Introduction To Planet "Earth"

The **oceans**[2] are the largest and most prominent feature on Earth. In fact, they are the single most defining feature of our planet. As viewed from space, our planet is a beautiful blue, white, and brown globe (see this chapter's opening photo). The abundance of liquid water on Earth's surface is a distinguishing characteristic of our home planet.

Yet it seems perplexing that our planet is called "Earth" when 70.8% of its surface is covered by oceans. Many early human cultures that lived near the Mediterranean (*medi* = middle, *terra* = land) Sea envisioned the world as being composed of large landmasses surrounded by marginal bodies of water. From their viewpoint, landmasses—not oceans—dominated the surface of Earth. How surprised they must have been when they ventured into the larger oceans of the world. Our planet is misnamed "Earth" because we live on the land portion of the planet. If we were marine animals, our planet would probably be called "Ocean," "Water," "Hydro," "Aqua," or even "Oceanus" to indicate the prominence of Earth's oceans. Let's begin our study of the oceans by examining some of the unique geographic characteristics of our watery world.

1.1 How Are Earth's Oceans Unique?

In all of the planets and moons in our solar system, Earth is the only one that has oceans of liquid water on its surface. No other body in the solar system has a confirmed ocean, but recent satellite missions to other planets have revealed some tantalizing possibilities. For example, the spidery network of fluid-filled cracks on Jupiter's moon Europa (**Figure 1.1**) almost certainly betrays the presence of an ocean of liquid water beneath its icy surface. In fact, a recent analysis of the icy blocks that cover Europa's surface indicates that the blocks are actively being reshaped in a process analogous to plate tectonics on Earth. Two other moons of Jupiter, Ganymede and Callisto, may also have liquid oceans of water beneath their cold, icy crust. Yet another possibility for a nearby world with an ocean beneath its icy surface is Saturn's tiny moon Enceladus, which displays geysers of water vapor and ice that have

[1]The most commonly used words in this chapter are shown by larger font sizes in this *word cloud,* which is a visual aid for identifying important terms. Look for word clouds of important vocabulary terms on the opening page of each chapter throughout this book.

[2]Note that all **bolded** words are key vocabulary terms that are defined in the glossary at the end of this book.

meanings of any of the words in the word cloud above you don't already know.[1]

ESSENTIAL LEARNING CONCEPTS

At the end of this chapter, you should be able to:

1.1 Compare the characteristics of Earth's oceans.

1.2 Discuss how early exploration of the oceans was achieved.

1.3 Explain why oceanography is considered an interdisciplinary science.

1.4 Describe the nature of scientific inquiry.

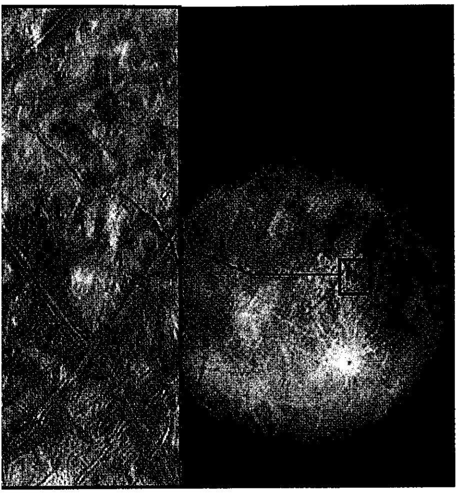
1.5 Explain how Earth and the solar system formed.

1.6 Explain how Earth's atmosphere and oceans formed.

1.7 Discuss why life is thought to have originated in the oceans.

1.8 Demonstrate an understanding of how old Earth is.

> ***"When you're circling the Earth every 90 minutes, what becomes clearest is that it's mostly water; the continents look like they're floating objects."***
>
> ***—Loren Shriver, NASA astronaut (2008)***



's moon Europa. Europa's network of dark
iggests the presence of an ocean beneath

SOMETIMES ASK . . .

discovery of other planets outside
em. Could any of them contain life?

ar system, more than 2000 exoplanets
covered orbiting other star systems,
cky exoplanets that are Earth-sized and
eir Sun-like stars at just the right dis-
remain liquid, potentially sustaining life.
ble to detect if these exoplanets have water
specific frequencies of light. New dis-
nets are a frequent occurrence, suggesting
e hundreds to billions of Earth-like worlds
the galaxy. However, most of these exo-
light-years away, so we may never know if
r life.

https://goo.gl/xwUwNX

recently been analyzed and, remarkably, contain salt. Recent analysis of the gravity field of Enceladus suggests the presence of a 10-kilometer (6.2-mile) deep saltwater ocean beneath a thick layer of surface ice. Also contained in the geysers' icy spray are tiny mineral grains, and in 2015 analysis of these particles indicated that the dust-sized grains likely form when hot, mineral-laden water from the moon's rocky interior travels upward, coming into contact with cooler water. This evidence of subsurface hydrothermal activity is reminiscent of underwater hot springs in the deep oceans on Earth, a place that may have been key to the development of life on Earth. And evidence continues to mount that Saturn's giant moon Titan has small seas of liquid hydrocarbons, suggesting that Titan may be the only other body in the solar system besides Earth known to have stable liquid at its surface. All these moons are enticing targets for space missions to search for signs of extraterrestrial life. Still, the fact that our planet has so much water, *and in the liquid form,* is unique in the solar system.

Earth's Amazing Oceans

Earth's oceans have had a profound effect on our planet and continue to shape our planet in critical ways. The oceans are essential to all life-forms and are in large part responsible for the development of life on Earth, providing a stable environment in which life could evolve over billions of years. Today, the oceans contain the greatest number of living things on the planet, from microscopic bacteria and algae to the largest life-form alive today (the blue whale). Interestingly, water is the major component of nearly every life-form on Earth, and our own body fluid chemistry is remarkably similar to the chemistry of seawater.

The oceans influence climate and weather all over the globe—even in continental areas far from any ocean—through an intricate pattern of currents and heating/cooling mechanisms, some of which scientists are only now beginning to understand. The oceans are also the "lungs" of the planet, taking carbon dioxide gas out of the atmosphere and replacing it with oxygen gas. Scientists have estimated that the oceans supply as much as 70% of the oxygen that humans breathe.

The oceans determine where our continents end and have thus shaped political boundaries and human history. The oceans conceal many features; in fact, the majority of Earth's geographic features are on the ocean floor. Remarkably, there was once more known about the surface of the Moon than about the floor of the oceans! Fortunately, our knowledge of both has increased dramatically over the past several decades.

The oceans also hold many secrets waiting to be discovered, and new scientific discoveries about the oceans are made nearly every day. The oceans are a source of food, minerals, and energy that remains largely untapped. More than half of the world population lives in coastal areas near the oceans, taking advantage of the mild climate, an inexpensive form of transportation, proximity to food resources, and vast recreational opportunities. Unfortunately, the oceans are also the dumping ground for many of society's wastes. In fact, the oceans are currently showing alarming changes caused by pollution, overfishing, invasive species, and climate change, among other things. All of these and many other topics are contained within this book.

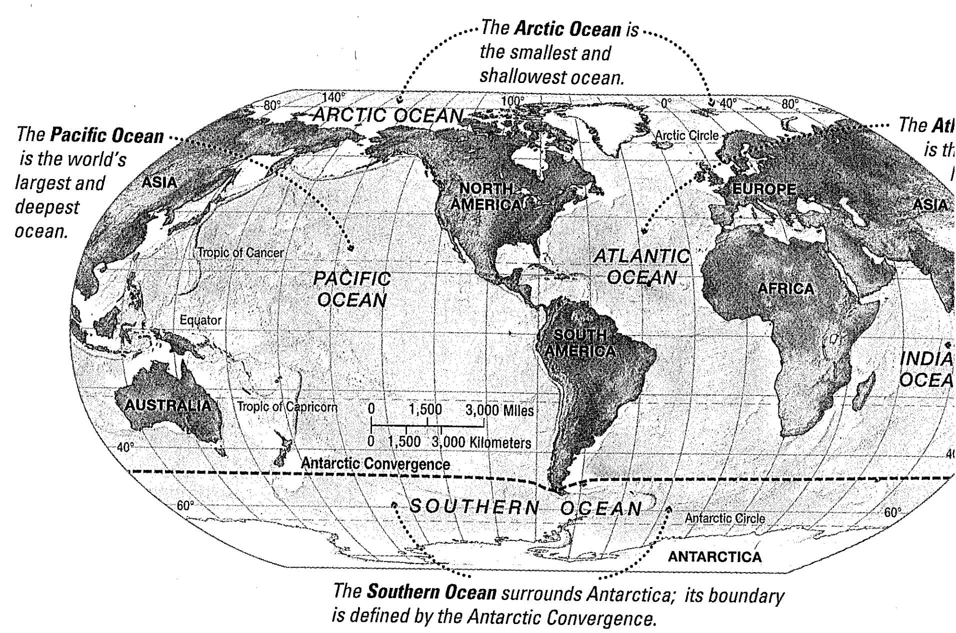
How Many Oceans Exist on Earth?

The oceans are a common metaphor for vastness. When one examines a world map (**Figure 1.2**), it's easy to appreciate the impressive extent of Earth's oceans. Notice that *the oceans dominate the surface area of the globe.* For those people who have traveled by boat across an ocean (or even flown across one in an airplane), the one thing that immediately strikes them is that the oceans are enormous. Notice, also, that *the oceans are interconnected* and form a single continuous body of seawater, which is why the oceans are commonly referred to as a "world ocean" (singular, not plural).

For instance, a vessel at sea can travel from one ocean to another, whereas it is impossible to travel on land from one continent to most others without crossing an ocean. In addition, *the volume of the oceans is immense.* For example, the oceans comprise the planet's largest habitat and contain 97.2% of all the water on or near Earth's surface (**Figure 1.3**).

The Four Principal Oceans, Plus One

Our world ocean can be divided into four principal oceans plus an additional ocean, based on the shape of the ocean basins and the positions of the continents (Figure 1.2).



SmartFigure 1.2 Earth's oceans. Map showing the four principal oceans plus the Southern Ocean, or Antarctic Ocean.
https://goo.gl/BJXqyt

PACIFIC OCEAN The **Pacific Ocean** is the world's largest ocean, covering more than half of the ocean surface area on Earth (**Figure 1.4b**). The Pacific Ocean is the single largest geographic feature on the planet, spanning more than one-third of Earth's entire surface. The Pacific Ocean is so large that *all* of the continents could fit into the space occupied by it—with room left over! Although the Pacific Ocean is also the deepest ocean in the world (**Figure 1.4c**), it contains many small tropical islands. It was named in 1520 by explorer Ferdinand Magellan's party in honor of the fine weather they encountered while crossing into the Pacific (*paci* = peace) Ocean.

ATLANTIC OCEAN The **Atlantic Ocean** is about half the size of the Pacific Ocean and is not quite as deep (Figure 1.4c). It separates the Old World (Europe, Asia, and Africa) from the New World (North and South America). The Atlantic Ocean was named after Atlas, who was one of the Titans in Greek mythology.

INDIAN OCEAN The **Indian Ocean** is slightly smaller than the Atlantic Ocean and has about the same average depth (Figure 1.4c). It is mostly in the Southern Hemisphere (south of the equator, or below 0 degrees latitude in Figure 1.2). The Indian Ocean was named for its proximity to the subcontinent of India.

ARCTIC OCEAN The **Arctic Ocean** is about 7% the size of the Pacific Ocean and is only a little more than one-quarter as deep as the rest of the oceans (Figure 1.4c). Although it has a permanent layer of sea ice at the surface, the ice is only a few meters thick. The Arctic Ocean was named after its location in the Arctic region, which exists beneath the northern constellation Ursa Major, otherwise known as the Big Dipper, or the Bear (*arktos* = bear).

SOUTHERN OCEAN, OR ANTARCTIC OCEAN Oceanographers recognize an additional ocean near the continent of Antarctica in the Southern Hemisphere (Figure 1.2). Defined by the meeting of currents near Antarctica called the Antarctic Convergence, the **Southern Ocean**, or **Antarctic Ocean**, is really the portions of the Pacific, Atlantic, and Indian Oceans south of about 50 degrees south latitude. This ocean was named for its location in the Southern Hemisphere.

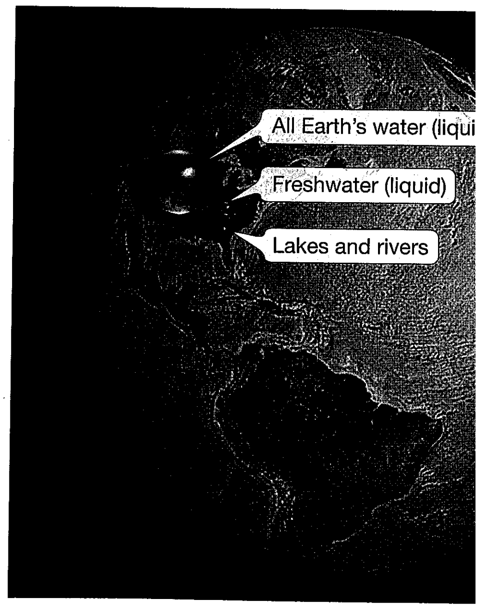


Figure 1.3 Relative sizes of the spheres of wa This image shows all of Earth's liquid water using t of proportional sizes. The big sphere is all liquid wa 97% of which is seawater. The next smallest sphe subset of the larger sphere, showing freshwater in swamps, and rivers. The tiny speck below it repres smaller subset of all the water—just the freshwater

RECAP

The four principal oceans are the Pacific, Atla Arctic Oceans. An additional ocean, the South Antarctic Ocean, is also recognized.

size and
proportions of
Earth's surface.
:he four principal
ocean depth.
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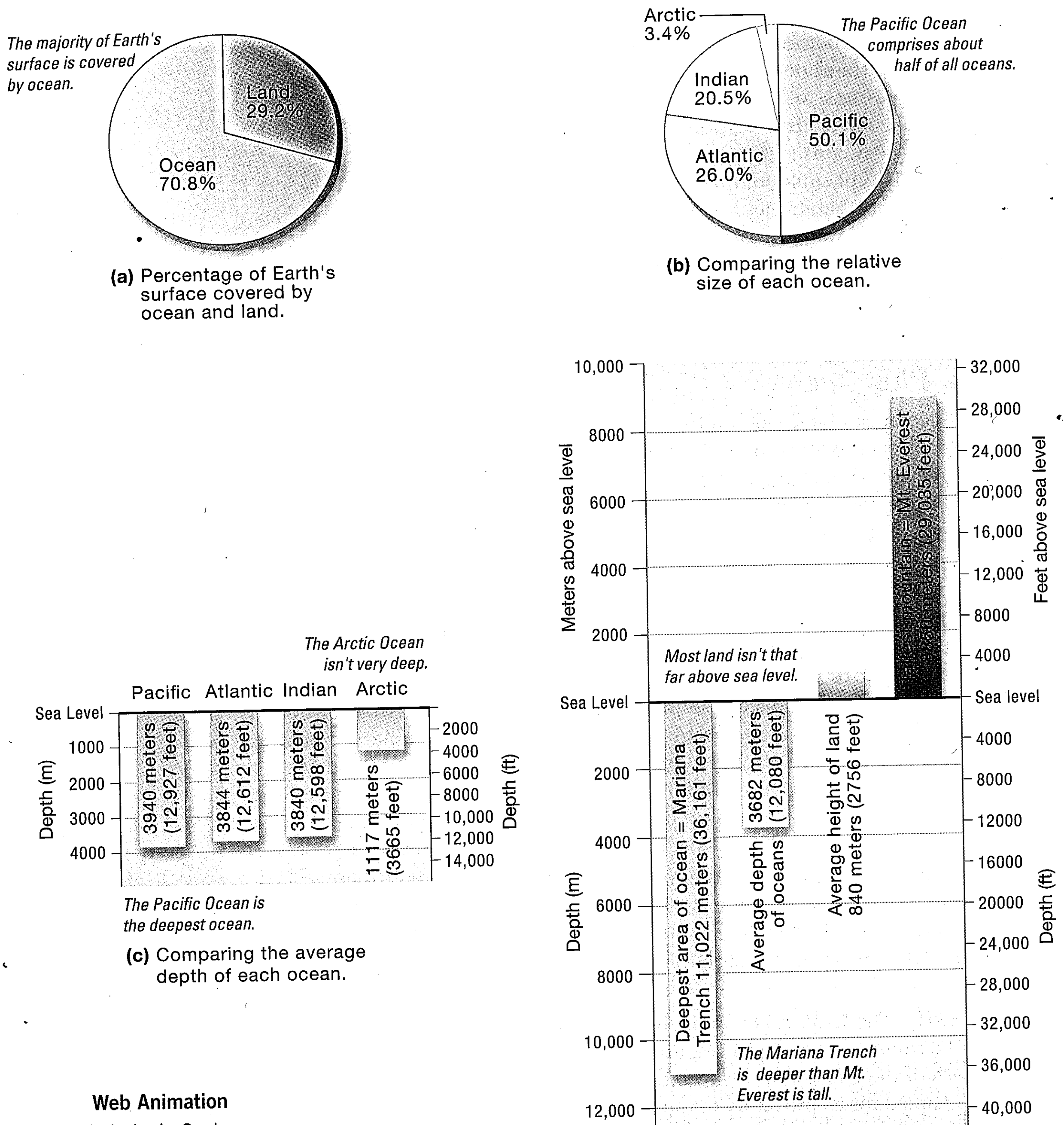


(a) Percentage of Earth's surface covered by ocean and land.

(b) Comparing the relative size of each ocean.

(c) Comparing the average depth of each ocean.

(d) Comparing the depth of the oceans to the height of land.

Web Animation
Earth's Water and the Hydrologic Cycle
http://goo.gl/kAo8FC

Oceans versus Seas

What is the difference between an ocean and a sea? In common use, the terms *sea* and *ocean* are often used interchangeably. For instance, a *sea* star lives in the *ocean*, the *ocean* is full of *sea* water, *sea* ice forms in the *ocean*, and one might stroll the *sea* shore while living on *ocean*-front property. Technically, however, a *sea* is defined as follows:

- Smaller and shallower than an ocean (this is why the Arctic Ocean might be more appropriately considered a sea)
- Composed of salt water (although some inland "seas," such as the Caspian Sea in Asia, are actually large lakes with relatively high salinity)

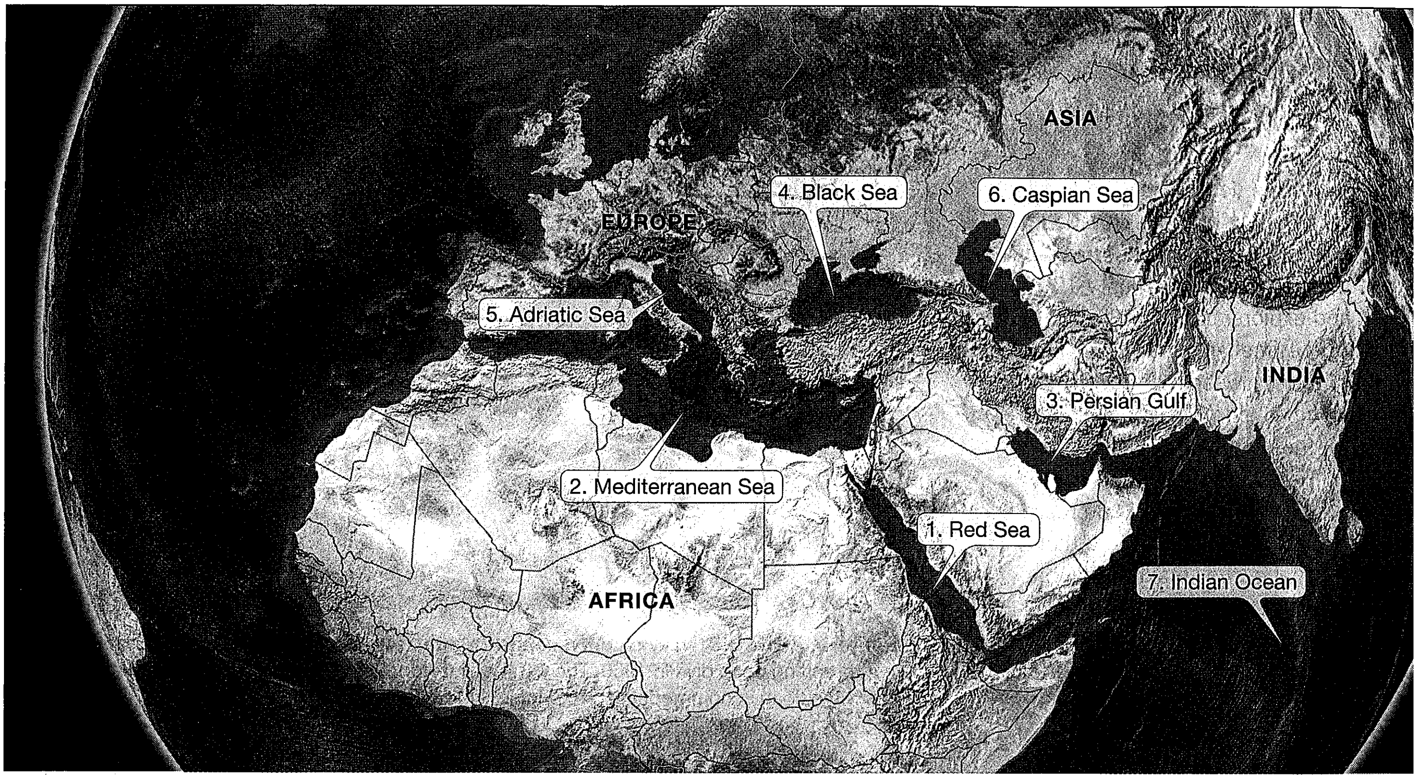


Figure 1.5 **Map of the ancient seven seas.** This map represents the extent of the known world to Europeans before the 15th century.

