2 History

STUDY PLAN

- Understanding the Ocean Began with Voyaging for Trade and Exploration
- Voyaging Combined with Science to Advance Ocean Studies
- The First Scientific Expeditions Were Undertaken by Governments
- Contemporary Oceanography Makes Use of Modern Technology

SIX MAIN CONCEPTS

1 The ocean did not prevent the spread of humanity. By the time European explorers set out to "discover" the world, native peoples met them at nearly every landfall.

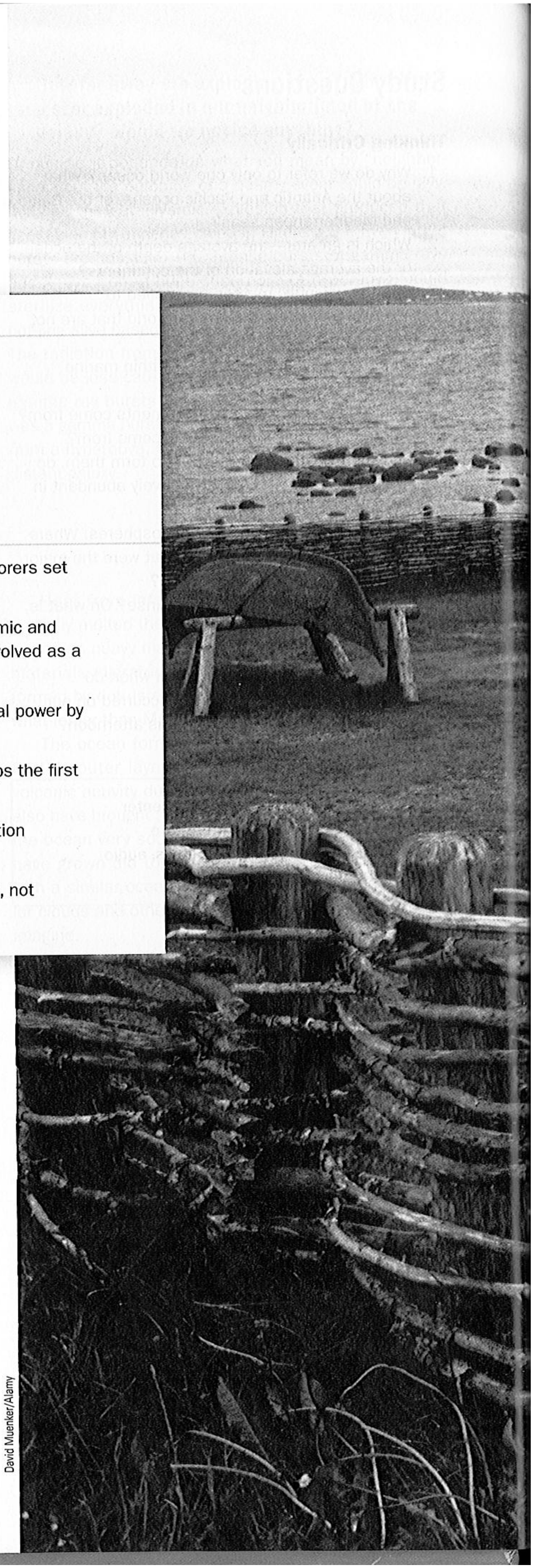
2 Any coastal culture skilled at raft building or small-boat navigation had economic and nutritional advantages over less-skilled competitors. Seafaring—voyaging—evolved as a way to maximize access to resources.

3 Periods of extensive maritime exploration and the marine projection of political power by nations preceded systematic scientific investigation of the ocean.

4 The three expeditions of Captain James Cook, British Royal Navy, were perhaps the first to apply the principles of scientific investigation to the ocean.

5 The voyage of H.M.S. *Challenger* (1872–1876) was the first extensive expedition dedicated exclusively to research.

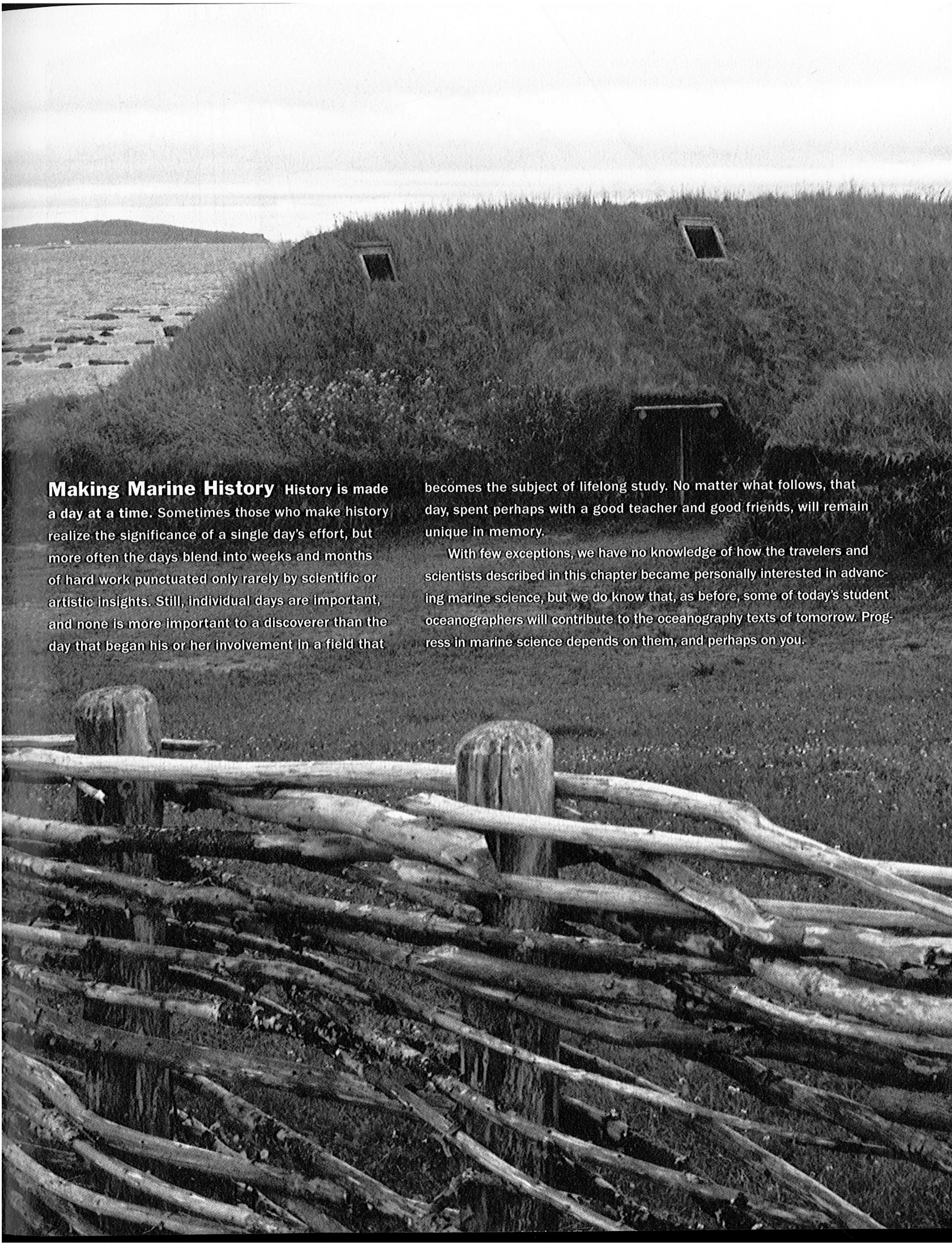
6 Modern oceanography is guided by consortia of institutions and governments, not individuals on single expeditions.



David Muenker/Alamy

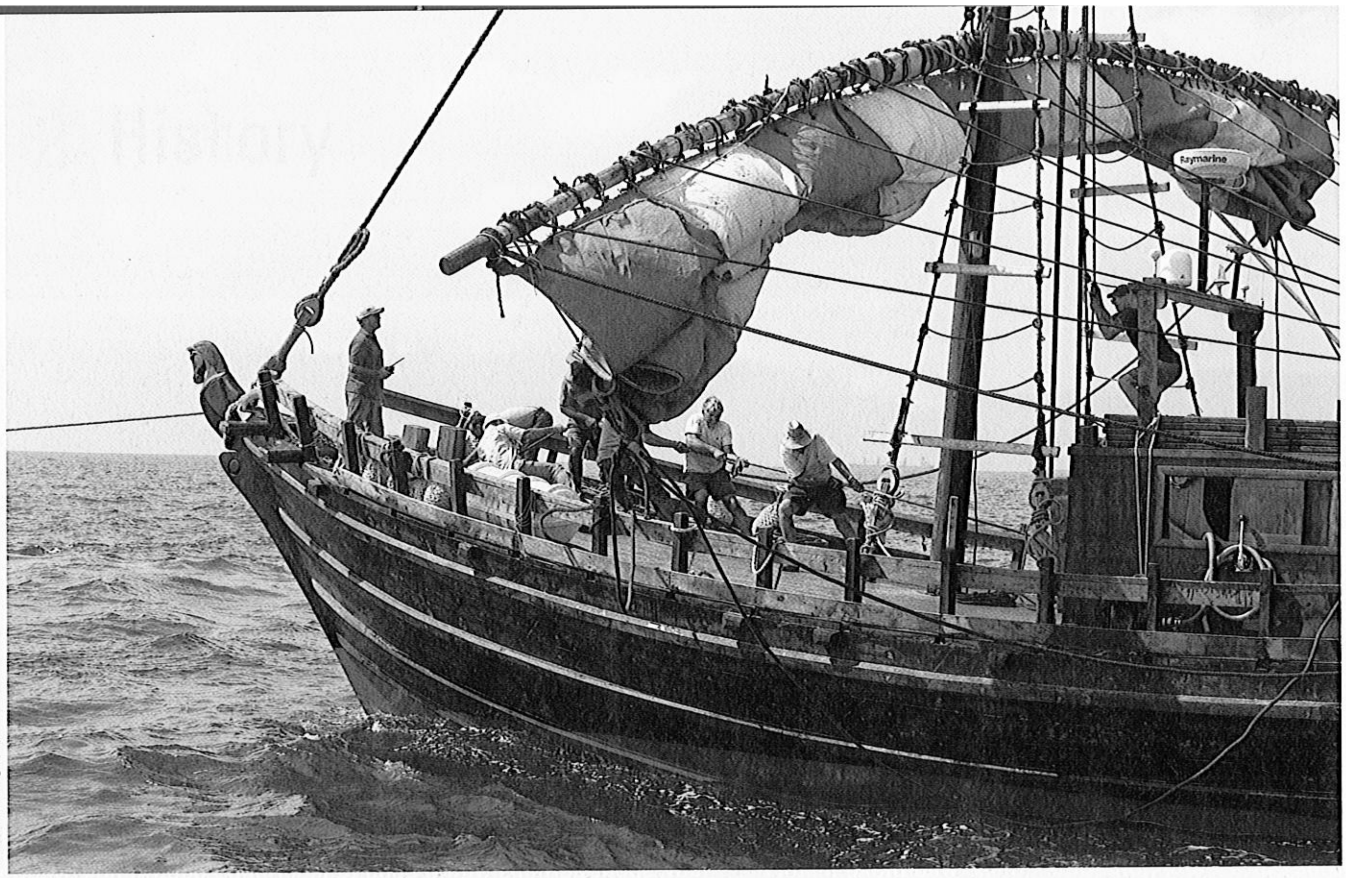
Climate changes history. This is a reconstruction of a Viking settlement in North America. This site, in L'Anse aux Meadows (Newfoundland, Canada), consisted of at least 8 buildings, including a forge and smelter, and a lumberyard that supplied a shipyard. As many as 150 settlers occupied the camp. At that time the climate in the North Atlantic was good and living conditions were favorable—the Norse sagas (stories) speak of mild snowless winters and excellent conditions for raising livestock in Greenland and at this site. But the mild climate deteriorated quickly and crops began to fail. Famine, combined with an increase in pack ice (which cut off trade with Europe), made life too difficult for the Vikings to stay, and the location was abandoned after about a decade of inhabitation.

The only constant about climate is change, and rapid climate change has had effects on human settlements and migrations through all of recorded history. Our present situation involves warming, not cooling, but as L'Anse aux Meadows suggests, either can be destructive to delicately balanced societies.



Making Marine History **History is made a day at a time.** Sometimes those who make history realize the significance of a single day's effort, but more often the days blend into weeks and months of hard work punctuated only rarely by scientific or artistic insights. Still, individual days are important, and none is more important to a discoverer than the day that began his or her involvement in a field that becomes the subject of lifelong study. No matter what follows, that day, spent perhaps with a good teacher and good friends, will remain unique in memory.

With few exceptions, we have no knowledge of how the travelers and scientists described in this chapter became personally interested in advancing marine science, but we do know that, as before, some of today's student oceanographers will contribute to the oceanography texts of tomorrow. Progress in marine science depends on them, and perhaps on you.



Jennie Hill Photography

Figure 2.1 A replica of a Greek ship from about 500 B.C.E. Such ships were used for trade to explore the Atlantic outside the Mediterranean.

Understanding the Ocean Began with Voyaging for Trade and Exploration 2.1

It has taken a long time for humans to appreciate the nature of the world, but we're a restless and inquisitive lot, and despite the ocean's great size, we have populated nearly every inhabitable place. This fact was aptly illustrated when European explorers set out to "discover" the world, only to be met by native peoples at nearly every landfall! Clearly the ocean did not prevent the spread of humanity. The early history of marine science is closely associated with the history of voyaging.

Early Peoples Traveled the Ocean for Economic Reasons Ocean transportation offers people the benefits of mobility and greater access to food supplies. Any coastal culture skilled at raft building or small-boat navigation would have economic and nutritional advantages over less-skilled competitors. From the earliest period of human history, then, understanding and appreciating the ocean and its life-forms benefited those patient enough to learn.

The first direct evidence we have of **voyaging,** traveling on the ocean for a specific purpose, comes from records of trade in the Mediterranean Sea. The Egyptians organized shipborne commerce on the Nile River, but the first regular ocean traders were probably the Cretans, or the Phoenicians who inherited maritime supremacy in the Mediterranean after the Cretan civilizations were destroyed by earthquakes and political instability around 1200 B.C.E. Skilled sailors, the Phoenicians carried their wares through the Strait of Gibraltar to markets as distant as Britain and the west coast of Africa. Given the simple ships they used, this was quite an achievement.

The Greeks began to explore outside the Mediterranean into the Atlantic Ocean around 900–700 B.C.E. (**Figure 2.1**). Early Greek seafarers noticed a current running from north to south beyond Gibraltar. Believing that only rivers had currents, they decided that this great mass of water, too wide to see across, was part of an immense flowing river. The Greek name for this river was *okeanos.* Our word *ocean* is derived from ***oceanus,*** a Latin variant of that root. Phoenician sailors were also very much at home in this "river," but like the Greeks they rarely ventured out of sight of land.

As they went about their business, early mariners began to record information to make their voyages easier and safer—the location of rocks in a harbor, landmarks and the sailing times between them, and the direction of currents. These first **cartographers** (chart makers) were probably Mediterranean traders who made routine journeys from producing areas to markets. Their first charts (from about 800 B.C.E.) were drawn to jog their memory for obvious features along the route. Today's **charts** are graphic representations that primarily depict water and water-related information. (*Maps* primarily represent land.) For more on maps and charts, please see Appendix V.

In this early time other cultures also traveled on the ocean. The Chinese began to engineer an extensive system of inland waterways, some of which connected with the Pacific Ocean, to make long-distance transport of goods more convenient. The Polynesian peoples had been moving easily among islands off the coasts of Southeast Asia and Indonesia since 3000 B.C.E. and were beginning to settle the mid-Pacific islands. Though none of these civilizations had contact with the others, each developed methods of charting and navigation. All of these early travelers were skilled at telling direction by the stars and by the position of the rising or setting sun.

Curiosity and commerce encouraged adventurous people to undertake ever more ambitious voyages. But these voyages were possible only with the coordination of astronomical direction finding (and knowledge of the shape and size of Earth), advanced shipbuilding technology, accurate graphic charts (not just written descriptions), and perhaps most important, a growing understanding of the ocean itself. Marine science, the organized study of the ocean, began with the technical studies of voyagers.

Systematic Study of the Ocean Began at the Library of Alexandria Progress in applied marine science began at the **Library of Alexandria,** in Egypt. Founded in the third century B.C.E. at the behest of Alexander the Great, the library constituted history's greatest accumulation of ancient writings. The library and the adjacent museum could be considered the first university in the world. Scholars worked and researched there, and students came from around the Mediterranean to study. Written knowledge of all kinds—characteristics of nations, trade, natural wonders, artistic achievements, tourist sights, investment opportunities, and other items of interest to seafarers—was warehoused around its leafy courtyards. When any ship entered the harbor, the books (actually scrolls) it contained were by law removed and copied; the *copies* were returned to the owner and the originals kept for the library. Caravans arriving overland were also searched. Manuscripts describing the Mediterranean coast were of great interest. Traders quickly realized the competitive benefit of this information.

Yet marine science was only one of the library's many research areas. For 600 years, it was the greatest repository of wisdom of all kinds and the most influential institution of higher learning in the ancient world. Here, perhaps, was the first instance of cooperation between a university and the commercial community, a partnership that has paid dividends for both science and business ever since.

Eratosthenes Accurately Calculated the Size and Shape of Earth The second librarian at Alexandria (from 235 B.C.E. until 192 B.C.E.) was the Greek astronomer, philosopher, and poet **Eratosthenes of Cyrene.** This remarkable man was the first to calculate the circumference of Earth. The Greek Pythagoreans had realized Earth was spherical by the sixth century B.C.E., but Eratosthenes was the first to estimate its true size.

Eratosthenes had heard from travelers returning from Syene (now Aswan, site of the great Nile dam) that at noon on the longest day of the year, the sun shone directly onto the waters of a deep, vertical well. In Alexandria, he noticed that a vertical pole cast a slight shadow on that day. He measured the shadow angle and found it to be a bit more than 7°, about 1/50 of a circle. He correctly assumed that the sun is a great distance from Earth, which means that the sun's rays would approach Syene and Alexandria in essentially parallel lines. If the sun were directly overhead at Syene but not directly overhead at Alexandria, then Earth's surface would have to be curved. But what was the *circumference* of Earth?

By studying the reports of camel caravan traders, he estimated the distance from Alexandria to Syene at about 785 kilometers (491 miles). Eratosthenes now had the two pieces of information needed to derive the circumference of Earth by geometry. **Figure 2.2** shows his method. The precise size of the units of length (stadia) Eratosthenes used is thought to have been 555 meters (607 yards), and historians estimate that his calculation, made in about 230 B.C.E., was accurate to within about 8% of the true value. Within a few hundred years most people in the West who had contact with the library or its scholars knew Earth's approximate size.

Even without the contributions of Eratosthenes, the significance of the Library of Alexandria to marine science is immense. In Alexandria, traders, explorers, scholars, and students had a place to conduct research and exchange information (and rumors) about the seas. Library researchers invented the astronomical, geometric, and mathematical base for **celestial navigation,** the technique of finding one's position on Earth by reference to the apparent positions of heavenly bodies.

Cartography flourished. The first workable charts that represented a spherical surface on a flat sheet were developed by Alexandrian scholars. Latitude and longitude, systems of imaginary lines dividing the surface of Earth, were invented by Eratosthenes. **Latitude** lines were drawn parallel to the equator, and **longitude** lines ran from pole to pole (**Figure 2.3**). Eratosthenes placed the lines through prominent landmarks and important places to create a convenient though irregular grid.

