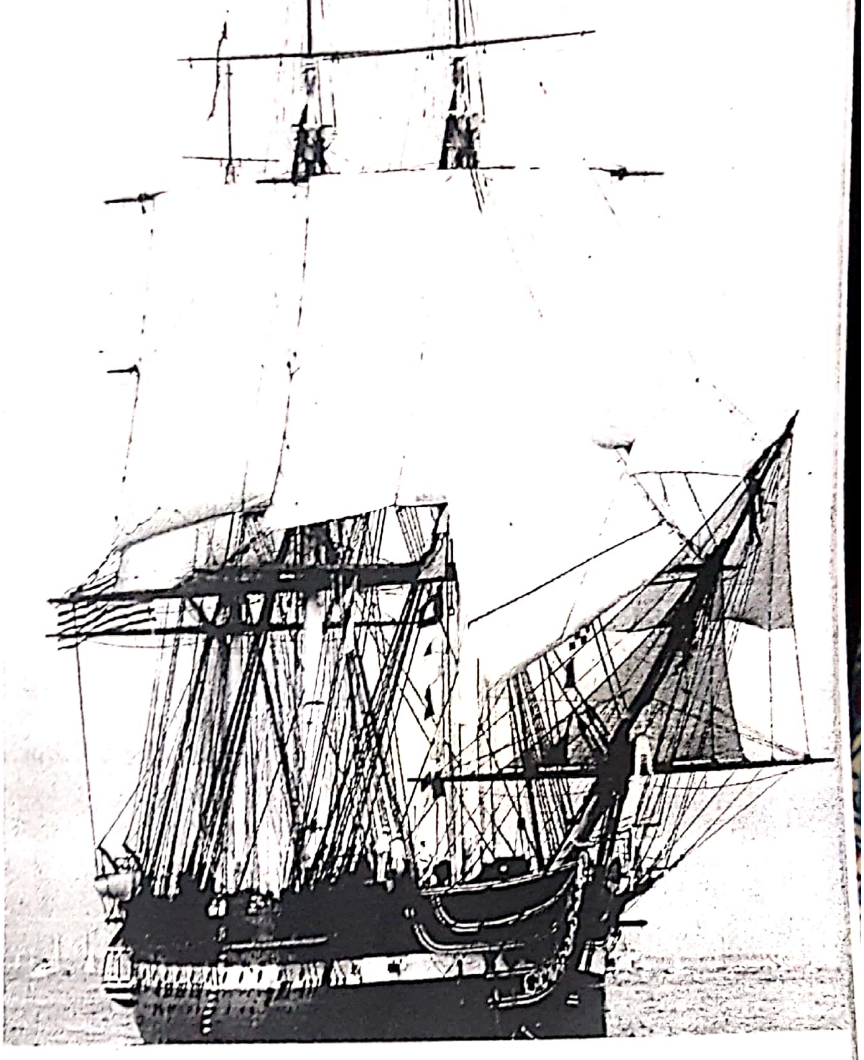


Chapter 1

History of Oceanography

LEARNING OBJECTIVES

After reading this chapter, you should be able to

- Understand the diversity of the sciences collected to form "oceanography."
- Understand the development of oceanography as a science.
- Follow the development of ocean knowledge from early voyages of exploration and discovery.
- Understand the significance of navigation in describing the oceans and making accurate maps of their extent and boundaries.
- Recognize the contributions of early U.S. oceanography to the developmen of marine commerce.
- Understand the role of early scientific voyages in the investigation of the world's oceans.
- Recognize the role of U.S. agencies in developing oceanography before an after World War II.
- Recognize the relationship between technology, international cooperation and the development of recent large-scale oceanographic programs.
- Discuss the programs being planned for the future.

Chapter Outline

Oceanography is a broad field in which many sciences focus on the common goal of understanding the oceans. Geology, geography, geophysics, physics, chemistry, geochemistry, mathematics, meteorology, botany, and zoology all play roles in expanding our knowledge of the oceans. Geological oceanography includes the study of Earth at the sea's edge and below its surface and the history of the processes that formed the ocean basins. Physical oceanography investigates the causes and characteristics of water movement such as waves, currents, and tides and how they affect the marine environment. It also studies 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 seawater, its processes, and its interactions. Biological oceanography concerns itself with the marine organisms and the relationship between these organisms and the environment in the oceans. Ocean engineering is the discipline of designing and planning equipment and installations for use at sea.

Our progress toward the goal of understanding the oceans has been uneven, and it has frequently changed direction. The interests and needs of nations as well as the intellectual curiosity of scientists have controlled the rate at which we study the oceans, the methods we use to study them, and the priority we give to certain areas of study. To gain some perspective on the current state of knowledge about the oceans, we need to know something of the events and incentives that guided previous investigations of the oceans.

1.1 The Early Times

People have been gathering information about the oceans for millennia, 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. As early humans moved slowly away from their inland centers of development, they took 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 found at the sites of ancient shore settlements show that our early ancestors gathered shellfish, and certain fish bones suggest that they also began to use 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. It is very likely that the artifacts that have been found only give us an idea of the minimum extent of ancient shore settlements.

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 B.C. to 146 B.C., were well known as excellent sailors and navigators. While their land was fertile it was densely populated so they were compelled to engage in trade with others 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 who 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 to 900 m (roughly 1000–3000 ft).

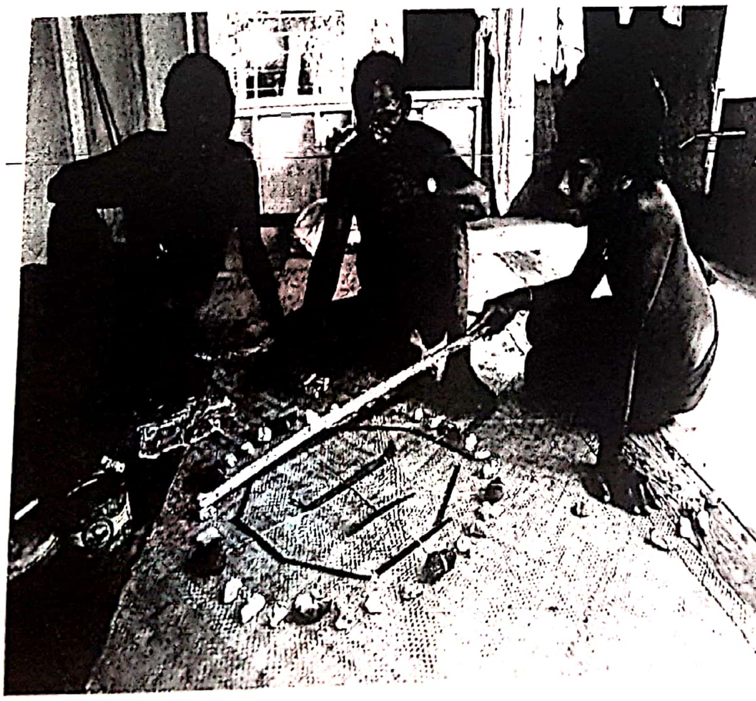
Extensive migration throughout the Southwestern Pacific may have begun by 2500 B.C. These early voyages were relatively easy because of the comparatively short distance between islands in the far Southwestern Pacific region. By 1500 B.C. the Polynesians had begun more extensive voyages to the east where the distance between islands grew from tens of miles at the edge of the western Pacific to thousands of miles in the case of voyages to the Hawaiian Islands. They successfully 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 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 along the horizon. Observed near the equator, the stars appear to rotate from east to west around Earth 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," dividing the horizon into 32 points where the stars for which the points are named rise and set. These points form a compass that provides a reference for recording information about the direction of winds, currents, waves, and the relative positions of islands, shoals, and reefs (fig. 1.1). The Polynesians also navigated by making close observations of waves and cloud formations. Observations of birds and the distinctive smells of land such as flowers and wood smoke alerted them to possible landfalls. Once islands had been 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. 1.2).

