriptive science, the sedimentary geology of the sea is still in an elementary stage. Compared with soil science on shore, our knowledge of the muds of the ocean deeps corresponds in a way to that of some steppe or prairie region, where the soil is so uniform over great areas that scattered tests will give a representative picture of the whole. But we know hardly more of the bottom in shoal regions than examination of a garden plot, here and there, would tell us of the agricultural possibilities of a land with widely diversified soil.

Knowledge of the agencies active in the complex conditions under which marine sediments are now being deposited is equally elementary in many respects. While in the case of an oyster bed, of a reef of corals, or of a swarm of Globigerinae, the progress of the event by which lime is added to the sea floor may be easily observed, great quantities of limy mud are now being laid down in tropical seas. Whether bacteria are responsible for the formation of these muds, as formerly supposed (Page 63), or whether they result from chemical or mechanical precipitation quite independent of bacteria, as now seems likely, is still a moot question: a question, however, of great interest, not only for its bearing on events now taking place in the sea, but in connection with the formation of oolitic limestones.

The organic content of the sea bottom is discussed from the biological standpoint elsewhere. It also has a direct geological bearing from many angles. Perhaps most important here, is the problem of the accumulation of the carbonaceous and bituminous substances on the sea floor, from which petroleum, natural gases, and other hydro-carbons are believed to have been derived. Practically all geologists[1] are agreed that petroleum, etc., is an end product

1. The materials for these remarks on the oil problem in sedimentation are condensed from Doctor Davis White's report to the U.S.Navy Conference on Oceanography, 1926.

of the natural distillation, under geologic processes, of organic material accumulating in the sediments, whether in the sea, in fresh water, or on land. It seems certain that in marine sediments more organic material is involved than the oil of the Copepods, Diatoms, etc.; similar though the latter be to petroleum in chemical composition. But it is still an open question whether it is the vegetable matter, or the animal fats that are the chief source for the geophysical and geo-chemical transformation in question. It is, therefore, important to learn to what extent the soft parts of animals are actually buried, and so preserved in the marine muds and oozes, and how they are transformed there by bacterial action.

The conditions of growth, and the environmental factors controlling the deposition and the burial in the sea of the remains of algae that make up a large part of the long buried carbonaceous sediments that now form the kerosene shales, algal coals, and oil shales, are still an open question. The fact that these algal deposits grade into the ordinary black shales, of marine origin, lends special interest to the origin of the latter which has received many interpretations. Is their blackness due to vegetable or to animal derivatives, or if to both, in what proportion? And by what chemical alterations have these shales been derived from the ordinary black marine muds?

The general problem of modern marine sediments as possible future sources of oil, and of the oil distillable therefrom, is now being attached experimentally with the financial support of the American Petroleum Institute.

Another pressing problem is that of the amount of water that is contained in the modern sediments of different sorts, and of the chemical composition of this water, which we have some reason to believe may differ widely from ordinary sea water. No satisfactory method of sampling it has yet been devised. To estimate the rapidity with which lime sediments are dissolved relative to their rate of deposition, a knowledge of the degree of alkalinity of this entrapped water and of that lying directly upon the sea bottom, is especially desired.

Interpreting "sedimentation" broadly, we may here mention the assistance that a detailed charting of the regional and depth distribution of the more monotonous communities of animals and plants of skeleton-building types, now living on the sea bottom (e.g., coral or Halimeda reefs, mussel or other shell beds, forests of deep sea crinoids) would give to the geologist in his attempts to interpret the age relationships of atrata that contain, in close association, fossil communities that differ equally widely in character.

The preceding remarks on marine sedimentation center around the horizontal distribution of the various sediments. We must equally emphasize the necessity of examining their vertical distribution, e.g., of penetrating below the superficial layer, and of probing the underlying mass. Here, however, as in so many submarine problems, we face a practical obstacle. With deposition proceeding almost everywhere in the sea (except right along the coastline, and in certain restricted localities where currents scour the bottom) there is no opportunity for a direct examination of geologic sections, because no transversely dissected sedimentary layers are left exposed there, or are accessible for examination if exposed. Furthermore, while it is easy enough to gather mud in any desired amount from the uppermost stratum, and in any depth of water, no method has yet been devised for obtaining vertical cores of the bottom, more than about 3-4 meters long, nor have any yet been obtained in the open ocean more than a meter long. Picture how far geology would have progressed on land, had there been no way of studying anything but the top soil!

One of the greatest needs today in the study of sedimentation is the collection of more cores with the rudimentary instruments so far devised, still more the development of apparatus to obtain longer cores. Only in this way can we learn anything about the thickness of the modern sediments, and about their variations in composition with distance below the surface of the mud.

The problems for which cores of the bottom are needed may be classed as (1) rate of deposition under given circumstances; (2) constancy or the reverse in the type of sediment laid down over long periods; (3) the chemical alterations that take place in the deeper layers of sediment that are protected from the water by the overlying ooze; (4) uplifts or subsidences of the sea floor revealed by the presence of one type of sediment upon another; (5) problems of glacial geology.

Some interesting beginnings have already been made in these fields. Although no cores more than about 80 cms. long have yet been obtained from deep water, those that have been taken in the north and south Atlantic basins, with their poleward extensions, show that it is the rule for even this thin superficial stratum to show a rather noticeable stratification. In this connection, we think especially of the soundings taken by the Nordske Nordhaus, German South Polar, "Michael Sars," and "Meteor" expeditions, as well as by the recent "Atlantis" cruise sent out by the Museum of Comparative Zoology. With the stratification usually taking the form of a difference in the amount of lime contained in the mud or ooze at different depths downward from its upper surface, its bearing on the formation of sedimentary limestones is obvious. Normally, there seems to be less and less lime the deeper one penetrates into the mud. How far does this decrease reflect the solvent action of the entrapped water, i.e., the age of the sediment? Does the decay of organic matter in the mud give this water such a load of CO_2 that its solvent power is much greater than that of sea water generally? Can it be that solution of this sort actually limits the thickness to which lime deposits can accumulate on the ocean floors of today, by dissolving calcium carbonate from the deeper layers as fast as it accumulates on top? How does all this bear on the depth of water in which the limestone rocks were originally laid down?

We know nothing definite about the rate at which the limy oozes are actually building up in thickness on the ocean beds, or even whether they are so building up at all. Our only direct evidence as to the rate of their deposition is the rapidity with which Globigerina ooze buries and so protects submarine telegraph cables. But it is certain that the sea floor generally, over all the vast area occupied by the Globigerina oozes, is not rising at as rapid a rate (an inch in ten years, or a fathom in every 720 years) as experience with cables would suggest if accepted at face value. How do the processes of solidification, of solution within the sediments, and of the sinkings of the earth's crust as weight increases (compensated by uplifts elsewhere) balance the tendency toward accumulation?

Does the failure of geologists to find any existing limestones to which abyssal origin can safely be credited mean that the

accumulation of thick beds of calcareous sediments has always been confined to shoal waters, or has taken place at great depths only under special circumstances?

The few stratifications so far studied have enlarged our views of climatic changes in the oceans in the past especially for high latitudes, enough to point the need of more numerous probings of the bottom to greater depths.

The thermal relationships of the various species of Foraminifera, shells of which have been identified at different depths below the uppermost layer of ooze, have proved highly significant as indices to changes in the temperature of the ocean. Similarly, the alternating strata of shell-bearing, and shell-less clays on the bottom of the Norwegian Seas emphasize the geologic fertility of studies in this field. The urgent need for more detailed information as to the temperature, and other vital optima, of the various pelagic shell builders here unites the biologist with the geologist.

We may also hope to learn much about the changes in level that the sea floor has undergone from the stratification to be seen even in such short cores of the ooze as have yet been taken, for we have an index to the depth of water at which the sediments were laid down in the fact that the limy oozes (as a class) accumulate only in depths less than about 2500 fathoms, (shoaler still in the Pacific) while it is only at depths greater than 3000 fathoms that the red clay, or the radiolarian and diatom oozes are practically uncontaminated by limy shells, except in the Pacific, when the type of sedimen is found in comparatively shallow water. Some short cores suggestive in this respect have already been obtained. The presence of abyssal red clay overlying Globergerina ooze has been used as an argument for a very considerable recent sinking of the sea floor in the mid-equatorial Atlantic. Seven such cases have already been recorded and we may expect still others, when detailed accounts of the results of the "Meteor" Expedition appear. Stratifications of the opposite sort, i.e., with Globigerina ooze or Diatom ooze overlying blue mud, such as even the short cores taken by the "Meteor" revealed over a considerable area off West Africa, between 13° N. latitude and the equator, point to the opposite process of subsidence. The layers of volcanic ash found in some of the "Meteor" sediments also open interesting problems. Similar cores, and if possible, longer ones, are desiderata for all the deep submarine troughs, and especially for those that fringe the continents, as possible clues to the ages of these depressions, relative to the permanence of the oceans as a whole, and to the ages of neighboring mountain chains on land.

The probability that cores would throw light on the actual rate of deposition in given circumstances, if some time marker could be established to start from, gives special importance to such work off coasts the character of which was determined in the last glacial period. Circumscribed basins, scoured out by the ice sheet, so deep that mud is entrapped within them, are especially attractive subjects for time-studies of this sort, if compared with the sediments deposited on land since glacial times, from materials laid down by the ice itself. Projects are, in fact, under way for obtaining cores

in bowls of this sort off New England.

The degree of alteration undergone by the particles that make up the abyssal red clay in its different layers would also show something of the age of this material relative to other geologic processes, even if it cannot be measured in years.

Cores are likewise needed to tell us the relative abundance of organic matter in the mud, from its upper surface downward, a question that bears on many of the chemical reactions that tend to alter the raw material sifting down on the bottom.

3. Submarine Dynamics

The study of dynamic and structural geology has been greatly handicapped in the past by the fact that two thirds or more of the earth's surface was put out of reach by its covering of water. While it was possible to survey the topography of the bottom, and to gather samples of the sediments, these are only two of the factors in the problem of the cause of basins and continents, or of the existence of troughs, submarine ridges and oceanic islands.

We still lack any means of obtaining samples of the rocks that underly the oceanic sediments. But studies of earthquakes and of the volcanic rocks of oceanic islands suggest that the regional grouping of these may throw light on the constitution of the crustal material below the oceans. And the recent development of a means for measuring the strength of the force of gravity at sea (as geophysicists have for many years been able to do on land) opens a wholly new field of oceanic research, for previously there had been no way of determining whether the high values of gravity that prevail on oceanic islands did or did not indicate an excess of material in the crust under the oceans as a whole. And an answer to this question is prerequisite for any general conclusion as to whether the state of hydrostatic equilibrium or "Isostasy" that has been proved to be the normal condition of the emergent portion of the earth's surface is equally characteristic of the ocean beds; in other words, whether these depressions represent the heavy sectors of the crust, just as the masses above sea level are compensated for by a deficiency of material (i.e. likeness of the crust) beneath the continents.

This is a major problem of geophysics because our interpretation of irregularities of the earth's surface must depend largely on determining the relative densities of the crust under oceans of different depths, compared with lands elevated to different heights above the mean crust level. Gravity measurements at sea supplemented by analyses of the igneous rocks found on oceanic islands may, therefore, be expected to throw much light on the causes of ocean basins and continents, of the sinkings and risings of oceanic islands, and of the volcanic activity occurring on the latter now or in the past. Such measurements may also be expected to show whether the processes that caused broad up-lifts in the past are now at work under the oceans, to make up-lifts that will appear above the sea in geologic ages to come.

Other questions equally broad are also involved; for instance, have the ocean beds tended to sink under their own weight with the lighter margins of the continents tending to buckle up in compensation? in areas, on the contrary, where the sea bottom is rising, is its lightness compared to the surrounding lands responsible? How is all this related to the weight of the sediments that accumulate on the sea floor, and this, in turn, to the new hypothesis (raising one of the most vital problems in modern science) that the huge blocks of the earth's crust that form the existing continents have moved horizontally?

For these reasons a net of gravity measurements is needed over the oceans. A beginning has already been made in this direction by determinations carried out by the Dutch Geodetic Commission, from submarines, on one voyage from Europe to the East Indies via the Mediterranean and Suez Canal, on another across the Atlantic and Pacific; more recently by the U. S. Navy in the West Indian-Caribbean region elsewhere . And a gravimetric marine survey of the East Indies is now in progress. These observations have opened interesting problems, for while the flatter parts of the sea floor (along the lines so far run) have given values roughly in accord with the isostatic principle, decided differences have been found between the observed and the theoretic values of gravity over and near some of the deeper submarine troughs, near oceanic islands and close to the margins of the continental shelves. Much more must be done before it will be safe to conclude whether these abnormalities of gravity, plus the fact that the grouping of submarine earthquakes is similar (the deep troughs seem, in particular, to be the seats of the strongest earthquakes), really reflects a lack of isostatic equilibrium or stability in these parts of the earth's crust, for other explanations are possible. For instance, the submarine earthquakes may be caused by expansion or contraction of the crustal material. In fact, the recent discovery (by sonic methods of sounding) of great submarine escarpments with steep slopes points in that direction. Or the abnormal values of gravity so far recorded at sea may reflect the presence of heavy or of light masses of material close under the surface of the crust in the immediate vicinity, rather than the mean density of the whole underlying thickness of the latter.[1] In this case there might be very little

1. In accordance with the gravitational law that masses attract each other inversely as one square of the distance, a mass of extra heavy material close to the observing station will cause an abnormally high value gravity, while a mass of light unconsolidated material nearby will cause a low value.

horizontal strain in the material underlying the stations in question.

The solution of dynamic questions such as these calls for intensive studies of the ocean deeps, of the regions around the oceanic islands, and of the margins of the continental shelves by means of gravity determinations in combination with detailed topographic surveys of the bottom. A combination of the data secured from the sediments, the configuration of the bottom and the values of gravity should lead to great advances in this general phase

of geophysics.

B. PHYSICS OF THE OCEAN

Sea water, next to air and fresh water, is the most uniform of all the common substances on this planet, in chemical and physical character. Therefore it does not offer to the physicist the opportunity that it does to the biologist for the solution of the basic problems that are today most alluring in his particular field of study. The immediate task of the ocean physicist is not so much to investigate the properties of matter, as to explain the existing manifestations of heat, light, and motion within the sea water.

The problems most immediately pressing in these fields center about the responses of the water to solar radiation, as well as to the atmospheric circulation to the force of gravity; and to the centrifugal force that is set up by the rotation of the earth. These forces are all directly measurable, and can be stated in quantitative terms. Essentially, therefore, Ocean Physics is an exact science. If we are not yet in a position to handle its manifestations in an exact way, it is more because our regional knowledge of the sea is still incomplete, and because our methods of mathematical analysis are not sufficiently advanced, than because of failure to understand the basic physical or cosmic principles involved.

Sea water occupies the greater part of the surface of our planet. A study of its physical and chemical characters and of the circulatory movements by which it responds to external and internal forces, is, therefore, an important item in our gradually broadening view of the geo-physics of the earth. We also have other impelling reasons for making Ocean Physics a primary subject in the fact that, as one contributor writes, "virtually all kinds of studies of the sea are crying for more information on physical conditions within it." The temperature of the water, its chemistry, and the mechanical manifestations of oceanic circulation, not only govern the whole economy of life in the ocean, but also produce important geological results, and go far to govern climates on land, past as well as present. With these last incentives, it was natural that a tendency developed to treat physical and especially dynamic Oceanography as a subject auxiliary to oceanic biology or to geology. The fact that oceanographic work on the two sides of the Atlantic has long drawn its chief impetus from the economic pressure of fisheries problems, has been largely responsible for this relegation of ocean physics _per se_, to a secondary position. This tendency, however, has seriously retarded the advance, not only of our knowledge of the physics of the ocean _per se_, but even of the very branches that it was hoped to further; for it may be taken as axiomatic that only when any scientific field is considered as a primary object, worthy of cultivation for its own sake, can satisfactory advance therein be expected.

The effect of this tendency has been that studies of the physical state of the waters have rarely been the primary object in the oceanographic activities of the past. This has applied, for example, to many of the deep-sea exploring expeditions; "Blake," "Albatross,"

"Valdivia," and "Siboga," among others. The programs of the recent German expedition to the South Atlantic on the "Meteor," and of the exploration of Davis Strait in 1928 by the U.S. Coast Guard cutter "Marion," have, by contrast, been primarily physical and dynamic, recalling the attention devoted to the Chemistry and Physics of the sea water on the cruises of the Challenger and of the Pola and this also applies to the current cruise of the "Carnegie."

New viewpoints, developed of late, have greatly stimulated interest in these questions, at all the centres where oceanographic research is now being actually prosecuted.

In America, where most of the older oceanographic exploration was sponsored by institutions whose chief interests lay in Biology, the physical side was even more neglected than in Europe, from the days of the "Blake" until the renaissance of Oceanography in this country in the first decade of the present century, described elsewhere (Page). Since then, however, Ocean Physics has been a primary object for the Scripps Institution in California, as well as for the International Ice Patrol operating around the Grand Banks; also for some of the Atlantic cruises of the Biological Board of Canada, of the U.S. Bureau of Fisheries, of the Museum of Comparative Zoology, and of the Carnegie Institution.

Until recently Physical Oceanography has been confined to the stage of exploration; first, because of the fragmentary state of our knowledge of all the phenomena involved, second, because of any method for calculating quantitatively, from data obtainable in practice, the tendency that internal hydrostatic forces exert to set the water in motion. Until Bjerknes' studies in hydro-dynamics led to the development of such a quantitative method, it was impossible to analyze the relative importance of the internal dynamics of the water, and of the external forces exerted by the wind, as the causes of ocean currents. In fact, this still remains one of the outstanding problems in Oceanography (Page 37).

At present, the attention of the ocean physicists is chiefly focused at present on the following fields: (1) the distribution of temperature and salinity within the sea, (2) its circulation in detail, (3) the penetration into it of the sun's rays.

1. Temperature and Salinity

There is as good reason from the biologic side as from the strictly physical for studying the temperature of the sea, because this, more than any other one feature of the water, directly controls the distribution of animal and plant life. Because of the important role of temperature in governing the rates of animal and plant metabolism, on which we have touched elsewhere (Page 53) the seasonal changes in the temperature of the water present special problems to the marine biologist in his studies of such events in the life cycles of animals and plants as their breeding periods, the duration of the periods of incubation or of larval life, rate of growth, feeding activity at different seasons, seasonal migrations, and many others. The temperature-optima and the lethal limits need also to be determined at different stages in development for every

species the life history of which is under examination. This question is of practical import in the case of several important food fishes, crustaceans and molluscs. The thermal knowledge that the biologist needs in such cases is, furthermore, of an extremely detailed sort.

Apart from the perfectly defensible wish to extend our knowledge of every phenomenon in the sea, the temperature of its water also engages the physical oceanographer as evidence of the movements of the different masses of water, (Page 35) because temperature is one of the two constants that control the internal hydro-static forces that tend to maintain a system of thermo-dynamic circulation in the oceans.

The close relationship that exists between the temperature of the surface of the sea and that of the overlying air, introducing the whole broad question of the control of land climates by the high thermal capacity of the sea water and by the regional distribution of heat within the latter, also gives a directly practical reason for studying the temperature of the oceans (Page 87).

Next to the regional charting of temperature (and approachable only thereby) the thermal problems now most pressing in the sea center chiefly around (a) detailed examination of the temperature-cycles of regions that may be especially interesting from one biological standpoint or another; (b) the general variation in temperature with the seasons off shore, especially in the deeper strata, (c) the irregular non-seasonal fluctuations that are known to occur from year to year, or over periods of years, with their causes; (d) the thermal relationship between the surface of the sea and the air above it; and (e) the interplay of the several cooling and warming agencies.

Under this last heading, empiric studies of the cooling effect of evaporation in different parts of the sea are now much to be desired. Quantitative analysis of the chilling that Arctic and Antarctic ice actually does (not theoretically may) bring about as it melts would be of great value. And tests are urgently needed as to whether the bottom water of the abyss does, in fact, receive an appreciable amount of heat from the underlying earth, as some recent observations suggest, because warming from below would have a far-reaching influence on the vertical circulation in the deepest layers.

Small regional differences in the salinity of the sea are insignificant in the biologic complex, compared to the variations in temperature. However, it is now generally appreciated that they offer the most reliable of all qualitative indices to the broad scale circulatory currents of the ocean basins, and to the sources of different water-masses. Regional problems now urgent in this respect include the entire oceanographic complex along and among the labyrinth of islands that fringe the coast of Alaska; the Asiatic fringing seas; the movements of the bottom waters of the Sulu Sea, as well as of other enclosed bowls; the expansions and contractions of the warm North Pacific Drift with the seasons; the transferences of water through Bering straits; the up-wellings along California - likewise in the Humbolt current along the coasts of Ecuador and Peru

where hardly anything is known about the regularity or amplitude of the seasonal variations in salinity, to mention only a few of the more urgent cases.

Profiles of temperature and salinity, along several meridians for the Indian and Pacific Oceans, similar to those obtained by the "Meteor" in the South Atlantic, are essential for working out the general circulatory systems of those oceans. First hand information is also needed as to the exact combination of temperature and salinity, from which to calculate the specific gravity around the sub-polar margins (where the formation of oceanic bottom water is believed to take place) at the season when mass-sinking may be expected to occur there (Page 29). It is because of the practical difficulty of obtaining this data we have so weak an observational basis for our theories of circulation in the crucial regions around the Antarctic and Arctic ice fronts.

Much more attention must also be paid to the processes that most directly affect the salinity of any given mass of surface water, namely, rainfall and evaporation. As has been recently remarked by a leading oceanographer, we still await an acceptable quantitative explanation for the fact that the waters of the North Pacific as a whole are considerably less saline than those of the Atlantic.

Quantitative measurements are also needed of the extent to which the freezing of sea ice actually increases the salinity - hence the specific gravity of Arctic and Antarctic Seas in the cold season, and how the process of freezing alters the chemical composition of those seas. Conversely, a better quantitative measure of the freshening of the surface that is caused by the melting of ice in lower latitudes, and of the difference in this respect between sea and glacier ice is essential before we can correctly estimate the importance of this process in the salinity complex.

Detailed knowledge of regional variations in salinity is also as essential as is that of temperature in every dynamic study of ocean currents, salinity being the other factor that determines the specific gravity of the water at any given time and place.

The temperature of the surface of the sea can so easily be measured, and the importance of a knowledge of ocean temperatures, not only to the geographer and to the biologist but to the navigator as well (as evidence of the current in which he sailed), was so early appreciated, that thousands of such readings had been recorded along a great variety of trade routes by the first half of the last century. In fact, as early as 1873 Thomson spoke of the number of such observations previously taken in the North Atlantic, as almost an infinite one, while Petterman had at his disposal more than 100,000 temperature-records for his paper on the Gulf Stream, published in 1870. Great numbers of surface temperatures had also been gathered from the other oceans, thanks largely to Maury's efforts, and have been accumulated since that time by the Hydrographic Services of the various maritime nations. In short, our knowledge of the general distribution of temperature at the surface of most parts of the sea has reached a point where no far-reaching modification of the existing thermal charts of the surface is likely.

However, there is no part of the open sea for which the normal surface temperature at any season, or the normal seasonal variations are yet known in the detail demanded for the solution of many pressing problems. And to trace the irregular fluctuations that exert wide reaching effects within the sea and in the atmosphere, but of whose amplitudes we, as yet, know very little, is one of the most urgent tasks that now face the oceanographer. Here are formidable undertakings, for they required the collection of great numbers of records over a wide range of localities, with their subsequent analysis. But no technical difficulty is involved.

Owing to the facts that an accurate and simple method of measuring the salinity is a recent development, and that appreciation of the real importance of a knowledge of this feature of the water is of recent growth, it was not until 1928 that an approximately adequate picture of the mean annual salinity of the surface of the oceans as a whole could be attempted. And even this most recent chart has necessarily been combined for different seasons in different parts of the picture, and from data spread over so many years that not all parts of it are comparable. Furthermore, important gaps still remain to be filled for the mean state of the surface for the year as a whole over considerable areas, while much more must yet be done before seasonal charts of the salinity can be even roughly constructed for any one of the ocean basins.

For example, all the measurements that have yet been made of the salinity of the Arctic extensions of the Atlantic, (including the Baffin's Bay source of the Labrador current, and the waters north of North America) have been for the summer months. Neither are winter records available for the off-shore parts of the Gulf of St. Lawrence, nor has anything yet been published on the salinity of Hudson's Bay. The mean state and seasonal variations still offer an equally attractive problem all along the Atlantic shelf of the United States south of Chesapeake Bay, in the Caribbean, in the Gulf of Mexico, and in the outflow from the latter through the straits of Florida; information essential for understanding the secular shifts in the Gulf Stream drift. Knowledge of the alterations that the highly saline water of the Sargasso Sea undergoes as it drifts outward from its center of concentration, with more detailed knowledge of the seasonal fluctuations in the African side that are associated with the seasonal migrations of the trade wind belts to north and south, is needed before we can reconstruct the intermovements of the surface waters in the tropical belt of the Atlantic.

Did we know as much about the salinity of the water off Morocco as we do of its temperature, we could better judge the importance (in the general Atlantic complex) of the water that wells up there from the deeps, in bringing up a supply of dissolved nutrients to help maintain the fertility of the surface stratum for plant life. The seasonal alterations in the salinity of the surface around South Africa, reflecting the alternate contractions and expansions of the warm Alguhlas and cold Benguela currents, also remain to be plotted in detail. And the only general parts of the Pacific for which an approximately adequate understanding of the seasonal cycle of salinity of the surface has yet been gained are the coast waters along California in the one side, Japanese waters and the Javan Sea in the other.

When so much is yet to be learned about the state of the surface of the sea, it is not surprising that much greater gaps remain to be filled in our knowledge of the underlying water. In fact, the only considerable regions for which oceanographers can yet claim even an outline-knowledge of the normal seasonal cycle of salinity combined with temperature from surface down to bottom, are the parts of the northeastern Atlantic with its marginal seas (Norwegian, North, Baltic, and Mediterranean) that have been covered by the cruises of the International Commissions (Page 138); a much smaller coastwise sector off the east coast of North America between Cape Cod and Labrador; Californian and Japanese coastal waters; and the Javan and South China Sea where records were obtained quarterly for the period 1917-1920. Even for these regions we need a much closer knowledge of the minor seasonal fluctuations with their causes, especially of the irregular annual transgressions of one or another water-mass which often play a disturbing (even destructive) role in the general economy of the sea.

In the ocean basins, the exploration of the underlying waters is much further advanced for temperature than it is for salinity, the thermal state being established in its broad outlines. So rapidly, in fact, did it prove possible to learn the abyssal temperature, once attention was focused thereon, that while Wyville Thomson, as late as 1873, found it necessary to combat the view that the whole ocean basin was filled with water of 4° Centigrade, ten years later the basic distribution of deep sea temperatures was generally understood. So many deep sea temperatures have subsequently been obtained in the North and South Atlantic that the general distribution, at different depths, can now be plotted with some confidence for these oceans, though as yet nowhere in detail.

But the general uniformity of the abyssal and mid-level temperatures over wide expanses, with the slow rate at which these alter from season to season, or from year to year, is our only present warrant for extending any generalization to the Pacific as a whole. Although a large number of serial and of deep bottom readings have accumulated from that ocean, most of them have been concentrated along the American seaboard; between California, the Aleutian Islands and Japan; around the western margin from Japan to Australia; between Australia, New Zealand and Samoa; thence to Samoa; thence to Hawaii; around that group; and along scattered profiles across the basins. The situation is no better for the Indian Ocean, except for the marginal zones.

Data so scattered allow only the roughest of regional plotting. In short, the thermal charts of these oceans cannot reach even to the elementary standard so far attained for the Atlantic until serial records of their temperatures for all depths, surface to bottom, have been obtained over a much wider range of well selected localities. And this minimal requirement would give only a first approximation to the completed picture that must be aimed at finally.

The gaps in present knowledge of the salinity of the ocean deeps are still more serious than for temperature, partly because only a fraction as many records have yet been obtained; partly

because the considerable significance of even the smallest variations (in the study of circulation) and the unexpectedly complex regional inequalities that have actually been found to exist, make it less safe to deduce the salinity of intervening sectors of water from widely separated observing stations.

Modern standards of research require simultaneous determination both of temperature and of salinity from the surface down to the bottom, if an oceanographic observing station is to be classed as complete, the time having long passed when a surface and a bottom reading were thought sufficient. And in the ocean basins, (with few exceptions) these requirements have been met only by the major deep sea expeditions, whose tracks, reasonably closed-meshed in the Atlantics, have covered the Pacific and Indian basins (and especially the Southern Ocean) with only a very sparse web indeed. Even in the Atlantic, north of 20° N. latitude, only about twenty such complete serial determinations of salinity combined with temperature had been published for depths greater than 1500 fathoms up to February 1, 1928, a depth-limit including the greater part of the basin in question. The case is far worse for the Pacific, where only thirty-one complete observations deeper than 500 fathoms had been published up to that date for all the vast area from the American coastline westward to longitude 180°; only 85 so deep for the entire Pacific basin; and only seven deeper than 1500 fathoms. And while a large number of serials deeper than 1000 meters (since published) have been taken in the eastern margin of the Pacific within the last few years by the U.S. Bureau of Fisheries, and by the U.S. Coast and Geodetic Survey, these have all been located close in to the American coast, or around the Hawaiian Archipelago. Up to 1928, a dozen stations, extending out from the coast of Chile, gave the only accurate data as to the salinity of the bottom of the Southern Pacific on the American side.

The whole southeastern part of that ocean was, therefore, nearly virgin ground with respect to its abyssal salinities until crossed by the "Carnegie" in 1928-1929; its northeastern abyss hardly less so. On the western side we find another vast blank, so far as the salinity of the deep water (for that matter, all except the surface) is concerned, extending westward from the longitude of the Hawaiian Archipelago nearly to the Tuscarora deep off Japan, and to the basin between the Japan and the Philippines, where a considerable number of deep records of salinity, as well as of temperature, have been obtained. This expanse, thousands of miles in extent, is crossed (east and west) by only one line of five observing stations at about the latitude of San Francisco. In fact, along only one meridional profile, falling between longitudes 140° W. and 160° W. are data available for reconstructing the sub-surface salinity of the central basin of the Pacific; even for this we must turn back to the observations taken by the "Challenger" half a century ago.[1] Not a single really deep salinity-determination has yet been obtained in the Antarctic extension of the Pacific.

1. Existing data have also allowed the construction of such a profile around the eastern margin of the Pacific.

On such ridiculously inadequate data must we needs base our present views as to the physical and chemical conditions and circulation of the bottom waters of the largest of the oceans.

On the deeps of the central part of the Indian Ocean (an area roughly as large as Australia) less than a dozen complete serial observations have been taken though information is more extensive around the African, Indo-Malaysian and Australian margins. Not a single deep record of salinity has been obtained to the south of Australia, and only six of abyssal temperature, though the Southern Indian Ocean further west has been made comparatively well-known by the various Antarctic exploring expeditions.

Thanks to the "Meteor," we have today a better picture of the physics of the deep waters of the South Atlantic, in its regional and bathymetric aspects, than for any of the other ocean basins as a whole, an interesting illustration of the amount of exploratory work that a single well planned and well equipped deep sea expedition can accomplish.

The fertility of the results that may be expected from equally detailed surveys of the other oceans may be judged from the fact that the meridional salinity profiles of the two sides of the South and Equatorial Atlantic, constructed from the Meteor's data, have necessitated an entire reconsideration of the views previously held as to the circulatory movements of the different strata in the mid-levels of the Atlantic basins as a whole, especially as to the northward extensions of water from the Antarctic, and as to the regions of sinking and up-welling.

2. Circulation

It is as essential for the oceanographer to understand the circulatory movements of the water, if he is to comprehend any of the events that take place in the sea, whether biologic or geophysical, as it is for the meteorologist to understand the systems of winds on land.

In practice, the study of ocean currents can never be divorced from that of the more static physical features of the water as represented by salinity and temperature, both because the latter give evidences of the former, and because the circulation is largely responsible for the distribution of temperature and salinity, as actually existing. It is, in fact, chiefly because of the transference toward the poles of great volumes of water that have been heated near the equator by the sun, because of the return movements toward the tropics of water cooled around the Arctic and Antarctic fronts, and because of the mass sinkings in high latitudes, that the distribution of temperature in the sea does not vary directly with the latitude, but that an asymmetrical distribution is maintained, warmest in the eastern sides of the oceans in the northern hemisphere, in the western sides in the southern,[1] and that the abyssal basins

1. This is controlled to some extent by differences in the efficiency of alternate summer warming and winter cooling, in situ, along the windward and leeward sides of the continents.

are keot icy cold.

Cold currents are also responsible for the drifts of ice from the Antarctic and Arctic to melt in lower latitudes, with all that this entails as to sea chilling, effects on terrestrial climates, etc., while this same melting process produces circulatory effects in the nearby waters that have been the subject of much dispute. It is, therefore, impossible to understand the thermal problems in the sea if we do not understand the phenomena and causes of its circulation, and vice-versa; this applies equally to the problems of salinity; likewise to the regional and bathic variations in the concentrations of oxygen, and of the various solutes. Circulation, of one kind or another, also plays an active part in the events of submarine geology, as it sorts and transports sediments, attacks shore lines and slopes, maintains conditions approaching equilibrium with regard to the alkalinity, etc., of the water, and so forth.

In short, no argument is needed to justify the study of ocean circulation from the geo-physical standpoint, for here we face an earthly phenomenon of the first rank. Currents in the sea also intrude constantly on the attention of oceanic biologists; partly because this would be true of anything that controls the temperature of the water, but also as agencies important in the migrations and dispersals of a great variety of animals and plants. This phase is of great concern to the student of the problems of the marine fisheries.

The mobility of the waters of the oceans (with their high specific gravity) also concerns the biologist as making possible the planktonic existence of many groups of animals and plants, while permitting other categories of animals to lead a stationary existence fixed to the bottom, where they depend on the waters to bring their food to them, instead upon their own powers of locomotion to carry them to their prey (Page 45).

The knowledge of currents that is needed by the biologist calls, furthermore, for examinations of special regions so detailed that we commence to see the circulatory bases for vital economy in only a few areas, all of them near land; the North, the Norwegian and the Barents Seas, for instance; the Baltic; the Mediterranean; the Gulf of Maine; the Gulf of St. Lawrence; the Californian and Japanese coastal waters.

Currents, like temperatures (Page 89), also bear directly on human affairs via the disturbing effect that any sporadic departure from the normal state must have on the temperature of the water, hence on the temperature and barometric pressure of the overlying air, to be reflected in weather abnormalities over the neighboring lands (Page 90). We also think here of the importance of ocean currents in navigation; not only as they assist or impede passing ships and as the relative directions of current and of wind affects the heights and shapes of waves, but also as the agencies responsible for the menace to the traffic lines by icebergs.

In short, there is no field of study, of sea or of its contents, that is not immediately concerned with the circulation of the water.

We must emphasize that this concern extends to every type of circulation taking place, and to every force, external or internal, that is able to set the water in motion, because every type of circulation that exists has far-reaching effects in all the fields just mentioned, while because of the almost perfect fluidity of water, a variety of forces produce motion within it. Furthermore, every circulatory problem involves both the observable events and their causes.

Circulatory phenomena in the sea may be divided into (a) tidal, set in motion by the gravitational attraction of the sun, of the moon, and of other heavenly bodies; and (b) non-tidal, including all other currents or disturbances of whatever sort.

The study of the tides is now so admirably taken care of by the tidal surveys of all the more important maritime nations that the tides will be omitted from this discussion.

For convenience, the non-tidal currents may, in turn, be divided into (a) the progressive horizontal, (b) the vertical, and (c) the non-progressive oscillations which do more work in the sea than is generally appreciated. The first of these groups includes all the more apparent ocean currents, also the slower mass-drifts, whether at the surface or in the deeps. The second group refers to the mass sinkings and up-wellings (equally important if less obvious elements in the closed system), likewise to the violent churnings taking place along certain sectors of coastline, as for example, at the mouth of the Bay of Fundy, and over some of the most productive fishing grounds; it also refers to the turbulent effects of tides and waves in general. The third refers to wave motion, including the so-called "tidal waves" which are really set up by volcanic action, or by earthquakes beneath the sea.

Every student of the sea has fully realized the importance of the horizontal ocean currents in the scheme of things; so has every intelligent seaman. The problems of this phase of oceanic circulation now unfold along three lines; (1) What is the normal current-system of the ocean in all its parts, in all its depths, and at all seasons of the year? (2) What is the magnitude of the variations from this normal state, and how often do they happen? (3) What are the motive forces for the continuing system of currents in the sea, and for the deviations therefrom?

No one who stops to consider the vast areas covered by the oceans, the great expense of special expeditions, and the difficulty of making direct measurements of the current anywhere except close to land and in very shoal water, will be surprised that even the mere pictorial representation of the circulation of the surface of the ocean is still far from complete.

The first important application of currents to be appreciated was the navigational. From the days of the Phoenecians, or earlier, ship captains have realized that knowledge of the currents was necessary for the safety and expedition of their voyages. By the middle of the last century the gradual collection and digestion of

vessels' log books had given the navigator a rough picture of such of the major currents as affected him the most, especially in the North Atlantic. And while it was chiefly by suiting the sailing routes to the prevailing winds that the use of Maury's sailing directions expedited voyages,[1] it is certain that advantage taken of the

1. The average voyage from England to America was shortened by about ten days thereby, from England to Australia and return by about sixty days.

prevailing current was partly responsible for the fact that British ship masters alone are said to have profited ten million dollars annually by using Maury's and more recent current charts, so long as sailing ships continued to carry the bulk of the world's commerce. And while full-powered steamers now run more independently of the current, continued collection of such data has been considered so important that the Hydrographic and Meteorologic offices of Great Britain, of Germany, of Holland, and of the United States had together gathered more than 37,000,000 notes on the wind, weather, surface temperature, and surface drift of the sea, up to 1904.

Notwithstanding the vast amount of data assembled, even the surface currents can yet be pictured only in a very generalized way. This is due in part to the nature of the information available from log books, in which any leeway that the ship may have made is usually included in the recorded "drift." But a more serious difficulty is that ocean currents do not progress like smooth flowing rivers, but are constantly varying in velocity and direction, eddying, even temporarily reversed by the wind, in a way so complex that it is not yet possible to state the details for any part of the sea, at any season of the year. Furthermore, surface data, taken by themselves, may give a very erroneous picture of the actual circulation, because a knowledge of the movements of the underlying water is equally essential. In this last respect, reports from passing ships do not help us at all.

Since it has not proved feasible to use current meters frequently enough in deep water, or at stations enough, to be of much value there, it is necessary to turn to indirect methods to learn the direction of the horizontal flow in the deeper layers. The sorts of data from which the latter may be deduced are various. The distribution of oxygen gives us some information. So does the distribution of the different kinds of sediments on the bottom; also the geographic distribution of various plants and animals. But far the most reliable indices to the movements of water-masses below the surface are their temperatures and salinities. Hence it was not until a satisfactory deep sea thermometer was invented, and an accurate method of measuring the salinity (or the specific gravity, for the one can be calculated from the other), that science was in a position to gather empiric knowledge of the movements that geographers had long postulated for the bottom waters of the ocean.

We are able, by expansions of cold or of warm water, of high salinities or of low, to recognize arctic or tropical currents; land water fanning out off river mouths; the lines of dispersal for the highly saline waters that result from evaporation at the surface

in certain enclosed seas (Mediterranean and Red Sea), as well as in the Trade Wind belts; the up-wellings from the abyss; the regions where water, chilled to a high specific gravity, pours downward from the surface; the regions of active turbulence, where the surface is chilled, the bottom warmed, etc. The evidence of salinity is especially instructive with respect to deep currents, because this feature of a body of water below the surface is altered only if it be forcibly intermingled with water of some other character, whereas cold water may be warmed, or warm water cooled, by radiation, without any such mixing. And while the knowledge of currents to be obtained from temperature and salinity (each weighed per se) is strictly qualitative, up to date it has given us almost our sole reliable clue to the movements of the waters of the deeps.

Even with the modern development of quantitative methods of studying ocean currents, the simpler lines of qualitative evidence must not be neglected, because the two illuminate different aspects of the circulatory problem. The former throw light on the direction and velocity of flow prevailing at the time of observation, and to be expected as long thereafter as conditions continue stable. But when we find, let us say, a tongue of cold water extending down along the Grand Banks from the north, with bergs floating in it, we see the result of events that have been taking place for some time previous: i.e., we glimpse oceanographic history. And by plotting these simple physical features of the water periodically, it is possible to follow the relative contractions and expansions of different water-masses as long as these continue. Thus in Physical Oceanography, as in every one of the geo-physical sciences, the qualitative-descriptive method of study must proceed hand in hand with the quantitative, if we are to gain a just picture of events as they actually occur in nature.

In this case, as is usually true of broad-scale phenomena, the dependability of the results rests largely on the number of observations taken. And as we have to do with dynamic phenomena, rather than with static, the more nearly simultaneous the observations can be made the better.

Naturally, these technical requirements have best been met in the more frequented and more fished parts of the North Atlantic and of its tributary seas. Qualitative studies of the currents at different depths have, in fact, been prosecuted so intensively in limited areas in the North Sea, the Norwegian Sea, the Bay of Biscay, the Straits of Gibralter, the Gulf of St. Lawrence, the Gulf of Maine, around the Grand Banks, and in the Straits of Florida, that the prevailing systems of motion have been worked out there, surface to bottom. This applies also along the coasts of southern California, likewise around Japan; but nowhere else as yet.

When we turn to the ocean basins, outside the margins of the continents, there is crying need for the raw data (temperature and salinity) for current plotting (Page 35). Lacking this we still fail to comprehend more than the most general aspects of the drifts over the floors of the abyss - movements that are as important a part of the picture from every point of view (except the navigational) as is the circulation of the surface. And our ideas as to the

dominant drifts and interchanges in the mid-strata of the ocean basins are only now crystallizing. This is especially true of the vast and lonely expanses of the Pacific, which have been traversed by scientific expeditions only at long intervals, and along tracks far apart. Knowledge of the underlying circulation of the Pacific and of the Indian Ocean might be expected to lag far behind that of the Atlantic, because of the great areas to be covered, and the expense involved, did not their closure to the north (complete for the Indian Ocean, nearly so for the Pacific), greatly simplify their circulatory characters. The immediate need here is for the accumulation of the raw data.

Vertical currents are not as apparent to the causal observer as are the horizontal drifts. In fact, movements of this sort are, as a rule, so slow that they are not to be detected by ordinary instrumental observation, but only indirectly by their effects upon the temperature and salinity of the surface waters of the regions in question. Since they are not of direct interest to the navigator (omitting the mythical or more actual whirlpools in narrow straits, etc.) their existence was not recognized until theoretic discussions of the circulatory systems of the oceans made clear the necessity for assuming the existence of something of the sort. Moreover, such vertical currents were later deduced from wind observations.

Modern oceanography is, however, much concerned with the up-wellings and sinkings that are now known to take place on a vast scale, because it is certain that the presence of a thick stratum of water in the abyss, much colder than the mean temperature of the underlying crust of the earth, is the result of mass sinkings, near the poles, of water cooled and so given a high specific gravity at the surface. Conversely, we need more than our present sketchy view of the compensating up-wellings, known to prevail along the coasts of Morocco; of Southwest Africa; of California; of Ecuador, Peru, and Chile. From what depths do these chiefly draw? What are their velocities, their seasonal fluctuations, the volumes of water involved? Just how do they control the physical characters of the upper strata of water, and what is their effect on the vital economy of the seas where their physical effects are greatest? Only for the California up-welling can we yet answer these questions even in the roughest way. The South American up-welling offers perhaps the most attractive problem in general Oceanography today.

Perhaps of first importance in this connection is the role of these upwellings as conveyors to the surface, of water rich in dissolved plant nutrients. It seems clear enough (in fact, numerous analyses of phosphates, nitrates, etc. establish) that as the carcasses of animals and plants are constantly sinking, the chemical compounds to which they finally decay would tend to accumulate in the deeper levels out of the reach of the photosynthetic plant world, were there no such up-drafts, and no churnings of the water. That planktonic plants have been found in some abundance at great depths does not argue against this, any more than does the fact that we can grow rhubarb etc., in our cellars, because they have been found most abundant under regions where the surface flora (hence the sinking carcasses) are also most abundant, suggesting that this abyssal plant Plankton really represents a saprophitic community. Diffusion in

motionless water takes place too slowly, and on too small a scale, to account for the regeneration of dissolved food stuffs in the upper stratum that is known to occur. But in the sea upwellings, eddy motions, and turbulence of all sorts, by effecting interchanges of water masses having different properties, produces an effect agreeing with what would happen if the coefficient of diffusion were very high. Empiric tests of the actual events are, however, much needed, because theory has far outstripped observation in this field.