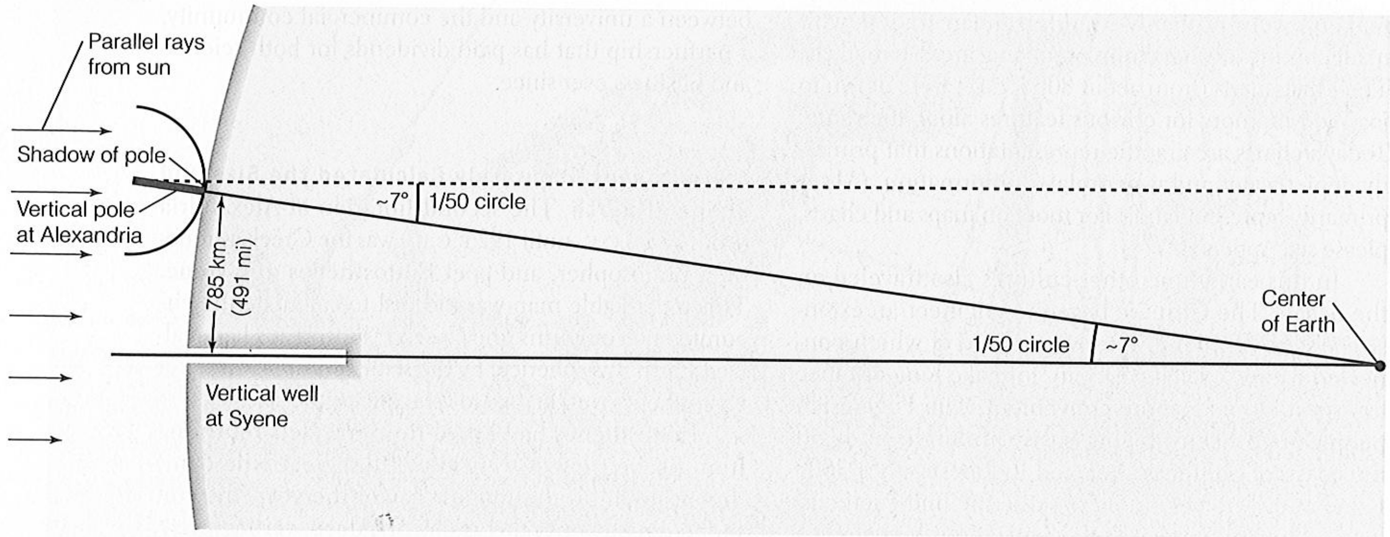


Figure 2.2 A diagram showing Erastosthenes' method for calculating the circumference of the Earth. As described in the text, he used simple geometric reasoning based on the assumptions that the Earth is spherical and that the sun is very far away. Using this method, he was able to discover the circumference of the Earth to within about 8% of its true value. This knowledge was available more than 1,700 years before Columbus began his voyages. (The diagram is not drawn to scale.)

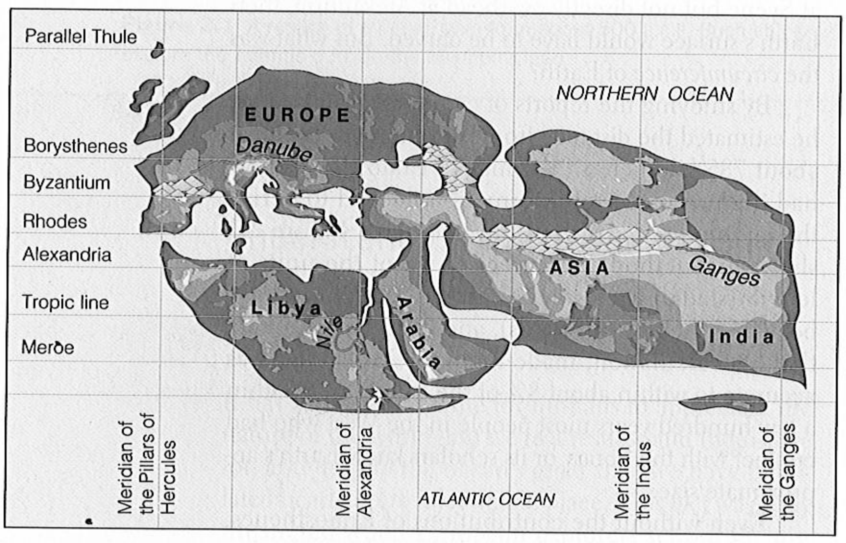


Figure 2.3 The world, according to a chart from the third century B.C.E. Eratosthenes drew latitude and longitude lines through important places rather than spacing them at regular intervals as we do today. The Alexandrian perception of the world is reflected in the size of the continents and the central position of Alexandria at the mouth of the Nile.

Our present regular grid of latitude and longitude was invented by Hipparchus (c.165–c.127 B.C.E.), a librarian who divided the surface of Earth into 360 degrees. A later Egyptian-Greek, Claudius Ptolemy (A.D. 90–168), *oriented* charts by placing east to the right and north at the top. Ptolemy's division of degrees into minutes and seconds of arc is still used by navigators. Latitude and longitude are explained in **Box 2.1**.

Ptolemy also introduced an "improvement" to Eratosthenes' surprisingly accurate estimate of Earth's circumference. Unfortunately, Ptolemy wrongly depended on flawed calculations of the effects of atmospheric refraction. He publicized an estimate of the size of Earth that was too small—about 70% of the true value. This error, coupled with his mistake of overestimating the size of Asia, greatly reduced the apparent width of the unknown part of the world between the Orient and Europe. More than 1,500 years later, these mistakes made it possible for Columbus to convince people he could reach Asia by sailing west.

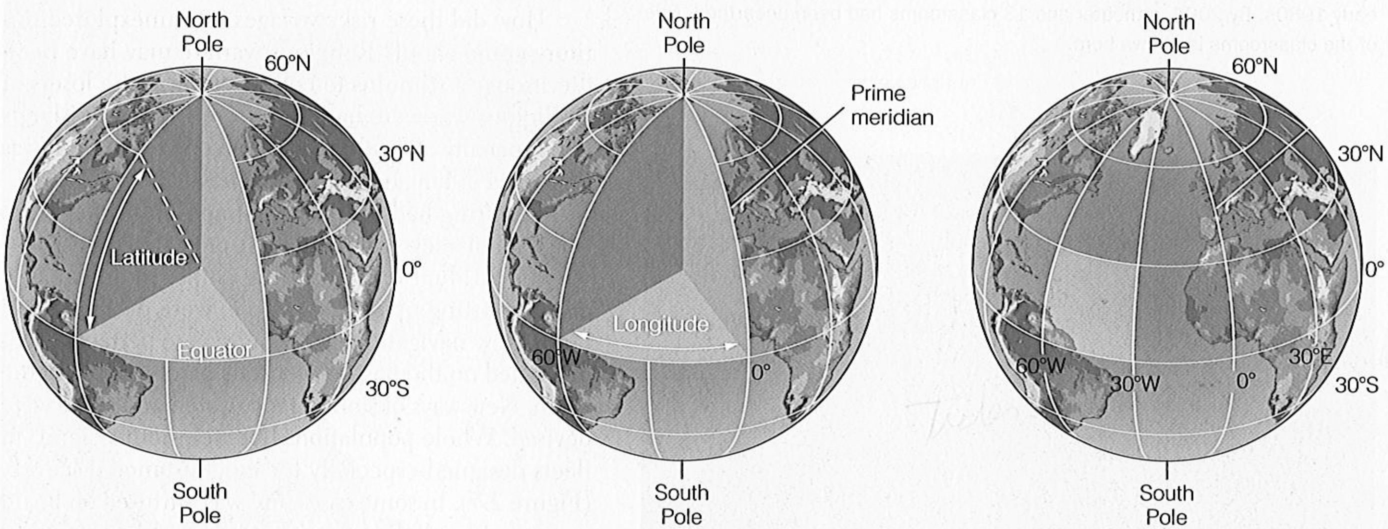
Though it weathered the dissolution of Alexander's empire, the Library of Alexandria did not survive the subsequent period of Roman rule. The last librarian was Hypatia, the first notable woman mathematician, philosopher, and scientist. In Alexandria she was a symbol of science and knowledge, concepts the early Christians identified with pagan practices. The mission of the library, as personified by the last librarian, antagonized the governors and citizens of the city of Alexandria. After years of rising tensions, in A.D. 415 a mob brutally murdered Hypatia and burned the library with all its contents. Most of the community of scholars dispersed, and Alexandria ceased to be a center of learning in the ancient world. The academic loss was incalculable, and trade suffered because shipowners no longer had a clearinghouse for updating the nautical charts and information they had come to depend on. All that remains of the library today is a remnant of an underground storage room and the floors of a few lecture halls (**Figure 2.4**). We will never know the true extent and influence of its collection of more than 700,000 irreplaceable scrolls.

BOX 2.1 Latitude and Longitude

A sphere has no edges, no beginnings or ends, so what should we use as a frame of reference for positioning and navigation? The question was first successfully addressed by geographers at the Library at Alexandria, in Egypt. In the third century B.C.E., Eratosthenes drew latitude and longitude lines through important places (see Figure 2.3). The Alexandrian perception of the world is reflected in the size of the continents and the central position of Alexandria.

A later Alexandrian scholar divided Earth into an orderly grid based on 360 increments, or "degrees" (*degre*, "step"). The equator was a natural dividing point for the north–south (latitude) positioning grid, but there was no natural dividing point for the east–west (longitude) grid. Not surprisingly, Alexandria was arbitrarily selected as the first "zero longitude" and a regular grid was laid out east and west of that city.

The general scheme has withstood the test of time, but there has been controversy. Though use of the equator as "zero latitude" has never been in question, each seafaring country wanted the prestige of having the world's longitude centered on its capital. For centuries, maritime nations issued charts with their own longitude "zeros." After much political disagreement, nations agreed in 1884 that the Greenwich meridian near London would be the world's "zero longitude" (**Figures a–c**). Given the accuracy of that meridian's known position and the long history and success of British navigation and timekeeping, Greenwich was an excellent choice.



(a) Latitude is measured as the angle between a line from Earth's center to the equator and a line from Earth's center to the measurement point.

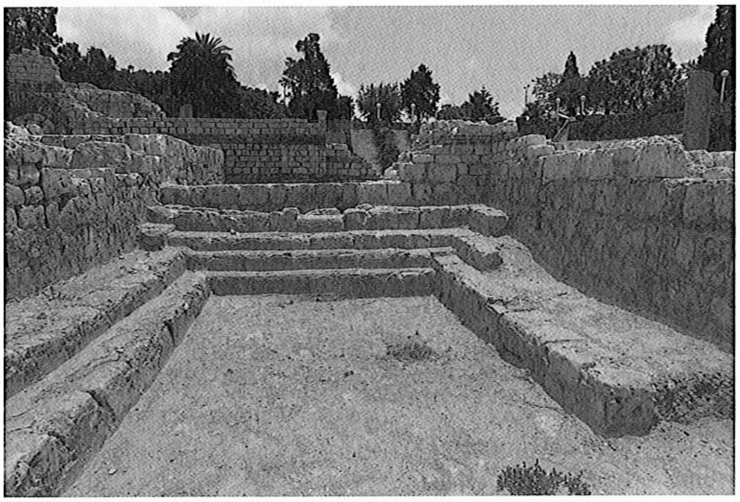
(b) Longitude is measured as the angle between a line from Earth's center to the measurement point and a line from Earth's center to the prime (or Greenwich) meridian, which is a line drawn from the North Pole to the South Pole passing through Greenwich, England.

(c) Lines of latitude are always the same distance apart, but the distance between two lines of longitude varies with latitude.

Western intellectual development slackened during the so-called Dark Ages that followed the fall of the Roman Empire in A.D. 476. For almost 1,000 years, until the European Renaissance, much of the progress in medicine, astronomy, philosophy, mathematics, and other vital fields of human endeavor was made by the Arabs or imported by them from Asia. For example, the Arabs used the Chinese-invented compass (shown later in Figure 2.10) for navigating caravans over seas of sand, and their understanding of the Indian Ocean's periodic winds—the monsoons—allowed an Arabian navigator to guide Vasco da Gama from East Africa to India in 1498. Earlier, at the height of the Dark Ages, Vikings raided and explored to the south and west. Half a world away the Polynesians continued some of the most extraordinary voyages in history.

Oceanian Seafarers Colonized Distant Islands In the history of human migration, no voyaging saga is more inspiring than that of the **Polynesian** colonizations, the peopling of the central and eastern Pacific islands. A profound knowledge of the sea was required for these voyages, and the story of the Polynesians is a high point in our chronology of marine science applied to travel by sea.

The Polynesians are one of four cultures that inhabited some 10,000 islands scattered across nearly



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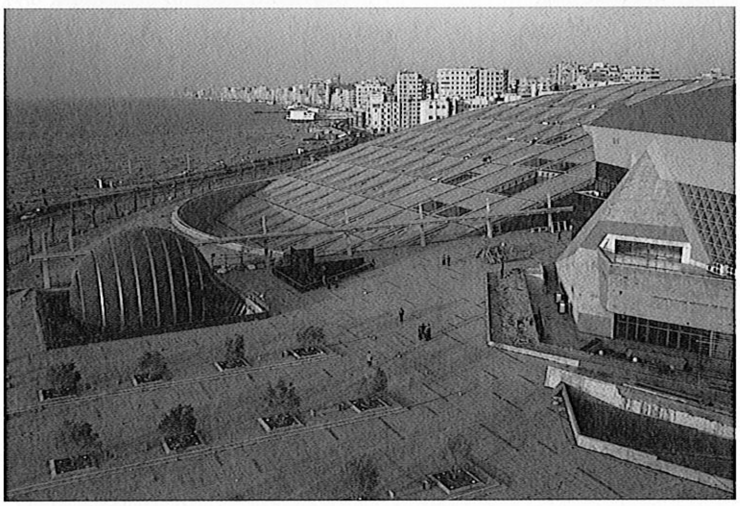
The exact site of the Library of Alexandria had been lost to posterity until the early 1980s. By 2004, a theater and 13 classrooms had been unearthed. One of the classrooms is shown here.



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b

The modern library of Alexandria. Opened in the spring of 2002, sponsors of the new *Bibliotheca Alexandrina* hope it will become "a lighthouse of knowledge to the whole world." The goal of this conference center and storehouse is not to restore the past, but to revive the ancient library's questing spirit.

Figure 2.4

26 million square kilometers (10 million square miles) of open Pacific Ocean (**Figure 2.5**). The Southeast Asian ancestors of the Oceanian peoples, as these cultures are collectively called, spread eastward in the distant past. Although experts differ in their estimates, there is some consensus that by 30,000 years ago New Guinea was populated by these wanderers and that by 20,000 years ago the Philippines were occupied. By between 900 and 800 B.C.E., the so-called cradle of Polynesia—Tonga, Samoa, the Marquesas, and the Society Islands—was settled. Oceanian navigators may already have been using shells attached to a bamboo grid to represent the positions of their islands. (A Micronesian stick chart from recent times is shown in **Figure 2.6**).

For a long and evidently prosperous period, the Polynesians spread from island to island until the easily accessible islands had been colonized. Eventually, however, overpopulation and depletion of resources became a problem. Politics, intertribal tensions, and religious strife shook society. Groups of people scattered in all directions from some of the "cradle" islands during a period of explosive dispersion. Between A.D. 300 and 600, Polynesians successfully colonized nearly every inhabitable island within the vast triangular area shown in Figure 2.5. Easter Island was found against prevailing winds and currents, and the remote islands of Hawai'i were discovered and occupied. These were among the last places on Earth to be populated.

How did these risky voyages into unexplored territory come about? Religious warfare may have been the strongest stimulus to colonization. If the losers of a religious war were banished from the home islands under penalty of death, their only hope for survival was to reach a distant and hospitable new land.

Seafaring had been a long tradition in the home islands, but such trips called for radical new technology. Great dual-hulled sailing ships, some capable of transporting up to 100 people, were designed and built. New navigation techniques were perfected that depended on the positions of stars barely visible to the north. New ways of storing food, water, and seeds were devised. Whole populations left their home islands in fleets designed especially for long-distance discovery (**Figure 2.7**). In some cases, fire was nurtured on board in case of landfall on an island that lacked volcanic flame. But a new island was only a possibility, a dream. Their gods may have promised the voyagers safe deliverance to new lands, but how many fleets set out from the troubled homelands only to fall victim to storms, thirst, or other dangers?

Yet, in that anxious time, the Polynesians practiced and perfected their seafaring knowledge. To a skilled navigator, a change in the rhythmic set of waves against the hull could indicate an island out of sight over the horizon. The flight tracks of birds at dusk could suggest the direction of land. The positions of the stars told stories, as did the distant clouds over an unseen island. The smell of the water, or its temperature, or salinity, or color, conveyed information—as did the direction of the wind relative to the sun, and the type of marine life clustering near the boat. The sunrise colors, the sunset colors, hue of the moon—every nuance had meaning; every detail had been passed in ritual from father to son. The greatest Polynesian minds were navigators, and reaching Hawai'i was their greatest achievement.

Of all the islands colonized by the Polynesians, Hawai'i is farthest away, across an ocean whose guide stars were completely unknown to the southern navigators.

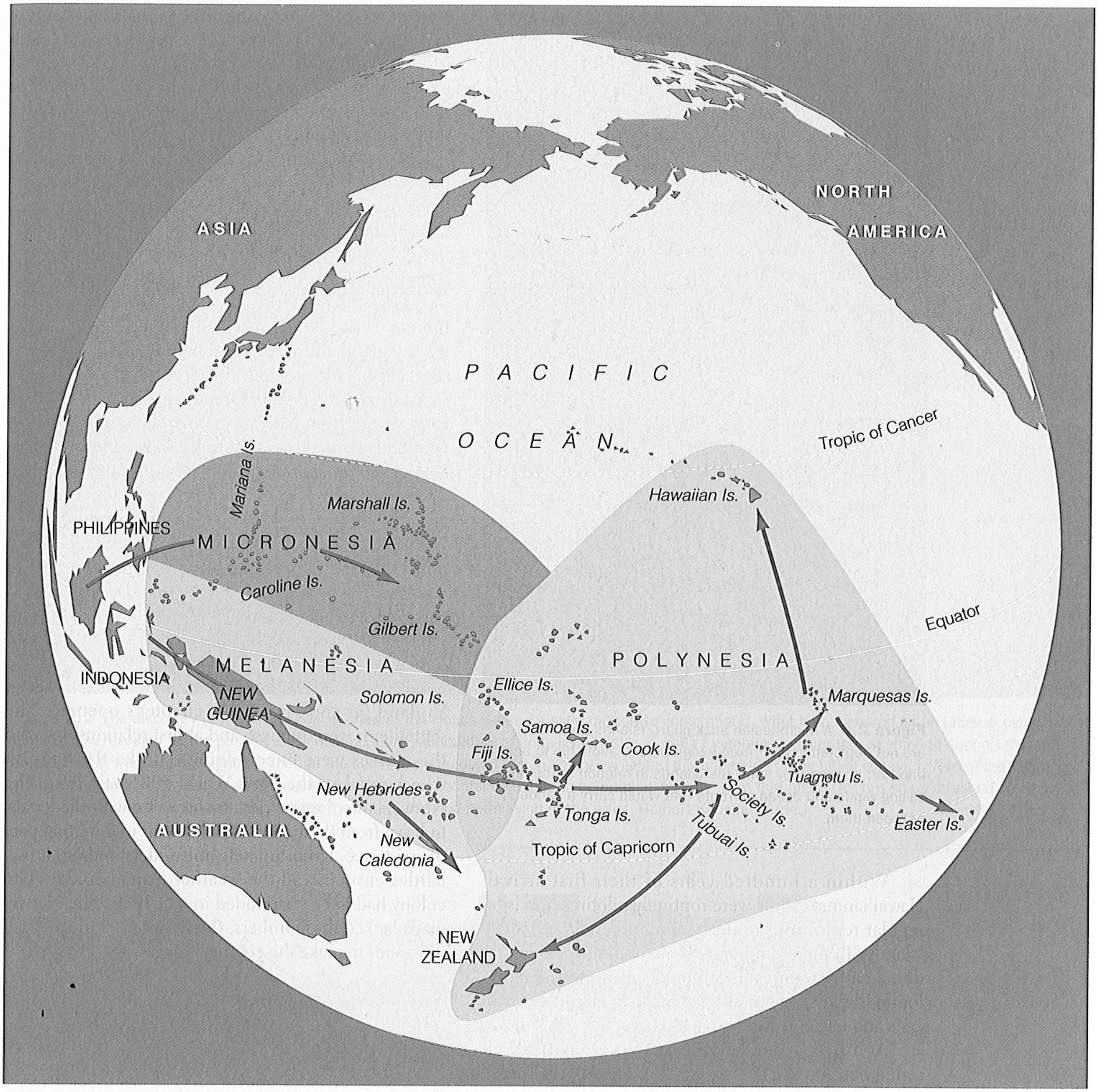
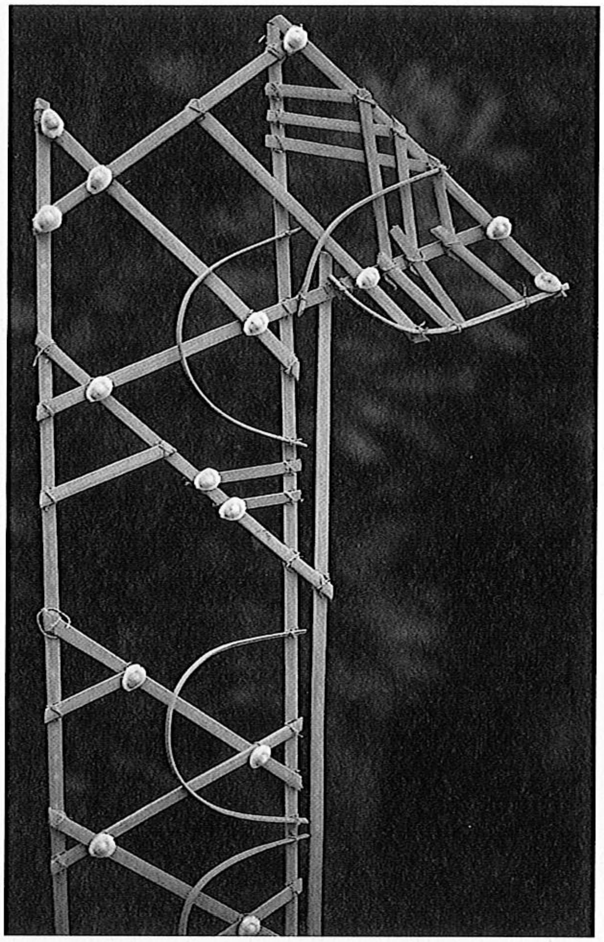


Figure 2.5 The Polynesian triangle. Ancestors of the Polynesians spread from Southeast Asia or Indonesia to New Guinea and the Philippines by about 20,000 years ago. The mid-Pacific islands have been colonized for about 2,500 years, but the explosive dispersion that led to the settlement of Hawai'i occurred about A.D. 450–600. Arrows show a possible direction and order of settlement.

