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The Changing Earth
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Geology

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Chapter 1

Earth's Changing Surface

THE BIG QUESTION
How did people's understanding of what was happening on Earth's surface change over time?

1570 CE world map

If you had lived in Europe during the Middle Ages, the idea that the earth changes would have seemed crazy. At that time, people believed that mountains, valleys, and other landscape features had always been there. True, rare natural **catastrophes** sometimes occurred. Earthquakes, for example, shook the ground and triggered landslides. In some places, volcanoes **erupted** and sent up fountains of lava, or red-hot melted rock. However, people viewed these catastrophes as punishments from God, not as the earth changing.

During the 1400s, 1500s, and 1600s, European explorers set sail on voyages of discovery. They found new continents and islands. Mapmakers created the first relatively accurate maps of the entire world. When people studied these maps, they noticed something interesting. Several continents looked as if they might fit together like pieces of a jigsaw puzzle. Take a look at a world map or globe. See how the eastern edge of South America looks as if it fits into the western edge of Africa? If you could somehow push these two continents together across the Atlantic Ocean, their edges would match up.

People wondered if the continents had once been joined and later moved apart. At first, this seemed like a ridiculous idea. How could continents move on a planet that never changed?

Powerful Forces and Gradual Change

During the 1700s and 1800s, many people skilled in scientific **observation** became convinced that Earth's surface features do indeed change. They noticed how great masses of rock appeared to have been lifted up to form cliffs and mountains over time. They began to believe that once-tall mountains had been worn down by wind, rain, and ice and that, over thousands of years, valleys had been carved by rivers flowing through them. These scientists found **evidence** that seemed to show that sea levels had been higher—and lower—at different times in the past. They found layers of rock on mountain peaks that contained **fossils**, the preserved remains of things that lived long ago. These scientists observed how big rocks gradually broke down into tiny pieces called **sediments**. They saw how new rocks formed as they observed volcanic lava cool and harden.

Fossils help provide information about the history of the earth.

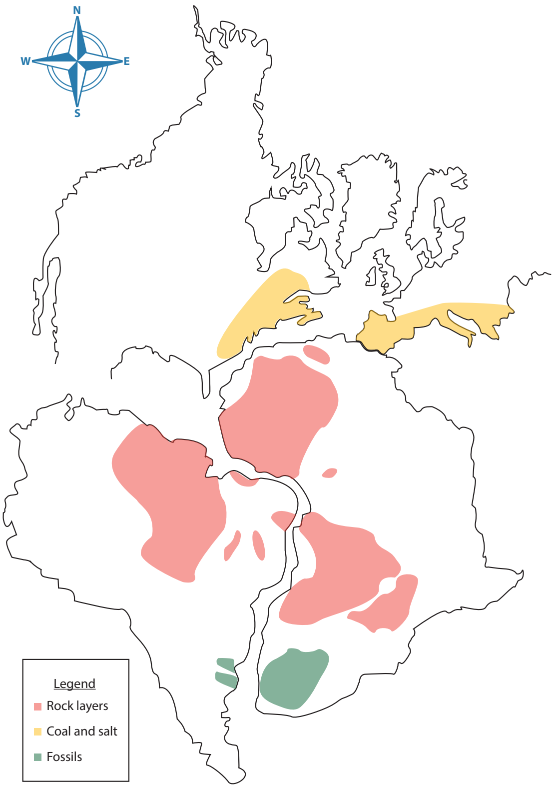
All these observations led many scientists to believe that powerful natural **forces** were at work changing Earth's surface. Most of these changes were thought to have taken place very slowly. Over long periods of time, slow, gradual changes added up to produce dramatic results. These scientists were convinced that Earth's rocky surface had changed continuously throughout the planet's long history. It had changed in the past, and Earth was changing in the present, too.

These ideas laid the foundation for the modern science of geology. Geology is the study of the makeup of the earth and the forces and processes that shape and change it. Rocks are very important in geology. That's because rocks hold clues to how Earth's surface has changed over time. Together with fossils, rocks provide information about the history of the earth.

Shen Kua's Observations

Shen Kua was a Chinese scientist and mathematician who lived from 1031–1095 CE. He studied rocks and fossils and made many observations of Earth's surface features. Shen Kua realized that Earth's surface is shaped very slowly by powerful forces. Some forces wear rocks down. Others make new rocks and push them up to become mountains. Shen Kua reached these conclusions hundreds of years before European scientists did.

Search for Clues



Discoveries of rock layers, as well as coal and salt, indicated that the continents had once been joined.

So what about the jigsaw-puzzle fit of the continents? During the 1800s and early 1900s, **geologists** studied rock layers on the continents. They made many intriguing discoveries. For example, rock layers along the northern and eastern coasts of South America match rock layers along Africa's western coast. Also, deposits of **coal** and salt in eastern North America are similar to those in southern Europe.

Geologists found fossils of an ancient fern called *Glossopteris* in similar rock layers in Africa, India, Australia, and South America. They found fossils of an ancient reptile, *Lystrosaurus*, in both southern Africa and India. In South America and Africa, fossils of another ancient reptile, *Cynognathus*, turned up directly across the Atlantic Ocean from each other.

These discoveries seemed to indicate that the continents had once been joined—but how? Furthermore, how had they become separated? Several scientists proposed explanations, but they were quite far-fetched. One involved a gigantic eruption from the center of the earth that ripped all the land apart. Another suggested that part of Earth's land broke away to become the moon and what was left became the continents. Few people paid much attention to these ideas. A better explanation was needed, one with evidence to support it. In the early 1900s, Alfred Wegener provided just that.

Enter Alfred Wegener

Born and educated in Germany, Alfred Wegener was interested in many scientific subjects, including weather, astronomy, and cold, polar regions. Around 1910, Wegener read a scientific paper about similar fossils and rock formations found on different continents. He was intrigued by the mystery of the matching continents and he wanted to solve this mystery.

Alfred Wegener

Wegener gathered evidence. He pulled together discoveries made by many other scientists about rock formations, fossils, and mountain ranges. Polar explorers had recently unearthed fossils of *Glossopteris* in Antarctica. Similar fossils had previously been found in other parts of the world. This seemed to indicate that ice-covered Antarctica might once have been joined to South America, Africa, India, and Australia. It also meant that Antarctica had once had a **climate** warm enough for ferns to grow.

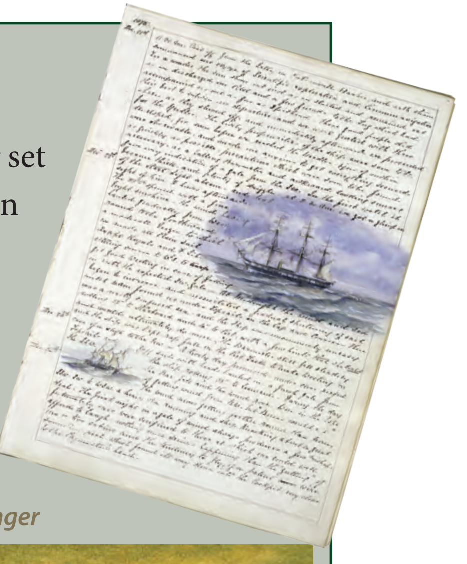
From this evidence, Wegener **concluded** that all the present-day continents had been joined as one huge landmass long ago. He understood, as with any new discovery, that his conclusions might be altered or challenged in the future by more evidence. Nonetheless, he believed that the existing evidence supported his conclusions.

Continents that Drift

If Wegener's conclusions were correct, then how had the continents moved apart? An important clue came from the ocean. The ocean was still largely unexplored in Wegener's day. In the 1870s, however, scientists discovered that much of the ocean bottom was made of basalt, a heavy, **dense** rock that is formed when lava cools and hardens. Lava is magma that has erupted up above Earth's crust from deep underground. Most rocks that make up the continents are lighter and less dense than basalt.

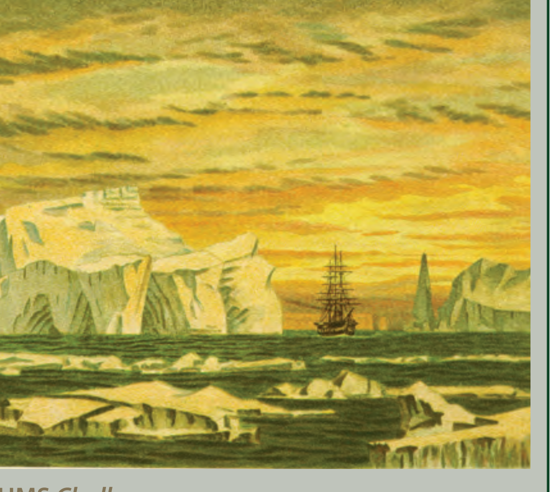
Seafloor Discoveries

In 1872, the research ship HMS *Challenger* set out on a four-year mission to gather information about the ocean floor. The ship visited every ocean except the Arctic Ocean. Scientists on board dredged up mud, rocks, and ocean creatures from the seafloor.

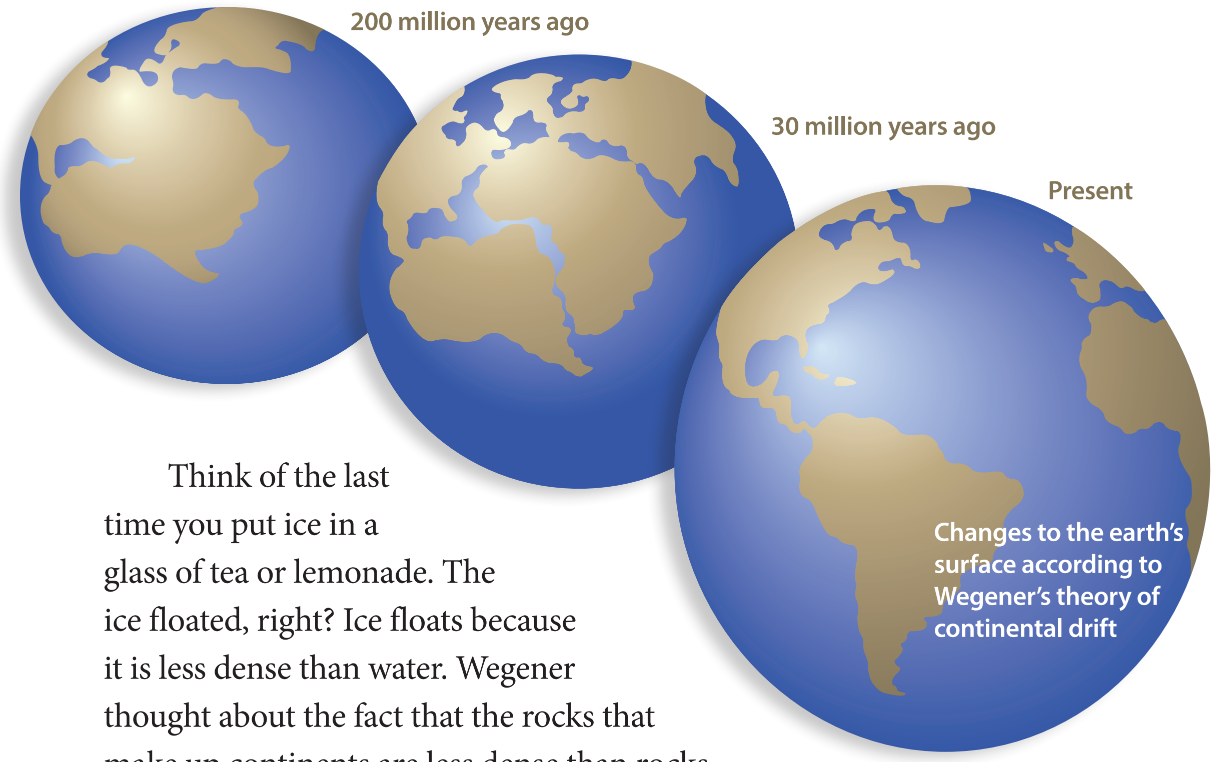


Journal of HMS *Challenger*

Challenger scientists also took soundings, or measures of water depth, by lowering weighted lines into the water. They measured out the line until the weight landed on the bottom. The scientists used the soundings to make rough maps of the seafloor in different places. They discovered that the seafloor has vast plains, tall mountain ranges, and deep valleys.



HMS *Challenger*



Changes to the earth's surface according to Wegener's theory of continental drift

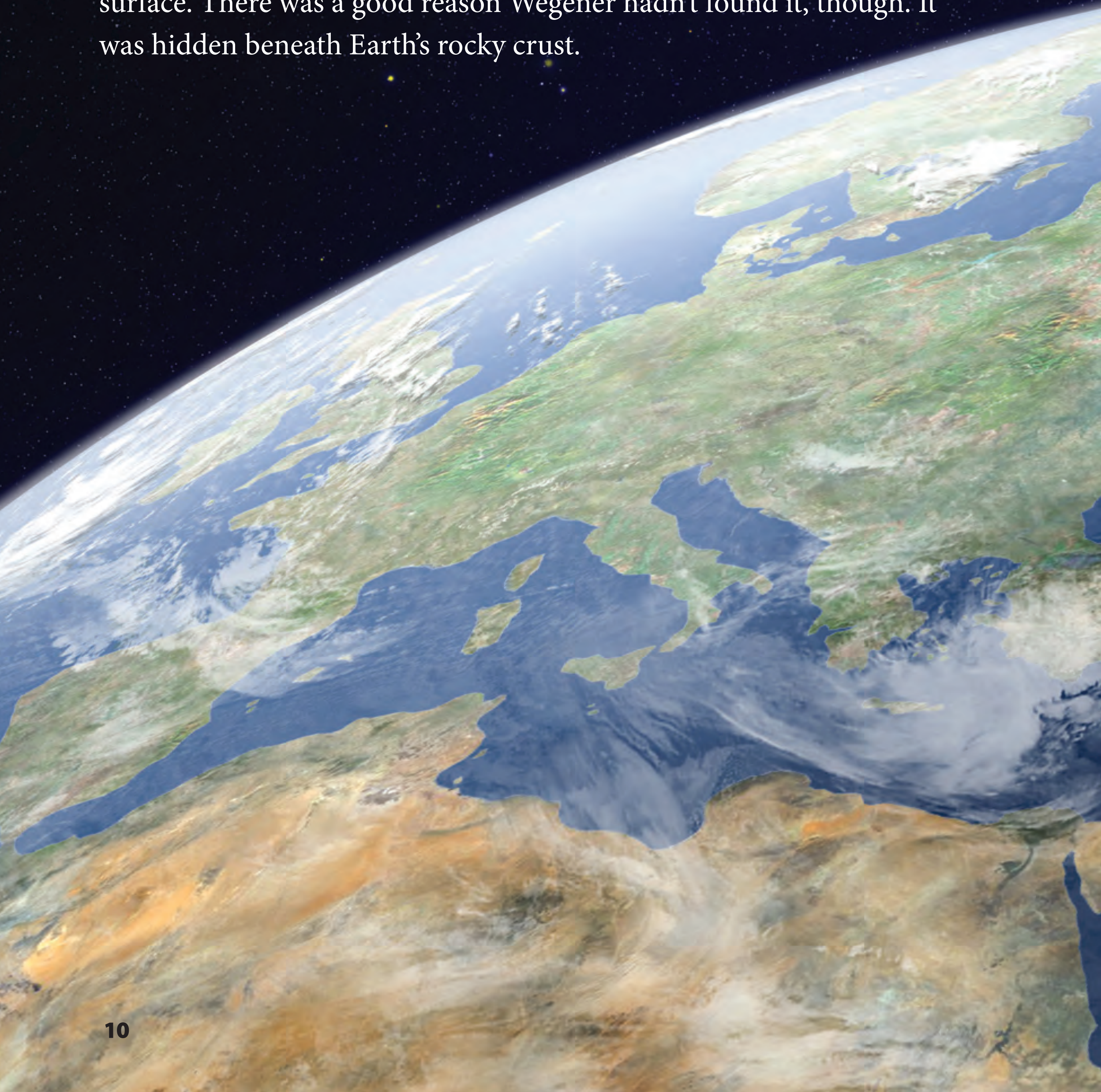
Think of the last time you put ice in a glass of tea or lemonade. The ice floated, right? Ice floats because it is less dense than water. Wegener thought about the fact that the rocks that make up continents are less dense than rocks on the seafloor. "What if continents were like enormous pieces of ice?" he wondered. "Could they float over the denser rocks of the ocean bottom and move around?"

In 1915, Wegener published a book titled *The Origins of Continents and Oceans*. In it, he presented his **hypothesis** about how the earth's continents had moved over time. He called the process **continental drift**.

Wegener proposed that millions of years ago, Earth had one huge landmass. He described it as a supercontinent and named it Pangaea, from the Greek word *pangaia*, meaning "all the Earth." At some point, Pangaea broke up, and the pieces—the continents—very slowly **drifted** away from each other. As the continents moved, mountain ranges pulled apart. Rock formations split. New oceans filled in the widening gaps between the landmasses. Groups of plants and animals that had once lived together were separated. As continents drifted, their climates changed. Antarctica's climate, for example, grew so cold that the continent's plants and animals died. Only their fossils remained, buried under snow and ice.

The Missing Puzzle Piece

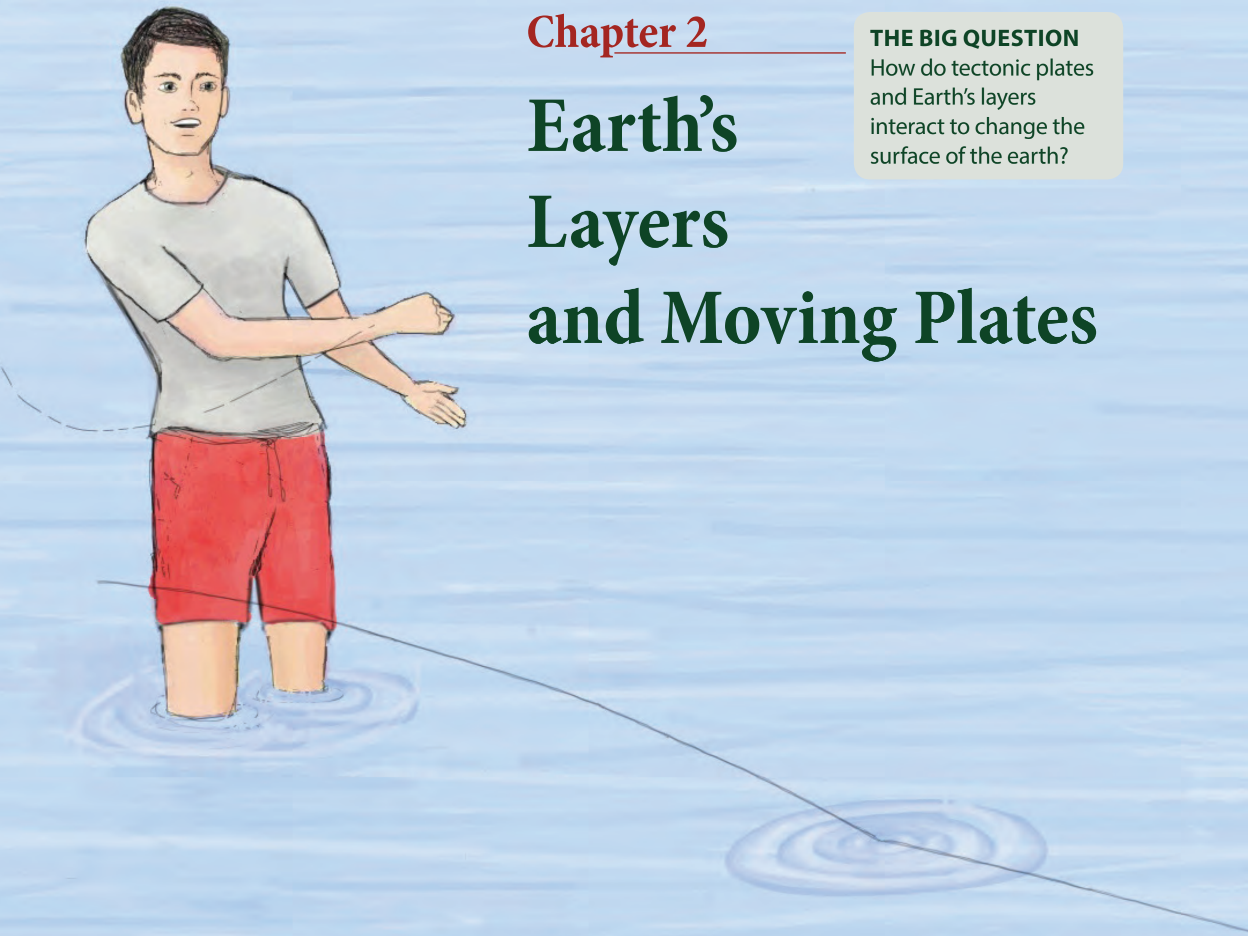
Wegener's continental drift hypothesis explained the fit of the continents. It explained how matching rocks, fossils, and land features ended up in different places. It explained how the climate had changed on some continents, too. Yet other scientists criticized Wegener's ideas and rejected his hypothesis. Why? It didn't explain how drifting continents actually moved. He had not identified a natural process powerful enough to slowly move enormous pieces of land across Earth's surface. There was a good reason Wegener hadn't found it, though. It was hidden beneath Earth's rocky crust.



Chapter 2

Earth's Layers and Moving Plates

THE BIG QUESTION
How do tectonic plates and Earth's layers interact to change the surface of the earth?



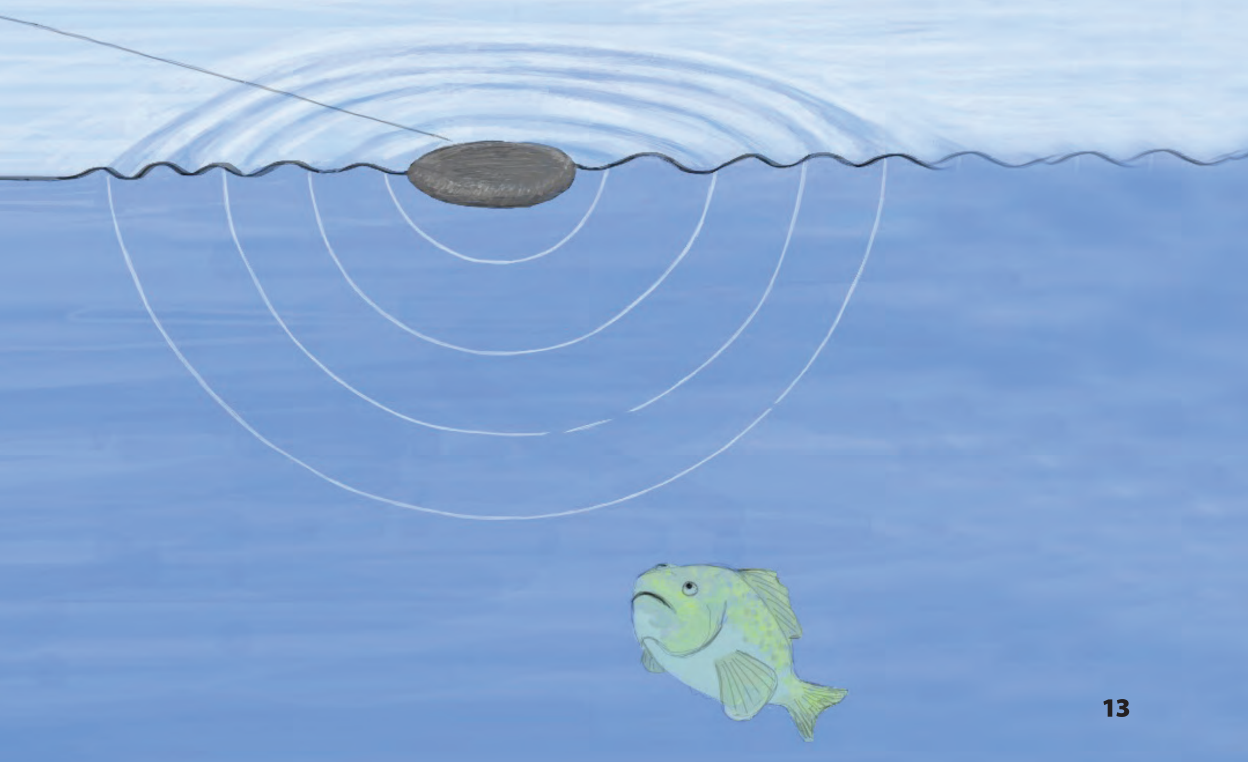
Alfred Wegener's continental drift hypothesis explained many of the "why" questions. It explained why the edges of some continents fit together like puzzle pieces. It explained why continents separated by vast oceans have similar types of rock formations and fossils. What the hypothesis couldn't explain was "how." How could a mass of solid rock as large as Asia or North America move thousands of miles across Earth's surface? It would take an enormously powerful force to do that. Geologists in Wegener's day didn't know of any force on Earth's surface powerful enough to move continents.

As a result, most geologists rejected the idea of continental drift. For decades, Wegener's hypothesis was harshly criticized. Still, a few geologists thought Wegener was on the right track. What if the driving force behind continental drift was below Earth's surface? How can you discover what lies beneath Earth's **crust**? Oddly enough, earthquakes helped scientists answer these questions.

What Waves Reveal

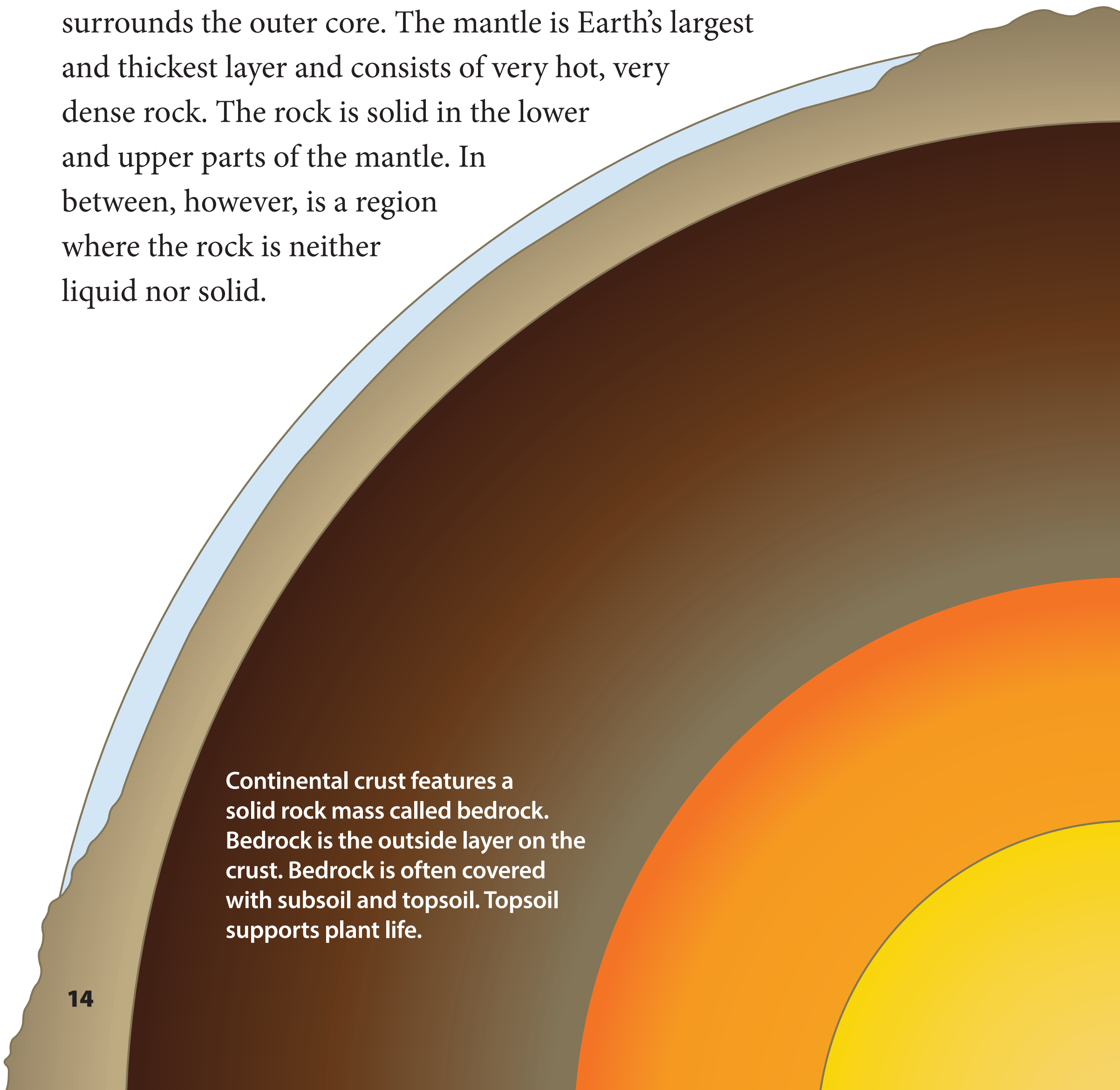
Have you ever tossed a small rock into a pond? Little waves travel out from the spot where the rock hits the water's surface. Although you can't see them, waves travel through the water below the surface, too.

