An Introduction to The World's Oceans

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Preface

This book is the result of many experiences. Lectures heard, books read, classes taught, and projects accomplished have all influenced our approach to the subject and our emphasis and choice of topics to be included. Our goals have been to write an introductory text on oceanography for the student without a background in mathematics, chemistry, physics, geology, or biology, and to emphasize the role of basic scientific principles in the processes that govern the oceans. To meet these goals we have chosen a descriptive approach. Emphasis has been placed on the physical and geological aspects of the oceans, which lend themselves to this method, while less emphasis has been given to the chemical and geochemical aspects, which require a more specific background of the student. A descriptive ecological approach has been used with the biological topics to integrate them with the other subjects in an effort to present oceanography as a cohesive, united study. Also, topics of current interest and practical concern are placed in the most appropriate chapter to maintain the continuity of the subject matter; for example, sea bed resources are considered with the geology of the ocean basins, and water quality is discussed with estuaries and fisheries with the biology chapters.

Both the student and the instructor will bring to this book their own knowledge and experience. The book is designed for a one-quarter or one-semester course, and it is expected that each instructor will emphasize and elaborate on some topics while skimming over or even deleting others. The lists of additional readings can help extend and enrich subjects as desired. Although our preference is for the order in which the topics are presented, we realize that not all will agree with us. Therefore, we have endeavored to make each chapter as self-sufficient and independent as possible, so that the order of study may be varied as desired.

As a book is the product of many experiences, it is also the product of people other than the authors. We owe much thanks to the reviewers of the original manuscript, William B. Harrison of Western Michigan University, Jere H. Lipps of the University of California at Davis, James McWhorter of Miami-Dade Community College, Barbara Nardin of Los Angeles Pierce College, Raymond Stanley of Florida State University, and John Wormuth of Texas A & M University; to our friends and colleagues, who answered questions and provided information; to the Addison-

Wesley staff, particularly Ron Pullins, Margaret Pinette, Art Ciccone, Bob Forget, and Nancy Kralowetz; and to our typists, Barbara Fulton, Su Fagerberg and Cathy Boyd Dayton. Without their coordinated efforts the completion of this volume would not have been possible. Again we thank you.

The oceans are controlled by fascinating, complex, and continuous processes. These processes are governed by nature but human actions can alter their results. Understanding these processes is necessary to maintain the ocean environment and to control human impact. We hope that this book will help you to gain such an understanding and to increase your appreciation for the unique planet on which you live.

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Prologue

Oceanography is a broad field, in which many sciences are focused on the common goal of understanding the oceans. Geology, geography, geophysics, physics, chemistry, mathematics, meteorology, botany, and zoology have all played roles in expanding our knowledge of the oceans. The field is so broad that oceanography today is usually broken down into four or more subdisciplines. Geological oceanography includes the study of the earth below the sea and the history of the processes that formed the ocean basins. Physical oceanography investigates how and why the oceans move; marine meteorology, which is the study of heat transfer and water cycles, is usually included here. Chemical oceanography studies the composition and history of the water, while biological oceanography concerns the marine organisms and the relationship between these organisms and the environment of the oceans. Ocean engineering is the discipline that designs and plans equipment and installations for use at sea.

The study of the oceans is promoted by intellectual and social forces as well as by our needs for marine resources, by trade and commerce, and by national security. Oceanography started slowly and informally; it began to develop as a modern science in the mid-1800s, and it has grown dramatically, if not explosively, in the last 40 years. Our progress toward the goal of understanding the oceans has been uneven, and it has frequently changed direction. The interests and needs of nations as well as the intellectual curiosity of scientists have controlled the rate at which we study the oceans, the methods we use to study it, and the precedence we give to certain areas of study. To gain some perspective on the current state of knowledge about the oceans, we need to know something of the history of oceanography: the events and the incentives that guided people's investigations of the oceans.

We know that early information about the oceans was collected mainly by explorers and traders. Around 1500 B.C. the Phoenicians, well known as excellent sailors and navigators, sailed out of the Mediterranean Sea and north along the Atlantic coast of Europe to trade in the British Isles. During the next thousand years the Arab traders explored the Indian Ocean, and the Polynesians made long voyages of discovery in the Pacific. While the Greeks traded and warred through-out the Mediterranean, they also asked themselves questions about the sea. Aristotle (384–322 B.C.) began to catalogue marine organisms. Eratosthenes (c. 265–194 B.C.) calculated the circumference of the earth and mapped his known world, and Pliny (c. 23–79 A.D.) related the phases of the moon to the tides and reported on the currents moving through the Strait of Gibraltar. Ptolemy, (c. 127–151 A.D.) produced the first world atlas and established world boundaries, including a great western ocean that reached around the earth to China and land boundaries on both sides of the Indian Ocean.

