

Processes That Shape Earth

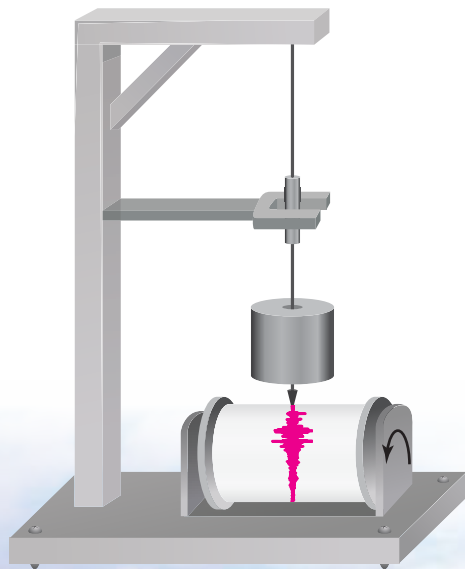
Earth's hot interior



Reader



Volcanic activity



Measuring and recording seismic waves

Weathering and erosion



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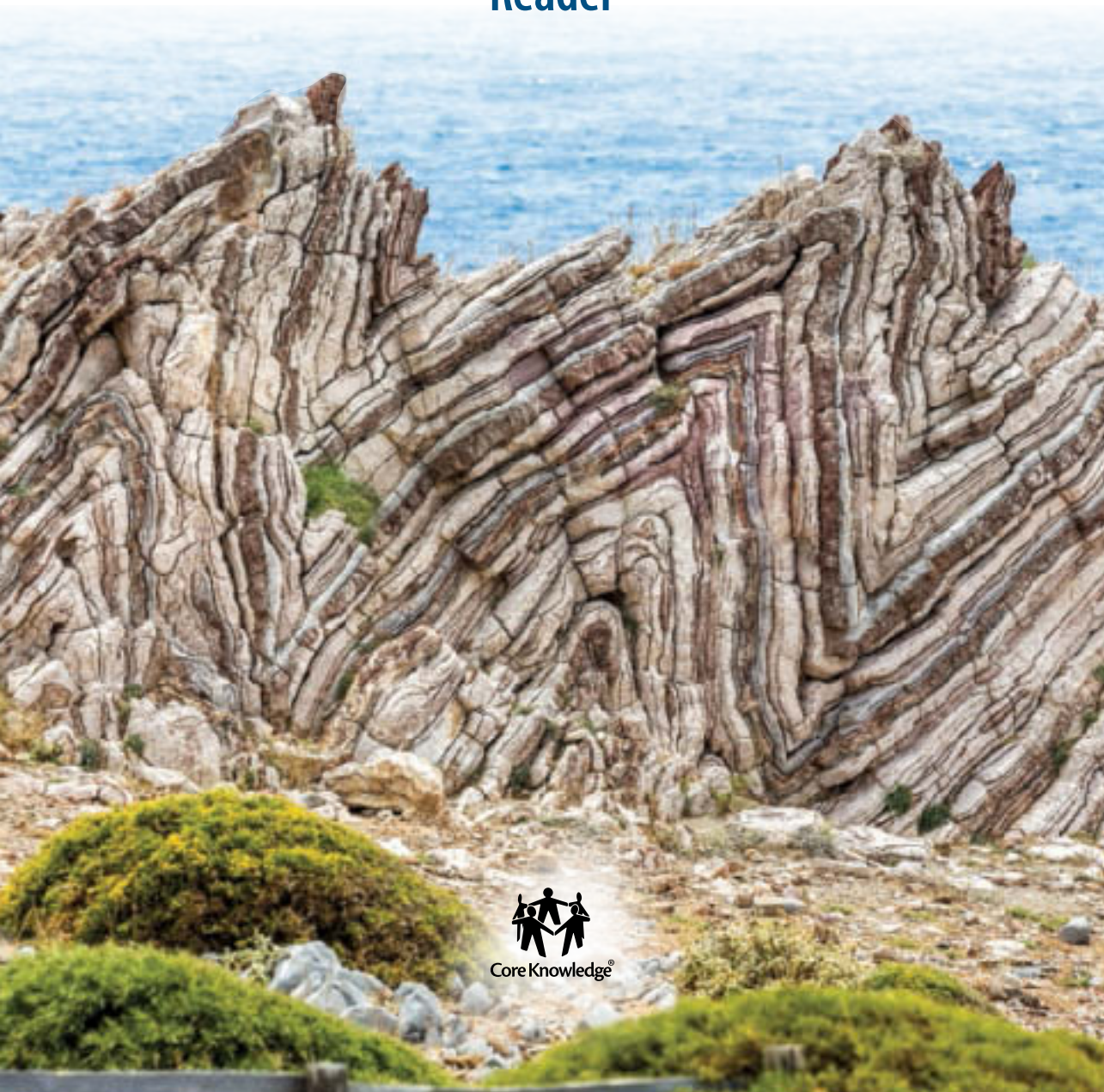
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Processes That Shape Earth

Reader



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Processes That Shape Earth

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Earth's Shifting Pieces

Chapter

1

The eastern coast of South America contains the **fossils** of a reptile that lived hundreds of millions of years ago. Fossils of this same reptile can be found about five thousand miles away, in Africa.

Geologists are scientists who study the earth, including rocks and the fossils of extinct organisms. Geologists found an interesting pattern when they looked at particular kinds of fossils. These fossils are discovered far apart, across oceans. These animals couldn't have travelled the thousands of miles that now separate their fossils. This presented geologists with a problem. Why are some fossils of the same kind of organism found thousands of miles apart on different continents?

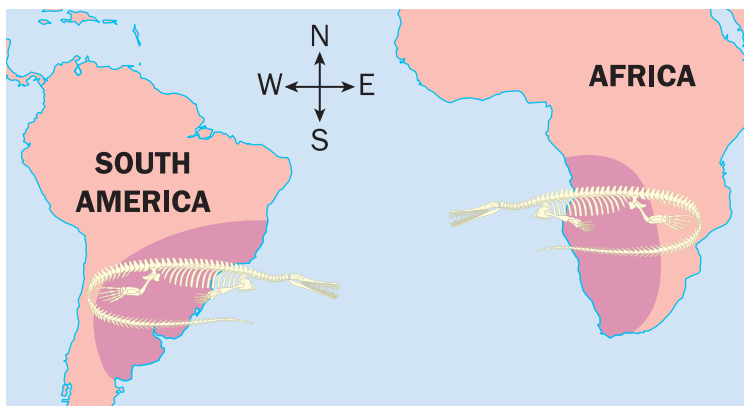
Big Question

Why are some fossils of the same type found thousands of miles apart on different continents?

Vocabulary

fossil, n. the remains of an organism preserved in rock form

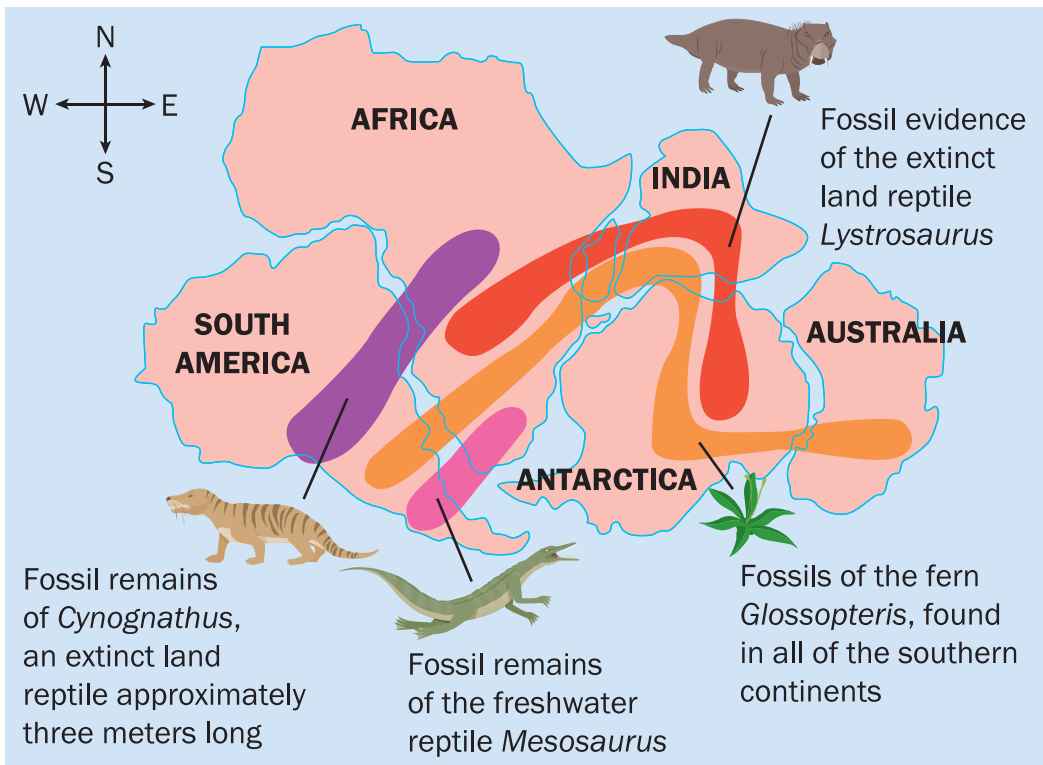
geologist, n. a scientist who studies what Earth is made of and how it changes over time