- Somewhat enclosed by land (although some seas, such as the Sargasso Sea in the Atlantic Ocean, are defined by strong ocean currents rather than by land)
- Directly connected to the world ocean

COMPARING THE OCEANS TO THE CONTINENTS **Figure 1.4d** shows that the average depth of the world's oceans is 3682 meters[3] (12,080 feet). This means that there must be some extremely deep areas in the ocean to offset the shallow areas close to shore. Figure 1.4d also shows that the deepest depth in the oceans (the Challenger Deep region of the Mariana Trench, which is near Guam) is a staggering 11,022 meters (36,161 feet) below sea level.

How do the continents compare to the oceans? Figure 1.4d shows that the average height of the continents is only 840 meters (2756 feet), illustrating that the average height of the land is not very far above sea level. The highest mountain in the world (the mountain with the greatest height above sea level) is Mount Everest in the Himalaya Mountains of Asia, at 8850 meters (29,035 feet). Even so, Mount Everest is a full 2172 meters (7126 feet) shorter than the Mariana Trench is deep. The mountain with the *greatest total height* from base to top is Mauna Kea on the island of Hawaii in the United States. It measures 4206 meters (13,800 feet) above sea level and 5426 meters (17,800 feet) from sea level down to its base, for a total height of 9632 meters (31,601 feet). The total height of Mauna Kea is 782 meters (2566 feet) higher than Mount Everest, but it is still 1390 meters (4560 feet) shorter than the Mariana Trench is deep. Therefore, no mountain on Earth is taller than the Mariana Trench is deep.

[3]Throughout this book, metric measurements are used (and the corresponding English measurements follow in parentheses). See Appendix I, "Metric and English Units Compared," for conversion factors between the two systems of units.

STUDENTS SOMETIMES A

Where are the seven seas?

"Sailing the seven seas" is a familiar p
and song, but the origin of the saying is
antiquity. To the ancients, the term "sev
meant "many," and before the 15th cen
considered these the main seas of the w

1. The Red Sea
2. The Mediterranean Sea
3. The Persian Gulf
4. The Black Sea
5. The Adriatic Sea
6. The Caspian Sea
7. The Indian Ocean (notice how "ocea
used interchangeably)

Today, however, more than 100 seas,
are recognized worldwide, nearly all of th
portions of the huge interconnected worl

;OMETIMES ASK ...

ɪr explored the deepest ocean ınything live there?

deed visited the deepest part of the ɜ there is crushing high pressure, com- l near-freezing water temperatures—and ɪr half a century ago! In January 1960, Nalsh and explorer Jacques Piccard ottom of the Challenger Deep region of in the *Trieste*, a deep-diving bathyscaphe *aphe* = a small ship) (**Figure 1.6**). At 00 feet), the men heard a loud cracking ıe cabin. They were unable to see that a ıch) Plexiglas viewing port had cracked ld for the rest of the dive). More than ɪing the surface, they reached the bot- ters (35,800 feet)—a record depth for ey did observe some small organisms life in the deep: a flatfish, a shrimp, and

ɔn James Cameron made a historic solo Trench in his submersible *DEEPSEA* **ıre 1.7**). On the seven-hour round-trip ɔent about three hours at the deepest spot ‹e photographs and collect samples for Other notable voyages to the deep ocean ꞉ discussed in MasteringOceanography **1.3**.

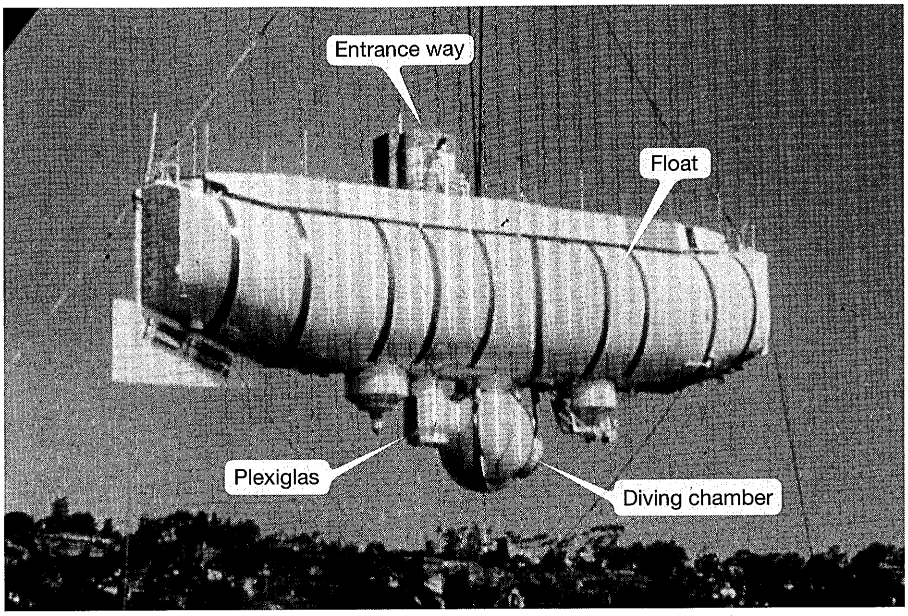


Figure 1.6 The U.S. Navy's bathyscaphe Trieste. The *Trieste* suspended on a crane before its record-setting deep dive in 1960. The 1.8-meter (6-foot) diameter diving chamber (the round ball below the float) accommodated two people and had steel walls 7.6 centimeters (3 inches) thick.

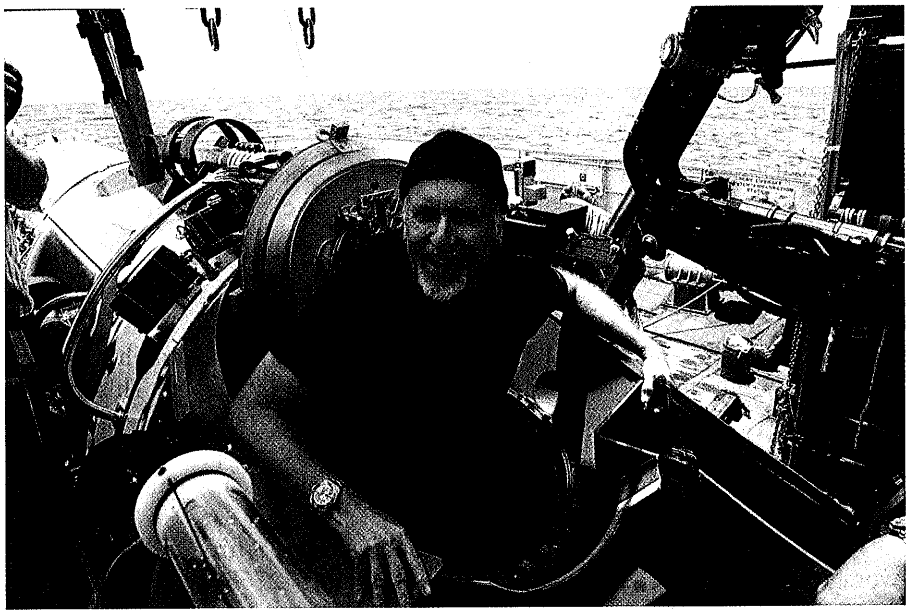


Figure 1.7 James Cameron emerges from the submersible *DEEPSEA CHALLENGER* after his solo dive to the Mariana Trench. In 2012, famous moviemaker James Cameron completed a record-breaking solo dive to the bottom of the Mariana Trench, becoming only the third human to visit the deepest spot on Earth.

ˌhe ocean is the Mariana Trench in the Pacific ıeters (36,161 feet) deep and has been visited ıs: once in 1960 and more recently in 2012.

CONCEPT CHECK 1.1 | Compare the characteristics of Earth's oceans.

1 How did the view of the ocean by early Mediterranean cultures influence the naming of planet Earth?

2 Although the terms *ocean* and *sea* are sometimes used interchangeably, what is the technical difference between an ocean and a sea?

3 Where is the deepest part of the ocean? How deep is it, and how does it compare to the height of the tallest mountain on Earth?

) SAILORS KNOW THEY ARE FROM STICK TO SATELLITES

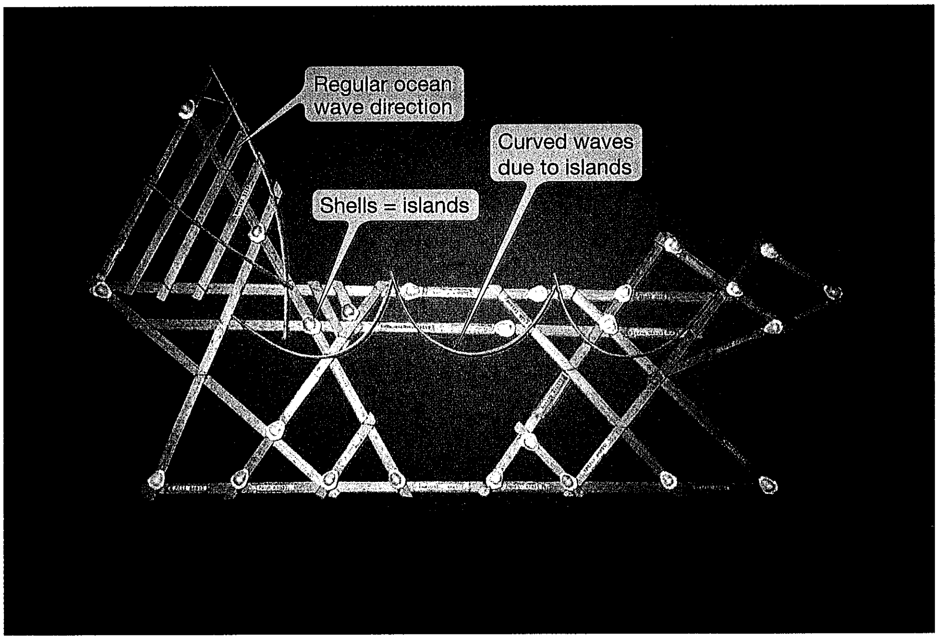
ou know where you are in the without roads, signposts, or any How do you determine the dis- ;tination? How do you find your good fishing spot or where you ed sunken treasure? Sailors have riety of navigation tools to help ons such as these by being able e they are at sea.

the first navigators were the Remarkably, the Polynesians uccessfully navigate to small d at great distances across the . These early navigators must y aware of the marine environ- n able to read subtle differences ind sky. The tools they used to igate between islands included Moon, the nighttime stars, the arine organisms, various ocean d an ingenious device called a **gure 1A**). Stick charts are like picts the dominant pattern of By orienting their vessels rela- egular ocean wave directions, successfully navigate at sea. The ections let them know when they lose to an island—even one that eyond the horizon.

The importance of knowing where you are at sea is illustrated by a tragic incident in 1707, when a British battle fleet was more than 160 kilometers (100 miles) off course and ran aground in the Isles of Sicily near England, with the loss of four ships and nearly 2000 men. **Latitude** (location north or south) was relatively easy to determine at sea by measuring the position of the Sun and stars using a device called a *sextant* (*sextant* = sixth, in reference to the instrument's arc, which is one-sixth of a circle) (**Figure 1B**).

The accident occurred because the ship's crew had no way of keeping track of their **longitude** (location east or west; see Appendix III, "Latitude and Longitude on Earth"). To determine longitude, which is a function of time, it was necessary to know the time difference between a reference meridian and when the Sun was directly overhead of a ship at sea (noon local time). The pendulum-driven clocks in use in the early 1700s, however, would not work for long on a rocking ship at sea. In 1714, the British Parliament offered a £20,000 prize (about $20 million today) for developing a device that would work well enough at sea to determine longitude within half a degree, or 30 nautical miles (34.5 statute miles), after a voyage to the West Indies.

A cabinetmaker in Lincolnshire, England, named **John Harrison** began working in 1728 on such a timepiece, which was dubbed the *chronometer* (*chrono* = time, *meter* = measure). Harrison's first chronometer, H-1, was successfully tested in 1736, but he received only £500 of the prize because the device was deemed too complex, costly, and fragile. Eventually, his more compact fourth version, H-4—which resembles an oversized



ıvigational stick chart. This bamboo licronesia's Marshall Islands shows ented by shells at the junctions of the ocean wave direction (represented by ps), and waves that bend around islands the curved strips). Similar stick charts arly Polynesian navigators.

pottery, had traveled on to Fiji, Tonga, and Samoa (Figure 1.8, *yellow arrow*). From there, Polynesians sailed on to the Marquesas (about 30 B.C.), which appear to have been the starting point for voyages to other islands in the far reaches of the Pacific (Figure 1.8, *green arrows*), including the Hawaiian Islands (about 300 A.D.) and New Zealand (about 800 A.D.). Surprisingly, new genetic research suggests that Polynesians populated Easter Island relatively recently, about 1200 A.D.

Despite the obvious Polynesian backgrounds of the Hawaiians, the Maori of New Zealand, and the Easter Islanders, an adventurous biologist/anthropologist pocket watch (**Figure 1C**)—was tested during a trans-Atlantic voyage in 1761. Upon reaching Jamaica, it was so accurate that it had lost only *five seconds* of time, a longitude error of only 0.02 degree, or 1.2 nautical miles (1.4 statute miles)! Although Harrison's chronometer greatly exceeded the requirements of the government, the committee in charge of the prize withheld payment, mostly because the astronomers on the committee wanted the solution to come from measurement of the stars. Because the committee refused to award him the prize without further proof, a second sea trial was conducted in 1764, which confirmed his success. Harrison was reluctantly granted £10,000. Only when King George III intervened in 1773 did Harrison finally receive the remaining prize money and recognition for his life work—at age 80.

Today, navigating at sea relies on the *Global Positioning System (GPS)*, which was initiated in the 1970s by the U.S. Department of Defense. Initially designed for military purposes but now available for a variety of civilian uses, GPS relies on a system of 24 satellites that send continuous radio signals to the surface. Position is determined by very accurate measurement of the time of travel of radio signals from at least four of the satellites to receivers on board a ship (or on land). Thus, a vessel can determine its exact latitude and longitude to within a few meters—a small fraction of the length of most ships. Navigators from days gone by would be amazed at how quickly and accurately a vessel's location can be determined, but they might say that it has taken all the adventu out of navigating at sea.

GIVE IT SOME THOUGHT

1. Why was longitude difficult to determin at sea?
2. Even though his invention solved the pr lem of determining longitude at sea, wh did John Harrison receive only a portion the British Parliament longitude prize?

Figure 1B Using a handheld sextant. This sextant is similar to the ones used by early navigators to determine latitude.

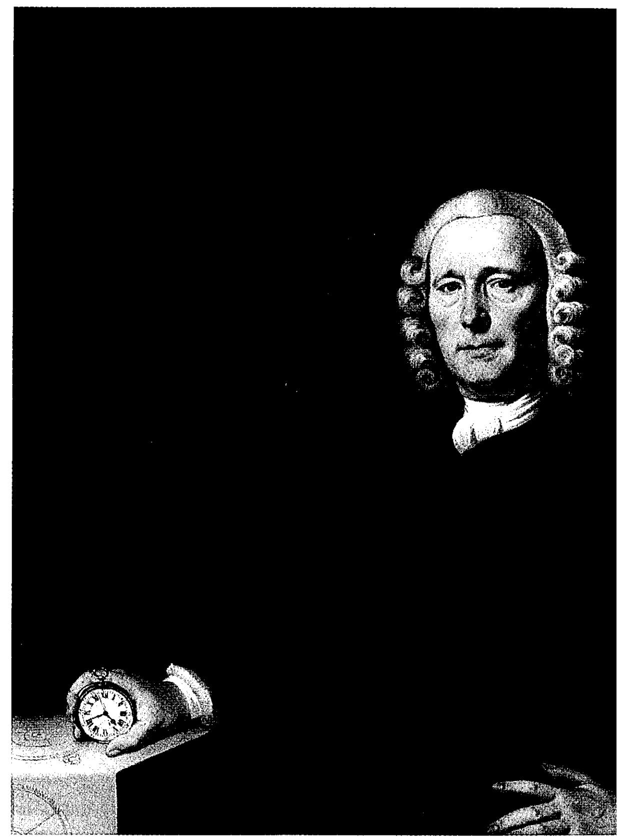
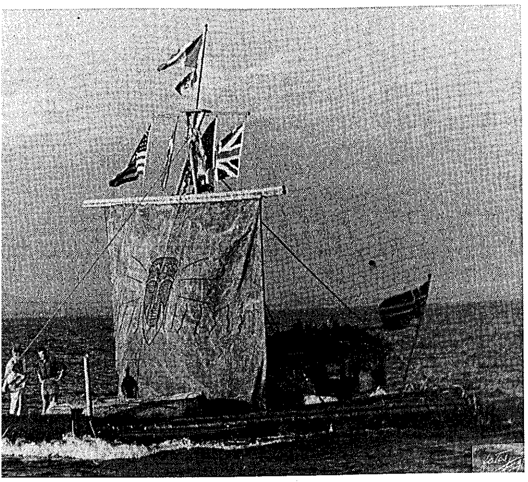
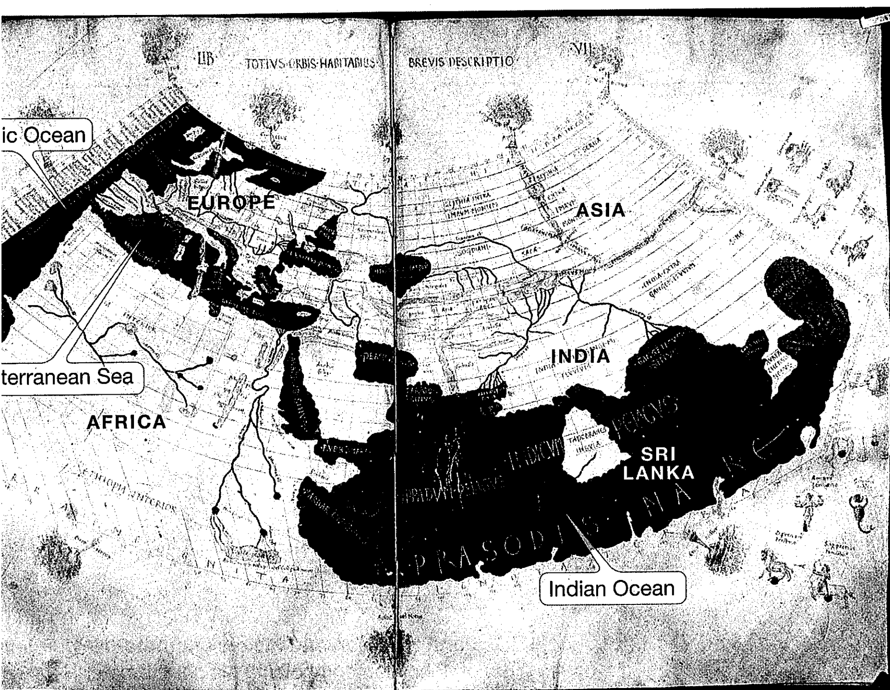


Figure 1C John Harrison and his chronometer H-4. Paintin (circa 1735) of John Harrison holding his chronometer H-4, whic was his life's work. The timepiece H-4 proved to be a vital techr logical breakthrough that allowed the determination of longitude sea and won Harrison the prize for solving the longitude probler

named **Thor Heyerdahl** proposed that voyagers from South America may have reached islands of the South Pacific before the coming of the Polynesians. To prove his point, in 1947 he sailed the ***Kon Tiki***—a balsa raft designed like those that were used by South American navigators at the time of European discovery (**Figure 1.9**)—from South America to the Tuamotu Islands, a journey of more than 11,300 kilometers (7000 miles) (Figure 1.8, *red arrow*). Although the remarkable voyage of the *Kon Tiki* demonstrates that early South Americans could have traveled to Polynesia just as easily as early Asian cultures, anthropologists can find no



The balsa raft ***Kon Tiki***. In 1947, Thor Heyerdahl ...uthentic wooden balsa raft named *Kon Tiki* from South ...Polynesia to show that ancient South American cultures ...ompleted similar voyages.



...0 **Ptolomy's map of the world.** In about 150 A.D., an ...reek geographer named Claudius Ptolomy produced ... the world that showed the extent of Roman geographic ... Note the use of a coordinate system on land, similar to ...l longitude used today.

evidence of such a migration. Further, comparative DNA studies show a strong genetic relationship between the peoples of Easter Island and Polynesia but none between these groups and natives in coastal North or South America.

