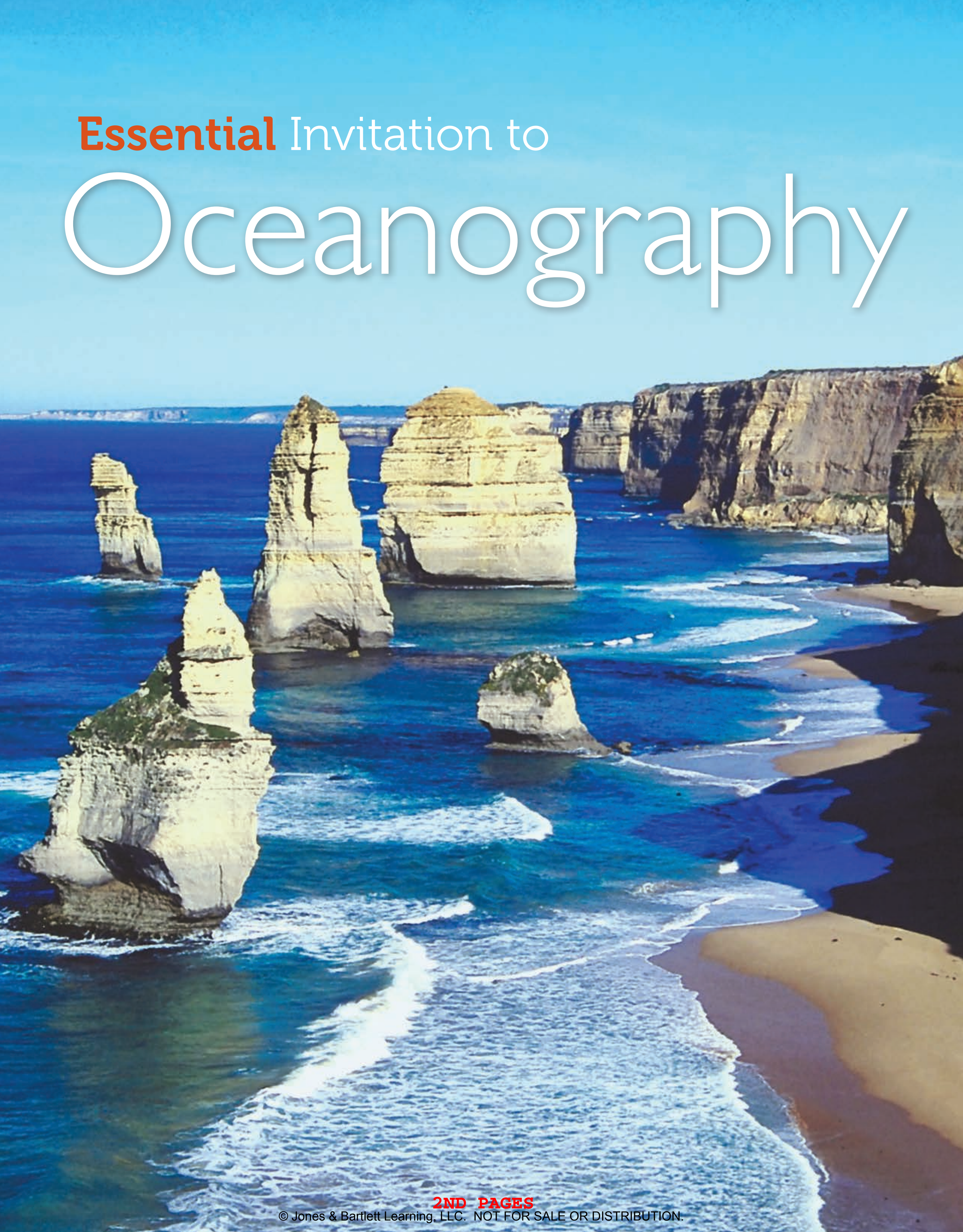
Essential Invitation to Oceanography



What is the sense of owning a good boat
if you hang around in home waters?

~ George Miller, Oyster River

The Growth of Oceanography

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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.

1-1 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 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. Thus, 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.

