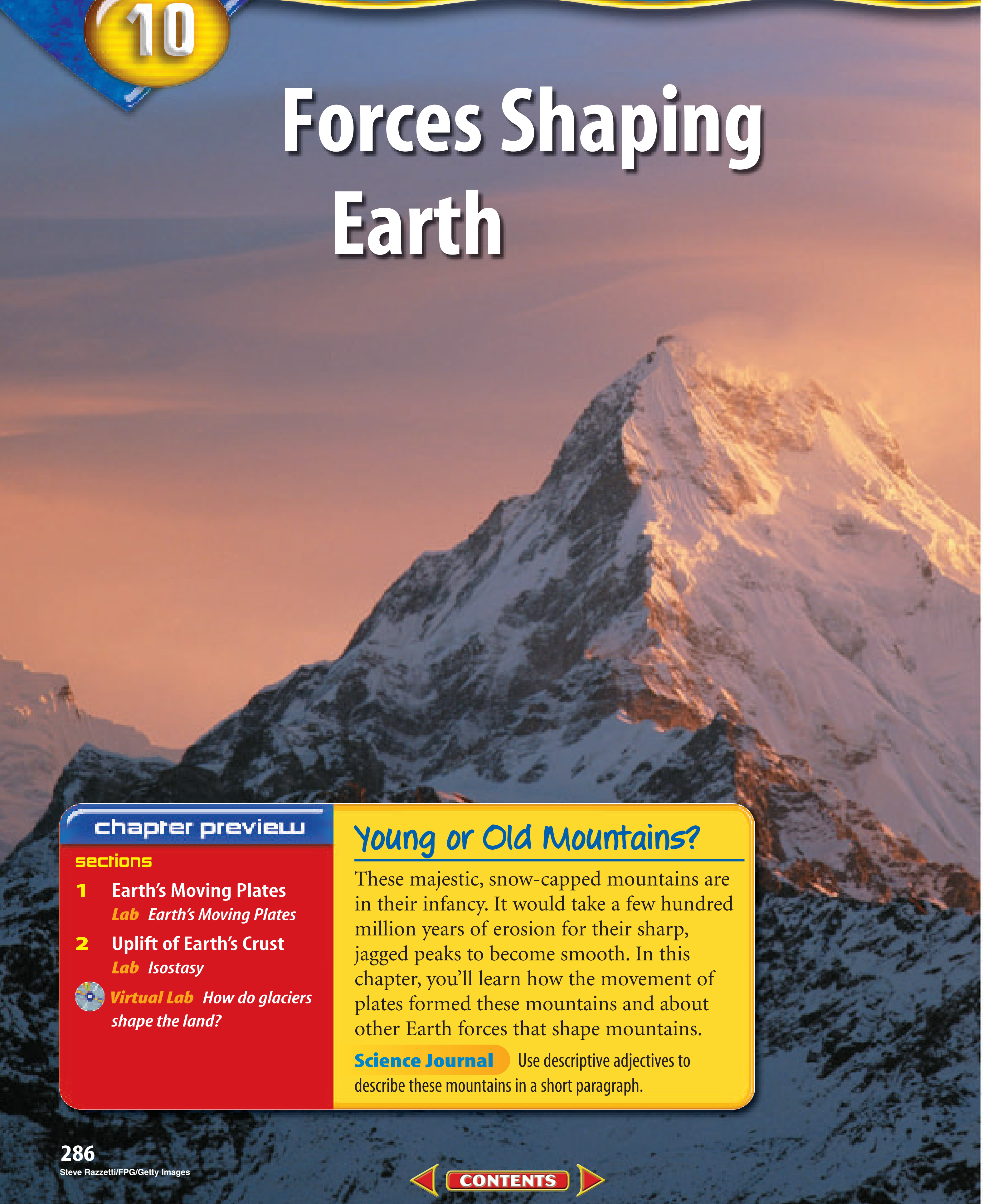
chapter 10

Forces Shaping Earth



chapter preview

sections

Young or Old Mountains?

These majestic, snow-capped mountains are in their infancy. It would take a few hundred million years of erosion for their sharp, jagged peaks to become smooth. In this chapter, you'll learn how the movement of plates formed these mountains and about other Earth forces that shape mountains.

Science Journal Use descriptive adjectives to describe these mountains in a short paragraph.

CONTENTS

Español

Start-Up Activities

Launch LAB

Model Earth's Interior

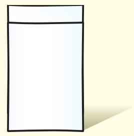
Geologists know many things about the interior of Earth even though its center is over 6,000 km deep. Use modeling clay to make a model of Earth's interior.

1. Obtain four pieces of different-colored clay.
2. Roll one piece of clay into a ball. This clay represents the inner core.
3. Wrap another piece of clay around the first ball of clay, making an even bigger ball. This clay represents the outer core.
4. Repeat step 3 with the third piece of clay, which represents Earth's mantle. Wrap your model with a thin layer of the fourth piece of clay to represent the crust.
5. Use a plastic knife to cut the ball of clay in half.
6. **Think Critically** Make a sketch of your model and label each of Earth's layers.

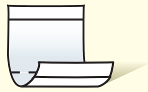
FOLDABLES™ Study Organizer

Earth's Interior and Surface Make the following cause and effect Foldable to help you understand the relationship between Earth's interior and surface.

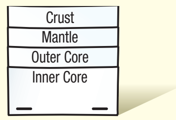
STEP 1 **Collect** 2 sheets of paper and layer them about 2.5 cm apart vertically. Keep the edges level.



STEP 2 **Fold** up the bottom edges of the paper to form 4 equal tabs.



STEP 3 **Fold** the papers and crease well to hold the tabs in place. Staple along the fold. **Label** each tab as shown.



Cause and Effect As you read the chapter, record information about each layer and how it is related to the layer above it under the tabs.

Science Online — Preview this chapter's content and activities at red.msscience.com

Steve Razzetti/FPG/Getty Images

section 1

Earth's Moving Plates

Aaron Horowitz/CORBIS

as you read

What You'll Learn

- **Describe** how Earth's interior is divided into layers.
- **Explain** how plates of Earth's lithosphere move.
- **Discuss** why Earth's plates move.

Why It's Important

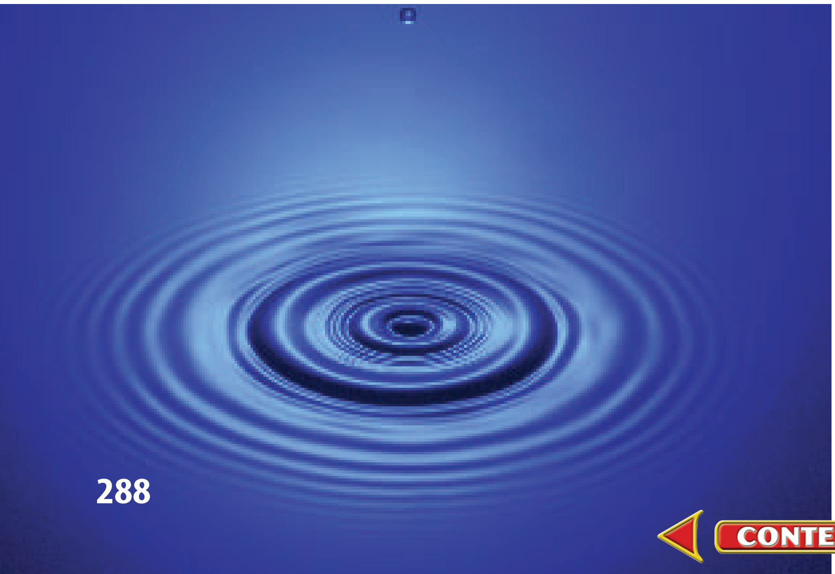
Forces that cause Earth's plates to move apart, together, or past each other cause events that shape Earth's surface, such as mountain building, volcanoes, and earthquakes.

Review Vocabulary
magma: melted rock material found beneath Earth's surface

New Vocabulary

- inner core
- outer core
- mantle
- crust
- lithosphere
- plate
- fault
- subduction

Figure 1 Waves carry energy across water just like seismic waves carry energy through Earth.



Clues to Earth's Interior

If someone gives you a wrapped present, how could you figure out what was in it? You might hold it, shake it gently, or weigh it. You'd look for clues that could help you identify the contents of the box. Even though you can't see what's inside the package, these types of clues can help you figure out what it might be. Because you can't see what's inside, the observations you make are known as indirect observations.

Geologists do the same thing when they try to learn about Earth's interior. Although the best way to find out what's inside Earth might be to dig a tunnel to its center, that isn't possible. The deepest mines in the world only scratch Earth's surface. A tunnel would need to be more than 6,000 km deep to reach the center, so geologists must use indirect observations to gather clues about what Earth's interior is made of and how it is structured. This indirect evidence includes information learned by studying earthquakes and rocks that are exposed at Earth's surface.

INTEGRATE Physics

Waves When you throw a rock into a calm puddle or pond, you observe waves like those shown in **Figure 1.** Waves are disturbances that carry energy through matter or space. When a rock hits water, waves carry some of the rock's kinetic energy, or energy of motion, away from where it hit the water. When an earthquake occurs, as shown in **Figure 2,** energy is carried through objects by waves. The speed of these waves depends on the density and nature of the material they are traveling through. For example, a wave travels faster in solid rock than it does in a liquid. By studying the speed of these waves and the paths they take, geologists uncover clues as to how the planet is put together. In fact, these waves, called seismic waves, speed up in some areas, slow down in other areas, and can be bent or stopped.

Figure 2 As seismic waves travel across Earth's surface, the ground shakes and damage occurs.

Rock Clues Another clue to what's inside Earth comes in the form of certain rocks found in different places on Earth's surface. These rocks are made of material similar to what is thought to exist deep inside Earth. The rocks formed far below the surface. Forces inside Earth pushed them closer to the surface, where they eventually were exposed by erosion. The seismic clues and the rock clues suggest that Earth is made up of layers of different kinds of materials.

Earth's Layers

Based on evidence from earthquake waves and exposed rocks, scientists have produced a model of Earth's interior. The model shows that Earth's interior has at least four distinct layers—the inner core, the outer core, the mantle, and the crust. Earth's structure is similar in some ways to the structure of a peach, shown in **Figure 3.** A peach has a thin skin covering the thick, juicy part that you eat. Under that is a large pit that surrounds a seed.

Inner Core The pit and seed are similar to Earth's core. Earth's core is divided into two distinct parts—one that is liquid and one that is solid. The innermost layer of Earth's interior is the solid **inner core.** This part of the core is dense and composed mostly of solid iron. When seismic waves produced by earthquakes reach this layer they speed up, indicating that the inner core is solid.

Conditions in the inner core are extreme compared to those at the surface. At about 5,000°C, the inner core is the hottest part of Earth. Also, because of the weight of the surrounding rock, the core is under tremendous pressure. Pressure, or the force pushing on an area, increases the deeper you go beneath Earth's surface. Pressure increases because more material is pushing toward Earth's center as a result of gravity. The inner core, at the center of Earth, experiences the greatest amount of pressure.

Figure 3 The structure of Earth can be compared to a peach.
Explain *If the part of Earth that you live on is like the skin of the peach, what does that tell you about this layer of Earth?*

(t)Barry Sweet/AP/Wide World Photos, (b)Mark Burnett

INTEGRATE Chemistry

Iron Core Earth's crust is composed of about five percent iron. However, geologists theorize that Earth's core is composed mostly of iron. Research the theory that Earth's core is composed mostly of iron. Analyze, review, and critique the strengths and weaknesses of this theory using scientific evidence and information.