Mesosaurus was a reptile that lived long ago. Its fossils have been found in both South America and Africa. This presented an interesting puzzle for scientists to figure out.

Continental Drift

Alfred Wegener provided a possible answer to the fossil evidence. He was a scientist who noticed how some of the continents appeared to fit together. Could the continents once have been close together and then moved apart? Wegner gathered evidence that supported the idea, which he called continental drift. One type of evidence used to support his theory was the fossil record. After studying fossil evidence, Wegener concluded that these continents had once been clustered together. Wegener's theory was incomplete, but it was the beginning of the study of Earth's plates and how they have changed over time.



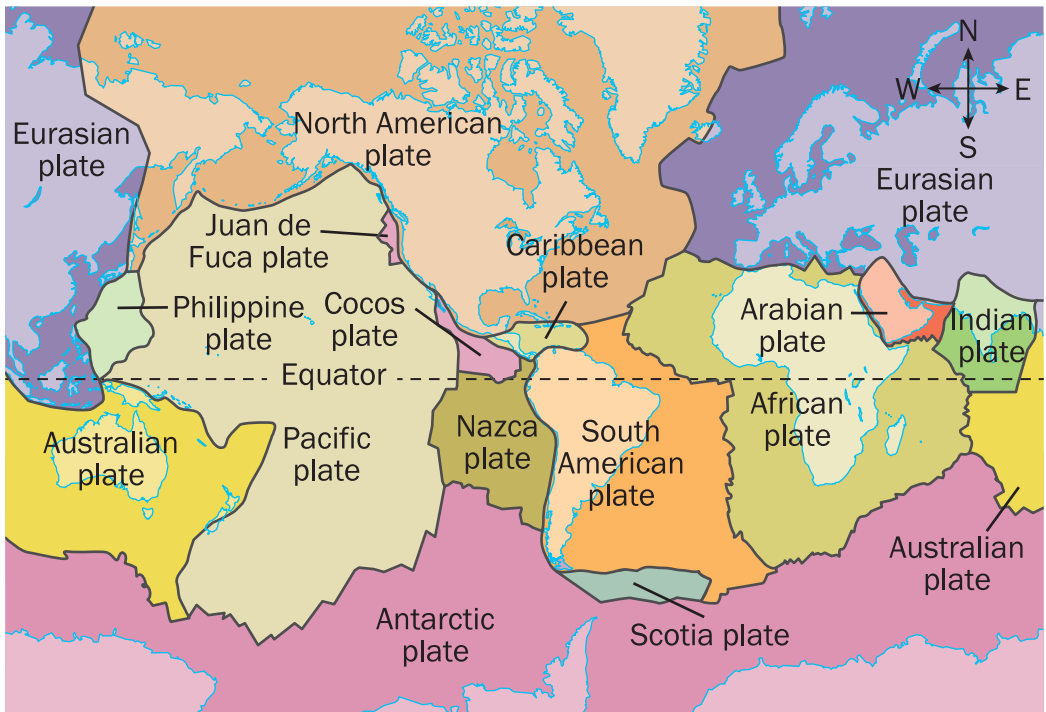
Look at the east side of South America and the west side of Africa on a world map. Why do you think the two coasts appear to fit together like two pieces of one puzzle?

Earth's Crust

Scientists now know that Earth's crust has different pieces called **plates**. These plates move and interact over large spans of space and time. Sometimes it is obvious when plate movements occur, such as if a group of islands pops up out of the sea after an earthquake. Most of the time, though, the movement of plates happens too slowly to notice.

Vocabulary

plate, n. in geology, a large fragment of Earth's crust and upper mantle



Can geologists observe and measure plate movement? They can. One tool they use is the Global Positioning System (GPS). GPS receivers are placed on different plates. They communicate with satellites that orbit Earth. The system locates each receiver and measures the distances between them. Scientists use these data to measure changes in the distances between receivers.

Why Do the Plates Move over Time?

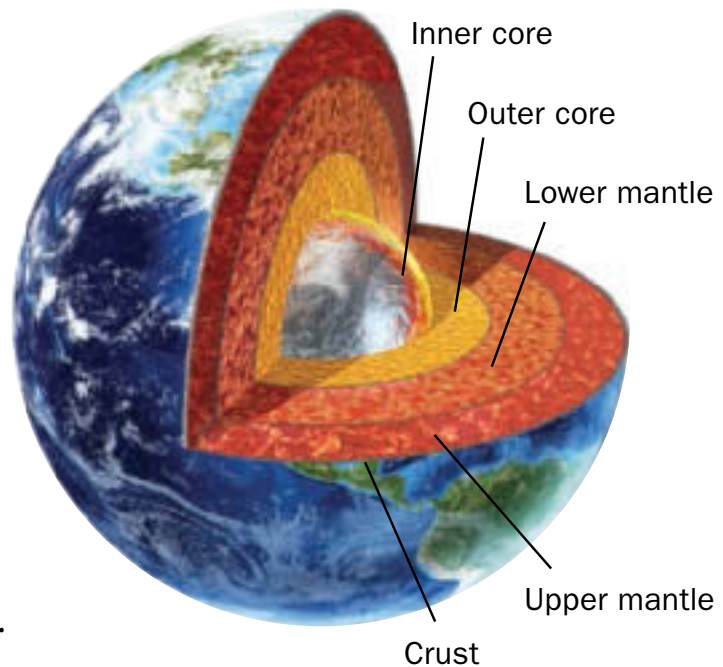
Liquid rock below Earth's surface is known as magma. It is very hot. The layer of Earth where magma forms is called the mantle.

Beneath the mantle lies Earth's core. The core has two layers: the outer core and inner core. The outer core is more molten than the inner core. Both layers of the core are made mostly of iron and nickel, two common metals. The core is very hot: 10,800°F, or about as hot as the surface of the sun.

The intense heat from Earth's core, plus pressure from above, produces currents in the mantle. These currents help transport the plates across Earth's surface.

This helps to explain how land masses and

fossils that once were located close together can now be found thousands of miles apart. The movement of plates is one process that shapes Earth.



Below Earth's crust are other layers that cause the crust to move.

Word to Know

Molten means liquified. It is usually used to describe liquified substances that are normally solid, such as metals and glass.

More Evidence of Earth-Shaping Processes

Chapter

2



Big Question

What evidence shows that Earth's surface has changed over time?

Over millions of years, layers of sediment eventually became solid rock. Then some of it eroded away.

The rust-red landforms of Monument Valley in Arizona are amazing to see. These structures are called buttes /byoots/ and are made of different types of rocks. When people first came across these buttes, they wondered how they formed. They asked many questions. Why are there different kinds of rocks stacked in matching layers from one butte to another? Did these formations always look like this?

Geologists look at the types of rocks that are present in an area to figure out how Earth's surface has changed and how it might change in the future. Monument Valley's buttes are evidence that the valley was not always there. The different layers are evidence of the types of rock that completely filled the valley long ago.