1-2 Historical Review of Oceanography

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

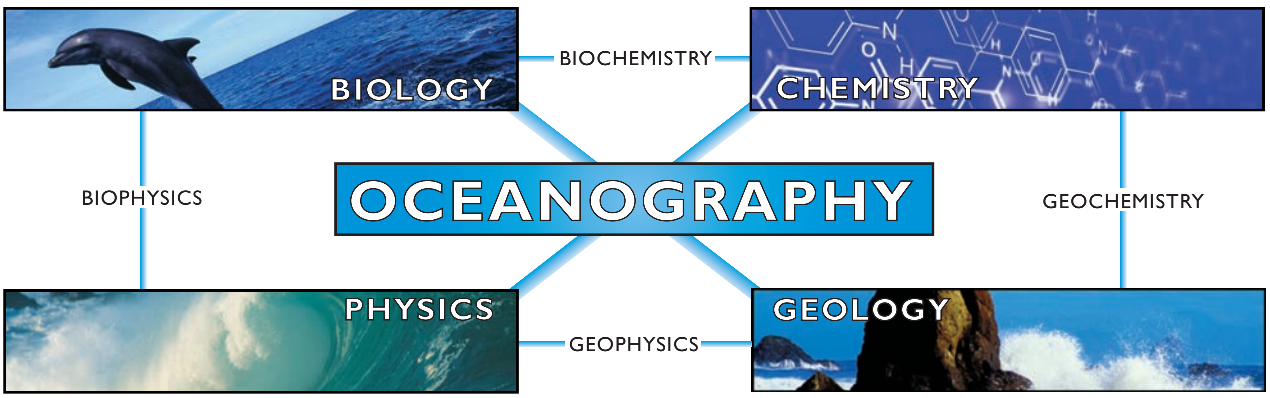


FIGURE 1–1 **The field of oceanography.** This diagram organizes oceanography into four principal categories—biological, geological, physical, and chemical oceanography—that are linked to one another by cross-disciplines.

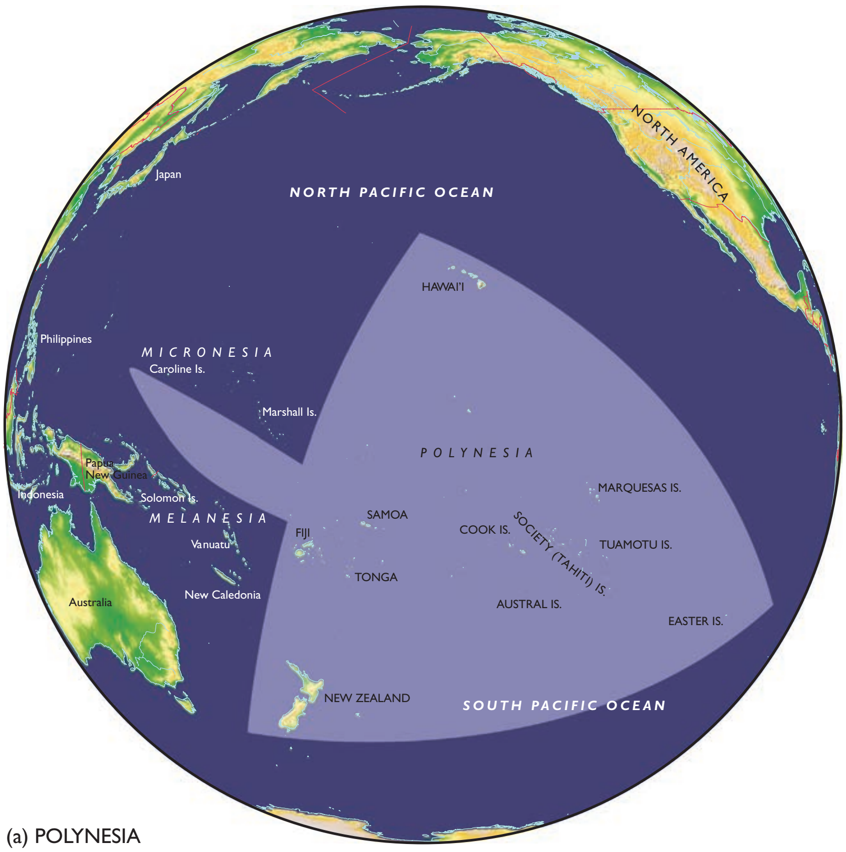
and more widely applied to probe the ocean's secrets, many beliefs of the past have been disproved. The lesson from history is clear-cut. Our ideas of the oceans today, which seem so appealingly final and are written about and taught with so much fervor and certainty, will be refined by the findings 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.

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



(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.

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 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