An earthquake is a bit like a rock plunking into water. During an earthquake, the ground shakes. The shaking is caused by waves of energy traveling out from the earthquake's source through the earth. Scientists call these **seismic waves**. Powerful seismic waves can travel very long distances. They can travel through Earth's crust and deep into its interior.



Around the time Alfred Wegener was thinking about continental drift, scientists were studying Earth's interior using seismic waves. How? Using instruments called **seismographs**, they tracked seismic waves traveling through the planet. Seismic waves move in slightly different ways as they move through different materials. For instance, they travel faster through solids than liquids. Studying seismic waves helped scientists identify Earth's four main layers.

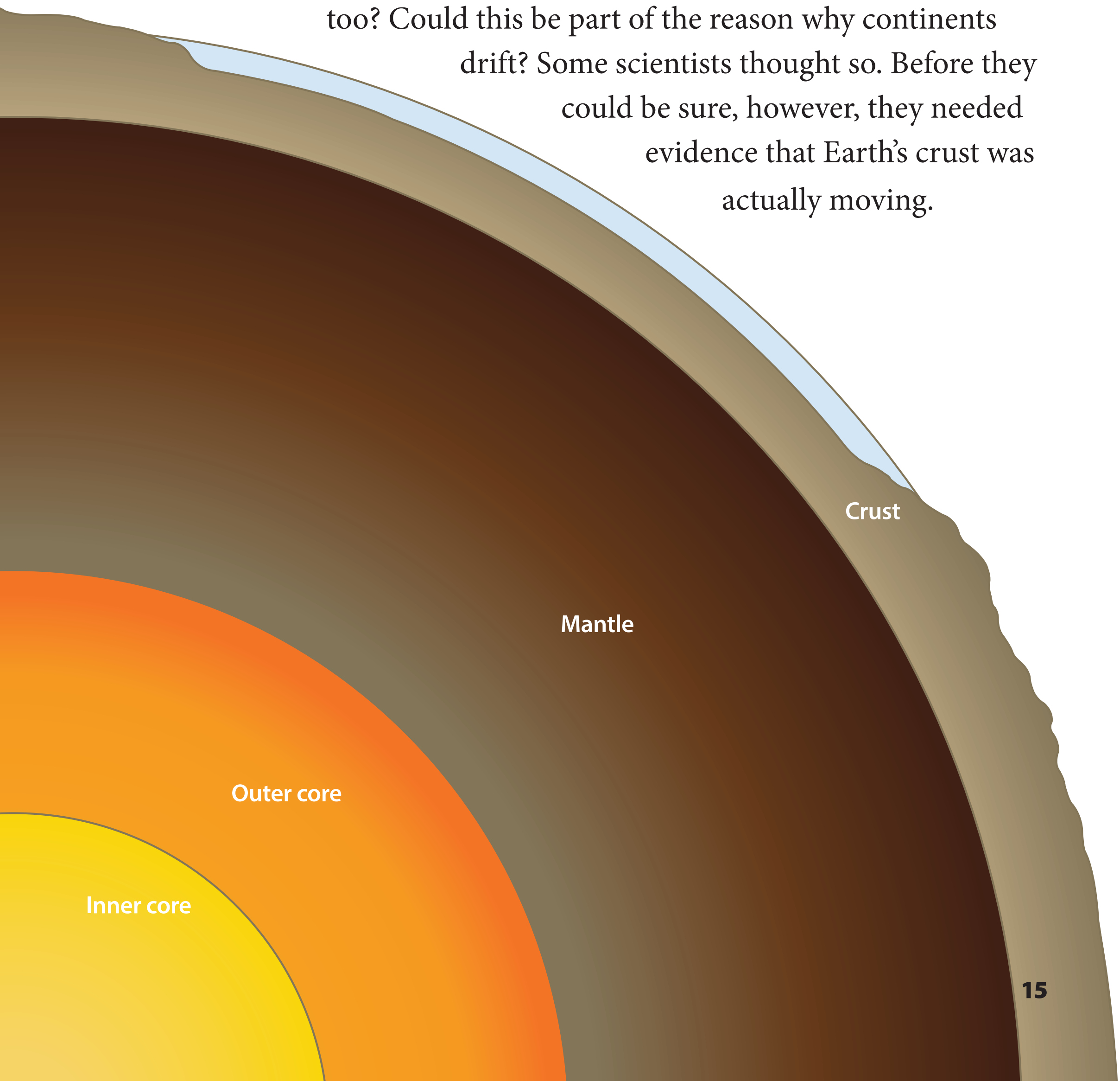
Earth's deepest layer is a solid **inner core** of very hot metal. This metal may be nearly as hot as the sun's surface. The next layer, the **outer core**, is also made of hot metal, but it's liquid, not solid. The **mantle** surrounds the outer core. The mantle is Earth's largest and thickest layer and consists of very hot, very dense rock. The rock is solid in the lower and upper parts of the mantle. In between, however, is a region where the rock is neither liquid nor solid.



Continental crust features a solid rock mass called bedrock. Bedrock is the outside layer on the crust. Bedrock is often covered with subsoil and topsoil. Topsoil supports plant life.

The slow movement and behavior of this material, caused by heat and **pressure**, have an impact on Earth's surface. Above the mantle is Earth's outermost layer, the thin, rocky crust. There are two types of crust: oceanic crust and continental crust. Oceanic crust is covered by ocean water. Most of the continental crust is dry land, but some of the crust around the edges is covered by water. Oceanic crust is thinner but heavier than continental crust.

For scientists interested in continental drift, it was the slowly moving material in the middle of the mantle that caught their attention. Did material movement in the mantle contribute to crust movement, too? Could this be part of the reason why continents drift? Some scientists thought so. Before they could be sure, however, they needed evidence that Earth's crust was actually moving.

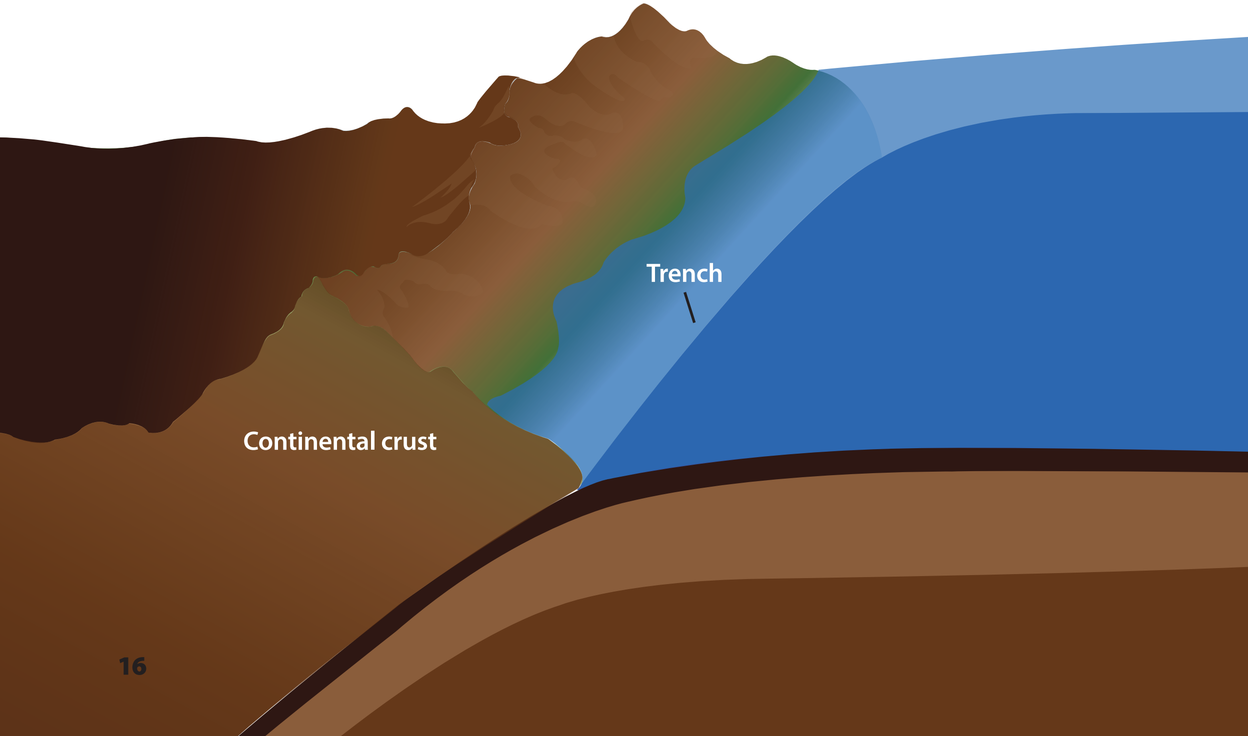


Clues from the Seafloor

During the 1940s and 1950s, new technology enabled scientists to make detailed maps of the seafloor. The maps revealed long chains of underwater mountains, called mid-ocean ridges, in all of Earth's oceans. There was a split, or rift, that ran down the center of these ridges. The rift was like a seam in a pants leg, where two pieces of fabric come together.

Scientists dredged up rock samples from mid-ocean ridges. All the rocks were **basalt**. Mid-ocean ridges seemed to be like long, skinny strings of volcanoes running along the seafloor.

Scientists collected rocks at various distances from the rift along a mid-ocean ridge. They discovered that rocks from the edge of the rift had formed very recently. Rocks farther away from the rift were older. The farther scientists got from the rift, on either side, the older the rocks were.

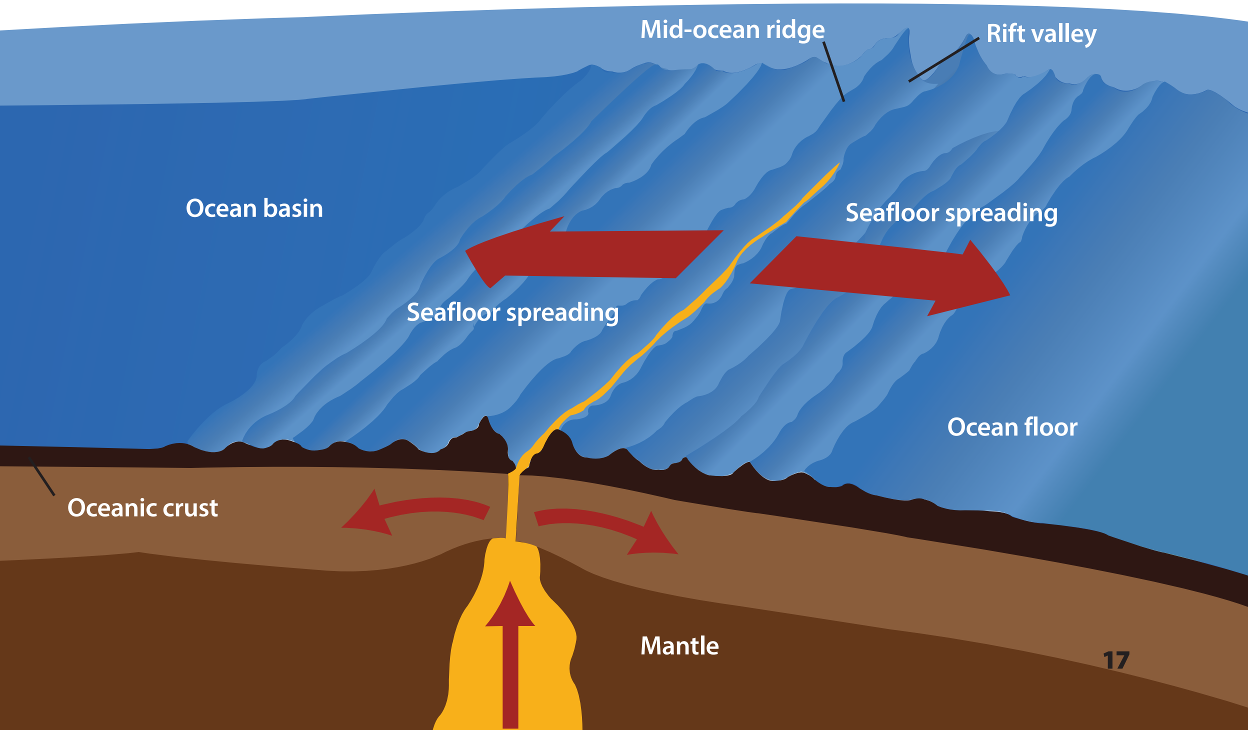


The scientists concluded that mid-ocean ridges form along huge cracks in Earth's crust. **Magma** beneath the crust erupts through these cracks as **lava**. The lava cools into basalt, creating new oceanic crust on either side of the rift.

As new crust is added, older crust gets pushed outward, away from the rift. Inch by inch, year after year, oceanic crust spreads outward into ocean **basins** on either side of mid-ocean ridges. Scientists called this process seafloor spreading. They theorized that as the seafloor slowly spreads, continents bordering the ocean slowly move apart. Here was one explanation of how continents could drift!

Scientists knew the earth wasn't getting bigger. If new crust forms along mid-ocean ridges, then old crust must be destroyed somewhere else. Scientists guessed that deep **ocean trenches** are places where crust is sinking down into the mantle.

In the 1960s, scientists formed a new **theory** about how Earth's surface changes. They called the theory **plate tectonics**.



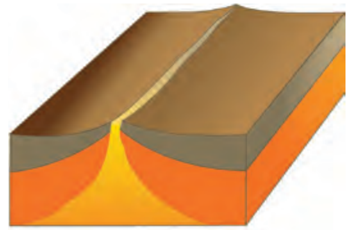
Moving Plates

Scientists are still learning about plate tectonics. The theory of plate tectonics states that Earth's crust, together with the solid top of the mantle, is broken up into sections. These huge, rocky slabs are called

tectonic plates. Tectonic plates fit tightly together. They aren't fixed in place though; they can move. They move because of heat and pressure in the mantle. As the material in the mantle slowly moves, it **exerts** enormous pressure on the overlying plates. All that pressure forces the plates to move as well—very, very slowly.

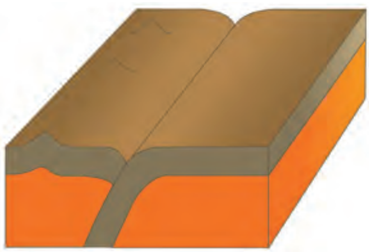
Earth's tectonic plates have been slowly moving and interacting for billions of years. They interact mostly along their edges, or boundaries. Plate boundaries are where two or more tectonic plates meet.

A Matter of Time



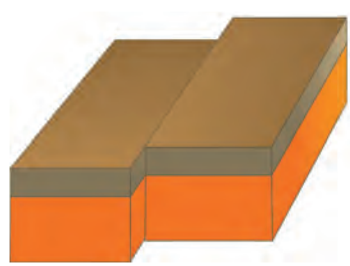
Tectonic plates move apart.

At some boundaries, tectonic plates are moving apart. As the plates separate, molten rock flows up from the mantle into the space between them, creating new crust. Mid-ocean ridges are an example of this type of plate interaction. Tectonic plates along the mid-ocean ridge in the Atlantic Ocean are moving apart at a rate of about 0.8 to 2 inches per year. That may not seem like much, but it adds up. Two hundred million years ago, the landmasses of North America and Europe were joined. So were South America and Africa. Thanks to separating plates, these continents now lie on opposite sides of a vast ocean.



Tectonic plates collide.

At other plate boundaries, tectonic plates are **colliding**, or crashing together. In some places, colliding plates slowly crash into each other. The crust at their edges gradually crumples and is pushed higher and higher, creating mountains. In other places, one of the colliding plates slides under the other. Two plates are colliding this way along the western coast of South America. A heavier oceanic plate is sliding under a lighter continental plate. Scientists call this process **subduction**. Subduction has created a deep ocean trench off the coast of Chile and Peru. It has also had a role in creating the towering Andes Mountains along the western edge of South America. Similar plate interactions have formed mountain ranges throughout Earth's long history.



Tectonic plates slide sideways past one another.

Finally, tectonic plates slide sideways past one another. It's never a smooth process. Plate edges press together hard. They often get stuck while the pressure keeps building. Eventually the pressure gets too great. The stuck edges break free, causing the plates to jerk past each other.

Providing the Answers

The theory of plate tectonics answered many questions in geology. It explained how Wegener's Pangaea broke apart. It explained how the continents have been slowly rearranged over millions of years. The movement of the plates also explained mid-ocean ridges, deep ocean trenches, patterns in the locations of mountains, and many other features on Earth's surface. The theory has become the cornerstone of modern geology.

As plates move, interesting things happen. Most of the time, they happen incredibly slowly. Sometimes, though, the effects of plate movements are sudden and dramatic. Think earthquakes and volcanoes!

Core Conclusions

You may never have heard of the Danish scientist Inge Lehmann. Among seismologists, however, she is famous. Around 1900, scientists thought the earth had just three layers: an outer crust, a solid mantle, and a liquid core. Lehmann studied seismograph records of earthquakes. She analyzed how seismic waves changed as they traveled through Earth's interior. Lehmann collected thousands of records organized in boxes—there were no computers back then! She saw patterns in how seismic waves behaved as they moved through Earth. Lehmann concluded that Earth's core has two parts: a liquid outer core and a solid inner core. In 1936, she announced her findings and changed our view of Earth!

Chapter 3

Earth's Shakes and Quakes

THE BIG QUESTION
What happens beneath Earth's surface to cause earthquakes?

Italian writer Francesco Petrarch penned the following **eyewitness** account in the Middle Ages. Can you guess what he was writing about?

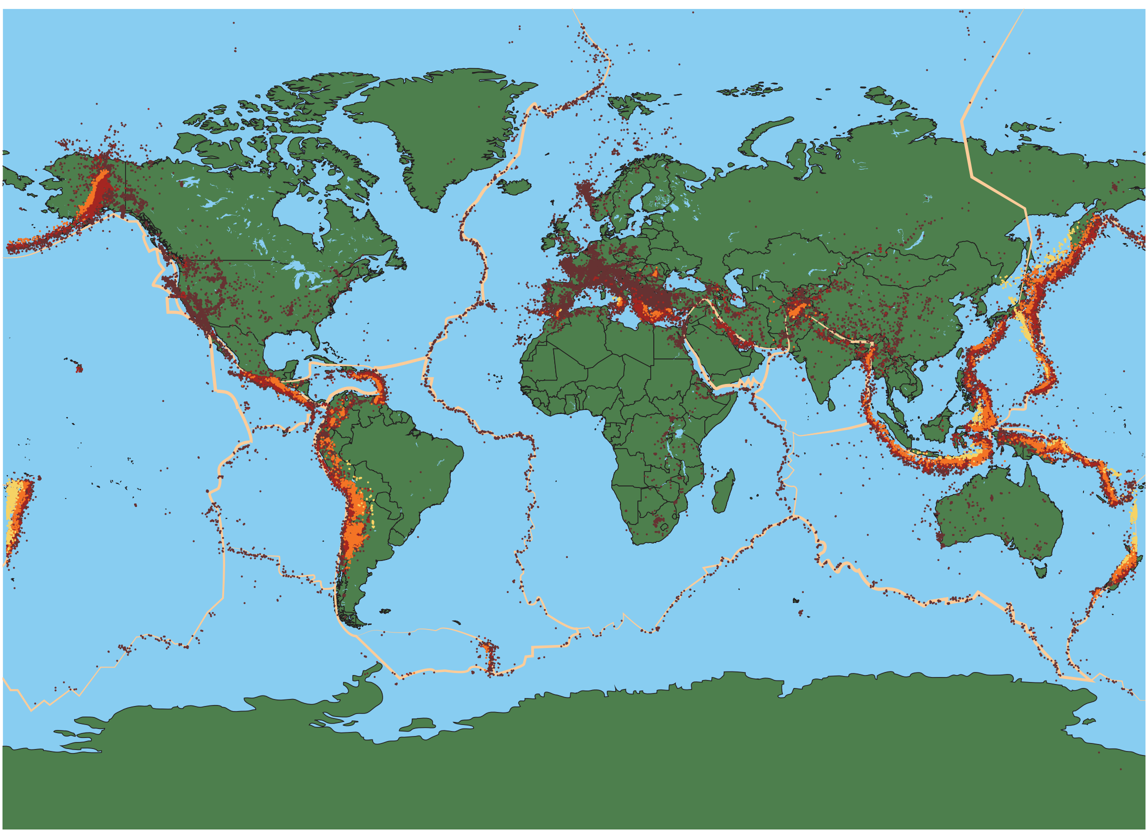
"The floor trembled under my feet; when the books crashed into each other and fell down I was frightened and hurried to leave the room. Outside I saw the servants and many other people running anxiously to and fro. All faces were pale."


Francesco Petrarch

If you said an earthquake, you're correct! People in northern Italy had good reason to be pale and frightened on a winter's day in 1348 CE. On that day, a large earthquake struck. Thousands of people lost their lives.

Earthquakes are violent natural disasters that strike without warning. Suddenly, the ground begins to shake. Furniture topples, objects tumble from shelves, and buildings may even collapse. In 1348 CE, people had no idea what caused earthquakes. Today we know that earthquakes are the result of powerful natural forces at work in Earth's crust and mantle.

As you read in Chapter 2, scientists developed the theory of plate tectonics in the 1960s. The theory explains how Earth's surface and interior change over very long periods of time. Some plates are pulling apart at their boundaries, other plates are colliding, and still others are sliding past each other. A lot happens at plate boundaries, including most earthquakes. In fact, one of the easiest ways to locate plate boundaries is to determine where earthquakes are occurring!



Locations of plate boundaries and past earthquake epicenters

Forces and Faults

Try a little **experiment**. Extend your arms out in front of you parallel to the floor and put your hands together. Keep your palms and fingers flat against each other. Now start pressing your hands together. Gradually increase the pressure. When you can't press any harder, let your right hand quickly slide forward. That sudden slipping is what happens at a **fault**.

A fault is a fracture, or crack, in Earth's crust. Most faults occur along the boundaries of tectonic plates. As plates move, huge rough blocks of rock along either side of a fault get stuck against each other. Beneath the plates, however, material in the mantle keeps moving. This material exerts more and more pressure on the plates to also keep moving. Pressure builds along the stuck edges of the fault. Think of your hands as these edges, pressing harder and harder together. The pressure builds until the stuck blocks of rock suddenly break and slip past one another. As they do, a tremendous burst of energy is released. How much energy? Well, all the energy that accumulated in the rocks during the time they were stuck and couldn't move.


A fault in Iceland

The Pacific Plate is Earth's largest tectonic plate. It lies beneath the Pacific Ocean. Imagine how much energy it takes to move that gigantic rocky plate plus all the water on top of it. Then imagine all that energy being released at a fault in just a moment. Such a colossal burst of energy travels outward from the fault in all directions as seismic waves. Seismic waves make the ground **heave** and shake. This violent shaking is what we call an earthquake.

San Andreas Fault

In the United States, one of the most famous faults is the San Andreas Fault in California. It lies along the boundary between two tectonic plates that are slowly moving past each other. The movement, however, is far from steady. For years at a time, blocks of rock bordering the San Andreas Fault stay stuck. Pressure slowly builds. Then—wham!—they slip and **trigger** an earthquake. The 1906 San Francisco earthquake was one of the worst in American history. The sudden slip that triggered it was huge. It caused rocks on either side of the fault to move more than 20 feet in just seconds!

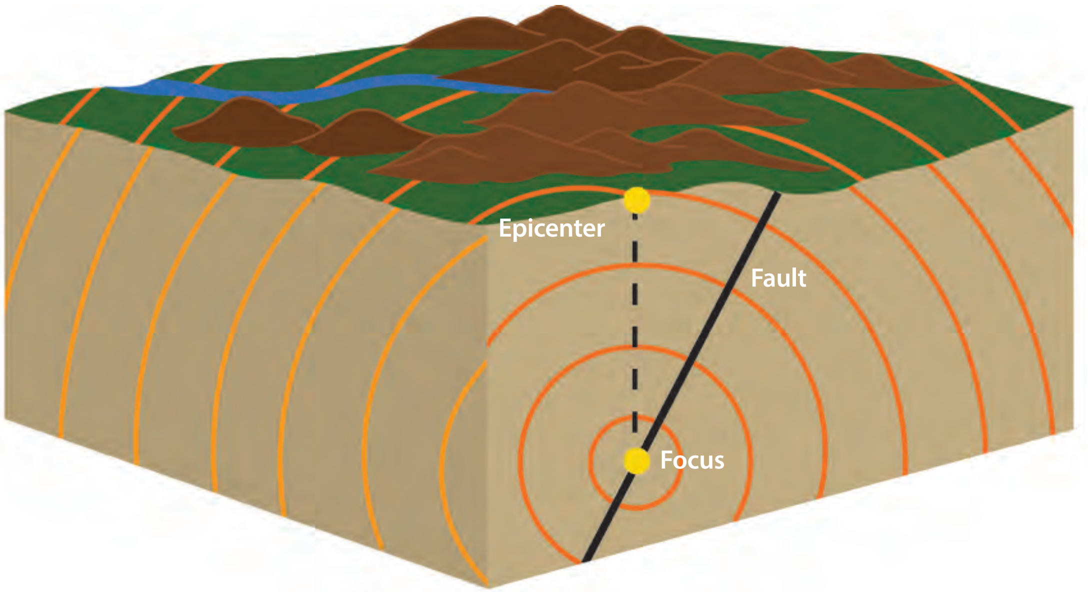
Effects of the 1906 San Francisco earthquake

Shake, Heave, Sway, and Lurch

All earthquakes begin with huge blocks of rock moving along faults. The place in Earth's crust where this happens is an earthquake's **focus**. Think of it as the earthquake's heart, the source of seismic waves. The focus may be deep in the crust or close to the surface.

The **epicenter** is the point on Earth's surface directly above an earthquake's focus. Some kinds of seismic waves produced by earthquakes travel deep into Earth's interior. Surface waves, however, are seismic waves that are first noticeable at the epicenter. During an earthquake, surface waves are what make the ground shake, heave, sway, and lurch. They are the cause of most earthquake damage.

In Chapter 2, you read about seismographs, which scientists use to record the shaking of Earth's surface caused by seismic waves. The time it takes for seismic waves to reach a seismograph is important in determining where the earthquake occurred. The longer that seismic waves take to reach a seismograph, the farther away the earthquake is from the seismograph.



The place in Earth's crust where an earthquake begins is its focus. Its epicenter is the point on Earth's surface directly above the focus.

Seismographs: Now and Then

A modern seismograph, also called a seismometer, records the shaking of Earth's surface caused by seismic waves. A **seismogram** is the record a seismograph makes. A seismogram shows seismic waves as jagged up-and-down lines. Scientists compare multiple seismograms in order to **pinpoint** an earthquake's epicenter.

Zhang Heng, a Chinese scientist, invented the first-known seismograph around 132 CE. It didn't look anything like a modern seismograph. It was shaped like a large vase. The vase had eight dragons around the outside, each looking downward and holding a ball loosely in its mouth. Below the eight dragons were open-mouthed frogs. When an earthquake struck, the balls fell into the frogs' mouths below. Depending on which balls fell, it was possible to estimate the distance and direction to the earthquake's source.