Closely associated with the phenomena of mass upwellings and sinkings are the problems of turbulence, in the shoal marginal seas where most of the important sea fisheries are concentrated. In such situations this type of circulation is a physical factor of the very first rank, because it there does the same work, in bringing rich water up from the bottom to the surface, and in maintaining the circulation of oxygen, that the great vertical currents do for the ocean basins far from land. In high latitudes the interchange of water between surface and bottom brought about by turbulence also plays an active role in the thermal complex of shoal seas, by bringing cold water from the deeps up within the direct influence of the sun and carrying warm water down in summer, while assisting the loss of heat by radiation in the same way in winter. The activity of turbulence at any given time and place is determined by the interplay of many factors; strength of the tidal current; shape of the bottom; contour of the coastline; strength of the wind; height and shape of the waves; likewise by the degree of vertical stability given to the water by the vertical distribution of specific gravity prevailing at the time.

Turbulence, moreover, varies from hour to hour with changes in the tide and wind. Thus wide regional and seasonal variations may exist in this respect between stations only a few miles apart, making local solution of the problems of turbulence extremely complex, and the turbulent movements are of such a nature as to preclude direct measurement. But interpretation of the local variations in the thermal and haline cycles in shoal northern seas (where the greatest abundance of plants and animals are concentrated), and of many events in the life histories of fishes and other animals, as well as of the periods of multiplication for the Planktonic plants, depend so directly on knowledge of the varying degrees of turbulence that this general subject deserves much more attention than it has received. We see a striking example of turbulence as a determining factor in the Bay of Fundy.

The problem of the distribution of oxygen in the sea is so closely associated with the general problems of vertical circulation in the ocean that it is best mentioned here. The intake of oxygen occurs exclusively at and near the surface, (1) in the surface film, or within the upper few feet where air bubbles are entrapped by breaking waves, and (2) throughout the upper illuminated zone where plants carry on photosynthesis. Quantitative data as to the rapidity with which any deficiency in oxygenis renewed from these sources (particularly the efficiency of the latter out in the open sea) are present <u>desiderata</u>. There are no sources from which the water can absorb free oxygen in the deeper levels. On the contrary the deeps are constantly being robbed of their dissolved oxygen, not only by

animals in their respiration, but by the oxidization of the decaying carcasses of animals and plants, and measurements of the actual rate of impoverishment under the varying conditions actually existing in the sea are much wanted in connection with a variety of biologic problems.

If there were no means of renewing oxygen from above, the underlying water would soon be absolutely stripped of this vital necessity, as the deeps of the Black Sea actually are, instead of which we find the bottom waters of the basins nearly saturated with oxygen, contrasting with considerable deficiencies in the mid-strata under the Tropical belt of the Atlantic, and generally in the mid-depths of the Pacific. The only known means by which this state can be maintained, is by sinking currents, or by turbulence, carrying down into the deeps the water that has become saturated with oxygen near the surface. We need to learn whether the mass sinkings of oxygen-laden water, that supply the bottoms of the basins, are as strictly confined to the Arctic and Antarctic Seas, in their respective winters, as now seems probable; also how this water comes to be distributed over the bottoms of the ocean basins so uniformly that the abyss is about uniformly rich in oxygen over vast areas, in spite of the wide local variations in abundance of animals etc.

The relationships that the paucity of oxygen in the equatorial mid-strata of the Atlantic bears to the drifts, toward the equator, of sinking water from mid-latitudes north and south, that are revealed by the "Meteor's" profiles, remains to be worked out; and we still await a satisfactory interpretation, in terms of circulation, of the poverty in oxygen of the mid-strata of the Pacific. The local factors (e.g. abundance of plants and animals, amount of decomposition of organic matter taking place at different levels) responsible for the very notable divergence between the quantitative distribution of oxygen and that of salinity, as revealed by the most recent meridional profiles of the oceans, also offer an interesting problem; likewise the relative importance, from the standpoint of oxygen intake, of coastlines of different characters, with their different types of wave action and of turbulence. How effective a source of oxygen supply for the surrounding neighborhood is, for instance, a rocky headland upon which the surf beats constantly? We have yet to learn how deep simple turbulence is able to maintain the oxygen supply close to the saturation point in different regions under different conditions. How are we to interpret, in this respect, the very rapid falling off of oxygen, with depth, in the upwelling waters off California;and is this falling off characteristic of the other regions where upwelling takes place on a broad scale?

Finally, the problems of the oscillatory (pure wave) currents of the sea deserve a word. Two classes of phenomena come in question here; one the ordinary storm waves, when not complicated by tidal churnings, the other the internal boundary waves or vertical undulations at some mid-level that winds and other forces are known to set in motion, and that have been observed, on occasions when no apparent cause could be ascribed to them.

Although the importance of learning the depth of storm-wave base, and the efficacy of storm-wave oscillation down to that level as a transporter of heavy materials, is obvious from the geologic

standpoint, very little is yet known (except for shoal waters) about the absolute depths to which it is effective. For example, can we assume as representative of the sub-tropical belt of the Atlantic as a whole the conditions prevailing on the Challenger Bank, off Bermuda, where storm waves roll considerable masses of calcareous algae to and fro, often enough for these to stay alive on all sides, down to a depth of 50 fathoms or so? How much deeper is effective wave-base in the Antarctic where swells might theoretically, travel right around the globe without meeting any obstacle - and perhaps actually do so? What is the actual speed of such oscillation at different depths, when set in motion by storm waves of different shapes, lengths, etc., and travelling at different speeds? For that matter the shapes and run of the surface waves themselves offer an interesting field; in fact the stereogrammic studies by recent expeditions, notably those of the "Meteor" have given the first exact topographic pictures of the very complex corrugations into which the surface of the sea is thrown by the wind.

Our present knowledge of submarine boundary (or internal waves in the open oceans has hardly advanced beyond the realization that such things exist, and that they may be set up by a variety of forces. We need to learn what conditions give rise to progressive boundary waves, what conditions to standing waves; their periods; their relation to the free tidal wave; and their role in general in the sea, including such points as their frequency in different regions at different seasons, their vertical amplitudes, their lengths from crest to crest, etc.

Perhaps the most pressing of the broad problems in physical oceanography today, made so by its direct bearing, not only on events of all sorts in the sea, but on land-climates as well, is that of the irregular fluctuations of the ocean currents, with the causes of such events.

It is certain that if the present scheme of ocean circulation were materially to change, the climates of the continents would soon differ widely from the present state; and for the worse, so far as man's welfare is concerned. The effect of the ocean currents on land climates is so much a commonplace, stressed in every textbook of physical geography or meteorology, that we need only cite (a classic example) the effect of the Gulf Stream or North Atlantic drift, making habitable the most northerly parts of western Europe, (reflected in the fact that the mean temperature for January is about 40° F. higher in Northern Norway than is normal for that latitude), contrasted with the opposite side of the Atlantic, where the icy Labrador current from the North chills the climate of the coastal strip all along Labrador and Newfoundland, making agriculture impossible at latitudes corresponding to those of Ireland and England. Any variations in the currents that shift the previously existing distribution of temperature in the sea, as any considerable alteration is bound to do, will have a still more direct bearing on animal and plant life in the sea; one almost certainly destructive to some species, but perhaps temporarily favoring the production, or extending the geographic boundaries of others. Cases in point are the almost total destruction of the tile fish off the east coast of the United States in 1884, presumably by a flooding with cold water, and the immigration of fishes of temperate thermal affinities

into the arctic, north of Europe, in 1922.

In a general way, the waters of the central parts of the open basins can be described as extremely stable, in their physical character, from year to year, and over long periods of years, if compared to the atmosphere. The close correspondence between temperatures and salinities recorded at several stations in mid-Atlantic by the "Challenger" in 1877-78, and at nearby localities by the "Michael Sars" in 1910, the "Bache" in 1914, illustrates this fundamental constancy. Around the oceanic fringes, however, and especially toward the outer boundaries of the several currents, conditions are far less constant, not only seasonally, but as a result of wide scale, but irregular, expansions or contractions in the currents, or of shifts in their relative locations. The most widely heralded event of this sort that has come under human observation in historic times (because its effects or accompaniments both on land and in the sea were destructive) was the abnormal development of the warm current from the north along the west coast of South America in the winter of 1925, accompanied either by a slackening of the cold Humboldt current (or upwelling) which normally bathes these shores, or, perhaps, by its diversion offshore. During that same winter a westward deviation of the cool Benguela current was reported as similarly accompanied by an expansion toward the south of the warm Guinea current along the west coast of South Africa. Spectacular events of the same sort have also taken place in high latitudes, within the memory of men now living. Between 1892 and 1897, for example, there occurred what has been described as a "tremendous outburst" of ice from the Antarctic, sending so many floes and icebergs northward into the southern ocean that the traffic between South America, Africa and Australia had to be diverted to more northern tracks. A similar outburst of Arctic ice in 1903 is fresh in the memories of Scandinavian fishermen, for it was followed by temporary failure of the cod and herring fisheries along the whole length of Norway, north to south. In that year, Barents Sea was full of pack ice up to May, while ice came closer to the Murman and Finmark coasts than ever before. On the other hand, a great expansion of warm Atlantic water was reported to have taken place into these northern seas in the summer of 1922.

It is true that departures from the normal so noticeable as these are rare events, and up to recently it has only been these major departures that have forced themselves on general attention. It has long been known, however, that smaller fluctuations do take place from year to year in the boundaries and extensions of the warm North Atlantic drift. Similarly, the International Ice Patrol has found that the interrelationships of the Labrador and Gulf Stream currents around the Grand Banks are not alike in any two successive years, either in the seasonal schedule, or in the volumes, temperatures, or velocities of the two currents. And these differences are reflected not only in the yearly variations in the amount of ice drifting down past the Grand Banks, but in the tracks followed by the individual bergs. In fact, wherever ocean currents have come under continuous observation for a period of years, they have been found to vary, more or less, in a non-periodic, and up to date in an unpredictable way.

There is, as yet, no general agreement of scientific opinion as to the causes of these variations, for all that has yet been possible, in any individual case, has been to show an apparent correlation between the event, and some outstanding solar or other cosmic happening. Some students have regarded such fluctuations as due, in the last analysis, to variations in the amount of energy (i.e., heat) that reaches the earth from the sun. But others maintain that these solar variations are insufficient to account for phenomena known to take place. And even if the solar control theory be accepted, the intervening mechanism by which solar variations might be translated into the variable pulses and curious dislocations shown by the ocean currents is still to be worked out. Does this take place via the medium of changes in the prevailing strength and direction of the winds, caused by shifts in the locations of the centers of high and low atmospheric pressure? Does more or less active heating of the waters around the Tropic belt send greater or lesser volumes of warm water poleward, or is the Antarctic shelf the cradle of all the world-wide disturbances in the current systems of the oceans, as at least one emminent oceanographer would have us believe?

Or must we conclude, as do some students, that the solar variations are too small, and the ability of the sea to absorb and smooth out their effects too great (owing to the great capacity of water for heat), for fluctuating currents to be explained in this way? In that case the theory that periodic changes in gravitation are responsible, caused by the regular secular changes in the relative positions of earth, moon, and sun, must be critically weighed.

The possibility that events taking place around the subantarctic belt, where vast masses of ice break off, may exert far-reaching effects, translated in the end into climatic variations in distant parts of the earth, brings to our attention another problem with which physical oceanographers have long been much concerned; namely the relative importance that melting ice plays in the complex of factors that keep the oceanic circulation in motion. Here the present need is not so much for rehashing the old arguments, pro and con, as for much more extensive investigation actually around the ice edge than has yet been possible. At first sight this might seem an especially favorable subject for experiment under laboratory control, for one can easily put a piece of ice in water and observe what takes place as the ice melts. But one of the reasons why the relative efficacy of melting ice as a causative agent for ocean currents is still a matter for dispute, is uncertainty as to whether the results seen in laboratory tanks, or in some small fjord, do actually simulate the conditions that prevail over the broad expanses of the open ocean, closely enough (quantitatively as well as qualitatively) to be accepted as representative of what actually happens in nature.

The regional and descriptive phases of oceanic circulation lead naturally to a presentation of the present state of knowledge as to the interplay of forces that maintain this circulation. New viewpoints in this field have followed the recent development of quantitative methods of estimating the relative efficiency of the two major forces most obviously concerned; namely, the internal hydrostatics of the water itself on the one hand, and the frictional

effect of the wind on the other. Until mathematical expressions were made available to take account of all the factors (e.g., wind and internal friction, regional differences in specific gravity, deflective force of earth rotation) quantitative measurement of the velocity of currents, in the sea, could be made only by current meter. But, generally speaking, the use of these instruments is confined to shoal waters near land, i.e., to situations where tidal currents are not only strongest, but are veering if not reversing, hence where they so constantly confuse the picture that continuous observations over long periods are necessary before the dynamic or other broad scale movements can be distinguished from the local and temporary ones.

Many such current measurements have been taken on special tidal surveys along the various coastlines, likewise from light ships in the North Sea, in the Baltic, and off the east and west coasts of North America; also in the straits of Florida, where Pillsbury carried out his classic studies of the volume and velocity of the outflow from the Gulf of Mexico. But, by the nature of the case, quantitative estimation of the drift of the whole mass of water for any considerable area of the open ocean demands more generally applicable and deductive methods. And for the development of these we must thank the theoretic advances in ocean physics that have followed Bjerknes' development of hydro-dynamics, chiefly at the hands of Scandinavian oceanographers; likewise Eckman's mathematical discussions of the problem of wind currents.

Mathematical calculation of dynamic circulation has now been so simplified that the method can be mastered by any physical oceanographer. Furthermore, the raw data that are needed are not only easily obtained but are of a sort that have long been collected in ordinary routine, i.e., a record of the temperature and of the salinity at a sufficient number of depths-levels, and at a net of stations sufficiently close, and taken nearly enough simultaneously, to allow horizontal projection of the dynamic state prevailing over the area as a whole. Unfortunately, however, neither this method (nor, for that matter, any other indirect method) can be the cure-all that its simplicity and its mathematic defensibility might suggest, because of certain very serious sources of possible error. In the first place the results are only relative to some other mass of water which may be taken as the base for calculation. Consequently, unless the velocity of the water chosen as base be measured, or unless it be known to be stationary, the calculated result cannot give the actual current. However, in favorable cases record of temperature and of salinity for a sufficiently dense network of stations can be so dealt with as materially to overcome this difficulty. Secondly, the contour of the bottom introduces a factor that can seldom be stated numerically, for if the dynamic current strike a ridge of the sea floor, or a coastline, it may be given a character quite different from that calculated for the "free ocean," of which all oceanographers speak so glibly, but which no one of us will ever see.

Therefore, we urgently need some general expression of the degree to which such calculations are applicable to regions where the depth differs much from station to station, or to compensate for this confusing factor of depth, some numerical allowance more rational than the arbitrary corrections that have so far been proposed.

We also need, as urgently, empiric tests on a much broader scale than it has yet been possible to make, of the magnitude of the error introduced into the calculations by the fact that even the deepest water-layer is actually not stationary, though it may be moving so slowly that it is usually considered motionless for the purpose of calculation.

To check the magnitudes of these several sources of error, regional dynamic studies of the sea should be carried on hand in hand with any direct means of discovering the velocity and the direction of the current that may be feasible, whenever and wherever opportunity allows. In the few cases where such a comparative examination has yet been undertaken the agreement between the calculated drift, and the type of circulation indicated by other lines of evidence as prevailing at the time, has been close. Thus repeated comparisons of the actual tracks followed by ice, drifting down past the Grand Banks, has shown so good a correspondence to the dynamic current charts made simultaneously by the Ice Patrol cutters, as to warrant the hope that such calculations offer a rational basis for predicting the drifts of individual bergs accurately enough to be of service to passing ships.

Similarly, a recent dynamic study of the velocity and direction of the outflow from the straits of Florida, based on observations taken by the United States Geodetic Coast Steamer "Bache" in 1914, agrees in general, with earlier measurements with current meters. Dynamic circulatory tendencies calculated for different seasons of the year for the Gulf of Maine are corroborated by various other lines of evidence, direct as well as indirect; so, too, for the Norwegian Sea, and for the northern sector of the Labrador current. In short, we now have at hand a tool by which it is possible to approximate, numerifally, the movements of the whole mass of water at a given time for situations where regional variations in specific gravity indicate a drift much greater than the probable error, i.e., where the current is certainly due to differences in hydrostatic pressure.

Other quantitative methods are needed, however, for situations where the dynamic gradients are slight. Thus a method based on the amount that the surface temperature departs from the value normal for the latitude and season, and on the thermal effects of evaporation, recently worked out at the Scripps Institution for Oceanography, and applied with promising results to the waters off the coast of California, will probably prove generally applicable to other regions where upwelling takes place on a broad scale. It also provides a useful check on horizontal velocities deduced from dynamical causes.

The perfection of quantitative methods, and the further amplifications of them that are to be expected, open two chief lines of attack upon circulatory problems. In the first place, they set the stage for a rapid advance in our knowledge of the state of circulation actually prevailing over large ocean areas, and at all depths from the surface downward, especially for regions where there is a wide regional variation in specific gravity. In fact recent dynamic studies of the North Eastern Atlantic by Scandinavian oceanographers have already materially altered the prevailing concept of the

northern boundaries of the general North Atlantic drift, and of its extension toward the Norwegian Sea. During the summer of 1928, the U. S. Coast Guard carried out a general dynamic survey of the circulation of the region of Davis Strait. And we similarly expect from the numerous observations taken by the "Meteor," in the Equatorial and South Atlantic, a general circulatory picture for that ocean, for comparison with the scheme deducible from the distribution of temperature and of salinity, and from the drifts reported in ship's logbooks.

From the standpoint of ocean geophysics as a whole, however, the greatest service to be expected from such developments in quantitative analysis is that here, at last, we have a means of numerically testing the actual efficiency, as a motive power of ocean currents, of one of the two great forces that have usually been invoked as the underlying causes for the existence of a continuing non-tidal circulation in the sea. We refer to the regional inequalities in the specific gravity of the ocean waters that are maintained by heating at low latitudes, chilling at high, combined with the regional differences in salinity that result from river-inflow, from evaporation, and fron rainfall.

In this field, the task immediately urgent is to determine, for as many sectors of different currents as possible, and for as many different ocean areas, whether the internal hydrostatic forces at work are, or are not, quantitatively sufficient, and do, in fact, act in the direction proper to produce the general type and velocity of circulation that other lines of evidence have shown to prevail. More specifically, examinations of particular sectors of the so-called "Gulf Stream," of the Labrador current, of the East Greenland, the Benguela, the Alguhlas, or the Japan currents (among others) may be expected to show how far such highly developed, and definitely localized drifts receive their impetus from internal archimedian forces acting along their courses, or how far some other force (i.e., the winds) must be invoked to explain their persistence. The dynamic studies carried on in the Northwestern Atlantic since 1926 have had this as one of their immediate objects, and their fertility justifies the extension of explorations with this definite aim.

Before the frictional effects of the winds relative to that of internal hydro-statics can be finally established as a major motive force (scientific opinion has long swung first to the one then to the other), wind currents must also be analyzed more searchingly and on a much larger scale than has yet been possible. The mechanical principle in question here is simply the downward propagation, into the water, by friction, of motion given to the surface film by the direct frictional drag of the wind. But it awaited Ekman's mathematical genius to prove that the earlier concepts of wind currents were erroneous because, they did not correctly allow for the deflective force of the earth's rotation, and to explain the peculiar spiralling of such currents with increasing depths. And the fact that the wind-drift actually recorded has usually failed to coincide, by many degrees of azimuth with the theoretic requirements shows that more critical quantitative treatment is still needed to establish some numerical expression for the effects of vertical density gradients and of the contour of the bottom (which have to

date, confused the calculations of the velocity, volume and direction of the current that any given wind will set up in shoal water) and to make sure that all the pertinent factors have been given due weight in the equations. Known methods of estimating the effect of a coastline in the direction of a wind driven current account for some of these apparent discrepancies, but others remain to be explained.

When we turn to the chief problem of the wind as a motive force i.e., how far the great Trans-oceanic drifts under the trade wind belts, and around the Antarctic Ocean, are, in fact, kept in motion by the wind, or in what proportion wind friction combines here with internal hydrostatics, we find few data at hand for quantitative treatment.

In these and similar cases, theoretic discussion of physical potentialities can provide a series of accurately solved type problems. And while the conditions to which such apply are far simpler than prevail in nature, the basis for synthesis that they afford corresponds to the actual state closely enough to meet present needs for the critical examination of test cases.

3. Penetration of Light

Light is so important in the vegetable and animal economy of the sea that the biologist constantly turns to the physicist for information as to the depth to which light-rays of different wave-lengths penetrate into the water, with intensity great enough to serve plants in their photosynthesis, or to govern animals in their tropisms, and in their metabolism. The theoretic coefficient of absorption of light by pure water has been measured many times. What is now needed is empiric tests of what does actually happen in the sea, at different localities, with the sun standing at different heights above the horizon, and under the widely differing conditions of turbidity that actually prevail. In this, as in other phases, the stage of quantitative measurement has been reached some time since; the next rational step is the accumulation of data over the widest possible range of latitudes, locations relative to the coastline, varying abundance of suspended silt or Plankton, different seasons of the year,etc.

C. CHEMICAL ASPECTS OF OCEANOGRAPHY

The studies of the Physical-Chemistry of sea water that are now in progress, like those of its physics, chiefly aim at enlarging our factual knowledge of regional variations and our understanding of events that take place in the cycle of matter there, rather than at clarifying the nature of chemical processes as such. They thus bear to the science of physical-chemistry as a whole a relationship more subsidiary than do oceanic biology or physiology to current attempts to fathom the riddle of life. We may also remark that a line should be drawn between problems in the sea that involve analysis of the chemical reactions that actually take place there, and those which include chemistry only in so far as it is necessary to determine the amounts of one substance, or another, in the solution or in the sediments that clothe the ocean bottom, as adjuncts to other problems. The first of these categories falls truly within the

province of the chemist; but the chemical phase of the latter consists merely of routine analyses, and so may concern the theoretic chemist only in somé secondary stage. As an example of the first category we might cite the problems of lime chemistry (Page 10). Examination of variations in the nitrate content of the sea water per se might illustrate the second category; it is promoted to the truly chemical category when the cause and the effect of the variations in the nitrate-concentration come into account.

As the whole cycle of matter in the sea depends upon the fact that the latter is filled with salt water (a solution not a mere mechanical mixture), it follows that chemical problems are more or less inherent in every phase of sea science. Consequently the reader will find repeated references to various chemical questions in the sections on oceanic biology and on submarine Geology. In the present chapter we wish simply to outline the sorts of chemical problems that center around the nature of sea water, and around the reactions taking place between its various constituents.

The most basic of these, as a part of Oceanography, concerns the processes which cause the extraordinary uniformity in composition of the waters in all parts of the sea. The oceans cover more than two thirds of the surface of the globe; in depth, temperature, light intensity, and pressure they run the whole gamut from warmth, bright illumination, and freedom from any pressure save that of the overlying atmosphere, to icy cold, permanent darkness and the subjection to pressures of 400 atmospheres and upwards per square inch. Furthermore the rivers that empty into the sea contribute solutes that only vary from river to river in their composition, but that as a whole differ widely from sea water in kind, while organic communities of different sorts withdraw different salts from the solution in different parts of the sea. Nevertheless the relative proportions of the different substances in the solution we name "sea water" are regionally so uniform all over the oceans that it is customary not only to regard sea water as a substance practically constant in its composition, but in practice to employ the concentration of one group of its salts as a dependable index to the total saltness.

This conception is not actually correct, for it has long been known that differences, both regional and seasonal, do exist in the proportionate amounts of different substances (especially among the rarer of these) dissolved in the water. Nevertheless sea water is certainly the most uniform in composition of any of the substances common upon our planet. And most geologists, arguing from the composition of the skeletons of marine animals that have lived in the past, together with that of sedimentary rocks that were laid down at different periods under the sea, believe that comparatively little change has taken place in the sea water itself (except in its total salinity), except that during the earlier geologic periods the proportion of lime salts in solution seems to have been much smaller than has been the case in more recent times. To unravel the interplay of factors (evaluating each) which maintains this uniformity at present, and has maintained it in the past, is one of the most attractive problems in geochemistry, for while various explanations have been proposed, we believe no one would seriously maintain that any of them is adequate.

An integral part of this basic problem is the more specific one of the chemical events by which the preponderance of calcium, and of carbonates, which characterizes river water as a whole, is so uniformly altered into the preponderance of sodium and of chlorides that characterizes the sea water, everywhere and at all times, even under the most diverse conditions. The fact (recently demonstrated) that this characteristic state obtains close in to the mouths of great rivers, although the diluting effect of the latter may be apparent for long distances, i.e., that the transition is more sudden with respect to the chemical composition of the water than with respect to its saline concentration, shows that we have here to do with something more fundamental than with a mere withdrawal of lime of shell-bearing organisms, such as would allow sodium to accumulate out of proportion.

Contrasted with the processes that succeed in maintaining sea water so nearly uniform all over the ocean are the chemical reactions that affect the regional and periodic variations that do exist in it, and which involve a wide range of substances, and combinations of substances. Basic problems, in this connection, because of their role in the general cycle of matter in the sea, (Page 65) center around the chemistry of lime and of carbonic acid, bound up with the degree of alkalinity of the water. The chemist has to do here with a very complex series of reactions in which gas tension between water and atmosphere at different temperatures, withdrawals of lime and carbon by organic agency, precipitation of lime, re-solution (which goes forward at different rates for different varieties of carbonate of lime and different lime salts; and at different rates according to amount of free carbon dioxide in the water) and alterations in the degree of ionic dissociation of different salts in the solution, all play a part.

The importance of this general field in its relation to submarine sedimentation, and to the accumulation of lime deposits generally, as well as in its more strictly biological aspect, is touched on in another section (Page 66). One significant chemical problem hinges on the fact that in spite of all the various reactions that tend to alter the proportion of total bases to total acid radicals, and that are therefore tending to alter the degree of alkalinity of the water (and do actually so alter it within narrow limits) by adding or withdrawing carbon dioxide and calcium, or by altering the relative proportions of the normal carbonates to acid bicarbonates in the solution, the balance is so closely maintained at all places and at all times in the open sea that the alkalinity never rises above or falls below the narrow limits within which the organic life (as regulated to marine conditions) is able to exist. This phenomenon is as important in ocean economy, and as deserving of the closest chemical analysis, as is the stability of the alkalinity of blood serum in human physiology.

In this instance, as in so many oceanographic problems, two phases are involved. First, the chemical potentialities in the case must be determined, and these have naturally been the subject of much discussion, leading to substantial agreement with regard to some. The significant task is then to determine in what proportion the theoretic reactions do actually take place in the sea, in what

order, and how induced; a task made difficult by the low concentrations of the solutions with which it is necessary to deal.

It is not necessary to mention here the multiplicity of problems of this sort. Chemical problems equally fundamental are inherent in present-day study of the sea floor, for the geo-physicist is directly concerned with the whole gamut of reactions that take place in the abyssal depths of the sea, it being an open question whether many of those that have been proposed (although doubtless falling within the range of potentialities) are actually of the importance that have been accredited to them on theoretic grounds. With regard to the sea bottom, as well as with regard to the water itself, first rank might be given to the problems of lime chemistry, with ramifications too complex for discussion in this report. The chemical aspects of the precipitation of calcium carbonate in tropical waters are now being taken up afresh. If this precipitation be chiefly mechanical, as now seems likely (Page 11), we need to learn which of the various reactions that have been suggested as the potential causes are actually operative on a large scale in the sea. The reactions that accompany the formation of phosphatic concretions and of glauconite on the bottom also need further examination, while the problem of the chemistry of the deposition of iron in the sea floor is a major one and to date practically untouched (Page 7).

So, too, the chemistry of the natural distillation of organic materials in the bottom muds that are now believed by many to have been responsible for the formation of petroleum and other hydrocarbons.

We have still to learn the chemical character of the water that is entrapped within the sediments, a very important question because the alterations that take place there in the solid materials depend upon its alkalinity, carbon dioxide content, etc., of this water. We think especially of the re-solution of lime there and in the abyssal waters generally. Some such process has been widely postulated to account for the fact that there is a limit to the depths down to which lime sediments chiefly accumulate, and it may explain the fact that the percentage of lime usually decreases in the oceanic sediments from the uppermost layer downwards for we have almost no empiric knowledge as to the actual details of the solution which proceeds at great depths! The problems of lime solution introduce the basic question of the efficiency of sea water as a solvent, not only for lime, but for silica, for the various volcanic substances that accumulate on the sea floor. Solution of a wide variety of minerals is also constantly taking place all around the shores of the continents, in combination with the processes of mechanical erosion by the waves and currents. And while this solution is slow, it is not only unceasing now but has been unceasing for past geologic ages. In short the total amount of material dissolved in this way has been enormous. Furthermore, some recent observations with regard to the concentration of silicates in the water suggest that solution of even these refractory materials may take place rapidly enough to produce regional differences in the amount of silicates in the water, according as different sectors of the coast contribute more or less to the sea. It is also certain that the last word has not yet been said as to the solution of lime from coral formations in tropical waters, or from the accumulations of precipitated calcium there.

A vast amount of work remains to be done before even an approximately adequate picture can be gained of the regularly periodic and regional variations in the amounts of the rarer substances in the sea water. But growing realization of the importance of these in the life cycle in the sea makes this a task so pressing that a considerable number of institutions are devoting their efforts thereto both in America and Europe. As knowledge increases, first one and then another of these rare substances move to be of vital importance. At the present time attention in this field centers chiefly around the concentration of phosphates, of nitrates, of silicates, and of the salts of ammonia. Adequate methods have already been developed to measure the amounts of some of these in the water. But we still lack a satisfactory technique for determining, with sufficient accuracy, the actual amounts of nitrates that are present in solution. And as attention becomes focused on other solutes, other developments of technique will be needed, because chemists have, in this case, to do with solutions so attenuate that they are close to the lower limit at which accurate analysis is possible. In fact, some of the rare substances are known to exist in sea water only because they have been detected in the bodies of marine animals and plants, which could only have obtained them from their aqueous environment, illustrating the delicacy of procedure that would be necessary to measure them in the water.

Recent observations have also led oceanographers to turn their attention afresh to the regional variations in the amounts of oxygen and of nitrogen-gas in the water, as indices to various physical and biological events there. Here again the immediate need is for thorough regional and bathymetric survey for this alone can give a sufficiently descriptive picture of the existing state.

D. LIFE IN THE SEA

While study of whatever manifestations or activity of life in the sea is a part of the fundamental science of Biology, differences in the disciplines employed, and in the nature of the immediate problems attacked, make it convenient to classify this branch of science under three headings: (1) Oceanic Biology, (2) Marine Physiology, (3) Marine Bacteriology.

The first of these is chiefly concerned with the ways in which the basic conditions of life in the sea are made manifest by the diversity in structure and in habits of animals and plants. This includes such subjects as Taxonomy and its relation to geographic and bathymetric distribution; the dependence of successful reproduction, growth, migrations, etc., on definite factors in the marine environment, including the general subject of life histories; the adaptations that enable various groups to populate particular parts of the sea; the interdependences of species of animals, and of animals as a group of plants; the environmental factors that govern plant growth; and all problems in cognate fields.

Marine Physiology covers the study of the general and basic conditions and phenomena of life that are common to marine animals and plants; study of the vital reactions between the cell, or aggregate of cells, and the external environment; and the inter-

actions between the various tissues, and the blood or lymph which constitutes what has been named the internal environment.

Marine Bacteriology covers all the activities of Bacteria in the sea.

1. Oceanic Biology

This heading covers much the same fields as does Terrestrial Biology; but there are several very good reasons for studying the oceanic phases of Biology as distinct from the terrestrial. There is, to begin with, ample justification from the empiric standpoint, namely to complete our knowledge of the kinds of animals and plants that exist on this planet, for many of the inhabitants of the sea (i.e., of 2/3 of the earth's surface) are still unknown, while our knowledge of many others is still far from complete, even as to their structures, let alone their activities. Collecting expeditions, at sea, are therefore still needed, especially along the less frequented coasts, and in the mid and abyssal-depths of the ocean basins, hand in hand with which must go the study, in Museums ashore, of the collections so gathered. In this way fishes, crustaceans, molluscs, etc., never before seen, are constantly being brought to light.

Oceanic Biology also has a very important and direct economic bearing, discussed in another chapter of this report (Page 67).

We find, however, another reason stronger than either of these for devoting special attention to the plant and animal communities of the oceans, in the fact that the peculiarities of the oceanic environment make it possible to study the basic relationship between the marine organism and its physical surroundings, and between different species or groups of animals and plants, in a more direct way in the sea than can be done on the land. The sea is, therefore, in many respects the most favorable natural laboratory for investigations into the laws that govern animal and plant economy.

The peculiarities of the sea that make this true are: (1) the simplicity of the marine environment as contrasted with the terrestrial; (2) its comparative constancy and uniformity in time as well as in space; and (3) the fact that the waters of the sea, as contrasted with the air, are emphatically a favorable environment, not only from the chemical standpoint (discussed under Physiology, Page 53), but also from the physical-mechanical.

The first and most obvious physical advantage of sea water as an environment is that it is not dry, like the air, but is an aqueous solution. The bearing of this fact is simple. On land every animal or plant must either develop some protection to prevent its vital substance from drying up, or its habitat must be restricted to places that are permanently damp. The basic value of the bark, of the rind, or of the impervious shells or skins of one kind or another, developed by terrestrial plants and animals, is not so much to protect against mechanical damage (although this secondary purpose must also be served), but to guard against the constant danger of drying up. Consider, for example, the fate of an earthworm, with its pervious skin, when caught out in the sun on the

brick pavement. Related to this necessity of reducing to a minimum the loss of moisture through the surface, is the equal necessity that almost every land animal or plant is under, of replacing such losses by taking in water; i.e., the need of drinking water. It is a commonplace of school boy instruction that the supply of drinking water, and the dampness of the air, together, go far to control the relative fertility of different parts of the lands, and the kinds of animals and plants that can inhabit them.

The very facts noted above, however, enable the land-organism more readily to perfect a "milieu interieur" adapted to specific purposes. Thus the evolutionary attempt, exerted on land, to escape this control by the water supply, has resulted in a great variety of protective adaptations, of which the water metabolism of desert insects, and the storage of water by the stomach of a camel, or in the stems and leaves of certain desert plants, are perhaps the most familiar examples. In fact, it is no exaggeration to say that the life of every animal or plant on land is directed by the need of metabolic water. Even the briefest failure in the supply is apt to be fatal.

From all this water-complex all the animals and plants of the sea are free. Not only is there no danger of their drying up, but drinking water is never a problem in the sea. Thus marine creatures are freed, as it were, at a stroke, from needing any of the adaptations requisite in this respect for life on land, and from the limitations that the water supply there imposes upon regional dispersions or colonizations. Free from this compelling factor, living substance may, in the sea, remain naked, or may cover its outer surface (in skeleton formation) with a greater variety of materials, not only with minerals, as lime, silica and even compounds of strontium, but with cellulose, agar, chitin, spongin, and various solidified proteins, such as the byssus threads of molluscs, and with protein exudations. Here nature has been able to give free rein to the process of diversification.

Second, while air is much lighter than protoplasm or than any of the derivatives of the latter, (e.g., bones, shells, etc.), sea water is of almost the same specific gravity as protoplasm. On land, because air gives so little support, the vital substances of any living being of any considerable size must in some way be protected against the pull of gravity, i.e., must have a supporting framework; otherwise, it will collapse of its own weight. This need for support is a basic reason for the development of the wood, and of the bony skeletons of land plants and animals. And while the skeleton of a bird or mammal equally serves another purpose, and one which we more usually appreciate, (the attachment of muscles), yet it is only for support that large animals and plants absolutely require complex skeletal structures.

This necessity for support not only introduces great complexity, but it limits size, for as size increases, so does the difficulty of providing adequate support: size of land animals is limited by the strength of bones and sinews.

In the sea there is no necessity for any support, no matter how large a marine animal or plant may be. No alga, for example, needs

develop a hard woody trunk. Because protoplasm is about as heavy as water, there is no gravitational limit to size. The only theoretic limit to the size of marine animals is the necessity for taking in, through the comparatively small part of the surface occupied by the mouth, enough food to support the entire bulk. Correlated with the relief from the force of gravitation, is the fact that the sea supports animals as large today as it ever has, and larger than any animals that ever existed on land. The skeletons of marine animals, then, serve only for external protection, or for the attachment of their muscles. And comparison between the framework of a whale, (which collapses of its own weight and suffocates if stranded on the beach by the ebbing tide), and that of an elephant, shows at a glance how much less is necessary in the one case than the other. In spite of their great muscular power, even the largest sharks have still feebler, and wholly cartilaginous skeletons without any hard bones; while an even more striking example of strength without framework is afforded by the giant squids, animals proverbially active, swift swimming, and muscular, though with only the rudiment of any sort of skeleton. No morphological development of this sort would be possible on land; in fact, sharks and squids, out of the water, fall flat of their own weight.

The fact that living matter is of about the same weight as water has another very important bearing, for it allows whole categories of plants and animals to pass their lives swimming or drifting suspended midway between surface and bottom, an ecologic category that has no parallel on land. The areal distribution of life thus extends to three dimensions in the sea, whereas on land the zone that is permanently habitable reaches upward only to the tops of the highest trees, downward a few feet into the soil.

The water of the sea being in constant motion, and carrying a vast assemblage of living things along with it, there is also a very much better chance that food will be brought by this purely mechanical process within the reach of a stationary animal in the sea than is the case on land; it need merely await whatever the current sweeps within its reach. While, therefore, the power of locomotion is so vital for land animals as a whole that we are accustomed to think of animals as creatures that move, of plants as those that do not, self-directed locomotion is not a basic requirement even for carniverous animals in the sea. In fact, whole categories of flesh-eaters manage very well without it there, and all gradations are to be seen there from such as swim actively to those that swim or crawl for part of their life, then becoming stationary (such as the barnacles), to others that are stationary or practically so throughout their entire lives, such as the stalked sea lilies (crinoids). And if density of aggregation, or numerical strength of individuals be an index to success in the struggle for existence, the oysters, mussels, clams, etc., the deep-sea crinoids, the reef corals, and the sponges find a stationary life highly successful. This applies, furthermore, not only to small animals, but to some of considerable size, such as the giant clam (Tridacna) of the coral reefs.

The constant circulation of the sea water also affords a purely mechanical means of transportation, whereby the problems of dispersal are solved for the floating animals and plants that are

carried from place to place. Thus the dissemination of whole groups of species is assured in the sea without directive swimming on their own part. And even the fishes benefit thereby in their egg and larval stages - or suffer if carried into unfavorable surroundings.

Thus, while it is true that many groups of animals in the sea have been controlled in their structural evolution, and in the development of their appendages, by adaptations for locomotion, such as stream-lined body-forms easy to drive through the water, many others are free from this factor in form regulation. The latter teach us, for example, that the possession of lateral limbs of any sort, or of the bilateral symmetry with which we are so familiar that we have almost come to look on them as a necessary feature of an animal, are actually not a basic necessity at all, but merely adaptations to a particular environment, or way of life.

The morphological simplicity of the many marine animals, even some comparatively high in the scale, that are freed from the necessity of this particular control, frees, in the sea, the study of the basic relation of animal to environment from much of the confusion that puzzles the terrestrial ecologist.

Corresponding simplicity in the internal metabolism of marine animals is associated with the thermal character of the medium in which they live. The more obvious of the complex ways that this factor advantages the oceanic biologist, as contrasted with his confrere on land, are as follows:-

Living surrounded by air, the thermal capacity of which is so low that it changes temperature very rapidly, and through a wide range of variation with changes in the thermal determinants (strength of the sun, direction of the wind, etc.), terrestrial plants and animals must, by and large, be able to accommodate themselves to wide variations in temperature, or else be able to guard themselves against the latter. With temperature controlling the rate of many chemical reactions, the activities of any animal living where the temperature range is wide from hour to hour, from day to day, or from season to season, are greatly limited if its own body temperature be the same as that of the surrounding air; still more so if its surface be pervious to direct solar radiation. A familiar example of this law is the sluggishness of snakes, turtles, etc., and of many insects, in cold weather, contrasted with their activity in warm. The only method that nature has yet evolved, by which animals can free themselves from this limitation of their vital activities by changes in the temperature of their surroundings, is by maintaining within their own bodies a comparatively constant temperature: i.e., by the invention of "warm blood." Contrast, for example, the efficiency as a vital machine, and the freedom from seasonal pulses in activity, of one of the higher mammals with the snake which, in high latitudes, must lie dormant half the year.

While the maintenance of a self-controlled body temperature does not require any general modification of the gross internal anatomy, it does involve metabolic adjustments so delicate that any disturbance of the regularity of the control is apt to be fatal. It also requires that the surface of the body be in some way

insulated against the passage of heat, as by the fur of mammals, the feathers of birds. From the need of such thermal adaptations marine life is freed, because the changes in temperature at any given place in the sea average not only very much smaller than they do in the air, but very much slower. Throughout the most of the ocean deeps, in fact, the temperature is practically unvarying from year's end to year's end. And while shoal waters in high latitudes do show considerable alterations, in this respect, with the change of the seasons, it is only close to the surface that such changes are great. And even there any animal can reach a nearly constant thermal environment by merely swimming down a few fathoms to avoid extremes of summer heat or of winter cold, as many fishes actually do in their regular bathic migrations.

On the whole, therefore, marine animals have not found it necessary to provide any specific protection against variations in temperature. The general rule in the sea is that the temperature of any animal is practically that of its surrounding water, rising or falling as the latter rises or falls. This, it is true, also applies to cold-blooded animals on land. But whereas the latter pass through alternating periods of activity and of stagnation everywhere except in the Tropics, no such rule governs in the sea, each species being attuned to a certain optimum range within which it passes most of its life, but within which range various phases of its vital activities, especially of its reproduction, are directly controlled by the temperature. Otherwise expressed, cold-water fishes may be quite as active as warm--witness the trouts and salmons. When, as sometimes happens, a sudden fatal shift in the temperature causes widespread destruction (Page 72), nature's only provision for the reestablishment of the species in the sea is by the production of many more eggs and young than can survive under normal conditions. But both the metabolic activity and the thermodynamic efficiency of the organism as a whole are far lower in cold blooded than in warm blooded animals. This suggests a field of endeavor of great interest.

The discovery of warm blood has never been made in the sea. On the contrary, all the warm-blooded animals that now inhabit the sea, whales, seals, walrus, etc., are descended from warm-blooded terrestrial ancestors. To maintain a high body temperature demands more rapid oxidization within the body, and more food. Thus, not only is it no advantage in the sea, but it is a positive handicap there, because the high thermal capacity of the surrounding water makes the maintenance of self-controlled temperature much more difficult than it is in the air, for cold water takes much heat from any warmer body before its own temperature rises equally. A familiar example of this is the use of water in the cooling systems of automobiles. It is to meet this problem of insulation that whales and seals are enclosed in a layer of blubber. But this blubber means added bulk; bulk not of direct service, except as protection against outside influences, but actually detrimental because its presence makes it more difficult to propel the body through the water; because, too, its maintenance requires more food. Contrast with this the happy condition of the fish for which fat is not needed at all for the purpose of insulation, but serves purely as a storehouse for energy that can be drawn on even to the point of total exhaustion whenever famine may require it.

Judged from the standpoints of individual abundance and of ability to people all parts of the sea, marine mammals have not been so successful as the fishes. On land, on the other hand, the warm-blooded mammals and birds have, in the long run, proven more successful than the cold-blooded reptiles or amphibians up to date.

These thermal differences between the aquatic and terrestrial environment make it far simpler to study the relationships that the activities of the organism as a whole (as distinguished from its several constituent tissues) bear to temperature among marine or fresh-water, than among land animals. And the control that temperature exerts on the life processes makes this a very important question in relation to animal economy in general.

The aquatic environment, by its comparative opacity to solar radiation also protects all of its inhabitants, except such as live close to the surface, from the effects of sunlight. This frees the organism from the need of developing any opaque covering to protect it for, essential though the sunlight be in vital economy, the shorter wave lengths are deadly to protoplasm. There is no danger in the sea of the sunburn against which every terrestrial animal must in some way protect its tissues. One of the chief factors that controls the development of pigmentation among land animals thus plays a much less important role in the sea, allowing pigment much more directly to reflect the internal metabolic activities. Connected with this is the very interesting general rule that, whereas on land animals living in darkness are usually colorless, in the ocean-abyss below the influence of the sun's rays they are as a rule intensely pigmented, and often velvety black. This difference reflects in the one case the loss of pigment previously developed by the ancestral forms that lived in sunlight, but in the other case the development of pigment untrammeled by light, its causes as yet unknown.

Because of the rapid gradation in the strength of light from the surface of the sea downward, and becasue of the ability of animals to escape light by sinking, the sea offers a far better opportunity than does the land to study the whole category of tropisms that light stimulation causes; also the natural economy of animals that live permanently in total darkness, as well as the whole complex of problems that center about animal luminescence.