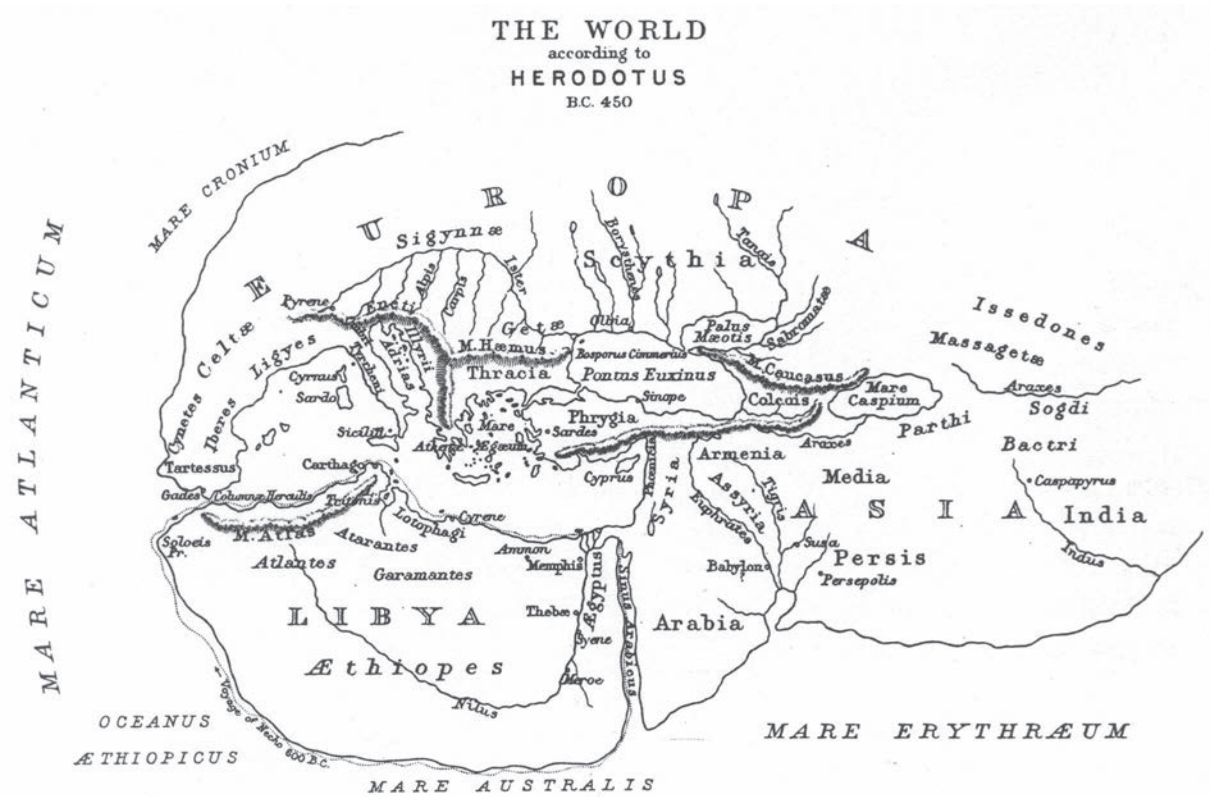


FIGURE 1–3 **The Greek world.** Herodotus compiled a map of the known world around 450 BCE, showing the Mediterranean Sea surrounded by the landmasses known as Europa, Asia, and Libya. Large tracts of ocean in turn surrounded this land, extending to the very edges of the world.

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 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).

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 Lief Eriksson (~1,000) in green.

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). 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.

