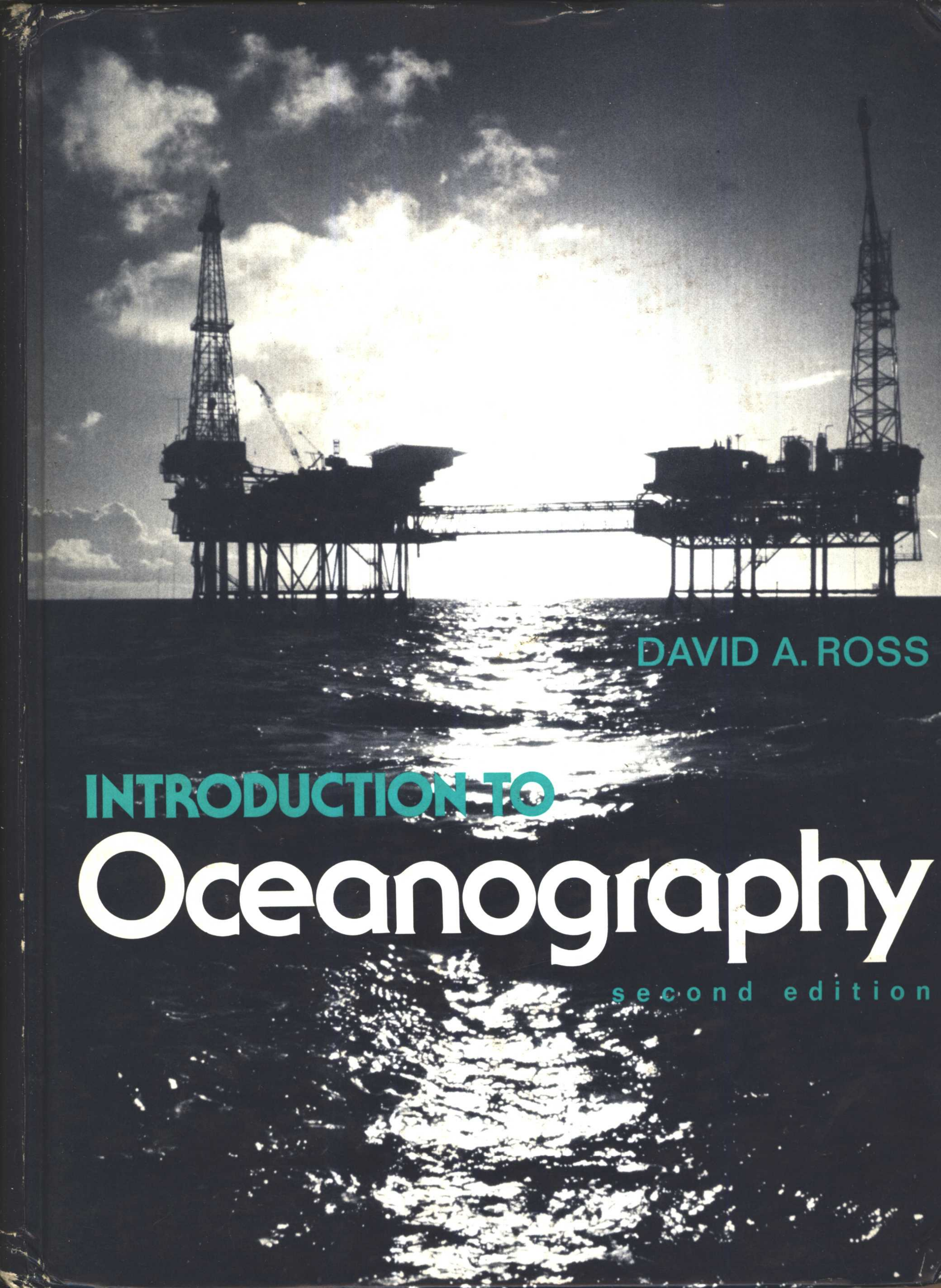