After Ptolemy, intellectual activity and scientific thought declined for about a thousand years. However, shipbuilding improved during this period; vessels became more seaworthy, and sailors extended their voyages. The mainly unrecorded voyages of the Vikings (700–1000 A.D.) colonized Iceland and Greenland and extended farther west to Vinland, or northeastern North America.

In the twelfth century, scholarship was reestablished. Arabic translations of early Greek studies were in turn translated into Latin and became available in northern Europe. By the 1300s Europeans had established successful trade routes, including some partial ocean crossings. An appreciation of the importance of navigational techniques grew as trade routes were extended. Prince Henry of Portugal founded a school of navigation in 1420. Although people feared the unknown oceans, their desire for the riches from new lands persuaded wealthy individuals to underwrite the costs of long voyages to all the oceans of the world.

The great age of discovery began when, in 1487, Bartholomeu Dias (1450?–1500) sailed round the Cape of Good Hope into the Indian Ocean looking for new and faster routes to the spices and silks of the east. Christopher Columbus (1451–1506) made four voyages across the Atlantic, believing he had found a way to the riches of Cathay, or China. Vasco da Gama (1469?–1524) journeyed south and east around the Cape of Good Hope to India searching for a sea route to the same lands. Vasco Núñez de Balboa (1475–1519) crossed the isthmus of Panama and found the Pacific Ocean, and in the same year Juan Ponce de Léon (1460?–1521) discovered Florida and the Florida current. Both claimed the new lands they found for their home countries. Although they had sailed for riches, not knowledge, news of their travels stimulated the sense of adventure in others. Ferdinand Magellan (1480?–1521) crossed the Pacific Ocean in 1520–1521, and his ship made the first circumnavigation of the earth. He even tried to test the depth of the Pacific with a hand line. By the latter half of the sixteenth century adventure and curiosity spurred on the efforts of Sir Martin Frobisher (1535?–1594), Henry Hudson (d. 1611), and others to find a northwest passage around North America. While European countries were setting up colonies and claiming new lands, Sir Francis Drake (1540?–1596) set out to show the English flag around the world. In 1580 he completed his journey and returned home with a cargo of Spanish gold, to be treated as a national hero. Queen Elizabeth I encouraged her sea captains' exploits as explorers and raiders because, when needed, their ships and their knowledge of the sea brought military victories as well as economic ones.

Although the practical needs of commerce, national security, and economic and political expansionism guided events at sea, during the same period on land scientists were beginning to show an interest in experimental science and the study of the specific properties of substances. Curiosity about the earth flourished. During the seventeenth century scientists wrote pamphlets and formed societies in which to discuss their discoveries. The works of Johannes Kepler (1571–1630) on planetary motion and those of Galileo Galilei (1564–1642) on mass, weight, and acceleration would be used to understand the oceans. Sir Isaac Newton (1642–1727) wrote his *Principia* in 1687, which gave the world the unifying law of gravity and an explanation of the processes governing the tides.

As colonies were established far away from their home countries and as trade and travel expanded, there was renewed interest in developing better charts and more accurate navigation techniques. Queen Anne of England authorized a public reward for a practical method of keeping time at sea in order to measure longitude. The first hydrographic office dedicated to mapping the oceans was established in France in 1770 and was followed in 1795 by the British Admiralty's appointment of a hydrographer. Captain James Cook (1728 – 1779) made his great voyage to chart the Pacific Ocean between 1776 and 1779. Cook's careful and accurate observations produced much valuable information and made him one of the founders of oceanography.

In the United States, Benjamin Franklin (1706–1790) became concerned about the time required for news and cargo to travel between Europe and America. In 1770 he had Captain Timothy Folger, a whaling captain from Nantucket, construct a chart of the Gulf Stream current. The chart was later published, and ships' captains were encouraged to sail within the Gulf Stream en route to Europe and to avoid it on the return passage. In 1802 Nathaniel Bowditch (1773–1838), another American, published the *New American Practical Navigator* and made the techniques of navigation available for the first time to every competent sailor. This book continues in print; its information is updated and expanded with each edition.

