Chapter 1

A sextant and marine charts. The sextant is an early navigational aid first constructed by John Bird in 1759.

The History of Oceanography

Chapter Outline

Learning Outcomes

After studying the information in this chapter students should be able to:

1. *describe* the difference between a scientific hypothesis and a theory,
2. *discuss* the interaction of early civilizations with the oceans,
3. *sketch* the major seafaring routes of the great voyages of discovery in the fifteenth and sixteenth centuries, James Cook's voyages of discovery, and the scientific voyages of Charles Darwin and the *Challenger* expedition.
4. *list* the major discoveries of the *Challenger* expedition,
5. *compare* and *contrast* the methods of making scientific measurements in the nineteenth and twentieth centuries, and
6. *describe* the difference in both the quantity of oceanographic data and the density of that data available to oceanographers now compared to the nineteenth century.

Oceanography is a broad field in which many sciences are focused on the common goal of understanding the oceans. Geology, geography, geophysics, physics, chemistry, geochemistry, mathematics, meteorology, botany, and zoology have all played roles in expanding our knowledge of the oceans. Oceanography today is usually broken down into a number of subdisciplines because the field is extremely interdisciplinary.

Geological oceanography includes the study of Earth at the sea's edge and below its surface, and the history of the processes that form the ocean basins. Physical oceanography investigates the causes and characteristics of water movements such as waves, currents, and tides and how they affect the marine environment. It also includes studies of the transmission of energy such as sound, light, and heat in seawater. Marine meteorology (the study of heat transfer, water cycles, and air-sea interactions) is often included in the discipline of physical oceanography. Chemical oceanography studies the composition and history of the water, its processes, and its interactions. Biological oceanography concerns marine organisms and the relationship between these organisms and the environment in the oceans. Ocean engineering is the discipline that designs and plans equipment and installations for use at sea.

Scientists make discoveries about the natural world, both as it is now and as it has been throughout its history, by gathering data through observation and experimentation. Data are the "facts" used by scientists. Scientific data are reproducible and accompanied by an estimate of error. If an observation is not reproducible and does not include an error estimate, it is not a *scientific* datum. Repeated observations and measurements by independent scientists are expected to yield data whose error regions overlap with the error regions around the original data.

A scientific **hypothesis** is an initial explanation of data that is based on well-established physical or chemical laws. If the data are quantitative (i.e., if they are represented as numbers), the hypothesis is often expressed as a mathematical equation. In order to be considered a *scientific* hypothesis, it must be subject to testing and falsification (demonstration that something is not true). A scientific hypothesis that has been repeatedly tested and found to be in agreement with observed facts is provisionally considered to be a valid hypothesis, recognizing that it may be replaced by a more complete hypothesis in the future.

If a hypothesis is consistently supported by repeated, different experiments, then it may be advanced to the level of a **theory**. The great value of a theory is its ability to predict the existence of phenomena or relationships that had not previously been recognized. Scientists use the word "theory" in a much more restrictive sense than the general public, who use the word in the same way the word "speculation" is used. A scientific theory is not an idle speculation, however. It is a tested, reliable, and precise statement of the relationships among reproducible observations.

A collection of hourly measurements of sea surface elevation at a specific point would comprise a set of scientific data or facts. An initial explanation of these data might be the hypothesis that sea surface elevation varies in response to tidal forces. This hypothesis could be expressed as a mathematical equation. If repeated measurements elsewhere in the oceans yielded reproducible data that continued to be accurately explained by the hypothesis, it would rise to the level of tidal theory (discussed in chapter 11).

Even when a hypothesis is elevated to the status of a theory, the scientific investigation will not necessarily stop. Scientists do not discard accepted theories easily; new discoveries are first assumed to fit into the existing theoretical framework. It is only when, after repeated experimental tests, the new data cannot be explained that scientists seriously question a theory and attempt to modify it.

The study of the oceans was promoted by intellectual and social forces as well as by our needs for marine resources, trade and commerce, and national security. Oceanography started slowly and informally; it began to develop as a modern science in the mid-1800s and has grown dramatically, even explosively, in the last few decades. Our progress toward the goal of understanding the oceans has been uneven and progress has frequently changed direction. The interests and needs of nations as well as the scholarly curiosity of scientists have controlled the ways we study the oceans, the methods we use to study them, and the priority we give to certain areas of study. To gain perspective on the current state of knowledge about the oceans, we need to know something about the events and incentives that guided people's previous investigations of the oceans.

1.1 The Early Times

People have been gathering information about the oceans for millennia, accumulating bits and pieces of knowledge and passing it on by word of mouth. Curious individuals must have acquired their first ideas of the oceans from wandering the seashore, wading in the shallows, and gathering food from the ocean's edges. During the Paleolithic period, humans developed the barbed spear, or harpoon, and the gorge. The gorge was a double-pointed stick inserted into a bait and attached to a string. At the beginning of the Neolithic period, the bone fishhook was developed and later the net (fig. 1.1). By 5000 B.C., copper fishhooks were in use.

As early humans moved slowly away from their inland centers of development, they were prepared to take advantage of the sea's food sources when they first explored and later settled along the ocean shore. The remains of shells and other refuse, in piles known as kitchen middens, have been found at the sites of ancient shore settlements. These remains show that our early ancestors gathered shellfish, and fish bones found in some middens suggest that they also used rafts or some type of boat for offshore fishing. Some scientists think that many more artifacts have been lost or scattered as a result of rising sea level. The artifacts that have been found probably give us only an idea of the minimum extent of ancient shore settlements. Drawings on ancient temple walls show fishnets; on the tomb of the Egyptian Pharaoh Ti, Fifth Dynasty (5000 years ago), is a drawing of the poisonous pufferfish with a hieroglyphic description and warning. As long ago as 1200 B.C. or earlier, dried fish were traded in the Persian Gulf; in the Mediterranean, the ancient Greeks caught, preserved, and traded fish, while the Phoenicians founded fishing settlements, such as "the fisher's town" Sidon, that grew into important trading ports.

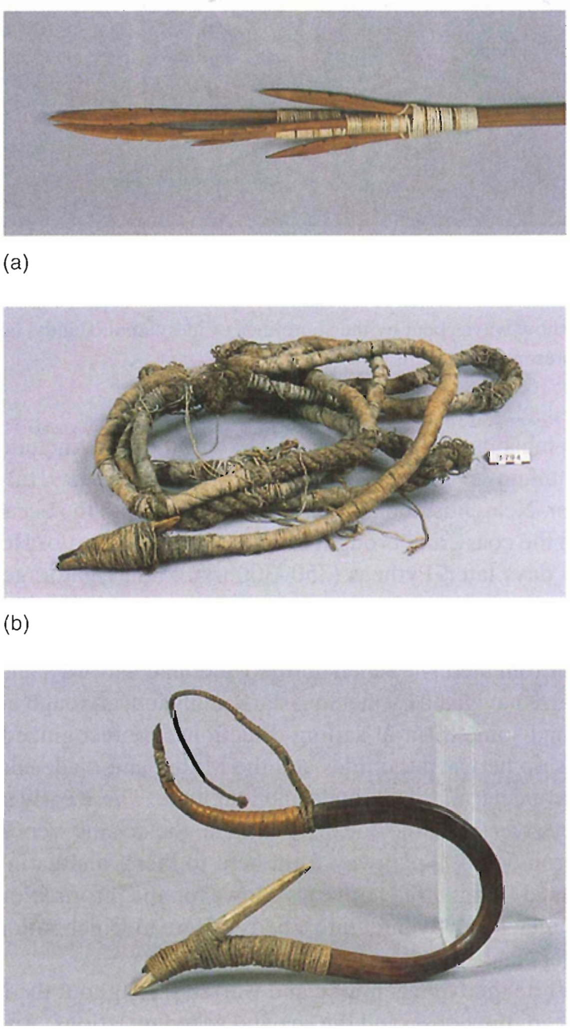


Figure 1.1 Traditional fishing and hunting implements from coastal Native American cultures of the Pacific Northwest. (a) A duck spear made of cedar. (b) A bone harpoon point and lanyard made of sinew, hemp, and twine. (c) A fishhook made of bone and steam-bent cedar root.

Early information about the oceans was mainly collected by explorers and traders. These voyages left little in the way of recorded information. Using descriptions passed down from one voyager to another, early sailors piloted their way from one landmark to another, sailing close to shore and often bringing their boats up onto the beach each night.

Some historians believe that seagoing ships of all kinds are derived from early Egyptian vessels. The first recorded voyage by sea was led by Pharaoh Snefru about 3200 B.C. In 2750 B.C., Hannu led the earliest documented exploring expedition from Egypt to the southern edge of the Arabian Peninsula and the Red Sea.

The Phoenicians, who lived in present-day Lebanon from about 1200 to 146 B.C., were well-known as excellent sailors and navigators. While their land was fertile it was also densely populated, so they were compelled to engage in trade to acquire many of the goods they needed. They accomplished this by establishing land routes to the east and marine routes to the west. The Phoenicians were the only nation in the region at that time that had a navy. They traded throughout the Mediterranean Sea with the inhabitants of North Africa, Italy, Greece, France, and Spain. They also ventured out of the Mediterranean Sea to travel north along the coast of Europe to the British Isles and south to circumnavigate Africa in about 590 B.C. In 1999, the wreckage of two Phoenician cargo vessels circa 750 B.C. was explored using remotely operated vehicles (ROVs) that could dive to the wreckage and send back live video images of the ships. The ships were discovered about 48 km (30 mi) off the coast of Israel at depths of 300–900 m (roughly 1000–3000 ft).

Extensive migration throughout the Southwestern Pacific may have begun by 2500 B.C. These early voyages were relatively easy because of the comparatively short distance between islands in the far Southwestern Pacific region. By 1500 B.C., the Polynesians had begun more extensive voyages to the east, where the distance between islands grew from tens of kilometers in the western Pacific to thousands of kilometers in the case of voyages to the Hawaiian Islands. They reached and colonized the Hawaiian Islands sometime between A.D. 450 and 600. By the eighth century A.D., they had colonized every habitable island in a triangular region roughly twice the size of the

Figure 1.2 On Satawal Island master navigator Mau Piailug teaches navigation to his son and grandson with the help of a star compass. The compass consists of an outer ring of stones, each representing a star or a constellation when it rises or sets on the horizon, and an inner ring of pieces of palm leaf representing the swells which travel from set directions and which together with the stars help the navigator find his way over the sea. In the center of the ring, the palm leaves serve as a model outrigger canoe.

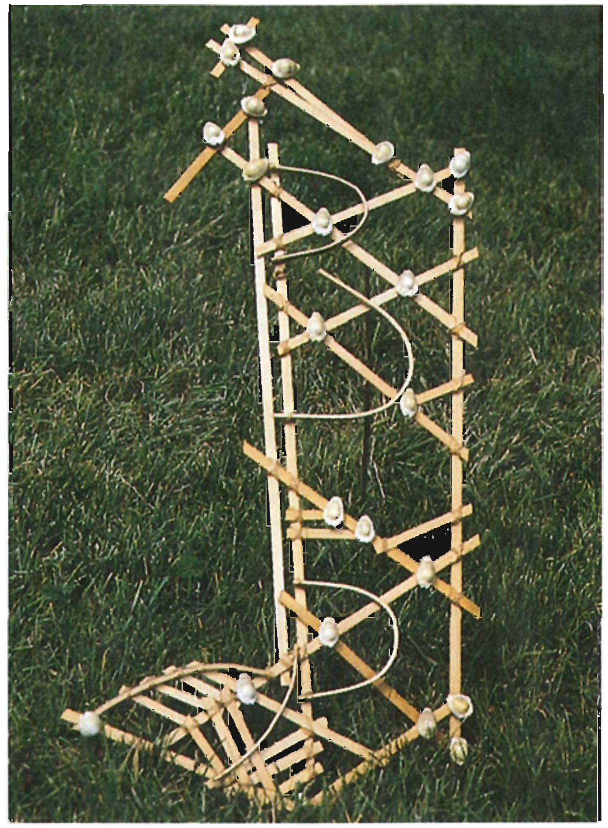


Figure 1.3 A navigational chart (*rebillib*) of the Marshall Islands. Sticks represent a series of regular wave patterns (swells). Curved sticks show waves bent by the shorelines of individual islands. Islands are represented by shells.

United States bound by Hawaii on the north, New Zealand in the southwest, and Easter Island to the east.

A basic component of navigation throughout the Pacific was the careful observation and recording of where prominent stars rise and set on the horizon. Observed near the equator, the stars appear to rotate from east to west on a north-south axis. Some rise and set farther to the north and some farther to the south, and they do so at different times. Navigators created a "star structure" by dividing the horizon into thirty-two segments where their known stars rose and set. These directions form a compass and provide a reference for recording information about the direction of winds, currents, waves, and the relative positions of islands, shoals, and reefs (fig. 1.2). The Polynesians also navigated by making close observations of waves and cloud formations. Observations of birds and distinctive smells of land such as flowers and wood smoke alerted them to possible landfalls. Once islands were discovered, their locations relative to one another and to the regular patterns of sea swell and waves bent around islands could be recorded with stick charts constructed of bamboo and shells (fig. 1.3).

As early as 1500 B.C., Middle Eastern peoples of many different ethnic groups and regions were exploring the Indian Ocean. In the seventh century A.D., they were unified under Islam and controlled the trade routes to India and China and consequently the commerce in silk, spices, and other valuable goods. (This monopoly wasn't broken until Vasco da Gama defeated the Arab fleet in 1502 in the Arabian Sea.)

The Greeks called the Mediterranean "Thalassa" and believed that it was encompassed by land, which in turn was surrounded by the endlessly circling river Oceanus. In 325 B.C., Alexander the Great reached the deserts of the Mekran Coast, now a part of Pakistan. He sent his fleet down the coast in an apparent effort to probe the mystery of Oceanus. He and his troops had expected to find a dark, fearsome sea of whirlpools and water spouts inhabited by monsters and demons; they did find tides that were unknown to them in the Mediterranean Sea. His commander, Nearchus, took the first Greek ships into the ocean, explored the coast, and brought them safely to the port of Hormuz eighty days later. Pytheas (350–300 B.C.), a navigator, geographer, astronomer, and contemporary of Alexander, made one of the earliest recorded voyages from the Mediterranean to England. From there, he sailed north to Scotland, Norway, and Germany. He navigated by the Sun, stars, and wind, although he may have had some form of sailing directions. He recognized a relationship between the tides and the Moon, and made early attempts at determining latitude and longitude. These early sailors did not investigate the oceans; for them, the oceans were only a dangerous road, a pathway from here to there, a situation that continued for hundreds of years. However, the information they accumulated slowly built into a body of lore to which sailors and voyagers added each year.

