A complete historical account of oceanographic exploration and research would be a massive undertaking. The record stretches back over several millennia to the time when ancient mariners built boats and ventured boldly onto the sea to explore the unknown. However, a brief sketch of maritime history is needed in a book that deals with the physical, chemical, geological, and biological processes of the ocean in a scientifically rigorous manner. First and foremost, this reminds us that for eons there have been people in the field of “oceanography”—people with an insatiable desire to make the unknown familiar. Knowledge that is commonplace today
Before delving into the science of oceanography, we should understand exactly what the word means. The first part of the term is coined from the Greek word οκεανός, or Oceanus, the name of the Titan son of the gods Uranus and Gaea, who was father of the ocean nymphs (the Oceanids). Eventually oceanus was applied to the sea beyond the Pillars of Hercules, the North Atlantic Ocean. The second part of the term comes from the Greek word γραφία, which refers to the act of recording and describing. In fact, the word oceanography is inadequate to describe the science of the seas, because scientists do much more than merely record and describe the ocean’s physical, chemical, geological, and biological characteristics. Oceanographers investigate, interpret, and model all aspects of ocean processes, using the most modern and sophisticated techniques of scientific and mathematical enquiry. The term oceanology (the suffix -ology meaning “the science of”) is etymologically more accurate. The distinction between oceanography and oceanology is similar to that made between geography [the physical description of the world and its biota] and geology [the scientific study of the Earth and its processes]. The word oceanology has not, however, displaced oceanography, because the latter term is solidly entrenched in the minds of the laypeople as well as the Western practitioners of the science. Hence, this book will follow convention, using the more familiar term to denote the scientific study of the oceans.

A common misconception is that oceanography is a pure science in its own right, practiced by women and men who are specifically and narrowly instructed in its investigative methods. Most oceanographers are, in fact, trained in one of the traditional sciences [physics, chemistry, biology, and geology] or a related field [engineering, meteorology, mathematics, statistics, or computer science] and choose to apply their research expertise to the study of the oceans. After obtaining undergraduate training in a traditional science, they gain...
experience conducting oceanographic research in graduate school or at a marine institute. Recently, new career opportunities in oceanography have developed in marine policy and management, marine law, resource and environmental assessment, and other related fields. Marine studies commonly rely on collaboration among many types of scientists, mathematicians, engineers, technicians, and policymakers.

It is customary to subdivide oceanography into the four fields of physical, geological, chemical, and biological oceanography (Figure 1–1). These fields are in turn linked to one another by the cross-disciplines of geochemistry, biochemistry, geophysics, and biophysics.

**Figure 1–1**
The field of oceanography. This diagram organizes oceanography into four principal categories—biological, geological, physical, and chemical oceanography—that are linked to one another by cross-disciplines.

Our perception and understanding of the oceans have changed markedly over time. Although this book stresses the most current ideas championed by marine scientists, these attitudes and impressions did not suddenly appear out of an intellectual vacuum. They grew out of—and evolved from—the ideas and deductions of prior generations of ocean explorers and scientists. Marine scientists are well aware of the fact that all of their work rests on the contributions of the innumerable investigators that came before them. But, obviously, this does not mean that all the conclusions of those early investigators have been validated. Rather, as the science of oceanography has matured and as research vessels, sampling devices, and electronic instrumentation have become increasingly sophisticated and more widely applied to probe the ocean's secrets, many beliefs of the past have been disproved. The lesson from history is clear-cut. Our ideas of the oceans today, which seem so appealingly final and are written about and taught with so much fervor and certainty, will be refined by the findings and thoughts of future generations of marine scientists.

The history of oceanography has not always been the gradual and systematic development of a body of thought. Rather, bold concepts and opinions have often burst onto the scene, necessitating critical reexamination of the wisdom of the past, and stimulating fresh insights into the workings of the oceans.

A practical means of organizing the historical record of oceanography is to arrange the events into three broad stages. The first includes the early efforts of individual mariners as they attempted to describe the geography of the Earth's oceans and landmasses. During this time of ocean exploration,
the very limits of the world were sought. The second includes the early systematic attempts to use a truly scientific approach to investigate the oceans. The third covers the growth of modern oceanography that has resulted from the widespread application of state-of-the-art technology and the international collaboration of scientists. We will conclude this historical review with an assessment of future prospects and try to predict the nature of oceanographic investigations in the middle part of the twenty-first century.

A limited number of the innumerable events that contribute to the rich history of oceanography can be highlighted in a single chapter. Although the details of only a few of the many important research cruises and studies are elaborated here, synopses of many others are cataloged chronologically in Table 1–1.

Also, books that discuss the historical context of ocean exploration and the science of oceanography are listed at the end of the chapter.

**OCEAN EXPLORATION**

Humans have been going to sea for tens of thousands of years. Anthropologists suspect, for example, that the ancestors of aboriginal people reached Australia by sea-going vessels some 40,000 to 60,000 years ago, an incredible feat requiring courage, skill, and determination. They lived through a glaciation and deglaciation, following the shoreline as sea level dropped and then rose to its present position. These events are recorded in their powerful myths and art.

In many respects the Polynesian migration to the many large and small islands of the Pacific Ocean [Figure 1–2], completed well before the birth of Christ, ranks as one of the most spectacular exploration feats ever. Their canoes, which they sailed and paddled, were made by hollowing out logs or by lashing planking together with braided ropes. These seaworthy vessels were built with simple tools made of rock, bone, and coral. In order to travel safely from one island to the next, these Pacific seafarers relied on sound seamanship, extensive navigational skills, and detailed local knowledge, all of which—in the absence of a written language—was passed on to others orally in the recitation of epic poems. Polynesian seafarers could depend on accurate, detailed lore of local wind, wave, current, and weather patterns as well as on the position of key navigational stars in making a planned landfall after a deep-sea crossing of hundreds, even thousands, of kilometers.

