

# Geological Activity from Plate Tectonics Processes

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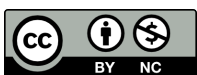
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## CHAPTER

## 1

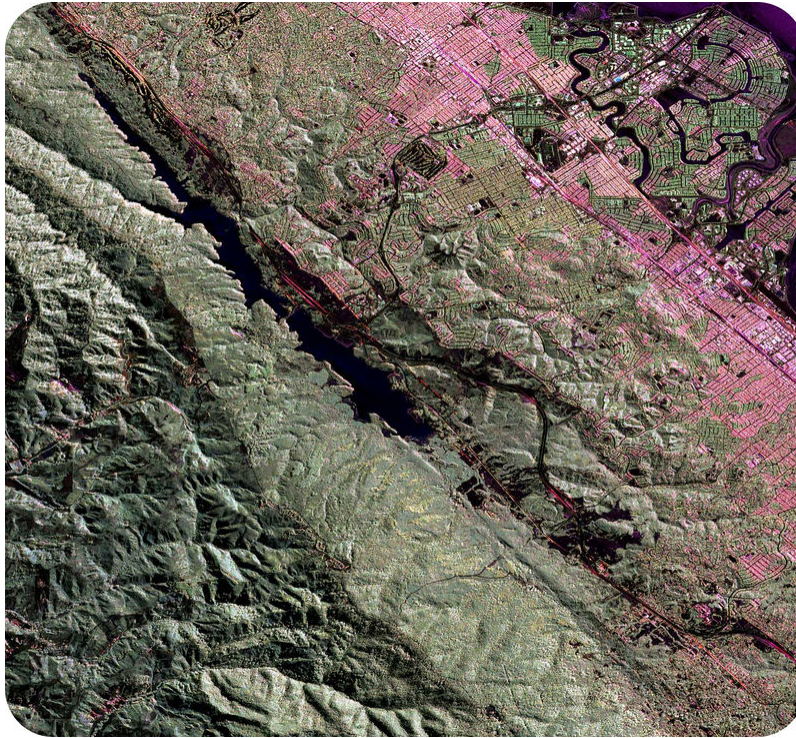
# Geological Activity from Plate Tectonics Processes

## CHAPTER OUTLINE

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- 1.1 Geological Stresses
  - 1.2 Principle of Horizontality
  - 1.3 Folds
  - 1.4 Faults
  - 1.5 Mountain Building
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## Introduction



### **Plate tectonics = natural disasters - weather disasters**

So many natural disasters occur because of plate tectonics processes. By using what we know about plate tectonics we can understand where most earthquakes and volcanic eruptions will strike. We can know where to look for many types of mineral deposits.

The scar in this satellite image is of the San Andreas Fault as it runs through the San Francisco Bay Area. The fault is seen from the upper left to the lower right of this image. The fault forms a trough that is filled with water at Crystal Springs Reservoir. The development in pink and green is San Mateo and Burlingame. Foster City, which is built on fill, has curved streets extending into the bay. Scientists will use space-based radar along this same flight path over the next years to look for changes in the ground surface along the fault.

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## 1.1 Geological Stresses

- Define the types of geological stress and describe their affect on various types of rock under a range of conditions.



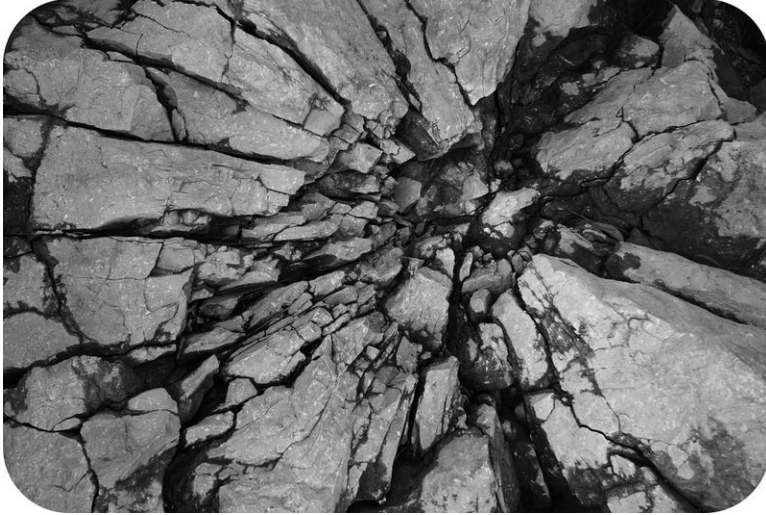
**When people have too much stress they may break. What happens if a rock gets too much stress?**

With all the movement occurring on Earth's surface —slabs of crust smashing into each other, sideways movements along faults, magma rising through solid rock —it's no wonder that rocks experience stress. Rocks respond differently to different types of stress and under different conditions.