EUROPEAN NAVIGATORS The first Mediterranean people known to have developed the art of navigation were the **Phoenicians**, who lived at the eastern end of the Mediterranean Sea, in the present-day area of Egypt, Syria, Lebanon, and Israel. As early as 2000 B.C., they investigated the Mediterranean Sea, the Red Sea, and the Indian Ocean. The first recorded circumnavigation of Africa, in 590 B.C., was made by the Phoenicians, who had also sailed as far north as the British Isles.

The Greek astronomer-geographer **Pytheas** sailed northward in 325 B.C. using a simple yet elegant method for determining latitude (one's position north or south) in the Northern Hemisphere. His method involved measuring the angle between an observer's line of sight to the North Star and line of sight to the northern horizon.[5] Despite Pytheas's method for determining latitude, it was still impossible to accurately determine longitude (one's position east or west).

One of the key repositories of scientific knowledge at the time was the **Library of Alexandria** in Alexandria, Egypt, which was founded in the 3rd century B.C. by *Alexander the Great*. It housed an impressive collection of written knowledge that attracted scientists, poets, philosophers, artists, and writers who studied and researched there. The Library of Alexandria soon became the intellectual capital of the world, featuring history's greatest accumulation of ancient writings.

As long ago as 450 B.C., Greek scholars became convinced that Earth was round, using lines of evidence such as the way ships disappeared beyond the horizon and the shadows of Earth that appeared during eclipses of the Moon. This inspired the Greek **Eratosthenes** (pronounced "AIR-uh-TOS-thuh-neez") (276–192 B.C.), the second librarian at the Library of Alexandria, to cleverly use the shadow of a stick in a hole in the ground and elementary geometry to determine Earth's circumference. His value of 40,000 kilometers (24,840 miles) compares remarkably well with the true value of 40,032 kilometers (24,875 miles) known today.

An Egyptian-Greek geographer named **Claudius Ptolemy** (c. 85 a.d.–c. 165 a.d.) produced a map of the world in about 150 a.d. that represented the extent of Roman knowledge at that time (**Figure 1.10**). The map not only included the continents of Europe, Asia, and Africa, as did earlier Greek maps, but it also included vertical lines of longitude and horizontal lines of latitude, which had been developed by Alexandrian scholars. Moreover, Ptolemy showed the known seas to be surrounded by land, much of which was as yet unknown and proved to be a great enticement to explorers.

Ptolemy also introduced an (erroneous) update to Eratosthenes's surprisingly accurate estimate of Earth's circumference. Ptolemy wrongly depended on flawed calculations and an overestimation of the size of Asia, and as a result, he determined Earth's circumference to be 29,000 kilometers (18,000 miles), which is about 28% too small. Nearly 1500 years later, Ptolemy's error caused explorer Christopher Columbus to believe he had encountered parts of Asia rather than a new world.

[5]Pytheas's method of determining latitude is featured in Appendix III, "Latitude and Longitude on Earth."

The Middle Ages

After the destruction of the Library of Alexandria in 415 A.D. (in which all of its contents were burned) and the fall of the Roman Empire in 476 A.D., the achievements of the Phoenicians, Greeks, and Romans were mostly lost. Some of the knowledge, however, was retained by the *Arabs*, who controlled northern Africa and Spain. The Arabs used this knowledge to become the dominant navigators in the Mediterranean Sea area and to trade extensively with East Africa, India, and Southeast Asia. The Arabs were able to trade across the Indian Ocean because they had learned how to take advantage of the seasonal patterns of monsoon winds. During the summer, when monsoon winds blow from the southwest, ships laden with goods would leave the Arabian ports and sail eastward across the Indian Ocean. During the winter, when the trade winds blow from the northeast, ships would return west.[6]

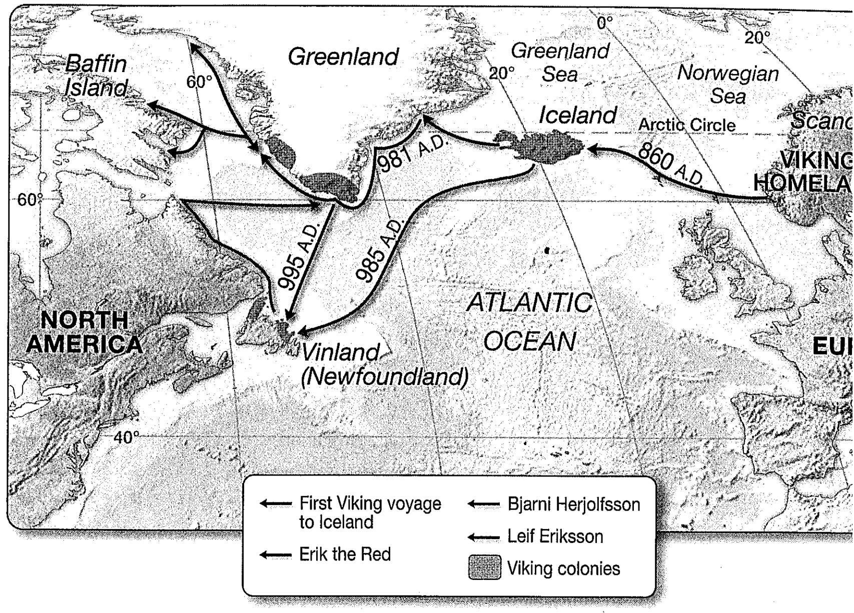


Figure 1.11 Viking colonies in the North Atlantic. Ma showing the routes and dates of Viking explorations and t locations of the colonies that were established in Iceland, Greenland, and parts of North America.

Meanwhile, in the rest of southern and eastern Europe, Christianity was on the rise. Scientific inquiry counter to religious teachings was actively suppressed, and the knowledge gained by previous civilizations was either lost or ignored. As a result, the Western concept of world geography degenerated considerably during these so-called *Dark Ages*. For example, one notion envisioned the world as a disk with Jerusalem at the center.

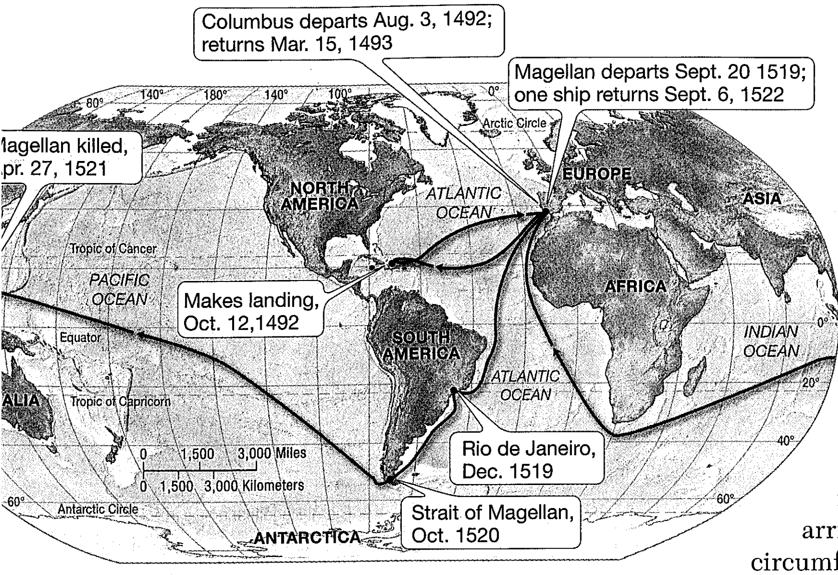
In northern Europe, the **Vikings** of Scandinavia, who had excellent ships and good navigation skills, actively explored the Atlantic Ocean (**Figure 1.11**). Late in the 10th century, aided by a period of worldwide climatic warming, the Vikings colonized Iceland. In about 981 A.D., **Erik "the Red" Thorvaldson** sailed westward from Iceland and discovered Greenland. He may also have traveled further westward to Baffin Island. He returned to Iceland and led the first wave of Viking colonists to Greenland in 985 A.D. **Bjarni Herjólfsson** sailed from Iceland to join the colonists, but he sailed too far southwest and is thought to be the first Viking to have seen what is now called Newfoundland. Bjarni did not land but instead returned to the new colony at Greenland. **Leif Eriksson**, son of Erik the Red, became intrigued by Bjarni's stories about the new land Bjarni had seen. In 995 A.D., Leif bought Bjarni's ship and set out from Greenland for the land that Bjarni had seen to the southwest. Leif spent the winter in that portion of North America and named the land *Vinland* (now Newfoundland, Canada) after the grapes that were found there. Climatic cooling and inappropriate farming practices for the region caused these Viking colonies in Greenland and Vinland to struggle and die out by about 1450.

The Age of Discovery in Europe

The 30-year period from 1492 to 1522 is known as Europe's **Age of Discovery**. During this time, Europeans explored the continents of North and South America, and the globe was circumnavigated for the first time. As a result, Europeans learned the true extent of the world's oceans and that human populations existed elsewhere on newly "discovered" continents and islands with cultures vastly different from those familiar to European voyagers.

Why was there such an increase in ocean exploration during Europe's Age of Discovery? One reason was that Sultan Mohammed II had captured Constantinople (the capital of eastern Christendom) in 1453, a conquest that isolated Mediterranean port cities from the riches of India, Asia, and the East Indies (modern-day Indonesia). As a result, the Western world had to search for new eastern trade routes by sea.

[6]More details about Indian Ocean monsoons can be found in Chapter 7, "Ocean Circulation."



2 **Voyages of Columbus and Magellan.** Map e dates and routes of Columbus's first voyage and the navigation of the globe by Magellan's party.

The Portuguese, under the leadership of **Prince Henry the Navigator** (1392–1460), led a renewed effort to explore outside Europe. The prince established a marine institution at Sagres to improve Portuguese sailing skills. The treacherous journey around the tip of Africa was a great obstacle to an alternative trade route. Cape Agulhas (at the southern tip of Africa) was first rounded by **Bartholomeu Diaz** in 1486. He was followed in 1498 by **Vasco da Gama**, who continued around the tip of Africa to India, thus establishing a new eastern trade route to Asia.

Meanwhile, the Italian navigator and explorer **Christopher Columbus** was financed by Spanish monarchs to find a new route to the East Indies across the Atlantic Ocean. During Columbus's first voyage in 1492, he sailed west from Spain and made landfall after a two-month journey (**Figure 1.12**). Columbus believed that he had arrived in the East Indies somewhere near India, but Earth's circumference had been substantially underestimated, so he was unaware that he had actually arrived in uncharted territory in the Caribbean. Upon his return to Spain and the announcement of his discovery, additional voyages were planned. During the next 10 years, Columbus made three more trips across the Atlantic.

Even though Christopher Columbus is widely credited with discovering North America, he never actually set foot on the continent.[7] Still, his journeys inspired other navigators to explore the "New World." For example, in 1497, only five years after Columbus's first voyage, the Italian navigator and explorer **Giovanni Caboto**, who was also known as **John Cabot**, landed somewhere on the northeastern coast of North America. Later, Europeans first saw the Pacific Ocean in 1513, when **Vasco Núñez de Balboa** attempted a land crossing of the Isthmus of Panama and sighted a large ocean to the west from atop a mountain.

The culmination of the Age of Discovery was a remarkable circumnavigation of the globe initiated by **Ferdinand Magellan** (Figure 1.12). Magellan left Spain in September 1519, with five ships and 280 sailors. He crossed the Atlantic Ocean, sailed down the eastern coast of South America, and traveled through a passage to the Pacific Ocean at 52 degrees south latitude, now named the Strait of Magellan in his honor. After landing in the Philippines in March, 1521, Magellan was killed about a month later in a fight with the inhabitants of these islands. **Juan Sebastian del Caño** completed the circumnavigation by taking the last of the ships, the *Victoria*, across the Indian Ocean, around Africa, and back to Spain in 1522. After three years, just one ship and 18 men completed the voyage.

Following these expeditions, the Spanish initiated many other voyages to take gold from the Aztec and Inca cultures in Mexico and South America. The English and Dutch, meanwhile, used smaller, more maneuverable ships to rob the gold from bulky Spanish galleons, which resulted in many confrontations at sea. The maritime dominance of Spain ended when the English defeated the Spanish Armada in 1588. With control of the seas, the English thus became the dominant world power—a status they retained until early in the 20th century.

The Beginning of Voyaging for Science

The English realized that increasing their scientific knowledge of the oceans would help maintain their maritime superiority. For this reason, Captain **James Cook** (1728–1779), an English navigator and prolific explorer (**Figure 1.13**), undertook three voyages of scientific discovery with the ships *Endeavour,*

[7]For more information about the voyages of Columbus, see Diving Deeper 6.1 in Chapter 6, "Air–Sea Interaction."

Resolution, and *Adventure* between 1768 and 1779. He searched for the continent Terra Australis ("Southern Land," or Antarctica) and concluded that it lay beneath or beyond the extensive ice fields of the southern oceans, if it existed at all. Cook also mapped many islands previously unknown to Europeans, including the South Georgia, South Sandwich, and Hawaiian Islands. During his last voyage, Cook searched for the fabled "northwest passage" from the Pacific Ocean to the Atlantic Ocean and stopped in Hawaii, where he was killed in a skirmish with native Hawaiians.

Cook's expeditions added greatly to the scientific knowledge of the oceans. He determined the outline of the Pacific Ocean and was the first person known to cross the Antarctic Circle in his search for Antarctica. Cook initiated systematic sampling of subsurface water temperatures, measuring winds and currents, taking *soundings* (which are depth measurements that, at the time, were taken by lowering a long rope with a weight on the end to the sea floor), and collecting data on coral reefs. Cook also discovered that a shipboard diet containing the German staple sauerkraut prevented his crew from contracting scurvy, a disease that incapacitated sailors. Scurvy is caused by a vitamin C deficiency, and the cabbage used to make sauerkraut contains large quantities of vitamin C. Prior to Cook's discovery about preventing scurvy, the malady claimed more lives than all other types of deaths at sea, including contagious disease, gunfire, and shipwreck. In addition, by proving the value of John Harrison's chronometer as a means of determining longitude (see Diving Deeper 1.1), Cook made possible the first accurate maps of Earth's surface, some of which are still in use today.

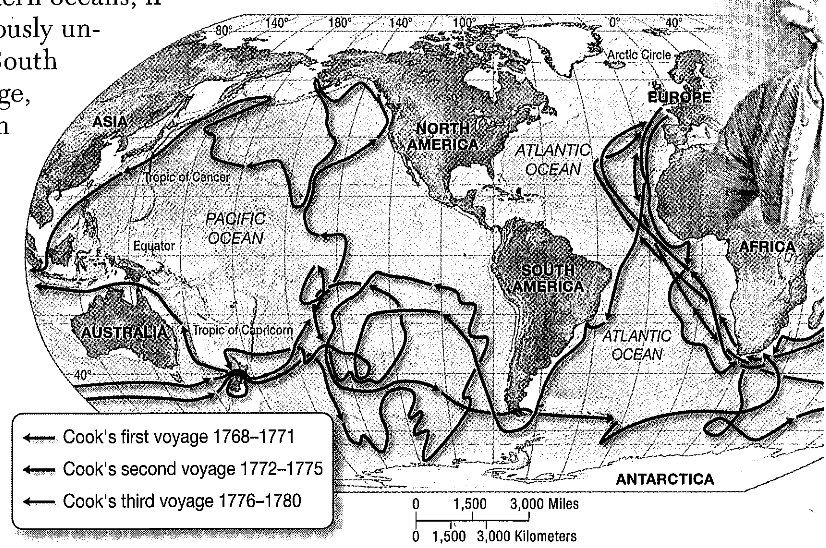


Figure 1.13 Captain James Cook (1728–1779) ar of exploration. Routes taken by Captain James Co his three scientific voyages, which initiated scientific of the oceans. Cook was killed in 1779 in Hawaii dur voyage.

History of Oceanography . . . To Be Continued

Much has changed since the early days of studying the oceans, when scientists used buckets, nets, and lines deployed from ships. And yet, some things remain the same. For example, going to sea aboard ships continues to be a mainstay of ocean science. Also, even though efforts to monitor the ocean are getting bigger and more sophisticated, vast swaths of the marine world remain unknown.

Today, oceanographers employ many high-technology tools, such as state-of-the-art research vessels that routinely use sonar to map the sea floor, remotely operated data collection devices, drifting buoys, robotics, sea floor observation networks, sophisticated computer models, and Earth-orbiting satellites. Many of these tools are featured throughout this book. Further, additional events in the history of oceanography can be found as Diving Deeper features in subsequent chapters. These boxed features are identified by the "Historical Feature" theme, and each introduces an important historical event that is related to the subject of that particular chapter.

CONCEPT CHECK 1.2 | Discuss how early exploration of the oceans was achieved.

1 While the Arabs dominated the Mediterranean region during the Middle Ages, what were the most significant ocean-related events taking place in northern Europe?

2 Describe the important events in oceanography that occurred during the Age of Discovery in Europe.

3 List some of the major achievements of Captain James Cook.

STUDENTS SOMETIMES ASK

What is NOAA? What is its role in ocean research?

NOAA (pronounced "NO-ah") stands for Na and Atmospheric Administration and is the the U.S. Department of Commerce that oversee graphic research. Scientists at NOAA work to e use of ocean resources through the National O the National Oceanographic Data Center, the N Fisheries Service, and the National Sea Grant (U.S. government agencies that work with ocear include the U.S. Naval Oceanographic Office, t Naval Research, the U.S. Coast Guard, and the logical Survey (coastal processes and marine g NOAA Website is at **www.noaa.gov.** In 2013, fe developed the National Ocean Policy Implemer which proposes moving NOAA to the Departme rior so that agencies dealing with natural resou be grouped within the same department.

RECAP

The ocean's large size did not prohibit early expl venturing into all parts of the ocean for discover conquest. Voyaging for science began relatively many parts of the ocean remain unknown.

1.3 What Is Oceanography?

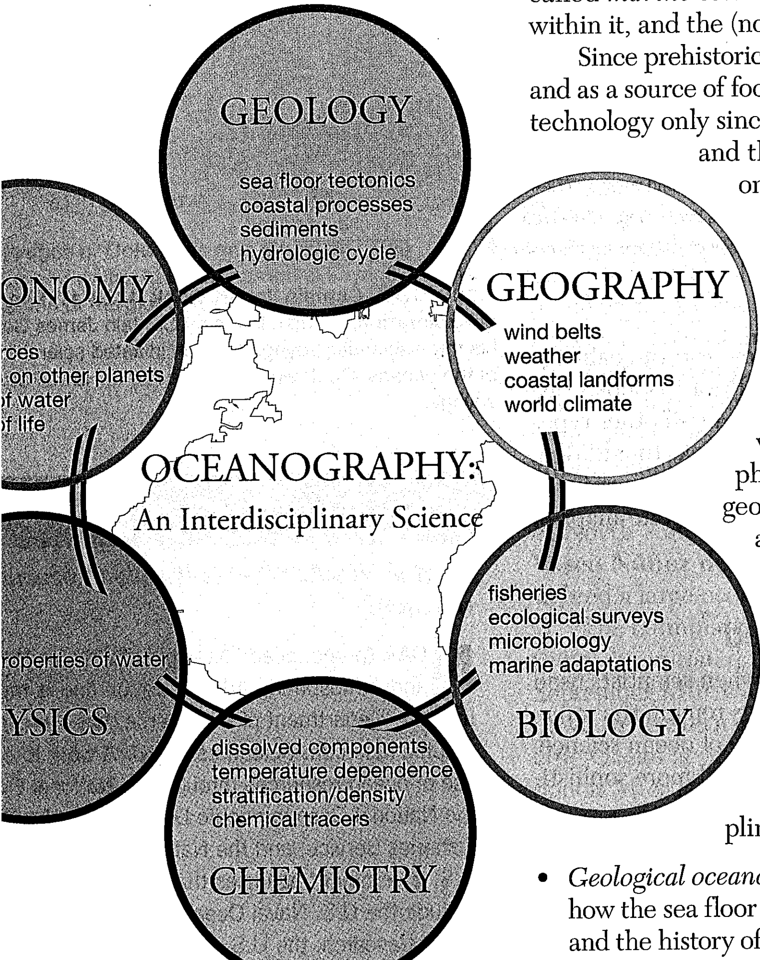
Oceanography (*ocean* = the marine environment, *graphy* = description of) is literally the description of the marine environment. Although the term was first coined in the 1870s, at the beginning of scientific exploration of the oceans, this definition does not fully portray the extent of what oceanography encompasses: Oceanography does much more than just *describe* marine phenomena. Oceanography could be more accurately called the scientific study of all aspects of the marine environment. Hence, the field of study called oceanography could (and maybe *should*) be called oceanology (*ocean* = the marine environment, *ology* = the study of). However, the science of studying the oceans has traditionally been called *oceanography*. It is also called *marine science* and includes the study of the water of the ocean, the life within it, and the (not so) solid Earth beneath it.