The ability to explore and chart the seas safely depends on navigation. Records of sailing vessels indicate maritime activity in Egypt as far back as 4000 B.C. It is likely that the extent of these voyages was restricted, with mariners remaining well in sight of land, probably in the immediate vicinity of the Nile River and the shores of the eastern Mediterranean Sea. By the sixth century B.C., however, Phoenicians had established sea routes for trading throughout the entire Mediterranean region and had even ventured westward into the Atlantic Ocean, sailing as far north as the coast of Cornwall in England. Historians suspect that Phoenicians, around 600 B.C., were probably the first to circumnavigate the continent of Africa. True ocean navigation was difficult at the time. Navigators charted the courses of their vessels according to the stars. Undoubtedly, sailors steered their craft in sight of the coastline whenever possible, relying on distinctive landmarks to find their way and establish their position. This process is called *piloting*.

By the third century B.C., the flourishing Greek civilization, plying the Mediterranean for trade as it established its influence and control over the entire region, was highly dependent on its maritime prowess. A notable sea adventurer of the time was Pytheas, the first Greek to circumnavigate England and gauge the length of its shoreline. Although his travels are not documented by first-hand accounts, some historians believe that Pytheas may have voyaged as far north as Norway and as far west as Iceland. If he did, this stands as an incredible navigational accomplishment. Historians have established that Greek mariners estimated latitude (Appendix IV) by the length of the day, correcting for the time of the year. However, without mechanical timepieces (accurate chronometers) it was impossible for them to determine longitude. Pytheas’s discovery that the tides of the Atlantic Ocean vary regularly with the phases of the moon underscores his deep understanding of ocean processes.
Polynesia. (a) Polynesians settled these Pacific Islands, navigating across an ocean area the size of a continent. (b) Polynesians used canoes made of hollowed-out logs or planks.
THE GROWTH OF OCEANOGRAPHY

ca. 4000 B.C. Egyptians developed the arts of shipbuilding and coastal piloting.

ca. 2000–500 B.C. Most islands of the Pacific Ocean settled by Polynesians.

ca. 1000–600 B.C. Phoenicians explored the entire Mediterranean Sea, sailed into the Atlantic to Cornwall, England, and probably circumnavigated Africa. They navigated by familiar coastal landmarks and by the stars.

A.D. 995 Leif Ericson, son of Eric the Red, established the North American settlement of Vinland in what is now Newfoundland.

A.D. 673–735 The English monk Bede published De Temporum Ratione, in which he discussed the lunar control of the tides and recognized monthly tidal variations and the effect of wind drag on tidal height.

A.D. 982 The Norseman Eric the Red completed the first transatlantic crossing and discovered Baffin Island in the Arctic region of Canada.

A.D. 995 Leif Ericson, son of Eric the Red, established the North American settlement of Vinland in what is now Newfoundland.

| TABLE I-1. A Chronology of Ocean Exploration |

<table>
<thead>
<tr>
<th>4000</th>
<th>3000</th>
<th>2000</th>
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<th>B.C.</th>
<th>A.D.</th>
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<th>1100</th>
<th>1200</th>
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<tr>
<td>ca. 4000 B.C. Egyptians developed the arts of shipbuilding and coastal piloting.</td>
<td>ca. 2000–500 B.C. Most islands of the Pacific Ocean settled by Polynesians.</td>
<td>ca. 1000–600 B.C. Phoenicians explored the entire Mediterranean Sea, sailed into the Atlantic to Cornwall, England, and probably circumnavigated Africa. They navigated by familiar coastal landmarks and by the stars.</td>
<td>450 B.C. The Greek Herodotus compiled a map of the known world that centered on the Mediterranean region (see Figure 1–3).</td>
<td>325 B.C. The Greek Pytheas explored the coasts of England, Norway, and perhaps Iceland. He developed a means of determining latitude from the angular distance of the North Star and proposed a connection between the phases of the Moon and the tides. Aristotle published Meteorologica, in which he described the geography and physical structure of the Greek world, and Historia Animalium, the first known treatise on marine biology.</td>
<td>276–192 B.C. The Greek Eratosthenes, a scholar at Alexandria, determined the circumference of the Earth with remarkable accuracy using trigonometry and noting the specific angle of sunlight that occurred at Alexandria and at Aswan (then known as Syene) in Egypt.</td>
<td>54 B.C.–A.D. 30 The Roman Seneca devised the hydrologic cycle to show that, despite the inflow of river water, the level of the ocean remained stable because of evaporation.</td>
<td>ca. A.D. 150 The Greek Ptolemy compiled a map of the entire Roman World that showed latitudes and longitudes.</td>
<td>A.D. 673–735 The English monk Bede published De Temporum Ratione, in which he discussed the lunar control of the tides and recognized monthly tidal variations and the effect of wind drag on tidal height.</td>
<td>A.D. 982 The Norseman Eric the Red completed the first transatlantic crossing and discovered Baffin Island in the Arctic region of Canada.</td>
</tr>
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</table>
Landmark Events in Early Ocean Exploration

1400 1425 1450 1475 1500 1525 1550 1575 1600 1625 1650 1675 1700

1452–1519
Leonardo da Vinci observed, recorded, and interpreted details about currents and waves and noted that fossils in the mountains of Italy implied that the level of the sea had been higher in the ancient past.

1492
Christopher Columbus rediscovered North America by sailing to the islands of the West Indies.

1500
Pedro Álvares Cabral discovered and explored Brazil.

1513
Juan Ponce de León described the swift and powerful Florida current.

1513–1518
Vasco Núñez de Balboa crossed the Isthmus of Panama and sailed in the Pacific Ocean.

1515
Peter Martyr proposed an origin for the Gulf Stream.

1519–1522
Ferdinand Magellan embarked on a circumnavigation of the globe; Sebastian del Cano completed the voyage.

1569
Gerardus Mercator constructed a map projection of the world that was adapted to navigational charts.

1674
Robert Boyle investigated the relation among temperature, salinity, and pressure with depth and reported his findings in “Observations and Experiments on the Saltiness of the Sea.”