The United States government formed the Coast and Geodetic Survey in 1807 (now the National Ocean Survey) and the U.S. Naval Hydrographic Office in 1830 (now the U.S. Naval Oceanographic Office). Both were dedicated to exploring the oceans and producing better ocean charts. In 1842 Lieutenant Matthew F. Maury (1806–1873) was assigned to the Hydrographic Office. He began a systematic collection of wind and current data from ships' logs. From these data he produced the first atlases of sea conditions and sailing directions. His work was enormously successful, and as a result ships were able to take days off their sailing times between large ports around the world. In 1855 he wrote *The Physical Geography of the Sea.* Many consider this the first textbook on oceanography and consider Maury the first true oceanographer. Again, national commercial interests were the driving force behind the study of the oceans.

As charts became more accurate and as information about the oceans increased, the oceans captured the interest of naturalists and biologists. Baron

Alexander von Humboldt (1769–1859) made observations on a five-year cruise to South America, from 1799 to 1804. Charles Darwin (1809–1882) joined the survey ship H.M.S. *Beagle* as the ship's naturalist from 1831 to 1836. He described, collected, and classified organisms from the land and sea. His theory of atoll formation is still the accepted explanation. At approximately the same time another English naturalist, Edward Forbes (1815–1854), began a systematic survey of marine life around the British Isles and the Mediterranean and Aegean seas. Based on his observations, he proposed a system of ocean depth zones, each characterized by specific populations. His systematic attempt to make orderly predictions about the oceans makes him another candidate for the title of founder of oceanography. The investigation of the minute drifting plants and animals of the ocean was not seriously undertaken until the German scientist Johannes Müller (1801–1858) began his work in 1846. He used a fine mesh tow net to collect these organisms, which he examined microscopically. This work was pursued by Victor Hensen (1835–1924), who gave these minute sea organisms the name plankton in 1887.

The most important single oceanographic expedition ever undertaken was planned by the Circumnavigation Committee of the British Royal Society. The Society obtained the use of the naval corvette H.M.S. *Challenger*. The corvette's guns were removed, and the ship was refitted with laboratories, winches, and equipment. Wyville Thomson (1830–1882), a professor of natural history, was selected as the expedition's leader, and his assistant was a young geologist, John Murray (1841–1914). The *Challenger* sailed from Portsmouth, England, on December 21, 1872, for a voyage that was to last nearly three and a half years. The Challenger Expedition's purpose was scientific research, and during its voyage the vessel logged 113,000 km, took soundings at 361 ocean stations, collected deep-sea water samples, investigated deep water motion, and made temperature measurements at all depths. Thousands of biological and sea bottom samples were collected. On May 24, 1876, the *Challenger* returned to England; Queen Victoria conferred a knighthood on Thomson, and the Challenger Expedition was over.

The work of organizing and compiling information, however, was about to begin. It continued for 20 years, until the last of the 50-volume *Challenger Reports* was issued. John Murray (later Sir John Murray) edited the reports after Thomson's death and wrote many of them himself. He is considered the first geological oceanographer. William Dittmar (1833–1892) prepared the information on seawater chemistry for the *Challenger Reports*. He identified the elements present in the water and confirmed the findings of earlier chemists that in a seawater sample the proportion of the elements to each other is constant. Oceanography as a modern science is usually dated from the Challenger Expedition. The *Challenger Reports* laid the foundation for the science of oceanography.

The example of the Challenger Expedition stimulated other nations to mount ocean expeditions. Although their avowed purpose was the scientific exploration of the sea, national prestige was at stake in large measure. Norway explored the North Atlantic with the SS *Voringen* in the summers of 1876–1878; Germany studied the Baltic and North seas in the SS *Pomerania* in 1871 and 1872 and in the SS *Crache* in 1881, 1882, and 1884. The French government financed cruises by the *Travailleur* and the *Talisman* in the 1880s. The Austrian ship *Pola* worked in the Mediterranean and Red seas in the 1890s. The United States vessel *Enterprise* circumnavigated the earth between 1883 and 1886, as did Italian and Russian ships between 1886 and 1889.

During the latter years of the nineteenth century and the early years of the twentieth century, intellectual interest in the oceans increased. Theoretical models of ocean circulation and water movement were developed. Oceanography was changing from a descriptive science to a quantitative one. Oceanographic cruises now had the goal of testing hypotheses by gathering data. The Scandinavian oceanographers were particularly active in the study of water movement. One of them, Fridtjof Nansen (1861–1930), tested his ideas about the direction of ice drift in the Arctic by freezing his vessel, *Fram*, in the polar ice pack and drifting with it from 1893 to 1896.