Since prehistoric time, people have used the oceans as a means of transportation and as a source of food. Ocean processes, on the other hand, have been studied using technology only since the 1930s, beginning with the search for offshore petroleum and then expanding greatly during World War II with the emphasis on ocean warfare. The recognition of the importance of marine problems by governments, their readiness to make money available for research, the growth in the number of ocean scientists at work, and the increasing sophistication of scientific equipment have all made it feasible to study the ocean on a scale and to a degree of complexity never before attempted nor even possible.

Consider, for example, the logical assumption that those who make their living fishing in the ocean will go where the physical processes of the oceans offer good fishing. How ocean geology, chemistry, and physics work together with biology to create good fishing grounds has been more or less a mystery until only recently, when scientists from those disciplines began to investigate the oceans with new technology. One insight from these studies was the realization of how much of an impact humans are beginning to have on the ocean. As a result, much recent research has been concerned with documenting human impacts on the ocean.

Oceanography is traditionally divided into different academic disciplines (or subfields) of study. The four main disciplines of oceanography that are covered in this book are as follows:

- *Geological oceanography,* which is the study of the structure of the sea floor and how the sea floor has changed through time; the creation of sea floor features; and the history of sediments deposited on it
- *Chemical oceanography,* which is the study of the chemical composition and properties of seawater, how to extract certain chemicals from seawater, and the effects of pollutants
- Physical oceanography, which is the study of waves, tides, and currents; the ocean–atmosphere relationship that influences weather and climate; and the transmission of light and sound in the oceans
- *Biological oceanography,* which is the study of the various oceanic life-forms and their relationships to one another, their adaptations to the marine environment, and developing sustainable methods of harvesting seafood



A Venn diagram showing the interdisciplinary eanography. Oceanography is an interdisciplinary overlaps into many scientific disciplines.

Other disciplines include ocean engineering, marine archaeology, and marine policy. Because the study of oceanography often examines in detail all the different disciplines of oceanography, it is frequently described as being an *interdisciplinary* science, or one covering all the disciplines of science as they apply to the oceans (**Figure 1.14**). In essence, this is a book about *all* aspects of the oceans.

Throughout this book you will see a multicolored interdisciplinary icon showing sections where interdisciplinary science is a featured topic. Two or more parts of the icon—geology, chemistry, physics, and biology—will be highlighted to show which disciplines in particular lend insights to the discussion.

Interdisciplinary Relationship

RECAP

A broad range of interdisciplinary science topic diverse fields of geology, chemistry, physics, a included in the study of oceanography.

CONCEPT CHECK 1.3 | Explain why oceanography is considered an interdisciplinary science.

1 What was the impetus for studying ocean processes that led to the great expansion of the science of oceanography?

2 What are the four main disciplines or subfields of study in oceanography? What other marine-related disciplines exist?

3 What does it mean when oceanography is called an interdisciplinary science?

1.4 What Is the Nature of Scientific Inquiry?

In modern society, scientific studies are increasingly used to substantiate the need for action. However, there is often little understanding of how science operates. For instance, how certain are we about a particular scientific theory? How are facts different from theories?

The overall goal of science is to discover underlying patterns in the natural world and then to use this knowledge to make predictions about what should or should not be expected to happen given a certain set of circumstances. Scientists develop explanations about the causes and effects of various natural phenomena (such as why Earth has seasons or what the structure of matter is). This work is based on an assumption that all natural phenomena are controlled by understandable physical processes and the same physical processes operating today have been operating throughout time. Consequently, science has demonstrated remarkable power in allowing scientists to describe the natural world accurately, to identify the underlying causes of natural phenomena, and to better predict future events that rely on natural processes.

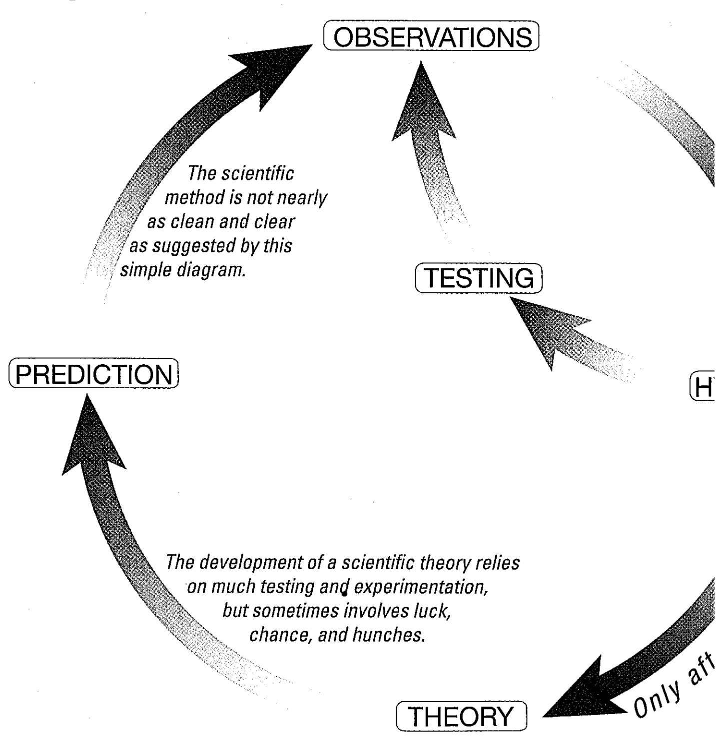
Science supports the explanation of the natural world that best explains all available observations. Scientific inquiry is formalized into what is -observations called the **scientific method** (**Figure 1.15**), which is used to formulate scientific theories and separate science from pseudoscience, fact from fiction.

Observations

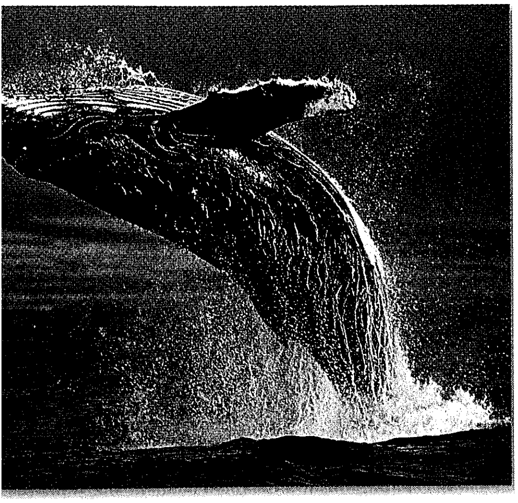
The scientific method begins with *observations*, which are occurrences we can measure with our senses. They are things we can manipulate, see, touch, hear, taste, or smell, often by experimenting with them directly or by using sophisticated tools (such as a microscope or telescope) to sense them. If an observation is repeatedly confirmed—that is, made so many times that it is assumed to be completely valid—then it can be called a *scientific fact*.

Hypothesis

As observations are being made, the human mind attempts to sort out the observations in a way that reveals some underlying order or pattern in the observations or phenomena. This sorting process—which involves a lot of trial and error—seems to be driven by a fundamental human urge to make sense of our world. This is how **hypotheses** (*hypo* = under, *thesis* = an arranging) are made.



SmartFigure 1.15 The scientific method. A circular diagram showing how the scientific method works. https://goo.gl/QPQ9Vz



A breaching humpback whale (*Megaptera* ɘ).

A hypothesis is sometimes labeled as an informed or educated guess, but it is more than that. A hypothesis is a tentative, testable statement about the general nature of reconsidered and modified observed. In other words, a hypothesis is an initial idea of how or why things happen in nature.

Suppose we want to understand why whales *breach* (that is, why whales sometimes leap entirely out of water; **Figure 1.16**). After scientists observe breaching many times, they can organize their observations into a hypothesis. For instance, one hypothesis is that a breaching whale is trying to dislodge parasites from its body. Scientists often have multiple working hypotheses (for example, whales may use breaching to communicate with other whales). If a hypothesis cannot be tested, it is not scientifically useful, no matter how interesting it might seem.

Testing

Hypotheses are used to understand certain occurrences that lead to further research and the refinement of those hypotheses. For instance, the hypothesis that a breaching whale is trying to dislodge its parasites suggests that breaching whales have more parasites than whales that don't breach. Analyzing the number of parasites on breaching versus nonbreaching whales would either support that hypothesis or cause it to be reconsidered and modified. If observations clearly suggest that the hypothesis is incorrect (that is, the hypothesis is *falsified*), then it must be dropped, and other alternative explanations of the facts must be considered.

In science, the validity of any explanation is determined by its coherence with observations in the natural world and its ability to integrate further observations. Only after much testing and experimentation—usually done by many experimenters using a wide variety of repeatable tests—does a hypothesis gain validity where it can be advanced to the next step.

Theory

If a hypothesis has been strengthened by additional observations and if it is successful in explaining additional phenomena, then it can be advanced to what is called a **theory** (*theoria* = a looking at). A theory is a well-substantiated explanation of some aspect of the natural world that can incorporate facts, laws (descriptive generalizations about the behavior of an aspect of the natural world), logical inferences, and tested hypotheses. A theory is not a guess or a hunch. Rather, it is an understanding that develops from extensive observation, experimentation, and creative reflection.

In science, theories are formalized only after many years of testing and verification. Thus, scientific theories have been rigorously scrutinized to the point where most scientists agree that they are the best explanation of certain observable facts. Examples of prominent, well-accepted theories that are held with a very high degree of confidence include biology's theory of evolution (which is discussed later in this chapter) and geology's theory of plate tectonics (which is covered in the next chapter).

Theories also have predictive value, that is, they are useful in predicting what should happen given a certain set of circumstances. If a theory makes no predictions at all, then it has little scientific value. But as is often the case, predictions lead to new observations and a continuation of the cycle that is the process of science.

Theories and the Truth

We've seen how the scientific method is used to develop theories, but does science ever arrive at the undisputed "truth"? Science never reaches an absolute truth because we can never be certain that we have all the observations, especially considering that new technology will be available in the future to examine phenomena in different ways. Notice that there is no end point to the process depicted here. New observations are always possible, so the nature of scientific truth is subject to change. Therefore, it is more accurate to say that science arrives at that which is *probably* true, based on the available observations.

ITS SOMETIMES ASK ...

accept a scientific idea if it's just a theory?

ost people use the word "theory" in everyday usually means an idea or a guess (such as the non "conspiracy theory"), but the word has a ent meaning in science. In science, a theory is or a hunch. It's a well-substantiated, well-sup- -documented explanation for observations about world. It's a powerful tool that ties together all out something, providing an explanation that fits rvations and can even be used to make predic- ence, a theory is a well-established explanation of ural world works. For a scientific theory to exist, ave to be *very* sure about it; in fact, theories are proven as anything in science can be. So, don't scientific idea because it's "just a theory."

It is not a downfall or weakness of science that scientific ideas are modified as more observations are collected. In fact, the opposite is true. Science is a process that depends on reexamining ideas as new observations are made. Thus, science progresses when new observations yield new hypotheses and modification of theories. As a result, science is littered with hypotheses that have been abandoned in favor of later explanations that fit new observations. One of the best known is the idea that Earth was at the center of the universe, a proposal that was supported by the apparent daily motion of the Sun, Moon, and stars around Earth.

The statements of science should never be accepted as the "final truth." Over time, however, they generally form a sequence of increasingly more accurate statements. Theories are the endpoints in science and do not turn into facts through accumulation of evidence. Nevertheless, the data can become so convincing that the accuracy of a theory is no longer questioned. For instance, the *heliocentric* (*helios* = sun, *centric* = center) *theory* of our solar system states that Earth revolves around the Sun rather than vice versa. Such concepts are supported by such abundant observational and experimental evidence that they are no longer questioned in science.

Is there really such a formal method to science as the scientific method suggests? Actually, the work of scientists is much less formal and is not always done in a clearly logical and systematic manner. Like detectives analyzing a crime scene, scientists use ingenuity and serendipity, visualize models, and sometimes follow hunches in order to unravel the mysteries of nature.

Finally, a key component of verifying scientific ideas is through the peer review process. Once scientists make a discovery, their aim is to get the word out to the scientific community about their results. This is typically done via a published paper, but a draft of the manuscript is first checked by other experts to see if the work has been conducted according to scientific standards and the conclusions are valid. Normally, corrections are suggested and the paper is revised before it is published. This process is a strength of the scientific community and helps weed out inaccurate or poorly formed ideas.

STUDENTS SOMETIMES AS

If a theory is proven again and again, become a law?

No, that's a common misconception. I collect facts, or observations, we use describe them (often using mathematics), theory to explain them. Natural laws are t sions based on repeated scientific experin vations over many years and which have b universally within the scientific communit the *law of gravity* is a description of the fo is the *theory of gravitational attraction,* wh the force occurs. Theories don't get "prom by an abundance of proof, and so a theory a law. They're really two separate things.

RECAP

Science supports the explanation of the natur explains all available observations. Because can modify existing theories, science is alwa

CONCEPT CHECK 1.4 | Describe the nature of scientific inquiry.

1 Describe the steps involved in the scientific method.

2 What is the difference between a hypothesis and a theory?

3 Briefly comment on the phrase "scientific certainty." Is it an oxymoron (a combination of contradictory words), or are scientific theories considered to be the absolute truth?

4 Can a theory ever be so well established that it becomes a fact? Explain. or slight changes in the emitted light of distant stars, such as the decrease in brightness as planets pass in front of them.

1.5 How Were Earth and the Solar System Formed?

Earth is the third of eight major planets[8] in our **solar system** that revolve around the Sun (**Figure 1.17**). Evidence suggests that the Sun and the rest of the solar system formed about 5 billion years ago from a huge cloud of gas and space dust called a **nebula** (*nebula* = a cloud). Astronomers base this hypothesis on the orderly nature of our solar system and the consistent age of meteorites (pieces of the early solar system). Using sophisticated telescopes, astronomers have also been able to observe distant nebula and planetary systems in various stages of formation elsewhere in our galaxy (**Figure 1.18**). In addition, more than 2000 planets have been discovered outside our solar system—including several that are about the size of Earth—by detecting the telltale wobble of distant stars or slight changes in the emitted light of remote stars, such as the decrease in brightness as planets pass in front of them.

[8]Pluto, which used to be considered the ninth planet in our solar system, was reclassified by the International Astronomical Union as a "dwarf planet" in 2006, along with other similar bodies.

The Nebular Hypothesis

According to the **nebular hypothesis** (**Figure 1.19**), all bodies in the solar system formed from an enormous cloud composed mostly of hydrogen and helium, with only a small percentage of heavip elements. As this huge accumulation of gas and dust revolved around its center, it began to contract under its own gravity, becoming hotter and denser, eventually forming the Sun.

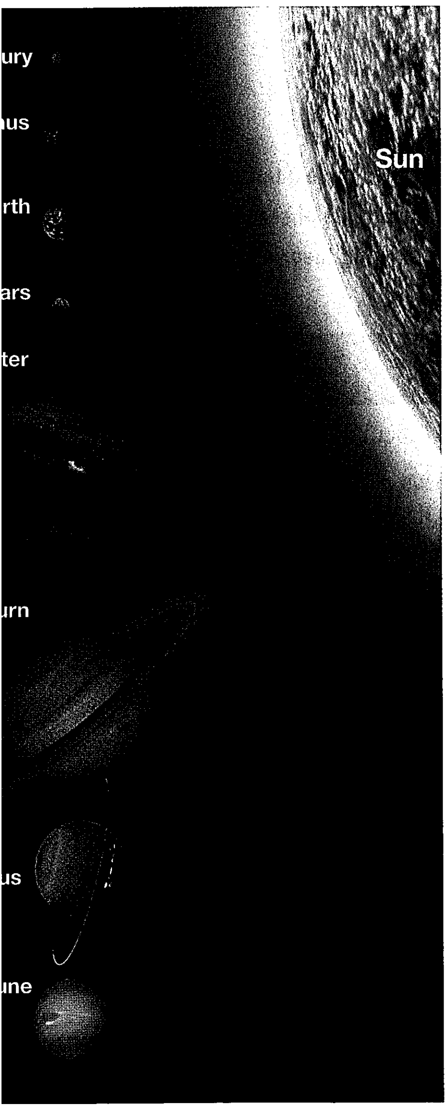
As the nebular matter that formed the Sun contracted, small amounts of it were left behind in swirling eddies, which are similar to small whirlpools in a stream. The material in these eddies was the beginning of the **protoplanets** (*proto* = original, *planetes* = wanderer) and their orbiting satellites, which later consolidated into the present planets and their moons.

Proto-Earth

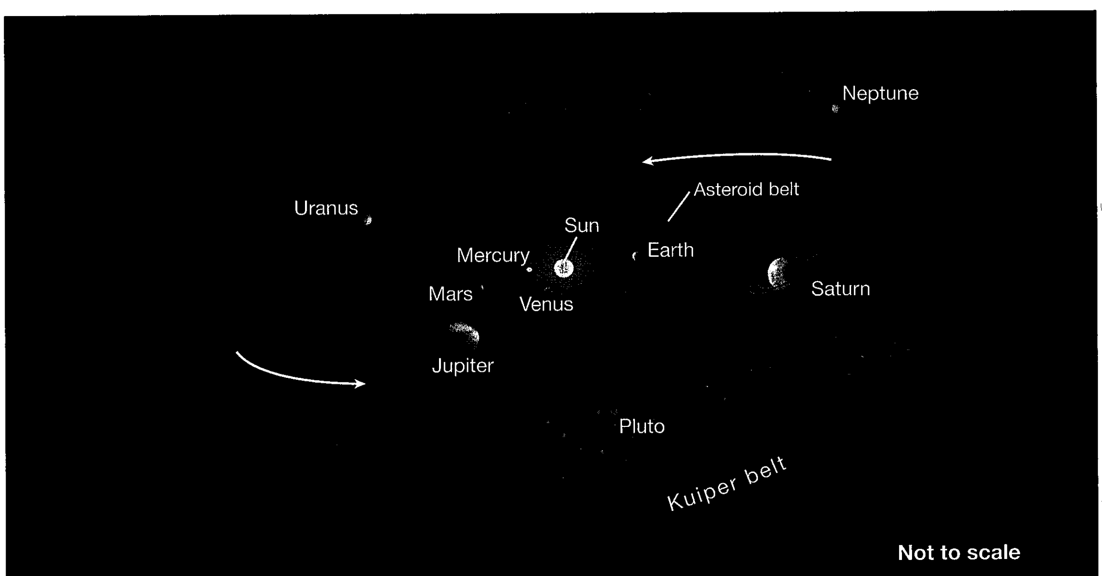
Proto-Earth looked very different from Earth today. Its size was larger than today's Earth, and there were neither oceans nor any life on the planet. In addition, the structure of the deep proto-Earth is thought to have been *homogenous* (*homo* = alike, *genous* = producing), which means that it had a uniform composition throughout. The structure of proto-Earth changed, however, as its heavier constituents sank toward the center to form a heavy core.

During this early stage of formation, many meteorites and comets from space bombarded proto-Earth (**Figure 1.20**). In fact, a leading theory states that the Moon was born in the aftermath of a titanic collision between a Mars-size planet named *Theia* and proto-Earth. While most of Theia was swallowed up and incorporated into the magma ocean it created on impact, the collision also flung a small world's worth of vaporized and molten rock into orbit. Over time, this debris coalesced into a sphere and created Earth's orbiting companion, the Moon.

During this early formation of the protoplanets and their satellites, the Sun condensed into a body so massive and hot that pressure within its core initiated the process of **thermonuclear fusion** (*thermo* = hot, *nucleos* = a little nut; *fusus* = melted). Thermonuclear fusion occurs when temperatures reach tens of millions of degrees and hydrogen **atoms** (*a* = not, *tomos* = cut) combine to form helium atoms, releasing enormous amounts of energy.[9] Not only does the Sun emit light, it also emits *ionized* (electrically charged) particles that make up the *solar wind*. During the early stages of



s and relative sizes of the Sun and
it major planets of the solar system.