Sedimentary, Igneous, and Metamorphic Rock

Geologists study rocks to understand Earth's history. Geologists categorize types of rocks based on patterns. These patterns tell how the rocks formed in the past.

Sedimentary rock is made of sediment, bits and pieces of rock, compacted together. Sediment settles out of water, is deposited by wind, or is moved by glaciers. One example of sedimentary rock is sandstone. It is made of sand grains that are cemented together by pressure. Another type of sedimentary rock is shale, which is made of very tiny, compacted sediment grains. Layers of sedimentary rock tend to form in places where wind, ice, or water break down larger pieces of rock into smaller pieces.

Vocabulary

sedimentary rock, n. rock made of sediment compacted together



Long ago, the Rocky Mountains were larger than they are now. They began to break down. The sediments were carried away by water, wind, and glaciers.

The rock that comes from Earth's interior and is cooled is called **igneous rock**. There are different ways for igneous rock to form. One way is when molten lava erupts from a volcano. Other igneous rocks form when magma intrudes into Earth's crust but remains stuck there, under pressure. The slower cooling process makes different patterns of minerals that show up as visible grains. Granite is an example of an igneous rock formed this way.



Minerals in lava crystallize in different ways, depending on the temperature. This explains the variety of igneous rocks.

Both igneous and sedimentary rock can change into the third type of rock, called **metamorphic rock**. This occurs when heat and pressure change those rocks into a different form. Marble is an example of metamorphic rock.



This marble was a sedimentary rock called limestone at an earlier point in time. Marble is frequently used for statues.

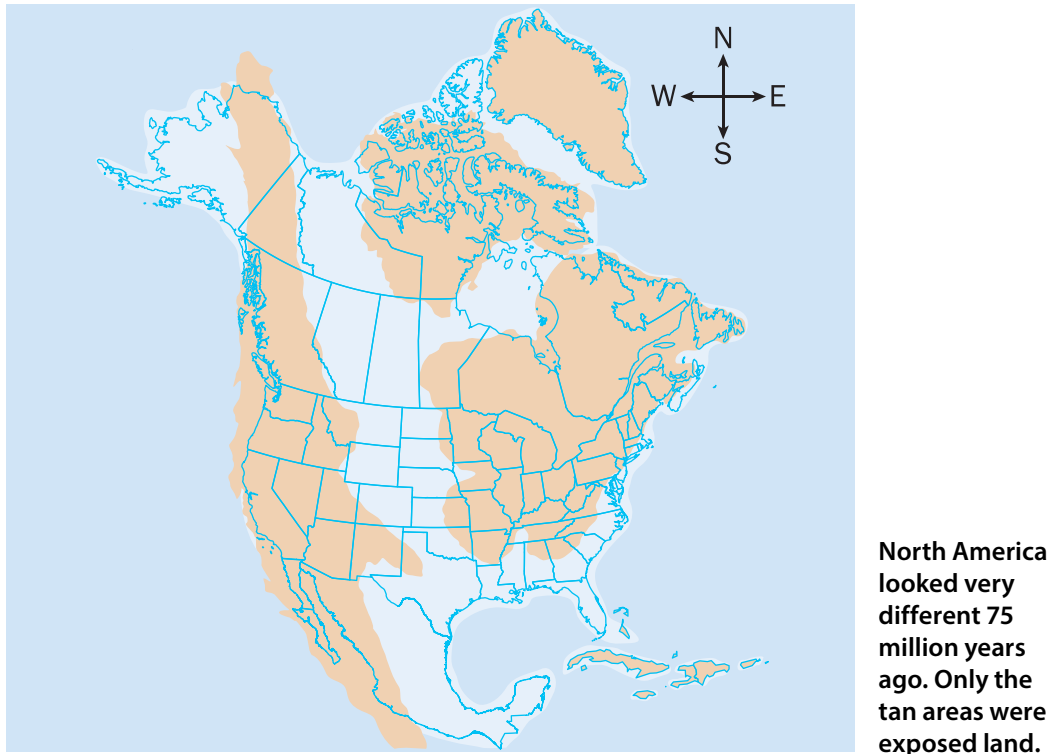
Vocabulary

igneous rock, **n.** rock made of magma or lava that has cooled and hardened

metamorphic rock, **n.** rock that forms when igneous or sedimentary rock is placed under tremendous heat or pressure

Fossils Are Often Found in Sedimentary Rocks

Throughout the middle of the United States, the fossils of sea creatures have been found. These are often found in deserts or very dry areas, far from the nearest ocean. Why are the fossils of sea creatures found in such places?



Geologists explain the discovery of these fossils this way: The central part of what is now the United States was actually covered by a large sea 75 million years ago. The sediment that accumulated at the bottom of the sea became sedimentary rock. Some of the organisms that died in the water left remains that settled into the sediment. Sediment moved by wind and water became layered on top of the dead organisms. Their fossils can be found in sedimentary rock today in states far from the ocean, such as Montana and South Dakota.

Comparing Rocks

Remember the buttes of Monument Valley, Arizona? Each butte is made up of layers of rock laid down at different times. Different buttes sometimes have the same layers running through them. At one time, the buttes were all part of a single strip of land. Over time, forces wore parts of the rock away, leaving the buttes behind. Then, some of the buttes wore away at different rates than others.

Examine the buttes in the picture. What do you see? Notice how similar the rock layers are in each. Both buttes have layers with the same thickness and color. That's because they were once a single strip of land. Over time, weather wore away the part between them, leaving individual buttes.



When geologists find similar types of rock in two different locations, they can draw conclusions about what happened to make the different locations look so similar. The Appalachian Mountains in North America and the Caledonian Mountains, which are scattered across the northern part of the British Isles and Scandinavia, have identical rock types and overall shapes. What could cause this to happen?



What evidence about the mountains would you see if you could slide North America and the northern part of Europe closer together?

Alfred Wegener wondered the same thing. He examined rock types and landforms in different locations around North America, Africa, and Europe. The mountains of these now-distant locations seemed to match up in terms of the rock types and the continental outlines. To Wegener and other scientists, this was evidence that the mountains formed in one place and then were separated as the continents drifted apart.

If two locations that are not very far apart have similar rock layers, but one location is missing one or more layers, geologists might conclude that some process has changed Earth's surface over time.

How Mountains Are Formed



What would cause this rock to fold like this?

Folded rocks are evidence of change. Some kind of force was applied to fold the once-flat layers into beautiful, wavy formations. As with mountain building, these forces can take thousands to millions of years to form folds.

Some types of mountains form when parts of Earth's crust push against each other. Earth's plates can meet and push against each other. Both plates may be forced upward, or one plate will slide beneath the other, pushing the top plate up. These are ways mountains form. Because Earth's plates move so slowly, it may take thousands to millions of years for mountains to form.



After these layers of sedimentary rock formed, forces caused them to fold. Much later, the plates met and pushed the top layer up, forming this mountain range.

Evidence of Major Events

Rocks and rock layers can provide evidence of other major events that change Earth’s surface. Consider this evidence from the rock layers.

Evidence of Causes for Dinosaur Extinction		
Dinosaur fossils have not been found in rock layers that are younger than 65 million years old. The size and different types of fossils from this period drop sharply as well. This evidence tells scientists approximately when the dinosaurs died.	A huge crater is discovered in rock layers in Mexico. This evidence supports the idea that a large asteroid struck Earth. The impact caused shockwaves, fires, large waves, and climate change that made it difficult to live on Earth.	Iridium, a rare element, is found in abundance in layers of Earth’s rocks from around the same time as the extinction. It is more common in meteorites than in Earth’s rocks. The iridium layer is evidence that a large meteorite struck Earth 65 million years ago.

Evidence from the rock layers shows that most large animals on Earth died off in a short period, that a large asteroid struck Earth around the same time, and that dust from the impact was thrown into the atmosphere. All three pieces of evidence lead scientists to propose that a large asteroid struck Earth around 65 million years ago, resulting in the extinction of dinosaurs.



What do you think happened to life on Earth immediately after this crater was created by an asteroid?

Earthquakes

Chapter

3

On the top floor of an office building, workers suddenly feel shaking. The shaking lasts a few seconds and then stops. The workers ask each other, “What *was* that?”