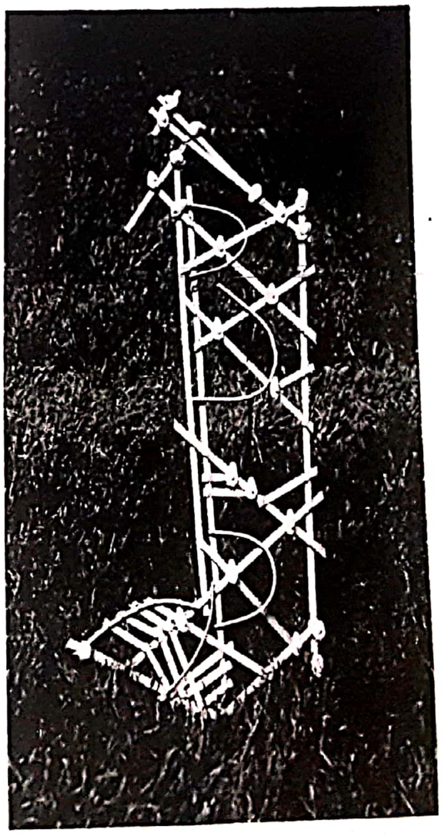
As early as 1500 B.C. Arabs of many different ethnic groups and regions were exploring the Indian Ocean. In the seventh century A.D. they were unified under Islam and began to control the trade routes to India and China and consequently the commerce in silk, spices, and other valuable goods (this monopoly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

These early sailors did not investigate the oceans; for them the sea was only a dangerous road, a pathway from here to there. This situation continued for hundreds of years. However, the information that they accumulated became a body of lore to which sailors and voyagers added from year to year.

While the Greeks traded and warred throughout the Mediterranean, they observed and also asked themselves questions about the sea. Aristotle (384–322 B.C.) believed that the ocean 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. 265–194 B.C.) of Alexandria, Egypt, mapped his known world and calculated Earth's circumference to be about 40,250 kilometers (km) or 25,000 miles (mi) (today's measurement is 40,067 km or 24,881 mi). Posidonius (c. 135–50 B.C.) reportedly measured an ocean depth to about 1800 meters (6000 ft) near the island of Sardinia, according to the Greek geographer Strabo (c. 63 B.C.–c. A.D. 21). Pliny the Elder (A.D. 23–79) related the phases of the Moon to the tides and reported on the currents moving through the Strait of Gibraltar. Ptolemy, in A.D. 127–151,



web link **Figure 1.1** 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.



web link **Figure 1.2** 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.

Figure 1.3 A chart from an Italian fifteenth-century edition of Ptolemy's *Geographia*.

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 on the other side (fig. 1.3). His atlas listed more than 8000 places by latitude and longitude, but his work contained a major error: he had accepted a value of 29,000 km (18,000 mi) for Earth's circumference. This shortened Earth distances and allowed Columbus, more than a thousand years later, to believe that he had reached the eastern shore of Asia when he landed in the Americas.

Name the subfields of oceanography.

What did early sailors use for guidance during long ocean voyages?

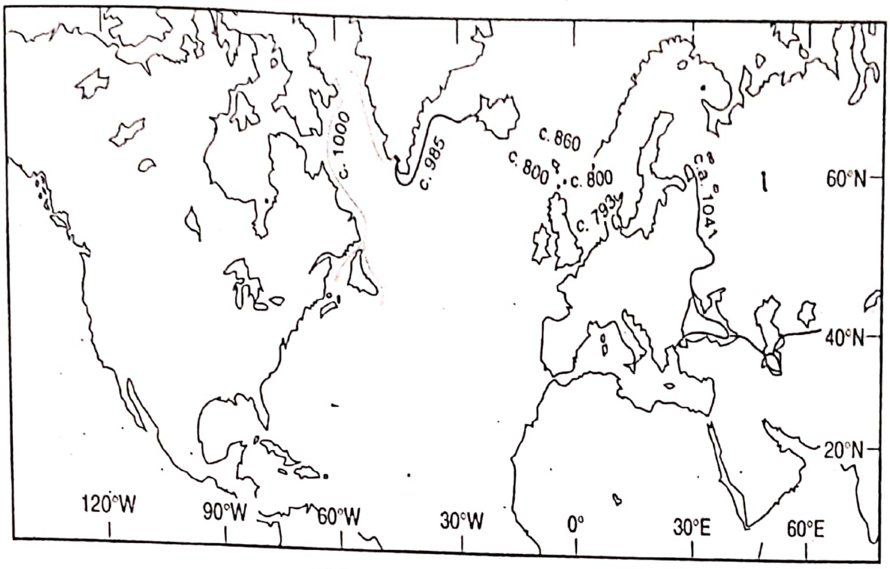
What kind of "compass" did the Polynesians use for navigation?

How long ago was Earth's circumference first calculated?

How did Ptolemy's atlas contribute to a greater understanding of world geography, and how did it produce confusion?

1.2 The Middle Ages

After Ptolemy, intellectual activity and scientific thought declined in Europe for about one thousand years. However, shipbuilding improved during this period; vessels became more seaworthy and easier to sail allowing sailors to extend their 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 985–6, 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.



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

To the south, in the Mediterranean region after the fall of the Roman Empire, the Arabs preserved the knowledge of the Greeks and the Romans, on which they continued to build. The Arabic writer El-Mas'údé (d. 956) gave the first description of the reversal of the ocean currents due to the seasonal monsoon winds. Using this knowledge of winds and currents, the Arabs established regular trade routes across the Indian Ocean. In the 1200s 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 static, 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. One example, 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.

As scholarship was reestablished in Europe, Arabic translations of early Greek studies were translated into Latin, which made them again available to northern European scholars. 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.

What advances occurred during the Middle Ages that allowed longer ocean voyages?

During the tenth century, which oceans were explored and by what people?

Where did the Vikings establish a large colony in the North Atlantic?

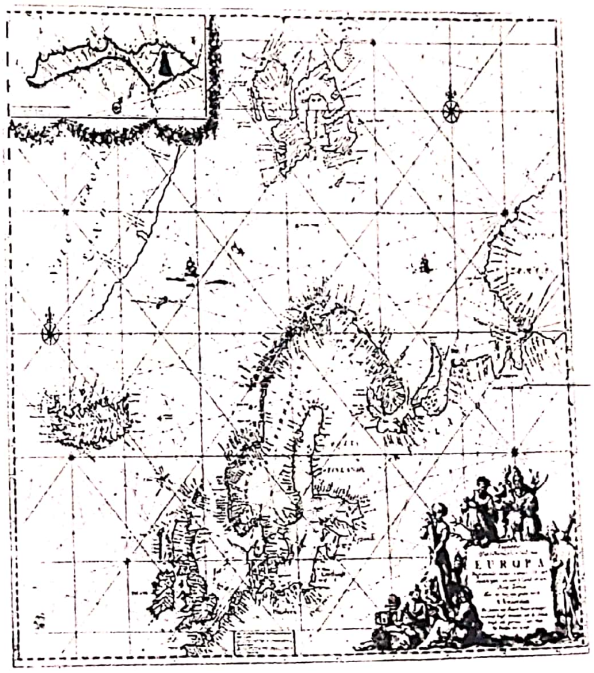


Figure 1.5 A navigational chart of northern Europe from Johannes van Keulen's *Sea-Atlas* of 1682–84.

1.3 Voyages of Discovery

Early in the fifteenth century the Chinese organized seven voyages to explore the Pacific and Indian Oceans. More than 300 ships, one more than 122 m (400 ft) long, participated in these ventures to extend Chinese influence and demonstrate the power of the Ming dynasty. 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 a 400-year period of isolation.