The Hawai'ian Islands are isolated in the northern Pacific. There are no islands of any significance for more than 2,000 miles to the south. Moreover, Hawai'i lies beyond the equatorial doldrums, a hot and often windless stretch across which these pioneers must somehow have paddled. And yet, some fortunate and knowledgeable people colonized Hawai'i sometime between A.D. 450 and 600. Try to imagine their feelings of relief and justification upon reaching a promised paradise under a new night sky. Think of that first approach to the high islands of Hawai'i, the first unlimited drink of fresh water, the first solid Earth after months of uncertainty!



Tom Garrison

Figure 2.6 A Micronesian stick chart. Islands (as shells) are not depicted in their fixed geographic relationship to one another; instead they show the islands in relation to the prevailing winds and ocean currents that would carry a canoe between them.

Within a hundred years of their first arrival, Hawai'ian navigators were routinely piloting vessels on regular return trips to the Marquesas and the Society Islands (Tahiti and others). Some of the trips were undertaken to import needed food species to the newly found islands, but others were made to recruit new citizens and leaders to "green-clad Hawai'i."

At a time when seafarers of other civilizations sailed beside the comforting bulk of a charted coast, Polynesians looked to the open sea for sustenance, deliverance, and hope. Their great knowledge of the ocean protected them.

Viking Raiders Discovered North America The Dark Ages were periodically punctuated by the raids of **Vikings**, bands of Scandinavian adventurers and treasure seekers whose remarkably fast, strong, and stable ships (**Figure 2.8**) enabled them to sail or row up rivers faster than a horse and rider could spread warning. Danish and Norwegian Vikings swept down the coast of Europe; they methodically pillaged Paris, robbed monasteries in Ireland, and looted Britain. The Swedish Vikings foraged as far away as Kiev and Constantinople! In A.D. 859, Vikings spent a week or so ashore in Morocco, rounding up prisoners for sale as slaves or to hold for ransom. Sixty-two Viking ships participated, a spectacular display of technology, sea power, seamanship, and navigation.

At first the Europeans were powerless against these marauders, but eventually the need for common defense overcame provincial hostility and xenophobia. One of the causes of the Renaissance in Europe may have been the experience of banding together for protection against these northern raiders.

As the French, Irish, and British defenses became more effective, the Norwegian Vikings began to look west. Iceland and Greenland had been discovered by ships blown off course during storms.[1] Iceland was colonized by about A.D. 850; Greenland by A.D. 996. In an early voyage from Norway to Greenland in A.D. 986, a commuter named Bjarni Herjulfsson was blown past his goal by unfavorable winds. For about five days he sailed up and down the coast of a new land (which was, in fact, North America) without landing or making charts. His sketchy reports kindled a real-estate fever; Leif, son of Eric the Red, purchased Bjarni's ship and returned. His party found salmon-filled lakes, vines and grapes, and fodder for cattle in what was probably the northeastern tip of Newfoundland. With a bit of advertising overstatement, he called the place *Vinland* ("wine-land").

By A.D. 1000, the Norwegians had colonized Vinland (as you saw in this chapter's opener). The settlements were modest, and at first relationships with the natives were encouraging. Unlike the Spanish who landed in the New World 500 years later, the Norwegian colonists tried to cooperate with the locals, to learn from them, and to help them in a mutual pact of assistance. Unfortunately, misunderstandings arose, battles ensued, and the weather turned colder. The colony had to be abandoned in A.D. 1020. The Norwegians lacked the numbers, the weapons, and the trading goods to make the colony a success.

The Chinese Undertook Organized Voyages of Discovery The extent of ancient Chinese contributions to oceanographic, geological, and geographic knowledge is only now becoming clear. By 1086, the Chinese philosopher Shen Kuo had deduced that Earth was of great age, and that land had been shaped by sedimentary deposit, rock formation, uplift, and erosion over great spans of time (**Figure 2.9**). (It should be noted that until the early nineteenth century most western European scientists believed Earth to be between 6,000 and 10,000 years old.)

Later, shipbuilding and distant investigations began to occupy Chinese rulers. As the Dark Ages distracted Europeans, **Chinese navigators** became more

[1] As one writer noted, it's hard to differentiate true seafaring from a bit of boating gone horribly wrong!

Figure 2.7 The discovery of Hawai'i: "Looking anew at the clouds we saw a sight difficult to comprehend. What had appeared as an unusual cloud formation was now revealed as the peak of a gigantic mountain, a mountain of unbelievable size, a white mountain—a pillar that seemed to support the sky! We watched in wonder until nightfall. Then to the south of that mountain a dull red glow lighted the underside of the lifting clouds, revealing the shape of another mountain. It brightened as the night darkened. That mountain seemed to be burning! No one slept that night. Our two ships thrashed along in the night wind, and the dreadful red beacon lighted our way." (By kind permission of the artist, Herbert Kauainui Kane.)

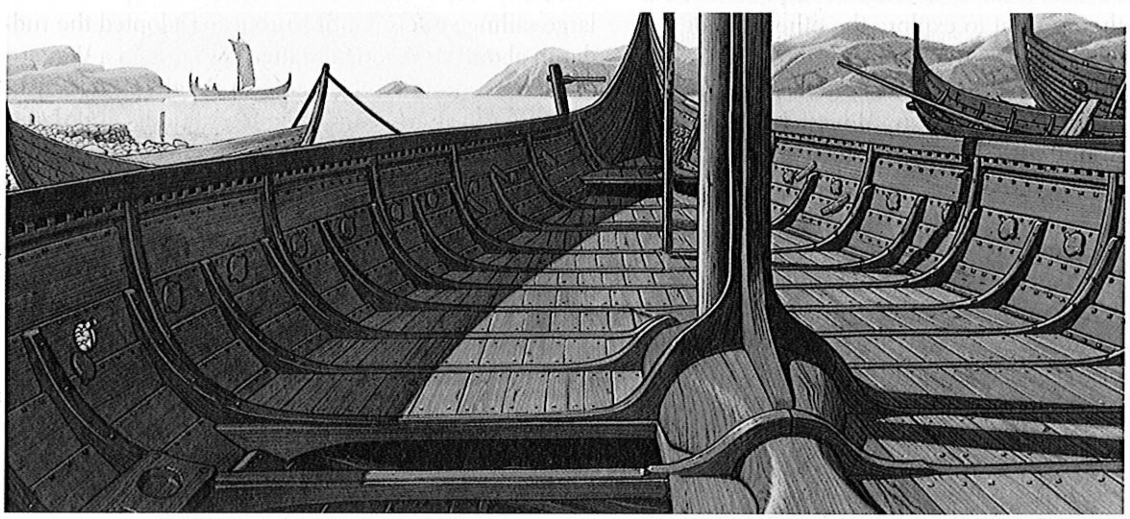


Figure 2.8 A Viking ship from around A.D. 900. This painting is a reconstruction drawn from a ship found in 1880 at the bottom of a Norwegian fjord. Sturdy and intended for travel over open water, the ship is 23.3 meters (76 feet) long and 5.25 meters (17 feet) wide. Oarsmen sat on loose benches or chests, and holes for the oars could be covered by small disks so that water would not flow in when the ship heeled under sail.

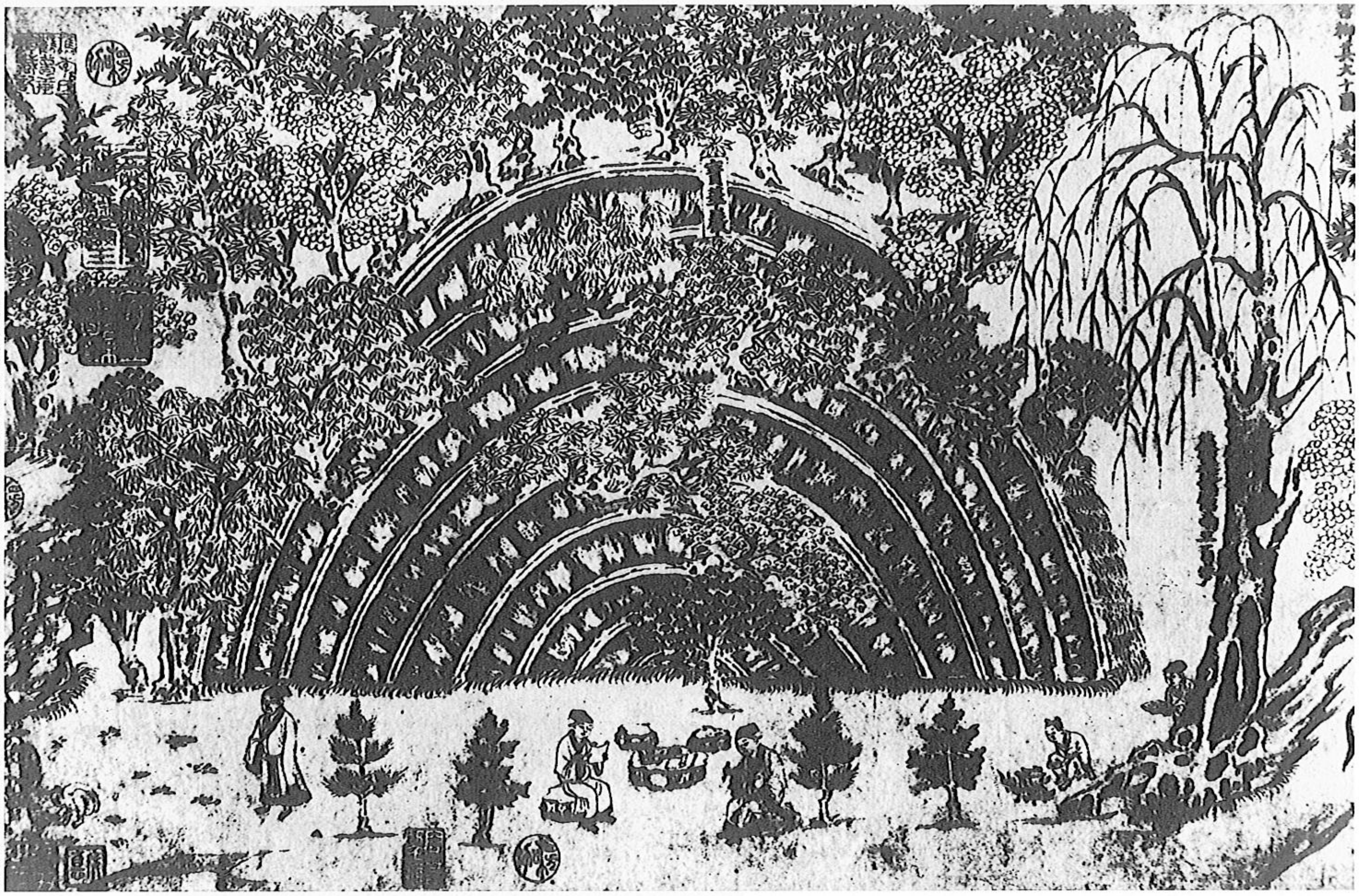
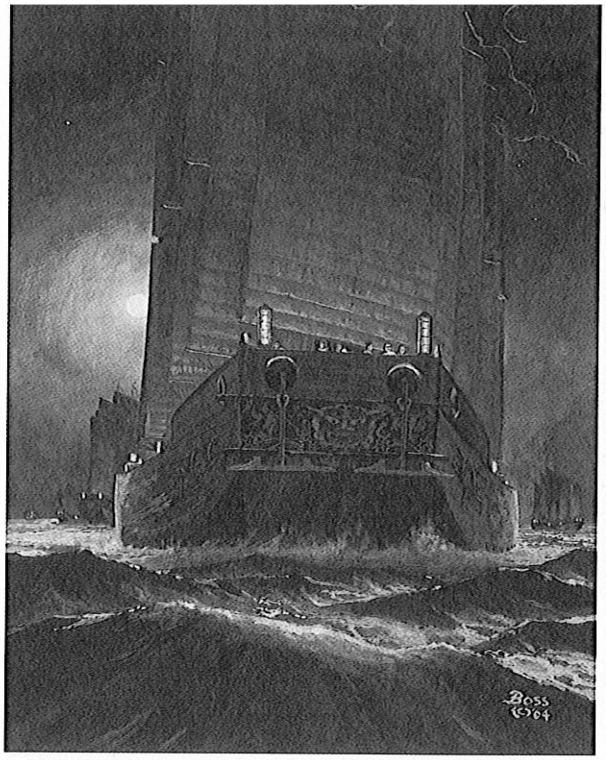


Figure 2.9 A painting by 11th century Chinese artist Li Kung-Lin showing an anticlinal arch, an exposed cliff of layered and twisted rock strata. Philosophers in China realized Earth was ancient, and that land had been shaped by sedimentation, rock formation, uplift, and erosion over great spans of time. Their European contemporaries didn't make this discovery until around 1800.

skilled, and their vessels grew larger and more seaworthy. They then set out to explore the other side of the world. Between 1405 and 1433, Admiral Zheng He (pronounced "jung huh") commanded the greatest fleet the world had ever known. At least 317 ships and 27,500 men undertook seven missions to explore the Indian Ocean, Indonesia, and around the tip of Africa into the Atlantic. Their aim: to display the wealth and power of the young Ming dynasty and to show kindness to people of distant places. The largest ship in the fleet, with nine masts and a length of 134 meters (440 feet) (**Figure 2.10**), was a huge treasure ship carrying objects of the finest materials and craftsmanship. The mission of the fleet was not to accumulate such treasure but to give it away! Indeed, the primary purpose of these expeditions was to convince all nations the fleet contacted that China was the only truly civilized state and beyond any imaginable need for knowledge or assistance.

Many technical innovations had been required to make such an ambitious undertaking possible. In addition to inventing the compass, the Chinese invented the central rudder, watertight compartments, and sophisticated sails on multiple masts, all of which were critically important for the successful operation of large sailing vessels. Until Europeans adopted the rudder in about 1100, long-distance voyaging in a Western ship large enough to be stable in rough seas was usually difficult. Early Mediterranean traders and, later, the Polynesians and the Vikings, had used specialized steering oars held against the right side (*steer-board* eventually became *starboard*) of their boats. Although this system worked well in protected waters, the small area of the steering oar (and the exposed position of the steersman) made it difficult to hold a course on long ocean passages. The centrally mounted, submerged rudder solved that problem. Also, dividing the ship into separate compartments below the waterline meant that flooding due to hull damage could be confined to a relatively small area of the ship, and the vessel could then be repaired and saved from sinking. Because sails provided the power to move, advances in sail design could drastically influence the success of any voyage. The Chinese fitted their trapezoidal or triangular sails with battens (pieces of bamboo inserted into stitched seams running the width of the sail) and placed the sails on multiple masts. The sails resembled venetian



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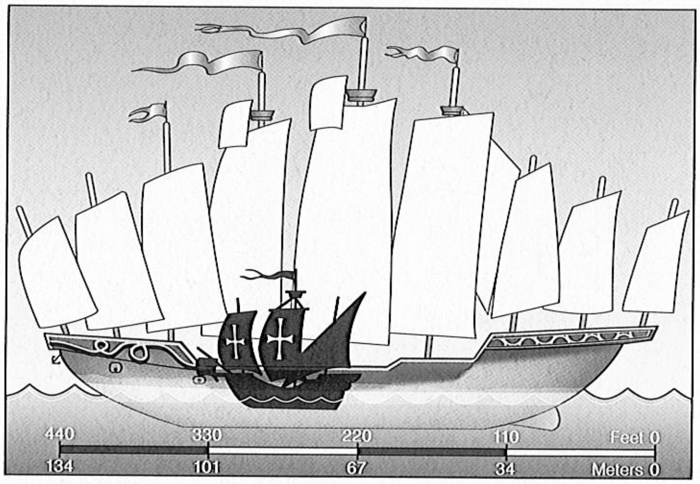
a

The treasure ship, largest in a vast Chinese fleet, whose purpose was to show kindness to people of distant places. The fleet sailed the Pacific and Indian oceans between 1405 and 1433. At the end of his voyages, Zheng He wrote: "We have traversed more than one hundred thousand li (64,000 kilometers, or 40,000 miles) of immense water spaces and have beheld in the ocean huge waves like mountains rising to the sky and we have set eyes on barbarian regions far away hidden in a blue transparency of light vapors, while our sails loftily unfurled like clouds day and night." (Quote from F. Viviano, "China's Great Armada," National Geographic, vol. 208, no. 1, July 2005.)



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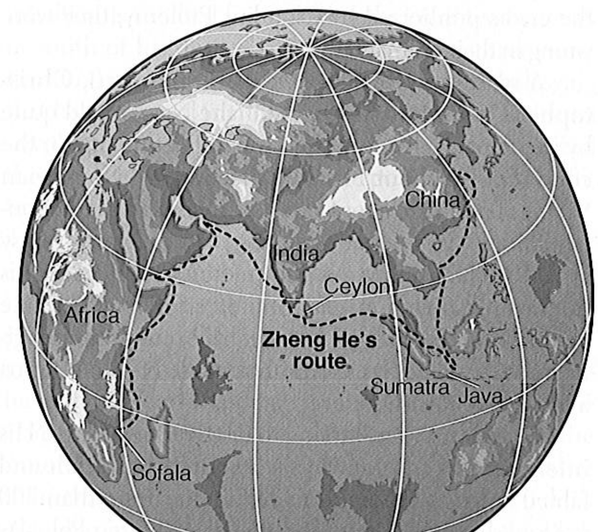
At least 10 ships of the types later used by Vasco da Gama or Christopher Columbus could fit on the treasure ship's 4,600-square-meter (50,000-square-foot) main deck. The rudder of one of these great ships stood 11 meters (36 feet) high—as long as Columbus's flagship *Niña*! (From Sailing Ships by Bjorn Landstrom, Copyright © 1969 by International Book Production. Used by permission of Doubleday, a division of Random House, Inc.)

Tom Garrison

c

A Chinese compass from the Ming era of exploration. The magnetized "spoon" rests on a bronze plate about 25 centimeters (10 inches) square. The handle of the "spoon" points south rather than north. The plate bears Chinese characters that denote the eight main directions.



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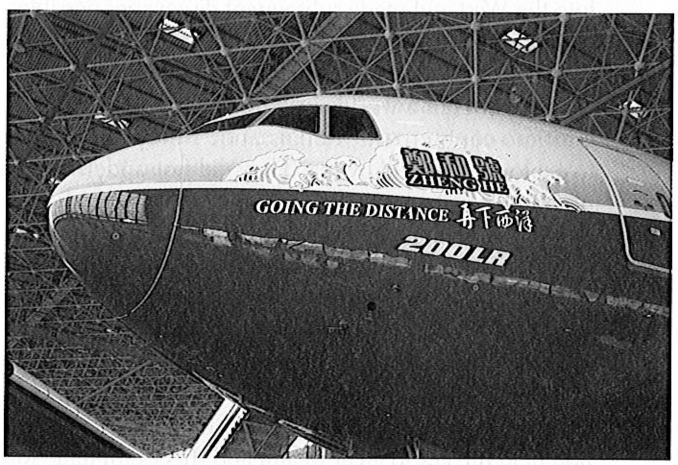
Zheng He's probable route from China to India and Africa.