Outer Core The **outer core** lies above the inner core and is thought to be composed mostly of molten metal. The outer core stops one type of seismic wave and slows down another. Because of this, scientists have concluded that the outer core is a liquid. The location of the outer core is similar to the location of the pit in the peach model. Even the wrinkled surface of the pit resembles the uneven nature of the boundary between Earth's outer core and its mantle as indicated by seismic studies.

Reading Check *What peach layer is similar to the outer core?*

Mantle The layer in Earth's interior above the outer core is the mantle. In the peach model, the mantle would be the juicy part of the peach that you would eat. The **mantle** is the largest layer of Earth's interior. Even though it's solid, the mantle flows slowly, similar to putty.

Crust Earth's outermost layer is the **crust.** In the model of the peach, this layer would be the fuzzy skin of the peach. Earth's crust is thin when compared to the other layers, though its thickness does vary. It is thinnest under the oceans and thickest through the continents. All features on Earth's surface are part of the crust.

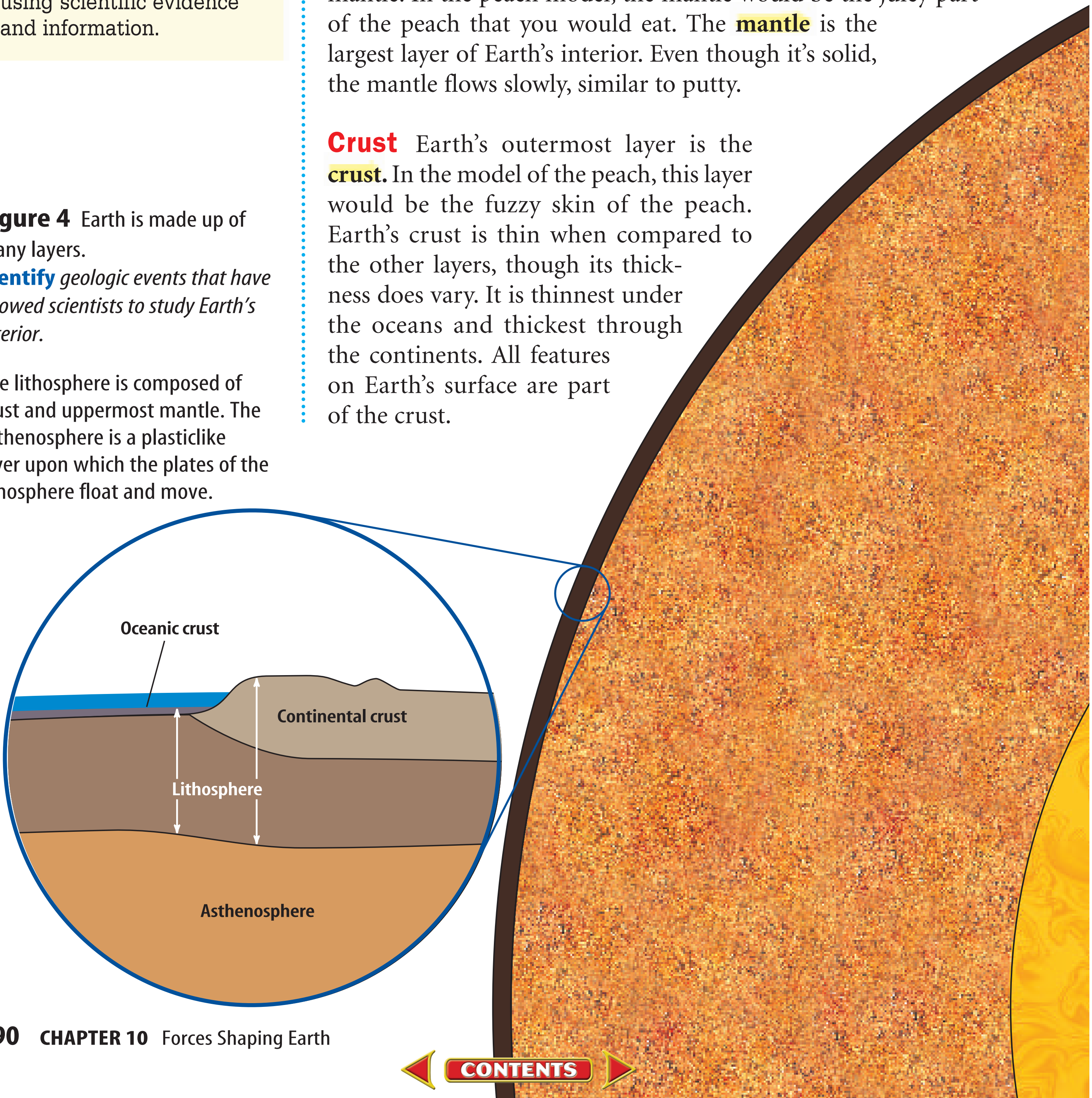
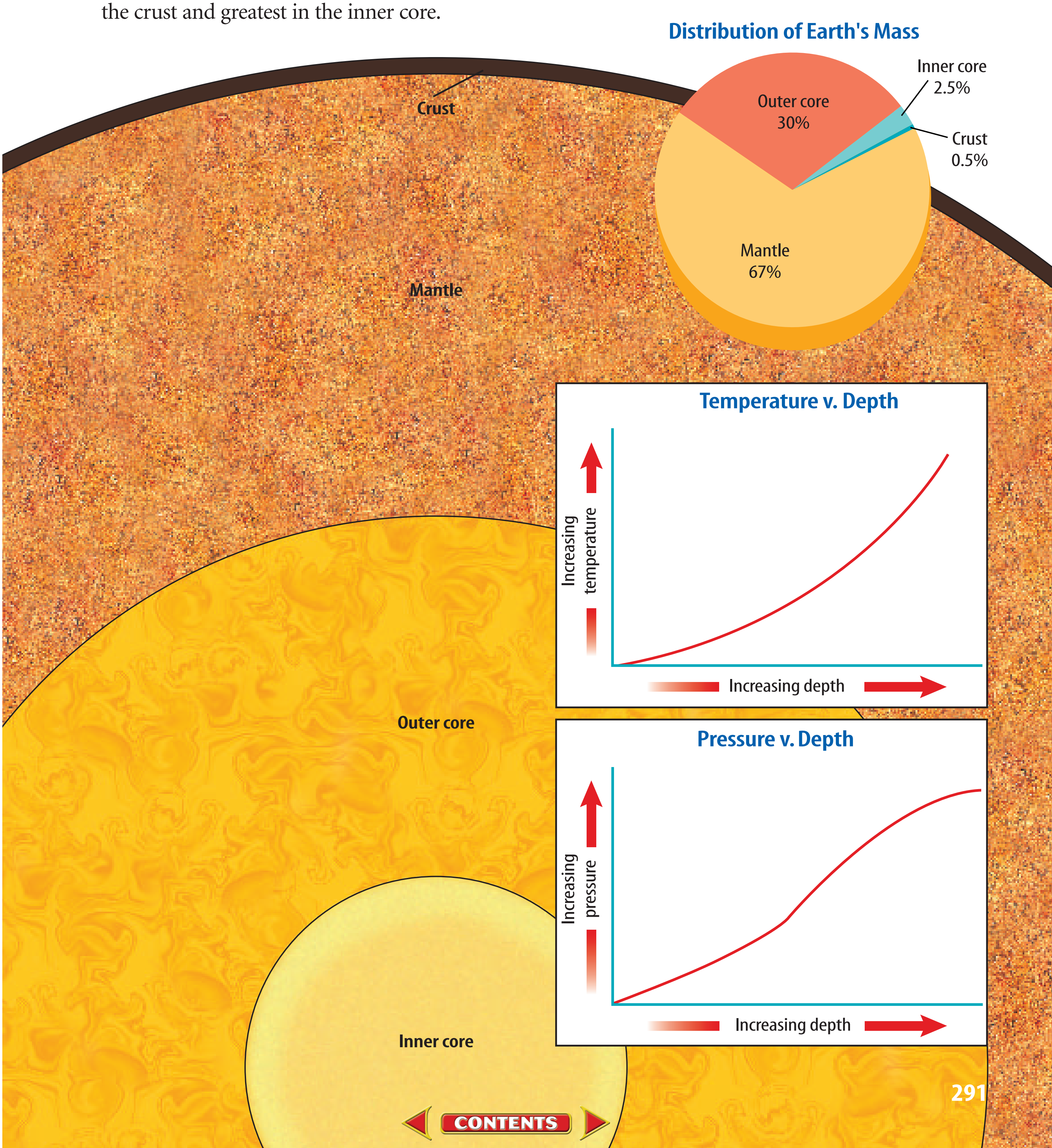


Figure 4 Earth is made up of many layers.
Identify *geologic events that have allowed scientists to study Earth's interior.*

The lithosphere is composed of crust and uppermost mantle. The asthenosphere is a plasticlike layer upon which the plates of the lithosphere float and move.

Earth's Structure

Although Earth's structure can be divided into four basic layers, it also can be divided into other layers based on physical properties that change with depth beneath the surface. **Figure 4** shows the structure of Earth and describes some of the properties of its layers. Density, temperature, and pressure are properties that are lowest in the crust and greatest in the inner core.



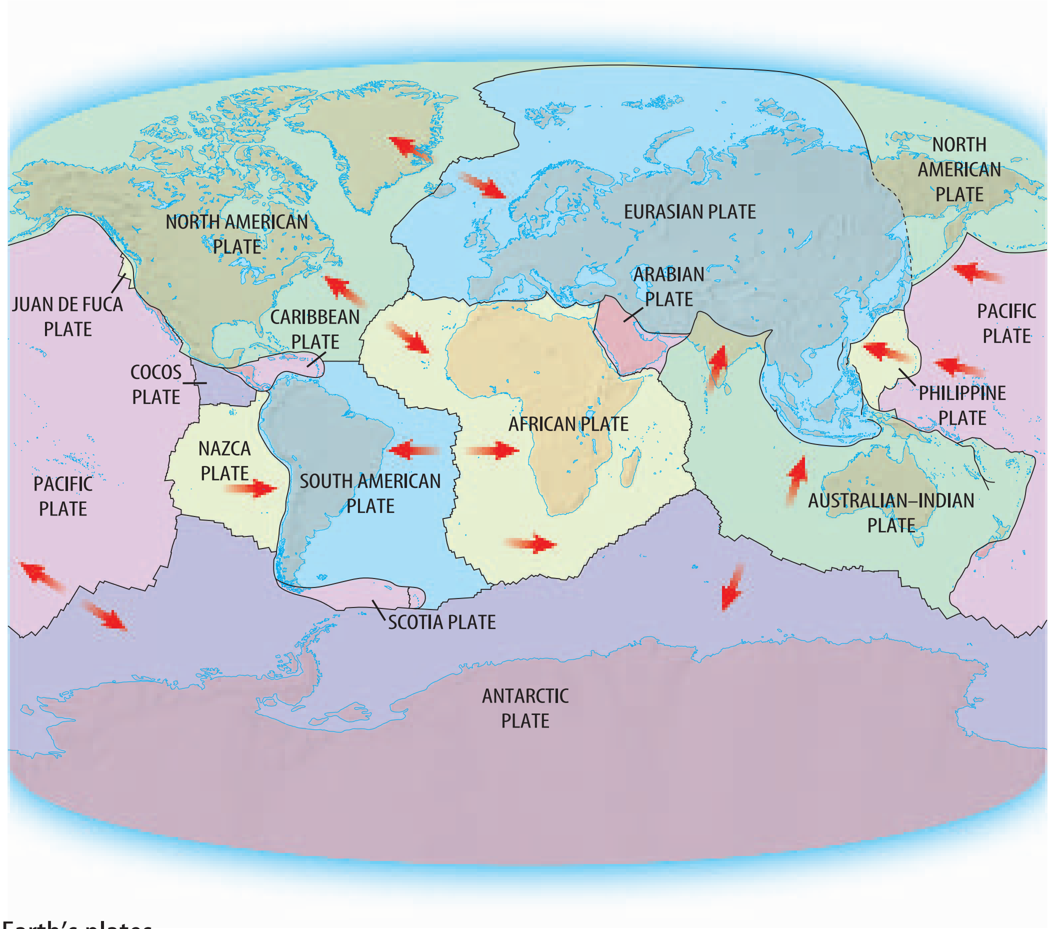


Figure 5 Earth's plates fit together like the pieces of a jigsaw puzzle.
Draw Conclusions *If the plates are moving, what do you suppose happens at the plate boundaries?*

Earth's Plates

Although the crust is separated from the mantle, the uppermost, rigid layer of the mantle moves as if it were part of Earth's crust. The rigid, upper part of Earth's mantle and the crust is called the **lithosphere.** It is broken into about 30 sections or **plates** that move around on the plasticlike asthenosphere, which also is part of the mantle. Earth's major plates vary greatly in size and shape, as shown in **Figure 5.**

Reading Check *What parts of Earth make up the lithosphere?*

The movements of the plates are fairly slow, often taking more than a year to creep a few centimeters. This means that they have not always looked the way they do in **Figure 5.** The plates have not always been their current size and shape, and continents have moved great distances. Antarctica, which now covers the south pole, was once near the equator, and North America was once connected to Africa and Europe.

