

CHAPTER

# 1



# The Growth of Oceanography

## LEARNING OBJECTIVES

- Gain familiarity with the history of ocean exploration and of oceanography.
- Critically evaluate the nature and power of the scientific method.
- Become proficient at reading graphs and doing unit conversions.

## PREVIEW

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 required painstaking investigations by numerous seafarers throughout centuries of exploration. Many intended to become rich by exploiting resources and controlling sea routes for commerce. All were driven by a yearning to understand the mysteries of the Earth and its seas.

Today's oceanographers (modern sea explorers) carry forward this quest to satisfy humankind's curiosity. They owe a huge debt to the courage and vision of earlier mariners, who by slow increments replaced ignorance and myth with knowledge.

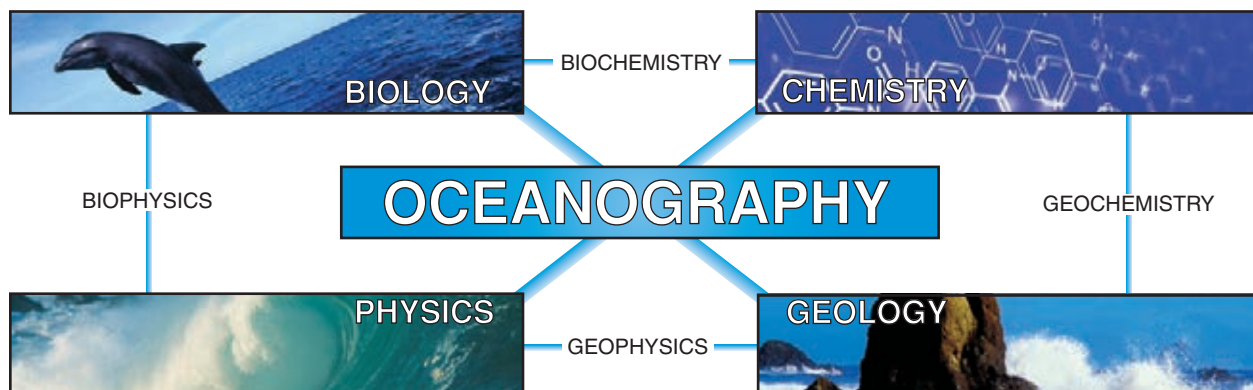
## Oceanography: What Is It?

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 *okeanos*, 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 *graphia*, 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 inquiry. 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. Thus, this text 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.

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## Historical Review of Oceanography

Our perception and understanding of the oceans have changed markedly over time. Although this text 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.

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**.

### 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 seagoing 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 common era (BCE), 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.

Records of sailing vessels indicate maritime activity in Egypt as far back as 4000 BCE. 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 BCE, however, Phoenicians had established sea routes for trading throughout the entire Mediterranean

TABLE  
1-1

## A Chronology of Ocean Exploration

4000



■  
ca. 4000 BCE  
Egyptians developed the arts of shipbuilding and coastal piloting.

3000



2000



■  
ca. 2000–500 BCE  
Most islands of the Pacific Ocean settled by Polynesians.



Courtesy of NOAA Central Library

1000



BCE CE



1000



1100



1200



1300



■  
ca. 1000–600 BCE

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.

■  
450 BCE

The Greek Herodotus compiled a map of the known world that centered on the Mediterranean region (see Figure 1-3).

■  
325 BCE

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.



© Photos.com

■  
276–192 BCE

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.

■  
54 BCE–30 CE

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.

■  
ca. 150 CE

The Greek Ptolemy compiled a map of the entire Roman World that showed latitudes and longitudes.

■  
673–735 CE

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.



© Stock Montage

■  
982 CE

The Norseman Erik the Red completed the first transatlantic crossing and discovered Baffin Island in the Arctic region of Canada.

■  
995 CE

Leif Eriksson, son of Erik the Red, established the North American settlement of Vinland in what is now Newfoundland.

BCE, before the common era  
CE, of the common era



## 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 Alvares Cabral discovered and explored Brazil.

1513

Juan Ponce de Leon 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

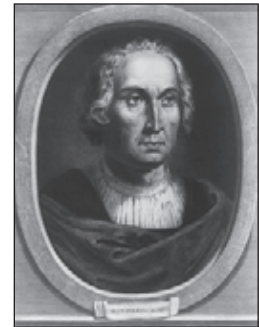
Peter Martyr proposed an origin for the Gulf Stream.

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.



Courtesy of Library of Congress, Prints & Photographs Division [LC-USZ62-8355]



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Courtesy of Library of Congress

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 Ingmarson, D. E., and Wallace, W. J. *Oceanography: An Introduction*, Table 1.2; McConnaughey, B. H., and Zottoli, R. *Introduction to Marine Biology*, Chapter 24; McCormick, J. C., and Thiruvathukal, J. V. *Elements of Oceanography*, Tables 1.1 and 1.2; Parker, H. S. *Exploring the Oceans*, Chapter 1; and Thurman, H. V. *Introduction to Oceanography*, Chapter 1.

## A Chronology of Ocean Exploration

1700

1725

1750

1775

1800

1825

1850

1725

Luigi Marsigli compiled *Histoire Physique de la Mer*, the first book to deal entirely with the science of the sea.

1740

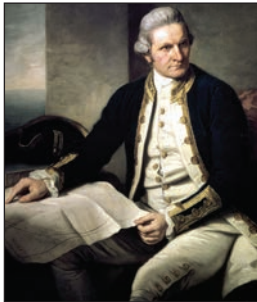
Leonhard Euler calculated the magnitude of the forces that generate ocean tides and related them to the attractive force of the Moon.

1769–1770

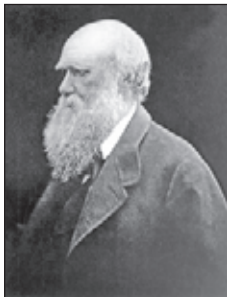
Benjamin Franklin published the first ocean chart of the Gulf Stream, which shippers consulted extensively as they crossed the North Atlantic Ocean.

1768–1771, 1772–1775, 1778–1779

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.



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1802

Nathaniel Bowditch published the *New American Practical Navigator*, a superb navigational resource that continues to be revised and published to this day.