Fluctuations in the abundance of commercial fish in the North Atlantic and adjacent seas and the effect of these changes on national fishing programs stimulated oceanographic research and international cooperation. As early as 1870 researchers began to realize their need for knowledge of ocean chemistry and physics in order to understand ocean biology. This understanding required the crossing of national boundaries, and in 1902 Germany, Russia, Great Britain, Holland, and the Scandinavian countries formed the International Council for the Exploration of the Sea (ICES) to coordinate and sponsor research in ocean fisheries.

Advances in the theory of oceanography sometimes could not interact with practical knowledge until new instruments and equipment were developed. Lord Kelvin (1824–1907) invented a tide-predicting machine in 1872 that made it possible to combine tidal theory with astronomic predictions to produce predicted tide tables. Deep-sea circulation could not be systematically explored until approximately 1910, when Nansen's water sampling bottles were combined with thermometers designed for deep-sea temperature recording, and when accurate methods for determining ocean water salinity were devised by the chemist Martin Knudsen (1871–1949). The reliable and accurate measurement of ocean depths had to wait until the development of the echo sounder, which was given its first extensive use on the 1925–1927 German cruise of the *Meteor* in the South Atlantic.

In the United States, government agencies related to the oceans had proliferated during the nineteenth century. These agencies were concerned with gathering information to further commerce, fisheries, and the Navy. After the Civil War, the replacement of sail by steam lessened government interest in studying winds and currents and in surveying the ocean floor. Private institutions and wealthy individuals took over the support of oceanography in the United States. Alexander Agassiz (1835–1910) financed a series of expeditions, and in the first 20 years of this century the Carnegie Institution funded a series of exploratory cruises. In 1927 the National Academy of Sciences established its first committee on oceanography, and in 1930 the Rockefeller Foundation allocated funds to stimulate programs in marine research. Oceanography in the United States began to move onto university campuses. In order to teach oceanography, the subject material had to be consolidated, and in 1942 *The Oceans* by Harald U. Sverdrup, Martin W. Johnson, and Richard H. Fleming was published. It captured between its covers nearly all the world's knowledge of oceanographic processes and trained a generation of ocean scientists.

Oceanography mushroomed during World War II, when practical problems had to be solved quickly. The United States and its allies needed to move men and materials by sea to remote locations, to predict ocean and shore conditions for amphibious landings, to know how explosives behaved in water, to chart beaches and harbors from aerial reconnaissance, and to find and destroy submarines. Academic studies ceased as oceanographers pooled their knowledge in a great national effort.

After the war oceanographers returned to their classrooms and laboratories with an array of new, sophisticated instruments, including radar, sonar, automated wave detectors, and temperature depth recorders. They also returned with large-scale government funding for research and education. The earth sciences in general and oceanography in particular blossomed during the 1950s. The numbers of scientists, students, educational programs, research institutes, and professional journals all increased. The Office of Naval Research (ONR) funded applied research programs and research vessels; the National Science Foundation (NSF) underwrote basic research; the Atomic Energy Commission (AEC) financed ocean work at the South Pacific atoll sites of atomic tests. International cooperation brought about the 1957–1958 International Geophysical Year (IGY) program, in which 67 nations cooperated to explore the seafloor and made discoveries that completely revolutionized geology and geophysics.

The decade of the 1960s brought giant strides in programs and equipment. As a direct result of the IGY exploration program, special research vessels and submersibles were built, and the Deep Sea Drilling Program, a cooperative venture between research institutions and universities, began to sample the earth's crust beneath the sea. Electronics developed by the space program were applied to ocean research. Computers went on board research vessels, and for the first time data could be sorted, analyzed, and interpreted at sea; experiments could be adjusted while in progress. Large-scale government funding allowed large-scale ocean experiments; ocean chemistry, water motion, and air-sea interaction were all studied by fleets of oceanographic vessels representing many institutions and nations. In these projects marine scientists shared their knowledge in the effort to understand the basic principles that control the oceans. The ability to predict ocean conditions depends on such knowledge.