Tom Garrison

e

The prototype of the world's longest-range commercial airliner, the Boeing 777-200LR, was appropriately named "Zheng He."

Figure 2.10

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Figure 2.11 Prince Henry of Portugal, the Navigator, looks westward from his monument in Portugal. In the mid-1400s, Henry established a center at Sagres for the study of marine science and navigation ". . . through all the watery roads."

blinds covered with cloth. It was not necessary for Chinese sailors to climb the masts to unfurl the sails every time the wind changed; everything could be done from the deck with windlasses and lines. The shape of the sails made it easier to sail close to the wind in confined seaways.

Perhaps most astonishing of all, the Chinese fleet could stay at sea for nearly four months and cover at least 8,000 kilometers (5,000 miles) without reprovisioning. They distilled fresh water from seawater, grew fresh vegetables on board, provided luxurious staterooms for foreign ambassadors, and collected and cataloged large numbers of cultural artifacts and scientific specimens.

Despite enjoying these advances, the Chinese intentionally abandoned oceanic exploration in 1433. The political winds had changed, and the cost of the "reverse tribute" system was judged too great. Less than a century later, it was a crime to go to sea from China in a multi-masted ship! In all, until late in the twentieth century, the Chinese made very few contributions to our understanding of the ocean. Still, their voyaging technology filtered into the West and made subsequent discoveries possible.

Prince Henry Launched the European Age of Discovery Half a world away from the Polynesian and Chinese counterparts, Renaissance Europeans set out to explore the world by sea. They did not undertake exploration for its own sake, however; any voyage had to have a material goal. Trade between East and West had long been dependent on arduous and insecure desert caravan routes through the central Asian and Arabian deserts. This commerce was cut off in 1453 when the Turks captured Constantinople, and an alternative ocean route was needed.

A European visionary who thought ocean exploration held the key to great wealth and successful trade was **Prince Henry the Navigator,** third son of the royal family of Portugal (**Figure 2.11**). Prince Henry established a center at Sagres for the study of marine science and navigation ". . . through all the watery roads." Although he personally was not well traveled (he went to sea only twice in his life), captains under his patronage explored from 1451 to 1470, compiling detailed charts wherever they went. Henry's explorers pushed south into the unknown and opened the west coast of Africa to commerce. He sent out small, maneuverable ships designed for voyages of discovery and manned by well-trained crews. For navigation, his mariners used the **compass**—an instrument (invented in China in the fourth century B.C.E. and shown in Figure 2.10c) that points to magnetic north. Although Arab traders had brought the compass from China in the twelfth century, navigators still considered it a magical tool. They concealed the compass in a special box (predecessor of today's binnacle) and consulted it out of view of the crew. Henry's students knew Earth was round, but because of the errors publicized by Claudius Ptolemy, they were wrong in their estimation of its size.

A master mariner (and skilled salesman), **Christopher Columbus** "discovered" the New World quite by accident. Native Americans had been living on the continent for about 11,000 years, and the Norwegian Vikings had made about two dozen visits to a functioning colony on the continent 500 years before his noisy arrival; yet Columbus gets the credit. Why? Because his interesting souvenirs, exaggerated stories, inaccurate charts, and promises of vast wealth excited the imagination of royal courts. Columbus made North America a media event without ever sighting it!

Columbus wasn't trying to discover new lands. His intention was to pioneer a sea route to the rich and fabled lands of the East, made famous more than 200 years earlier in the overland travels of Marco Polo. As "Admiral of the Ocean Sea," Columbus was to have a financial interest in the trade routes he blazed. He was familiar with Prince Henry's work and, like all other competent contemporary navigators, knew Earth was spherical. He believed that by sailing west, he could come close to his eastern destination, whose latitude

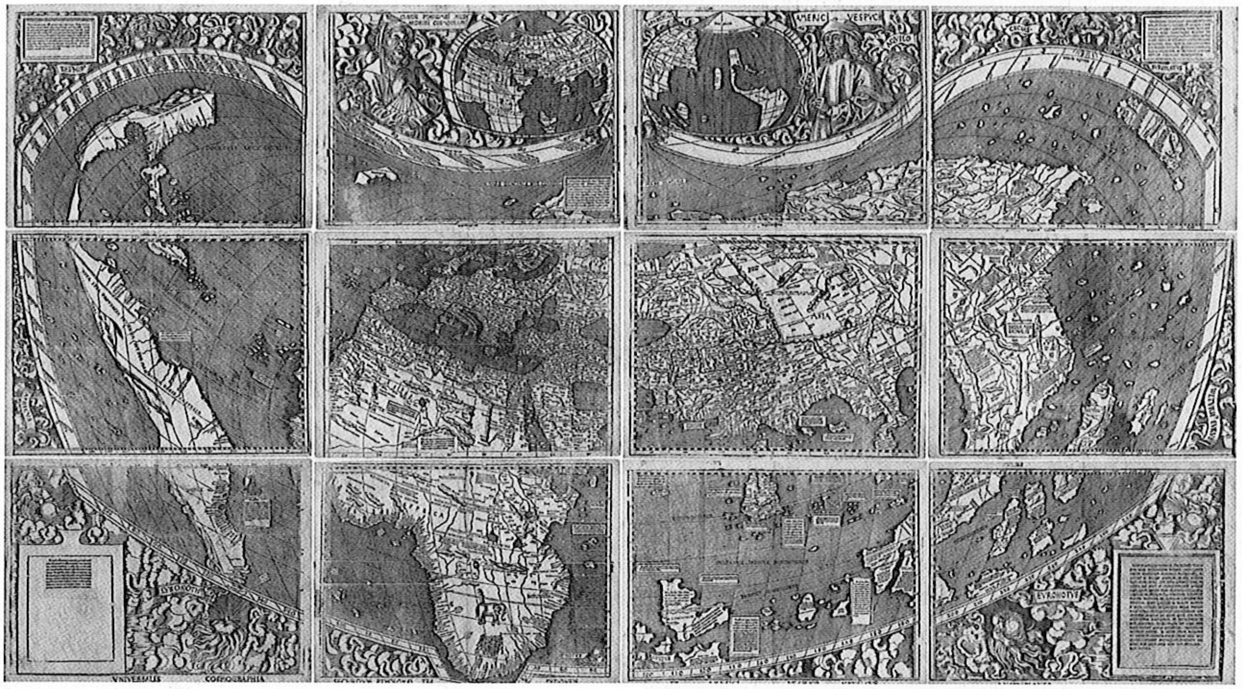


Figure 2.12 The Waldseemüller Map, published in 1507—the first map to name America and to show the New World as separate from Asia. This is an image of the only known copy to survive of the 1,000 printed from 12 wood blocks. It was purchased in 2007 by the U. S. Library of Congress for US$10,000,000.

he thought he knew. Because of wishful thinking and dependence on Ptolemy's data, however, Columbus made the *smallest* estimate of Earth's size by any navigator in modern history; he assumed Earth to be only about half its actual size!

Not surprisingly, Columbus mistook the New World for his goal of India or Japan. He thought that the notable absence of wealthy cities and well-dressed inhabitants resulted from striking the coast too far north or south of his desired latitude. He made three more trips to the New World but went to his grave believing that he had found islands off the coast of Asia. He never saw the mainland of North America and never realized the size and configuration of the continents whose future he had so profoundly changed.

Other explorers quickly followed, and Columbus's error was soon corrected. Charts drawn as early as 1507 included the New World (**Figure 2.12**). Such charts perhaps inspired **Ferdinand Magellan** (**Figure 2.13a**), a Portuguese navigator in the service of Spain, to believe that he could open a westerly trade route to the Orient. Unfortunately, the chart makers estimated the Americas and the Pacific Ocean to be much smaller than they actually are. (Compare Figure 2.10 with Magellan's route, shown in **Figure 2.13b.**) In the Philippines, Magellan was killed, and his men decided to continue sailing west around the world under the command of Juan Sebastián El Cano. Only 18 of the original crew of 260 survived, and they returned to Spain three years after they had set out. They had proved it was possible to circumnavigate the globe.

The Magellan expedition's return to Spain in 1522 marks the end of the European Age of Discovery. An unpleasant era of exploitation of the human and natural resources of the Americas followed. Native empires were destroyed, and objects of priceless cultural value were melted into coin to fund European warfare and greed.

CONCEPT CHECK

1. **What advantages would a culture gain if it could use the ocean as a source of transport and resources?**
2. **How was the culture of the Library of Alexandria unique for its time? How was the size and shape of Earth calculated there?**
3. **What were the stimuli to Polynesian colonization? How were the long voyages accomplished?**
4. **What stimulated the Vikings to expand their exploration to the west? Were they able to exploit their discoveries?**
5. **What innovations did the Chinese bring to geology and ocean exploration? Why were their remarkable exploits abruptly discontinued?**
6. **If he was not a voyager, why is Prince Henry of Portugal considered an important figure in marine exploration?**
7. **What were the main stimuli to European voyages of exploration during the Age of Discovery? Why did it end?**

To check your answers, see the book's website. The website address is printed at the end of the chapter.

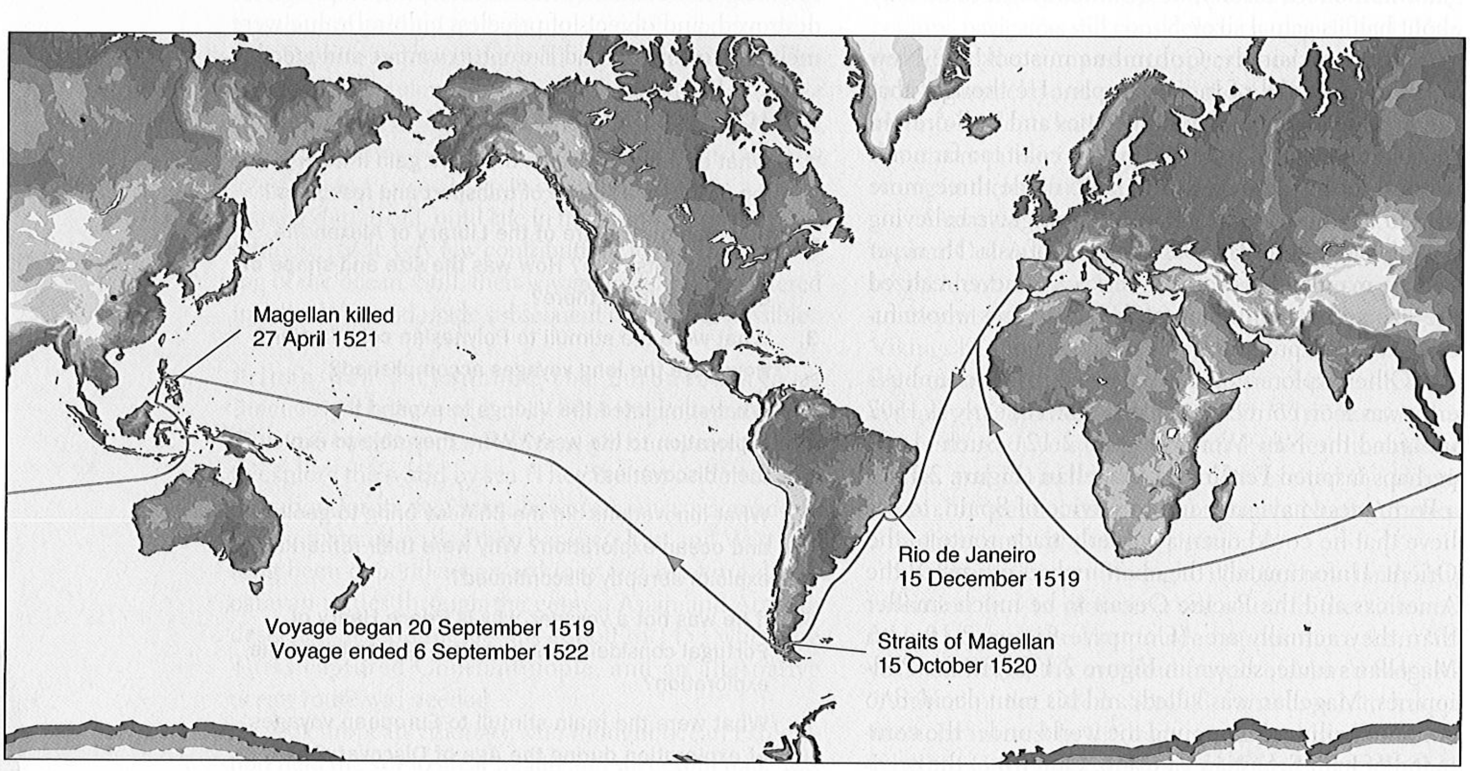
a

Ferdinand Magellan, a Portuguese explorer in service to Spain whose expedition was first to circumnavigate the world.

Voyaging Combined with Science to Advance Ocean Studies 2.2

British sea power arose after the Age of Discovery to compete with the colonial aspirations of France and Spain. Sailing ships require dependable supply and repair stations, especially in remote areas. The great powers sent out expeditions to claim appropriate locations, preferably inhabited by friendly peoples eager to help provision ships half a globe from home. The French sent Admiral de Bougainville into the South Pacific in the mid-1760s. His 1768 claim for France of what is now called French Polynesia opened the area to the powerful European nations. The British followed immediately.

Captain James Cook Was the First Marine Scientist Scientific oceanography begins with the departure from Plymouth Harbor in 1768 of HMS *Endeavour* under the capable command of **James Cook** of the British Royal Navy (**Figure 2.14**). An intelligent and patient leader, Cook was also a skillful navigator, cartographer, writer, artist, diplomat, sailor, scientist, and dietitian. The primary reason for the voyage was to



b

Figure 2.13 Track of the Magellan expedition, the first voyage around the world. Magellan himself did not survive the voyage; only 18 out of 260 sailors managed to return after three years of dangerous travel.

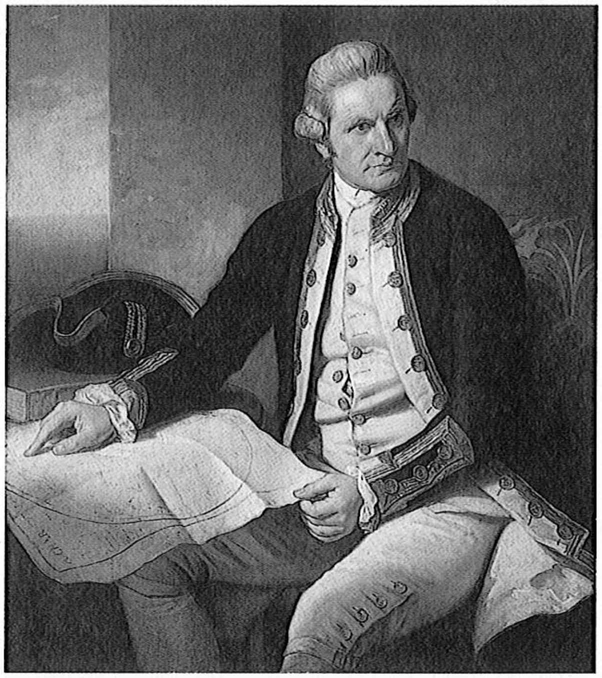


Figure 2.14 Captain James Cook, Royal Navy, painted in 1776 by Nathaniel Dance, shortly before embarking on his third, and fatal, voyage. Cook is depicted here as a fully matured, self-confident captain who has twice circled the globe, penetrated into the Antarctic, and charted coastlines from Newfoundland to New Zealand.

assert the British presence in the South Seas, but the expedition had numerous scientific goals as well. First, Cook conveyed several members of the Royal Society (a scientific research group) to Tahiti to observe the transit of Venus across the disk of the sun. Their measurements verified calculations of planetary orbits made earlier by Edmund Halley (later of comet fame) and others. Then, Cook turned south into unknown territory to search for a hypothetical southern continent, which some philosophers believed had to exist to balance the landmass of the Northern Hemisphere. Cook and his men found and charted New Zealand, mapped Australia's Great Barrier Reef, marked the positions of numerous small islands, made notes on the natural history and human habitation of these distant places, and initiated friendly relations with many chiefs. Cook survived an epidemic of dysentery contracted by the ship's company while ashore in Batavia (Djakarta) and sailed home to England, completing the voyage around the world in 1771. Because of his insistence on cleanliness and ventilation, and because his provisions included cress, sauerkraut, and citrus extracts, his sailors avoided scurvy—a vitamin C-deficiency disease that for centuries had decimated crews on long voyages.

The Admiralty was deeply impressed. Cook was promoted to the rank of commander and in 1772 was given command of the ships *Resolution* and *Adventure*, in which he embarked on one of the great voyages in scientific history. On this second voyage he charted Tonga and Easter Island and discovered New Caledonia in the Pacific and South Georgia in the Atlantic. He was first to circumnavigate the world at high latitudes. Though he sailed to 71° south latitude, he never sighted Antarctica. He returned home again in 1775.

Posted to the rank of captain, Cook set off in 1776 on his third, and last, expedition, in *Resolution* and *Discovery*. His commission was to find a northwest passage around Canada and Alaska or a northeast passage above Siberia. He "discovered" the Hawai'ian Islands (Hawai'ians were there to greet him, of course, as shown in **Figure 2.15**) and charted the west coast of North America. After searching unsuccessfully for a passage across the top of the world, Cook retraced his route to Hawai'i to provision his ships for departure home. On February 14, 1779, after an elaborate farewell dinner with the chief of the island of Hawai'i, Cook and his officers prepared to return to *Resolution*, anchored in Kealakekua Bay. The Englishmen somehow angered the Hawai'ians and were beset by the crowd. Cook, among others, was killed in the fracas.

Cook deserves to be considered a scientist as well as an explorer because of the accuracy, thoroughness, and completeness in his descriptions. He and the scientists aboard took samples of marine life, land plants and animals, the ocean floor, and geological formations; they also reported the characteristics of these samples in their logbooks and journals. Cook's navigation was outstanding, and his charts of the Pacific were accurate enough to be used by the Allies in World War II invasions of the Pacific islands. He drew accurate conclusions, did not exaggerate his findings, and opened friendly diplomatic relations with many native populations. Cook recorded and successfully interpreted events in natural history, anthropology, and oceanography. Unlike many captains of his day, he cared for his men. He was a thoughtful and clear writer. This first marine scientist peacefully changed the map of the world more than any other explorer or scientist in history.

Accurate Determination of Longitude Was the Key to Oceanic Exploration and Mapping How did Cook (or Columbus, or any ocean explorer) know where he was? Unless explorers could record position accurately on a chart, exploration was essentially useless. They could not find their way home, nor could they or anyone else find the way back to the lands they had discovered.