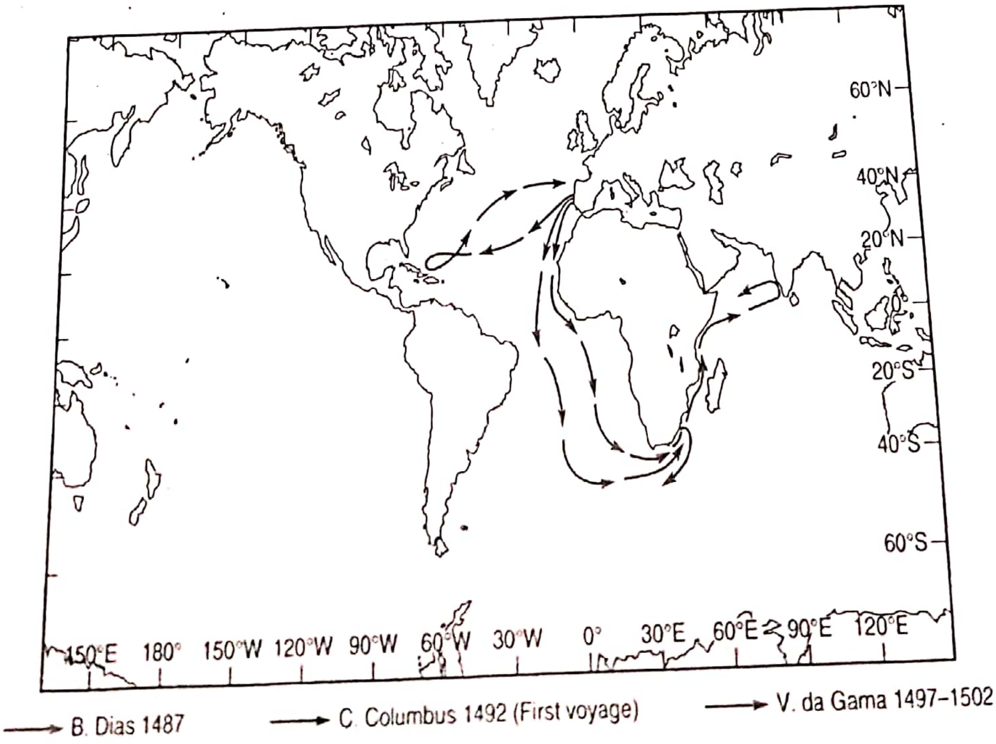
In Europe the desire for riches from new lands persuaded wealthy individuals, often representing their countries, to underwrite the costs of long voyages to all the oceans of the world. The individual most responsible for the great age of European discovery was Prince Henry the Navigator (1394–1460) of Portugal. He established a naval observatory for the teaching of navigation, astronomy, and cartography about 1450. Prince Henry sent expedition after expedition down the west coast of Africa to secure trade routes and to establish colonies. Bartholomeu Dias (1450?–1500) rounded the Cape of Good Hope in 1487 in the first of the great voyages of discovery (fig. 1.6). Dias sailed in search of new and faster routes to the spices and silks of the East.

Portugal's slow progress down the west coast of Africa in search for a route to the east finally came to fruition with Vasco da Gama (1469–1524). In 1498 he followed Bartholomeu Dias' 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 challenged along the way by Arab ships. In 1502, da Gama returned with a flotilla of 14 heavily armed ships and defeated the Arab fleet. By 1511, the Portuguese mastered the spice routes and had access to the Spice Islands. In 1513, Portuguese trade extended to China and Japan.

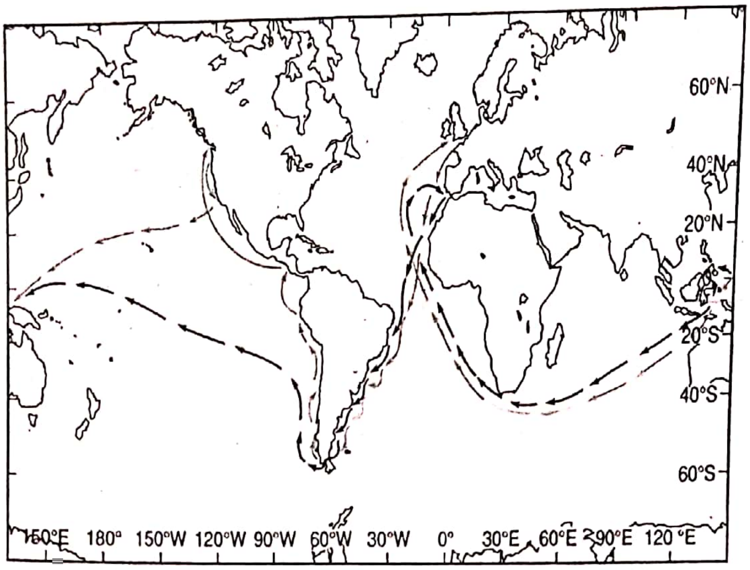
Christopher Columbus (1451–1506) made four voyages across the Atlantic Ocean in an effort to find a new route to the East Indies by traveling west rather than east. By relying on inaccurate estimates of Earth's size he badly underestimated the distances involved and believed he had found islands off the coast of Asia when he reached the New World. The Italian navigator Amerigo Vespucci (1454–1512) made several voyages to the New World (1499–1504) for Spain and Portugal; he accepted South America as a new continent, not part of Asia. In 1507, the German cartographer Martin Waldseemüller applied the name "America" to the continent in Vespucci's honor. Vasco Nuñez de Balboa (1475–1519) crossed the *Isthmus of Panama* and found the Pacific Ocean in 1513. All claimed the new lands they found for their home countries. Although they had sailed for 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 18 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 Earth's circumference.

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 the north side of North America. Sir Martin Frobisher (1535?–94) made three voyages in the 1570s, and Henry Hudson (d. 1611) made four voyages between 1607 and 1610, dying with his son when set adrift in Hudson Bay by his mutinous crew. The Northwest Passage continued to beckon, and William Baffin (1584–1622) made two attempts in 1615 and 1616.



web link **Figure 1.6** The routes of Bartholomeu Dias and Vasco da Gama around the Cape of Good Hope and Christopher Columbus's



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

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 Straits 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 their knowledge of the sea brought military victories as well as economic gains.

What stimulated the long voyages of the fifteenth and sixteenth centuries?

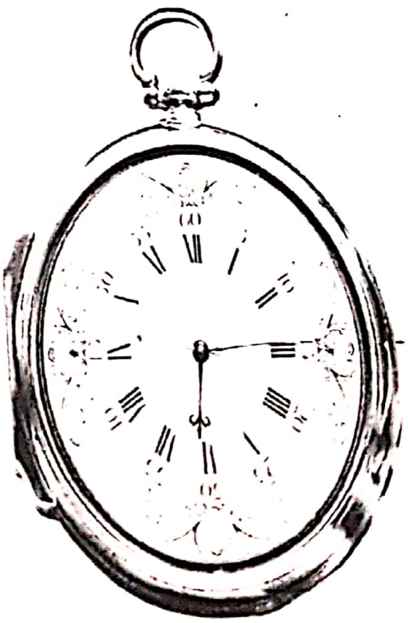
Who was Amerigo Vespucci, and how was he honored?

Why was Magellan's voyage of such great importance?

What is the Northwest Passage? Why was there an interest in finding it?

1.4 The Importance of Charts and Navigational Information

As colonies were established far away from their home countries, and as trade and travel expanded, there was renewed interest in developing better charts and more accurate navigation techniques. To obtain the precise location of landfall or ship's position, it is necessary to know the location of the Sun or the stars related to time, and because early clocks did not work well on rolling ships, precise navigational measurements were not possible on early voyages. In 1714 the British Parliament offered 20,000 pounds sterling for a clock that could keep time with an error not greater than two minutes on a voyage to the West Indies from England. John Harrison, a clock maker, accepted the challenge and built his first sea-going clock in 1735. It was not until 1761 that his fourth model (fig. 1.8) met the test, losing only 51 seconds on the 81-day voyage.



web link Figure 1.8 John Harrison's fourth chronometer. A copy of this chronometer was used by Captain James Cook on his 17 voyage to the southern oceans.