During these years of expanding programs, earth scientists began to recognize the need for policy and management decisions to keep the planet from further degradation. Students were attracted to the marine sciences in record numbers, and marine policy programs and ocean management courses were added to curricula. As more and more nations were turning to the sea for food and as tech-

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nology was increasing our ability to harvest the sea, problems of dwindling fish stocks and the need for fishery management had to be faced as well.

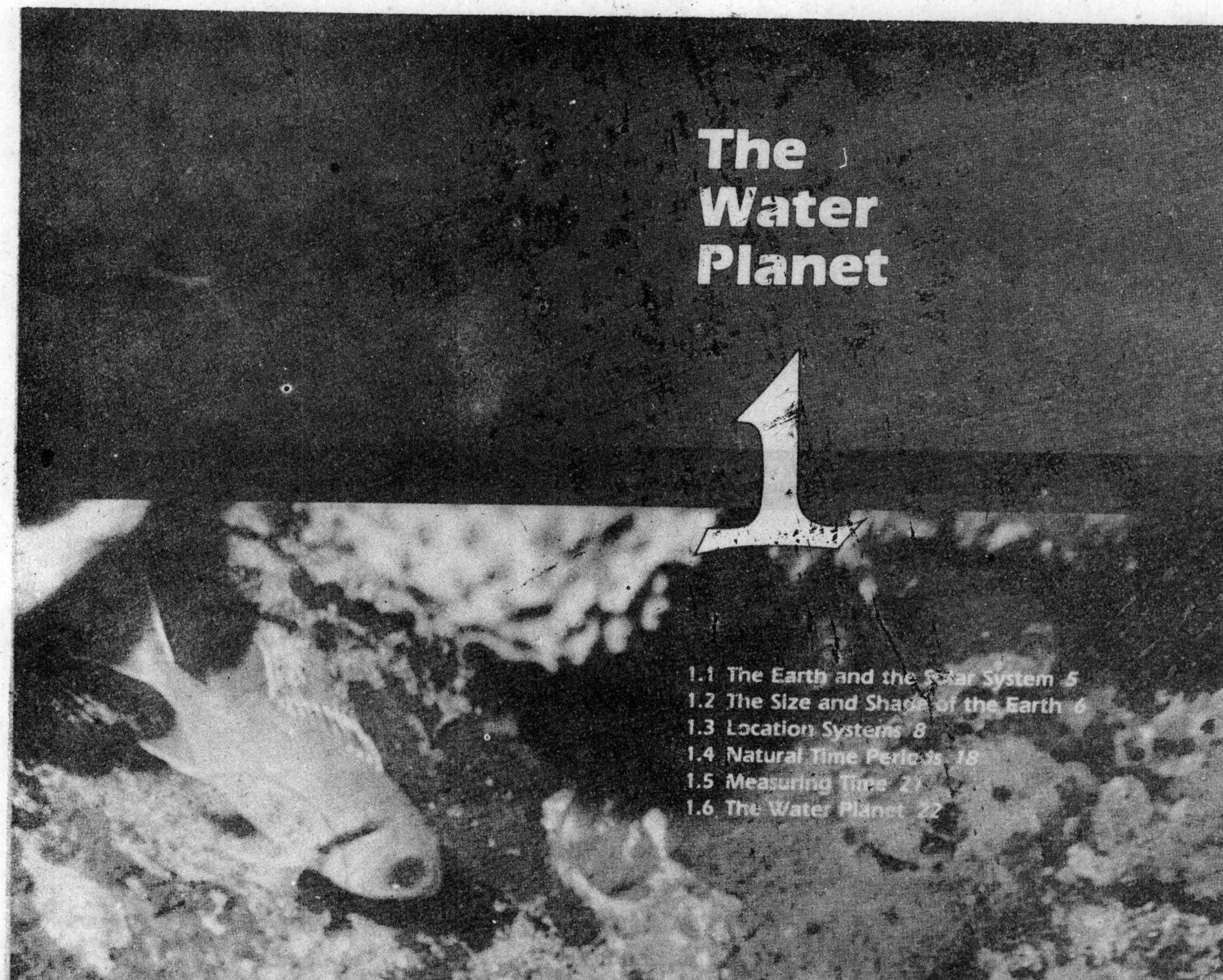
Oceanography in the 1970s was faced with sharp inflation, which translated into a reduction in funding for ships and basic research; nonetheless, the discovery of deep-sea hot water vents and their associated animal life and mineral deposits renewed the excitement over deep-sea biology, chemistry, geology, and ocean exploration in general. Instrumentation continued to become more sophisticated and expensive as deep-sea moorings and the remote sensing of the ocean by satellite became possible, while cooperation among institutions for ship time was closely monitored by cost-conscious scientists and funding agencies.