Adapted from D. E. Ingman and W. J. Wallace, Oceanography: An Introduction, Table 1.2 (Belmont, Calif.: Wadsworth, 1979); B. H. McConnaughey and R. Zottoli, Introduction to Marine Biology, Chapter 24 (St. Louis, Miss.: Mosby, 1983); J. C. McCormick and J. V. Thiruvathukal, Elements of Oceanography, Tables 1.1 and 1.2 (New York: Saunders College Publishing, 1981); H. S. Parker, Exploring the Oceans, Chapter 1 (Englewood Cliffs, N.J.: Prentice-Hall, 1985); and H. V. Thurman, Introduction to Oceanography, Chapter 1 (Columbus, Ohio: Merrill, 1988).
# A Chronology of Ocean Exploration

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1700</td>
<td>Luigi Marsigli compiled <em>Histoire Physique de la Mer</em>, the first book to deal entirely with the science of the sea.</td>
</tr>
<tr>
<td>1725</td>
<td>Leonhard Euler calculated the magnitude of the forces that generate ocean tides and related them to the attractive force of the Moon.</td>
</tr>
<tr>
<td>1725</td>
<td>Benjamin Franklin published the first ocean chart of the Gulf Stream, which shippers consulted extensively as they crossed the North Atlantic Ocean.</td>
</tr>
<tr>
<td>1768–1771, 1772–1775, 1778–1779</td>
<td>Captain James Cook commanded three major ocean voyages, gathering extensive data on the geography, geology, biota, currents, tides, and water temperatures of all of the principal oceans.</td>
</tr>
<tr>
<td>1820</td>
<td>Alexander Marcet, a London physician, noted that the proportion of the chemical ingredients in seawater is unvarying in all oceans.</td>
</tr>
<tr>
<td>1802</td>
<td>Nathaniel Bowditch published the <em>New American Practical Navigator</em>, a superb navigational resource that continues to be revised and published to this day.</td>
</tr>
<tr>
<td>1807</td>
<td>President Thomas Jefferson mandated coastal charting of the entire United States and established the U.S. Coast and Geodetic Survey.</td>
</tr>
<tr>
<td>1817–1818</td>
<td>Sir John Ross ventured into the Arctic Ocean to explore Baffin Island, where he sounded the bottom successfully and recovered starfish and mud worms from a depth of 1.8 kilometer.</td>
</tr>
<tr>
<td>1820</td>
<td>Sir Edward Forbes published <em>The History of British Star-Fishes</em> (1841) and then his influential book, <em>Distribution of Marine Life</em> (1854), in which he argued that sea life cannot exist below about 600 meters (the so-called azoic zone).</td>
</tr>
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</table>
**Milestones in Early Oceanography**

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>1855</td>
<td>Matthew Fontaine Maury compiled and standardized wind and current data recorded in U.S. Navy ship logs and summarized his findings in <em>The Physical Geography of the Sea</em>.</td>
</tr>
<tr>
<td>1868–1870</td>
<td>Charles Wyville Thomson, aboard the HMS Lightning and HMS Porcupine, made the first series of deep-sea temperature measurements and collected ample life from great depths, disproving Forbes’s azoic zone.</td>
</tr>
<tr>
<td>1871</td>
<td>The U.S. Fish Commission was established with a modern laboratory at Woods Hole, Massachusetts.</td>
</tr>
<tr>
<td>1872–1876</td>
<td>Under the leadership of Charles Wyville Thomson, the HMS Challenger conducted worldwide scientific expeditions, collecting data and specimens that were later analyzed in over fifty large volumes of the <em>Challenger Reports</em>.</td>
</tr>
<tr>
<td>1873</td>
<td>Charles Wyville Thomson published a general and popular book on oceanography called <em>The Depths of the Sea</em>.</td>
</tr>
<tr>
<td>1877–1880</td>
<td>Alexander Agassiz, an American naturalist, extensively sampled life in the deep sea while aboard the U.S. Coast and Geodetic Survey ship Blake. He also founded the Museum of Comparative Zoology at Harvard University and the first U.S. marine station, the Anderson School of Natural History, on Penikese Island, Buzzards Bay, Massachusetts.</td>
</tr>
<tr>
<td>1884–1901</td>
<td>The USS Albatross was designed and constructed specifically to conduct scientific research at sea and undertook numerous oceanographic cruises.</td>
</tr>
<tr>
<td>1888</td>
<td>The Marine Biological Laboratory was established at Woods Hole, Massachusetts, and Dr. Charles Otis Whitman served as its first director.</td>
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<tr>
<td>1893</td>
<td>The Norwegian Fridtjof Nansen had the Fram constructed with a reinforced hull for use in sea ice; he confirmed the general circulation pattern of the Arctic Ocean and the absence of a northern continent.</td>
</tr>
</tbody>
</table>
The International Geophysical Year (IGY) was organized—an ambitious international effort to coordinate the geophysical investigation of the Earth, including its oceans.

A Chronology of Ocean Exploration

1900

1905

1910

1915

1920

1925

1930

1935

1940

1945

1950

1955

1902

Danish scientists with government backing established the International Council for the Exploration of the Sea (ICES) to investigate oceanographic conditions that influence North Atlantic fisheries. Council representatives were from Great Britain, Germany, Sweden, Norway, Denmark, Holland, and the Soviet Union.

1903

The Friday Harbor Oceanographic Laboratory was established by the University of Washington, Seattle.

1903

The Scripps Institution of Biological Research, which later became the Scripps Institution of Oceanography, was founded at La Jolla, California.

1912

The German meteorologist Alfred Wegener proposed his theory of continental drift.

1925–1927

A German expedition aboard the research vessel Meteor studied the physical oceanography of the Atlantic Ocean as never before, heralding the modern age of oceanographic investigation. Scientists used an echo sounder extensively for the first time.

1930

The Woods Hole Oceanographic Institution was established on the southwestern shore of Cape Cod, Massachusetts.

1932

The International Whaling Commission was organized to collect data on whale species and to enforce voluntary regulations on the whaling industry.