Captain James Cook (1728–79) made his three great voyages to chart the Pacific Ocean between 1768 and 1779 (fig. 1.9). During his voyages, he explored and charted much of the South Pacific and the coasts of New Zealand, Australia, and northwest North America. He took a copy of Harrison's fourth chronometer on his second voyage of discovery to the south seas, and with this timepiece he was able to produce accurate charts of new areas and to correct previously charted positions. He searched for a way to the Atlantic from the Bering Sea and discovered the Hawaiian Islands, where he was killed. He made soundings to depths of 400 m (1300 ft) and logged accurate observations of winds, currents, and water temperatures. Cook takes his place as one of history's greatest navigators and sailors as well as a fine scientist. His 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 amount of 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), which encouraged captains to sail within the Gulf Stream enroute to Europe and to avoid it on the return passage. 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 with a map of the Gulf Stream shown in figure 1.11 based on the average sea surface temperature during 1996.

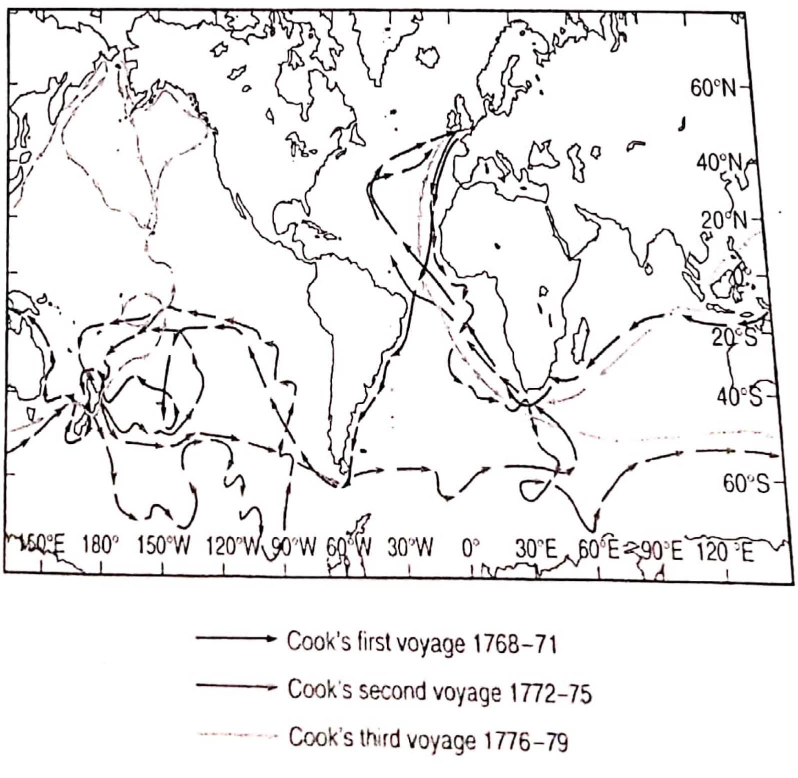
The U.S. Naval Hydrographic Office, now the U.S. Naval Oceanographic Office, was set up in 1830. In 1842, Lieutenant Matthew F. Maury (1806–73) was assigned to the Hydrographic Office and founded the Naval Depot of Charts. He began a systematic collection of wind and current data from ships' logs. He produced his first wind and current charts of the North Atlantic in 1847: these became a part of the first published atlases of sea conditions and sailing directions. 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, and the first contour chart of the North Atlantic sea floor. See figure 1.12 for the Gulf Stream chart from this book and compare the change in detail and style with the Franklin-Folger chart in figure 1.10. Many 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.

Why was John Harrison's clock important to ocean exploration?

What did Captain James Cook's voyage contribute to the science of oceanography?

Why was Benjamin Franklin interested in the Gulf Stream?

Who was Matthew F. Maury, and what was his contribution to ocean science?



web link Figure 1.9 The three ...

web link Figure 1.10 The Franklin-Folger map of the Gulf Stream, 1769.

web link Figure 1.11 Average sea surface temperature for the year 1996. The red-orange streak of 28°C to 30°C water shows the Gulf Stream.

web link Figure 1.12 Matthew F. Maury's chart of the Gulf Stream and North Atlantic Ocean surface currents from *Physical Geography of the Sea*, 1855.

1.5 Ocean Science Begins

As charts became more accurate and as information about the oceans increased, the oceans captured the interest of naturalists and biologists. Charles Darwin (1809–82) joined the survey ship *Beagle* and served as the ship's naturalist from 1831 to 1836. He described, collected, and classified organisms from the land and sea. His theory of atoll formation (described in chapter 4) 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 the Mediterranean and Aegean Seas. He collected organisms in deep water and, based on his observations, proposed a system of ocean depth zones, each characterized by specific animal populations. However, he also mistakenly theorized that the environment below 550 m (1800 ft) was without life. His announcement is curious, since twenty years earlier the Arctic explorer Sir John Ross (1777–1856) had taken bottom samples at over 1800 m (6000 ft) depth in Baffin Bay and had found worms and other animals living in the mud. His 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.

The investigation of the minute drifting plants and animals of the ocean was not seriously undertaken until the German scientist Johannes Müller (1801–58) began to examine these organisms microscopically. Victor Hensen (1835–1924) introduced the quantitative study of these minute drifting organisms and gave them the name *plankton* in 1887. A portion of a plate from an 1899 publication describing these organisms is seen in figure 1.13.

Although science blossomed in the seventeenth and eighteenth centuries, there was little scientific interest in the sea beyond the practical needs for navigation, tide prediction, and safety. By the early nineteenth century, ocean scientists were still few and usually only temporarily attracted to the sea.

How did Edward Forbes advance understanding of the oceans, and in what way was he mistaken?

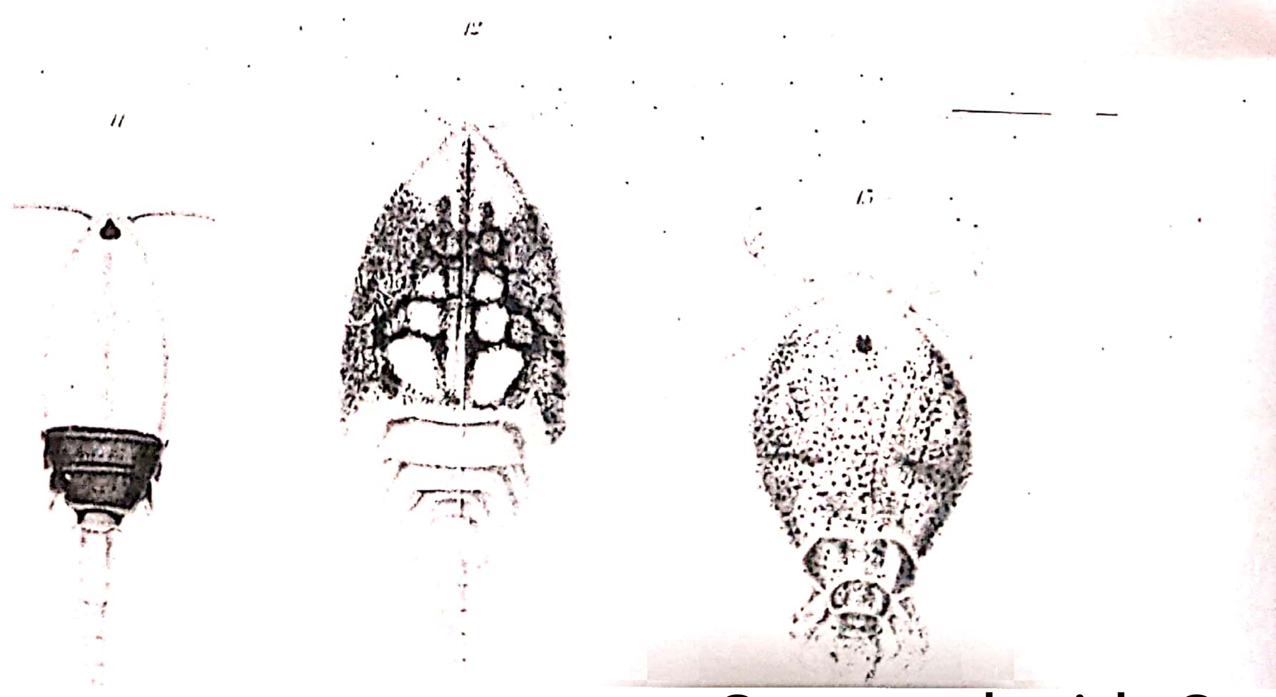
What kinds of organisms were investigated by Müller and Hensen?