The targets for investigation in the 1980s and 1990s include the ocean's climate and circulation, the management of living and nonliving resources, the continental margins and the ocean seabed, the energy sources of the sea, methods of decreasing the cost of ocean transport, and food availability. At the same time, the use of refined sensors and techniques will allow scientists to continue to seek answers to the basic questions of how and why ocean processes occur and the relationship of these processes to sea resources and to ourselves.

The enormous increase in oceanographic information during the last 35 to 40 years presents problems for student, instructor, and textbook author alike, especially at the introductory level. There is too much information over too broad a subject area for any single textbook or course to cover, and therefore some things must be emphasized at the expense of others. In particular, the plant and animal life of the oceans is so rich, so varied, and so profuse that extreme selectivity is required. Entire books are written concerning waves, beach processes, currents, seawater chemistry, and the many other aspects of ocean science. You are encouraged to explore the suggested readings given at the end of this book or any other source that is available to you, so as to follow your interests in greater depth.

In this textbook, you will find that the emphasis has been placed on basic scientific principles, illustrated when possible by the findings of recent research. Our intent is to help you build an understanding of ocean processes in time and space, integrating physical, chemical, geological and biological principles. We hope that at the end of your introductory study you will have gained a perspective of the oceans as a dynamic system and an appreciation of the oceans' complexity and their relationship to your land environment.

Abridged Contents



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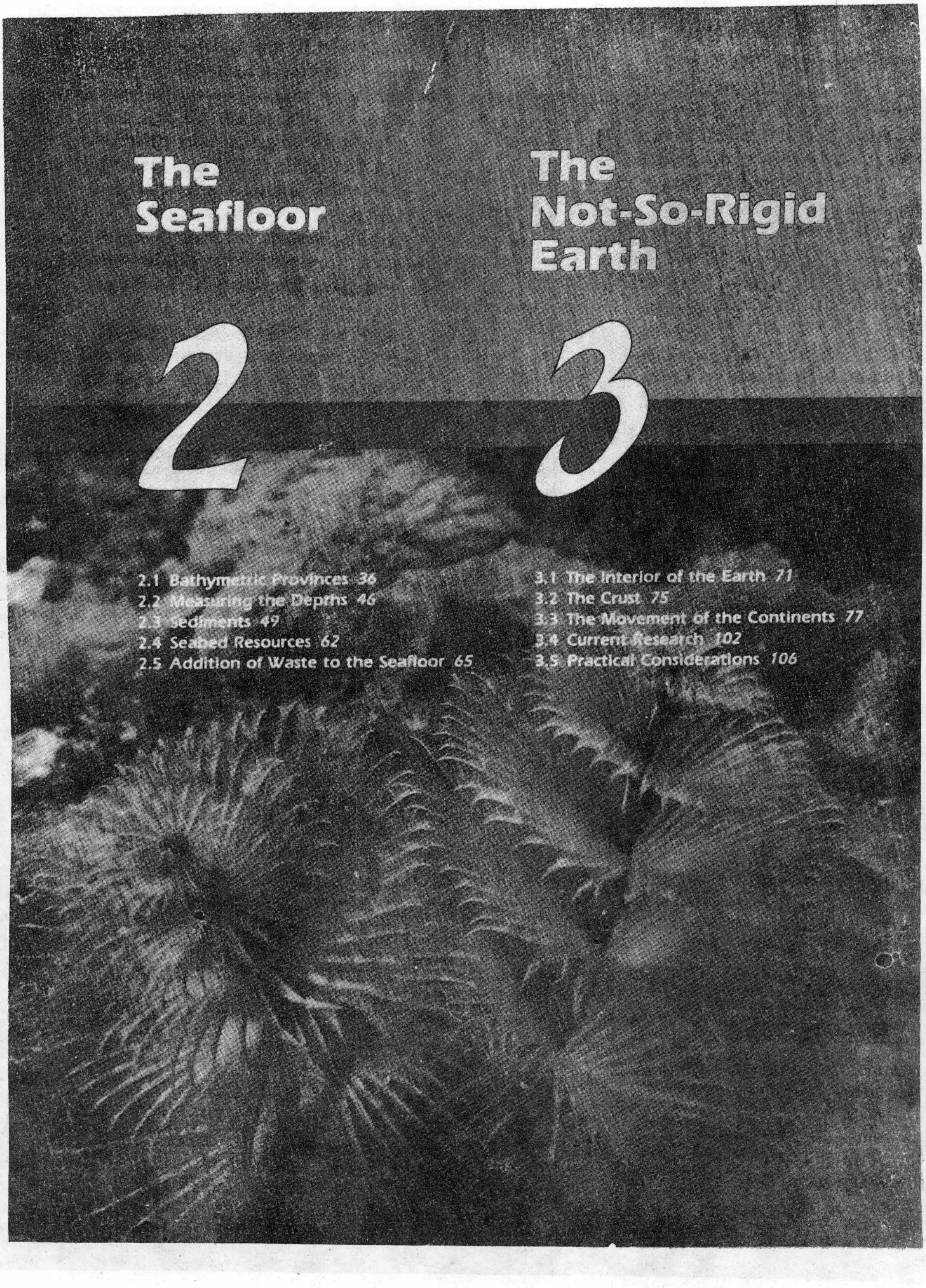