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

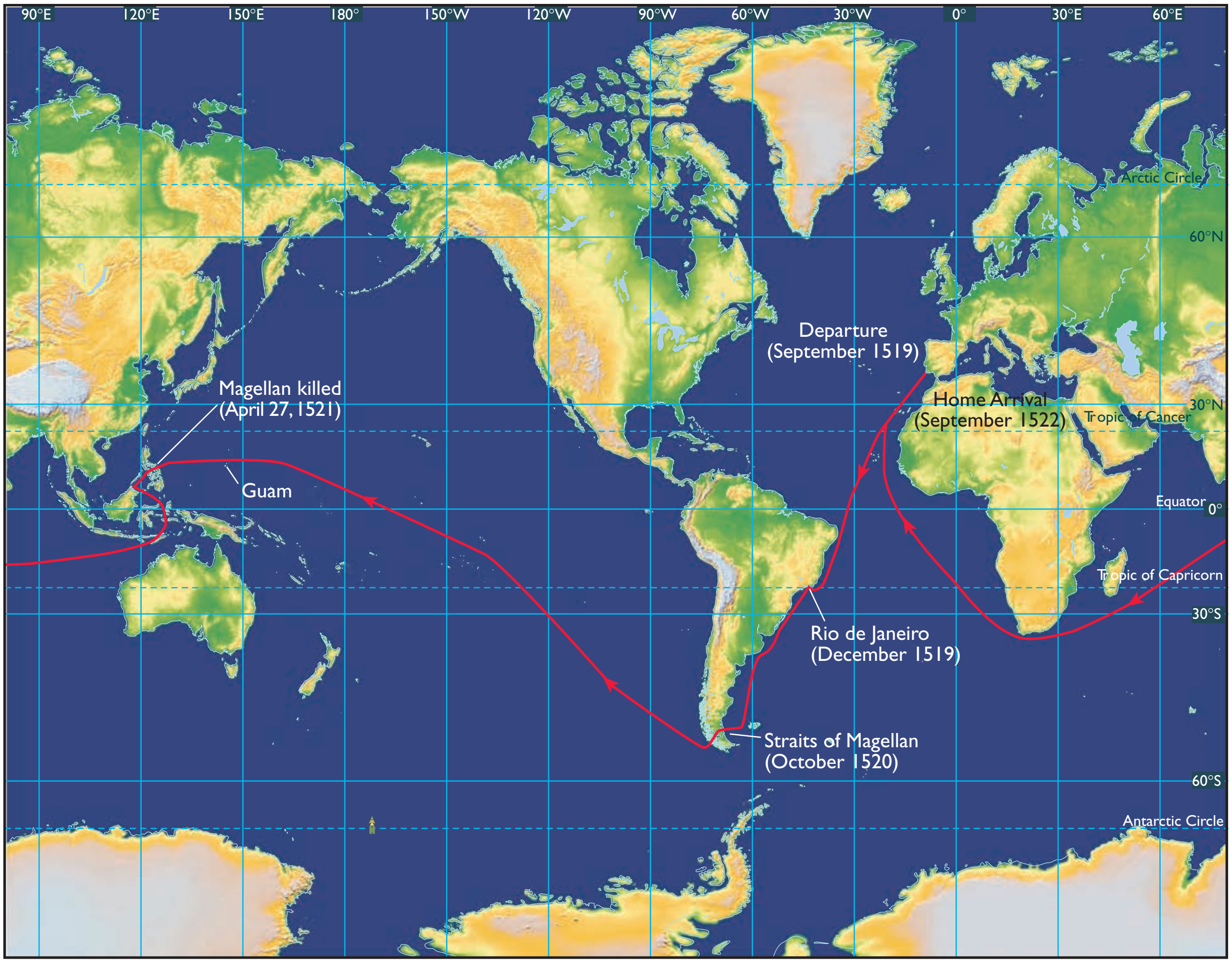


FIGURE 1–5 **The circumglobal voyage of Magellan.** Ferdinand Magellan embarked on a three-year-long voyage in 1519, intent on discovering a seaway to the East Indies. In 1520 he rounded the Straits of Magellan and continued to the Philippines, where he was killed during a skirmish with natives. Sebastian del Cano completed the journey as leader of the expedition.

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 was an equal proportion 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.

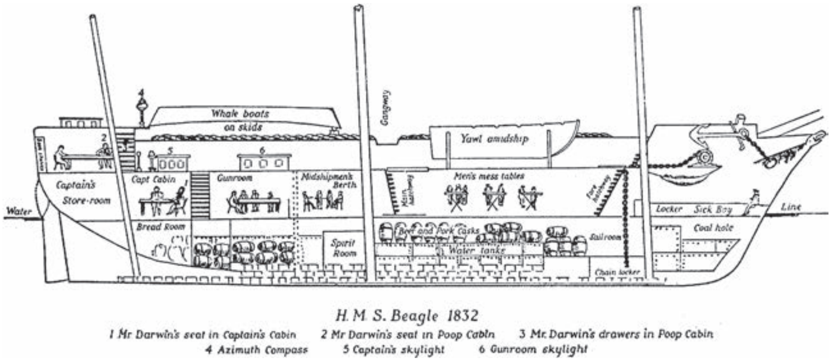
Important work in marine science during the mid-nineteenth century was conducted by **Matthew Fontaine Maury**, director of the U.S. Naval Depot of Charts and Instruments. While compiling *Wind and Current Charts*, a task that began in 1842, Maury realized the need for international cooperation in making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