At night, Columbus and his European predecessors used the stars to find latitude and, as a consequence, knew their position north or south of home. You can do this, too. In the Northern Hemisphere, take a simple protractor and measure the angle between the

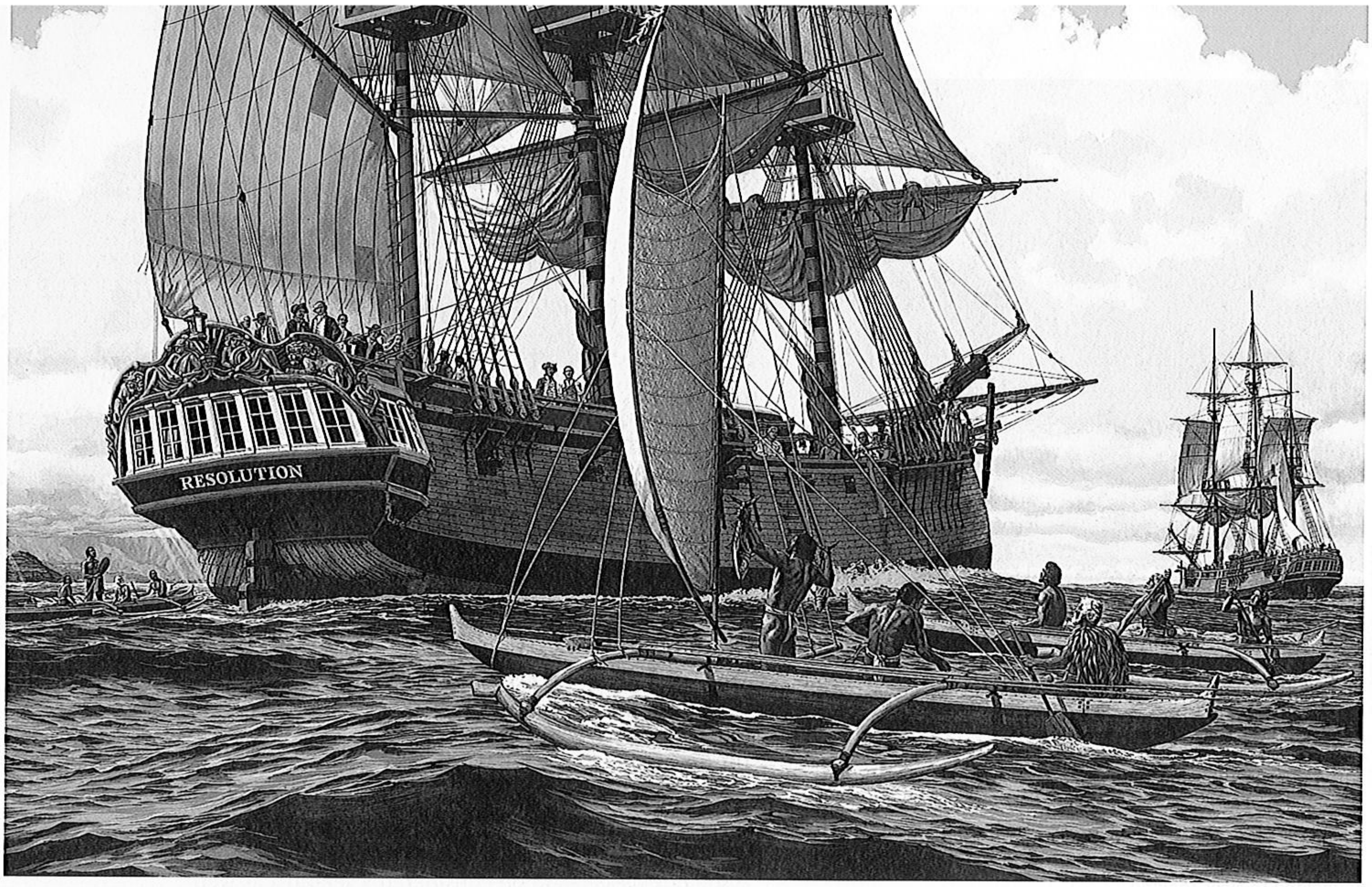


Figure 2.15 First contact! Capt. James Cook, commanding HMS *Resolution*, off the Hawai'ian island of Kaua'i, wrote in 1778: "It required but little address to get them to come along side, but we could not prevail upon any one to come on board; they exchanged a few fish they had in the canoes for anything we offered them, but valued nails, or iron above every other thing; the only weapons they had were a few stones in some of the canoes and these they threw overboard when they found they were not wanted."

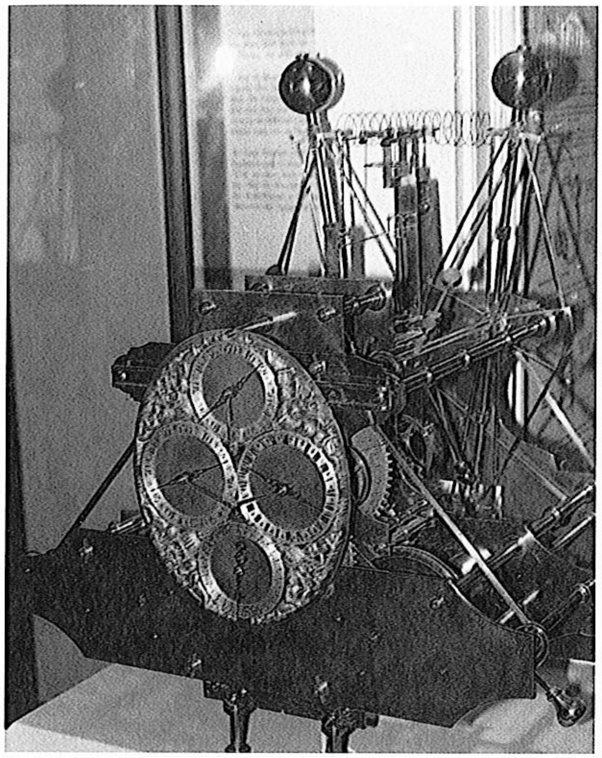
horizon, your eye, and the north polar star. The protractor reads approximately in degrees of latitude. To find the Indies, for example, Columbus dropped south to a line of latitude and followed it west. But to pinpoint a location, you need both latitude *and* the east–west position of longitude.

You can find longitude with a clock. First, determine local noon by observing the path of the shadow of a vertical shaft—it is shortest at noon—and set your clock accordingly. After traveling some distance to the west, you will notice that noon according to your *clock* no longer marks the time when the shadow of the *shaft* is shortest at your new location. If "clock" noon occurs 3 hours before "shaft" noon, you can do some simple math to see how far west of your starting point you have come. Earth turns toward the east, making one rotation of 360° in 24 hours, so its rotation rate is 15° per hour (360°/24 hours = 15°/hour). The 3-hour difference between "clock" noon and "shaft" noon puts you 45° west of your point of origin (3 × 15° = 45°). The more accurate the clock is (and the measurement of the shaft's shadow), the more accurate is your estimate of westward position.

The time method just described would work in theory, but in Columbus's time—and for many years afterward—no clocks were accurate enough to make this calculation practical after a few days at sea. Indeed, they were governed by pendulums, which are useless in a rolling ship.

The key to the longitude problem was inventing a sturdy clock that ran at a constant rate under any circumstance, even the changeable conditions of a ship at sea. In 1728, **John Harrison**, a Yorkshire cabinetmaker, began working on a clock that would be accurate enough to determine longitude. His radical new timepiece, called a **chronometer**, was governed not by a pendulum but by a spring escapement. His first version was tested at sea in 1736, and Harrison was awarded £500 as encouragement to continue his efforts. Over the next 25 years he built three more clocks, culminating in 1760 in his Number Four (**Figure 2.16**), perhaps the most famous timekeeper in the world.

A sea trial of Number Four was begun in HMS *Deptford* in 1761. Harrison, too old and infirm to accompany the chronometer, sent his son and



Tom Garrison

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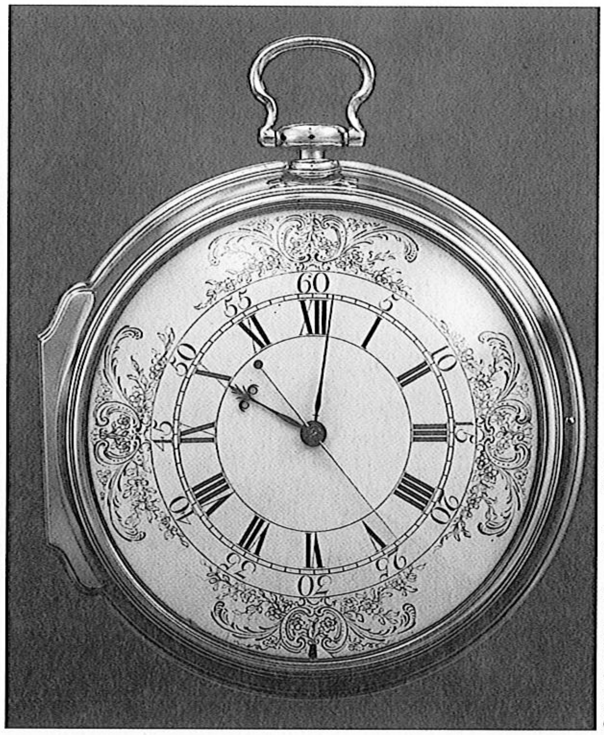
Harrison's Number One timekeeper, a clock built to prove principles but unfit for use at sea.



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b

The Number Four timekeeper, which won the £20,000 award offered by the British Board of Longitude. Both are functioning and are on display at the National Maritime Museum in Greenwich, England.

Figure 2.16 The first chronometers.

collaborator to tend the instrument. *Deptford* crossed the Atlantic from England to Jamaica and made a near-perfect landfall. After taking the clock's known error rate into account—its "rate of going" was $2\frac{2}{3}$ seconds a day—the clock was found to be only 5 seconds slow. This would have meant an error in longitude of only 2.3 kilometers (1.4 miles), an astonishing achievement by then-current standards of long-distance navigation.

Technically, Harrison had won the prize—Number Four had more than met the criteria set by the British Board of Longitude—but he was granted only part of the promised reward. Understandably, the officials would not hand over the money until it had been determined that the clock's secrets could be applied to quantity production. Just as understandably, Harrison did not wish his life's work compromised without compensation. He feared (correctly, as it turned out) that once the clockwork was examined by a competent watchmaker, his ideas would be copied. Finally, in 1769, a single copy was made; its success clinched Harrison's achievement. Captain Cook took a copy of Harrison's fourth chronometer on his last two voyages, but Harrison received the balance of the prize only in 1773 (when he was 80), and then only through the direct intervention of King George III.

All four of Harrison's chronometers are on view functioning in Britain's National Maritime Museum at Greenwich, in eastern London. Greenwich is an ideal site for the museum; in 1884 the Greenwich meridian, a longitude line at the naval observatory there, became "longitude zero" for the world (**Figure 2.17**). Not since Eratosthenes's selection of Alexandria as the first "longitude zero" had Western nations recognized a common base for positioning.

Collecting Sediment and Water Samples Provided Data for Scientific Analysis Marine science advances by the analysis of samples. The chronometer permitted investigators to determine the precise location at which they collected samples of water, bottom sediments, and marine life; but first they had to overcome the difficulty of actually *obtaining* a sample. Sampling of floor sediments or bottom water is not an easy task in the deep ocean. The line used to suspend the sampling device snakes back and forth as currents strike it, and the weight of the line itself makes it difficult to tell when the sampler has hit bottom. Deploying and recovering the line are

Tom Garrison

Figure 2.17 A tourist peers through the zero longitude transit circle's northward extension in Greenwich, England. The longitude line may be seen on the pedestal extending toward the floor.

laborious and time-consuming, and sometimes the sampling device does not work properly. Early bottom-sampling devices (such as those used by Cook) were simple wax-covered lead weights lowered to shallow bottoms to pick up sediments and test the suitability of anchorages. Later devices took deep-water samples, extracted cores from the sediments, grabbed samples of the bottom, or scooped biological specimens from the ocean floor.

The first researchers to attack the deep-sampling problem successfully were British explorers Sir John Ross and his nephew Sir James Clark Ross. During an expedition to scout the Northwest Passage in 1818, Sir John Ross obtained a bottom sample from 1,919 meters (6,294 feet) near Greenland by using a clamping sampler to trap the specimen. Sir James Clark Ross, discoverer of the Ross Sea and the area of Antarctica known as Victoria Land, obtained depth **soundings** (depth measurements) of 4,433 meters (14,545 feet) and 4,893 meters (16,054 feet) in the South Atlantic.

Sampling techniques improved through the century. Using a sounding method perfected in the late 1840s by a U.S. Navy midshipman, American commodore Matthew Maury used a long lightweight line and lead weight to discover the Mid-Atlantic Ridge, an important hidden range of mountains. Fridtjof Nansen perfected the deep-water sampling bottle bearing his name near the end of the century. Even today, in spite of modern advances, deep sampling remains difficult. Remotely operated vehicles can work at great depths and return samples and pictures to the surface, but their electronic complexity makes them delicate and expensive to operate.

CONCEPT CHECK

8. Captain James Cook has been called the first marine scientist. How might that description be justified?

9. Why was determining longitude so important? Why is it more difficult than determining latitude? How was the problem solved?

10. Marine science moves ahead by the analysis of samples. Why were samples difficult to obtain and analyse?

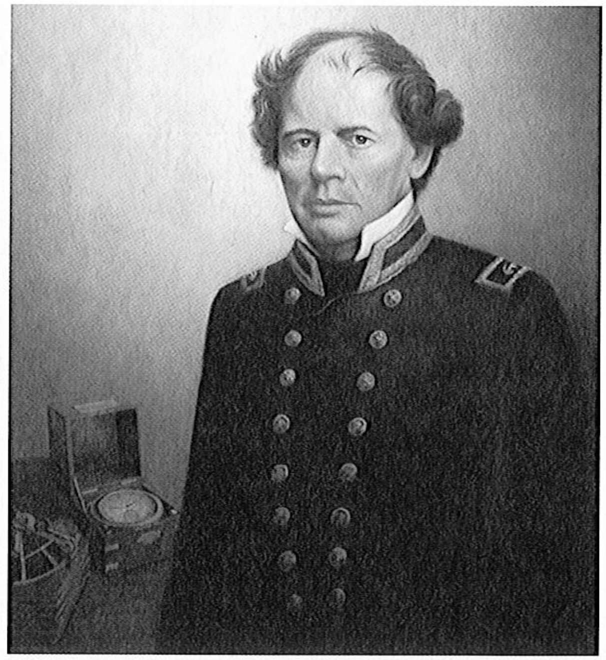
To check your answers, see the book's website. The website address is printed at the end of the chapter.

The First Scientific Experiments Were Undertaken by Governments 2.3

Great as Cook's contributions undoubtedly were, his three voyages (and those of the Rosses) were not purely scientific expeditions. These men were British naval officers engaged in Crown business, concerned with charting, foreign relations, and documenting natural phenomena as they applied to Royal Navy matters. The first genuine *only-for-science* expedition may well have

United States Naval Academy Museum

Figure 2.18 Lieutenant Charles Wilkes soon after his return from the United States Exploring Expedition. Wilkes commanded the largest number of ships sent on such an expedition since the fifteenth century voyages of Chinese Admiral Zheng He's in 1431.



U.S. Naval Observatory Library. Artist: Beverly Stautz

Figure 2.19 Matthew Fontaine Maury, compiler of winds and currents. Maury was perhaps the first person for whom oceanography was a full-time occupation.

been the British *Challenger* expedition of 1872–76, but the United States got into the act first with a hybrid expedition in 1838.

The United States Exploring Expedition Helped Establish Natural Science in America After a 10-year argument over its potential merits, the **United States Exploring Expedition** was launched in 1838. It was primarily a naval expedition, but its captain was somewhat freer in maneuvering orders than Cook had been. The work of the scientists aboard the flagship USS *Vincennes* and the expedition's five other vessels helped establish the natural sciences as reputable professions in America. Had it not been for the combative and disagreeable personality of its leader, Lieutenant Charles Wilkes (**Figure 2.18**), this expedition might have become as famous as those of Cook or the later *Challenger* voyage.

The expedition departed on a four-year circumnavigation. Its goals included showing the flag, whale scouting, mineral gathering, charting, observing, and pure exploration. One unusual goal was to disprove a peculiar theory that Earth was hollow and could be entered through huge holes at either pole.

Wilkes's team explored and charted a large sector of the east Antarctic coast and made observations that confirmed the landmass as a continent. A map of the Oregon Territory produced in 1841, one of 241 maps and charts drawn by members of the expedition, proved especially valuable when connected to the map of the Rocky Mountains prepared the following year by Captain John C. Fremont. Hawai'i was thoroughly explored, and Wilkes led an ascent of Mauna Loa, one of the two highest peaks of Hawaii's largest island. James Dwight Dana, the Expedition's brilliant geologist, confirmed Charles Darwin's hypothesis of coral atoll formation (about which more will be found in Chapter 12). The expedition returned with many scientific specimens and artifacts, which formed the nucleus of the collection of the newly established Smithsonian Institution in Washington, D.C. No evidence of polar holes was found!

Upon their return in 1842, Wilkes and his "scientifics" prepared a final report totaling 19 volumes of maps, text, and illustrations. The report is a landmark in the history of American scientific achievement.

Matthew Maury Discovered Worldwide Patterns of Winds and Ocean Currents At about the time the Wilkes expedition returned, **Matthew Maury** (**Figure 2.19**), a Virginian and fellow U.S. naval officer, became interested in exploiting winds and currents for commercial and naval purposes. After being crippled in a stagecoach accident, Maury was given charge of the Navy's Depot of Charts and Instruments in 1842 . There he studied a huge and neglected treasure trove of ships' logs, with their many regular readings of temperature and wind direction. By 1847, Maury had assembled much of this information into coherent wind and current charts. Maury began to issue these charts free to mariners in exchange for logs of their own new voyages.

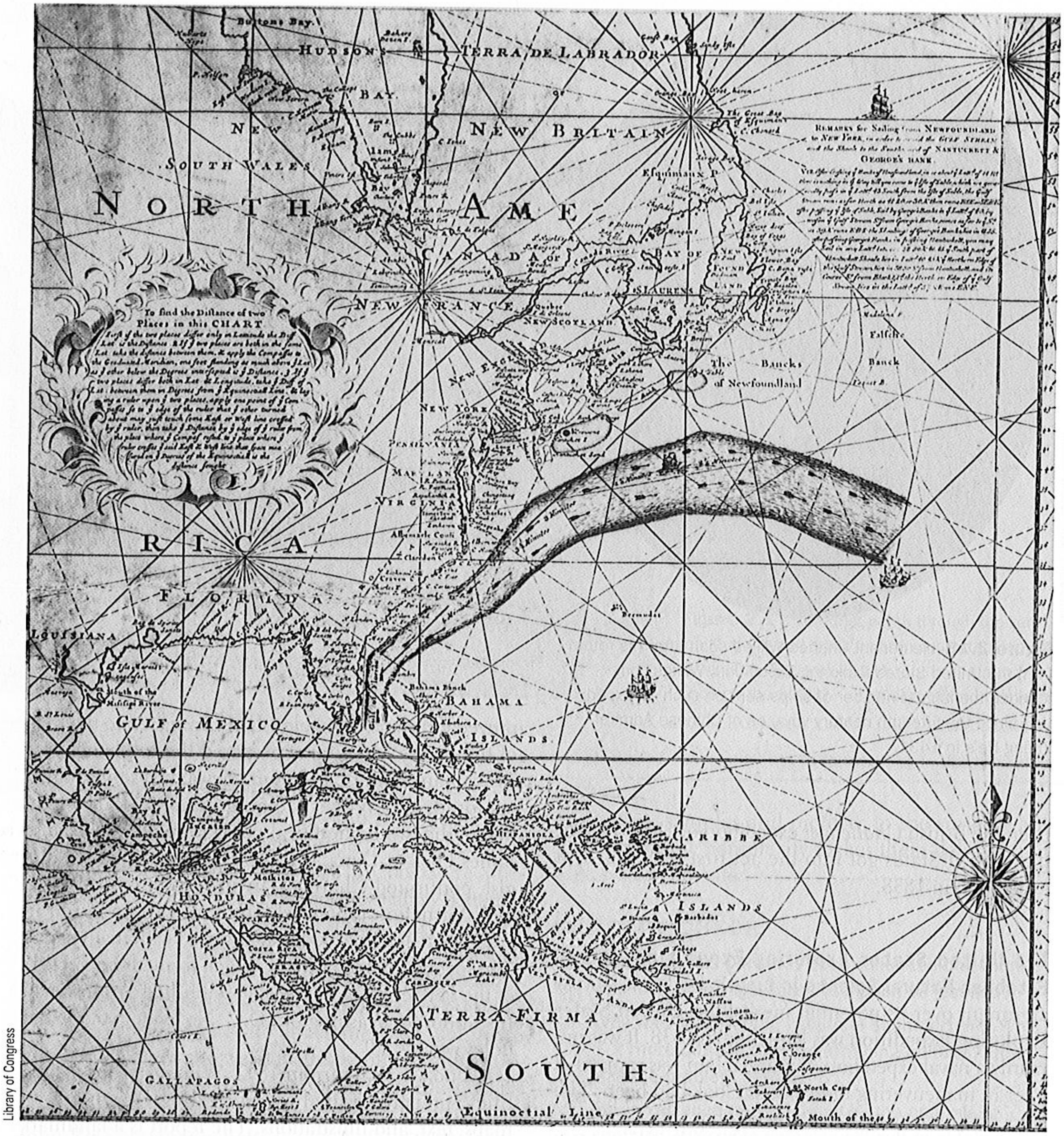


Figure 2.20 Benjamin Franklin's 1769 chart of the Gulf Stream system. His cousin, Timothy Folger, discovered that Yankee whalers had learned to use the Gulf Stream to their advantage. Others, especially English shipowners, were slower to learn. Folger, himself a sea captain, wrote that Nantucket whalers "... in crossing it have sometimes met and spoke with those packets who were in the middle of and stemming it. We have informed them that they were stemming a current that was against them to the value of three miles and hour and advised them to cross it, but they were too wise to be counseled by simple American fishermen."