Lasers and satellites are used to measure the small plate movements, which can add up to great distances over time. If a plate is found to move at 2 centimeters per year on average, how far will it move in 1,000 years? What about in 10 million years?

Plate Boundaries

The places where the edges of different plates meet are called plate boundaries. The constant movement of plates creates forces that affect Earth's surface at the boundaries of the plates. At some boundaries, these forces are large enough to cause mountains to form. Other boundaries form huge rift valleys with active volcanoes. At a third type of boundary, huge faults form. **Faults** are large fractures in rocks along which movement occurs. The movement can cause earthquakes. **Figure 6** shows the different plate motions.

Plates That Move Apart Plates move apart as a result of pulling forces that act in opposite directions on each plate. This pulling force is called tension. **Figure 7** shows what happens as tension continues to pull two plates apart.

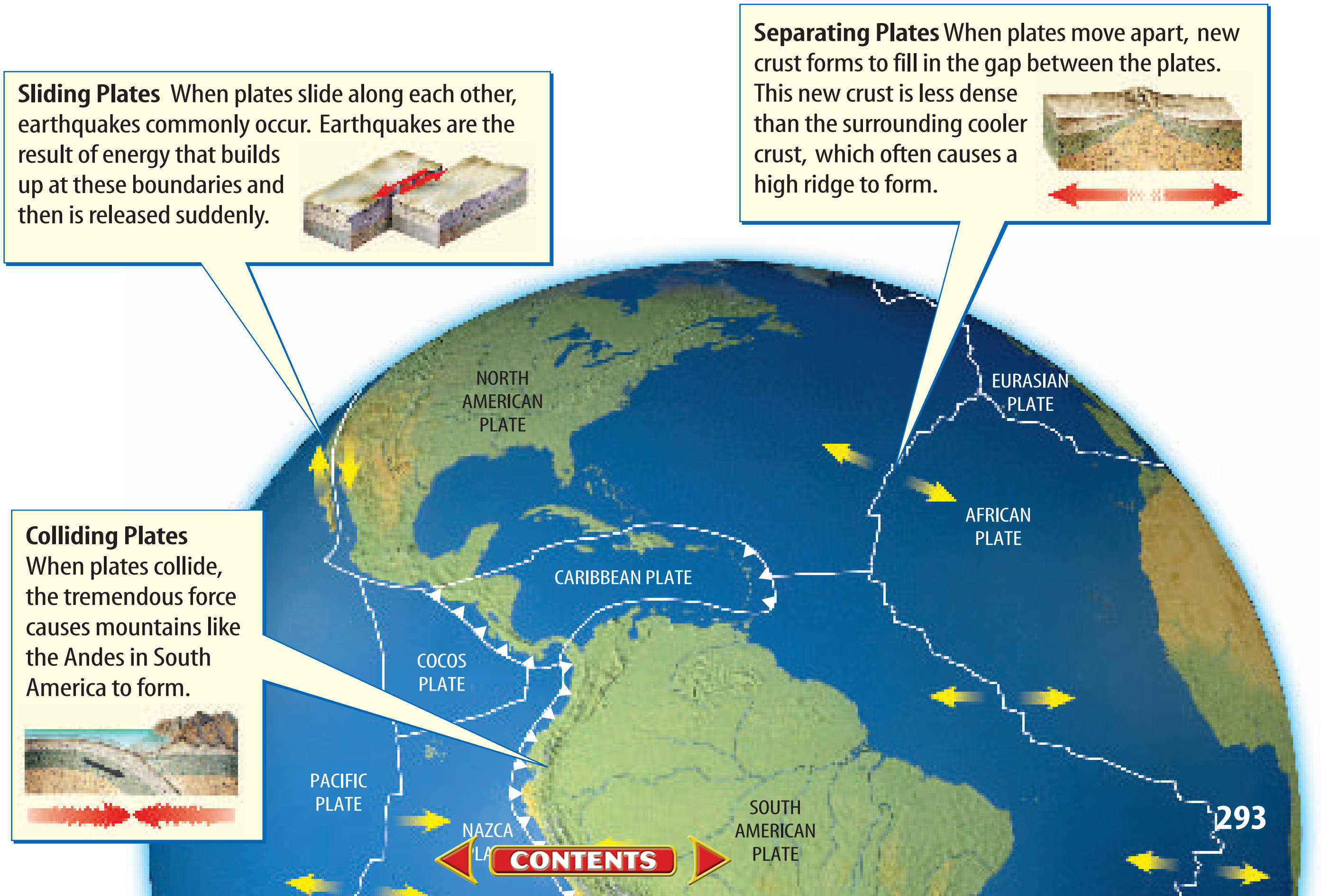
One important result of plates separating is the formation of new crust. New crust forms in gaps where the plates pull apart. As tension continues along these boundaries, new gaps form and are filled in by magma that is pushed up from the mantle. Over time, the magma in the gaps cools to become new crust. This process of plate separation and crust formation takes place under the oceans at places called mid-ocean ridges. As new crust moves away from the mid-ocean ridges, it cools and becomes denser.

Science Online

Topic: Plate Boundaries
Visit red.msscience.com for Web links to information about Earth's plates and the different boundaries that they form.

Activity Create a table of the information on plates and plate boundaries. Try to include specific plates and boundary locations. Share your findings with your classmates.

Figure 6 Earth's plates can collide, move away from each other, or slide past each other.



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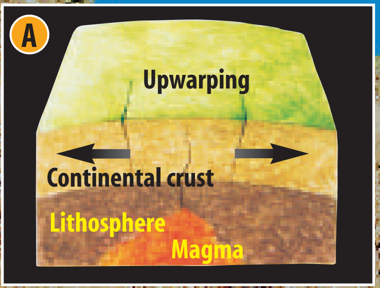
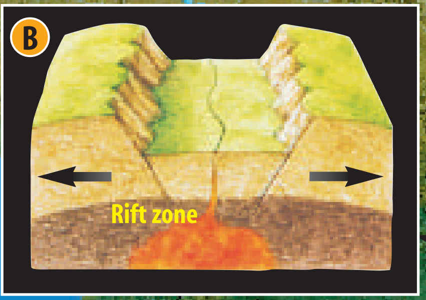
NATIONAL GEOGRAPHIC VISUALIZING RIFT VALLEYS

Figure 7

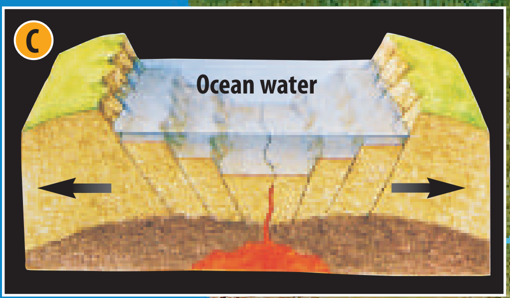
When two continental plates pull apart, rift valleys may form. If spreading continues and the growing rift reaches a coastline, seawater floods in. Beneath the waves, molten rock, or magma, oozes from the weakened and fractured valley floor. In time, the gap between the two continental slabs may widen into a full-fledged ocean. The four steps associated with this process are shown here. Africa's Great Rift Valley, which cuts across the eastern side of Africa for 5,600 km (right), represents the second of these four steps. If rifting processes continue in the Great Rift Valley, East Africa eventually will part from the mainland.



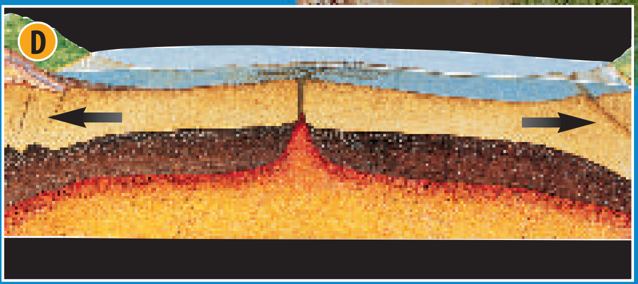
Rising magma forces the crust upward, causing numerous cracks in the rigid crust.



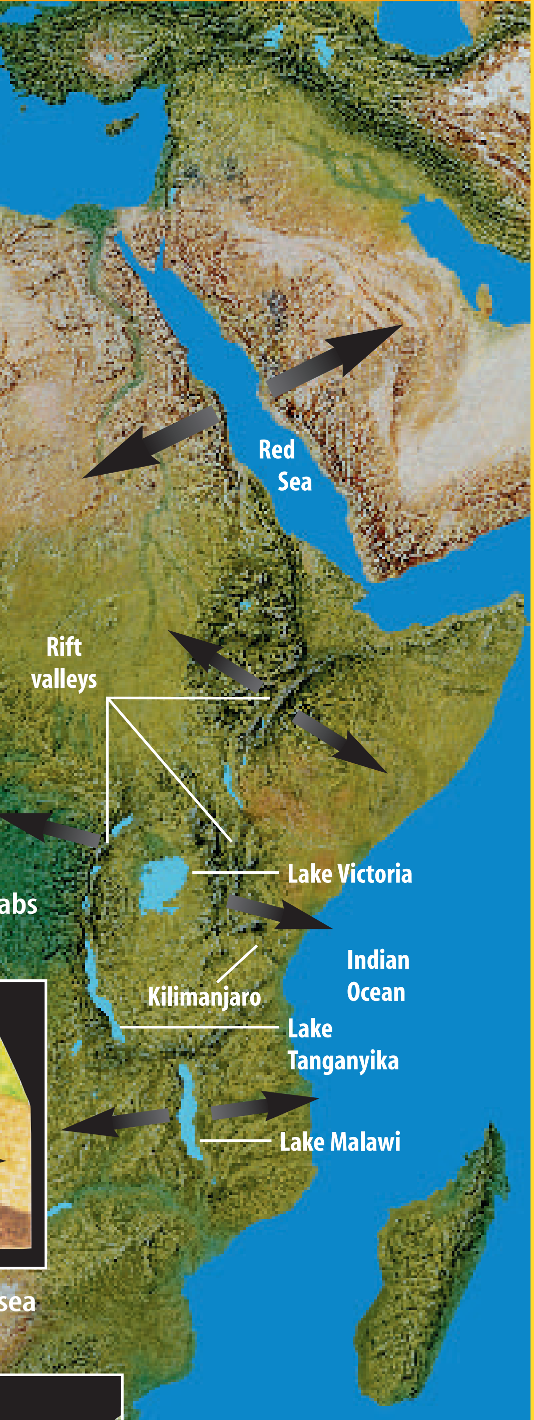
As the crust is pulled apart, large slabs of rock sink, generating a rift zone.