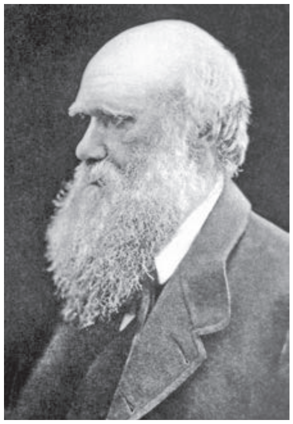
One of the more successful and significant scientific voyages of the nineteenth century was directed by **C. Wyville Thomson** aboard the 2,360-ton corvette, the HMS *Challenger* (FIGURE 1–7a and b). Between 1872 and 1876, the *Challenger* completed a globe-encircling voyage, covering almost 125,000 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. 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.

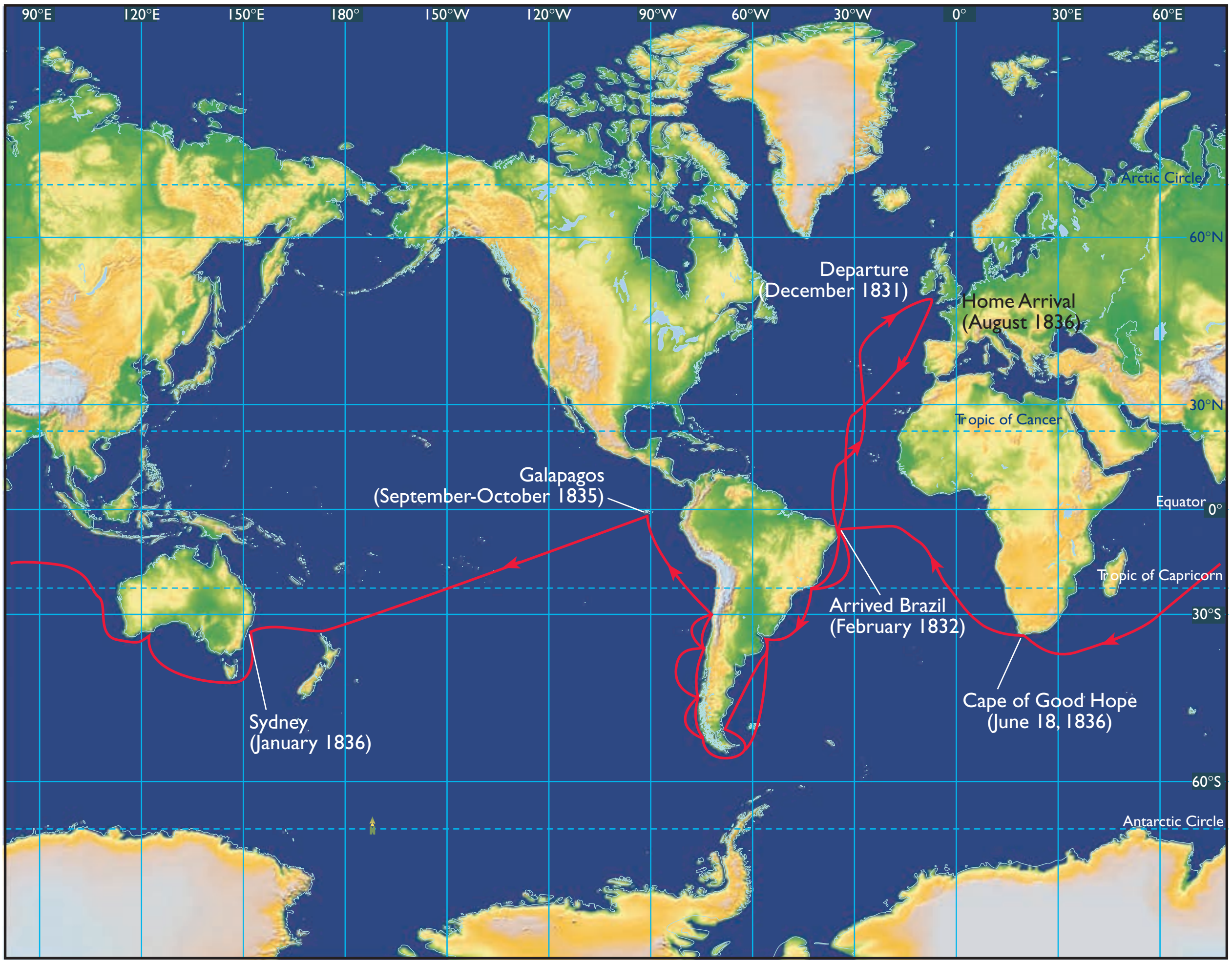
Near the end of the nineteenth century, the Norwegian explorer **Fridtjof Nansen** embarked on a remarkable journey in an effort to study the circulation of the Arctic Ocean and to be the first man to reach the North Pole. Nansen's scheme was to construct a robust, hardy research vessel that could be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