### Causes and Types of Stress

**Stress** is the force applied to an object. In geology, stress is the force per unit area that is placed on a rock. Four types of stresses act on materials.

- A deeply buried rock is pushed down by the weight of all the material above it. Since the rock cannot move, it cannot deform. This is called **confining stress**.
- **Compression** squeezes rocks together, causing rocks to fold or fracture (break) ( **Figure 1.1**). Compression is the most common stress at convergent plate boundaries.



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**FIGURE 1.1**

Stress caused these rocks to fracture.

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- Rocks that are pulled apart are under **tension**. Rocks under tension lengthen or break apart. Tension is the major type of stress at divergent plate boundaries.
- When forces are parallel but moving in opposite directions, the stress is called **shear** ( **Figure 1.2**). Shear stress is the most common stress at transform plate boundaries.



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**FIGURE 1.2**

Shearing in rocks. The white quartz vein has been elongated by shear.

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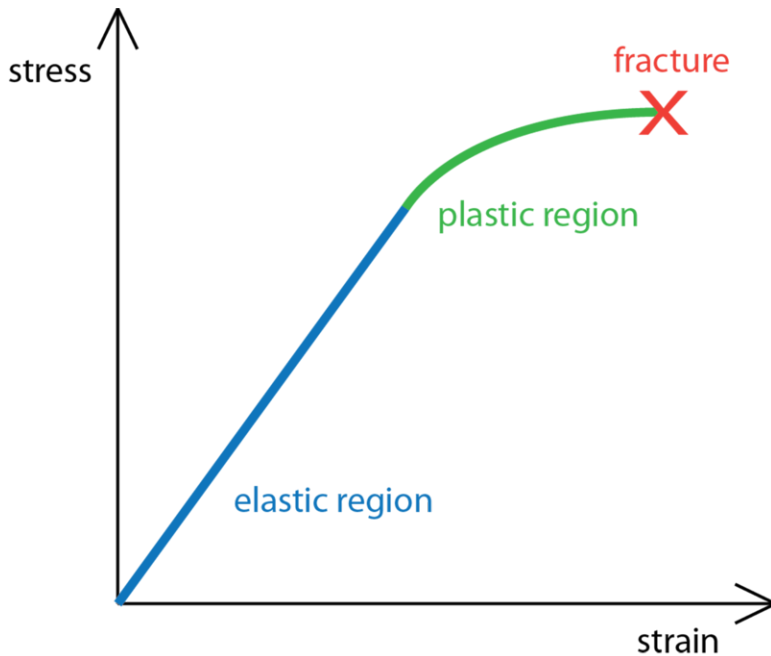
When stress causes a material to change shape, it has undergone **strain** or **deformation**. Deformed rocks are common in geologically active areas.

A rock's response to stress depends on the rock type, the surrounding temperature, the pressure conditions the rock is under, the length of time the rock is under stress, and the type of stress.

## Responses to Stress

Rocks have three possible responses to increasing stress (illustrated in **Figure 1.3**):

- **elastic deformation:** the rock returns to its original shape when the stress is removed.
- **plastic deformation:** the rock does not return to its original shape when the stress is removed.
- **fracture:** the rock breaks.



**FIGURE 1.3**

With increasing stress, the rock undergoes: (1) elastic deformation, (2) plastic deformation, and (3) fracture.

Under what conditions do you think a rock is more likely to fracture? Is it more likely to break deep within Earth's crust or at the surface? What if the stress applied is sharp rather than gradual?

- At the Earth's surface, rocks usually break quite quickly, but deeper in the crust, where temperatures and pressures are higher, rocks are more likely to deform plastically.
- Sudden stress, such as a hit with a hammer, is more likely to make a rock break. Stress applied over time often leads to plastic deformation.

## Summary

- Stress is the force applied to an object. Stresses can be confining, compression, tension, or shear.
- Rocks under stress may show strain or deformation. Deformation can be elastic or plastic, or the rock may fracture.
- Rocks respond to stress differently under different conditions.

## Explore More

Use this resource to answer the questions that follow.

This video goes into more depth than the questions will ask for.

<https://www.youtube.com/watch?v=FXZmBPEG9wM>

1. What is stress defined as?
2. What are body forces and what are they proportional to?
3. What are surface forces?
4. Why does stress need to be studied in vector components?
5. In what direction do the forces go in normal stress? What about in shear stress?
6. What is strain?