Further spreading generates a narrow sea or lake.



Eventually, an expansive ocean basin and ridge system are created.



(bkgd)National Geographic Maps

Plates That Collide When plates move toward each other, they collide, causing several different things to occur. As you can see in **Figure 8,** the outcome depends on the density of the two plates involved. The crust that forms the ocean floors, called oceanic crust, is more dense than the continental crust, which forms continents.

If two continental plates collide, they have a similar density which is less than the mantle underneath. Therefore, the collision causes the crust to pile up. When rock converges like this, the force is called compression. Compression causes the rock layers on both plates to crumple and fold. Imagine laying a piece of fabric flat on your desk. If you push the edges of the cloth toward each other, the fabric will crumple and fold over on itself. A similar process occurs when plates crash into each other, causing mountains to form.

Flat rock layers are pushed up into folds. Sometimes the folding is so severe that rock layers bend completely over on themselves, turning upside down. As rock layers are folded and faulted, they pile up and form mountains. The tallest mountains in the world, the Himalaya in Asia, are still rising as two continental plates collide.

Plate Subduction When an oceanic plate collides with another oceanic plate or a continental plate, the more dense one plunges underneath the other, forming a deep trench. When one plate sinks underneath another plate, it's called **subduction.** When a plate subducts, it sinks into the mantle. In this way, Earth's crust does not continue to grow larger. As new crust material is generated at a rift, older crustal material subducts into the mantle.

Mini LAB

Modeling Tension and Compression

Procedure

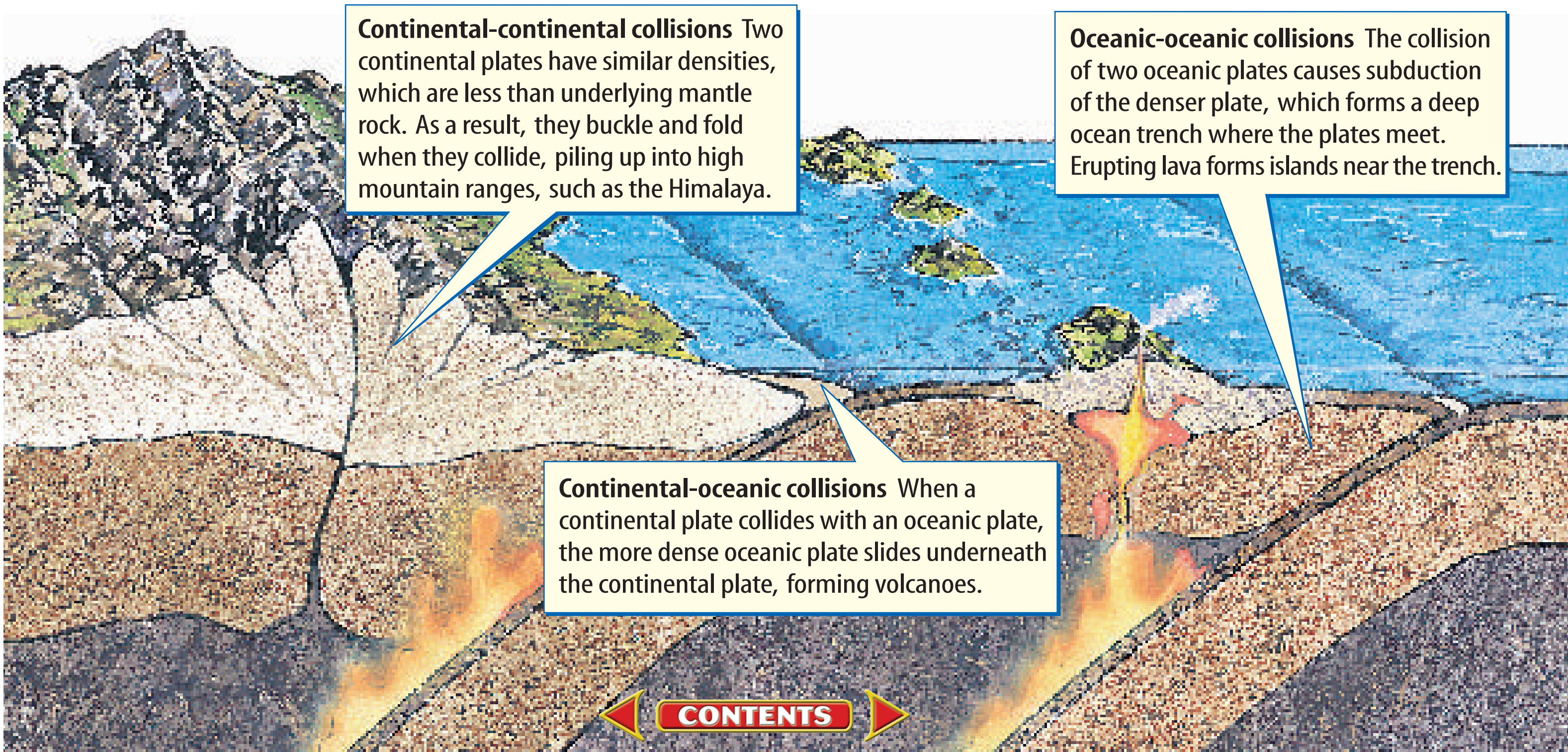
1. Obtain two bars of **taffy.**
2. Hold one bar of taffy between your hands and push your hands together.
3. Record your observations in your **Science Journal.**
4. Hold the other bar of taffy between your hands and pull gently on both ends.
5. Record your observations in your Science Journal.

Analysis

1. On which bar of taffy did you apply tension? Compression?
2. Explain how this applies to plate boundaries.

Try at Home

Figure 8 There are three types of convergent plate boundaries.



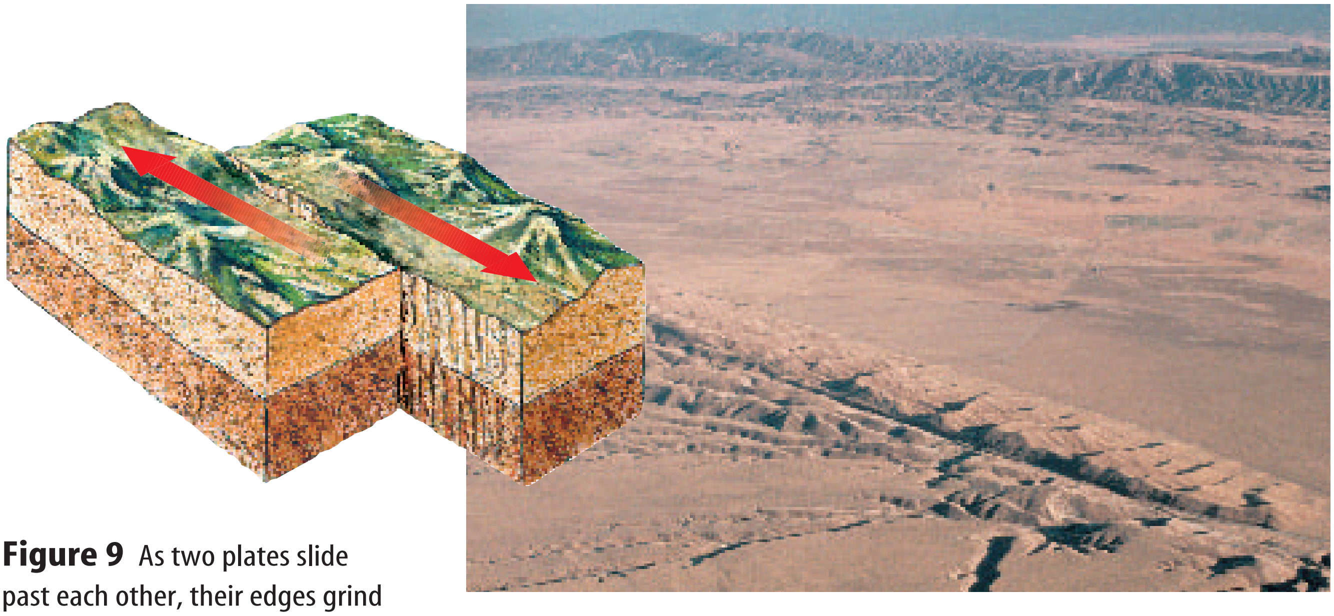


Figure 9 As two plates slide past each other, their edges grind and scrape. The jerky movement that results causes earthquakes like those frequently felt in California along the San Andreas Fault.

Plates That Slide Past In addition to moving toward and away from one another, plates also can slide past one another. For example, one plate might be moving north while the plate next to it is moving south. The boundary where these plates meet is called a transform boundary. When a force pushes something in two different directions, it's called shearing. Shearing causes the area between the plates to form faults and experience many earthquakes. **Figure 9** shows part of the San Andreas Fault near Taft, California, which is an example of the features that form along a transform boundary.

Why do plates move?

As you can see, Earth's plates are large. To move something so massive requires a tremendous amount of energy. Where does the energy that drives plate movement come from? The reason plates move is complex, and geologists still are trying to understand it fully. So far, scientists have come up with several possible explanations about what is happening inside Earth to cause plate movement. Most of these theories suggest that gravity is the driving force behind it. However, gravity pulls things toward the center of Earth, and plates move sideways across the globe. How does gravity make something move across the surface of Earth?

One theory that could explain plate movement is convection of the mantle. Convection in any material is driven by differences in density. In the mantle, density differences are caused by uneven heating, which results in a cycling of material, as shown in **Figure 10.** The theory suggests that the plates move as part of this circulation of mantle material.

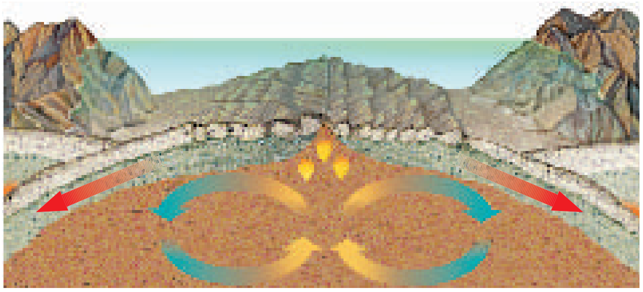
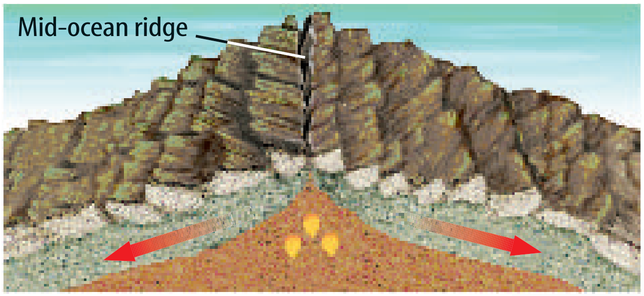
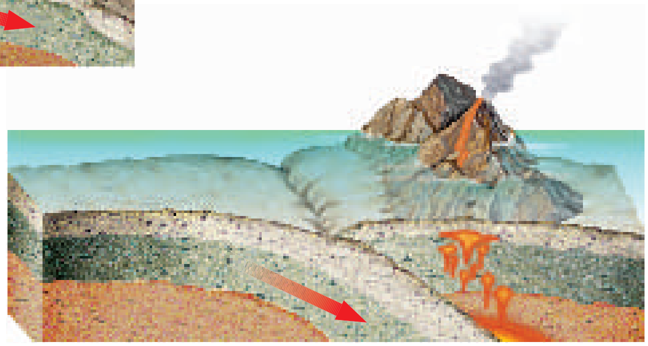


Figure 10 Convection, ridge-push, and slab-pull might all contribute to the motions of Earth's plates.