(a) HMS *BEAGLE*



(b) CHARLES DARWIN

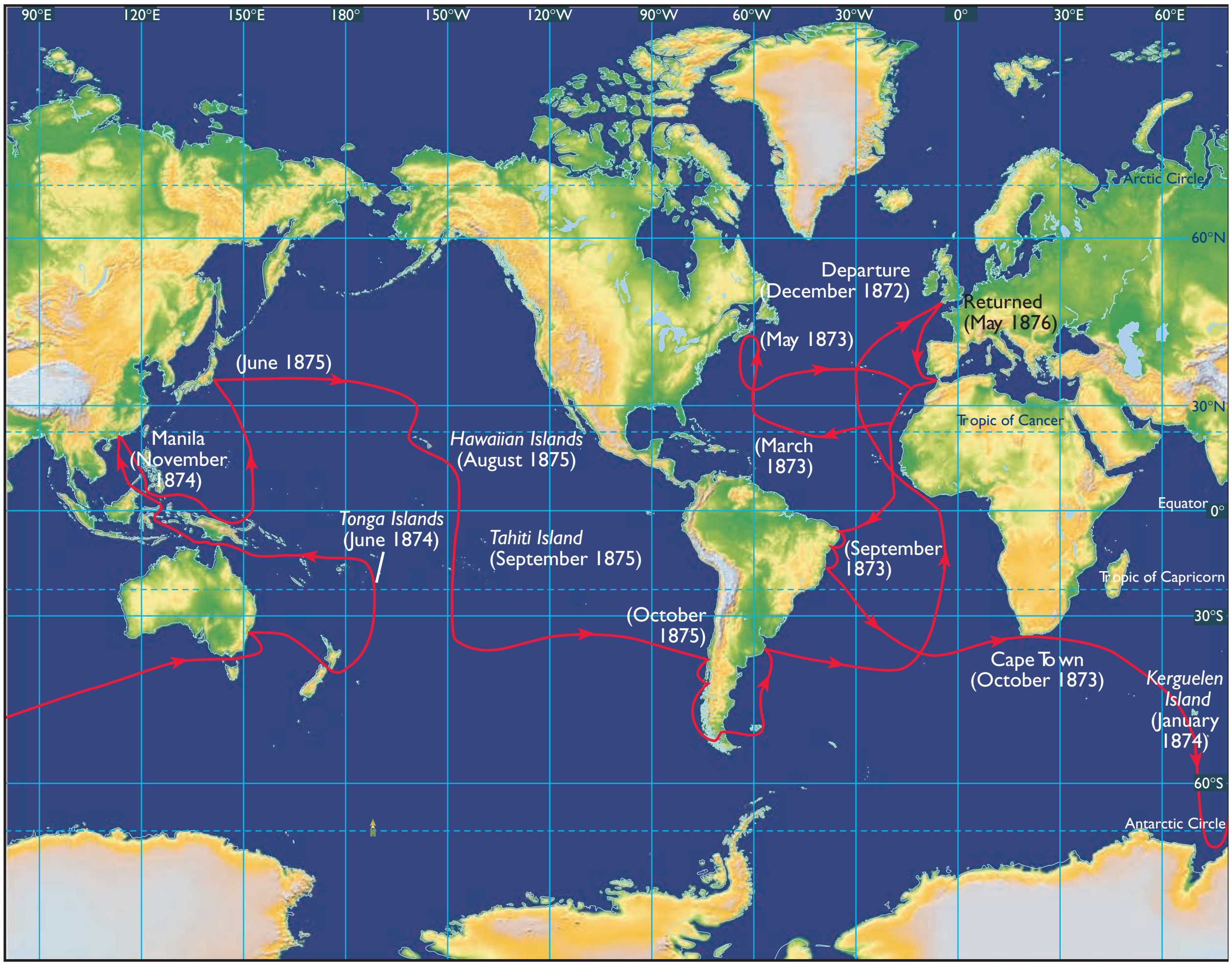


(c) ROUTE OF HMS *BEAGLE*

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*.

(a) HMS *CHALLENGER*

(b) CHARLES WYVILLE THOMSON



(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.

The Process of Science

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 the truth. A flow diagram of this version of the scientific method is presented as FIGURE B1–1.

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.

Visit **http://science.jbpub.com/oceanlink6e** for more information.

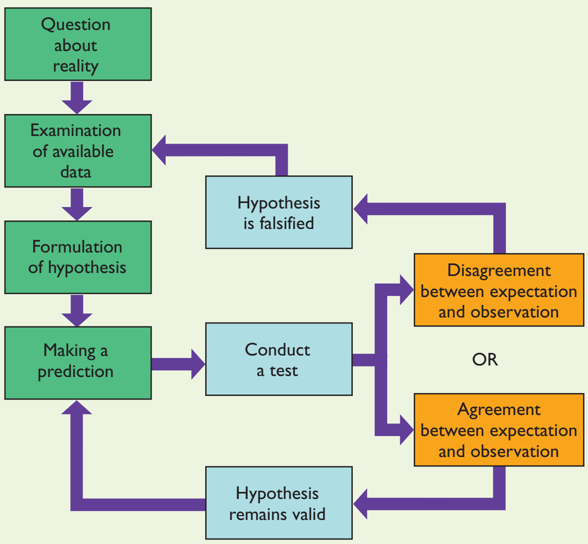


FIGURE B1–1 **The process of science.** A version of the scientific method is presented as a simple flow diagram.

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.

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.

(a) THE *FRAM*

(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.

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

THE OCEAN SCIENCES

PHYSICS Marine Archeology

Searching Davy Jones's 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 side-scan 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 Jeremy Project

This ambitious venture, a collaborative effort by the National Park Service, NASA, the U.S. Navy and Coast Guard, the Alaska State 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.

USS Monitor

In 1973, Duke University marine scientists located the USS *Monitor*, a Union Civil War vessel that was the first steam-powered ironclad warship constructed without masts and sails (FIGURE B1–2). She was found in the "Graveyard of the Atlantic," some 25 kilometers (15.6 miles) off Cape Hatteras, North Carolina in about 70 meters (~230 feet) 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 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 *Brummer, Koln,* and *Dresden* and the battleships *Wilhelm, Konig, 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 multibeam echo sounder, SAC is surveying the wrecks and has obtained a remarkable set of images of many of these warships (FIGURE B1–3), some lying on their sides, others overturned with keels pointing upward.

Visit http://science.jbpub.com/oceanlink6e for more information.

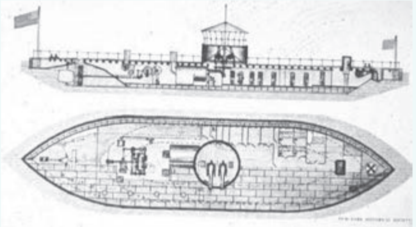


FIGURE B1–2 USS *Monitor.* This image of the *Monitor* shows how the steam-powered ironclad was constructed. NOAA salvagers raised the main gun turret from the seabed off Cape Hatteras where the vessel sank while being towed during an 1862 gale.

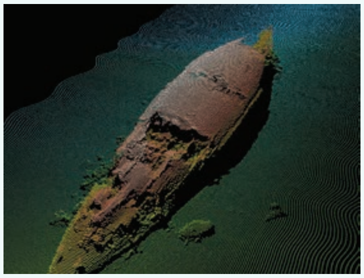


FIGURE B1–3 This multi-beam echosounder image displays in remarkable, three-dimensional detail the remains of the SMS *Markgraf,* one of the Imperial German Navy warships scuttled in Scapa Flow (Orkney, Scotland) in 1919.

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** (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 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

(a) THE *GLOMAR CHALLENGER*

(b) THE *JOIDES RESOLUTION*

(c) THE *CHIKYU*

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.