While the Greeks traded and warred throughout the Mediterranean, they observed the sea and asked questions. Aristotle (384–322 B.C.) believed that the oceans occupied the deepest parts of Earth's surface; he knew that the Sun evaporated water from the sea surface, which condensed and returned as rain. He also began to catalog marine organisms. The brilliant Eratosthenes (c. 264–194 B.C.) of Alexandria, Egypt, mapped his known world and calculated the circumference of Earth to be 40,250 km, or 25,000 mi (today's measurement is 40,067 km, or 24,881 mi). Posidonius (c. 135–50 B.C.) reportedly measured an ocean depth of about 1800 m (6000 ft) near the island of Sardinia, according to the Greek geographer Strabo (c. 63 B.C.–A.D. 21). Pliny the Elder (c. A.D. 23–79) related the phases of the Moon to the tides and reported on the currents moving through the Strait of Gibraltar. Claudius Ptolemy (c. A.D. ~85–161) produced the first world atlas and established world boundaries: to the north, the British Isles, Northern Europe, and the unknown lands of Asia; to the south, an unknown land, "Terra Australis Incognita," including Ethiopia, Libya, and the Indian Sea; to the east, China; and to the west, the great Western Ocean reaching around Earth to China. His atlas listed more than 8000 places by latitude and longitude, but his work contained a major flaw. He had accepted a value of 29,000 km (18,000 mi) for Earth's circumference. This value was much too small and led Columbus, more than 1000 years later, to believe that he had reached the eastern shore of Asia when he landed in the Americas.

1.2 The Middle Ages

After Ptolemy, intellectual activity and scientific thought declined in Europe for about 1000 years. However, shipbuilding improved during this period; vessels became more seaworthy and easier to sail, so sailors could make longer voyages. The Vikings (Norse for *piracy*) were highly accomplished seamen who engaged in extensive exploration, trade, and colonization for nearly three centuries from about 793 to 1066 (fig. 1.4). During this time, they journeyed inland on rivers through Europe and western Asia, traveling as far as the Black and Caspian Seas. The Vikings are probably best known for their voyages across the North Atlantic Ocean. They sailed to Iceland in 871 where as many as 12,000 immigrants eventually settled. Erik Thorvaldsson (known as Erik the Red) sailed west from Iceland in 982 and discovered Greenland. He lived there for three years before returning to Iceland to recruit more settlers. Icelander Bjarni Herjolfsson, on his way to Greenland to join the colonists in 985–86, was blown off course, sailed south of Greenland, and is believed to have come within sight of Newfoundland before turning back and reaching Greenland. Leif Eriksson, son of Erik the Red, sailed west from Greenland in 1002 and reached North America roughly 500 years before Columbus.

To the south, in the region of the Mediterranean after the fall of the Roman Empire, Arab scholars preserved Greek and Roman knowledge and continued to build on it. The Arabic writer El-Mas'údé (d. 956) gives the first description of the reversal of the currents due to the seasonal monsoon winds. Using this knowledge of winds and currents, Arab sailors established regular trade routes across the Indian Ocean. In the 1100s, large Chinese junks with crews of 200 to 300 sailed the same routes (between China and the Persian Gulf) as the Arab dhows.

During the Middle Ages, while scholarship about the sea remained primitive, the knowledge of navigation increased. Harbor-finding charts, or *portolanos,* appeared. These charts carried a distance scale and noted hazards to navigation, but they did not have latitude or longitude. With the introduction of the magnetic compass to Europe from Asia in the thirteenth century, compass directions were added. A Dutch navigational chart from Johannes van Keulen's *Great New and Improved Sea-Atlas or Water-World* of 1682–84 is shown in figure 1.5. The compass directions follow the pattern used in early fourteenth-century *portolanos.*

Although tides were not understood, the Venerable Bede (673–735) illustrated his account of the tides with data from the British coast. His calculations were followed in the tidal observations collected by the British Abbot Wallingford of Saint Alban's Monastery in about 1200. His tide table, titled "Flod at London Brigge," documented the times of high water. Sailors made use of Bede's calculations until the seventeenth century.

As scholarship was reestablished in Europe, Arabic translations of early Greek studies were translated into Latin and thus became available to European scholars. The study of tides continued to absorb the medieval scientists, who were also interested in the saltiness of the sea. By the 1300s, Europeans had established successful trade routes, including some partial ocean crossings. An appreciation of the importance of navigational techniques grew as trade routes were extended.

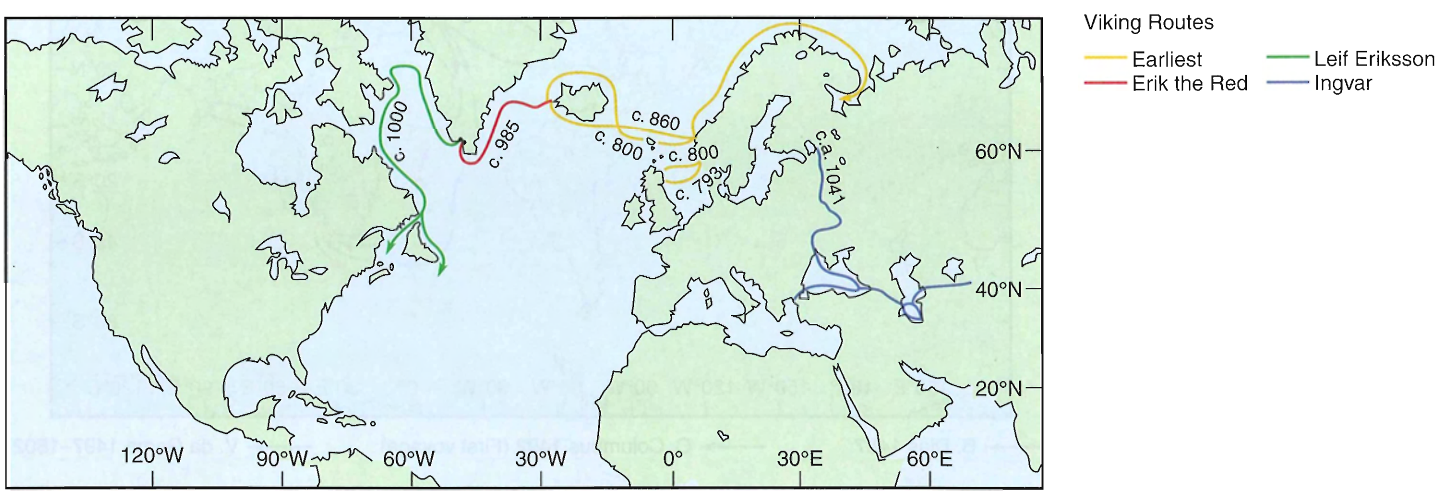


Figure 1.4 Major routes of the Vikings to the British Isles, to Asia, and across the Atlantic to Iceland, Greenland, and North America.

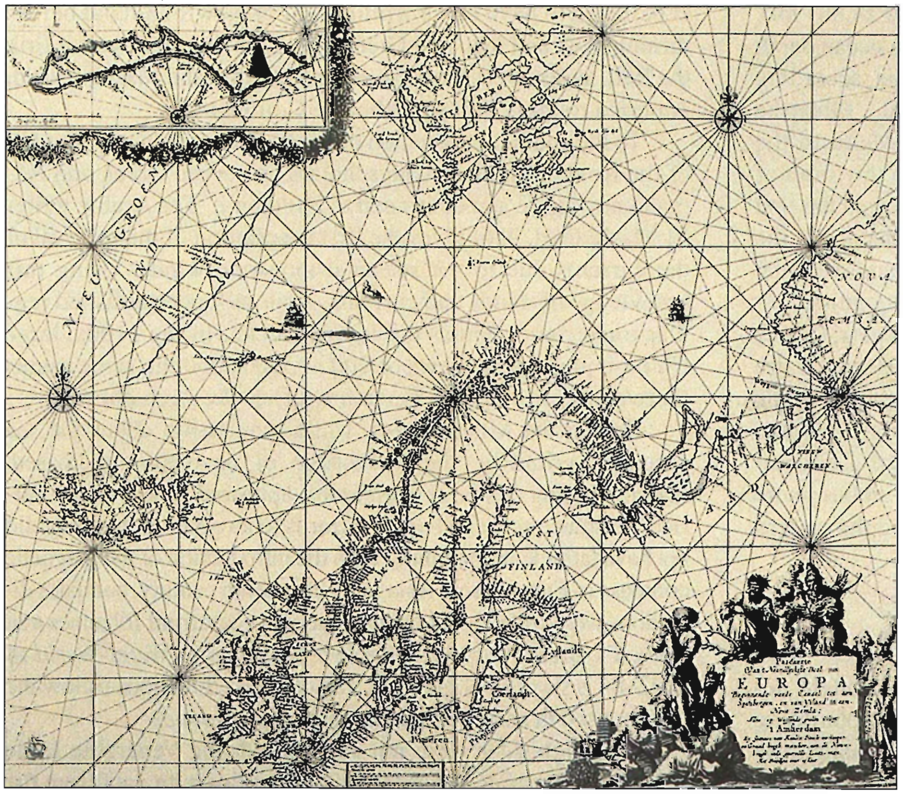


Figure 1.5 A navigational chart of northern Europe from Johannes van Keulen's *Sea-Atlas* of 1682–84.

1.3 Voyages of Discovery

From 1405 to 1433, the great Chinese admiral Zheng He conducted seven epic voyages in the western Pacific Ocean and across the Indian Ocean as far as Africa. Zheng He's fleet consisted of over 300 ships. The fleet is believed to have included as many as sixty-two "treasure ships" thought to have been as much as 122 m (400 ft) long and 52 m (170 ft) wide; this was ten times the size of the ships used for the European voyages of discovery during this period of time. The purpose of these voyages remains a matter of a debate among scholars. Suggested reasons include the establishment of trade routes, diplomacy with other governments, and military defense. The voyages ended in 1433, when their explorations led the Chinese to believe that other societies had little to offer, and the government of China withdrew within its borders, beginning 400 years of isolation.

In Europe, the desire for riches from new lands persuaded wealthy individuals, often representing their countries, to underwrite the costs of long voyages to all the oceans of the world. The individual most responsible for the great age of European discovery was Prince Henry the Navigator (1394–1460) of Portugal. In 1419, his father, King John, made him governor of Portugal's southernmost coasts. Prince Henry was keenly interested in sailing and commerce, and studied navigation and mapmaking. He established a naval observatory for the teaching of navigation, astronomy, and cartography about 1450. From 1419 until his death in 1460, Prince Henry sent expedition after expedition south along the west coast of Africa to secure trade routes and establish colonies. These expeditions moved slowly due to the mariners' belief that waters at the equator were at the boiling point and that sea monsters would engulf ships. It wasn't until twenty-seven years after Prince Henry's death that Bartholomeu Dias (1450?–1500) braved these "dangers" and rounded the Cape of Good Hope in 1487 in the first of the great voyages of discovery (fig. 1.6). Dias had sailed in search of new and faster routes to the spices and silks of the East.

Portugal's slow progress along the west coast of Africa in search for a route to the east finally came to fruition with Vasco da Gama (1469–1524) (fig. 1.6). In 1498, he followed Bartholomeu Dias's route to the Cape of Good Hope and then continued beyond along the eastern coast of the African continent. He successfully mapped a route to India but was

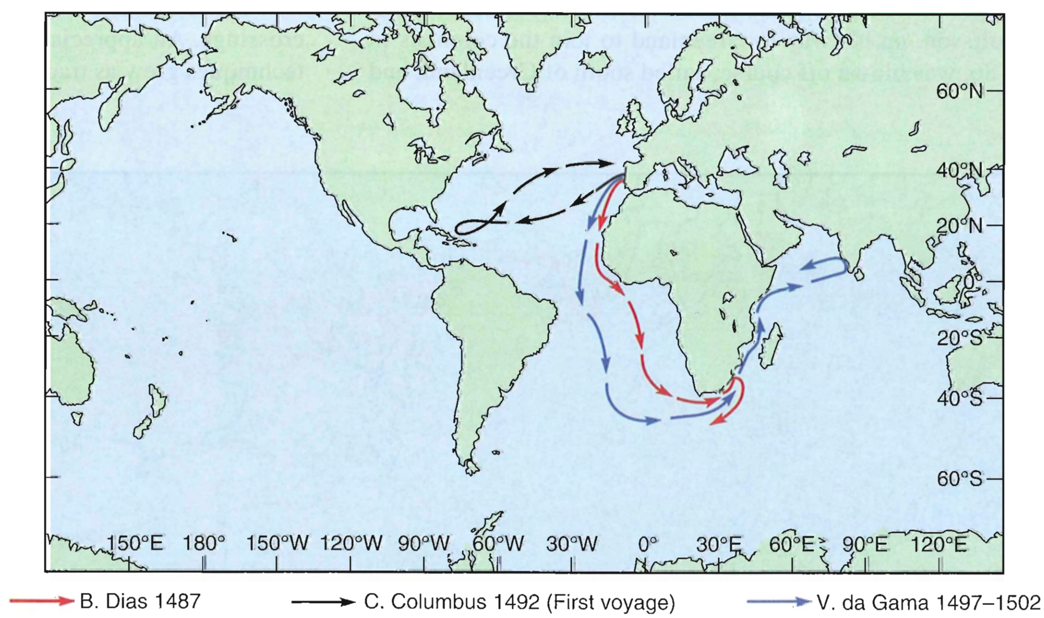


Figure 1.6 The routes of Bartholomeu Dias and Vasco da Gama around the Cape of Good Hope and Christopher Columbus's first voyage.

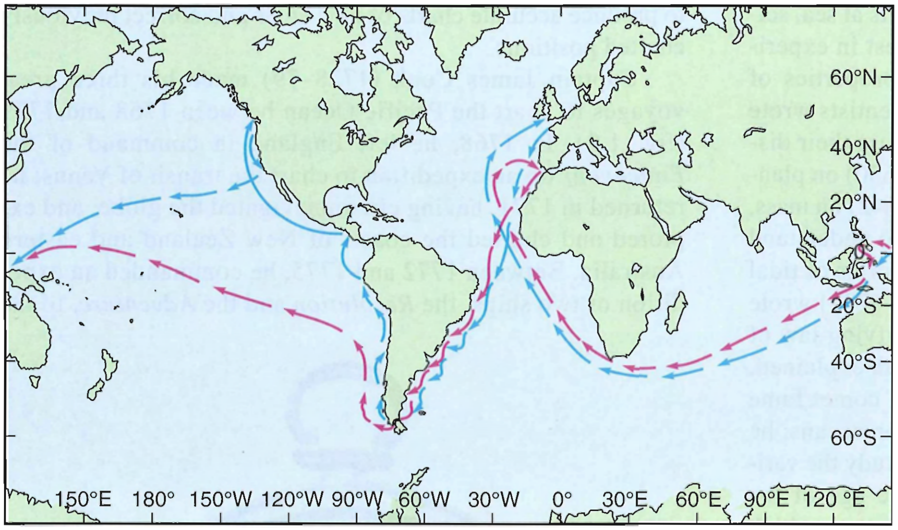


Figure 1.7 The sixteenth-century circumnavigation voyages by Magellan and Drake.

challenged along the way by Arab ships. In 1502, da Gama returned with a flotilla of fourteen heavily armed ships and defeated the Arab fleet. By 1511, the Portuguese controlled the spice routes and had access to the Spice Islands. In 1513, Portuguese trade extended to China and Japan.