Uneven heating of the upper mantle could cause convection.



Ridge-push could occur at mid-ocean ridges.



Slab-pull could occur where oceanic plates meet other oceanic or continental plates.

Ridge-push and Slab-pull Other factors, as shown in **Figure 10,** that could play a role in plate movement are ridge-push and slab-pull. Ridge-push occurs at mid-ocean ridges, which are higher than surrounding ocean floor. The plates respond to gravity by sliding down the slope. Slab-pull occurs as the plates move away from the mid-ocean ridges and become cooler, which makes them more dense. A plate can get so dense that it sinks when it collides with another plate. When the more dense plate begins to sink, it becomes easier for it to move across Earth's surface because resistance to movement is reduced.

section 1 review

Summary

Clues to Earth's Interior

- Earth's interior has been explored using information from seismic waves and rocks.

Earth's Layers

- The interior of Earth is made of the inner core, outer core, mantle, and crust.

Plate Boundaries

- Plates can move apart, collide, subduct, or slide past each other.
- Plates probably move by convection and factors such as ridge-push and slab-pull.

Self Check

1. **Explain** How are earthquake waves used to provide information about Earth's interior?
2. **Identify** Give examples of where the three types of plate movements occur.
3. **Describe** the layer of Earth's interior that is the largest.
4. **List** the layers of Earth's interior in order of density.
5. **Think Critically** How can slab-pull and ridge-push contribute to the movement of a plate at the same time?

Applying Skills

6. **Compare and contrast** the following pairs of terms: *inner core, outer core; ridge-push, slab-pull.*

LAB

EARTH'S MOVING PLATES

You have learned that Earth's surface is separated into plates that move apart, move together, or slide past each other. In this lab, you will observe a process that is thought to cause this plate movement.

Real-World Question

What process inside Earth provides the energy for plate motion?

Goals

- **Observe** movement of solid plates on a liquid.
- **Identify** the cause of plate movement on Earth's surface.

Materials

1-L beakers (2)
food coloring
aluminum foil
pencil
rubber band
water (warm and cold)
2-cm paper squares (3)
small, clear-plastic cup

Safety Precautions

WARNING: *Handle the warm water with care. Water from the tap should be warm enough.*

Procedure

1. Fill one of the 1-L beakers with cold water.
2. Fill the small cup with warm water.
3. Add four drops of food coloring to the cup of warm water and cover the top with aluminum foil. Secure the aluminum foil with a rubber band. No air should be underneath the foil.
4. Carefully place the cup of colored, warm water in the bottom of the second 1-L beaker.
5. Carefully pour the cold water from the first 1-L beaker into the second 1-L beaker. Take care not to disturb the cup of colored water.

6. Place the pieces of paper on the surface of the water in the second 1-L beaker.
7. Use a long pencil to make two small holes in the aluminum foil covering the cup.
8. **Observe** what happens to the contents of the cup and to the pieces of paper. Record your observations in your Science Journal.

Conclude and Apply

1. **Describe** What happened to the colored, warm water originally located in the cup?
2. **Infer** What effect, if any, does the warm water have on the positions of the floating paper?
3. **Compare and Contrast** How is what happens to the warm water similar to processes that occur inside Earth? How is it different?
4. **Explain** After observing the pieces of paper floating on the cold water, explain what features on Earth's surface they are similar to.

Communicating Your Data

Compare your conclusions with those of other students in your class. **For more help, refer to the Science Skill Handbook.**

Amanita Pictures

CONTENTS

section 2

Uplift of Earth's Crust

Building Mountains

One popular vacation that people enjoy is a trip to the mountains. Mountains tower over the surrounding land, often providing spectacular views from their summits or from surrounding areas. The highest mountain peak in the world is Mount Everest in the Himalaya in Tibet. Its elevation is more than 8,800 m above sea level. In the United States, the highest mountains reach an elevation of more than 6,000 m. There are four main types of mountains—fault-block, folded, upwarped, and volcanic. Each type forms in a different way and can produce mountains that vary greatly in size.

Age of a Mountain As you can see in **Figure 11,** mountains can be rugged with high, snowcapped peaks, or they can be rounded and forested with gentle valleys and babbling streams. The ruggedness of a mountain chain depends largely on whether or not it is still forming. Mountains like the Himalaya are currently forming at a rate of several centimeters per year, while much older mountains like the Ouachita Mountains in Arkansas stopped forming millions of years ago and are now being eroded by geological processes.

as you read

What You'll Learn

- **Describe** how Earth's mountains form and erode.
- **Compare** types of mountains.
- **Identify** the forces that shape Earth's mountains.

Why It's Important

The forces inside Earth that cause Earth's plates to move around also are responsible for forming Earth's mountains.

Review Vocabulary

erosion: process by which products of weathering are moved

New Vocabulary

- fault-block mountain
- folded mountain
- upwarped mountain
- volcanic mountain
- isostasy

Figure 11 Mountains can be high and rugged like the mountains of the Himalaya shown on the left, or they can be large, gently rolling hills like the Ouachita Mountains in Arkansas, shown above.

Infer *What determines how rugged and high a mountain chain is?*

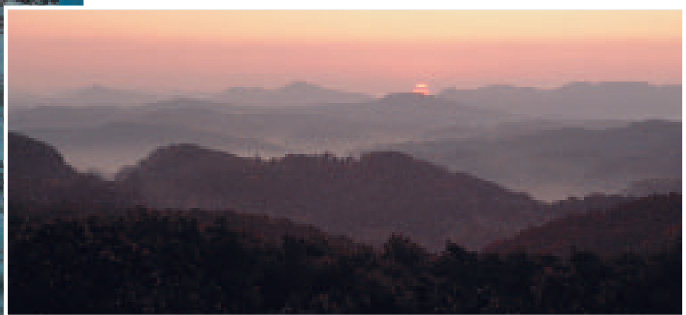
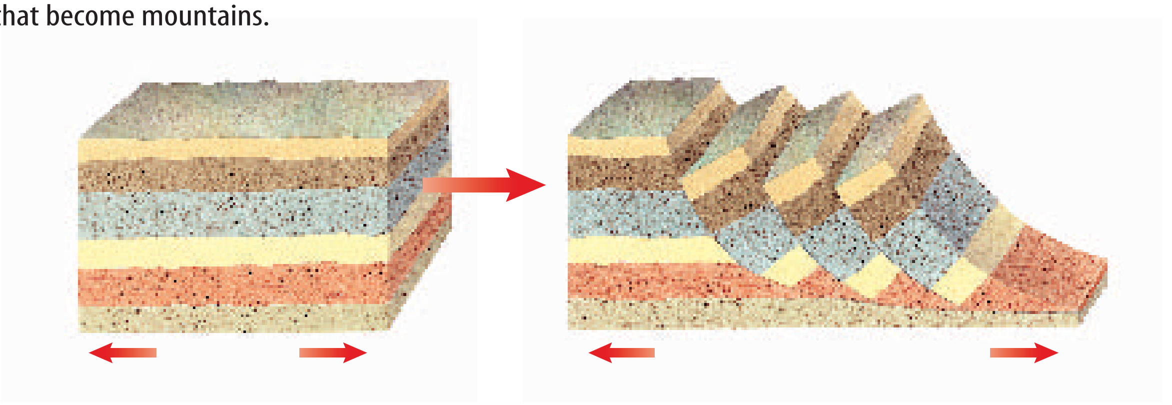


Figure 12 Before tension is applied, the layers of rock are even and fairly level. After tension is applied, huge blocks of rock separate and slip downward. This leaves large, tilted blocks that become mountains.



Fault-Block Mountains The first mountains you'll study are fault-block mountains. Some examples are the Sierra Nevada in California and the Teton Range in Wyoming. Recall that pulling, or tension, forces that occur at the boundaries of plates moving apart, work to create surface features such as rift valleys and faults. Fault-block mountains also form from pulling forces. **Fault-block mountains** are made of huge, tilted blocks of rock that are separated from surrounding rock by faults. When rock layers are pulled from opposite directions, large blocks slide downward, creating peaks and valleys, as shown in **Figure 12.**

Models of Mountain Building If you hold a candy bar between your hands and then begin to pull it apart, cracks might form within the chocolate. Similarly, when rocks are pulled apart, faults form. Unlike rocks deep in Earth, rocks at Earth's surface are hard and brittle. When they are pulled apart, large blocks of rock can move along the faults. The Teton Range of Wyoming formed when a block of crust was tilted as one side of the range was uplifted above the neighboring valley. As shown in **Figure 13,** if you travel to the Grand Teton National Park, you will see sharp, jagged peaks that are characteristic of fault-block mountains.

Now, hold a flat piece of clay between your hands and then push your hands together gently. What happens? As you push your hands together, the clay begins to bend and fold over on itself. A similar process causes rocks to fold and bend, causing folded mountains to form on Earth's surface.

Figure 13 The Teton Range in the Grand Teton National Park has sharp, jagged peaks that are characteristic of fault-block mountains.

Folded Mountains Traveling along a road that is cut into the side of the Appalachian Mountains, you can see that rock layers were folded just as the clay was when it was squeezed, or compressed. Tremendous pushing forces exerted by two of Earth's plates moving together squeezed rock layers from opposite sides. This caused the rock layers to buckle and fold, forming folded mountains. **Folded mountains** are mountains formed by the folding of rock layers caused by compression forces.

Reading Check *What type of force causes folded mountains to form?*

The Appalachian Mountains are folded mountains that formed about 250 million to 300 million years ago. A small part of the folded Appalachians is shown in **Figure 14.** The compression occurred as the North American Plate and the African Plate moved together. The Appalachians are the oldest mountain range in North America, and also one of the longest. They extend from Alabama northward to Quebec, Canada. Erosion has been acting on these mountains since they were formed. As a result, the Appalachians are small compared to other mountain ranges. At one time, the Appalachian Mountains were higher than the Rocky Mountains are today.

Upwarped Mountains The Adirondack Mountains in New York, the southern Rocky Mountains in Colorado and New Mexico, and the Black Hills in South Dakota are examples of upwarped mountains. **Upwarped mountains** form when forces inside Earth push up the crust. With time, sedimentary rock layers on top will erode, exposing the igneous or metamorphic rocks underneath. The igneous and metamorphic rocks can erode further to form sharp peaks and ridges.

Mini LAB

Modeling Mountains

Procedure

1. Use layers of **clay** to build a model of each major type of mountain.
2. For fault-block mountains, cut the layers of clay with a **plastic knife** to show how one block moves upward and another moves downward.
3. For folded mountains, push on the layers of clay from directly opposite directions.
4. For upwarped mountains, push a large, round object, such as a **ball,** upward from below, forcing the layers of clay to warp.
5. For volcanic mountains, place layer upon layer of clay to form a cone-shaped feature.

Analysis

1. Do any of the mountains you have modeled look similar? Explain.
2. How could you recognize the different types of mountains?

Figure 14 This roadcut in Maryland exposes folded rock layers that formed when the North American Plate and the African Plate collided.