1807

President Thomas Jefferson mandated coastal charting of the entire United States and established the U.S. Coast and Geodetic Survey.

1817–1818

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 kilometers.

1820

Alexander Marcet, a London physician, noted that the proportion of the chemical ingredients in seawater is unvarying in all oceans.

1831–1836

The epic journey of Charles Darwin aboard the *HMS Beagle* led to a theory of atoll formation and later to the theory of organic evolution by natural selection.

1839–1843

Sir James Ross, nephew of the Arctic explorer Sir John Ross, led a scientific expedition to Antarctica, recovering samples of deep-sea bottom life down to a maximum depth of 7 kilometers.

1841, 1854

Sir Edward Forbes published *The History of British Star-Fishes* (1841) and then his influential book, *Distribution of Marine Life* (1854), in which he argued that sea life cannot exist below about 600 meters (the so-called azoic zone).



Courtesy of NOAA Central Library



## Milestones in Early Oceanography

1855

Matthew Fontaine Maury compiled and standardized the wind and current data recorded in U.S. Navy ship logs and summarized his findings in *The Physical Geography of the Sea*.

1860

1865

1870

1875

1880

1885

1890

1895

1900

1868–1870

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.

1871

The U.S. Fish Commission was established with a modern laboratory at Woods Hole, Massachusetts.

1872–1876

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 *Challenger Reports*.

1873

Charles Wyville Thomson published a general and popular book on oceanography called *The Depths of the Sea*.

1877–1880

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.

1884–1901

The USS *Albatross* was designed and constructed specifically to conduct scientific research at sea and undertook numerous oceanographic cruises.

1888

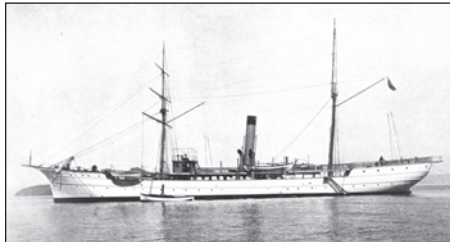
The Marine Biological Laboratory was established at Woods Hole, Massachusetts, and Dr. Charles Otis Whitman served as its first director.

1893

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.



Courtesy of Steve Nicklas, NOS,NGS/NOAA



Courtesy of Steve Nicklas, NOS,NGS/NOAA



## 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 Russia.

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.



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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.



Courtesy of John Bortniak/NOAA

1932

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

1942

Harald Sverdrup, 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.



## The Era of Modern Oceanography

1960 1965 1970 1975 1980 1985 1990 1995 2000 2005



1958

The nuclear submarine *USS Nautilus*, commanded by C.D.R. Andersen, reached the North Pole under the ice.



1959–1965

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.



1966

The U.S. Congress adopted the Sea Grant College and Programs Act to provide nonmilitary funding for education and research in the marine sciences.



Courtesy of U. S. Navy Submarine Force



1968, 1975

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.



1970

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.



1970s

The United Nations initiated the International Decade of Ocean Exploration (IDOE) to improve our scientific knowledge of all aspects of the oceans.



1972

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.



1978

*Seasat-A*, the first oceanographic satellite, was launched, demonstrating the utility of remote sensing in the study of the oceans.



Courtesy NASA/JPL-Caltech



1980s–1990s

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) continued the geological exploration of the oceans.



1992

NASA launched the *TOPEX/Poseidon* satellite to monitor sea level and to keep track of changes in current patterns as climate fluctuates.



Courtesy NASA/JPL-Caltech



1997

Kyoto Climate Protocol.



1998

International Year of the Ocean is organized to educate the public about the value and importance of the ocean's resources.



2001

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.

# The Era of Modern Oceanography

1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015



2003

Japan and the United States create the Integrated Ocean Drilling Program (IODP).

2006

Launching by IODP of a new ocean drilling vessel, Japan's *Chikyu*.

2008

The International Year of Planet Earth.

2009

The Copenhagen Global Climate Accord.

2010

Climate Change Conference Cancun, Mexico.

2011

International Climate Summit Durban, South Africa.