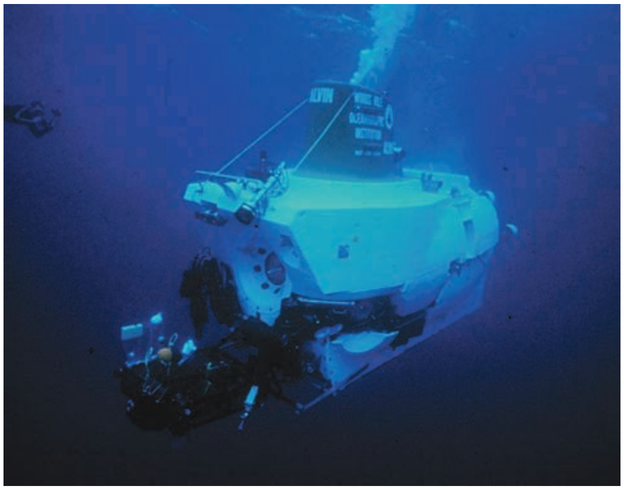
reconstituted as the **International Program of Ocean Drilling** (IPOD) with the support and active participation of France, the United Kingdom, the Soviet Union, Japan, and the Federal Republic of Germany, as well as the United States. The *Glomar Challenger* was retired in 1983 and another drilling 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

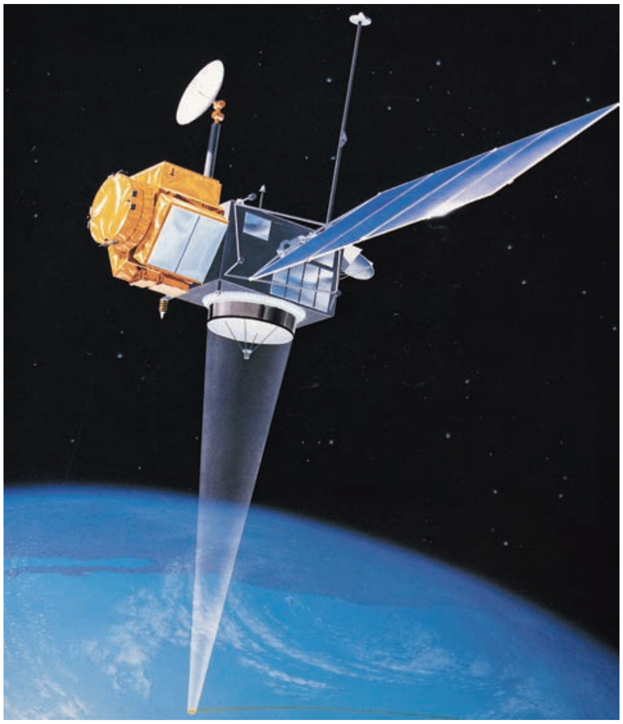
The methods of oceanographic investigation are changing drastically. Without doubt, this trend will continue (probably at an even more accelerated pace) as technology is applied to the study of the sea in many new and ingenious ways.

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 undertakings at sea. The successes of such large-scale endeavors as the IDOE and DSDP assure 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



(a) *ALVIN*



(b) TOPEX/POSEIDON SATELLITE

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.

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.

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 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, 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.
4. Modern oceanography, 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 international 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. In what ways are future oceanographic research techniques likely to differ from present ones?
5. What is GPS, and why is it critically useful for oceanographers?
6. What exactly is the scientific method? Can scientists "prove" their hypotheses?

Tools for Learning

Tools for Learning is an on-line review area located at this book's web site OceanLink (**http://science.jbpub.com/oceanlink6e**). 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.

Environmental Issues

Introduction to Issues in Ocean Sustainability

Introduction

"The findings are shocking. This is a very serious situation demanding unequivocal action at every level. We are looking at consequences for humankind that will impact in our lifetime, and worse, our children's and generations beyond that."

The speaker was Dr. Alex Rogers, scientific director of the International Programme on the State of the Ocean (IPSO), and he was referring to a 2011 report[1] issued by this international group of marine scientists on the impact of humans on the oceans. The panel concluded that a mass marine extinction unprecedented in human history was inevitable in the absence of "urgent actions to restore the structure and function of marine ecosystems."

To what "impact of humans" was the panel referring? Could humans, a species that has been on the planet for a relatively short time, be directly responsible for a massive extinction in the global ocean? And what specifically are the "urgent actions" that need to be taken?

These are questions we will be answering (and asking you to analyze) in twelve two-page *Issues in Ocean Sustainability* boxes placed between selected chapters, with links to additional information and activities on this book's companion website. Each of these self-contained issues is designed to be a thought-provoking, science-based, interactive introduction to a real-life, not hypothetical marine issue, many of which you may have never considered. As the name implies, these issues focus on sustainability, so let's start by defining sustainability and applying the concept to the ocean.

What Is Sustainability?

Sustainability, or sustainable development, was defined in 1987 by the World Commission on Environment and Development[2] as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Sustainability involves a transformation from a wasteful *linear* model of resource use in which natural resources (be they living or nonliving) are extracted, used, then thrown "away," to a *cyclical* model built around reduction, reuse, and recycling. Sustainability also extends beyond environmentalism to include economic and social justice.

Achieving Sustainable Oceans

Achieving a sustainable ocean requires addressing a number of seemingly unrelated issues. These include fisheries, forests, energy, biodiversity, climate change (ocean warming, sea level rise, and acidification), manufacturing and industry, agriculture, justice and equity and, of course, human population growth (FIGURE 1).