The high specific gravity of sea water, the fact that it is an aqueous solution, its comparatively constant temperature, the protection that a very thin film of it gives against sunlight, and its incessant motion, makes the whole problem of reproduction much simpler for marine than for terrestrial animals. Eggs need less protection, and the young hatched therefrom are capable of independent existence at an earlier stage in development than is the rule on land. So we find that even the most highly organized of the animals of direct marine ancestry (the bony fishes) as a group solve the reproductive problem merely by producing a great many eggs, without any complex arrangements for nursing the latter, or caring for the young, while larvae development is much more usual in the sea than on land. It is true that some fishes (notably the sharks) are viviparous, but jedged by the usual criteria this does not seem to have been of any great advantage in group evolution in the sea.

In the sea, in a word, all living beings are far more in-intimately and directly dependent upon the environment, and at the same time far more at its mercy than they are on land.

All the respects, so far discussed, in which the marine environment differs from the terrestrial may be classified as freedom from danger: i.e., as negative rather than as positive benefits. And it may be stated as a general rule that there is no respect in which the sea is fundamentally unfavorable for life, fatal though immersion in sea water be to all the animals and plants that through the ages have been attuned to a terrestrial existence. With relief from unfavorable factors, coupled with this fundamental fitness of the sea water as an environment, the evolutionary processes are freed from many limitations and barriers in the sea, allowing free expansion. Thus we find there an opportunity to study highly complex colonial developments, and manifestations of the division of labor, among lowly-organized groups.

On the other hand, as a corollary to the freedom that marine animals enjoy from some of the most serious difficulties that beset their relatives on land, even the most highly organized of them show a low degree of mentality. Thus there is nothing among the crustaceans comparable to the societies that some of their insect relatives (ants, bees, termites, etc.) have developed. Nor have any of the fishes of the sea developed anything of social organization beyond such rudiments as the tendency of schools to hold together in their wanderings. Thus in the sea the animal psychologist has at his command an excellent opportunity to examine what may be called the basic mental processes of a great variety of animals comparatively high in the evolutionary scale, unobscured by the confusing psychic developments that have been stimulated on land by the struggle against the unfavorable environment.

The problems of large-scale behavior, as illustrated by the phenomena of schooling, can certainly be studied to best advantage in the sea - at least they can be most clearly seen there. And the uniformity of the surroundings in which marine animals live makes the sea a far more promising environment than is the land for researches into the stimuli or receptive senses responsible for the so-called "voluntary" migrations.

It is still a mystery how fishes, and other marine animals are able to direct their long journeys, often in darkness, and always through a medium in which temperature, and chemical composition are so nearly uniform over long distances that the most delicate tests are needed to reveal any difference at points many miles apart. The problem here is akin to that of bird-migration.

In short, the study of the basic life-processes is not obscured in the sea by all sorts of protective adaptations: we there come closer to the basic tasks of protoplasm, such as to incorporate within itself materials from outside; to grow; to reproduce itself. The sorts of biological problems that may be most profitably studied in the two environments, marine and terrestrial, differ accordingly. On land the most fertile results may be hoped from studying the manifest adaptations by which animals and plants make their un-

favorable environment serve their ends; adaptations whether of structure as examined by the anatomist and taxonomist, of stages in development, as seen by the embryologist, of habits, to be traced by the ecologist, or of vital processes, which fall within the province of the physiologist. For the Oceanic Biologist, however, the most productive subjects group around the animal forms and habits that have developed, free on the one hand from the stimulus, and on the other free from the limitations that are imposed by the necessity of guarding against unfavorable surroundings.

This freedom we see illustrated by the fact that all of the phyla of the animal kingdom, now recognized, are at home in the sea; whereas only seven of them have been able to conquer the terrestrial environment.

The fact that the ocean is the home of the oldest and simplest types of the various Phyla, and the exclusive home of at least one of the latter[1] explains why the comparative anatomist must have

1. Of a second, also, if the Ctenophora be considered a separate Phylum.

access to marine organisms. The embryologist profits for the same reason, while for him certain marine forms, Selachians, Echidoderms, Ctenophores, and many others, are classic material. When he turns to experimental analysis he finds the eggs of Echinoderms, Nemerteans, certain marine Annelids, Molluscs, and fishes better fitted for studies of fertilization, and cleavage than any others, both because they can be obtained in unlimited quantities, and because they are laid and will develop in sea water over considerable ranges of temperature, they are suitable for experimental procedure. Contrast this with the scarcity in number, and inaccessibility to experiment, of the eggs of mammals. Except in the water, furthermore, no eggs are laid without extraneous protective devices.

Owing to the inherent suitability of the ocean as a home for life, various marine organisms offer unique opportunities for biological studies there, and this has been the consideration that has led to the existence of Marine Biological Stations. The history of these begins with the Naples Station founded by Anton Dohrn in 1873, and with the Penikese Station established by Louis Agassiz during that same year. Since that time marine laboratories, to exploit the advantages offered by marine organisms, and therefore contributing to the biologic aspects of oceanography have multiplied in Europe and America. Some of them have been associated with economic, especially Fisheries investigations; others, among which the Naples and Woods Hole Stations are conspicuous, have served as headquarters for theoretical problems.

2. Marine Physiology

The general physiologist, whether he works with marine, with terrestrial, or with fresh water animals, seeks a better understanding of the life processes that are common to all animals and plants, and of the ways in which the basic properties of protoplasm are translated into all the complex manifestations of animal and plant life that we see about us, on the basis of what can be learned

concerning the behavior of living systems. Hence Physiology is not so much a department of Biology as a method of dealing with the whole of that field, insofar as it concerns the properties and relations of living organisms, and parts of living organisms. Physiologists, therefore, turn to researches involving marine organisms for reasons as various as those that influence other biologists. It is the special advantages offered by sea animals and plants as subjects for physiological study that we wish to emphasize here.

In the first place, they answer the requirement that for many purposes experimentation shall be carried out under conditions such that no irreversible changes are induced, and on a large scale, in the case of such energy relations as involve (1) temperature, (2) light, (3) gravitation, (4) ionic composition of the medium. They likewise offer the most favorable opportunity for relating the experimental results to the phenomena actually occuring in nature. The investigation of abstract problems, in these fields, requires, in the first place, the selection of the type of organism that (so far as can be foretold), is the most nearly suitable for the specific question in hand. For this reason, alone, if for no other, the marine biological laboratories should continue and expand their functions as foci for much physiological research, since by contrast with the faunal and floral equipment of the land, or of fresh waters, the sea is extremely rich, both as to individual numbers and as to variety of types. Because, for example, of the abundance and diversity of luminous forms in the sea, contrasted with their paucity on land, and practical absence in fresh water; because, too of the wide range of colonial animals; and because of the expression of types of symmetry other than the bilateral, and of various forms of appendages, etc., among the marine population.

It is not generally recognized how greatly General Physiology is indebted to the study of marine organisms for progress in some of its most fundamental problems. The large size, abundance, constancy of physiological condition, and simple cultural requirements of the eggs of sea urchins and starfish, among others, make them incomparable material for cellular physiology, whether surface processes or internally colloidal phenomena are in question, and whether studied by temperature variations, by chemical means, or by micro-dissection. It was, therefore, no accident that general physiology arose in America at the Marine Biological Laboratory at Woods Hole, or that its leader, Jacques Loeb carried on his studies in artificial parthenogenesis, in balanced solutions, etc, there, and at Pacific Grove, rather than at some inland laboratory.

The activities of individual marine organisms, especially those of the littoral zone provide the widest variety of subjects. Very attractive opportunities are open for researches concerning the many shoal water animals that are of commercial importance, the sane conservation of which depends upon knowledge of life history. Unfortunately much of the work so far attempted in this field has failed to command full confidence, both because of technical procedure, and because of the character of the result sought. The incentive to put such matters on a more sound basis is, therefore, strong. This cannot very well be done unless students are brought into direct contact with marine conditions during their formative years.

There has never yet been an opportunity to study the physiology of the animals that live in the depths of the oceans, by the help of

which many significant matters might be approached, if it could be made feasible to control them in the laboratory.

Physiology, furthermore, is concerned, not only with the activities of individual forms, both as such, and as they illuminate specific problems, but also with the inter-connected activities of different organic groups. The sea offers the readiest subjects for such investigations, and those likely to provide results of the widest significance.

The most impelling lodestone to draw physiologists to the sea is, however, the physical and chemical nature of the salt-water environment. This aspect of the case has often been emphasized of late.[1]

[1]See especially J. H. Henderson. "The Fitness of the Environment".

We need merely point out that, protoplasm being organized as it actually is, sea water is as nearly perfect a medium for it we can conceive of. In fact, it is this very fitness alone that makes life possible anywhere in the sea outside as well as inside a very narrow coastal strip, for were sea water not nearly as heavy as protoplasm (thus making flotation easy) and did it not carry in solution a variety of chemical compounds usable by plants as food, the abundant plant life of the seas could not exist at all except close to the lands. Without plants there could be no animals there, so that the whole oceanic basin would be a desert.

Marine Physiology, therefore, centers around sea water as an environment for life, and, as has been pointed out by others, sea water is a fluid of quite special interest, both because it is the commonest substance in the world, and because it so closely resembles protoplasm and blood plasm, minus their organic constituents. This entails studies of the sea water itself, because our knowledge of its physical and chemical conditions is still incomplete, and our knowledge of it as a system very meagre. And it is upon the picture of the major cyclic changes there occurring, as a background that the physiologist must diagram, in quantitative terms, the rhythmic changes of significant chemical constituents, before he can consider the part that organisms of various types play in the ocean-equilibrium. From the physiological standpoint, we only now begin to understand the progressions of nutritive substances and the regulation of their level of concentration, as related to depth, to distance from land, to seasonal periodicities etc.

The marine environment also offers very practical advantages for physiology, because of affording the most convenient working conditions, depending upon availability of a wide variety of organisms throughout the year, which is a primary requirement.

As a final thought on a somewhat different plan, contributed by a leading physiologist, we may point out that one of the present duties of physiology is the revivification and modernization of general natural history. Long experience with fragmentary investigations of the sea has at least made it clear that this association of interests is desirable, and that life in the sea is one of its most fruitful fields. Perhaps this is due to the fact that a certain mental humility often follows contact with the ocean, its complexity and its immensity.

its immensity.

In presenting certain of the more specific opportunities open to marine physiology, we may for convenience class these under two headings: (a) those phases best attacked via the relationship between the tissue and the blood or lymph, and (b) that between the protoplasm of the cell and its immediate environment.

Under the first of these subdivisions the application to the comparative physiology of marine animals of the methods now practiced in the investigations of the respiratory, circulatory and blood physiology of man offers a most promising field. An emminent physiologist, indeed, gives it as his opinion that this is one of the great scientific opportunities of the coming half-century; and that voyages of well equipped expeditions, making use of experimental methods of this kind, promise to put the natural history of the sea on a new level.

Thus, to take perhaps the most obvious example, we know very well that the distribution of marine animals, in fact their whole economy, is largely controlled by temperature. All of them have an optimum range within which they live, with lethal limits above and below. But in many cases the vegetative metabolic activities (expressed as growth) and the reproductive proceed most successfully at different temperatures - witness the growth of the lobster to large size in cold water, but the inability of its larvae to survive at all except in warm.

The question how this temperature control works on the internal activities is now to the fore. Is this a simple matter of difference in the rates of the chemical reactions involved (for certainly the metabolic rates do vary with temperature) or is something more at work?

Study of the effect of temperature on the respiratory processes of various marine animals also offers a fertile field, and a very attractive one, because this effect is great enough to render tissues that are adapted to the harmonious exercise of respiratory functions (i.e. to the transport of oxygen) at one temperature quite worthless at another, no matter how much oxygen there may be dissolved in the water. A study of the temperature factor in this relation may contribute to an understanding of the thermal control of geographical distribution. May this, for example, be one cause of the great differences in thermal requirements between closely related species - or between geographical races of a given species, such as we know to exist among the cod fish and the herring, which find their optimum at one temperature in one region, at another temperature in another? In the Straits of Belle Isle, for example, the cod prefer and seek much lower temperatures than they do on Nantucket Shoals.

Especially intriguing in this connection are the specific properties of the respiratory proteins as determinants of the pressure of oxygen gas in the blood. In fact, the whole question of the oxygen requirements of different animals and of the same animal at different temperatures is little understood. What, for instance, is the difference between the blood of active fishes and molluscs, such as trout and squid, and that of their more sluggish relatives, and the difference between the tissues that perform respiration among

animals with different thermal optima that have no blood, but take in oxygen directly through their epithelial surface, all of the coelenterates, for example?

Very little, too, is known about the respiration of the marine mammals; sundry interesting problems spring to mind in this connection. How must we assay as factors governing the distribution, the seasonal activities, and a host of other phenomena that are controlled to a greater or less degree by temperature, the existence of well defined critical temperatures such as have been made out, both in a Natural History way, and experimentally?

We even know very little about the actual internal temperature of marine animals compared to that of the water in which they live.

The temperature problem is not only one of the most important in vital economy, but has the added advantage (from the practical standpoint) that temperature is a convenient factor with which to work, being readily controlled under experimental conditions, while the effects are readily measured.

Other comparative studies of this sort, which can favorably be carried out on sea animals, might prove of assistance to the human physiologist in his attempts to interpret the phenomena he has to deal with. Especially interesting in this connection is the occurrence in mammalian blood of salts in proportion similar to sea water, with the contrasting fact that while, in sea fishes, the body fluids are nearly the same as sea water in this respect, they are never precisely so. The whole question of the physiological significance of the different salts is, in fact, a most important one, to explain which no satisfactory theoretic basis has yet been arrived at. For studies in this field sea water is again the most favorable environment. Here new lines of attack are opened by recent advances in the physical-chemistry of salt solutions, for which marine animals, because of their simplicity, are the most promising subjects.

In like manner, the key to the riddle of the secretion of gas, over which there has been much controversy in the field of pulmonary respiration, may well be found in the physiology of the swim bladder of fishes, about which little is yet known with certainty. Many questions of nutrition, too, such as might well be attacked in marine animals, would find their reflection in the physiology of the higher animals - so, too, the manner of excretion of waste products by the animal groups that have no special organs for that purpose. This, for example, would include the intra-cellular pigments, and the crystalline secretions of medusae.

Calcium metabolism, as reflected by the deposition of lime salts in bones, is another field on which studies in marine physiology should throw much light. Thus the relation between ocean temperature, the occurrence of lime-secreting animals, and the amount of lime they secrete, suggests the importance of investigations into the role played in calcium secretion by the effect that other electrolytes may have on the solubility of calcium carbonate.

In the whole field of the physiology of light, too, especially attractive subjects are to be found among the great variety of marine animals of widely divergent groups that live normally in regions of

very dim light, or of darkness, and so have developed no adaptive physiologic protection against the lethal or other metabolic effects of the whole of the sun's spectrum, or of any part of the latter. This in turn, lends to the very interesting problem of luminescence, so highly developed among marine animals.

The physical simplicity of the marine environment also opens to the investor many promising lines of attack upon the problems centering around the widely diverse functions of the different classes of organic substances that we group together as "pigments", simply because they chance to possess absorption bands falling within the region of wave frequency to which the human retina is sensitive, which does not necessarily mean that they are similar either chemically or vitally.

The basic nature of the respiratory pigments, for example, is a subject that has hardly been touched on as yet, from the standpoint of specific differences within a given group of animals, or of larger differences between different groups. Crustacea, worms and fishes especially lend themselves to investigation here. For example, study of the qualities with respect to oxygen of the compounds, that in lower animals, are analogous to haemoglobin in the higher, may lead to better understanding of the blood physiology of mammals, and so of man. Respiratory pigments are only one of a great number of substances that cry for study from this point of view. In fact, the whole relationship between chemical composition and systematic relationships among different groups of animals and plants is still a practically virgin field, and one offering most fertile possibilities to the marine physiologist.

Carrying the chain a link further, what is the oxidation-reaction mechanism of the pigments of the marine and fresh-water animals, such as the green Serpulids, the Sipunculids, etc., and the plankton inhabitants (belonging to many groups) of the mid-depths of the North Pacific that live in very low oxygen tensions? A large number of marine bacteria are also colored. Do these pigments also possess oxido-reductive power?

This introduces us to the still more basic problem of photosynthesis, an energy capturing process in which, so far as we now know, certain pigments invariably play an active role. This, it is true, is not specifically a marine problem, but it is in the marine environment that photosynthesis shows its greatest variation, for in the ocean the pigments concerned with photosynthesis are developed in greatest diversity. An intensive study of the properties of these pigments, chemical, physical, and physiological, is one of the major tasks that now faces the general physiologist; a task whose accomplishment would throw light on our present ignorance of the ways that solar energy is turned to the service of living beings on our planet.

It is not necessary to list more examples, for there is general agreement as to the opportunity that marine organisms, in their sea-water environment, offer the comparative physiologist. But for him to make the most of these opportunities (and especially in America) has heretofore been difficult, chiefly because the problems are technically too elaborate to be successfully attacked as isolated projects

during the brief and discontinuous periods of study to which most university professors must limit their researches. As headquarters for such work a shore laboratory is needed, equipped for first-class investigations of the chemical and physiological problems that will arise from preliminary and exploratory studies made on shipboard. A further obstacle is the need in most of such problems for continuous cooperation between students specializing in different fields.

The sea water environment offers even a better opportunity to expand our knowledge of the reactions of the protoplasm of the cell itself to the chemical solution that forms its immediate surroundings, by furnishing large, free living cells, as objects for experimentation. Reference must be made on the one hand to the considerations which led to work upon balanced solutions, and to the recent and very suggestive work on selective permeability and accumulation of ions. It is from knowledge gained in this field that we see our greatest hope of comprehending the processes and reactions that set all living matter apart from all non-living.

Sea water being not only a favorable, but what is more important, a complete environment (for it contains in solution all the known elements not only in simple inorganic, but in organic combination), having properties, i.e. temperature, total salt content, concentrations of different solutes, ionic dissociations, osmotic pressure, etc. that can be precisely defined, measured and altered at will under controlled laboratory conditions, it offers our best opportunity to study all those interactions between protoplasm and its surroundings by which life is sustained, none of which can be directly traced in the air, nor could be in fresh water unless the latter carried substances of some sort or another in solution. In fact, it seems probable, if not certain, that the quantitative treatment of the problem of cellular interchange with the environment must always be founded in large part upon the use of sea water. However, while we now have at our service methods by which the physical and chemical properties of sea water can be measured with a high degree of refinement, we still need, for a rational beginning, a physiological interpretation of what sea water really is. As one contributor points out, we know that it is frequently far from being in equilibrium with the atmosphere. At times and places it is supersaturated with oxygen and with calcium carbonate. On the other hand, while sea water carries in solution every known element, many of these are in such attenuated concentration (and perhaps entirely ionized) that they have defied detection by ordinary chemical analysis, though their presence in the shells or tissues of marine animals proves that they exist in the solution. As examples of this we might mention the Strontium in the shells laid down by certain unicellular animals belonging to the group Radiolaria; the Vanadium recognized in the blood of Ascidians and in Holuthurians; the Cobalt in the tissues of lobsters and mussels; the lead found in the ash of various marine organisms though not yet detected in the water itself.

It seems that some of these rare substances are of great vital importance. And the question by what mechanism the cell is able to select them out of the water opens the whole problem of the specific affinity of different cells for certain chemicals, which forms the basis for all the structures that protoplasm manufactures. We might

mention the secretion by sponges and diatoms of silica (an element rare in sea water) in such great quantity as almost to exhaust the water of it; the ability of sea weeds to draw iodine and potassium from the surrounding water so much more efficiently than man can, that is is far more economical to obtain these substances from the ash of sea weeds than it would be to concentrate them direct from the water by any method yet perfected, or likely to be developed. If any sea weed made equal use of gold, the extraction of gold from sea water (in which on the average there are about 5 mgm. per cubic meter) would not be the will-o-the-wisp it has actually proved. A more familiar example of the ability of the living cell to select particular substances from the outside is the secretion of limy shells by a great variety of plants and animals, an ability responsible for vast deposits of calcareous sediments, of limestone rocks and of the modern coral reefs.

Why is it the organisms withdraw more lime in high temperatures and shoal water, more silica in low temperatures and in the deeps? The chemical reactions that have been proposed to account for this do not wholly explain it.

The degree of permeability of membranes for different solutions also holds the key to the riddle whether marine animals can feed direct on the organic substances in solution in the water that have not yet been reduced to their constituent nitrates, carbonates, etc. The theory that they do so (the so-called "Putter's" theory) has been much discussed, but is still open.

This, too, introduces the whole question of basic nutrition; such as the nature of the substances in the oil of copepods and diatoms, and of the carbohydrates of unicellular marine plants, which, in the words of one contributor, form "the daily fare of most things in the sea."

Allied to this is the question of the selection, by different vegetable cells, of specific solutes for their nourishment, or of the same solutes in different proportion. The vital mechamism back of this selectivity (perhaps the most fundamental of all the peculiarities of living substance) is still a mystery to us. But though its solution (akin to the solution of life itself) may never be reached, it is certain that its manifestations can be most directly studied in the sea, where, for example, we often find one group of unicellular plants thriving in water that some other group had already rendered barren for itself by denuding it of the chemical on which it subsisted.

In fact, the whole range of phenomena associated with the specific affinity of these simple organisms for particular substances is best studied in the sea where is is carried out on a larger scale by the simplest organisms. And such studies offer the best opportunity, now in sight, to learn how it is that our own body cells select one substance or another from our own food via the blood stream, a question about which we are still almost wholly in the dark.

In a broader aspect, adds one contributor, is it, after all, an inherent character of living substance that the specific chemical solution we call sea water should prove so much more favorable an

environment, judged by the variety of animal forms that have developed in it, than the other natural brines of very different character, such as the salt lakes, that also support life? Or does this merely reflect a colonization of the latter by protoplasm, the characteristic properties of which reflect a marine or terrestrial origin? The study of such brines should, by their abnormality, enlighten us as to the oceanic environment.

All of this converges in turn upon the basic riddle (of the real answer to which we have not yet gained even an inkling) of the basis for the group and specific differences in protoplasm: differences that are reflected in all the diversity of life that has existed on our planet.

3. Marine Bacteriology

Present-day familiarity with medical science makes us prone to think first of Bacteriology in its relation to human diseases. The problem of disease, however, seems not to be of great moment in the sea. Thus, while fishes (and no doubt other marine animals) do suffer from a variety of bacterial infections, and while the human aspects of bacteriology do reach into the sea to some extent, when typhoid - and other disease-bacteria, coming from the land, gain foot-hold in the bodies of oysters, clams, and other shell-fish, most of the pathogenic bacteria (though capable of living and multiplying in sea water, with added nutrients) have been found to succumb rapidly in normal sea water. By and large, the disease-bacteria of man and of the higher animals do not thrive in the open sea.

The problems of Marine Bacteriology that we wish to emphasize here are more akin to those of soil bacteriology; they center around the rôle that bacteria play in keeping in motion the cycle of matter through its organic and inorganic stages in the sea.

If we write less confidently on this subject that we have on Oceanic Biology (page 43), or on Marine Physiology (page 50), it is because our knowledge of bacteria in the sea is still scant. But such glimpses as we have gained of their activities there are enough to show that these must be assayed before we can hope to understand the maintenance of organic fertility in the oceans.

The simplest task of Marine Bacteriology is perhaps to trace the direct service these lowly organisms render to the higher, in providing the latter with proteid food. That protozoans do feed on bacteria in the sea is established. In fact, recent studies suggest that in this passive way the bacteria that thrive on the organic detritus that accumulates in shoal waters, and the protozoa that prey upon the bacteria are essential links in the food chain of coastal waters, where the molluscs and other animals that feed on detritus gain their nourishment, less from the food stuffs therein contained, than from the bacteria and protozoa eaten at the same time.

This question is a quantitative one; the answer depends on the numerical distribution of bacteria regionally and with depth. In general, the sea water is much richer in bacteria near shore, where land drainage maintains a state more fertile for them, than out in the open ocean; especially is this true of the forms that subsist on the excreta of animals. But viable bacteria are also known to exist

in the open sea, away from coasts, increasing in number down to a certain depth, while many of them at least are killed by strong sunlight. It is certain, too, that bacteria are abundant in many of the muds in moderate and in considerable depths. Do these serve the whole category of mud-eaters as food on the sloped of the continents, and should bacteria be regarded as the primordial meat supply of that belt of the ocean; or is their rôle in this respect important only locally? We know nothing of their relative abundance at great depths, or in the abyssal mud, except that there, too, they exist; but it is here that the problem assumes the greatest importance, because of the absence of plants.

If we trace the food chain back another link, we face a problem far more significant than this simple one of bacteria as prey for animals, namely, their relationship to the circulation of nitrogen through its organic and inorganic phases in the sea. While the sea water has been found nearly saturated with nitrogen gas, none of the ordinary marine plants, so far as we know (and certainly none of the marine animals) can use nitrogen in this elemental form, though every one of them requires nitrogenous nutriment. For the animals, this food comes in the long run from the plants; and so far as we know all marine plants (except certain bacteria) depend for their existence on the presence of certain salts of nitrogen (chiefly nitrates) in solution in the sea water.

It has long been known that in the soil certain bacteria are able to assimilate atmospheric nitrogen, and to fix it in compounds usable by ordinary plants, if they are supplied with other non-nitrogenous sources of energy. These same kinds of bacteria have also been found widespread in the sea in shoal water, at localities as far apart as the Baltic, the North Sea, and the Indian Ocean; also in the Plankton where the organic carbon going into solution in the water from the break-down of the bodies of defunct animals and plants supplies them with the chemical energy that they require to carry on nitrogen fixation. In fact, we have experimental evidence that they do fix the nitrogen gas with which sea water is saturated, just as they do the atmospheric nitrogen in the soil, on land. So far as it goes, their conversion of nitrogen to nitrates must be of direct importance in marine economy, by making available for marine plants this gaseous source of nitrogen. But we have yet to learn how to assay, in terms of marine economy, the frequency with which such bacteria have been found associated with sea weeds in shoal waters (where the concentrations of life are the greatest), for we have no direct information as to the scale on which they actually operate in the sea. In fact, there is no general agreement as yet as to the actual importance of such of the nitrogen fixers as live free in the soil on land; and this is the group to which belong the marine nitrogen fixers so far known. Neither do we know whether there is anything in the sea comparable to the symbiosis between other nitrogen fixers and leguminous plants that exist on land. Solution of the general problem of nitrogen fixation by bacteria in the sea would be one of the great gifts that marine bacteriologists could offer to Oceanic Biology.

Opposed to these nitrogen-fixing bacteria, are the denitrifying bacteria, that (so far as they operate at all in the sea) tend to reduce the concentration of nitrates (i.e. of available plant food) held in solution in the water, by breaking these down to nitrite, ammonia, or even to nitrogen and its oxides, and so putting

them out of reach for ordinary plants. Denitrifiers exist in the sea, and much discussion has centered around their supposed activities there. But, lacking quantitative information, we have no clear concept of the scale on which they actually affect such losses in the open ocean, both because of our ignorance of their actual abundance in its different parts, and (more important) because the factors that govern their denitrifying activities there are not yet fully understood. It has long been supposed that bacteria of this group operate more efficiently at high temperatures than at low. Hence it has often been suggested that the scarcity of nitrates actually recorded in the tropics, as contrasted to colder waters, reflects the greater activity of these bacteria in warm seas, and consequently that the regional differences in the losses of nitrogen that they affect are responsible for the genral paucity of phytoplankton in the Tropics, as compared with higher latitudes.

But this theory, like many others that have been set up in Oceanic Biology, is based on only one factor in the environment, when actually others may be more important; and on a numerical abundance of the organisms concerned, which, while easily maintained in the laboratory, may never exist in the open sea. Recent experiments, for example, have suggested that while temperature controls the rate of activity of the denitrifiers, perhaps they actually attack nitrates only when oxygen is deficient. If true, this points to great possible losses of nitrogen by their activities in the bottoms of certain enclosed basins, in the mud generally and wherever oxygen is relatively scarce in the mid-strata of the oceans, but to little or no activity on their part in the surface layers which are nearly saturated with oxygen. If, however, these bacteria are active in the mid-depths, the results of their cumulative work there may lead to a great loss of nitrogen, that must be made up in some other way, for most of the decomposition of dead carcasses sifting down from above, takes place at this level. What is needed here is not theoretic discussion of what might happen, so much as empiric determination of what actually does happen.

How active the denitrifiers are in the mud is equally a live question, because the sediments on the sea floor, in deep water as well as in shoal, contain considerable quantities of organic nitrogenous compounds, which, so long as they continue in chemical combinations, are a potential food supply, that may be brought to the plants in the upper waters by vertical currents. In the Gulf of Maine, for instance, the bottom muds contain on an average about as much nitrogen as good garden soil, much of which is distributed throughout the water at the seasons when vertical circulation is most active. It may be assumed that a scarcity of oxygen everywhere in the mud below the superficial skim sets the stage for the destructive effect of the denitrifiers there, unless the temperature be too low for them. But we are still entirely in the dark as to how effectively they act in the mud, i.e. what role they play in preventing the accumulation of nitrates in the submarine deposits, for while these salts are extremely soluble in the sea water, organic particles tend to be trapped in the mud wherever sedimentation is rapid, and thereby protected from the action of the water. Any nitrogen locked up in this way would be a dead loss to the oceanic complex until it should in some way be brought again into circulation.

While bacteria of certain sorts may perhaps be acting constantly to denude the sea water of its nitrates, the fact there is any

nitrate or nitrite at all there, in solution, reflects the activity either *in situ*, or on land, of other groups, not only the nitrogen-fixers just mentioned, but of the putrefactive bacteria, and of the so-called nitrifiers. And until the complex proteids and carbohydrates from the bodies of dead animals are reduced to simple compounds, they are usable only by animals, by fungi and by bacteria, not by the photosynthetic plants. Great amounts of nitrogen, it is true, in combinations directly usable by plants, are contributed to the sea by the discharges of river water that carry with them the drainage from the land; also from air. But a greater potential source is the decomposition of the carcasses of marine animals and plants. Bacteria of decay seem to be as ubiquitous in the sea as they are on the land; witness the rapidity with which carcasses rot in the water at moderately high temperatures. And not only can they usually be isolated from decaying fish, but certain of them are normal intestinal inhabitants of Haddock, no doubt of other species. But how do temperature, darkness, pressure and the supply of available oxygen affect the activities of this putrefactive group in the deeps?

This question is important in oceanic economy because the rapidity with which decomposition takes place (one of the two factors that in the end control the fertility of the sea) controls that state in which organic detritus reaches the sea floor in its descent from the upper layers, to maintain the reserve supply of dissolved phosphates, etc., in the abyssal water.

A very important question in connection with the rôle of the nitrifiers is to what extent marine plants can use the ammonia compounds to which the putrefactive bacteria reduce the complex animal and vegetable proteins, and the ammonia which the sea absorbs from the atmosphere and from atmospheric electric discharges. What evidence has yet been obtained suggests that sea weeds (differing in this respect from land plants) cannot, as a group, utilize ammonia salts directly, but only after the latter have been altered to nitrates or to nitrites. This alteration is the task of the nitrate and nitrite bacteria. It has been proven that this nitrigying group does exist in the sea i.e. that the ammonia salts formed there *in situ* and received from the air, are actually a potential source of plant food locally. We have here both the indirect evidence that when the store of nitrates in the water is exhausted by rich growth of plants, it shortly becomes renewed when the latter die out, with experimental knowledge of the chemical reactions that this group of bacteria affect in sea water under controlled conditions in the laboratory, and the direct evidence that members of this group have been discovered free in the sea water as well as in bottom deposits from many localities over a considerable range of depth. However, empiric knowledge of the scale on which they actually operate in the sea is still practically *nil*.

We can safely interpret their responses (in rate of multiplication and efficient action) to variations in temperature, light, ozygen and state of the ammonia and other organic compounds present, by analogy with their activities on land? Or do they follow different laws in the sea? What is their relative rôle in deep and in shoal water, under the conditions actually existent? These questions (about which different views are held) must be answered, before we can assess the relative importance of different depth zones in the ocean as sources for the renewal of nitrates and nitrites. What

relationship in maintaining and renewing the nitrates for photosynthetic plants do the activities of these bacteria in the sea bear to the contributions of nitrates and nitrites that the sea receives from its tributary rivers? This question is of direct practical importance if we are to understand the regional variations in the abundance and season of multiplication of floating plants along our coastlines.

Yeasts and other fermenting organisms have been found in the sea water, although they do not appear to destroy sugars and fats there according to the customary chemical schemes. Their existence and enzymic activity there is indicated by the fact that carbohydrates, and fats, like proteins, disappear in the sea (just as on land) after the death of the animal or plant. But how do they actually work in different parts or levels of the sea? How do they play their part in maintaining the circulation of carbon, the draft on which, by plant growth, must be as constantly replaced, either by the absorption of carbon dioxide from the atmosphere, or by reduction in the sea of organic compounds of carbon to their end states, CO_2 and water? What part, if any, do bacteria play in the break-down of oil?

It is because of the generally accepted belief that animal life in the modern ocean depends on the presence of photosynthetic plants for its ultimate food supply, that we have so far stressed the general problems of the rôle that bacteria may play in keeping the sea water fertile for these plants by maintaining the stock of dissolved nitrates and nitrites, or by replenishing the water with these substances when they have been locally exhausted.

But in attempting to interpret the life cycle in the sea, bacteriologists must also take into account another possibility, namely, that the sea may harbor enough bacteria of the sorts that can change carbon dioxide to organic carbon <u>without</u> sunlight, to form an important food for animals and so to short-circuit the line from animal to plant and back to animal. The nitrifying bacteria just discussed fall in this autotrophic category, being able to obtain all their vital requirements from inorganic chemical compounds. And there are other groups of bacteria similarly chemosynthetic; for example, the methane, hydrogen, carbon monoxide, and sulphur bacteria. Beyond the fact that the nitrifiers and perhaps some of the others do exist in the sea, we have as yet no empiric knowledge as to how important they are as direct links in the food chain in the sea, or, in fact, what vital rôle they play there. This again, is a quantitative as much as a qualitative problem because the numerical abundance and regional distribution of such bacteria, more than their chemical potentialities, would govern their importance as direct sources of food for animals, and hence determine the degree to which they free the latter from dependence on the activities of photosynthetic plants. It is with regard to the inhabitants of the abyss where no ordinary plants can exist that this question is the most intriguing.

We also need to know what part bacteria play in breaking down the refractory organic substances that would accumulate on the bottom of the sea if there were not some mechanism to disintegrate them and to bring them into solution in the water. Specifically, what bacteria in the sea, if any, are responsible for the mass destruction of the agar from the stalks and fronds of sea weeds that is constantly

taking place under water; a substance so resistant to ordinary bacteria that it is commonly used in the laboratory as an indifferent substance for solidifying culture media. The agar liquifying organisms now known have actually come from sea water, but the conditions necessary for their growth do not seem to prevail in the ocean. Is this a case of bacterial action at all, or does the annual disintegration of millions of tons of kelp, etc. simply reflect the solvent action of the sea water itself? We face this same problem with regard to the destruction of the chitin in the shells of dead crabs, shrimps, and other crustacean. Benecke's Bacillus chitinivorus will digest chitin in the laboratory, but apparently not under conditions met with in the sea.

All this bears on the composition and structure of these refractory organic compounds, whose constitution is still chemically unknown. It may be possible, by means of the organisms that attack agar and chitin to unravel the composition of the latter, and during the breakdown to recover substances of commercial value.

How, too, is the oil destroyed, that is formed by diatoms, algae, Copepods, etc.? Does it undergo fermentation through anerobic organisms to hydrogen carbons in the bottom muds, or is it oxidized as in the animal organisms?

Bacteria also play other important rôles, of which we, as yet, have only glimpses, in the chemical changes following the alteration and decomposition of organic matter that takes place in the deepest water and in the bottom sediments. Here we think at once of the forms that reduce sulphates in the absence of oxygen to sulphides, of whose activities the vast deposits of stinking mud in shoal waters (especially in enclosed basins with little circulation) bear witness. Bacteria, too, are indirectly responsible for the accumulation of sulphurated hydrogen in the deeps of the Black Sea and of certain fjords. We greatly desire more detailed Bacterio-chemical studies of the deep water of other such basins, e.g. of the Sulu Sea. The activity of these same groups needs to be studied in the open ocean, where, because of the active circulation of the water, their effects are not so apparent. We know almost nothing about the rôle bacteria play in other chemical changes that take place in the abyssal muds.

The whole question of calcium precipitation in the sea is still an open one, and one so important that it is now being made a major subject of investigation at the Scripps Institution. But this necessarily involves companion studies of the physioco-chemical relationships in the sea water, to show what chemical changes such precipitation involves. When this is known it will not be enough to find out whether bacteria can bring these changes about; we must also learn whether they are associated with the mass precipitations in the sea in significant numbers; also whether there is sufficient nutrient in these situations to support their growth. The necessity for uniting several disciplines in this case illustrates how broad a view we must take of bio-physical and bio-chemical problems as a whole in the ocean.

A few more live problems that have a general bearing both on bacteriology per se and on the science of the ocean, may be mentioned. What, for instance, are the energy relationships in the sea, the

thermophilic associations, and pigment function of the widespread purple bacteria? What rôle is played by the luminous bacteria, whether as saprophytes or as normal symbionts with animals and plants? Do these bacteria exist at absysssal depths? If so, are they sufficiently abundant for their luminescence to be important in the vital economy of deep sea animals? Do they, perhaps, help to make vision possible for the large eyed benthonic fishes of the abyss, most of which are non-luminous themselves?

The marine anaerobes have received scant attention. Here the recent discovery that CO_2 tension rather than oxygen tension is the requirement that distinguishes them from aerobes, emphasized the necessity for further information as to chemical conditions in the water.

A bacteriophage has also been found in the sea by French oceanographers. How generally this principle (destructive to bacteria) is distributed in the sea, and how effectively it combats their manifold activities ther, if at all, remains to be learned.

Finally it should be said that microorganisms other than bacteria have been found in the ocean and that they may have a quantitative importance in the chemical processes that have been enumerated, comparable to that of the bacteria proper. This relationship has been well established in the case of soil micro-biology. The Actinomyces may be cited as a group that are as worthy of attention as are the bacteria themselves.

The answers to the principal questions that the oceanographer may properly ask of the bacteriologist are not as directly available as their mere enumeration might suggest; for it seems certain that no great headway can be made toward appreciating the rôle of bacteria are perfected.

No one instrument will solve the problem of bacteriological sampling in the sea. For purposes of enumeration the sample must be large and not necessarily taken with utmost bacterial precaution. Concentrating the sample prior to microscopic enumeration is a more difficult task. It would appear that a sound procedure for this purpose has been introduced in Russia primarily for fresh water work, but capable of adaptation to the sea. The sampling of water for culture work, when small volumes suffice, presents few obstacles. More difficult is the sampling of mud for in this case it is necessary to recover an undistrubed specimen so that the sample can be examined serially, commencing for example with the top millimeter, unmixed with lower layers and unwashed by superposed water on the ascent.

And it should, in general, be emphasized that random procedure, and approximate technic can never serve as the basis for evaluating the general share of bacteria in the economy of the sea. We have also to learn what modifications of the routine media, or of those favorable for soil organisms, will give the maximum counts of bacteria from a given sample of ocean water. We shall not be able to assay the significance that should be attached to the physiological activity of marine bacteria until we are able to grow most of the organisms that can be found in the water. The fact that this will certainly require study both of pure and of mixed cultures is

an additional reason for the development of efficient media.

4. Physical, Chemical and Biological Unity in the Sea

In the preceding pages we have, for the sake of clarity, outlined certain underlying biologic aspects of Oceanography as though the marine environment were physically and chemically a stable thing, controlling while in no way affected by the activities of life within it. But this is far from the truth. In a practical way the biologist may, if he chooses, regard Biology as the apex of the oceanographic pyramid, with Physics and Chemistry as its bases; actually, however, the oceanic situation is dynamic, not static, better represented as a vortex (moved by the activities of organisms and by solar energy) of materials through living matter back again to the inorganic physical and chemical end-states. That is to say, while the nature of the sea water governs the lives of the animals and plants that inhabit it, at the same time the functions of the latter are as constantly altering the nature of their environment in a way to which we see nothing comparable on land. Perhaps the most obvious example of this (one already mentioned) is the constant draft that so many animals and plants make on the water for the materials with which they build their sleletons. As a result of these drafts vast quantities of lime and of silica are constantly being withdrawn. And while some of this goes back into solution when the organisms die, other vast quantities accumulate on the sea floor, in deposits of lime compounds, and of silicates.

On the whole, by this process, lime is accumulating toward the equator, and around the coast lines, silica toward the poles and in the ocean deeps. But, although we may temporarily find the water nearly denuded of one or another substance, on the whole the relative proportion of its solutes is close to constant over all the oceans. How, then, is the loss made good? And what part does living matter play in transforming the great preponderance of carbonates that characterize the saline load carried into the sea by river water, into the great preponderance of chlorides that is everywhere and at all times characteristic of sea water and also characteristic of protoplasm? Why is it that lime accumulates more rapidly on the bottom in shoal water than in deep? Is the solvent power of deep water the greater, as has often been supposed, or have we to do with some bacterial action? While land drainage, added to whatever salt may have been in the sea from the beginning aids in the maintenance of the present stable state, the agent back of the stable state is life; hence, at bottom the composition of the sea water is a biologis as much as a chemical problem, even though in many cases its solution may come only <u>via</u> Chemistry.

The mass productions of plants in the sea withdraws temporarily from circulation the nutrients they need, and there is a certain permanent loss after their death, as of nitrates decomposing to the gaseous state, and of phosphates going into chemical union with bottom sediments. Just how are these losses made up so that the balance is maintained? How far is the pulse in the available supply of these nutrient substances in the sea responsible for the sudden outbursts of unicellular plants in such unbelievable numbers that they are the most spectacular events in marine economy: "explosions de la vie" as these sudden developments of great masses of living matter have been named? Is it their exhaustion of the water that

destroys them, or are they self limited in some other mysterious way? In like manner, while the degree of alkalinity of the sea like that of our own blood-serum is constant within narrow limits and any wide variation means death, the great drafts of carbon that plants make in their photosynthetic activities, added to various other biologic and chemical happenings are as constantly tending to alter the ionic concentration of the various electrolytes in the solution, and thereby to raise or lower the alkalinity. But while alterations so caused may actually progress to the fatal limit in enclosed pools this never happens in the open sea. What rôle in maintaining this fundamental balance, against their own tendency to upset it, is played by living creatures, and how do they affect the cognate matter of the CO_2 tension of the sea water relative to that of the air?

As an eminent physiologist has asked, what underlying geophysical changes allow the give and take of this vast cycle of matter to be continuous; a continuity upon which depends the continuity of life in the sea? Are the events involved similar to those observed in the soil on land, or are they sui-generis?

This, then, is the real goal of the marine biologist - to understand the cycle of matter and of energy in the ocean. But he is helpless without the assistance of the chemist, of the physicist, of the bacteriologist, of the geologist.

E. OCEANOGRAPHY AS AN AID TO METEOROLOGY

The relationship between Oceanography and Meteorology is of an order different from that between it and Geology, because meteorologic events do not take place within the sea, as geologic do. But the state of the surface of the sea so directly affects that of the air above it that meteorologists are much concerned with certain phases of Oceanography, as Professor C. F. Brooks explains in the following statement:-

"Oceanography can contribute much to meteorology, for nearly three-quarters of the atmosphere rests on the ocean, the heated surface of which provides all the vapor for the air and controls its temperature to a considerable height. The oceanic factors involved in this discharge of vapor and in this heat regulation are not only the temperature of the surface, but also the salinity of the surface, the storage of heat below the surface and, through convection, its availability to the surface, and the horizontal movements of these waters in currents and drifts.

Since, because of their high thermal capacity, the surface waters of the oceans contain enormous amounts of available heat, they exert a steadying and moderating effect on the climate of the world. The oceans take in and give off heat slowly and regularly, and temperature conditions of the water tend to persist a long time and to travel slowly. Sea temperature observations across the ocean indicate the persistence of unusual warmth or coolness of extended masses of water for months - even for a year, or perhaps two - as, carried in the various currents and drifts, they make the circuit of the North Atlantic, or cross the Pacific. This leads one to believe that (quoting Petterson) "besides trying to predict the extremely variable state of the fickle atmosphere, one should give more attention to the conservative element of meteorology, the surface sheet of the ocean, where changes at one place may be observed months before " they reach, and affect the weather of, some other region.

Indirectly, the sea has another effect on world weather. Differences in vapor content and in air temperature determine the contrasts in density and, therefore, in pressures of the atmosphere between different portions of the oceans and between the oceans and the lands. And these pressure differences make the winds. Thus the temperatures of the surface of the sea, and their background, the storage of heat in the sea and the currents that carry this stored heat, are fundamental to meteorology.