(a) POLYNESIA



(b) POLYNESIAN CANOE

**Figure 1–2 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.

© Photo Resource Hawaii/Alamy

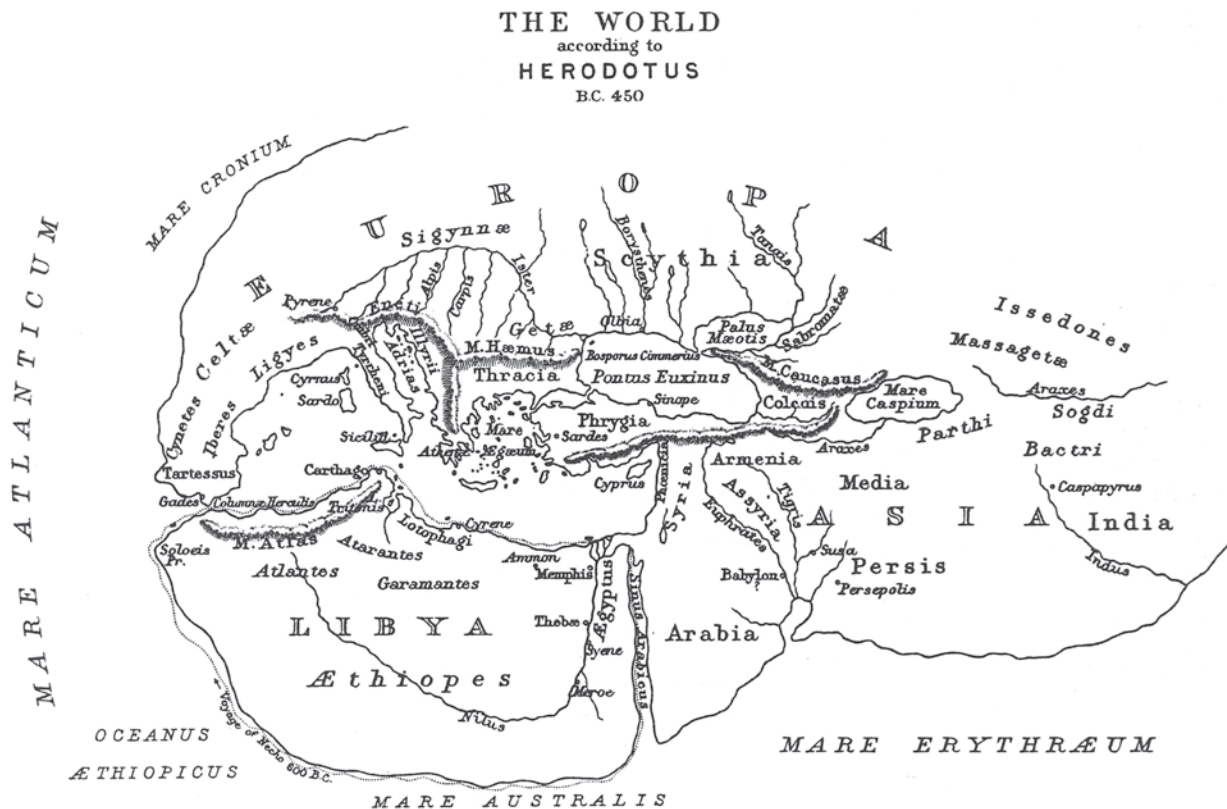


region and had even ventured westward into the Atlantic Ocean, sailing as far north as the coast of Cornwall in England. Historians suspect that Phoenicians, around 600 BCE, were probably the first to circumnavigate the continent of Africa. True ocean navigation was difficult at the time. Navigators 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 BCE, 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.

A map compiled by **Herodotus** in 450 BCE 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



**Figure 1-3** The Greek world. Herodotus compiled a map of the known world around 450 BCE, showing the Mediterranean Sea surrounded by the landmasses known as Europa, Asia, and Libya. Large tracts of ocean in turn surrounded this land, extending to the very edges of the world.

Courtesy of MEER

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 CE), there was little ocean exploration by Europeans, with the notable exception of the Viking seafarers. Between the ninth and the twelfth centuries, 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” (1430 to 1850 CE) 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 Vikings’ 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 1519, Magellan proceeded southwestward with his flotilla of five age-worn ships to the northeastern coast of Brazil (Figure 1-5).

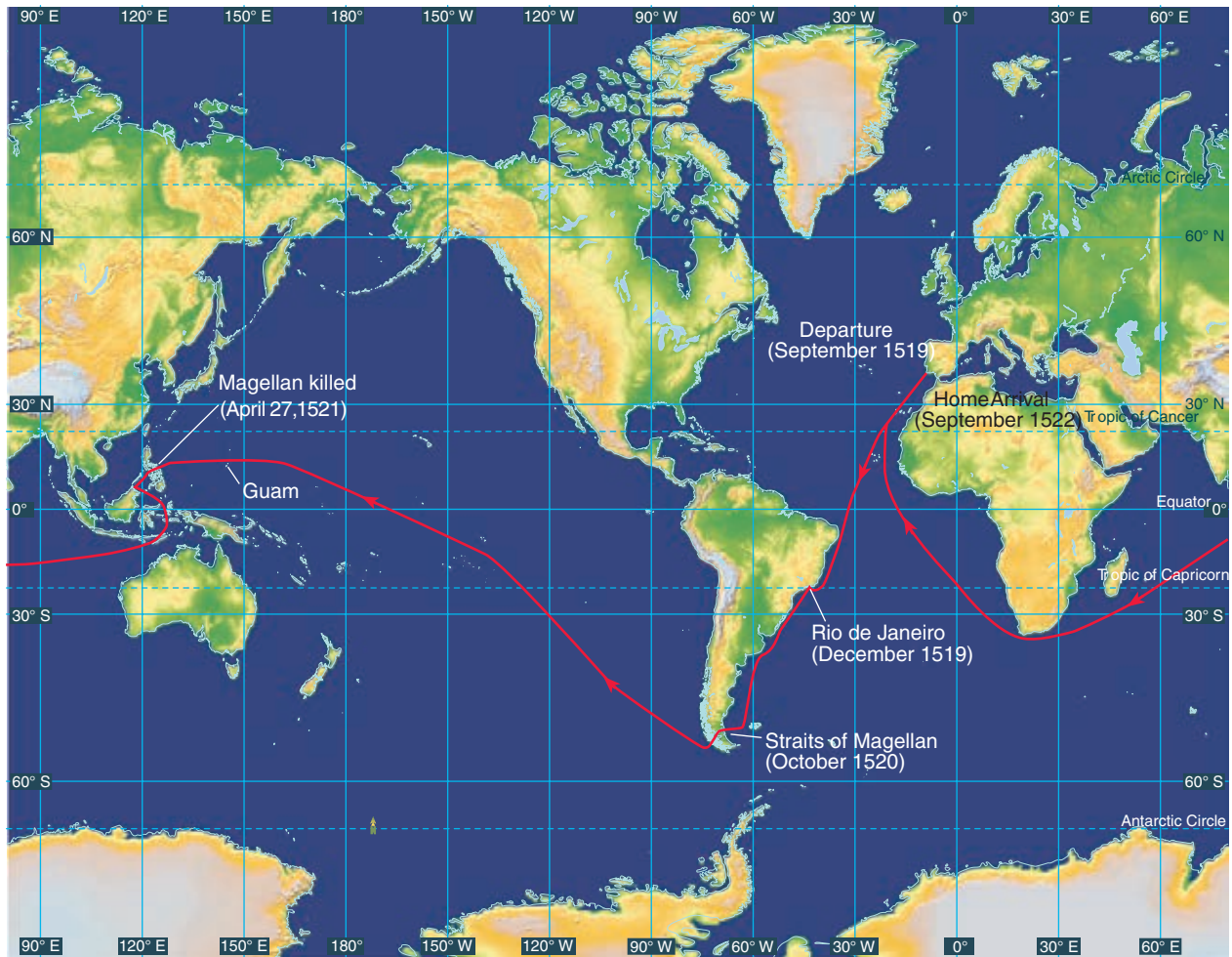


**Figure 1-4** A Viking chart of the North Atlantic Ocean.

This Viking map, dated at about 1570, demonstrates how extensive the knowledge of the North Atlantic Ocean was at that time. Familiar land features include Great Britain, Ireland, Iceland, Greenland, and a portion of the northeastern shoreline of Canada. The voyages of Erik the Red (982) are shown in red, those of Leif Eriksson (~1000) in green.