A hundred miles away, a gardener finds himself on the ground. The tremors had been strong enough to knock him down. He even saw his lawn roll like waves. He looks over at the road and sees large cracks.

All of these effects are the result of an **earthquake**—sudden shaking of the ground that usually occurs at or near places where the plates of Earth’s crust meet. Communities near these sites are more likely to experience earthquakes than communities far away.

Big Question

Why are some communities more likely to experience an earthquake than others?

Vocabulary

earthquake, n.
shaking of the ground caused by a seismic wave

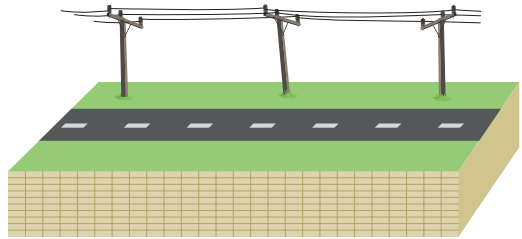


An earthquake can shake, rock, and shatter things on Earth’s surface.

Moving Plates Cause Earthquakes

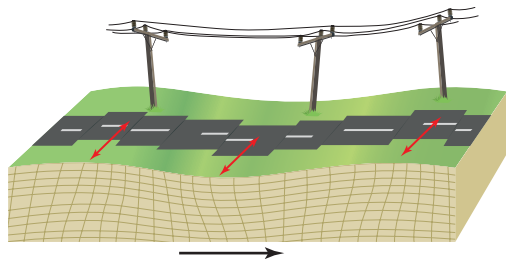
Plate movements cause earthquakes. When the plates push against each other, pressure builds up. Over time, one plate can suddenly slip over, under, or alongside the other plate. These interactions can involve so much friction that the plate edges that are in contact become stuck. While the plates keep moving, the edges buckle and bend. The rocks store up the immense amounts of energy required to push the plates. Stress builds up in them. Eventually, the stress is too much for the plates to bear, and they suddenly move! One or both plate edges may move several or even dozens of meters in the span of seconds. The energy waves that are released are known as seismic waves.

Before the earthquake, the ground is flat, the road is intact, and the power lines are tight.

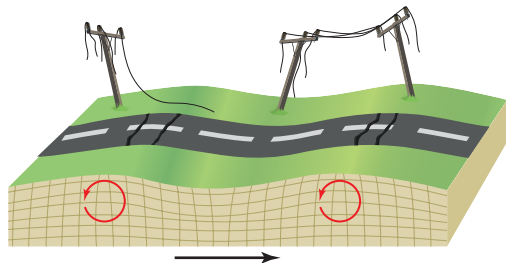


As the seismic waves move through the earth, the ground can move in different ways. The ground can

- expand and contract in the same direction as the wave.
- move up and down.
- move back and forth across the direction of the wave.
- move in a circular motion.



Notice the type of damage caused when the ground moves back and forth across the direction of the wave.



Notice the type of damage caused when the ground moves in a circular motion.

The map here shows the locations of nearly one thousand earthquakes. Notice how the circles that mark the earthquakes are mostly along the gray lines. The gray lines mark boundaries between plates. Earthquakes along these boundaries are caused by plate movements. People who live near these areas experience more earthquakes than people who live elsewhere. There is also significant volcanic activity along these plate boundaries.



In which areas would people experience effects of earthquakes? Which areas would have earthquakes that would not immediately impact people?

Surface Effects of Earthquakes

How an earthquake affects Earth's surface depends on the size of the seismic waves, what the ground is made of, and what is on the surface. In some places, the ground can be made up of loose or water-saturated soil. When seismic waves pass through it during an earthquake, anything that is in or on top of soil could sink or topple over. Firmer ground shakes less, but it can move up or down relative to its original position. This can cause a lot of damage to any structures built over that area.



When a powerful earthquake struck the San Francisco area in October 1989, much of the worst damage occurred in areas such as the Marina District, which was built on loose soil.

Earthquakes can also loosen rocks and sediment from slopes. When this happens, landslides can occur. Landslides can damage or destroy both natural and human-made structures. Communities where there are many hills or mountains and where it rains a lot are more likely to experience landslides than communities where the land is mostly flat.



When landslides occur in areas where many people live, there can be much damage to human-made structures.

Measuring and Detecting Earthquakes

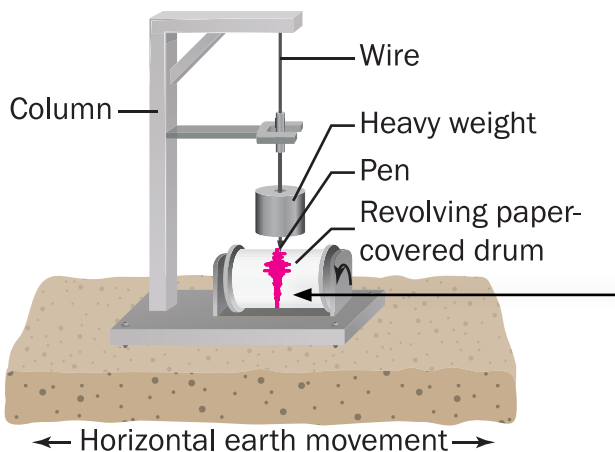
Earthquakes are detected and measured by tools called seismographs. These tools, also known as seismometers, convert the vibrations caused by seismic waves into lines that look like a graph. The greater the peaks, the stronger the earthquake.

Seismic waves can travel across Earth's surface and through Earth's mantle and crust. And seismometers can detect earthquakes that are thousands of miles away. Seismologists study the readings from seismographs and work together to help communities prepare for danger in their areas.

Geologists measure earthquake strength on a scale of **magnitude**. The scale is based on how much energy the earthquake releases and the size of the seismic waves. A magnitude-3 earthquake generates waves ten times larger than a magnitude-2 earthquake.

Vocabulary

magnitude, n. the size or extent of an earthquake



When parts of Earth move, a pen leaves a mark on the paper beneath it recording the motion.



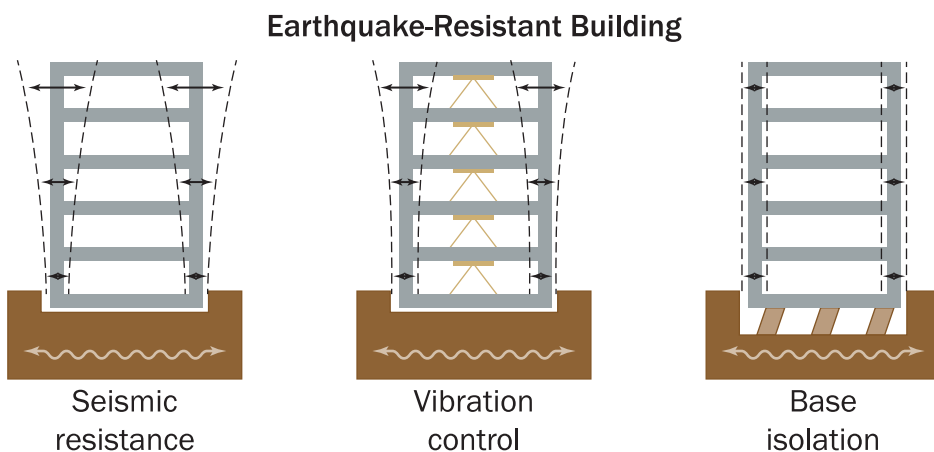
This seismogram is from the devastating 2011 earthquake that struck Japan.

Living with Earthquakes

In Japan, earthquakes are common. They have caused much damage. The construction industry there has developed new designs to make buildings more resistant to seismic waves. There are many criteria and constraints the industry had to consider. Criteria are the things the solution must do or have. Constraints are the things that limit possible solutions.

Having alarm systems that provide notice of an earthquake before its waves strike is one way of coping with earthquakes. Another is to avoid building in areas where the ground is vulnerable to landslides.

When an earthquake occurs, you should take shelter under a table or desk. If there is neither of these, take shelter along an interior wall. Remain on your knees, and bend over. If possible, cover your head, neck, and back. If possible, hold onto something sturdy until the shaking stops.



Buildings can be resistant to earthquakes if they are made of strong materials that vibrate without breaking. Braces can transmit the vibrations more evenly throughout the building. Small structures at the building's base can wobble or roll without transferring much motion to the rest of the building.