Modern seismograph

First-known seismograph

Measuring an Earthquake's Strength

Scientists also use seismographs to measure an earthquake's strength, or **magnitude**. During a small earthquake, Earth's surface may shake only a little. The seismogram shows these relatively low-energy seismic waves as little wiggles. During a big earthquake, Earth's surface shakes a lot harder. The seismogram shows these high-energy waves as big zigzags.

The Richter scale is another way scientists measure an earthquake's magnitude. The Richter scale assigns a number to an earthquake based on the largest seismic wave recorded for that earthquake. The higher the Richter scale number, the stronger the earthquake. For example, a magnitude 5.0 earthquake on the Richter scale causes 10 times as much ground shaking as a magnitude 4.0 earthquake. A magnitude 6.0 earthquake causes 10 times more shaking than a 5.0, and so on.

Damage caused by earthquakes

The Modified Mercalli Intensity Scale also uses numbers to measure earthquake strength. The numbers are based on survivors' descriptions and the amount of earthquake damage. The higher the number, the stronger the earthquake. The Mercalli scale is less scientific than the Richter scale, as few people describe events in the same way.

Pressure along faults can build up for years, even centuries. When blocks of rock along a fault finally move, the resulting earthquake happens very quickly. Most earthquakes last just a few seconds. Still, the trouble may not be over after the ground stops shaking. Large earthquakes are often followed by **aftershocks**. Aftershocks are like mini-earthquakes. They are usually smaller and weaker than the main earthquake event. Aftershocks happen as blocks of rock along the newly slipped fault settle into place.

<table>
<tr><th colspan="2">Modified Mercalli Scale</th><th colspan="2">Richter Scale</th></tr>
<tr><td>I</td><td>Felt by almost no one</td><td rowspan="2">2.5</td><td rowspan="2">Generally not felt, but recorded on seismometers.</td></tr>
<tr><td>II</td><td>Felt by very few people</td></tr>
<tr><td>III</td><td>Noticed by many, but they often do not realize it is an earthquake.</td><td rowspan="3">3.5</td><td rowspan="3">Felt by many people</td></tr>
<tr><td>IV</td><td>Felt indoors by many; feels like a truck has struck the building.</td></tr>
<tr><td>V</td><td>Felt by nearly everyone; many people awakened. Swaying trees and poles may be observed.</td></tr>
<tr><td>VI</td><td>Felt by all; many people run outdoors. Furniture moved; slight damage occurs.</td><td rowspan="2">4.5</td><td rowspan="2">Some local damage may occur.</td></tr>
<tr><td>VII</td><td>Everyone runs outdoors. Poorly built structures considerably damaged; slight damage elsewhere.</td></tr>
<tr><td>VIII</td><td>Specially designed structures damaged slightly; others collapse.</td><td rowspan="2">6.0</td><td rowspan="2">A destructive earthquake</td></tr>
<tr><td>IX</td><td>All buildings considerably damaged; many shift off foundations. Noticeable cracks in ground.</td></tr>
<tr><td>X</td><td>Many structures destroyed. Ground is badly cracked.</td><td rowspan="2">7.0</td><td rowspan="2">A major earthquake</td></tr>
<tr><td>XI</td><td>Almost all structures fall. Very wide cracks in ground.</td></tr>
<tr><td>XII</td><td>Total destruction. Waves seen on ground surfaces; objects are tumbled and tossed.</td><td>8.0 and up</td><td>Great earthquakes</td></tr>
</table>

The Mercalli scale is less scientific than the Richter scale.

Earthquakes at Sea

Remember that most earthquakes occur along the boundaries of tectonic plates. Several plate boundaries are in the ocean, so many earthquakes occur in the oceanic crust that forms the seafloor. This is especially true around the Pacific Ocean. The Pacific has many deep ocean trenches along the edges of its ocean basin. Ocean trenches form where one tectonic plate is sliding, or subducting, beneath another plate. Earthquakes are very common in the continental crust along ocean trenches.

Earthquakes that occur in the crust forming the ocean bottom can cause the seafloor to shift. This shift can cause seawater, from the ocean bottom to its surface, to suddenly start to move. The result is a gigantic wave called a **tsunami**.

Tsunamis travel fast—as much as 500 miles per hour. Out in deep water in the middle of the ocean, you'd hardly notice this great pulse of water passing by. All that water piles up as the tsunami approaches a coastline. It becomes a towering wall of water that may be as tall as a three- or four-story building. The tsunami crashes onto the shore with incredible force. It **surges** far inland. Then it goes roaring and churning back out to sea. Tsunamis can cause terrible destruction.

While scientists cannot predict earthquakes, they are able to give some warning for tsunamis. Depending on its starting point, a tsunami may take many minutes, even hours, to reach land. Several countries have set up tsunami warning systems in the Pacific and other oceans.

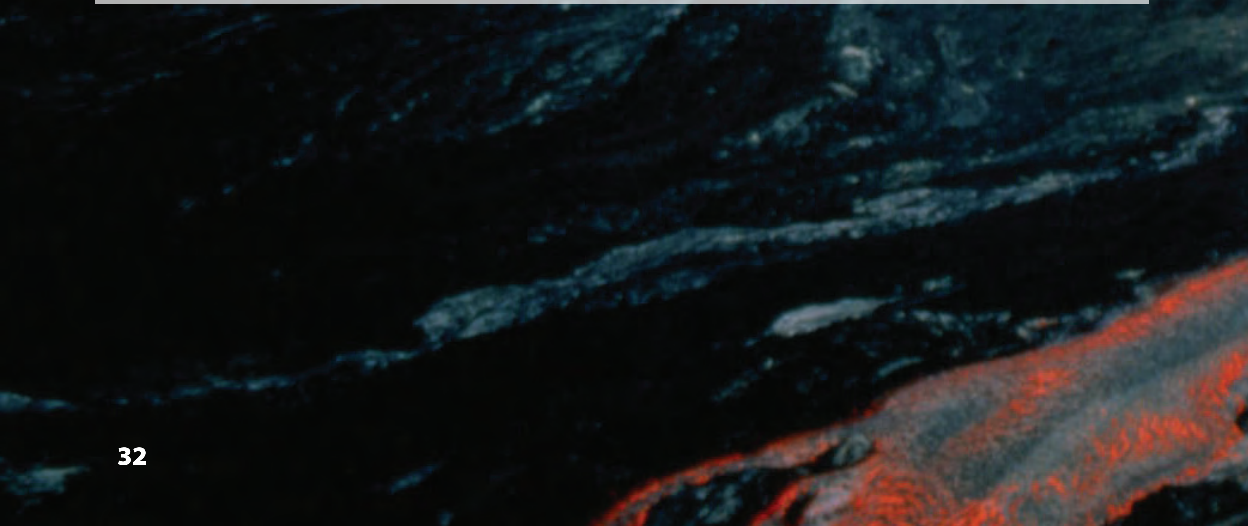
Chapter 4

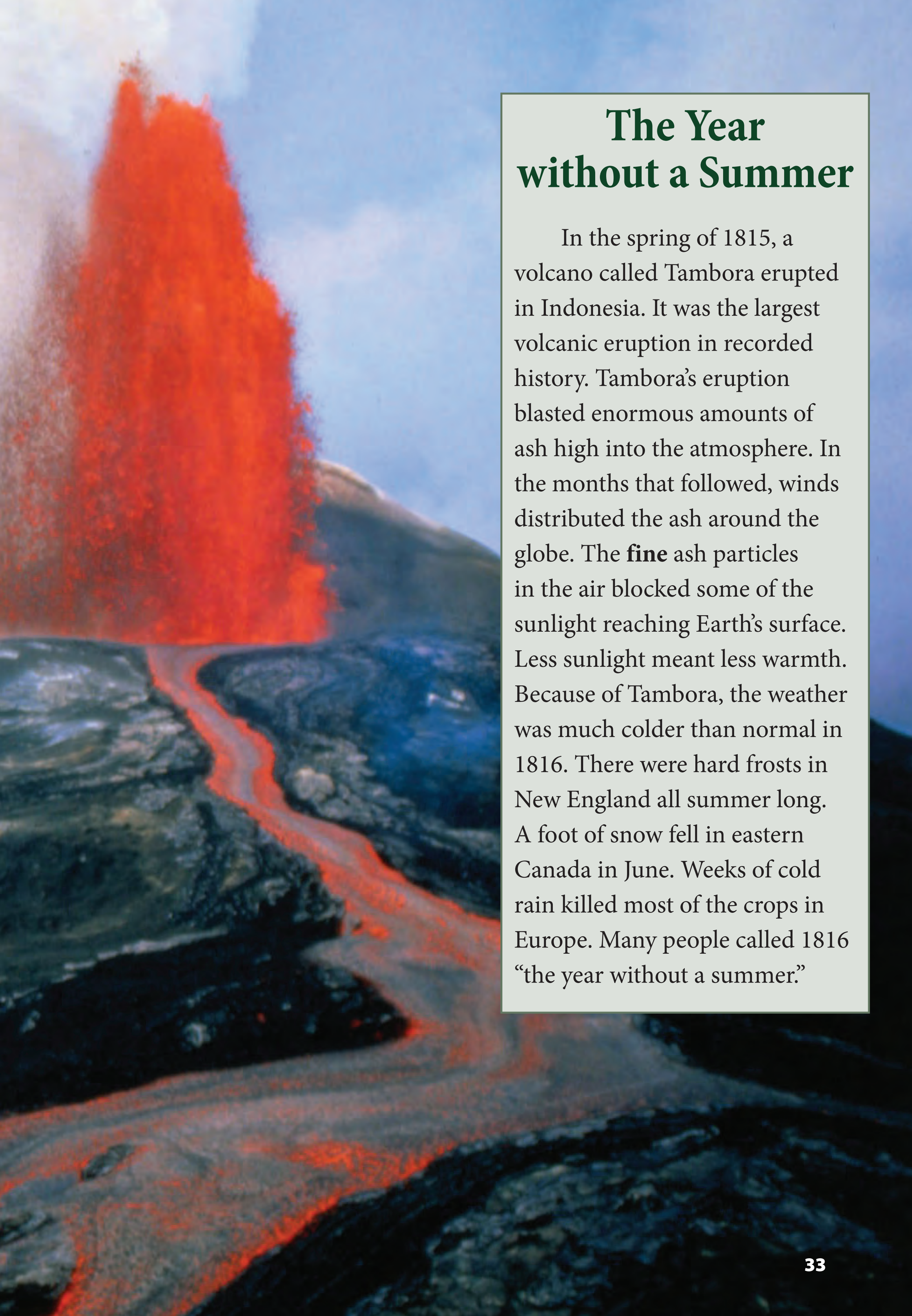
Earth's Fiery Volcanoes

THE BIG QUESTION
How do scientists determine where volcanoes might develop?

Imagine seeing new land form right before your eyes. You can do just that on the island of Hawaii in the Hawaiian Island chain. There, the Kilauea **volcano** has been erupting continuously since 1983. At times, red-hot lava shoots out of the **crater** at the volcano's top. More often, lava oozes out of cracks on the volcano's sides. As the lava flows downhill, it cools and hardens into volcanic rock. When lava flows all the way to the ocean, it cools to form rock along the shore. This adds new land to the island, making it a little bigger than it was before.

Erupting volcanoes are dramatic natural events. They can be a creative force, adding new land—even whole islands—to our planet. They also bring minerals from deep inside the earth to the surface. However, volcanoes can be dangerous and destructive. Large volcanic eruptions can flatten entire forests. They can fill the air with poisonous gases and hot, choking ash. They can release rivers of lava that burn and bury everything in their path. Erupting volcanoes can also trigger earthquakes, tsunamis, and landslides. They can even change the weather all around the world.



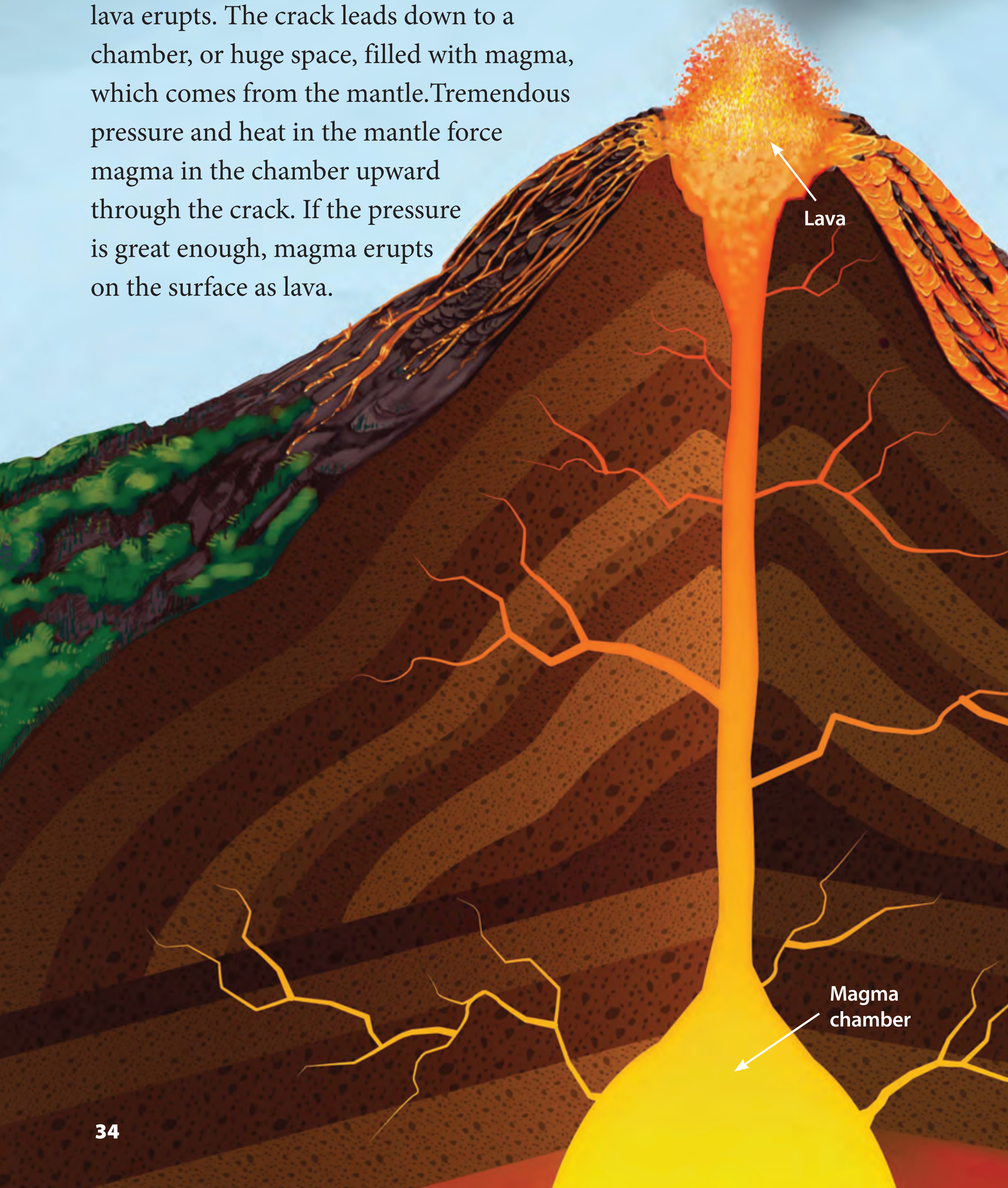


The Year without a Summer

In the spring of 1815, a volcano called Tambora erupted in Indonesia. It was the largest volcanic eruption in recorded history. Tambora's eruption blasted enormous amounts of ash high into the atmosphere. In the months that followed, winds distributed the ash around the globe. The **fine** ash particles in the air blocked some of the sunlight reaching Earth's surface. Less sunlight meant less warmth. Because of Tambora, the weather was much colder than normal in 1816. There were hard frosts in New England all summer long. A foot of snow fell in eastern Canada in June. Weeks of cold rain killed most of the crops in Europe. Many people called 1816 "the year without a summer."

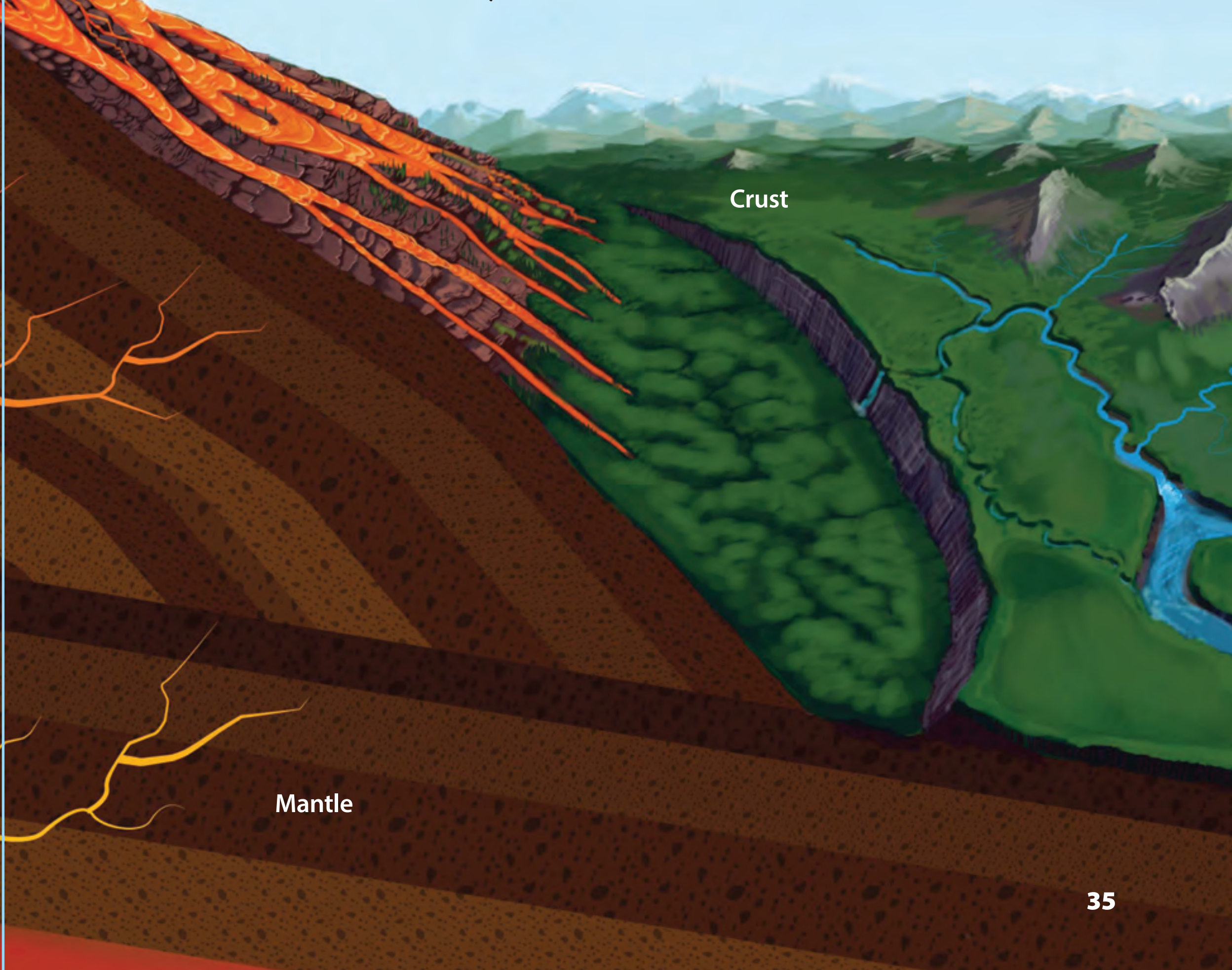
What is a Volcano?

A volcano is a hill or mountain that forms over a crack in Earth's crust from which lava erupts. The crack leads down to a chamber, or huge space, filled with magma, which comes from the mantle.Tremendous pressure and heat in the mantle force magma in the chamber upward through the crack. If the pressure is great enough, magma erupts on the surface as lava.



Some volcanic eruptions are relatively calm and quiet whereas others are sudden and violent. Each time lava erupts, a new layer of rock forms, making the volcano bigger and bigger. Many volcanoes gradually become high, cone-shaped mountains. Mount Vesuvius in Italy and Mount Fuji in Japan are good examples of volcanoes with this distinctive shape.

Vesuvius and Fuji have something else in common. They are **active volcanoes**. An active volcano is one that has erupted in the past 10,000 years and is likely to erupt again. When an active volcano hasn't erupted in a long time, it is considered a **dormant volcano**. **Extinct volcanoes** are those that have not erupted for at least 10,000 years.



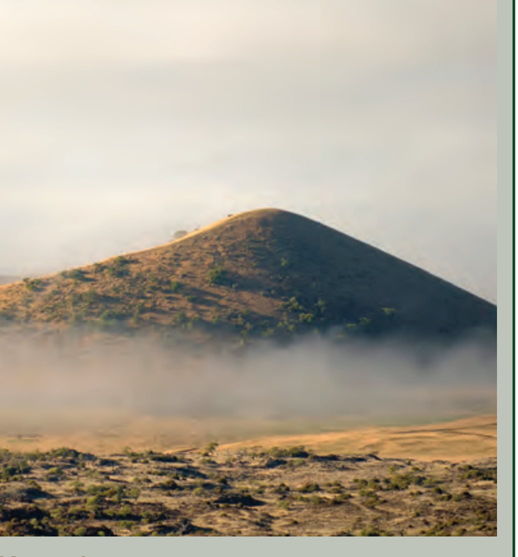
Action at the Edge

If you wanted to see a lot of volcanoes, where would you look? Volcanoes form where there are cracks and weak spots in Earth's crust. You'll find those mostly along the boundaries of tectonic plates that are moving apart. Volcanoes are also common where two plates are slowly colliding and one plate is subducting under the other.

The Pacific Plate is one of Earth's largest tectonic plates. It lies beneath the Pacific Ocean. Along its boundaries, the Pacific Plate is subducting under several other plates. Geologists call the places where this is happening **subduction zones**. Deep ocean trenches and many volcanoes have formed along subduction zones. This is because the edge of a subducting plate melts as it **descends** into Earth's hot mantle. Magma moves up through cracks in the crust and erupts to form volcanoes above the subduction zone.

World's Tallest Mountain

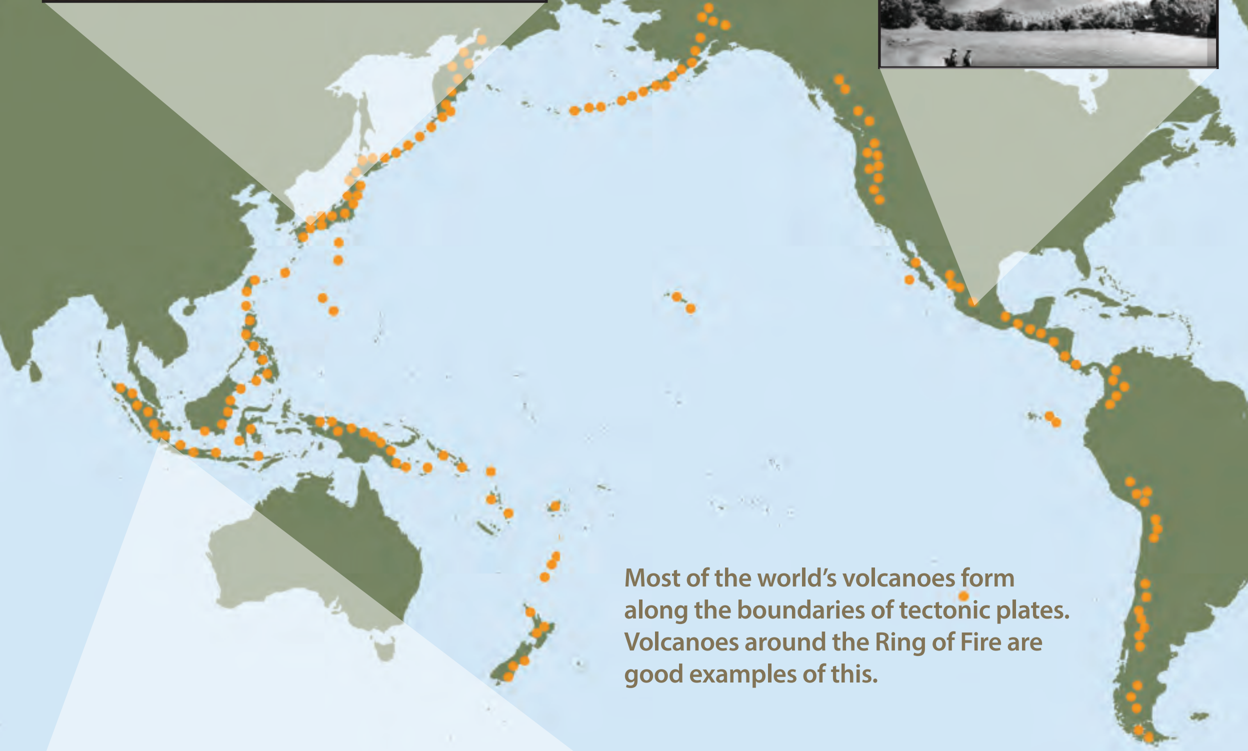
The largest active volcano is Mauna Loa, a volcano on the island of Hawaii. Mauna Loa's last big eruption was in 1984. The volcano's peak is 13,796 feet above sea level but its base sits on the seafloor. From top to bottom, this enormous volcano measures more than 33,000 feet. Mount Everest is considered the world's highest mountain at 29,029 feet above sea level, even though Mauna Loa is taller. This is because nearly 20,000 feet of Mauna Loa are hidden beneath the sea.



Mauna Loa

Mount Fuji in Japan

Paricutin volcano
in Mexico



Most of the world's volcanoes form along the boundaries of tectonic plates. Volcanoes around the Ring of Fire are good examples of this.

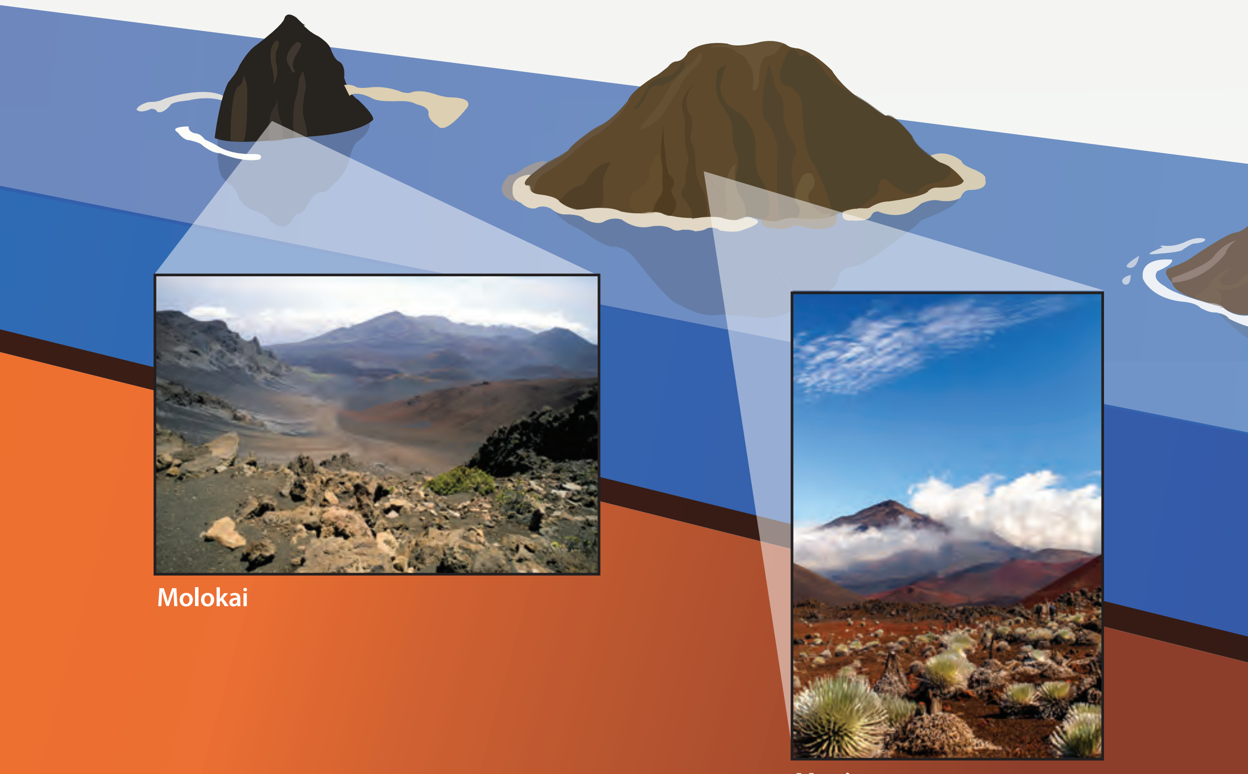
Krakatoa volcano in Indonesia

More than 450 active volcanoes lie around the edges of the Pacific Plate. Those are just the ones on land! Many more rise up from the seafloor and are hidden beneath the ocean's surface. Together, all these volcanoes form what is called the Ring of Fire around much of the Pacific Ocean. It is one of the most volcanically active regions on Earth.