1942

Harald Sverdro, Richard Fleming, and Martin Johnson published the scientific classic The Oceans, which is still consulted today.

1949

The Lamont (later changed to Lamont Doherty) Geological Observatory at Columbia University in New York was established at Torrey Cliffs Palisades on the bedrock cliffs of the Hudson River.

1957–1958

The International Geophysical Year (IGY) was organized—an ambitious international effort to coordinate the geophysical investigation of the Earth, including its oceans.
<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>1958</td>
<td>The nuclear submarine USS Nautilus, commanded by C.D.R. Andersen, reached the North Pole under the ice.</td>
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<tr>
<td>1959–1965</td>
<td>The International Indian Ocean Expedition was established under the auspices of the United Nations to make a systematic investigation of the oceanography of the Indian Ocean.</td>
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<tr>
<td>1966</td>
<td>The U.S. Congress adopted the Sea Grant College and Programs Act to provide nonmilitary funding for education and research in the marine sciences.</td>
</tr>
<tr>
<td>1968, 1975</td>
<td>The U.S. National Science Foundation organized the Deep Sea Drilling Project (DSDP) to core through the sediments and rocks of the oceans. This effort was reorganized in 1975 as the International Program of Ocean Drilling, which continues to be active in all of the world’s oceans today.</td>
</tr>
<tr>
<td>1970</td>
<td>The U.S. government created the department of the National Oceanic and Atmospheric Administration (NOAA) to oversee and coordinate government activities that have a bearing on oceanography and meteorology.</td>
</tr>
<tr>
<td>1972</td>
<td>The Geochemical Ocean Sections Study (GEOSECS) was organized to obtain accurate measurements of seawater chemistry in an effort to explain the nature of ocean circulation and mixing and the biogeochemical recycling of chemical substances.</td>
</tr>
<tr>
<td>1978</td>
<td>Seasat-A, the first oceanographic satellite, was launched, demonstrating the utility of remote sensing in the study of the oceans.</td>
</tr>
<tr>
<td>1980s–1990s</td>
<td>The Coordinated Ocean Research and Exploration Section program (CORES) was organized to continue the scientific work of the IDOE into the 1980s. The Ocean Drilling Program (ODP) continues the geological exploration of the oceans.</td>
</tr>
<tr>
<td>1992</td>
<td>NASA launched the TOPEX/Poseidon satellite to monitor sea level and to keep track of changes in current patterns as climate fluctuates.</td>
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<tr>
<td>1997</td>
<td>Kyoto Climate Protocol.</td>
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<tr>
<td>1998</td>
<td>International Year of the Ocean is organized to educate the public about the value and importance of the ocean’s resources.</td>
</tr>
<tr>
<td>2001</td>
<td>Joint launching of Jason-1 satellite by NASA and the French Space Agency to improve forecasting of currents and climate. Implementation of GLOBEC (GLOBal Ocean ECosystem Dynamics), an international research program designed by oceanographers, marine ecologists, and fishery scientists.</td>
</tr>
<tr>
<td>2003</td>
<td>Japan and the United States create the Integrated Ocean Drilling Program (IODP).</td>
</tr>
<tr>
<td>2006</td>
<td>Launching by IODP of a new ocean drilling vessel, Japan’s Chiyou.</td>
</tr>
<tr>
<td>2008</td>
<td>The International Year of Planet Earth.</td>
</tr>
</tbody>
</table>
A map compiled by Herodotus in 450 B.C. shows the extent of the Greeks’ understanding of world geography (Figure 1–3). The Mediterranean Sea prominently occupies the center of the map and is surrounded by three landmasses of enormous proportions—Libya (northern Africa), Europe, and Asia. The polar limits and coastline configurations of the latter two continents were unexplored at the time and are not marked on the map. All of the familiar land is surrounded by enormous expanses of ocean that the Greeks believed extended to the very ends of the world.

Throughout the Middle Ages (between 500 and 1450 A.D.), there was little ocean exploration by Europeans, with the notable exception of the Viking seafarers. Between the ninth and the twelfth century, Scandinavians extended their influence over Europe and across the Atlantic Ocean by acquiring new lands. The Norse ventured boldly to Iceland, Greenland, and the Baffin Islands, for example, and established a North American settlement known as Vinland in the area that we now call Newfoundland. These Viking outposts eventually were abandoned because of the harsh climates. Also, the onset of the “Little Ice Age” (A.D. 1430 to 1850) caused the extensive buildup of sea ice that cut off the northern sea routes from Scandinavia.

The Norsemen—the most adept and experienced navigators in the Western world at that time—sailed westward by maintaining a course on a predetermined line of latitude. They accomplished this navigational feat by sailing to a coastal point along Norway and measuring the angular height of the North Star. They then kept it at the same angle on the starboard beam of the vessel throughout the night. Their daytime navigation relied on the careful calculation of the sun’s position for the time of year. A map dated at about 1570 shows the remarkable state of the Viking’s geographic knowledge of the North Atlantic Ocean (Figure 1–4).

Economic, political, and religious motives encouraged western Europeans to undertake long
sea explorations in the fifteenth and sixteenth centuries, they crossed the Atlantic and ventured into the Pacific Ocean. Portuguese sailors were particularly successful explorers during this time. In 1487 and 1488 Bartholomew Diaz rounded the Cape of Good Hope at the southern tip of Africa. After sailing around the Cape of Good Hope in 1498, Vasco da Gama continued as far eastward as India.

Perhaps the crowning achievement of this age is the circumnavigation of the globe by Ferdinand Magellan. Departing from Spain in late September of 1519, Magellan proceeded southwestward with his flotilla of five age-worn ships to the northeastern coast of Brazil (Figure 1–5). There he began to search for a seaway to the Pacific and, in the process, lost two of his vessels, one by desertion. Almost one year after his departure from Spain, Magellan located the 500-kilometer-wide (~310 miles) passage that now bears his name and sailed around South America and into the Pacific Ocean. The following three months were desperate for Magellan’s crew, who endured starvation, disease, and doubtless suffered much from fear of the unknown. They eventually reached Guam on 6 March 1521. After proceeding to the Philippines later that month, Magellan was killed on 27 April on the small island of Mactan while participating in a dispute among local tribes. Sebastian del Cano eventually completed the circumnavigation under tremendous hardship, reaching Spain on 8 September 1522, in the last remaining vessel of the expedition, the Victoria. Of the original 230 seamen, only 18 reached Seville and completed their three-year-long circumnavigation of the globe.