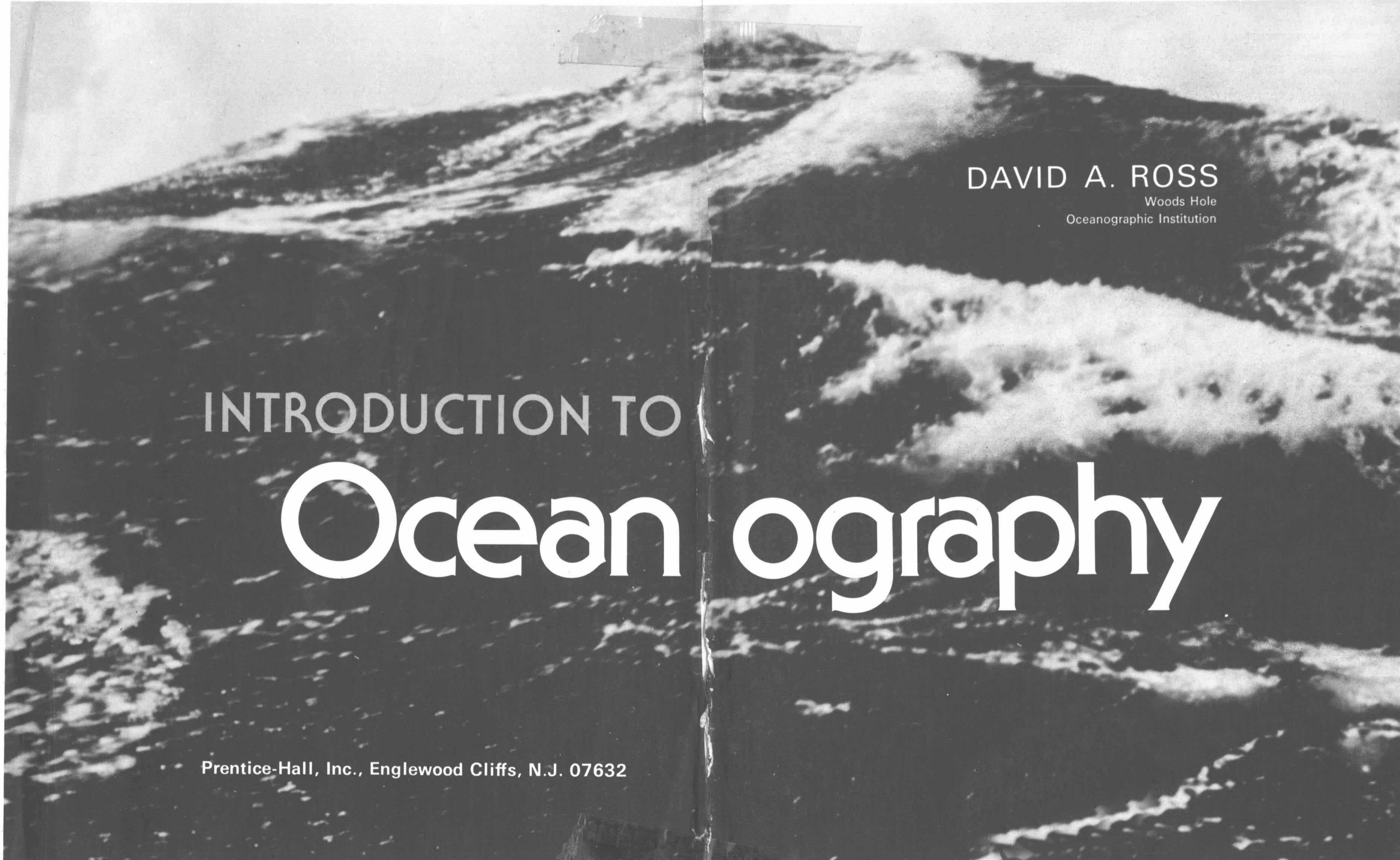