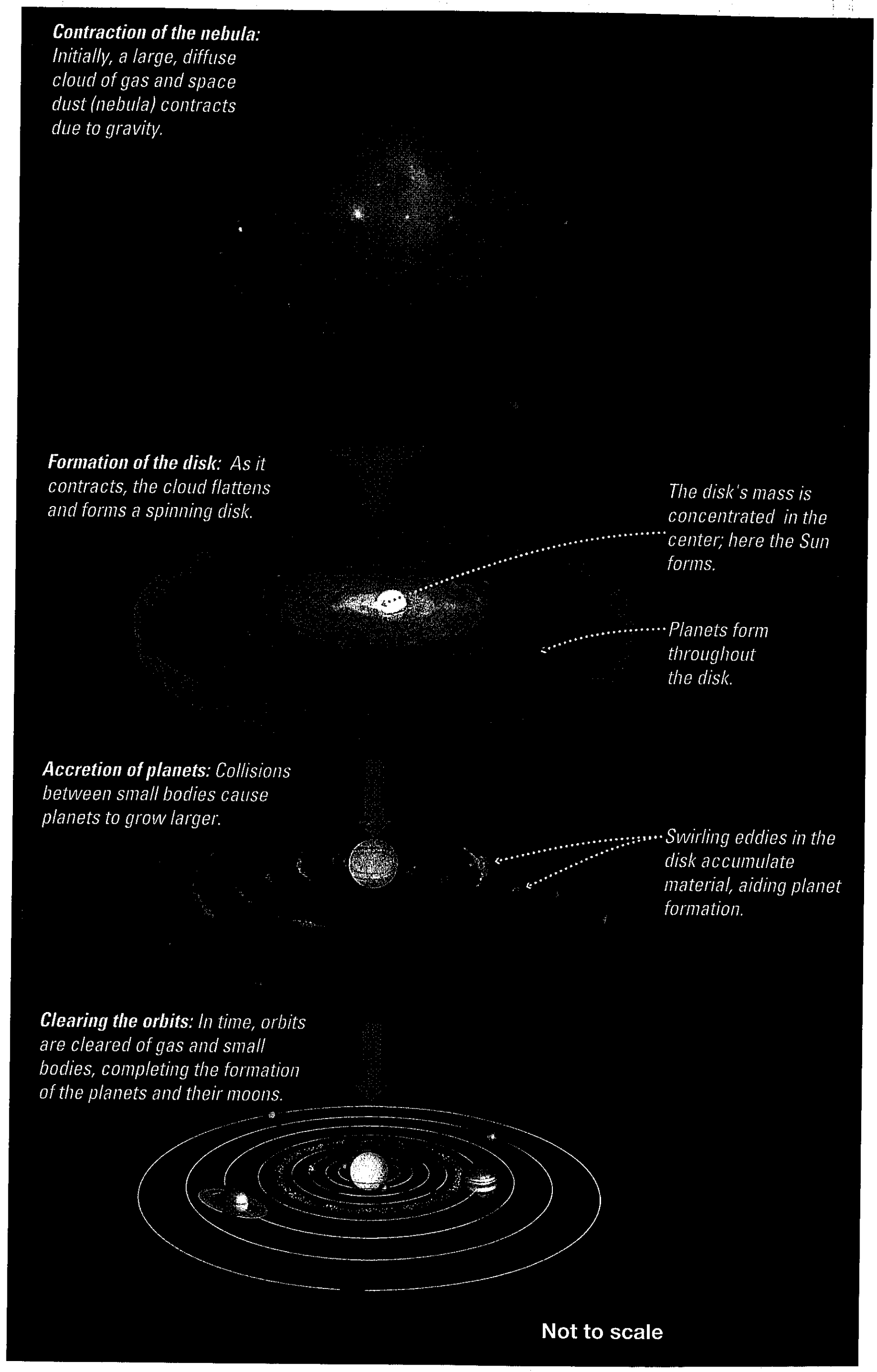


(b) Orbits and relative positions of various features of the solar system.

17 **The solar system.** Schematic views of the solar system, which includes the Sun and eight major planets.

Figure 1.18 The Ghost Head Nebula. NASA's Hubble Space Telescope image of the Ghost Head Nebula (NGC 2080), which is a site of active star formation.

Figure 1.20 Proto-Earth. An artist's conception of what Earth may have looked like early in its development.



SmartFigure 1.19 The nebular hypothesis of solar system formation. According to the nebular hypothesis, our solar system formed from the gravitational contraction of an interstellar cloud of gas and space dust called a *nebula*.
https://goo.gl/FoY7Yt

Web Animation

The Nebular Hypothesis of Solar System Formation
http://goo.gl/KObsRK

formation of the solar system, this solar wind blew away the nebular gas that remained from the formation of the planets and their satellites.

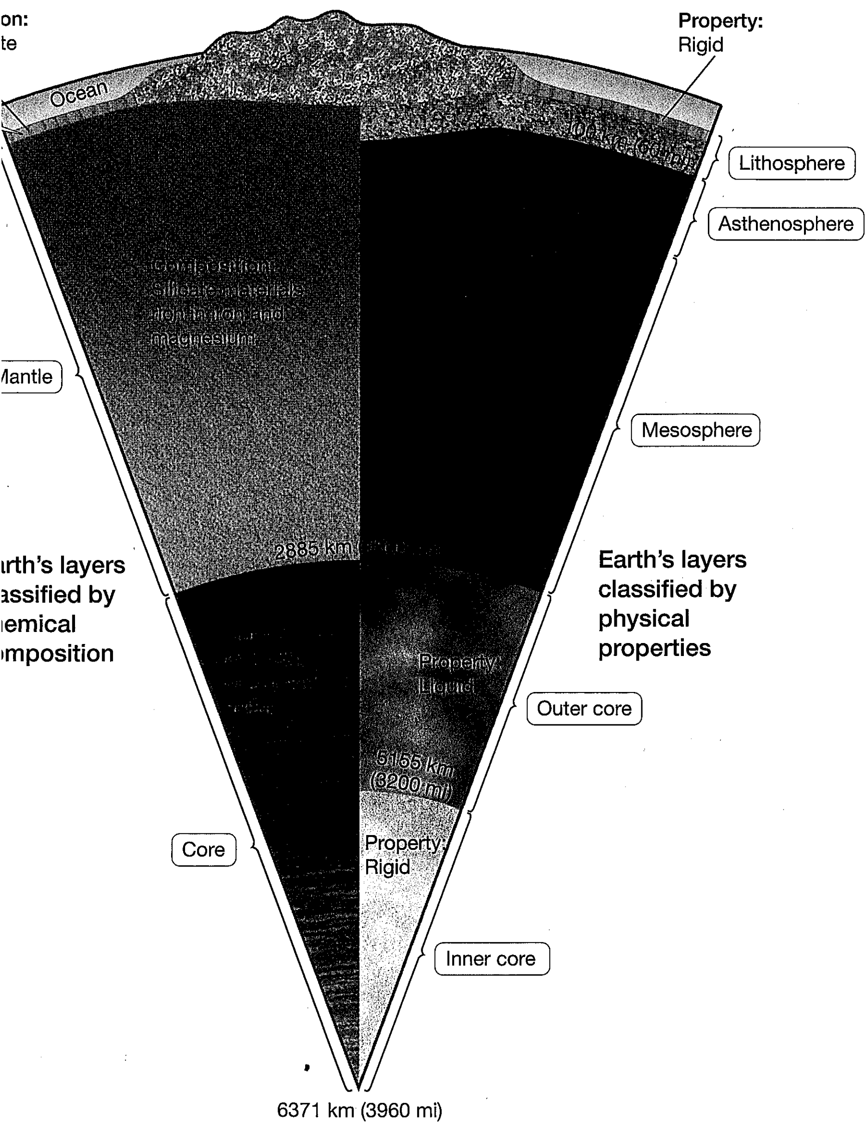
The protoplanets closest to the Sun (including Earth) also lost their initial atmospheres (mostly hydrogen and helium), blown away by the bombardment by ionized solar radiation. At the same time, these rocky protoplanets were gradually cooling, causing them to contract and drastically shrink in size. As the protoplanets continued to contract, another source of heat was produced deep within their cores from the spontaneous disintegration of atoms, called *radioactivity* (*radio* = ray, *acti* = to cause).

[9]Thermonuclear fusion in stars also creates larger and more complex elements, such as carbon. It is interesting to note that as a result, all matter—even the matter that comprises our bodies—originated as stardust long ago.

Density and Density Stratification

Density, which is an extremely important physical property of matter, is defined as mass per unit volume. In common terms, an easy way to think about density is that it is a measure of *how heavy something is for its size*. For instance, an object that has a low density is light for its size (like a dry sponge, foam packing, or a surfboard). Conversely, an object that has a high density is heavy for its size (like cement, most metals, or a large container full of water). Note that density has nothing to do with the *thickness* of an object; some objects (like a stack of foam packing) can be thick but have low density. In reality, density is related to molecular packing, with higher packing of molecules into a certain space resulting in higher density. Density is an extremely important concept that will be discussed in many other chapters in this book. For example, the density of Earth's layers dramatically affects their locations within Earth (Chapter 2), the density of air masses affects their positions in the atmosphere and other properties (Chapter 6), and the density of water masses determines how deep in the ocean they are found and how they move (Chapter 7).

On the early Earth, heat generated at the surface by the bombardment of space debris and heat released internally by the decay of radioactive elements was so intense that Earth's surface became molten. Once Earth became a ball of hot liquid rock, the elements were able to segregate according to their densities in a process called **density stratification** (*strati* = a layer, *fication* = making), which occurs because of *gravitational separation*. The highest-density materials (primarily iron and nickel) concentrated in the core, whereas progressively lower-density components (primarily rocky material) formed concentric spheres around the core. If you've ever noticed how oil-and-vinegar salad dressing settles out into a lower-density top layer (the oil) and a higher-density bottom layer (the vinegar), then you've seen how density stratification causes separate layers to form.



tFigure 1.21 **Comparison of Earth's chemical composition and physical** . A cross-sectional view of Earth, showing Earth's layers classified by omposition along the left side of the diagram. For comparison, Earth's layers y physical properties are shown along the right side of the diagram. Layers rface are enlarged for clarity.
.gl/JjglcZ

Earth's Internal Structure

As a result of density stratification, Earth became a layered sphere based on density, with the highest-density material found near the center of Earth and the lowest-density material located near the surface. Let's examine Earth's internal structure and the characteristics of its layers.

CHEMICAL COMPOSITION VERSUS PHYSICAL PROPERTIES The cross-sectional view of Earth in **Figure 1.21** shows that Earth's inner structure can be subdivided according to its chemical composition (the chemical makeup of Earth materials) or its physical properties (how the rocks respond to increased temperature and pressure at depth).

CHEMICAL COMPOSITION Based on chemical composition, Earth consists of three layers: the **crust**, the **mantle**, and the **core** (Figure 1.21). If Earth were reduced to the size of an apple, then the crust would be its thin skin. It extends from the surface to an average depth of about 30 kilometers (20 miles). The crust is composed of relatively low-density rock, consisting mostly of various *silicate minerals* (common rock-forming minerals with silicon and oxygen). There are two types of crust—oceanic and continental—that will be discussed in the next section.

Immediately below the crust is the mantle. It occupies the largest volume of the three layers and extends to a depth of about 2885 kilometers (1800 miles). The mantle is composed of relatively high-density iron and magnesium silicate rock.

Beneath the mantle is the core. It forms a large mass from 2885 kilometers (1800 miles) to the center of Earth at 6371 kilometers (3960 miles). The core is composed of even higher-density metal (mostly iron and nickel).

Interdisciplinary Relationship

PHYSICAL PROPERTIES Based on physical properties, Earth is composed of five layers (Figure 1.21): the **inner core**, the **outer core**, the **mesosphere** (*mesos* = middle, *sphere* = ball), the **asthenosphere** (*asthenos* = weak, *sphere* = ball), and the **lithosphere** (*lithos* = rock, *sphere* = ball).

The lithosphere is Earth's cool, rigid, outermost layer. It extends from the surface to an average depth of about 100 kilometers (62 miles) and includes the crust plus the topmost portion of the mantle. The lithosphere is *brittle* (*brytten* = to shatter), meaning that it will fracture when force is applied to it. As will be discussed in Chapter 2, "Plate Tectonics and the Ocean Floor," the plates involved in plate tectonic motion are the plates of the lithosphere.

Beneath the lithosphere is the asthenosphere. The asthenosphere is *plastic* (*plasticus* = molded), meaning that it will flow when a gradual force is applied to it. It extends from about 100 kilometers (62 miles) to 700 kilometers (430 miles) below the surface, which is the base of the upper mantle. At these depths, it is hot enough to partially melt portions of most rocks.

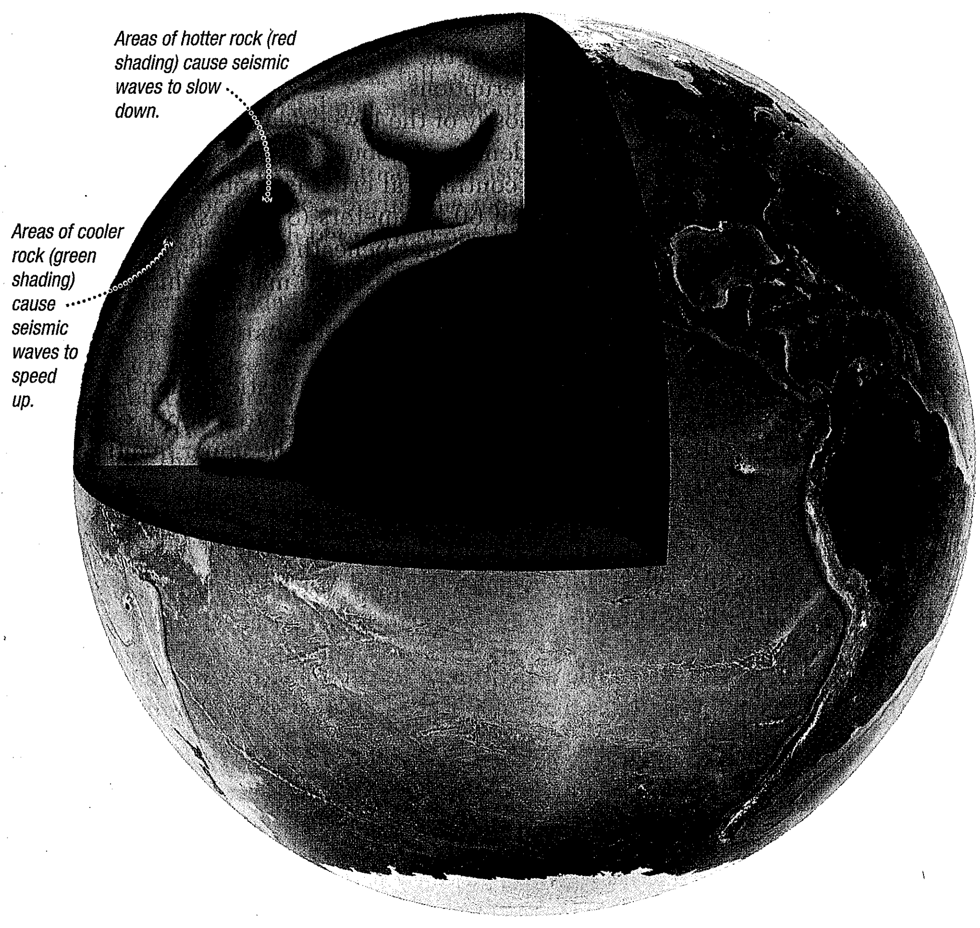


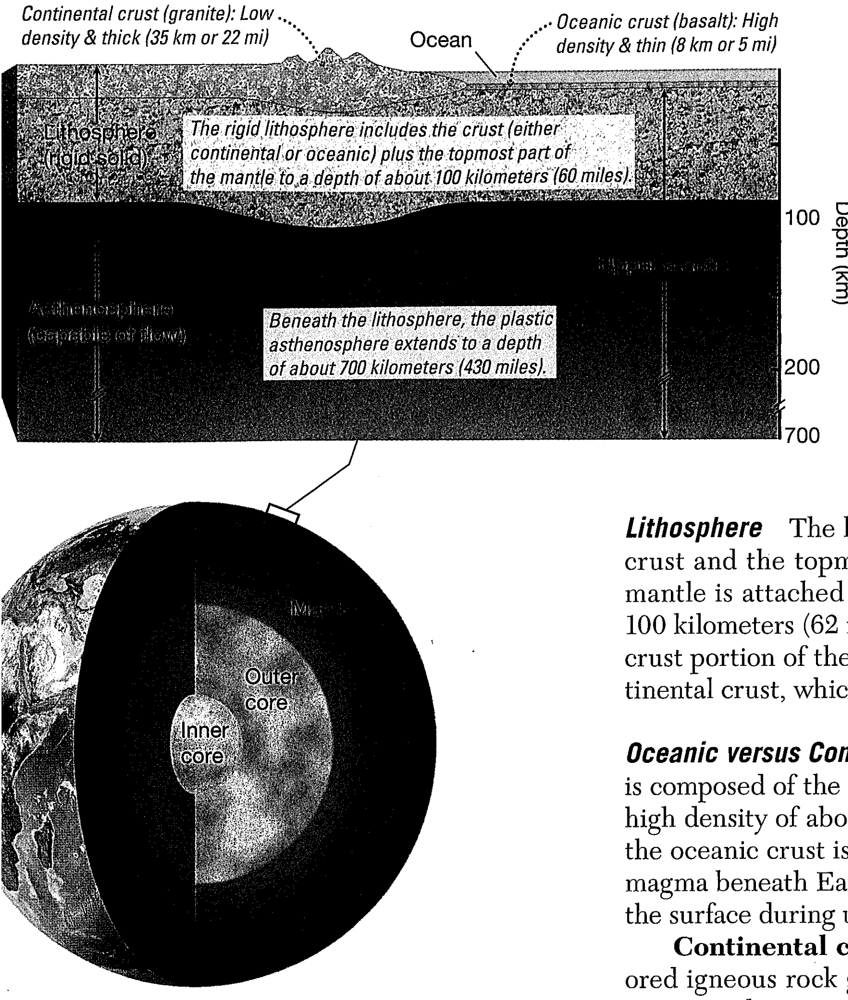
Figure 1.22 Determining the internal structure of Earth. By analyzing how various seismic waves travel through Earth, scientists are able to map Earth's complex inner structure.

Web Animation
How Seismic Waves Reveal Earth's Internal Layers
http://goo.gl/Kx4DtO

STUDENTS SOMETIMES ASK ...

How do we know about the internal structure of

You might suspect that the internal structure of Earth has been sampled directly. However, humans have never penetrated beneath Earth's crust! Instead, the internal structure of Earth is determined by analyzing earthquakes that send vibrations through the deep interior of our planet. Th vibrations are called *seismic waves*, which change th speed and are bent and reflected as they move throu zones having different properties. For example, seisn waves travel more slowly through areas of hotter roc speed up thorough colder rock. An extensive networ monitoring stations around the world detects and re these vibrations. The data are analyzed and used to mine the structure and properties of the deep Earth they change over time. In fact, repeated analysis of waves that pass through Earth has allowed research construct a detailed three-dimensional model of Ear interior—similar to an MRI in medical technology— reveals the inner workings of our planet (**Figure 1.22**



e 1.23 **Internal structure of Earth showing an enlargement ers close to the surface.**

CAP

ı has differences in composition and physical properties ɔreate layers such as the brittle lithosphere and the plastic ɘnosphere, which is capable of flowing slowly over time.

Beneath the asthenosphere is the mesosphere. The mesosphere extends to a depth of about 2885 kilometers (1800 miles), which corresponds to the middle and lower mantle. Although the asthenosphere deforms plastically, the mesosphere is rigid becasue of the increased pressure at these depths.

Beneath the mesosphere is the core. The core consists of the outer core, which is liquid and capable of flowing, and the inner core, which is rigid and does not flow. Again, the increased pressure at the center of Earth keeps the inner core from flowing.

NEAR THE SURFACE The top portion of **Figure 1.23** shows an enlargement of Earth's layers closest to the surface.

Lithosphere The lithosphere is a relatively cool, rigid shell that includes all the crust and the topmost part of the mantle. In essence, the topmost part of the mantle is attached to the crust, and the two act as a single unit, approximately 100 kilometers (62 miles) thick. The expanded view in Figure 1.23 shows that the crust portion of the lithosphere is further subdivided into oceanic crust and continental crust, which are compared in **Table 1.1**.

Oceanic versus Continental Crust **Oceanic crust** underlies the ocean basins and is composed of the igneous rock **basalt**, which is dark colored and has a relatively high density of about 3.0 grams per cubic centimeter.[10] The average thickness of the oceanic crust is only about 8 kilometers (5 miles). Basalt originates as molten magma beneath Earth's crust (typically from the mantle), some of which comes to the surface during underwater sea floor eruptions.

Continental crust is composed mostly of the lower-density and lighter-colored igneous rock **granite**.[11] It has a density of about 2.7 grams per cubic centimeter. The average thickness of the continental crust is about 35 kilometers (22 miles) but may reach a maximum of 60 kilometers (37 miles) beneath the highest mountain ranges. Most granite originates beneath the surface as molten magma that cools and hardens within Earth's crust. No matter which type of crust is at the surface, it is all part of the lithosphere.

Asthenosphere The asthenosphere is a relatively hot, plastic region beneath the lithosphere. It extends from the base of the lithosphere to a depth of about 700 kilometers (430 miles) and is entirely contained within the upper mantle. The asthenosphere can deform without fracturing if a force is applied slowly. This means that it has the ability to flow but has high **viscosity** (*viscosus* = sticky). Viscosity is a measure of a substance's resistance to flow.[12] Studies indicate that the high-viscosity asthenosphere is flowing slowly through time; this has important implications for the movement of lithospheric plates.

ISOSTATIC ADJUSTMENT **Isostatic adjustment** (*iso* = equal, *stasis* = standing)—the vertical movement of crust—is the result of the buoyancy of Earth's lithosphere

[10] Water has a density of 1.0 grams per cubic centimeter. Thus, basalt with a density of 3.0 grams per cubic centimeter is three times denser than water.