Slowly a picture of planetary winds and currents began to emerge. Maury himself was a compiler, not a scientist, and he was vitally interested in the promotion of maritime commerce. His understanding of currents built on the work of **Benjamin Franklin**. Nearly a hundred years earlier, Franklin had noticed the peculiar fact that the fastest ships were not always the fastest ships; that is, hull speed did not always correlate with out-and-return time on the European run. Franklin's cousin, a Nantucket merchant named Tim Folger, noted Franklin's puzzlement and provided him with a rough chart of the "Gulph Stream" that he (Folger) had worked out. By staying within the stream on the outbound leg and adding its speed to their own, and by avoiding it on their return, captains could traverse the Atlantic much more quickly. It was Franklin who published, in 1769, the first chart of any current (**Figure 2.20**).

But Maury was the first person to sense the worldwide pattern of surface winds and currents. Based on his analysis, he produced a set of directions for sailing great distances more efficiently. Maury's sailing directions quickly attracted worldwide notice: He had shortened the passage for vessels traveling from the American East Coast to Rio de Janeiro by 10 days, and to Australia by 20. His work became famous in 1849 during the California gold rush—his directions made it possible to save 30 days on the voyage around Cape Horn to California. Applicable U.S. charts still carry the inscription "Founded on the researches of M. F. M. while serving as a lieutenant in the U.S. Navy." His crowning achievement, *The Physical Geography of the Seas*, a book explaining his discoveries, was published in 1855.

Maury, considered by many to be the father of physical oceanography, was perhaps the first man to undertake the systematic study of the ocean as a full-time occupation.

The *Challenger* Expedition Was Organized from the First as a Scientific Expedition The first sailing expedition devoted completely to marine science was conceived by Charles Wyville Thomson, a professor of natural history at Scotland's University of Edinburgh, and his Canadian-born student, John Murray. Stimulated by their own curiosity and by the inspiration of Charles Darwin's voyage in HMS *Beagle*, they convinced the Royal Society and British government to provide a Royal Navy ship and trained crew for a prolonged and arduous voyage of exploration across the oceans of the world. Thomson and Murray even coined a word for their enterprise: **oceanography**. Though the term literally implies only marking or charting, it has come to mean the science of the ocean. Prime Minister Gladstone's administration and the Royal Society agreed to the endeavor provided that a proportion of any financial gain from discoveries was handed over to the Crown. Thus arranged, the scientists made their plans.

HMS *Challenger*, a 2,306-ton steam corvette (**Figure 2.21**), set sail on December 21, 1872, on a four-year voyage around the world, covering 127,600 kilometers (79,300 miles). Although the captain was a Royal Navy officer, the six-man scientific staff directed the course of the voyage. *Challenger's* track is shown in **Figure 2.22**.

One important mission of the *Challenger* expedition was to investigate Edinburgh professor Edward Forbes's contention that life below 549 meters (1,800 feet) was impossible because of high pressure and lack of light. The steam winch on board made deep sampling practical, and samples from depths as great as 8,185 meters (26,850 feet) were collected off the Philippines.

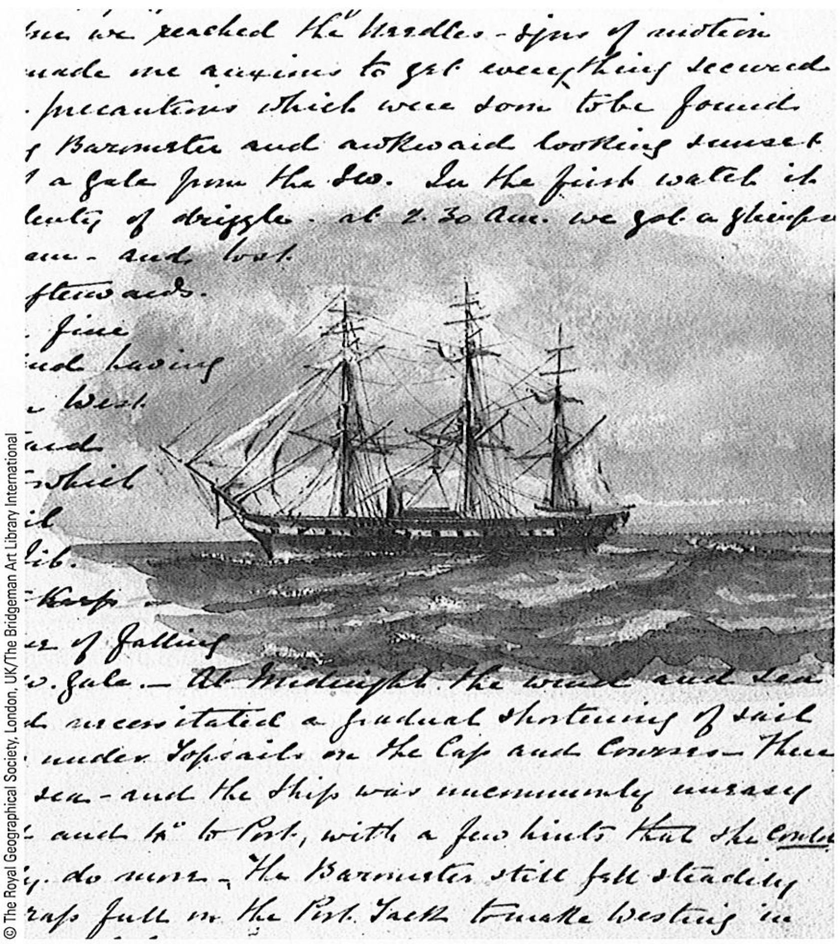


Figure 2.21 Lt. Pelham Aldrich, first lieutenant of HMS *Challenger*, kept a detailed journal of the *Challenger* Expedition. With accuracy and humor he kept this record in good weather and bad, and had the patience and skill to include watercolors of the most exciting events. This is part of the first page of his journal.

Through the course of 492 deep soundings with mechanical grabs and nets at 362 stations (including 133 dredgings), Forbes was proved resoundingly wrong. With each hoist, animals new to science were strewn on the deck; in all, staff biologists discovered 4,717 new species! **Figure 2.23** depicts researchers making some of these discoveries.

The scientists also took salinity, temperature, and water density measurements during these soundings. Each reading contributed to a growing picture of the physical structure of the deep ocean. They completed at least 151 open water trawls, and stored 77 samples of seawater for detailed analysis ashore. The expedition collected new information on ocean currents, meteorology, and the distribution of sediments; the locations and profiles of coral reefs were charted. Thousands of pounds of specimens were brought to British museums for study. Manganese nodules, brown lumps of mineral-rich sediments, were discovered on the seabed, sparking interest in deep-sea mining. The work was agonizing and repetitive—a quarter of the 269 crew members eventually deserted!

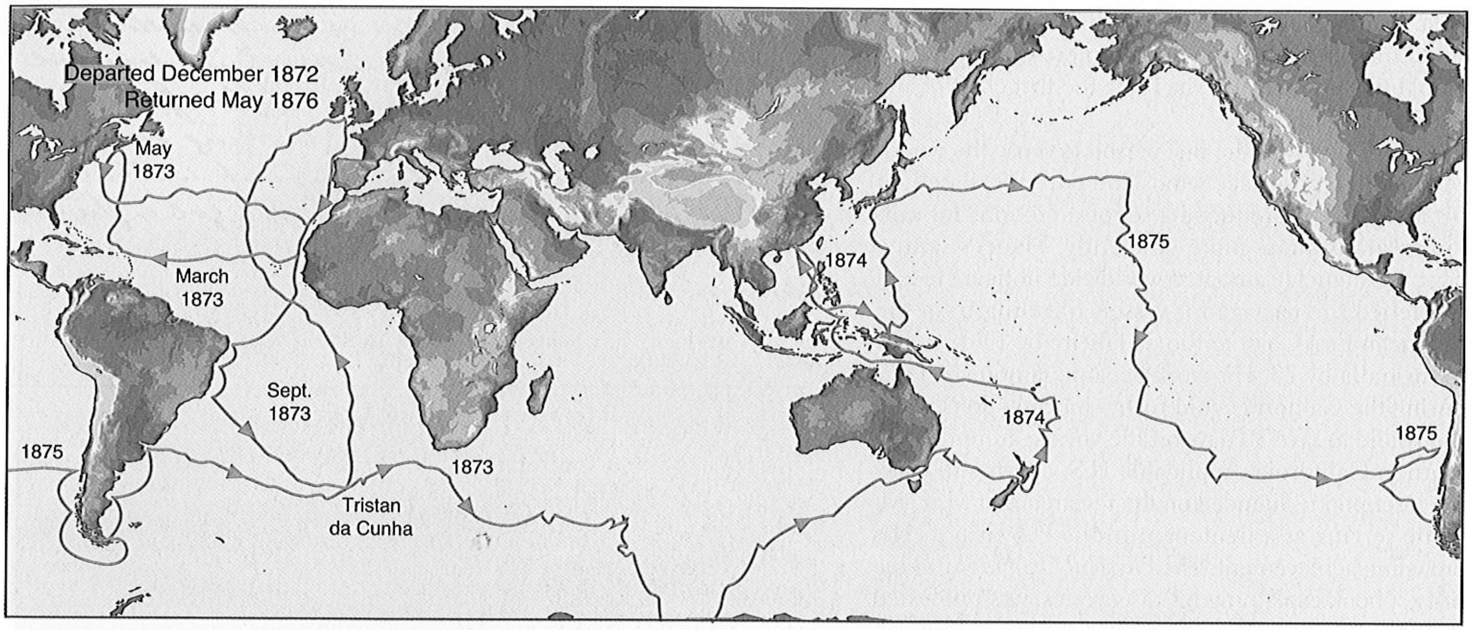


Figure 2.22 HMS *Challenger*'s track from December 1872 to May 1876. The *Challenger* Expedition remains the longest continuous oceanographic survey on record.

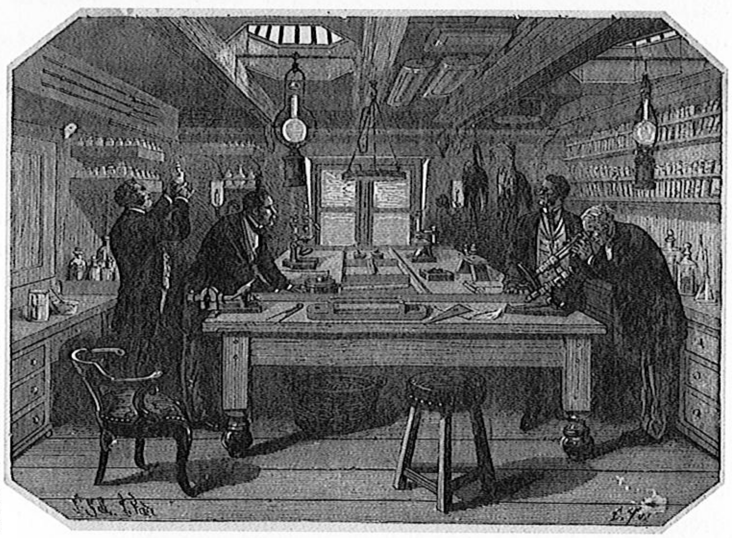


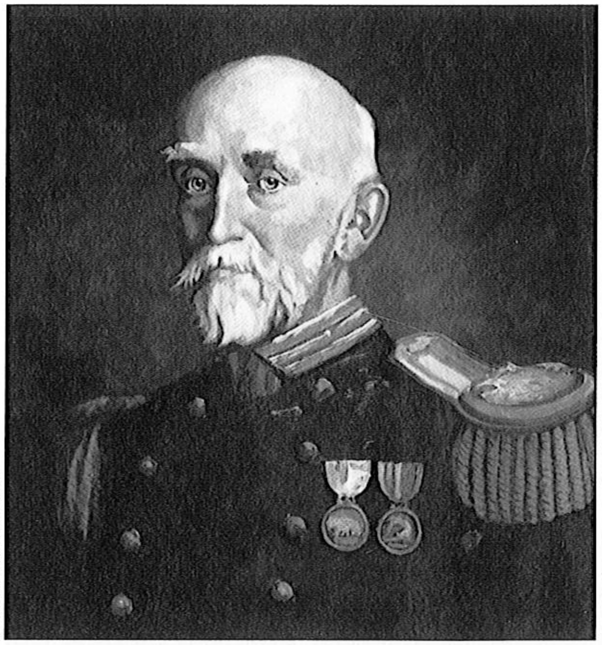
Figure 2.23 Scientists investigate specimens in the zoology laboratory aboard HMS *Challenger*.

In spite of the drudgery, this first pure oceanographic investigation was an unqualified success. The discovery of life in the depths of the oceans stimulated the new science of marine biology. The scope, accuracy, thoroughness, and attractive presentation of the researchers' written reports made this expedition a high point in scientific publication. The *Challenger Report*, the record of the expedition, was published between 1880 and 1895 by Sir John Murray in a well-written and magnificently illustrated 50-volume set. It is still used today. Indeed, it was the 50 volume *Report*, rather than the cruise, that provided the foundation for the new science of oceanography. The expedition's many financial spin-offs indicated that pure research was a good investment, and the British government realized quick profits from the exploitation of newly discovered mineral deposits on islands. The *Challenger* expedition remains history's longest continuous scientific oceanographic expedition.

With successes like these, the pace of exploration accelerated. American naturalist Alexander Agassiz, sailing in 1877 in the U.S. Coast and Geodetic Survey ship *Blake*, collected data corroborating the *Challenger* material at 355 deep-sea stations. The distribution of manganese nodules was found to be widespread. Further work by Agassiz and his students around the turn of the twentieth century in the survey ship *Albatross* helped train a generation of influential American marine biologists. In 1886, the Russians entered the field of marine exploration with the three-year cruise of *Vitiaz* under the leadership of S. O. Makarov; their main contribution was a careful analysis of the salinity and temperature of North Pacific waters.

Ocean Studies Have Military Applications Marine science is also applied to military interests. **Sea power** is the means by which a nation extends its military capacity onto the ocean. History has been greatly influenced by sea power—for example, the defeat of the Persian fleet by the Greeks at Salamis in 480 B.C.E. and the triumph of British admiral Horatio Nelson over French forces at Trafalgar in 1805 led to eras of cultural and economic supremacy by both nations.

In 1892, **Alfred Thayer Mahan (Figure 2.24)**, an American naval officer and historian, published *The Influence of Sea Power upon History, 1660–1783*. Based on his studies of the rise and fall of nation-states, this book had profound consequences for the development



United States Naval Institute

Figure 2.24 Alfred Thayer Mahan, naval historian and strategist. Mahan served in the Union Navy in the American Civil War, and was later appointed commander of the new *United States Naval War College* in 1886. He organized his lectures into his most influential book, *The Influence of Sea Power upon History, 1660–1783*. Received with great acclaim, his work was closely studied in *Britain* and *Germany*, influencing their buildup of forces in the years prior to *World War I*.

of the modern world. Mahan stressed the interdependence of military and commercial control of seaborne commerce, and the ability of safe lines of transportation and communication to influence the outcomes of conflicts. Coming at a time of unprecedented technological improvements in shipbuilding, Mahan's work was read avidly in Great Britain, Germany, and the United States. For better or worse, the naval hardware, strategy, and tactics of the last century's greatest wars—along with their outcomes—was influenced by his clear analysis.

CONCEPT CHECK

11. What were the goals and results of the United States Exploring Expedition? What U.S. institution greatly benefited from its efforts?

12. What were Matthew Maury's contributions to marine science? Benjamin Franklin's?

13. What was the first purely scientific oceanographic expedition, and what were some of its accomplishments? What contributions did the earlier, hybrid expeditions make?

14. What was Sir John Murray's main contribution to the HMS *Challenger* expedition and to oceanography?

15. In what ways did the work of Alfred Thayer Mahan influence the history of the twentieth century?

To check your answers, see the book's website. The website address is printed at the end of the chapter.

Contemporary Oceanography Makes Use of Modern Technology 2.4

In the twentieth century, oceanographic voyages became more technically ambitious and expensive. Scientist-explorers sought out and investigated places that once had been too difficult to reach. Though the deep ocean floor was coming into reach, it was the forbidding polar ocean that attracted their first attentions.

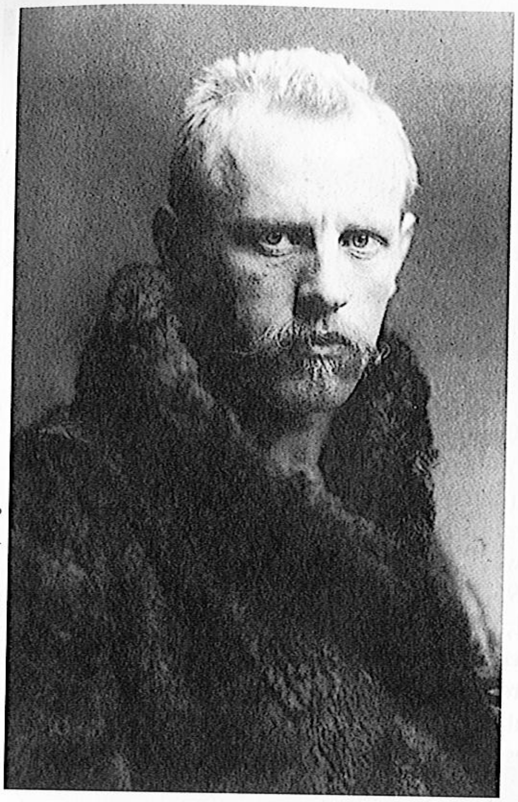
Polar Exploration Advanced Ocean Studies Polar oceanography began with the pioneering efforts of Fridtjof Nansen (**Figure 2.25a**). Nansen courageously allowed his specially designed ship *Fram* to be trapped in the Arctic ice, where he and his crew of 13 drifted with the pack for nearly four years (1893–96), exploring to 85°57′N, a record for the time. *Fram's* 1,650-kilometer (1,025-mile) drift proved that no Arctic continent existed. Nansen's studies of the drift, of meteorological and oceanographic conditions, of life at high latitudes, and of deep sounding and sampling techniques form the underpinnings of modern polar science.

Living up to its name—*Fram* means "forward" in Norwegian—Nansen's ship continued to play a pivotal role in exploration (**Figure 2.25b**). In 1910, Roald Amundsen, a student of Nansen's, set out in the sturdy little vessel for the coast of Antarctica, the first leg of a journey to the South Pole. Nansen himself settled down to a long and distinguished career as an oceanographer, inventor, zoologist, artist, statesman, and professor. He was awarded the Nobel Peace Prize in 1922 for his unstinting work in worldwide humanitarian causes.

Scientific curiosity, national pride, new ideas in shipbuilding, advances in nutrition, and great personal courage led in the early years of the last century to the golden age of polar exploration. After some heroic attempts by a number of explorers to reach the poles, an American naval officer, Robert E. Peary, accompanied by his African American assistant, Matthew Henson, and four Inuit (Eskimos), reached the vicinity of the North Pole in April 1909. A party of five men led by Roald Amundsen of Norway achieved the South Pole in December 1911.

Modern technology has eased the burden of high-latitude travel. In 1958, under the command of Capt. William Anderson, the U.S. nuclear submarine *Nautilus* sailed beneath the North Pole during a submerged transit beneath the Arctic pack from Point Barrow, Alaska, to the Norwegian Sea.

