CHAPTER 5

Plate Boundaries and California

The BIG Idea

California is located on a plate boundary, where major geologic events occur.

LESSON 1 1.c, 1.d, 1.e, 7.g

Interactions at Plate Boundaries

Main Idea There are three main types of plate boundaries, where stresses cause rocks to deform.

LESSON 2 1.e, 1.f, 7.a, 7.b, 7.e

California Geology

Main Idea Many of California's landforms were produced by plate tectonic activity, which continues today.

Whose fault is it?

California and Nevada share more than just a border—they share faults. The fault shown in this photo lies within the Sierra Nevada. About 25 million years ago, the Sierra Nevada started to rise and tilt to the west. Rivers cut deep canyons. Uplift of the Sierra Nevada continues today, especially along its eastern side. This uplift causes faults and large earthquakes.

Science Journal Imagine you are an explorer and it is 1776. On your expedition, you see the Sierra Nevada for the first time. Write your description of the mountains and your thoughts as you view these mountains.

Roger Ressmeyer/CORBIS

Launch Lab

00:10 minutes

How do objects deform?

Depending on what they are made of and how stress is applied to them, solids can change shape, or deform. What will happen to objects when you place a force on them?

Procedure

1. Complete a lab safety form.
2. Obtain a **small stick,** a **paper clip,** and a **small rubber band.**
3. Observe what happens when you bend or stretch each object with your hands.
4. Experiment with the bending and stretching at different rates.

Think About This

- **Describe** the ways each object deformed.
- **Determine** which objects remained deformed after forces were removed.

1.d, 7.e

Try at Home

Science Online

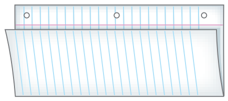
Visit ca6.msscience.com to:

- view Concepts in Motion
- explore Virtual Labs
- access content-related Web links
- take the Standards Check

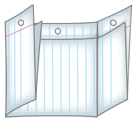
FOLDABLES™ Study Organizer

Plate Boundaries Make the following Foldable to help you visualize information about plate boundaries.

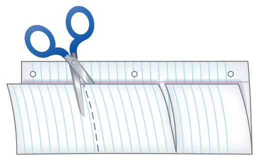
STEP 1 **Fold** a sheet of paper in half lengthwise. Make the back edge about 2 cm longer than the front edge.



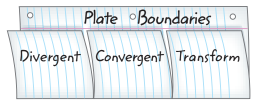
STEP 2 **Fold** into thirds.



STEP 3 **Unfold** and **cut** along the folds of the top flap to make three flaps.



STEP 4 **Label** the flaps as shown.



Reading Skill ELA6: R 2.4

Visualizing

As you read this chapter, visualize each type of plate boundary and draw it under its tab. Then give examples of places in California where each type of plate boundary can be found.

Matt Meadows

Get Ready to Read

Visualize

1 Learn It! Visualize by forming mental images of the text as you read. Imagine how the text descriptions look, sound, feel, smell, or taste. Look for any pictures or diagrams on the page that may help you add to your understanding.

2 Practice It! Read the following paragraph. As you read, use the underlined details to form a picture in your mind.

> When two plates are moving apart, tension <u>pulls lithosphere apart</u> so that it <u>stretches and becomes thinner</u>. This stretching and thinning is the deformation that results from tension stress.
>
> —*from page 211*

Based on the description above, try to visualize tension stress. Now look at the diagram on page 211.

- How closely does it match your mental picture?
- Reread the passage and look at the picture again. Did your ideas change?
- Compare your image with what others in your class visualized.

3 Apply It! Read the chapter and list three subjects you were able to visualize. Make a rough sketch showing what you visualized.

Target Your Reading

Use this to focus on the main ideas as you read the chapter.

1. **Before you read** the chapter, respond to the statements below on your worksheet or on a numbered sheet of paper.
   - Write an **A** if you **agree** with the statement.
   - Write a **D** if you **disagree** with the statement.
2. **After you read** the chapter, look back to this page to see if you've changed your mind about any of the statements.
   - If any of your answers changed, explain why.
   - Change any false statements into true statements.
   - Use your revised statements as a study guide.

Reading Tip

Forming your own mental images will help you remember what you read.

Before You Read A or D	Statement	After You Read A or D
	1 Part of California will eventually break off and fall into the Pacific Ocean.	
	2 The San Andreas Fault is part of a plate boundary.	
	3 Plate boundaries extend deep into Earth's lithosphere.	
	4 Subduction occurs when oceanic and continental lithospheric plates move toward each other.	
	5 Mountains in western South America result from a continent-to-continent convergent plate boundary.	
	6 Faults are surfaces where rocks break and move.	
	7 Los Angeles and San Francisco are moving closer to one another because of a transform plate boundary.	
	8 When rocks are subjected to compression stress, they become thinner.	
	9 The Cascade Range forms on a divergent plate boundary.	

Science Online

Print a worksheet of this page at ca6.msscience.com.

Science Content Standards

1.c Students know lithospheric plates the size of continents and oceans move at rates of centimeters per year in response to movements in the mantle.
1.d Students know that earthquakes are sudden motions along breaks in the crust called faults and that volcanoes and fissures are locations where magma reaches the surface.
1.e Students know major geologic events, such as earthquakes, volcanic eruptions, and mountain building, result from plate motions.
Also covers: 7.g

Reading Guide

What *You'll* Learn

- **Describe** types of stress that deform rock.
- **Relate** geologic features of Earth's surface to types of plate boundaries.

Why *It's* Important

Understanding geologic events that occur at plate boundaries can save lives and prevent damage to property.

Vocabulary

fracture
fault
divergent plate boundary
continental rifting
rift valley
convergent plate boundary
subduction
transform plate boundary

Review Vocabulary

lithospheric plate: large, brittle pieces of Earth's outer shell composed of crust and uppermost mantle (p. 183)

Interactions at Plate Boundaries

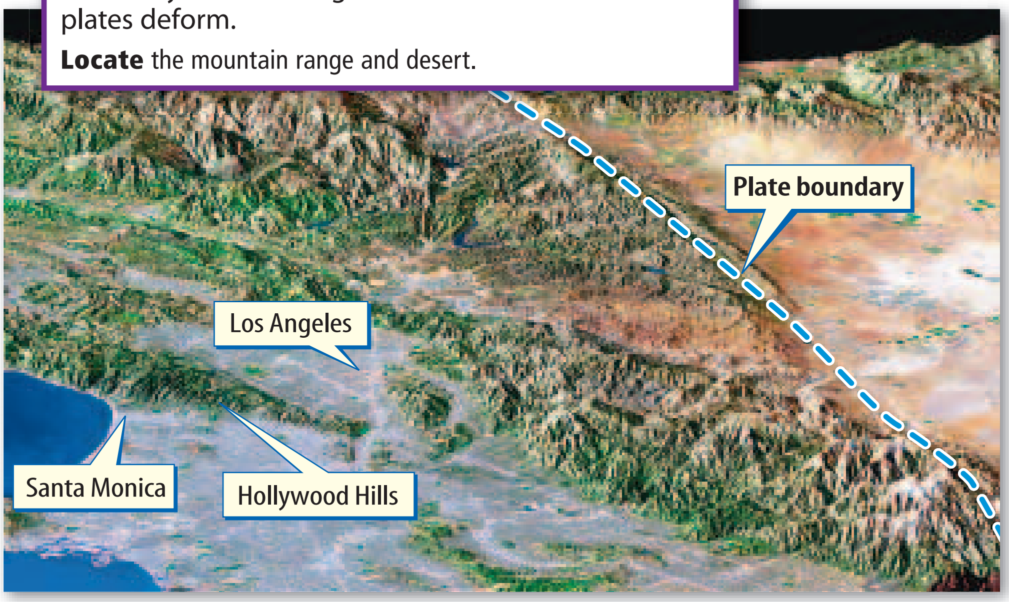
Main Idea There are three main types of plate boundaries, where stresses cause rocks to deform.

Real-World Reading Connection Have you ever been stuck in traffic on the freeway? Often, there are bumper-to-bumper cars moving slowly. If all the drivers carefully go the same speed and in the same direction, there are no crashes. But, if a car slows down, speeds up, or turns, there can be a collision, causing crumpled vehicles. Like cars in traffic, Earth's plates can also collide and deform.

Stress and Deformation

In Chapter 4, you read how Earth's lithosphere—made partly of crust and partly of upper mantle—is broken into plates. These plates are packed together more closely than cars in traffic. They also travel at different speeds and in different directions, so there are collisions. Earth's plates move very slowly, not like cars on the freeway. They are so massive that their collisions are very powerful. Such interactions cause stress at plate boundaries. And, like crashing cars, the stresses cause deformation, as shown in **Figure 1.**

Figure 1 This satellite image shows part of a plate boundary near Los Angeles. Mountains are formed as plates deform.
Locate the mountain range and desert.



Deforming Rocks

It's hard to imagine, but rocks sometimes can bend under stress without breaking. When rocks are stressed at high temperatures and pressures, they can change shape permanently by folding. Scientists call this plastic deformation. Rocks are more likely to deform in a plastic way when stresses are applied to them slowly, or at high temperatures. Sometimes, rocks can snap back to their original shapes after stress is removed, which is called elastic deformation.

Maybe you've found a rock and you wanted to see what it looked like on the inside. If you placed stress on the rock by breaking it with a hammer, you caused the rock to deform in a brittle way. A break, or crack, in rock is called a **fracture**. In nature, if the rocks on one side of a fracture have moved relative to the rocks on the other side, the fracture is a **fault**.

Types of Stress

Three main types of stress can cause faulting. Rocks experience forces that can produce tension, compression, or shear stress. You can explore this in **Figure 2.** It is important to understand that combinations of these stresses are common in nature. Also, a particular type of stress can cause more than one type of fault.