Christopher Columbus (1451–1506) made four voyages across the Atlantic Ocean in an effort to find a new route to the East Indies by traveling west rather than east. By relying on inaccurate estimates of Earth's size, he badly underestimated the distances involved and believed he had found islands off the coast of Asia when, in fact, he had reached the New World (fig. 1.6).

Italian navigator Amerigo Vespucci (1454–1512) made several voyages to the New World (1499–1504) for Spain and Portugal, exploring nearly 10,000 km (6000 mi) of South American coastline. He accepted South America as a new continent not part of Asia, and in 1507, German cartographer Martin Waldseemüller applied the name "America" to the continent in Vespucci's honor. Vasco Núñez de Balboa (1475–1519) crossed the Isthmus of Panama and found the Pacific Ocean in 1513, and in the same year, Juan Ponce de León (1460?–1521) discovered Florida and the Florida Current. All claimed the new lands they found for their home countries. Although these men had sailed for fame and riches, not knowledge, they more accurately documented the extent and properties of the oceans, and the news of their travels stimulated others to follow.

Ferdinand Magellan (1480–1521) left Spain in September 1519 with 270 men and five vessels in search of a westward passage to the Spice Islands. The expedition lost two ships before finally discovering and passing through the Strait of Magellan and rounding the tip of South America in November 1520. Magellan crossed the Pacific Ocean and arrived in the Philippines in March 1521, where he was killed in a battle with the natives on April 27, 1521. Two of his ships sailed on and reached the Spice Islands in November 1521, where they loaded valuable spices for a return home. In an attempt to guarantee that at least one ship made it back to Spain, the two ships parted ways. The *Victoria* continued sailing west and successfully crossed the Indian Ocean, rounded Africa's Cape of Good Hope, and arrived back in Spain on September 6, 1522, with eighteen of the original crew. This was the first circumnavigation of Earth (fig. 1.7). Magellan's skill as a navigator makes his voyage probably the most outstanding single contribution to the early charting of the oceans. In addition, during the voyage, he established the length of a degree of latitude and measured the circumference of Earth. It is said that Magellan tried to test the mid-ocean depth of the Pacific with a hand line, but this idea seems to come from a nineteenth-century German oceanographer; writings from Magellan's time do not support this story.

By the latter half of the sixteenth century, adventure, curiosity, and hopes of finding a trading shortcut to China spurred efforts to find a sea passage around North America. Sir Martin Frobisher (1535?–94) made three voyages in 1576, 1577, and 1578, and Henry Hudson (d. 1611) made four voyages (1607, 1608, 1609, and 1610), dying with his son when set adrift in Hudson Bay by his mutinous crew. The Northwest Passage continued to beckon, and in 1615 and 1616, William Baffin (1584–1622) made two unsuccessful attempts.

While European countries were setting up colonies and claiming new lands, Francis Drake (1540–96) set out in 1577 with 165 crewmen and five ships to show the English flag around the world (fig. 1.7). He was forced to abandon two of his ships off the coast of South America. He was separated from the other two ships while passing through the Strait of Magellan. During the voyage Drake plundered Spanish shipping in the Caribbean and in Central America and loaded his ship with treasure. In June 1579, Drake landed off the coast of present-day California and sailed north along the coast to the present United States–Canadian border. He then turned southwest and crossed the Pacific Ocean in two months' time. In 1580, he completed his circumnavigation and returned home in the *Golden Hind* with a cargo of Spanish gold, to be knighted and treated as a national hero. Queen Elizabeth I encouraged her sea captains' exploits as explorers and raiders because, when needed, their ships and knowledge of the sea brought military victories as well as economic gains.

1.4 The Beginnings of Earth Science

New ideas and new knowledge had stimulated the practical exploration of the oceans during the fifteenth and sixteenth centuries, but most of the thinking about the sea was still rooted in the ideas of Aristotle and Pliny. In the seventeenth century, although the practical needs of commerce, national security, and economic and political expansionism guided events at sea, scientists on land were beginning to show an interest in experimental science and the study of the specific properties of substances. Curiosity about Earth flourished; scientists wrote pamphlets and formed societies in which to discuss their discoveries. The works of Johannes Kepler (1571–1630) on planetary motion and those of Galileo Galilei (1564–1642) on mass, weight, and acceleration would in time be used to understand the oceans. Although Kepler and Galileo had theories of tidal motion, it was not until Sir Isaac Newton (1642–1727) wrote his *Principia* in 1687 and gave the world the unifying law of gravity that the processes governing the tides were explained. Edmund Halley (1656–1742), the astronomer of comet fame and a friend of Newton, also had an interest in the oceans; he made a voyage in 1698 to measure longitude and study the variation of the compass, and he suggested that the age of the oceans could be calculated by determining the rate at which rivers carry salt to the sea. The physicist John Joly followed Halley's suggestion and in 1899 reported an age for the oceans of 90–100 million years based on the mass of salt in the oceans and the annual rate of addition of salt to the oceans. This estimate was far too young because he did not account for the recycling of salt, the incorporation of salt into seafloor sediments, or marine salt deposits.

1.5 The Importance of Charts and Navigational Information

As colonies were established far from their home countries and as trade, travel, and exploration expanded, interest was renewed in developing more accurate charts and navigational techniques. The first hydrographic office dedicated to mapping the oceans was established in France in 1720 and was followed in 1795 by the British Admiralty's appointment of a hydrographer.

As early as 1530, the relationship between time and longitude had been proposed by Flemish astronomer Gemma Frisius, and in 1598, King Philip III of Spain had offered a reward of 100,000 crowns to any clockmaker building a clock that would keep accurate time onboard ship (see the discussion of longitude and time in chapter 2, section 2.4). In 1714, Queen Anne of England authorized a public reward for a practical method of keeping time at sea, and the British Parliament offered 20,000 pounds sterling for a seagoing clock that could keep time with an error not greater than two minutes on a voyage to the West Indies from England. A Yorkshire clockmaker, John Harrison, built his first chronometer (high-accuracy clock) in 1735, but not until 1761 did his fourth model meet the test, losing only fifty-one seconds on the eighty-one-day voyage. Harrison was awarded only a portion of the prize after his success in 1761, and it was not until 1775, at the age of eighty-three, that he received the remainder from the reluctant British government. In 1772, Captain James Cook took a copy of the fourth version of Harrison's chronometer (fig. 1.8) to produce accurate charts of new areas and correct previously charted positions.

Captain James Cook (1728–79) made his three great voyages to chart the Pacific Ocean between 1768 and 1779 (fig. 1.9). In 1768, he left England in command of the *Endeavour* on an expedition to chart the transit of Venus; he returned in 1771, having circumnavigated the globe, and explored and charted the coasts of New Zealand and eastern Australia. Between 1772 and 1775, he commanded an expedition of two ships, the *Resolution* and the *Adventure,* to the

Figure 1.8 John Harrison's fourth chronometer. A copy of this chronometer was used by Captain James Cook on his 1772 voyage to the southern oceans.

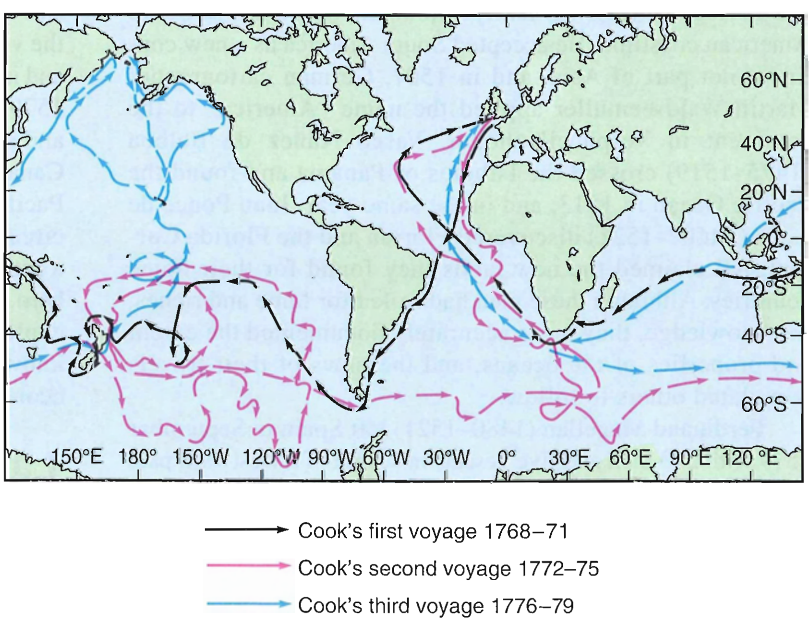


Figure 1.9 The three voyages of Captain James Cook.

South Pacific. On this journey, he charted many islands, explored the Antarctic Ocean, and, by controlling his sailors' diet, prevented vitamin C deficiency and scurvy, the disease that had decimated crews that spent long periods of time at sea. Cook sailed on his third and last voyage in 1776 in the *Resolution* and *Discovery.* He spent a year in the South Pacific and then sailed north, discovering the Hawaiian Islands in 1778. He continued on to the northwest coast of North America and into the Bering Strait, searching for a passage to the Atlantic. He returned to Hawaii for the winter and was killed by natives at Kealakekua Bay on the island of Hawaii in 1779. Cook takes his place not only as one of history's greatest navigators and seamen but also as a fine scientist. He made soundings to depths of 400 m (1200 ft) and accurate observations of winds, currents, and water temperatures. Cook's careful and accurate observations produced much valuable information and made him one of the founders of oceanography.

In the United States, Benjamin Franklin (1706–90) became concerned about the time required for news and cargo to travel between England and America. With Captain Timothy Folger, his cousin and a whaling captain from Nantucket, he constructed the 1769 Franklin-Folger chart of the Gulf Stream current (fig. 1.10). When published, the chart encouraged captains to sail within the Gulf Stream en route to Europe and return via the trade winds belt and follow the Gulf Stream north again to Philadelphia, New York City, and other ports. Since the Gulf Stream carries warm water from low latitudes to high latitudes, it is possible to map its location with satellites that measure sea surface temperature. Compare the Franklin-Folger chart in figure 1.10 to a map of the Gulf Stream shown in figure 1.11 based on the average sea surface temperature during 1996. In 1802, Nathaniel Bowditch (1773–1838), another American, published the *New American Practical Navigator.* In this book, Bowditch made the techniques of celestial navigation available for the first time to every competent sailor and set the stage for U.S. supremacy of the seas during the years of the Yankee clippers. When Bowditch died, his copyright was bought by the U.S. Navy, and his book continued in print. Its information was updated and expanded with each edition, serving generations of mariners and navigators.

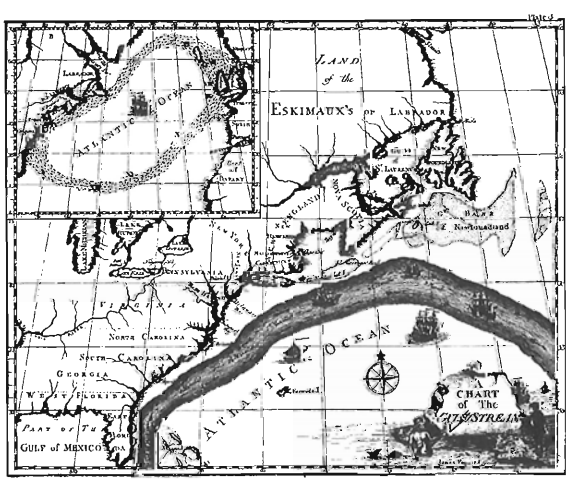


Figure 1.10 The Franklin-Folger map of the Gulf Stream, 1769. Compare this map with figure 1.11.

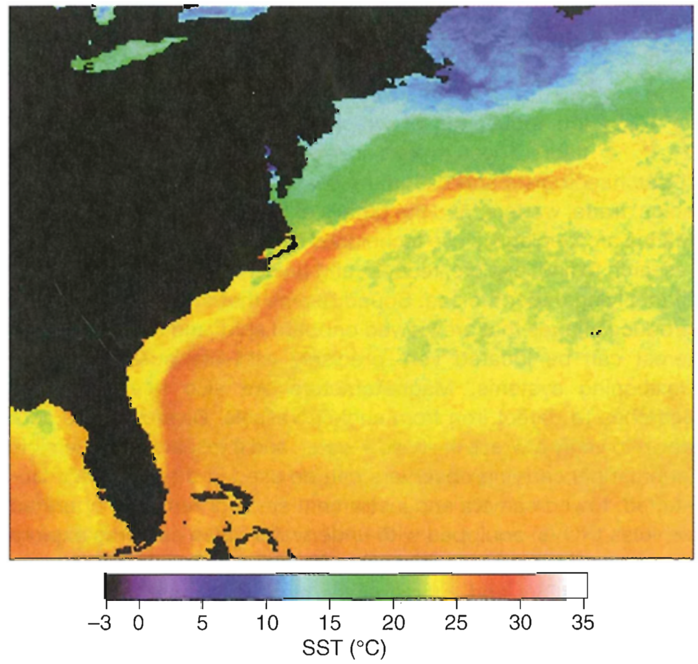


Figure 1.11 Annual average sea surface temperature for 1996. The *red-orange streak* of 25° to 30°C water shows the Gulf Stream. Compare with figure 9.8.

In 1807, the U.S. Congress, at the direction of President Thomas Jefferson, formed the Survey of the Coast under the Treasury Department, later named the Coast and Geodetic Survey and now known as the National Ocean Survey. The U.S. Naval Hydrographic Office, now the U.S. Naval Oceanographic Office, was set up in 1830. Both were dedicated to exploring the oceans and producing better coast and ocean charts. In 1842, Lieutenant Matthew F. Maury (1806–73), who had worked with the Coast and Geodetic Survey, was assigned to the Hydrographic Office and founded the Naval Depot of Charts. He began a systematic collection of wind and current data from ships' logs. He produced his first wind and current charts of the North Atlantic in 1847. At the 1853 Brussels Maritime Conference, Maury issued a plea for international cooperation in data collection, and from the ships' logs he received, he produced the first published atlases of sea conditions and sailing directions. His work was enormously useful, allowing ships to sail more safely and take days off their sailing times between major ports around the world. The British estimated that Maury's sailing directions took thirty days off the passage from the British Isles to California, twenty days off the voyage to Australia, and ten days off the sailing time to Rio de Janeiro. In 1855, he published *The Physical Geography of the Sea.* This work includes chapters on the Gulf Stream, the atmosphere, currents, depths, winds, climates, and storms, as well as the first bathymetric chart of the North Atlantic with contours at 6000, 12,000, 18,000, and 24,000 ft. Many marine scientists consider Maury's book the first textbook of what we now call oceanography and consider Maury the first true oceanographer. Again, national and commercial interests were the driving forces behind the study of the oceans.