Tsunamis

Chapter

4

A fishing boat heads into the Indian Ocean. The captain listens to a report on the radio: *A powerful earthquake, magnitude-9.0, has been detected in Indonesia.* The captain thinks, “That’s a very strong earthquake, but it’s a thousand miles from here.” Two hours later, he feels the boat rise. An unusually broad wave has just passed beneath the boat. He watches the wave grow taller as it approaches shore. It becomes a wall of water that crashes onto the shore, flooding the nearest town.

The captain has witnessed a **tsunami**—a wave or series of waves produced by a large displacement of water. This means water was forced out of place. Displacement can be caused by the seafloor lifting up or dropping down. Earthquakes can cause tsunamis, too.

Big Question

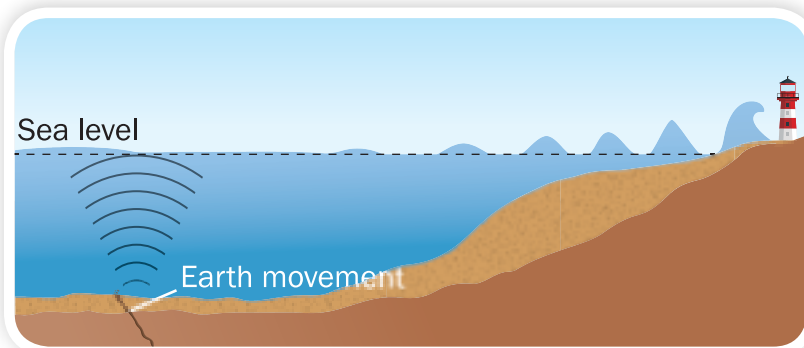
How can communities better protect themselves from tsunamis?

Vocabulary

tsunami, n. a wave or series of waves caused by displaced water

Word to Know

To *displace* something means to move into its space and push it out of position.



As the seafloor slopes upward nearer the coastline, displaced water is forced higher, forming a massive wall of water.

The Size and Scale of Tsunamis

Tsunamis can cause damage and change Earth's surface over a very wide area. This is because a tsunami can travel thousands of miles and spread across an entire ocean.

This is what happened in 2004. The tsunami began just off the coast of Sumatra, a large island in Indonesia. It happened when an earthquake caused a huge area of the seafloor to rise up by several meters, displacing all the ocean water above it. The tsunami waves struck Indonesia first and then nearby nations such as Thailand and Sri Lanka. Hours later, the waves reached Africa and Australia. Waves continued to travel, reflect, and bounce around the Indian Ocean and beyond for more than a full day. In the open ocean, the tsunami was only about half a meter high, very broad, and very fast—about as fast as a jet airliner. Near the shore, the tsunami slowed and grew to heights of about one-hundred feet!



This before-and-after picture shows the effects of a tsunami. What structures are still standing after the tsunami?

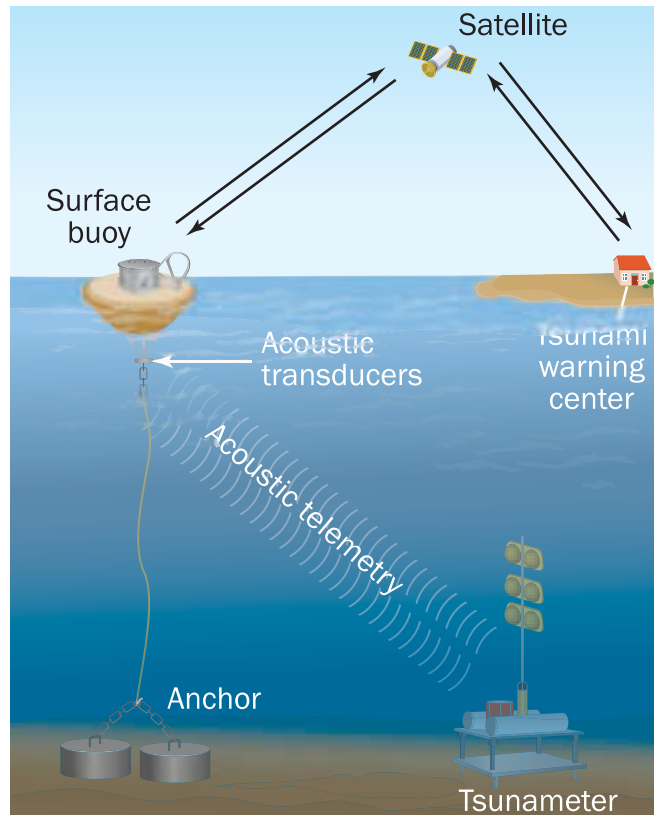
Tsunami History

The term *tsunami* is Japanese for “harbor wave.” Japan has had many tsunamis because it is close to where several of Earth’s plates meet. This is where the majority of tsunamis occur.

Japan has records of large waves that struck coastal areas dating back more than 1,500 years. Tsunamis were common enough that people took the time to carve warnings into stone tablets and plant them as markers on coastal hillsides.

This suggests that earthquakes and tsunamis occur somewhat regularly and should be expected in areas that have experienced them before.

Today, countries with coastal areas vulnerable to tsunamis use special buoys in the ocean to detect the rise and fall of water waves. These warn scientists when a potential tsunami is headed to shore. These devices are called tsunameters. Tsunami warnings may also be issued when an earthquake strikes.

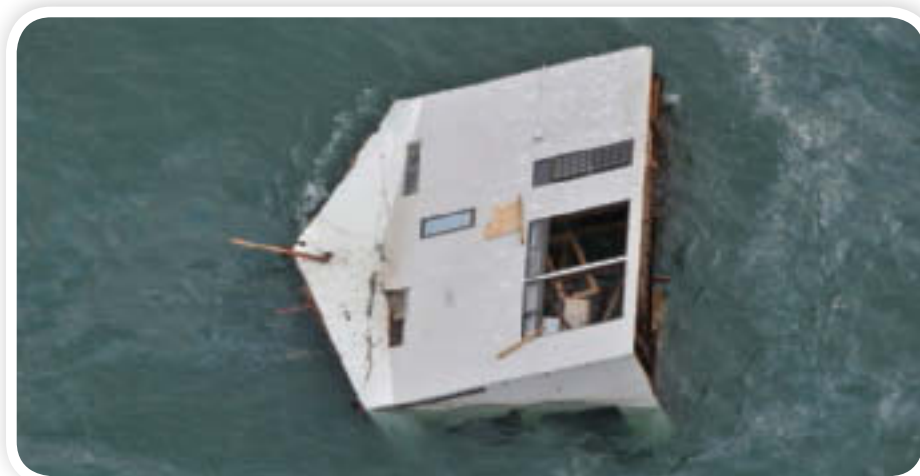


Tsunameters can be found all over the ocean floor. Acoustic transducers on the buoy send signals to the tsunameter, which sends information to a satellite, which sends the information to a warning center. This helps give warnings about earthquakes at sea that can cause tsunamis.

Tsunami Effects

Tsunamis can cause damage both directly and indirectly. The wall of water that rushes onto shore can harm animals, topple trees and buildings, and cause extensive damage to the land. The flood of salt water can spoil the soil and kill plants. A tsunami can also damage facilities or structures that people depend on. This is how tsunamis inflict terrible damage, including beyond the loss of life.

The electricity that Fukushima used was generated by a nuclear power plant. The electricity that kept the reactors going was generated downhill from the plant, near the water. When the March 11, 2011 earthquake struck and caused a tsunami, a wave as tall as a five-story building destroyed the backup generators that helped keep the reactors cool. Workers tried other ways of cooling the reactors, but within several days, the reactors suffered meltdowns. They exploded and released dangerous radiation into the environment. This caused extensive damage to the area that made it unsafe for people to go near the plant afterward.



A photo shot from a U.S. Navy helicopter shows a home adrift at sea after the 2011 tsunami that struck Japan. Debris was drawn out to sea as the waves receded. Some debris drifted all the way to California and Oregon.

Tsunami Preparedness

What can communities do to better prepare for tsunamis?