[11] At the surface, continental crust is often covered by a relatively thin layer of surface sediments. Below these, granite can be found.

[12] Substances that have high viscosity (a high resistance to flow) include toothpaste, honey, tar, and Silly Putty; a common substance that has low viscosity is water. Note that a substance's viscosity often changes with temperature. For instance, as honey is heated, it flows more easily.

SMARTTABLE 1.1 COMPARING OCEANIC AND CONTINENTAL CRUST

	Oceanic crust	Continental crust
Main rock type	Basalt (dark-colored igneous rock)	Granite (light-colored igneous rock)
Density (grams per cubic centimeter)	3.0	2.7
Average thickness	8 kilometers (5 miles)	35 kilometers (22 miles)

SmartTable 1.1 Comparing oceanic and continental crust.
https://goo.gl/EneJOI

as it floats on the denser, plastic-like asthenosphere below. **Figure 1.24**, which shows a container ship floating in water, provides an example of isostatic adjustment. It shows that an empty ship floats high in the water. Once the ship is loaded with cargo, though, the ship undergoes isostatic adjustment and floats lower in the water (but hopefully won't sink!). When the cargo is unloaded, the ship isostatically adjusts itself and floats higher again.

Interdisciplinary Relationship

Similarly, both continental and oceanic crust float on the denser mantle beneath. Oceanic crust is denser than continental crust, however, so oceanic crust floats lower in the mantle because of isostatic adjustment. Oceanic crust is also thin, which creates low areas for the oceans to occupy. Areas where the continental crust is thickest (such as large mountain ranges on the continents) float higher than continental crust of normal thickness, also because of isostatic adjustment. These mountains are similar to the top of a floating iceberg—they float high because there is a very thick mass of crustal material beneath them, plunged deeper into the asthenosphere. Thus, tall mountain ranges on Earth are composed of a great thickness of crustal material sometimes referred to as a root, that in essence keeps them buoyed up.

Areas that are exposed to an increased or decreased load experience isostatic adjustment. For instance, during the most recent ice age (which occurred during the Pleistocene Epoch between about 1.8 million and 10,000 years ago), massive ice sheets alternately covered and exposed northern regions such as Scandinavia and northern Canada. The additional weight of ice several kilometers thick caused these areas to isostatically adjust themselves lower in the mantle. Since the end of the most recent ice age, the reduced load on these areas caused by the melting of ice caused these areas to rise and experience **isostatic rebound**, which continues today. The rate at which isostatic rebound occurs gives scientists important information about the properties of the upper mantle.

Further, isostatic adjustment provides additional evidence for the movement of Earth's tectonic plates. Because continents isostatically adjust themselves by moving *vertically*, they must not be firmly fixed in one position on Earth. As a result, the plates that contain these continents should certainly be able to move *horizontally* across Earth's surface. This remarkable idea will be explored in more detail in the next chapter.

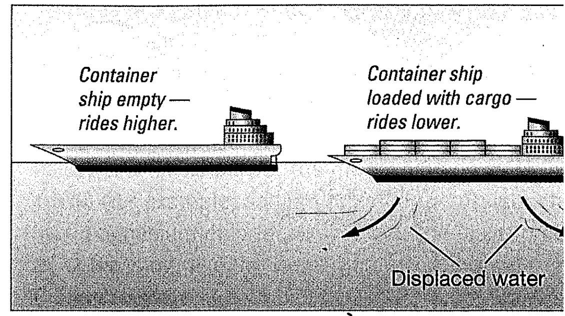


Figure 1.24 A container ship experiences isostatic adjustment. A ship will ride higher in water when it is emp and will ride lower in water when it is loaded with cargo, illustrating the principle of isostatic adjustment.

Web Animation
Isostatic Adjustment
https://goo.gl/esrK8U

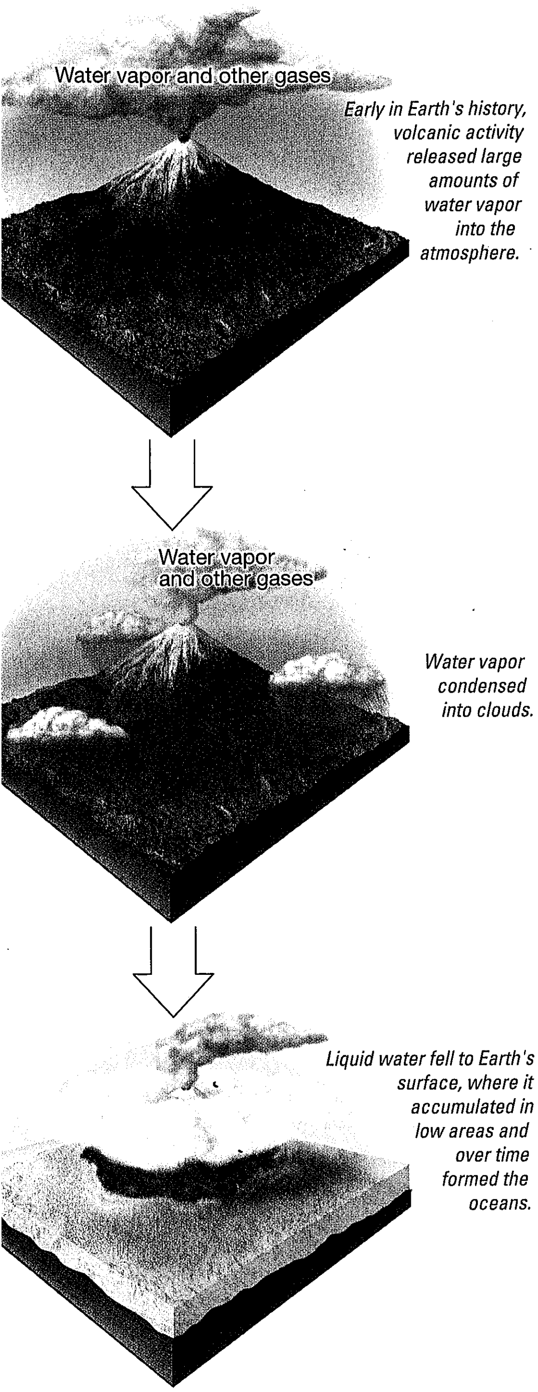
CONCEPT CHECK 1.5 | Explain how Earth and the solar system formed.

1 Discuss the origin of the solar system using the nebular hypothesis.

2 How was proto-Earth different from Earth today?

3 What is density stratification, and how did it change proto-Earth?

4 What are some differences between the lithosphere and the asthenosphere?



e 1.25 **Formation of Earth's oceans.**

Web Animation
Formation of Earth's Oceans
https://goo.gl/gCXrDg

1.6 How Were Earth's Atmosphere and Oceans Formed?

The formation of Earth's atmosphere is related to the formation of the oceans; both are a direct result of density stratification.

Origin of Earth's Atmosphere

Where did the atmosphere come from? As previously mentioned, Earth's initial atmosphere consisted of leftover gases from the nebula, but those particles were blown out to space by the Sun's solar wind. After that, a second atmosphere was most likely expelled from inside Earth by a process called **outgassing**. During the period of density stratification, the lowest-density material contained within Earth was composed of various gases. These gases rose to the surface and were expelled to form Earth's early atmosphere.

What was the composition of these atmospheric gases? They are believed to have been similar to the gases emitted from volcanoes, geysers, and hot springs today: mostly water vapor (steam), with small amounts of carbon dioxide, hydrogen, and other gases. The composition of this early atmosphere was not, however, the same composition as today's atmosphere. The composition of the atmosphere changed over time because of the influence of life (as will be discussed shortly) and possibly because of changes in the mixing of material in the mantle.

Origin of Earth's Oceans

Where did the oceans come from? Similarly, their origin is linked directly to the origin of the atmosphere. Because outgassing releases mostly water vapor, this was the primary source of water on Earth, including supplying the oceans with water. **Figure 1.25** shows that as Earth cooled, the water vapor released to the atmosphere during outgassing condensed, fell to Earth, and accumulated in low areas. Evidence suggests that by at least 4 billion years ago, most of the water vapor from outgassing had accumulated to form the first permanent oceans on Earth.

Recent research, however, suggests that not all water came from inside Earth. Comets, which are composed of about half water, were once widely held to be the source of Earth's oceans. During Earth's early development, space debris left over from the origin of the solar system bombarded the young planet, and there could have been plenty of water supplied to Earth in this way. However, spectral analyses of the chemical composition of three comets—Halley, Hyakutake, and Hale-Bopp—during near-Earth passes they made in 1986, 1996, and 1997, respectively, revealed a crucial chemical difference between the hydrogen in comet ice and that in Earth's water. In 2014, the European Space Agency's Rosetta spacecraft reached the orbit of a comet to gather data on its ice. Although the lander sent to the comet's surface failed to send back data, the orbiter was able to analyze the comet's ice and determined that it, too, did not chemically match the water in Earth's oceans. If similar comets supplied large quantities of water to Earth, much of Earth's water would still exhibit the telltale type of hydrogen identified in these comets.

Even though comet ice doesn't match the chemical signature of Earth's water, there are a variety of small bodies in the solar system that could have supplied water to Earth. For example, recent analysis of a comet from the Kuiper Belt (an icy debris disk in the outer solar system that includes Pluto) indicates it *does* contain water with nearly the correct type of hydrogen that is found in Earth's water. In addition to Kuiper Belt objects, asteroids—rocky bodies that contain ice and orbit the Sun between Mars and Jupiter—also have a similar type of hydrogen and thus could have contributed water to an early Earth. These finds point to an emerging picture of a complex and dynamic evolution of the early solar system. Although it seems likely that most of Earth's water was derived from outgassing, other sources of water may have contributed to Earth's oceans as well.

ᴐAP

ially, Earth had no oceans. The oceans (and atmosphere) from inside Earth as a result of outgassing and were nt by at least 4 billion years ago.

THE DEVELOPMENT OF OCEAN SALINITY The relentless rainfall that landed on Earth's rocky surface dissolved many elements and compounds and carried them into the newly forming oceans. Even though Earth's oceans have existed since early in the formation of the planet, its chemical composition must have changed. This is because the high carbon dioxide and sulfur dioxide content in the early atmosphere would have created a very acidic rain, capable of dissolving greater amounts of minerals in the crust than occurs today. In addition, volcanic gases such as chlorine became dissolved in the atmosphere. As rain fell and washed to the ocean, it carried some of these dissolved compounds, which accumulated in the newly forming oceans.[13] Eventually, a balance between inputs and outputs was reached, producing an ocean with a chemical composition similar to today's oceans. Further aspects of the oceans' salinity are explored in Chapter 5, "Water and Seawater."

CONCEPT CHECK 1.6 | Explain how Earth's atmosphere and oceans formed.

1 Describe the origin of Earth's oceans.

2 Describe the origin of Earth's atmosphere. How is its origin related to the origin of Earth's oceans?

3 Have the oceans always been salty? Why or why not?

1.7 Did Life Begin in the Oceans?

The fundamental question of how life began on Earth has puzzled humankind since ancient times and has recently received a great amount of scientific study. The evidence required to understand our planet's prebiotic environment and the events that led to first living systems is scant and difficult to decipher. Still, the inventory of current views on life's origin reveals a broad assortment of opposing positions. One recent hypothesis is that the organic building blocks of life may have arrived embedded in meteors, comets, or cosmic dust. Alternatively, life may have originated around hydrothermal vents—hot springs—on the deep-ocean floor. Yet another idea is that life originated in certain minerals that acted as chemical catalysts within rocks deep below Earth's surface.

According to the fossil record on Earth, the earliest-known life-forms were primitive bacteria that lived in sea floor rocks about 3.5 billion years ago. Unfortunately, Earth's geologic record for these early times is so sparse and the rocks are so deformed by Earth processes that the rocks no longer reveal life's precursor molecules. In addition, there is no direct evidence of Earth's environmental conditions (such as its temperature, ocean acidity, or the exact composition of the atmosphere) at the time of life's origin. Still, it is clear that the basic building blocks for the development of life were available from materials already present on the early Earth. And the presence of oceans on Earth was critical because this is the most likely place for these basic materials to interact and produce life.

The Importance of Oxygen to Life

Interdisciplinary Relationship

Oxygen, which comprises almost 21% of Earth's present atmosphere, is essential to human life for two reasons. First, our bodies need oxygen to "burn" (*oxidize*) food, releasing energy to our cells. Second, oxygen in the upper atmosphere in the form of *ozone* (*ozone* = to smell[14]) protects the

[13]Note that some of these dissolved components were removed or modified by chemical reactions between ocean water and rocks on the sea floor.

[14]Ozone gets its name because of its pungent, irritating odor.

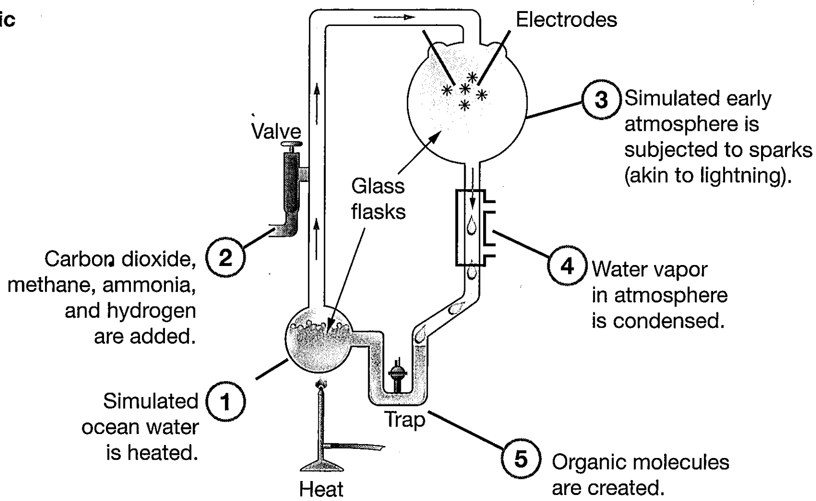
STUDENTS SOMETIMES ASK ...

Have the oceans always been salty? Are the oc growing more or less salty through time?

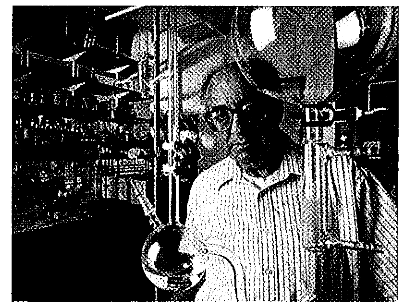
It is likely that the oceans have always been salty because wherever water comes in contact with th of Earth's crust, some of the minerals dissolve. This source of salts in the oceans, whether from stream or dissolving directly from the sea floor. Today, new als are forming on the sea floor at the same rate as solved materials are added. Thus, the salt content c ocean is in a "steady state," meaning that it is not ing or decreasing.

Interestingly, these questions can also be answe by studying the proportion of water vapor to chlorid Cl^-, in ancient marine rocks. Chloride ion is importa because it forms part of the most common salts in ocean (for example, sodium chloride, potassium chl and magnesium chloride). Also, chloride ion is prod by outgassing, like the water vapor that formed the Currently, there is no indication that the ratio of wat vapor to chloride ion has fluctuated throughout geol time, so it can be reasonably concluded that the oc salinity has been relatively constant through time.

1.26 Creation of organic ules.



(a) Laboratory apparatus used by Stanley Miller to simulate the conditions of the early atmosphere and the oceans. The experiment produced various organic molecules and suggests that the basic components of life were created in a "prebiotic soup" in the oceans.



(b) Stanley Miller in 1999, with his famous apparatus in the foreground.

surface of Earth from most of the Sun's harmful ultraviolet radiation (which is why the atmospheric ozone hole over Antarctica has generated such concern).

Evidence suggests that Earth's early atmosphere (the product of outgassing) was different from Earth's initial hydrogen–helium atmosphere and different from the mostly nitrogen–oxygen atmosphere of today. The early atmosphere probably contained large percentages of water vapor and carbon dioxide and smaller percentages of hydrogen, methane, and ammonia but very little free oxygen (oxygen that is not chemically bound to other atoms). Why was there so little free oxygen in the early atmosphere? Oxygen may well have been outgassed, but oxygen and iron have a strong affinity for each other.[15] As a result, iron in Earth's early crust would have reacted with the outgassed oxygen immediately, removing it from the atmosphere.

Without oxygen in Earth's early atmosphere, moreover, there would have been no ozone layer to block most of the Sun's ultraviolet radiation. The lack of a protective ozone layer may, in fact, have played a crucial role in several of life's most important developmental milestones.

Stanley Miller's Experiment

In 1952, **Stanley Miller** (**Figure 1.26b**)—then a 22-year-old graduate student of chemist Harold Urey at the University of Chicago—conducted a laboratory experiment that had profound implications about the development of life on Earth. In Miller's experiment, he exposed a mixture of carbon dioxide, methane, ammonia, hydrogen, and water (the components of the early atmosphere and ocean) to ultraviolet light (from the Sun) and an electrical spark (to imitate lightning) (**Figure 1.26a**). By the end of the first day, the mixture turned pink, and after a week it was a deep, muddy brown, indicating the formation of a large assortment of organic molecules, including amino acids—which are the basic components of life—and other biologically significant compounds.

Interdisciplinary Relationship

Miller's now-famous laboratory experiment of a simulated primitive Earth in a bottle—which has been duplicated and confirmed numerous times

[15]As an example of the strong affinity of iron and oxygen, consider how common rust—a compound of iron and oxygen—is on Earth's surface.

since—demonstrated that vast amounts of organic molecules could have been produced in Earth's early oceans, often called a "prebiotic soup." This prebiotic soup, perhaps spiced by extraterrestrial molecules aboard comets, meteorites, or interplanetary dust, was fueled by raw materials from volcanoes, certain minerals in sea floor rocks, and undersea hydrothermal vents. On early Earth, the mixture was energized by lightning, cosmic rays, and the planet's own internal heat, and it is thought to have created life's precursor molecules about 4 billion years ago.

Exactly how these simple organic compounds in the prebiotic soup assembled themselves into more complex molecules—such as proteins and DNA—and then into the first living entities remains one of the most tantalizing questions in science. Research suggests that with the vast array of organic compounds available in the prebiotic soup, several kinds of chemical reactions led to increasingly elaborate molecular structures. In fact, research suggests that small, simple molecules could have acted as templates, or "molecular midwives," in helping the building blocks of life's genetic material form long chains and thus may have assisted in the formation of longer, more elaborate molecular complexes. Among these complexes, some began to carry out functions associated with the basic molecules of life. As the products of one generation became the building blocks for another, even more complex molecules, or polymers, emerged over many generations that could store and transfer information. Such genetic polymers ultimately became encapsulated within cell-like membranes that were also present in Earth's primitive broth. The resulting cell-like complexes thereby housed self-replicating molecules capable of multiplying—and hence evolving—genetic information. Many specialists consider this emergence of genetic replication to be the true origin of life.

RECAP

Organic molecules were produced in a simulation of E early atmosphere and ocean, suggesting that life mos originated in the oceans.

Evolution and Natural Selection

Every living organism that inhabits Earth today is the result of **evolution** by the process of **natural selection** that has been occurring since life first existed on Earth. The theory of evolution states that groups of organisms adapt and change with the passage of time, causing descendants to differ morphologically and physiologically from their ancestors (**Diving Deeper 1.2**). Certain advantageous traits are naturally selected and passed from one generation to the next. Evolution is the process by which various **species** (*species* = a kind) have been able to inhabit increasingly numerous environments on Earth.

As we shall see, when species adapt to Earth's various environments, they can also modify the environments in which they live. This modification can be localized or nearly global in scale. For example, when plants emerged from the oceans and inhabited the land, they changed Earth from a harsh and bleak landscape as barren as that of the Moon to one that is green and lush.

Plants and Animals Evolve

The very earliest forms of life were probably **heterotrophs** (*hetero* = different, *tropho* = nourishment). Heterotrophs require an external food supply, which was abundantly available in the form of nonliving organic matter in the ocean around them. **Autotrophs** (*auto* = self, *tropho* = nourishment), which can manufacture their own food supply, evolved later. The first autotrophs were probably similar to present-day **anaerobic** (*an* = without, *aero* = air) bacteria, which live without atmospheric oxygen. They may have been able to derive energy from inorganic compounds at deep-water hydrothermal vents using a process called **chemosynthesis** (*chemo* = chemistry, *syn* = with, *thesis* = an arranging).[16] In fact, the detection of microbes deep within the ocean crust as well as the discovery of 3.2-billion-year-old microfossils of bacteria from deep-water marine rocks support the idea of life's origin on the deep-ocean floor in the absence of light.

Interdisciplinary Relationship

[16]More details about chemosynthesis are discussed in Chapter 15, "Animals of the Benthic Environment."

