CHAPTER I

Introduction

Oceanography embraces all studies pertaining to the sea and integrates the knowledge gained in the marine sciences that deal with such subjects as the ocean boundaries and bottom topography, the physics and chemistry of sea water, the types of currents, and the many phases of marine biology. The close interrelation and mutual dependence of the single marine sciences have long been recognized. Thus, the first report, in 1902, of the administration of the International Council for the Study of the Sea, states:

> . . . it was seen from the beginning that the study of the physical conditions, of the chemical nature of the ocean waters, of the currents, etc., was of the greatest importance for the investigation of the problems connected with life, that on the other hand, the study of the floating organisms had particular worth for the solution of hydrographic problems, and consequently that a sharp line should never be drawn between these two main divisions. . . .

The same idea is expressed even more clearly in the prospectus which in 1908 accompanied the first number of the *Internationale Revue der gesamten Hydrobiologie und Hydrographie:*

> Above all, the editors recognize the necessity of a *synthesis of our biological and hydrographic-geological knowledge* of the waters. These two spheres of investigation are inseparable, since the water, whether as river, lake, or sea, is never a factor in the shaping of the earth without being also a medium for life, and, on the other hand, is never a medium for life without at the same time having an important influence in the shaping of the earth's surface.
>
> As the biology of the waters has now passed from the description of what is found therein to inquire into the causes and origins of the animal and plant life and the phenomena accompanying it, the absolute necessity has arisen for the biologist to really understand the nature of the separate waters, their physics and chemistry as well as their form and the history of their bed.

Since 1900, great advances have been made within all of the marine sciences, and the contacts between the special fields have become more and more intimate. The development is due partly to improved technique and partly to the application to the phenomena in nature of theoretical research and results of laboratory studies.

At the beginning of the twentieth century the distribution of land and sea was known with the exception of parts of the Arctic and the Antarctic, but now most coast lines are charted. The introduction of radio time signals has made possible the exact determination of longitudes and, thus, the correction of minor errors that previously could not be avoided. About twenty-five years ago, knowledge of the submarine topography was very scant, except in shallow-water areas of importance to navigation, where detailed soundings with lead and line could be made rapidly. Since a single sounding in deep water, say 6000 m or more, required several hours, however, such soundings were few and far between, and it was generally considered that the deep-sea bottom was a flat, monotonous plain devoid of rugged relief. In 1911, Fessenden made the first attempts to determine depths by sonic methods, and from about 1920 sonic depth finders have been in use with which soundings can be taken in a few seconds from a vessel running full speed. This new method has in a few years completely altered our concept of the topography of the ocean bottom. Basins and ridges, troughs and peaks have been discovered, and in many areas a bottom topography has been found as rugged as the topography of any mountain landscape.

The increased knowledge of the character of the bottom topography has greatly facilitated the understanding of the flow of the bottom water, and has helped toward explaining observed differences of hydrographic conditions in neighboring areas. Such differences, on the other hand, have been used for determining the height of barriers separating different basins in areas in which few soundings had been made.

Knowledge of bottom sediments has been advanced partly by the introduction of refined physical and chemical methods for the study of the fine-grained inorganic materials and partly by improved methods of obtaining long cores of bottom deposits and specimens of solid rock. The presence of stratification in core specimens from the open ocean has stimulated great interest in the processes controlling the character of the sediments and the rate of sedimentation. These advances have led to the rapid development of the science of submarine geology, which deals with the topographic features of the sea bottom, the agencies that have been active in the development of these features, the types and distribution of sediments, and the processes of sedimentation. The foundation for submarine geology was laid by Sir John Murray, who, with various co-workers, discussed the bottom samples of the *Challenger* Expedition, 1873–1876, and examined virtually all bottom samples collected prior to his death in 1914. The recent rapid development of interest and the application of new techniques is due mainly to American scientists such as Piggott, Revelle, Shepard, Stetson, and Vaughan, and to the German workers, Correns and Pratje.

Numerous problems within submarine geology cannot be studied properly without knowledge of the nature of ocean currents, the physics and chemistry of the sea water, the general character of the organisms that contribute to the marine sediments, and the transformative activities of the bacteria in the sediments. Thus, submarine geology is dependent upon the results of nearly every other marine science.

Within physical oceanography the study of waves and tides stands in a separate class, because theoretical investigations preceded the accumulation of information as to the exact character of the phenomena. Thus, the theory of surface waves was developed by Gerstner as early as 1802 and was improved by Stokes in 1847. In this early work, however, the water was considered to be an ideal fluid, and many results were more mathematically beautiful than practically applicable, but during the last decades studies, particularly by H. Jeffreys, have partly filled the gap between theory and observation.