Communities build seawalls and have warning systems to help them prepare. Seawalls can absorb some of the force of tsunami waves. These can also help prevent the flood from overwhelming the shore. But the 2011 tsunami showed that seawalls can do only so much unless they are high enough and strong enough to block the flood. Communities can avoid some harm by not building too much in areas most vulnerable to tsunamis.



The 2011 tsunami proved too large, even for ten-meter seawalls built around coastal harbors.

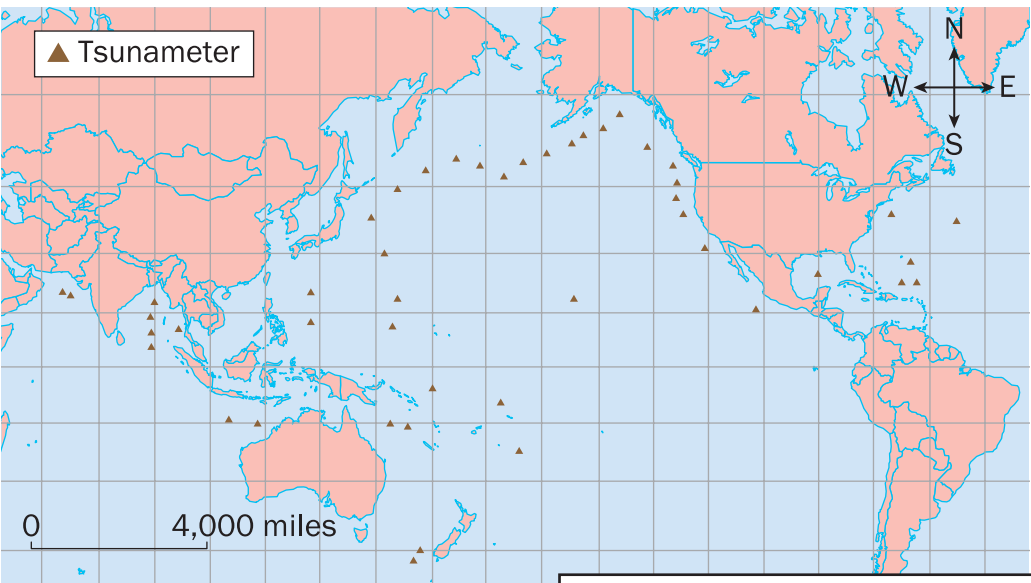
Leaving natural barriers in place can reduce some of the impact of a tsunami. Coastal wetlands can act as a buffer that absorbs some of the force of the waves and slows the flood. Mangrove forests in areas affected by the 2004 tsunami suffered less damage than nearby areas that had lost their mangroves. Mangroves and wetland grasses can also hold onto sediment and soil better than an exposed beach or developed shoreline.



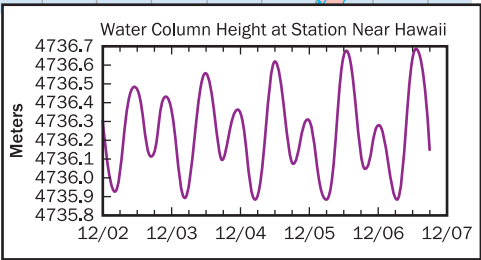
These mangroves will grow into a forest that may protect the coast from tsunami waves in the future.

Tsunameters are anchored at different points in the ocean. They are part of a network that helps coastal areas receive warnings of tsunamis. The map shows where tsunameters are located.

If a large wave passes under a tsunameter, the wave’s height is measured and sent via satellite signal to the network of scientists that record these data. A tsunami warning can be automatically sent out, giving people who live at or near sea level some time to flee to higher ground. Boat captains who may be in shallow water can also receive the warning and head out to deeper waters, where the tsunami will not be as tall or dangerous. Tsunami warnings can also be triggered by earthquakes alone, because earthquakes are so often the first step in producing a tsunami.



Sea level is measured and graphed based on data sent by the tsunameter near Hawaii. The peaks are the high tides, and the valleys are the low tides. Note that the sea level swings by about one meter with the tides and that these swings take hours to occur.



Volcanoes

Chapter

5

Near a chain of volcanic islands in the Pacific Ocean, the ocean boils and froths. Gases explode into the air, along with fragments of lava that have been cooled and hardened by contact with the air and seawater. This is the birth of a **volcano**. For several days, the volcano erupts at the surface of the sea, forming an island of solid igneous rock. One week later the eruption has stopped. As time passes, organisms eventually settle on the island, and over decades, a forest grows. Then, seemingly out of nowhere, the volcano erupts again. Mauna Loa, a volcano on Big Island, Hawaii, has erupted thirty-three times since 1843. These eruptions are constantly changing the landscape of the island.

Big Question

Can scientists predict when a volcano is going to erupt?

Vocabulary

volcano, n. an opening in Earth's crust through which lava erupts onto the surface



A volcano releases lava, ash, and gases onto Earth's surface.

This is how a new volcanic island can form and change over time. It's a process that has occurred thousands of times in Earth's history. The same process can produce volcanoes on continents, when lava emerges on land.

Volcano Hazards

When a volcano first appears, it may not pose any hazard to people if it happens far from where people live. But volcanic activity can be extremely hazardous. Some of the world's most dangerous natural disasters have been volcanic eruptions.

The explosion of Krakatau, a volcanic island in Indonesia, in August 1883 could be felt thousands of miles away. A huge portion of the island exploded into the air. It sent a shower of debris into the ocean. This produced tsunami waves that swept away over 150 villages. The sound of the explosion was so loud that it was heard 2,200 miles away in Australia. Ash from the eruption reached fifty miles into the atmosphere. Not only did the eruption change Earth's surface, it even changed the climate. There was so much ash and volcanic gas released that Earth's surface was cooler by two degrees Fahrenheit for several years. This volcanic eruption was a global event that affected everyone on Earth.



The 1883 explosion of Krakatau was a major disaster that devastated that part of Indonesia and affected the entire world. Today, another volcano is rising in its place.

Ways Volcanoes Erupt

Not all volcanoes erupt explosively.

Magma is the term for **lava** before it reaches Earth's surface. Before it reaches the surface, magma can slowly accumulate in a chamber deep inside the volcano. Depending on the way the magma produces gases under pressure, the volcano may explode with force or erupt more quietly. Quieter volcanoes include those of the Hawaiian Islands.

Vocabulary

magma, n. molten material from Earth's mantle below Earth's surface

lava, n. molten material from Earth's mantle after it has reached Earth's surface

When a volcano with a large magma chamber explodes in a violent eruption, the chamber can empty so quickly and forcefully that the volcanic rock above it collapses. This fills the chamber



Crater Lake in Oregon is the water-filled remainder of a volcano that exploded about 7,700 years ago. The release of magma and gas from the chamber caused the rock above to collapse down into the void. Over time, it filled with water.

and forms a crater on the surface. If the volcano is at sea level, the crater can become part of the ocean's seafloor. If the volcano is on land, the crater might eventually fill with water and become a lake.

Volcanoes and Plate Boundaries

When scientists mapped the location of all the known volcanoes on Earth, they found a pattern. Most volcanoes are located where Earth's plates meet. Remember that Earth's crust is made up of large plates. Where these plates meet, they sometimes push over or under each other. This leads to both earthquakes and volcanic activity.

Earth's largest plate is known as the Pacific plate. It sits beneath the Pacific Ocean. All around the Pacific plate, where it meets other plates, are many volcanoes. There are so many volcanoes that the pattern they form is called the Ring of Fire. There are around 500 active volcanoes in the world. Over 450 of these can be found along the Ring of Fire. Krakatau was one volcano along the Ring of Fire. Others can be found in Alaska, Oregon, and Washington in the United States.



Notice how the pattern of volcanoes is similar to the pattern of earthquakes shown on page 15.

Hot Spots

Scientists studying the islands of Hawaii noticed something. Each island was formed by volcanic activity under the sea. They also noticed that these islands are not located near plate boundaries. What they found instead was that the islands in the state are still forming as the volcanoes there erupt. Because Kauai is the oldest and Hawaii is the youngest, geologists have determined that the Pacific plate is moving over a **hot spot**.