DAVID A. ROSS

INTRODUCTION TO Oceanography

second edition



INTRODUCTION TO Oceanography

DAVID A. ROSS
Woods Hole
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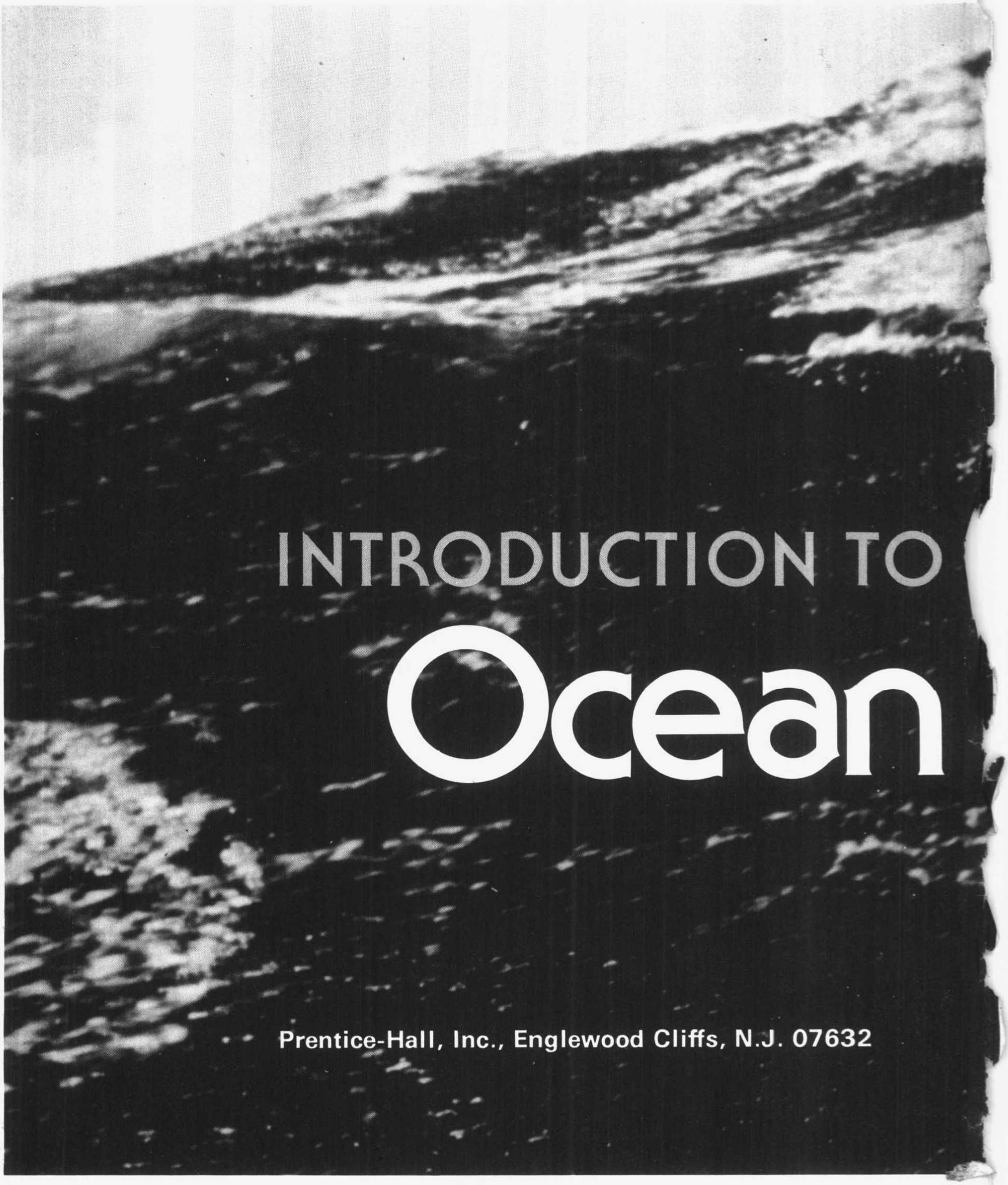