Courtesy of Royal Library

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 and 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.



**Figure 1–5** The circumglobal voyage of Magellan. 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.

## Early Scientific Investigations

A number of remarkably sophisticated scientific probings 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 continent then believed to extend into the polar latitudes, conjectured on the conviction there were equal proportions of land and ocean on the Earth). He then proceeded westward to Australia and explored and mapped its eastern coast, almost foundering on the Great Barrier Reef.

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 (Hale, J. R. *Age of Exploration*. New York: Time, Inc., 1966, 192).

Cook's final voyage (1778–79) led him to the Pacific Ocean once again, where he discovered numerous islands, including the Hawaiian Islands. Becoming the first mariner to sail the polar seas of both hemispheres, Cook also ventured northward into the Bering Sea until stopped by pack ice at a north latitude of 70° 44'. After returning to Hawaii, Cook was killed while attempting to recover a large boat stolen by a group of natives.

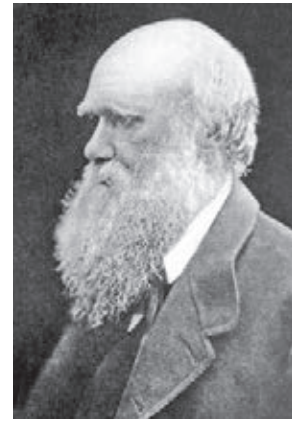
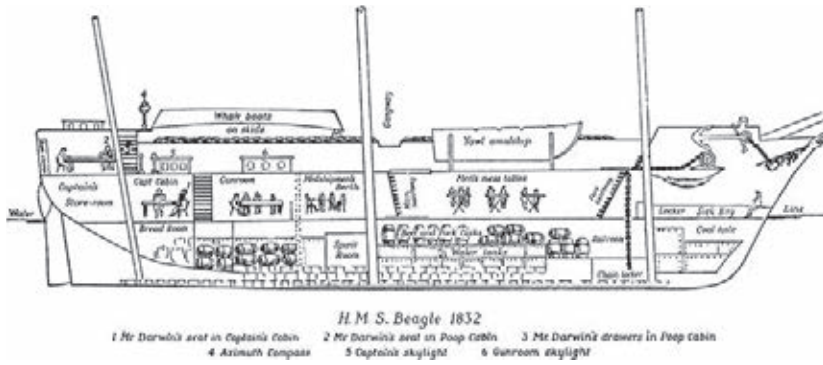
Important work in marine science during the mid-nineteenth century was conducted by **Matthew Fontaine Maury**, director of the U.S. Naval Depot of Charts and Instruments. While compiling *Wind and Current Charts*, a task that began in 1842, Maury realized the need for international cooperation in making 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 (**Figure 1-6**). 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.

One of the more successful and significant scientific voyages of the nineteenth century was directed by **C. Wyville Thomson** aboard the 2,360-ton corvette, the HMS *Challenger* (**Figure 1-7a and b**). Between 1872 and 1876, the *Challenger* completed a globe-encircling voyage, covering almost 125,000 kilometers (~77,500 miles) (**Figure 1-7c**). A primary goal of the cruise was to resolve the controversy about whether or not life existed in the abyss of the oceans. **Edward Forbes** (1815–1854), an influential English naturalist, maintained that the ocean depths below 550 meters (~1,750 feet) were azoic (lifeless). A staff of six scientists tirelessly followed the dictates of the Royal Society of London, determining the chemical composition of seawater and the distribution of life forms at all depths, conducting observations of coastal and ocean currents, and describing the nature of the sedimentary deposits that blanket the sea floor. This global approach to ocean studies represented a fundamental step in the evolution of marine science and heralded a new era in ocean exploration.

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 (**Figure 1-8**). 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.