THE VOYAGE OF HMS *BEAGLE*: HOW IT SHAPED CHARLES DARWIN'S THINKING ABOUT THE THEORY. OF EVOLUTION

"Nothing in biology makes sense except in the light of evolution."
—Geneticist Theodosius Dobzhansky (1973)

To help explain how biologic processes operating in nature were responsible for producing the many diverse and remarkable species on Earth, the English naturalist *Charles Darwin* (1809–1882) proposed the *theory of evolution* by natural selection, which he referred to as "common descent with modification." Many of the observations upon which he based the theory were made aboard the vessel HMS *Beagle* during its famous expedition from 1831 to 1836 that circumnavigated the globe (**Figure 1D**).

Darwin became interested in natural history during his student days at Cambridge University, where he was studying to become a minister. Because of the influence of John Henslow, a professor of botany, he was selected to serve as an unpaid naturalist on HMS *Beagle*. The *Beagle* sailed from Devonport, England, on December 27, 1831, under the command of Captain Robert Fitzroy. The major objective of the voyage was to complete a survey of the coast of Patagonia (Argentina) and Tierra del Fuego and to make chronometric measurements. The voyage allowed the 22-year-old Darwin—who was often seasick—to disembark at various locations and study local plants and animals. What particularly influenced his thinking about evolution were the discovery of fossils in South America, the different tortoises throughout the Galápagos Islands, and the identification of 14 closely related species of Galápagos finches. These finches differ greatly in the configuration of their beaks (Figure 1D, *left inset*), which are suited to their diverse feeding habitats. After his return to England, Darwin noted the adaptations of finches and other organisms living in different habitats and concluded that all organisms change slowly over time as products of their environment.

Darwin recognized the similarities between birds and mammals and reasoned that they must have evolved from reptiles. Patiently making observations over many years, he also noted the similar skeletal framework of species such as bats, horses, giraffes, elephants, porpoises, and humans, which led him to establish relationships between various groups. Darwin suggested that the differences between species were the result of adaptation over time to different environments and modes of existence.

In 1858, Darwin hastily published a summary of his ideas about natural selection because fellow naturalist *Alfred Russel Wallace*, working half a world away cataloguing species in what is now Indonesia, had independently discovered the same idea. A year later, Darwin published his remarkable masterwork *On the Origin of Species by Means of Natural Selection* (Figure 1D, *right inset*), in which he provided extensive and compelling evidence that all living beings—including humans—have evolved from a common ancestor. At the time, Darwin's ideas were highly controversial because they stood in stark conflict with what most people believed about the origin of humans. Darwin also produced important publications on subjects as diverse as barnacle biology, carnivorous plants, and the formation of coral reefs.

Over 150 years later, Darwin's theory of evolution is so well established by evidence and reproducible experiment that it is considered a landmark influence in the scientific understanding of the underlying biologic processes operating in nature. Discoveries made since Darwin's time—including genetics and the structure of DNA—confirm how the process of evolution works. For example, the sequencing of the genomes of all 15 species of Darwin's finches was published in 2015, confirming Darwin's ideas about their evolutionary history.

It is interesting to note that most of Darwin's ideas have been so thoroughly accepted by scientists that they are now the underpinnings of the modern study of biology. That's why the name *Darwin* is synonymous with evolution. In 2009, to commemorate Darwin's birth and his accomplishments, the Church of England even issued this formal apology to Darwin: *"The Church of England owes you an apology for misunderstanding you and, by getting our first reaction wrong, encouraging others to misunderstand you still."*

GIVE IT SOME THOUGHT

1. Describe the three different types of organisms that Charles Darwin observed during his voyage on the *Beagle* that influenced his thinking about the theory of evolution.

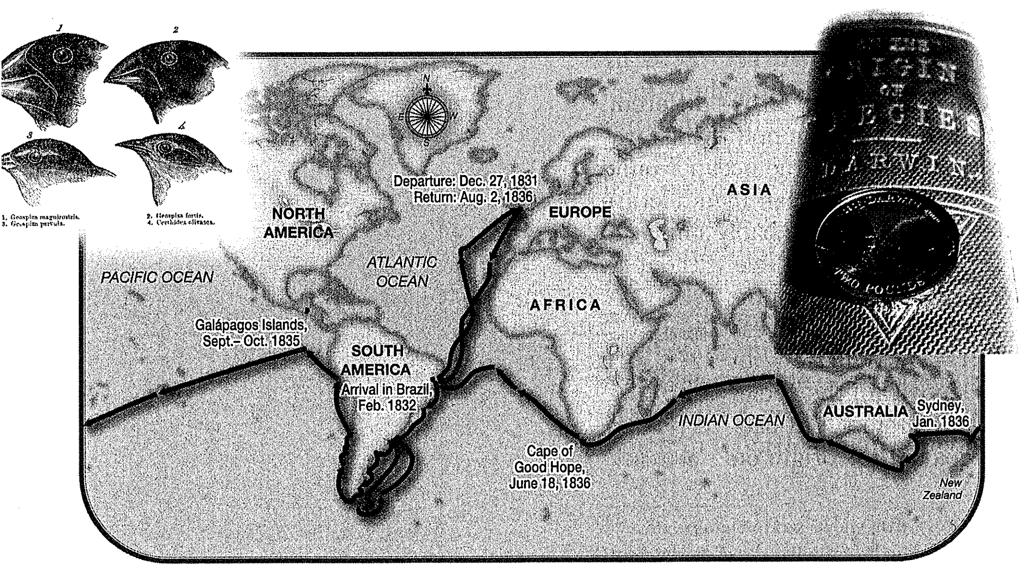
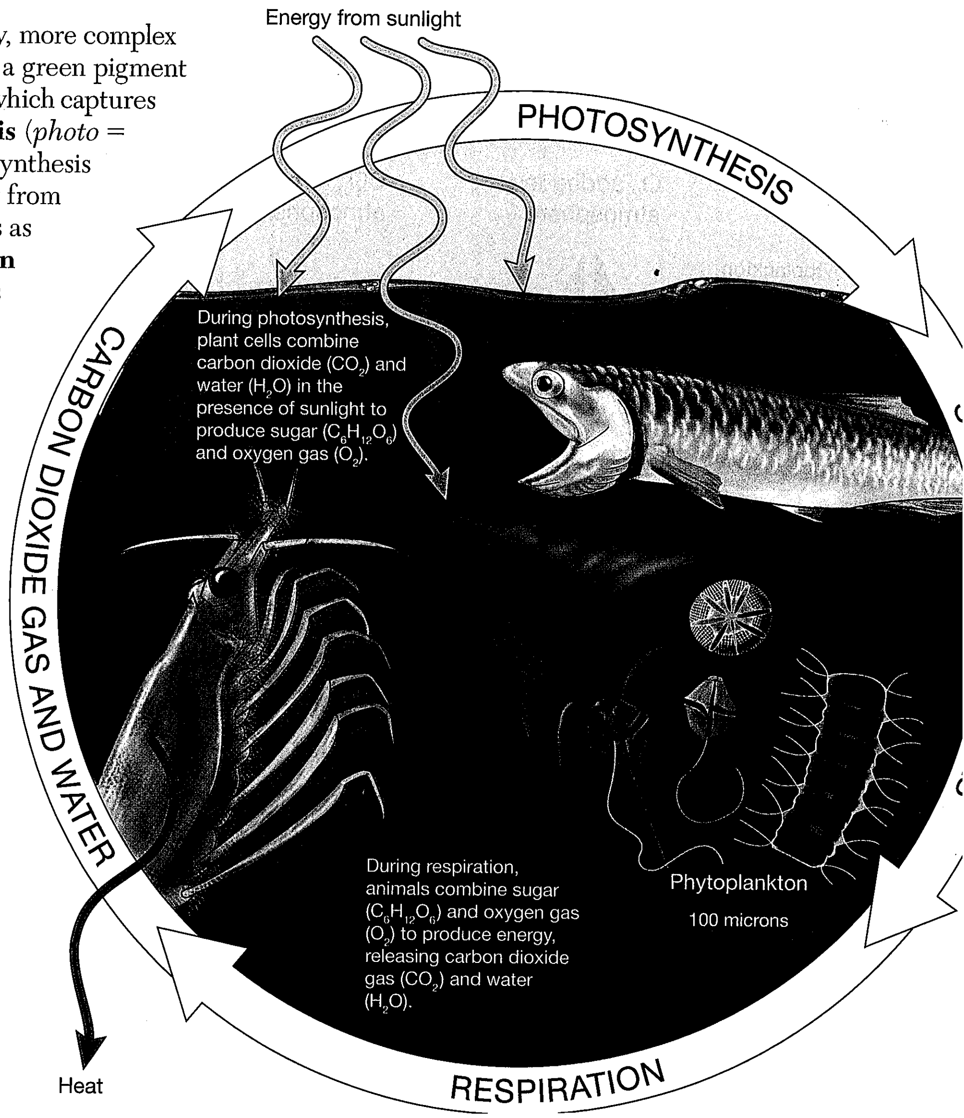


Figure 1D Charles Darwin's legacy: Galápagos finches, route of the HMS *Beagle*, and *On the Origin of Species*. Map showing the route of the HMS *Beagle*, beak differences in Galápagos finches (*left inset*) that greatly influenced Charles Darwin and the British two-pound coin commemorating Darwin and his masterwork *On the Origin of Species* (*right inset*).

PHOTOSYNTHESIS AND RESPIRATION Eventually, more complex single-celled autotrophs evolved. They developed a green pigment called **chlorophyll** (*chloro* = green, *phyll* = leaf), which captures the Sun's energy through cellular **photosynthesis** (*photo* = light, *syn* = with, *thesis* = an arranging). In photosynthesis (**Figure 1.27**), plant and algae cells capture energy from sunlight and store it as sugars, releasing oxygen gas as a by-product. Alternatively, in cellular **respiration** (*respirare* = to breathe) (Figure 1.27), animals who consume the sugars produced by photosynthesis combine them with oxygen, releasing the stored energy of the sugars to carry on cellular tasks important for various life processes.

Figure 1.27 shows that photosynthesis and respiration are complimentary processes, with photosynthesis producing what is needed for respiration (sugar and oxygen gas), and respiration producing what is needed for photosynthesis (carbon dioxide gas and water). In fact, the cyclic nature of Figure 1.27 shows that autotrophs (algae and plants) and heterotrophs (most bacteria and animals) began to develop a mutual need for each other.

The oldest fossilized remains of organisms are primitive photosynthetic bacteria recovered from rocks formed on the sea floor about 3.5 billion years ago. However, the oldest rocks containing iron oxide (rust)—an indicator of an oxygen-rich atmosphere—did not appear until about 2.45 billion years ago. This indicates that photosynthetic organisms needed about a billion years to develop and begin producing abundant free oxygen in the atmosphere. Another possible scenario is that a large amount of oxygen-rich (ferric) iron sank to the base of the mantle, where it was heated by the core and subsequently rose as a plume to the ocean floor, releasing large amounts of oxygen through outgassing about 2.5 billion years ago.

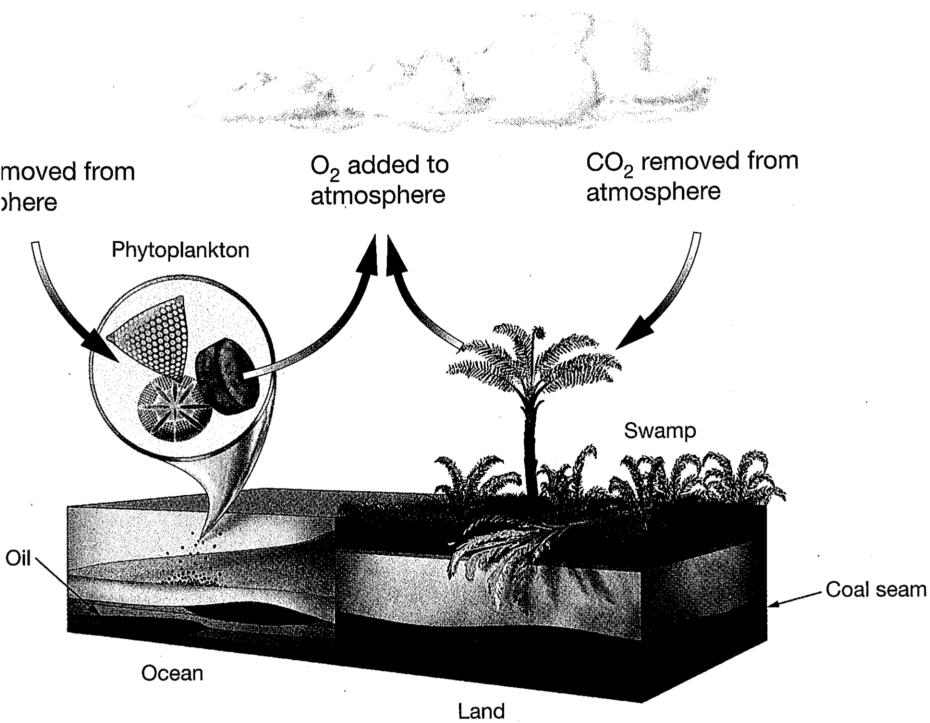


SmartFigure 1.27 Photosynthesis and respiration are cyclic and complimentary processes that are fundamental to life on Earth. https://goo.gl/SsyVda

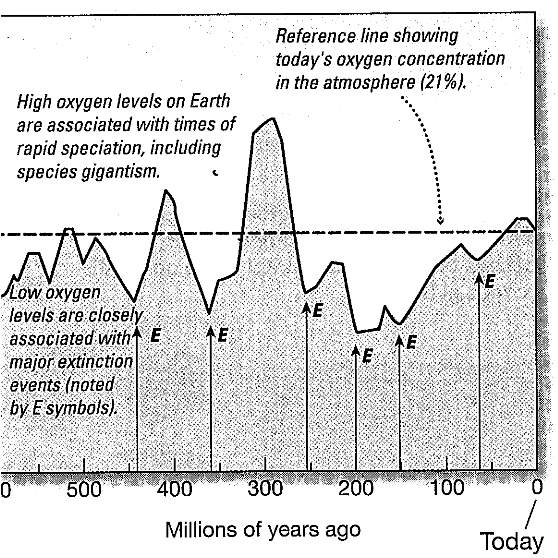
THE GREAT OXIDATION EVENT/OXYGEN CRISIS Based on the chemical makeup of certain rocks, Earth's atmosphere became oxygen rich about 2.45 billion years ago—called the *great oxidation event*—and fundamentally changed Earth's ability to support life. Particularly for anaerobic bacteria, which had grown successfully in an oxygen-free world, all this oxygen was nothing short of a catastrophe! This is because the increased atmospheric oxygen caused the ozone concentration in the upper atmosphere to build up, thereby shielding Earth's surface from ultraviolet radiation—and effectively eliminating anaerobic bacteria's food supply of organic molecules. (Recall that Stanley Miller's experiment created organic molecules but needed ultraviolet light.) In addition, oxygen (particularly in the presence of light) is highly reactive with organic matter. When anaerobic bacteria are exposed to oxygen and light, they are killed instantaneously. By 1.8 billion years ago, the atmosphere's oxygen content had increased to such a high level that it began causing the extinction of many anaerobic organisms. Nonetheless, descendants of such bacteria survive on Earth today in isolated microenvironments that are dark and free of oxygen, such as deep in soil or rocks, in landfills, and inside other organisms.

Interdisciplinary Relationship
Climate Connection

Although oxygen is very reactive with organic matter and can even be toxic, it also yields nearly 20 times more energy



1.28 **The effect of plants on Earth's environment.** As opic photosynthetic cells (*inset*) became established in the Ξarth's atmosphere was enriched in oxygen and depleted ɪn dioxide. As organisms died and accumulated on the oor, some of their remains were converted to oil and gas. ıe process occurred on land, sometimes producing coal.



1.29 **Atmospheric oxygen concentration.** Graph g how the concentration of oxygen in Earth's atmosphere ied during the past 600 million years, including major on events (*E*).

than anaerobic respiration—a fact that some organisms exploited. For example, blue-green algae, which are also known as *cyanobacteria* (*kuanos* = dark blue), adapted to and thrived in this new oxygen-rich environment. In doing so, they altered the composition of the atmosphere.

CHANGES TO EARTH'S ATMOSPHERE The development and successful evolution of photosynthetic organisms are greatly responsible for the world as we know it today (**Figure 1.28**). By the trillions, these microscopic organisms transformed the planet by capturing the energy of the Sun to make food and releasing oxygen as a waste product. By this process, these organisms reduced the high amount of carbon dioxide in the early atmosphere and gradually replaced it with free oxygen. This created a third and final atmosphere on Earth: one that is oxygen rich (about 21% today). Little by little, these tiny organisms turned the atmosphere into breathable air, opening the way to the diversity of life that followed.

The graph in **Figure 1.29** shows how the concentration of atmospheric oxygen has varied during the past 600 million years. When atmospheric oxygen concentrations are high, organisms thrive, and rapid speciation occurs. At such times in the past, insects grew to gargantuan proportions, reptiles took to the air, and the forerunners of mammals developed a warm-blooded metabolism. More oxygen was dissolved in the oceans, too, and so marine biodiversity increased. At other times when atmospheric oxygen concentrations fell precipitously, biodiversity was smothered. In fact, some of the planet's worst mass extinctions are associated with sudden drops in atmospheric oxygen.

The remains of ancient plants and animals buried in oxygen-free environments have become the oil, natural gas, and coal deposits of today. These deposits, which are called *fossil fuels*, provide more than 90% of the energy humans consume to power modern society. In essence, humans depend not only on the food energy stored in today's plants but also on the energy stored in plants during the geologic past—in the form of fossil fuels.

Because of increased burning of fossil fuels for home heating, industry, power generation, and transportation during the industrial age, the atmospheric concentration of carbon dioxide and other gases that help warm the atmosphere has increased, too. Scientists predict that these human emissions will increase global warming and cause serious environmental problems in the not-too-distant future. This phenomenon is referred to as the atmosphere's *enhanced greenhouse effect* and is discussed in Chapter 16, "The Oceans and Climate Change."

AP

Earth has evolved over time and changed Earth's ıment. For example, abundant photosynthetic organisms ɪ today's oxygen-rich atmosphere.

CONCEPT CHECK 1.7 | Discuss why life is thought to have originated in the oceans.

1 How does the presence of oxygen in our atmosphere help reduce the amount of ultraviolet radiation that reaches Earth's surface?

2 What was Stanley Miller's experiment, and what did it help demonstrate?

3 Earth has had three atmospheres (initial, early, and present). Describe the composition and origin of each one.

1.8 How Old Is Earth?

How can Earth scientists tell how old a rock is? It can be a difficult task to tell if a rock is thousands, millions, or even billions of years old—unless the rock contains telltale fossils. Fortunately, Earth scientists can determine how old most rocks are by using the radioactive materials contained within rocks. In essence, this technique involves reading a rock's internal "rock clock."

Radiometric Age Dating

Most rocks on Earth (as well as those from outer space) contain small amounts of radioactive materials such as uranium, thorium, and potassium. These radioactive materials spontaneously break apart or decay into atoms of other elements. Radioactive materials have a characteristic **half-life**, which is the time required for one-half of the atoms in a sample to decay to other atoms. The older the rock is, the more radioactive material will have been converted to decay product. Analytical instruments can accurately measure the amount of radioactive material and the amount of resulting decay product in rocks. By comparing these two quantities, the age of the rock can thus be determined. Such dating is referred to as **radiometric age dating** (*radio* = radioactivity, *metri* = measure) and is an extremely powerful tool for determining the age of rocks.

Interdisciplinary Relationship

Figure 1.30 shows an example of how radiometric age dating works. It shows how uranium 235 decays into lead 207 at a rate where one-half of the atoms turn into lead every 704 million years. By counting the number of each type of atom in a rock sample, one can tell how long it has been decaying (as long as the sample does not gain or lose atoms). Using uranium and other radioactive elements and applying this same technique, hundreds of thousands of rock samples have been age dated from around the world.

The Geologic Time Scale

The ages of rocks on Earth are shown in the **geologic time scale** (**Figure 1.31**; see also MasteringOceanography **Web Diving Deeper 1.2**), which lists the names of the geologic time periods as well as important advances in the development of life-forms on Earth. Initially, the divisions between geologic periods were based on major extinction episodes as recorded in the fossil record. As radiometric age dates became available, they were also included on the geologic time scale. The oldest known rocks on Earth, for example, are about 4.3 billion years old, and the oldest known crystals within terrestrial rocks have been dated at up to 4.4 billion years old.[17] No rocks older than this have been found because few likely survived Earth's molten youth, a time when Earth was being bombarded by meteorites. However, radiometric dating of space rocks left over from the formation of the solar system indicates Earth is about 4.6 billion years old.

RECAP

Earth scientists can accurately determine the age of mos rocks by analyzing their radioactive components, some o which indicate that Earth is 4.6 billion years old.