Hotspots

Not all volcanoes form along plate boundaries. Some occur in places that geologists call **hotspots**. A hotspot is a very hot region deep within the mantle. A huge magma chamber forms beneath Earth's crust at a hotspot. Magma periodically erupts from the chamber through cracks in the crust.

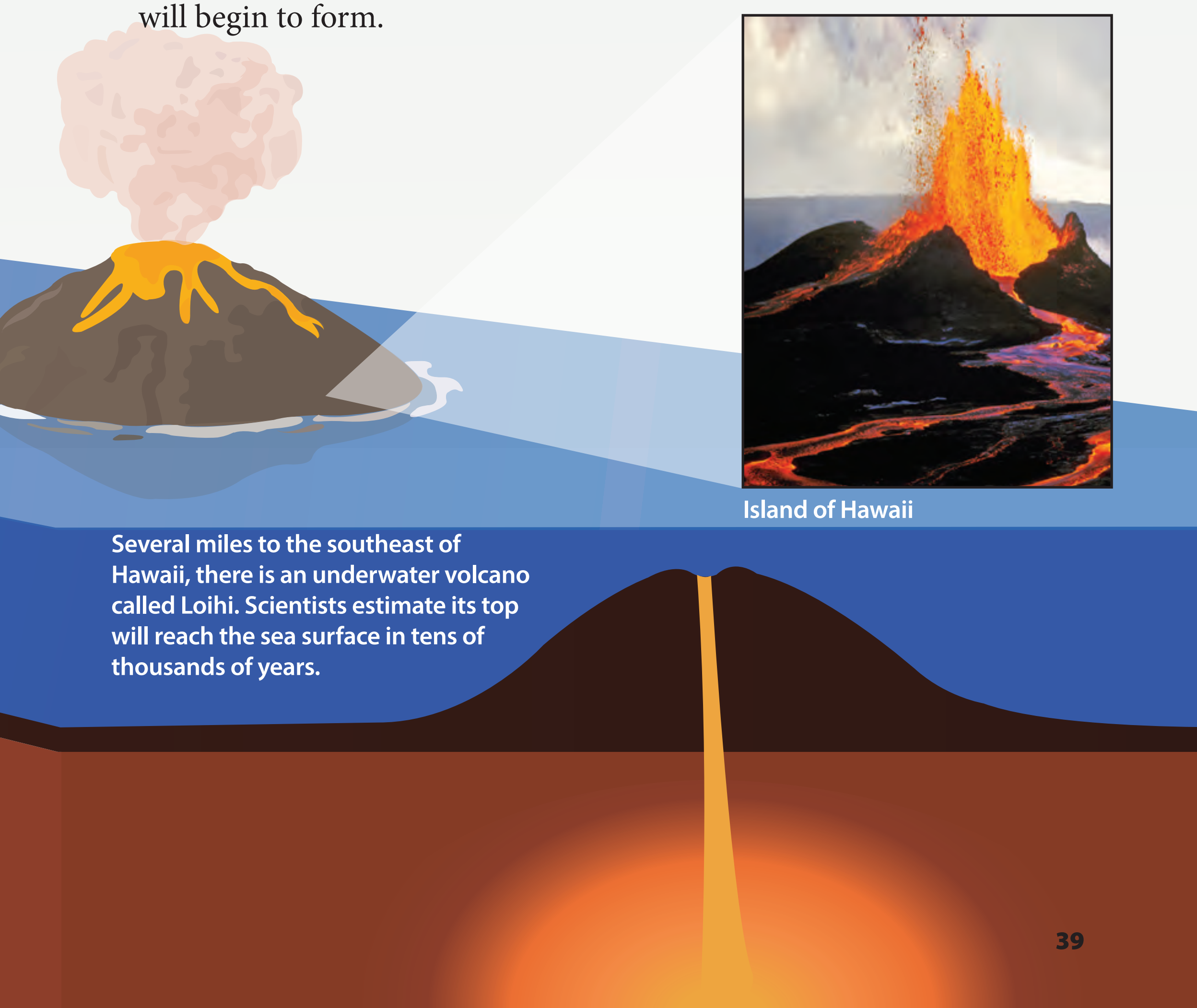
Geologists have identified dozens of hotspots worldwide. Some are beneath continental crust. Others are beneath oceanic crust. Hotspots underneath oceanic crust have formed many islands. The process begins when magma erupting from a hotspot forms a volcano on the seafloor. With repeated eruptions, the volcano grows taller and taller over time. Eventually the top of the volcano may rise above the ocean's surface and form an island.



Molokai

Maui

Over a very long period of time, ocean hotspots may form chains of islands. This is because hotspots remain in the same place while tectonic plates slowly keep moving. The Hawaiian Islands, for example, were formed by a hotspot located beneath the middle of the Pacific Plate. The island of Kauai formed about 5 million years ago. It began as an undersea volcano that grew tall enough to rise above the water. As the Pacific Plate inched its way northwest, however, Kauai moved along with it. At some point, the island was no longer directly above the hotspot. A new underwater volcano began forming on the seafloor. This volcano grew to form the island of Oahu. Next came the island of Molokai, then Maui, and finally the island of Hawaii. Hawaii currently lies over the hotspot, which is why it has so many active volcanoes. Eventually, Hawaii will drift away from the hotspot and a new island will begin to form.



Island of Hawaii

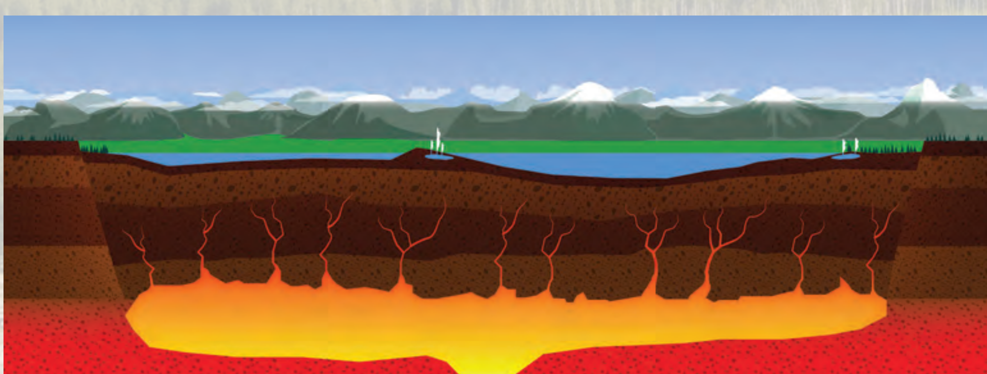
Several miles to the southeast of Hawaii, there is an underwater volcano called Loihi. Scientists estimate its top will reach the sea surface in tens of thousands of years.

A Garden of Geysers

Have you ever been to Yellowstone National Park? If so, you've stood over North America's largest hotspot. A great **plume** of magma rises from the mantle at this spot. It fills an enormous magma chamber beneath Earth's crust. In short, Yellowstone sits on top of one of the world's largest volcanoes. Geologists call it a supervolcano.

Heat from the magma beneath Yellowstone is what creates the park's **hot springs** and **geysers**. Geysers are hot springs that periodically erupt, like volcanoes of hot water. Geysers form when water drains down into openings in the ground above the magma chamber. Heat from the magma turns the water scalding hot. As the hot water rises back up through the openings, some of it turns to steam. This increases the pressure, forcing the mixture of steam and hot water to rush and bubble upward. When it reaches the surface, a hissing fountain of hot water and steam explodes out of the ground. Yellowstone's most famous geyser is called Old Faithful. It got its name because it erupts reliably more than a dozen times a day.

Magma itself hasn't erupted from the Yellowstone hotspot for hundreds of years. Could the Yellowstone supervolcano erupt again? It's possible, geologists say, but most doubt it will happen anytime soon.

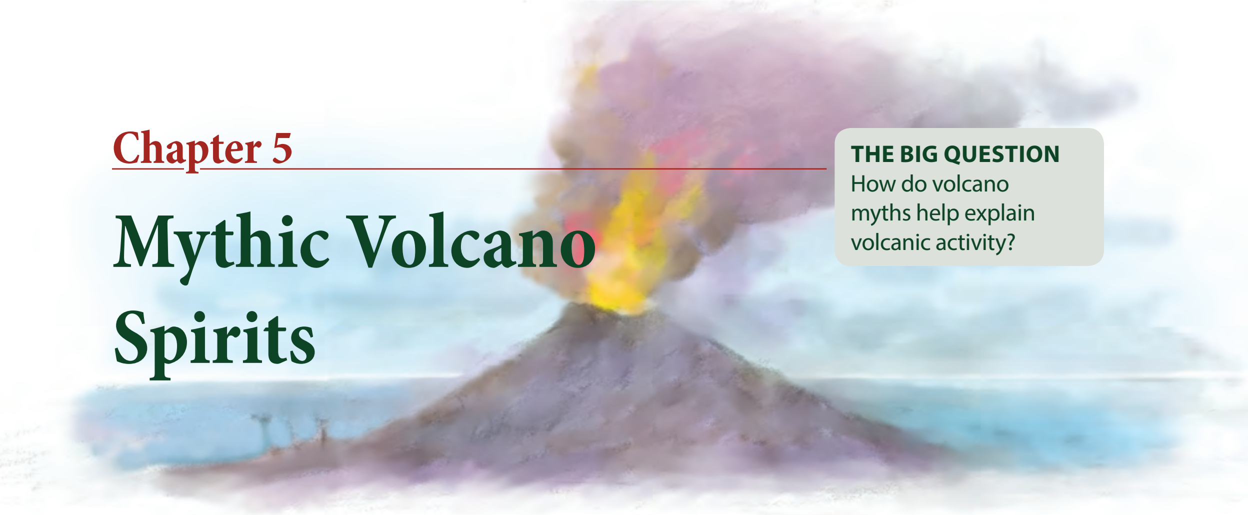


Yellowstone National Park's geysers and hot springs are all created by the heat of the huge pool of magma below the ground.

Old Faithful in Yellowstone National Park

Chapter 5

Mythic Volcano Spirits



THE BIG QUESTION
How do volcano myths help explain volcanic activity?

An erupting volcano seems almost alive. It hisses, rumbles, and makes the ground shake. It's easy to understand why ancient cultures thought powerful spirits lived inside volcanoes. Belief in volcano gods helped people make sense of volcanic eruptions. Some believed that when volcanoes were quiet, it meant the volcano gods were content. Some people also believed that when volcanoes erupted, it meant the gods were angry. People tried to keep volcano gods happy with **offerings** of food, flowers, and animals.

People told stories to help explain why unpredictable events like volcanoes occurred. Many stories included volcano gods as part of the explanation. These stories, or myths, were retold again and again. Over time, volcano myths became an important part of a culture's history and tradition. The myths were creative explanations for natural processes and events.

Hawaii's Goddess of Fire

Pele is the ancient Hawaiian goddess of fire and volcanoes. She is known for creating volcanic mountains and islands. When she unleashes fiery lava, she also destroys land and everything on it. Belief in Pele began centuries ago. Native Hawaiians believe the goddess lives in Kilauea, an active volcano on the island of Hawaii in the Hawaiian Island chain. This Hawaiian volcano myth tells the story of how she came to make her home there.

Long ago, Pele lived in the spirit world with her parents and many brothers and sisters. Pele was ***strong-willed*** *and had a short temper. When she got angry, she caused things to burn and lava to erupt from the ground. Pele got along with most of her siblings except for her sister, Na-maka-o-kaha'i, the goddess of the ocean and seawater. Over time, Pele and Na-maka-o-kaha'i became* ***bitter*** *enemies. Pele decided to find a new home, so she set off across Earth's ocean in a great canoe. Several of her brothers and her youngest sister, Hi'iaka, came with her.*

The canoe landed on Kauai, the northernmost island in the Hawaiian Island chain. There, Pele met and fell in love with Lohi'au, the island's king. She boldly asked him to marry her. After a moment's hesitation, Lohi'au agreed. Who could say no to a goddess? Before the wedding could take place, however, Pele insisted on creating a suitable place for the couple to live. Pele's idea of a good home was a huge hole in the ground, warmed by fires of hot lava.

Pele had a magic digging stick. When she jabbed the stick into the ground, a crater would open up in which volcanic fires burned. Pele began digging along Kauai's rocky coast. Every time she made a crater, seawater mysteriously flooded in and put out the flames. Much to her dismay, Pele discovered that her sister, Na-maka-o-kaha'i, had followed Pele to Kauai. Na-maka-o-kaha'i was trying to ruin Pele's plans to build a home and get married.

Hoping to ***outsmart*** *her hateful sister, Pele fled to Oahu, the next island in the Hawaiian chain. She took her youngest sister, Hi'iaka, and her brothers with her. Na-maka-o-kaha'i followed them and, once again, she caused seawater to fill every crater Pele dug. So Pele kept moving, traveling to the islands of Molokai and then Maui. There, too, Na-maka-o-kaha'i worked her watery magic. Time and again, she turned Pele's craters into cold, wet holes in the ground.*

Finally, Pele reached Hawaii, the largest island in the chain. Pele climbed the mountain called Kilauea and dug a crater at its top. The bright orange flames of volcanic fire flared and did not go out. Pele's crater on Kilauea was far above the sea, out of the reach of the ocean goddess.

Pele was pleased with her new home. She sent Hi'iaka to fetch her husband-to-be from Kauai. She told her little sister to be back in less than 40 days. She also warned Hi'iaka not to fall in love with Lohi'au herself. In turn, Hi'iaka made Pele promise to protect a grove of beautiful trees that grew on Kilauea. Hi'iaka adored the trees. She was afraid that if Pele lost her temper, she would send out rivers of lava to burn them down.

The journey took much longer than Hi'iaka expected. By the time she reached Kauai and found Lohi'au, more than 40 days had passed. On the trip back to Hawaii, Hi'iaka grew increasingly fond of Lohi'au. She also grew increasingly afraid of how Pele would react to their being so late in returning.

When Hi'iaka finally reached Kilauea with Lohi'au, she looked in horror on her beautiful forest. It was gone, burned to the ground by Pele's volcanic fire. To punish her older sister, Hi'iaka kissed Lohi'au. Enraged, Pele sent a huge river of lava streaming down the side of Kilauea. Lohi'au was buried beneath it.

Driven by the need for ***revenge****, Hi'iaka dug into the rocky side of the volcano. Lava began draining out and flowing toward the sea. One of Pele's brothers stopped Hi'iaka before all of Pele's volcanic fire drained away. Because so much lava had already been lost, the top of Kilauea collapsed. A great* ***caldera****, or bowl-shaped depression, was left behind. It is still visible at the volcano's top.*

Two of Pele's brothers took pity on the dead king—and on Hi'iaka, who truly loved him. They dug Lohi'au out of the lava *and brought him back to life. Hi'iaka and Lohi'au were married and lived happily ever after, while Pele remained in her* ***lofty*** *volcano home.*

Some people believe that Pele still lives in Kilauea. When the volcano erupts, they say it's a sign her fiery temper is flaring again.

Princess Power

In 1880, Mauna Loa erupted. A large lava flow crept down the mountainside toward the city of Hilo. The Hawaiian princess Ruth Keelikolani traveled to the scene as the lava neared the city. Princess Ruth stood directly in the path of the advancing lava. She recited ancient chants and made offerings to Pele. The next day the lava flow stopped. This helped keep belief in Pele alive.

The Origin of Crater Lake

The Klamath Indians of the Pacific Northwest have a myth about the creation of Oregon's Crater Lake. This deep, nearly circular lake fills the large caldera of an ancient, dormant volcano called Mount Mazama. Mazama is part of a chain of volcanoes that makes up a portion of the Cascade Mountain Range. Scientists believe that Mazama's caldera formed during its last major eruption nearly 8,000 years ago. Rain and melted snow filled the caldera to create what came to be known as Crater Lake. The following Klamath myth about Mazama's eruption and the lake's formation has its roots in these geological events.

Crater Lake in Oregon

Long ago, the world was home to two great Spirit Chiefs. The Chief of the Below World, Monadalkni, lived inside the earth and ruled below ground. The Chief of the Above World, Sahale Tyee, ruled above ground, from Earth's surface to the starry heavens overhead.

Sometimes, Monadalkni visited the Above World. He climbed up through the inside of a snow-covered mountain and emerged from a hole at the top. From there, he could see far and wide. He could see the forests, the rivers, the lakes—and the camps of the Klamath people.

One day Monadalkni spotted the Klamath chief's daughter, Loha. Monadalkni thought Loha was the most beautiful woman he had ever seen. Immediately he wanted her to be his wife. He came down from the mountaintop and proposed to Loha. He promised her ***eternal*** *life if she would agree to marry him. Loha refused.*

So Monadalkni sent one of his Below World servants to ask again. The servant brought many gifts. He laid them out before Loha and tried to persuade her to marry his master. He reminded her that if she did, she would have eternal life and live in the mountain forever. Loha refused.

She ran to her father and asked for help. The chief of the Klamath people called the tribal ***elders*** *together. They all agreed that Loha should try to hide from Monadalkni, so she did.*

Monadalkni was very angry when he found out that Loha had refused him yet again. He raged inside his mountain, making it shake and rumble. He threw lightning bolts and spewed fireballs from his mouth. The top of the mountain exploded, which sent hot lava and choking clouds of ash raining down on the land. The Klamath people waded into streams and lakes trying to escape Monadalkni's fiery revenge. They cried out to Sahale Tyee for help.

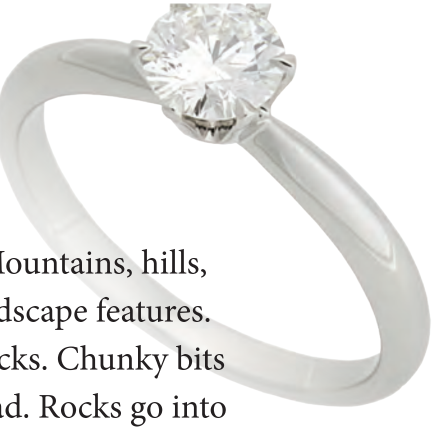
The Chief of the Above World came to the aid of his people. He fought Monadalkni and the two spirits waged a violent, fiery battle. Sahale Tyee eventually gained the upper hand and forced Monadalkni back down into his mountain. Sahale Tyee caused the top of the mountain to collapse, forever shutting off this entrance to the Below World.

The Klamath elders prayed for rain. The rains came and put out the volcanic fires. Rainwater filled the caldera on the mountaintop, creating the high, deep body of water known today as Crater Lake.

Chapter 6

Earth's Building Blocks

THE BIG QUESTION
How can changes in rocks over time be explained by the rock cycle?



You don't have to look hard to find rocks. They are all around you—and under you, too! Earth's crust is made almost entirely of rocks. Mountains, hills, and cliffs are huge masses of rock that form landscape features. Pebbles in a streambed are smooth, rounded rocks. Chunky bits of broken rock form the gravel on a country road. Rocks go into making sidewalks and streets. Slabs of rock cover the outside of many buildings. Indoors, pieces of rock often make up floors, walls, stairs, and countertops. Museums are good places to see rocks that artists have carved into sculptures. The polished stones in some types of jewelry are rocks that people wear.

Rocks are all around. Some are carved into sculptures, others are used for jewelry.

All the varieties of rocks can be organized into three classes.

Rocks and Building Blocks

Just what are rocks, exactly? Rocks are naturally occurring materials made of solid, nonliving substances called **minerals**. Think of minerals as the building blocks of rocks. Some rocks are formed from just one mineral. Most rocks, however, are combinations of two or more minerals. Minerals appear as different-sized pieces, or grains, in rocks. Some rocks have very tiny mineral grains, giving the rocks a smooth, even **texture**. Other rocks have larger mineral grains and a rougher texture.

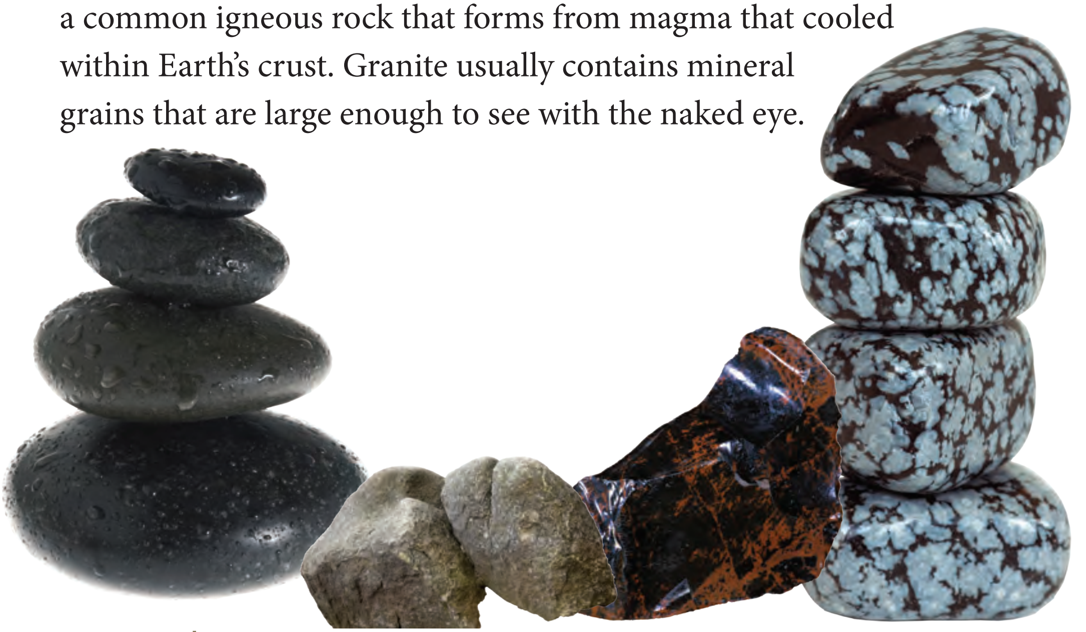
Imagine hiking up a mountain and picking up rocks along the way. When you reach the top, you'll probably have quite a collection. Your rocks may have different colors and textures. Some may have stripes or layers. Some might be hard and others crumbly. Some have tiny grains whereas others have large grains that glitter when they catch the light. All this variety might seem confusing. Yet geologists organize all rocks into just three classes, or basic types: igneous, sedimentary, and metamorphic.

Born from Magma: Igneous Rock

Let's start with **igneous rocks**, the most abundant class of rocks on the earth. Igneous rocks form when magma cools and **solidifies**. When you think of igneous rocks, think of volcanoes.

There are two basic types of igneous rock. One type forms from magma that erupts onto Earth's surface as lava. The lava cools and hardens into rock. The faster it cools, the smaller the mineral grains will be in the resulting rock. **Obsidian** is an igneous rock formed from lava that cooled very quickly, so quickly, there wasn't time for the minerals to form grains. As a result, obsidian is as smooth and shiny as glass. In fact, it is often called volcanic glass. Basalt is an igneous rock formed from lava that took longer to cool. Basalt is typically a dark-colored rock. It has fairly small mineral grains that give it a fine-grained texture.

The second type of igneous rock forms from magma that solidifies below Earth's surface. Magma cools very slowly when it's deep beneath the surface. Slow cooling leads to igneous rocks with relatively large mineral grains. The slower the cooling, the larger the grains. **Granite** is a common igneous rock that forms from magma that cooled within Earth's crust. Granite usually contains mineral grains that are large enough to see with the naked eye.



Igneous rocks

The Art of Making Stone Tools

Many prehistoric cultures made tools out of rock. Scientists working in East Africa have found obsidian stone tools that are nearly two million years old. Obsidian was especially prized by ancient tool makers. Obsidian breaks into pieces with sharp edges that are good for cutting and piercing.

To make a very sharp cutting tool, ancient tool makers struck a block of obsidian with another, harder rock. This caused a long, thin blade of obsidian to flake off. Although the blade was fragile, it had incredibly sharp edges. In fact, the edges of obsidian blades are much sharper than metal scalpels used by surgeons today.

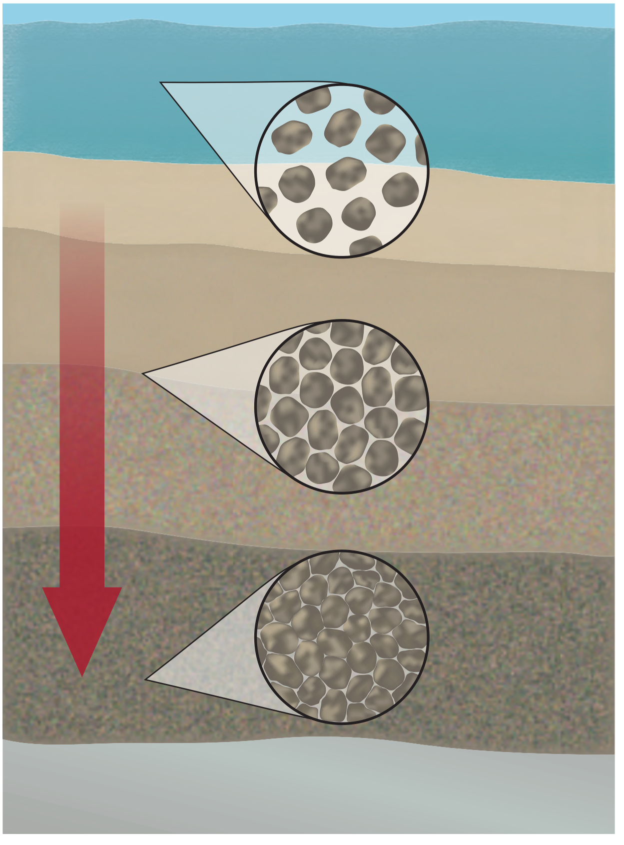
Spear tip

Making a spear tip or arrowhead was more time consuming. The tool makers started with a relatively flat piece of obsidian. They shaped it by striking off tiny flakes of rock, one after another, from the edges. They gradually shaped it into a sharp, **durable**—and often beautiful—pointed tool.

Arrowheads

Layer after Layer: Sedimentary Rock

Sedimentary rock is the second major class of rocks. Sedimentary rocks are made of sediments. Sediments are tiny bits of rock and sand combined with fragments of once-living things. Sediments collect in low-lying areas both on land and in bodies of water. They form layers, one on top of another. Over long periods of time, the weight of overlying layers **compacts** the sediments in deeper layers, squeezing them closer together. Sediments also become cemented, or glued, together as **dissolved** minerals fill the spaces between the sediments. As the sediments dry, the dissolved minerals turn into solids, binding the sediments together. Over time, compacting and cementing processes transform sediments into sedimentary rock.


The weight of overlying layers compacts the sediments, squeezing them closer together.

Most sedimentary rocks are more easily broken than most igneous rocks. Hit a sedimentary rock with a hammer, and it will crumble or break apart. Some sedimentary rocks contain fossils. **Limestone** is a sedimentary rock often packed with the fossilized skeletons and shells of tiny ocean creatures. Some sedimentary rocks get their name from their sediments. Sandstone started as grains of sand, whereas mudstone formed from ancient mud.