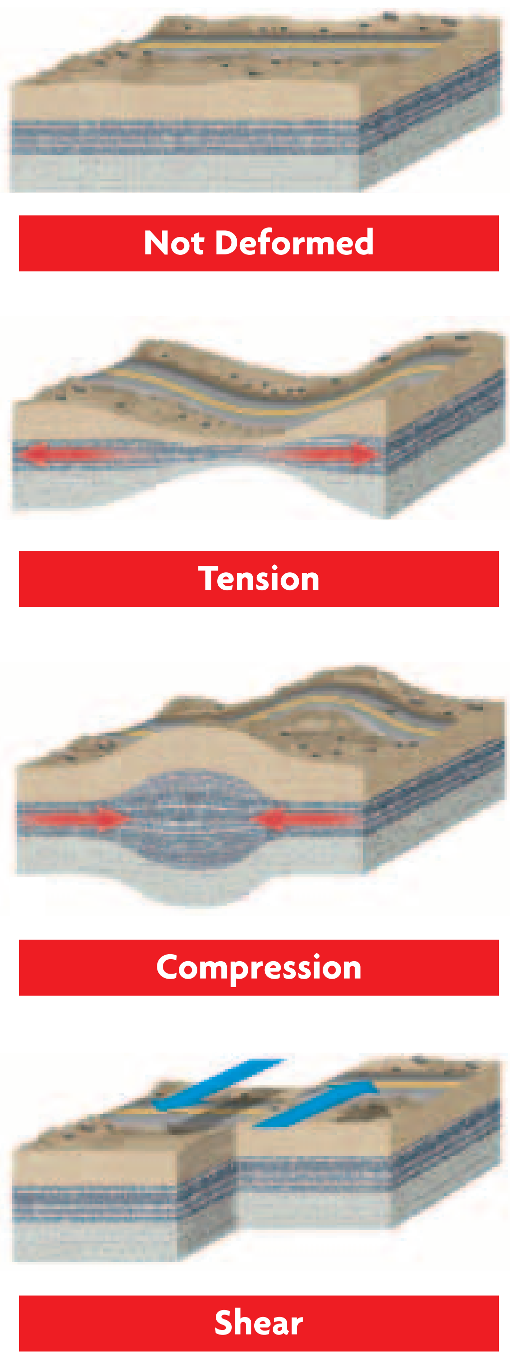
Tension The top diagram in **Figure 2** shows layered rocks that are not deformed. When two plates are moving apart, tension pulls lithosphere apart so that it stretches and becomes thinner. This stretching and thinning is the deformation that results from tension stress.

Compression If rocks are squeezed, as shown in **Figure 2,** the stress is called compression. Where two lithospheric plates are forced together, compression makes the rocks thicker.

Shear When rocks slide horizontally in opposite directions, the stress is called shear. The lithosphere neither thins nor thickens as a result of shear stress.

Figure 2 Three main types of stress are tension, compression, and shear.

Demonstrate tension stress using a rubber band or putty.



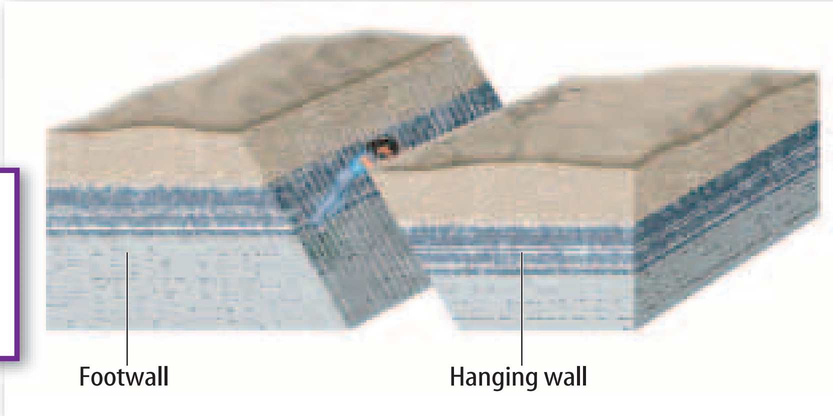


Figure 3 If a fault's surface is inclined, the block of rock above the fault is the hanging wall, and the block of rock below the fault is the footwall.

Types of Faults

Examining a fault helps scientists determine the stresses that caused it. Geologists measure the angle of the fault's surface and try to determine which way the broken sections of the rock have moved. They look for objects that were broken by the fault to determine which direction the rocks moved.

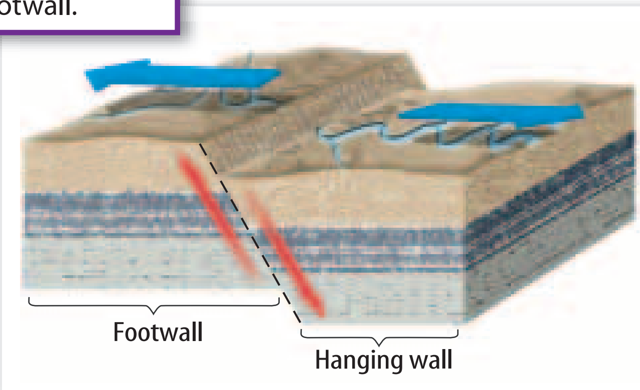
Academic Vocabulary
inclined (in KLIND)
(adjective) sloping, slanting, or leaning relative to the horizontal or vertical
The slide at the swimming pool is inclined about 30° from the horizontal.

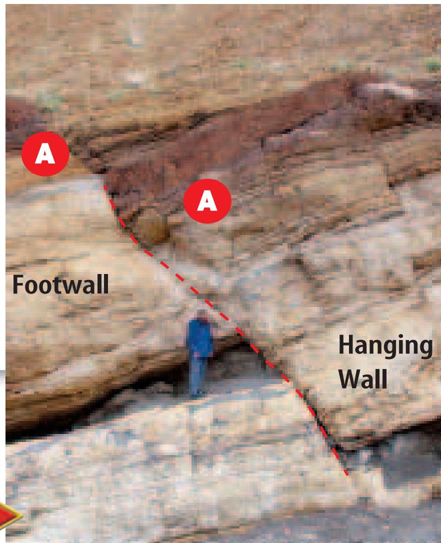
Figure 3 shows an **inclined** fault surface cutting across rocks. Imagine that the rocks were pulled apart at the fault's surface so you could fit between them. If you were to reach up, you could touch the hanging wall. The hanging wall is the block of rock that lies above the fault from which you would be able to hang. The block of rock that lies below the fault is called the footwall. You can imagine stepping on the footwall if the blocks of rock were separated.

Visual Check **Figure 3** Compare and contrast a hanging wall and a footwall to the ceiling and the floor of your home.

Normal Faults The rocks along faults can move up, down, or sideways. Tension stresses inside Earth pull rock apart, producing normal faults. Normal faults slope at an angle, such as the fault in Death Valley, shown in **Figure 4.** When rock breaks and slips along a normal fault, the hanging wall moves down the footwall.

Figure 4 This is a normal fault in Death Valley, California. The fault is the break in the rocks just above the person's head. The labeled rock layers show how the hanging wall block has moved down the footwall.





(t)CORBIS, (b)Roger Ressmeyer/CORBIS

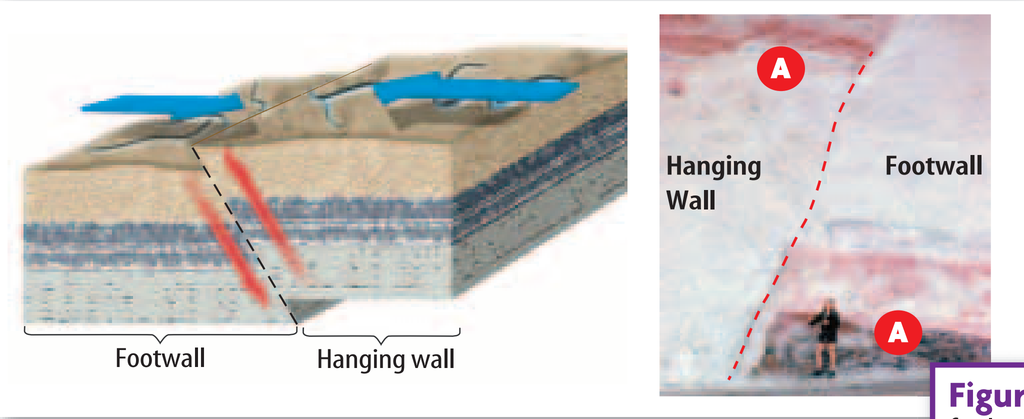


Figure 5 Reverse faults look like normal faults, but their motions are different. The labeled rock layers show how the hanging wall block has moved up the footwall.
Explain how the footwall has moved relative to the hanging wall.

Reverse Faults In places where rocks are pushed together, compression stresses produce reverse faults. A reverse fault looks similar to a normal fault, but the blocks of rock move differently. As rocks are pushed together, the hanging wall moves up the footwall. **Figure 5** shows the direction of movement along a reverse fault in the Appalachian Mountains.

Reading Check How does the movement of rock along a reverse fault differ from the movement along a normal fault?

Strike-Slip Faults When plates slide horizontally past each other, shearing stresses produce strike-slip faults. Unlike normal and reverse faults, strike-slip faults often are vertical, not inclined. Instead of moving mostly up or down, the rocks slide past each other sideways, or horizontally.

In **Figure 6,** a small strike-slip fault has broken the asphalt on the road. Imagine standing on the white road lines on one side of this fault. The road lines that are across the fault from you have moved to your right compared to the lines you are standing on. Analyzing movement along a fault like this one helps scientists determine the stresses that caused the faulting.

Figure 6 A small strike-slip fault broke the asphalt on this road. The rocks did not move up or down, but slid past each other.

MiniLab

Try at Home

00:25 minutes

How can you model movement of a fault?

A fault is formed when rocks are deformed to the point of breaking, and movement occurs along the break. Scientists observe the movement of faults in nature. This allows them to determine the types of stresses that caused the faulting.

Procedure

1. Read and complete a lab safety form.
2. Cut a **shoe box lid** in half along its width.
3. Turn the **shoe box** over. The bottom of the box will represent the surface of Earth.
4. Use **scissors** to cut the shoe box in half along its width. Cut at an angle to model an inclined fault surface. Examine **Figures 4, 5,** and **6** for examples of how faults look in three dimensions.
5. **Tape** the two halves of the shoe box lid over the shoe box halves to make the fault slope.
6. Model fault movement for a normal, a reverse, and a strike-slip fault.
7. Challenge option: Use **poster paints** to paint rock layers on a side of the shoe box before it is cut to see how the layers move relative to each other.

Analysis

1. **Illustrate** fault movement for each scenario. Use arrows to show how the shoe box halves move relative to each other.
2. **Relate** a type of stress to each of the fault types that you modeled. Use arrows to indicate the directions of stress on your illustrations.

Science Content Standards

1.d Students know that earthquakes are sudden motions along breaks in the crust called faults and that volcanoes and fissures are locations where magma reaches the surface.
7.g Interpret events by sequence and time from natural phenomena (e.g., the relative ages of rocks and intrusions).