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title page	Seas breaking during a storm, photograph courtesy Woods Hole Oceanographic Institution.
chapter 1	The research vessel *Westward* in Labrador waters. This ship is used by the Sea Education Association of Woods Hole for training of young students. Photograph courtesy Dr. Peter Beamish.
2	Apollo astronaut exploring large rock on the moon. The Apollo 17 photograph was provided by the National Space Science Data Center.
3	Part of the Woods Hole Oceanographic Institution. Photograph courtesy Woods Hole Oceanographic Institution.
4	The deep submergence vessel *Alvin* in rough seas after returning from a dive. Photograph courtesy Woods Hole Oceanographic Institution.
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6	Electron microscope photograph of the coccolith *Emiliania huxleyi*. Each individual sphere is a separate organism and is about 4 microns in diameter. Photograph courtesy Dr. Sus Honjo.
7	Operations at sea during storm conditions. Photograph courtesy Benthos Corporation, North Falmouth, Mass.
8	Physiographic diagram of the North Atlantic Ocean. Photograph courtesy Aluminum Company of America (Alcoa).
9	The tanker *Torrey Canyon* aground off the southern coast of England. Photograph from Her Majesties' Stationary Office.
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11	Two offshore drilling platforms. Photograph courtesy Exxon Corporation.
cover	Two offshore drilling platforms. Photograph courtesy Exxon Corporation.

Preface

The field of oceanography has undergone several changes since I wrote the first edition of this book. One of the most important is the growing awareness of marine pollution and how it affects the coastal zone and ocean. Another development is the desire of many countries and industries to turn to the ocean for mineral resources, especially sources of energy such as oil and gas. The past dream of feeding much of the world's population from the sea has been somewhat abandoned, in part replaced by a dream to get more of the world's energy needs from the ocean. Finally, the last few years have witnessed an increasing legal interest in the ocean as the world's nations are claiming more and more of the sea floor. These claims have led to several Law of the Sea Conferences, which so far have failed to satisfactorily resolve the claims. Because of these developments, I have added two new chapters—Marine Pollution and The Law of the Sea—and I have rewritten the chapter on Marine Resources. The other chapters have all been updated to include much of the new scientific information of the last seven years. Over a hundred new figures have been added.

As before, I have attempted to describe and explain oceanography in a manner that is understandable to nonscientists. Since oceanography is the application of all science to the phenomenon of the ocean, I have tried to show the role of the separate scientific disciplines in the study of the ocean, but more important, how they interact. I have also discussed modern marine technology and mentioned some historical aspects of oceanography.

I have been very fortunate in having the opportunity to discuss aspects of this book with my colleagues at the Woods Hole Oceanographic Institution and elsewhere and would like to acknowledge this assistance. The number of people who have given me photographs and other material is too long to list here, but acknowledgment has been given in the appropriate places within the text. However, I wish to thank especially several people who have provided me with particularly large amounts of material; these include Robert Ballard, Vicky Briscoe, K. O. Emery, George Grice, George Hampson, Douglas Heath (Environmental Protection Agency), Charles Hollister, Susumu Honjo, Phyllis N. Laking, John M. Mason, Jr., and Leigh A. Stoecker.

Frank Medeiros, Donald Souza, and Vicky Briscoe have also been very helpful in assisting me in compiling the photographic material. A special degree of thanks and appreciation is due to Miss Francy Forrestel (now Mrs. Francy Zingale) who helped in almost all stages of preparation. In addition Mrs. Kathy J. Vermersch and Mrs. Donna Allison also assisted in various parts of the manuscript preparation. I wish also to thank Mr. William Grimshaw, Dr. Logan Campbell, Miss Zita de Schauensee, and Mrs. Lee Cohen of Prentice-Hall for their encouragement and help.

Finally, I would like to thank my wife Edith who, as with the first edition, encouraged me when I needed encouragement, helped me when I needed help, and left me alone when I needed privacy.