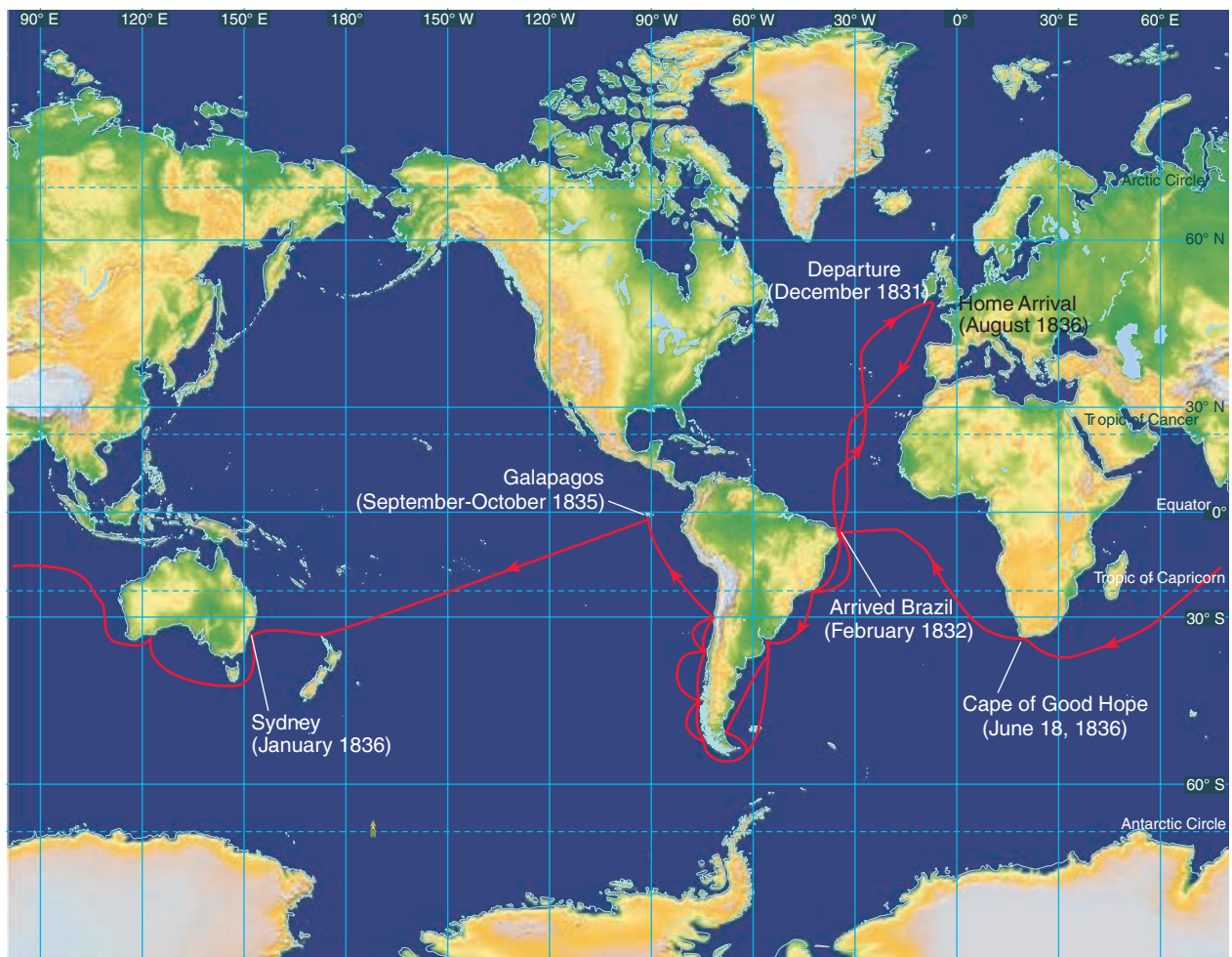


(a) HMS BEAGLE

Reproduced with permission from John van Wyhe ed. The Complete Work of Charles Darwin Online. (<http://darwin-online.org.uk/>)

(b) CHARLES DARWIN

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**Figure 1–6** 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*.



# SCIENCE by the Numbers

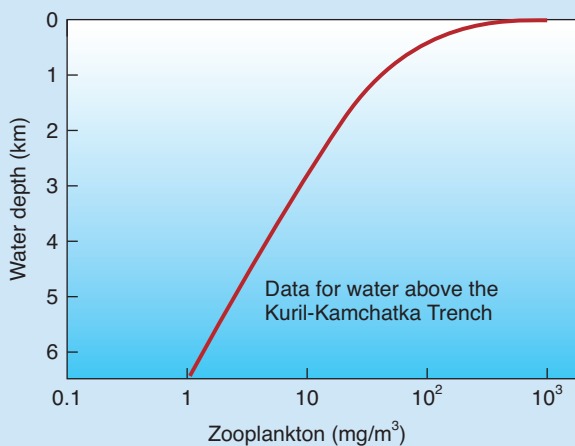
## Graphs

As you know, scientists strive to display information clearly and accurately. A useful and revealing way to display data is to plot the information on a graph. A data plot summarizes the information quickly and reveals trends and relationships among variables. Sometimes the relationship between variables is direct, meaning that an increase in one leads to an increase in the value of the other, and a decrease leads to a corresponding decrease. Other times, the relationship is inverse, meaning that an increase in one leads to a decrease in the other, and vice versa.

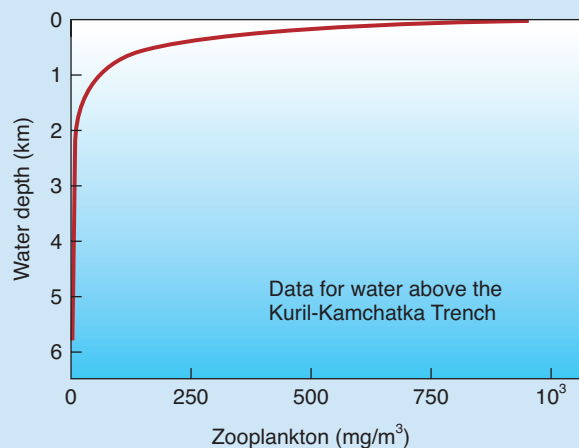
In many cases, relationships between variables are not linear but are curved in some complicated way. Also, scientists may choose not to use linear scales for one or both variables plotted on a graph. Oceanographers, for example, commonly graph a variable as a power of 10. Let's look at **Figure B1-1**. At first glance, it appears as if the concentration of tiny zooplankton suspended in the water above the Kuril-Kamchatka Trench of the northwestern Pacific Ocean decreases regularly with water depth, except near the sea surface, where the zooplankton are a bit more abundant than they are lower down in the water column (the vertical extent of water from sea

surface to sea bottom). The relationship between water depth and zooplankton abundance is inverse. To the unsuspecting, the plot suggests that zooplankton concentrations decrease gradually downward and that significant numbers of zooplankton exist even at depths below 5 kilometers. This impression is not, however, correct because the zooplankton abundances are plotted on a scale that varies as the power of 10. Thus, the minute quantities of zooplankton found in water deeper than 1 kilometer are amplified by the scale chosen to plot them.

A conventional plot of the data using a linear scale for zooplankton concentrations shows a very different graph (**Figure B1-2**). This reveals that zooplankton are essentially confined to water that is no deeper than 1 kilometer below the sea surface. Below 2 kilometers, there are virtually no zooplankton. Also, the sharp downward curve of the graph between 1 and 2 kilometers is masked by plotting the data along a scale that varies as a power of 10 (compare Figures B1-1 and B1-2). The lesson to be learned from this is that one must always note the scale intervals that are used for all the variables plotted on a graph.



**Figure B1-1** Nonlinear plot.



**Figure B1-2** Linear plot.

# The Process of Science

Test tubes: © Alfred Bondarenko/Shutterstock, Inc.

## The Scientific Process

As this chapter on the history of oceanography indicates, scientists make statements about the natural world; they assume that natural processes are orderly and therefore knowable by a rational mind. Statements made by scientists are not merely random opinions about the workings of the world. Rather they are logical explanations, termed hypotheses, that are grounded solidly on a set of observations and tested rigorously in order to evaluate their credibility.

Scientific investigations are begun typically by people who develop an interest in answering a question about the natural world. Examples of such questions in oceanography might be:

- What is the geologic origin of a particular estuary?
- How does the chemistry of the seawater in this estuary vary over time?
- What is the water current pattern in this estuary and what controls it?
- What effect does lead dissolved in the water have on a species of clam in this estuary?

The questions can be general or specific, theoretical or applied, abstract or concrete.