The planetary belts of temperature, pressure, wind, and storm are best developed over the sea, and dominate the world's climates. The general homogeneity of the sea surface favors approximately equal humidities and temperatures along any parallel of latitude as the sun goes through its

seasonal swing northward and southward. And this even distribution of humidity and temperature (except near the continents) favors rather uniform belts of pressure and of winds, with their fair weather where the pressure is high, in latitudes about 20° to 40°, and their showery or stormy weather where the pressure is low, near the equator and from high middle to sub-polar latitudes. Furthermore, the flatness of the surface of the ocean permits the maximum development of rotary storm movements, such as the winds of a West Indian hurricane.

Where lands lie athwart these wind and storm belts they receive a full measure of oceanic weather on their windward margins, as on our North Pacific coast. If, however no high mountains, like our western ones, form a barrier, marine influences are felt hundreds, even thousands of miles inland, as in Europe and the eastern United States. Winds and storms from the Gulf of Mexico and other tropical waters of the western Atlantic thus traverse eastern North America and provide the rainfall for this vast agricultural region.

The continents throw a diverse land surface across the latitudinal belts of moisture, temperature, pressure, winds and storminess fostered by the oceans, and thereby interrupt the continuity of these belts. The lower humidities of the air over land, the high temperatures in summer and the low ones in winter favor strongly contrasted pressure conditions in the warm and cold seasons. In summer the continental air is expanded and a considerable quantity is forced to overflow into the cooler oceans; in winter the air over land is chilled and contracted so much that great masses of air return aloft from the sea. Thus continental air pressures tend to be low in summer and high in winter, while oceanic air pressures tend to be high in summer and low in winter. The major areas of high and low pressure, which are essentially the oceanic and continental sections of the planetary pressure belts modified, as just outlined, by the contrasted humidity and temperature conditions, have long been known as the grand centers of action. They are the large areas of high or low pressure around and from which or around and into which the prevailing winds blow.

Recalling that only one of the half dozen centers of action by which our Atlantic seaboard, in fact, the eastern half of the United States, is dominated either in winter, or in summer, is continental, the importance of the oceanic centers is at once apparent.

If these centers of action went through their seasonal transformations with consistent regularity year after year, their nature and underlying causes would not give us much of a challenge; but such is not the case.

It is, of course, easy to surmise that if appreciable

variations in sea surface temperature over large areas occur irregularly there should be, through the changes in vapor discharge to the air and in the temperature of the air, a greater favoring of high atmospheric pressure when the sea is colder and of low when it is warmer. European meteorologists have long recognized this relation in the northeastern Atlantic. Two apparently significant examples may be cited from our Gulf Stream. A body of unusually warm water coming through the straits of Florida in Januray 1916, on spreading over the western Atlantic south and east of New England appears to have been responsible for the eastward deflection and intensification of many western low pressure areas that reached the Atlantic seaboard. Consequently, northerly winds, cold weather and frequent snows prevailed from Pennsylvania to Nova Scotia. In the same manner, unusually warm water passing through the Straits of Florida in October, November and December 1925, paradoxically favored storminess and coldness during these and later months in the eastern United States.

Recognizing the importance of a knowledge of the surface temperatures of the western Atlantic, from the meteorological viewpoint, the U.S.Weather Bureau, the Canadian Meteorological Office, the International Ice Patrol, Clark University, and the American Meteorological Society have, within the past three years, installed eight seawater thermographs to record several surface profiles regularly across the area from the Grand Banks, Bermuda and Porto Rico westward to Canada and the United States and southwestward to Cuba, Honduras and the Canal Zone. A body of accurate sea surface temperature data is thus being assembled for comparison with seasonal weather abnormalities and for study to reveal such progressive movements and persistence of sea surface temperature departures as there may be in the Gulf Stream and Antilles Current.

The regular recording of surface temperatures should be extended, and regular determinations of the heat storage in the top 25 to 100 meters, and of the horizontal movements of these waters, should be made, Investigations should be made of the dependence of atmospheric humidity, temperature and pressure distribution, on the temperatures of the ocean surface, and attempts to relate the results to seasonal weather abnormalities in various parts of the world. The empirical seasonal rainfall indications cautiously issued by the Scripps Institution, from the results of the investigation of the Pacific, and the forecasts of seasonal rainfall issued by the government bureaux of India and Java, all depend on oceanographic studies for their advancement.

We may also point out that oceanographic expeditions to the less travelled seas offer excellent opportunities, at little extra cost for obtaining a wide variety of meteorologic data.

Chapter II

ECONOMIC VALUE OF OCEANOGRAPHIC INVESTIGATIONS

There is hardly an aspect of Oceanography but affects one or another phase of modern civilization; and naturally so, for this science is concerned with the physical and biological economy of some seventy percent of the earth's surface.

When Oceanography is considered from the severely practical standpoint of human economics, a distinction must be drawn between the study of such oceanic phenomena as exercise a basic control over the habitability of the lands, and of such others as man can turn to his benefit by his own efforts, but which will neither serve nor harm him otherwise. The first category includes the general influence that the oceans exercise on the climates of the continent. The second covers all the ways in which man can draw raw material for his use from the sea; also it covers the knowledge he needs to make the latter a safe highway for his commerce. It is with this second category that we are now concerned.

Food and safe navigation always have been, and now are man's most urgent demands from the sea. The lines of oceanographic study from which the most direct and economic advantages may be hoped are, therefore, investigations into: (1) the biology of the animals that support the commercial fisheries; (2) the various events in the sea that affect navigation. In fact, it has only been as knowledge has increased, with the progress of civilization, that greater and greater utilization of the biologic resources of the sea (fisheries) has become possible, and that navigation has been made reasonably safe. With the increasing press of population all over the habitable globe, the demand for more complete utilization of the fisheries resources of the sea grows more insistent, a demand that can only be met by a more complete understanding of the pertinent phases of Oceanography. Without this our efforts must be hit-or-miss, as so many fisheries undertakings have been in the past. Investigation as to whether the relationship that the temperature of the sea water and its circulation bears to the temperature, pressure and circulation of the overlying air, can be made to afford a basis for long-range forecasts of climatic variations, is also an economic problem.

A partial list of other subjects less promising of immediate commercial advantage, but which may eventually lead to useful developments, includes: (1) study of the characteristics of coastwise currents, as affecting harbor construction, etc. along sandy shores; and (2) more detailed exploration of the contour of the bottom to make easier and cheaper the construction of submarine cables, and (3) the possibility of profitably extracting from the total sea salt, that has so long been an important object of commerce, or from sea water, direct, the many other substances that it contains beside sodium chloride.

I. THE SEA FISHERIES

Much has been written of late about the total productivity of the sea, and the fact that this may be greater (per unit of area) than that of the land has been emphasized repeatedly. Under present

conditions of civilization, however, the great majority of the species of marine animals and of marine plants must be left out of account as promising sources of human food. And even if economic pressure should finally drive the white races to turn to such unfamiliar sources as sea urchins, holothurians, or sea weeds, for important additions to the food supply,[1] it is safe to predict that the land will always be the chief source for human food, at least for as long a period as it is worthwhile to be concerned with the future course of events.

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[1] All of these are eaten, more or less, in various parts of the world.

It is not necessary, however, to credit the sea with any fanciful possibilities in order to bring out the great importance that sea foods have always played in human economy. Each year man draws an enormous amount of human and stock - food from fishes, crustaceans, mollusks, even from sea weeds; also oil from fish as well as from the blubber of seals and whales; and fertilizer, while the manufacture of leather from shark skin is growing to an industry of considerable proportions. The increasing pressure of population upon agriculture on the land makes expansion and the proper conservation of the harvest of the sea every year a more pressing problem. We must assume that this pressure, not only on the resources of the Atlantic, but of the Pacific and Indian Oceans as well, will continue and become more intense, for as population multiplies in the countries bordering on those seas, fisheries will correspondingly advance in efficiency of method, and in intensity of effort, extending at the same time farther and farther to regions where the supply has hardly been tapped as yet.

The following statistics may make the economic value of these products of marine animals and plants more concrete. The sea food, for example, taken in an average year within the confines of the Gulf of Maine (comprising the 200-mile sector between Cape Cod and the Scotian Banks) amounts to about four hundred million pounds, or enough to give one hundred pounds, more or less, to every inhabitant of the New England states, and of those parts of the maritime provinces that border on this sector of the sea. The fisheries of California on the opposite side of the continent yield about one hundred million pounds annually. The combined yield of the fisheries of the United States and of Canada is about three billion three hundred million pounds annually, worth more than one hundred million dollars to the fishermen. The annual catch of food fishes off the Atlantic coast of the United States is six to seven hundred million pounds; of fish for oil and fertilizer, about as great; of shellfish (without the shells) more than one hundred and forty million pounds. The catch of cod alone in the western north Atlantic has averaged annually about one billion one hundred million pounds for the past forty years. As long ago as 1904 the value of the fishes of the countries of northwestern Europe was about ninety million dollars. The annual world yield of aquatic products (most of it marine) is more than twenty-seven billion pounds in weight, and more than a billion dollars in value. Surely, an industry of this magnitude deserves the most intelligent management possible.

The correct management is predetermined by the fact that most of this vast supply (mostly utilized as human food, but also including important by-products), is a truly natural resource, as contrasted

with the yields of agriculture on land, because man has nothing whatever to do with its production or maintenance, but merely takes a part of the wild crop that the pastures of the sea nourish. It is true that numbers (that seem enormous by any absolute standard) of sea fishes have been artificially propogated, and returned to the sea every year, but it is doubtful if these efforts have had any appreciable effect on the stock of any important commercial marine species; this is recurred to below (Page 71), and while shellfish are cultivated to some extent, this industry is in its infancy. The sea fisheries are thus more nearly on a par with forestry than with agriculture; and the methods of management, to be successful, must conform more nearly to the procedure followed in a forest where natural reproduction is depended upon to maintain the supply, than to the management of any cultivated crop.

We see a measure of the productivity of the sea-pastures in the fact that while no wild crop on land, plant or animal, can long withstand intensive harvesting, unless replaced by human effort, we still fish for cod on the Grand Banks as successfully as did the fishermen who first ventured to the shores of Newfoundland.

Vast, however, though the supply of fish and shellfish be, fishermen have long appreciated that the stock of fishes in the sea is not inexhaustible; the rapid disappearance of whales almost to the point of extinction, when they are hard hunted, is a warning. And greatly though the extent of the oceans exceeds that of the lands, all the great fisheries (except for whales) are confined to the shelves and to the slopes of the continents, in comparatively shoal water. On the American side of the North Atlantic, for example, the outermost of the productive fishing grounds lie only about 250 miles out from the land (off the shores of Newfoundland). And the grounds or banks on which the important commercial species are plentiful enough to support profitable fisheries occupy only a fraction of the area between the coastline and the continental slope that marks their offshore boundary. In the deeps outside the latter no great fishery has ever been developed, nor is there any hope of such.

The case is similar on the opposite side of the North Atlantic. In fact, the whole basin of the North Atlantic outside the 1000-meter contour is barren from the fisheries standpoint. Nor is this barrenness due to distance from land or to the difficulty of fishing at great depth, but to the fact that, in spite of the long list of fish-species that people the open oceans at all depths, these are few in individuals compared to the population of the in-shore grounds, while most of the oceanic species are small. Consequently, there is no reason to hope that any deep-sea fish will ever support an important fishery, or that great fisheries will ever be developed in the North Atlantic much farther out from the land than at present.

In the South Atlantic, Pacific, and Indian Oceans a still smaller part of the total area offers commercial fishing possibilities than in the North Atlantic. In short, only a small fraction of the total area of the sea supports practically all the fish species (and individuals) from which mass production of human food, or other useful products, can be hoped. The whale fishery alone leads out into the high seas far from land, and no increase in the yield can be expected from that source: on the contrary, how to maintain the stock of whales in the

face of even a moderate kill, not how to utilize them more fully, is now a crying problem.

The past quarter century has seen a rapid increase in the intensity of fishing in the North Atlantic, in response to the increasing demand for fish, favored by more effective methods of harvesting the catch, by improved transportation, and by better systematized marketing. For all these reasons the demand for sea food, and for the by-products of the Fisheries (oil, soap, fertilizer, leather, etc.) will continue to increase; to meet this increasing demand, the stock of herring, cod, haddock, halibut, lobsters and the rest will be subjected to a more and more intensive drain. The intensity of the British Steam Trawl Fishery, for example, increased by 11% from 1913 to 1920. Yearly, more and more fishing is done on the American side of the Atlantic with better and better gear, resulting in a corresponding increase in the yearly catch. And wherever in the sea fishermen can catch their fares, the story will soon be the same, if it is not so already. Under these circumstances, the questions immediately urgent of solution are: (1) how much fishing can each species stand without depletion at the hands of man; (2) what measures of regulation should be taken to prevent depletion when danger of the latter seems imminent or to restore a depleted stock; (3) what is the possibility of extending the fisheries to new grounds; (4) what hope is there of marketing fish, or other marine products not utilized at present; (5) can we find a rational basis for predicting in advance the great fluctuations in the abundance of fishes that are known to occur from natural causes and thus order our fishing efforts more economically.

The first of these questions is the basic problem in all economic fisheries research, for on the answer to it must depend the whole scheme of intelligent use and conservation. But the answer in any given case can only be reached by intensive study of the general biology of the species in question, combined with actual experience as expressed by the statistics of that particular fishery.

The history of the fisheries includes sundry examples of depletion; not only of the whales, just mentioned, but also when one or another fish, crustacean, or mollusk has been fished down to a point where pursuit was no longer profitable on grounds which yielded abundant fares when first exploited.

In North American waters the halibut perhaps affords the most striking example of this. For the Atlantic, the annual catch brought in by the New England Fishermen from the Banks off the Gulf of Maine, off Nova Scotia, and to the north and east, having fallen from about fifteen million pounds in 1879, to three million pounds in 1926. In the North Pacific, too, it is certain that a decline in the catch of halibut on the older grounds from nearly 300 pounds per unit of gear in 1906 to less than 50 lbs. in 1926, and the fact that no more fish are now taken off an 1800 mile stretch of coastline than were formerly caught along 600 miles, has directly resulted from over-fishing. The speed with which an over-drain on the stock is reflected in the fishery for the halibut may also be illustrated by the fact that newly developed grounds in the Pacific that yielded 160 lbs. per unit of gear in 1923, yielded only 100 lbs. three years later, and less still in 1927. It seems equally certain that the great decrease in the catch of albacore off California also reflects too intensive

fishing. Similarly, the striped bass has been practically exterminated on parts of the New England coast, though holding its own better along the southern shores; the catch of lobsters per unit of effort has greatly declined since early days, and the smelt fails to hold its own. In north European waters this is equally true of the plaice. In this case the average size of the individual fish caught has also declined, and it was this decline in the plaice fishery, with the fears felt for the future of other equally important fisheries in the North Sea, that led the nations bordering on the latter to organize the International Council for the Exploration of the Sea in 1902 (page 137)

Other commercial developments on land may also damage the fishery. The effects, on shell fish beds, of pollution either by sewage or by industrial wastes is often serious; sometimes directly, sometimes indirectly as when the oysters or clams are contaminated with bacteria of diseases. The damming of tidal estuaries may also have a destructive effect, not only within, but by altering the circulation of water in the general vicinity. The probable effects of one project of this sort on the "sardine" fishery and packing industry for young herring in the region of the Bay of Fundy (a two-million dollar industry, based on one of the most important local fisheries of the Atlantic coast of North America), is now causing concern to the Fisheries Services of Canada and of the United States. The difficulty is that the detailed understanding of the biology of the herring, and of the hydrography of the region that is needed for positive prediction, is lacking.

It is obvious that when any species is being fished down below the limit of safety, the remedy lies in regulation of the fishery, in order to allow the stock to recover; whether by closed seasons, by closed areas, or by otherwise limiting the catch. But regulation of this sort invariably must cause great disturbance, loss and hardship to the fishing industry. It is, therefore, of great importance from the economic standpoint to be able to state whether a shrinkage in the catch of one or other of the important species does actually mean that depletion is in progress. It is true that in the past any sudden decrease in the yield of the fisheries has usually been blamed, forthwith, to overfishing, or to the development of modern methods more effective than those of the past. In fact, whenever any improved method of fishing is introduced, a wail of calamity arises; it is claimed that the young fish are destroyed, the sea bottom disturbed, etc. etc. and investigation is demanded. Such an investigation of the otter-trawl fishery is, in fact, in progress in Canadian waters at present, though this method has been employed for many years off the United States and northern Europe. But when it happens, as it often has in the past, that the stock of some fish that had been at a low ebb over a period of years, reestablishes itself in the face of a fishery perhaps even increasing in intensity, it is clear that some factor other than overfishing is at work. In such cases it is the industry that requires protection more than the fish. It has, indeed, been amply proven that the stocks of many sea fishes (perhaps of all) may vary greatly in abundance from year to year, or over periods of years, from strictly natural causes, with which the hand of man has had nothing whatever to do.

Natural fluctuations of this sort have been so freely discussed in fisheries literature during the past quarter century that only a few instances need be mentioned here. In general, they mirror the fact

that a year of highly successful reproduction is a decidedly rare event for many species; and that when (by a happy combination of circumstances) such an event does occur, its product dominates the stock for a long period thereafter, either until they drop out of the picture by the natural death rate, or until another rich year class is produced. Thus, the fish hatched in 1904 dominated the stock of sea-herring in Norwegian waters until 1919, having supported the fishery for 15 years. Had they not been succeeded by another abundant year class before they died (or were killed off), the Norwegian Herring Fishery would have failed utterly for the time being; and no human endeavor could have staved off the calamity. Off the Newfoundland coast of the Gulf of St. Lawrence the crop of 1904 was likewise responsible for most of the commercial catch of herring as late as 1915. Even a more striking example of fluctuations in abundance is afforded by the mackerel, causing vicissitudes to the fishing industry that have become proverbial. Similar, if less spectacular, fluctuations in abundance have been recorded for cod, for haddock, and for other species as far back as the history of the fisheries runs, and long before the latter was intensive enough to make any serious drain on the stock.

Perhaps the decline and recovery of the Blue fish off southern New England in the late 1700's and early 1800's is our best local illustration of the fact that events of this sort may be wholly independent of the acts of man, for decline, total disappearance, and subsequent recovery of this species took place before any intensive fishery for its species had developed. Similarly, the recovery of the stock of mackerel in North American waters, from its lowest ebb in 1910, occurred in the face of a very intensive fishery. In Norway, too, the historic record discloses a succession declines and recoveries in the stock of cod over a long period of years. In Scotland the Haddock failed in 1792, but recovered thereafter; the French (true) sardine has also undergone wide fluctuations in abundance, while many other instances of this sort might be mentioned, the economic sequellae of which have been far reaching, alternately bringing prosperity and disaster to the fishermen.

The stock of a given species may also be suddenly reduced almost to the vanishing point by some unfavorable shift in the environment; most often by abnormally low temperatures. We have record of such an event as far back as 1789, when seafarers brought back word that the surface of Barents Sea, north of Europe, was covered with large haddock and coalfish in dying condition; probably they had been chilled by some sporadic flooding of the bottom by Artic water. A more recent and much heralded instance of destruction of this same sort was that of the tile fish off the eastern United States. In the spring of 1882 vessel after vessel reported these fish dead and dying on the surface. In fact, the destruction was so nearly complete that it was not until ten years later that a single live tile fish was again seen. But by 1898 they were again as plentiful as ever. These events have in no way depended on the fisheries.

Most of the clear cases of depletion or of indirect damage by industrial developments have affected species living so close to land as to be especially vulnerable. In fact, it is doubtful whether the hand of man has, up to the present time, been able appreciably to damage the stock of any of the species that support the great off-

shore fisheries, except for the plaice and the halibut. But acute apprehension is now felt for the haddock in American waters, because its concentration on grounds where steam trawlers can easily work makes it especially vulnerable to a rapidly expanding fishery.

With the stock of any species of fish in the sea likely at any time to diminish, and to stay at a low ebb for years, from natural causes, as well as standing in danger of depletion by man, it is economically of great importance to be able to state whether a shrinkage in the catch falls in the one category or in the other, because the procedure proper for the industry to follow is quite different in the one case than in the other. If depletion is taking place, regulation, as already remarked, is in order, for it is certain that we cannot maintain any of the true marine fishes by artificial propogation if they be overfished. Boast as we may of the billions of young cod, haddock or pollock that are dumped into the sea by the government hatcheries, these are less than a drop in the bucket: the product of only a handful of parents in populations to be numbered by the million. But if fish diminish as some one dominant year class dies off, before another year of abundant production has come, the fishery itself needs to be safe-guarded against the disastrous results of the sudden cessation of the supply. Theoretically, extensive protective regulation might seem called for in this case also: practically however, this has not proved to be the case, because we know of no instance, up to the present, where the stock of a species that has shrunk from natural causes has failed to recover from such a decline in spite of the drain upon it by the fishery. When fish are scarce there is less fishing done, so that this side of the picture takes care of itself. And the oceanographer stands in the best position to guard the fishery (and the consuming public) against fluctuations of this sort for he alone has the opportunity to discover a rational basis for predicting such events in advance. Until that can be done, we can only proceed "hit-or-miss".

The basic fisheries problem, then, is to make the greatest possible use of the food recources of the sea that is compatible (a) with avoiding the danger of overfishing; (b) with safeguarding the industry against the disastrous effects of unpreventable fluctuations in the available supply of fish.

Although the problems involved in these two cases are fundamentally distinct, in each case the solution can only come from investigations of the life histories of the fishes involved, and of their reactions to their environment, animate and inanimate, combined with statistical study of the commercial catch. In other words, the technique of oceanic biology must be employed, whether the aim be protection or prediction.

Whenever any fishery increases greatly in intensity, as is now happening with the American haddock fishery, the immediately practical task is to estimate the strain of fishing that the species in question may reasonably be expected to withstand; or when any fishery shows a serious decline, to determine whether this reflects overfishing, or results from a natural decrease in the stock in the sea. In either case the species concerned must be studied as populations, not as individuals, by methods similar to those developed in the science of Vital Statistics. This part of the economic fisheries problem is

already being tolerably well handled; the technique is constantly being developed in America by the Fisheries Services of Canada and of the United States, and has been carried still farther by the International Council for the Exploration of the Sea in North Europe. In fact, the statistical studies of various fisheries that have been published have already reached proportions that make analysis almost impossible. But for reasons inherent in the governmental operation of scientific establishments, these bureaux have not been able to make commensurate progress in the biological side of the matter, without which the attempt to interpret the trends that the statistics of the catches disclose, whether up, down or stationary, will probably prove idle or even misleading. Thus there is no general agreement as to the meaning of the fluctuations in the plaice fishery as a whole, nor in the relative abundance of small and large plaice in the commercial catch, one school explaining the recorded phenomena in one way, another in another, although this fish has been under statistical examination by many hands for many years.

In fact, it is not too much to say that if we regard the time and effort that has been expended on investigations of the sea fisheries as capital, little has yet been returned as interest to the fishing industry, or through them to the consumer ashore.

The reason for such a poverty of result from so great an effort has been our ignorances of the interrelationships of the very complex chain of events in the sea that govern the comparative success or failure of its inhabitants in the struggle for life. Nothing in the sea falls haphazard. If we cannot predict, it is because we do not know the cause, or how the cause works. The obstacle to the advance of knowledge, here lies in part in the technical difficulty of carrying on the needed investigations into the basic biology of the commercial fishes on a scale broad enough to serve as foundation for the easier-gathered statistical data. A more serious obstacle, when seeking support (intellectual or financial) for such work, is that in every case the matter is so obscure that it is impossible to predict in advance what particular phase in the fishes' life history will prove to be the vital one, or even that knowledge of any one is more important than of any other. The whole life chain must be traced link by link before any sound understanding of it can be reached, which calls for critical and protracted investigations in biology (including physiology), often ramifying into chemistry and physics. Thus, if the conservation and development of the marine fisheries is to rest on a sound basis, many problems must be attacked in the sea that seem at first sight utterly remote from any practical application. But at present it is almost impossible to secure the necessary financial support for such work over a period long enough for the study to reach a productive stage. The result has been that in fisheries investigations the statistical has far outstripped the biologic, whereas logically the reverse ought to be the case. In short, we have too often been building the structure from the roof downward.

This one-sided development has its reflection in the fact that great as has been the amount of thought and effort centered on fisheries problems during the past quarter century, and great the amount of money expended, we do not yet know what precise combination of factors favors or opposes a good year of production for a single species of marine fish. Worse yet, from the economic standpoint, we

do not know at what age it is wisest to catch and market the crop of any species, i.e. whether the best yields will result in the long run if the fish are taken near the lower limit of marketable size, or whether they should be allowed to grow larger and to spawn several times.

Obviously, if a species is to persist some individuals must grow to breeding age. But as only a fraction of each year's crop can do so in any event (else the universe would be a solid mass of fish) in some cases it may be wise for the fishermen to utilize the smaller sizes, most of which could not mature. For instance, we are totally in the dark as to whether the great destruction of immature fish, too small for the market, that is wrought by the otter-trawlers, and by the pound nets along our Atlantic coast, so often heralded by calamity-criers, does any real damage to the stock; it may conceivably be a benefit, paradoxical though this may seem. To be more specific, there is no positive evidence that the annual capture of a billion or more of small herring in the Gulf of Maine, to be packed as "sardines", year after year, has had any effect whatever on the numerical strength of the stock of adults breeding there. Could a large catch of the latter have been made with equal impunity? We cannot answer. Similarly, it is now a moot question whether it is wiser to protect the small lobsters and market the large, or _vice versa_; nor can this be settled correctly by acrimonious argument, any more than can the question whether large catches of small plaice in the North Sea are really as destructive to the stock as has often been supposed.

For few species can we yet so much as glimpse an answer to the question "Where ought the fish to be caught", though this may be an important one in the maintenance or development of any given fishery. Practical fishermen have long feared the results of hard fishing on the spawning grounds, especially in the case of the flat fishes, though economic pressure has forced them to do just this for it is often on the spawning grounds that drift-netting and otter-trawling are the most productive. Certainly it is safest to kill breeding fish just after, rather than just before spawning, so ensuring at least that one crop of eggs. But to translate this academic theory into practical regulation calls for a knowledge of spawning grounds and seasons which can only be gained in sufficient detail by intensive study at sea.

On the other hand, we already know that there are certain grounds where no amount of fishing for certain species (even to the verge of temporary extermination) will have any permanent effect upon the general stock. This applies in cases where there is a regular emigration away from the spawning areas to grounds far distant, with no return migration. Thus the lobsters that stray to the Bay of Fundy cannot reproduce in the low temperatures prevailing there, though they find these cool conditions favorable to mature growth. It would be pure economic waste not to catch them. The case is similar for the Rose Fish (Sebastes) off the west coast of Greenland, which are recruited from fry produced in higher temperatures in the Atlantic to the south, with no return movement. In instances of this sort the only sound limit to fishing is the economic one. But the understanding of such cases involves a knowledge of the lines of dispersal and migrations in general, which in turn demands long

continuing study (by all available methods) of ocean currents as carriers of eggs and larvae; and of the length of time during which these latter drift at the mercy of the current; information which, again, can only be gained at sea.

At first sight it might seem that the question "how" best to harvest the crop would be purely economic, not biologic. Actually, however, this is not the case, for many reasons. Thus, different kinds of gear take fish of different sizes, while the type of gear used may also determine the fishing grounds frequented, and the depth-zone available for fishing. The otter-trawl, for instance, can be used only on comparatively smooth bottom, the Purse Seine only close to the surface, and in smooth weather; the pound-net or weir only close to the shore-line, and only during the warm months if ice forms during the winter; hook and line only where fish are feeding, etc. Whether the grounds, depths or seasons, so determined by the method adopted, are wise from the standpoint of conservation, or the reverse, can be settled only by knowledge of the life history of the particular fish.

For these same reasons, statistics of the amount of fish caught may give a wholly erroneous picture of the abundance of the species in the sea. When the purse seiners report "no mackerel", for example, it may merely mean that the fish are keeping down deeper in the water; when otter-trawlers report "few cod" the latter may simply have concentrated on the rougher bottom where the trawlers do not fish. Similarly, the reported landings, as classified by localities, may give a false impression of the regional abundance of the fish in the sea, unless the actual locality of the capture is stated, which it has seldom been possible to do except in a very loose way.

"How to fish" has another biological aspect that cannot be neglected: namely the effect that the fishery may have on enemy-species that are caught incidentally, or on species upon which the commercial fishes prey. Any method that will take and destroy large numbers of destructive species may actually benefit the primary object of the fishery, in spite of the draft that fishing makes on the latter. In North American waters this applies especially to the destruction of the Dog fish, of Skates, and of the Goose, - or Monk fish. But off other coasts, where the last two are used for food, the relationship is different. To destroy annually several hundred million Menhaden, as is done to supply the demand for fish oil and for fertilizer, may seriously lessen the food supply for the Blue fish, and so react against the latter. But the lives of so many Menhaden are saved whenever a Blue fish is caught that the death of the latter may be economic gain. The interrelationships of different species, as food or enemies, is thus a vital factor in the situation; to disentangle this skein falls directly within the province of the oceanic biologist.

Ever since man first cast line into the sea, "can we broaden our fishing grounds?" has been a live question. With the passage of the years one new fishing bank has been developed after another, and no one can dispute that the discovery of new grounds and of new bodies of fish from which no toll has previously been taken, is so much pure gain. Every fisheries bureau is therefore interested in testing the possibilities of unfished parts of the sea by actual fishing

experiments, hoping to discover new banks, as the U. S. Bureau of Fisheries has recently done off the Carolinas. Less direct methods have also proved fertile from this standpoint. For example, highly productive cod grounds have been developed off Norway by deducing the existence of spawning schools from the distribution of their eggs floating at the surface of the water. And while it is certain that the major fishing grounds off the North Atlantic coasts of North America and of Europe are already being exploited - so, too, off our North Pacific coast - great possibilities of expansion still remain in the Gulf of Mexico, in the South Atlantic, in the eastern and western Pacific, and in the Indian Ocean, as well as in Arctic and Antartic seas.

The question of extension of grounds is, however, not a simple one of exploration, because expansion might in certain cases prove detrimental to some of the most important species. If, for example, the wintering grounds of the American mackerel, of the Weakfish, of the Sea Bass the Scup, and of various other fishes that vanish from the eastern coast of North America during the winter, were to be mapped, and the fishing of the species extended throughout the season, it is questionable whether the stocks would stand the added strain.

To what extent, too, do grounds where cod, haddock, etc. are little fished at present serve as reservoirs of supply for banks fished more intensively because more accessible; and what protection, if any, should they receive on this score? That banks do serve as reservoirs for one another in this respect is certain, because when small grounds close to land are so fished out that it no longer pays to fish there (as happens often, and sometimes very soon) they presently recover if the fishermen abandon them for a term of years. In fact, a power of rapid recuperation seems almost an invariable law in the sea; any species, indeed, that did not possess this power would soon vanish from the scene, fishing or no fishing, by so many dangers and so constant are they all beset. What role in this recuperation is played by immigration from surrounding grounds, what by local reproduction? In the case of the Pacific halibut this is a live question today, and the answer to it will govern the regulations to be adopted. Its solution can only be reached through a study of migration, and of the factors determining the success of breeding, so that the International Fisheries Commission is governing its procedure accordingly.

The possibility of discovering new fishes, or of mapping the centers of abundance for species whose existence has long been known but which have not been made the object of any regular fishery, because their abundance is not suspected, is closely associated with the development of new grounds. One might hardly have expected that the existence of a large and valuable food fish, in great abundance, and close to the fishing ports of the eastern United States, would have remained unsuspected until 1879. Such, however, was the history of the Tile fish. While the first specimen of this species was brought in by a fisherman, it needed the explorations of the Federal Bureau of Fisheries to make its geographic distribution and abundance known, and to introduce it to the market. Thanks to these efforts, the tile fish has of late yielded much good food. And while history can hardly be expected to repeat itself in this spectacular way in the North Atlantic, unlimited possibilities for this sort of expansion are still

open in the other oceans. In fact, the sea is certainly capable of yielding vastly more food to man than at present. Expansion of this sort also offers attractive possibilities for fish products other than food, especially for fertilizer, for stock food, for oil, for glue, etc. and for fish skins as a source for leather(elsewhere) In fact the catch of one species alone (the Menhaden) used exclusively for fertilizer, scrap, and oil along the Atlantic coast of the United States, is about 700,000,000 lbs. yearly.

In the case of the shell fisheries (for clams, oysters, mussels, abalones, pearl-oysters, etc.) the great problem is to guard against depletion by overfishing, or to maintain the stock by cultural methods. This danger is much more imminent for the molluscs than it is for most of the marine fishes, both because all of the shellfish now used for food live close to shore in shoal water, and because they are so stationary that once a center of abundance is found it is soon fished with great intensity. The result is that the maintenance of the stocks of oysters, clams, abalones, etc. around our coasts is already an urgent matter, and it has been found necessary severely to regulate the pearl fishery, wherever this is carried on in the Indo-Pacific. To emphasize the economic importance of the shellfish (molluscs, lobsters, crabs and shrimps) we may point out that they form about one-fifth[1] of the total sea foods harvested from the Atlantic Coast of the United States, while oyster shells also yield about 6,000 tons of lime as a by-product yearly.

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[1]Footnote: oysters and clams figured without their shells.

The stationary nature, however, of the shell fishes, and the possibility of cultivating them, as is now successfully done for clams and oysters, makes it easier to safeguard them than the fishes. But detailed knowledge of their lives and ecological relationships is an absolute essential, not only for cultivation, but equally for regulating the catch from grounds, or of species the cultivation of which is not practical. And this knowledge can come only from detailed studies falling in the field of marine physiology.

In short, every problem of the marine fisheries, except such as center directly around the education of the human palate to appreciate new foods and of human industries to employ raw products from new sources, or around improved methods of distribution, handling, and marketing, is a problem in oceanic biology, just as every problem in plant or animal husbandry on land is one in terrestrial biology: consequently, a problem falling directly within the direct scope of Oceanography. Every such problem demands for its solution precisely the procedure that would be employed had it no economic bearing whatsoever; results gained in any other way can never be better than haphazard; i.e. of the sort proper to a past age.

This means that whatever marine animal be in question, and whatever be the question regarding it, an understanding of its whole life cycle is needed for the answer, because only when the whole chain is known can we hope to distinguish its strong from its weak links. Fisheries-biologists have long appreciated this truth. And a growing demand for information on such points as spawning grounds, rate of

growth, feeding habits, and migrations, makes it evident that the fishery-industry is also coming to appreciate it.

It is no reflection on science that only certain of the links in the life chain are yet known for any single fish in the sea, for every case is one of great complexity. Each investigation also involves the life histories of all the species of plants and of animals, that may either serve the fish in question as food in one stage or another of its development, that may serve as the food of its food, or that may prey upon it. Thus one food chain, not too imaginary would lead from the common mackerel shark to the American pollock on which it feeds in part; the latter may feed on young mackerel; the mackerel on larval herring, the latter on shrimps; these last on copepods; the copepods on unicellular pelagic plants; while the existence of the latter depends on the supply of nutrient salts in solution in the sea water. Whatever reacts favorably or unfavorably on the one, will react likewise on all the rest. The most important problem for every individual fish, as for every man and woman on land is that of food. Consequently, the welfare of the minute creatures in the sea on which young fishes feed, finally harking back (via their own food) to such elemental matters as the salts in the sea, and the amount of sunlight falling on the surface of the water, is a matter of practical importance to fishermen, and so, in turn, to the purse of the consumer.

The study of the life history of any marine fish involves the physiological state of the parent as determining the viability of the eggs and sperm; temperature and salinity as governing the hatch; the character of the eggs whether buoyant or not; the duration of incubation, and the drift of the water as governing their dispersal; as well as the supply of food (unicellular plants or minute animals) available when the little fishes hatch (this last is probably the most vulnerable stage, and the one most vital link in the life chain). The toll taken of the larvae by enemies is also important. Probably these headings include the factors that chiefly govern the relative success of reproduction from year to year; hence knowledge of these is essential for understanding the annual fluctuations of the stock, and it is about precisely these matters that we still remain in the deepest darkness.

The direction and duration of the involuntary migrations of the larvae, their food, their rate of growth, and the age at which they either take to the bottom or begin to direct their own journeys, is one factor; wanderings of the older fish the other, that governs the interchange of fish between different banks, and the degree to which certain grounds serve as nurseries for others. This with the importance of temperature as a vital factor, makes the study of the ocean currents perhaps the most important single item in fisheries research Knowledge of such matters as the food and spawning habits, the rate o growth, the dominance of particular year classes, the enemies, the general distribution, and the optimum temperature and salinity for th older fish, are equally essential for intelligent management of the fishery.

There is nothing fanciful or extreme in the foregoing: the whol field must be covered if effective remedies are to be found for even

the clearest cases of depletion. This is now accepted by all who concern themselves with the preservation of the deep-sea fisheries, as illustrated by the program of the International Fisheries Commission, now charged by treaty between the United States and Canada with the proper regulation of the halibut fishery off the northwest coast of North America. Rapid depletion makes regulation necessary in this case, as already remarked (page 70).In fact, as the U. S. Commissioner of Fisheries has pointed out, the fishery is in a very serious condition from overfishing. But to arrive at a basis for action the Commission has found it necessary to search for the eggs and larvae, to map the drift of the same, to examine the dynamic oceanography of the region as governing this drift, to trace the wanderings of the adult halibut, to chart the spawning grounds, and to trace the interrelationships between the stocks of halibut on different grounds.

When seeking a basis from which to predict the productivity of a fishery in advance, the method of procedure is essentially similar. The U. S. Bureau of Fisheries has for example, undertaken an intensive study of much these same phases in the life history of the American mackerel, hoping to enable the industry to guard itself against the disastrous effects of the violent but uncontrollable fluctuations in the supply that come from natural causes. And though this study has been in progress for only two years, prediction of the mackerel fishery for 1928, based on the state of the stock in 1927, was close to correct. Predictions of the abundance or reverse of herring and of sardines in European waters, based on similar studies, have also been successful enough to justify the hope that they will be of great value, when a better knowledge of the governing causes has been gained.

It is idle to suppose that oceanwide expeditions, undertaken at long intervals, will be of much value in advancing investigations of this sort. What is needed is intensive study either of regions, of individual species, or of particular fisheries, as the case may be. These must be so long continued (because covering so wide a field and concerned with the natural economy of generation after generation), and so intensive (because of the nature of the problems involved), that individual investigators can make but slow progress. In no field, in fact, are joint efforts, and the services of cooperative agencies more needed in American Oceanography, than in fisheries Biology. The work of the Federal Fisheries Services of North America would benefit greatly by the assistance of any institution that could initiate and encourage research in the basic fields of oceanic biology, to which the governmental agencies cannot give due attention because of legislative allocation of their funds to objects that may seem more directly profitable from the economic standpoint.

II. UTILIZATION OF OTHER MARINE PRODUCTS.

At the present time the problems involved under this heading are more Technological and economic, than oceanographic. At present, too, it is impossible to foresee how rapidly the exploitation of the sea will develop in this direction. We think it sufficient therefore to point out that the status is covered by D. K. Tressler, in his book "Marine products of Commerce".

III. NAVIGATION

In a general way, the sea, as a high road for commerce, now serves man's purposes adequately. But now and then, even today in the era of full-powered steamers, and elaborate safety devices, we have brought home to us in a tragic way that the sea has its dangers. We may be shocked to hear of a collision with ice, as chanced to the Titanic in 1912; of the foundering of a steamer, its plates stove in by the force of the sea; or of the stranding of some ship put out of her reckoning by an unexpected current. The high rates of marine insurance, as compared with insurance on goods in transit on land, mirror the risk to property run on every passage; the risk to life is equally grave.

A. STUDIES OF TIDAL AND OTHER CURRENTS

Probably the greatest gain that Oceanography could offer in cheapening, expediting and safeguarding commerce on the seas, and the only considerable gain to be hoped from it in this respect at present, would come from adding detail to our knowledge of ocean drifts and of tidal currents, and of the depths of water off coasts not yet accurately charted.

The importance of ocean currents in ordinary day-to-day navigation is so obvious as to need no emphasis here. Ignorance of the direction and velocity of the current is responsible for some of the discrepancies between the true position of the ship as determined by astronomical sights and that calculated for her by dead reckoning, though log errors, bad steering, leeway, etc., all enter in. A recent example of the tragic effects an unrecognized drift may have is afforded by the difficulty that ships coming to the assistance of the ill-fated Vestris had in finding her; the fact that she was more than 30 miles from the calculated position, in a run of only two days, being best explained in this way. Many wrecks have been caused by ignorance of the direction and strength of the current near shore at the time.

It is self evident that to follow a favoring current hastens, to stem a contrary current retards passages. This is made particularly true off the east coast of the United States by the proximity of the so-called "Gulf Stream", the drift of which must always be taken into account. Every hour wasted steaming against the current entails so much extra cost; wherever it is possible to go with the drift fuel is saved. And either small savings, or small losses, when cumulative, reach staggering proportions in the course of years. This factor is of far greater moment for the slow freighters, in which most of the world's maritime commerce is carried, than for the fast passenger liners which can often disregard the current. In parts of the South Atlantic, Indian and Pacific Oceans we still lack sufficiently detailed knowledge of velocities and precise directions, of the effects on these of varying winds, and of seasonal variations, to allow intelligent planning of routes for slow ships, even though the general characteristics of the oceanic circulation are understood. The aggregate economic loss from such ignorance, if measured in dollars and cents, would be very large. Even if the current arrows are true enough as an indication of the mean direction, the actual drift at any given date may differ widely from that shown, and this is

what the navigator needs to know.

The need of bettering present knowledge of the major currents is fully appreciated by the Hydrographic Services of the seafaring nations. For this reason the United States Hydrographic Office, the British Admiralty, and the German Marine Observatory are continually accumulating a vast amount of data from vessels' log books, as well as from all other available sources, in the hope of improving their yearly and monthly current charts. This, of course, is most important for the regions where the direction of the dominant drift reverses from season to season, as in parts of the Indian Ocean; or which fall within the sweep of a great current at one season, but not at another; or over which the daily velocity varies greatly from season to season with varying winds.

In certain regions, especially along the west coast of Africa, rapid advances in knowledge of the currents have been gained within the last few years. But to illustrate the urgent need of still further improvements in more travelled seas, we need only instance the present vagueness of our understanding of the secular variations in the geographic location of the inner edge of the Gulf Stream drift off the east coast of North America, and of the eddying movements plus counter drifts that confuse the orderly procession of that body of tropic water toward the northeast. That the Gulf Stream has shifted its position is a frequent report; one, too, that includes more than a grain of truth.

Knowledge of the southerly drift along the west coast of North America is still vague. More detailed information is made especially urgent there for the sake of safety at sea by the scarcity of good harbors of refuge along the coasts of Oregon and California. And "sketchy" fairly describes our present picture of the currents among the Polynesian, Philippine and Malayan Archipelagoes, to mention only striking instances.

Ocean currents affect navigation indirectly as well a directly, and in a disastrous way, by bringing icebergs and field ice down from the Artic, a frequent menace to the shipping lanes between America and Europe. This menance the maritime nations now meet in part by maintaining the International Ice Patrol, during the danger season, in the region of the Grand Banks, where the steamer routes between the United States and Northern Europe touch the principal lane followed by the bergs in their drift southward from Davis Straits. But betterment of the Patrol demands more detailed examination of the variations in the two great currents (Labrador and Gulf Stream) that meet there, the first bringing the bergs, the latter melting them. To gain a better understanding of the factors that control the journeying of the bergs, the Patrol has recently expanded its activities to include a dynamic survey of the whole region between Labrador and Greenland, as described in another section (page). And should the Patrol be extended to include the more northern routes it will become increasingly important to make periodic surveys of these northern waters in the hope of explaining, and perhaps predicting the wide variations in the amount of ice that comes southward from year to year, and the varying tracks that the bergs follow.

As demands grow for an extension of maritime trade routes more

and more to the north, the need of more detailed information as to the state of the Artic ice from season to season correspondingly increases. Thus it is a live question how many months in the year open water can be depended upon in Hudson Strait and in the northern and northeastern parts of Hudson Bay. The answer will determine the practicability of developing the harbors on the Bay as export centers for wheat, etc., from the Canadian North-West, in competition with the harbors in the Gulf of St. Lawrence and to the southward. In this case, it is the drift of ice from the North that will govern, not the ice frozen locally in these comparatively low latitudes. This drift, in turn is determined by the dominant movement of the water in its course out of the Bay, and through the Straits. The Canadian Government is fully alive to the importance of this matter, has already sent several expeditions to the Straits, and has done so again in the summer of 1929.

At the Conference on Oceanography at the U. S. Navy Department in 1926 the United States Coast Guard urged the importance of a study of the expansions and contractions of polar ice through Bering Straits, to safeguard the voyages of the whalers to the Arctic coasts of Alaska and Canada.

The rapid development of air navigation, leading to attempts to develop safe flying routes over the top of the world (to shorten the distance from America to northern Europe), gives added significance to the state of the ice in the Arctic, especially to the northward of Spitzbergen, from season to season, and from year to year.