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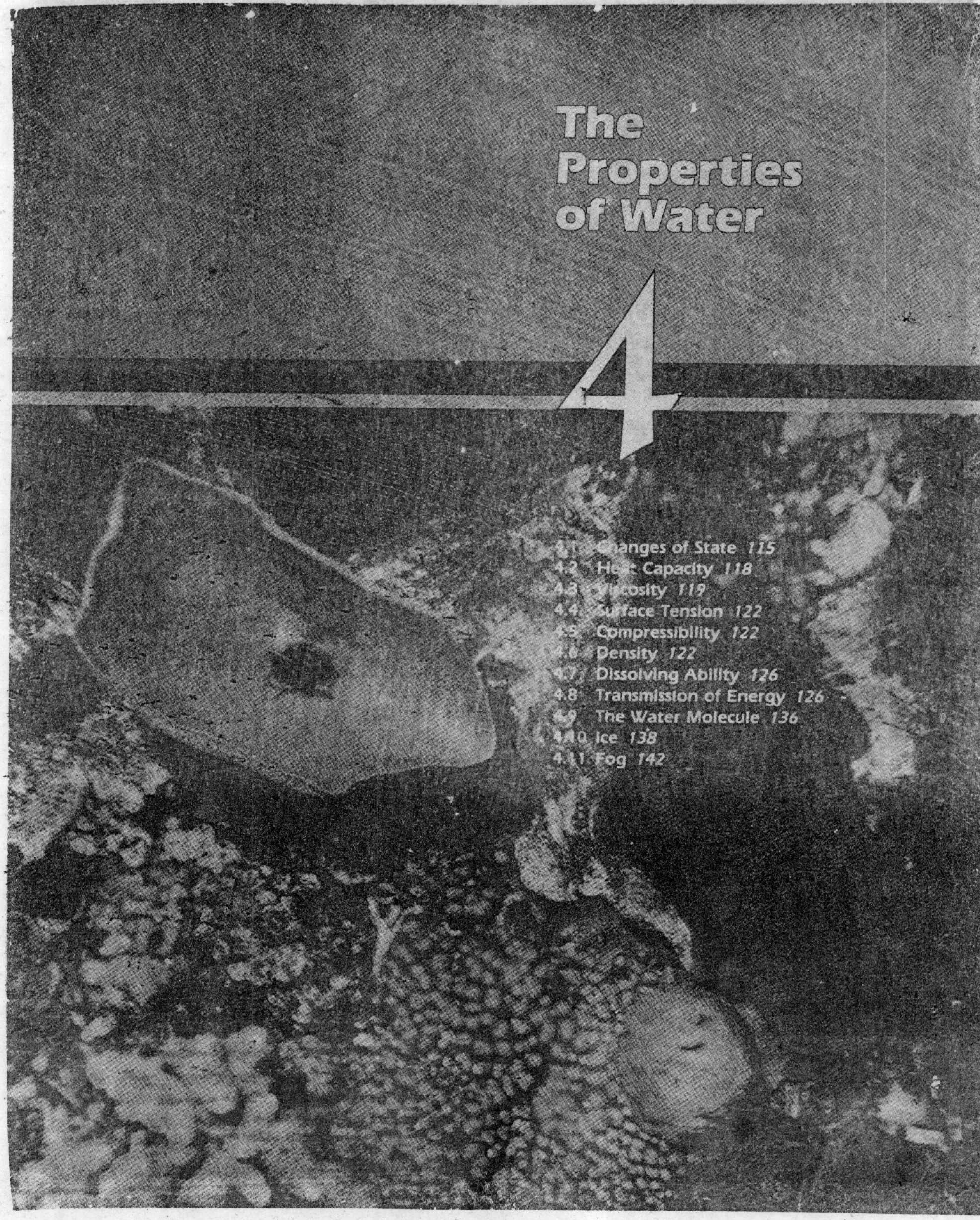