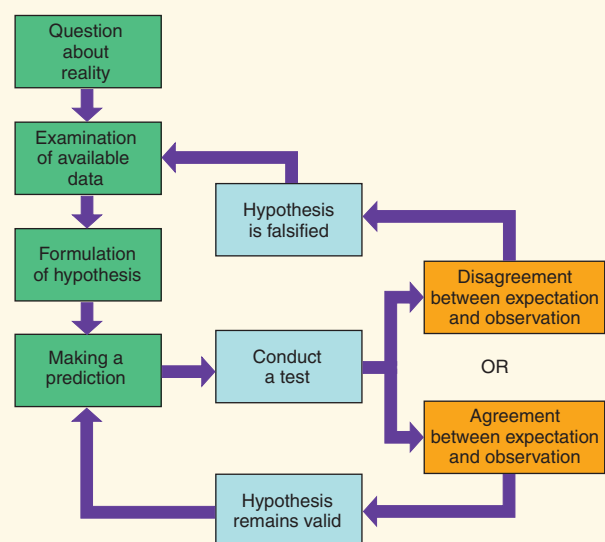
Scientists interested in a question then conduct laboratory, field, or modeling (mathematical) experiments in order to generate accurate facts (observations) that bear on an answer to the question being investigated. A legitimate answer (the hypothesis) to a scientific question is one that can be tested. A hypothesis is always considered to be a tentative explanation. Scientists first and foremost are skeptics, trying to disprove hypotheses in order to eliminate falsehoods from the scientific understanding of the natural world.

Depending on the results of tests, hypotheses may be verified, rejected, or modified. When a hypothesis is tested repeatedly in different ways and not disproved, scientists then assume that it is “correct” and the hypothesis becomes a theory, as new facts continue to support it. For example, Charles Darwin proposed his hypothesis of biological evolution by natural selection during the middle part of the nineteenth century. Today, after repeated tests and countless facts that support the idea, his hypothesis of biological evolution by natural selection has been elevated to the status of a theory.

In summary, scientists are not, as many believe, primarily concerned about discovering and gathering facts. Rather, researchers ask crucial questions about the natural world and then try to answer them by

proposing hypotheses—creative insights about what the truthful responses to those questions might be. What really separates the scientific method from other ways of knowing is its reliance on the rigorous testing of each hypothesis by experimentation or by the gathering of additional observations; 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 reality. A flow diagram of this version of the scientific method is presented as **Figure B2-1**.

In this text, 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.



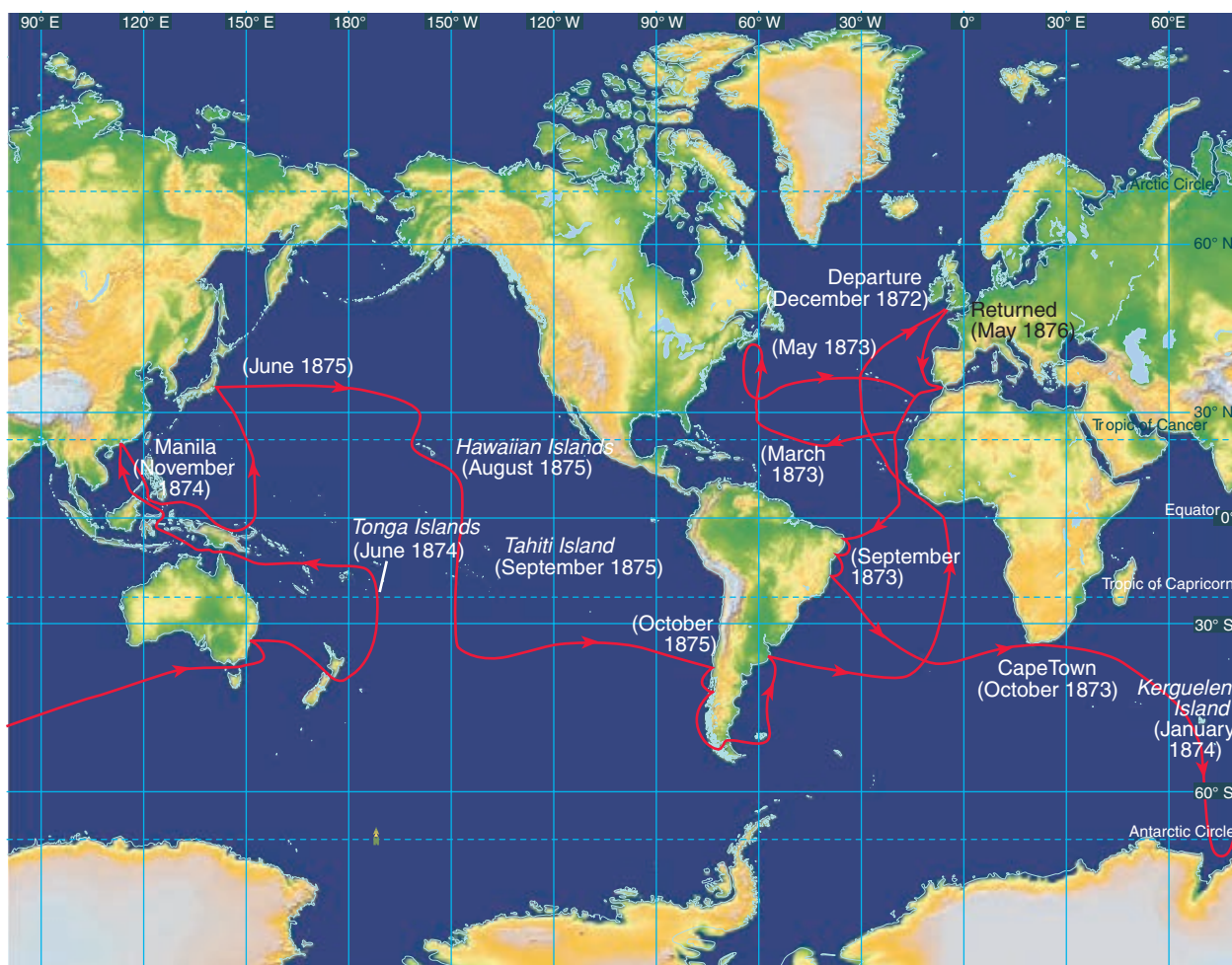
**Figure B2-1** The process of science. A version of the scientific method is presented as a simple flow diagram.