For all these navigational reasons, as well as in the interests of the fisheries (page 67),and for the general advancement of science, we need not only a better knowledge of the circulatory events in the sea, but better understanding of the underlying forces that keep the ocean currents in motion, as well as of the relative effects of the conflicting factors that influence their set and drift. This understanding cannot be gained by continued compilation of log-reports, no matter how extensive, because the underlying waters are involved, as well as the surface. Quite a different proceding is called for; one that finds its most modern expression in mathematical analyses of the dynamic factors in the sea, such as are now being actively undertaken at various centers in Europe and North America. Work of this sort, however, can hardly be attempted on a large scale by any governmental establishment, because the difficulty of demonstrating an immediate economic result makes legislative support difficult to win. And while the development of methods of attack, etc., often draws inspiration from one or another isolated center or individual, successful application to the oceans demands cooperation between many institutions, because the field is oceanwide. Observations must also be carried on for many years to trace the long-time fluctuations that are already known to occur. Some center of inspiration and coordination is sorely needed to encourage work of this sort in America.

In many parts of the world the tidal currents run with velocities much greater than those of the ocean drifts on the high seas, and they are usually strongest next to the land, just where ships meet their greatest danger.[1] In fact they may play their greatest economic role within busy harbors.

[1]Contrary to the belief common among landsmen, the well-found ship is safest when far out at sea: when skirting the land she is in constant risk.

It is easier to study tidal currents than ocean drifts because most of the work can be done near land, in shallow, and often within enclosed waters. Under such conditions the direction and speed can be measured directly from hour to hour as the tide ebbs and flows by current meters, by chip-log, or by float. And an enormous amount of this work has been done by the tidal service of the different countries, including continuous observations over periods of many weeks or months at strategic locations (lightships, for instance). But while the stage of the tide can now be predicted in advance for any time of the day with great accuracy for most of the important harbors of the world, in few cases (and perhaps nowhere off open coasts) is it yet possible to do this for the velocity or precise direction of the current, because the latter is so often complicated by the wind, and by whatever non-tidal drift may dominate the particular region in question.

Rapid advances are being made in current work along the coasts and in the harbors of the more important maritime nations. Thus the U. S. Coast and Geodetic Survey is making comprehensive current surveys of the more important harbors and waterways of the United States. But this is necessarily slow work with the appropriations available. Hence present knowledge is in many frequented waterways insufficient-witness the necessity the engineers for the projected tidal-power development in Passamaquoddy Bay have been under of making their own survey of the strengths and directions of the tidal currents there. And for administrative reasons the coastal and tidal surveys of the different governments are seldom able (never able in the case of the United States) to extend this work beyond their own coasts or those of their dependencies. It follows that there are serious gaps in our knowledge of the tidal currents around the shorelines and in the bays and estuaries of all the countries that are more backward in this respect. And what is known of such regions has necessarily been gained more or less haphazard, as opportunities offered for some man-of-war or other ship to take current measurements while on foreign station. The paucity of detail as to the direction and velocity of the tidal currents given in the sailing pilots for the South Atlantic, for the Central Pacific, and for the Eastern Archipelago will make this clear. Here a wide field lies open for oceanographic research, where knowledge gained will sooner or later be of practical advantage to the navigator.

B. SOUNDINGS

Knowledge of the topography of the sea bottom, i.e. of the depth of the water along the coast, is, to the navigator, as important as is the detailed charting of the coastline itself. Not only does his ability to enter harbors in safety depend on this knowledge, but by sounding he can feel his way, and often can locate his position when fog or storm hide every visible land mark, terrestrial or celestial.

Until very recently it has chiefly been in comparatively shoal water, say less than 100 fathoms, that soundings have been helpful to the navigator, and the importance of mapping the depth near land in the greatest possible detail has so long been fully appreciated, and so much effort has been devoted to this, that existing charts leave little to be desired for navigational purposes, for the more frequented coasts.

An example of the accuracy of some of the older work is afforded by the fact that charts of the Maldive Group in the Indian Ocean, based on soundings taken nearly a century ago are so accurate that we found no appreciable error, in 1901-1902 except such as would naturally result from subsequent growth or death of coral heads. Even off the coasts of the northeastern United States, however, pinacle rocks have recently been discovered, and surveys must be repeated at frequent intervals off sandy coasts and inlets where bars shift, and channels change. In fact, few laymen appreciate the extent of the coasts where knowledge of the depth is still more or less imperfect. For an example we need seek no further than the east coast of Labrador where soundings are not only so few, but are so often inaccurate, that a stranger must proceed with the greatest caution, while considerable stretches of the coastline itself are still to be filled in on the chart. In Alaskan waters employment of the "wire drag" method has recently added much important information, especially as to the location of pinnacle rocks, such as are apt to be overlooked in other kinds of surveys.

Now that sonic methods of sounding have reached the stage of practicability the application of measurement of depths to navigation enters a new phase. In the first place it is now possible to survey a given area much more rapidly than by the old methods. In the second, detailed information of the edges and slopes of the continents becomes more important, for as more and more of the larger ships install sonic gear with which they can sound at any depth while running at full speed, they find it more and more helpful to pick up the slope as an index to their distance from land, in thick weather. Thus the Ice Patrol, during the season of 1928 found the sonic fathometer of great assistance in navigating in the fog around the slopes of the Grand Banks of Newfoundland. But at the same time the Patrol cutters also found that had these slopes been better charted, they could have placed much more dependence on the positions indicated by their own soundings.

IV. CURRENTS AS AFFECTING HARBOR CONSTRUCTION, AND THE PROTECTION OF SHORE PROPERTY

We can only reiterate what was pointed out at the Conference on Oceanography at the U. S. Navy Department in 1924, by General Edgar Jadwin, that the direction of the current must be taken into account in planning harbor entrances on sandy coasts in order that the entrance jetties may be designed and constructed either to catch and hold the drifting sand, or to divert the latter past the entrance so as to prevent the filling of the channel with sand. The currents of importance in this case are those close along the tide line; and at the times when these are strong enough to drift the sand along the shore, they may either be parallel to or opposite to the general dominant drift off-shore, depending on the direction from which the storm waves travel, and the angle at which these strike the coastline. At the tip of Cape Cod, for example, the only storms that drive heavy enough seas against the beach to move much sand are from the eastern quadrant. Consequently, the beach-drifting is toward the west and southwest, whereas the dominant movement of the water only a short distance off-shore is in the opposite direction.

In any given case, therefore, a more detailed knowledge of beach drifting is requisite than has yet been gained for any considerable

sector of the North American coastline. An attempt recently made to reopen New Inlet, Dare County, N. C. affords an excellent example of what is apt to happen when harbor work is undertaken in ignorance of the beach currents. This Inlet, which had recently closed, was dredged open by the State of North Carolina at a large expense. But because of ignorance of the movements of the water along the beach, the channel was not protected against the resultant drift of sand. The result was that before three months had passed the cut had entirely closed again, all the money that had been spent on the work was wasted, and the benefits that reopening of this Inlet would have brought to the local fishery were lost. A small sum spent on studying the beach drift there, during storms, would have safe-guarded work worth many thousands to the State.

All this applies equally to construction undertaken to protect shore property, much of which has defeated its own purpose, by setting in motion unexpected currents that have cut into the very stretches of beach they were planned to protect.

V. SOUNDINGS IN CONNECTION WITH THE LAYING OF SUBMARINE CABLES

According to a statement by Col. C. A. Seons to the Oceanographic Conference, 1924, it is usual to allow 10% of length in excess in cable laying for what is termed "slack", and it is not likely that any cable had been laid over a long distance with less than 8% of slack, until methods of sounding by echo were developed. Taking advantage of this improvement through surveys made by the U. S. Navy, the U. S. Army was able to relay its Alaskan cable with considerably less slack than ever had been done before, at a corresponding saving in cost, thanks to the more detailed knowledge of the topography of the bottom so gained.

Many other cable routes in different parts of the world have been projected and cables will be laid as the commercial demand increases. If surveys of the routes can be made by the echo method (allowing far more detail to be learned in far less time than could ever be possible by the old methods), not only will the expense be considerably less, but the cable routes can be planned to better advantage in avoiding the ridges and depressions of the bottom. It is stated that an adequate survey of the Japan Deep and of neighboring regions would be especially valuable from this standpoint, because lying in the route which will probably be chosen when additional cables are laid across the North Pacific. Projects to connect up the American with the British Trans-Pacific cables will entail surveys between the Hawaiian and Fanning Islands. According to Col. Seone's statement a survey is also needed direct from the Panama Canal to Honolulu; also additional information all along the Pacific coasts of South Central America, and South America, including those of outlying islands, (the Galapegoes for instance) that might sometime be chosen for relay stations. As soon as commercial development in the southern hemisphere demands the extension of the present cable systems across the South Atlantic, South Pacific and Indian Oceans, information far more detailed and accurate than is now available will be certainly required as to the depths and shapes of the bottom. The recent expedition of the "Meteor" has already given a satisfactory preliminary picture of the bottom of the South Atlantic, but we believe we are correct in stating that until the "Carnegie" undertook her present cruise, only one line of sonic soundings had been run

across the South Pacific. To this the Carnegie has already added several lines in that ocean, with others in prospect. And as this is the only method yet discovered by which detailed surveys of large areas of deep ocean can be made economically, important additions to present knowledge of submarine topography are to be expected from her projected passages across the North Pacific and Indian Oceans.

VI. OCEANOGRAPHY, AND SEASONAL WEATHER FORECASTS

The question whether, or not, a rational basis for forecasting certain features of the weather, for any part of the world, can be found in the variations that take place in the temperature of the sea, has been much discussed of late, both by meteorologists and by oceanographers.

In introducing this matter we must point out that its economic status falls in a category quite different from that of the phases of Oceanography already discussed in this chapter. The economic bearing of the exploration of tidal currents, for example, of the charting of coastlines and harbor-approaches, or of the sounding out of shoals is not only direct but immediate; that of many specific problems in fisheries biology is equally direct, if less immediate; and the practical importance of the more general phases of oceanic biology is unquestioned, if more remote. But there is, as yet, no general agreement whether, or to what degree, forecasts of the weather, based on the temperature or on any other feature of the water, can ever be made reliable enough to prove of general service to man, unless it be in specially favorable regions.

The first economic problem, then, to be solved in the general investigation of the interaction between sea and air is whether this does indeed offer reasonable prospect of yielding direct practical benefits, with a favorable answer pointing the need of analyzing the possible methods by which such benefits might be attained.

Furthermore, a clear distinction must be drawn between the type of weather prediction that could be furthered by studies of the atmosphere itself over the oceans (this is not a part of Oceanography), and the type for which some meteorologists believe a rational basis can be found in the variations of the thermal state of the water. The first type corresponds mostly to the sort of daily weather charting and forecasting now carried out on shore. If enough stations can be arranged for, and properly distributed over the oceans, it would be possible to forecast the tracks of storms, directions of winds, and state of the weather a day or two in advance over the sea just as is now done on land. Meteorologists - the shipping interests too, have long realized the desirability of such forecasts; the reason that their development has lagged in the past has been the difficulty and prohibitive expense of organizing a sufficient number of recording stations, the necessity for taking all observations from ships which makes it impractical to establish fixed stations, and the weakening of the chain that would result from a failure to obtaining regular reports from the less frequented seas. An attempt to meet these difficulties is now being made by the several weather services, by the designation of certain ships as reporting stations according to a uniform plan. The data so collected may be expected to serve as the nucleus for statistical studies, embracing also the vast amount of data that is concurrently collected by the great maritime nations.

There is no reason to suppose that any study of the surface temperature of the sea, of the evaporation, or of the variations in the ocean currents, no matter how detailed, could ever assist the general daily forecast, whether for sea or for land, because whatever changes take place within the sea (either with the alternations of the seasons or following extra-terrestrial causes) are events inordinately slow as contrasted with the sudden fluctuations in the atmosphere. The goal that some students believe attainable here is quite a different one, namely, the prediction of the seasonal weather character over the adjacent lands to leeward.

Ordinary weather forecasting, such as is now carried on by most of the civilized governments, has become so much a matter of course, is usually so well verified and is so universally used as a guide, that there is a constant demand for longer range prediction of just the sort that the proponents of forecasts based on sea temperatures hope to see realized; namely, to tell us weeks or months in advance whether high or low temperatures, much or little rainfall will prevail. Even in regions where the weather fluctuates widely from day to day it would, in many cases, be of great economic value to know in advance the direction of abnormality to be anticipated in these respects, even if its amount could not be foreseen. Thus a departure of a degree or two, plus or minus, from the normal temperature in winter may govern whether most of the precipitation of a northern region comes as rain, or as snow, correspondingly affecting the ease of transportation, etc. In short, advance information of this sort would be so helpful a guide to many industries (we need only instance the clothing trades, power and transportation companies, and certain branches of agriculture) that attempts in that direction are constantly being made. And proof that industry as a whole would actually welcome assistance of this sort is found in the fact that many concerns are willing to pay high for such forecasts, even while realizing that their dependability is doubtful, to say the least.

Forecasts of this sort are given out from one source or another in all parts of the world, but most of them soon prove worthless. In fact few of them have had any physical basis, while the sponsors of those few would be the first to declare that the data for their calculations have been far from adequate. Even such of the long range forecasts as are based on tangible factors have, as a rule, been purely empiric: deduced, for example from Astronomical cycles, (planetary or solar), from correlations, or on the assumption that a periodicity recorded in the past will recur in the future. In most cases the publication of long-range forecasts has been abandoned before long, discredited by too frequent a failure, on the part of the weather, to substantiate the predictions. (It is necessary to except India from this statement, government forecasts of the summer monsoon rainfall, based on oscillations in atmospheric pressure at stations bordering the Indian ocean, having been reasonably successful in the long run, and well verified in occasional years, though poorly in other years.)

In short, no one has yet worked out a dependable sequence from antecedent events, whether in sky, in sea, or on land, from which the weather to come can yet be forecasted far in advance for any considerable part of the earth's surface, reliably enough to serve as a trustworthy guide to man's activities, year after year.

It has often been suggested, however, that at least a partial basis for such a sequence could be found in the sporadic variations that are known to take place in the surface temperature in various parts of the sea, combined with any corresponding expansions or contractions of the ocean currents, and with the rate of evaporation from the surface. This suggestion has been removed from the realm of purely theoretical potentiality to the stage of actual test by the comparisons between the physical state of the sea water and the local weather that are now being carried on, especially in the North Atlantic, in Canada, in California, and in Java. For example, marine temperatures are now being used in an attempt to determine whether the weather in the South Atlantic states or in Europe shows dependence on conditions in the Gulf Stream. And predictions of the weather of southern California developed at the Scripps Institution from the temperature of the adjacent sea during the preceding months (as an index of the strength and permanence of the north Pacific high) have been verified to an encouraging degree for the past twelve years. Recent investigations also show a sequence in temperatures of pressure and temperatures across the Pacific Ocean, extending over some months, which suggest the effects of a transportation of heat by ocean currents.

It is obvious that studies of this sort, if looking toward weather prediction, presuppose the occurrence of longer or shorter term fluctuations of temperature in the sea, of a sort that cannot be described as regularly "seasonal". And as pointed out on page , this supposition is justified, variations of this sort having been observed so frequently that they must be accepted as characteristic of every part of the sea where the temperature has been studied in detail. But before the claim that these events can be used as a basis for weather prediction can be upheld, it is necessary to establish, not only that a regular correlation exists between the two classes of phenomena for the parts of the earth in question, but that the changes in the sea regularly antedate the changes in the atmosphere, and not the reverse; also whether the former are so great that their effects are not entirely masked by the complex atmospheric phenomena that immediately control the weather.

This quantitative aspect of the problem is especially pressing, because meteorologists and oceanographers have to do here mostly with minor fluctuations in the thermal state of the sea, seldom with major alterations of a sort that would strikingly be reflected in the weather of some part of the world, such as the heavy rains over parts of the Peruvian desert early in 1925, or the droughty and other consequences of unusual outbursts of polar ice. While these minor fluctuations are known to occur commonly, little is known about them except in the marginal seas in high latitudes (where they may be expected to reach their widest range). And while a progressive movement of such temperature abnormalities as develop may be expected to take place along the tracks of the major ocean currents, precise information on this point is much needed.

In the northern hemisphere, for example, easterly movements of this sort have, for the most part, been traced in high latitudes north of the 40th parallel. But this may partly be because the temperature abnormalities so far actually recorded (not surmised) have been much greater in high latitudes than in low, allowing their progression to be followed more certainly. To illustrate the

difficulty of tracing, across the oceans, the small thermal variations that have been recorded in the tropics, from the usual records supplied by passing ships, we may instance the Caribbean Sea where data tabulated by the United States Weather Bureau for the nine years 1920-1929 showed a maximum monthly departure of 1.2° F from the mean; with only 39 months of the 108 showing deviations greater than 0.5° F.

The crux of the matter is, however, to establish whether or in what parts of the ocean, temperature-abnormalities or other changes in the water do actually antedate alterations in the weather of the over-lying air. Nor can any general rule be assumed to apply in this respect whether regionally or seasonally, the whole question being an extremely complex one. In the Gulf of Maine,to note a simple example, it is sufficiently demonstrated that the temperature and direction of the wind largely control the temperature of the water in winter. However, the subsequent effects on New England weather of these weather-produced water temperatures are unknown.

Off Southern California again, the wind affects the temperature of the surface both by producing upswelling from below, and by sweeping cold water down from the North. How these Temperatures react on the Temperature of the air, and so on the weather, is now the subject of active investigation at the Scripp's Institution. In most cases, in short, the sequence is not clear, even for regions where sea and air temperatures have been under observation for many years. In Scandinavia, for example, it has often been stated that various atmospheric and terrestrial phenomena follow the cycle of sea temperature. But recent students have found the sequence to be the reverse, for while a close correlation exists between air and water temperatures along the coast of Norway, it now seems that the variations in air temperature precede those in the water. Nevertheless, this does not necessarily indicate that the atmospheric changes are the primary ones, for the more mobile air may bring departures in Temperature to a given coast more rapidly than the possibly activating warmer or colder water can come.

This uncertainty as to the true sequence applies not only to the states regularly prevailing over one part of the sea or another, but even to sporadic events that have often been invoked as evidence of the climatic effects of marine abnormalities; to the torrential rains, for instance, that accompanied the abnormal development of the warm "El Niño" current along the coasts of Ecuador and of northern Peru early in 1925. Although most, if not all, students who have published accounts of this event, have looked to the high temperature of the seas as the cause of the exceptional rainfall that attended, it has been pointed to us that no definite proof of this has yet been brought out, but that while the alteration of ocean currents in the regions were probably a contributing factor, it is also likely that both events were coincident results of a marked reduction in the strength of the trade winds.

Uncertainty of another sort as to which is cause, which effect, is illustrated in the North Atlantic where recent and very searching investigations point to the direction of the wind as the cause of variations in the winter temperature of the surface of the sea, but where the winds in turn reflect the locations and intensities of the permanent or semipermanent centers of high and low atmospheric

pressures, which may themselves be more or less affected by such changes in the temperature. In fact, alterations in the best known of these centers of atmospheric permanent high or low pressure, the "Azores high" and the "Icelandic low" have been explained on this basis by some students. But here no general agreement has been reached, this being one of the cases (common in geophysics) where postulation has been much easier than demonstration.

The Northeast Pacific semi-permanent high is also known to shift north in summer, south in winter: and storms moving from the Aleution region toward California sometimes linger over the northeast Pacific for five to ten days, during which time it is only reasonable to suppose that their intensity is affected by evaporation from the water, and by the accompanying surface temperature. But very little is known as to the less regular shifts in position of this or of other oceanic highs or lows, or to what extent these shifts are caused by changes in sea temperatures if at all.

Solution of the general relationship in this respect between sea and air is an essential preliminary to any attempt to establish whether or not oceanic variations are actually translated into weather abnormalities, except, perhaps, for localities where the climate is strictly oceanic (as on some islands), or where the wind constantly blows inward from the sea over the land.

To add to the difficulty that attends synthesis in this general field, alterations in the atmospheric centers may have climatic effects quite the opposite of what the uninitiated might expect. Thus it has been pointed out that in the colder months unusually warm water off the southeastern United States may be expected to favor oceanic low pressure and cold weather in the eastern states, not warm. On the other side of the Atlantic, however, any intensification of the Icelandic low may be expected to bring warm weather along the land by strengthening the southerly component of the winds. Nor is the temperature the only element of climate affected by such alterations in the winds as may follow shifts in the highs and lows, for effects on the rainfall may equally be expected. Thus variations in the mean air temperature and rainfall for India may hark back, in part, to variations in the amount of ice melting from year to year in the Antarctic Sea; variations in the rain that falls on the south-central part of the United States may in part reflect variations in the evaporation and air movement from the Caribbean Sea and Gulf of Mexico; while evidence so far obtained suggests that the dampness and temperature of winds blowing in from the sea (consequently the temperature of the ocean surface for a considerable distance up wind) has a part in governing the rainfall of southern California.

Sir Napier Shaw, in his book "Forecasting Weather" (1923, P. 160) has recently remarked that actual analysis of North Atlantic weather "has been destructive of any hope of simple rules of weather sequence or for the movement of high and low pressure areas. The atmosphere over the North Atlantic is shown to be throughout the year in a state of turmoil which defies simplicity of description, and it is clear that something more than a process of classification is required before the sequences will become amenable to formulated law." This statement by one of the most eminent of living meteorologists sufficiently emphasizes the difficulty with which any institution - far more any individual - is faced who undertakes serious investigation of the role that sea temperatures may play in the weather complex.

Although surface-temperatures almost past counting have been collected in the past, it has been appreciated for many years that one of the difficulties of such investigation lies in the need for gathering reliable observations at shorter intervals, for various parts of the ocean, for only by such data would it be possible to follow, in detail, just what changes do occur in the sea.

It is pertinent here to consider how far the machinery that would be necessary for analytical investigation in this field now exists. So far as physical equipment goes, the answer would be encouraging for the North Atlantic where steamers are regularly on so many routes that a close net of continuous Oceanographic data could be obtained easily, if thermographs, barographs, etc. could be installed on a sufficient number of ships and if arrangements could be made for the ships' officers to give these instruments the needed attention; also to care for the records. In fact, continuous sea water thermographs have already been installed on steamers running in various parts of the world under the observations of several different institutions with highly instructive results. The hydrographic services also receive a continuous stream of observations from a variety of sources, and the weather bureaux are now developing a scheme of coordinated investigation as noted on Page . In the other oceans data are much needed from regions that lie outside the regular steamship tracks, hence, cannot be obtained without special arrangement.

The most serious obstacle to the advance of knowledge as to the general relationship between sea temperatures on one hand, and atmospheric temperatures and pressures on the other has not been any intrinsic difficulty in obtaining the marine observations, but the inability of any existing agency to undertake analysis of the enormous mass of data that has already been amassed, and that will continue to accumulate at an appalling rate if continuous observations are taken on many ships running along as many different routes. For such investigation to be of any practical value whatever, this analysis is essential. And it is necessary to face not only the volume of work entailed, but also its extreme complexity.

The magnitude of such an undertaking, if it were to be applied to any one of the ocean basins as a whole with the fringing lands, is quite beyond the capabilities of any private institution now existing or likely to be established. At present it is equally beyond the reach of any of the governmental weather services. The United States Weather Bureau is now appealing to Congress for funds for the task of compiling and analyzing its ocean temperature records. But as meteorologists, as a body, cannot promise the legislatures that such analysis (even if continued for ten or twenty years) will produce commensurate economical results, it is not likely that governmental funds can be secured for large-scale investigations of this sort. Furthermore, there could be no attempt at official long-range weather forecasting based on sea temperatures (except perhaps for some locality especially favorable) until a rational basis for prediction be established by the proof that a correlation exists; until a sound method for translating such correlations into terms of weather be found; and until arrangements be made for the regular collection of the necessary data. Even assuming these requirements to be met, official forecasts could hardly be given out until the methods had been tried out for a long term of years, because such forecasts to

engender confidence, must be verified by the event in a substantial majority of cases.

These difficulties unite to make this a field in which fertile results may be soonest expected from the "case system" of investigation, while the extreme complexity of the basic problem makes it essential that the simplest cases be the first attacked, thus approaching as nearly as possible to the laboratory method. Furthermore, the impossibility (if we are to be intellectually honest) of promising direct economical benefits therefrom, makes research institutions particularly appropriate centers for certain aspects of such work, in cooperation with the governmental weather bureaux. The very encouraging progress that has been made in the experiment now being carried out by the Scripps' Institution corroborates this view.

The results of twelve years' work there, to date, appear to show that in that region a useful correlation does exist between oceanic conditions in the offing, and the weather ashore, for (over this brief period of years) when the sea surface near southern California has been cooler than normal from August to October, but the mid-Pacific warmer, the rainfall of southern California has been greater than usual during the following winter; and vice-versa. Attempts to predict the amount of rainfall have been about 75% verified. Thus it appears at present that, for southern California at least, temperature departures in the various parts of the Pacific are one of the classes of indicators that can be combined into cumulative forecasts of seasonal rainfall and perhaps of temperatures.

Much work yet remains to be done to uncover the effect of other factors that are undoubtedly concerned, and to place the system on an assured basis. But the suggestive results of this attempt, to date, not only justify the continuation of this line of work in southern California, for which the Scripps' Institution has plans, but point the need of investigations of the same sort in other representative regions chosen on the basis just stated (Page). The relationship that rainfall in Ecuador and northern Peru bears to ocean temperatures off that coast offers a very promising case for study. Other American vantage points that seem favorable, because interpretation promises less difficulty there than in most parts of the world, appear to be Northeastern Brazil, British Columbia, Southern Alaska, and the Gulf coast and south Atlantic seaboard of the United States.

It is obvious that efforts to work up the great mass of ocean Temperatures already accumulated at several places would be an essential item in any broad-scale research in this general field. And all institutions so doing, whether governmental or private should be encouraged to follow a common plan.

All such data should also be published promptly, in order to be generally available, again according to some general plan.

CHAPTER III

PRESENT SITUATION IN OCEANOGRAPHY IN AMERICA

I. INTRODUCTION

The last half of the past century may be named the heyday of the deep-sea exploring expedition, in which phase of oceanography the United States played a leading role with the cruises of the "Blake" and "Albatross". It was then that the broad relief of the submarine floor was mapped, the general nature of its sediments determined, and the general character of the deep-sea fauna explored. In all this American ships and oceanographers took a leading part. But there followed in America a period of stagnation, when the day of pioneering passed, and when continued exploration in these preliminary lines proved more corroborative than novel. As in many a new science, so in Oceanography in America, a period of quiescence succeeded a peak of activity, as soon as persistence in the old methods and habits of thought no longer yielded new and wonderful discoveries. In Europe, however, synchronous with this American decline, there had arisen new schools centering their attention not so much on regional surveys of the oceans as on the biologic economy of its inhabitants as governed by their physical and chemical environment. This change of viewpoint, from the descriptive to a conscious attempt to interpret oceanic phenomena in terms of its organic inhabitants, marks the beginning of the modern science of Oceanic Biology, and it is interesting that the real incentive came, in this case, from the demands of declining fisheries for betterment, i.e. from economic necessity.

At the same time, the foundation was being laid in Scandinavia for our present-day understanding of ocean dynamics which was destined to raise the study of the circulation of the sea to a new plane.

At first the opening of these new gateways to an understanding of life in the sea, and of the physics of the latter, seemed to have passed almost unnoticed in America, at least so far as translation of recognition of the new viewpoint into active participation is concerned. It is, in fact, hardly an exaggeration to describe Oceanography in America during the first years of the present century as "dead", with the old ways no longer yielding advances commensurate with the effort. This period of stagnation, however, was short, and the awakening that followed must fairly be credited to the example of the International Committee for the Exploration of the Sea, in North European waters.

As is so usually the case, the first evidences of this reawakening were not only several, but these several nearly simultaneous. Modern Oceanography in America may, we think, be dated from the following events: the establishment, in 1904, of The Tortugas Laboratory of the Department of Marine Biology of the Carnegie Institution of Washington; the adoption of a regular program of oceanographic study at the Scripps' Institution for biologic research at La Jolla, California in 1908; the institution in 1908 of studies of the bottom sediments, shore line geology and physics of the waters around Florida and the Bahamas, of which the Committee on Sedimentation of the National Research Council was an outgrowth; the inception of the cooperative study of the natural economy of the Gulf of Maine by the U. S. Bureau of Fisheries, and the Museum of Comparative

Zoology in 1912; the development since 1910 of oceanic biology as a major project at the St. Andrews Laboratory of the Biological Board of Canada leading directly to the Canadian Fisheries expedition in 1915; and the inclusion by the International Ice Patrol of studies of oceanic circulation as part of its regular duties since 1914. The rapid development of oceanic biology, dynamic oceanography, and in submarine geology (this last movement one of the most important for the promotion of Oceanography in the United States) which has followed in American waters has been largely as an outgrowth from these scattered beginnings.

II. ANALYSIS BY PROJECTS

Discussion of the several distinct lines of activity today will give a better picture of the present status of Oceanography in America than would a regional or institutional examination. From this standpoint marine investigations may be classed rather arbitrarily as: (a) active exploration at sea; (b) investigations in seaside laboratories or at other shore centers; (c) coordinating institutions; (d) opportunity for instruction offered by universities, and (e) last but not least, available libraries.

A. ACTIVE EXPLORATION AT SEA

Oceanographic exploration, whether its aims be biologic or physical, has by natural process of evolution developed along two lines. It may be carried on by great deep-sea exploring expeditions, oceanwide in scope, but comparatively short in duration; and sent out as more or less isolated events in the general progress of science. As the need of more intensive knowledge developed, continuous or at least periodic study of areas within a few hundred miles of the home station have proved more and more fertile, such as can be carried out on a small vessel at small expense. It is this procedure that has contributed most to the modern advance of Oceanic Biology. The deep-sea expedition was the method of early days of the science. As just remarked, the day is passing for expeditions of this sort, except in the realms of physical and chemical Oceanography. Here, when it is a case of examining great areas of the sea, an occasional extended expedition is essential, vide, the contributions recently made to our knowledge of the circulation of the South Atlantic by the "Meteor".

The last few years have seen a reawakening of interest in such cruises in America, and we find evidence that American science is alive to their value in last summer's dynamic exploration of Davis Strait by the Coast Guard Cutter MARION (Page 96); in the Museum of Comparative Zoology cruises in the Atlantic, (Page 97); and more notably, in the present cruise of the CARNEGIE sent out by the Carnegie Institution of Washington. This last is the most ambitious undertaking of the sort sponsored in America for many years, and the expansion of the activities of the Department for Terrestrial Magnetism of the Carnegie Institution into the realms of Oceanography deserves emphasis, as illustrating the present-day virility of ocean science in the United States. This expedition is planned for three years, to cover a net-work of 110,000 miles across all the great oceans. In addition to the regular magnetic work, and to observations of atmospheric electricity, an extensive program of physical oceanography is planned, including soundings in little-known parts of the ocean basins, dynamics of the water along the tracks covered,

collection of bottom sediments, and special study of thermal interchange between the surface of the sea and the overlying air. The biological program, as described by the biologist of the expedition, is to be directed chiefly toward the study of the chemical and physical environment of the plankton, and of some of the physiological conditions of existence of individual groups of animals, for which field observations can be linked with laboratory experiments. Other collections will also be made as opportunity offers.

Whether this expedition is to be the precursor of continued activities in the oceanographic field by the Carnegie Institution of Washington, it is too early to prophesy.

The incentive for the Davis Strait expedition of the Coast Guard, 1928, just mentioned, was fundamentally economic: to gain better understanding of the ocean currents that are responsible for the ice menace to vessels passing the Grand Banks of Newfoundland, and so to better the actual patrol. But the fact that to attain this end it was thought necessary to apply the most rigorous technique of modern Oceanography to a dynamic study of the area in question proves the growing appreciation in America of the practical value of marine researches. A general dynamic exploration of the oceanic triangle Hatteras-Bermuda-Nova Scotia during the summer of 1927, and a traverse of the North atlantic during the summer of 1928 under the auspices of the Museum of Comparative Zoology, extend this method of attack to other areas, and link up with similar cruises from Europe.

The "Arcturus" Expedition of the New York Zoological Society to the Sargasso Sea and the Galapagoes region in 1925, by contrast, revived the more discursive methods of the past era, while it is too early to comment on the explorations around Bermuda carried on by the Society during summer of 1929.

Fertile, however, though such expeditions may be, it is by the method of periodic surveys of definite areas, or by continuous attack on definitely limited problems, that Oceanography in American waters is most rapidly advancing at present, and may be expected most rapidly to develop in the future. This phase is perhaps best presented on a geographic basis.

Following the North-eastern American shelf, from the Artic southward, we find first, the Canadian Hydrographic Service obtaining physical data, and measurements of magnetic variation in Hudson Bay and straits; likewise off the north shore of the Gulf of St. Lawrence. In Newfoundland, the program of the present government includes support of scientific work in connection with the Fisheries. But work has not yet been undertaken there on a serious scale.

The International Ice Patrol operated by the U. S. Coast Guard yearly carries out a detailed dynamic survey of the circulation of the water-masses in the vicinity of the Grand Banks, with the severely practical aim of guarding shipping from the ice menace. Here the most advanced methods of dynamic oceanography are put to practical use in plotting the periodic variations in the direction and velocity of the flow that carries floating bergs, and it is here, at the hands of the U. S. Coast Guard, that the soundness of this method of attack has received its most impressive confirmation. The recent extension of this survey northward to the narrows of Davis Strait, as mentioned

above, (page 95), presages future study of the physics of this Artic expansion of the Western Atlantic.

The sphere of activity of The Biological Board of Canada overlaps the cruising areas of the Ice Patrol. The marine researches of this Board have a different ultimate aim, being centered about oceanic biology, especially in relation to fisheries problems. But in this connection, the Board likewise attacks a broad range of physical and chemical problems, because of their bearing on the natural economy of the sea. Surveying its field of activity from north to south, we see it sponsoring physical and biological observations (temperatures, salinities and towings) in the Labrador current-Baffinsland-Hudson Bay region at times when special expeditions offer opportunity. In this way, a considerable body of material is being accumulated which will eventually be of great value. Further south the cruises of the Board, since 1915, are making the Gulf of St. Lawrence, with its entrant straits, fairly well known both physically and biologically; and very significant results of economic value have already been gained as to the dependence here of the local cod, in their migrations, on the temperature of the water. The Board has in progress a continuing study of the circulation of the coastal waters from Hudson Strait to the Bay of Fundy, by drift bottles, put out either by its own boat or by governmental and commercial vessels. In the Bay of Fundy region, by short cruises and periodic observations at standard stations, it carries out an intensive study of the physical effects of the churning of the water by the violent tidal currents, and of the biological reflection of the latter.

The Board itself operates small vessels only. When expeditions too extensive for their capabilities are to be undertaken (as in the case of the Canadian Fisheries Expedition of 1915) arrangements are made with related government Services for the use of the larger Patrol ships. The Board has been very successful in carrying out tagging experiments from commercial fishing vessels.

And by cooperation with the Canadian Hydrographic Service and with commercial shipping companies, it has begun gathering continuous readings of the surface temperature by recording thermograph, along various trade routes in the Western Atlantic, while the meteorological branch of the Canadian Department of Marine carries on similar work in the North Pacific.

In the Gulf of Maine the U. S. Bureau of Fisheries, jointly, with the Museum of Comparative Zoology of Harvard University, has, for the past sixteen years, prosecuted a general oceanographic survey, covering the interrelationship that the physical state and circulatory movements of the water bear to the Plankton and to the Biology of the local fish fauna. The procedure here has been by periodic cruises, successively by the "Grampus", the "Halcyon", the "Albatross", and the "Albatross II", taking observations, physical and biologic, at standard stations, at different seasons; a program modelled on that followed by the International Council for the exploration of the sea in the Northeastern Atlantic. This exploration is now being extended to the coast sector Cape Cod to Chesapeake Bay, by the periodic cruises of the Fisheries steamer "Albatross II", along representative profiles, combined with tagging and other fisheries experiments.

The chief limitation to the oceanographic undertakings of the

Bureau is the necessity of confining most of its cruises to the waters over the continental shelf, in comparatively shallow water and near land, where practically all the important fisheries are located; for as explained elsewhere (page 121), it is to these fisheries that the Bureau must devote most of its attention. In the past, when funds have been available from other sources for fuel (which is the chief item of expense) long voyages have been made on the high seas by the vessels of the Bureau. And there is every reason to suppose that the Bureau will continue this policy whenever cooperation with outside agencies makes funds available, because it is now fully appreciated that the key to many of the riddles of marine economy in our shoal waters is to be sought in the fluctuations in the flow and in the temperature of the waters of the oceanic basins.

No program of regular oceanographic cruises is now in progress off the Atlantic coast of the United States south of Chesapeake Bay, or anywhere in the Gulf of Mexico. But a general oceanographic exploration of the triangle Hatteras-Bermuda-Florida was made by the Coast and Geodetic Survey jointly with the Bureau of Fisheries on the BACHE in 1914; while the ALBATROSS in 1920 again ran profiles across the Straits of Florida. These, with the intensive study of various problems in the chemistry of sea water, sponsored from the Tortugas Laboratory of the Carnegie Institution (page 103), may, we hope, be forerunners to future activity in that very interesting oceanic province.

So far as we can learn, no regular continuing program of oceanic exploration other than the collection of surface temperatures and salinities, is now being sponsored anywhere from the east or west coasts of South America, and it is too early to foresee how much work of the sort will be done from the Fisheries vessel recently acquired by the Argentine Government. The "Discovery" Expedition, recently at work in the Atlantic, and continued in 1938-1939 by the "William Scoresby" from headquarters in the Falkland Islands is British, and in any case falls, rather, in the category of occasional exploration.

Neither are there any centers of oceanographic exploration along the west coasts of Central America, or Mexico. But serial measurements of temperature (with water samples) are taken by the survey ships of the United States Coast and Geodetic Survey on their cruises between the east and west coasts, as well as north and south along the latter.

Oceanography is well served in the coastal belt along southern California, and for a couple of hundred miles out to sea, by the periodic cruises of the Scripps' Institution of Oceanography of the University of California, which constitute the most extensive continuing program of the sort now in progress off the Pacific Coast of North America. The institution's vessel, of the type usually used for fishing in that region, is fully equipped for the collection of all sorts of routine data, biological as well as physical-chemical, down to considerable depths (about 1800 meters). And thanks to the narrowness of the continental shelf there, she is able to extend her cruises out into the ocean basin, as well as for considerable distances along the coast to north and south. The temperatures, salinity and chemical state of the water of the area thus recorded and collections of Plankton obtained, form the basis for many of the

studies carried on at the Institution's Laboratory, summarized on page .

In cooperation with the United States Lighthouse Service, with the United States Coast and Geodetic Survey, with the United States Navy, with commercial vessels running on various routes, and with private yacht owners, the Institution is able to expand the work done from its own vessel by the collection of extensive series of surface temperatures and water samples, both at shore stations and widespread over the north and south Pacific. How successful this auxilliary program has proved is made clear by the receipt of no less than 3.785 water samples (salinity determined at the La Jolla laboratories), and 13,237 readings of temperatures during the year 1927-1928 (report of the Committee on Submarine Configuration and Oceanic Circulation of the National Research Council for 1928.) The Institution's efforts represent, in fact, the most successful project of this sort yet undertaken by any American agency since the days of Maury.

Further north, the California coast is now seeing the birth of a new project, in the exploration of the oceanic biology of Monterey Bay and of its offing, by short cruises through the joint efforts of the California Fish and Game Commission and of the Hopkins Marine Station. It is yet too early to do more than point out that a working agreement has been arrived at, that special attention is being paid to the biological side, and that the observations are to be taken periodically from one of the Patrol boats of the Commission at standard stations.

The Friday Harbor Station of the University of Washington is the site of increasing oceanographic activity, especially in chemical problems, in ocean Physics, and in studies of the Plankton. Important physico-chemical observations and plankton studies are now regularly obtained in the neighborhood of the Pacific Biological Station of the Biological Board of Canada at Nanaimo, B. C., (jointly with the University of British Columbia) on a considerable scale, as more fully described below (page 102). And while no attempt has yet been made to extend these out into the oceanic basin off this sector of the Pacific coast, the International Fisheries Commission, operating under treaty between Canada and the United States, has undertaken a program of sub-surface sections off the Alaskan coast (supplemented by current measurements) to serve as the basis of dynamic calculations of the movements of sub-surface waters in connection with its studies of the life history of the halibut. This last is an isolated project with no assurance of its continuance. But the thoroughness of the work, not only in ocean physics but especially in its biological aspects, make it a most important contribution to our knowledge of the natural economy of the northwestern pacific.

The topographic explorations of the United States Coast and Geodetic Survey, along the two coasts of the United States, and in the Hawaiian and Philippine Archipelagoes, fall in a different category. Here the individual cruises are units in a continuing program, but various projects are successively attacked off one part of the coast or another as need arises. In the fields covered, (tidal studies and hydrographic surveys) the sea-work of the Survey sets the standard.

It is not necessary to mention here in detail the occasional

cruises carried out on private yachts, on which a certain amount of biological collecting is done, for oceanographic work is in this case only incidental. Furthermore, it is difficult to estimate whether the increasing frequency of such undertakings reflects any corresponding appreciation of the value of marine research, or whether they simply evidence the interest that some persuasive Museum Director has been able to arouse in the individual yacht owner.

B. SEA-SIDE LABORATORIES, AS HEADQUARTERS FOR OCEANOGRAPHIC INVESTIGATIONS

In addition to the ship work just summarized, certain fields of investigation, especially in oceanic biology, and in chemistry, are now being prosecuted at sea-side laboratories on both coasts, and at other stations, the more important of which must be mentioned.

1. Atlantic Coast

On the Atlantic Coast these phases of Oceanography are being actively attacked at the Atlantic Biological Station of the Biological Board of Canada at St. Andrews, and work in this direction is projected for the new marine laboratory of the Board at Halifax, N. S. The station-program here includes investigations into many fields where fisheries questions are most obviously dependent on the underlying problems of organic production in the sea. It is not necessary to list these here; they have to do chiefly with the general physiology of marine organisms, and (on the oceanographic side) include studies on the penetration of light; on the circulation of the water as making the dissolved food stuffs available for plant production; on the sources of these food stuffs and, (at St. Andrews) a very detailed study of tidal currents as agents in maintaining the great organic fertility of that region.

The Mt. Desert Island Biological Laboratory has, during the past year, undertaken a joint exploration of the local waters, in cooperation with the Buffalo Society of Natural History, to include both the Biological and the Physics-Chemical aspects. The Woods Hole and Beaufort Laboratories of the United States Bureau of Fisheries and the Marine Biological Laboratory at Woods Hole are also centers for such activities.

At the Woods Hole Laboratory of the Bureau of Fisheries, where for administrative reasons it has only recently been possible to outline any definite station program, the problems under study are fundamentally similar, with especial emphasis on the life histories and general ecology of individual species of commercial importance. This laboratory has been made the head-quarters for various of the projects attacked on the periodic cruises. Thus the investigations on the Physiology of the oyster have recently centered here, likewise those on the life history of the mackerel, on the distribution and dispersal of fish eggs and larvae by ocean currents, on the migrations of the cod fish, and on fish metabolism, to mention only a few.[1]

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[1]The Woods Hole Laboratory of the Bureau of Fisheries also admits outside investigators many of whose problems are not oceanographic.

Little oceanographic work is being sponsored at present from the Tortugas Laboratory of the Carnegie Institution, which is operating on only a modest scale. But this Laboratory offers unique advantages for tropical work under the flag of the United States, and during the past fifteen years it has been an important head-quarters for reseach on marine sediments, reef-forming organisms, and marine geologic processes, including the chemistry of sea-water. Besides routine record of temperature, salinity, hydrogen in concentration, etc.; the projects (too numerous to detail) have included repeated investigations of the precipitation of calcium carbonate in the Tropics; carbon dioxide tension; electric conductivity, alkalinity of ocean waters, solubility of calcites and calcareous sediments, and investigations of marine bacteria. This Laboratory has also sponsored coral reef studies in the Pacific, and in the region of Torres Straits, as well as in the Atlantic.

The newly established Laboratory of Professor Conseil, at Fort au France on the Island of Bartinique also includes oceanographic research in its program. But it is too early to estimate its accomplishment in this field.

2. Pacific Coast.

The Scripps' Institution of Oceanography of the University of California occupies a position at present unique in American oceanography, because it is the only establishment on the continent that is expressly organized and maintained for the investigation of the problems of this science, without economic bias. The Institution, at its headquarters at La Jolla, California maintains a marine laboratory excellently equipped for physical, chemical, and marine sediments as well as for a wide variety of biological investigations, and operates a research vessel as described on page .

Using the data gathered on the cruises of the station boat, and otherwise, as just described (page 98), the station centers its efforts on such subjects as the calculation of dynamic circulation in the region studied, the development of new mathematical methods of analysis, and to attempts to discover whether Californian weather may be forecast from the ocean temperatures. Chemical analyses of the water are here performed in routine as indices to its varying fertility as a food medium for the plankton. New methods of analysis are developed, and this general field is being constantly expanded. Studies of the variations in the amount of plankton in local waters, seasonal, regional, and bathymetric, compared with the amount of dissolved food stuffs in the water, are a regular part of the program, and this has recently been expanded to include studies of bacteria in the sea. The biological investigations also include the physiology of fishes and pelagic fish eggs and larvae. The study of marine bottom deposits is also a part of the regular program of the Institution.