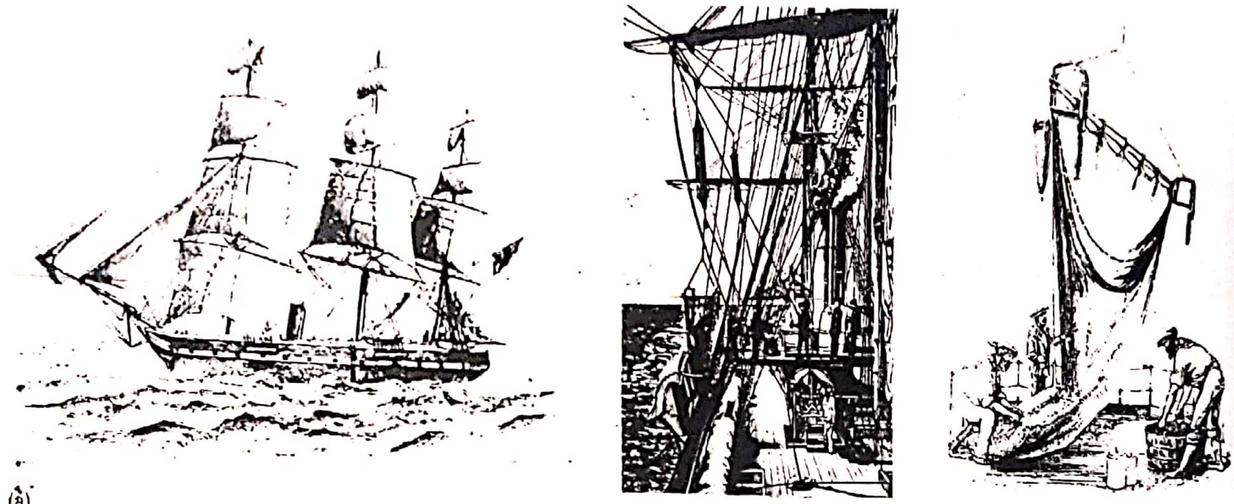
1.6 The *Challenger* Expedition

Charles Wyville Thomson (1830–82), a professor of natural history at Edinburgh University in Scotland, participated in a series of deep-sea expeditions during the years 1868–70. The deep-sea organisms recovered by these expeditions caught the public's attention, and with public interest running high, the British Royal Society was able to persuade the British Admiralty to organize the *Challenger* expedition, the most comprehensive single oceanographic expedition ever undertaken. The leadership of this expedition was offered to the Scottish professor Charles Wyville Thomson, who named as his assistant a young geologist, John Murray (1841–1914). At this time, Thomson also wrote *The Depths of the Sea*, based on his participation in the previous scientific expeditions. This very popular book was published in 1873 and is regarded by some as the first book on oceanography.

The naval corvette *Challenger* was refitted with laboratories, winches, and equipment; it sailed from England on December 21, 1872, for a voyage that was to last nearly three and a half years (fig. 1.14). During this voyage the vessel logged 110,840 km (68,890 mi), and returned to England on May 24, 1876. The *Challenger* expedition's purpose was scientific research; during the voyage the crew took soundings at 361 ocean stations (the deepest at 8180 m or 26,850 ft), 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. *Challenger* brought back evidence of an ocean teeming with life at all depths and opened the way for the era of descriptive oceanography that followed.

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 edited the reports after Thomson'

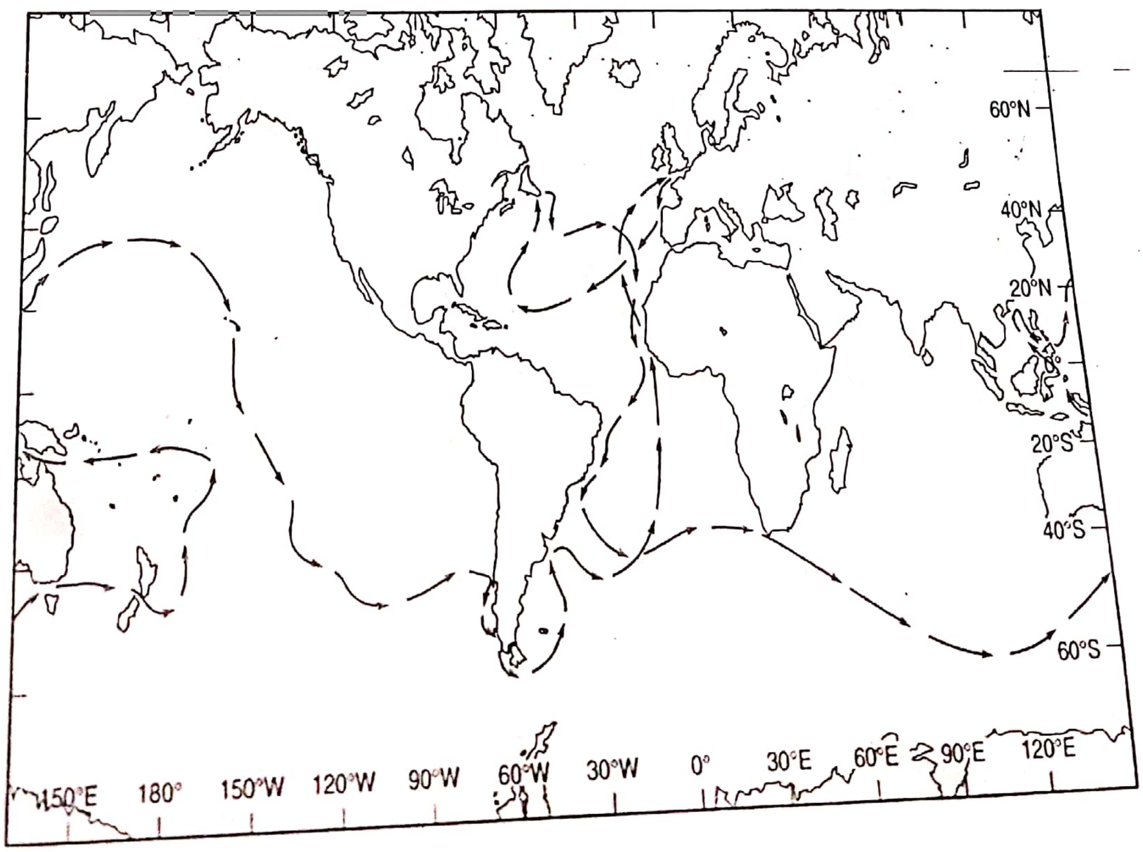




(a) (b) (c)

(d)

web link Figure 1.14 The *Challenger* expedition: December 21, 1872–May 24, 1876. Engravings 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) "Dredging and Sounding Arrangement on board *Challenger*." Rigging is hung from the ship's yards to allow the use of 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. (c) 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. (d) "H.M.S. *Challenger* at St. Paul's Rocks," in the equatorial mid-Atlantic. (e) The cruise of the *Challenger*, 1872–76, the first major oceanographic research effort.



(e)

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*, confirming the findings of earlier chemists that in seawater around the world, the proportion of the major dissolved elements to each other is constant. Oceanography as a modern science is usually dated from the *Challenger* expedition. The *Challenger Reports* laid the foundation for the science of oceanography.

Explain the significance of the *Challenger* expedition and the *Challenger Reports*.

The *Challenger* and its expedition are often called unique. Why is this term used?

1.7 Exploratory Science

During the late nineteenth century and the early twentieth century, 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. 1.15), a well-known athlete, explorer, and zoologist, was interested in the current systems of the polar seas. He 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; he expected in this way 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-meter (128-ft) *Fram* ("to push forward"), shown in figure 1.15, was built with a smoothly rounded, wooden hull and planking over 60 cm (2 ft) thick. Nansen with thirteen men departed from Oslo in June 1893.