A number of remarkably sophisticated scientific prodings of the ocean’s secrets were made in the eighteenth and nineteenth centuries. The British were preeminent during this stage of ocean investigation. Through government sponsorship, and often under the auspices of major scientific societies such as the Royal Society of London, they expanded their geographic and scientific knowledge about the world’s seas, which was vital if they were to uphold their maritime and economic superiority. Captain James Cook best represents the British seafaring adventurer of that day. Cook constructed accurate charts of coastlines and made important observations about the geology and biology of unexplored regions, as well as of the customs of native populations. In 1768, on his first major voyage commanding the HMS Endeavour, Cook sighted the coast of New Zealand and charted much of its shoreline. He demonstrated convincingly that it was not part of Terra Australis (a large
Ferdinand Magellan embarked on a three-year-long voyage in 1519, intent on discovering a seaway to the East Indies. In 1520 he rounded the Straits of Magellan and continued to the Philippines, where he was killed during a skirmish with natives. Sebastian del Cano completed the journey as leader of the expedition.

During his second major voyage between 1772 and 1775, commanding the HMS Adventure and the HMS Resolution, Cook used the prevailing westerly winds to round the Cape of Good Hope and circumnavigate the globe. He maintained a course as close to the latitude 60°S as possible, continually avoiding icebergs. In the final report of his findings, Cook wrote:

Thus, I flatter myself that the intention of the voyage has in every respect been fully answered, the Southern Hemisphere sufficiently explored and a final end put to the searching after a Southern Continent, which has at times engrossed the attention of some of the maritime powers for near two centuries past, and the geographers of all ages. That there may be a continent or large tract of land near the pole, I will not deny. On the contrary I am of the opinion there is. (John R. Hale, Age of Exploration [New York: Time, Inc., 1966], 192)
Important work in marine science during the mid-nineteenth century was conducted by Matthew Fontaine Maury, director of the U.S. Naval Depot of Charts and Instruments. While compiling Wind and Current Charts, a task that began in 1842, Maury realized the need for international cooperation in making ocean measurements: “[A]s these American materials are not sufficient to enable us to construct wind and current charts of all parts of the ocean, it has been judged advisable to enlist the cooperation of the other maritime powers in the same work.” In 1855 Maury published an important and successful book, The Physical Geography of the Sea, to familiarize the general public with the most
recent scientific findings about the ocean. His book went through eight editions in the United States and nineteen editions in England and was translated into several languages. This first book dedicated entirely to the science of oceanography earned him the title, “father of physical oceanography.”

One of the best known ocean expeditions of the nineteenth century was the cruise of the HMS Beagle, with Captain Robert Fitzroy as commander and Charles Darwin as the ship’s naturalist. The Beagle embarked on a five-year voyage, beginning in late December of 1831; Darwin spent the bulk of that time studying the geology and biology of the South American coastline. He was particularly impressed by the unique animal populations of the Galápagos Islands off Ecuador and by the latitudinal changes in the makeup of the biota of the coastal environments of South America. After the successful completion of the voyage, Darwin spent the next twenty years examining and reflecting on his copious data. He eventually developed a most elegant theory of organic evolution, suggesting that the appearance and evolution of new species result by natural selection, which operates slowly over very long periods of deep geologic time. His arguments, observations, and conclusions led to the publication of his seminal work, On the Origin of Species, in 1859. In addition, Darwin’s numerous observations on the morphology of coral reefs in the Pacific Ocean resulted in an insightful theory of their geological development that remains the accepted explanation today.

One of the more successful and significant scientific voyages of the nineteenth century was...
The explicit intent of the test is to determine whether the hypothesis is false or true. If the test results disagree with the prediction, then the hypothesis being evaluated is disproved, meaning that it cannot be a legitimate account of reality. Then it is either modified into a new hypothesis that is compatible with the test findings or discarded altogether and replaced by other, still-to-be-tested hypotheses. Keep in mind, however, that agreement between expected and experimental test results is not proof that the hypothesis is true. Rather, it means only that the hypothesis continues to be a valid version of reality for the time being. It may not survive the next test. If a hypothesis repeatedly avoids falsification, then scientists regard it as a close approximation of the truth. A flow diagram of this version of the scientific method is presented as Figure B1–3.

In this book, we describe the results of a long-standing interest among scientists in answering questions about the workings of the oceans. It is a current update of the facts, hypotheses, and theories of ocean processes. Undoubtedly, as oceanographers continue to conduct scientific work in the world's oceans, some of these ideas will be disproved and replaced by other hypotheses. This is the way it must be; this is the scientific process.

Researchers were jubilant with the scientific success of the Challenger Expedition. The crew completed more than 360 deep-sea soundings and raised an equal number of dredged samples off the bottom. They obtained no fewer than 7,000 sea-life specimens, some from as great a depth as 9 kilometers (~5.6 miles). Each specimen was described, cataloged carefully, and preserved for later laboratory analysis. The findings of the Challenger crew left no doubt that organisms lived
The voyage of the HMS Beagle. (a) Drawing depicting the HMS Beagle, which was commanded by Captain Robert Fitzroy. (b) Charles Darwin, who occupied the post of naturalist aboard the Beagle, made astute observations and ample collections of the biota and rocks that he encountered everywhere during the five-year voyage. Reflection on these data later led him to postulate the evolution of all organisms by natural selection. (c) Route of the HMS Beagle.
The *Challenger* expedition. (a) This painting shows the HMS *Challenger* plying the seas between 1872 and 1876. (b) Charles Wyville Thomson commanded the circumnavigation of the globe expeditions. (c) The track of the *Challenger* expedition shows that measurements were made in all parts of the world’s oceans, except for the northern Indian Ocean and the Arctic Ocean.
at all depths in the ocean, finally demolishing the age-old belief championed by Forbes that the cold temperature, darkness, and high water pressure of the deep sea precluded life there. Almost 5,000 new species of marine organisms were identified and described. For the first time, preliminary charts that delineated sea-bottom topography and the distribution of deep-sea sedimentary deposits for much of the ocean were sketched out. More than twenty-three years were required to analyze all of the data and specimens collected by the *Challenger* Expedition. These findings, including observations of indigenous populations, were published in fifty large volumes (Figure 1–8b) that marine researchers still consult today.