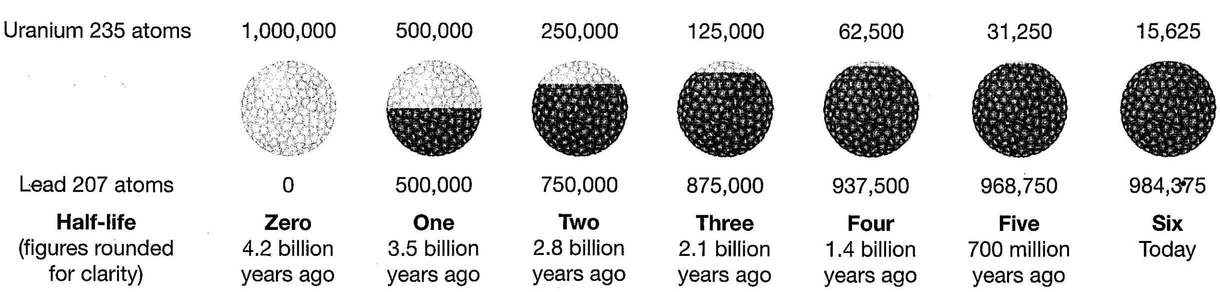
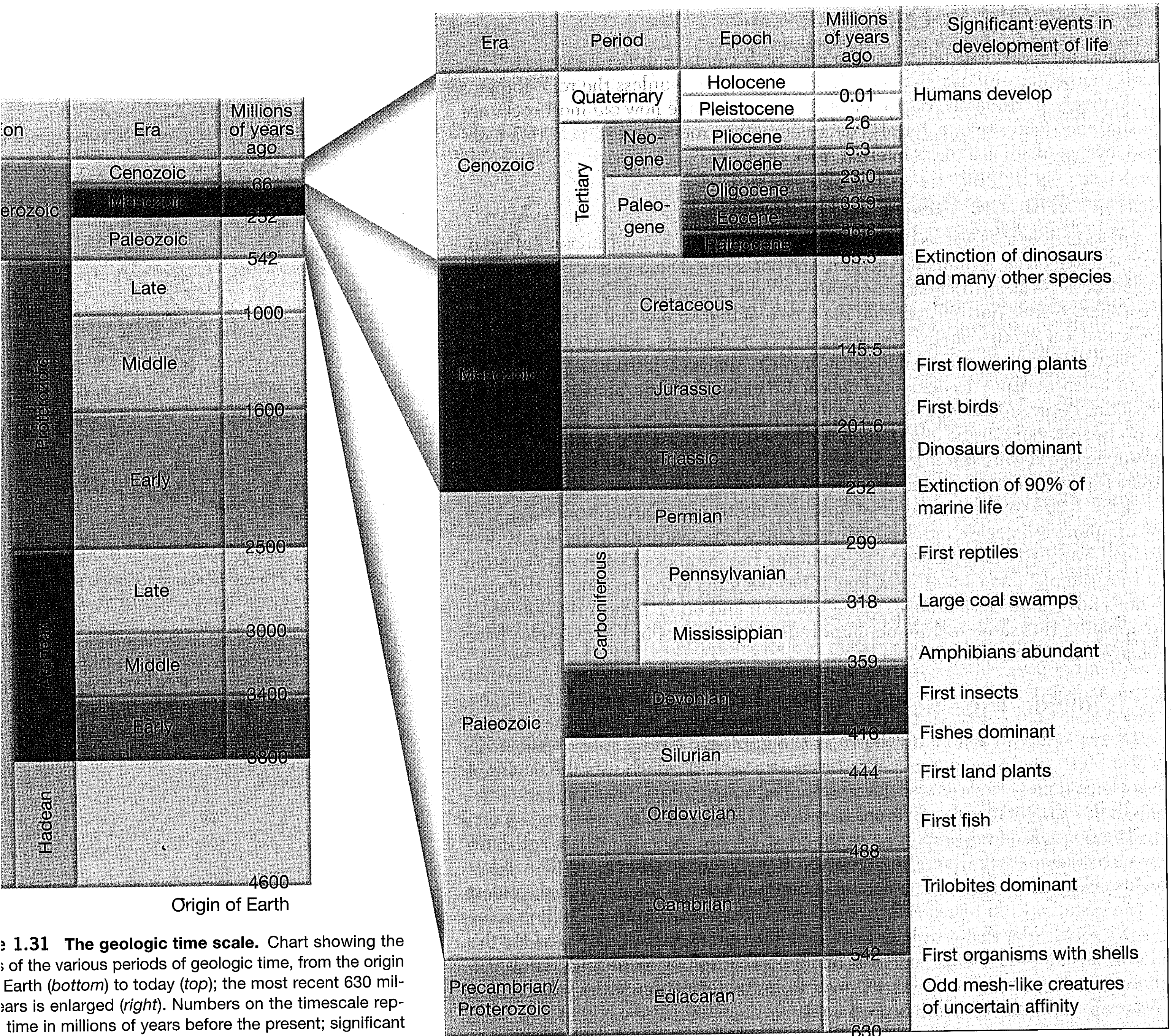


Figure 1.30 Radiometric age dating. During one half-life, half of all radioactive uranium 235 atoms decay into lead 207. With each successive half-life, half of the remaining radioactive uranium atoms convert to lead. By counting the number of each type of atom in a rock sample, the rock's age can be determined.

Web Animation
Radioactive Decay
http://goo.gl/iMQIID

[17]Research suggests that crystals this old imply that significant continental crust must have formed on Earth early on, perhaps by nearly 4.5 billion years ago.



e 1.31 The geologic time scale. Chart showing the s of the various periods of geologic time, from the origin Earth (*bottom*) to today (*top*); the most recent 630 mil-ears is enlarged (*right*). Numbers on the timescale rep- time in millions of years before the present; significant ces in the development of plants and animals on Earth so shown.

CONCEPT CHECK 1.8 | Demonstrate an understanding of how old Earth is.

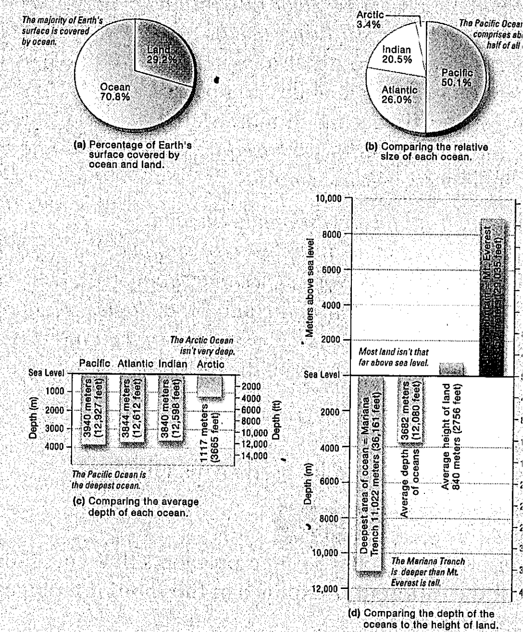
1 Describe how the half-life of radioactive materials can be used to determine the age of a rock through radiometric age dating.

2 What is the age of Earth? Describe the major events that demark the boundaries between these time periods: (a) Precambrian/Proterozoic, (b) Paleozoic/Mesozoic, (c) Mesozoic/Cenozoic.

ESSENTIAL CONCEPTS REVIEW

1.1 How are Earth's oceans unique?

- *Water covers 70.8% of Earth's surface.* The world ocean is a *single interconnected body of water,* which is large in size and volume. It can be divided into *four principal oceans* (the Pacific, Atlantic, Indian, and Arctic Oceans), plus an additional ocean (the Southern Ocean, or Antarctic Ocean). Even though there is a technical distinction between a *sea* and an *ocean*, the two terms are used interchangeably. In comparing the oceans to the continents, it is apparent that *the average land surface does not rise very far above sea level* and that *there is not a mountain on Earth that is as tall as the ocean is deep.*



Study Resources

MasteringOceanography Study Area Quizzes, MasteringOceanography Web Animation, MasteringOceanography Web Diving Deeper 1.1 and 1.3

Critical Thinking Question

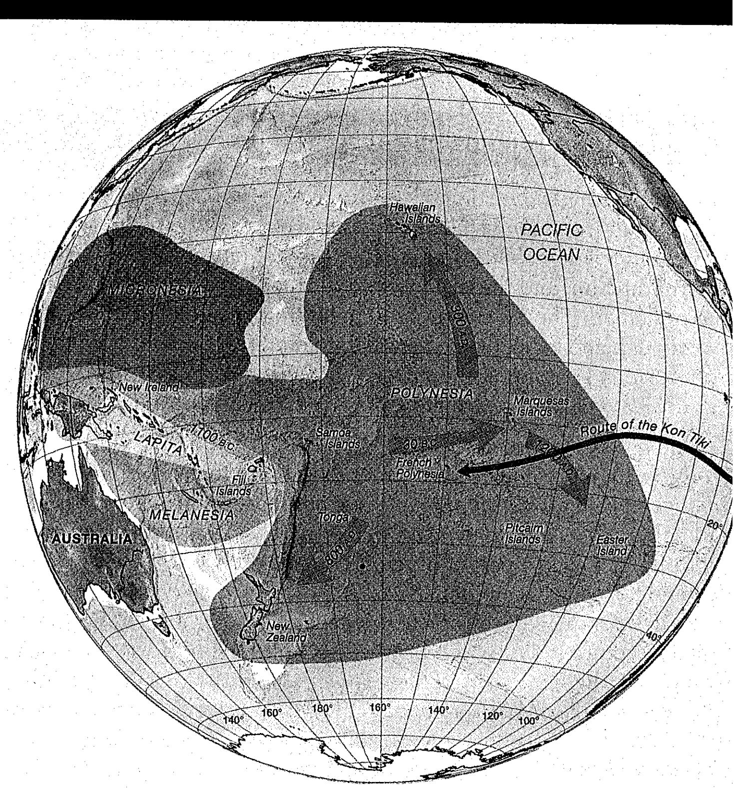
NASA has discovered a new planet that has an ocean. Using today's technology, how would you propose studying that ocean, all that's in it, and the sea floor beneath it? Assume an unlimited budget.

Active Learning Exercise

If all Earth's glaciers melted, sea level would rise by about 70 meters (230 feet). Since the average height of the continents is only 840 meters (2756 feet), a rise in sea level of this magnitude would seriously impact human activities, especially in low-lying areas. Based on your knowledge of worldwide geography, which areas of the globe would most likely be affected? Be sure to include major population centers that would be under water. Assess these impacts, and discuss as a group.

1.2 How was early exploration of the oceans achieved?

- In the Pacific, *people who populated the Pacific Islands may have been the first great navigators*. In the Western world, the *Phoenicians* were making remarkable voyages as well. Later the *Greeks, Romans,* and *Arabs* made significant contributions and advanced oceanographic knowledge. During the Middle Ages, the *Vikings* colonized Iceland and Greenland and made voyages to North America.
- The *Age of Discovery* in Europe renewed the Western world's interest in exploring the unknown. It began with the voyage of *Christopher Columbus* in 1492 and ended in 1522 with the first circumnavigation of Earth by a voyage initiated by *Ferdinand Magellan. Captain James Cook* was one of the first to explore the ocean for scientific purposes.



Study Resources

MasteringOceanography Study Area Quizzes

Critical Thinking Question

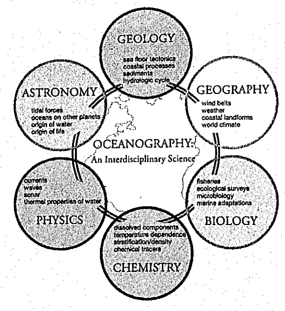
Discuss the technological advantages that allowed sea-faring Arabs during the Middle Ages to dominate the Mediterranean Sea and trade with East Africa, India, and southeast Asia.

Active Learning Exercise

Make a list of the 10 essential items you'd need to take with you on a month-long boat expedition to study the ocean (exclude clothes, personal items, and food). Compare and discuss your list with another student in class. How would your list of 10 essential items be different if you created it during the beginning of voyaging for science in the 1700s?

What is oceanography?

ceanography, or marine science, the scientific study of all aspects ˙ the marine environment. During 'orld War II, *a tactical advantage as gained by studying ocean pro-:sses*, leading to great advances in chnology and the ability to observe• ıd study the oceans in more detail. *›day, much study is focused on hu-an impacts on the ocean.*



ceanography is traditionally divided to four academic disciplines (or subfields) of study. These four dis-plines are: (1) *geological oceanography*, (2) *chemical oceanography*, ;) *physical oceanography*, and (4) *biological oceanography*. *Ocean-;raphy is frequently described as being an interdisciplinary science* эcause it encompasses all the different disciplines of science as they ›ply to the oceans.

ly Resources
teringOceanography Study Area Quizzes

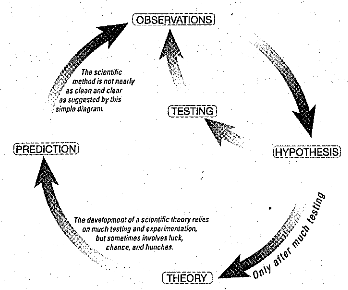
ical Thinking Question

cribe one of today's ocean problems that encompasses at least of the different disciplines in the multidisciplinary science that :eanography.

ive Learning Exercise

ı another student in class, make a list of all the types of careers would be qualified for with a degree in oceanography or marine nce. As an example of someone who works in oceanography or ine science, consider your instructor.

1.4 What is the nature of scientific inquiry?



- The *scientific method* is used to understand the occurrence of physical events or phenomena and can be stated as *science supports the explanation of the natural world that best explains all available observations.* Steps in the scientific method include making *observations* and establishing *scientific facts*; forming one or more *hypotheses* (a tentative, testable statement about the general nature of the phenomena observed); extensive *testing* and *modification of hypotheses*; and, finally, developing a *theory* (a well-substantiated explanation of some aspect of the natural world that can incorporate facts, laws, logical inferences, and tested hypotheses). Science never arrives at the absolute "truth"; rather, *science arrives at what is probably true* based on the available observations and can *continually change because of new observations.*

Study Resources
MasteringOceanography Study Area Quizzes

Critical Thinking Question

What is the difference between a fact and a theory? Can either (or both) be revised?

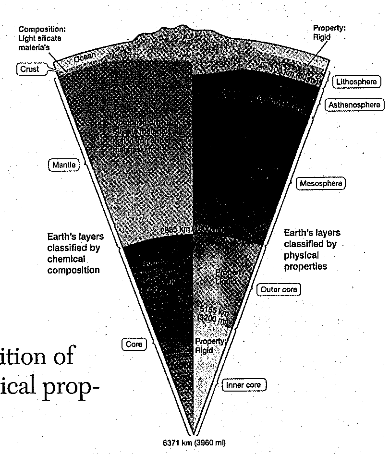
Active Learning Exercise

With another student in class, discuss if you believe nature is simple enough for humans to truly understand. Give reasons why or why not. If not, do you think it is still reasonable for scientists to make this assumption in applying the scientific method in their work?

How were Earth and the solar system formed?

›ur *solar system*, consisting of *the Sun and eight major planets*, probbly formed from a *huge cloud of gas and space dust* called a *nebula*. ccording to the *nebular hypothesis*, the nebular matter contracted › form the Sun, and the planets were formed from eddies of material ıat remained. The Sun, composed of hydrogen and helium, was mas-ve enough and concentrated enough to emit *large amounts of energy* ·om fusion. The Sun also emitted *ionized particles that swept away ny nebular gas* that remained from the formation of the planets and ıeir satellites.

'roto-Earth, more massive and larger than Earth today, *was molten and omogenous*. The *initial atmosphere*, composed mostly of hydrogen nd helium, *was later driven off into space* by intense solar radiation. 'roto-Earth began a period of rearrangement called *density stratifica-on* and formed a *layered internal structure based on density*, resulting ı the development of the *crust*, *mantle*, and *core*. Studies of Earth's in-ərnal structure indicate that brittle plates of the *lithosphere* are riding n a plastic, high-viscosity *asthenosphere*. Near the surface, the litho-phere is composed of *continental* and *oceanic crust*. Continental crust onsists mostly of granite and oceanic crust consists mostly of basalt. *;ontinental crust is lower in density, lighter in color, and thicker than oceanic crust.* Both types of crust float isostatically on the denser mantle below.



Study Resources
MasteringOceanography Study Area Quizzes, MasteringOceanography Web Animations, Mastering-Oceanograhy Web Videos

Critical Thinking Question

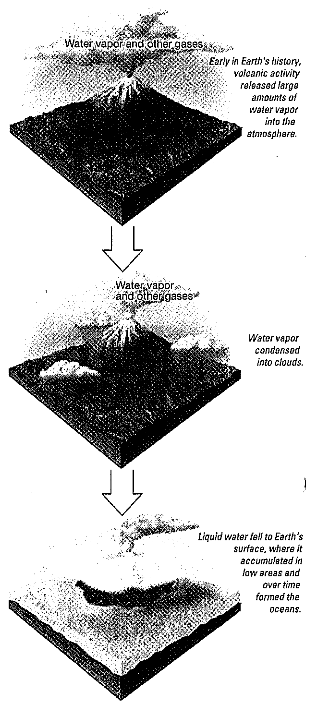
Describe how the chemical composition of Earth's interior differs from its physical properties. Include specific examples.

Active Learning Exercise

The nebular hypothesis of solar system formation is a scientific hypothesis. Based on your understanding of the scientific method, describe to another student in class how sure of this hypothesis you think scientists really are. Why would scientists have this level of certainty?

1.6 How were Earth's atmosphere and oceans formed?

- *Outgassing produced an early atmosphere* rich in water vapor and carbon dioxide. Once Earth's surface cooled sufficiently, the *water vapor condensed and accumulated to give Earth its oceans. Rainfall on the surface dissolved compounds that,* when carried to the ocean, *made it salty.*



Study Resources
MasteringOceanography Study Area Quizzes

Critical Thinking Question

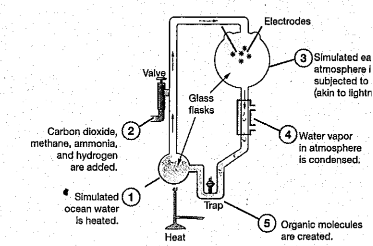
Compare the two ways in which Earth was supplied with enough water to have an ocean. Which is likely to have contributed most of the water on Earth?

Active Learning Exercise

With another student in class, describe in your own words how Earth's oceans became salty.

1.7 Did life begin in the oceans?

- *Life is thought to have begun in the oceans. Stanley Miller's experiment* showed that ultraviolet radiation from the Sun and hydrogen, carbon dioxide, methane, ammonia, and inorganic molecules from the oceans may have combined to produce *organic molecules such as amino acids*. Certain combinations of these molecules eventu produced *heterotrophic organisms* (which cannot make their food) that were probably similar to present-day anaerobic bact Eventually, *autotrophs evolved* that had the ability to make t own food through *chemosynthesis*. Later, some cells develc *chlorophyll*, which made *photosynthesis* possible and led to the *velopment of plants*.



(a) Laboratory apparatus used by Stanley Miller to simulate the conditions of the atmosphere and the oceans. The experiment produced various organic mole and suggests that the basic components of life were created in a "prebiotic s in the oceans.

- *Photosynthetic organisms altered the environment* by extracting bon dioxide from the atmosphere and also by releasing free oxy thereby creating today's *oxygen-rich atmosphere*. Eventually, l *plants and animals evolved* into forms that could survive on land.

Study Resources
MasteringOceanography Study Area Quizzes

Critical Thinking Question

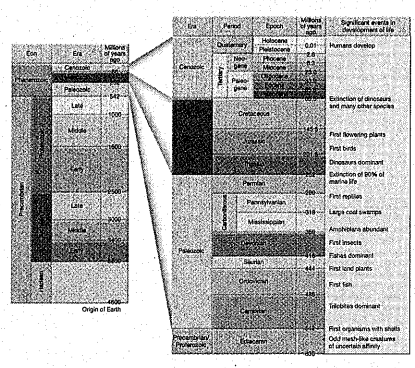
How would you answer the accusation, made by some religious groups, that scientific theories such as Stanley Miller's theory on th origin of life on Earth are inherently weak because it is a historic e that no one actually observed? Please explain your answer in detail

Active Learning Exercise

With another student in class, discuss which of these two stateme has more validity: (1) the greatest environmental crisis of all time was the build-up of toxic oxygen in Earth's atmosphere 2 billion years ago or (2) humans are causing the greatest environmental c sis of all time.

1.8 How old is Earth?

- *Radiometric age dating* is used to determine the age of most rocks. Information from extinctions of organisms and from age dating rocks comprises the *geologic time scale,* which indicates that Earth has experienced a long history of changes since *its origin 4.6 billion years ago.*



Study Resources
MasteringOceanography Study Area Quizzes, MasteringOceanography Web Diving Deeper 1.2, MasteringOceanography Web Animation

Critical Thinking Question

Explain how radiometric age dating works. Why does the parent material never totally disappear completely, even after many half-lives?

Active Learning Exercise

Working as a team, construct a representation of the geologic time scale, using an appropriate quantity of any substance (other than dollar bills or toilet paper, which are used as examples in MasteringOceanography Web Diving Deeper 1.2). Be sure to indicate some of the major changes that have occurred on Earth since its origin, such as "Origin of Earth," "Origin of oceans," "Earliest known life-forms," "Oxygen-rich atmosphere first occurs," "First organisms with shells," "Dinosaurs die out," and "Age of humans."

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