Mark Burnett/Stock Boston

Volcanic Mountains Occasionally, magma from inside Earth reaches the surface. When this happens, the magma is called lava. When hot, molten lava flows onto Earth's surface, volcanic mountains can form. Over time, layer upon layer of lava piles up until a cone-shaped feature called a **volcanic mountain** forms. Washington's Mount St. Helens and Mexico's Mount Popocateptl, shown in **Figure 15,** are examples. Next, you will take a closer look at how volcanic mountains form.

Some volcanic mountains form when large plates of Earth's lithosphere sink into Earth's mantle at subduction zones. As the plates sink deeper into the mantle, they cause melting to occur. The magma produced is less dense than the surrounding rock, so it is forced slowly upward to Earth's surface. If the magma reaches the surface, it can erupt as lava and ash. Layers of these materials can pile up over time to form volcanic mountains.

Science Online

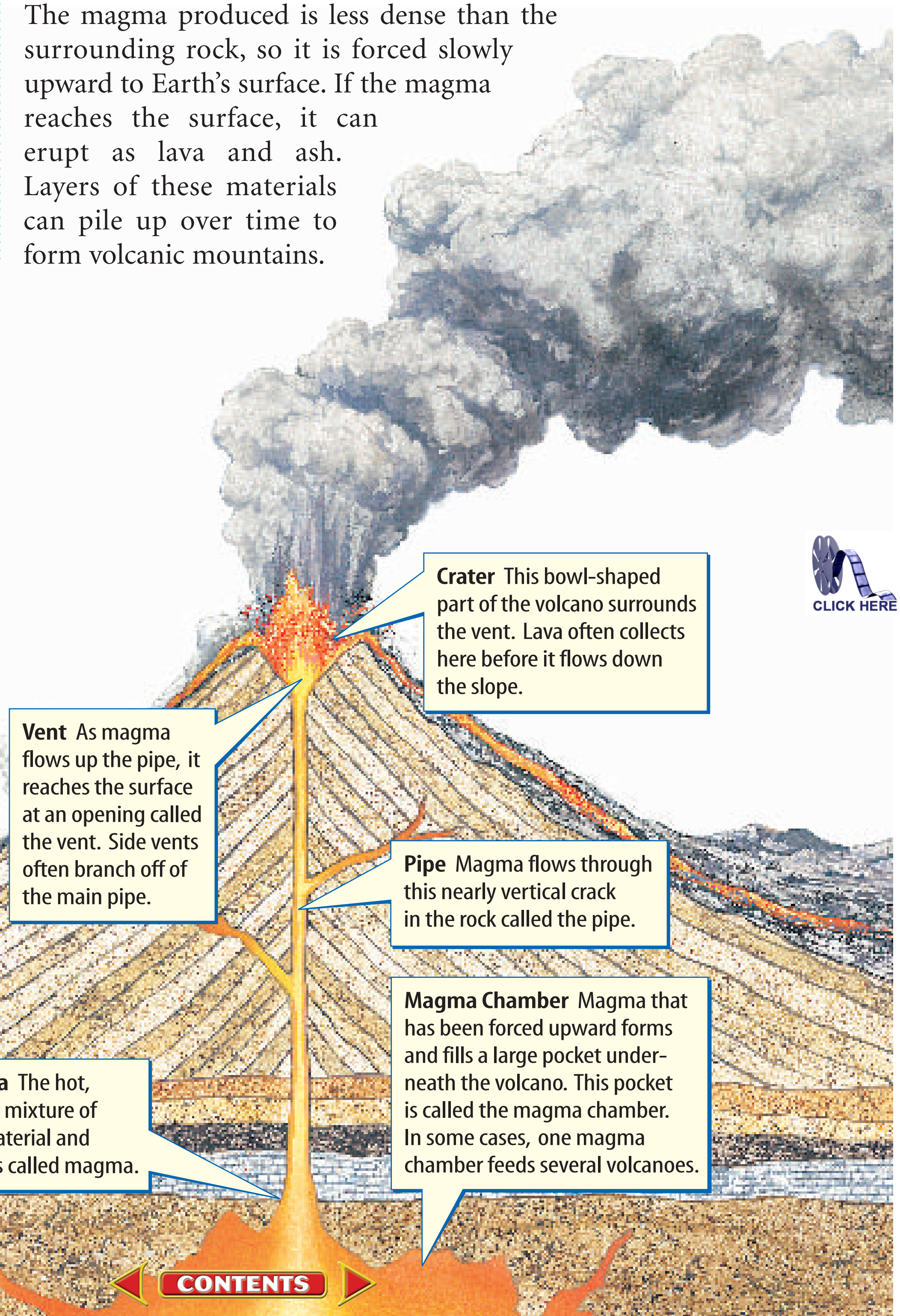
Topic: Volcanic Mountains

Visit red.msscience.com for Web links to information about volcanic mountains.

Activity Collect as many photographs of volcanic mountains as possible. Create a large map of the world with the photographs in their proper locations. Include some information about the volcanic mountains and the impact they have had on the environment around there.

AFP/CORBIS

Figure 15 Volcanic mountains form when lava and ash build up in one area over time.



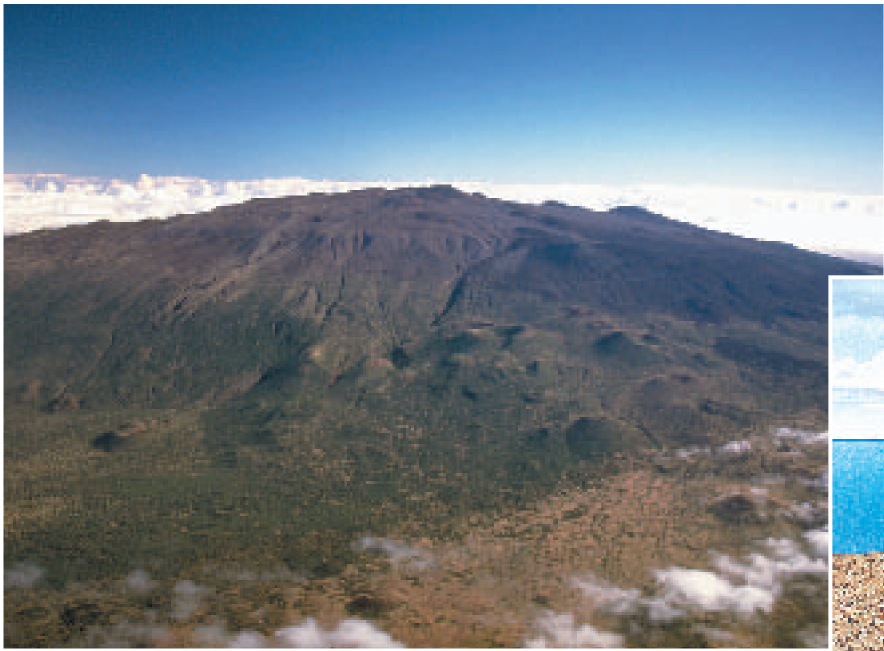
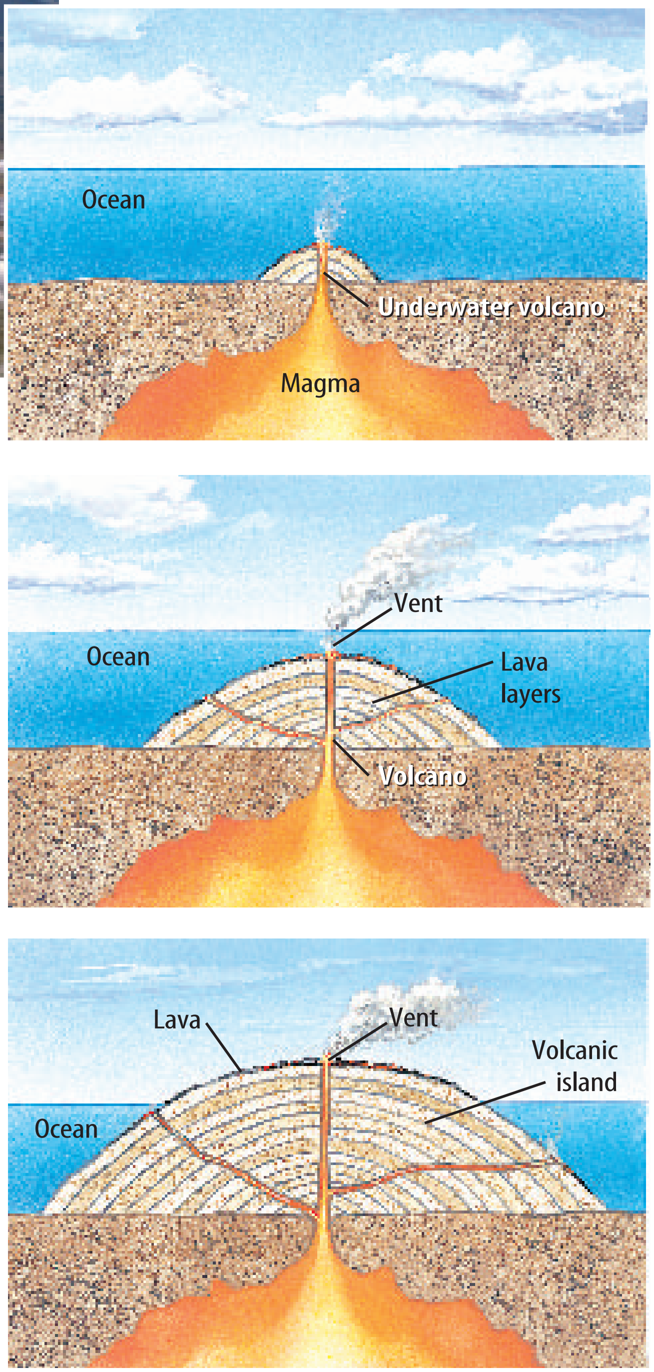


Figure 16 The Hawaiian Islands are a series of volcanic mountains that have been built upward from the seafloor. They began to form as lava erupted onto the ocean floor. Over time, the mountain grew so large that it rose above sea level.



Underwater Volcanic Mountains You know that volcanic mountains form on land, but did you know that these mountains also form on the ocean floor? Underwater eruptions can produce mountains beneath the sea. Eventually, if enough lava is erupted, these mountains grow above sea level. For example, Hawaii, shown above in **Figure 16,** is the peak of a huge volcanic mountain that extends above the surface of the water of the Pacific Ocean. **Figure 16** also illustrates how the Hawaiian Islands formed.

Volcanic mountains like the Hawaiian Islands are different from the volcanic mountains that form where one plate subducts beneath another. The Hawaiian Islands formed from material that came from near the boundary between Earth's core and mantle. Hot rock is forced upward through the mantle as a plume and melts to form a hot spot in Earth's crust. As plates travel over the hot spot, a series of volcanoes, as seen in Hawaii, forms. Magma from subduction volcanoes forms much closer to Earth's surface. Hot spot volcanoes also are much larger and have more gently sloping sides than subduction volcanoes.

Reading Check *What type of mountains make up the Hawaiian Islands?*

Michael T. Sedam/CORBIS

Other Types of Uplift

You have learned about the origin of the pushing forces that bend crustal rocks during mountain-building processes. However, another force also works to keep mountains elevated above the surrounding land. If you place wooden blocks of various thicknesses in a container of water, you will notice that different blocks of wood float in the water at different heights. Also, the thicker blocks of wood float higher in the water than the thinner blocks do. The buoyant force of the water is balancing the force of gravity. A similar process called isostasy occurs in Earth. According to the principle of **isostasy** (i SAHS tuh see), Earth's lithosphere floats on a plasticlike upper part of the mantle, the asthenosphere.