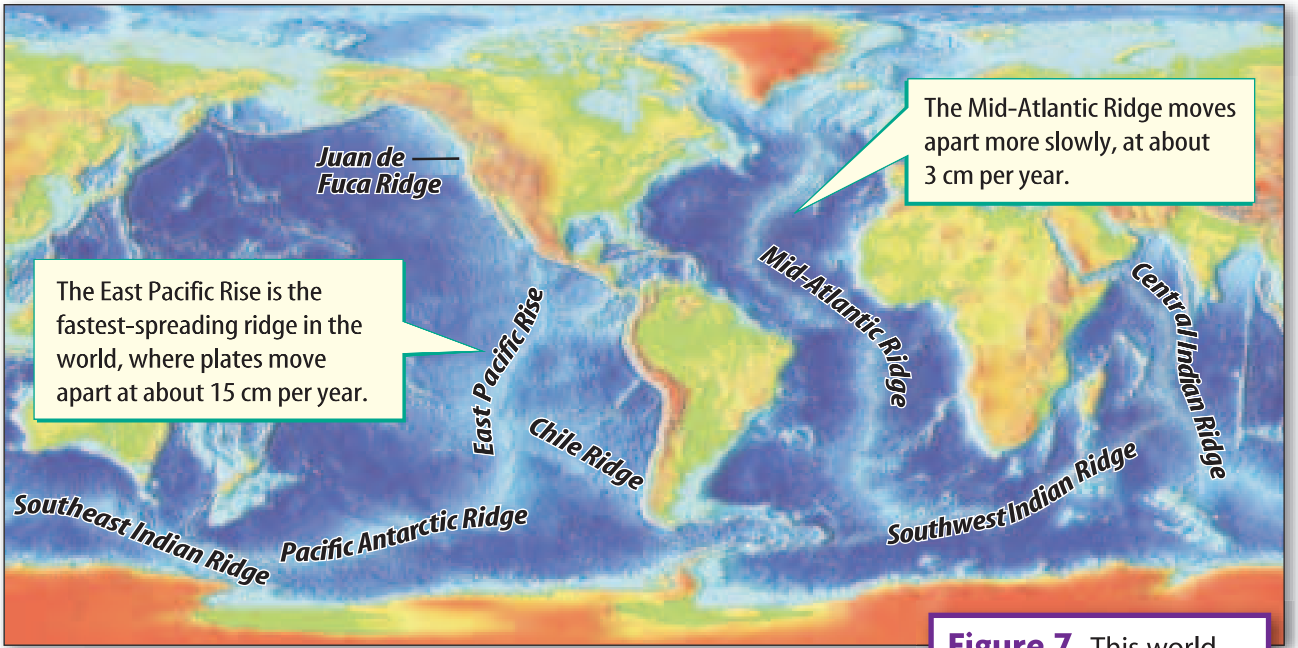


Figure 7 This world map shows the locations of mid-ocean ridges.

Locate a region where a mid-ocean ridge emerges above sea level.

Types of Plate Boundaries

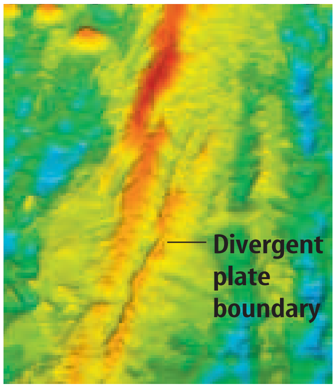
The edges of Earth's plates meet at plate boundaries that extend deep into the lithosphere. Faults form along these boundaries. Like faults, there are three major types of plate boundaries. They are classified according to how rocks on either side of the plate boundary move. The kinds of geologic features that form depend on the type of plate boundary and the stresses generated along the boundary.

Divergent Plate Boundaries

When two lithospheric plates are moving, or pulling apart, it is called a **divergent plate boundary.** Mid-ocean ridges, shown in **Figure 7,** occur along divergent plate boundaries. As the two plates move apart, new seafloor forms. Tension stresses stretch and thin the lithosphere and cause earthquakes to occur when rocks break and move.

Mid-Ocean Ridges **Figure 8** shows an example of a mid-ocean ridge—the East Pacific Rise. Notice that the seafloor located farther from a divergent plate boundary is deeper underwater than the seafloor near the ridge. This is because as rock cools and contracts it becomes denser and moves away from the center of the ridge. It is difficult for scientists to study mid-ocean ridges because they are about 2 km below sea level.

Figure 8 Mid-ocean ridges, such as the East Pacific Rise, are topographic features on the seafloor.



Continental Rifting Most divergent plate boundaries are located on the seafloor. But, divergent plate boundaries can also form on land when a continent is pulled apart. The process that pulls a continent apart is called **continental rifting.** This is shown in **Figure 9.**

Remember that divergent plate boundaries form where tension stresses cause the lithosphere to stretch and become thinner. Tension stresses in the lithosphere form normal faults. As the hanging wall blocks slip down, a long, flat, narrow **rift valley** forms.

Reading Check How does a rift valley form?

Sediment collects on the floor of the rift valley. Oceanic crust made of gabbro and basalt is formed, which is dense and causes the valley to sink. Eventually, ocean water flows into the valley. There are places on Earth today where scientists can directly observe continents rifting.

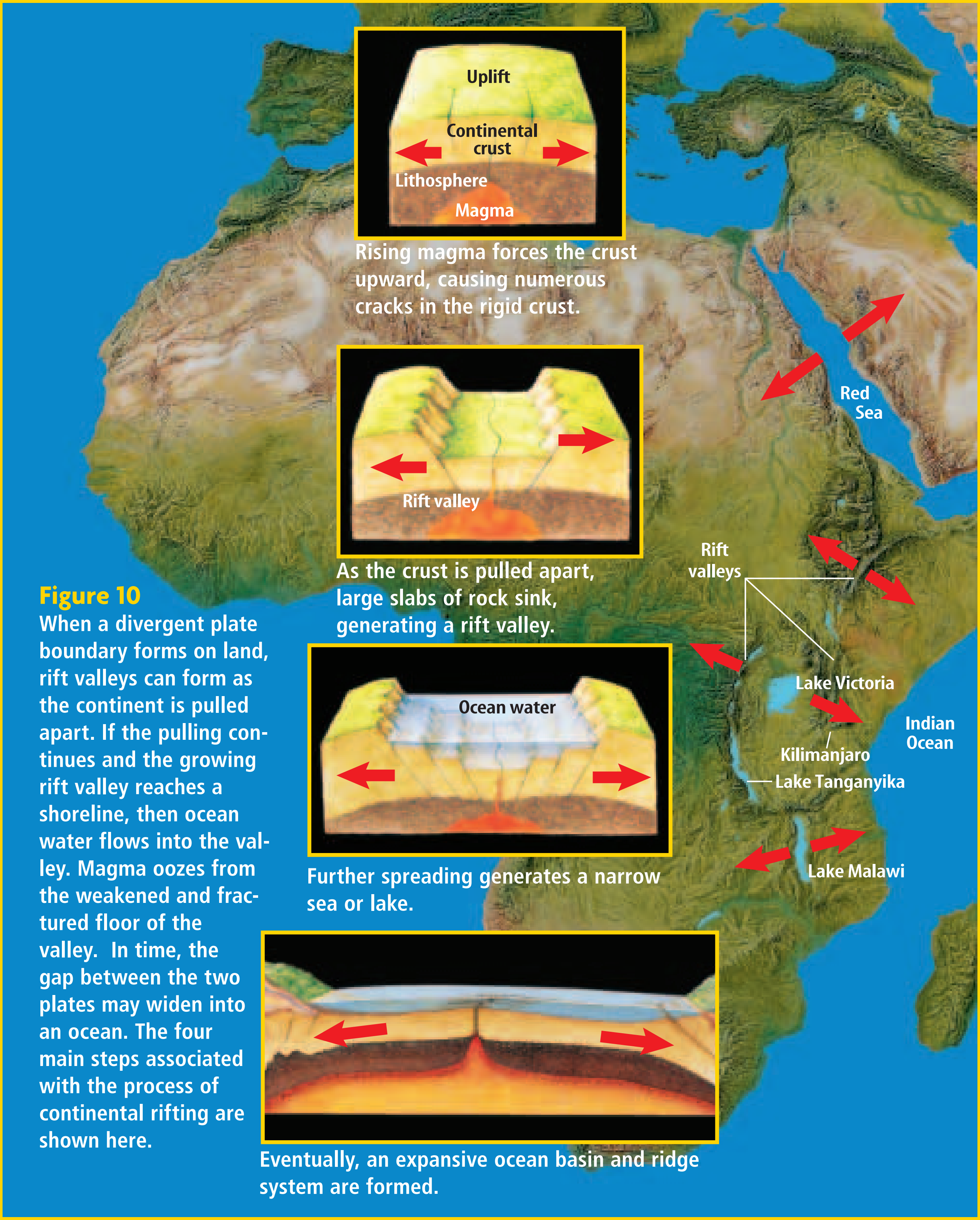
Visual Check **Figure 9** Identify the numerous cracks and rift valley of the East African Rift.

Examples of Continental Rifting The East African Rift cuts across the eastern side of Africa for 5,600 km. It is a rift valley where crust is being pulled apart and large slabs of rock are sinking. This generates a rift zone, which is shown in **Figure 10.** If continental rifting continues, then East Africa will eventually part from West Africa.

The Gulf of California is also an example of continental rifting. The bottom of the rift valley has dropped low enough so that ocean water now fills it.

Figure 9 This photo shows how the African continent is separating along the East African Rift.

Visualizing Rift Valleys



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 valley.

Further spreading generates a narrow sea or lake.

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

Figure 10 When a divergent plate boundary forms on land, rift valleys can form as the continent is pulled apart. If the pulling continues and the growing rift valley reaches a shoreline, then ocean water flows into the valley. Magma oozes from the weakened and fractured floor of the valley. In time, the gap between the two plates may widen into an ocean. The four main steps associated with the process of continental rifting are shown here.

Contributed by National Geographic

Convergent Plate Boundaries

A **convergent plate boundary** is formed when two lithospheric plates move toward each other. Interactions between the two lithospheric plates depend upon whether the plates are composed of continental or oceanic lithosphere. There are three possible types of interactions. Both plates can be made of oceanic lithosphere, one plate can be oceanic and the other continental, or two plates with continental lithosphere can converge. In all cases, large earthquakes occur and new geologic features form.

Word Origin
boundary
from Latin *boudina;* means *boundary, boundary marker*

Ocean-to-Ocean Where two oceanic plates move toward each other, one of the plates sinks beneath the other, as shown in the top diagram of **Table 1.** This process, in which one plate is forced down into the mantle beneath another plate, is called **subduction.** The density of the plate determines which plate subducts. Generally, the colder, older, denser slab is forced down into the mantle, forming a deep ocean trench on the seafloor where it bends.

Reading Check What forms on the seafloor where a slab bends?

As it sinks deeper into the mantle, high temperatures and pressures release water from minerals in the slab. Where this water rises up into the mantle, it causes mantle rocks to melt. This forms a supply of magma for volcanic eruptions, producing a curved line of volcanoes in the overlying plate.