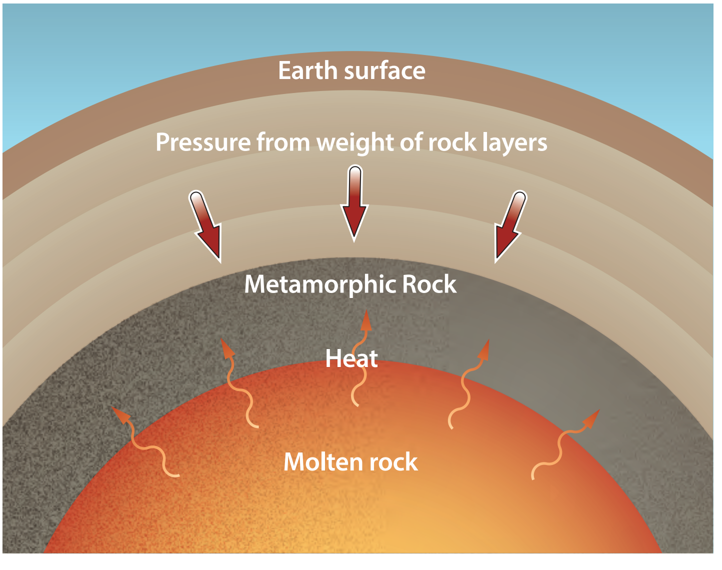
The eroded formations of these sedimentary rocks in Badlands National Park in South Dakota show their distinct layers. The oldest layers are at the bottom.

Changing Form: Metamorphic Rock

The third major class of rocks is **metamorphic rock**. Metamorphic rocks form when igneous or sedimentary rocks are exposed to extreme heat and pressure. They can even form from older metamorphic rocks. High temperatures and crushing pressure alter the minerals in the rocks. Mineral grains may be flattened or rearranged into layers, swirls, or stripes. They may also be changed into completely different minerals!

Remember granite, the igneous rock? When granite is subjected to intense heat and pressure, it becomes a metamorphic rock called gneiss. When the sedimentary rock limestone is squeezed and heated deep below ground, it becomes a metamorphic rock called marble.

Metamorphic rocks tend to form deep within Earth's crust. The pressure from countless tons of overlying rock is tremendous. Equally powerful is the heat rising from hot magma in the mantle beneath the crust. Metamorphic rocks often form where tectonic plates are slowly colliding. They can also form as magma travels up through cracks in Earth's crust and heats the rocks around the cracks. If the heat of the magma completely melts the rock again, then it becomes igneous rock. If the rock is heated just enough to be changed, however, it instead becomes metamorphic rock.



Agnes Nyanhongo's Stone Sculptures

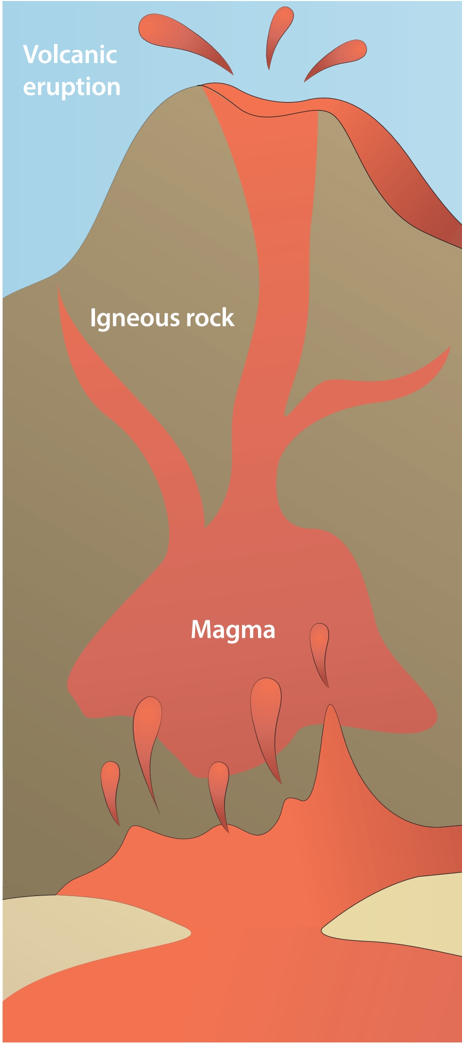
Agnes Nyanhongo

Zimbabwean sculptor Agnes Nyanhongo became interested in carving rock at an early age. Her father, Claud Nyanhongo, was a sculptor. She worked in his studio as a young girl and learned how to cut and polish rock. She is now one of Zimbabwe's most well-known artists. Agnes Nyanhongo carves many of her sculptures from a type of rock called serpentine. Serpentine is a metamorphic rock. The type of serpentine Agnes Nyanhongo uses for many of her sculptures is very dark in color. She usually polishes only some parts of her sculptures, leaving the rest simply raw stone.

Sculptures carved from serpentine

The Rock Cycle

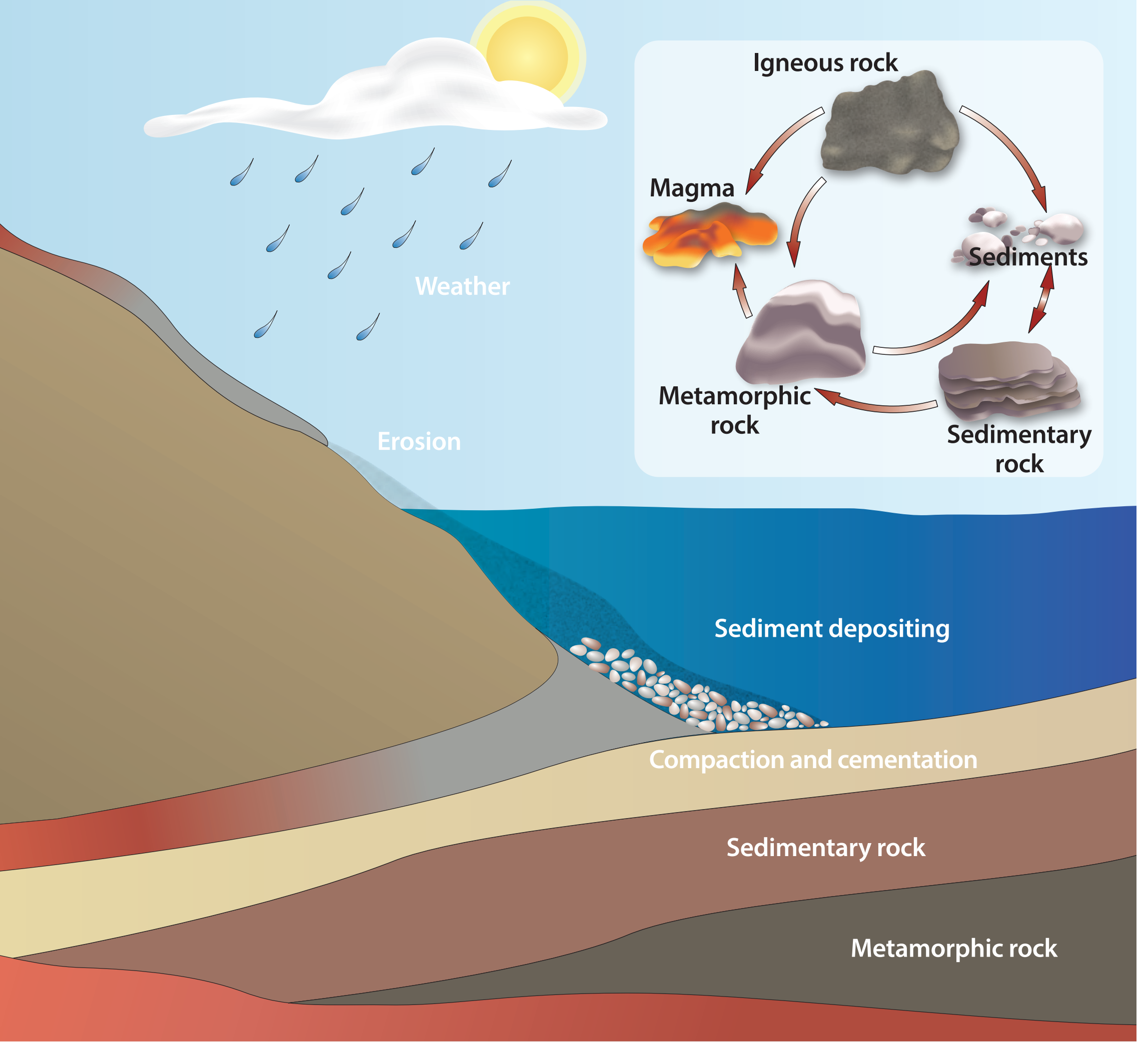
Rocks you see in the world around you might seem like permanent fixtures. Given enough time, however, all rocks change. They are created, destroyed, and recreated in a continuous cycle. Geologists call this ongoing process the **rock cycle**.



The rock cycle has no starting or ending point. You can jump in anywhere to see how it works. Let's begin with magma erupting from a towering volcano. The magma (now lava) cools and hardens into igneous rock. Over the course of thousands of years, sun, wind, rain, and freezing temperatures cause the rock to **weather**, or break down into smaller pieces. The pieces continue to weather, slowly breaking down into sediments. Howling winds, flowing water, and gravity gradually move the sediments down the sides of the volcano and beyond. Movement of sediments from place to place is called **erosion**.

Imagine that the sediments end up in a lake, where they settle to the bottom. Over long periods of time, more layers of sediments are deposited on top of them. Compacting and cementing processes eventually turn the deeply buried sediments into sedimentary rock.

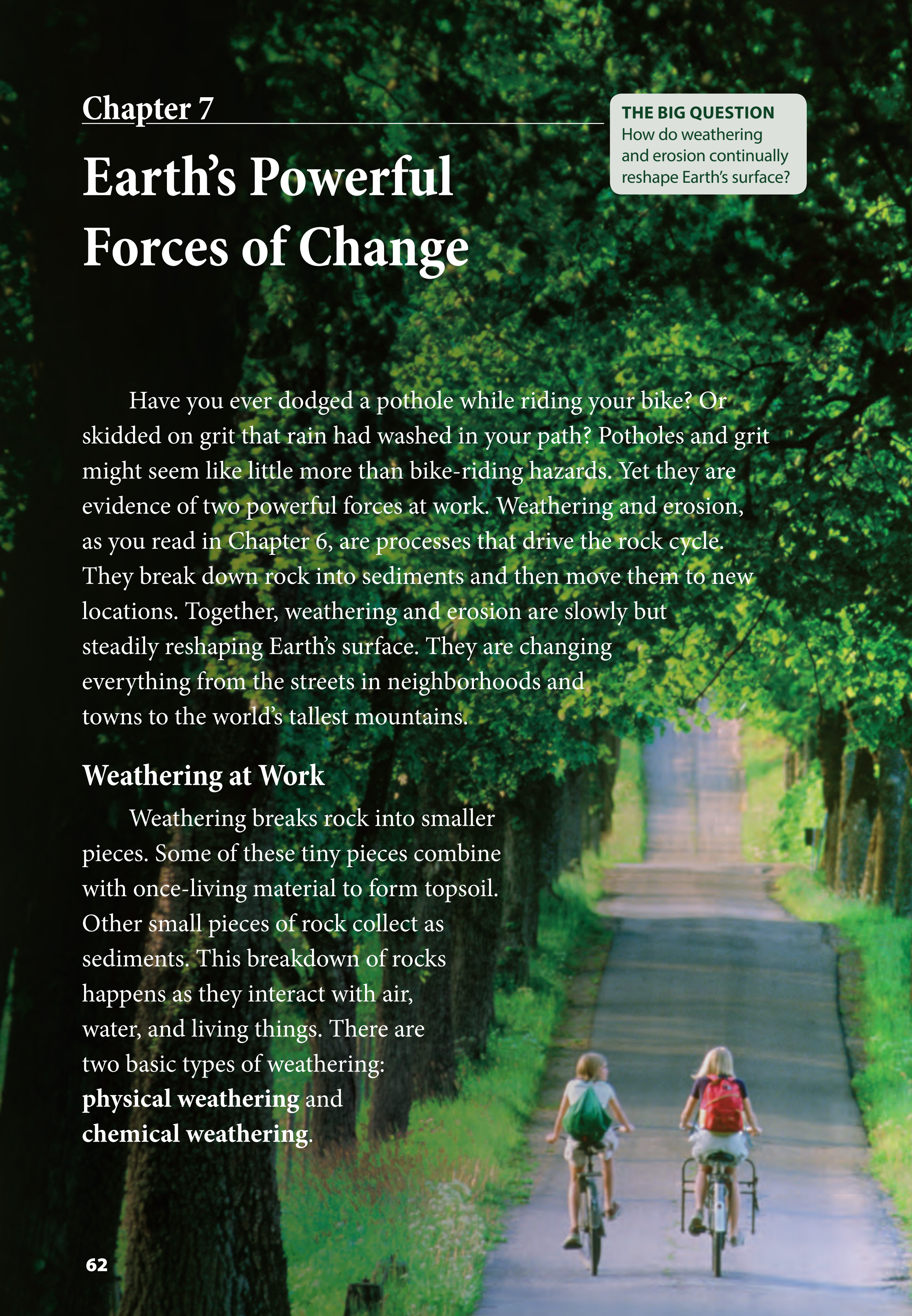
Now imagine that the sedimentary rock is near the edge of a tectonic plate. The plate collides with another plate—very slowly, of course. Tremendous heat and pressure generated by the collision gradually turn the sedimentary rock into metamorphic rock. As the plates continue colliding, their rocky edges crumple. The metamorphic



rock is slowly pushed up higher onto Earth's surface. Think mountains! Exposed to air, rain, and snow, the rock begins to weather and erode.

Alternatively, one tectonic plate might be sliding beneath another. The metamorphic rock along the edge of the descending plate gets hotter and hotter as it nears the mantle. At some point it melts into magma—magma that someday might erupt from a volcano again.

Understanding how rocks change helps geologists understand how Earth has changed over time.



Chapter 7

Earth's Powerful Forces of Change

THE BIG QUESTION
How do weathering and erosion continually reshape Earth's surface?

Have you ever dodged a pothole while riding your bike? Or skidded on grit that rain had washed in your path? Potholes and grit might seem like little more than bike-riding hazards. Yet they are evidence of two powerful forces at work. Weathering and erosion, as you read in Chapter 6, are processes that drive the rock cycle. They break down rock into sediments and then move them to new locations. Together, weathering and erosion are slowly but steadily reshaping Earth's surface. They are changing everything from the streets in neighborhoods and towns to the world's tallest mountains.

Weathering at Work

Weathering breaks rock into smaller pieces. Some of these tiny pieces combine with once-living material to form topsoil. Other small pieces of rock collect as sediments. This breakdown of rocks happens as they interact with air, water, and living things. There are two basic types of weathering: **physical weathering** and **chemical weathering**.

Physical weathering breaks big rocks into smaller ones without changing the minerals they contain. Widely swinging temperatures cause physical weathering. For example, rocks in a desert bake during the day beneath the sun's scorching heat. As rocks get hot, they **expand**. At night, temperatures in the desert fall. As rocks cool down, they **contract**, or shrink slightly. Expand, contract, expand, contract—this endless cycle gradually causes the rocks' outer layer to crumble or flake off.

Water also causes physical weathering. Water seeps into tiny cracks in rocks. If temperatures drop below freezing, the water turns to ice. Water expands as it freezes, pushing outward and enlarging the cracks. Geologists call this process **ice wedging**. Each time the water freezes, it opens cracks a little wider. Eventually, the rocks split apart. Ice wedging is what makes potholes in streets, too.

Plants and animals also cause rocks to weather. Tree roots squeeze into the cracks in rocks. As the roots grow, they act like wedges, forcing the cracks wider and wider. Eventually the rocks break apart. Badgers, chipmunks, and other animals burrow into cliffs and hillsides like tiny bulldozers. As they dig or tunnel into the ground, they push buried rocks to the surface where most weathering takes place.

Examples of physical weathering

Chemical weathering breaks down rocks by changing the minerals they contain. Rain is a powerful chemical weathering force. As rain falls, it mixes with the gas carbon dioxide in the air. The result is acid rain. Acid rain is strong enough to dissolve some minerals in rocks. Once dissolved, the minerals easily wash away, weakening the rock. Acid rain very slowly carves some rocks into different shapes. It gradually erases the lettering on old gravestones, and blurs the faces of stone statues. It eats away at the outside of ancient and even modern buildings. Where rain seeps into the ground, carbonic acid causes weathering of buried rocks as well. Over long periods of time, this often unobserved weathering creates caves deep underground.

Another gas in the air—oxygen—causes chemical weathering in rocks. With a little help from water, oxygen reacts with iron-containing minerals. The reaction changes the minerals, making the rocks brittle and crumbly, and turning them a rusty red color.

Some plants release rock-weathering substances. Take a peek under a patch of moss growing on a rock and you'll see little pits in the rock's surface. Acid from the moss plant caused the damage.

As a result of all weathering, rocks are broken down into smaller pieces and **ultimately** into sediments. Erosion is what gets those sediments moving.

Towering rock formations created by chemical weathering rise straight up out of the ground near Kunming, the capital of China's Yunnan Province. Some formations are as tall as a 10-story building. The Chinese call this place Shilin, or the Stone Forest.

Sediments on the Move

Geologists describe erosion as any process or force that moves sediments to new locations. Wind, flowing water, moving ice, and gravity all transport sediments from place to place. These forces are the primary causes of erosion.

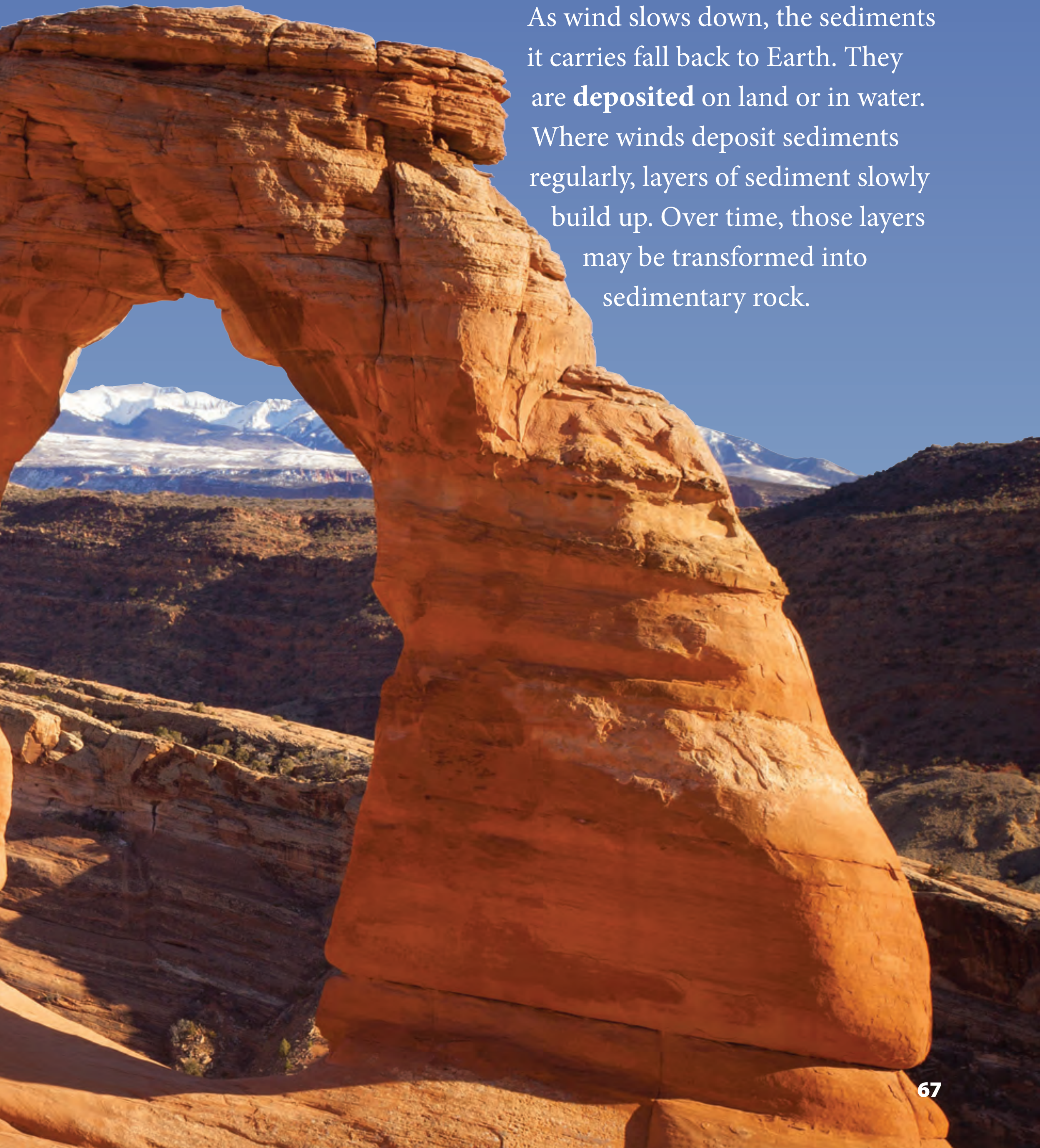
Have you ever stood on a sandy beach on a windy day? Did you notice that gusts of wind sent sand flying past? When air moves quickly across the ground, it picks up sediments and carries them away. Powerful winds can carry sediments for hundreds, even thousands, of miles.

On the windy beach, did your skin sting as it was struck by blowing sand? Wind carrying sediments can act like a sandblasting machine to wear away rocks in its path. When wind-driven sand

Delicate Arch, Arches National Park, Utah

hits rock, it chips off tiny pieces. The wind then whisks the pieces away. Over time, this form of weathering can polish rock surfaces or **pepper** them with tiny holes. It can shape huge blocks of rock into delicate stone arches and lofty towers. Weathering and wind erosion can also leave massive boulders balanced on slim supports. Have you seen wind-carved rocks like this?

As wind slows down, the sediments it carries fall back to Earth. They are **deposited** on land or in water. Where winds deposit sediments regularly, layers of sediment slowly build up. Over time, those layers may be transformed into sedimentary rock.




Glaciers, like this one in Alaska, are powerful forces that can cause erosion.

Heading Downstream

Like wind, water also causes erosion. The tug of gravity pulls sediments out of wind and water. Flowing water picks up sediments and carries them downhill to new locations. A summer rain can wash fine sediments onto sidewalks and into gutters. A rushing mountain stream can sweep small stones into a valley. A flooded river can surge along with enough force to move large rocks many miles downstream.

As moving water slows, sediments sink to the bottom of the river or stream. The heaviest sediments are the first to be deposited. The finest sediments are the last. Layers of sediment accumulate at the mouths of rivers and on the bottoms of lakes. Vast layers of sediment are also deposited on the ocean floor over long periods of time. Like wind-deposited sediments, those laid down by water may someday be transformed into sedimentary rock.

Water doesn't have to be in its liquid **state** to erode sediments. Glaciers are enormous masses of ice found in polar regions and near the tops of tall mountains. Although ice is solid, glaciers do move. They flow—very, very slowly—downhill. As countless tons of ice creep over land or down mountainsides, they push, drag, and carry eroded sediments along. Moving glaciers also create sediments as they grind against rocks beside or below them. Glaciers are such powerful forces that they can carve huge U-shaped valleys through mountain ranges.

When glaciers melt, they deposit the sediments they have been carrying. About 20,000 years ago, glaciers covered large parts of North America, Europe, and Asia. As the climate warmed, the glaciers melted and retreated northward. They left behind massive deposits of sand, gravel, and **silt**, along with collections of rocks and boulders. You can still see these deposits as hills, mounds, and ridges on the landscape.

Weathering, Erosion, and Time

Weathering and erosion work slowly. It takes a long time to see their effects. Given time, these processes reshape Earth's surface on a scale so large it's almost impossible to grasp. For example, the Grand **Canyon** in the southwestern United States did not exist when dinosaurs roamed North America. Wind, rain, and the Colorado River slowly created it. These forces cut and shaped the landscape into what it is today—one of the world's largest canyons.

The Grand Canyon

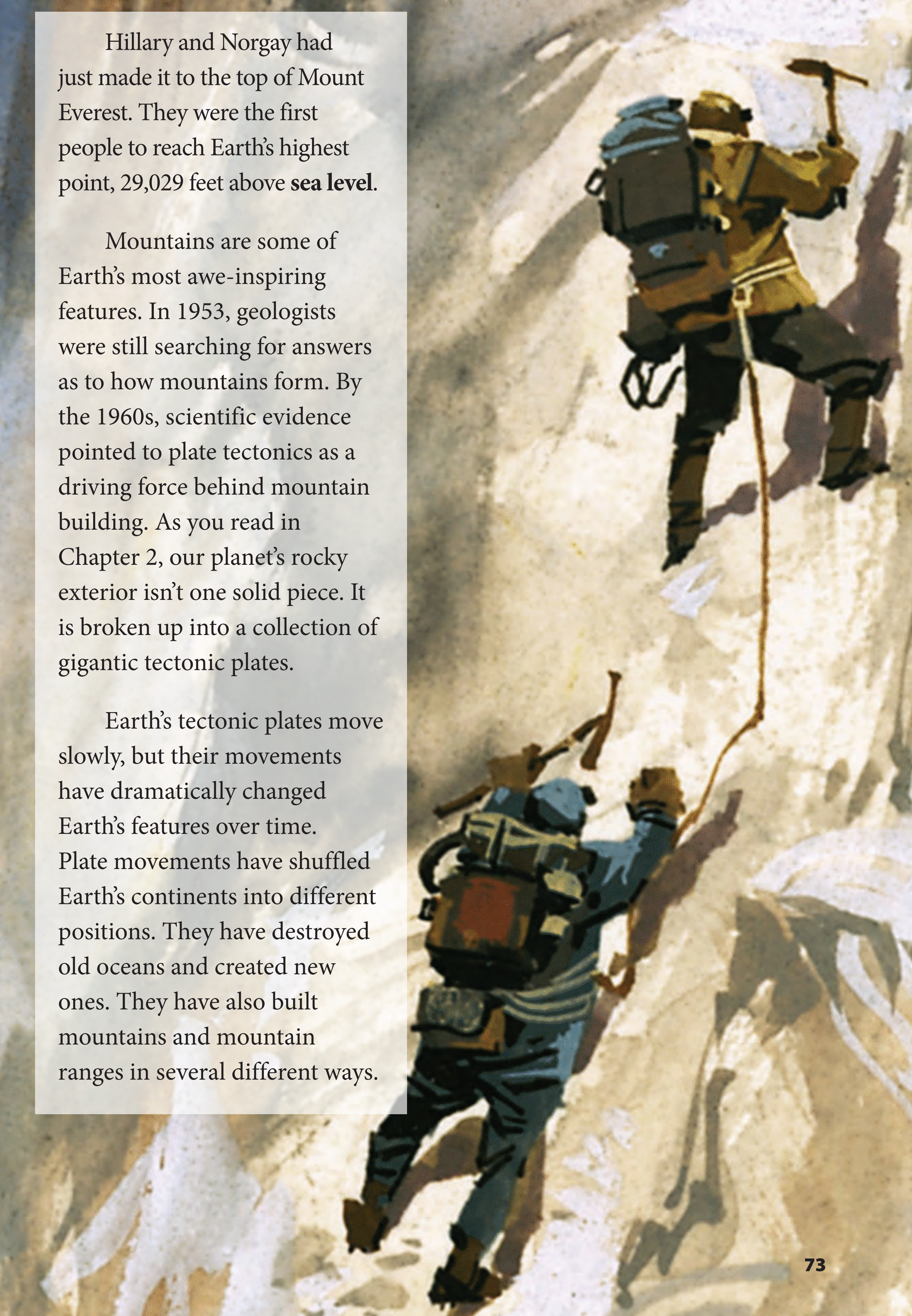
Millions of years ago, the Appalachian Mountains in eastern North America were a towering mountain range. The highest peaks may have been more than 20,000 feet above sea level. Weathering and erosion gradually wore the Appalachians down. Their highest point today is just 6,684 feet high. As permanent as mountains seem, weathering and erosion inevitably change them. Even Earth's tallest peaks—Everest in Asia, Aconcagua in South America, Africa's Kilimanjaro, and Europe's Mont Blanc—won't last. They will eventually be worn down by these endless geological processes. But don't worry. Other geological processes are creating new mountains to take their place.