The effects of isostasy were first noticed near large mountain ranges. Earth's crust is thicker under mountains than it is elsewhere. Also, if mountains continue to get uplifted, the crust under the mountains will become thicker and will extend farther down into the mantle. This is similar to the floating wooden blocks. If you pile another wooden block on a block that is already floating in the water, you will see that the new, larger block will sink down into the water farther than before. You also will see that the new block floats higher than it did before.

INTEGRATE Language Arts

The Isostasy Story
Using the principle of isostasy, explain in your Science Journal why large features on Earth's surface, such as mountains, float on the layers of Earth beneath them.

Applying Science

How can glaciers cause land to rise?

About 20,000 years ago, much of North America was covered by a large glacial ice sheet. How do you think an ice sheet can affect Earth's crust? What do you think happens when the ice melts?

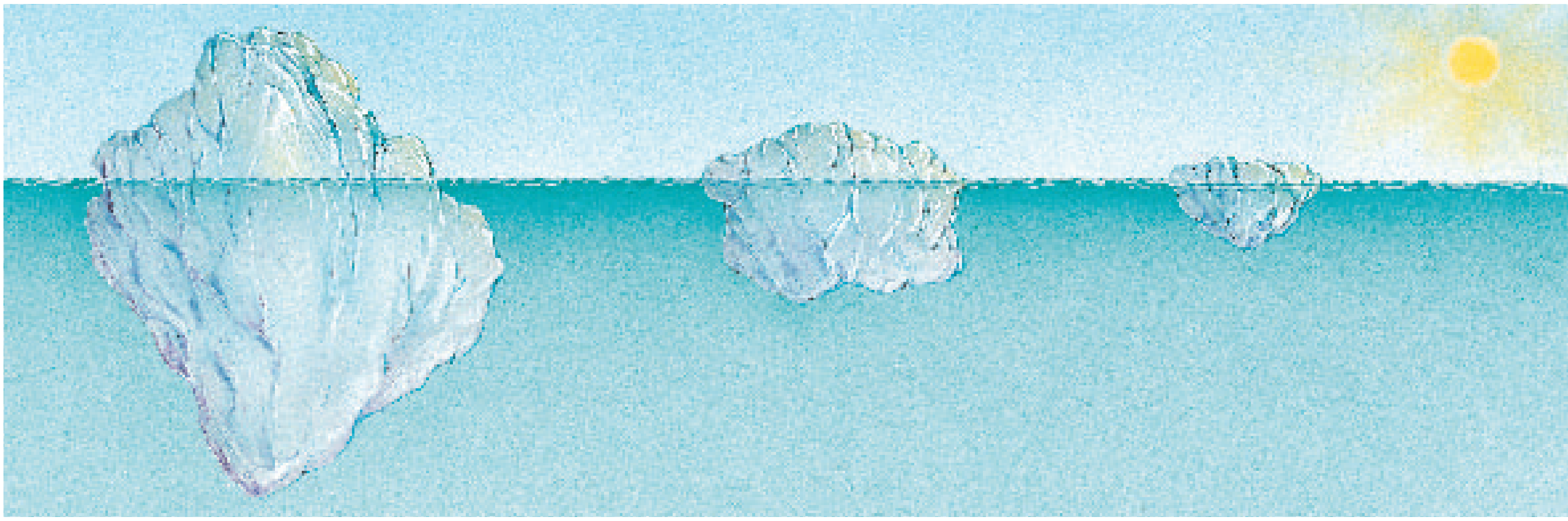
Identifying the Problem

More than 100 years ago, people living in areas that once had been covered by glaciers noticed that features such as old beaches had been tilted. The beaches had a higher elevation in some places and a lower elevation in others. How do you think old beaches could be tilted?

Solving the Problem

1. The weight of glaciers pushes down Earth's crust. What do you think happens after the glacier melts?
2. How could rising crust cause beaches to be tilted? Do you think the crust would rise the same amount everywhere? Explain.

Mark E. Gibson/Visuals Unlimited



Adjusting to Gravity Similar to the wooden blocks, if mountains continue to grow larger, they will sink even farther into the mantle. Once mountains stop forming, erosion lowers the mountains and the crust rises again because weight has been removed. If the process continues, the once-thick crust under the mountains will be reduced to the thickness of the crust where no mountains exist.

Icebergs behave in much the same way, as shown in **Figure 17.** The iceberg is largest when it first breaks off of a glacier. As the iceberg floats, it melts and starts to lose mass. This causes the iceberg to rise in the water. Eventually, the iceberg will be much smaller and will not extend as deeply into the water. How is this similar to what happens to mountains?

Figure 17 Isostasy makes Earth's crust behave in a similar way to these icebergs. As an iceberg melts and becomes smaller, ice from below the water's surface is forced up.

section 2 review

Summary

Building Mountains

- A rugged, tall mountain is geologically young. An old mountain is rounded and lower in elevation.
- There are four main types of mountains: fault block, folded, upwarped, and volcanic.
- Volcanic mountains can form on the surface of the continents or under the ocean at ridges.

Other Types of Uplift

- The principle of isostasy explains how the lithosphere floats on the asthenosphere.
- The crust will also adjust to gravity as erosion and weathering wear away older mountains.

Self Check

1. **Predict** If compression were exerted on rock layers, what type of mountains would form?
2. **Describe** how fault-block mountains form.
3. **Explain** how a volcano forms.
4. **Think Critically** Put the Appalachian, Himalaya, and Rocky Mountains in order from youngest to oldest knowing that the Himalaya are most rugged and the Appalachians are the least rugged.

Applying Skills

5. **Concept Map** Make a chain-of-events concept map that describes how folded mountains form.

LAB

Model and Invent

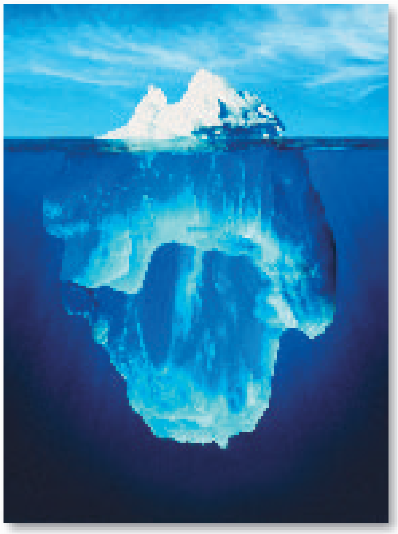
Isostasy

Goals
- **Observe** the results of isostasy.
- **Predict** what will happen to floating objects when mass is removed or added.

Possible Materials
5-cm × 5-cm × 2-cm wooden blocks (3)
10-cm × 35-cm × 15-cm clear-plastic storage box or other bin
water
permanent marker
ruler

Safety Precautions

Real-World Question



The principle of isostasy states that Earth's crust floats on the more dense mantle beneath. This is similar to the way objects float in water. What do you think will happen when you add mass to a floating object? What if you take away mass? How does adding or removing mass affect the way an object floats in a fluid?

Make the Model

1. **Decide** what object(s) you will float in the water initially. How will you remove mass from that object? How will you add mass?
2. What will you observe as the mass changes? How will you record the effects of adding or removing mass?
3. How much water will you use? What problems might you encounter if you have too much or too little water?

(t)Ralph A. Clevenger/CORBIS, (b)Paul Chesley/Stone/Getty Images

4. Will you make any additional measurements or record any other data?
5. **List** all the steps that you plan to do in this activity. Are the steps in a logical order?
6. **Compare** your model plans to those of other students.
7. Make sure your teacher approves your plans before you start.

Test the Model

1. Fill the storage box or bin with an appropriate amount of water.
2. Start by floating the initial object you planned to use in the water. Observe and record relevant data.
3. Follow the list of steps you planned in order to obtain data for removing and adding mass. Observe your model and record all relevant data in your Science Journal.

Conclude and Apply

1. **Describe** What did your initial object look like? What level did the water rise to when your initial object was placed in the bin? How did you add and remove mass?
2. **Summarize** What happened to the amount of the object that was submerged and the amount sticking out of the water when mass was removed from the object?
3. **Summarize** What happened to the amount of the object that was submerged and the amount sticking out of the water when mass was added?
4. **Explain** How can you explain your observations about how much of the object was submerged and how much was sticking out of the water? How is this similar to processes that occur in Earth?

Communicating Your Data

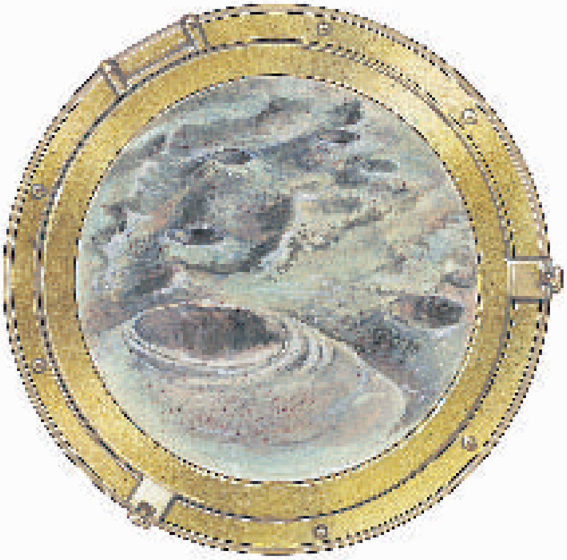
Make a poster that illustrates what you have learned about isostasy. **For more help, refer to the** **Science Skill Handbook.**

KS Studios

Science Stats

Mountains

Did you know...



... The world's longest mountain range is underwater. The mid-ocean ridge that winds around Earth beneath the Arctic, Atlantic, and Pacific Oceans is 65,000 km long. That's four times longer than the combined lengths of the Andes Mountains, the Rocky Mountains, and the Himalaya.

... The beautiful Appalachian Mountains are among the oldest in the world. By 250 million years ago, their formation was complete. Today, the mountains aren't among the tallest because they have been worn down by many millions of years of erosion.

... In 1963, Surtsey, a small island, formed when an underwater volcano erupted off the coast of Iceland. The 1.6-km-long island rose to the height of 183 m—about as tall as a 55-story building.

Applying Math Using this relationship, how many meters would there be in a one-story building?

Find Out About It

Research a mountain on red.msscience.com/science_stats. Pinpoint its location on a map, and then accurately draw the mountain and the view from its top.

Reviewing Main Ideas

Section 1 Earth's Moving Plates

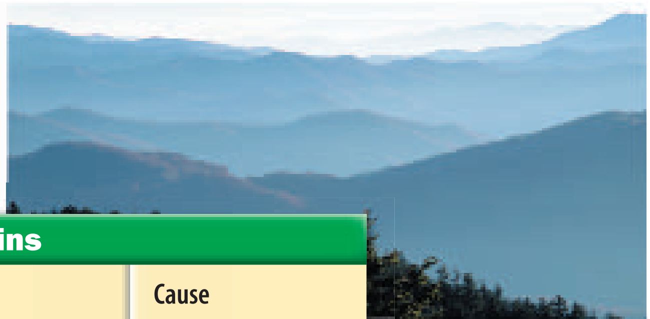
1. Earth's interior is divided into four layers, the inner core, the outer core, the mantle, and the crust.
2. Earth's inner and outer cores are thought to be composed mostly of iron. The outer core is thought to be liquid and the inner core is solid.
3. Plates composed of sections of Earth's crust and rigid upper mantle move around on the plasticlike asthenosphere.
4. Earth's plates move together, move apart, and slide past each other.
5. Convection in Earth's mantle, ridge-push, and slab-pull might all contribute to plate movement.