Ocean-to-Continent If one of the converging plates is oceanic and the other is continental, the oceanic plate always subducts. Most continental rocks are less dense than oceanic rocks. In **Table 1,** the second diagram shows the oceanic plate subducting underneath the continental plate. The melting that results forms a curved string of volcanoes along the leading edge of the overlying continental plate.

Continent-to-Continent Which plate subducts when two plates made from continental rocks collide? Rocks, like granite and shale, aren't dense enough to sink into the mantle, so neither continental plate subducts. Instead, compression stresses force crust to rise up, thicken, and shorten. You can imagine this shortening if you try pushing a stack of paper together from two opposite ends. In nature, the leading edges of colliding continents are uplifted, forming tall mountains.

Concepts In Motion

Interactive Table Organize information about convergent plate boundaries at ca6.msscience.com.

Table 1 Types of Convergent Plate Boundaries

<table>
<tr><th>Boundary Type</th><th>Description</th></tr>
<tr><td>

Ocean-to-Ocean

- Older, colder oceanic plate subducts.
- Magma forms in mantle above subducted slab.
- Curved line of volcanoes forms as magma makes its way to Earth's surface.
- example: Marianas Islands

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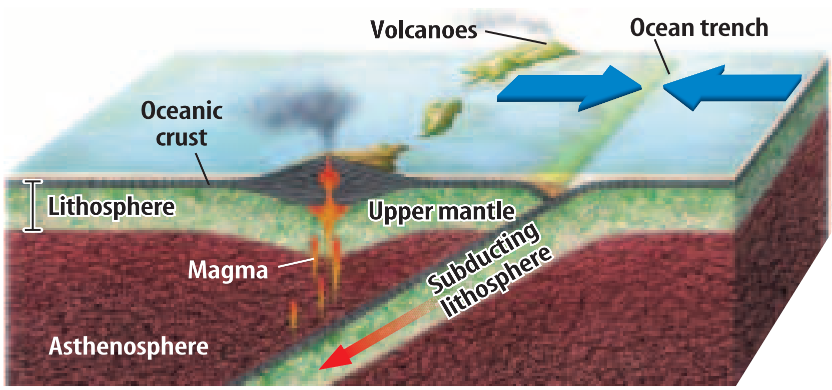

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Ocean-to-Continent

- Oceanic plate subducts beneath continental plate.
- Magma forms in mantle above subducted slab.
- A string of volcanoes forms along the leading edge of the continent.
- example: Cascade Range

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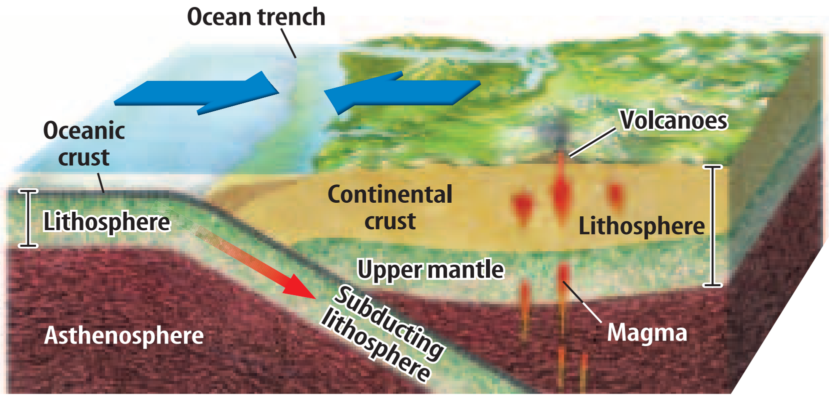

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Continent-to-Continent

- Neither continental plate subducts.
- Continental crust rises up, thickens, and shortens due to compression stresses.
- Uplift of lithosphere forms tall mountains.
- example: Himalayas

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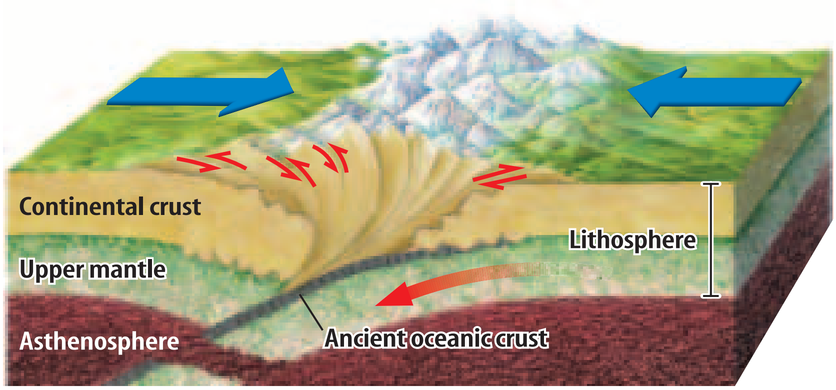

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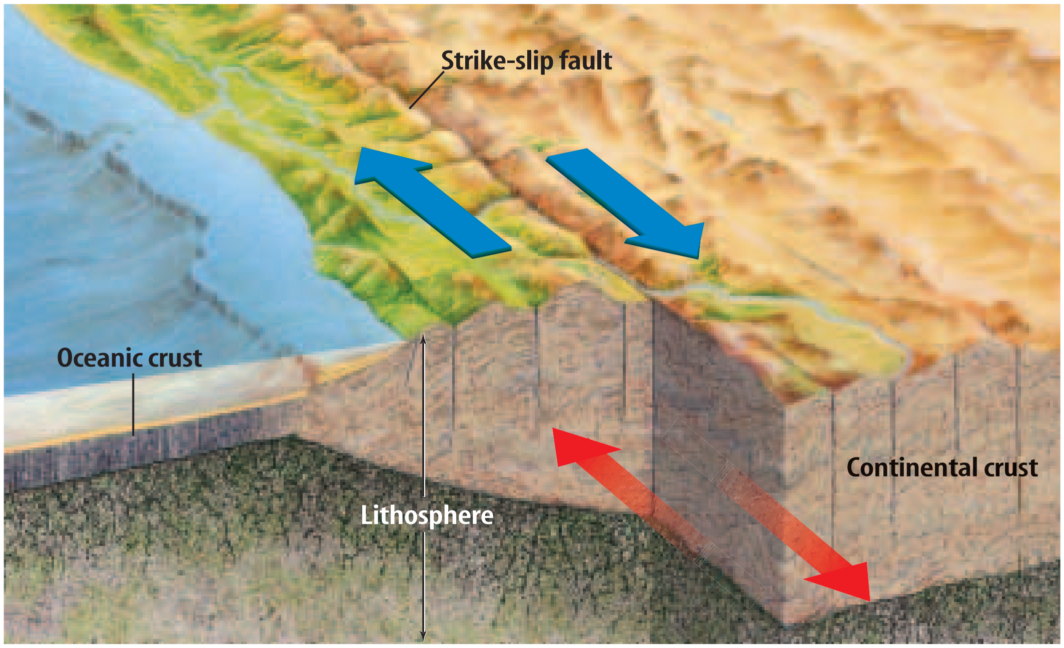
Figure 11 At a transform plate boundary, motion is mostly parallel to Earth's surface.



Transform Plate Boundaries

Where two plates slide horizontally sideways past one another, a **transform plate boundary** exists. Lithosphere is neither formed nor recycled at these boundaries. **Figure 11** shows how a transform plate boundary is similar to a huge strike-slip fault. When the plates slide sideways past each other and eventually slip, rocks break, causing earthquakes.

Oceanic Oceanic transform plate boundaries connect pieces or segments of the mid-ocean ridges. The ridges are not completely straight but made of many shorter pieces. Most oceanic transform boundaries are relatively short. But, there are a few long transform boundaries on Earth. These are located on the continents.

Reading Check What connects segments of the mid-ocean ridges?

Continental Some transform plate boundaries slice through continental lithosphere as huge strike-slip faults. Earthquakes resulting from movement along these faults can be very destructive if they occur in populated areas.

The San Andreas Fault in California is the best-studied continental transform plate boundary in the world. Most of California lies on the North American Plate. But, a small portion of California, west of the San Andreas Fault, lies on the Pacific Plate. The continental transform plate boundary separates these two plates.

SCIENCE USE V. COMMON USE
fault
Science Use a fracture where rocks on one side have moved relative to the rocks on the other side. *The movement along the fault produced a large earthquake.*
Common Use error or mistake. *The accident was the driver's fault.*

Deformation and Plate Boundaries

You've read how stresses can cause rocks to deform. Deformation leaves clues for scientists to use when unraveling Earth's complicated history such as fractures and faults. Analyzing how rocks bend and break helps scientists determine the types of stresses exerted on them. From these data, the direction and distance that the lithospheric plates have moved and the way they have interacted at plate boundaries can be determined.

LESSON 1 Review

Summarize

Create your own lesson summary as you design a **visual aid.**

1. **Write** the lesson title, number, and page numbers at the top of your poster.
2. **Scan** the lesson to find the **red** main headings. Organize these headings on your poster, leaving space between each.
3. **Design** an information box beneath each **red** heading. In the box, list 2–3 details, key terms, and definitions from each **blue** subheading.
4. **Illustrate** your poster with diagrams of important structures or processes next to each information box.

ELA6: R 2.4

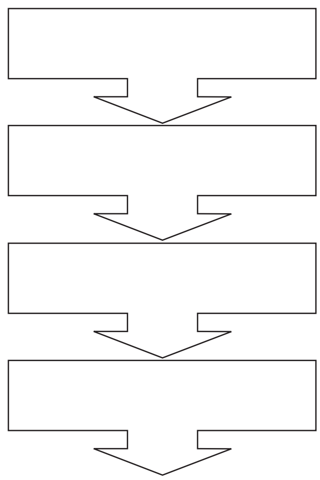
Standards Check

Using Vocabulary

1. Distinguish between *fracture* and *fault*. 1.d
2. In your own words, write a definition for *rift valley*. 1.e

Understanding Main Ideas

3. Which of the following best describes the direction of movement of rock along a strike-slip fault? 1.d
   A. downhill
   B. uphill
   C. sideways
   D. vertical
4. **List** three different types of faults. 1.d
5. **Classify** three types of convergent plate boundaries based on the densities of the plates involved. 1.c
6. **Relate** the three major types of plate boundaries to types of stress expected at these boundaries. 1.e
7. **Sequence** Draw a diagram to show the stages of continental rifting. 1.e



Applying Science

8. **Predict** whether Iceland will become larger or smaller in the future. Defend your prediction. 1.e
9. **Decide** if you would rather live close to a plate boundary or far away from one. Explain your decision. 1.e

Science Online
For more practice, visit **Standards Check** at ca6.msscience.com.

Applying Math

Speed of Lithospheric Plates

1.c

MA6: NS 1.2, AF 2.3

Earth's lithospheric plates move at rates of centimeters per year. Plate movement can be measured in an absolute speed that is approximated in the table.