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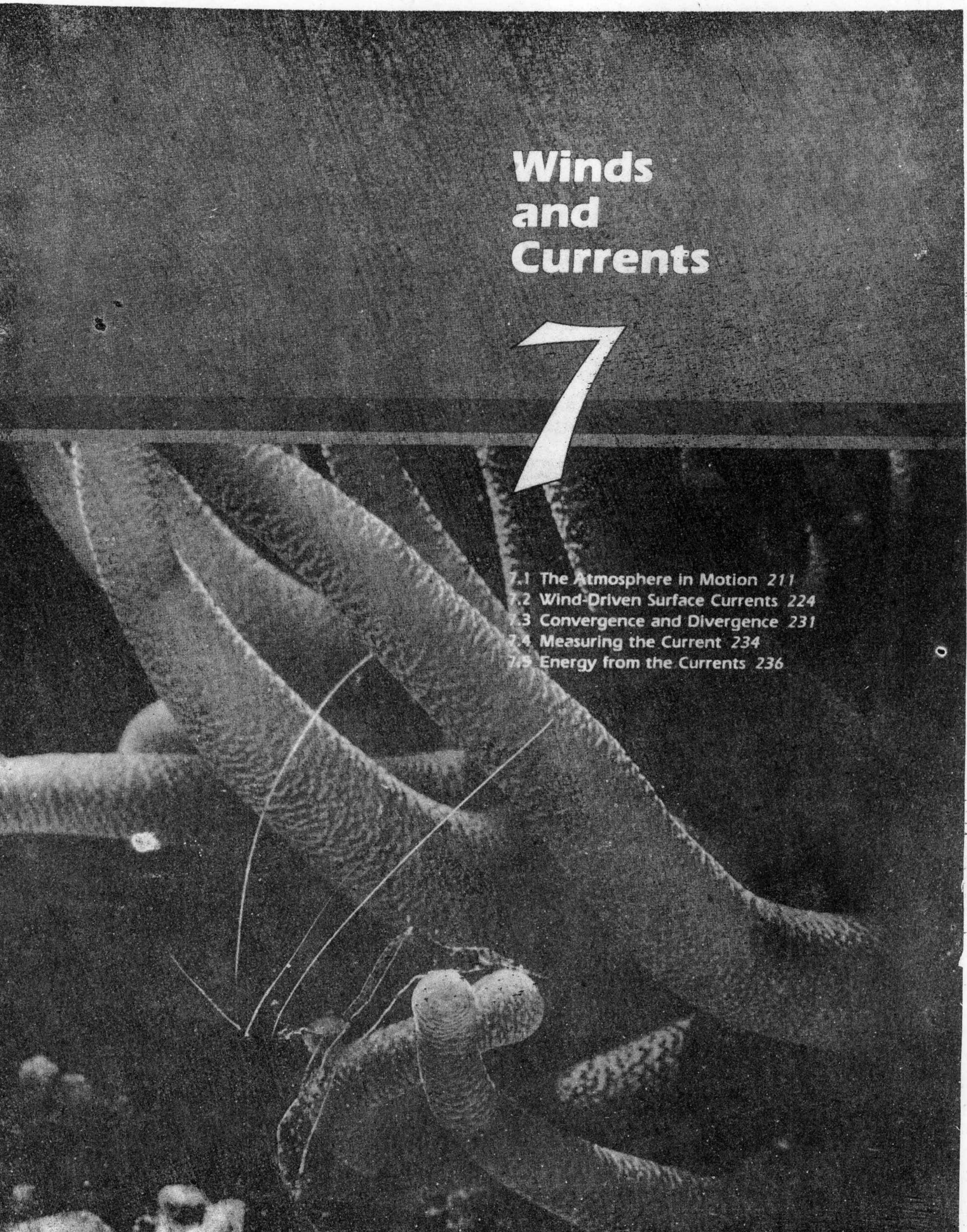

Winds and Currents

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