Chapter 8

Earth's Mighty Mountains

THE BIG QUESTION
How do the movements and forces of tectonic plates build mountains?

The year was 1953. Mountain climbers Edmund Hillary and Tenzing Norgay stood on the hard-packed snow. They gasped for breath in the thin air. Their faces burned from the bitter cold wind. Despite this, they were grinning from ear to ear.



Hillary and Norgay had just made it to the top of Mount Everest. They were the first people to reach Earth's highest point, 29,029 feet above **sea level**.

Mountains are some of Earth's most awe-inspiring features. In 1953, geologists were still searching for answers as to how mountains form. By the 1960s, scientific evidence pointed to plate tectonics as a driving force behind mountain building. As you read in Chapter 2, our planet's rocky exterior isn't one solid piece. It is broken up into a collection of gigantic tectonic plates.

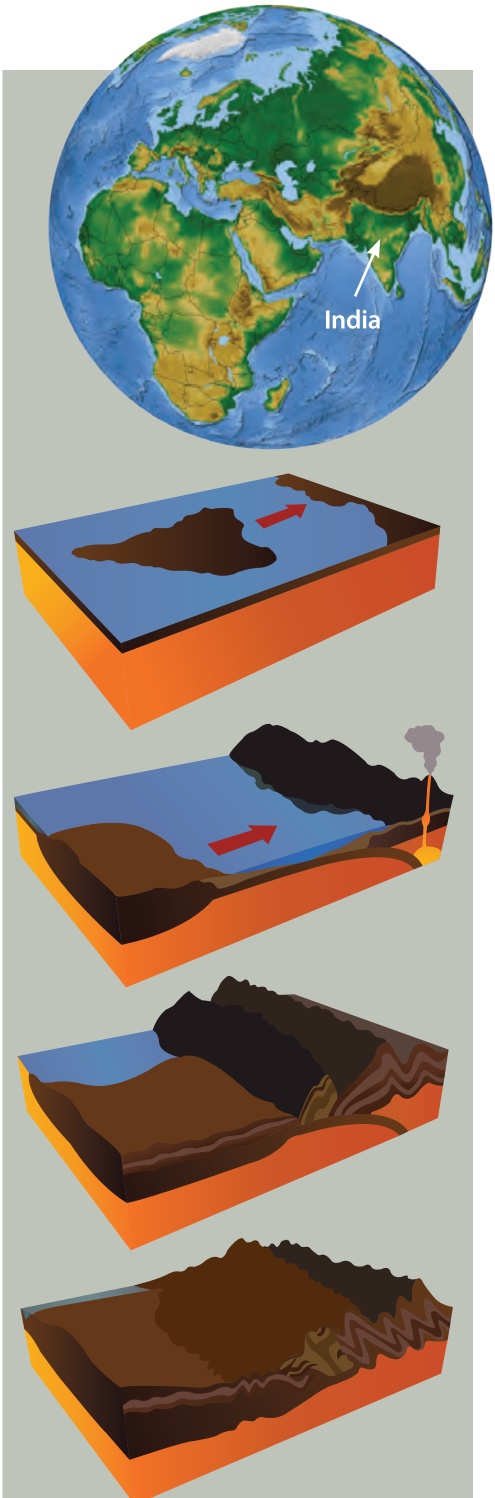
Earth's tectonic plates move slowly, but their movements have dramatically changed Earth's features over time. Plate movements have shuffled Earth's continents into different positions. They have destroyed old oceans and created new ones. They have also built mountains and mountain ranges in several different ways.

Colliding Continents

Some of Earth's highest mountain ranges formed as sections of continental crust collided over millions of years. The collision that formed Mount Everest is a good example. Everest is part of the Himalayas, a vast, towering mountain range between India and China. The Himalayas formed when continents on two tectonic plates met head-on.

Can you find India on the map? It lies along the southern edge of Asia. India wasn't always where it is today. Hundreds of millions of years ago, India was an island. It sat out in the middle of the Indo-Australian Plate. It was separated from Asia, which sits on the Eurasian Plate, by an ancient ocean called the Tethys Sea.

The Indo-Australian Plate began creeping northward about 200 million years ago. Driven by moving magma in the mantle below, it slowly collided with the Eurasian Plate. Where the two plates met, subduction took place. The heavier oceanic crust of the Indo-Australian Plate slid under the lighter continental crust of the Eurasian Plate.



The Indo-Australian Plate moved slowly northward, carrying India along with it.

As the Indo-Australian Plate kept moving northward, India was carried along. It inched closer and closer to Asia. The Tethys Sea began to disappear. India finally collided with Asia around 40 million years ago. India's rocky continental crust pressed directly against Asia's continental crust.

As the two landmasses continued to be pushed harder and harder together, the continental crust began to crumple. Enormous pressure created by the moving tectonic plate caused the rocky crust to heave upward. Great masses of rock gradually rose up into a series of enormous folds. The Himalayas were born!

More and more rocks were uplifted as the Indo-Australian Plate kept moving. The Himalayas rose higher and higher. In fact, they are still rising. They are growing taller at about the same rate that your fingernails grow!

Geologists classify the Himalayas as **fold mountains**. The name refers to the way rocks are pushed up into huge folds by moving tectonic plates. The Alps, Europe's highest mountains, are fold mountains that formed much like the Himalayas. The Appalachians in North America and the Urals in Russia also formed through collisions of continental crust.

Like many other fold mountains, the Himalayas contain quite a bit of sedimentary rock. Why? In the case of the Himalayas, it started with the Tethys Sea. For millions of years, erosion washed sediments from Asia and the ancient island of India into the Tethys Sea. Countless layers of sediments, along with remains of ocean animals, were deposited on the seafloor. Over time, pressure and heat helped turn these sediments into sedimentary rock.

As plate movements slowly brought India and Asia together, some of these seafloor sedimentary rocks were pushed up. Heat and pressure from the colliding plates transformed some of them into metamorphic rocks. Other sedimentary rocks remained relatively unchanged. This is how fossils of ancient ocean animals ended up on top of Mount Everest.

Fossils at the Top of the World

Trilobites and crinoids are two of the most common types of fossils on Mount Everest. Trilobites were hard-shelled ocean animals related to modern-day crabs and lobsters. Trilobites lived on the bottom of Earth's ancient oceans, including the Tethys Sea. Crinoids were animals, too, but they looked more like plants. Trilobites and most crinoids became extinct about 250 million years ago. A few types of crinoids still survive far below the ocean's surface.

The Andes Mountains in Peru are fold mountains.

Folding at the Edges

Along South America's western coast, the oceanic Nazca Plate has been sliding under the South American Plate for millions of years. This has caused massive folds of rock to pile up along the edge of the continent. These folds are now the Andes Mountains, the longest mountain range on land.

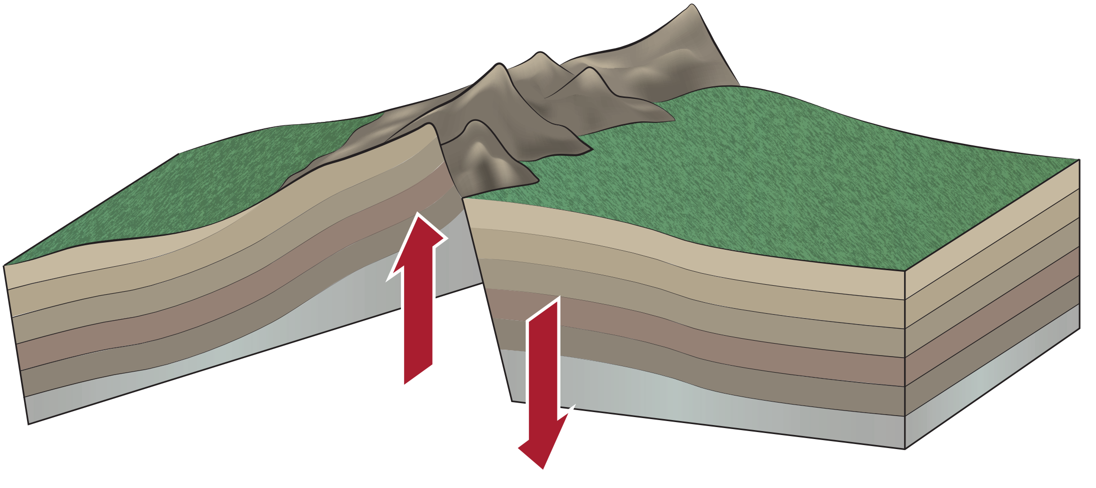
As you read in Chapter 4, the edge of a subducting plate melts as it descends into Earth's hot mantle. The resulting magma moves up through cracks in the crust. It may erupt on the surface to form volcanoes. The edge of the Nazca Plate is melting as it slides beneath the South American Plate. Erupting magma has created many volcanoes in the Andes Mountain range.

Faults and Blocks

The longest, highest mountain ranges on land are mostly fold mountains. However, moving tectonic plates build mountains in other ways. **Fault-block mountains** form when gigantic blocks of rock move up and down along faults.

At some faults, such as the San Andreas Fault in California, blocks of rock move horizontally past each other as they slip. At other faults, slips cause blocks of rock on one side of the fault to move up. These slips also cause blocks on the other side of the fault to move down. Repeated slips gradually force these rock blocks higher—and lower—to create fault-block mountain ranges.

Fault-block mountains typically have one steep side and one sloping side. The steep side forms a high, **sheer** cliff. Germany's Harz Mountains are one example of fault-block mountains. Others include the Grand Tetons in Wyoming and the Basin and Range Province of Utah, Nevada, and Arizona.



Fault-block mountains form when blocks of rock move up and down along fault lines.

The Grand Teton Mountains in Wyoming are fault-block mountains.

Under the Dome

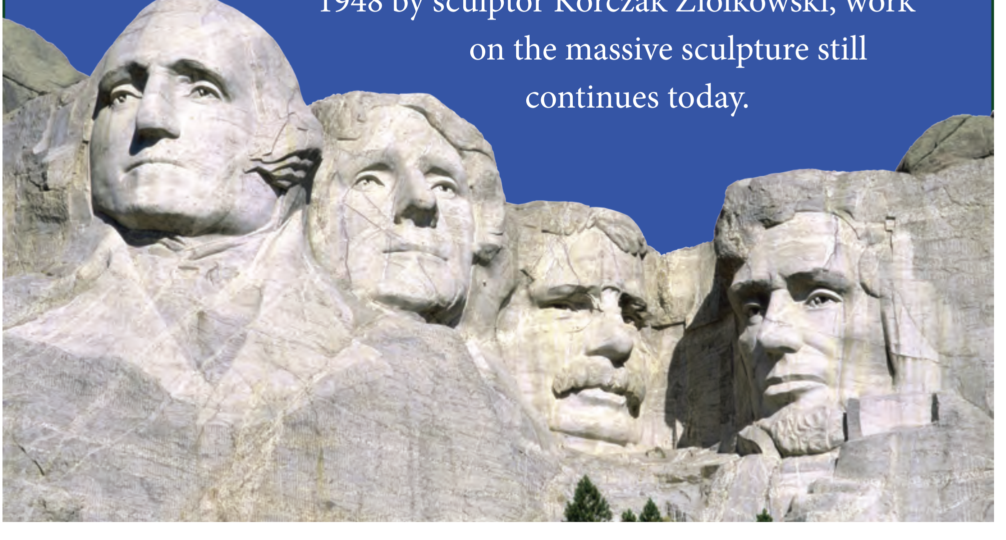
Most people think of sharp, jagged peaks when they hear the word *mountains*. **Dome mountains** are quite different. Dome mountains look like great humps of rock with rounded tops. They usually occur as isolated mountains on otherwise flat plains.

Some dome mountains form when magma pushes upward into Earth's crust from the mantle. The magma cools into igneous rock before reaching the surface. This huge lump of igneous rock causes the crust above it to **bulge**, like a blister on skin. Utah's Navajo Mountain is a good example of a dome mountain that formed this way.

Navajo Mountain, Utah

Mountains on the Prairie

You can see the Black Hills of western South Dakota from a long way off. These dome mountains rise up from the surrounding grassy plains as dark, hunched shapes. They are the highest mountains east of the Rocky Mountains. Very ancient granite forms the core of the Black Hills. Millions of years of weathering and erosion have exposed this igneous rock in many places. The sculptor Gutzon Borglum made one tall granite formation in the Black Hills famous. He carved the faces of four presidents into the rock to create Mount Rushmore National Memorial. Another sculpture in the Black Hills has also gained attention—as the world's largest sculpture in progress. Crazy Horse Memorial honors North American Indian heritage and depicts the face of the Sioux leader Crazy Horse. Started in 1948 by sculptor Korczak Ziolkowski, work on the massive sculpture still continues today.



Chapter 9

Earth's Undersea World

THE BIG QUESTION
How does the movement of tectonic plates shape and change the seafloor?

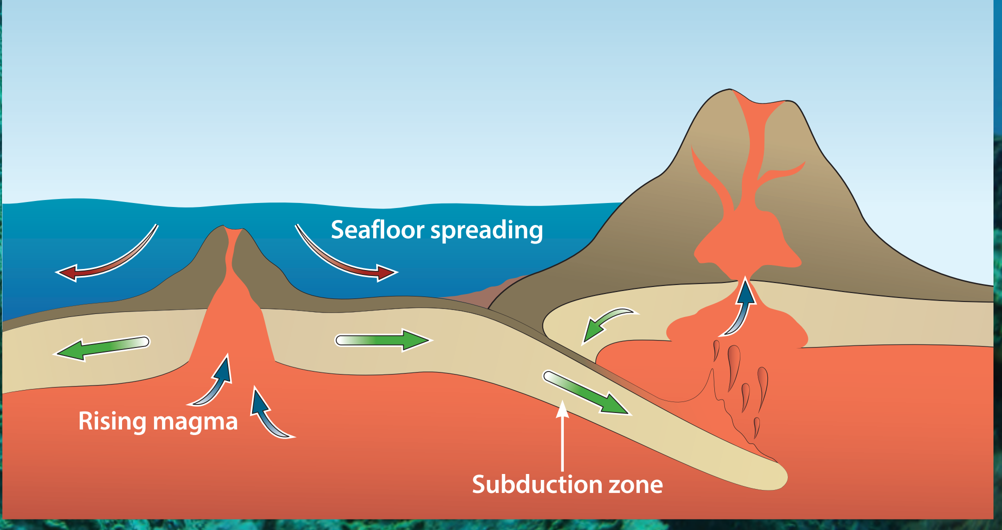
Imagine that you are dropping down, down, down into the middle of the Atlantic Ocean. The seawater outside the **submersible** gets darker and darker. Soon the light fades completely. Outside is a watery world as black as night. Finally, the sub's lights pick up shapes below as the ocean bottom comes into view. You see lumpy hills and looming peaks of dark volcanic rock. Welcome to the Mid-Atlantic Ridge. The ridge marks the boundary between several enormous tectonic plates. Portions of these plates form the bottom of the Atlantic Ocean.

Mountains and Moving Plates

In Chapter 8, you learned some of the ways Earth's slowly moving tectonic plates build mountains. Over millions of years, their movements have created many mountains and mountain ranges on land. Moving plates also build mountains underwater. In fact, there are more mountains on the seafloor than on all of Earth's continents and islands combined.

The Mid-Atlantic Ridge is a long, **rugged** underwater mountain range. It runs for thousands of miles along the boundary between tectonic plates that meet in the center of the Atlantic Ocean. The plates are very slowly moving apart at this boundary.

Remember Alfred Wegener? Wegener proposed the idea of continental drift in the early 1900s. At the time, though, no one knew of any force powerful enough to move continents around on Earth's surface. The theory of seafloor spreading was a big clue to solving the mystery.

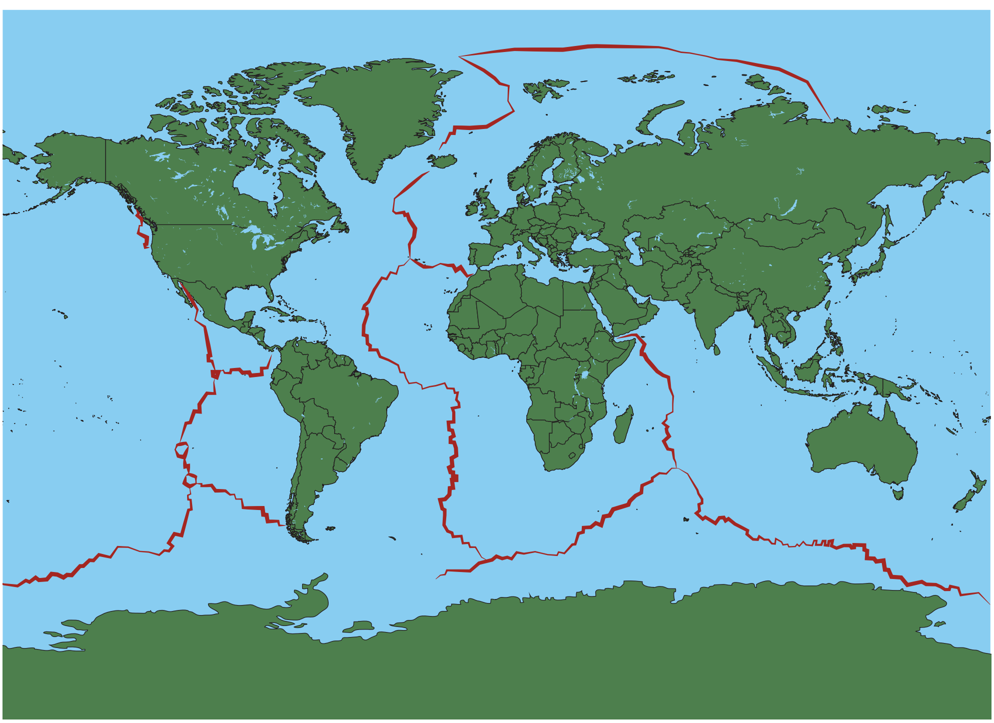


Seafloor spreading was one of several key pieces of geological evidence that led to the theory of plate tectonics. Think of the continents as riding on top of the plates. As the plates move, so do the continents.

It was the study of the Mid-Atlantic Ridge that first made scientists consider the possibility of seafloor spreading. They concluded that, as the seafloor spreads, the continents on either side of the Atlantic are pushed farther apart.

Scientists soon discovered that the Mid-Atlantic Ridge is just one of many mid-ocean ridges. These ridges are found in all the world's oceans, wherever tectonic plates are slowly moving apart. Altogether, mid-ocean ridges form a near-continuous chain of mountains that wraps around the earth like the stitching on a baseball. Spanning 40,389 miles, the chain of mid-ocean ridges is by far the world's longest mountain range. It is also the most volcanically active.

The Mid-Atlantic Ridge is just a part of this gigantic underwater mountain chain. Erupting lava has built up high walls of basalt on either side of the rift. The rift itself is nearly as deep as the Grand Canyon! If you travel along the ridge, you'll soon see more than just high walls of dark rock.



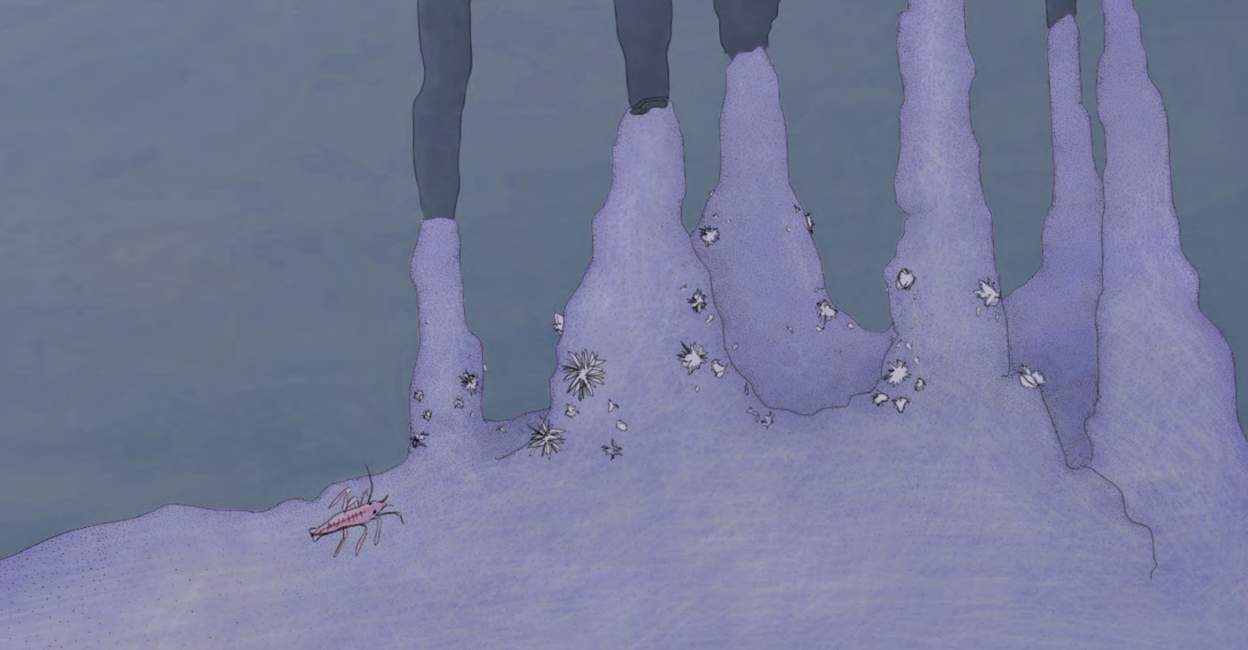
Mid-ocean ridges form a near-continuous chain of underwater mountains.

Hydrothermal Vents

At first glance, it looks like a fire. Black smoke is billowing up from a spot in the ridge. It's not smoke, though. It's searing hot, dark water gushing out of cracks in the rock. It's a **hydrothermal vent**.

Hydrothermal vents are a bit like geysers in Yellowstone National Park. These deep-sea geysers are much, much hotter than anything on land. Hydrothermal vents form as seawater sinks down through cracks in the oceanic crust. As it nears the magma lying below the crust, the water is heated to incredibly high temperatures. It can reach an astonishing 750°F! The water is so hot that it dissolves minerals from the surrounding basalt. The minerals become part of the hot liquid, like salt does when it's stirred into a glass of water.

At a hydrothermal vent, the super-heated, mineral-rich water comes roaring back up through cracks in the crust. It shoots out of the rock with the force of water blasting out of a fire hydrant. When hot vent water meets cold seawater, the dissolved minerals in vent water become solid again. They form tiny particles. The particles make the vent water look like dark smoke.



Hunting for Hydrothermal Vents

Hydrothermal vents

How do scientists find hydrothermal vents? They hunt for them from ships at sea. Hot, mineral-rich vent water moves slowly away from hydrothermal vents. It forms a plume, or cloud, of mineral particles that drifts away from the vent, like smoke from a chimney. If the scientists locate a plume, they send down a robot vehicle. When it locates the vent, the robot sends pictures back to the scientists.

There is more to hydrothermal vents than clouds of hot, black water. Communities of amazing and unusual animals live around many of these deep-sea geysers. Red-topped giant tube worms are the largest animals near vents. Some types of giant tube worms can grow as tall as a person. The vents are also home to ghostly white crabs, football-sized clams, and pale, blind shrimp.

Scientists believe there are tens of thousands of hydrothermal vents along the world's mid-ocean ridges. Scientists, however, have explored only a handful of them. Finding a new one is always exciting. Scientists often discover new types of animals as well.

Giant tube worms near a hydrothermal vent in the Pacific Ocean

Seamounts and Subduction Zones

Seamounts are another type of underwater mountain. Seamounts are underwater volcanoes that come in many shapes and sizes. Some are just a few hundred feet high. Others tower thousands of feet above the seafloor, although their tops are still far beneath the ocean's surface. If a seamount grows high enough to rise above the ocean's surface, it becomes an island.

Seamounts can form wherever magma is erupting through the oceanic crust. Many seamounts form alongside mid-ocean ridges or along subduction zones.

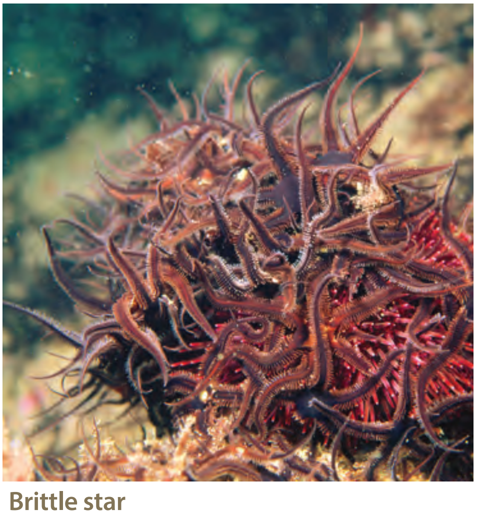
Finally, seamounts can also form over hotspots far from plate boundaries. The islands that make up the Hawaiian Island chain began as seamounts. As you read in Chapter 4, each island formed over a hotspot that **underlies** the center of the Pacific Plate. As a result of repeated volcanic eruptions, each island began as a small seamount that grew over time. Eventually, its top broke the water's surface, making it an island.

Seamount that grew into an island

Scientists estimate that there are at least 100,000 seamounts over 3,000 feet tall in the world's oceans. Since most seamounts are far below the ocean's surface, studying them is a challenge. Scientists have explored a few **firsthand**, traveling down in submersibles. More often, they send robot vehicles down to do the investigating.

No two seamounts are exactly alike. Many are teeming with life, even those that are very deep. Water flowing around these deep-sea volcanoes brings up nutrients from the ocean bottom. Nutrients fuel the growth of tiny, single-celled organisms in the water. These, in turn, become food for larger organisms, including animals that live on and around seamounts. Seamounts are often home to deep-sea corals, sponges, brittle stars, crabs, and anemones. Great **schools** of fish live around seamounts, too.

Deep-sea coral



Brittle star

Into the Trenches

Seamounts aren't the only undersea features that form along subduction zones. Where one plate slides under another, the seafloor dips down to create narrow, extremely deep valleys. These ocean trenches are the deepest places on the planet.

The Mariana Trench in the Pacific Ocean is the deepest ocean trench. It lies just off the Mariana Islands, east of the Philippines. The Mariana Trench is hundreds of miles long, but just 43 miles wide. It is like a deep slash in the ocean bottom. The trench's deepest known point is an area called the Challenger Deep. It is 36,070 feet beneath the ocean's surface, which is almost 7 miles down. By comparison, the average depth of the ocean is about 14,000 feet.

What is it like in the ocean's deepest spot? It is pitch black. The temperature of the water is only a few degrees above freezing. The water pressure is very high—equivalent to having three big SUVs pressing down on every inch of your body!

Only three people have traveled to the bottom of the Mariana Trench. (More people have landed on the moon!) Several robot vehicles have also made the trip. These visits have provided only brief glimpses of this remote and extreme environment.

The Lucky Three

As of 2014, people have traveled to the bottom of the Mariana Trench only twice. The first expedition took place in 1960. The explorers were U.S. Navy Lieutenant Don Walsh and Swiss scientist Jacques Piccard. Their underwater vehicle was *Trieste*. It took *Trieste* almost five hours to descend from the ocean's surface to the bottom of Challenger Deep. Piccard and Walsh peered out a small window onto a part of the planet that humans had not seen before.


Piccard and Walsh in *Trieste*

In 2012, Canadian filmmaker and ocean explorer James Cameron also made the trip. His vessel, *Deepsea Challenger*, was a slim, one-person, underwater vehicle. Cameron's descent took just over two and a half hours. He did something Walsh and Piccard weren't able to do. He filmed the descent and the view he had of the ocean floor at 35,756 feet.

Enrichment

The Rock Towns of Cappadocia

Few houses are as old—or as unusual—as those in Cappadocia, Turkey. The houses have rock walls, rock floors, and rock ceilings. Their doors and windows are simply openings in rock. Some houses have tall, pointed rock towers rising from their rock roofs. Others have hidden rooms, secret passageways, and tunnels that lead deep underground. Everything is made of rock.