(a) HMS CHALLENGER  
Courtesy of Steve Nicklas, NOS, NGS/NOAA



(b) CHARLES WYVILLE THOMSON  
© National Library of Medicine



(c) ROUTE OF THE CHALLENGER EXPEDITION

**Figure 1-7** 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.



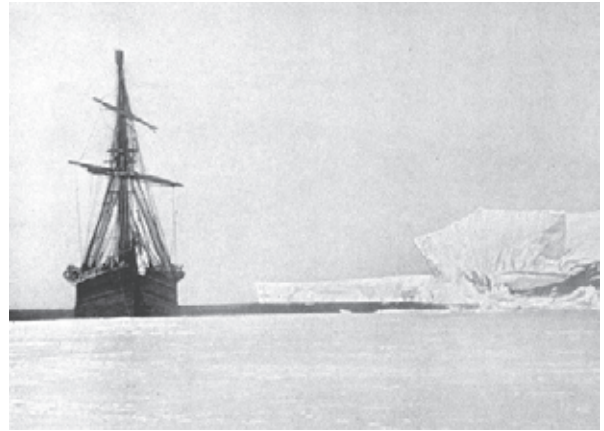
**Figure 1-8** The *Challenger* expedition. A small collection of the 360 dredge samples taken during the *Challenger's* circumnavigation of the world, 1872–76.

Copyright Natural History Museum, London

The findings of the *Challenger* crew left no doubt that organisms lived 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. More than twenty-three years were required to analyze all of the data and specimens collected by the *Challenger* expedition. These findings were published in fifty large volumes that marine researchers still consult today.

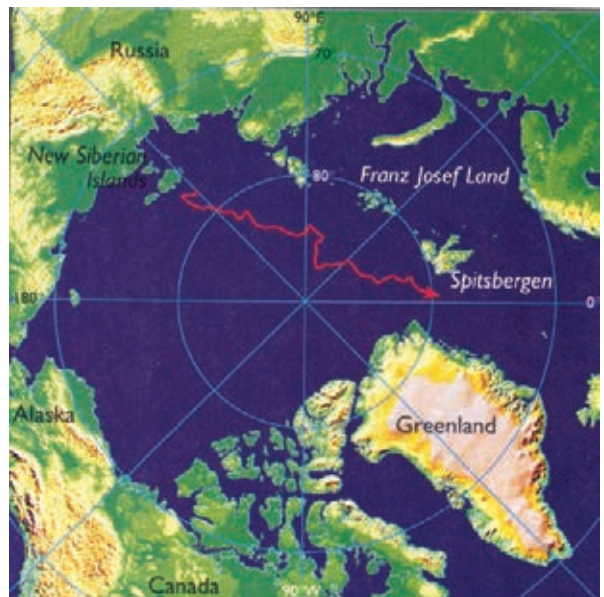
Near the end of the nineteenth century, the Norwegian explorer **Fridtjof Nansen** embarked on a remarkable journey in an effort to study the circulation of the Arctic Ocean and to be the first man to reach the North Pole. Nansen's scheme was to construct a robust, hardy research vessel that could be 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 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 **Fredrick Johansen** left the vessel in a courageous



(a) THE *FRAM*

Courtesy of Steve Nicklas, NOS, NGA/NOAA



(b) DRIFT ROUTE OF THE *FRAM*

**Figure 1-9** The Arctic voyage of the *Fram*. (a) The Norwegian vessel *Fram*, amid the ice of the Arctic Ocean. (b) The *Fram*, gripped solidly in sea ice, drifted for almost three years across the Arctic Ocean.

attempt to reach the North Pole by dogsled. After much hardship, they abandoned their quest after fourteen months, getting only as far as  $86^{\circ}14'$ . 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 reliance on highly complex instruments and sampling devices. A case in point is the expedition in 1925–27 of the *Meteor* to the South Atlantic Ocean. For twenty-five months, the German scientists used highly developed oceanographic equipment 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 **International Geophysical Year (IGY)**, the 1959–65 **International Indian Ocean Expedition** under the auspices of the United Nations, and the **International Decade of Ocean Exploration (IDOEO)** 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 techniques, 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 confirm seafloor spreading and global plate tectonics, which were at the time recent theories about the mobility of the oceanic crust. Furthermore, scientists 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 seabed 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.

### 1-3 Current and Future Oceanographic Research

The methods of oceanographic investigation are changing drastically. Without doubt, this trend will continue (probably at an even more accelerated pace) as technology is applied to the study of the sea in many new and ingenious ways.

The future directions that marine research will take are manifold. A greater reliance on international efforts involving many scientists and flotillas of research vessels is an inevitable result of increases in the magnitude and complexity of scientific problems and the accompanying price tag for such ambitious



(a) THE *GLOMAR CHALLENGER*  
Courtesy of Integrated Drilling Program



(b) THE *JOIDES RESOLUTION*  
Courtesy of Ocean Drilling Program, Texas A&M University

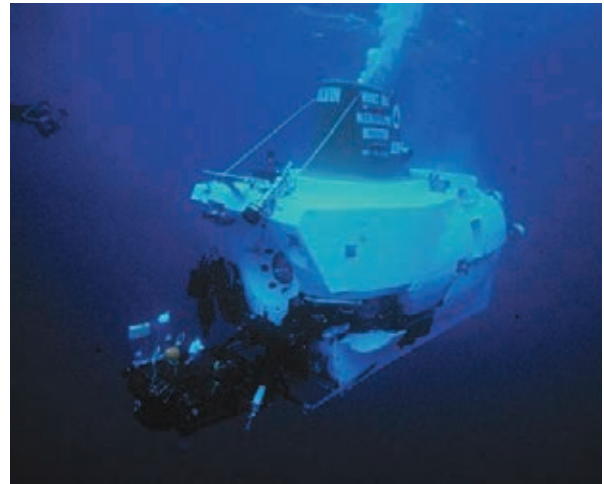


(c) THE *CHIKYU*  
© Kyodo/Landov

**Figure 1–10** Ships designed for deep-sea drilling. (a) The *Glomar Challenger*, a unique drilling vessel 122 meters long, could manage about 7.6 kilometers of drill pipe. (b) The *Joides Resolution*, about 300 meters long, can handle over 9.1 kilometers of drill pipe and operate safely in heavier seas and winds than the *Glomar Challenger* could. (c) The 210-meter-long *Chikyu* can drill in water depths up to 2.5 kilometers and carries enough drill pipe to continue 7.5 kilometers below the seafloor.