Theories of tides were developed by Newton (1642–1727) and Laplace (1749–1827). Laplace's formulation of the problems is still valid, but the mathematical difficulties of the theory have not yet been overcome. In recent years notable advances toward the understanding of the tides have been made by the staff of the Liverpool Tidal Institute, headed by Proudman, which has solved fundamental problems for ocean basins of analytically defined geometrical shape, and by the Austrian School, notably Defant and Sterneck, which has used the principles of hydrodynamics in the studies of tides in bays of irregular form. American workers in the U. S. Coast and Geodetic Survey have made notable contributions in the analysis of observed tides and the prediction of tides in coastal areas.

A third type of waves, internal waves or boundary waves, was discussed by Stokes in 1847. The theory treated only the case of waves at the boundary of two ideal fluids of different density, but in 1904 it was successfully applied by Ekman to explain the phenomenon of "dead water." Subsequent observations indicated that other types of internal waves, generally of tidal periods, were present in the open ocean, and the study of these was greatly furthered by Fjeldstad's theory, which was advanced in 1933 and which deals with internal waves in a liquid whose density increases continuously with depth.

The physical properties of sea water can conveniently be divided into two groups: those that are independent of the ocean currents and of such impurities as suspended particles of inorganic or organic origin—for example, density, specific heat, osmotic pressure, and others; and those that depend upon currents and suspended particles—for example, eddy viscosity, conductivity, diffusion, and transparency. The properties in the first group were accurately determined at the beginning of the century, although still more refined measurements have been made in recent years. Examination of the properties of the second group is still in rapid development. In the study of the processes of diffusion, knowledge of certain results in marine biology is needed, because distributions of dissolved substances that are influenced by the activity of organisms are often examined. For the explanation of the observed transparency of sea water, biological processes have to be considered, because reduction of the transparency appears in part to be caused by dissolved substances produced by the marine organisms. Knowledge of the physical properties of sea water is essential, on the other hand, in many problems in the other marine sciences.

The general physical theories of ocean currents were developed at the beginning of the present century, notably by Scandinavian oceanographers. Helland-Hansen applied V. Bjerknes' theorem of circulation in a nonhomogenous fluid to the ocean, and Ekman developed the theory of wind-driven currents. The practical application of the Bjerknes theorem was made possible largely through the ingenuity of Fridtjof Nansen, who, about the year 1900, achieved increased accuracy of temperature and salinity determinations. Rossby and his collaborators in the United States have applied results from fluid mechanics to the dynamical problems of the sea. It cannot be foreseen to what extent these new ideas will modify the concepts of the dynamics of ocean currents, but Rossby's work has given new impetus to the theoretical and practical examination of the phenomena. The application of his and of the earlier theories has become increasingly important, owing to the rapid accumulation of temperature and salinity observations and of current measurements.

In the field of physical oceanography, the greater part of the theoretical and practical work can be conducted with little or no attention to results in other marine sciences. Occasionally, conclusions are tested by examining distributions of properties that are influenced by biological activity—for instance, the dissolved oxygen content—but often studies in physical oceanography can be carried out independently. For this reason several oceanographic institutions, such as the *Institut für Meereskunde* of the University of Berlin, and the Division for Oceanography at the Geophysical Institute, Bergen, Norway, are devoted to research within physical oceanography only, and for this same reason the International Association of Physical Oceanography exists as part of the International Union of Geodesy and Geophysics, and separate from other branches of oceanography. The linking of physical oceanography to the geophysical sciences is logical. Many problems, particularly those related to the dynamics of the atmosphere and the sea, are so similar in meteorology and physical oceanography that the theoretical approach is nearly identical. and the field dealing with the interaction between the atmosphere and the sea is of equal importance whether considered from the meteorological or the oceanographic point of view.

Although physical oceanography is to a great extent independent of the other marine sciences, its results are used extensively in marine biology and submarine geology. In marine biology it is necessary to know the physical and chemical characteristics of the medium in which the organisms live, the types of currents that may regulate the distribution of the organisms, the vertical motion that carries subsurface waters rich in plant nutrients toward the surface, the depth to which light penetrates, and so on. In submarine geology, knowledge of the large-scale ocean currents is needed for the study of dispersal of fine material brought into the sea by rivers; and information as to the currents at the bottom, their velocity, and their state of turbulence is required for an understanding of the character of sediments found in different localities and of the processes of sedimentation. Because of this wide application it is desirable that the physical oceanographer be acquainted with problems in other marine sciences in order to make his own conclusions better understood and more available to workers in other fields.

In the field of chemistry, the major constituents of the salts that are dissolved in sea water were accurately determined in the 1880's by Dittmar, and around 1900 the empirical relations between chlorinity, salinity, and density were established by Knudsen. These relations are of such importance to physical oceanography that the chemical methods for determining density are considered as necessary tools in that field. Later determinations of the major constituents have introduced only small changes in the early results, but refined methods of analysis have led to the detection of more and more elements in sea water, and in many instances have made possible accurate measurements of the amounts of these minor constituents.