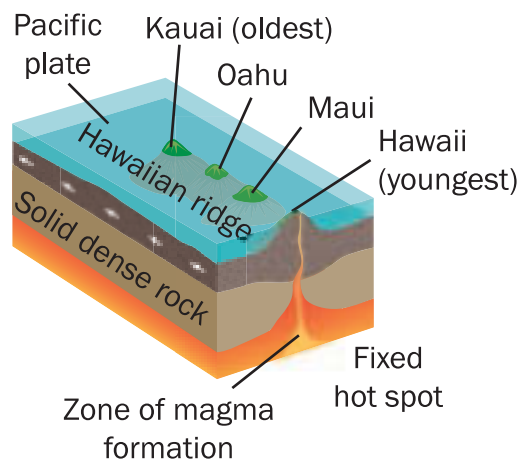
A plume of magma can form in one spot under Earth's crust if enough heat and material in Earth's mantle happens to be rising there. Geologists call this a hot spot. The plume pierces Earth's crust and produces a volcano on the surface. As the plate moves over time but the plume does not, the volcanic activity produces a chain of volcanoes. This is how the Hawaiian Islands and the seamounts near the islands formed. The volcanoes to the northwest of the hot spot are older and more weathered and eroded. The younger volcanoes, including those on Big Island, are less weathered and larger.

Vocabulary

hot spot, n. in geology, a plume of magma that causes eruptions through Earth's crust without plates interacting

Word to Know

A seamount is a mountain on the ocean floor made from volcanic activity.



As the Pacific plate moved over the hot spot, the islands and seamounts of Hawaii were formed. The island of Hawaii is still over the hot spot and still erupting and growing.

Predicting Eruptions

The oldest volcano on Big Island is Kohala. The volcano is around one million years old. Scientists are fairly certain that Kohala will not erupt again. They believe it is now extinct because the movement of the plate has shifted that portion of Big Island away from the hot spot. Kohala last erupted around 120,000 years ago.

Often, scientists can predict when volcanoes are going to erupt. Communities around Kohala have little to fear. But communities around Mauna Loa have more to worry about because Mauna Loa is still an active volcano. The first step in predicting volcano hazards is identifying the volcanoes, hot spots, and plate boundaries in an area. For that, you can use a map and historical records. If there is a volcano in the area, it is important to know whether it is active, dormant, or extinct.



How does this orange magma change as it cools?

An active volcano is one that has erupted recently and is likely to erupt again. An extinct volcano is one that has not erupted in a very long time and is unlikely to erupt ever again. A dormant volcano is in between: it hasn't erupted in a while, but it could erupt again.

Active volcanoes can be monitored in different ways. Devices called tiltmeters can be set up on the volcano's surface. Tiltmeters sense when the surface is tilting more or less than it was the moment before. If tiltmeters suggest that a volcano's slopes are getting more tilted, this can mean the chamber inside is swelling with magma. This could be a sign that an eruption is going to occur soon.



Tiltmeters are devices that scientists use to measure how a volcano moves. This helps them predict when a volcano might erupt.

If the volcano is releasing particular kinds of gases, devices called spectrometers can analyze that air. If the air above a volcanic vent has more sulfur dioxide than it did a week before, this can be a sign that gas and magma are building up in the chamber.

The buildup of pressure in a volcano can produce earthquakes as the volcano expands. Seismometers can detect these earthquakes. If a pattern of seismic activity is observed, this could be another sign that an eruption is near.

As with tsunamis and earthquakes, volcanic eruptions cannot be stopped. The Earth processes that cause eruptions are too big for humans to control. Yet, communities can prepare for when an eruption occurs.

People in places such as Hawaii are encouraged to listen for alerts and to follow evacuation orders or take shelter in an appropriate place. They are also encouraged to avoid areas near eruptions. They need to protect themselves from falling ash and should not drive if there is heavy ashfall.



A spectrometer allows geologists to measure the amount of sulfur dioxide in gas plumes released from Kilauea, an active volcano in Hawaii.

Erosion

Chapter

6

A family in a truck pulls onto a dirt road, heading home. Gravel kicks away from the tires as the truck climbs the steep slope. They arrive at their front yard and notice that rain water has caused ruts to form in the earthen driveway.

These changes to the land are examples of **erosion**. Erosion is a process that carries **sediment**, or the pieces of dirt and rock that have broken down over time, away from a location. Erosion is one of the processes that changes Earth continually.

Big Question

How do communities protect themselves from erosion?

Vocabulary

erosion, n. movement of sediment from one location to another

sediment, n. small pieces of rock or other hard material that has broken down over time



When erosion has carried away enough sediment gradually, more sudden movements can occur.

Slow Erosion Can Be Hazardous

Think of an oceanfront property sitting on a sand dune or cliff above the sea. The soil and sediment that hold up the home are likely to erode over time. This erosion occurs slowly due to different forces. The wind blows, ocean waves carry away bits of sediments, and even animal activity can move the sediment small pieces at a time. The point at which this movement of sediment becomes hazardous might be hard to identify. But if the process of erosion continues, that home can become vulnerable to falling into the ocean. The overall process is slow, but the danger is real.

The slow creep of a sloped yard can turn into a hazard. Over time, soil is pulled downhill by gravity. If not stopped, it can slide onto walking paths, making them dangerous.



This edge of the cliff is wearing away and the building is getting closer to falling into the sea because the sedimentary rock it is built on is eroding.



A retaining wall helps prevent soil from eroding away.

Word to Know

Creep is a word people often use to refer to the slow process of erosion.

Causes of Erosion

Water is one of the more dangerous agents of erosion. Soil that becomes saturated can collapse in a mudslide. Quickly flowing water brought on by a flood or strong storm can also erode tremendous amounts of sediment quickly.



Flowing water, such as the riverlike flood shown in this desert terrain, can cause a lot of erosion.

Living organisms can also be agents of erosion. Animals that burrow move sediment out of their way as they dig. Animals also cause erosion by climbing up hillsides, herding across plains, or building nests in riverbeds. Plants can cause weathering, but they are more likely to prevent erosion. For example, beach grasses and shrubs help sand dunes keep their shape. Plants are often a reliable way of holding soil in place.

Erosion from Weathering

Weathering occurs when rock breaks into smaller pieces—sediment. Erosion occurs when sediment moves from one location to another. Weathering occurs in different ways.

Vocabulary

weathering, n. the process of breaking rock into smaller pieces



These layers of rock were once part of the seafloor. Sediment was deposited slowly, becoming layers of sedimentary rock long ago. They are now exposed on the seashore, where fossil hunters can pick through them.

A large rock at the top of a mountain can tumble and break into smaller fragments as gravity pulls it downhill. Cracks in rock can fill with rainwater or snowmelt. If the water freezes, it expands, breaking the rock even more. Over time, this freeze-thaw cycle can break down large rocks into smaller pieces. As the pieces are knocked together, they continue to break down.

Weathering produces the sediment that can be eroded. Eventually, the force that eroded the sediment weakens or stops, and the sediment comes to rest in a new location.

Chemical Weathering

A **sinkhole** is an example of erosion that happens beneath the ground and cannot always be seen. Some areas, such as the state of Florida, are made up largely of limestone. Limestone is a sedimentary rock formed from the ancient remains of marine organisms. It can be weathered by water that is slightly acidic. This is a form of chemical weathering. The limestone breaks down into small pieces, which can then be carried away, or eroded, by the water. If a small space in the limestone is continually weathered by acidic water and the water continues to erode the sediment, the space can get larger and become a cave. If the cave happens to be below a house, the roof of the cave can collapse, and the house will fall into the sinkhole. This destroys the house and threatens the lives of anyone inside.

Vocabulary

sinkhole, n. a hole in Earth's surface that develops when the ground collapses into space beneath it



Collapsed sinkholes that flood with water can become beautiful sites for scuba diving. On the surface, however, they can be extremely destructive to homes and other things that happen to be built above them.

Erosion Hazards

Some erosion and erosion hazards can be prevented simply by leaving landscapes alone and not having human activities such as construction in those areas. When a steep coastal hillside is carved up to build a scenic highway, this can lead to more erosion because the sediment is disturbed and slopes might be steeper than they were before. This puts people in harm's way because erosion was already happening there even before any construction and now it is likely worse. Instead of building the scenic coastal highway, it might make more sense to build the highway farther inland on flatter terrain.