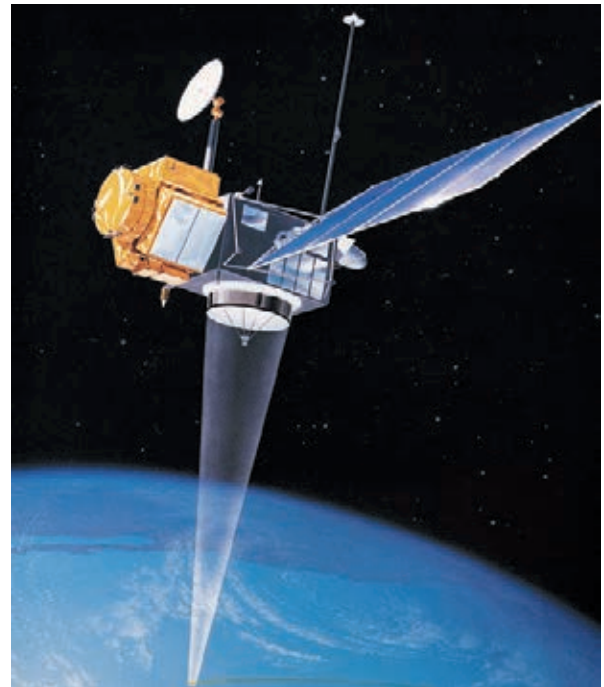
undertakings at sea. The successes of such large-scale endeavors as the IDOE and DSDP ensure that they will continue. To cite examples, *Joides* is developing multidisciplinary research strategies and identifying specific drilling sites to investigate climate variability over short- and long-term time 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). A new, state-of-the-art, 210-meter-long (~229 yards), deep-drilling vessel, the *Chikyu* (Figure 1-10c), was constructed in Japan and delivered in July 2005. Currently, the Center for Deep Earth Research (CDEX), a consortium of Canada, several European nations, China, and South Korea, is using the vessel to drill a series of deep holes in seismic zones of the Pacific seafloor. 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 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.



(a) ALVIN

Courtesy of OAR/National Undersea Research Program (NURP), Woods Hole Oceanographic Inst./NOAA



(b) TOPEX/POSEIDON SATELLITE

Courtesy NASA/JPL-Caltech

**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.

Perhaps the newest research development is a much greater dependence on remote-sensing techniques. Many marine scientists in the future

# SCIENCE by the Numbers

## Conversions

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

$$\frac{1\text{ km}}{1\text{ km}} = \frac{1,000\text{ m}}{1\text{ km}} \quad \text{or} \quad 1 = \frac{1,000\text{ m}}{1\text{ km}}$$

Dividing both sides by 1,000 m yields

$$\frac{1\text{ km}}{1,000\text{ m}} = \frac{1,000\text{ m}}{1,000\text{ m}} \quad \text{or} \quad \frac{1\text{ km}}{1,000\text{ m}} = 1$$

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:

$$(1,200\text{ m})\left(\frac{1\text{ km}}{1,000\text{ m}}\right) = 1,200\text{ m} / 1,000 = 1.2\text{ km.}$$

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

$$(1,200\text{ m})\left(\frac{1,000\text{ m}}{1\text{ km}}\right) = (1,200)(1,000)\text{m}^2 / \text{km.}$$

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

$$\frac{1\text{ km}}{1\text{ km}} = \frac{0.621\text{ miles}}{1\text{ km}} = 1 \quad \text{or} \quad \frac{1\text{ km}}{0.621\text{ miles}} = \frac{0.621\text{ miles}}{0.621\text{ miles}} = 1$$

Therefore,

$$(1.2\text{ km})\left(\frac{0.621\text{ miles}}{1\text{ km}}\right) = (1.2)(0.621)\text{ miles} = 0.745\text{ miles.}$$

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



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 will 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 tracts 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.

# STUDY Guide

## KEY CONCEPTS

1. Oceanographers are well-trained scientists who investigate the ocean, its organisms, and its processes. Oceanographic work is often multidisciplinary in character, involving the collaboration of many types of scientists (Figure 1-1), mathematicians, engineers, technicians, and policymakers.
2. Early efforts to learn about the oceans involved exploration by ship. The geography of the world, both its landmasses and oceans, was mapped in increasingly more accurate detail as techniques in piloting, navigation, and surveying were developed and refined. The preeminent sea voyagers were the Egyptians, Phoenicians, Greeks, and Norsemen (Table 1-1), their pioneering explorations culminating with Magellan's epic circumnavigation of the globe (Figure 1-5) between 1519 and 1521.
3. During the eighteenth and nineteenth centuries, long, large-scale expeditions were organized to sample sea life, chart the sea bottom, measure currents, and determine the chemical makeup of seawater in all parts of the world. Notable scientific achievements were made by Cook (1768-79), Darwin (1831-36) (Figure 1-6c), Thomson (1872-76) (Figure 1-7c), and Nansen (1893-95) (Figure 1-9b), among others (see Table 1-1).
4. Modern oceanography (Table 1-1), which began in earnest with the cruise of the German ship the *Meteor* to the Atlantic Ocean in 1927, relies on sophisticated instruments to make accurate and efficient measurements of the oceans' properties. Also, marine institutions have been established specifically to promote research in the sea.



The newest development is the organization of major collaborative programs involving marine scientists from many nations. The International Decade of Ocean Exploration (1970s), the Deep Sea Drilling Project (1968–75), and the International Program of Ocean Drilling (1975–present) are among them.

5. Future scientific studies of the ocean will rely more and more on large inter-

national programs and remote-sensing techniques, including measurements from satellites, ocean buoys, unmanned platforms at sea, and exact location by the Global Positioning System (GPS). Computers for storing, handling, and processing the enormous quantities of data and for modeling ocean processes are playing an ever-increasing role in ocean research.

## QUESTIONS

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. Gerardus 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 kilometers of drill core from the ocean floor. How many feet and miles of core is 320 kilometers? (See Appendix II: Conversion Factors.)

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