Approximate Speed of Lithospheric Plates

Name of Plate	Approximate Speed (cm/yr)
Antarctic	2.05
African	2.15
Arabian	4.65
Caribbean	2.45
Cocos	8.55
Eurasian	0.95
Indian-Australian	6.00
Nazca	7.55
North American	1.15
Pacific	8.10
Philippine	6.35
South American	1.45

How much faster is the Caribbean Plate moving than the Antarctic Plate?

What you know:

- Caribbean Plate velocity: 2.45 cm/yr
- Antarctic Plate velocity: 2.05 cm/yr

What you need to find:

- How much faster is the Caribbean Plate moving than the Antarctic Plate?

Divide the faster speed by the slower speed to find how many times faster:

1. $\frac{2.45}{2.05}$
2. approximately 1.20 cm/yr

The Caribbean Plate is moving at a rate of about 1.20 times faster than the Antarctic Plate.

Practice Problems

1. Approximately how much faster is the Pacific Plate moving than the Eurasian Plate?
2. Approximately how many more centimeters per year does the Indian-Australian Plate move than the North American Plate?

Science Online
For help visit ca6.msscience.com.

LESSON 2

California Geology

Science Content Standards

1.e Students know major geologic events, such as earthquakes, volcanic eruptions, and mountain building, result from plate motions.
1.f Students know how to explain major features of California geology (including mountains, faults, volcanoes) in terms of plate tectonics.
7.a Develop a hypothesis.
7.b Select and use appropriate tools and technology (including calculators, computers, balances, spring scales, microscopes, and binoculars) to perform tests, collect data, and display data.
Also covers: 7.e

Reading Guide

What *You'll Learn*

- **Describe** California's current plate tectonic setting and how plate movements have produced landforms.
- **Predict** future changes in California's tectonic setting and topography.

Why *It's Important*

Interactions between the North American Plate and the Pacific Plate produce California's mountains and basins and cause earthquakes and volcanoes.

Vocabulary

San Andreas Fault

Review Vocabulary

uplift: any process that moves Earth's surface to a higher elevation (p. 79)

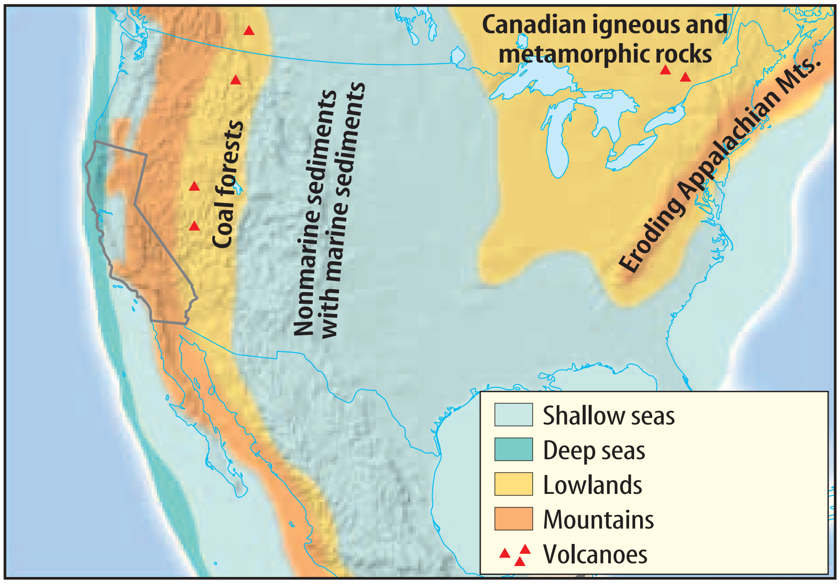
Main Idea Many of California's landforms were produced by plate tectonic activity, which continues today.

Real-World Reading Connection Have you ever gone back to a former home or an old favorite spot—one that you haven't visited for a long time? Had things changed from the way you remembered them? Similarly, California geology has changed much over millions of years.

Plate Tectonics in California

As shown in **Figure 12,** California's landscape is different now compared to how it was in the past. Movements of plates have changed California dramatically. Seas have disappeared. While old mountains have eroded away, new mountains have been uplifted. Plate boundaries have formed and then disappeared. Today, a continental transform plate boundary cuts across the state. At the northern end of California, a convergent plate boundary sits offshore. This active plate tectonic setting produces earthquakes, volcanoes, and mountains.

Figure 12 This is what scientists think California might have been like 80 million years ago, a time when dinosaurs roamed Earth. Many parts of the state were covered by shallow seas. Tall mountains stood where valleys now exist.



ACADEMIC VOCABULARY

adjacent (ad JAY sunt)

(adjective) not distant, nearby

The city and adjacent suburbs were placed under a tornado warning.

Transform Plate Boundary

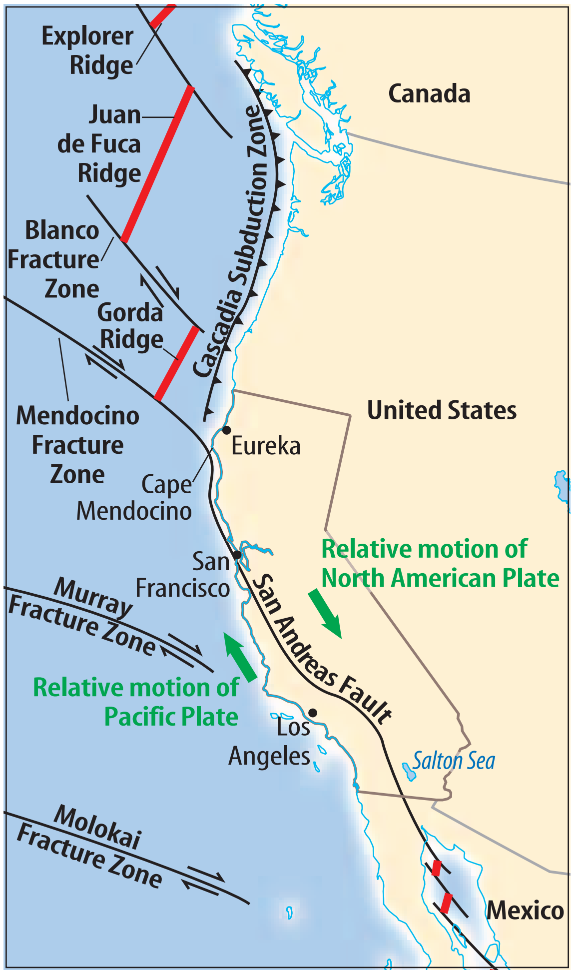
Most of California is situated on the North American Plate. A small part of California, west of the San Andreas Fault, lies on the **adjacent** Pacific Plate. The Pacific Plate moves northwest, relative to the North American Plate, at a velocity of about 3.4 cm per year. The plate does not slide smoothly, but sticks much of the time and moves in jerks. Each time a jerky movement occurs, an earthquake happens.

The **San Andreas Fault** is a transform plate boundary that is located between the North American Plate and the Pacific Plate. Because the San Andreas Fault is a transform plate boundary, it is also a strike-slip fault. **Figure 13** shows how the San Andreas Fault extends all the way from Cape Mendocino in the north to the Salton Sea in the south.

Figure 13 also shows that the San Andreas Fault is not a straight line. Where there are bends in the fault, blocks of rock get pushed up or drop down, making mountains or basins. The Transverse Ranges and the Coastal Ranges of California have been pushed up as the Pacific Plate moves past the North American Plate. The Los Angeles Basin, the Venture Basin, and the San Francisco Bay are all blocks of rock that have dropped down.

Figure 13 The San Andreas Fault extends out to sea north of Cape Mendocino. There it becomes an oceanic transform plate boundary.

Describe the relative motion of the Pacific Plate to the North American Plate.



Convergent Plate Boundary

Just offshore of Northern California, there are two small oceanic lithospheric plates. **Figure 13** shows where these plates, known as the Gorda and Juan de Fuca, are subducted beneath the coast at the Cascadia Subduction Zone. This subduction forms a convergent plate boundary. Melting above this subduction zone produces the volcanic mountains of the Cascade Range.

California's Mountains

California's mountains often formed from interactions at several plate boundaries. For example, as rocks on one side of a transform plate boundary grind and push against the rocks on the other plate, mountains, such as the Transverse Ranges, can form.

Subduction

California's convergent plate boundaries, both in the past and present, have been important in forming California's mountains. Granitic rocks form under volcanic mountains where plates converge. And, during mountain building, compressive stresses and heat produce metamorphic rocks. The Klamath Mountains, Coastal Ranges, Peninsular Ranges, and Sierra Nevada all contain igneous and metamorphic rocks that formed far below the surface.

Reading Check List two rock types that form far below Earth's surface.

In continental lithosphere above the Cascadia Subduction Zone in northern California, granitic rocks are forming deep in the crust. At the same time, volcanic activity produces the Cascade Range on the surface. Both Lassen Peak and Mount Shasta are active volcanoes in this mountain range.

Rifting

There are even some mountains in California that have formed because of tension stresses. The Panamint Range just west of Death Valley is rising up as the crust in eastern California stretches. Locate all these mountain ranges on **Figure 14.** Mountains help scientists understand processes that are part of California's rich tectonic history.

Figure 14 Interactions at several plate boundaries have formed mountains ranges in California.
Locate a mountain that formed as a result of subduction.

Future Plate Movement

How will California's landscape change in the future? Scientists can estimate the directions and speeds that the plates are moving. They can predict future plate boundary interactions. For example, the small part of California that is on the Pacific Plate, including Los Angeles, will continue moving northwest along the coast relative to the North American Plate. This means that Los Angeles and San Francisco are approaching each other about as fast as your fingernail grows.

LESSON 2 Review

Summarize

Create your own lesson summary as you design a **study web.**

1. **Write** the lesson title, number, and page numbers at the top of a sheet of paper.
2. **Scan** the lesson to find the **red** main headings.
3. **Organize** these headings clockwise on branches around the lesson title.
4. **Review** the information under each **red** heading to design a branch for each **blue** subheading.
5. **List** 2–3 details, key terms, and definitions from each **blue** subheading on branches extending from the main heading branches.