Near the end of the nineteenth century, the Norwegian explorer, **Fridtjof Nansen**, embarked on a remarkable journey in an effort to study the circulation of the Arctic Ocean and to be the first man to reach the North Pole. Nansen's scheme was to construct a robust, hardy research vessel that could be frozen into the sea ice and drift safely in this icy grip for three years or more. Despite considerable opposition from scientists and mariners alike, Nansen obtained funding and built the *Fram*, a 38-meter (~125 feet), three-masted schooner with the unheard-of hull thickness of 1.2 meters (~4 feet) (Figure 1–9a). In late September of 1893, the *Fram*, with its crew of thirteen men and provisions for five years, was successfully locked into the sea ice north of Siberia. There it remained trapped in the ice for three years, slowly drifting at an average rate of 2 kilometers (~1.2 miles) per day, and got as close as 400 kilometers (~248 miles) to the North Pole (Figure 1–9b). When the ice-locked *Fram* drifted to a north latitude of 84°, Nansen and Frederick Johansen left the vessel in a courageous attempt to reach the North Pole by dogsled. After much hardship, they abandoned their quest after fourteen months, getting only as far as 86°14'. Fortunately, they were sighted and picked up by a British expedition on Franz Josef Land. The crew members aboard the *Fram* made many oceanographic and atmospheric observations during their sojourn, establishing the absence of a polar continent, the water depths along the drift path, and the water-mass structure of the Arctic Ocean. Today the *Fram* can be seen on display in Oslo, Norway.

**MODERN OCEANOGRAPHY**

Modern oceanographic research is rather arbitrarily taken to begin sometime in the twentieth century, with the design of elaborate experiments involving a truly interdisciplinary approach and a
Searching Davy Jones’ locker for ancient treasures is not an easy matter. The depths of the sea are mysterious and dangerous, and yet hauntingly beautiful and captivating. Exploration of this dark underwater world requires all manner of sophisticated equipment and techniques, lots of specialized multidisciplinary expertise, collaborative efforts among government, industrial, and academic experts, a deep funding pocket, and considerable luck. Typically, a project begins on land with years of extended study, searching historical documents and ancient maps for specific clues about the location of a shipwreck. After consulting current, tide, and bathymetric charts, the appropriate vessel, geophysical gear, and technical and support personnel are deployed in the project area when the weather conditions are best for maximizing the chances of success. The indirect search of the sea bottom typically relies on sophisticated geophysical equipment, such as echo sounders, magnetometers, high-resolution sidescan sonar and sub-bottom profilers, manned submersibles, and remotely operated vehicles (ROVs). Once a wreck is located, the site and its artifacts are explored systematically and mapped accurately, relying heavily on navigational and global positioning system (GPS) technology. If artifacts are retrieved, they must be treated immediately to protect wood and metal from deteriorating rapidly once exposed to air.

There is nothing more exhilarating than successfully finding and then studying an ancient shipwreck on the sea floor. To experience vicariously the frustrations and elations of underwater explorers, you are encouraged to search the web and investigate these ambitious projects.

**THE SCAPA FLOW MARINE ARCHEOLOGY PROJECT (SCAPAMAP)**

Scapa Flow, located in the isolated Orkney Islands off the northeast shores of Scotland, is a site where 52 WWI German warships, part of the German High Seas Fleet of the time, were scuttled and sank to the rough sea bottom of Scapa Flow where they had been anchored during the early summer of 1919. The warships included the cruisers *Brunnen*, *König*, and *Dresden* and the battleships *Wilhelm, König, Markgraf*, and *Kronprinz*. Since their sinking, there have been salvaging efforts by numerous groups that, in some cases, have damaged and weakened some of the vessels. Also, the site has always been a mecca for sports divers, attracting thousands each year. In an effort to protect the vessels for posterity, the ScapaMap Acoustic Consortium (SAC) was founded. Using a state-of-the-art multi-beam echo sounder, SAC is surveying the wrecks and has obtained a remarkable set of images of many of these warships (Figure B1–5), some lying on their sides, others overturned with keels pointing upward.

**USS MONITOR**

In 1973, Duke University marine scientists located the *USS Monitor*, a Union Civil War vessel, which was the first steam-powered ironclad warship constructed without masts and sails (Figure B1–4). She was found in the “Graveyard of the Atlantic,” some 25 km (15.6 miles) off Cape Hatteras, North Carolina in about 70 m (~230 ft) of water where she sank during an 1862 gale while being towed to port. During the summer of 2001, U.S. Navy divers in collaboration with NASA personnel recovered the Monitor’s unique steam engine and donated it to the Mariners Museum in Newport News, Virginia, where it was electrochemically treated for preservation and public display. During 2002, divers salvaged the Monitor’s armored revolving gun turret, now displayed at The Mariners Museum. The Mariners Museum will be the official depository for all artifacts and salvage of the *USS Monitor*.