Marine Archaeology

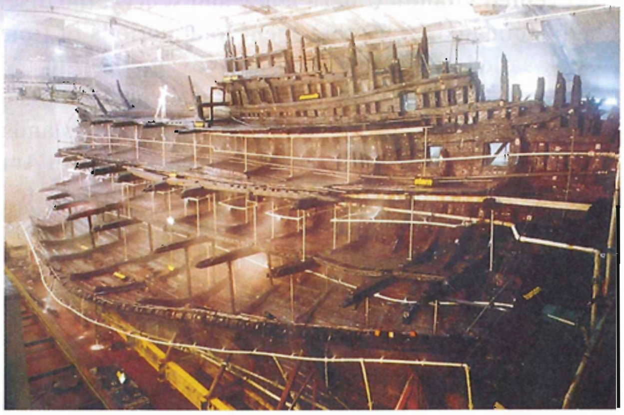
More than 2000 years of exploration, war, and trading have left thousands of wrecks scattered across the ocean floors. These wrecks are great storehouses of information for archaeologists and historians searching for information about ships, trade, warfare, and the details of human life in ancient times. Marine archaeologists use techniques developed for oceanographic research to find, explore, recover, and preserve wrecks and other artifacts lying under the sea. Sound beams that sweep the sea floor produce images that are viewed onboard ship, and an object of interest can be located very precisely with computer-controlled positioning systems. Magnetometers are also used in these searches to detect iron from sunken vessels. Divers can be sent down to verify a wreck in shallow water, and a research submersible (submarine) carrying observers can be used in deeper water. Unstaffed, towed camera and instrument sleds or remotely operated vehicles (ROVs) equipped with underwater video cameras explore in deep water or areas that are difficult or unsafe for divers and submersibles. ROVs and submersibles also collect samples to help identify wrecks.

The oldest known shipwreck, from the fourteenth century B.C., a Bronze Age merchant vessel, was discovered in 1983 more than 33 m (100 ft) down in the Mediterranean Sea off the Turkish coast. Divers have recovered thousands of artifacts from its cargo, including copper and tin ingots, pottery, ivory, and amber. Using these items, archaeologists have been able to learn about the life and culture of the period, trace the ship's trade route, and understand more about Bronze Age people's shipbuilding skills.

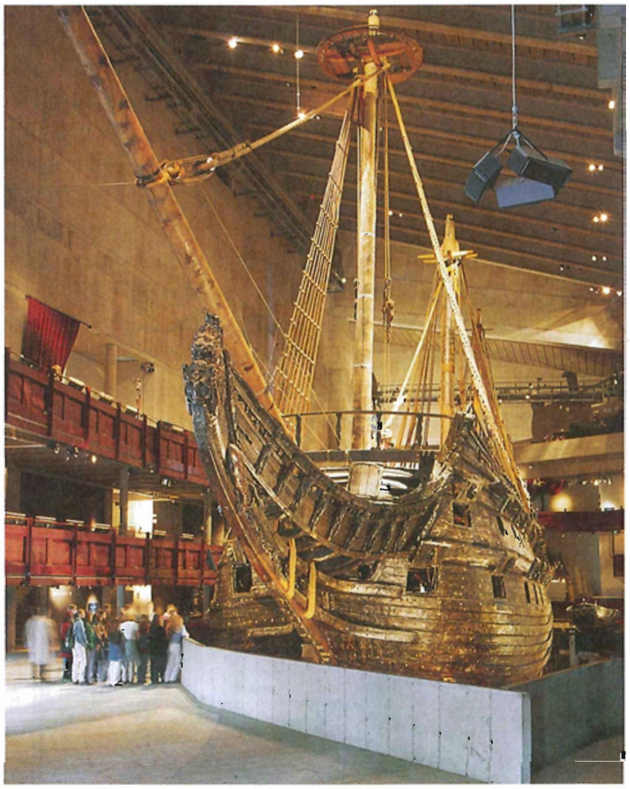
The waters around northern Europe have claimed thousands of wrecks since humans began to trade and voyage along these coasts. Two vessels, found in shallow water, have provided quantities of information for historians and archaeologists. In the summer of 1545, the English warship *Mary Rose* sank as it sailed out to engage the French fleet. The ship was studied in place and raised in 1982. More than 17,000 objects were salvaged from it, giving archaeologists and naval historians insights into the personal and working lives of the officers and crew of a naval vessel at that time. The portion of the hull that was buried in the mud was preserved and is on display at Portsmouth, England (box fig. 1). The Swedish man-of-war *Vasa* sank in 1628 in Stockholm Harbor at the beginning of its maiden voyage. The ship was located in 1956 and raised in 1961. The *Vasa* was a great ship, over 200 ft long and, like others of the period, fantastically decorated with carvings and statues. Divers searched the seabed every summer from 1963–67 and recovered sculptures and carved details that had adorned the ship. Because the water of the Baltic Sea is much less salty than the open ocean, there were no shipworms to destroy the wooden hull, and the *Vasa* is now on exhibit in Stockholm, Sweden (box fig. 2).

Another fighting ship of this period, the Spanish galleon *San Diego,* sank in 1600 as it engaged two Dutch vessels off the Philippine coast. An intensive, two-year archaeological excavation began in 1992. Relics recovered include hundreds of pieces of intact Chinese porcelain, a bronze astrolabe for determining latitude, and a bronze and glass compass. Most of the hull had been destroyed by shipworms and currents; surviving pieces were measured and then covered with sand for protection.

Wrecks that lie in deep water are initially much better preserved than those in shallow water because they lie below the depths of the strong currents and waves that break up most shallow-water wrecks. Shallow-water wrecks are also often the prey of treasure hunters who destroy the history of the site while they search for adventure and items of market value. Over long periods, the cold temperatures and low oxygen content of deep water favor preservation of wooden vessels by slowing decomposition and excluding the marine organisms that bore into wood in shallow areas. Also, the



Box Figure 1 The hull of the *Mary Rose* in its display hall at Portsmouth Dockyard, England. To preserve and stabilize it, the remaining wood is constantly sprayed with a preservative solution.



Box Figure 2 The *Vasa,* a seventeenth-century man-of-war, is on permanent display in Stockholm, Sweden. Most of the *Vasa* is original, including two of the three masts and parts of the rigging.

muds and sands falling from above cover objects on the deep-sea floor much more slowly than they do in shallow water.

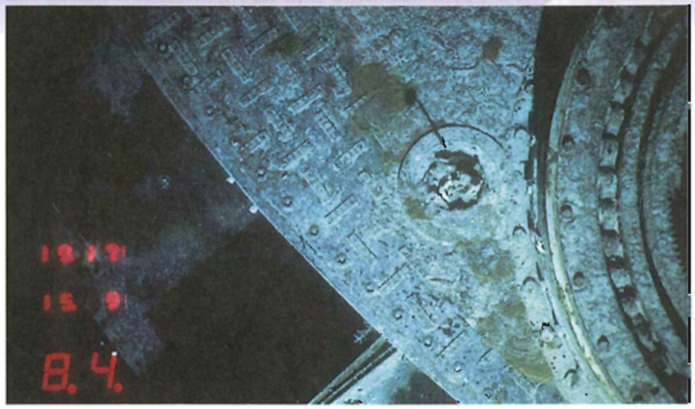
In 1685, the *Belle,* the ship of the explorer Robert Cavelier, Sieur de la Salle, sank in a storm in Matagordo Bay, along the Texas coast. In 1995, this wreck was located by scanning the bay for magnetic anomalies caused by iron in the wreckage. Reaching the vessel, under 4 m (12 ft) of water and tons of mud required a cofferdam made of two concentric octagonal walls of interlocking steel plates. It was constructed 12 m (40 ft) below the bay floor and 6 m (18 ft) above sea level. The water and mud were then pumped out of the cofferdam to allow access to the *Belle* (box fig. 3). The wreck yielded a rich harvest of artifacts, including cannons, brass pots, candlesticks, coils of rope and brass wire, personal belongings, and trade goods such as rings, glass beads, and combs.

Robert Ballard of the Institute for Exploration in Mystic, Connecticut, has led several expeditions using sophisticated electronic and robotic equipment to find both ancient and modern vessels. He discovered the wreck of the *Titanic* in 1985, 4790 m (15,700 ft) down in the North Atlantic. In 1989, he searched 518 km^2 (200 mi^2) of ocean to find the German battleship *Bismarck,* sunk in 1941 after one of the most famous sea battles of World War II. The ship lies 4750 m (15,600 ft) below the surface (box fig. 4). Both ships were located using a towed underwater camera sled, controlled from the vessel at the surface. Once the wrecks were found, observers descended via submersible for direct observation and further inspection of the vessels. Photographic surveys using ROVs that could be maneuvered to take pictures inside and outside the wrecks documented both vessels.

In 1997, a team of oceanographers, engineers, and archaeologists led by Ballard discovered a cluster of five Roman ships, along with thousands of artifacts, on the bottom of the Mediterranean Sea. The ships lie in 762 m (2500 ft) of water beneath an ancient trade route, where they were lost sometime between about 100 B.C. and A.D. 400. Prior to this discovery, no major ancient shipwrecks had been discovered and explored by archaeologists in water deeper than 61 m (200 ft). The ships were remarkably well preserved, having been protected from looting and encrustation with coral by the deep water in which they sank. The vessels were spread over an area of about 52 km^2 (20 mi^2) and probably sank when they were caught in sudden, violent storms. The ships were initially located using the U.S. Navy's nuclear submarine *NR-1.* The *NR-1* is capable of searching over large areas for extended periods of time, and its long-range sonar can detect objects at a much greater distance than conventional sonar systems typically used by oceanographers. Once the site had been identified, the small ROV *Jason* was used for detailed mapping, observation, and the recovery of over 100 artifacts selected to help the archaeologists date the ancient wrecks.

These expeditions have moved marine archaeology from the shallow waters into the deep sea. Today's oceanographic instrumentation makes all shipwrecks available to archaeologists.

Box Figure 3 Surrounded by a cofferdam to keep out mud and water, archaeologists excavate amidships of the wreck of the *Belle.* Shop vacuums and water hoses are used to expose the ship's structure and cargo, including casks and boxes of muskets.



Box Figure 4 The World War II German battleship *Bismarck* was sunk in 1941 and lies 4790 m (15,700 ft) below the surface in the North Atlantic. In 1989, the towed camera sled Argo photographed part of the ship's superstructure.

To Learn More About Marine Archaeology

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1.6 Ocean Science Begins

As charts became more accurate and as information about the oceans increased, the oceans captured the interest of naturalists and biologists. Baron Alexander von Humboldt (1769–1859) made observations on a five-year (1799–1804) cruise to South America; he was particularly fascinated with the vast numbers of animals inhabiting the current flowing northward along the western coast of South America, the current that now bears his name. Charles Darwin (1809–82) joined the survey ship *Beagle* and served as the ship's naturalist from 1831–36 (fig. 1.12). He described, collected, and classified organisms from the land and sea. His theory of atoll formation is still the accepted explanation.

At approximately the same time, another English naturalist, Edward Forbes (1815–54), began a systematic survey of marine life around the British Isles and in the Mediterranean and Aegean seas. He collected organisms in deep water and, on the basis of his observations, proposed a system of ocean depth zones, each characterized by specific animal populations. However, he also mistakenly theorized that there was an azoic, or lifeless, environment below 550 m (1800 ft). His announcement is curious, because twenty years earlier, the Arctic explorer Sir John Ross (1777–1856), looking again for the Northwest Passage, had taken bottom samples at over 1800 m (6000 ft) depth in Baffin Bay with a "deep-sea clamm," or bottom grab, and had found worms and other animals living in the mud. Ross's nephew, Sir James Clark Ross (1800–62), took even deeper samples from Antarctic waters and noted their similarity to the Arctic species recovered by his uncle. Still, Forbes's systematic attempt to make orderly predictions about the oceans, his enthusiasm, and his influence make him another candidate as a founder of oceanography.

Christian Ehrenberg (1795–1876), a German naturalist, found the skeletons of minute organisms in seafloor sediments and recognized that the same organisms were alive at the sea surface; he concluded that the sea was filled with microscopic life and that the skeletal remains of these tiny organisms were still being added to the sea floor. Investigation of the minute drifting plants and animals of the ocean was not seriously undertaken until German scientist Johannes Müller (1801–58) began his work in 1846. He used an improved fine-mesh tow net similar to that used by Charles Darwin to collect these organisms, which he examined microscopically. This work was continued by Victor Hensen (1835–1924), who improved the Müller net, introduced the quantitative study of these minute drifting sea organisms, and gave them the name *plankton* in 1887.

Although science blossomed in the seventeenth and eighteenth centuries, there was little scientific interest in the sea except as we have seen for the practical reasons of navigation, tide prediction, and safety. In the early nineteenth century, ocean scientists were still few and usually only temporarily attracted to the sea. Some historians believe that the subject and study of the oceans were so vast, requiring so many people and such large amounts of money, that government interest and support were required before oceanography could grow as a science. This did not happen until the nineteenth century in Great Britain.