ELA6: R 2.4

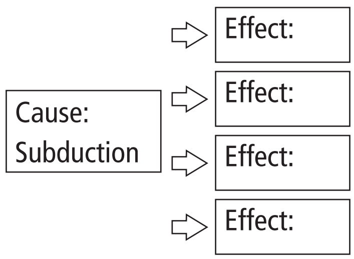
Standards Check

Using Vocabulary

1. The ______ is located between the North American Plate and the Pacific Plate. **1.f**

Understanding Main Ideas

2. In California, which direction is the Pacific Plate moving relative to the North American Plate? **1.f**
   - **A.** east
   - **B.** northeast
   - **C.** northwest
   - **D.** west
3. **Explain** how uplift can occur at all types of plate boundaries. **1.e**
4. **Identify** a California mountain range that formed as a result of tension stress. **1.f**
5. **Relate** the San Andreas Fault to a main type of stress. **1.f**
6. **Determine Cause and Effect** Draw a diagram like the one below. List some effects of subduction. **1.e**



Applying Science

7. **Predict** what type of plate boundary will exist in northern California after the Juan de Fuca and Gorda Plates are completely subducted. Hint: Examine **Figure 13.** **1.f**

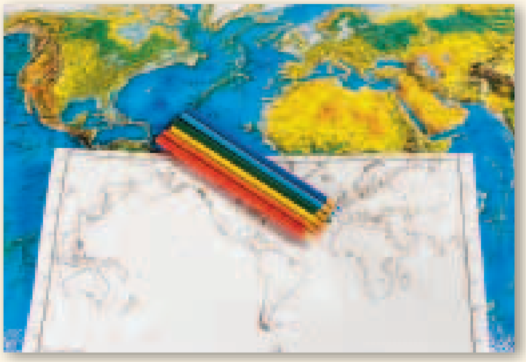
Science Online

For more practice, visit **Standards Check** at ca6.msscience.com.

DataLab

00:30 minutes

How do landforms define plate boundaries?



Earth's surface is made up of interacting plates. What landforms occur near plate boundaries? How do these landforms indicate where a plate boundary is?

Data Collection

1. Examine a topographic or raised relief map of the world.
2. Obtain a blank world map from your teacher.
3. Locate some of Earth's mountain ranges on your map. Color them purple.
4. Locate some major fault zones that occur on Earth's surface. Color them red.
5. Locate some areas of recent volcanic activity. Color them orange.

Data Analysis

1. **Compare** your locations of mountain ranges and volcanic activity to a plate boundary map.
2. **Determine** the approximate widths of mountain ranges and fault zones you investigated.
3. **Relate** your answers to questions 1 and 2 to the role of plate boundaries in shaping Earth's topography.
4. **Explain** the existence of some mountain ranges today that aren't located near a plate boundary.

Science Content Standards

1.e Students know major geologic events, such as earthquakes, volcanic eruptions, and mountain building, result from plate motions.

7.e Recognize whether evidence is consistent with a proposed explanation.

MA6: MR 2.1, MR 2.3

Design Your Own Lab

Use the Internet:
Earthquake Depths and Plate Boundaries

Materials

world map with latitude and longitude lines
plate boundary map
graph paper
computer with internet access

Science Content Standards

1.e Students know major geologic events, such as earthquakes, volcanic eruptions, and mountain building, result from plate motions.
7.a Develop a hypothesis.
7.b Select and use appropriate tools and technology (including calculators, computers, balances, spring scales, microscopes, and binoculars) to perform tests, collect data, and display data.
7.e Recognize whether evidence is consistent with a proposed explanation.

Problem

Not all earthquakes occur at the same depth in the lithosphere. Use your knowledge of types of plate boundary to determine a general relationship between plate boundary and the depths of earthquakes.

Form a Hypothesis

- **Describe** the types of stress that cause earthquakes.
- **Review** the basic structure of divergent boundaries, transform boundaries, and convergent boundaries. **Hint:** Refer back to **Figure 10, Figure 11,** and **Table 1.**
- Earthquakes range in depth from zero, at Earth's surface, to about 700 kilometers deep. The shallow range is from 0 km to about 70 km deep, intermediate earthquakes are about 70 km to 300 km deep, and deep earthquakes occur from about 300 to 700 km below the surface.
- **Make a statement** about which boundaries you think will have shallow, intermediate, or deep earthquakes associated with them.

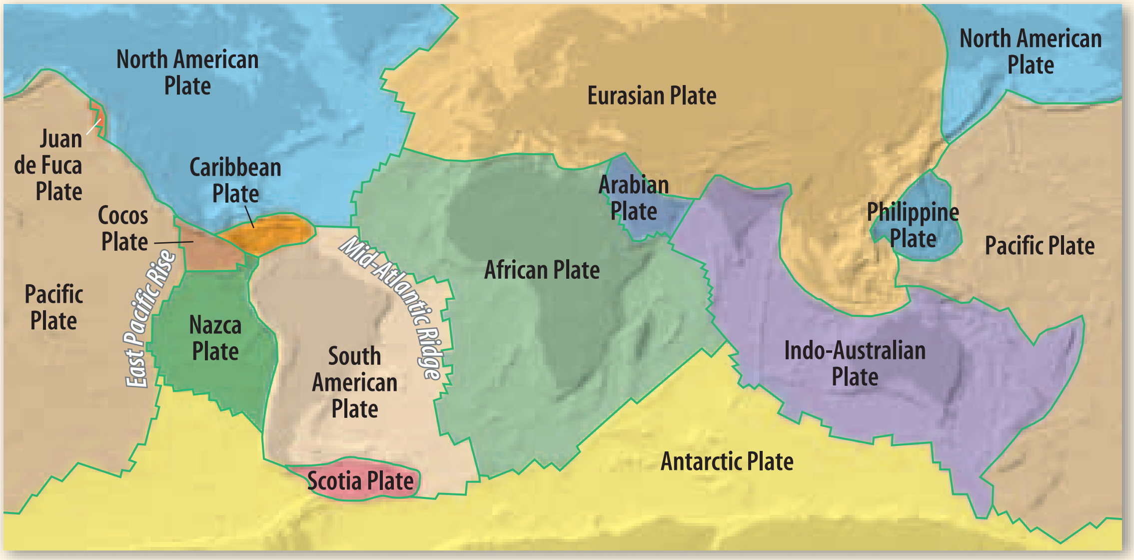
Collect Data and Make Observations

1. Visit ca6.msscience.com to research data on recent earthquakes.
2. Make a data table like the one shown on page 229.
3. Record latitude, longitude, depth (km), and a location for each earthquake. Leave the plate boundary column blank for now.

Earthquake Locations and Depths				
Latitude	Longitude	Depth (km)	Location	Plate Boundary Type

Analyze and Conclude

1. **Compare** the earthquake locations you plotted with the plate boundary map below.
2. **Specify,** in the table, the type of plate boundary associated with each earthquake or whether an earthquake was not associated with any plate boundary.
3. **Determine** which plate boundaries experience the deepest earthquakes.



Communicate

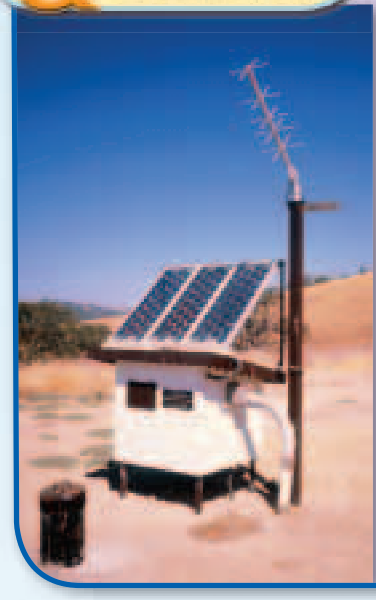
WRITING in Science ELA6: W 1.3

Compare and Contrast Write a paragraph that compares and contrasts the depths of earthquakes that you would expect to occur at transform and at ocean-to-continent convergent plate boundaries. Explain any differences in depth ranges for these types of plate boundaries.

Real World Science

Science & Career

Studying Earth's Plate Boundaries



As a geophysicist and professor at Stanford University, Dr. Paul Segall is interested in Earth processes. Segall's students benefit from his work with the Plate Boundary Observatory (PBO) project. In this project, Segall and other scientists use data from tools called strain-meters as well as Global Positioning System (GPS) to understand the relationship between plate movement and deformation along plate boundaries. An example of a strainmeter is shown in the photo.

Understanding the Big Picture Visit Careers at ca6.msscience.com to record information about the rationale, anticipated results, employment opportunities, and benefits of the EarthScope program. **Prepare** an oral report justifying support for this program which Dr. Segall might present to a funding committee.

ELA6: W 2.5

Finding Faults

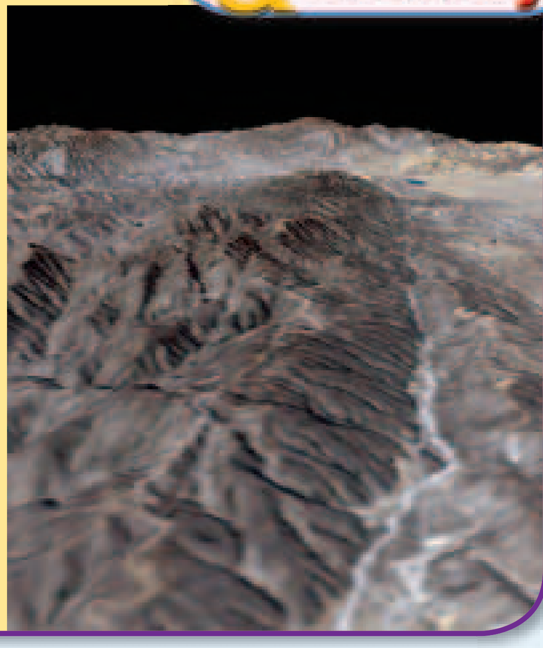
Science & Technology

The Quaternary Fault and Fold Database is now available to structural engineers, state disaster planners, and the public. This technology identifies areas in the continental United States where the crust has fractured or folded. The database provides historical details as well as recent fault data.

Faults in Your Region of California Visit Technology at ca6.msscience.com to access the Quaternary Fault and Fold Database. Use the map-based function to find faults nearest your area. **Create** a chart showing available data for these faults. **Analyze** the data to identify the most active fault or faults in your area.

Science & History

The View from Space



The San Andreas Fault is among California's best-known landforms. Measuring roughly 1,200 km, this strike-slip fault is the longest fault in California. Data from the Shuttle Radar Topography Mission on the Space Shuttle *Endeavor* were used to create this image, which shows the San Andreas Fault along the center, and the North American and Pacific Plates on the right and left.

Online Geologic Fieldtrip Visit History at ca6.msscience.com to take a geotour with the California Geological Survey. Choose a geological landmark within one of the major geomorphic provinces to explore. **Create** a brochure that a local tourism department might use to advertise this landmark. ELA6: W 1.5

Science & Society

A Shaky History

Parkfield, California sits directly on the San Andreas Fault. Strong earthquakes have occurred regularly in this tiny community. How do Parkfield residents, who number less than 40, deal with living on one of the world's most famous faults? Students have school earthquake drills, and residents are taught to stockpile food and keep fresh batteries in flashlights. Perhaps most importantly, they learn not to panic during emergencies.