Section 2 Uplift of Earth's Crust

1. Uplift causes mountains to form. Faulting, folding, upwarping, and volcanic eruptions are all processes that build mountains.
2. Four main types of mountains are fault-block, folded, upwarped, and volcanic.
3. As erosion removes material, the mass of the mountains is reduced. Isostasy, then forces the crust upward.

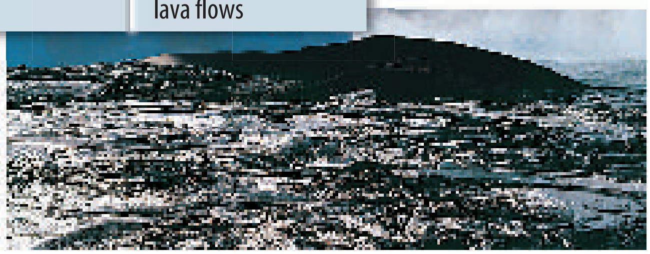
Visualizing Main Ideas

Copy and complete the following table comparing examples and causes of the four types of mountains.

The Four Types of Mountains

Mountain Type	Example	Cause
Fault-block mountain	Teton Range	
Folded mountain		compression
Upwarped mountain	Adirondack Mountains	
Volcanic mountain		lava flows

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chapter 10 Review

Using Vocabulary

crust p. 290
fault p. 293
fault-block mountain p. 300
folded mountain p. 301
inner core p. 289
isostasy p. 304
lithosphere p. 292
mantle p. 290
outer core p. 290
plate p. 292
subduction p. 295
upwarped mountain p. 301
volcanic mountain p. 302

Answer the following questions with complete sentences.

1. Which part of Earth's core do scientists think is liquid?
2. The Sierra Nevada mountains in California are which type of mountain?
3. What type of mountains form in areas where rocks are being pushed together?
4. What process occurs when a more dense plate sinks beneath a less dense plate?
5. Which type of mountain forms when magma is forced upward and flows onto Earth's surface?

Checking Concepts

Choose the word or phrase that best answers the question.

6. Which part of Earth is largest?
   A) crust
   B) mantle
   C) outer core
   D) inner core

7. Earth's plates are pieces of which layer of Earth?
   A) lithosphere
   B) asthenosphere
   C) inner core
   D) mantle

8. Which force pushes plates together?
   A) tension
   B) compression
   C) shearing
   D) isostasy

9. Which force occurs where Earth's plates are moving apart?
   A) tension
   B) compression
   C) shear
   D) isostasy

10. Which layer of Earth is thought to be solid and composed mostly of the metal iron?
    A) crust
    B) mantle
    C) outer core
    D) inner core

11. Which suggests that Earth's lithosphere floats on the asthenosphere?
    A) tension
    B) compression
    C) shear
    D) isostasy

12. Which type of mountain forms because of compression forces?
    A) fault-block mountains
    B) folded mountains
    C) upwarped mountains
    D) volcanic mountains

13. Which type of mountain forms because forces inside Earth push up overlying rock layers?
    A) fault-block mountains
    B) folded mountains
    C) upwarped mountains
    D) volcanic mountains

14. Which type of plate movement occurs at transform boundaries?
    A) plates moving together
    B) plates moving apart
    C) plates sinking
    D) plates sliding past each other

15. Which type of plate movement produces deep rifts such as the mid-ocean rift?
    A) plates moving together
    B) plates moving apart
    C) plates sliding past each other
    D) plates sinking

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Thinking Critically

16. Explain Which is older, the Great Rift Valley in East Africa, or the Mid-Atlantic Ridge in the Atlantic Ocean?

17. Explain how you can determine whether or not a mountain is still forming.

18. Infer Seismic waves slow down when entering the asthenosphere. What does this tell you about the nature of the asthenosphere?

19. Predict what would happen to the elevation of the island of Greenland if the ice sheet were to melt away.

20. Describe If you wanted to know whether a certain mountain was formed by compression, what would you look for?

21. Compare and contrast volcanic and folded mountains. Draw a diagram of each type of mountain. Label important features.

22. Make Models Use layers of clay to make a model of fault-block mountains. Draw a diagram of your model.

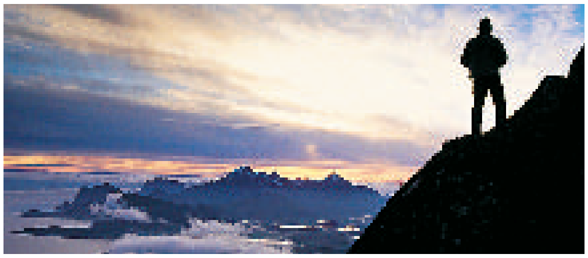
23. Draw Conclusions The speed of seismic waves suddenly increases when they go from the upper mantle into the lower mantle. What does this indicate about the comparative densities of the rock in both layers?

24. Use graphics software to generate a scale illustration of Earth's interior. Include the thickness of each layer in kilometers.

25. Recognize Cause and Effect What is the effect of subduction at the boundary of two plates?

Performance Activities

26. Poem Write a poem in a style of your choosing about the spectacular view often associated with mountains. You may wish to write about the scene from the top of a mountain or the one you see from the bottom of the mountain looking up to its peak.



Applying Math

27. Mountain Climbing The most standard climb for climbers of Mount Everest is up to Base Camp, an elevation of 5400 m. If the summit is 8850 m high, what percentage of Mount Everest's elevation is the Base Camp?

Use the map below to answer question 28.

28. Moving Cities The distance between San Francisco and Los Angeles is 616 km. If the San Andreas fault is moving at an average rate of 2.0 cm per year, how long will it be before Los Angeles is next to San Francisco?

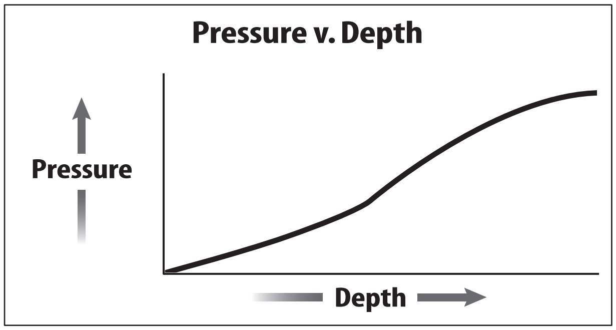
Pat Hermansen/Stone/Getty Images

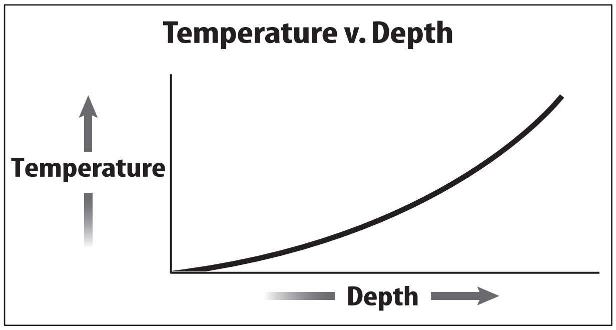
Part 1 Multiple Choice

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

1. How is energy from an earthquake carried through the ground?
   A. isostasy **C.** sound
   B. seismic waves **D.** varying density

Use the graph below to answer questions 2 and 3.





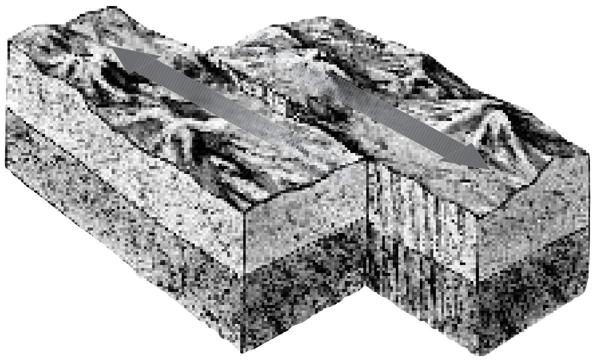
2. In general, what happens to pressure as you move outward from Earth's interior?
   A. decreases
   B. decreases then increases
   C. increases
   D. increases then decreases

3. What happens to temperature as you go deeper into Earth?
   A. decreases
   B. decreases then increases
   C. increases
   D. increases then decreases

4. Which lists layers of Earth's interior from the inside out?
   A. crust, mantle, outer core, inner core
   B. inner core, outer core, crust, mantle
   C. inner core, outer core, mantle, crust
   D. mantle, crust, outer core, inner core

5. Which mountains form when forces pull from opposite directions?
   A. fault-block **C.** upwarped
   B. folded **D.** volcanic

Use the illustration below to answer question 6.



6. Which type of force is involved when Earth's plates slide past each other?
   A. compression **C.** shear
   B. isostasy **D.** tension

7. Which type of mountain is built up from layers of lava and ash?
   A. fault-block **C.** upwarped
   B. folded **D.** volcanic

8. Which of the following is believed to cause plate movement?
   A. compression **C.** isostasy
   B. convection **D.** tension

9. Which force is responsible for Earth's crust and lithosphere floating on the mantle?
   A. compression **C.** shear
   B. isostasy **D.** tension

Part 2 Short Response/Grid In

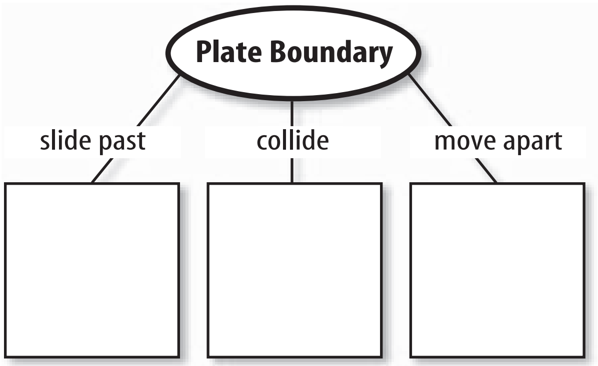
Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

10. How are seismic waves used to determine Earth's structure?

11. If new crust is being added at rift zones, why doesn't Earth's crust get larger and larger?

12. Why is Earth's crust thicker under mountains than it is elsewhere?

Use the illustration below to answer question 13.



13. Provide the missing information about what takes place at plate boundaries.

14. Compare and contrast the lithosphere and the asthenosphere.

15. What causes earthquakes along a transform boundary?

16. Explain how slab-pull is involved in the subduction of one plate under another.

17. Contrast how compression works to form folded mountains with how tension works to form fault-block mountains.

Test-Taking Tip

Diagrams Study a diagram carefully, being sure to read all labels and captions.

Part 3 Open Ended

Record your answers on a sheet of paper.

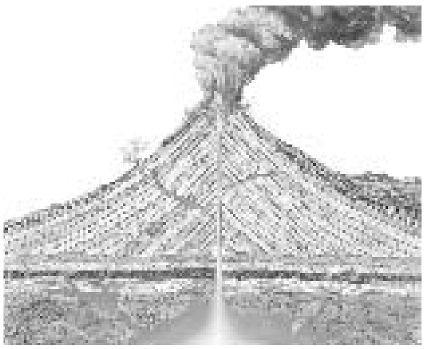
18. Compare and contrast Earth's inner core and outer core.

Use the photo below to answer question 19.

19. What type of mountain is in this picture? Identify the characteristics that distinguish these mountains from others and explain how they formed.

20. Explain how the Hawaiian Islands were formed and why they are unique.

Use the illustration below to answer question 21.



21. How do characteristics of this volcanic mountain differ from mountains formed in other ways?

22. Because of isostasy, what happens to a landmass previously covered with glacial ice, once the ice melts?

23. Explain how do we know that Earth's outer core is liquid?

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