In the last part of the nineteenth century, laying transatlantic telegraph cables made a better knowledge of the deep sea a necessity. Engineers needed to know about seafloor conditions, including bottom topography, currents, and organisms that might

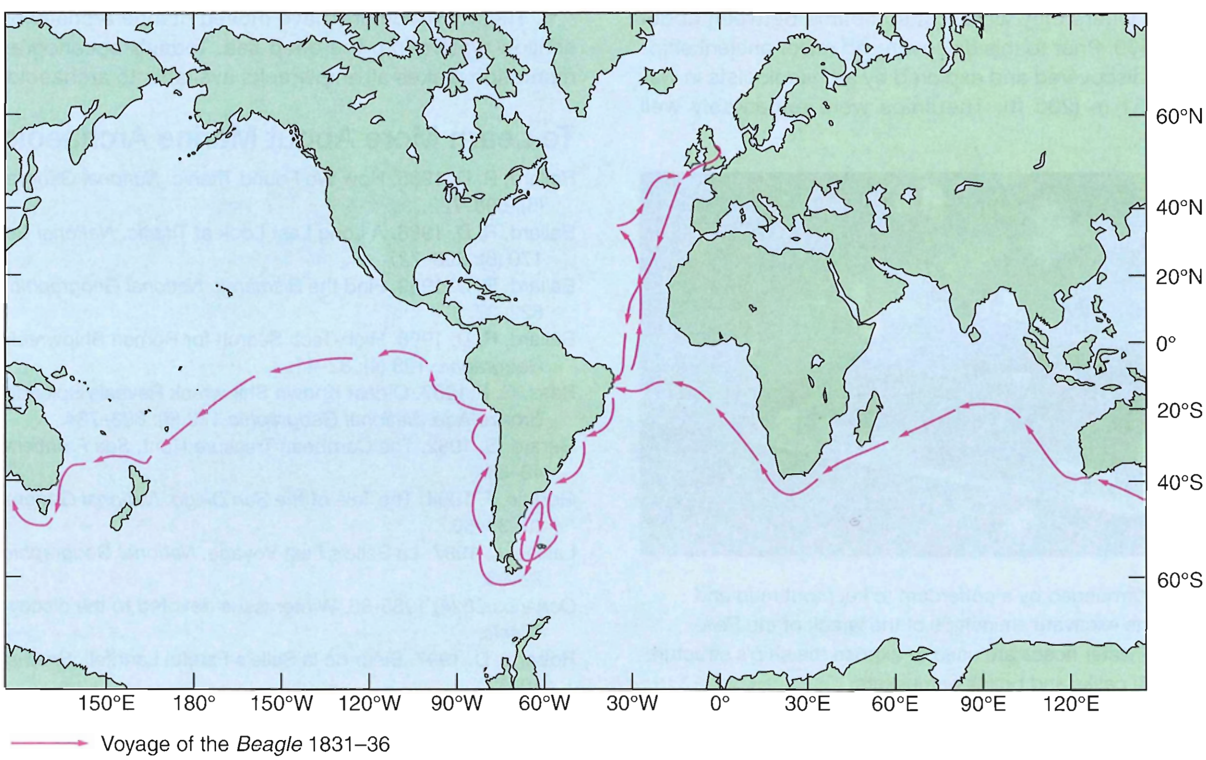


Figure 1.12 The voyage of Charles Darwin and the survey ship HMS *Beagle,* 1831–36.

dislodge or destroy the cables. The British began a series of deep-sea studies stimulated by the retrieval of a damaged cable from more than 1500 m (5000 ft) deep, well below Forbes's azoic zone. When the cable was brought to the surface, it was found to be covered with organisms, many of which had never been seen before. In 1868, the *Lightning* dredged between Scotland and the Faroe Islands at depths of 915 m (3000 ft) and found many animal forms. The British Admiralty continued these studies with the *Porcupine* during the summers of 1869 and 1870, dredging up animals from depths of more than 4300 m (14,000 ft). Charles Wyville Thomson (1830–82), like Forbes, a professor of natural history at Edinburgh University, was one of the scientific leaders of these two expeditions. On the basis of these results, he wrote *The Depths of the Sea,* published in 1873, which became very popular and is regarded by some as the first book on oceanography.

English biologist Thomas Henry Huxley (1825–95), a close friend and supporter of Charles Darwin, was particularly interested in studying the organisms that inhabit the deep sea. Huxley was a strong supporter of Darwin's theory of evolution and believed that the organisms of the deep sea could supply evidence of its validity. In 1868, while examining samples of mud recovered from the deep-sea floor of the Atlantic eleven years before and preserved in alcohol, Huxley noticed that the surface of the samples was covered by a thick, mucus-like material with small embedded particles. Under the microscope it appeared as if these particles moved, leading him to conclude that the mucus was a form of living protoplasm. Huxley named this "organism" *Bathybius haeckelii* after the noted German naturalist Ernst Haeckel (fig. 1.13*b*). Haeckel, also a strong supporter of the theory of evolution, viewed this protoplasm as the primordial ooze from which all other life evolved. He believed it blanketed the deep-sea floor and provided an inexhaustible supply of food for higher order organisms of the deep ocean. One of the primary scientific objectives of the *Challenger* expedition, described in the next section, was to study the distribution of *Bathybius haeckelii.*

1.7 The *Challenger* Expedition

With public interest running high, the Circumnavigation Committee of the British Royal Society was able to persuade the British Admiralty to organize the most comprehensive oceanographic expedition yet undertaken. The Society obtained the use of the naval corvette *Challenger,* a sailing vessel with auxiliary steam power. All but two of the corvette's guns were removed, and the ship was refitted with laboratories, winches, and equipment, including 232 km (144 mi) of sounding rope. The leadership was offered to Charles Wyville Thomson, whose assistant was a young geologist, John Murray (1841–1914). The *Challenger* sailed from Portsmouth, England, on December 21, 1872, for a voyage that was to last nearly three-and-a-half years, during which time the vessel logged 110,840 km (68,890 mi) (fig. 1.13). The first leg of the voyage took the vessel to Bermuda, then to the South Atlantic island of Tristan da Cunha, around the Cape of Good Hope, and east across the southernmost part of the Indian Ocean; this vessel was the first steamship to cross the Antarctic Circle. It continued on to Australia, New Zealand, the Philippines, Japan, and China. Turning south to the Marianas Islands, the vessel took its deepest sounding at 8180 m (26,850 ft). Sailing across the Pacific to Hawaii, Tahiti, and through the Strait of Magellan, it returned to England on May 24, 1876. Queen Victoria conferred a knighthood on Thomson, and the *Challenger* expedition was over.

The *Challenger* expedition's purpose was scientific research; during the voyage, the crew took soundings at 361 ocean stations, collected deep-sea water samples, investigated deep-water motion, and made temperature measurements at all depths. Thousands of biological and sea-bottom samples were collected. The cruise brought back evidence of an ocean teeming with life at all depths and opened the way for the era of descriptive oceanography that followed.

The numerous dredges of deep-sea sediments obtained during the expedition failed to find any evidence of *Bathybius haeckelii* in fresh samples. One of the naturalists noticed, however, when alcohol was added to a sample, something similar to *Bathybius haeckelii* was produced. Rather than being the primitive life form from which all other organisms evolved, *Bathybius haeckelii* was shown to be a chemical precipitate produced by the reaction of the sediment with alcohol.

Although the *Challenger* expedition ended in 1876, the work of organizing and compiling information continued for twenty years, until the last of the fifty-volume *Challenger Reports* was issued. John Murray (later Sir John Murray) edited the reports after Thomson's death and wrote many of them himself. He is considered the first geological oceanographer. William Dittmar (1833–92) prepared the information on seawater chemistry for the *Challenger Reports.* He identified the major elements present in the water and confirmed the findings of earlier chemists that in a seawater sample, the relative proportions of the major dissolved elements are constant. Oceanography as a modern science is usually dated from the *Challenger* expedition. The *Challenger Reports* laid the foundation for the science of oceanography.

The *Challenger* expedition stimulated other nations to mount ocean expeditions. Although their avowed purpose was the scientific exploration of the sea, in large measure prestige was at stake. Norway explored the North Atlantic with the *Voringen* in the summers of 1876–78; Germany studied the Baltic and North Seas in the SS *Pomerania* in 1871 and 1872 and in the *Crache* in 1881, 1882, and 1884. The French government financed cruises by the *Travailleur* and the *Talisman* in the 1880s. The Austrian ship *Pola* worked in the Mediterranean and Red seas in the 1890s. The U.S. vessel *Enterprise* circumnavigated Earth between 1883 and 1886, as did Italian and Russian ships between 1886 and 1889.

1.8 Oceanography as Science

During the late nineteenth and early twentieth centuries, intellectual interest in the oceans increased. Oceanography was changing from a descriptive science to a quantitative one. Oceanographic cruises now had the goal of testing hypotheses by gathering data. Theoretical models of ocean circulation and water movement were developed. The Scandinavian oceanographers were particularly active in the study of water movement. One of them, Fridtjof Nansen (1861–1930) (fig. 1.14*a*), a well-known

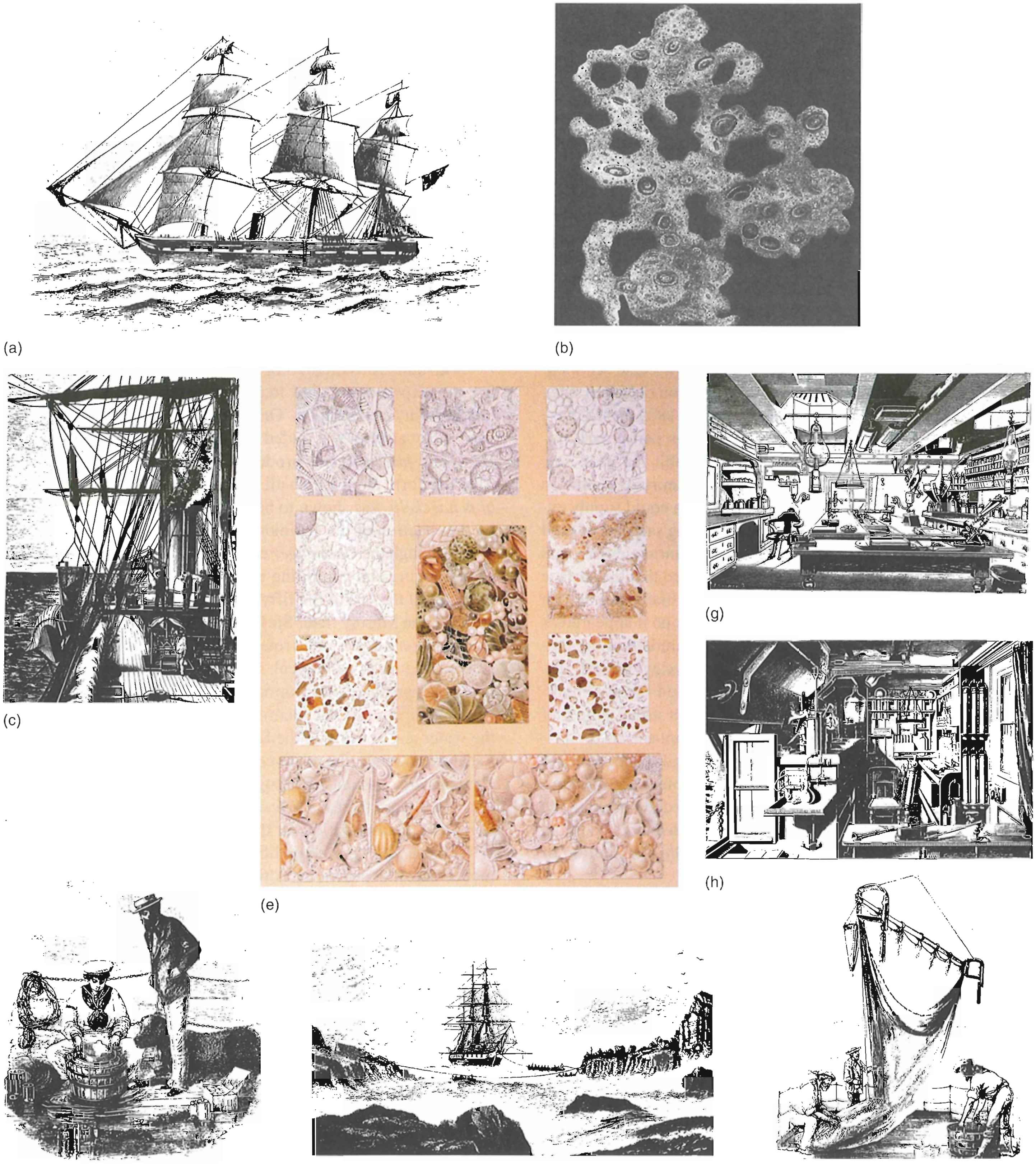


Figure 1.13 The *Challenger* expedition: December 21, 1872, to May 24, 1876. Engraving from the *Challenger Reports,* volume 1, 1885. (a) "H.M.S. *Challenger*—Shortening Sail to Sound," decreasing speed to take a deep-sea depth measurement. (b) *Bathybius haeckelii,* the supposed primordial protoplasm believed to cover the ocean floor. (c) "Dredging and Sounding Arrangement on board *Challenger.*" Rigging is hung from the ship's yards to allow the use of the over-the-side sampling equipment. A biological dredge can be seen hanging outboard of the rail. The large cylinders in the rigging are shock absorbers. (d) Sieving bottom samples for organisms. (e) "Deep Sea Deposits." This plate shows the shells of microscopic organisms making up different kinds of muds and clays from the floor of the deep sea. (f) "H.M.S. *Challenger* at St. Paul's Rocks," in the equatorial mid-Atlantic. (g) "Zoological Laboratory on the Main Deck." (h) "Chemical Laboratory." (i) A biological dredge used for sampling bottom organisms. Note the frame and skids that keep the mouth of the net open and allow it to slide over the sea floor.

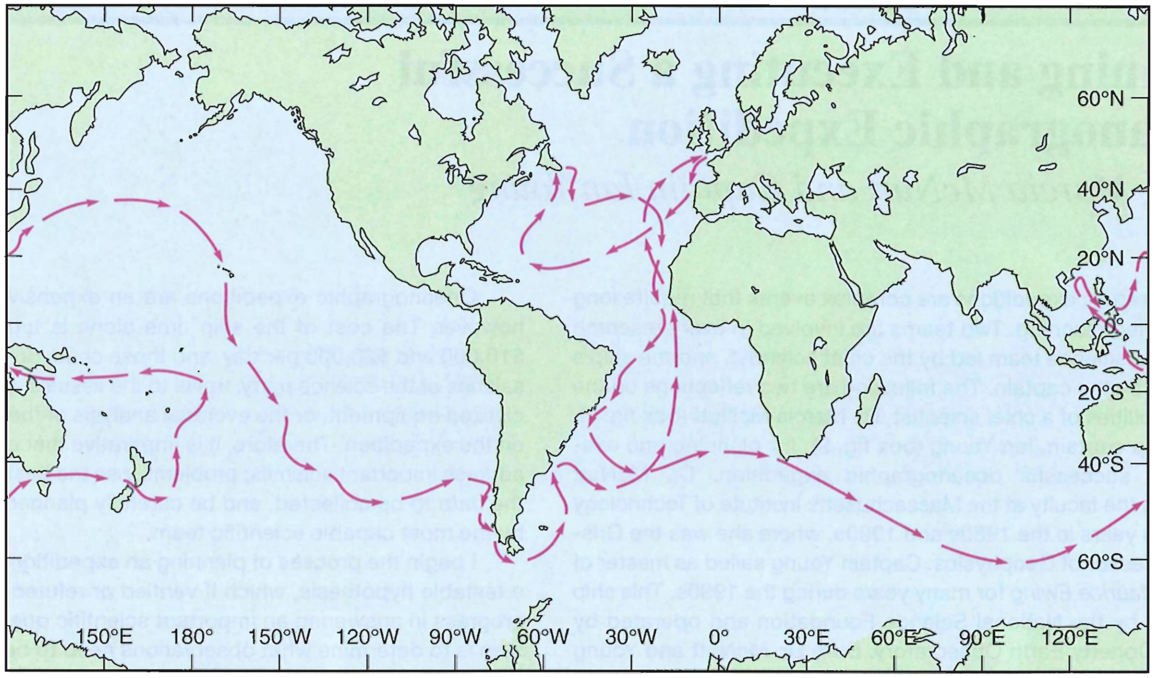


Figure 1.13 (continued) (j) The cruise of the *Challenger*, the first major oceanography research effort.

(a)

(b)

Figure 1.14 (a) Fridtjof Nansen, Norwegian scientist, explorer, and statesman (1861–1930), using a sextant to determine his ship's position. (b) The *Fram* frozen in ice. As the ice pressure increased, it lifted its specially designed and strengthened hull so that the ship would not be crushed.

athlete, explorer, and zoologist, was interested in the currents of the polar seas. This extraordinary man decided to test his ideas about the direction of ice drift in the Arctic by freezing a vessel into the polar ice pack and drifting with it to reach the North Pole. To do so, he had to design a special vessel that would be able to survive the great pressure from the ice; the 39 m (128 ft) wooden *Fram* ("to push forward"), shown in figure 1.14*b*, was built with a smoothly rounded hull and planking over 60 cm (2 ft) thick.