David A. Ross

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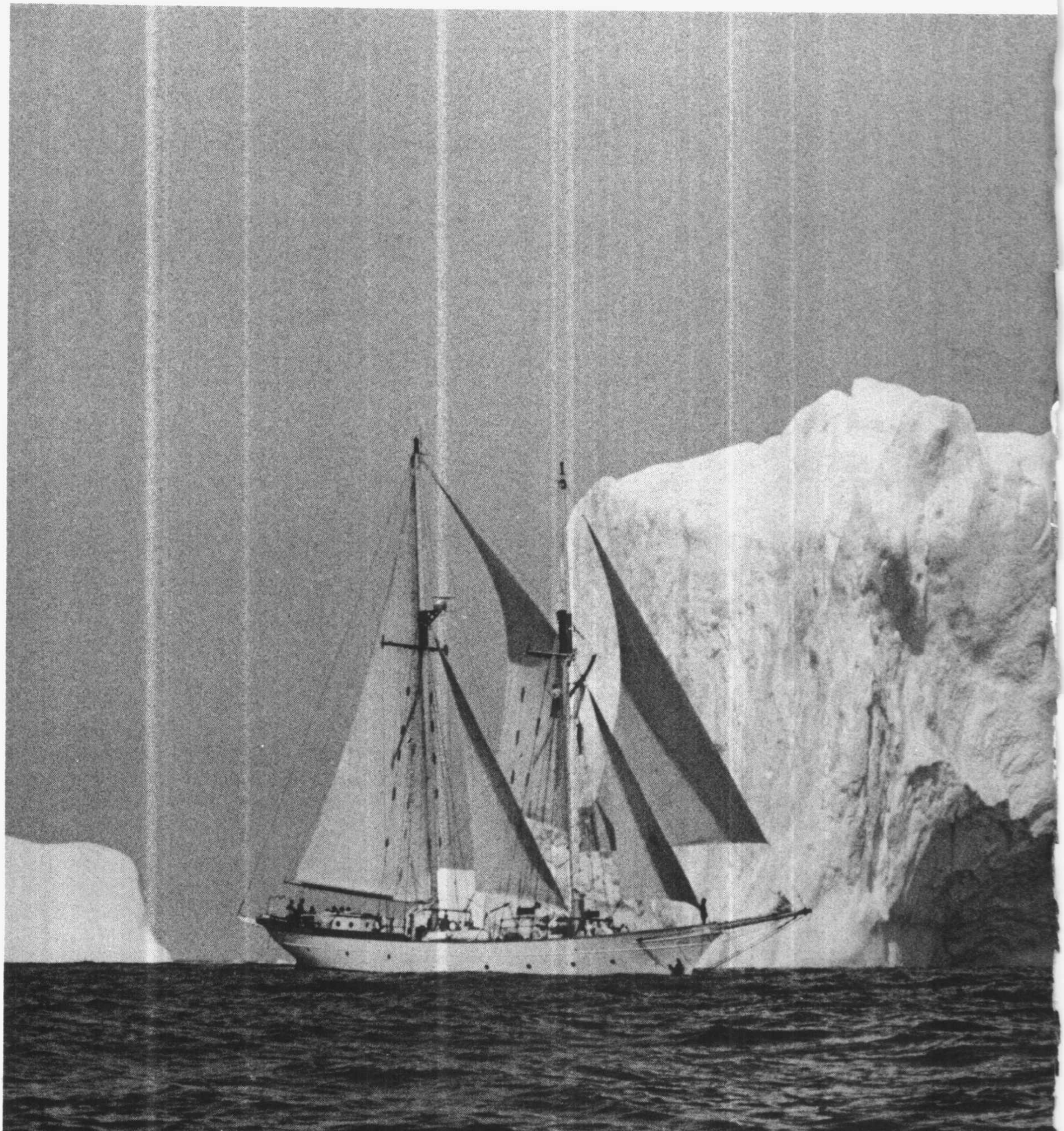

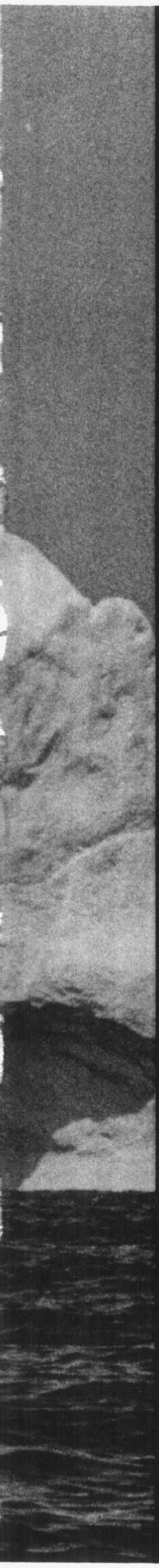

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Oceanography: The Science of the Ocean

The oceans are one of the last frontiers available to the human race. Even as we are slowly learning scientifically more and more about the marine environment, we are, according to many, polluting it beyond a level from which it may recover. In the political arena, many countries of the world are now anxiously dividing up the ocean to increase their share of its supposed resources. The food and oil shortages of recent years have also caused people to look toward the ocean for at least a partial solution to these problems. The answers and implications of all the above are not completely known by those people who study the ocean. The main objective of this book is to tell what we do know and what we can do.