In recent years, notable advances have been achieved in the development of rapid methods for determining the biologically important plant nutrients, and in this field the contacts between marine biology and the chemistry of sea water are so intimate that it is difficult to indicate where the biology stops and the chemistry begins. Concepts and results in physical chemistry have been especially useful in explaining the biologically important carbon dioxide system in the sea water. Important contributions have been made by Harvey, Atkins, and Cooper in Great Britain; Moberg, Rakestraw, and Thompson in the United States; by Wattenberg in Germany, and by Buch in Finland.

Early biological observations were naturally concerned mainly with the larger animals and plants obtainable by simple methods of collecting. This was true even as late as 1839, when Edward Forbes pioneered in the study of marine organisms in relation to their physical environment. It was then generally thought that life could not exist at great depths because of the adverse living conditions believed to prevail in very deep water. Later this idea of an "azoic zone" below about 600 m was abandoned as a result of positive discoveries of animals inhabiting the abyssal depths.

The realization that life is possible at all depths was of great biological interest, but the discovery of a community of floating microscopic organisms inhabiting the upper water strata was a vastly more significant one, as far as the economy of the sea is concerned. The use of townet and microscope in the study of this ubiquitous multitude of tiny drifting plants and animals of the sea was begun by Johannes Müller about 1846. In 1887 Victor Hensen applied the name *plankton* to this community and initiated the first quantitative studies. The discovery of plankton made possible an approach to the understanding of the economy of the sea as a whole, for it is the prolific production of this community of organisms that supports the larger forms of life and that is responsible for variations in the distribution of certain chemical elements in the sea.

Most of the older marine biological studies were of necessity chiefly exploratory and descriptive in nature, for only through systematic description and cataloguing of the myriads of forms could a foundation for future work be laid and tools for analysis provided. The descriptive studies must continue, but, as the taxonomic groups become defined and their structure becomes known, the need for such work diminishes and, especially in the better-known areas of the ocean, the emphasis has already shifted to questions of interrelations of the organisms with each other and with the inanimate environment. Near the close of the last century and at the beginning of the present, this point of view was given much impetus by many workers, among whom may be mentioned Brandt, Hjort, Gran, Johnstone, Lohmann, Johannes Schmidt, and Steuer in Europe, and Agassiz, Bigelow, Fraser, Kofoid, and Ritter in America. It is this view which has been carried forward to the present time.

The pressing need for elucidation of the many biological phenomena of the sea has been a motivating force not only in inspiring the application of known aspects of physical and chemical oceanography, but also in stimulating studies of such problems as penetration of light, viscosity, osmotic pressure, the carbon dioxide system, and especially researches on the biologically important elements. Conversely, the distribution and fluctuations of these elements are explicable only through the assistance of biological observations.

During the last decades, for which the trend in oceanographic research has been briefly reviewed, the knowledge of the oceans has been greatly increased. Prior to about 1900, deep-sea observations had been accumulated mainly on large-scale expeditions, foremost among which stands the expedition that represents the beginning of oceanography, the British

Challenger Expedition during the years 1873–1876. Around 1900 the establishment of permanent stations for marine studies gained speed, particularly in northwestern Europe, where the oceanographic investigations were carried out as an assistance to research dealing with fisheries problems of economic importance. Year by year oceanographic institutions and marine biological stations have been added all over the world to the existing stations, and well-equipped expeditions have been sent out, both prior to and after the World War of 1914–1918. Reference to the results from these expeditions will be made repeatedly in the following chapters.

A comprehensive review of the present status of oceanographic exploration and information on the location, history, and facilities of every establishment engaged in marine research was compiled by T. W. Vaughan and published in 1937 by the National Academy of Sciences under the title *International Aspects of Oceanography.* This book, together with H. B. Bigelow's *Oceanography, Its Scope, Problems, and Economic Importance*, published by the National Academy in 1931, summarizes the present facilities for oceanographic research and the aims toward which the work is directed. The development of the exploration of the sea is described in such books as Sir John Murray's *Summary of the Scientific Results of the "Challenger" Expedition of 1873–1876*, Murray and Hjort's *Depths of the Ocean*, and Herdman's *Founders of Oceanography*.

Our knowledge of the oceans is still fragmentary and inadequate. In the Pacific and Indian Oceans, large regions exist from which absolutely no information is available, and from most areas only general conditions in certain seasons of the year are known. Expeditions are needed for filling in gaps and for carrying out systematic exploration of regions from which only scattered data are available. The need is even greater for systematic work at sea by well-equipped oceanographic stations that will represent many of the marine sciences, so that findings in different fields can be correlated. Only through such correlation can the marine sciences become the unified science of Oceanography that was visualized at the time the International Council for the Study of the Sea was established.