Climate Change

The speed with which human-induced climate change is occurring is overwhelming the ability of natural ecosystems to adapt. Rising sea levels will flood and destroy coastal salt marshes, and increased ocean temperatures threaten communities like coral reefs. Moreover, the ability of oceans to absorb CO_2, the chief climate-changing gas, has been exceeded; as a result, the oceans are acidifying at a rate that alarms marine scientists. Climate change is the 600-pound gorilla in the corner for each Issue, that is, no issue can be considered without considering the added impact of climate change.

Fisheries

Contemporary industrial-style fishing methods and, surprisingly some recreational fishing, impose significant environmental costs. Yields from global fisheries are declining, leading to expansion of aquaculture often at the expense of coastal ecosystems and wild fish.

Protecting Forests and Other Terrestrial Ecosystems

Forests retard sediment loss and filter runoff that can poison near-shore marine ecosystems such as coral reefs. Forests also store carbon, mediating climate change and thereby reducing excess carbon dioxide dissolved in seawater, which can lead to acidification of the oceans.

Energy

Sustainable societies cannot be built on nonrenewable energy resources. Burning fossil fuel emits the pollutants that cause climate change as well as others that have been

[1] Rogers, A.D. & Laffoley, D.d'A. 2011. *International Earth system expert workshop on ocean stresses and impacts*. Summary report. IPSO Oxford, 18 pp. Available at http://www.stateoftheocean.org/pdfs/1906_IPSO-LONG.pdf

[2] World Commission on Environment and Development (Gro Harlem Brundtland, Chair). 1987. Our Common Future. Oxford: Oxford University Press.

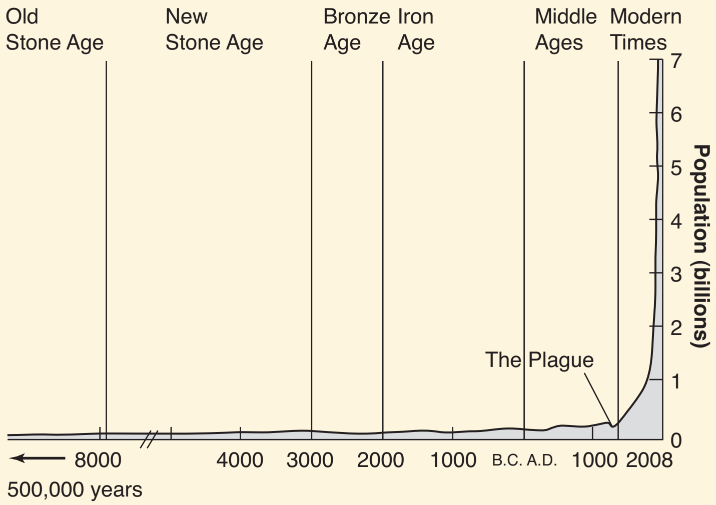


FIGURE 1 **Human population growth.** World population growth, which exhibits a J-shape, or exponential, curve. Is it possible for human population growth to continue forever? Why or why not?

distributed throughout the oceans. Moreover, the transport of petroleum by tanker inevitably results in oil spills that degrade and may destroy sensitive marine habitats.

Biodiversity

Our very survival as a species could ultimately rely on maintaining the integrity of marine ecosystems that we are only beginning to understand. Biodiversity, the mix of organisms within an ecosystem, is particularly critical for sustainability because of the specialized (and often little-understood) roles each species plays in maintaining the dynamic state of ecological balance.

Manufacturing and Industry

Human societies generate waste in unprecedented quantities, some of it artificial chemicals, such as DDT and dioxin, never before seen on Earth. In nature, waste eventually becomes something else's food, but industrial chemicals like persistent organic pollutants are dangerous when they enter marine food webs. Trans-oceanic transport of raw materials and manufactured products by ship uses fossil fuels (most notably high sulfur bunker fuel) and introduces invasive species. These are critical problems for a world five-sixths of whose population is trying to develop along Western-style free-market lines.

Agriculture

Agricultural runoff, from fertilizer and animal excrement, contributes excessive amounts of nutrients to coastal waters, leading to the creation of dead zones, ocean zones devoid of oxygen. Virginia Institute of Marine Science biologist Robert Diaz calls dead zones, which occur in the Gulf of Mexico, Chesapeake Bay, Baltic Sea, and other areas, "the biggest environmental issue in the…marine realm in the 21st century."

Justice and Equity

Injustice, including lack of adequate housing and sanitation, a lack of access to education, an inadequate supply of pure water, exposure to environmental toxins, and environmental degradation related to industrial pollution, often drives rapacious and unsustainable use of marine natural resources (e.g. coral reef fisheries and mangrove wetlands).

Population Growth

The population of humans surpassed 7 billion in 2011, and we are on a trajectory to exceed 10 billion before beginning to stabilize sometime in mid-century. Although humans exert a substantial positive impact with our enormous ingenuity, we also have a profound physical impact on the marine environment, and the marine environment also impacts us.

Question 1. You should consider all of the above issues as you read this textbook, and we anticipate your views on what it will take to achieve a sustainable ocean will evolve and mature over time. For now, discuss which of the above issues you would address first, and what steps you would take to move toward achieving a sustainable ocean.

Now, go to our website to continue this analysis.