The ship was frozen into the ice nearly 1100 km (700 mi) from the North Pole and remained in the ice for thirty-five months. During this period, measurements made through holes in the ice showed that the Arctic Ocean was a deep ocean basin and not the shallow sea that had been expected. The crew recorded water and air temperatures, analyzed water chemistry, and observed the great plankton blooms of the area. Nansen became impatient with the slow rate and the direction 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 a dogsled toward the pole, but after four 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. The crew of the *Fram* continued to drift with the ship until they freed the vessel from the ice in 1896 and also returned to Oslo. Nansen's expedition had laid the basis for future Arctic research. His name is familiar today from the Nansen bottle, which he designed to collect and isolate water samples at depth.

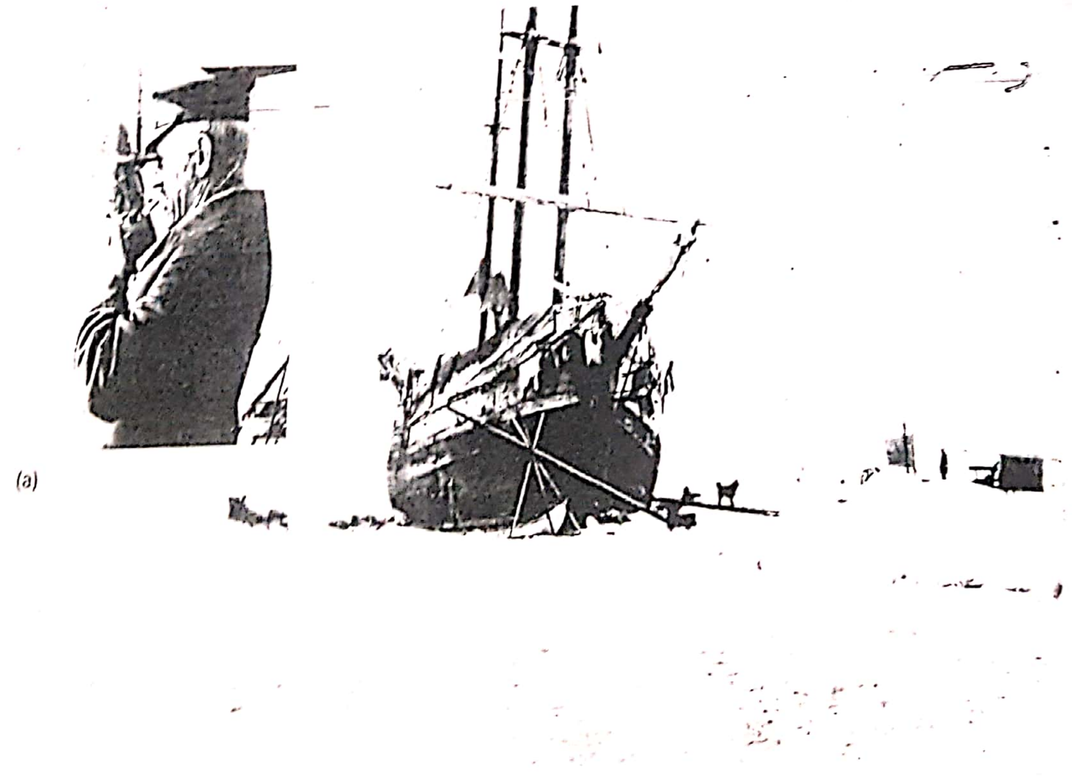


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Figure 1.15 (a) Fridtjof Nansen, Norwegian scientist, explorer, and statesman (1861–1930), using a sextant to determine his ship's position. (b) The *Fram*, frozen in ice. As the ice pressure increased, it lifted her specially designed and strengthened hull so that she would not be crushed.

The *Fram* paid another visit to polar waters carrying the Norwegian explorer Roald Amundsen (1872–1928) to Antarctica on his successful 1911 expedition to the South Pole. It was also Amundsen who finally made a Northwest Passage in the *Gjoa* (fig. 1.10), leaving Norway in 1903 and arriving in Nome, Alaska, three years later.

Fluctuations in the abundance of commercial fish in the North Atlantic and adjacent seas, and the effect of these changes on national fishing programs, stimulated oceanographic research and international cooperation. As early as 1870, researchers began to realize their need for knowledge of ocean chemistry and physics in order to understand ocean biology. Advances in theoretical oceanography often could not be verified with practical knowledge until new instruments and equipment were developed. Lord Kelvin (1824–1907) invented a tide-predicting machine in 1872 that made it possible to combine tidal theory with astronomical predictions to produce predicted tide tables. Deep-sea circulation could not be systematically explored until approximately 1910, when Nansen's water-sampling bottles were combined with thermometers designed for deep-sea temperature measurements, and an accurate method for determining the water's salt content 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* in the central and southern Atlantic Ocean.

Who was Fridtjof Nansen, and why was his work important?

Give examples of nineteenth- and early twentieth-century advances in technology that helped ocean studies.

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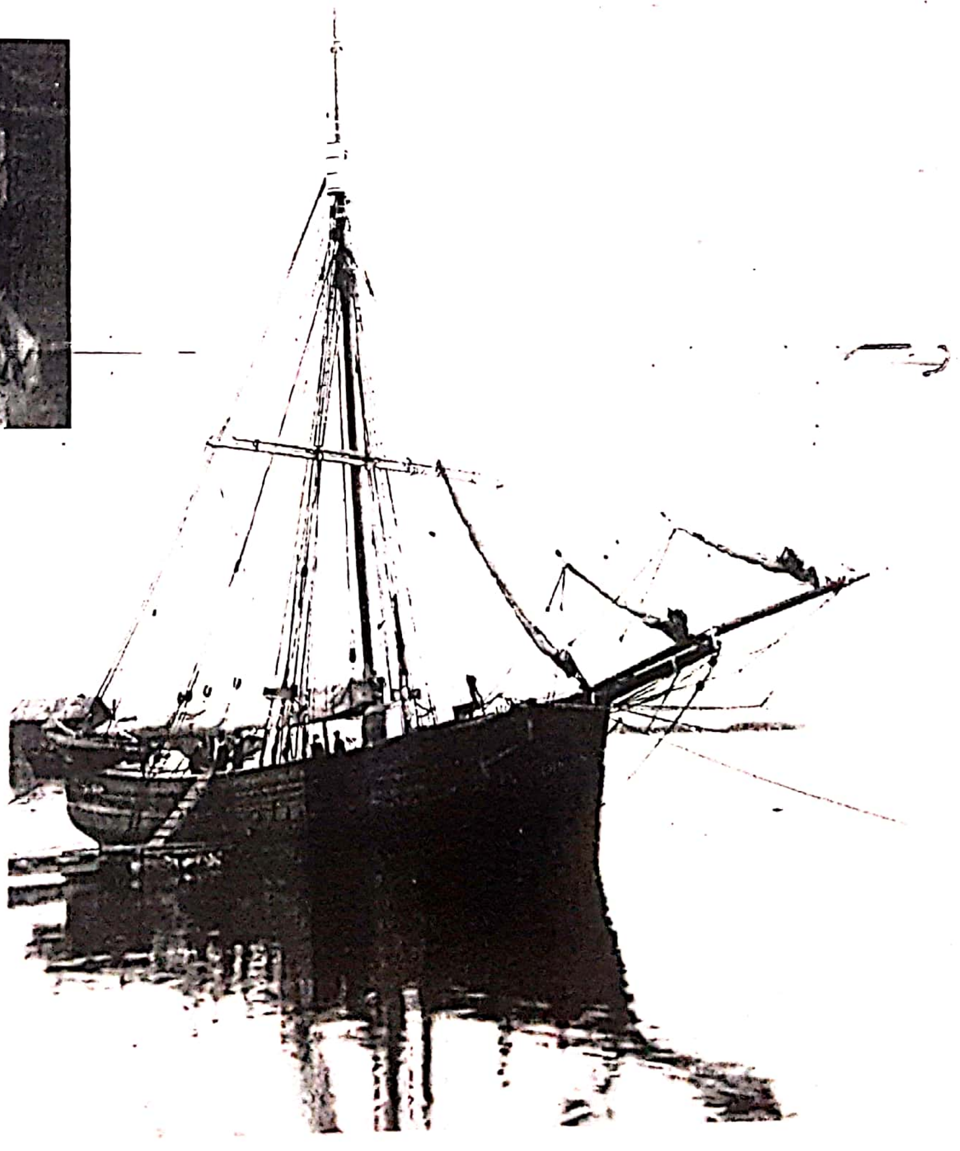