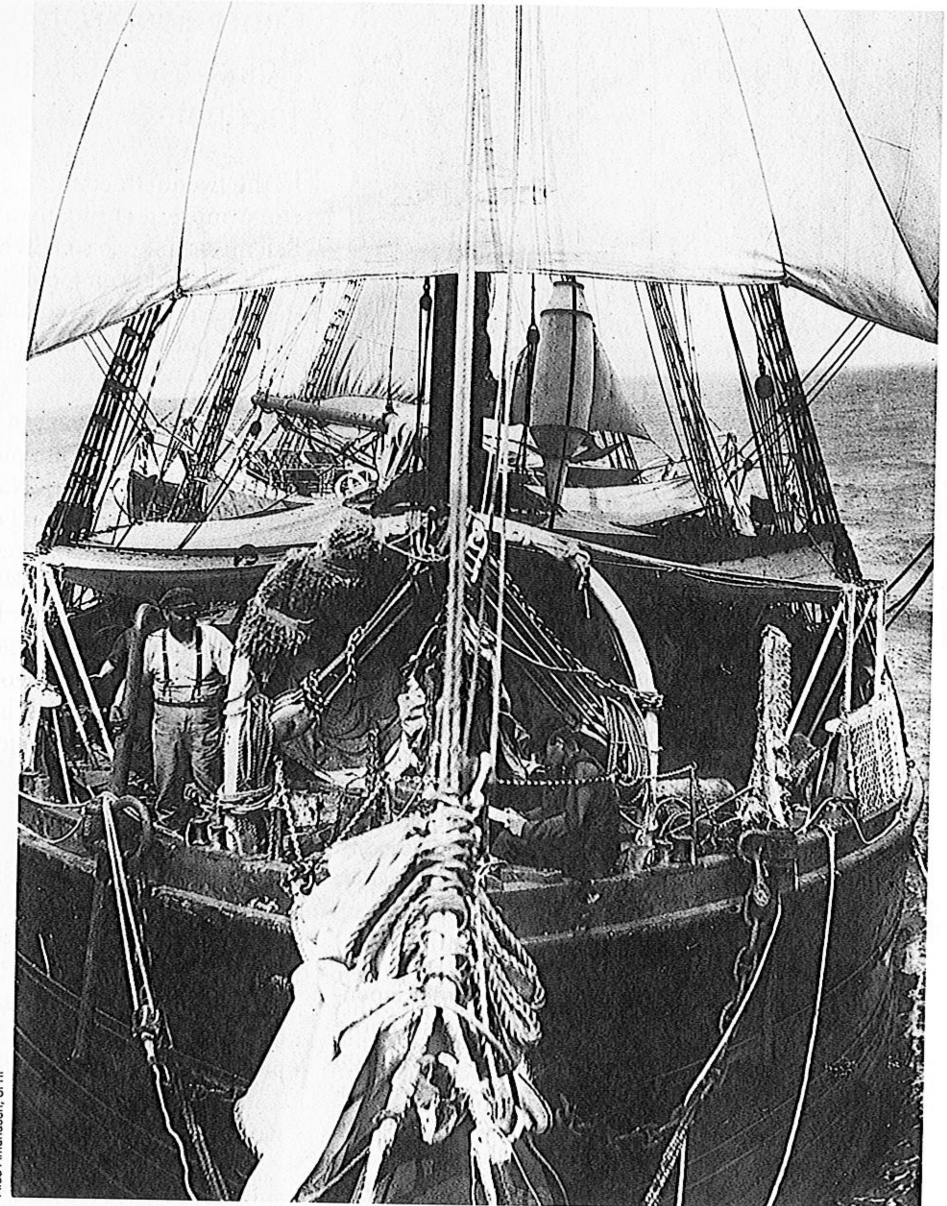
New Ships for New Tasks In 1925, the German *Meteor* **expedition**, which crisscrossed the South Atlantic for two years, introduced modern optical and electronic equipment to oceanographic investigation. Its most important innovation was use of an **echo sounder**, a



Topical Press Agency/Hulton Archive/Getty Images

a

Fridtjof Nansen, pioneering Norwegian oceanographer and polar explorer, looking every inch the Viking. In 1908, Nansen became the first professor of oceanography, a post created for him at Christiania University.



Alda Amundsen, SPRI

b

Nansen's 123-foot schooner *Fram* ("forward"). With 13 men, *Fram* sailed on June 22, 1893, to the high Arctic with the specific purpose of being frozen into the ice. *Fram* was designed to slip up and out of the frozen ocean and drifted with the pack ice to within about 4° of the North Pole. The whole harrowing adventure took nearly four years. The ship's 1,650-kilometer (1,025-mile) drift proved no Arctic continent existed beneath the ice. Living conditions aboard can be sensed from this recently rediscovered photograph.

Figure 2.25

device that bounces sound waves off the ocean bottom, to study the depth and contour of the seafloor (**Figure 2.26**). The echo sounder revealed to *Meteor* scientists a varied and often extremely rugged bottom profile rather than the flat floor they had anticipated.

In October 1951, a new HMS *Challenger* began a two-year voyage that would make precise depth measurements in the Atlantic, Pacific, and Indian oceans and in the Mediterranean Sea. With echo sounders, measurements that would have taken the crew of the first *Challenger* nearly four hours to complete could be made in seconds. *Challenger II*'s scientists discovered the deepest part of the ocean's deepest trench, naming it Challenger Deep in honor of their famous predecessor. In 1960, U.S. Navy lieutenant Don Walsh and Jacques Piccard descended into the Challenger Deep in *Trieste*, a Swiss-designed, blimplike bathyscaphe.

In 1968, the drilling ship *Glomar Challenger* set out to test a controversial hypothesis about the history of the ocean floor. It was capable of drilling into the

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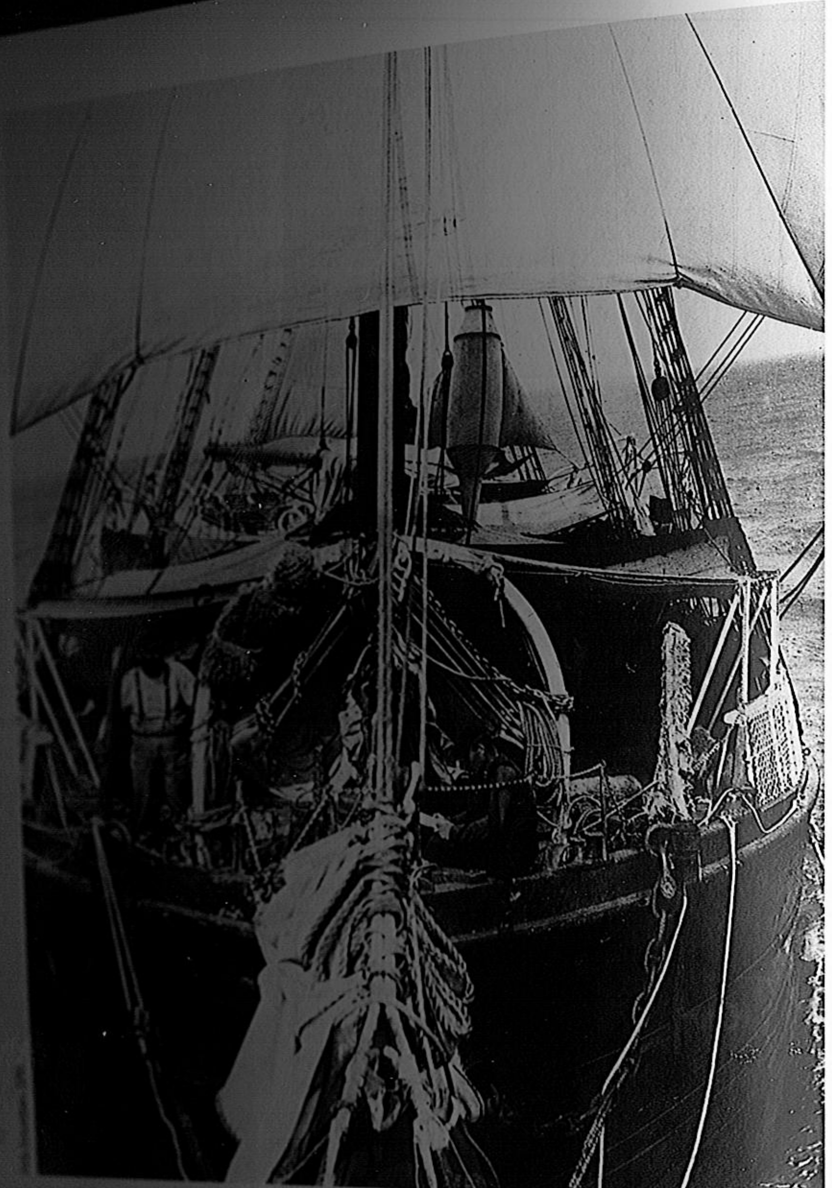

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In 1968, the drilling ship *Glomar Challenger* set out to test a controversial hypothesis about the history of the ocean floor. It was capable of drilling into the ocean bottom beneath more than 6,000 meters (20,000 feet) of water and recovering samples of seafloor sediments. These long and revealing plugs of seabed provided confirming evidence for seafloor spreading and plate tectonics. (The wonderful details will be found in Chapter 3.) In 1985, deep-sea drilling duties were taken over by the much larger and more technologically advanced ship *JOIDES Resolution*. Beginning in October 2003, deep-drilling responsibilities were passed to the Integrated Ocean Drilling Program (IODP), an international research consortium that operated a successor to *JOIDES Resolution* and an even larger drillship, R/V *Chikyu* ("Earth") (**Figure 2.27**). The new Japanese ship, fully operational in 2007, contains equipment capable of drilling cores as much as 11 kilometers (7 miles) long! The vessel has equipment to control any flows of oil or gas, so it can safely drill deep into sedimentary basins on continental margins considered unsafe for *JOIDES Resolution*. This ship cost US$500 million and houses one of the most completely equipped geological laboratories ever put to sea.

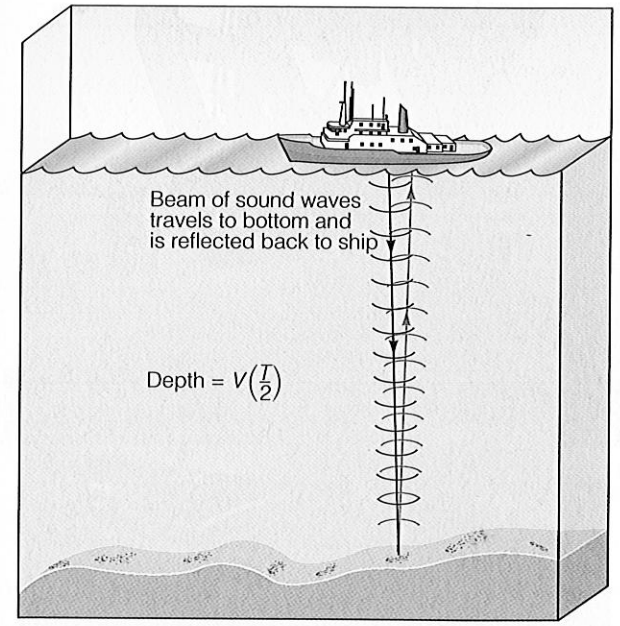


Figure 2.26 Echo sounders sense the contour of the seafloor by beaming sound waves to the bottom and measuring the time required for the sound waves to bounce back to the ship. If the round-trip travel time and wave velocity are known, distance to the bottom can be calculated. This technique was first used on a large scale by the German research vessel *Meteor* in the 1920s.

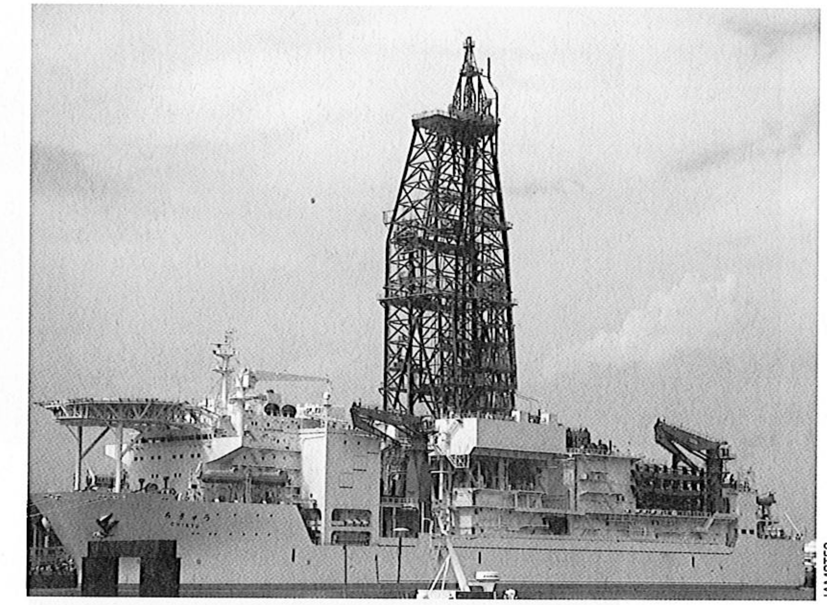


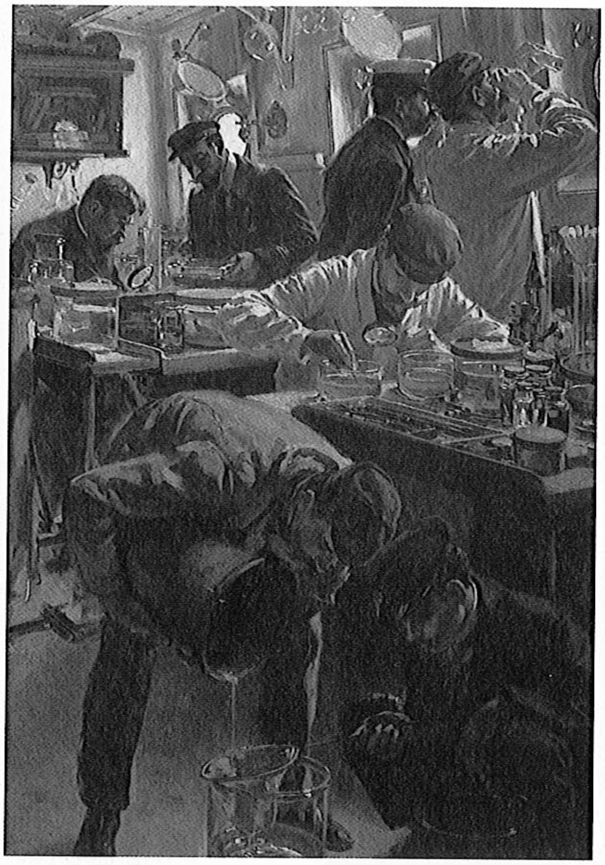
Figure 2.27 R/V *Chikyu* ("Earth") nears the end of its outfitting period in late 2005. *Chikyu*, lead vessel in the 18-nation International Ocean Drilling Program, is 45% longer and 2.4 times the mass of *JOIDES Resolution*, the ship it replaces.

Oceanographic Institutions Arose to Oversee Complex Research Projects The demands of scientific oceanography have become greater than the capability of any single voyage. Oceanographic institutions, agencies, and consortia evolved in part to ensure continuity of effort. The first of these coordinating bodies was founded by Prince Albert I of Monaco, who endowed his country's oceanographic laboratory and museum in 1906 (**Figure 2.28**). The most famous alumnus of Albert's Institut Océanographique is Jacques Cousteau, co-inventor in 1943 of the scuba underwater breathing system. Monaco also became the site of the International Hydrographic Bureau, founded in 1921 as an association of maritime nations. This bureau published one of the first general charts of the ocean showing bottom contours.

A consortium of Japanese industries and governmental agencies established the Japan Marine Science and Technology Center (JAMSTEC) in 1971. In 1989, JAMSTEC launched *Shinkai 6500*, now the deepest-diving manned submersible. *Kaiko*, a remotely controlled robot sister that became fully operational in 1995, is the deepest-diving unmanned vehicle presently in service (**Figure 2.29**). JAMSTEC is a major contributor to the IODP program.

In the United States, the three pre-eminent oceanographic institutions are the Woods Hole Oceanographic Institution on Cape Cod, founded in 1930 (and associated with the Massachusetts Institute of Technology and the neighboring Marine Biological Laboratory, founded in 1888); the Scripps Institution of Oceanography, founded in La Jolla, California, and affiliated with the University of California in 1912 (**Figure 2.30**); and the Lamont–Doherty Earth Observatory of Columbia University, founded in 1949.[2]

[2]There are, of course, other prominent institutions involved in studying the ocean. Some thoughts on how a student might enter the field appear in Appendix X.



Archives du Palais Princier de Monaco J. M. Moll.

Figure 2.28 Scientists and technicians at work in the first autonomous oceanographic institution. Founded by Prince Albert I of Monaco in 1908, the Institut Océanographique continues research and public education programs in Monaco and Paris.

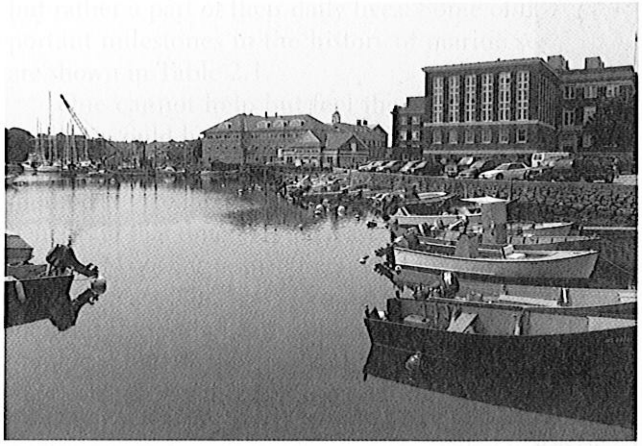
JAMSTEC

Figure 2.29 *Kaiko*, the deepest-diving vehicle presently in operation, descended to a measured depth of 10,914 meters (35,798 feet) near the bottom of the Challenger Deep on March 24, 1995. The small ROV (remotely operated vehicle) sends information back to operators in the mothership by fiber-optic cable. *Kaiko* is operated by JAMSTEC, a Japanese marine science consortium.

The U.S. government has been active in oceanographic research. Within the Department of the Navy are the Office of Naval Research, the Office of the Oceanographer of the Navy, the Naval Oceanic and Atmospheric Research Laboratory, and the Naval Ocean Systems Command. These agencies are responsible for oceanographic research related to national defense. The National Oceanic and Atmospheric Administration (NOAA), founded within the Department of Commerce in 1970, seeks to facilitate commercial uses of the ocean. NOAA includes the National Ocean Service, the National Weather Service, the National Marine Fisheries Service, and the Office of Sea Grant.

Satellites Have Become Important Tools in Ocean Exploration The National Aeronautics and Space Administration (NASA), organized in 1958, has become an important institutional contributor to marine science. For four months in 1978, NASA's *Seasat*, the first oceanographic satellite, beamed oceanographic data to Earth. More recent contributions have been made by satellites beaming radar signals off the sea surface to determine wave height, variations in sea-surface contour and temperature, and other information of interest to marine scientists.

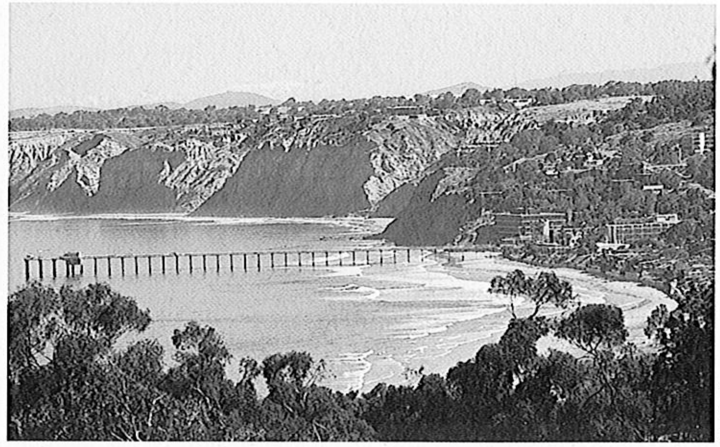
The first of a new generation of oceanographic satellites was launched in 1992 as a joint effort of NASA and the Centre National d'Études Spatiales (the French space agency). The centerpiece of ***TOPEX/Poseidon***, as the project is known, is a satellite orbiting 1,336 kilometers (835 miles) above Earth in an orbit that allows coverage of 95% of the ice-free ocean every 10 days. The satellite's *TOPography EXperiment* uses a positioning device that allows researchers to determine its position to within 1 centimeter (1/2 inch) of Earth's center! The radars aboard can then determine the height of the sea surface with unprecedented accuracy. Other experiments in this five-year program include sensing water vapor over the ocean, determining the precise location of ocean currents, and determining wind speed and direction.



Tom Garrison

a

The Woods Hole Oceanographic Institution, Woods Hole, Massachusetts. Marine science has been an important part of this small Cape Cod fishing community since Spencer Fullerton Baird, then assistant secretary of the Smithsonian Institution, established the U.S. Commission of Fish and Fisheries there in 1871. The Marine Biological Laboratory was founded in 1888, the Oceanographic Institution in 1930. The institution buildings seen here surround calm Eel Pond.



Tom Garrison

b

The Scripps Institution of Oceanography, La Jolla, California. Begun in 1892 as a portable laboratory-in-a-tent, Scripps was founded by William Ritter, a biologist at the University of California. Its first permanent buildings were erected in 1905 on a site purchased with funds donated by philanthropic newspaper owner E. W. Scripps and his sister, Ellen.

Figure 2.30

Jason-1 and *Jason-2*, NASA's ambitious follow-up to *TOPEX/Poseidon*, were launched in December 2001 and June of 2008. Now flying one minute and 370 kilometers (230 miles) apart on an identical ground track, their primary task is to monitor global climate interactions between the sea and the atmosphere.