**THE JEREMY PROJECT**

This ambitious venture, a collaborative effort by the National Park Service, NASA, the U.S. Navy and Coast Guard, the Alaska State and Historic Preservation Office, and the Minerals Management Service, is the search in the cold, dark waters of the Chukchi Sea of Alaska for the remains of a nineteenth century New Bedford, Massachusetts whaling fleet that in 1871 got trapped by sea ice; all 32 vessels were crushed and sank. Several of these whaling ships have been located, using a telepresence remotely operated vehicle (TROV), a stereoscopic video device that generates a three-dimensional image of objects on the sea bottom.
ment to complete an unprecedented survey of an ocean. They delineated, as never before, the rugged bottom topography of the deep sea and gathered vertical profiles of salinity, water temperature, and dissolved oxygen at numerous hydrographic stations. No data of such quality or density had ever before been gathered from the ocean. From that day onward, many large ocean surveys patterned themselves after the cruise of the Meteor.

The world wars had important effects on the development of marine research. The advent of modern warfare, with its reliance on sophisticated vessels, weaponry, and electronic instruments, made the U.S. Navy aware of an urgent need to understand the nature of ocean processes. Civilian scientists were recruited, and the navy enacted a program to finance basic oceanographic research, with an emphasis on physical rather than biological problems. This financial support by a government agency stimulated large-scale research enterprises, and restricted the activities of many oceanographers to problems that were of interest mainly to the military. Postwar government-sponsored support led not only to great and rapid advances in instrumentation, but also eventually to the establishment of sea-grant colleges, patterned after already existing land-grant colleges that conducted important agricultural research.

A new development for promoting and facilitating oceanographic research was the establishment of marine institutions. In North America such research centers encouraged and supported both small- and large-scale, local and foreign research by providing funds, laboratory, and library facilities, equipment, research vessels, and scientific expertise. Furthermore, marine institutions gave young people the opportunity to obtain graduate training and valuable experience in conducting science at sea. In the United States, the first such center—The Scripps Institution of Biological Research, which later became The Scripps Institution of Oceanography—was founded at La Jolla by the University of California in 1903. Two oceanographic centers were later established on the East Coast: the Woods Hole Oceanographic Institution in 1930 on the south shore of Cape Cod, Massachusetts, and the Lamont Doherty Geological Observatory in 1949 [now known as Lamont Earth Observatory] above the massive basalt cliffs of the Hudson River in New York. Today a number of
universities have major oceanographic programs
and large, sophisticated seagoing research vessels.
The trend recently has been to organize major
collaborations among marine scientists from
many disciplines and nations. Three noteworthy
programs of this type were the 1957–58 Interna-
tional Geophysical Year (IGY), the 1959–65 Inter-
national Indian Ocean Expedition under the aus-
pices of the United Nations, and the International
Decade of Ocean Exploration (IDOE) of the 1970s,
which was supported jointly by the United Nations
and National Science Foundation of the United
States. Research became less descriptive and more
quantitative, and instruments, sampling tech-
niques, and data storage and analysis became
increasingly more complex. In fact, many of the
concepts we will examine in the remainder of this
book are the direct result of such cooperative
efforts by teams of scientists.
Beginning in the 1960s, the National Science
Foundation organized and generously funded the
1968–75 Deep-Sea Drilling Project (DSDP). The
goals of this ambitious program included drilling
into the sediments and rocks of the deep sea to con-
firm sea-floor spreading and global-plate tectonics,
which were at the time recent theories about the
mobility of the oceanic crust. Furthermore, scien-
tists were to assess the oceans’ resources for the
benefit of humankind. The Glomar Challenger—
a 10,500-ton-displacement vessel [Figure 1–10a]
designed and built to serve as a drilling platform—
employed the latest electronic equipment for
dynamic positioning over a borehole. Samples of
sediment and rock obtained by drilling below the
sea bed helped geologists reconstruct the history of
the Earth and its oceans. The success of the DSDP
venture, from both an engineering and a scientific
perspective, exceeded the expectations of even its
most optimistic supporters. In 1975 the program
was reconstituted as the International Program of
Ocean Drilling (IPOD) with the support and active
participation of France, the United Kingdom, the
Soviet Union, Japan, and the Federal Republic of
Germany, as well as the United States. The Glomar
Challenger was retired in 1983 and another
drilling vessel, the Joides Resolution [Figure 1–10b],
continues the geologic exploration of the oceans.
To date, the DSDP and IPOD programs have drilled
over 2,900 holes into the sea bottom and retrieved
over 320 km of mud, sand, and rock core.
Units are defined for the measurement of length, mass, and time. Most Americans use the English system of units whereby length is expressed as inches, feet, and miles; mass as ounces, pounds, and tons; and time as seconds, minutes, hours, and years. Much of the rest of the world, including scientists, uses the metric system. In this scheme, length is measured in centimeters, meters, and kilometers, and mass is expressed in grams, kilograms, and metric tons. The units of time in the metric system are identical to those of the English system. Because this is a book of science, it uses the metric system of measurement throughout, but English equivalents are included in parentheses. Appendix II lists the conversion factors that link the two systems of measurement.

A very useful technique is the conversion of a unit from one system of measurement into another system. For example, you may want to express a water depth of 1,200 meters in feet or miles. How does one do this? It is a simple matter. The key is knowing the conversion factors (Appendix II) and keeping track of the units.

Let's try a few problems.

Convert 1,200 meters into kilometers. According to Appendix II, 1 kilometer = 1,000 meters. Dividing both sides by 1 kilometer yields

\[
\frac{1 \text{ km}}{1 \text{ km}} = \frac{1,000 \text{ m}}{1,000 \text{ m}}
\]

Dividing both sides by 1,000 m yields

\[
\frac{1 \text{ km}}{1,000 \text{ m}} = \frac{1,000 \text{ m}}{1,000 \text{ m}}
\]

JOIDES is developing multidisciplinary research strategies and identifying specific drilling sites to investigate climate variability over short- and long-term time scales, the dynamics of the Earth’s crust and interior, the evolution and paleobiology of the marine biosphere, the nature of catastrophic processes such as earthquakes, volcanic eruptions, and meteorite impacts, and past variations in the sea-ice cover of the Arctic Ocean. In 2003, Japan and the United States created the Integrated Ocean Drilling Program (IODP). By 2006, they expect to be joined by 20 countries and have a state-of-the-art drilling vessel, Japan’s Chikyu [Figure 1–10c]. Also, the use of submersibles [Figure 1–11a], both manned and unmanned, for probing the depths of the sea, will undoubtedly increase as the technology and the design of such crafts continue to improve.