(b)

... (1872–1928). (b) The *Gjoa* preparing

1.8 Oceanography in the Twentieth Century

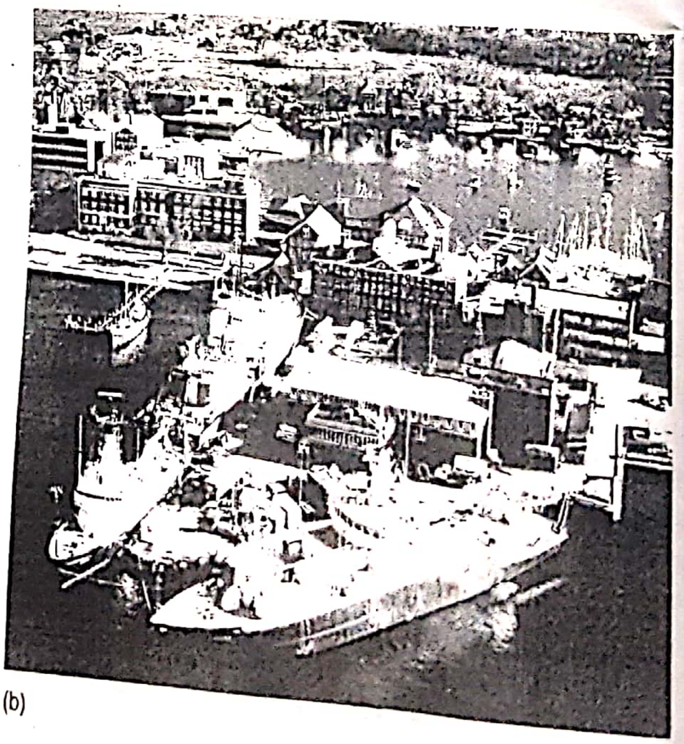
In the United States, government agencies related to the oceans proliferated during the nineteenth century. These agencies were concerned with gathering information to further commerce, fisheries, and the Navy. After the Civil War, the replacement of sail by steam lessened government interest in studying 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), marine scientist and Harvard Professor, financed a series of expeditions that greatly expanded knowledge of deep-sea biology. One of Agassiz's students, William E. Ritter, a professor at the University of California, Berkeley, established a permanent marine biological field station in San Diego in 1903 with financial support from members of the Scripps family, who had made a fortune in newspaper publishing. This was the beginning of the University of California's Scripps Institution of Oceanography (fig. 1.17a). 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. 1.17b). It was funded largely by a grant from the Rockefeller Foundation. The Rockefeller Foundation allocated funds to stimulate other programs in marine research and construct additional laboratories at this same time and oceanography began to move onto university campuses.

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 men and materials by sea to remote locations, to predict ocean and shore conditions for amphibious landings, to know how explosives behave in seawater, to chart beaches and harbors from aerial reconnaissance, and to find and destroy submarines. Academic studies ceased as oceanographers pooled their knowledge in the national effort.

After the war, oceanographers returned to their classrooms and laboratories with an array of new sophisticated instruments, including radar, improved sonar devices, automated wave detectors, and temperature-depth recorders. They also returned with large-scale government funding for research and education. 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 (ONR) and the National Science Foundation (NSF). The Atomic Energy Commission (AEC) financed oceanographic work at the South 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 completely revolutionized geology and geophysics. As a direct result of the IGY program, special research vessels and submersibles were built to be used by both federal agencies and university research programs.


(a)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web link **Figure 1.17** (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 the new *Atlantis*, stern forward, on the opposite side of the pier.

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 (DSDP), a cooperative venture between research institutions and universities, began to sample Earth's crust beneath the sea (fig. 1.18a, discussed in more detail in chapter 3) using the specially built drill ship *Glomar Challenger*. It was finally retired in 1983 after 15 years of extraordinary service. The *Glomar Challenger* was named after the ship used during the *Challenger* expedition of 1872–76. 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 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.

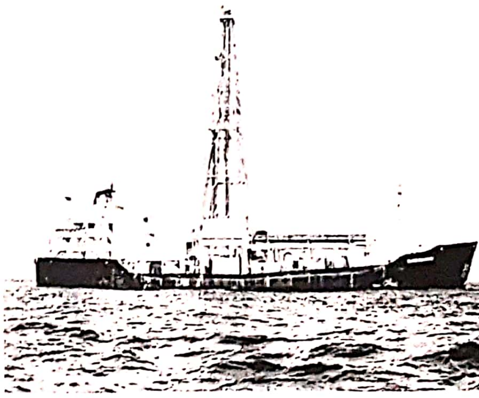
In 1970 the U.S. government reorganized its Earth science agencies once more. The National Oceanic and Atmospheric Administration (NOAA) was formed under the Department of Commerce. NOAA combined several formerly independent agencies including the National Ocean Survey, National Weather Service, National 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 29 individual programs located in each of the coastal and Great Lakes states. Sea Grant encourages cooperation in marine science and education among government, academia, and industry. The ten-year International Decade of Ocean Exploration (IDOE) occurred in the 1970s. IDOE was a multi-national effort to survey seabed mineral resources, improve environmental forecasting, investigate coastal ecosystems, and modernize and standardize the collection, analysis, and use of marine data.

Oceanography in the 1970s faced a reduction in funding for ships and basic research; nonetheless, the discovery of deep-sea hot water vents and their associated animal life and mineral deposits renewed the excitement over deep-sea biology, chemistry, geology, and ocean exploration in general. Instrumentation grew ever more sophisticated and expensive as deep-sea moorings, deep-diving submersibles, and the remote sensing of the ocean by satellites were used more and more often.

It is not possible to equip enough research vessels to study more than a small area of one ocean at one time, but with satellites oceanographers can study the oceans as a global system. Each satellite makes millions of observations every day as it follows changing conditions across the world's oceans. The huge amounts of information satellites provide are processed and manipulated by sophisticated computers to increase knowledge of currents, waves, plant life, sea ice, storms, and even the sea floor. Oceanographic vessels are linked to satellites via computers allowing scientists to use immediate data to plan their sampling programs while at sea.

SEASAT, a specialized oceanographic satellite, was launched in June 1978 but remained operational only until October. Its radar could measure the distance between the satellite and the sea surface with an accuracy of about 5 cm (2 in), allowing the measurement of wave heights. Sea surface temperatures, wind speeds, sea ice cover, currents, and plant production were also monitored.

During the 1970s and 1980s Earth scientists began to recognize the signs of global degradation and the need for management of living and nonliving resources. As more and more nations turned to the sea for food and as technology increased their abilities to harvest the sea, problems of resource ownership, dwindling fish stocks, and the need for fishery management became more and more evident.



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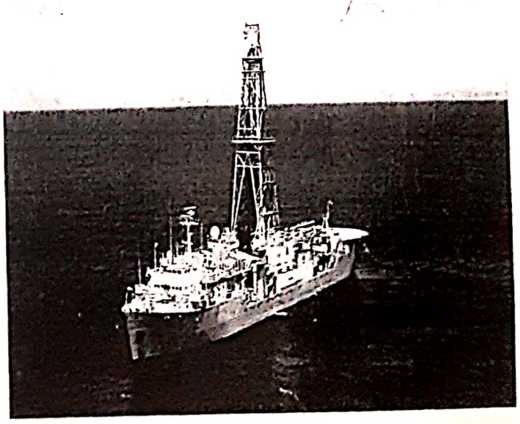


(b)

web link **Figure 1.18** (a) The *Glomar Challenger*, the Deep Sea Drilling Program drill ship used from 1968 to 1983. (b) The *JOIDES Resolution*, the Ocean Drilling Program drill ship in use since 1985.