Cappadocia is a region of Turkey found in the west-central part of the country. Its cave-like rock houses are famous, and there are thousands of them. The houses are **clustered** into rock villages and towns. People have been carving and living in these houses for more than 2,000 years.

Volcanoes, however, laid the original **foundations**.

Rock houses in Cappadocia

Eruptions and Erosion

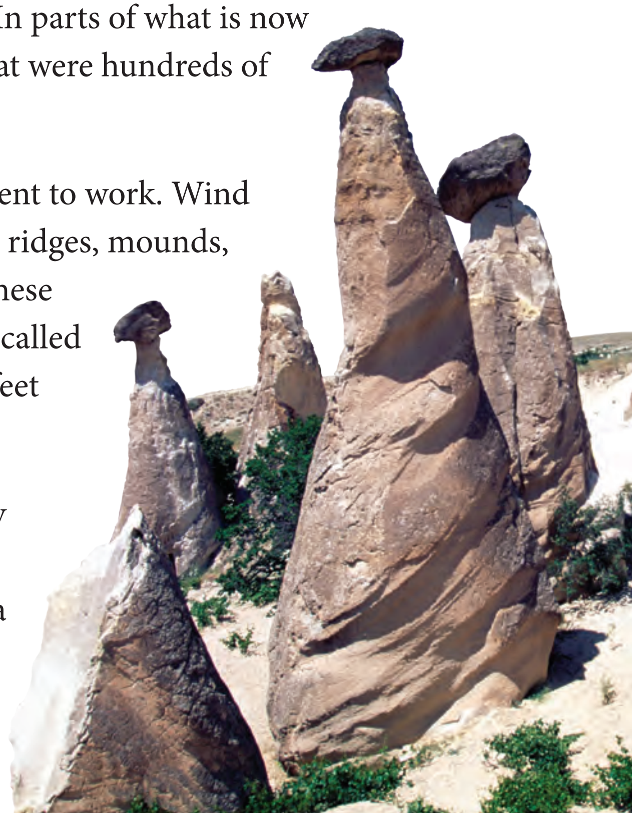
Mount Erciyes looms on the horizon near Cappadocia's rock towns. It is an active volcano and the highest mountain in this part of Turkey. Erciyes's rocky peak is 12,848 feet high. In winter, it is often dusted with snow.

Effects of volcanic rock erosion in Cappadocia

Only minor eruptions have shaken Erciyes in recorded history. At times in the **distant** past, however, Erciyes and other volcanoes near it were much more active. During one or more major eruptions, these volcanoes blasted out enormous amounts of ash. The volcanic ash rained down on the surrounding countryside. It collected in some areas to form large, thick deposits. Over time, this volcanic ash solidified. It hardened into a type of volcanic rock geologists call **tuff**. In parts of what is now Cappadocia, layers of tuff formed that were hundreds of feet thick.

Then weathering and erosion went to work. Wind and water slowly carved the tuff into ridges, mounds, and sharp **pinnacles**. The tallest of these slender, soaring rock formations are called **hoodoos**. Some rise more than 100 feet above the Cappadocian landscape.

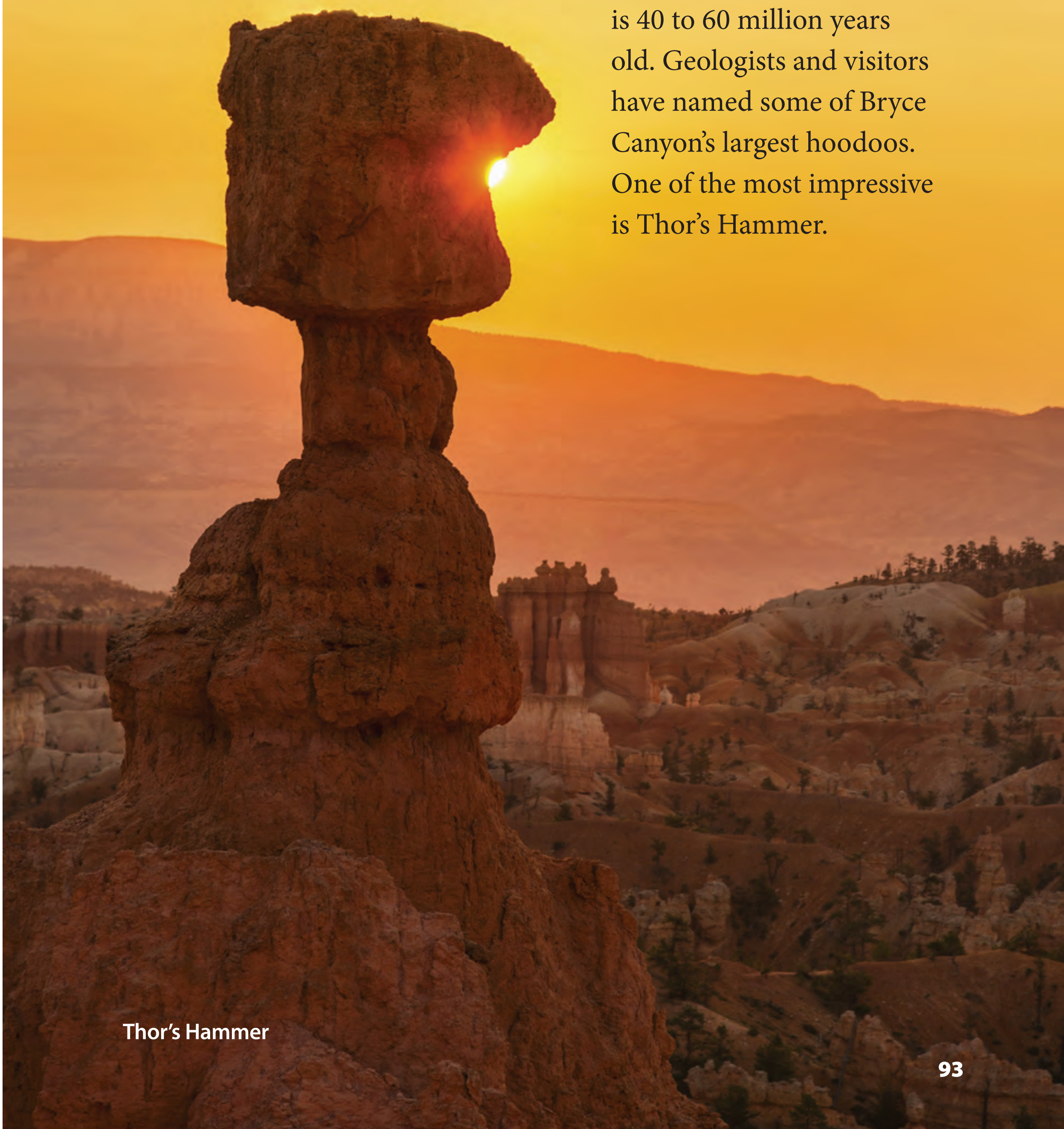
Some people call hoodoos "fairy chimneys" because they look like something you might read about in a fairy tale.



Fairy chimneys

Hoodoos around the World

You can find hoodoos on almost every continent. Most are formed from sedimentary rock rather than volcanic tuff. All of them, though, are the product of weathering and erosion. Bryce Canyon in the western United States has an abundance of hoodoos. Wind, rain, and ice wedging have carved them out of sedimentary rock that is 40 to 60 million years old. Geologists and visitors have named some of Bryce Canyon's largest hoodoos. One of the most impressive is Thor's Hammer.

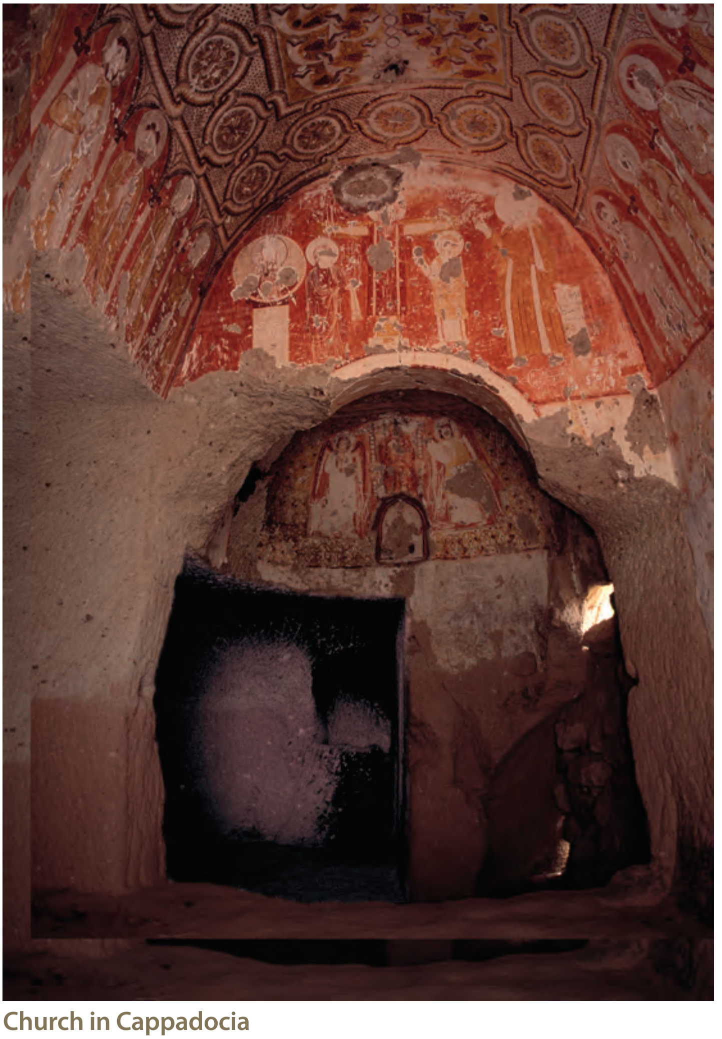


Thor's Hammer

Carving Out Caves

No one knows who first carved into Cappadocia's rock formations to make living—or hiding—spaces. Creating a cave wasn't difficult. Tuff is quite soft before it is exposed to air. Scrape away the hard outer surface and the fresh rock can be cut easily with simple tools. The surface of newly carved rock hardens quickly in dry air. After that, it will keep its shape for hundreds of years.

During the 300s, Cappadocia became a destination for many early Christians. It was a place where they felt safe and isolated from the rest of the world. These religious refugees expanded the existing caves into larger rock **dwellings**. They created rooms for eating and sleeping. They carved out stables for animals and storage areas for food. They cut staircases into hoodoos and formed high towers. The towers had windows that looked out onto the surrounding plains. From these high places, they could see trouble coming from a long way off. Blocks of dwellings grew into villages, then towns.



Church in Cappadocia

Beautiful paintings cover the walls and ceilings of this church in Cappadocia.

The early Christian settlers expanded underground, too. They dug into the underlying tuff, carving out living areas more than five stories deep. A maze of tunnels, staircases, and passageways connected different sections. There were even rock ventilation systems for bringing down fresh air from above ground! The underground **excavations** eventually grew into several dozen towns. They were large enough to shelter thousands of people. If invaders or any other kind of threat appeared, inhabitants of the rock towns above ground headed underground.

By the 600s, Christian monks had built more elaborate rock dwellings. They built large monasteries in which to live. These monasteries had sleeping quarters, large kitchens, and cellars for stored food and drink. Each monastery had its own church. At first the churches were simple and plain. Over time they became more elaborate. By the 1000s and 1100s, Cappadocian monks were building churches with high, arched ceilings and large **altars**. Artists decorated the walls and ceilings with beautiful paintings. Thanks to the region's dry climate, many of these works of art have survived for hundreds of years with little damage.

Preserving the Past

In 1985, part of Cappadocia's rock town complex was made a World Heritage Site. World Heritage Sites are considered special places that are important to protect. The rock houses of Cappadocia are being carefully maintained to preserve their historical value.

People entering an underground town

Tourists come from all over the world to visit these unique rock towns. Guides lead them through tunnels and passageways, as it is easy to get lost. Visitors can stay in rock houses that have been turned into small hotels. Imagine spending the night in a rock room carved by hand hundreds of years ago! One thing visitors discover is that there is no need for air conditioning or central heating. Houses made of tuff stay cool in summer and warm in winter.

Many people walking the streets of Cappadocia's rock towns are not tourists. They live there, and the rock houses are their homes. The walls and floors are hundreds of years old, but the houses have running water, carpets on the floor, and curtains in the windows. When homeowners make changes, though, they sometimes get a surprise. Some have tried to make new rooms in their rock houses. They've started scraping the walls only to break through into old caves that have been undisturbed for hundreds of years.


Hotel in a hillside of Cappadocia

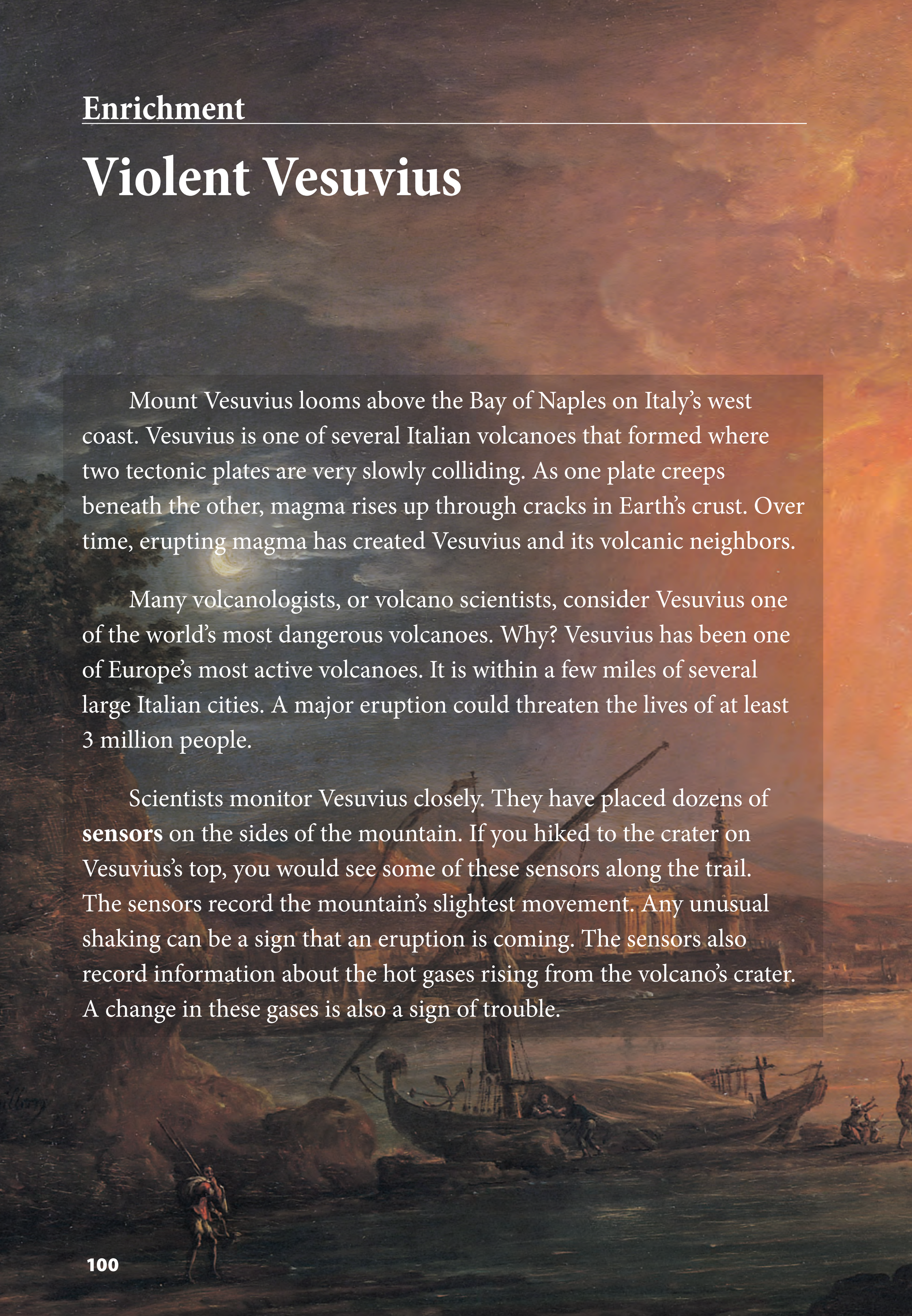
The Tuff Carvers of Easter Island

Easter Island is another place famous for structures carved from tuff. Hundreds of giant statues dot the hills of this South Pacific island. The statues, called **moai**, are partial human figures with large heads, high cheekbones, and heavy brows. Except for differences in height, all the moai on the island look very much the same. The Rapa Nui people, the native inhabitants of Easter Island, carved the moai from tuff. The tuff came from the sides of a volcanic crater near Maunga Terevaka, the island's largest volcano.

To make the statues, Rapa Nui carvers used blocks of tuff cut from the crater walls. They used sharp stone tools made of basalt to cut and shape the softer rock. The carvers shaped moai right in the wall of the crater. When the fronts were finished, they chipped the huge statues free from the crater wall. Then the moai were moved to a final destination. Scientists are still debating how they think the Rapa Nui moved the moai. However they did it, it was quite a task. The largest moai weigh over 80 tons!

The biggest mystery still surrounding the moai is why the Rapa Nui carved them. Some people have suggested that moai were carved to honor chiefs or possibly ancient ancestors, but no one knows for sure.

Moai of Easter Island



Enrichment

Violent Vesuvius

Mount Vesuvius looms above the Bay of Naples on Italy's west coast. Vesuvius is one of several Italian volcanoes that formed where two tectonic plates are very slowly colliding. As one plate creeps beneath the other, magma rises up through cracks in Earth's crust. Over time, erupting magma has created Vesuvius and its volcanic neighbors.

Many volcanologists, or volcano scientists, consider Vesuvius one of the world's most dangerous volcanoes. Why? Vesuvius has been one of Europe's most active volcanoes. It is within a few miles of several large Italian cities. A major eruption could threaten the lives of at least 3 million people.

Scientists monitor Vesuvius closely. They have placed dozens of **sensors** on the sides of the mountain. If you hiked to the crater on Vesuvius's top, you would see some of these sensors along the trail. The sensors record the mountain's slightest movement. Any unusual shaking can be a sign that an eruption is coming. The sensors also record information about the hot gases rising from the volcano's crater. A change in these gases is also a sign of trouble.

Mount Vesuvius erupting

People living around the Bay of Naples must live with the threat of a Vesuvius eruption.

Scientists analyze sensor data 24 hours a day. They issue a warning if the data suggests an eruption is brewing. When this happens, people living around the Bay of Naples are urged to **evacuate**. Scientists worry, however, that there might not be enough time for thousands of people to get a safe distance away from the volcano. Vesuvius has a history of erupting very suddenly.

Vesuvius's last eruption occurred in 1944. For nearly two weeks, the volcano released billowing clouds of ash and gas. Fountains of lava shot up from the volcano's crater. Yet this eruption was minor compared to the eruption in 79 CE. It was the largest, most devastating Vesuvius eruption in recorded history. Millions of tons of hot ash and volcanic rock buried several ancient Roman towns at the volcano's base. As many as 16,000 people died.

The 79 CE eruption of Vesuvius happened almost 2,000 years ago. Yet we know a great deal about it because of evidence left behind. Part of the evidence is an eyewitness account. A 17-year-old Roman known as Pliny the Younger lived through the disaster and wrote about it in a letter.

Eyewitness to Disaster

In the summer of 79 CE, Pliny and his mother were staying with his uncle. They lived in Misenum, a town at the northern edge of the Bay of Naples. Misenum was about 20 miles from Vesuvius. They could see Vesuvius across the bay.

On an August afternoon, Pliny's mother noticed a strange cloud forming across the bay. Pliny described it in his letter:

"The cloud was rising from a mountain that we later learned was Vesuvius. Its shape was a pine tree. It rose into the sky on a trunk that seemed to have branches."

What Pliny and his mother saw was the first stage of Vesuvius's eruption. Hot gas from deep inside the volcano had erupted, sending a gigantic column of ash and volcanic rock blasting up into the air. At its top, the cloud was spreading outward. It created a shape like a mushroom or umbrella—or in Pliny's imagination, an Italian pine tree.

A Vesuvius eruption depicted in a wood engraving

While his uncle sailed across the bay to investigate, Pliny stayed behind with his mother. Earthquakes shook the ground again and again. Ash and smoke filled the air. By morning, the sky was still dark. The air was so thick with volcanic ash that sunlight was blocked. Ash fell like snow from the sky. Pliny and his mother decided to head for the hills above Misenum. They were joined by a crowd of **panicked**, terrified people from the town.

From the hillside above the town, Pliny looked back across the bay toward Vesuvius. The towering pine-tree-shaped cloud above the volcano was still there, but had turned black. Lightning and **sheets** of orange flame flickered inside it. Then, as Pliny watched, the gigantic cloud seemed to collapse. It fell from the sky and swept down the side of the volcano. Part of it surged out over the water of the bay and rolled toward them. Pliny grabbed his mother's hand and tugged her farther up the hillside. He wrote:

"A dense cloud came up behind us. It spread over the earth."

Towering black cloud forms over Vesuvius

Have you ever been in a room with no windows when the lights went out? That is how Pliny described the darkness. He and his mother crouched down, afraid to move because they couldn't see anything at all. He described the scene:

"Ashes began to fall again, this time in heavy showers. We shook them off, otherwise we would have been buried beneath them."

Darkness surrounds the erupting Vesuvius

Time dragged. Pliny was sure he was going to die. Then gradually, the darkness lifted. The ashfall slowed and eventually stopped. He saw that everything around him was covered in drifts of volcanic ash. He was sure the worst was over.

A few days later, Pliny and his mother learned that his uncle was dead. He had died trying to help evacuate people from Pompeii, a nearby city.

What about the towns around the bottom of the volcano? Pompeii and other towns at the volcano's base were gone, completely buried under volcanic ash and rock.

Buried Evidence

Pliny's letter gave scientists important clues about Vesuvius's eruption in 79 CE. The buried towns, and in particular Pompeii, provided even more information. It took hundreds of years, however, to unearth them. In 1748, people looking for Roman artifacts began digging near what had been Pompeii.

As shovels cut into the soft volcanic rock, the diggers discovered that volcanic ash had preserved Pompeii. Buildings were still standing. Streets were still **littered** with objects people had dropped as they tried to escape. Inside homes, loaves of bread and food inside clay jars were still recognizable.

Excavation activity at Pompeii

The remains of some living things were also eerily recognizable. As the volcanic cloud swept down from Vesuvius, hot volcanic ash covered people and animals in seconds. They were **entombed** where they had fallen.

Excavations continue at Pompeii. Herculaneum, another town buried by Vesuvius in 79 CE, has also been uncovered. Workers have restored many of the houses, temples, and streets in these towns. They have cleaned and repaired paintings, sculptures, and mosaics. If you visit Pompeii and Herculaneum, you can walk down ancient Roman streets that look much like they did the day before the volcanic disaster.

You can see where children your age played games, ate their meals, and slept. You can look out ancient windows and see Vesuvius, still active, high above the towns.

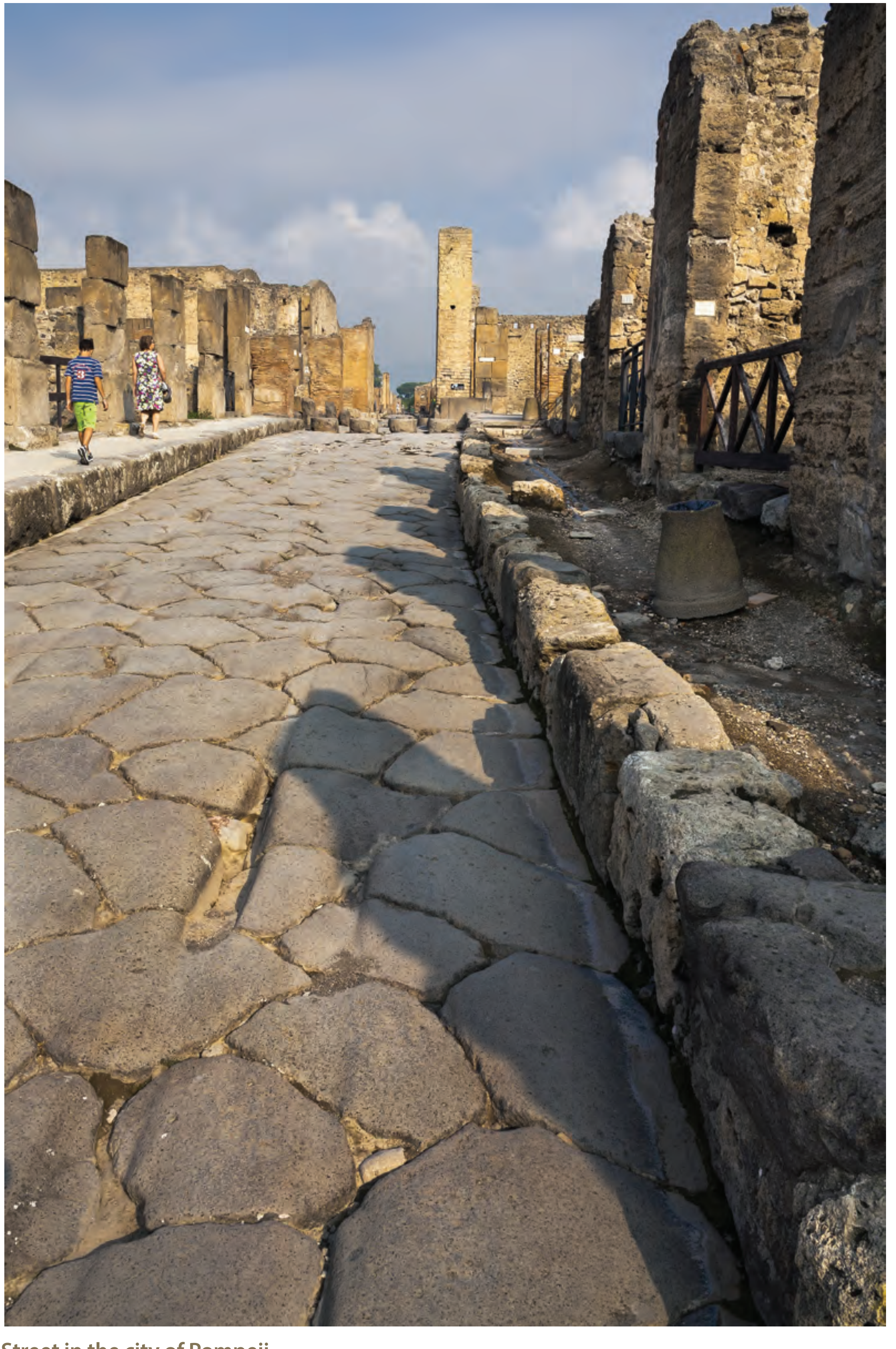

Clay jars unearthed from the ruins of Pompeii

Details of the Disaster

Scientists have pieced together a detailed account of the event. When Vesuvius erupted, it created the enormous cloud that Pliny saw. Hot volcanic material rained down from this cloud onto Pompeii and other nearby towns. Hot ash fell and accumulated into piles on the ground. Yet most people living in the towns at the volcano's base apparently survived the ashfall. Some fled on foot or in boats. Most of the people stayed and returned to their homes. Scientists suspect they thought the worst was over. They were wrong.

The towering cloud that hung above Vesuvius collapsed. Pliny witnessed it from his position across the bay. As millions of tons of hot volcanic materials dropped toward Earth, they gained speed, creating what scientists call **pyroclastic flows**. A pyroclastic flow is a sort of avalanche of intensely hot ash, rock fragments, and volcanic gas. It rolls down the side of a volcano as fast as a speeding train.