A crucial technological breakthrough in oceanographic research has been the navigational accuracy provided by the Global Positioning System (GPS), developed by the U.S. Department of Defense during the 1970s. Relying on coded satellite signals, a state-of-the-art GPS receiver can determine latitude.
This is not surprising, because if the two units are equal, dividing one by the other must equal 1. This means that multiplying a value by either ratio does not change the value, because you are multiplying it by 1, and any value times 1 is that value. So in order to convert 1,200 meters into kilometers, we multiply 1,200 meters by the proper conversion ratio that eliminates the meter units. Let’s do this:

\[
(1,200 \text{ m})(1 \text{ km}/1,000 \text{ m}) = 1,200 \text{ km}/1,000 = 1.2 \text{ km}.
\]

Notice that if we use the other conversion ratio, the meter units will not cancel out:

\[
(1,200 \text{ m})(1,000 \text{ m}/1 \text{ km}) = (1,200)(1,000) \text{ m}^2/\text{km}.
\]

Now, let’s convert 1,200 meters into miles. We know from the above conversion that 1,200 meters = 1.2 kilometers. According to Appendix II, 1 kilometer = 0.621 miles. This means that

\[
\frac{1 \text{ km}}{1 \text{ km}} = \frac{0.621 \text{ miles}}{1 \text{ km}} = 1 \quad \text{or} \quad \frac{1 \text{ km}}{0.621 \text{ miles}} = \frac{0.621 \text{ miles}}{1 \text{ km}} = 1.
\]

Therefore,

\[
(1.2 \text{ km})(0.621 \text{ miles}/1 \text{ km}) = (1.2)(0.621) \text{ miles} = 0.745 \text{ miles}.
\]

It bears repeating that the key to accurate conversion is keeping careful track of the units.

**FIGURE 1-11**

New technology for probing the sea. (a) Submersibles, such as Alvin, are useful for the close examination and sampling of the fauna, sediment, and rock of the deep sea. (b) The TOPEX/Poseidon satellite launched by NASA in 1992 has provided detailed, accurate data on the level of the sea surface, crucial for predicting changes in current and climate patterns.
and longitude and vertical position of a receiver to within a few meters. This is accomplished by accurate measurements of the travel time of radio signals from a series of orbiting satellites, each with a unique transmission code, to a GPS receiver aboard a ship or aircraft. Twenty-four GPS satellites, monitored continually from five ground-based stations, constitute the worldwide system; the measurement of the precise distance between a receiver and four of the GPS satellites suffices to establish almost instantly the receiver's location. In effect, knowing where you are exactly in the middle of the ocean, where there are no landmarks, is now a standard procedure for oceanographers.

Perhaps the newest research development is a much greater dependence on remote-sensing techniques. Many marine scientists in the future will never go to sea; they will remain in laboratories (some located far inland away from the coastline), and satellites will continually transmit data to them from oceanographic buoys and unmanned platforms at sea at an unprecedented rate. Some of these research techniques are already in use. Sophisticated electronic instruments have been installed in satellites that can accurately detect sea-surface temperatures and can estimate concentrations of microscopic plants and the topography of the sea surface. For example, the TOPEX/Poseidon satellite (Figure 1–11b), launched by NASA in 1992, can determine the level of the sea surface to within an accuracy of 13 cm (~5.1 inches). Recently, the Deep Ocean Exploration Institute of Woods Hole Oceanographic Institution and the University of Washington have begun planning to install a grid of fiber-optic submarine cables that will crisscross at nodes. These cables will power deep-sea sensors and robotic vehicles, which would be in communication with oceanographers on land. This cable network will provide detailed surveys and long-term measurements, which will be invaluable for developing more sophisticated computer models of ocean processes.

These remote techniques enable scientists to survey large tracks of ocean quickly, efficiently, and at reasonable cost. Large computers are also playing an increasingly more important role in ocean research, not only as a tool for storing, sorting, and analyzing the large quantities of information being generated, but also for modeling the ocean's processes and conducting experiments to trace changes over time, ranging from time scales of a few years (El Niño cycles) to millions of years (the opening of ocean basins). The possibilities remain limitless and exciting. The findings of these future research programs will enhance our understanding of the workings of the planet and perhaps even contribute to the very survival of humankind!
1. What exactly is oceanography, and how does it differ from other fields of science?

2. Briefly describe the successes of the Egyptians and Phoenicians in ocean exploration.

3. What distinguishes modern oceanography from earlier scientific investigations of the oceans?

4. Briefly discuss the scientific achievements (consult Table 1–1) of the following:
   a. Pytheas
   b. Geradus Mercator
   c. Seneca
   d. Sir John Ross
   e. Nathaniel Bowditch
   f. Matthew Maury
   g. C. Wyville Thomson

5. In what ways are future oceanographic research techniques likely to differ from present ones?

6. What is GPS and why is it critically useful for oceanographers?

7. What exactly is the scientific method? Can scientists “prove” their hypotheses?

8. The DSDP and IPOD have recovered over 320 km of drill core from the ocean floor. How many feet and miles of core is 320 km? [See Appendix II: Conversion Factors.]
SELECTED READINGS


Oceanus. 1988–89. DSV Alvin: 25 years of discovery. Special issue 31 [4].
Oceanus. 1993–94. 25 years of ocean drilling. Special issue 36 [4].

Tools for Learning

Tools for Learning is an on-line review area located at this book’s web site OceanLink [www.jbpub.com/oceanlink]. The review area provides a variety of activities designed to help you study for your class. You will find chapter outlines, review questions, hints for some of the book’s math questions (identified by the math icon), web research tips for selected Critical Thinking Essay questions, key term reviews, and figure labeling exercises.