Analyzing Seismic Attitudes In a small group, brainstorm two questions that measure the attitude of California residents about living in a seismically active state. **Develop** a brief class survey. Have 5–10 friends or family members complete the survey, then analyze class results.

CHAPTER 5

Standards Study Guide

The BIG Idea California is located on a plate boundary, where major geologic events occur.

Lesson 1 Interactions at Plate Boundaries

1.c, 1.d, 1.e, 7.e

Main Idea **There are three main types of plate boundaries, where stresses cause rocks to deform.**

- Stress can break and bend rocks.
- There are three main types of stress that can result in faulting.
- Lithospheric plates move apart at divergent boundaries.
- Divergent boundaries produce mid-ocean ridges and continental rifts.
- Plates move toward each other at convergent boundaries.
- The densities of converging plates determine what type of convergent boundary forms.
- Plates grind past each other at transform boundaries, with the motion mainly sideways, parallel to Earth's surface.
- Most transform boundaries are on the seafloor, but some are on continents.

- **continental rifting** (p. 216)
- **convergent plate boundary** (p. 218)
- **divergent plate boundary** (p. 215)
- **fault** (p. 211)
- **fracture** (p. 211)
- **rift valley** (p. 216)
- **subduction** (p. 218)
- **transform plate boundary** (p. 220)

Lesson 2 California Geology

1.e, 1.f, 7.a, 7.b, 7.e

Main Idea **Many of California's landforms were produced by plate tectonic activity, which continues today.**

- The San Andreas Fault is a continental transform boundary that runs through California, from Cape Mendocino to the Salton Sea.
- Northern California is located above a subduction zone.
- California's mountains were produced by interactions at plate boundaries.
- Mountains form at all three types of plate boundaries.
- The western sliver of California that is on the Pacific Plate will continue to move northwest, relative to the rest of the North American Plate.

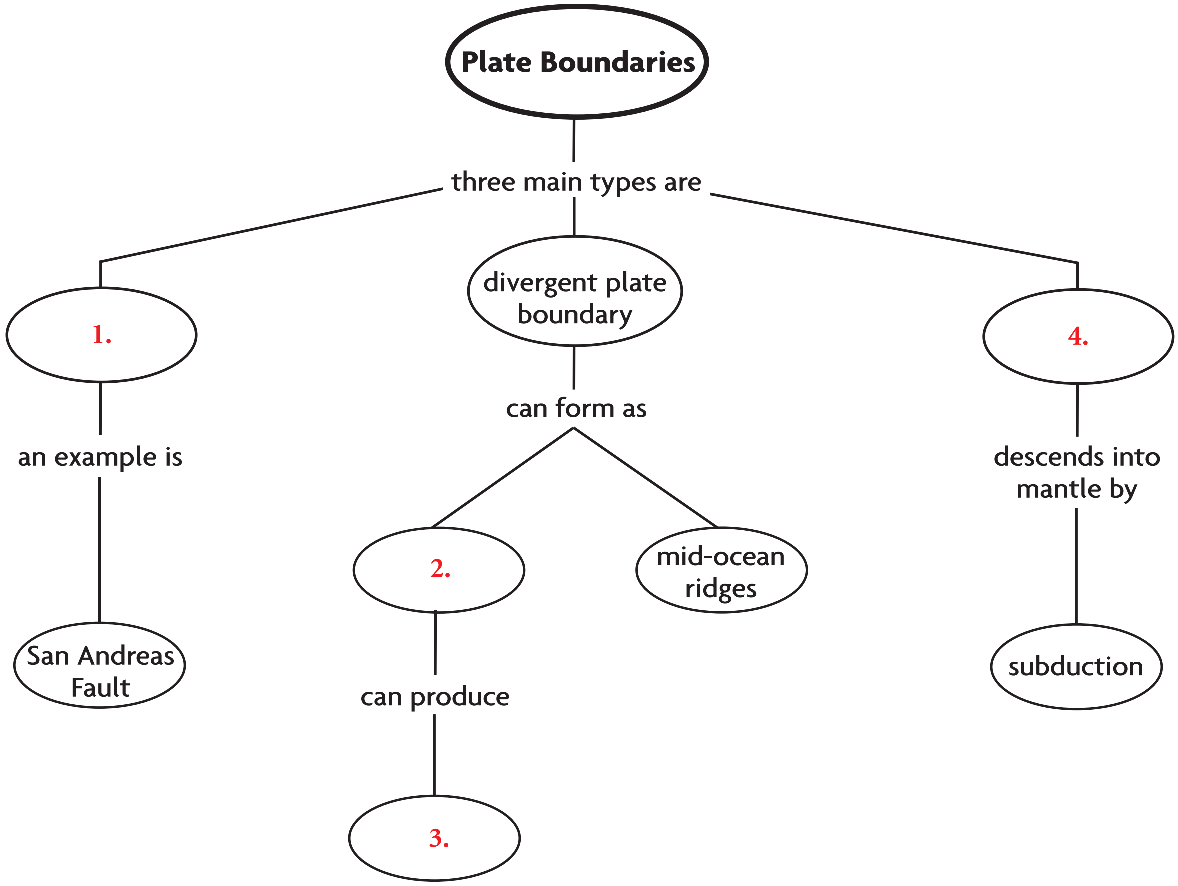
- **San Andreas Fault** (p. 224)

STUDY TO GO

Download quizzes, key terms, and flash cards from ca6.msscience.com.

Linking Vocabulary and Main Ideas

Use vocabulary terms from page 232 to complete this concept map.



Science Online
Visit ca6.msscience.com for:
- Vocabulary PuzzleMaker
- Vocabulary eFlashcards
- Multilingual Glossary

Using Vocabulary

Fill in the blank with the correct vocabulary words. Then read the paragraph to a partner.

The Mariana ocean trench in the Pacific Ocean is an area of deep ocean water that results from ____5.____. A curved string of volcanic islands also forms along this ocean-to-ocean ____6.____. Volcanic eruptions also are common at ocean-to-continent ____7.____ and ____8.____ boundaries.

Understanding Main Ideas

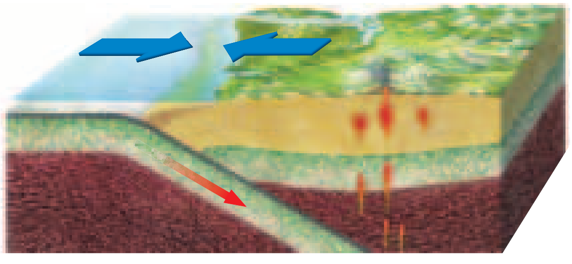
Choose the word or phrase that best answers the question.

1. Which form the highest mountains?
   A. mid-ocean ridges
   B. continent-to-continent convergent boundaries
   C. ocean-to-continent convergent boundaries
   D. transform boundaries 1.e

2. What type of stress is acting on rocks in Death Valley?
   A. tension
   B. compression
   C. convection
   D. shear 1.f

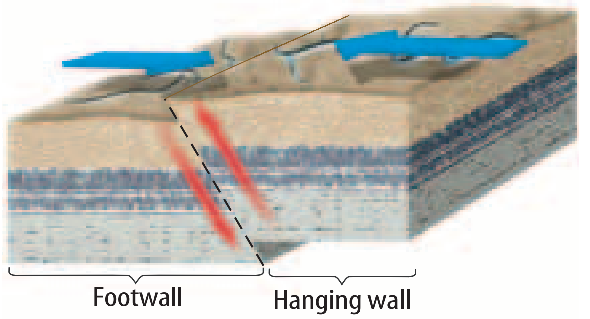
3. Along which type of plate boundary did the transverse ranges form?
   A. divergent
   B. ocean-to-ocean convergent
   C. continent-to-continent convergent
   D. transform 1.f

4. The diagram below illustrates a subduction zone.



   Why do volcanoes form above subduction zones?
   A. Tension stresses bring magma to the surface.
   B. Convection currents heat the slab.
   C. Water from the slab causes mantle rocks to melt.
   D. The slab melts when it goes into the mantle. 1.e

Use the figure below to answer questions 5 and 6.



5. What type of fault is shown in this illustration?
   A. normal
   B. reverse
   C. convergent
   D. strike-slip 1.d

6. In which direction did the hanging wall move relative to the footwall?
   A. down
   B. sideways
   C. up
   D. vertically 1.d

7. At the Mid-Atlantic Ridge, plates are moving apart at about what rate?
   A. 0.03 cm/year
   B. 0.3 cm/year
   C. 3 cm/year
   D. 30 cm/year 1.c

8. Where is continental rifting occurring today?
   A. east Africa
   B. west coast of South America
   C. the Himalayas
   D. the Aleutian Islands 1.e

9. What type of plate boundary occurs along the Mid-Atlantic Ridge?
   A. divergent
   B. continent-to-continent convergent
   C. ocean-to-ocean convergent
   D. transform 1.e

Applying Science

10. **Compare and contrast** the types of rocks formed at divergent boundaries to those formed at convergent boundaries. 1.e

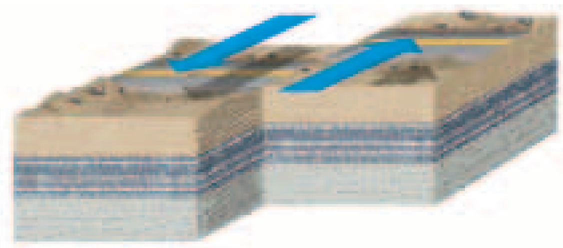
11. **Construct** a diagram showing where different rock types form at a convergent boundary. 1.e

12. **Imagine** a new continent made from two existing continents. Describe how the new continent forms. 1.e

13. **Evaluate** the suggestion that people should dispose of hazardous waste by dropping it down oceanic trenches and letting it sink into the mantle with the subducting slab. 1.e

14. **Illustrate** how chains of volcanoes and deep ocean trenches relate to subduction zones. 1.e

15. **Identify** the type of stress that is illustrated in the diagram below. 1.e



WRITING in Science

16. **Select** a park in California that includes landforms shaped by the interaction of lithospheric plates. Research the park. Prepare a travel brochure that describes how plate boundaries influenced the landforms that a visitor to the park might see. ELA6: W 1.5

Cumulative Review

17. **Evaluate** the benefit of a profile view. 7.f

18. **Compare and contrast** the two types of Earth's crust. 1.b

19. **Describe** three methods of thermal energy transfer. 3.c

Applying Math

Use the table below to answer questions 20–24.