What is oceanography? Many definitions are possible; a simple one is, *the application of all science to the phenomena of the ocean.* The key word in this definition is "all," for to truly understand the ocean and how it works, one must know something about almost all fields of science and their relationship to the marine environment. Thus, oceanography is not a single science but rather a combination of various sciences. Most oceanographers divide oceanography into four main parts: (1) chemical oceanography; (2) biological oceanography; (3) physical oceanography; and (4) geological oceanography, which includes marine geology and geophysics. In recent years a fifth and even sixth part of oceanography have developed. The fifth division is ocean engineering and the sixth is sometimes called marine policy.

The chemical oceanographer is concerned with chemical reactions that occur both in the ocean and on the sea floor. The biological oceanographer studies the distribution and environmental aspects of life in the ocean. Physical reactions, such as changes and motion of seawater, are included in the realm of the physical oceanographer. The marine geologist, or geological oceanographer, studies the sediments and topography of the ocean floor. The deeper structure of the ocean floor and its physical properties are the domain of the marine geophysicist. The ocean engineer is mainly concerned with the development of technology for oceanographic research and exploitation. The field of marine policy is not well-defined but is generally considered as the application of social and political sciences such as economics, law, and policy toward the use and management of the ocean.

Although these divisions seem to break oceanography up into neat little niches, in practice it is otherwise. For example, a marine geologist taking a sample of the sediment under the equatorial Pacific would obtain a sediment composed mainly of the shells of dead microscopic organisms. Most of these organisms lived in the surface waters more than 2 miles above the bottom. If samples were taken of the ocean bottom 100 miles north or south of the equator, the number of shells obtained would be considerably less. This is because unique physical conditions exist in the region of the equator, where the right combination of currents and winds keeps the water well mixed. The mixing, in turn, influences the chemistry of the water; nutrients that are necessary for the life cycle of the organisms are brought from depth to the surface where they can be used. Thus, these geological deposits on the sea floor are intimately influenced by the chemistry, physics, and biology of the water above.

This example suggests that perhaps the different divisions of oceanography are artificial and unnecessary since an oceanographer should be versed in all of these fields. Oceanography has advanced so rapidly, however, that it is nearly impossible for a scientist to be expert in all its aspects. Consequently, most oceanographers specialize in one or two of the divisions listed earlier. The reader should always remember that the divisions are not rigid and that the different fields are closely related.

In this book I treat biological oceanography, chemical oceanography, physical oceanography, and marine geology and geophysics in separate chapters. A detailed discussion of ocean engineering is beyond the scope of this book, but I have included a chapter on important oceanographic instrumentation. Marine policy is discussed in the sections on mineral resources, pollution, and law of the sea.

WHY STUDY OCEANOGRAPHY?

Now that we have defined oceanography we can consider some general aspects of the science; one is why does a person study oceanography? Clearly the ocean is a hostile environment that does not easily yield its secrets. This very secrecy, this lure and romance of the sea, has drawn many persons to oceanography. Equally enticing is the knowledge that water covers about 72 percent of the world, and people have always been interested in their environment and the depths of the ocean are no exception.

To the trained marine scientist the ocean may have the answer to some of man's important scientific questions and problems. Within the sediment layers of the ocean floor are recorded the geological and, in fossils, the biological history of the earth. Life on earth undoubtedly began in the ocean a few billion years ago, and since that time evolution has produced the vast quantities and varieties of life now found in the ocean. This abundance of life has been an important source of food for man for many centuries and holds the promise of solving some of today's food problems. Other biological products of the sea such as pearls or the shells of dead organisms have varied uses—some shells, for example, are especially valuable as building materials. The ocean is also an important source of commercially valuable chemical resources, including iodine, bromine, potassium, magnesium, manganese, and other elements. Desalinization of ocean water is yielding increasingly important amounts of freshwater in arid areas of the world. Sea-floor mineral accumulations, like phosphorite, manganese nodules, heavy-metal-rich muds, sand, and gravel, are valuable commodities that in some instances are already being exploited. Accumulations of oil and gas below the sea floor are important natural resources, supplying already almost 20 percent of the world's needs. Much of the solar energy that reaches the earth is stored in the ocean. This energy, when released, helps power the earth's atmospheric circulation. In this manner the ocean plays an important, but incompletely understood, role in influencing the weather and climatic patterns of the earth.