The activities of the Institution find expression in a regular institution program carried out continuously by the members of the staff assisted by visiting investigators. In developing this program the physical and dynamic aspects of the sea, chemistry, biology, and geology have each received coordinate attention, so that the institution is now making the most concerted effort in America toward the theoretic synthesis of these several fields of sea science. By

tradition, and present activity, the Institution leads Oceanography on the Pacific coast.

It is only within the last year that the Hopkins Marine Station at Pacific Grove, California, has definitely expanded its program to include Oceanography. But arrangements have now been made to carry out Plankton and other biological studies with chemical analyses of the water in connection with the periodic cruises just mentioned (page 99). And at the new Jacques Loeb Laboratory of the Station, plans are maturing to devote special attention to problems in the physiology of marine animals and plants, likewise to marine bacteriology. This Station may, therefore, be expected to serve before long as one of the centers for the development of oceanic biology.

Important studies on the chemistry of sea water and on the Plankton are now in progress at the Friday Harbor Station of the University of Washington, where measurements of the penetration of light have also been made.

The Laboratory of the Biological Board of Canada at Nanaimo, B. C. is the headquarters on the Pacific coast of Canada, for participation by various universities in the marine investigations of the Board, just as St. Andrews Laboratory is in the Atlantic coast. The oceanographic work being most actively prosecuted at Nanaimo centers at present about the physical and chemical factors influencing the Plankton in the Straits of Georgia and adjacent waters. Observations are made through the year, with special reference to temperature, salinity, hydrogen-ion concentration, oxygen content, etc; correlated with the circulation of the water and with the distribution and character of the plankton. Records are also being taken less regularly in other nearby localities. And since 1926 these have been extended to the open Pacific off the Fraser River mouth. Physiological problems, oceanic in bearing, are also actively attacked from the Nanaimo Laboratory, as they affect the economic species of fishes and crustacea, and a great variety of more strictly biological problems are constantly under investigation.

The Biological Laboratory of the University of Hawaii must also be mentioned, as headquarters for extensive experiments on the Ecology of corals.

So far as we can learn, no other seaside Laboratory in America (North, Middle, or South), other than those mentioned above, is now regularly carrying on oceanographic investigations as a primary object, although several others are admirably situated for this, and have boats large enough for work in their local waters. On the east coast of the United States, the new establishment of the University of New Hampshire at the Isle of Shoals, is especially well situated for intensive studies in the northern sector of the coastal water; the Marine Biological Laboratory at Woods Hole for the sector next to the South. The Beaufort Laboratory of the Bureau of Fisheries is equally well situated for the South Atlantic Sector. Should present plans for the reorganization of the Bermuda Biological Station successfully mature, its location would give it a unique opportunity to serve as headquarters for intensive exploration of the chemistry, physics and circulation of the abyssal waters of the Atlantic, and of the physiology of deep-sea animals.

How far these Laboratories may expand their activities in this direction the future we can not predict, nor is it necessary to consider here the occasional problems, related incidentally to oceanography, that are studied from time to time at one or another of them by visiting scientists. We must, however, emphasize the influence that the Marine Biological Laboratory at Woods Hole has exerted, in preparing the way for systematic investigations in Oceanography such as are now proposed. If it has not constituted much in a direct way to Oceanography as now defined, this is because the subject is still poorly developed in America at the present time. This, and the other Marine Biological Laboratories are the most important organizations for the development of Marine Physiology, as here defined (page 50).

C. OTHER OCEANOGRAPHIC STATIONS

No picture of the present status of Oceanography in America would be complete without some account of such phases of the oceanographic activities of other institutions, not at the sea shore, as are not covered in the preceding account of current expeditions and of periodic cruises. To avoid any implication of relative importance, these are here arranged alphabetically.

The American Museum of Natural History, New York while not regularly engaged in Oceanography, has recently sponsored studies of the surface temperature, etc., along the west coast of South America, in relation to the periodic development of the warm "El Nino" current there. It has also participated of late in explorations in Artic waters.

Brown University enters the oceanographic field only by offering instruction (elsewhere).

The Buffalo Society of Natural History, recently organized, has already participated in an investigation of the submarine sediments, and plankton, of the Bahamian region, jointly with Princeton University (elsewhere), and is now engaged on a joint program, in the Gulf of Maine, with the Mt. Desert Island Biological Laboratory. Its program contemplates considerable expansion in this direction, especially in plankton studies in Northern Seas.

The Department of Terrestrial Magnetism of the Carnegie Institution of Washington is the home office for the expedition of the CARNEGIE (elsewhere), and for the publication of the reports therefrom, several of which have already appeared; it now includes a Laboratory and instrument-shop for the design of methods and instruments for work at sea.

The plans of the Carnegie Institution relative to Oceanography have not yet been defined specifically. In general it is the policy of this Institution not to attempt to cover completely any large field of scientific research, but to arrange for its work to fit readily into the larger schemes already under way, without conflicting with other agencies. The Institution touches Oceanography at three points: namely, by the development of the marine laboratory at Tortugas, by scientific researches regularly carried on diatoms, and by the present cruise of the "Carnegie." We are informed that it does not (at present) contemplate extending these researches beyond

the range just indicated; nor is it likely that the Institution will continue to operate the Carnegie as an oceanographic research ship after the summer of 1931. But the Carnegie Institution has offered to put the ship, for a term of years, at the disposal of the Scripps Institution if the latter can raise funds for her running expenses. And it may be taken for granted that the Carnegie Institution would gladly correlate its work with any general program of oceanographic study that might be developed in America. The oceanographic activities of the Tortugas Laboratory are mentioned on Page .

Clark University has recently arranged for the installation of recording thermographs on steamers running on commercial routes in the Atlantic. And while the immediate purpose here is climatologic, not oceanographic, the continuous record of surface temperature now being obtained ia an important addition to present knowledge of secular fluctuations in the parts of the ocean being covered.

The Museum of Comparative Zoology at Harvard University, from its foundation in 1859, has held Oceanography as one of the major fields of activity; by inheritance and tradition this is equally true today. Its present participation in active exploration is touched on above (page 97), and its cooperation in this respect with the U. S. Bureau of Fisheries and with the U. S. Coast Guard (through the Ice Patrol), has long been most happy. There remains to be mentioned the service of its oceanographic laboratories as headquarters for the study of the plankton collections and for the synthesis for the physical and chemical data collected on the periodic cruises in the northwestern Atlantic just mentioned (page 97). Here are being worked up recent explorations in the Pacific; the studies of the Bureau of Fisheries on the voluntary and involuntary migrations of the cod based on the tagging experiments, and other studies on the biology of fishes; the dynamic analysis of the waters of the Grand Banks area by the Ice Patrol; and the results of the Museum's own recent Atlantic expeditions. Studies of submarine sediments are also being carried on in the Museum, stimulated by improvements in the methods of collection that make it possible to obtain long cores in deep water.

The New York Zoological Society, through its Department of Tropical Research, is headquarters for the preparation and publication of the reports on the collections brought in by the "Arcturus" expedition, and for Bermudan explorations carried on during the summer of 1929.

The only present oceanographic project sponsored by Princeton University is its cooperation during the summer of 1928 with the Buffalo Society of Natural History in studies of submarine sedimentation in the region of the Bahamas.

Active participation by the Smithsonian Institution in Oceanography, is through the National Museum, several of whose staff are concerned in the biologic aspect of oceanographic problems, though the researches carried on in the Museum are chiefly taxonomic. At present the Museum does not, of its own initiative carry on Oceanographic exploration; nor does it maintain ships for the purpose.

The Washington office of the United States Coast and Geodetic Survey is the headquarters for the study of tidal currents near shore and for the charting of the topography of the bottom from the coast-

line out to the continental edge of the United States and of its insular dependencies; for inshore cartography; and for geodetic and isostastic studies. The standard of excellence is here so high that it would be unwise for any other institution to enter these fields except in cooperation with the Survey. And any expansion in this direction should be through assistance offered directly to the latter. For additional description of its oceanographic activities, see page .

The U. S. Hydrographic Office, with its local branches in many cities has long served as the shore center in the United States for the synthesis of data collected from many sources as to the currents of the high seas, and as to other oceanic phenomena, just as the Coast and Geodetic Survey serves for the coastal waters, as well as for the publication of ocean charts, geophysical (magnetic) charts, sailing pilots, pilot charts, etc.

The University of Minnesota has of late sponsored occasional researches, of oceanographic import, in the Pacific, in such subjects as submarine illumination, plankton, animal physiology and general ecology.

The University of Washington, through its College of Fisheries, offers opportunities for research in Oceanography as related to the Fisheries; and studies in this field are undertaken from time to time at its Laboratory at Friday Harbor in Puget Sound, in addition to other oceanographic activities (p.102).

The University of Wisconsin is at present the headquarters of the committee on sedimentation of the National Research Council of the United States.

Yale University at present carries on no field work in oceanography and offers no instruction; but by arrangements made recently with the Bingham Oceanographic collection, Yale may within the next few years be expected at least to cooperate in field studies of the biology of marine fishes, which may develop into a broader oceanographic program in the future.

D. COORDINATING INSTITUTIONS

The rapid advances in Oceanography that have taken place in northern Europe in the last quarter century have largely drawn their impetus from the fact that the maritime nations there combine to support two institutions with the definite purpose of coordinating the efforts of all participants in the fields of fisheries research; and underlying the latter, in Oceanography in general: the older of these, the "Conseil International pour l'Exploration de la Mer", with headquarters in Copenhagen, has largely dominated sea-science in northwestern Europe for the past quarter century. The younger, the "Council for the Scientific Exploration of the Mediterranean Sea", is now functioning as an effective liaison between the nations bordering that body of water.

No such institution existed in America until the foundation of the North American Committee for Fisheries Investigations in 1920. The membership of this body is intended to include representatives

from the governments of the several nations that participate in the great sea fisheries of the northwestern Atlantic, selected as a rule (but not necessarily) from the Fisheries Services or other governmental scientific establishments. At present Canada, Newfoundland, France and the United States are represented on the Committee. This body receives no appropriation from any source, consequently it has no executive powers but is purely advisory. On the other hand, its functions in that respect are unlimited, and it has proven effective in coordinating the scientific investigations of the several governments in those fields of oceanic biology where all have a common interest. Its actual accomplishments have been to unify efforts in such problems as the migration of the mackerel, cod and other fish; the dispersal by currents of fish eggs and larvae; the study by drift bottles of the dominant non-tidal circulatory movements of the water along the coast of north-eastern America; the secular variation in temperature, etc.; as well as of subjects more directly concerned with the Fisheries that need not be listed here. And the success it has enjoyed without powers of any sort is one of the strongest arguments for the establishment of the proposed Institution.

Cooperation in encouraged in a somewhat different way by several committees of the National Research Council of the United States and of Canada, likewise of the Pacific Science Association. Four of the committees of the first of these councils have direct oceanographic contact, namely, those on sedimentation, on shore line investigation of the Atlantic and Gulf coasts, on features and changes of the shoreline of the Pacific coast, and on submarine configuration and oceanic circulation, under which there is a subcommittee on the submarine topography and structural history of the Caribbean-Gulf region. These are consultive rather than executive bodies, though the committee on sedimentation has been able to give financial support to actual projects from royalties realized from the sales of the treatise on sedimentation and color chart for description of sediments published by the National Research Council. Other publications (dealing with land geology) are also in course of publication by it. And its work has led to the development of courses on sedimentation in several colleges and universities. The committee on shoreline investigation of Atlantic and Gulf coasts is carrying on studies of variation of sea level in cooperation with the United States Coast and Geodetic Survey. The most useful contribution to Oceanography that the other committees of this group are now making is through their annual summaries of the various projects that are actually in progress around the coasts of America and in other parts of the world.[1]

[1] See annual reports of division of Geology and Geography, National Research Council, Washington, D. C.

We wish especially to call attention to the annual report of the committee on submarine configuration and oceanic circulation, which makes it possible for independent workers to keep in touch with all the more important projects falling within its field.

The committee on Oceanography of the Canadian Research Council was appointed to cooperate with the several committees organized under the Pacific Science Congress at a meeting in Japan in 1926. It has been concerned chiefly with developing ways of making available the data that have been accumulating in various departments of

the Canadian Government.

The Pacific Science Association, at the Congress at Tokio in 1929, established two international committees (since merged into one) on the Oceanography of the Pacific, which has proved highly effective in promoting and unifying Oceanographic projects in that ocean.

It purposes, carried on through national committees and sub-committees are as follows:

1. To assemble for each county information as to the oceanographic programs and investigations, private and governmental, then in progress, and to make the information available to the countries interested.

2. To aid in the standardization of oceanographic methods, so that the results obtained by any one group will be useable by any other group.

3. To aid in coordinating the researches of different countries on the Pacific, so that the program of each will fit into the programs of all the others.

4. To stimulate researches in subjects to which adequate attention is not being paid, and to suggest programs of more extended scope.

The committee has no funds, but is actively functioning as an advisory council for Oceanographic research in the Pacific.

Its more important accomplishments have been the establishment of the publication "Records of Oceanographic Work in Japan" by the National Research Council of Japan: work on ocean dynamics off the Coast of Alaska in connection with the International Fisheries Commission; stimulus for the extensive program of research that has been formulated by the Russians, and the development of a general program for the exploration of the major oceanographic features of the Pacific.

E. LIBRARIES

Fortunately for the oceanographer, American centers of learning are well provided with the literature that he especially requires. In part, this is of course due to the fact that publication of oceanographic studies has largely been in the serials of learned institutions, which the more important scientific libraries in America regularly receive in exchange. The other most important vehicles for such publication have been the Hydrographic bulletins of one sort of another issued by maritime nations. These again are to be found in many of the large libraries both public and private.

Special efforts to accumulate oceanographical literature have also been made at all the institutions, governmental and educational, that participate at all actively in this field, both in the United States and in Canada. The result is that extensive collections on this subject are, for example, to be found at the Laboratories of the Biological Board of Canada; in the libraries of Harvard University,

which contain nearly every oceanographic paper of importance; in the Library of Congress; in the U. S. Bureau of Fisheries at Washington and Woods Hole; in the Marine Biological Laboratory at Woods Hole, at the U. S. Coast and Geodetic Survey; at the U. S. Hydrographic Office; at the Scripps Institution of Oceanography; at the Fisheries Laboratory of the Californian Fish Commission; at the Department of Tropical Research of the New York Zoological Society; likewise in many of the large Libraries of Universities, scientific Societies, and in Public Libraries. In short, thanks largely to the newness of this field of research, Oceanography is perhaps as well served in America from this standpoint as is any other science.

F. SITUATION AS TO UNIVERSITY INSTRUCTION IN OCEANOGRAPHY

In this respect the advance of Oceanography in America now suffers from one of its greatest handicaps, for progress in this science is a matter not only of ships, laboratories and money, but far more of men, which implies opportunities for education. And it is of men that there is now the most serious shortage.

Examination of the published announcements, correspondence with the Deans of instruction of most of the important American Universities makes it evident that where the descriptive phases of Physical Oceanography are presented at all in undergraduate instruction, in more than the most cursory way, it is usually in connection with courses in general Geology, Physiography, Meteorology, etc.

The general paucity of opportunities for instruction in this general field is so obvious that it needs no detailed survey for corroberation. We need merely add that so far as we have been able to discover from a cursory survey, no American University today offers a satisfactory course to undergraduates in oceanic Geophysics, as a concrete and sufficiently inclusive subject. Neither, we believe, does any American University cover the various phases of the subject, in courses under other names, in detail enough for the average undergraduate to gain a sound grasp of it through formal instruction.

Oceanic biology is better served, both by courses in general biology, ecology, hydrobiology, etc., and by those food fishes and allied subjects offered at the Colleges of Fisheries.

The graduate student, sufficiently devoted to the subject to have mastered these difficulties, and fitted for advanced instruction or research, finds several avenues open, though far fewer than the importance of this field of science demands.

Here, again, it is not worth while to present a detailed list, for no doubt graduate students of certain phases of oceanic biology would be accepted in the biological laboratories of most universities, and the situation is somewhat similar with regard to submarine geology. Naturally, however, seaside connections of some sort are almost essential for efficient advanced instruction in these marine fields, while but few American Universities now number active investigators in Oceanography among their teaching staffs.

Among these few, advanced instruction and research courses under direction, leading to the higher degrees, are regularly offered in

Physical Oceanography; in the Chemistry of sea water and in several fields of oceanic biology and submarine sedimentation by the University of California at the Scripps Institution of Oceanography. Harvard University offers research courses (but at present no formal instruction) in these same subjects; the University of Washington offers Oceanography as related to the Fisheries; the University of British Columbia teaches both the physical and biologic aspects; while the Universities of Iowa and Wisconsin offer courses and opportunities for advanced work in marine sediments.

Opportunities are also afforded to students from Canadian Colleges and Universities in general for supervised research, leading to degrees, at the Laboratories of the Biological Board of Canada. And this opportunity, largely taken advantage of by students from most of the important Canadian schools, is an especially fertile contribution to the problem of oceanographic education in America today.

As the foregoing suggests, opportunities for university instruction in Oceanography as a separate science are extremely scanty in America, as compared with other sciences. It is, in fact, one of the most serious obstacles to advances in this field that it is not now possible for a student to obtain a course of instruction, properly graded upward from the elementary introduction to advanced research, in any one American University. In America the oceanographer must today be largely self-taught in the basic aspects of his subject.

G. NUMBER OF OCEANOGRAPHERS IN AMERICA

To a certain extent, the activity in any field of science can be estimated by the number of investigators and teachers engaged in it. This number cannot be stated precisely for Oceanography in America, because of the impossibility of defining the term, for every student of marine biology, of marine physiology, of marine plants or animals, of seismology, of isostasy, of structural geology, of coast lines, or of ocean meteorology touches the fringe of Oceanography, and so, is, to some extent, a potential oceanographer. This generalization is illustrated by the fact that while the "Liste des oceanographes" of Canada and of the United States, compiled by the International Geophysical Union in 1925-1927 (Bulletin 6 (a,b) Conseil Internationale-Union Goedesique et Geophysique Internationale) includes 124 names, certainly not half of these find their chief interests in the ocean itself. Thus the membership of the section of Oceanography of the American Geophysical Union, which includes practically the whole roster of American Physical Oceanographers, as well as several whose interests are primarily biologic, numbered only 31 in 1927.

Probably it is safe to assert that the number of students in North America whose studies are devoted to the physical, geologic, chemical or biologic aspects of the ocean as an entity, as contrasted with those to whom the oceanic aspect of the projects in which they are engaged is secondary, is not greater than fifty, all told. And fewer still are actually engaged in oceanographic investigation.

While the number of graduate students working in problems bearing on Oceanography is considerable, there is no immediate prospect

of any rapid increase in the number of oceanographers in America, because very few professional openings for teaching or investigation are open, except in the very special lines of work carried on in the government service.

III. SUMMARY

Oceanography is today a "live" science in America, but at the same time an "infant" science, struggling against many and serious obstacles to its growth. These obstacles do not result from any lack of general interest in the subject, as evinced at scientific gatherings, etc., but from a complex of practical obstacles which hold to a minimum the amount of oceanographic effort now actually being exerted in America.

True, it would be possible to present the foregoing survey in such a way as to suggest that Oceanography is today well served in America. This, in fact, is true, so far as Libraries, and opportunities for laboratory study of data otherwise gathered, are concerned. But in every other way Oceanography, though very much alive, lags far behind all the other sciences with which it is commensurate in importance.

Consider, for example, the paucity of effort directed primarily toward oceanic exploration, as measured by the fact that in America today there are only three research institutions outside the government services and state universities that either devote their chief energies to Oceanography (physical or biological), or include this subject as a major item in their fields of investigational activity.

It is too early to prophesy whether the recent entrance of the various other institutions, mentioned above, into Oceanography, by individual projects, actually presages the dawning of a better day; this will depend largely on how soon the practical obstacles analyzed elsewhere (page 143) can be overcome.

Chapter IV.

COOPERATION IN OCEANOGRAPHIC RESEARCH TO BE EXPECTED FROM FEDERAL GOVERNMENT AGENCIES IN AMERICA, AND FROM STATE FISHERIES COMMISSIONS, WITH SUMMARY OF THEIR OCEANOGRAPHIC ACTIVITIES

I. INTRODUCTION

Several government bureaux in America prosecute oceanographic investigations as a part of their regular duties, as described in a previous chapter. From time to time in the past, broad schemes of oceanic exploration have been undertaken to be carried out either by some one government bureau, or by several in cooperation. As the most notable example of these, in America, we may cite the explorations of the U. S. Coast and Geodetic Survey steamer BLAKE off the east coast of the United States and in the West Indian Caribbean region from 1877 to 1880. A more recent example is the exploration of the oceanic triangle between Chesapeake Bay, Bermuda and the Bahamas, carried out in 1914 by the Survey on the BACHE in cooperation with the U. S. Bureau of Fisheries. But all these institutions must devote their energies primarily, and in most cases the whole of their appropriations, to the special field for which they were primarily established, and for which Congress or Parliament supports them.

There is also a natural tendency to concentrate their efforts in the areas of particular national importance. Furthermore scientific institutions supported by public funds are, for the most part, organized for the practical applications of scientific research. And while increasing interest on the part of the public makes it likely that government agencies will be given more support for pure research in the future, the demands for funds to support investigations directly economic in aim are now and increasingly so insistent that Legislatures are not likely for years to come to lend ear to pleas for marine investigations in "pure science" on any broad scale.

For these reasons it is not to be expected that any of the services of the Federal government, whether of the United States or of Canada, either separately or jointly, will be in a position much to expand their oceanographic programs, at least for many years, without outside stimulus or encouragement of some kind.

Thus, the proposed Naval Oceanographic Expedition planned at the Conference on Oceanography held at the U. S. Navy Department in the summer of 1924, failed of fruition because it demanded a large grant from Congress which was not forthcoming, and which, in fact, there was no reason to expect would be forthcoming.

Without a changed attitude on the part of the Congress of the United States, or the Parliaments of Canada or of Newfoundland toward such scientific investigations as bear only remotely on econo-

mic problems, the Federal Governments cannot be expected to undertake broadly organized or long continuing exploration of the basic problems of physical and biologic Oceanography. Under present conditions private institutions, alone, or the state universities, can originate and carry on a coordinated attack in this field, and it is by helping to fill this gap that the proposed Institute would have its greatest usefulness.

Nevertheless, analysis of the programs of the several Federal bureaux which carry out marine work shows in Canada and the United States that they are in a position to offer practical assistance of various sorts in any large plan for oceanographic study that might be initiated elsewhere under authoritative auspices. In this connection the vague predictions of "full cooperation as far as facilitis allow", such as inquiry would elicit from any of the Federal agencies at all concerned with exploration of the ocean, are of no real help. What is needed is a definite estimate of the fields in which the several bureaux can lend active aid and of the amount of such assistance that can actually be expected from each.

An important factor in making such an estimate is that the Federal Government of the United States, by acts of Congress of April 12, 1892, and March 3, 1901*, allows the use of the Scientific and and Technical research facilities of the Government by private investigators or institutions.

* Supplement to Revised Statutes of the United States, Vol. 2, 1892-1901, pp. 71, 72. and Deficiency Appropriation Act, Chap. 831, Vol. 2, 1892-1901: Supplement to the Revised Statutes, p. 1532.

And since most of the U. S. Federal establishments of present concern are expressly included in these acts, as are the rest by implication, it is not too much to state that the United States Government is definitely committed in advance to the general policy of cooperation in scientific undertakings as a whole.

Every governmental institution now at all concerned in Oceanography, whether Canadian or United States, would, no doubt, gladly expand its operations in that field if its appropriations would allow. For the reasons stated, however, greater liberality in that direction cannot be reckoned upon. Equally, without additional funds from some source allocated to that particular purpose, none of them can so expand. And any considerable participation in a general program would result in a drain on the Bureau concerned both as to the time of its personnel, and otherwise, which could be met only on a small scale, unless combined with regular duties.

It is then, not so much a question of willingness in this respect (this may be postulated in advance), but the more practical one of the extent to which existing facilities and administrative limitations will allow the government establishments to lend active assistance.

An important factor here is that the functions of each of the bureaux is definitely laid down, and that each of them has been in operation for so many years that a precedent is established in the eyes not only of legislatures but of the public. Consequently,

there is every reason to expect that their activities will continue for a long period in the future to follow the same lines along which they have developed in the past. This rigidity of organization makes it more allowable to predict the extent to which they may be expected to take part in joint projects that might be sponsored by the proposed Institute, and to foresee the fields within which each Bureau will be forced to confine its activities, than would be the case for private institutions, the policies of which often change abruptly with changes in the point of view of the controlling personnel.

Consequently, the following estimate gives little weight to the active sympathies toward Oceanography of the Officials at present in control of the Bureau of Fisheries, the Coast and Geodetic Survey, the Bureau of Standards, etc., but is based rather on the established fields of activity, and on the legal limitations within which these Bureaux operate.

The case of the U. S. Navy, however, is otherwise. For it, research in Oceanography must always be incidental to the naval duties for which the Service is maintained. At the same time the numerous cruises carried out by naval ships offer frequent opportunity for very important explorations of the sea water without much additional expense. The degree of cooperation to be expected from the Navy will, therefore, depend on the inclination of the officers influential in the Service toward such undertakings, combined with the possibility of meeting the extra cost. This also applies to the United States Shipping Board and to the Lighthouse Service.

The question whether federal bureaux are allowed to utilize funds that may be provided from outside sources is important: for instance, for the expense of fueling ships, or for the purchase of supplies.

II. ANALYSIS BY SUBJECTS

The several fields in which an important degree of cooperation may be expected from the government can be summarized as follows:-

A. DETAIL OF SHIPS FOR SPECIAL CRUISES.

In any scheme of marine exploration the most expensive item of equipment is the ship and her navigating personnel. This item, too, is difficult to supply at short notice, even if money be available. Under present conditions no governmental agency, whether Canadian of United States, is able, without contributions of outside funds, to send a ship on special cruises of any great length, unless these can be combined with regular duties.

Provided the expenses of a deep-sea expedition could be met, past precedent makes it safe to assume that a sea-going ship could frequently be detailed by the Bureau of Fisheries stands in a peculiar position, as explained below (Page 121). As the Fisheries Research Steamer is in active service for only part of the year, it is often possible to detail her for special cruises of considerable duration, without in any way interfering with her regular duties. This, in fact, the Bureau has frequently done in the past, with

very satisfactory results. There being no legal barrier to prevent the Bureau's ships from operating anywhere on the high seas, the proposed Institute might thus arrange joint periodic cruises along representative profiles in the Atlantic Basin off the United States of just the sort that are now most needed to show the secular changes that take place there, not only in the physical state of the water, but also in its organic communities.

How far the U. S. Navy can undertake special service of this sort, will be governed by a complex of factors, such as the possibility of sparing a ship and personnel from regular duties: the possibility of combining the proposed exploration with one of the regular practice cruises: and most important of all, the attitude of the higher officers of the Navy toward marine explorations at the time. The growing interest within the service, in oceanic exploration is now crystallized into a definite policy, which includes recommendation, by the Naval Board on oceanography, that a naval vessel, specially fitted, be employed exclusively for oceanographic investigation if, in the future, circumstances so permit.

By the adoption of this oceanographic program the navy is committed to increasing participation. But no Naval vessels are at present equipped with laboratory facilities, or with any of the apparatus used in Oceanography, except for sounding: nor does the Service at present include any trained oceanographers among the younger officers. Consequently, it would be necessary to supply scientific personnel to any Naval vessel undertaking general oceanographic work.

No federal institutions of the United States, other than the Navy and the Bureau of Fisheries, can now spare ships from their regular duties for more than a short time. On the contrary, the demands on the vessels both of the Coast Guard, Coast and Geodetic Survey and Lighthouse Service are greater than can be met, and these demands grow so rapidly that the building of new ships has hardly kept pace with the expansion of their duties.

No assistance under this category is to be expected from the State Fish Commissions on the Atlantic coast of the United States under present conditions. On the Pacific coast, however, the present participating of the California Fish Commission in a joint scheme of exploration of the Monterey region, and its generally close relationships with scientific institutions, make it likely that it will occasionally be willing to detail one of its patrol boats to short cruises in the coastal waters off California, as explained below (page131). Occasional cooperation of the same sort in projects properly sponsored, may also be expected of the Canadian Department of Marine and Fisheries, and of the Canadian Hydrographic Service, if any of their vessels could be spared from their regular duties at the time.

B. SPECIAL OBSERVATIONS TO BE CARRIED OUT AS AN INCIDENTAL OR SECONDARY PROGRAM ON SHIPS EMPLOYED ON OTHER DUTIES

More or less cooperation under this heading may be expected

from all the government agencies that operate ships on the high seas, not only United States but also Canadian, especially by the U. S. Navy, the U. S. Coast and Geodetic Survey, and the U. S. Light House Service. It is under this heading that cooperation with the Government may be expected to prove most productive.

The U. S. Navy now has definitely undertaken a program of sounding (by the echo method) on a much wider scale than heretofore, (Page 127), both on the regular cruises, and whenever feasible, in regions unsurveyed, or especially interesting for other reasons. Continuous readings of the surface temperatures by recording thermographs along the many trans-oceanic routes traversed by the vessels of the U. S. Shipping Board, could be depended upon, were the expense of the instruments and installation met from outside sources: The statement made by representatives of the Shipping Board to the Naval Conference of 1924 makes clear that there need be no apprehension on score of cooperation. And even without such assistance, the installation of Thermographs may fall within the present oceanographic program of the Navy. Data so gathered would be of the highest value in connection with climatological studies, consequently of economic importance.

The operation of such instruments does not require a trained scientist, but can be carried out by a competent quartermaster or junior watch officer. Excellent thermographs can now be had, nor is the cost of their purchase and installation prohibitive.

In many parts of the ocean, notably in the Pacific, very valuable additions to our knowledge of temperature are still to be obtained by surface readings with ordinary thermomoters such as are taken at intervals of two or four hours on many steamers as part of the ordinary routine of navigation. The cost of such instruments is negligible, and observations of this sort are taken on so many ships that they can easily be arranged for. But for records obtained in this way to measure up to modern standards of accuracy, they must be taken with much greater care than is ordinarily done. To insure this on commercial vessels it would be necessary (a) to arouse a special interest, and an appreciation of the need for accuracy, on the part of the Quartermasters of Watch Officers who would actually read the instruments· (b) to train them to read accurately, for, simple though this be, it requires some instruction. Unless some such precautions are taken, ordinary thermometer readings are apt to be so rough that only by averaging large numbers of them can an approximately correct value be arrived at. And the day for work of this sort is past, except for certain very lonely parts of the Pacific and Antarctic.

The U. S. Navy now definitely provides in its oceanographic program for the collection of surface Temperatures, with standardized instruments, and for this subsequent analysis in the Hydrographic Office.

Collections of water samples along the same routes could doubtless be arranged for by commercial vessels, especially if some small compensation be given to the Quartermasters or other Petty Officers charged with this duty. More important, the U. S. Navy has definitely expressed to your committee its willingness to coop-

erate in the collection of surface samples by its vessels in transit.

The great success of the Scripps Institution of Oceanography in developing cooperation along these lines within the past few years illustrates the possibilities.

The possibility of making pendulum measurements of gravity at sea, from submarines, enables the Navy to render great scienttific service, on its regular cruises, if personnel and apparatus be supplied. Such measurements have, in fact, been recently carried out on a U. S. Submarine, under the joint direction of the Naval Observatory and of the Carnegie Institution.

Serial observations below the surface of whatever kind are so timeconsuming and interfere so seriously with ordinary routine, that they could never be expected from ships running on scheduled routes: for the same reason they are not always feasible even from vessels employed in sounding. To be carried out on a large scale, they must be regarded as a primary part of the program. However, the Coast and Geodetic Survey and the Canadian Hydrographic Service will in the future, as they have in the past, be able to obtain serial temperatures and water samples in connection with their current measurements and hydrographical work. But they will usually be forced to restrict this to the routes covered in their routine duties, which will often not be those most interesting from other points of view.

More assistance in this particular respect may be depended on from the U. S. Bureau of Fisheries within the areas where its marine investigations are concentrated: which, in fact, would be but continuing its present policy for the collection of serial data from the surface to the bottom is now a regular routine duty on Albatross II: one too, that could equally be undertaken on the Bureau's vessels on the Pacific coast. And the Biological Board of Canada is constantly collecting data of this sort in connection with various special problems in oceanic biology.

Unique op ortunities for obtaining continuous sub-surface records, both physical and biologic, of the sorts now most needed in North American coastal waters, are offered by the U. S. Lighthouse Service from its lightships as explained on page : opportunities in fact, that could not be equalled in any other way without altogether prohibitive expense. And past experience suggests great willingness on the part of this Service to cooperate in this way (page). Similar cooperation can be expected of the Canadian Lighthouse Service. But for the full development of such work not only must all apparatus be supplied from outside sources, and some small compensation be offered to the crews for the extra work, but trained observers as well. Without the latter the regular personnel of the lightships can only be expected to use apparatus that is simple in operation and not too time-consuming.

The U. S.Coast Guard has in the past (and so may in the future) added the collection of plankton on a small scale to its routine dynamic surveys in the ice regions in the North Atlantic. Much wider cooperation in this field is naturally to be expected

from the U. S. Bureau of Fisheries, not only by the special detail of its ships, but also on its routine cruises in continental waters in connection with fisheries studies. In this field the Biological Board of Canada is also an active leader.

C. PROVISION OF LABORATORY FACILITIES ON SHORE

Acts of Congress (Page 112) authorize the use of the research facilities (hence the scientific laboratories) of the U. S. Government by scientific investigators generally, so far as the officers in charge may determine.

The Bureau of Fisheries, at its two marine laboratories at Woods Hole, Mass. and at Beaufort, N. C., offers facilities for visiting students of marine problems and supplies them with all apparatus, etc., demanding only that their researches shall in some way be germane to the biological problems with which the Bureau is concerned, a proviso that covers practically the whole field of modern Oceanography. Similar facilities are offered, with a similar proviso, by the Biological Board of Canada at its biological laboratories at St. Andrews, N. B., at Halifax, N. S., and at Nanaimo, B. C. The Scripps Institution of oceanography at La Jolla, Califotnia (belonging to the state supported University of California) also offers the hospitality of its laboratory to workers who are qualified to carry on investigations in various phases of oceanography, as does the Friday Harbor Station of the University of Washington.

All these laboratories, being situated at the seashore, offer temporary headquarters for any sort of marine exploration that might be carried out in these particular sectors under the auspices of the proposed institution. In this one respect the requirements are therefore fairly well covered for isolated projects. The general relationship that the Bureau of Fisheries maintains with educational institutions throughout America also warrants the prophesy that it would always be able to find table space (as it would cergainly offer the facilities of its Library) for the visiting oceanographer at its Washington headquarters, overcrowded though this now is.

The California Fisheries Commission can also accomodate an occasional visitor at its Fisheries Laboratory at Terminal Island, near San Pedro, Cal., where he will find simple accomodation and a convenient Library.

The U. S. National Museum also offers hospitality, and expert assistance, to students engaged in classifying and describing collections of marine animals.

In the field of instrumental development--one of the most important in modern Oceanography--the prospect for governmental assistance is equally rosy, for the U. S. Bureau of Standards offers unique laboratory facilities, and already has in successful operation a plan for cooperative research in this field. Under this*

* Quoted from Circular 296, Bureau of Standards, Foreword.

"it makes research possible for any organization by loaning equip-

ment, providing quarters, and affording facilities, data and supervision, giving to qualified workers training and experience in research under Bureau auspices and cooperation." This is effected by the reception by the Bureau of research associates from commercial or educational institutions, paid by the latter, but working in the well equipped laboratories of the Bureau under direct oversight by specialists in their particular fields. This opens an opportunity for the improvement or devising of instruments of precision that could hardly be equalled in any other way. The Canadian Research Council is now developing National Laboratories where similar assistance may be expected.

Express mention of the Geological Survey in the enabling act of 1892 equally authorizes reception of outside students. And we are informed by the Survey that it can offer the hospitality of its laboratories to investigators from private institutions if no expense to the Survey is involved. This opens the way to studies of sediments, etc. under supervision: but present facilities allow the reception of only about three such visitors to the physical and chemical laboratories of the Survey, and the demand is so constant that there would only be room occasionally for a visiting oceanographer. Little assistance, then, can be expected from the Survey in this way, unless its facilities should be considerably expanded of which there seems no immediate prospect.

The Geological Survey of Canada also (we are informed) would offer the hospitality of its laboratory, library, and other facilities in Ottawa to qualified students.

The U. S. Naval Observatory is also, by law, authorized to receive outside students, but its special fields of activity are so remote from most of the problems now urgent in Oceanography that the facilities it might offer are hardly germane to the present discussion. The Observatory is the only scientific division of the Navy in which extension of research facilities is definitely authorized: nor could such general hospitality fairly be asked of the Naval Research Laboratory because of the danger that confidential information of military value might be disclosed.

D. DETAIL OF PERSONNEL TRAINED IN OCEANOGRAPHY

Little assistance can be expected from the Governments in this respect. The Federal Services do, it is true, include a considerable number of scientists trained and experienced in one or another field of Oceanography: but rarely could any of these leaders leave their regular duties, even temporarily, without disrupting the projects for which they are officially responsible.

The U. S. National Museum would, on occasion, detail a biologist to care for the collections on some important expedition: the U. S. Bureau of Fisheries, or the Biological Board of Canada might temporatily contribute an expert to oversee the handling of collecting gear· the U. S. Weather Bureau and the Canadian Meteorological Service, a meteorologist, etc. But this would apply only to isolated projects. Oceanographers, to carry on long continuing explor-

ations, must be found elsewhere· and the scarcity of students in this field has been one of the drags on the development of this science in America.

E. ADVISORY ASSISTANCE.

Constant assistance can always be depended upon in this respect in all the fields of marine research in which Governments regularly take part. And it is perhaps by its expert advice that they can most forward the general progress of oceanographic science. Requests for cooperation in the development of working programs, for instruction in the use of instruments, etc. and for general advice in working up the results of field data, would always be gladly met by the bureaux concerned. The Coast and Geodetic Survey and the Hydrographic Office will, for example, give expert advice as to sounding procedure, the exploration of submarine topography, and the measurement of currents; the Geological Survey as to sedimentation; the Coast Guard as to dynamic surveys of ocean waters; the Bureau of Fisheries and the Biological Board of Canada as to marine ecology in general. All these establishments do, in fact, answer frequent calls for such assistance.

F. STORAGE AND IDENTIFICATION OF BIOLOGICAL SPECIMENS

This is the particular province of the U. S. National Museum, which is, by law, the repository for all specimens collected by governmental expeditions of the United States. Great assistance in identification of specimens may be expected from the staff of the Museum. At present the Canadian National Museum has no specialists in Marine Biology. And it must be realized that no one museum, whether governmental or private, can ever carry on its staff specialists in all groups of marine animals and plants. Consequently, it will be necessary in the future, as it has been in the past, to send collections to the students who are best fitted to work them up, wherever these authorities may be located.

G. ANALYSIS OF SUBMARINE SEDIMENTS

The U. S. Geological Survey, we are informed, would always be inclined to assist in the analysis and geologic study of submarine sediments, especially of those from the continental shelf of North America, but also of collections from the ocean beds in general. But only to a small extent could such assistance be depended upon, because (with its present facilities) the Survey could undertake such studies only by displacing some other project that might well be more directly germane to its major fields of activity. The Canadian Geological Survey also informs us that it could undertake some analytical work, its extent depending upon the interest taken by the Survey in each particular investigation.

H. CHEMICAL ANALYSES OF SEA WATER AND DETERMINATION OF ITS SPECIFIC GRAVITY.

No government agency could reasonably be expected to undertake routine determinations of salinity and specific gravity for outside institutions. But on the rare occasions where such determinations of the highest possible degree of accuracy are needed, in the stan-

dardization of instruments or of methods, the U. S. Bureau of Standards is willing to make such tests. At present it is perhaps better fitted to do so than any other agency in America.

We may hope (from precedent) that the chemical laboratory of the Geological Survey might similarly make occasional chemical analyses in connection with problems of outstanding interest or in the development of new methods. The present limitations of personnel and facilities make it impossible for the Survey to undertake such work except rarely and on a small scale. But, as it is able to accept outside funds (Page 118), a development of cooperation in this chemical field is possible. In this field assistance may also be hoped from the Laboratories now projected by the National Research Council of Canada.

I. INSTRUMENTATION

The progressive development of instruments of precision has played an important role in the advance of Oceanography. It is, in fact, hardly too much to say that modern knowledge of the physics of the sea dates from the perfection of the deep-sea thermometer. And the increasingly rigorous demands of oceanic science can be met only by a corresponding development of apparatus. A striking case of this is the method of determining salinity by electric conductivity, recently developed at the Bureau of Standards to meet the needs of the International Ice Patrol Service. Recording instruments for continuous record of the density of the sea-water along a vessel's track are also much to be desired, as are improvements to the present type of deep-sea thermometer.

All this falls directly within the province of the U. S. Bureau of Standards: in fact, any oceanographic institution in the United States will find itself forced to turn constantly to the latter for assistance in this field. And while federal and state agencies have prior claim on its services, the Bureau is in a position and willing to do much work of this sort if reasonable time be allowed it. All the reversing deep-sea thermometers used by the U. S. Bureau of Fisheries are standardized by the Bureau of Standards, and it is desirable that all instruments of this sort used by other institutions in America receive this same test. Hydrometers equally require standardization, as do current-meters and various other pieces of apparatus.

In the development of new apparatus the most extensive cooperation that the Bureau can offer is through its system of research associates, explained on page , but as work of this sort is expensive, funds must be provided from other sources, for any extensive project. The Canadian Research Council is also in process of developing a system of National Laboratories corresponding to those of the U.S. Bureau of Standards. And when these are in operation they will afford assistance in the general field of instrumentation, and hospitality to student workers of the same sort as is now provided by the Bureau of Standards.

The U. S. Coast and Geodetic Survey would likewise assist in the improvement of instruments for measuring ocean currents (now much needed) as well as for taking soundings, both by expert instruction and (funds being provided) by the construction of experimental models in its own shops. Similarly, the Naval Research Laboratory can often help by consultation, and can be called upon for aid in particular cases, if not endangering military secrets.

J. PUBLICATION

Little assistance can be expected from government agencies in publication of the results of general oceanographic investigations carried on by other institutions, their funds for publication being too definitely allocated to other purposes. The U. S. National Museum would, no doubt, be willing to publish accounts of such biological collections as might come into its possession. And the U. S. Geological Survey can publish in its regular series the results of any studies that its own staff might make in the fields of sedimentation or submarine geology generally. But publication of outside work on any large scale, by these or other bureaux, would demand provision of funds from outside sources. And assuming that such funds could be accepted, the question would arise whether other scientific serials would not provide a more fitting vehicle.

III ANALYSIS BY INSTITUTIONS

The following remarks on the scope and limitation of the several governmental agencies from which the greatest amount of cooperation is to be expected, will serve as explanation of the foregoing survey. These have been prepared in each case in consultation with their administrative officers.

A. FEDERAL ESTABLISHMENTS OF THE UNITED STATES

1. United States Bureau of Fisheries.

The Bureau of Fisheries stands in a position toward Oceanography different from any other governmental insitution in the United States, for its entire program of research, and of conservation of the marine fisheries, is intimately bound up with basic oceanographic problems. There is perhaps no field of Oceanography, biologic or physical, in which the Bureau of Fisheries has not participated to a greater or less extent in the past, nor has there been a time, since the Bureau was founded, when it has not had some sort of oceanographic investigation under way.

In the original joint resolution of Congress, approved Feb. 9, 1871, providing for the appointment of the first Commissioner of Fish and Fisheries, it was resolved: "that it shall be the duty of said Commissioner to prosecute investigations----with a view to ascertaining whether any and what diminution in the number of food fishes in the coast and lakes of the United States has taken place, and if so, to what causes the same is due: and also whether and what particular prohibitory or precautionary methods should be adopted---." With so broad a statutory program, the activities of

the Bureau of Fisheries may thus be said to cover the whole biological economy of American seas.

The fundamental marine fishery problem is today the estimation of the actual abundance of the stock of fishes in the sea, of the drain to which they are now subjected with commercial fisheries, and of the strain which they will safely stand. Consequently, the ultimate aims of most of the projects undertaken by the Bureau in its marine work must be primarily economic. To reach this goal, however, the only sound route is through the study of the biology of the species in question, which leads far afield into the realms of physical and chemical oceanography, as explained more fully in another chapter (Page 67). This applies equally to two other groups of problems now facing the Bureau: namely (1) attempts to explain or to predict the great temporal fluctuations now known to occur in the stocks of many of the most important commercial fisheries: (2) the development of artificial propogation for such animals as can be so maintained,--the oyster for example.