Nansen departed with thirteen men from Oslo in June 1893. The ship was frozen into the ice nearly 1100 km (700 mi) from

Field Notes

Planning and Executing a Successful Oceanographic Expedition

by Dr. Marcia McNutt and Captain Ian Young

Oceanographic expeditions are complex events that require long and detailed planning. Two teams are involved in every research cruise: the science team led by the chief scientist, and the ship's crew, led by the captain. The following are two reflections on the responsibilities of a chief scientist, Dr. Marcia McNutt (box fig. 1), and a ship captain, Ian Young (box fig. 2), for planning and executing a successful oceanographic expedition. Dr. McNutt served on the faculty at the Massachusetts Institute of Technology for fifteen years in the 1980s and 1990s, where she was the Griswold Professor of Geophysics. Captain Young sailed as master of the R/V *Maurice Ewing* for many years during the 1990s. This ship is owned by the National Science Foundation and operated by Lamont-Doherty Earth Observatory. Both Dr. McNutt and Young are employed at the Monterey Bay Aquarium Research Institute (box fig. 3), where Young sails on the R/V *Western Flyer* and Dr. McNutt is the president and CEO.

The Role of the Chief Scientist

Box Figure 1 Dr. Marcia McNutt.

All scientists are motivated by the thrill of discovery. For oceanographers such as myself, discovery does not lie in a test tube in the lab but in the ocean itself. Most of the deep sea remains either completely unexplored or observed in only a cursory sense with modern technology, and thus there are ample opportunities to go where no one has gone before and to see what is there through new sets of technological "eyes." My own expeditions invariably return with wondrous new discoveries that were not predicted by any prevailing theories. For that reason, I live for going to sea.

Oceanographic expeditions are an expensive undertaking, however. The cost of the ship time alone is typically between $10,000 and $20,000 per day, and those costs do not include the salaries of the science party, travel to the vessels, use of very specialized equipment, or the eventual analysis of the data collected on the expedition. Therefore, it is imperative that each expedition address important scientific problems, use the best technology for the data to be collected, and be carefully planned and executed by the most capable scientific team.

I begin the process of planning an expedition by formulating a testable hypothesis, which if verified or refuted, would lead to progress in answering an important scientific question. The next step is to determine what observations need to be made or what experiment needs to be performed to test the hypothesis. From this consideration naturally flows the equipment that must be assembled and the expertise needed from my team. I select other team members primarily based on their scientific ability and expertise, but personal considerations (such as do you want to be confined for 30–60 days on 250 ft of floating steel with this person) weigh in as well.

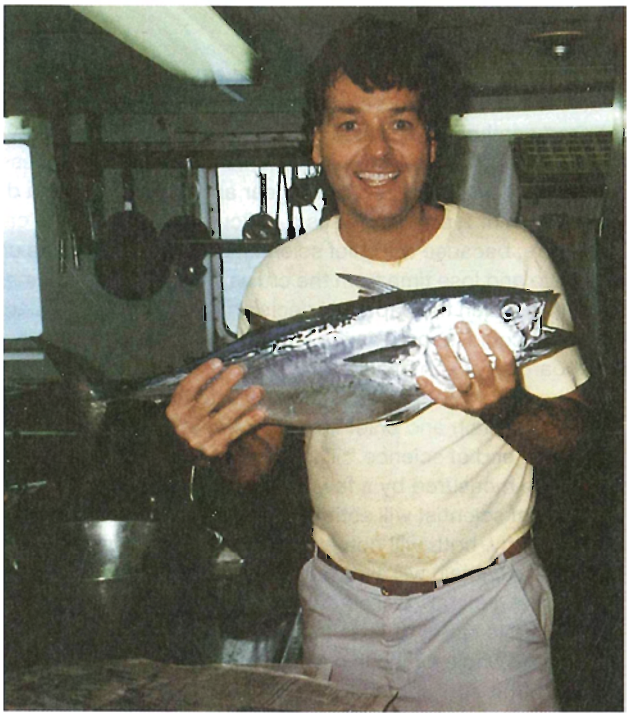
The team then writes a proposal to a funding agency, commonly the National Science Foundation, to support the expedition and waits. And waits. The proposal is reviewed by other scientists who make recommendations on which projects should be funded with the limited money available. Typically, about six months later a decision is reached as to which expeditions will be supported. If my team is one of the lucky ones, we are then placed on the schedule for one of the ships in the national fleet of vessels operated by academic institutions. To which ship we are assigned depends on the type of equipment needed on the ship and where the research area is. Much of my own work is specialized enough that only one or two ships can conduct the mission. Therefore, we may have to wait another year or more for that ship to eventually sail to the right part of the world to conduct our experiment.

Once the ship is determined, I write up a summary of the proposed work for the benefit of the captain and technical personnel on the designated ship. Unlike the science proposal, which is meant to excite other scientists about the importance of the proposed expedition, this summary is a detailed account of where we will go, what equipment we will use, and how we will use it. Several months before the expedition, I meet with the operators of the ship and its captain to discuss the mission and answer questions they may have about the summary. This is our chance to make sure that no unpleasant surprises surface after we set sail (e.g., "We thought that you were bringing liners for the piston core." "No, I thought the ship already stocked liners for the core!"). This is also the time when we make sure that we have the necessary permits to work in the territorial waters of other nations.

If this is my first meeting with the captain, I want very much to impress him with my knowledge of marine operations and thoroughness of preparation. Our teamwork must be built on a foundation of mutual respect: I must trust him not to place limitations on our scientific operations at sea unless he truly feels that the safety of the vessel and its occupants are at risk. On the other hand, he must feel confident that I would not ask for anything extra from the crew or the ship unless the success of the science mission depended on it.

Once at sea, we make the most of every minute. Operations go around the clock, with subsets of the crew and science party assigned to pairs of four-hour watches. As chief scientist, it is my responsibility to make sure that the captain and mates on the bridge know well in advance what the science plan is for the next watch. From a science perspective, the very best expeditions are those in which the cruise plan is constantly in flux as we follow up on new discoveries. But such expeditions are not always the favorite on the bridge, nor do they allow the chief scientist to get eight hours of uninterrupted sleep!

In the final analysis, the success of any expedition can often be attributed to the willingness of the captain and his crew to put in the extra effort necessary to achieve what are invariably ambitious objectives in the face of bad weather, temperamental equipment, and Murphy's laws. That is why the last line in so many oceanographic research publications is some variant of the following: "Special thanks to the captain and crew of the R/V _____ for making this expedition such a success."



Box Figure 2 Captain Ian Young.

The Role of the Ship's Captain

I've sailed professionally for more than twenty years on various types of vessels, with different levels of responsibility. Whether signed on a freighter as third mate bound for Africa or wandering the world's oceans on a tramp research vessel, I've always loved being "safely back to sea."

As captain of a modern research vessel, I am primarily concerned with the readiness of the ship. Usually, no two expeditions are alike, and each requires unique preparations. Information about each scientific voyage is provided by the chief scientist either through the ship's marine office or directly to the captain one to three months in advance.

The captain starts planning for the cruise months before it begins. The five Ps apply at all times: **P**roper **P**lanning **P**revents **P**oor **P**erformance. This includes ordering charts for the research site, preparing equipment, and performing needed maintenance on the ship's machinery and systems (electrical and mechanical) that will be needed during the next cruise for around the clock operations.

The captain relies on the crew—science technician, chief mate, chief engineer, and steward—to make all preparations for each cruise. The ship's science technician is responsible for making sure that the ship's data collection systems are ready and compatible with science computers. The chief mate will perform deck maintenance to have equipment ready and deck space clear for storing, staging, launching, and recovering equipment. All safety equipment has to be in good working order as required by the U.S. Coast Guard. The chief engineer plans ahead to order fuel, lubricating oil, hydraulic oil, and spare parts for all the systems under his care. These systems are all important for the success of the science mission. A failure in any one of these systems can delay, slow, or stop an expedition. The ship's steward must choose and stock adequate provisions for forty people for a thirty- to fifty-day voyage, a job that requires experience and attention to detail to ensure quality meals.

Ideally, clearances from the State Department will arrive prior to the vessel sailing. These clearances give the vessel legal permission to work in the territorial waters of foreign sovereign nations and are required to avoid conflict with foreign governments. Depending on the proposed location for the research, multiple countries may need to be contacted for the same expedition. The ship's marine office typically applies for the necessary clearances six to twelve months in advance of the cruise. A delay in the receipt of a clearance can have serious consequences because it can force a cruise to be rescheduled for a later date. Rescheduling can result in the expedition missing the optimum weather window for the research site, which can degrade the quality and quantity of data collected.

The captain has to work closely with the chief scientist to make sure the cruise objectives are achieved. This starts with the first science meeting held between them. Here, the captain gets the first full view of the cruise for which he has been preparing the vessel. The cruise can have many different aspects: station work, towed gear deployments, bottom instrument launches, buoy recoveries, and grid surveys. This meeting provides an opportunity for the captain to contribute operations suggestions to help the scientists make better use of time and equipment because he knows the capabilities of the ship and personnel.

(continued)

(concluded)

The captain is always watching the weather. Sometimes work can be scheduled around certain weather patterns. Quite often there are "weather days" when work has to stop for the safety of the people on deck and the vessel. This may require the vessel heaving-to for a night or retrieving gear and leaving the area due to a hurricane or typhoon. This is a difficult decision for the captain to make, because the chief scientist never wants to stop collecting data and lose time from the cruise. This is one of the many situations in which the captain's decision has to be right; an error in judgment could jeopardize the safety of the vessel and the people on board or cost him his job.

At the end of the voyage, there is a time-honored ritual involving the captain and chief scientist: negotiating the break-off time for the "end of science." The distance to port from the work area may be measured by a few hours or a few weeks. The captain and chief scientist will estimate the time required to return to port; frequently, both will come up with different answers to this question. The captain will allow for weather and currents, while the chief scientist generally will not. At this point in the cruise, the chief scientist likes to state: "If I can't have time to collect the last bit of data, then the whole expedition will be for nothing." Of course, this isn't true, but it contributes to the drama required to end a successful cruise. Usually, the time requested to finish the scientific mission is within reason, and the captain is able to safely return to port on schedule. Even though there are days of transit to the next port, in the captain's mind, this trip is over, and he is already preparing for the next expedition.

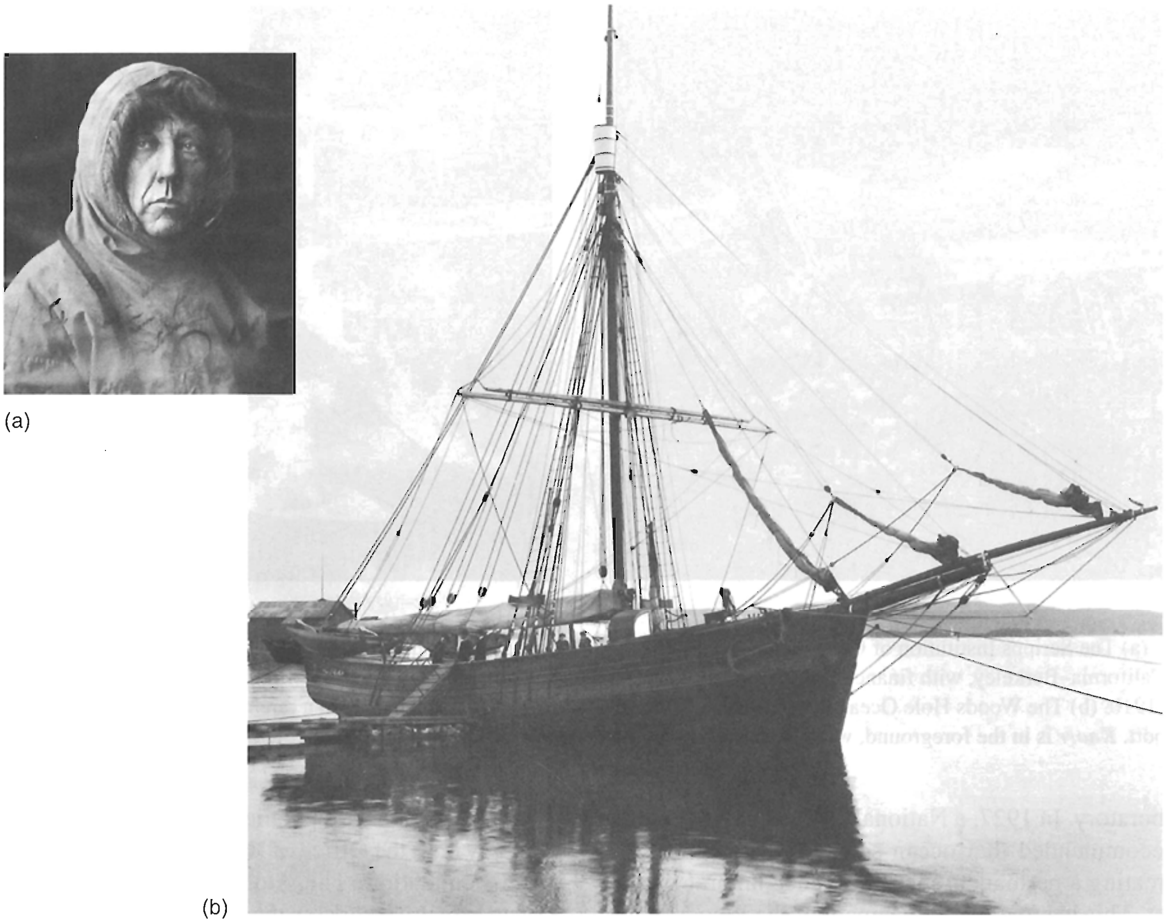
Box Figure 3 Aerial view of the Monterey Bay Aquarium Research Institute.

the North Pole and remained in the ice for thirty-five months. During this period, measurements were made through holes in the ice that showed that the Arctic Ocean was a deep-ocean basin and not the shallow sea that had been expected. Water and air temperatures were recorded, water chemistry was analyzed, and the great plankton blooms of the area were observed. Nansen became impatient with the slow rate of drift and, with F. H. Johansen, left the *Fram* locked in the ice some 500 km (300 mi) from the pole. They set off with dogsleds toward the pole, but after four and a half weeks, they were still more than 300 km (200 mi) from the pole, with provisions running low and the condition of their dogs deteriorating. The two men turned away from the pole and spent the winter of 1895–96 on the ice, living on seals and walrus. They were found by a British polar expedition in June 1896 and returned to Norway in August of that year. The crew of the *Fram* continued to drift with the ship until they freed the vessel from the ice in 1896 and returned home. Nansen's expedition had laid the basis for future Arctic work.