Highway 1 stretches along most of California's coast. Many people drive along the highway to take in some of California's most famous landmarks and to see the Pacific Ocean. But Highway 1 is threatened by erosion. Wildfires can strip the area of vegetation. Heavy rains can seep into the dirt, turning it into mud. When this happens, erosion of the soil can occur. There have been times when this erosion has even destroyed parts of the highway.



California's Highway 1 is a scenic, convenient roadway. But it is hazardous because it is built into a steep slope of sediment and rock. Erosion can weaken a section of the highway threatening the road itself.

California has taken steps to help prevent erosion of its coastline from occurring. One of these steps is to plant different species of vegetation along the coast. The species that are selected have roots that grow deep into the soil. This helps hold the soil together. Other communities work to prevent erosion by building walls or terraces, or they divert water drainage.



One way to avoid having a house collapse as the hillside is eroded is to lay down plastic that minimizes erosion.

If living or construction in a community with erosion hazards cannot be avoided, engineering can help minimize or prevent erosion. For example, if people inhabit a small area that is hilly and vulnerable to erosion, hillsides can be reinforced with netting, plants, walls, or other materials.



Surveying and Marking the Land

Erosion hazards can be better avoided if people are aware of them.

Geologists can survey risky sites to assess whether the chance of hazardous erosion is changing.

Weather conditions or simply the advance of the

slow process that has been underway for years can both be factors to watch. Imagine a home on a cliff above a beach. The beach has been eroding for years, wearing the cliff below the house away. Geologists can help figure out how long before the house will tumble down the eroding cliff. If that point

is near, it might be time for the home to be abandoned or moved to a new location. People must assess the costs and benefits and figure out when the hazards posed by erosion are too much to overcome.



Signs can warn people about erosion hazards.

Word to Know

A *survey* is a procedure of study used to examine and measure features of an area of land.



Should the parking lot be rebuilt, or is the erosion going to continue to eat away at this area?

Landslides

Chapter

7

The Lituya Bay, Alaska, tsunami of 1958 began with a magnitude-7.9 earthquake. The earthquake caused a landslide. Some thirty million cubic meters of rock slid into the bay. This displaced a huge volume of water. The tsunami, a third of a mile high, crashed up onto the slope at the head of the bay. The tsunami swept away thousands of trees.



The lighter sections on either side of the bay are the areas where the tsunami washed the plants away.

Big Question

How can communities prepare for landslide hazards?

Vocabulary

landslide, n. a form of mass movement in which a large section of a slope slides downhill all at once

mass movement, n. downhill movement of a mass of earth surface material

A rockslide is a type of **landslide**. A landslide is a form of **mass movement**, which is a downhill movement of sediment and other earth materials as one mass. Unlike a mudslide, a landslide involves relatively dry material, such as sand, rocky sediment, larger rocks, or dry soil. A landslide occurs in a matter of moments. It is usually triggered by an earthquake or extreme weather. Because a lot of heavy, hard material moves all at once, landslides can be extremely hazardous.

What Causes Landslides?

There are many causes for landslides. On the previous page, you learned how an earthquake triggered a landslide and a tsunami. But there are other major causes as well. In 1980, a volcano in the state of Washington erupted. Mount St. Helens, as it was called, is part of the Cascade Mountain Range. It exists along the Ring of Fire, a line of volcanoes that are located where Earth's largest plate, the Pacific plate, meets other plates. When the volcano erupted, the side of the volcano collapsed. This displaced 2.8 cubic kilometers (or two-thirds of a cubic mile) of dirt, rock, and other debris on its north side.



When Mount St. Helens erupted in 1980, it caused a massive landslide on one side. Where that landslide occurred, the wall of the volcanic crater is now gone.

There were many smaller communities around the volcano. Most of these cleared out before it erupted and the landslide occurred. That's because the eruption was preceded by two months of smaller seismic activity. Remember that *seismic activity* is another term for earthquakes. When there are movements in Earth's crust, seismic waves are sent out. There are many ways for scientists to detect seismic waves and earthquakes. Because of this, it is also possible to predict approximately when a volcanic eruption and any landslide associated with it might occur.

Because scientists could tell that Mount St. Helens was about to erupt, they were able to issue warnings. They told the people and communities around the volcano to evacuate. Most people did. Still, between the earthquakes, the eruption itself, and the massive landslide that followed, much property was destroyed. Many organisms were also killed by the natural hazard.



The landslide caused by the eruption of Mount St. Helens buried miles of forest and surrounding property in dirt, rock, debris, and ash.

Gravity can cause landslides by pulling down on dirt, rock, and debris on a slope. Water can also contribute to landslides. It can get into rock and freeze. Over time, this can cause the rock to break apart and erode, leading to a landslide. Where there is little vegetation, water can cause the ground to turn muddy. If on a slope, it can then become a type of landslide called a mudslide.

In December 2017, a large fire destroyed dry vegetation around Montecito, California. Called the Thomas Fire, the fire quickly spread over 282,000 acres of land. When the fire was over, California experienced much rainfall. Most of this land was made up of hills. With little vegetation holding the ground together, the land on the slopes became muddy. Because it sat on a foundation of rock, the mud soon began to move and slide. This mud also carried large rocks and boulders with it. These presented a danger to people in the area. Homes and other property were destroyed in the mudslides.



These landslides damaged both natural objects and human-made structures.

Evidence for Future Landslides and Solutions

Can people predict landslides? Visible evidence of erosion, such as new boulders at the base of a slope, can be a warning sign. Tilting trees or other objects, including poles, can indicate that a slope is about to give way.



Exposed roots in a hillside mean some of the slope has already eroded, possibly in a landslide. Boulders and other fallen debris at the base of a slope are another sign that erosion is occurring and a large-scale landslide may soon occur.

Natural Solutions

One way that some communities have tried to solve the problem of mudslides and landslides is to plant more vegetation. Some types of vegetation have roots that grow deep and strong in the soil, causing the soil to cling together. This makes landslides less likely. But events such as wildfires followed by a heavy rain can clear an area of vegetation and make it more likely that landslides will happen. In some areas, people have built walls or terraces on hills to make landslides less likely.

Human-Made Solutions

Communities that are vulnerable to landslides can reduce some of the hazards they face. A home that is going to be built on a slope can be protected by having a retaining wall above and below the house.



These walls change a steep slope into something more like a staircase. Each level holds a certain amount of sediment.

Another technique is to use concrete and steel pillars to support hillside structures. These pillars can be anchored into solid bedrock so the structures are more likely to stay in place even if the looser sediment tumbles down the slope during a



How would these structures help reduce or prevent landslides?

landslide. The foundation remains anchored to the part of Earth's surface that does not collapse. However, it is possible that the debris flow could crash into the structure and knock it off its secure foundation.

Glossary

E

earthquake, n. shaking of the ground caused by a seismic wave (13)

erosion, n. movement of sediment from one location to another (33)

F

fossil, n. the remains of an organism preserved in rock form (1)

G

geologist, n. a scientist who studies what Earth is made of and how it changes over time (1)

H

hot spot, n. in geology, a plume of magma that causes eruptions through Earth's crust without plates interacting (29)

I

igneous rock, n. rock made of magma or lava that has cooled and hardened (7)

L

landslide, n. a form of mass movement in which a large section of a slope slides downhill all at once (41)

lava, n. molten material from Earth's mantle after it has reached Earth's surface (27)

M

magma, n. molten material from Earth's mantle below Earth's surface (27)

magnitude, n. the size or extent of an earthquake (17)

mass movement, n. downhill movement of a mass of earth surface material (41)

metamorphic rock, n. rock that forms when igneous or sedimentary rock is placed under tremendous heat or pressure (7)

P

plate, n. in geology, a large fragment of Earth's crust and upper mantle (3)

S

sediment, n. small pieces of rock or other hard material that has broken down over time (33)

sedimentary rock, n. rock made of sediment compacted together (6)

sinkhole, n. a hole in Earth's surface that develops when the ground collapses into space beneath it (37)

T

tsunami, n. a wave or series of waves caused by displaced water (19)

V

volcano, n. an opening in Earth's crust through which lava erupts onto the surface (25)

W

weathering, n. the process of breaking rock into smaller pieces (36)



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