Consequently, the Bureau must necessarily devote much of its resources to the investigation of what is often called "pure science" concerned with basic problems in the natural economy of the sea. And the more urgent the practical problems of conservation become, the more imperative will it be for the Bureau to keep in close touch with all advances in the science of Oceanography, even if limitation of its resources prevent it, as an institution, from expanding its own efforts into the fields which at the moment seem the more remote from practical application, but which the future may prove to be of the most vital importance.

The allocation by Congress of the funds of the Bureau to certain fixed objects makes it impossible for the Bureau itself to undertake broad oceanographic explorations. And this condition will probably continue because of the imminence of the problems immediately vital in the conservation of marine resources,and of the growing appreciation by Congress that these problems must be attacked.

But it is safe to assume that for as long a period as it is worthwhile to attempt to predict the course of human affairs the Bureau of Fisheries will always be ready to participate, so far as its resources allow, in the oceanographic programs, whether biological or physical, of private institutions, or of other governmental bureaux, especially within striking distance of the coasts of North America.

There is, in fact, a precedent of long standing for such cooperation by the Bureau: for instance the cruises of the Albatross in the Pacific under the direction of Alexander Agassiz· the recent exploration in the north-western Atlantic in cooperation with the Museum of Comparative Zoology; the joint expedition of the Bureau and of the U. S. Coast and Geodetic Survey to the oceanic triangle between the United States,Bermuda and the Bahamas in 1914: and the expedition to the Galapagos Islands in the winter ot 1928.

For many years the Bureau has maintained a sea-going ship capable of long-sustained cruises with a well arranged laboratory fully equipped for dredging, towing and other biological work as well as for the ordinary routine observations of temperature, salinity,

etc., and manned by a personnel fully trained in oceanographic procedure. The Fisheries Steamer "Albatross II" is now actively employed in studies of the biology and especially the migrations of cod, mackerel and other food fish of the north-western Atlantic. In the Pacific the Bureau maintains vessels for the patrol of Alaskan waters and for the transport of supplies to the Pribilov Islands, but which could add oceanographic work to their routine duties without serious interference. And on both coasts it has several smaller craft, fit for research work in the coastwise waters.

The Bureau's activities are not limited by statute to territorial waters, but can be extended to the high seas, and experience in the past justifies the assumption that the Bureau will often be ready to detail its vessels for well considered exploration, if they can be spared from other duties, and if the cost of fueling and the other expenses incident upon withdrawal from their ordinary routine duties, can be met from outside sources.

Besides its ships the Bureau maintains well equipped biological laboratories especially for the study of fisheries biology, at Woods Hole, Mass., and at Beaufort, N. C., where problems in oceanic biology are constantly under study. At all of these laboratories visiting scientists are made welcome, and provided with full facilities up to the Bureau's capacity.

More specifically, the Bureau will cooperate by advice in the development of programs of research: by the occasional detail of its vesells and their crews (when expenses can be met)· by detailing members of its staff, from time to time, to direct the actual work at sea: by the loan of apparatus (this has proved most helpful in the past): and by freely offering the facilities of its laboratories.

2. United States Coast Guard

Scientific research was not among the duties for which this Service was originally established in 1790. Its entrance into the field of Oceanography was occasioned by the delegation to it of the duty of maintaining the International Ice Patrol in the North Atlantic, as a result of the International Conference on Safety of Life at Sea, held in London, Nov. 12, 1913. A convention signed on January 20, 1914, provided for the inauguration of an international derelict destruction, ice observation, and ice patrol service to patrol the ice regions of the North Atlantic during the season of danger from icebergs. The Government of the United States was invited to undertake the management of this service, the expenses to be defrayed by the thirteen powers interested in trans-Atlantic navigation: and on February 7, 1914 the President of the United States directed the Revenue Cutter Service (now the Coast Guard) to begin the international ice observation and patrol service that has been maintained ever since.

In addition to the routine work of locating icebergs and warning the passing vessels of the danger limits, the Patrol is also directed to make a study of the ice situation, particularly as to the currents in the vicinity of the Grand Banks, and of the physical properties and drifts of the ice. Beginning in 1914 the Revenue Cutter Service (now the Coast Guard) thus undertook the study of the physical oceanography of the north-western Atlantic in that general

region, with special reference to the interrelationships of the Labrador and Gulf Stream currents there. And this oceanographic program has ever since been continued as a regular part of the routine duty of the Coast Guard.

On the Patrol the Coast Guard has cooperated with the Hydrographic Office, and has offered the hospitality of its ships to representatives of the Weather Bureau, of the U. S. Bureau of Fisheries and of the Museum of Comparative Zoology, arranging for the installation of the necessary meteorological instruments, and adding the collection of plankton to its regular program. Cooperation in ways such as these, that do not interfere with the practical duties of the Patrol, can be depended upon in the future. But this will be limited to the Grand Banks region and to the season of ice menace (usually April to June), while the constant necessity of devoting the energies of the Patrol to the practical tasks of locating the position of the ice and of broadcasting warnings to shipping means that oceanographic observations can be taken only as circumstances permit.

The demands on the Coast Guard for the services of its vessels in the various fields over which its activities are now spread are so insistent that there is no possibility of its devoting a ship primarily to scientific researches. Neither do the cruises of its cutters or patrol boats (except those on Ice Patrol) follow schedules or tracks regular enough for the development of a promising program of incidental observations (on the temperature of the water, etc.) of the sorts that offer such attractive possibilities in the case of the Navy, the Shipping Board, and Lighthouse Service. The barrier in this case is not only the cost of operating the cutter on special service, but, more serious, the impossibility of withdrawing ships or personnel from their primary duties. But whatever joint or independent researches this service can undertake will be prosecuted with first-class efficiency by its highly trained commissioned personnel.

And the Coast Guard's experience in the operation of the Ice Patrol, with the presence in the service of a trained and experienced physical oceanographer enable it to render direct and practical advisory service in the organization of oceanographic cruises, as well as in the management of research vessels generally.

3. United States Coast and Geodetic Survey.

Certain restricted lines of oceanographic research occupy an important place in the regular functions of this Bureau.

The marine activities of the U. S. Coast and Geodetic Survey are, by statute, devoted chiefly to (a) hydrographic surveys of the coast lines and slopes of the United States and dependencies for the purpose of cartography: and (b) to the study of tidal and ocean currents as these affect shipping.

The oceanographic field of this Survey is thus much narrower than that of the Bureau of Fisheries. But within this field it constantly carries on important original researches, and in the

past it has always shown itself ready to cooperate with other agencies in investigations of the coastwise waters of the United States, so far as this has not interfered with its routine duties.* The

*With the Bureau of Fisheries, for example, the Museum of Comparative Zoology, and the Scripps Institution for Oceanography.

Survey would undoubtedly be glad to extend its studies of currents well out into the Pacific and Atlantic, if funds were available, appreciating that the drifts of the waters closer in to the coast are but a part of the general circulatory scheme of the oceans, hence to be understood must be studied as a part of the latter. And there appears to be nothing in the Act of February 10, 1807 (of which the Survey is an outgrowth) to restrict its activities to territorial waters. The vessels of the Survey have done much wire sounding in deep water in the past. And a number of them are now equipped with Sonic sounding apparatus, enabling them to carry out Topographic surveys of the bottom at great depths economically and in great detail. They have recently taken a large number of serial observations of temperature in salinity down to considerable depths and have gathered many samples of the sea bottom. The Survey also devotes much attention to the study of Isostasy and may be expected to lend assistance in this field to any well considered program at sea, both by the use of its vessels, when these can be spared from other duties, and by supplying trained personnel. With regard to the latter, i.e. personnel, it should be pointed out that in the study of ocean currents by direct methods of observation, especially by current meters, the personnel of the Coast and Geodetic Survey is notably efficient, as it is in all its scientific operations. It maintains excellent sea-going ships and the officers and crews are thoroughly trained in surveying procedure.

In short, the Coast and Geodetic Survey may always be expected to cooperate cordially in any studies of tidal and other currents in the territorial waters around the United States and in study of the topography of the sea-bottom, by assisting with the preparation of apparatus, and by carrying out such observations as will not interfere too seriously with its regular routine duties. Moderate contributions of money from outside sources would not of themselves enable it to undertake any considerable oceanographic program other than that just outlined, even within territorial waters, because its ships are fully employed in their regular duties, the demands on them constantly being greater than can be met. However, the Survey is one of the bureaux that has shown very rapid growth in the past. It is now making rapid progress in the charting of the Pacific coast of the United States and will within a few years complete the first survey of the Hawaiian and Philippine Archipelagoes, when a vessel might be spared from the charting work. In that case, according to its acting Director, no objection need be anticipated to her employment in Oceanography if the necessary appropriation could be obtained for her operating expenses.

4. United States Lighthouse Service.

The regular duties of the Lighthouse Service do not include work of direct oceanographic importance. Nevertheless, this Service is in a better position to make certain sorts of oceanic observations than is any other agency in the country, governmental or private. We refer here to such observations as can be taken from

the lightships. The Service maintains a considerable number of these on the Atlantic and Pacific coasts, several of them being stationed so far out at sea and in such exposed positions that they offer unique stations from which constant record of the state of the ocean can be obtained.

The personnel of the lightships are not trained in special scientific procedure, but are skilled in the handling of various signalling and navigational apparatus. If methods of observation can be standardized and simplified sufficiently to be carried out by persons of reasonable intelligence, lightships offer opportunities which could hardly be matched for the continuous record of the temperatures of the surface such as can be obtained with recording thermographs; for periodic record of the deep water temperatures; for measurements over long periods of the velocity and direction of the currents; for periodic collection of water samples at various depths for future analysis in some laboratory; and for meteorological observations. Biological collections could also in many cases be obtained from the lightships by the simple process of streaming townets from the ship with the tide.

In the past the Lighthouse Service has shown itself ready to cooperate by arranging for its personnel upon the lightships to make temperature observations, many of which have been accumulated. And as the important lightship stations are reasonably permanent, such general cooperation may be expected in the future.

Furthermore, if observations of an intricacy beyond the capabilities of the crews of the lightships were desired, arrangements could no doubt be made to station special observers on these ships for longer or shorter periods.

Records of temperature have also been taken from lighthouses along the coast. And, while it is difficult in such situations to obtain results accurate according to modern requirements, with a little care they may prove useful to illustrate seasonal and annual variations. Here again experience in the past shows that ready cooperation is to be expected. In fact the Lighthouse Service utilizing lighthouses, lightships and vessels, is now actually cooperating with the Scripps Institution for Oceanography in an extensive program of investigation on the Pacific coast in the collection of temperatures, water samples, plankton, and meteorological data; also with the U. S. Bureau of Fisheries as well.

5. United States Navy.

It is less easy to predict the cooperation to be expected from the United States Navy than for the other government bureaux so far discussed, because its marine explorations must always be incidental to other duties.

There is precedent for participation by the Navy in many fields of oceanic exploration. We need only mention Lieutenant Maury's achievements when, as head of the Naval Observatory, he laid the foundation for our modern knowledge of the circulation of the surface waters of the oceans.

From the early years, in fact, the Navy has taken active part in scientific expeditions: sometimes of its own initiative: sometimes supported by special act of Congress*: sometimes in cooperation with other institutions, for example in the recent gravity expedition of the Naval Observatory in cooperation with the Carnegie Institution of Washington· and frequently by the detail of officers and men to man the Bureau of Fisheries' steamer Albatross.

* (a) Act of Congress of May 14, 1836, authorizing the U. S. Exploring Expedition in the Pacific Ocean and the South Seas.
(b) Act of Congress of March 3, 1849, authorizing the test of new routes and perfecting the discoveries of Maury in the course of his investigations of the winds and currents of the ocean.
(c) Exploration and Surveys in the Valley of the Amazon, under instructions from the Navy Department in 1851.
(d) Act of Congress of August 1852, authorizing the U. S. North Pacific Surveying Expedition.
(e) The Exploration of the Valley of the Rio de la Plata and its Tributaries, under instructions from the Navy Department, February 1853.
(f) Act of Congress authorizing the Secretary of the Navy to accept and take charge of, for purposes of North Polar Exploration, the U. S. S. JEANETTE in 1879.
(g) Act of Congress making appropriations for Hall's Arctic Expedition in 1870.
(h) Act of Congress of March 2, 1891, "To enable the President to cause careful soundings to be made between San Francisco, Cal., and Honolulu, in the Kingdom of the Hawaiian Islands for the purpose of determining the practicability
66 of laying a telegraphic cable between those points."

Precedent and tradition thus give reason to assume that the Navy would always be glad to join in attacking problems of such immediate navigational concern as ocean currents, and in extending the surveys of little-known coasts. This, in fact, was definitely stated at the Oceanographic Conference at the Navy Department in the summer of 1924.

And the Navy has now entered a broader field of Oceanographic research, by the approval, by the Secretary of the department, of the following recommendations by the Naval Board on Oceanography:

"(1) The preparation and issue to the service of a world chart, showing unsurveyed areas of the ocean.

(2) That instructions be issued to commanders-in-chief and to vessels operating signly, providing that vessels suitably equipped for sounding operations take soundings in unsurveyed areas whenever their operation permit: that these soundings be transmitted promptly to the Hydrographic Office of the Navy Department.

(3) That in addition the Department indicate, when circumstances permit, to vessels making passage at sea a particular line of soundings which the Department desires made.

The preceding recommendations are based upon the idea of a

systematized and coordinated effort in developing contours of the ocean bottom.

(4) That a standard thermometer for the taking of ocean temperature, both of the air and of the surface water, be adopted, and that suitable instructions be issued by the Hydrographic Office standardizing methods of taking and recording observations and of transmitting these to the Hydrographic Office: that these instructions include the methods of standardizing the instruments from time to time and of data sheets furnished the Hydrographic Office, the last time of standardization, and any comments that appear appropriate regarding the reliability of the data submitted.

(5) That the Department express to the National Academy of Sciences its willingness to cooperate in obtaining samples of the surface water of the sea by vessels in transit: that it suggest to the National Academy of Sciences the desirability of standardized containers of small size for this water with labels in suitable form for the recording on those labels of identifying data.

(6) That when the nature of naval operations permit, suitably equipped vessels operating in the vicinity of ocean deeps be directed to make a survey of these deeps, that they be directed to do so, and that a standardized plan be prepared by the Hydrographic Office for the conducting of these special examination of deeps, so that the data furnished will meet the requirements of those scientists specially interested in ocean deeps."

The Hydrographic Office receives the only appropriation Congress has so far given the Navy for ocean surveys, and its regular work in the collection, analysis and publication of data on ocean currents, drifts of ice, storm tracks, and wind directions and force, as well as in surveys of insufficiently charted coast lines, is directly oceanographic: indirectly so is its cartographic work.

Of late years the Navy has taken a leading part in the application of recently devised methods of echo sounding to charting submarine topography along the routes followed in its periodic cruises. And rapid expansion in this field of exploration is presaged, the recommendations just listed.

The Naval Observatory, also has recently taken an active part in Oceanography through its recent direction of a gravity expedition (Page 16). During the past few years, too, the Navy has recorded a large number of temperature readings during its voyages in the Pacific: has contributed much data to the Scripps Institution, and contemplates a rapidly expanding program in this field of endeavor.

If the increased expense for fuel, etc. could be met (hardly possible from present appropriations) no limits could be set to the opportunity open to the Navy to extend its research downward into the deeper water-strata. With its fleet of auxiliary vessels, large and small, and with its highly efficient officers, the Navy is far better equipped for this than any other agency in the country, so far as physical plant is concerned. It is, furthermore, the present purpose of the Department to cooperate with outside agencies in all practicable ways in studies of the oceans: a purpose exemplified

by the joint gravity expedition of the Naval Observatory and of the Carnegie Institution, by present cooperation with the Scripps Institution in the study of the srufsce temperatures of the Pacific, and by adoption of the recommendations, just quoted, that the oceanographic activities of the Navy be extended. In short, we are assured that the active interest in Oceanography expressed at the Conference at the Navy Department in 1924 has not decreased.

But these favoring factors are partly counterbalanced by the impossibility of the Navy's financing any special oceanographic cruises from present appropriations: and by the improbability that Congress will increase the latter for this purpose.

In short, it is only in the following fields that active assistance can be expected from the Navy at present:

(a) Routine observations such as can be taken on the regular cruises either by the ship's personnel or by observers detailed from some scientific institution, without adding materially to the cost of operating the ship. Projects of this class include the gravity measurements just mentioned, the collection of surface temperatures, meteorological data, and echo sounding. A promising development would be the installation of recording thermographs, especially on the transports running to the Philippines and Hawaii (page).

(b) Occasional topographic surveys of special areas of the sea bottom.

(c) Participating in general oceanographic programs by the Hydrographic Office in a directional or an advisory capacity. Although only a suggestion of this is possible here, it offers interesting possibilities.

(d) Assistance from the Naval Research Laboratory in the development of acoustic and other apparatus.

6. United States Shipping Board.

It is obvious that the policy that the Congress of the United States decides to pursue with regard to the operation, or disposal of the American Mercantile Marine will determine what cooperation is to be expected under this heading.

But so long as the Shipping Board continues to operate vessels on the principal trade routes of the world, it is in a position to render peculiar services to Oceanographh. We refer here to the continuous record of the surface temperatures of the sea by recording thermographs, coincident with record of the temperature of the overlying air, and of the atmospheric barometric pressure to other records of temperature, and the collection of samples of the surface water as outlined above (Page).

7. United States Bureau of Standards.

This Bureau has no direct concern in Oceanography per se, but it is one of the most important factors in any estimate of the co-

operation to be expected from the Government for the reasons stated on page 120 . Prediction that it can and will render the assistance in instrumentation and in laboratory researches summarized above is based on the fact that these particular fields of service are expressly included among the principal activities of the Bureau as stated in its circular describing its general policy (Letter Circular 209, U. S. B. S. Sept. 24, 1926), and in a statement by the Acting Director.

Thus the perfection of new apparatus falls within the general development of devices in science and industry, this being one of the fields of research in which the Bureau is regularly engaged. Furthermore standardizations of thermometers and of other instruments are routine tasks of the sort the Bureau regularly carries on. 1. The qualification that such work shall not involve competition with commercial laboratories does not apply in the present case. The Bureau may refuse or postpone such work if it would delay more important projects. But the calls for assistance from any oceanographical institution would be relatively so few, and its need for the most authoritative standardization so great that the Bureau would not be likely to refuse its modest requests if reasonable time were allowed for the reports, and if the small fees for testing could be met.

8. United States Geological Survey.

The direct interest of this Survey in Oceanography is confined to the strictly geological aspect, and is further limited by the fact that the survey's own work is confined, by law, to the United States and dependencies. It has no ships or personnel for work at sea and can undertake no marine explorations of its own initiative. On the other hand, many geologic problems (Page) require information on such questions as the advance or erosion of shore lines, the distribution of sediments of terrigenous origin over the sea floor, and the relation of submarine deeps to nearby shores and islands. Therefore the Survey would always be interested in oceanographical projects that included studies of sedimentation and of the configuration of the bottom, especially over the shelf of the North American continent, of the Antilles, and of the Hawaiin and Philippine Archipelagoes. It is its concern in such questions that justifies the cooperation it can offer in laboratory facilities, etc. summarized above (Page 118).

9. United States Bureau of Soils.

The United States Bureau of Soils is in a position to assist in the study of submarine sediments by analyzing the mechanical composition of the samples, which must be done before microscopic examination can be undertaken: also, in ascertaining the amount of colloid material present by the methods developed in soil work.

As so often, however, the Bureau could not undertake any considerable amount of such work unless expenses are borne from some outside source, because its resources now are fully employed.

B STATE FISHERIES COMMISSIONS

1. Atlantic Coast.

The State Commissions of Fisheries on the Atlantic Coast are chiefly concerned with problems of regulation and patrol and have devoted only a small amount of attention to problems of oceanic biology. There is reason to believe, however, that several of these would gladly take part in a study of the biology of the fishes of their particular parts of the coast, if money were available. For example, the State Commission of Rhode Island has in the past carried out important studies of the fish fauna of that state. The State Commission of Maine is at present concerned with the status of the lobster along that part of the coast. The State of New Jersey has devoted considerable attention to the oyster in the Barnegat Bay region, and the State of Connecticut has within the past few years carried on investigations of the life history of the shad, while other instances of the same sort might be mentioned. At present, however, none of them maintain vessels fit for off-shore cruising, include oceanographers on their staffs, or regularly offer laboratory facilities. Consequently, no assistance can be expected from them in those respects.

2. Pacific Coast.

The importance of the fisheries to Californian industry, and the very serious decline which many of the individual fisheries have shown within the past few years have made the problem of oceanic biology imminent for that state. The Californian Commission, jointly with Stanford University, has recently undertaken an informal cooperative study of the oceanography, plankton and fish fauna of the Monterey region. This entrance into the field of general oceanography is evidence of the growing appreciation of the importance, even from the strictly economic side, of a thorough understanding of the life histories of important fishes if conservation is to be sane and effective. Personal contacts with its officials have convinced us that the Commission would gladly participate in any project bearing upon the oceanic biology along the Californian coast, if this did not clash seriously with its primary duties. But with its activities directed by the Legislature chiefly to economic aims, such as the statistical study of the trends of the several fisheries, it can only devote a small part of its income to scientific work the immediate worth of which cannot be demonstrated in economic terms. Furthermore, the Commission's boats are so fully occupied by patrol-duties that any considerable expansion of its oceanographic program would presuppose the addition of one or two vessels to its fleet; also provision of the money to operate them, either from the Legislature or from some outside source.

The Commission is not in a position to carry out extended cruises, because its boats are small, its patrol activities along the Californian coast being best and most economically prosecuted with vessels not more than 80 to 100 feet long. These, however, can work comfortably over the whole breadth of the Continental Shelf

along the coast of California and out over the slope, where knowledge (biologic, physical and chemical) is so scanty that anything done will prove valuable. And they are so economical of operation that it would not be difficult to raise the small sum to cover the cost of fuel for occasional trips of a week or two, whenever one of them could be spared from patrol.

From time to time the Commission could accomodate a student of some special local problem in its Laboratory at Terminal Island (Page 117).

In short, cooperation along the same lines and with the same limitations may be expected from this State Service within its own geographic sphere, on a small scale, as from the U. S. Bureau of Fisheries on a larger (Page 121). This, in fact, would be but a progressive development of its present activities.

C. CANADIAN ESTABLISHMENTS

1. Biological Board of Canada.

This board stands in fundamentally the same relationship to Oceanography as does the United States Bureau of Fisheries: it as constantly has oceanographic projects in effect, and the excellence of its investigations is internationally recognized. Many of its marine investigations,[1] as in the case of the Bureau of Fisheries, center around the biological problems of the Fisheries, but differences in organization leave the Board more free, than the Bureau, to carry on investigations in the more theoretic fields of oceanic biology, and in physical oceanography, the practical bearings of which may seem remote. In general, the board serves as official adviser to the Canadian government in all such matters. It maintains two marine biological laboratories, one at St. Andrews, N. B., one at Nanaimo, British Columbia, as well as fisheries laboratories at Halifax, Nova Scotia, and at Prince Rupert, B. C. In these biological laboratores a system has been developed by which students and instructors from Canadian colleges and universities actively participate in the investigations of the board, under such direction as the case demands. Special attention has, in fact, been directed to the laboratory method of attacking oceanographic problems, resulting in a type of cooperation with educational institutions that may well be taken as a model. For a summary of the vessel-operations of the board see Page 97 .

1. Its work in fresh water does not concern us here.

2. National Research Council of Canada

The proposed development of national laboratories by the National Research Council of Canada is mentioned on page . Up to the present time the participation of the council in oceanography has been confined chiefly to the appointment of a committee on the Pacific coast to cooperate with committees organized under the Pacific Science Association at its meeting in Japan in November, 1926.

3. Canadian Hydrographic Service.

This service, through its tidal and current survey, formerly carried out important studies of currents around the Canadian coasts. And while it has done little work of this sort during the past few years, plans are maturing for its resumption in the near future. The survey also plans to equip its survey steamers with the apparatus necessary for recording salinity and temperature in connection with their regular program of soundings.

4. Geological Survey of Canada

This Survey, like that of the United States, has neither ships nor personnel for work at sea, nor is it ever likely to participate actively in marine investigations because its fields of work lie primarily on land. Its staff, however, are interested in problems of marine sedimentation, etc., and we are informed by the director of the survey that its laboratory, library and other facilities at Ottawa will be freely available to any oceanographer. The Survey is also in a position to undertake some analytical work, the extent of this depending on its interest in each particular investigation. There is no regulation to prevent the Survey from accepting contributions from private sources, such as might be acceptable in case it partook of any investigation outside of Canada.

5. Canadian Department of Marine and Fisheries.

The fisheries branch of this department has contact with oceanographical investigations chiefly through its association with the Biological Board of Canada.

IV. SUMMARY.

The cooperation to be hoped from establishments of the Federal Governments as at present organized and financed in North America may be summarized as follows:

Detail of ships for special cruises, without contributory funds to meet the extra expense - - - - - - - - - - - - - - Negligible

Detail of ships for special cruises, the extra expense met by contributory funds - - - - - - - - - - - - - - - - - Considerable

Observations as incidental program on ships employed on other duties - Excellent

Detail of scientific personnel - - - - - - - - - - Slight

Expansion of present regular duties to include special oceanographic work - Negligible

Laboratory facilities on shore - - - - - - - - Excellent

Identification of biological specimens - - - Active

Analysis of marine sediments, of sea water, etc. Slight

Instrumentation - - - - - - - - - - - - - - - - - Very important

Chapter V.

PRESENT ACTIVITIES IN OCEANOGRAPHY IN EUROPE

I. INTRODUCTION

In this chapter we wish merely to emphasize the contrasts between present day Oceanography in Europe and in America. No attempt is made to present a detailed picture.

We have pointed out in an earlier chapter that Oceanography in America passed through a period of stagnation during the last years of the past century. Nothing of this sort happened in Europe where oceanographic investigations, developing in scope, have been actively prosecuted without a break, from the time when the "Challenger" expedition set the standard for such work, down to the outbreak of the World War. And during the years when America's participation in oceanographic exploration on the high seas[1] was confined to the cruises of a single ship (the "Albatross") European countries were sending out a succession of such expeditions to many seas, either strictly oceanographic in scope, or making oceanographic investigations incidental to other objects. To illustrate this continuity of investigation, it is only necessary to mention the expeditions of the "Pola" (Italian) in 1892-1898; of the "Fram" (Norwegian) 1893-1896; "Ingolf" (Danish) 1895-1896; "Valdivia" (German) 1898-1900; "Siboga" (Dutch) 1901-19; the several Antarctic expeditions of1901-1904; of the "Planet" (German) 1906-1907 and 1912-1913; of the "Thor" (Danish) 1908-1910; of the "Michael Sars" (Norwegian and British) 1910; of the "Deutschland" (German) 1911; of the "Dana" (Danish) 1920-1922; of the "Maude" (Norwegian) 1918-1925; of the "Meteor" (German) 1925-1927; and of the "Discovery" (British) in 1927-1928.

During this same period, not only were all the maritime nations of Europe stimulated to intensive studies of their home waters by the importance of fisheries in their economic lives, but there was an active development of marine biological laboratories around the coasts of Europe, either under the auspices of the state universities or of private scientists.

Oceanographic activities were, for the most part, suspended in Europe during the war, but soon resumed thereafter. And continuing interest in the problems of the sea has been made evident since then, not only by the activities of the several research institutions in their home waters (most of which managed to survive the years of stress), but also by renewed explorations of the oceans on a broader scale. As instances of the latter we may mention the recent voyage of the "Meteor" in the South Atlantic, the cruises recently carried out by the "Discovery" in the Antarctic, and the fact that a successor to that famous ship is now under construction in England.

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1. We omit reference here to bathymetric surveys carried out in connection with cable construction, or incidentally.

II. INSTITUTIONS NOW ACTIVE

A brief survey of the institutions in Europe that are now actively concerned in one or another phase of ocean study may help to illustrate the variety and volume of the work now being carried on from them. A list[1] recently published names upwards of 70 of these

1. Bull. 7. Section d'Oceanographique Conseil Internationale de Recherches: Union Geodesique et Geophysique Internationale in 1927.

in European countries.

A. INSTITUTIONS PRIMARILY FOR RESEARCH

These institutions are extremely diverse in their magnitudes and in the fields to which their activities are directed. We might first mention the Hydrographic Services that are maintained by all the important maritime nations, which in general carry on the same sorts of investigations as do the United States Coast and Geodetic Survey (Page134) and the United States Hydrographic Office, (Page128). Notable among these, for the extent to which they have advanced scientific knowledge of the sea, in addition to performing more strictly practical duties, are the British Admiralty, the German Marine Observatory (Deutsche Seewarte), and the French and Russian Hydrographic Services. The laboratories and offices of the Fisheries Services of the different nations form another group, those of Norway, Great Britain, Denmark, Germany, Holland, and France having contributed greatly to the theoretic problems of oceanic biology, as well as to those more directly concerned with the fisheries. Several European governments also maintain separate Hydrographic-biological establishments, expressly for investigations into basic problems in marine biology and ocean physics: the Swedish Hydrographic-biological Commission, the Danish Committee for the Exploration of the Sea, the Danish Biological Station, the Commission for the Scientific Investigation of German Seas, the Thalassographic Institute of Finland, the Royal Thalassographic Committee with its several branches in Italy, the Scientific Maritime Institute in Russia, and the Oceanographic Station of Salammbo in Tunis, make only a partial list. These establishments correspond more nearly in the scope of their activities, and in their organization to the Biological Board of Canada than to any other scientific Institution in America.

Independent or semi-independent oceanographical Institutions which are not under government control form another natural group: Here fall the Oceanographic Institute of Monaco which, during the lifetime of the late Prince Albert I (and since then) has been one of the most productive centers of activity in this field of science; the Institut fur Meereskunde of the University of Berlin, under whose auspices the "Meteor" expedition was carried out: likewise, the Geophysical Institute of Bergen, now an active center for ocean dynamics in particular. Several of the independent or university-supported European marine biological laboratories[1] also carry on re-

1. The account of the Biologic Stations of Europe published by Kofoid in 1910 (Bull. 4 for 1910, Whole number 440 U. S. Bureau of Education), is still generally applicable, most of these stations having survived the war.

gular station-programs of research in the basic fields of Oceanic biology, including chemical as well as Biological investigations. The Marine Biologic Station of the Marine Biological Association of the United Kingdom, at Plymouth, England, and the Station of the University of Liverpool at Port Erin, have been especially productive in this field. The Plymouth Laboratory, in fact, is now one of the most active of European centers of sea science and in many respects a present-day leader in investigations of this sort.

Another group as related to Oceanography would include the many other marine biological laboratories that dot the coasts of Europe. Even though they do not, as institutions carry station-programs of explorations at sea, their combined influence can hardly be over-valued in the general advance of sea science, because the purely biological work done at them during the last half of the 19th century (in embryology, physiology, etc.) laid the indispensable foundation for our modern views as to the cycle of life in the ocean. And they continue equally to serve in this respect today, by offering facilities to independent investigators for the study of problems for which the data can be obtained near at hand and which need the laboratory method for their prosecution.

One notable characteristic of present day oceanography in Europe, is, then, the translation of a widely disseminated interest in the sea into the development of a large number of institutions, not only designed to encourage researches in a wide variety of fields, biological, physical, and chemical, but in many cases actually endowed with the material means, and with the personnel requisite for that purpose.

Corresponding to the great number of institutions, the volume of work now being undertaken by them is correspondingly greater in Europe than in America: without making invidious comparisons the quality must be classed at least as high. To a lesser degree this development, which (as we now see it) is the climax of a process extending over more than half a century, has had its counterpart on a smaller scale in America.

B. COORDINATING INSTITUTIONS

A second outstanding characteristic of the present situation in oceanography in Europe, namely the establishment of an International and Official Agency with executive power to insure coordination of scientific effort between the fisheries Bureaux of the various European countries, has no direct parallel elsewhere. We refer to the Permanent International Council for the Exploration of the Sea, an institution that has been familiar (at least by name) to every student of the sea for the past quarter century.

1. International Council for the Exploration of the Sea.

With the multiplicity of agencies that were already in existence at the beginning of the present century (most of them well equipped and functioning actively) there was no lack of facilities in Europe for the study of whatever phase of the sea. But

it is certain that if these agencies (especially such of them as were maintained directly by the different governments) had continued to operate independently, each in part ignoring or perhaps envious of the program of the others, with all the rivalries, suspicions, and jealousies that so easily spring up between different nationalities, the advance of oceanography would have continued slow and spasmodic, especially in the synthetic fields in which new ideas were just then opening fresh vistas. But just when the need for general coordination in this science became most pressing, an impelling stimulus in that direction was provided by growing fears of depletion of the sea fisheries, coupled with growing appreciation of the obvious truth that it would be idle to seek remedial measures unless all the nations whose fisheries drew from the threatened areas would unite in joint examination of the existing status. It is not necessary to describe here the preliminary steps that finally crystallized in the establishment of the International Council for the Exploration of the Sea in 1902: and in the delegation to it of official authority strong enough to insure that the program of investigation on which the council decided should actually be carried out. In the annals of oceanography, this event may fairly be ranked with the inception of the "Challenger" expedition in its importance as a landmark of progress, because the policies of the Council have controlled the lines along which oceanography has since advanced in Northern Europe, to an extent that no other single institution can parallel.

This control has resulted from the fact that throughout its existence the Council has been entrusted with the duty of coordinating the scientific researches of the Fisheries Services to insure that the cruises of all shall correspond as to date, as to methods and as to subjects of study, etc; entrusted too, with allocating to each nation the part of the sea to be covered by it, and with choosing the fisheries problems for which each nation should be primarily responsible. The following list of nations that subscribe at present to the council shows how widely inclusive it is: Germany, Belgium, Denmark, Spain, France, Great Britain, Irish Free State, Italy Norway, Holland, Poland, Portugal, Sweden, Finland, and Latvia.[1]

1. During the life of the council there have been several changes in national membership, perhaps the most important being the disaffection of Russia since the revolution.

Corresponding to this widely inclusive international membership, the quarterly cruises have criss-crossed the seas north of Russia and from Norway out to Iceland, the Atlantic off Ireland, the North and Baltic Seas, and have been extended since the war to the Bay of Biscay. Thus a continuous record has been obtained of the physical state of the whole North Eastern Atlantic with its tributary seas, of the major seasonal fluctuations in the plankton, and of the distribution, migrations, etc. of fish eggs and larval fishes: not to mention the very extensive series of studies into the biology of various food fishes that the Council has stimulated.

The general and avowed aim of the Council being to develop rational exploration of the sea on a scientific basis, it has naturally followed that the individual membership consists chiefly of the directors and investigators of the European bureaux of fisheries.

The central office of the council, supported by grants from the different governments (in 1928-29 these government grants totalled 177,000 Danish kröner) and operating through a complex system of sub-committees[1], plans the general program, and allocates the work

1. The report of the Council for 1926 lists the following committees: Consultative, North Eastern Area, North Western Area, North Sea (with two divisions), Transition Area, Atlantic Slope, Hydrographical, Plankton, Statistical, Limnological, Editorial, Finance, Moray Firth, and Whaling.

as just stated. But the actual field projects are carried on by the Fisheries or other services of the several associated governments. As a rule these services have at their disposal medium sized steamers of 400-800 tons, which carry out quarterly cruises, sometimes acting as patrol vessels in addition. In some instances small naval vessels are assigned to the work of the council, while a few of the governments maintain vessels for this especial purpose, e.g. the Scottish "Explorer", the Portuguese "Albacora" and the Norwegian "Johan Hjort".

The scientific examination of the biological collections is also carried out for the most part by the government laboratories. But as physical oceanographers are seldom included within the staff of investigators in European fisheries services, it has frequently been necessary to relegate the discussion of physical data to scientists not directly connected with them, or with the council. In fact much of the physical material still remains to be worked up. The detailed results, especially those of the biologic investigations, are also published in many cases by the governments as official documents. But the central office of the Council itself maintains several series of periodicals for the publication both of raw data (statistical as to the fisheries, hydrographic, and lists of plankton) and of summaries and reports of progress for various aspects of the investigations. The Council has also paid much attention to developing improved apparatus, the need for which was especially pressing during the early years of its life, and to encouraging the use of standardized methods.

In general the executive machinery of the Council has proved excellently adapted for insuring a continuing program of study over large areas of the sea, by concerted international effort, and over a period long enough to outline the regular seasonal variations in the latter, as well as to show the smaller irregular fluctuations. It has also proved a highly successful way of accumulating a vast amount of raw data covering a wide range of marine problems, both physical and biological, as well as data concerning the life histories and economic relationships of the food fishes. But systematic analysis (especially the synthesis of results gained in different fields) has not kept pace with the accumulation of facts, illustrating the general rule that it is much easier to arrange for the collection of data at sea (which soon becomes a routine affair) than it is for the analytic study, by competent scientists, of the vast amount of material that soon accumulates when any joint project is carried on continuously over a term of years. To arrange that this

digestion shall proceed is one of the chief difficulties with which modern Oceanography is faced.

2. International Council for the Exploration of the Mediterranean Sea.

The administrative success that the International Council for the Exploration of the sea has enjoyed, and the leading role that it has played in Oceanography in Northern Europe, has recently led to the establishment of a less formal association of the nations bordering on the Mediterranean, known as the International Council for the Scientific Exploration of the Mediterranean Sea. This association, founded in 1919 under the leadership of the late Prince Albert I of Monaco, is not a replica of the older Permanent Council for the Exploration of the Sea in its organization, for it has no direct executive authority and makes no attempt to lay down definite programs for the several nations to carry out. Its aim is rather the exchange of information as to the work in progress by each and the encouragement of coordination, generally, between the different national services that actually have scientific investigations in progress in the Mediterranean. But as it is directly supported by the several governments, and since its individual membership (nominated by the subscribing governments) includes the directors of the Fisheries Services of most of the subscribing nations, it is in a position to exert very strong influence in the programs of marine investigations actually adopted. Thus, both in organization, and in actual practice, it corresponds closely to the North American Committee on Fisheries Investigation: an interesting example of parallel but independent development, to fulfill similar needs for international coordination. Although this Council is still in the formative stage, some joint projects have already been arranged, both in the biological and in the more strictly oceanographic fields: and it performs a real service in its annual reports, by summarizing the progress of the scientific projects actually under way in the Mediterranean year by year.

3. International Hydrographic Bureau.

In this same general category, so far as organization is concerned, we may class the International Hydrographic Bureau, with headquarters at Monaco, an association of the National Hydrographic Services of most of the important maritime nations, which aims to coordinate the efforts of its signatories in the fields of hydrography, of tidal phenomena, and of physical oceanography, especially as effecting navigation. The Bureau does not of itself initate exploration. But the official standing of the national delegates to its meetings gives the recommendations of the latter much weight in the development of programs of investigation by the various governments.

4. Other Coordinating Institutions.

The coordinating institutions so far mentioned either exercise executive powers directly (as in the case of the Permanent International Council for the Exploration of the Sea) or indirectly as they influence the Marine Investigations of the governments through including the executive officers of the national fisheries

or hydrographic services in their membership. The years since the war have also seen the development of another type of institution in Europe (as in America), aiming to encourage oceanography in general and to urge cooperative effort in particular, but without any such authority to enforce its wishes. This type is exemplified in Europe by the Section on Oceanography of the International Geodetic and Geophysical Union, the latter a child of the International Research Council. The Section has sub-committees on tides, on the Atlantic, on the Pacific, on the Mediterranean, and on the unification of methods and instruments of Oceanography. But while it exercises some indirect influence by the discussions at its meetings, this influence has not been as great up to date as its rather pretentious organization might suggest. Its stated object is the coordination of the activities of the different countries, especially of the several international Commissions and Institutions active in marine investigation and the encouragement of the use of standard methods of research. Thus it corresponds more nearly to the corresponding subdivisions of the National Research Council in the United States, than to any other institution concerned with oceanography in America. At the present time its most active contributions may be expected to come from the proposed publication of an oceanographic encyclopedia, and of a yearly bibliography of oceanography. The Section held its first meeting in 1920; in 1927 its membership definitely included representatives from Belgium, Canada, the United States, France, Great Britain, Italy, Norway, and Sweden, while the national adherents to the parent Union numbered 32.

III. SUMMARY

From the material standpoint oceanography may then be described as in a much more active state in Europe than in America, with interest in this science much more widespread, especially among educational and research institutions. Corresponding to the larger number of institutions concerned with oceanography, a much larger number of professional openings exist in Europe for young men interested in the sciences of the sea, especially in the fields of fisheries biology.

We must point out, however, that the development of oceanography in Europe has been somewhat one-sided during the past quarter century, from the intellectual standpoint. This has been largely due to the dominating role played by the Permanent International Council for the Exploration of the Sea, the main object of which is to develop the sea fisheries on a scientific basis, and which consequently has tended to keep biologic problems in the foreground, often at the expense of the physical and chemical aspects of the sea that are the rational basis for a correct understanding of marine biology. In the regular investigations carried on by the fisheries services of the subscribing governments, the tendency has been to take up physical oceanography only to the extent that it may be expected to have direct bearing on fisheries problems, with the result that hydrographic data have not always been chosen most wisely for the solution of physical problems. Though the work of the International Council has contributed materially to the quantitative knowledge of the circulation of the waters off western and northern Europe, it would have contributed still more to the general understanding of the natural economy of those seas had the physical and

chemical features been given consideration equal to the biologic in the arrangement of the investigational programs.

The physical aspects of Oceanography have also long suffered to some extent in Europe, from another prevailing tendency (the origin of which we do not pretend to explain) to regard them as subservient to oceanic biology (Page 17) rather than to give them the importance that they deserve as a branch of geophysics.

Chapter VI.

HANDICAPS TO THE DEVELOPMENT OF OCEANOGRAPHY IN AMERICA AND BEST REMEDIES

I. HANDICAPS

Study of the ocean and its contents is amply justified for the various reasons we have attemtped to present in Chapter I , quite independent of the economic benefit that may reasonably be expected to accrue therefrom. The growing interest in Oceanography, reflected by the foundation, one after another, of a number of committees in various countries, aiming to further one or another branch of sea study, is evidence that scientists and laity alike are agreed as to this. Yet the actual progress that has been made in the study of the sea has not been commensurate with the importance of the subject, nor with the amount of energy that has been devoted, of late, to meetings, to discussions, to tentative plans and to propaganda in general.

That Oceanography as a distinct division of learning continues to lag is due to the fact that certain very definite obstacles, both material and intellectual, hamper its advance. One of the primary duties of this committee is, therefore, to consider the ways in which these most effectively can be overcome.

These basic impediments have a two-fold source, being dependent upon (a) The fact that water is not man's native environment, and (b) Upon the great area of the sea and on the complex interrelationships of all the phenomena to be studied therein.

The fact that it is necessary to study the majority of oceanic events and phenomena, whether physical, geologic, or biologic, actually within the sea, imposes very practical limitations. Being a terrestrial, not an aquatic mammal, man cannot venture at all upon the sea, much less descend into it and live, without expensive mechanical means of transportation. The biologist who turns to marine animals simply for convenience, can pick up many things of interest on a stroll along the tide line, but to investigate any phase of the ocean he must have a boat. If he is to venture out more than a mile or two from the land, his boat must be large enough to contain living quarters and to navigate safely in all weathers. Even if his investigation be of a sort that can be carried on in a laboratory on shore, his raw data must be gathered at sea. And it is our duty to emphasize that Oceanography is impossible unless someone does go to sea, whether for short trips or for long. That is to say, for one man to gather information of any kind about the ocean, requires labors of many men, reflected in the provision of a seagoing craft with a crew to man her, with supplies for their subsistence, also (in these days) with fuel for her propulsion. And as any craft larger than a row boat is a very expensive means of conveyance for a small number of passengers, it follows, without exception, that ex-

ploration into the economy of the high seas is and always must be a decidedly expensive undertaking.

Because of the unavoidable expense, only one of the several educational institutions in North America that include work in Oceanography as a recognized item in their permanent research programs regularly maintains and operates its own oceanographic research vessel: we refer to the Scripps Institution. Lacking their own boats for research, or, if they possess boats, lacking the means to operate them continuously, all the oceanographic investigations that have of late been undertaken independently by other educational institutions in America have necessarily been more or less isolated projects. This applies, for instance, to the expeditions recently sent out by the New York Zoological Society and by the Museum of Comparative Zoology; likewise to the present oceanographic program of the Carnegie Institution, so far as the sea work of the "Carnegie" is concerned (elsewhere).

To enable any of these institutions, or others like them, to carry on continuous programs of exploration at sea, without government assistance, special funds for the purpose would be needed, and corresponding additions to their scientific staffs. Lacking these, they must either confine their research activities to parts of the sea so close at hand that small boats will answer, or they must be content with occasional projects further afield that can be financed privately, unless they are able to arrange some scheme of cooperation with one of the several federal or dominion establishments whose duties include marine investigations of one sort or another.