After the expedition's findings were published, Nansen continued to be active in oceanography, and his name is familiar today from the Nansen bottle, which he designed to collect water samples from deep water. In 1905, he turned to a career as a statesman, working for the peaceful separation of Norway from Sweden. After World War I, he worked with the League of Nations to resettle refugees, for which he received the 1922 Nobel Peace Prize. The well-designed *Fram* paid another visit to polar waters, carrying the Norwegian explorer Roald Amundsen (1872–1928) to the Antarctic continent on his successful 1911 expedition to the South Pole. It was also Amundsen who finally made a Northwest Passage entirely by water in the *Gjoa,* leaving Norway in 1903 and arriving in Nome, Alaska, three years later (fig. 1.15).

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

Advances in theoretical oceanography sometimes could not be verified with practical knowledge until new instruments and equipment were developed. Lord Kelvin (1824–1907) invented a machine in 1872 that made it possible to combine tidal theory with astronomical predictions to predict the tides. Deep-sea circulation could not be systematically explored until approximately 1910, when Nansen's water-sampling bottles were combined with thermometers designed for deep-sea temperature



(a)

(b)

Figure 1.15 (a) Roald Amundsen, Norwegian explorer of the Arctic and Antarctic (1872–1928). (b) The *Gjoa* preparing for its journey through the Northwest Passage (1903).

measurements and an accurate method for measuring salinity was devised by the chemist Martin Knudsen (1871–1949). The reliable and accurate measurement of ocean depths had to wait until the development of the echo sounder, which was given its first scientific use on the 1925–27 German cruise of the *Meteor.* Although the *Meteor* expedition was supposedly sent out for purely oceanographic reasons, it was also an attempt by the German government to find an affordable way to separate dissolved gold from seawater. Although the expedition failed to find a cheap way to produce gold, it did accumulate a great deal of information about the South Atlantic.

1.9 Oceanography in the Twentieth Century

In the United States, government agencies related to the oceans proliferated during the nineteenth century. These agencies were concerned with gathering information to further commerce, fisheries, and the navy. After the Civil War, the replacement of sail by steam lessened government interest in studying winds and currents and in surveying the ocean floor. Private institutions and wealthy individuals took over the support of oceanography in the United States. Alexander Agassiz (1835–1910), mining engineer, marine scientist, and Harvard University professor, financed a series of expeditions that greatly expanded knowledge of deep-sea biology. Agassiz served as the scientific director on the first ship built especially for scientific ocean exploration, the U.S. Fish Commission's *Albatross,* commissioned in 1882. He designed and financed much of the deep-sea sampling equipment that enabled the *Albatross* to recover more specimens of deep-sea fishes in one haul than the *Challenger* had collected during its entire three-and-a-half years at sea.

One of Agassiz's students, William E. Ritter, became a professor of zoology at the University of California–Berkeley. From 1892–1903, Ritter conducted summer field studies with his students at various locations along the California coast. In 1903, a group of business and professional people in San Diego established the Marine Biological Association and invited Ritter to locate his field station in San Diego permanently. With financial support from members of the Scripps family, who had made a fortune in newspaper publishing, Ritter was able to do this. This was the beginning of the University of California's Scripps Institution of Oceanography (fig. 1.16*a*). The property and holdings of the Marine Biological Association were formally transferred to the University of California in 1912.

Also, in the first twenty years of the century, the Carnegie Institute funded a series of exploratory cruises, including investigations of Earth's magnetic field, and maintained a

(a)

(b)

Figure 1.16 (a) The Scripps Institution of Oceanography in La Jolla, California. Established in 1903 by William Ritter, a zoologist at the University of California–Berkeley, with financial support from E. W. Scripps and his daughter Ellen Browning Scripps. The first permanent building was erected in 1910. (b) The Woods Hole Oceanographic Institution in Woods Hole, Massachusetts. In a rare moment, all three WHOI research vessels are in port. *Knorr* is in the foreground, with *Oceanus* bow forward and *Atlantis* stern forward, on the opposite side of the pier.

biological laboratory. In 1927, a National Academy of Sciences committee recommended that ocean science research be expanded by creating a permanent marine science laboratory on the East Coast. This led to the establishment of the Woods Hole Oceanographic Institution in 1930 (fig. 1.16*b*). It was funded largely by a grant from the Rockefeller Foundation. The Rockefeller Foundation allocated funds to stimulate marine research and to construct additional laboratories, and oceanography began to move onto university campuses. Teaching oceanography required that the subject material be consolidated, and in 1942, *The Oceans,* by Harald U. Sverdrup, Martin W. Johnson, and Richard H. Fleming, was published. It captured nearly all the world's knowledge of oceanographic processes and was used to train a generation of ocean scientists.

Oceanography mushroomed during World War II, when practical problems of military significance had to be solved quickly. The United States and its allies needed to move personnel and materials by sea to remote locations, to predict ocean and shore conditions for amphibious landings, to know how explosives behaved in seawater, to chart beaches and harbors from aerial reconnaissance, and to use underwater sound to find submarines. Academic studies ceased as oceanographers pooled their knowledge in the national war effort.

After the war, oceanographers returned to their classrooms and laboratories with an array of new, sophisticated instruments, including radar, improved sonar, automated wave detectors, and temperature-depth recorders. They also were aided with large-scale government funding for research and education. The Earth sciences in general and oceanography in particular blossomed during the 1950s. The numbers of scientists, students, educational programs, research institutes, and professional journals all increased.

Major funding for applied and basic ocean research was supplied by both the Office of Naval Research and the National Science Foundation. The Atomic Energy Commission financed oceanographic work at the west-central Pacific atoll sites of atomic tests. During the 1950s, the Coast and Geodetic Survey expanded its operations and began its seismic sea wave (tsunami) warning system. International cooperation brought about the 1957–58 International Geophysical Year (IGY) program, in which sixty-seven nations cooperated to explore the sea floor and made discoveries that changed the way geologists thought about continents and ocean basins. As a direct result of the IGY program, special research vessels and submersibles were built to be used by federal agencies and university research programs.

The decade of the 1960s brought giant strides in programs and equipment. In 1963–64, another multinational endeavor, the Indian Ocean Expedition, took place. In 1965, a major reorganization of governmental agencies occurred. The Environmental Science Services Administration (ESSA) was formed by consolidating the Coast and Geodetic Survey and the Weather Bureau, among others. Under ESSA, federal environmental research institutes and laboratories were established, and the use of satellites to obtain data became a major focus of ocean research. In 1968, the Deep Sea Drilling Program, a cooperative venture between research institutions and universities, began to sample Earth's crust beneath the sea (fig. 1.17*a*) (see chapter 3) using the specially built drill ship *Glomar Challenger.* It was finally retired in 1983 after fifteen years of extraordinary service. The *Glomar Challenger* was named after the ship used during the *Challenger* expedition. Electronics developed for the space program were applied to ocean research. Computers went aboard research vessels, and for the first time, data could be sorted, analyzed, and interpreted at sea. This made it possible for

(a)

(b)

Figure 1.17 (a) The *Glomar Challenger,* the Deep Sea Drilling Program drill ship used from 1968–83. (b) The *JOIDES Resolution,* the Ocean Drilling Program drill ship in use since 1985.

scientists to adjust experiments while they were in progress. Government funding allowed large-scale ocean experiments. Fleets of oceanographic vessels from many institutions and nations carried scientists studying all aspects of the oceans.

In 1970, the U.S. government reorganized its earth science agencies once more. The National Oceanic and Atmospheric Administration (NOAA) was formed under the Department of Commerce. NOAA combined several formerly independent agencies, including the National Ocean Survey, National Weather Service, National Marine Fisheries Service, Environmental Data Service, National Environmental Satellite Service, and Environmental Research Laboratories. NOAA also administers the National Sea Grant College Program. This program consists of a network of twenty-nine individual programs located in each of the coastal and Great Lakes states. The Sea Grant College Program encourages cooperation in marine science and education among government, academia, and industry.

The International Decade of Ocean Exploration (IDOE) in the 1970s was a multinational effort to survey seabed mineral resources, improve environmental forecasting, investigate coastal ecosystems, and modernize and standardize the collection, analysis, and use of marine data.

At the end of the 1970s, oceanography faced a reduction in funding for ships and basic research, but the discovery of deep-sea hot-water vents and their associated animal life and mineral deposits renewed excitement over deep-sea biology, chemistry, geology, and ocean exploration in general. Instrumentation continued to become more sophisticated and expensive as deep-sea mooring, deep-diving submersibles, and the remote sensing of the ocean by satellite became possible. Increased cooperation among institutions led to the integration of research at sea between subdisciplines and resulted in large-scale, multifaceted research programs. Although collection of oceanographic data from vessels at sea expanded, data collected by satellites since the 1970s have increasingly presented researchers with the ability to observe the sea surface on a global scale. Currents, eddies, algae production, sea-level changes, waves, thermal properties, and air-sea interactions are all monitored via satellite, allowing scientists to develop computerized prediction models and to test them against natural phenomena.

During these years of expanding programs, Earth scientists began to recognize the signs of global degradation and the need for progressive policies and management of living and nonliving resources. Students were attracted to the programs, and ocean management courses were added to curricula. As more and more nations were turning to the sea for food and as technology was increasing our ability to exploit sea resources, problems of resource ownership, dwindling fish stocks, and the need for fishery management had to be faced.

In 1983, the Deep Sea Drilling Project became the Ocean Drilling Program (ODP). The ODP was managed by an international partnership of fourteen U.S. science organizations and twenty-one international organizations called the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES). The ODP replaced the retired drilling ship *Glomar Challenger* with a larger vessel, the *JOIDES Resolution* (fig. 1.17*b*), named after the HMS *Resolution*, used by Captain James Cook to explore the Pacific Ocean basin over 200 years ago. The *JOIDES Resolution* started drilling operations in 1985 and was in continuous service until ODP ended in 2003. The total crew included fifty scientists and technicians and sixty-five ship crew members.

NASA's *NIMBUS-7* satellite, launched in 1978, carried a sensor package called the Coastal Zone Color Scanner (CZCS) that detected multiband radiant energy from chlorophyll in sea and land algae. The sensor operated from 1978–86. CZCS images can be used to determine levels of biological productivity in the oceans. They can also indicate how and where physical processes in the oceans influence the distribution and health of marine biological communities, particularly the small marine plants called phytoplankton, which are discussed in detail in chapter 16 (fig. 1.18). The CZCS sensor was the predecessor to the ocean color measuring sensors SeaWiFS (Sea-viewing Wide Field-of-view Sensor) and MODIS (Moderate Resolution Imaging Spectroradiometer) which are in orbit today. SeaWiFS

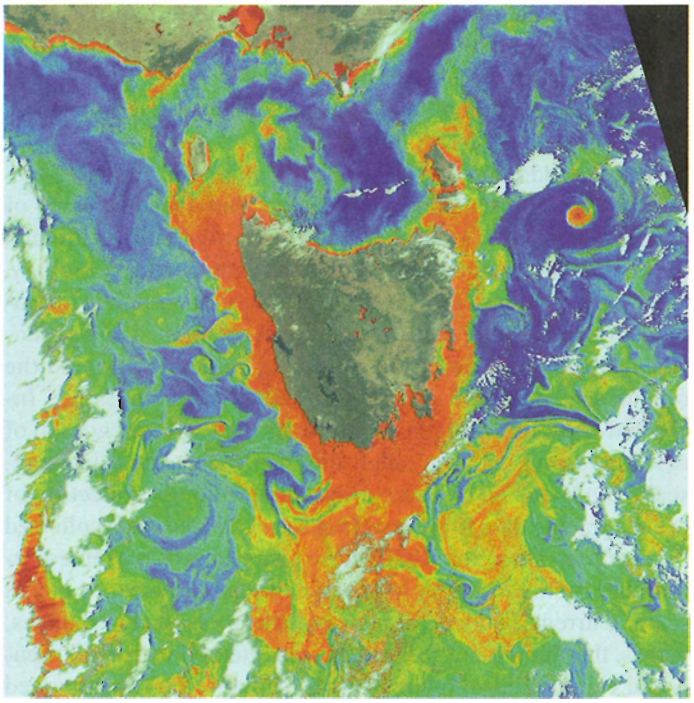


Figure 1.18 False color image centered on the island of Tasmania. Tasmania is located south of the eastern coast of Australia. *Yellow* and *reds* indicate high concentrations of phytoplankton, *greens* and *blues* low concentrations, and *dark blue* and *purple* very low concentrations. The complex current interactions, indicated by swirling color patterns, around the island have significant influence on the distribution of phytoplankton.

has now operated continuously for more than ten years (1997–2007). MODIS began recording data in 2002. SeaWiFS is carried by the *SEASTAR* satellite and MODIS is onboard the *Aqua* satellite. These are discussed further in section 1.10.

In 1985, the U.S. Navy *Geodynamic Experimental Ocean Satellite (GEOSAT)* was launched. It was designed to collect data for military purposes, but its orbit was changed to replace the failed *SEASAT.* From 1986–90, it monitored topography, surface winds and waves, local gravity changes, and sea surface "boundaries" caused by abrupt changes in salinity and temperature. *GEOSAT* was a predecessor to the *TOPEX* and *Jason* missions discussed in section 1.10.

1.10 The Recent Past, the Present, and the Future of Oceanography

Today's scientists see Earth not as a single entity but as a complex of systems and subsystems acting as a whole. Projects that emerged in the 1990s and continue in the 2000s require that scientists cross from one discipline to another and share information for common goals. Satellites are used for global observation. Earth and ocean scientists are able to retrieve and manipulate data quickly by computer at sea or on land, and they share it rapidly over the Internet. In addition, successful integrated approaches to Earth studies require that governments, agencies, universities, and national and international programs agree to set common priorities and share program results.

Several large-scale oceanographic programs have been developed to better understand the rôle of the oceans in processes of the atmosphere-ocean-land system. These programs provide data for models that scientists use to predict the evolution of Earth's environment as well as the consequences of human-influenced changes. The World Ocean Circulation Experiment (WOCE) studies the world oceans using computers and chemical tracers to model the present state of the oceans and predict ocean evolution in relation to long-term changes in the atmosphere. This effort combines sampling by ship, satellites, and floating buoys with sensors. The U.S. Joint Global Ocean Flux Study (JGOFS) is the largest and most complex ocean biogeochemical research program ever organized. Begun in 1988, the JGOFS program resulted in over 3000 ship days (more than eight years) of research and 343,000 nautical miles of ship travel (almost sixteen times around the globe) before ending in 2003. The goal of JGOFS research programs was to measure and understand on a global scale the processes controlling the cycling of carbon and other biologically active elements between the ocean, atmosphere, and land. This knowledge is needed to better predict the ocean's response to change, especially global climate change. The Global Ocean Atmosphere-Land System (GOALS) studies the energy transfer between the atmosphere and the tropical oceans to better understand El Niño and its effects and to provide improved large-scale climate prediction.