The ocean is necessary to commerce, communication, and national defense. Much of the trade between countries is carried by ships over the ocean; beneath the ocean are transoceanic cables linking the communication networks of many of the world's countries. The seas have been a battlefield for most of man's history, and some of today's oceanic research is concerned with national defense. Finally, the ocean is important for recreation; the sports of fishing, boating, water skiing, and scuba diving, as well as swimming, attract ever greater numbers of persons each year. This underscores one of the major problems facing man—pollution, which if not controlled can make some of these activities become things of the past.

OCEANOGRAPHY AS A CAREER

The modern oceanographer generally receives his training in one of two ways: either through formal graduate school training in oceanography or from an education in an associated scientific field. Because oceanography is the application of all science to the phenomena of the ocean, an aspiring oceanographer would do best to obtain a sound training in the basic sciences as an undergraduate and then to specialize in an aspect of oceanography in graduate school.

There are many universities and research laboratories where good training in oceanography is available. The four largest research institutions are Scripps Institution of Oceanography (Figure 3-6), Woods Hole Oceanographic Institution (Figure 3-7), School of Marine and Atmospheric Science of the University of Miami, and Lamont–Doherty Geological Observatory. These large institutions and others such as those associated with the University of Rhode Island, Texas A and M, Oregon State University, University of Hawaii, and the University of Washington usually emphasize deep-sea research. In smaller institutions, research is generally, although not always, directed toward more local, nearshore problems.

College graduates having a bachelor's degree in one of the associated sciences and wanting employment in marine science usually first work as laboratory or research assistants. Scientists with more advanced training or experience may have teaching or research positions. Whatever their training, most marine scientists spend part of their time at sea. Generally oceanographic cruises last from a few days to several months. Most of the time at sea is spent acquiring data, sometimes under adverse conditions.

Oceanographers are employed by universities, research laboratories, and the Federal Government. The Federal Government has several agencies engaged in marine science: the National Marine Fisheries Service; the Naval Oceanographic Office; NOAA, or the National Oceanic and Atmospheric Administration; and the United States Geological Survey, to name a few. The outlook for future employment in the field of oceanography is considered to be good, especially in environmental- and energy-related work.

The Federal Government, recognizing the increasing importance of oceanography, has established several long-range programs, such as the International Decade of Ocean Exploration and Sea Grant. The programs associated with the International Decade of Ocean Exploration encourage the participation of scientists from foreign countries in studies of worldwide oceanographic phenomena. The Sea Grant Program, a part of NOAA, is a combined effort involving education, research, and advisory services emphasizing marine resources. Participation in this program is not limited to marine scientists; it also involves interdisciplinary work involving lawyers, teachers, economists, and the like. The Sea Grant Program is similar in concept to the Land Grant Program initiated about 100 years ago that developed our national agricultural and engineering capabilities.

There are about 2,000 people in the United States that would qualify as trained marine scientists, or about 1 for every 100,000 of our population, a very small percentage indeed, especially when one considers that 72 percent of the earth's surface is covered by water.

Before we turn, in following chapters to the origin of the ocean, the history of oceanography, and oceanographic instrumentation, I will mention some terms and statistics commonly used in oceanography and some basic characteristics of the ocean.

TERMS AND STATISTICS

Oceanographers, for various reasons, use a confusing mixture of terms when discussing the ocean. The metric system, adopted by most scientists, is generally used in oceanography. This system is based on multiples of 10. The smallest unit we shall be concerned with is a micron (μ); 1,000 microns equal 1 millimeter (mm), 10 millimeters equal 1 centimeter (cm), 100 centimeters equal 1 meter (m), and 1,000 meters equal 1 kilometer (km). A kilometer is about 0.6 mile (Tables 1-1 and 1-2).

Depth is measure either in fathoms or in meters. A fathom is 6 feet (ft),