At present the advance of Oceanography in America is so largely dependent on cooperation of this last kind that our report includes a special chapter devoted to the possibilities now open in this field.

Although such cooperation, notably that between the Museum of Comparative Zoology and the United States Bureau of Fisheries, and between Canadian Universities and the Biological Board of Canada, has often proved highly productive, it has two serious limitations. First, as the Federal Government of the two countries are organized, continuity of effort over long periods, such as is required in many ocean investigations, cannot be assured. Second, the stress that all the governmental bureaux must lay on questions of direct economic importance makes it difficult for them to contribute materially to projects whose practical bearing seems remote, though it be agreed that their eventual significance may be great even if measured by dollars and cents.

As a practical proposition, the fact that only one of the marine laboratories in the United States, or in Canada, that are independent of the Federal Governments, is at present in a position to carry out periodic cruises in the open ocean in its offing, seriously limits the convenient headquarters for oceanic research off the North American coast. And while the laboratories of the United States Bureau of Fisheries and of the Biological Board of Canada are better off in this respect, the insistence that they must unavoidably lay on fisheries problems limits their freedom of scientific action when it comes to laying out the station programs. In short, the general conditions of the government services, as outlined else-

where, make it unlikely that they can lead in the attack on the underlying problems of the sea.

Oceanographic research below the surface of the sea also entail technical difficulties, because of the necessity of obtaining data of various kinds with delicate instruments at the end of a long wire, and from a base (the ship) which, ideally stationary, is actually drifting, often rolling and pitching: also because observations of various kinds, must be made with recording instruments, that must work under great pressures. All this results in an undue concentration of work close to shore, in particular sectors of the coastal waters, not always selected because of their scientific importance, but often for more practical reasons of convenience, accessibility, etc., leaving other sectors entirely untouched, though they may be more significant. It is difficult to see how this can be remedied under present conditions.

If one great need of Oceanography today is money, another is men. We doubt if it be generally realized that the number now professionally and primarily engaged in firsthand investigation of ocean problems in North America today, outside of the government surveys of the United States and of Canada, probably does not exceed fifty. It would be difficult to state the number of productive oceanographers within the governmental bureaux, because it is impossible to draw any definite line there between scientific investigators and technical recorders, tabulators or cartographers in the strictly navigational and fisheries fields. But thirty-five would probably include all who are now actively engaged on problems, not economic, in which the oceanic phase is paramount. While a considerable list of institutions concerned with one or another phase of Oceanography is mentioned in chapter III , most of these include only one or two oceanographers on their staffs, or none at all. So few, indeed, is the roster of investigators in Oceanography in the United States and in Canada, that if one drops from the ranks, some interesting project or another is handicapped, if not entirely put a stop to. This state of affairs is so apparent that there is no need of attempting to enumerate the professorships, curatorships, fellowships, now maintained, in this field in America. To do so would, in fact, require a special survey, so often does the title of a university chair fail to describe the scientific interests and activities of its incumbent.

The material and technical handicaps just mentioned, that limit single handed marine exploration to a very small scale except for the few financially fortunate, only account in part for the paucity of oceanographers: psychology must also be reckoned with. It is essential for the oceanographer to have an intimate firsthand acquaintance with the sea, because this alone can give him the mental appreciation of its vastness and of the complex inter-relation of its internal economics that he requires as the background for his detailed studies, no matter in what field these may fall. Therefore, he must spend some of his days out on the sea· often on a boat far too small for comfort, contending with rough seas, wet and cold: sea-sickness must be no bugbear to him, nor cramped quarters.

He must, in a word, be sea-minded, just as a forester must be forest minded. Furthermore, marine explorations at all ambitious are necessarily the work of a party whose efforts the oceanographer in charge must direct· therefore, he must have some of the qualities of leadership: it will be easier for him if he be seaman enough to lend a hand, when needed, and if he have some knowledge of navigation. Practical experience shows that these requirements of personality and especially of love for the sea will always limit the number of budding scientists from whose ranks the supply of oceanographers can be drawn.

Perhaps an even more serious limitation is the fact that there are very few professional openings for oceanographers in America, outside the government bureaux, whether in teaching or in research institutions. Consequently, but very few in each year can enter this field, however they might be disposed thereto. And, we think here not only of the teaching and research professions definitely announced as in "Oceanography", but of professorships in Biology, Geography, Chemistry, etc. whose tenants could devote their research abilities to ocean problems. Nor is the case much better in the government service, for in few cases are the incumbents of positions in the United States Hydrographic Office, United States Bureau of Fisheries, United States Coast and Geodetic Survey, or the Biological Board of Canada able to exercise that freedom of choice as to research problems that is prerequisite for orderly scientific progress.

The fact that American Universities, as a whole, offer few opportunities for instruction in the basic aspects of ocean geophysics, or in the oceanic phases of biology, is a fatal handicap, because today the American oceanographer must too largely be self-taught. This, furthermore, cuts two ways because, with so few students available, it seldom happens that any young student with training in the basic interrelationships of ocean science is available when an opening does come for research in some marine problem, making it usually necessary to turn to some chemist, physicist, or biologist who has never before given serious thought to this branch of geophysics or to any other. Thus the coordination of different disciplines that is needed, is apt to be seriously interfered with.

Another obstacle of an intellectual sort must be recognized. Perhaps any scientist would affirm that the manifold problems of the sea open attractive avenues for research. But if the individual investigator have vision he is apt to stand appalled at the complexity of the problems to which any marine investigation necessarily introduces him: appalled too, at the great extent of the area of sea that must be taken into account. He soon appreciates, also, that if he is to advance from observing and recording isolated phenomena to synthesizing and accounting for them in biological or geophysical terms, he must have more than an elementary acquaintance with widely diverse fields of science, and that this diversification must continue throughout his professional career.

For this reason fertile results in the more basic problems of Oceanography can be expected only through cooperation between indiv-

idual scientists specializing in different fields, between institutions with different facilities, and between nations fronting on different sectors of the ocean. The many international committees that have been organized of late prove that the necessity of this last type of cooperation is generally recognized.

It is in Oceanography, of all sciences, that coordination (to endure over long periods, to embrace simultaneously many subjects of study, and between agencies far apart) is the most vital, for an orderly advance of the whole. But this is difficult to establish.

On the Pacific Coast the Scripps Institution is rapidly developing into a centre of stimulus in this respect, while, as pointed out on page 107, the committee on the oceanography of the Pacific, of the Pacific Science association, has proved highly effective.

The American oceanographer also faces a difficulty when ready to publish his work--often highly technical--for only one scientific periodical, devoted especially to his subject, is published in America today, and that one being the vehicle for the work done at the Scripps Institution, would seldom, if ever, find space for contributions by outside investigators. The scattering of oceanographic papers in Biologic, Geologic, Geographic, Chemical, and Fisheries journals also hampers advance, by making it almost impossible for the individual student to keep abreast of the work of all his colleagues in various parts of the world. And, up to the present time, no complete bibliographic service has been available, although several international oceanographic commissions now have the publication of annual bibliographies in prospect.

II. POSSIBLE REMEDIES

Your committee has given much thought to the possible remedies for this state of affairs, and to the practical ways in which Oceanography can most effectively be supported and stimulated in America.

It is obvious from the preceding considerations that Oceanography in America is in great need of additional financial support if it is to progress in a degree at all commensurate with its general and economic importance. But at the same time, it is wasteful to spend the time and the energy of the few working oceanographers of America on "drives" for funds.

From the financial standpoint it does not seem practicable to deal with the entire field as a unit, but rather with certain key situations as specific projects.

The requirements of personality may always tend to limit the number of oceanographers, but much could be done to counteract the other factors that now act in the same way. We think especially of any means for enlarging the opportunities for instruction, and for multiplying the professional openings in sea-science in colleges, in universities, and in the seaside laboratories, through fellow-

ships, by the foundation of teaching or research chairs in the subject, or by in any way strengthening the oceanographic departments in the universities that now maintain such.

We would emphasize the importance of support via the universities, because we are convinced that with few exceptions sound advances in any field of knowledge can be expected only through them or through research institutions fed by their graduates. But some provision for field instruction in the technical procedure of the different subdivisions of Oceanography is also much to be desired, which can be provided only from some headquarters at the seaside. This requires a permanent institution that would furnish the example of actual investigations, carried on in fields chosen especially to show the real scientific fertility of ocean-research, and in localities chosen to illustrate the fact that truly important advances can often be made near land, with comparatively inexpensive boats and equipment: The same institution would serve also for the stimulation of oceanographic researches in other institutions, and for the development of cooperation between the several agencies already active in that field, private, governmental and international.

On geographical grounds, and because of existing institutional conditions, the Atlantic and Pacific coasts are best treated as separate provinces in this connection. On the Pacific coast, where there are several seaside laboratories already devoted wholly or in part to Oceanography, we believe the most effective course would be financially to assist and otherwise to strengthen these, combined with the establishment of some sort of inter-institutional board to serve as a clearing house for information, and to encourage cooperation between them.

On the Atlantic coast, where no laboratory has yet been established primarily for ocean researches, and where the degree to which the several marine biological laboratories can serve for headquarters is limited by the various factors already outlined, support could most effectively be given through the foundation of a central institution for Oceanography. We are convinced that in the long run, any such institution will benefit this science more by devoting its energies to supporting education, by planning its firsthand investigations to serve as examples, and by encouraging cooperation, than it could by spending its resources on a succession of expeditions, unless these resources were practically limitless.

Such an institution could most effectively serve oceanography in the following ways: (1) It should, itself, carry on field investigations in a wide variety of those fields of sea-science that lend themselves most directly to synthesis. If the institution be fitly located, allowing ready access to waters that illustrate a wide range of ocean phenomena, biological and physical (and the northeastern coast of North America offers an opportunity unrivalled in this respect), this can be done well on short periodic cruises with a small ship, cheap to operate. To this end, researches by its own staff and by visiting students from universities and from government institutions should constantly be encouraged as its most essential activity. It should maintain an oceanographic journal,

appearing monthly or quarterly, offering opportunity for prompt publication of the results of work carried on under its auspices: the Biological Bulletin published by the Marine Biological Laboratory at Woods Hole would be an excellent model.
(2) Through sub-stations it should include within its field of activity Arctic waters and the oceanic abyss, as well as the temperate coast waters that will naturally be most easily accessible from its headquarters.
(3) It should offer opportunity to visiting students for instruction in Oceanographic field methods, likewise opportunity to take active part in the boat work: it should offer laboratory facilities to them and should provide one or more fellowships to serve as an incentive to promising students.
(4) It should offer opportunities for research to all qualified investigators in oceanographic problems. To that end it should develop continuing relations with universities and scientific organizations, as headquarters for their summer work in this field. And it would be reasonable to expect that the special expense of such arrangements be met in large part by the institutions concerned.
(5) It should constantly make it a primary object to encourage the unification of effort that is needed, especially in America, if the study of the ocean is to advance with a just balance between its different parts, and to center on the parts of the ocean where basic problems can best obviously be attacked. Such support of cooperation will always be more a question of personality than of organization.

Such an institution may also be expected to attract the interest, and hence the support of private individuals interested in the ocean through yachting, or of corporations concerned with projects of oceanic meteorology, etc.

The time is ripe for the project just outlined. If a strong oceanographic institution can be established on the Atlantic coast, and those now existing on the Pacific coast be adequately strengthened, we believe that through their cooperation, the interests of oceanographic research in America will continue to receive needed attention in the future.

Chapter VII

PRINCIPLES THAT SHOULD DETERMINE THE TYPE OF ORGANIZATION FOR AN INSTITUTION FOR OCEANOGRAPHY IN EASTERN NORTH AMERICA.

The degree to which an oceanographical institution, supported by private funds, would actually forward the aims outlined in chapter VI, would largely depend on the details of its organization. It is, therefore, worth developing the principles on which the latter should be based, (a) as determining its relations with other institutions, and (b) as governing its own activities. The administrative systems by which these two phases of its activities would be controlled may, for convenience, be termed its external organization and its internal.

I. EXTERNAL ORGANIZATION

As the proposed institution would receive no financial support from the government, its external organization would be determined in the first place by entire freedom from any governmental control, and second, by the decision whether it were to be added as a new department to some existing institution, or whether it were to be founded as an independent entity. If the first of these alternatives were decided upon, precedents would naturally be sought among the semi-independent research laboratories, observatories, etc., that are maintained by various universities, though some new administrative development would be needed, to insure that the institution should serve its primary end of encouraging cooperation, and to guard against the danger of its becoming nothing more than an appendage of the larger body. The following discussion is based on the assumption of an entirely independent foundation.

In an independent institution of this sort it would be necessary to hold a just balance between two aims that might be sometimes conflicting,(1) to encourage the closest cooperation with other agencies engaged in oceanic research: but (2), at the same time to insure the permanent independence of the institution, lest it eventually become dominated by some one university, or group of universities.

In considering the advantages and disadvantages of various possible schemes of external organization for an independent institution, one would naturally turn, for possible models, to the existing establishments that now carry on marine investigation in various countries, were it not that the great majority of these are either governmental bureaux, pure and simple, or at least are largely supported by state grants, consequently are more or less controlled by the state in their activities. Thus all the Fisheries Services and Laboratories of the different maritime nations, all their Hydrographic Services, Naval Services, etc., are state establishments. In America this includes such outstanding examples as the United States Hydrographic Office, United States Coast Guard, United States Coast and Geodetic Survey, Biological Board of Canada, U. S. Bureau of Fisheries, Canadian Hydrographic Service, etc., it also includes all

like establishments in other countries.

The oceanographic undertakings sponsored by the International Council for the Exploration of the Sea, and by the International Council for the Scientific Exploration of the Mediterranean Sea, are likewise carried on wholly by the state services (chiefly by the Fisheries Services) of the subscribing nations. Such productive headquarters in other countries as the Commission for the Scientific Investigation of German Seas, the Danish Biological Station at Copenhagen, the Danish Commission for the Exploration of the Sea, the several Spanish Oceanographical Institutions, the Finnish Thalassographic Institute, all the Russian Scientific Establishments, and the Royal Italian Thalassographic Committee with its several subdivisions and laboratories, are also state-supported. The Geophysical Institute at Bergen, too, is closely associated with the government, for while connected with the Bergen Museum, its salaries and part of the current expenses are paid by the government, which also confirms the appointments to the staff, and exercises some control over the budget.

As the administrative organization of the institutions of this group all provide for some degree of control, either as to personnel or as to policies, by the state, it is obvious that they could not be taken as models in the present case. Hence, we need only add that out of 86 establishments outside of North America that are listed by the International Geodetic and Geophysical Union as occupied with the study of the seal, more than 60 are operated direct-

1. Bulletin 7, Conseil Internat. de Recherches. Union Geodesique et Geophysique Internationale.

ly as governmental establishments.

The remainder fall into two general groups: (a) departments of universities, whether state supported or private, and (b) independent or semi-independent establishments. Notable examples of the first of these groups are the Institut für Meereskunde in Berlin, the department of Oceanography and Port Erin Laboratory of the University of Liverpool, and several French Marine Biological Laboratories in Europe: the Scripps Institution for Oceanography of the University of California, the Hopkins Marine Station of Stanford University, the Marine Biological Laboratory of the University of Washington, and the Museum of Comparative Zoology of Harvard University in America. The dominance of each of these by its parent university puts them in a class as far apart from the proposed institution as are the state laboratories, so far as external organization is concerned.

It is among the independent (or semi-independent) Marine Laboratories or other institutions of America or Europe, that models may most reasonably be sought. The Naples Zoological Station: the Marine Biological Laboratory at Plymouth, England: the Millport Laboratory in Scotland: the Oceanographic Institute of Monaco: the Carnegie Institution of Washington: and the Marine Biological Laboratory at Woods Hole come at once to mind in this connection, either

because they have been productive from the oceanographic standpoint, or have been so successful from the institutional, that various of the more recently established laboratories have been modeled upon them. The first three of these, it is true, have derived the greater part of their annual budgets from state grants. But the state exercises so little influence on their operation that they can be fairly termed independent, so far as the present discussion is concerned.

These independent institutions exemplify three different types of organization. Until the operation of the Naples Station was interrupted by the War,1 it was not only a private institution, but

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1. Since the war the Naples Station has come under Italian Governmental control.

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was the property of its director, the only restrictions being those under which its site was granted to it by the Italian government. It was also wholly free from official connection with any other institution, and escaped all the misfortune of beaurocratic control, an annual report to the German Minister of foreign affairs being its only external obligation, although it received grants from various governments. Its international character was maintained (a) by the so-called table system, whereby institutions in various countries that subscribed toward the upkeep of the station, had the privilege of sending investigators there, and (b) by two advisory committees, a large and a small.

Obviously this type of organization carries its own danger, for success depends wholly upon the director, and upon the confidence felt in him by the scientific world at large. The fact that the continued existence, and wide usefulness of this pioneer station so long depended on the capability of its first director, and the difficult days through which it has passed since the war, forbids its adoption as a model in the present case.

A second type of organization is represented by endowed institutions, such as the Oceanographic Institute of Monaco, and the Carnegie Institution of Washington. The former with its beautiful Museum and its Paris branch, draws its support entirely from the endowments left it by the late Prince Albert I of Monaco. It is controlled by a small administrative council of six, with an advisory committee of 24 drawn from leading oceanographers of various nations, of which Prince Albert was president up to his death. This type of organization has been so successful, not only during the life of the founder, but since his death, as evidenced by the important oceanographic contributions appearing in three series of publications of the Institute, that it deserves special consideration. Its chief characteristic may be described as efficiency resulting from ownership and control by a few capable hands, combined with total independence of governments or other establishments, but with contact maintained with outside interests through its advisory committee.

The Carnegie Institution represents another type. Oceanography being only one of its several fields of activity. But the accomplishments of the Institution in this field, as in others, equally illustrate the successful accomplishments of a small and strong board, where the aim is first hand investigation, rather than the general cooperative encouragement of one or another branch of science. In this case the endowment is owned and controlled by a self-perpetuating board of not more than 27 trustees, holding office continuously, who appoint an executive committee of 7 for the actual administration of the affairs of the institution.

The aims of the three establishments so far discussed, Naples, Monaco, and the Carnegie Institution of Washington, differ somewhat from those for which we urge the foundation of the proposed institution. Thus, the purpose of the Naples Station in its heyday was simply to provide convenient laboratory facilities and materials for individual students working on whatever problems they may select; that of the Woods Hole Laboratory is the same with a program of instruction in addition: that of the Monaco Institution is to provide instruction by public lectures, to encourage researches by its own staff, and to publish the results: while the oceanographic program of the Carnegie Institute is strictly one of research. We doubt whether the corporate organization of either of the last two would provide for the encouragement of oceanographic contacts with other institutions, for enlisting their interest in the general field, and for developing cooperation between them to the extent that is needed, which is one of the chief objects for which the new institution is proposed, because no liaison with other institutions is provided for, nor are the boards of control large enough to keep close touch with oceanographers generally.

This phase seems better assured by the Plymouth and Woods Hole Laboratories, which (while differing fundamentally one from the other as shown below) agree in enlisting the material and moral support of the scientific communities of their respective countries by the large size, and broadly representative nature of the membership in the one case, and of the corporation in the other. Contrasting with the small committees of the institute of Monaco, and of the Carnegie Institute, the corporation of the Marine Biological Laboratory at Woods Hole numbered 310 in 1927, representing many universities and other institutions, while the several classes of membership of the Marine Biological Association of the United Kingdom (which owns and operates the Plymouth Laboratory) numbers 322. In neither case is there any numerical limit to membership.

There is, however, an essential difference in organization between these two laboratories, and one well worth weighing. In the case of Plymouth, which receives approximately two thirds of its funds from the government, its endowment being so small as to be negligible, the Ministry of Agriculture and Fisheries annually nominates one member of the governing council, ("Governors") which also includes members nominated by several insitutions that have made a specified contribution to the funds of the Society: also certain individual contributors. Thus not only the government, but the subscribing institutions as well, are in a position to influence the

operation of the Biological Station. And its by-laws are so framed that for all practical purposes, the council is a self-perpetuating body. The universities, etc. that subscribe to the support of the Marine Biological Laboratory at Woods Hole have, however, no such power to make nominations to the governing board ("Trustees"), all of whom are elected by the corporation of the laboratory. In this way entire control of the affairs of the institution is kept in the hands of the persons interested in its welfare as an independent institution, so that there is no danger of domination by any one university, or particular scientific coterie. There is also an essential difference in the two institutions in that the (Trustees) of the Woods Hole Laboratory administer a considerable endowment fund, but receive no financial support whatever from the government.

Each of these schemes has certain advantages: Woods Hole can can claim total independence of action, freedom from outside control, and equal opportunities for all universities to participate in the activities of the Laboratory: Plymouth can point to a definite program of research which has yielded rich fruit in various fields of Oceanography, and to stimulation of widespread interest in this general field of science.

The Woods Hole scheme has proved itself so admirably adapted to the conditions under which science operates in North America, that we recommend adopting it or some modification of it, rather than the Plymouth system, or the systems represented by the Monaco or Carnegie Insitutions, as the model for the external organization of the proposed institution, turning, however to Plymouth, in the case of the internal administration.

This implies putting the ownership of the institution in the hands of a broadly representative corporation, whose numbers may be expected to grow, with growing interest in the institution, and may eventually come to represent all the institutions in America that are actively concerned with the study of the sea. But the actual control of expenditure, and determination of policies must be delegated to a smaller board, of manageable size, elected from the general membership of the corporation.

II. INTERNAL ORGANIZATION

Whether an institute for Oceanography, with the aims here proposed, be founded as an independent institution or as a department of some existing laboratory or university, the factors which should determine its internal organization would be the same, the prime necessities, in either case being, (1) To Carry out the fundamental purposes of the institution and (2) To meet the technical requirements of the particular science--Oceanography--that is is proposed to serve. Because of this second requirement, the system that has been so successful at Naples, at Villefranche, and the Marine Biological Laboratory at Woods Hole would not be so effective in this case. At all these laboratories, and at various others of like scope, the institutional activities (apart from instruction, sale of specimens, etc.) are centered around providing laboratory facilities and the desired material for individual workers, most of whom are pursuing programs totally independent of one another.

Obviously such entire personal independence would prove much less fertile at an oceanographical institute, because the necessity of obtaining the raw data for the major oceanographic problems at sea from a boat confines the projects that could be undertaken at any one time to such as could be provided for, jointly, by the station's fleet. This means that the activities, not only of the staff of the institution, but of visiting investigators as well must, so far as major problems are concerned, be directed. And this would apply, in particular, to investigations involving the synthesis of various divisions of science, which it should be the special aim of the institution to foster. It is, therefore, essential that the internal organization provide for direction of the station program, at once efficient, sympathetic, and broad-minded. At the same time it should always encourage, and give every opportunity to, individual workers who might elect to attack, independently, any problems the data for which could be obtained from pier or small boats.

It must also be recognized that limitations of men, if not of money, would always prevent any one institution from adequately covering all phases of ocean science at one time: equally that it is impossible to foresee today what fields or general problems will be the ones that will seem the most pressing (and hence the ones to attract students) some years hence. Consequently it is of prime importance that the internal organization shall be fluid enough to allow evolution, or even sudden alteration of the station-program from time to time, as circumstances may dictate. Basic though the subjects may seem that most concern us today, such as the maintenance of chemical fertility and the dependence of plant growth thereon, the principles and the calculation of dynamic circulation, the factors that control the success of reproduction for fishes, or the chemistry of lime in the sea, we may be sure that the law of diminishing returns will presently begin to operate in all of these subjects; and in any others we might mention. And we may be equally sure that with the passage of time the intellectual leaders of oceanography will open new vistas--as yet unguessed--which the institution ought eagerly to follow, but which it can not follow if it has been organized around selected subjects, or if its staff has crystallized into determined fields.

Thus a real problem must be faced in providing for a Directorate rigid enough to carry out an effective program and to provide direction both authoritative and stimulating, but at the same time loose enough to insure the requisite fluidity. We believe that these requirements can only be met if the program of the institution be built up around men and projects, never around subjects. In our opinion, to divide the institution along departmental lines would in the long run be ruinous, even if it should apparently prove fertile in the beginning. The very essence of a successful institution in this field is that it be so free that it can be dominated at one time by one phase of the science, at another by another, as the state of Oceanography at the time shall determine.

Chapter VIII

CONSIDERATIONS THAT SHOULD GOVERN THE LOCATION OF AN OCEANOGRAPHIC INSTITUTION ON THE EAST COAST OF NORTH AMERICA

I. LOCATION OF THE CENTRAL INSTITUTION

Choice of the location for an oceanographic institution, founded with the aims set forth in Chapter VI, must be governed by intellectual, as well as by practical and geographic factors, these intellectual requirements being predicated on the thesis that productive research, in continued abundance can only be expected to come in studious and intellectually stimulating surroundings. Specifically, the requirements in this respect are:

(1) Convenient access to existing libraries covering all phases of Oceanography, essential because it would require many years for a new institution to accumulate an extensive and comprehensive library.

(2) Proximity to established laboratories of Physics, Chemistry, and Biology, to facilitate consultation, advice, etc., and for convenience in cooperative investigations, in which several fields of sciences are involved. Close association with other centers of scientific activity and general culture is also desirable for its stimulating effect. This can be met only near some one of the great educational centers.

(3) The climate must be favorable for intellectual work at all seasons of the year. Extremely hot summers would be a serious drawback.

Practical requirements, so obvious as to need no explanation are,

that living conditions be good and that some of the ammenities of modern social life be easily available. It is also essential that the station be within easy reach, by boat or by train, from the university cities of North America.

The station must be located on the shores of a protected and easily accessible harbor, from which the open sea can be reached in a short time: and it is highly desirable that the harbor should be ice-free the year round.

The station should be within easy reach of ship yards, marine supplies of all sorts, etc.

It must, on the one hand, lie outside the belt of tropical hurricanes, and on the other, at a latitude where the sea in the offing, as well as the harbor, is not seriously obstructed with ice in any season.

It must be located where a suitable site can be purchased at a reasonable price.

The chief geographic requirement is easy access to the greatest possible oceanographic diversity, so that the widest range of

problems can be attacked without long voyages. This means a location where the nearby waters offer a maximum variety of biological, physical, and chemical phenomena: it demands coastline and bottom varied in topography, with deep waters as well as shoal close at hand; with large rivers in the vicinity to illustrate the effects of great contrasts of salinity from fresh water to full ocean strength. It also implies a situation so far north that there is a wide seasonal variation, both in temperature, and in salinity, to offer material for studies on the relative effectiveness of different environmental determinants. It is most desirable that the nearby waters should also show a wide regional variation in circulation, especially in the degree of turbulence. And the vicinity of some one of the great ocean currents, especially if this differed widely in its physical characters from the local coast waters, would offer opportunities for important studies.

Allied to this last desideratum is that of reasonable proximity to the transition zone between coast and ocean waters, and to the edge of the continent, so that the deep basin can easily be reached. On the other hand, it is essential that the station be within easy reach of protected waters, as well as of exposed, to enable work of various sorts to be carried on from small boats in all weathers. The biologic phase can be served only if the local fauna and flora be rich and varied; and it would best be served in the vicinity of productive sea fisheries to provide mass material and data.

The requirement of convenience to educational centers at once bars any site on the Atlantic coast of North America to the north of Nova Scotia on the one hand, or to the south of the mouth of Chesapeake Bay on the other.

The practical and geographical requirements equally confine the choice to the mid-coast sector of the continent. Thus to the north of Nova Scotia ice would prevent, or at least hinder oceanographic work in winter and spring, while the inconvenience of access from inland parts of the continent would make it out of the question to establish the central institution either in the maritime provinces, in Newfoundland or anywhere to the north of the Gulf of St. Lawrence. On the other hand, the summer climate to the south of Chesapeake Bay is too hot: furthermore, this coast line is too monotonous to answer the specific requirements, no matter how desirable investigation of special problems there may be. And any site to the south of Cape Hatteras would fall within the hurricane belt, adding risk to work at sea during a large part of the year.

Within the sector between Chesapeake Bay and Nova Scotia, the intellectual requirements can be met only at some site within easy reach either of Washington, Baltimore, New York, Philadelphia or Boston. The first three, are, however, so far inland that they could not serve as convenient headquarters for the continuous explorations in the open sea that may be expected to prove one of the institution's most fertile activities; hence they may be eliminated without further comment. There would be obvious drawbacks to the choice of a site near New York, not only in the impossibility of procuring a satisfactory site with good anchorage, and with facilities for docks, etc. for a reasonable price, but (more fatal still) in the pollution of the local waters, as well as in the monotony of the coastline for

considerable distances in either direction. The geographic factor also argues against the vicinity of New Haven, or against any other site on Long Island Sound, both because of the considerable distance it would be necessary to run in order to reach the open sea, and because of the uniformity of conditions for considerable distances in both directions along that sector of the continental shelf.

It may be stated without further argument that the sector from Cape Cod to Halifax, Nova Scotia offers geographic advantages for such an institution that not only make it the logical choice on the American coastline, but which are unique for their general illustrative value. This results from the topography of the coastline, and of the neighboring parts of the continental shelf, as well as from the fact that in only one other region (around the Grand Banks of Newfoundland) is so sudden transition to be met from cold coastal waters on the one hand, to tropical oceanic on the other, or as great a contrast to be found as along the edge of this sector of the North American continent.

These contrasting waters include the so-called "Gulf Stream" (most discussed of ocean currents), typical coast and banks waters: an ice chilled spring current of coastal origin: the zone of manufacture for the so-called "slope water". And a few days sail brings one to the Labrador current, one of the best developed of the Arctic overflows. The ease with which the zones of transition from one kind of water to another can be reached from headquarters anywhere from Cape Cod to Halifax, and the fact that so few features dominate the local oceanographic situation, makes it easier here than perhaps anywhere else in the world to investigate the complicated experiments that are carried out by nature on a magnificent scale. We include not only the biological phenomena associated with the zones where waters of widely different character mix (phenomena reflected in the extraordinary richness of the animal communities and in the great productivity of the off shore fishing banks of this region), but also the opportunity to interpret internal hydro-dynamic forces in terms of circulation, opened here by the very wide variations in the specific gravity of the waters to be met within short distances. The wide variety as to the physical conditions of the waters, and as to the topography of the bottom, condensed into the small area of the Gulf of Maine and its vicinity, could hardly be matched elsewhere.

Here the student finds deep troughs freely open to the ocean: enclosed basins: a most varied coastline including deeply dissected bays, Archipelago Islands, and long sandy beaches: off shore banks of great extent which are the site of some of the most important fisheries of the world: and a straight steep oceanic slope to the abyss. Here, within short distances, he can trace the transition from regions of extreme turbulence to others where a high degree of stability develops in the summer. Here, too, he sees a wide seasonal range of temperature in some regions and depths, but in other regions and depths almost uniform conditions throughout the year. The absolute thermal range within this sector is from temperature below the freezing point of fresh water to values almost tropical: there is a wide variation in the fertility of the waters for pelagic plants as reflected by the duration of their periods of mass pro-

duction: a wide variation in the transparency of the water: and a wide variety in the nature of the sediments that clothe the sea floor. The faunal provinces accessible are correspondingly varied, both as to their bathymetric and as to their thermal relationships: while abundant material of a great variety of animal and plant species, planktonic as well as bottom dwelling, can easily be obtained, including the pelagic eggs and larvae of many fishes. In fact, there is hardly an oceanographic problem that cannot be hopefully attacked here, except those associated either with the tropical shallows, with the Arctic ice, or with mid-oceanic conditions: for these substations are needed.

The sector in question also meets the practical requirements of lying outside the tropical hurricane belt, but with the open sea ice-free in all seasons and with many of the harbors also kept ice-free by the strong tides, while the weather often allows oceanographic work to be carried on from small craft even in winter, as has already been proven by experience.

The selection of the most favorable site within the Cape Cod-Halifax sector would naturally be determined by practical and intellectual considerations in combination. On the whole these favor the vicinity of Boston for the following reasons: - (1) One of the most nearly complete collections of oceanographic literature is concentrated in the libraries of Boston and of Cambridge: (2) Two of the most important institutions now active in Oceanography, namely, the Woods Hole Laboratory of the U. S. Bureau of Fisheries, and the Museum of Comparative Zoology are within convenient reach: also the Marine Biological Laboratory at Woods Hole which (while not avowedly oceanographic in purpose) has long been the headquarters for marine biology on the Atlantic coast of North America: (3) The chemical, physical, geological, and mineralogical laboratories, also the Mathematic departments of Harvard University and of the Massachusetts Institute of Technology are conveniently available for consultation and assistance: (4) The mass landings of many species of sea fish in the great fishing ports of Boston and Gloucester would provide the raw data for a wide variety of fishery studies that could hardly be obtained in any different way.

While an oceanographical institution could be successfully and profitably maintained at any suitable site around the coastlines of the Gulf of Maine, of the Bay of Fundy, or of outer Nova Scotia, the choice of the precise site would naturally be governed by practical considerations to be weighed at the proper time, such, for instance, a convenient location for the station's own docks, good harborage, nearness to the open sea.

The fact that the Marine Biological Laboratory and the Laboratory of the United StatesBureau of Fisheries are already located at Woods Hole is a strong argument for also locating the proposed institution there. And the great and obvious advantages of close association with these centers of scientific activity seem to us to outweigh the objection to Woods Hole as the site, that might be urged on the score of distance from the open sea, and of isolation in winter.

II. LOCATION OF SUBSTATIONS.

The Sub-stations recommended on Page are proposed for investigations of special conditions, consequently the success of their operations would depend chiefly on the choice of suitable locations: in this case the geographic requirement is, therefore, paramount.

A. ARCTIC SUB-STATION

One of the most important problems, perhaps the most important, in oceanic biology is how temperature determines the distribution, and the various cyclic events in the lives of marine animals and plants. Therefore the behavior under controlled conditions, of the sorts of animals that are at home near the lower limit of temperature is as important as that of animals living near the upper limit. But no regular studies of low temperature biology in the sea are now in progress, in fact, none are feasible under existing auspices.

We also need to learn the character and biological economy of the Arctic waters as a whole, because of the extraordinary faunal richness of the regions where they meet the tropic waters, introducing much discussed problems such as the relative fertility of the two, the limitation of plant life in the Arctic by the amount of sunlight, and the causes of the association between plant flowerings and the melting of ice. The outstanding Arctic problem, from the standpoint of physical Oceanography, is the effect of melting ice in the general oceanic complex.

Problems such as these can be attacked only from some headquarters where truly Arctic and ice laden water is at hand. And the northeastern coast of North America offers an opportunity as unique in this respect as in others (Page 153), because nowhere else in the world does a major overflow from the Arctic Ocean, and one preserving those Arctic Characters unadulterated, closely skirt the coastline at latitudes so low, and near centers of population so large. The coasts of Europe offer nothing comparable, in this respect, to the Labrador current: neither does northwestern America or Asia in the north: Africa or Australia in the south. To match the Labrador current it would be necessary to turn to some Arctic or Antarctic coast, the fatal disadvantages of which, as the headquarters for a permanent oceanographic station, are too obvious to need comment.

The primary requirement that should determine the location of an Arctic sub-station on the east coast of North America is, then, ready access to the Labrador current: and a situation so far north that the latter retains its Arctic temperature.. Secondary requirements are (1) A good harbor protected from drift ice in summer, convenient to the open sea, but with sheltered water at hand: (2) Accessibility to waters of different thermal character and origin, (i.e. warmer) for comparative studies: (3) A reasonable degree of accessibility, by some regular commercial transportation line: one preferably in operation throughout the year. This last proviso we believe to be made more urgent by the fact that oceanographic studies around the Arctic margins have, as a rule, been confined to the summer season, emphasizing the need of learning the condition in

winter, whenever and wherever the state of the ice will allow this to be done in safety: (4) The general advantages of a settlement of some size are not as essential in this case as they are for the central headquarters, because living quarters can be constructed for the few investigators who would be apt to visit an Arctic Station, and arrangements can be made for supplies of all sorts to be forwarded. But, obviously, the operation of the station would be vastly facilitated if it could be located within reach of a port where ship supplies could be obtained, and repairs effected.

The Arctic requirement, combined with the requirement of accessibility, limits the choice of a feasible site to the sector extending northward from St. John, Newfoundland, to the vicinity of Battle Harbor on the outer coast of Labrador. In fact, this is the only coast-sector, anywhere in the northern hemisphere, that answers these requirements. This coast also has the further advantage of proximity to considerable depths, allowing a comparative study of the true polar water and of the deep bottom water at different seasons, which introduces problems of great general interest.

From the geographic standpoint, some one of the harbors at the northeastern entrance of the Strait of Belle Isle would be an especially favorable site, because closely skirted by the unadulterated polar current, on the one hand, while on the other this location would be within easy reach of warmer coastal waters within the Gulf of St. Lawrence. At present, regular steamboat communication is maintained to this region in summer, while some supplies and ships stores (including fuel oil) are obtainable at Battle Harbor: the last item is an especial advantage. But in winter the dog-sled is still the only certain means of communication with Quebec, making winter operation of a station on the shores of the Straits of Belle Isle practically out of the question.

The best alternative would be some one of the several harbors on the east coast of Newfoundland that are easily reached from St. Johns, where supplies of all kinds are to be had, and the general facilities of a large city. And while the Labrador current loses something of its purely Arctic character by the time it has drifted as far south as this in summer, the outer Newfoundland coast offers excellent opportunities for studying fiord conditions under very low temperatures, as for instance, in White Bay; equally for studying the contrasting conditions that develop in summer as the result of local warmings. The chief geographic advantage of this sector however, would be the possibility of working occasionally in winter as well as in summer, though ice and bad weather would always make winter work at sea uncertain and hazardous off the Newfoundland coast.

B. OCEANIC SUB-STATION.

If an oceanic sub-station is to serve its purpose it must be favorably situated for the study of problems that have to do with the abyssal water, and with mid-oceanic conditions generally. This would include the physiology and life histories of animals living under abyssal conditions of light, temperature, and pressure: the relationships between pelagic plants and the chemistry and physics

of the open sea, with their average abundance relative to the florae of coastal seas: the various problems of oceanic sedimentation: the role of bacteria in the deeps: the drift of the abyssal water and its chemistry, etc. The headquarters for such work must not only be within easy reach of great depths, but, equally, it must be so far out from the continental edge that it is not influenced by land drainage, by terrigenous sedimentation, by marginal circulation, or by the violent thermal alternations that are associated with the continental climates. At the same time, some small extent of shoal and protected water close at hand, seems almost indispensable so that comparative studies may be carried on. Therefore the ideal headquarters would not be an artificial island, anchored in mid-ocean, as some have suggested, but rather some small oceanic island rising steeply from the sea floor, but including shoal waters within its boundary reefs. This general requirement greatly restricts the choice of a suitable site in the Atlantic, as do administrative and residential requirements of the sorts that apply to other stations, such as need of a good harbor, reasonable accessibility, favorable climate, good living conditions, and a convenient source of supplies. A station founded, say, on St. Paul's rocks, or on the island of Ascension, would be doomed to failure from the start, though surely oceanic enough.

In the North Atlantic the choice would necessarily fall between some locality in the Azores, in the Canaries, in the Cape Verdes, in the Bahamas, in the Antilles, or in Bermuda. The requirement of accessibility would forbid the choice of any one of the first three of these Archipelagos as the site of a sub-station of an institution having its headquarters in North America. Furthermore, these three island groups all arise from plateaux so extensive that their own submarine topography considerably obscures the oceanic picture in their immediate vicinity. This applies equally to the whole Antillean arc. And while oceanographic conditions are made so interesting there by the relationship between submarine topography and ocean currents (likewise by the close vicinity of the deepest of the North Atlantic troughs) that a more fertile situation could hardly be found for special factual investigation, the climatic factor argues against the choice of an Antillean headquarters for a year-round station, as does the fact that this general region lies within the hurricane belt. These same drawbacks apply to the Bahamas region, similarly attractive though it be from the viewpoint of special investigations, especially as regards shoal water sedimentation, and lime deposition in tropic seas. And while very valuable investigations of various marine problems have been sponsored at the Tortugas laboratory of the Carnegie Institution, its situation within the Straits of Florida makes access to the ocean basin inconvenient and inexpensive.

On the whole, Bermuda seems to the committee the best situation in the North Atlantic for investigation into the phenomena that are fundamentally characteristic of the ocean basins. Its advantages may be summarized as follows:

(1) Its slopes rise so steeply from the sea floor that depths greater than 2000 fathoms are reached within a few miles from sheltered waters. This would make it possible to carry on serious investigations at great depths with small and inexpensive vessels.

And the fact that such work could be done in one-day trips would allow an advantageous unity between field and laboratory work.

(2) The Bermudan cone occupies so small an area that the fundamentally oceanic character of the neighboring waters is not disturbed thereby.

(3) There are two entirely submerged cones close to Bermuda, the "Argus" and "Challenger" banks.

(4) In spite of the precipitous nature of their slopes, the Bermudan reefs enclose a considerable and entirely protected area of shoal water, supporting a rich and varied fauna, and illustrating many phenomena of lime deposition, erosion, etc.

(5) There are several excellent harbors, and sites made almost ideal for laboratory purposes by their sheltered anchorage and convenience to the open sea.

(6) All the facilities of the city of Hamilton, with its shipyards, shops, etc. are at hand.

(7) The climate is mild, with no extremes, favoring work the year round, while living conditions are excellent with all the ammenities of modern civilization.

(8) Bermuda is conveniently reached by fast steamer from New York, and communication is good the year round.

(9) If the Bermuda biological station be reorganized, arrangements could probably be made for the proposed oceanographic substation to occupy part of its property at little or no expense; and this property is admirably located with its own small harbor. Proximity to a well equipped biological laboratory would be a decided advantage, especially in encouraging synthetic investigations involving both the biologic and physical aspects.

(10) The negotiations that have been carried on with regard to the reorganization of the Bermuda biological station have shown that the local government and population would welcome scientific activities on the island, which is a consideration of some importance.

Recommendations to accompany the Report of the Committee on Oceanography of the National Academy of Science as submitted to the Academy, November 18, 1929.

The outstanding feature of the oceanographic situation in the United States of America is that we face about equally on two great oceans, the Atlantic and the Pacific, each of which presents, in addition to the universal problems of the ocean, certain problems either peculiar to it or capable of more ready attack within it. Neither can be regarded as more important than the other from the point of view of oceanographic research. In the development of oceanography in America, therefore, equal attention should be paid to the needs of research from the Eastern and from the Western coasts.

In the preparation of the report herewith submitted to the Academy it has been possible to obtain a reasonably complete and clear picture of the present status of oceanographic research throughout the world, which would not be materially improved by farther study. The question of the requirements for the best development of oceanographic research in America, however, presents such a complex of factors, including the utilization of educational facilities in the universities, the creation of new agencies, and the correlation of all existing agencies in America with one another and with those of other countries, that no approach to completeness in the treatment of recommendations is now attempted. The following recommendations therefore concern only steps now clearly seen to be necessary for the furtherance of oceanographic research in America. They are presented with the understanding that the Committee desires to make additional recommendations at a future time.

On the Pacific coast the conditions and outlook for oceanographic research are at present better than on the Atlantic, owing to the activities of the Scripps Institution of Oceanography of the University of California located at La Jolla. The expanding needs and well considered program of future work of this institution, however, demand and should receive additional support at an early date. Oceanographic research on the Pacific coast is also aided in an important way by the recent additions to the program of the Hopkins Marine Station of Stanford University, located at Pacific Grove.

On the Atlantic coast the existing situation renders it desirable to center attention on the development of such a type of institution as would most fully meet the needs for oceanographic work in that region. At the present time there is no institution on the Atlantic coast committed to comprehensive oceanographic investigation, even though numerous agencies are concerned with various isolated aspects of the subject as parts of more immediate programs. There is need, therefore, on the Atlantic coast, of a new organization committed to oceanographic investigation as its

exclusive field; and this seems to the Committee to be the greatest need at the present time, both from the point of view of American Oceanography and also for adequate participation of this country in a study necessarily international.

A single well equipped oceanographic institution in a central location on the Atlantic Coast is needed to supply necessary facilities for research and education, hitherto lacking, and to encourage the establishment of oceanography as a university subject. Such a central institution would contribute to the advancement of oceanographic research not only by the productivity of its staff but also by the impetus that it would give to studies in this field in various universities. The proposed institute would also serve a most important purpose by providing facilities for visiting investigators, and by co-ordinating the scattered interests of numerous governmental agencies and private organizations already active in parts of the field. (Cf. Chs. III, IV of the report).

The central institution should be supplemented as soon as possible by two branch stations, one sub-arctic and the other truly oceanic in location. The latter location would be served admirably by the Bermuda Biological Station for Research, Inc., which has the support of the Committee in its efforts to complete its organization.

On account of the fundamental significance of oceanographic research for the world sciences of geophysics and biology, and also on account of the immense economic interests involved, the Committee believes that the establishment and endowment of an Atlantic Oceanographic Institute should be realized at the earliest possible moment. The present time also seems to be favorable for insuring the success of such an undertaking.