Approximate Speed of Lithospheric Plates	
Name of Plate	**Approximate Speed (cm/yr)**
Antarctic	2.05
African	2.15
Arabian	4.65
Caribbean	2.45
Cocos	8.55
Eurasian	0.95
Indian-Australian	6.00
Nazca	7.55
North American	1.15
Pacific	8.10
Philippine	6.35
South American	1.45

20. How much faster is the North American Plate moving than the Eurasian Plate? MA6: NS 1.2, AF 2.3

21. Approximately how many more centimeters per year does the North American Plate move than the Eurasian Plate? MA6: NS 1.2, AF 2.3

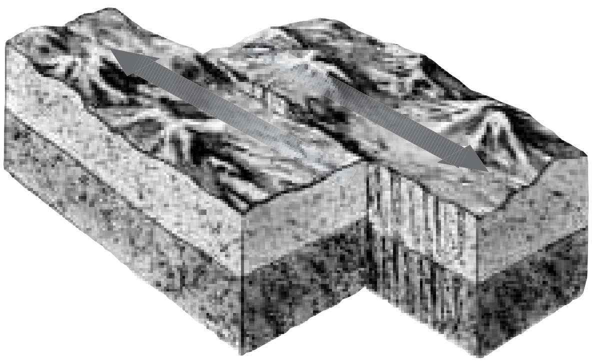
22. How much faster is the Cocos Plate moving than the Nazca Plate? MA6: NS 1.2, AF 2.3

23. Approximately how many more centimeters per year does the Cocos Plate move than the Nazca Plate? MA6: NS 1.2, AF 2.3

24. How much faster is the Philippine Plate moving than the Arabian Plate? MA6: NS 1.2, AF 2.3

CHAPTER 5 Standards Assessment

1 **The illustration below shows two plates moving past each other.**



Which type of stress occurs when Earth's lithospheric plates scrape past each other?

1.d

A compression

B isostasy

C shear

D tension

2 **About how fast do plates move?**

1.c

A a few millimeters per year

B a few centimeters per year

C a few meters per year

D a few kilometers per year

3 **Earth's lithospheric plates scrape past each other at**

1.e

A convergent plate boundaries.

B divergent plate boundaries.

C transform plate boundaries.

D subduction zones.

4 **Which best describes a fault?**

1.d

A the point where two plates of lithosphere move apart and new seafloor forms

B a point inside Earth where movement first occurs during an earthquake

C the surface of a break in a rock along which there is movement

D the snapping back of a rock that has been strained by force

5 **In which direction is the Pacific Plate moving?**

1.f

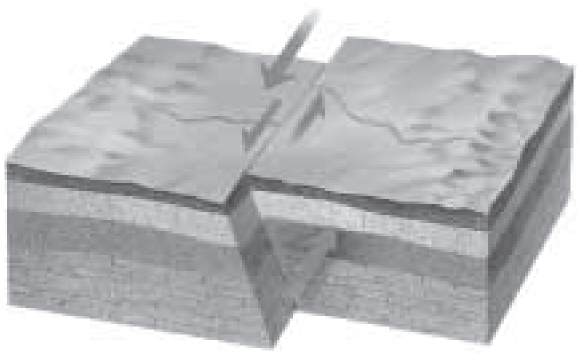
A northwest

B northeast

C southwest

D southeast

6 **The illustration below shows a fault in Earth's crust.**



What type of fault is shown?

1.d

A normal fault

B reverse fault

C strike-slip fault

D thrust fault

7 **The table below shows the number of convergent and divergent boundaries for different plates in Earth's crust.**

Plate Boundaries

Plate	Number of Convergent Boundaries	Number of Divergent Boundaries
African	1	4
Antarctic	1	2
Indo-Australian	4	2
Eurasian	4	1
North American	2	1
Pacific	6	2
South American	2	1

Which plate has the most spreading boundaries?

1.c

A African

B Antarctic

C Indo-Australian

D Pacific

8 **Between the North American Plate and the Pacific Plate lies the San Andreas Fault, which forms a**

1.f

A continental rift.

B divergent plate boundary.

C mid-ocean ridge.

D transform plate boundary.

9 **Which has played an important role in forming California's mountains?**

1.f

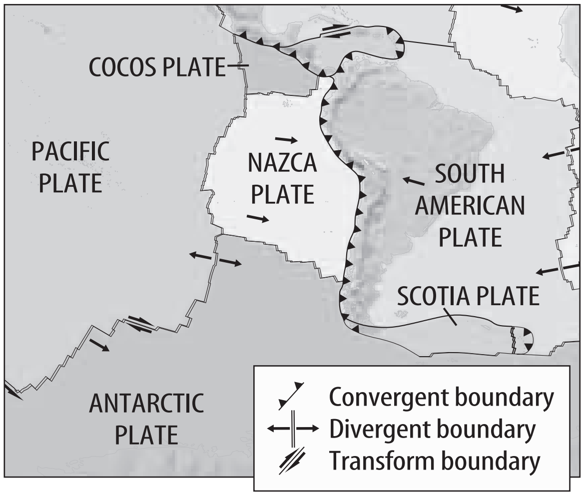
A continental rifting

B a convergent plate boundary

C a divergent plate boundary

D a mid-ocean ridge

10 **The map below shows the major plates near South America, their direction of movement, and the type of boundary between them.**



What boundary feature most likely occurs along the Nazca and South American Plates?

1.e

A a strike-slip fault

B new oceanic crust

C rift valleys

D volcanoes

11 **Which type of fault is produced by tension stresses?**

1.d

A inclined fault

B normal fault

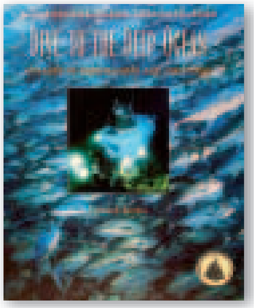
C reverse fault

D strike-slip fault

Reading on Your Own...

From the Recommended Literature for Science and Math

Are you interested in learning more about Earth's structure, its geological features, and the forces that created them? If so, check out these great books.



Nonfiction

Dive to the Deep Ocean, by Deborah Kovacs, a marine scientist, explores both the organisms and the geologic features of the deep ocean. This book provides accurate information about tectonic movement, volcanic action, and undersea technology. ***The content of this book is related to*** *Science Standard 6.1.*

Nonfiction

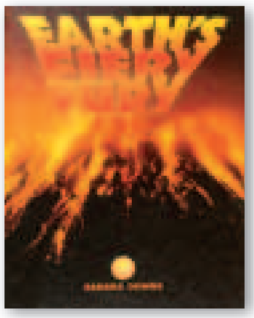
Shaping the Earth, by Dorothy Hinshaw Patent, features full-color photographs highlighting the geological features on Earth's surface. The book explains the forces that created these features. ***The content of this book is related to*** *Science Standard 6.1.*

Narrative Nonfiction

The Pebble in My Pocket: A History of Our Earth, by Meredith Hooper, follows a pebble beginning with the cooling of lava from an ancient volcano. The book follows the changes in the formation and development of life on Earth and includes a time line of Earth's history. ***The content of this book is related to*** *Science Standard 6.2.*

Narrative Nonfiction

Earth's Fiery Fury, by Sandra Downs, describes the volcanic and geothermal activity of Earth and the features associated with thermal energy. This book helps the reader understand how thermal energy and Earth's inner fire shape Earth. ***The content of this book is related to*** *Science Standard 6.3.*



CONTENTS

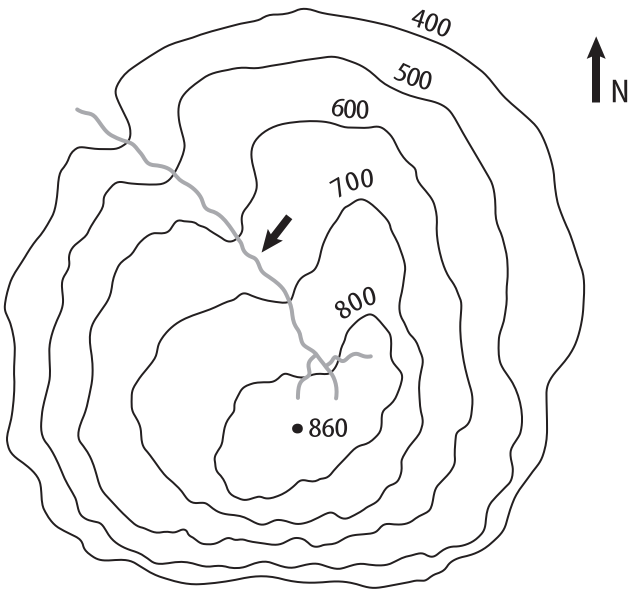
UNIT 1 Unit Test

Choose the word or phrase that best answers the question.

1. Which features are evidence that many continents were once near Earth's south pole?
   A. glacial deposits
   B. earthquakes
   C. polar ice caps
   D. mid-ocean ridges 1.a

2. What hypothesis states that continents slowly moved to their present positions on Earth?
   A. subduction
   B. erosion
   C. continental drift
   D. seafloor spreading 1.c

3. The numbers on the contour map represent meters above sea level.

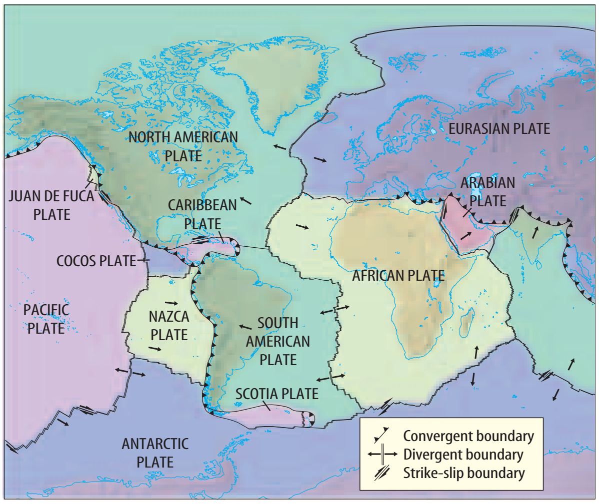


   Which side of the feature has the steepest slope?
   A. north side
   B. east side
   C. west side
   D. south side 7.f

Write your responses on a sheet of paper.

4. **Compare and contrast** rocks and minerals. 1.b

Use the map below to answer questions 5 and 6.



5. **Analyze** why many earthquakes, but only a few volcanic eruptions, occur in the Himalayas. 1.e

6. **Explain** the action of the plates along the San Andreas Fault and why volcanoes do not form there. 1.e

7. **Analyze** why the fossil of an ocean fish found on two different continents would not be good evidence of continental drift. 1.a

8. **Infer** A winter jacket is lined with insulating material that contains air spaces. How do the insulating properties of the jacket change when the insulating material becomes wet? 3.c

9. **Apply** When might you use a topographic map instead of a geologic map? 7.f

10. **Design an Experiment** Some colors of clothing absorb heat better than other colors. Design an experiment that will test various colors by placing them in the Sun for a period of time. Explain your results. 3.d