In 1983 the Deep Sea Drilling Project became the Ocean Drilling Program (ODP). The objectives of the ODP included drilling into the thick sediments near continental margins. ODP uses a larger drilling ship, the *JOIDES Resolution* (fig. 1.18b), to replace the retired *Glomar Challenger* (fig. 1.18a). The *JOIDES Resolution* is named after the *HMS Resolution*, used by Captain James Cook to explore the Pacific Ocean basin over 200 years ago.

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 plants. The sensor operated from 1978 to 1986 when it finally failed. 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 11 (fig. 1.19).

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 to 1990 it monitored sea-level topography, surface winds and waves, local gravity changes, and abrupt "boundaries" in the ocean caused by changes in salinity and temperature.

web link **Figure 1.19** False color image of the oceans centered on the island of Tasmania. Tasmania is located south of the eastern coast of Australia. Yellows and reds indicate high concentrations of phytoplankton, greens and blues low concentrations, and dark blue and purple very low concentrations. The complex current interactions around the island have significant influence on the distribution of phytoplankton.

How did the U.S. oceanographic research focus change after the Civil War?

How has each of the following affected twentieth-century oceanography? (a) economics, (b) commerce and transportation, (c) military needs.

Compare the U.S. government's institutional support of oceanography before and after World War II.

How did the emphasis on ocean research change in the 1960s, 1970s, and 1980s?

Why are oceanographers interested in data collected by satellite as well as data from research vessels?

1.9 Oceanography of the Recent Past, Present, and the Future

Today's scientists see Earth not as a single system 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 manipulate online and archival data quickly by computer at sea or on land, and they share it rapidly by 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 to share program results.

Several large-scale oceanographic programs have been developed to better understand the role 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 the Earth's environment as well as the consequences of human-influenced changes. The World Ocean Circulation Experiment (WOCE) studies the world oceans using computer models and chemical tracers to model the present state of the oceans and then predict ocean evolution in relation to long-term changes in the atmosphere. This effort combines sampling by ship, satellites, and floating independent buoys with sensors. The U.S. Joint Global Ocean Flux Study (JGOFS) is the largest and most complex ocean biogeochemical research program ever organized. First begun in 1988, the JGOFS program has resulted in over 3000 ship days (more than eight years) of research and 343,000 nautical miles of ship travel (almost 16 times around the globe). The goal of JGOFS research programs is 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.

Two large international programs, the Deep Ocean Drilling Program (DODP) and the Ridge Interdisciplinary Global Experiment (RIDGE) explore the Earth's ocean floors and the margins of the continents. They investigate the structure and history of the Earth and probe the ocean's great mountain range systems and their relationships to the chemistry of the oceans.

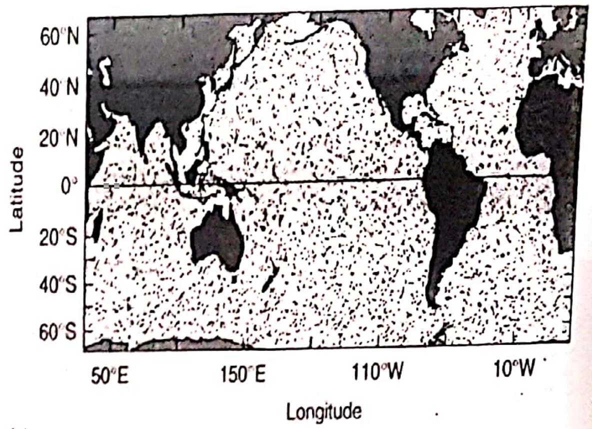
In August 1992, the satellite *TOPEX/Poseidon* was launched in a joint U.S.-French mission to explore ocean circulation and its interaction with the atmosphere. *TOPEX/Poseidon* measures sea level along the same path every 10 days. This information is used to relate changes in ocean currents with atmospheric and climate patterns. The measurements obtained allow scientists to chart the height of the seas across ocean basins with an accuracy of less than 10 centimeters (4 inches). *TOPEX/Poseidon*'s three-year prime mission ended in fall 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 it is designed to acquire continuous data over longer periods of time in order to measure long-term circulation processes more accurately.

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 6.14 in chapter 6) 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 will deploy an array of 3000 independent instruments, or floats, throughout the oceans by the year 2006 (fig. 1.20a). As of February 2004, 1,057 active Argo floats have been deployed. Each float is programmed to descend to a depth of 2000 m (6560 ft, or about 1.25 mi), where it remains for ten to fourteen days (fig. 1.20b). 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.

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.

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



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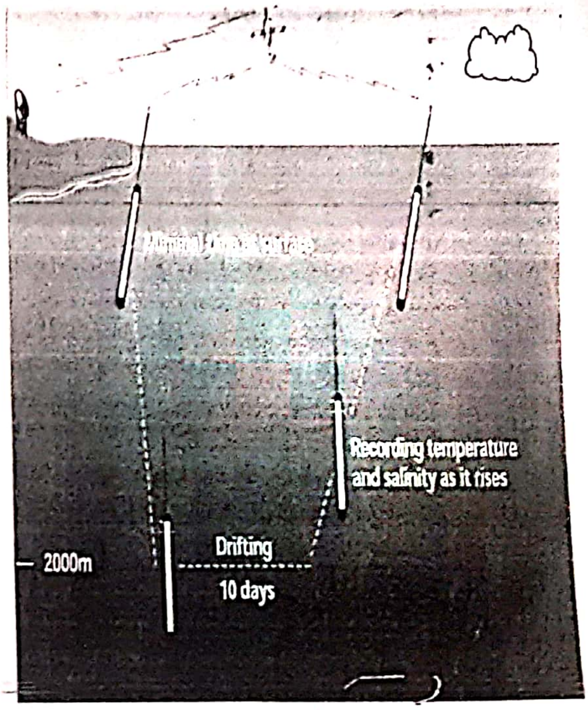

(b)

web link **Figure 1.20** (a) The Argo array will consist of 3000 autonomous floats spread throughout the oceans. (b) Every ten days the float will ascend to the surface, measuring temperature and salinity as it rises. When it reaches the surface it will transmit the data to shore via satellite and then descend to 2000 m (6560 ft) once again.

Source: Dean Roemmich and W. Breechner Owens in Oceanography, *vol. 13, no. 2, 2000, pp. 45–50.*

worldwide effort to develop regional, coastal, and global ocean observatories. Project NEPTUNE is scheduled to begin operation in 2007 and will last at least thirty years.

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 h... abled us to build an understanding of the dynamic and co... systems that are Earth's oceans.

List some of oceanography's current research targets

In what ways do satellites create ocean study opportunities that are not available to research vessels?

Why are oceanographers interested in a global approach to ocean science?

What role does the individual scientist play in advancing our knowledge?

Summary

Oceanography is a multiscience 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 Earth's circumference, and Ptolemy produced the first world atlas.

During the Middle Ages, the Vikings crossed the North Atlantic, while shipbuilding and chartmaking improved. In the fifteenth and sixteenth centuries the Chinese, Dias, Columbus, da Gama, Vespucci, and Balboa made voyages of discovery. Magellan's expedition became the first to circumnavigate the 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 sponsored 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 phases of oceanography. Exploration of the Arctic and Antarctic oceans 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.

Critical Thinking

1. Why have Captain James Cook, Edward Forbes, Charles Wyville Thomson, and Matthew F. Maury all been called the "founder of oceanography?" Can one individual be considered as oceanography's founder? Why or why not? If one individual were to be selected, which would you select and why?
2. How is oceanography affecting global trade, resource use, and military operations at the present time? Search for examples in print media, television, and the Internet as you continue your study of the oceans.
3. What are some advantages of using satellites for oceanographic research? Are there any disadvantages?
4. The ability to establish a precise ocean location in both space and time has occupied humans for thousands of years. Beginning with the stick charts of the Polynesians and ending with today's satellites, discuss the importance of this endeavor.
5. What do you think should be the goals of oceanographic science for the next ten to twenty years? Try answering this question again when you have finished your class in oceanography and compare your answers.