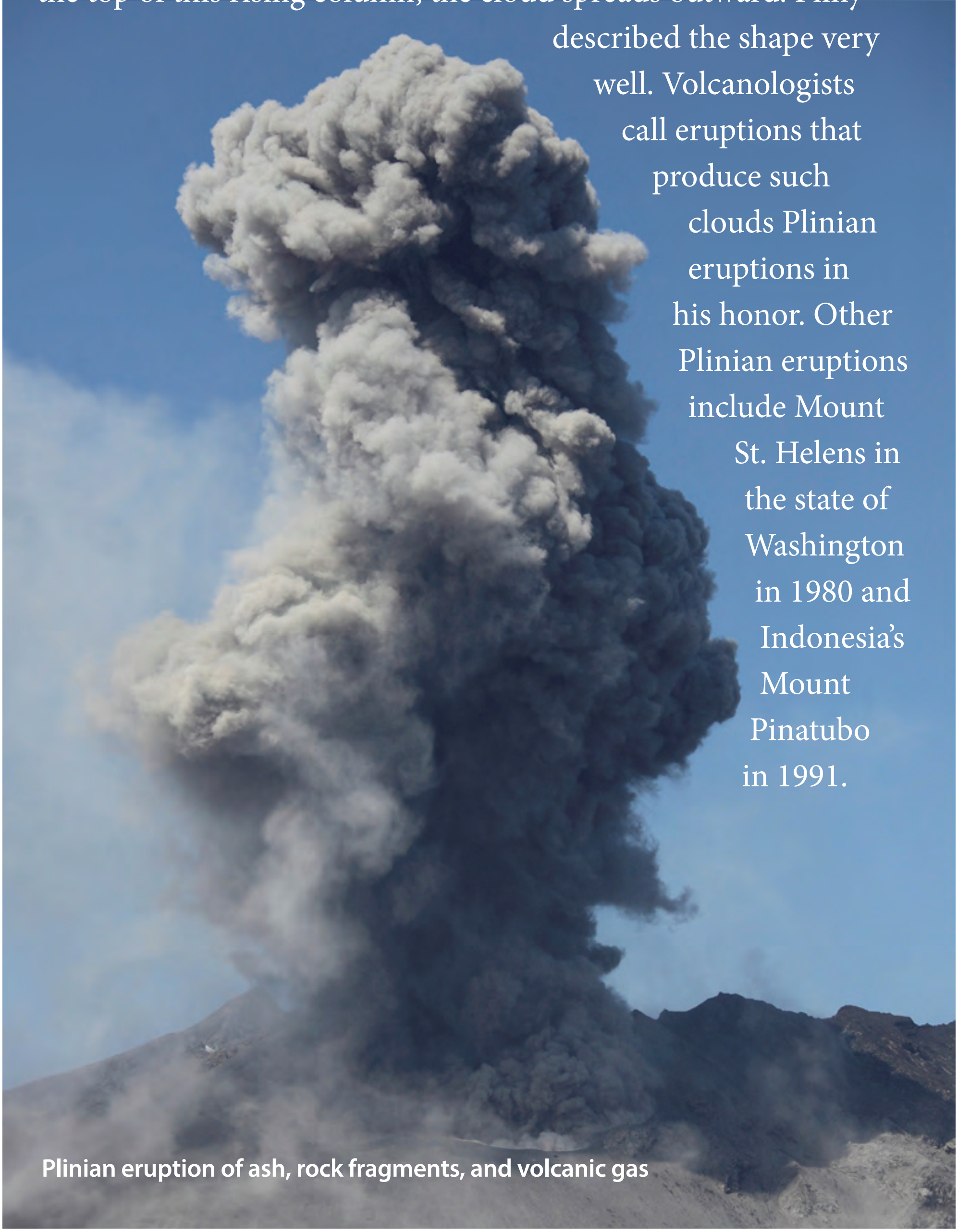
When Vesuvius's pyroclastic flows hit Pompeii and Herculaneum, there was no time for people to react. In seconds, these volcanic avalanches swallowed up everything in their path. They preserved a moment in time. It was a terrifying moment for the towns' inhabitants. For us, it is a unique glimpse into a world long ago.



Street in the city of Pompeii

Plinian Eruptions

The most powerful volcanic eruptions produce an enormous cloud of ash, bits of rock, and toxic gas. The cloud shoots skyward at hundreds of feet per second. This **eruption column**, as scientists call it, can soar several dozen miles into the air. At the top of this rising column, the cloud spreads outward. Pliny described the shape very well. Volcanologists call eruptions that produce such clouds Plinian eruptions in his honor. Other Plinian eruptions include Mount St. Helens in the state of Washington in 1980 and Indonesia's Mount Pinatubo in 1991.



Plinian eruption of ash, rock fragments, and volcanic gas

Enrichment

A Deep-Sea Detective Story

The discovery of seafloor spreading at mid-ocean ridges was a turning point in geology. It helped explain how continents move. It became a key part of the theory of plate tectonics.

The discovery of mid-ocean ridges also changed how many scientists thought about the ocean bottom. Up until that time, many considered it to be a fairly boring place—cold and dark and relatively lifeless. Now, suddenly, they'd found all this volcanic activity along mid-ocean ridges. Was that all, or were other interesting things happening at mid-ocean ridges?

Some scientists thought about volcanic activity on land. For example, Yellowstone National Park is a volcanically active place. True, no lava is erupting at Yellowstone (at least it hasn't for a very long time). But geysers and hot springs are all over the park. Scientists understood how Yellowstone's geysers form. Water seeps into deep cracks in the crust. The water is heated to very high temperatures by magma lying below the crust. Then a mix of hot water and steam shoots back to the surface, where it explodes out of the ground.

"Were there geysers along mid-ocean ridges?" scientists wondered. All the ingredients were there: water, cracks in the crust, and magma just below. If seawater seeped down into cracks along the mid-ocean ridges, wouldn't it be heated by magma beneath the crust? Wouldn't this hot seawater then erupt to form deep-sea geysers?

The idea made sense, but scientists needed to prove that these deep-sea geysers—or hydrothermal vents—really did exist. The scientists became **detectives**. Their first step was to look for clues along mid-ocean ridges.

Deep Heat

In the 1880s, a Russian ship traveling across the Red Sea collected water samples from the seafloor. Water on or near the ocean bottom is normally just a few degrees above freezing. Sunlight cannot reach such great depths. Cold water, like cold air, sinks. As a result, the ocean bottom is typically a dark, chilly place. Surprisingly, though, the water samples the Russians collected from the Red Sea's floor were warm. They were warmer than water at the surface!

By the 1960s, ocean scientists knew there was a mid-ocean ridge in the Red Sea. They came across the old Russian water data. They decided to collect their own samples from the seafloor near the Red Sea's mid-ocean ridge. One water sample from near the ridge measured a toasty 111°F. That's quite a hot bath! A sample of mud from the ridge was even warmer: 133°F. That's hot enough to **scald** skin! Interestingly, the hot sediment contained all sorts of minerals. Scientists wondered why these minerals were there.

Colored Rocks

In the early 1970s, scientists took water samples along other mid-ocean ridges. Time and again, they found places where the seawater was unexpectedly warm. The scientists dredged up rocks from these sites. Most were dark volcanic basalt. A few rocks, however, were brightly colored. The scientists analyzed these colored rocks. They discovered that the rocks had started out as basalt but their minerals had changed. The changes were characteristic of rocks exposed to very hot water.

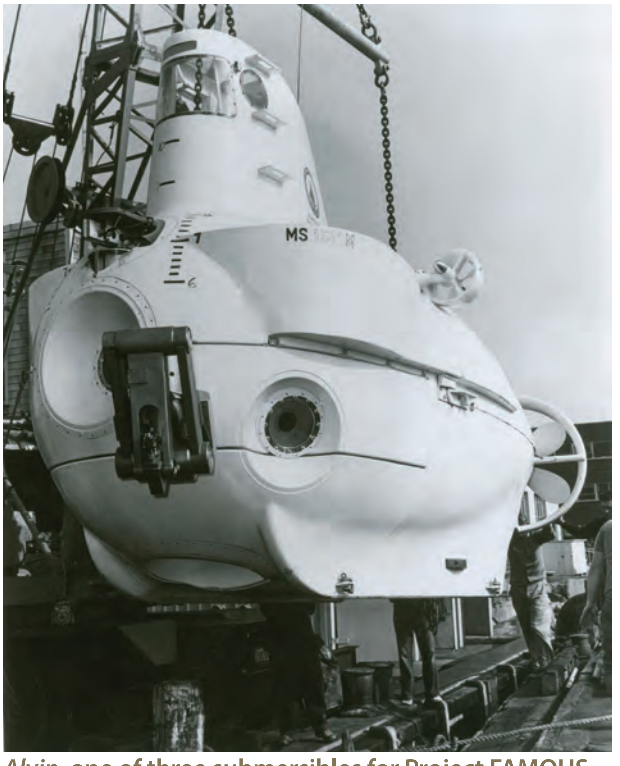
Was hot water from hydrothermal vents what had changed the rocks? The scientists suspected it was. They guessed that as magma-heated seawater rises up through cracks in oceanic crust, it heats the basalt around it. The heat changes minerals in the basalt. Furthermore, some of those minerals dissolve in the hot water. As the hot water erupts from the seafloor, these dissolved minerals turn solid again and leave the water to mix with seafloor sediments.

At this point, the scientists were convinced that hydrothermal vents existed on mid-ocean ridges. The next step was to find one.

The Search Begins

Scientists headed into the Atlantic and Pacific Oceans aboard research ships. They sailed along mid-ocean ridges. They lowered instruments to measure water temperature and dredged up rocks. At sites that looked promising, they sent down small robots with cameras to snap pictures of the scene far below. Some photos showed mounds of rock covered with mineral deposits. Were these warm, mineral-rich sites the hydrothermal vents they were looking for? To be sure, they needed to get a firsthand look.

At the time, there were only a few underwater vehicles that could carry people all the way to the seafloor. These small submersibles belonged to the military. They were designed to retrieve objects from the ocean bottom and help rescue sailors trapped in sunken ships. Many people thought using submersibles for ocean exploration would be a waste of time and money. Even so, the scientists looking for hydrothermal vents eventually won support for a joint French-American expedition. It was called Project FAMOUS for French-American Mid-Ocean Undersea Study. Its destination was the Mid-Atlantic Ridge.



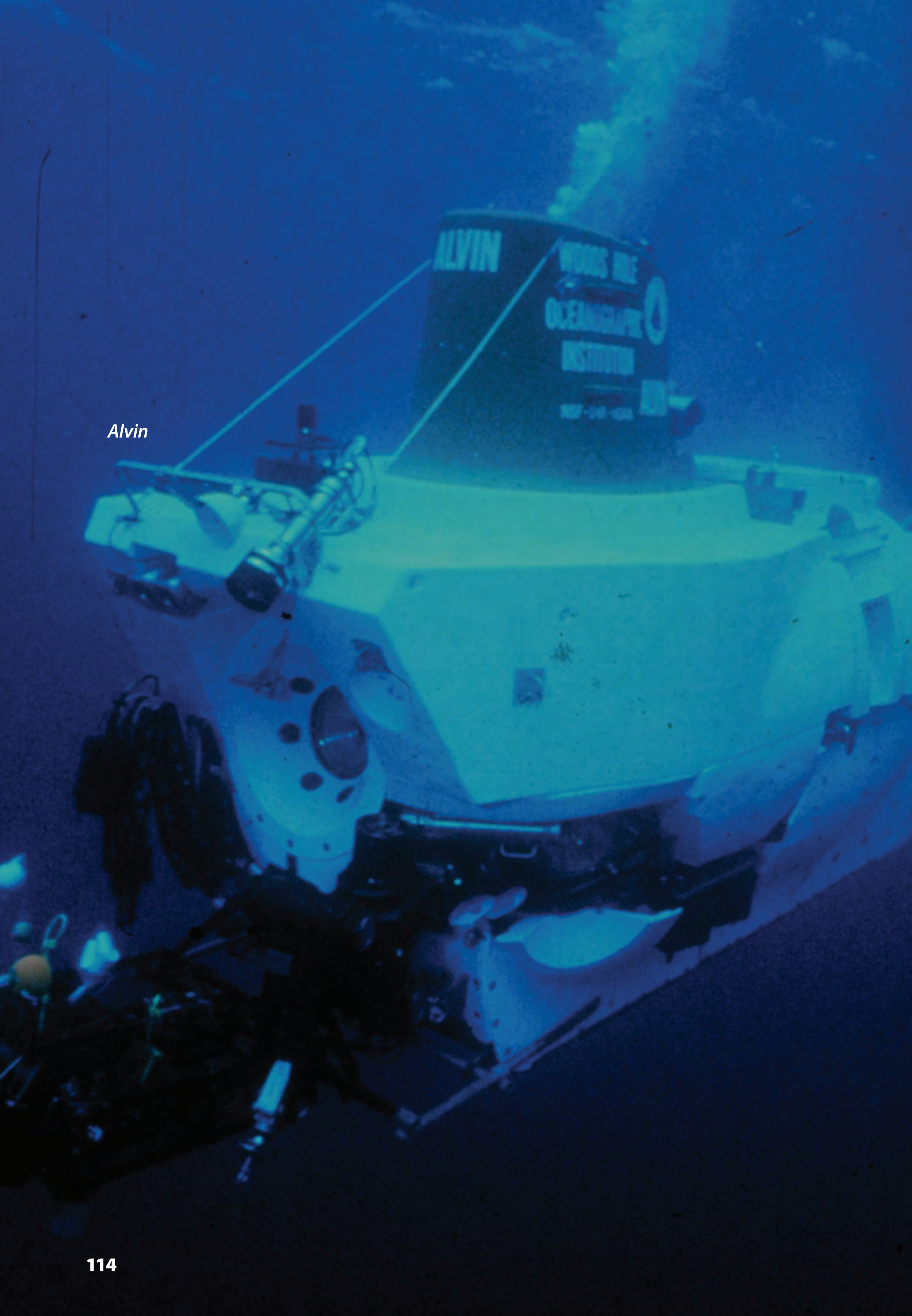
Alvin, one of three submersibles for Project FAMOUS

Project FAMOUS expedition begins

The expedition was a huge **undertaking**. It took two years to get everything ready. Three submersibles took part, including one called *Alvin*. In 1974, a handful of lucky scientists became the first people to come face-to-face with a mid-ocean ridge. They saw great mounds of volcanic rock. They even saw the narrow rift along the top of the ridge where lava erupts to create new crust. However, they didn't see a single hydrothermal vent.

Galapagos Luck

The scientists were disappointed but didn't give up. Another team decided to look for vents along the Galapagos Rift. This is a mid-ocean ridge west of Central America. Data gathered by instruments and cameras revealed both warm water and mineral deposits at several sites along this ridge.



Alvin

The Galapagos Hydrothermal Expedition began in early February 1977. The science team had many instruments, but just one submersible: *Alvin*. The expedition began with scientists lowering a camera-equipped vehicle down near the seafloor. For many hours, they towed the little vehicle over the ridge. It snapped a picture every few seconds.

The scientists studied the photos carefully. It took a long time because there were 3,000 photos! Nearly all showed only barren volcanic rock, but 13 photos made the scientists' hearts beat faster. The photos were taken at a place on the ridge where the temperature was higher. They clearly showed rocks covered with mineral deposits. Nestled among the rocks were hundreds of large white clams. Were the animals there because the water was warm? Were they clustered around a hydrothermal vent?

On February 17, 1977, *Alvin* headed down to the site. A pilot and two scientists sat cramped together inside the small submersible. When the sub reached the ridge, the men stared out through small **portholes** at an amazing sight. Jets of hot, shimmering water were gushing out of cracks in the rock. As it mixed with cold water, the hot vent water instantly turned cloudy as dissolved minerals solidified. Tiny mineral particles fell like snow.

They had done it! The scientists had followed the clues to a major discovery. For the first time, they had located a hydrothermal vent along a mid-ocean ridge. Along with the vent, they had also discovered unexpected life. Seeing big white clams in a photograph was one thing. Seeing them in person was much more exciting. The clams around the vent were huge, unlike any clams the scientists had ever seen.

Mussels, crabs, and shrimp live along hydrothermal vents.

Communities of animals live off bacteria and bacteria-eaters around hydrothermal vents.

The Big Surprise

In the months and years that followed, scientists found many more hydrothermal vents. Bizarre animals lived around most of them. What were the animals doing there? How did they survive in a world of total darkness with only rock, minerals, and hot water? Research provided the answer, and the answer shocked the world.

On or near Earth's surface, most living things depend on sunlight as the ultimate source of energy. Green plants and algae use sunlight to make food. They do this through a process called photosynthesis. Many animals eat plants or algae. Other animals eat plant-eaters.

Sunlight doesn't reach the seafloor, so how do vent dwellers survive? Scientists discovered the animals survive thanks to bacteria. Vents are home to unusual types of bacteria that use chemicals in hot vent water—instead of sunlight—to make food. The process is called chemosynthesis. Around hydrothermal vents, chemosynthetic bacteria are like plants and algae in the sunlit world above. Some vent animals eat the bacteria directly. Others eat the bacteria-eaters. It is a deep-sea food chain scientists didn't know existed until 1977. Finding deep-sea hydrothermal vents—and their communities of animals—was one of the most important discoveries of the 1900s.

Bacteria grows near hydrothermal vents.

Glossary

Words with an asterisk (*) are important bolded words in this Reader that are not part of the reading lessons.

A

*__active volcano__, ***n.*** a type of volcano that has erupted in the past 10,000 years and is likely to erupt again (**active volcanoes**)

aftershock, ***n.*** a smaller, weaker earthquake that often follows a main earthquake event (**aftershocks**)

altar, ***n.*** a platform or table used as a center of worship in religious ceremonies or services (**altars**)

B

basalt, ***n.*** heavy, dense rock formed from cooled, hardened lava

basin, ***n.*** a large area in the earth that is lower than the area around it (**basins**)

bitter, ***adj.*** **1.** resentful and angry because of unfair treatment; **2.** very cold

bulge, ***v.*** to stick out or swell

C

caldera, ***n.*** a crater caused by the collapse of the top of a volcano

canyon, ***n.*** a deep valley with steep sides and often a stream or river flowing through it (**canyons**)

catastrophe, ***n.*** a terrible, sudden event (**catastrophes**) *__chemical weathering__, ***n.*** a process that breaks down rocks by changing the minerals they contain

climate, ***n.*** the average weather conditions of a particular area

clustered, ***adj.*** grouped close together

*__coal__, ***n.*** a dark, solid substance in the earth formed from plant fossils and used as fuel

*__collide__, ***v.*** to crash together with strong force (**colliding**)

compact, ***v.*** to closely pack or press together (**compacts**, **compacting**)

conclude, ***v.*** to decide something or form an opinion based on information you have (**concluded**, ***n.*** **conclusion**)

continental drift, ***n.*** a process in which continents slowly move over time on the surface of the earth

contract, ***v.*** to shrink slightly or get smaller

crater, ***n.*** a bowl-shaped opening at the top of a volcano or geyser

*__crust__, ***n.*** Earth's outermost layer, featuring a rocky surface

D

dense, ***adj.*** thick or heavy (**denser**)

deposit, **1.** ***v.*** to put or leave something in a particular place; **2.** ***n.*** material laid down or left by a natural process (***v.*** **deposited**, ***n.*** **deposits**)

descend, ***v.*** to move downward (**descends**)

detective, ***n.*** a person whose job is to find information about someone or something (**detectives**)

dissolved, ***adj.*** mixed with liquid so no solid pieces are visible anymore

distant, ***adj.*** far away in time *__dome mountains__, ***n.*** mountains generally formed when magma pushes upward into Earth's crust from the mantle and cools into igneous rock underground, causing the crust above it to bulge; usually occur as isolated mountains on otherwise flat plains

*__dormant volcano__, ***n.*** a type of volcano that is considered active but hasn't erupted for a very long time

*__drift__, ***v.*** to slowly move with water, wind, or other natural processes (**drifted**)

durable, ***adj.*** able to last a long time in good condition

dwelling, ***n.*** a place where someone lives (**dwellings**)

E

elder, ***n.*** a person who is older, respected, and often in a position of authority (**elders**)

entomb, ***v.*** to bury (**entombed**)

*__epicenter__, ***n.*** the point on Earth's surface directly above an earthquake's focus

*__erosion__, ***n.*** any process or force that moves sediments to new locations

erupt, ***v.*** to send out rock, lava, and ash in a sudden explosion (**erupted**, ***n.*** **eruption**)

eruption column, ***n.*** an enormous cloud of ash, bits of rock, and toxic gas produced by a volcanic eruption that can travel hundreds of feet per second

eternal, ***adj.*** lasting forever, with no beginning and no end

evacuate, ***v.*** to remove people from a dangerous place

evidence, ***n.*** proof; information and facts that are helpful in forming a conclusion or supporting an idea

excavation, ***n.*** a hollowed-out place formed by digging or carving (**excavations**)

exert, ***v.*** to cause a force to be felt or have an effect (**exerts**)

expand, ***v.*** to get bigger

experiment, ***n.*** a scientific test to try out something in order to learn about it

*__extinct volcano__, ***n.*** a type of volcano that has not erupted for at least 10,000 years (**extinct volcanoes**)

eyewitness, ***n.*** a person who has seen something happen and is able to describe it

F

fault, ***n.*** a crack in Earth's crust (**faults**)

*__fault-block mountains__, ***n.*** mountains formed when gigantic blocks of rock move up and down along faults

fine, ***adj.*** very small

firsthand, ***adv.*** coming directly from actually seeing or experiencing something

*__focus__, ***n.*** the place in Earth's crust where huge blocks of rock move along a fault, triggering an earthquake

*__fold mountains__, ***n.*** mountains formed when rocks are pushed up into huge folds by moving tectonic plates

*__force__, ***n.*** strength, power (**forces**)

fossil, ***n.*** the preserved remains of things that lived long ago (**fossils**)

foundation, ***n.*** the basis of something, the support upon which something else is built (**foundations**)

G

geologist, ***n.*** a scientist who studies the makeup of the earth and the forces and processes that shape and change it (**geologists**)

*__geyser__, ***n.*** an underground hot spring that periodically erupts, shooting hot water and steam into the air (**geysers**)

granite, ***n.*** a common igneous rock that forms from magma that cooled within Earth's crust

H

heave, ***v.*** **1.** to move up and down over and over; **2.** to lift, pull, push, or throw with a lot of effort

hoodoo, ***n.*** the tallest kind of pinnacle (**hoodoos**)

hotspot, ***n.*** a very hot region deep within Earth's mantle where a huge magma chamber forms (**hotspots**)

hot spring, ***n.*** a naturally flowing source of hot water (**hot springs**)

hydrothermal vent, ***n.*** a deep-sea geyser that forms as seawater sinks down through cracks in the oceanic crust and then releases extremely hot, mineral-rich water back up through cracks in the crust (**hydrothermal vents**)

hypothesis, ***n.*** an idea that has been suggested and may be true but has not yet been proven

I

*__ice wedging__, ***n.*** a process in which water alternately freezes and thaws and breaks rocks apart

*__igneous rock__, ***n.*** rock that forms when magma cools and solidifies (**igneous rocks**)

*__inner core__, ***n.*** Earth's deepest layer, made of very hot, solid metal

L

lava, ***n.*** red-hot melted rock that has erupted above Earth's crust from deep underground

*__limestone__, ***n.*** a sedimentary rock often packed with the fossilized skeletons and shells of tiny ocean creatures that is commonly used for building

litter, ***v.*** to scatter in disorder (**littered**)

lofty, ***adj.*** high up

M

magma, ***n.*** melted rock in Earth's mantle

magnitude, ***n.*** an earthquake's strength

*__mantle__, ***n.*** Earth's largest and thickest layer that consists of very hot, very dense rock

*__metamorphic rock__, ***n.*** rock that forms when minerals in igneous, sedimentary, or older metamorphic rocks are changed due to extreme heat and pressure (**metamorphic rocks**)

mineral, ***n.*** a solid, nonliving substance found in the earth that makes up rocks (**minerals**)

moai, ***n.*** statues on Easter Island carved from tuff in the shape of partial human figures with large heads, high cheekbones, and heavy brows

O

observation, ***n.*** **1.** the act of paying careful attention to gather information; **2.** a statement based on paying careful attention to something (**observations**)

obsidian, ***n.*** a dark rock or natural glass formed from lava that cooled very quickly

ocean trench, ***n.*** a narrow, extremely deep valley formed when the seafloor dips down as one tectonic plate slides under another (**ocean trenches**)

offering, ***n.*** something that is presented as an act of worship (**offerings**)

*__outer core__, ***n.*** the layer within Earth between the inner core and the mantle that is made of very hot, liquid metal

outsmart, ***v.*** to trick or defeat someone by being clever

P

panic, ***v.*** to be fearful in a sudden and overpowering way (**panicked**)

pepper, ***v.*** to sprinkle or cover

*__physical weathering__, ***n.*** a process that breaks big rocks into smaller rocks without changing the minerals they contain

pinnacle, ***n.*** a slender, soaring rock formation made of tuff (**pinnacles**)

pinpoint, ***v.*** to figure out the exact location of something

plate tectonics, ***n.*** a theory that Earth's crust and the solid top part of the mantle are broken up into sections that fit together but move against each other

plume, ***n.*** a column of magma that rises from the mantle into a chamber beneath Earth's crust

porthole, ***n.*** a small, round window on the side of a ship, submersible, or aircraft (**portholes**)

pressure, ***n.*** the weight or force produced when something presses or pushes against something else

pyroclastic flow, ***n.*** a sort of avalanche of intensely hot ash, rock fragments, and volcanic gas that rolls quickly down the side of a volcano (**pyroclastic flows**)

R

revenge, ***n.*** the act of getting even for a wrongdoing

*__rock cycle__, ***n.*** the continuous cycle in which rocks are created, destroyed, and recreated

rugged, ***adj.*** having a rough, uneven surface

S

scald, ***v.*** to burn with very hot water or steam

school, ***n.*** a large number of ocean animals of one type swimming together (**schools**)

sea level, ***n.*** the average height of the ocean's surface

seamount, ***n.*** an underwater volcano that forms wherever magma is erupting through oceanic crust (**seamounts**)

*__sediment__, ***n.*** rock, sand, or dirt that has been carried to a place by water, wind, or other natural processes (**sediments**)

*__sedimentary rock__, ***n.*** a rock that is made of sediments that have been naturally compacted and cemented together (**sedimentary rocks**)

seismic wave, ***n.*** a surge of energy traveling out from an earthquake's source through the earth (**seismic waves**)

*__seismogram__, ***n.*** the record a seismograph makes, showing seismic waves as jagged up-and-down lines

*__seismograph__, ***n.*** an instrument used to track seismic waves traveling through the earth (**seismographs**)

sensor, ***n.*** an instrument that detects and measures changes, and then sends information to a controlling device (**sensors**)

sheer, ***adj.*** very steep, almost straight up and down

sheet, ***n.*** a broad stretch of something (**sheets**)

silt, ***n.*** very small sediments deposited by water

solidify, ***v.*** to make or become hard or solid (**solidifies**)

state, ***n.*** the condition of being a solid, liquid, or gas

strong-willed, ***adj.*** determined to do what you want even if other people tell you not to

*__subduction__, ***n.*** a process in which a heavier oceanic plate slides under a lighter continental plate

subduction zone, ***n.*** the place where one tectonic plate is sliding beneath another tectonic plate (**subduction zones**)

submersible, ***n.*** a small vehicle that can travel deep under water for research (**submersibles**)

surge, ***v.*** to move forward quickly, suddenly, and with force (**surges**)

T

texture, ***n.*** the size, shape, and sorting of mineral grains in rocks

theory, ***n.*** an explanation for why something happens based on evidence

trigger, ***v.*** to cause something to start or happen (**triggered**)

tsunami, ***n.*** a gigantic wave of seawater caused by an earthquake in oceanic crust (**tsunamis**)

tuff, ***n.*** a type of volcanic rock formed from hardened volcanic ash

U

ultimately, ***adv.*** finally; at the end of a process

underlie, ***v.*** to be located under something (**underlies**)

undertaking, ***n.*** something that someone takes on as a task or duty

V

volcano, ***n.*** a hill or mountain that forms over a crack in Earth's crust from which lava erupts (**volcanoes**)

W

*__weather__, ***v.*** to break down into smaller pieces (***n.*** **weathering**)

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