SEASTAR, launched by NASA in 1997, carries a color scanner called SeaWiFS (sea-viewing wide-field-of-view sensor). This device measures the distribution of chlorophyll at the ocean surface, a measure of marine productivity.

AQUA, one of three of NASA's next generation Earth-observing satellites, was launched into polar orbit on May 4, 2002. It is the centerpiece of a project named for the large amount of information that will be collected about Earth's water cycle, including evaporation from the oceans; water vapor in the atmosphere; phytoplankton and dissolved organic matter in the oceans; and air, land, and water temperatures. *AQUA* flies in formation with sisters *TERRA*, *AURA* (**Figure 2.31**), *PARASOL*, and *CloudSat* to monitor Earth and air.

A satellite system you can use every day? The U.S. Department of Defense has built the **GPS (Global Positioning System)**, a "constellation" of 24 satellites (21 active and 3 spare) in orbit 17,000 kilometers (10,600 miles) above Earth. The satellites are spaced so that at least four of them are above the horizon from any point on Earth. Each satellite contains a computer, an atomic clock, and a radio transmitter. On the ground, every GPS receiver contains a computer that calculates its own geographical position using information from at least three of the satellites. The longitude and latitude it reports are accurate to less than 1 meter (39.37 inches), depending on the type of equipment used. Handheld GPS receivers can be purchased for less than US$70. (You might have one built into your cell phone!) The use of the GPS in marine navigation and positioning has revolutionized data collection at sea.

Satellite oceanography is an important frontier, and discoveries made by satellites are discussed in later chapters.

Governments and Institutions Cooperate to Fund Major Research Programs Oceanography has become big science. Governments and institutions now cooperate in funding research to describe large-scale marine processes, not just to describe the nature of small attributes of the ocean. The largest programs are known by their acronyms—words formed from the first letters of their titles. Here are a few of the most important:

- WCRP. The goal of the *World Climate Research Programme* is to develop a fundamental scientific understanding of the physical climate system and climate processes to support studies of global

© Rick Baldridge

Figure 2.31 The atmosphere-observing satellite AURA is launched into polar orbit from California on July 15, 2004.

change. Among WCRP's programs is CLIVAR (CLImate VARiability and Predictibility) program, which continues the work of the TOGA (Tropical Ocean and Global Atmosphere) program, which officially ended in 1994, and the WOCE (World Ocean Circulation Experiment), which ended in 1998. It is the largest scientific program ever attempted by physical oceanographers. CLIVAR's three goals are: (1) to study seasonal climate variability and the dynamics of the global ocean-atmosphere-land system; (2) to study climate variability and predictability in the 10- to 100-year range; and (3) to detect human-induced changes to atmospheric temperature and circulation.

- IGBP. The *International Geosphere-Biosphere Programme* also studies global change. Among the IGBP's projects is the GLOBEC (Global Ocean Ecosystem Dynamics) program, which will increase our understanding of the causes of variations in the populations of marine organisms resulting from global climate change. Though mainly focused on zooplankton biology, the program will also address issues of biological diversity. Also included is JGOFS (Scientists in the Joint Global Ocean Flux Study), which concentrates on the ocean's chemical, physical, and biological processes to increase understanding of the ocean's carbon cycle. Together their goals are to determine what processes control the movement of carbon between the ocean and the atmosphere and to improve our ability to make global-scale predictions of the likely response of the ocean and atmosphere to human activities.
- IODP. The successor to the ODP (Ocean Drilling Program), the *Integrated Ocean Drilling Program* is an international consortium that will use advanced technology and a new vessel (R/V *Chikyu*, see again Figure 1.31) to drill into the deep seabed. IODP's goal is to discover the geological histories of the ocean basins and their margins. ODP's discoveries figure prominently in the history of the ocean floor discussed in Chapters 3 and 4, and IODP will continue to make important contributions.
- RIDGE. The *Ridge Interdisciplinary Global Experiments* (and its international component *Inter-RIDGE*) are directed at the dynamics of mid-ocean spreading centers. As you will learn in the next chapter, ridges are the boundaries along which new oceanic crust is created. Remotely piloted research vehicles are playing an important role in these studies.

As we have seen, hundreds of marine scientists and their students are using an impressive array of equipment to probe the world ocean. *Marine science is by necessity a field science*: Ships and distant research stations are essential to its progress. The business of operating the ships and staffing the research stations is costly and sometimes dangerous, yet these researchers are willing to meet the daily challenge. They feel a sense of continuity within their separate specialties because oceanographers must be familiar with the scientific literature, the written history of their fields. History is not an abstract area of interest, but rather a part of their daily lives. Some of the important milestones in the history of marine science are shown in Table 2.1.

One cannot help but feel that the Alexandrian scholars would have appreciated the 2,000-year effort to understand the ocean. Application of the scientific method to oceanographic studies has yielded many benefits in that time, not the least of which is the satisfaction of knowing a small fraction of the story of Earth and its ocean. The lure of voyaging has been behind many of these discoveries. Scientists in the oceanographic research ships, laboratories, and libraries of the world go on collecting knowledge today. With luck and support, their efforts will continue into the distant future.

CONCEPT CHECK

16. **Why were oceanographic conditions at Earth's poles of interest to scientists?**

17. **How is the echo sounder an improvement over a weighted line in taking soundings? Which expedition first employed an echo sounder? Can you think of a few things that might cause echo sounding to give false information?**

18. **What stimulated the rise of oceanographic institutions?**

19. **Satellites orbit in space. How can a satellite conduct oceanography research?**

20. **What role does field research play in modern oceanography?**

To check your answers, see the book's website. The website address is printed at the end of the chapter.

Table 2.1 Time Line for the History of Marine Science

Date	Event
4000 B.C.E.	Egyptian trade on Nile.
3800 B.C.E.	First maps showing water (river charts).
1200 B.C.E.	Phoenicians trade from Mediterranean to Britain and West Africa.
1000 B.C.E.	Polynesians first inhabit Tonga, Samoa.
900 B.C.E.	Greeks first use the term *okeanos*, root of our word *ocean*.
800 B.C.E.	First graphic aids to marine navigation.
600 B.C.E.	Greek Pythagoreans assume a spherical Earth.
325 B.C.E.	Pytheas voyages to Britain, links tides to movement of the moon (see **Chapter 11**); Chinese invent the compass.
300 B.C.E.	Library founded at Alexandria.
230 B.C.E.	Eratosthenes calculates circumference of Earth, invents latitude and longitude (see **Chapter 2**).
127 B.C.E.	Hipparchus arranges latitude and longitude in regular grid by degrees.
A.D. 150	Claudius Ptolemy errs in estimating Earth's circumference.
A.D. 415	Library of Alexandria destroyed.
A.D. 500	Hawai'i colonized by Polynesians.
A.D. 780	Viking raids begin.
1000	Norwegian colonies in North America.
1460	Prince Henry the Navigator dies.
1492	Columbus's first voyage.
1522	Magellan's crew completes first circumnavigation.
1609	Hugo Grotius publishes *Mare Liberum*, the foundation for all modern law of the sea (see **Chapter 18**).
1687	Isaac Newton's publication of *Principia Mathematica*, which includes an explanation of the operation of gravity (see **Chapter 11**).
1742	Anders Celsius invents the centigrade temperature scale (see **Chapter 6**).
1758	Carolus Linnaeus publishes tenth edition of *Systema Naturae*, in which biological nomenclature is formalized (see **Chapter 13**).
1760	John Harrison's Number Four chronometer (see **Chapter 2**).
1768	James Cook's first voyage of discovery (see **Chapter 2**).
1769	Benjamin Franklin publishes first chart showing an ocean current (see **Chapter 2**).
1779	James Cook dies in Hawai'i.
1818	John Ross takes first deep-water and sediment samples.
1831	Charles Darwin departs on five-year voyage aboard HMS *Beagle* (see **Chapter 13**).
1835	Gaspard Coriolis publishes first papers on an object's horizontal motion across Earth's surface (see **Chapter 8**).
1836	William Harvey devises a taxonomy of seaweeds (see **Chapter 14**).
1838	Departure of the United States Exploring Expedition.
1847	Hans Christian Oersted observes plankton (see **Chapter 14**).
1855	Matthew Maury publishes *Physical Geography of the Seas* (see **Chapter 2**).
1859	Darwin's *Origin of Species* published (see **Chapter 13**).
1872	Departure of *Challenger* expedition.
1877	Alexander Agassiz begins research in *Blake*.
1880	William Dittmar determines major salts in seawater (see **Chapter 7**).
1888	Marine Biological Laboratory founded at Woods Hole, Massachusetts.
1890	Alfred Thayer Mahan completes *The Influence of Sea Power upon History*.
1891	Sir John Murray and Alphonse Renard classify marine sediments (see **Chapter 5**).
1893	Fridtjof Nansen in Arctic in *Fram* (see **Chapter 2**).

(Continued)

Table 2.1 Time Line for the History of Marine Science (Continued)

Date	Event
1900	Richard D. Oldham identifies P and S waves on seismograph (see **Chapter 3**).
1906	Prince Albert I of Monaco establishes the Institut Océanographique.
1907	Bertram Boltwood calculates age of Earth by radioactive decay (see **Chapter 3**).
1911	Roald Amundsen first at South Pole.
1912	Alfred Wegener's Frankfurt lectures on continental drift (see **Chapter 3**).
1912	Scripps Institution allied with the University of California.
1918	Vilhelm Bjerknes formulates theory of atmospheric fronts (see **Chapter 8**).
1921	International Hydrographic Bureau founded.
1925	Departure of *Meteor* expedition; first echo sounder in operation (see **Chapters 2** and **3**).
1930	Woods Hole Oceanographic Institution founded.
1931	*Atlantis* launched.
1937	*E. W. Scripps* launched.
1942	*The Oceans*, first modern reference text, published.
1943	Jacques Cousteau and Emile Gagnan invent the scuba regulator and tank combination, the "aqualung."
1949	Maurice Ewing forms the Lamont–Doherty Earth Observatory (see **Chapters 2** and **3**).
1958	U.S. nuclear submarine *Nautilus* makes first submerged transit of the Arctic ice pack, passes through North Pole (see **Chapter 2**).
1960	Bathyscaphe *Trieste* carrying Jacques Piccard and Don Walsh reaches bottom of deepest trench at 10,915 meters (35,801 feet).
1962	Rachel Carson's book *Silent Spring* initiates the U.S. environmental movement (see **Chapter 18**).
1968	*Glomar Challenger* returns first cores, indicating the age of Earth's crust. The cores support theory of plate tectonics (see **Chapters 3** and **5**).
1969	Santa Barbara, California, oil well blowout captures national attention (see **Chapter 18**).
1970	National Oceanic and Atmospheric Administration (NOAA) established.
1970	John Tuzo Wilson writes brief history of the tectonic revolution in geology in *Scientific American* (see **Chapter 3**).
1974	Project FAMOUS (French-American Mid-Ocean Undersea Study) maps and samples the Mid-Atlantic Ridge, a zone of seafloor spreading (see **Chapter 3**).
1977	*Alvin* finds hydrothermal vents in the Galápagos rift (see **Chapters 4** and **16**).
1978	*Seasat*, the first satellite dedicated to ocean studies, is launched.
1985	*JOIDES Resolution* replaces *Glomar Challenger* in Deep Sea Drilling Project (see **Chapters 2** and **3**).
1985	R. D. Ballard locates wreck of *Titanic*.
1987	Observations of supernova 1987A confirm theories of the origin of elements (see **Chapter 1**).
1991	*JOIDES Resolution* researchers bore to a depth of 2 kilometers (1.24 miles) beneath the seafloor near the Galápagos Islands (see **Chapter 3**).
1992	U.S.–French *TOPEX/Poseidon* satellite launched.
1995	*Kaiko*, a small remotely controlled Japanese submersible, sets a new depth record: 10,978 meters (36,008 feet) in the Challenger Deep.
1998	*Galileo* spacecraft finds possible evidence of an ocean on Jupiter's moon Europa (see **Chapter 1**).
2000	*Mars Global Surveyor* photographs channels perhaps carved by flowing water (see **Chapter 1**).
2002	*R/V Chikyu*, lead ship of the Integrated Ocean Drilling Program, is launched (see **Chapters 2** and **3**).
2003	Inauguration of the Integrated Ocean Drilling Program (IODP) (see **Chapters 3** and **4**).
2004	Mars *Rover* explores Gusev crater to seek evidence of water. Lethal tsunami strikes the Indian Ocean. NOAA establishes GOESS (Global Earth Observation System of Systems).
2005	Researchers aboard *JOIDES Resolution* recover rocks more than 1,416 meters (4,644 feet) below the sea floor. Most active Atlantic hurricane season on record.
2006	President George W. Bush establishes the largest marine sanctuary in the tropical Pacific. Lakes of liquid methane found on Saturn's moon Titan.
2007	R/V *Chikyu* drills first deep ocean cores (see **Chapters 2** and **3**).
2008	*Jason-2*, an ocean-sensing satellite, is launched (see **Chapter 2**).
2009	European Space Agency launches the Gravity Field and Ocean Circulation Explorer satellite (GOCE).
2009	NOAA dispatches *Okeanos Explorer*, the first vessel with a permanent mission to explore the deepest reaches of the ocean.

Questions from Students

1 If the Alexandrian Library was so powerful and of such great value to learning and intelligent discourse, why was it so easy to turn local sentiment against its mission? Didn't the citizens of Alexandria appreciate the institution in their midst?

Perhaps the Library was an easy target for destruction because there is no record of any of the researchers explaining or popularizing the monumental discoveries being made there. Scientific inquiry was the province of a privileged few, and—except for economic information available to traders—the Librarians' intellectual achievements had little practical value. As Carl Sagan wrote, "Science never captured the imagination of the multitude. There was no counterbalance to stagnation, to pessimism, to the most abject surrenders to mysticism. When, at long last, the mob came to burn the Library down, there was nobody to stop them."[3]

2 If Columbus was unsuccessful in his attempt to sail around the world, and Magellan died without completing his circumnavigation, who was the first captain to complete the trip?

Sir Francis Drake, of England, was the first captain to sail his own ship around the world. His expedition, begun in 1577, lasted three years. In the eastern Pacific he raided Spanish merchantmen and captured a fortune in gold, silver, coins, and precious stones. He was the first European to sight the west coast of what is now Canada, and claimed California for Queen Elizabeth I. His transit of the Pacific lasted 68 days, and on his return to England he concluded spice trade negotiations with various heads of state; some of the agreements remain in effect to this day! On 26 September 1580, he returned to England a wealthy man, was knighted by the Queen, and went on in 1588 to help defeat the Spanish Armada.

Little was know of his explorations until comparatively recently. The trade and geographical information he brought home to England was considered so valuable that it was given the highest security classification—thus few people saw it or benefited from it!

3 What was James Cook's motivation for those extraordinary voyages?

One could say simply that he was a serving Royal Naval Officer and was ordered to go. But Beaglehole, Hough, and other biographers suggest the story is much more complex. How did a relatively unschooled man become leader of one of the first scientific oceanographic expeditions? Cook had the usual attributes of a successful person—intelligence, strength of character, meeting the right people at the right time, health, focus, luck—but he also had a driving intellectual curiosity and a rare (for that era) tolerance and respect for alien cultures. As Hough (1994) writes, "Cook stood out like a diamond amidst junk jewelery. . . ." It was no surprise that the Lords of the Admiralty settled upon this unique man to lead the adventure.

4 What would you say is the most important "unknown" early marine oceanographic expedition?

A French expedition into the Pacific occurred between after Cook's last voyage but before Wilkes's. Backed by Napoléon and led by Nicolas Baudin, two lavishly equipped ships conveyed 23 scientists to study and map Australia from 1800 to 1804. They discovered 2,542 new species and returned the largest and most valuable natural history collection of its time—some 200,000 specimens and 30 live animals! Baudin's exploits are little known outside Australia because of British primacy in the area, but the French are rediscovering this part of their maritime history and voyage documents are being made available. Will I need to replace H.M.S. *Challenger* as the first purely scientific oceanography expedition? Watch this space!

5 How do modern navigators find their position at sea?

Very dull story. They push a few buttons on a small box and read their latitude and longitude directly on a screen. This is accomplished by analysis of radio transmissions from satellites. For about US$70, you can now buy a small, hand-held portable receiver (or even a cell telephone) capable of receiving Global Positioning System satellite signals. The GPS system is accurate to about 1 meter (3 feet), and can even tell you which direction to go to get home (or anywhere else you want to go)! None of these methods is nearly as much fun as the old-fashioned sextant-and-chronometer method, but I suspect that any of the explorers mentioned in this chapter would be very impressed by our new tools.

6 What's this about a chronometer not having to keep perfect time? I thought you had to know exactly what time it is to be able to calculate your longitude.

Yes, you need accurate time. But a chronometer is valuable not because it necessarily keeps perfect time but because it loses or gains time at a constant, known rate. Each day, the navigator multiplies the number of seconds the clock is known to gain (or lose) by the number of days since the clock was last set—and then adds the total to the time shown on the chronometer's face to obtain the real time. The value of a chronometer lies entirely in its consistency.

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[3] Sagan, Carl. 1980. *Cosmos*. Random House. See especially pages 331–345.

7 **Did Columbus discover North America?**

No. He *never saw* North America.

8 **You wrote that the future of oceanography lies in the big institutions. Is there a place for individual initiative in marine science?**

Always. Every adventure begins with a person sitting quietly nurturing an idea. The notion may seem crazy at first, or it may seem impossible to prove or disprove, but the idea won't go away. He or she shares the idea with colleagues. If a research consensus is reached, plans are made, grants are proposed and funded, data flow. But the trail always begins with one person and his or her idea.

Chapter in Perspective

In this chapter you learned that science and exploration have gone hand-in-hand. Voyaging for necessity evolved into voyaging for scientific and geographical discovery. The transition to scientific oceanography was complete when the *Challenger Report* was completed in 1895. The rise of the great oceanographic institutions quickly followed, and those institutions and their funding agencies today mark our path into the future.

In the next chapter you will learn about Earth's inner layers—layers that are density stratified. You'll find these layers to be heavier and hotter as depth increases, and you'll learn how we know what's inside our planet even though we've never been past the outermost layer. As you'll see, today's earthquakes and volcanoes, and the slow movement of continents, are all remnants of our distant cosmological past.

Terms and Concepts to Remember

AQUA
cartographer
celestial navigation
Challenger expedition
chart
Chinese navigators
chronometer
Columbus, Christopher
compass
Cook, James
echo sounder
Eratosthenes of Cyrene
Franklin, Benjamin
GPS (Global Positioning System)
Harrison, John
Jason-1, Jason-2
latitude
Library of Alexandria
longitude
Magellan, Ferdinand
Mahan, Alfred Thayer
marine science
Maury, Matthew
Meteor expedition
oceanography
oceanus
Polynesians
Prince Henry the Navigator
Sea power
SEASTAR
sounding
TOPEX/Poseidon
United States Exploring Expedition
Vikings
voyaging

Study Questions

Thinking Critically

1. How could you convince a 10-year-old that Earth is round? What evidence would a child offer that it's flat? How can you counter those objections?
2. How did the Library of Alexandria contribute to the development of marine science? What happened to most of the information accumulated there? Why do you suppose the residents of Alexandria became hostile to the librarians and the many achievements of the library?
3. How did Eratosthenes calculate the approximate size of Earth? Which of his assumptions was the "shakiest"?
4. If Columbus didn't discover North America, then who did?
5. Sketch briefly the major developments in marine science since 1900. Do individuals, separate voyages, or institutions figure most prominently in this history?

Thinking Analytically

1. Imagine that you set your watch at local noon in Kansas City on Monday and then fly to the Coast on Tuesday. You stick a pole into the ground on a sunny day at the beach, wait until its shadow is shortest, and look at your watch. The watch says 10:00 A.M. Are you on the East Coast or the West Coast? What is the difference in longitude? (Hint: 360°, divided by 24 hours, is 15°. The sun moves through the sky at a rate of 15 degrees per hour.)
2. Look at Box 2.1, figure (b). Provide a rough estimate of the latitude and longitude of your present position.
3. Magellan's crew kept very careful records of their circumnavigation, yet when they returned home, they were one day "off." Why? Had they gained a day, or lost a day?
4. Replicate Eratosthenes' measurement of the diameter of Earth. Try this technique: Contact a friend who lives about 800 kilometers (500 miles) north or south of you (a distance comparable to the distance between Alexandria and Syene.) Drive a tall pole into the ground at each location. Make sure the poles are vertical (using a weight on a string). Watch around noon, and when the pole casts the shortest shadow, measure the sun's angle of inclination from the shadow cast. Can you take it from there?

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