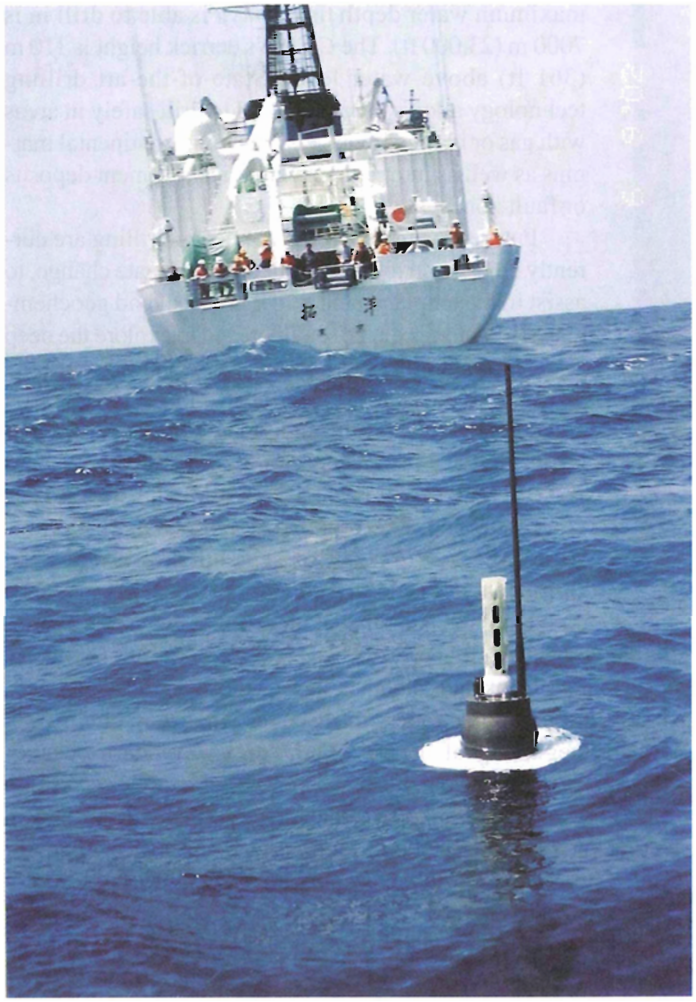
In August 1992, the satellite *TOPEX/Poseidon* was launched in a joint U.S.–French mission to explore ocean circulation and its interaction with the atmosphere. *TOPEX/Poseidon* measures sea level along the same path every ten days. This information is used to relate changes in ocean currents with atmospheric and climate patterns. The measurements allow scientists to chart the height of the seas across ocean basins with an accuracy of 3 cm (1.1 in). *TOPEX/Poseidon*'s three-year prime mission ended in the fall of 1995 and is now in its extended observational phase. A major follow-on mission to continue these studies began in December 2001, with the launch of *Jason-1. Jason-1*'s mission is the same as *TOPEX/Poseidon*'s, but the satellite is designed to acquire continuous data over longer periods of time to monitor global climate interactions between the atmosphere and the oceans (see the discussion of rising sea level in chapter 12).

In 1991, the Intergovernmental Oceanographic Commission (IOC) recommended the development of a Global Ocean Observing System (GOOS) to include satellites, buoy networks, and research vessels. The goal of this program is to enhance our understanding of ocean phenomena so that events such as El Niño (see section 7.8 in chapter 7) and its impact on climate can be predicted more accurately and with greater lead time. The successful prediction of the 1997–98 El Niño six months in advance made planning possible prior to its arrival.

An integral part of the GOOS is an international project called Argo, named after the mythical vessel used by the ancient Greek seagoing hero Jason. Argo consists of an array of 3000 independent instruments, or floats, throughout the oceans (fig. 1.19*a,b*). Each float is programmed to descend to a depth of up to 2000 m (6560 ft, or about 1.25 mi), where it remains for ten to fourteen days (fig. 1.19*c*). It then ascends to the surface, measuring temperature and salinity as it rises. When it reaches the surface, it relays the data to shore via satellite and then descends once again and waits for its next cycle. The floats drift with the currents as they collect and transmit data. In this fashion, the entire array will provide detailed temperature and salinity data of the upper 2000 m of the oceans every ten to fourteen days. Argo floats have a life expectancy of four years. Roughly one quarter of the floats will have to be replaced each year.

In 1997 NASA launched the *SeaStar* satellite for a planned five-year mission to record ocean color with the SeaWiFS color scanner. Now, ten years after launch, SeaWiFS is still operational providing information about basic marine biology, including oceanic primary productivity, plant biomass, and plant diversity.

The United Nations designated 1998 as the Year of the Ocean. Goals included (1) a comprehensive review of national ocean policies and programs to ensure coordinated advancements leading to beneficial results and (2) raising public awareness of the significance of the oceans in human life and the impact that human life has on the oceans. Also in 1998, the National Research Council's Ocean Studies Board released a report highlighting three areas that are likely to be the focus of future research: (1) improving the health and productivity of the coastal oceans, (2) sustaining ocean ecosystems for the future, and (3) predicting ocean-related climate variations.



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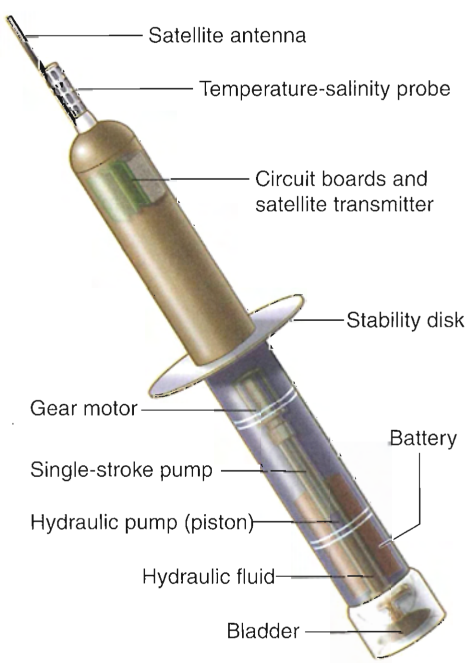

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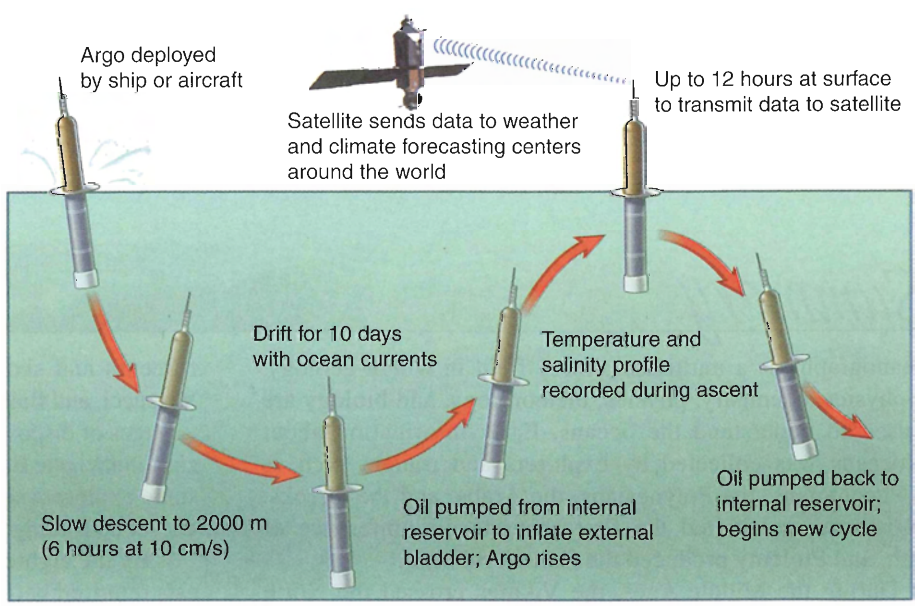

(c)

Figure 1.19 (a) The Japanese coast guard cutter *Takuyo* prepares to retrieve an Argo float (photo courtesy of the International Argo Steering Team). (b) Schematic of an Argo float. The float's buoyancy is controlled by a hydraulic pump that moves hydraulic fluid between an internal reservoir and an external flexible bladder that expands and contracts. (c) A single measurement cycle involves the slow descent of the float to a depth of up to 2000 m (6560 ft) where it remains for about ten days before hydraulic fluid is pumped into the external bladder and the float rises again to the surface to transmit data before descending again.

Figure 1.20 The drill ship *Chikyu* from its launching ceremony in January 2002.

In 2002, NASA launched the Earth Observing System (EOS) satellite *Aqua* with the color sensor MODUS to collect information about Earth's water cycle, including evaporation from the oceans, the extent of sea ice, radiative energy flux from the oceans, water temperature, and the distribution of phytoplankton and dissolved organic matter in the oceans.

Following the end of the ODP in 2003, a new ocean drilling program began. The Integrated Ocean Drilling Program (IODP) is an international marine drilling program involving sixteen countries and hundreds of scientists. The U.S. involvement is directed by a consortium called the Joint Oceanographic Institutions (JOI). IODP is the third phase of scientific ocean drilling succeeding the Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP). IODP utilizes two major drilling vessels, the *JOIDES Resolution*, operated by the United States, and a new vessel, the *Chikyu* (fig. 1.20), built and operated by Japan.

The *Chikyu* hull was launched in January 2002, and initial sea trials began in December 2004. Scientific drilling cruises began in 2007. The deepest hole drilled by the *JOIDES Resolution* to date is 2994 m (9823 ft) in 5333 m (17,498 ft) of water. The *Chikyu* is designed to drill up to 7500 m (24,600 ft) beneath the sea floor initially, with plans to increase that to 8000 m (26,250 ft). The maximum water depth the *Chikyu* is able to drill in is 7000 m (23,000 ft). The *Chikyu*'s derrick height is 110 m (361 ft) above water level. State-of-the-art drilling technology allows the new vessel to drill safely in areas with gas or hydrocarbon deposits along continental margins as well as into regions with thick sediment deposits or fault zones.

Future research priorities of ocean drilling are currently envisioned to investigate global climate change, to assist in the emplacement of geophysical and geochemical observatories on the sea floor, and to explore the deep structure of continental margins and oceanic crust.

One of the largest and most ambitious research and education programs under development is Project NEPTUNE. An international, multi-institutional project, NEPTUNE is part of a worldwide effort to develop regional, coastal, and global ocean observatories. Project NEPTUNE is scheduled to last at least thirty years. It is described in more detail in chapter 3.

Until the late nineteenth century, the great oceanographic voyages were largely voyages of exploration. Explorers such as James Cook and scientists such as those on the *Challenger* set sail into unknown waters to discover what they could find. With the beginning of the twentieth century, modern oceanographic science matured to become a process of hypothesis testing. Modern-day oceanographers typically first form an idea based on existing knowledge and then carefully design an experiment to test it. The sense of exploration has largely been in the background in recent decades with a few clear exceptions, such as the discovery of hydrothermal vent systems on mid-ocean ridges. The Office of Ocean Exploration (OOE) at NOAA was created in 2001 to encourage and fund new exploratory missions in the oceans. The OOE will also fund the development of new technology to support underwater exploration, such as manned or robotic submersibles and underwater-imaging systems.

Although large-scale, federally funded studies are presently in the forefront of ocean studies, it is important to remember that studies driven by the specific research interests of individual scientists are essential to point out new directions for oceanography and other Earth sciences. In the following chapters, you will follow the development of the ideas that have enabled us to build an understanding of the dynamic and complex systems that are Earth's oceans.

Summary

Oceanography is a multidisciplinary field in which geology, geophysics, chemistry, physics, meteorology, and biology are all used to understand the oceans. Early information about the oceans was collected by explorers and traders such as the Phoenicians, the Polynesians, the Arabs, and the Greeks. Eratosthenes calculated the first accurate circumference of Earth, and Ptolemy produced the first world atlas.

During the Middle Ages, the Vikings crossed the North Atlantic, and shipbuilding and chartmaking improved. In the fifteenth and sixteenth centuries, Dias, Columbus, da Gama, Vespucci, and Balboa, as well as several Chinese explorers, made voyages of discovery. Magellan's expedition became the first to circumnavigate Earth. In the sixteenth and seventeenth centuries, some explorers searched for the Northwest Passage, while others set up trading routes to serve developing colonies.

By the eighteenth century, national and commercial interests required better charts and more accurate navigation techniques. Cook's voyages of discovery to the Pacific produced much valuable information, and Franklin compiled a chart of the Atlantic's Gulf Stream. A hundred years later, the U.S. Navy's Maury collected wind and current data to produce current charts and sailing directions and then wrote the first book on oceanography.

Ocean science began with the nineteenth-century expeditions and research of Darwin, Forbes, Müller, and others. The three-and-a-half-year *Challenger* expedition laid the foundation for modern oceanography with its voyage, which gathered large quantities of data on all aspects of oceanography. Exploration of the oceans in Arctic and Antarctic regions was pursued by Nansen and Amundsen into the beginning of the twentieth century.

In the twentieth century, private institutions played an important role in developing U.S. oceanographic research, but the largest single push came from the needs of the military during World War II. After the war, large-scale government funding and international cooperation allowed oceanographic projects that made revolutionary discoveries about the ocean basins. Development of electronic equipment, deep-sea drilling programs, research submersibles, and use of satellites continued to produce new and more detailed information of all kinds. At present, oceanographers are focusing their research on global studies and the management of resources as well as continuing to explore the interrelationships of the chemistry, physics, geology, and biology of the sea.

Key Terms

All key terms from this chapter can be viewed by term or definition when studied as flashcards on this book's website at **www.mhhe.com/sverdrup10e**.

hypothesis, 2
theory, 2

Study Questions

1. Eratosthenes estimated the circumference of Earth at approximately 40,250 km (25,000 mi). Compare this estimate with the circumference used by Ptolemy. What difference would it have made to later voyages of discovery if Eratosthenes's measurement had been used rather than that of Ptolemy?
2. Who first assigned the name "America" to the New World? For whom was it named?
3. Why was there such great interest in finding and establishing a Northwest Passage?
4. Who first understood the tides and published an explanation of them?
5. What were Captain James Cook's contributions to our understanding of the oceans?
6. Why did Benjamin Franklin consider it so important to chart the Gulf Stream?
7. Who was Matthew F. Maury, and why is he considered by many to be the founder of oceanography?
8. Why do you think Edward Forbes concluded that there was no life in the oceans below 550 m (1800 ft)?
9. What did the engineers who laid the first transatlantic cable need to know about the oceans?
10. The *Challenger* and its expedition are often called unique. Why is this term used? What were the benefits of this expedition to the science of the oceans?
11. What was Fridtjof Nansen trying to prove by freezing the *Fram* into the polar ice?
12. The amount of ocean data has been expanding at an ever-increasing rate since the early years of ocean exploration. Why?
13. How has each of the following affected twentieth-century oceanography? (a) Economics. (b) Commerce and transportation. (c) Military needs.
14. In what ways have computers altered oceanography?
15. What are the reasons for the increased interest in resources of the sea? What types of management do you think may be required for these resources in the future?