### Explore More Answers

1. force per unit area
2. Body forces are exerted by a body and are proportional to the mass of the body.
3. Surface forces are forces that act on a body.
4. Vectors allow for stresses in more than one direction.
5. In normal stress, force is downward. In shear stress it is horizontal.
6. deformation

### Review

1. What type of stress would you find at a transform fault? At a subduction zone? What type of stress at a continental rift zone?
2. Compare and contrast fracture, plastic deformation, and elastic deformation.
3. What do you think happens with stressed rocks in an earthquake zone?

### Review Answers

1. Transform faults have shear stress; subduction zones have compression; continental rifts have tension.
2. When stress is applied to a rock its fate depends on how much stress. If enough for elastic deformation, when the stress is removed the rock will go back to its original shape; if plastic, the rock will not return to its original shape if the stress is removed; if fracture, then the rock breaks and it cannot return to its original shape.
3. When enough stress builds up the rock will fracture.

## 1.2 Principle of Horizontality

- Identify rules for the formation and deformation of sedimentary rock.
- Explain how sedimentary rock helps scientists study geological history.



### Why does the Grand Canyon resemble these cakes?

If you go to the Grand Canyon, you'll see a layer cake of geological formations. Some people call this "layer cake geology." Just like the cake, the bottom layer is put down first and then subsequent layers moving upward. If a layer is not horizontal it must have been deformed. We'll learn about deformation in the next several concepts.

### Sedimentary Rock Rules

Sedimentary rocks follow certain rules.

1. Sedimentary rocks are formed with the oldest layers on the bottom and the youngest on top.
2. Sediments are deposited horizontally, so sedimentary rock layers are originally horizontal, as are some volcanic rocks, such as ash falls.
3. Sedimentary rock layers that are not horizontal are deformed.

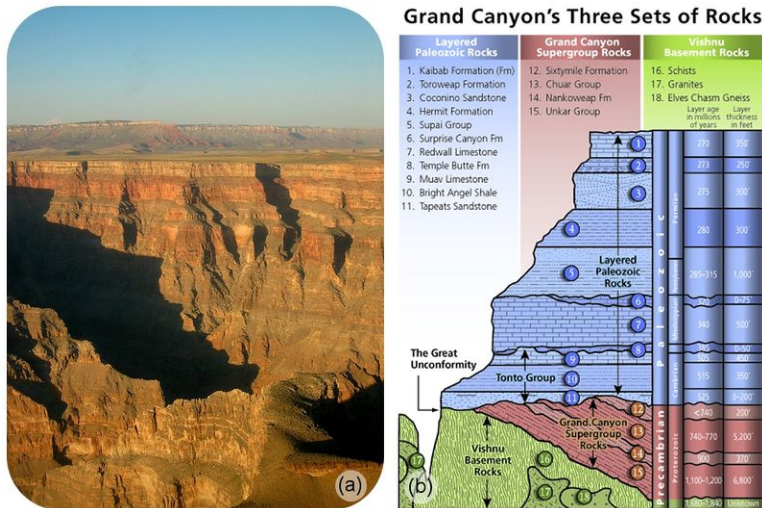
Since sedimentary rocks follow these rules, they are useful for seeing the effects of stress on rocks. Sedimentary rocks that are not horizontal must have been deformed.

You can trace the deformation a rock has experienced by seeing how it differs from its original horizontal, oldest-on-bottom position. This deformation produces geologic structures such as folds, joints, and faults that are caused by stresses.

## Geologic History

You're standing in the Grand Canyon and you see rocks like those in the **Figure 1.4**. Using the rules listed above, try to figure out the geologic history of the geologic column. The Grand Canyon is full mostly of sedimentary rocks, which are important for deciphering the geologic history of a region.

In the Grand Canyon, the rock layers are exposed like a layer cake. Each layer is made of sediments that were deposited in a particular environment - perhaps a lake bed, shallow offshore region, or a sand dune.



**FIGURE 1.4**

(a) The rocks of the Grand Canyon are like a layer cake. (b) A geologic column showing the rocks of the Grand Canyon.

In this geologic column of the Grand Canyon, the sedimentary rocks of groups 3 through 6 are still horizontal. Group 2 rocks have been tilted. Group 1 rocks are not sedimentary. The oldest layers are on the bottom and youngest are on the top.

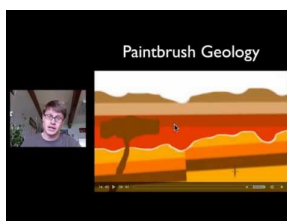
The ways geologists figure out the geological history of an area will be explored more in the chapter Earth History.

## Summary

- Sedimentary rocks are laid down horizontally.
- Rocks are laid down from oldest to youngest.
- Sedimentary rocks that are not horizontal have been deformed.
- Sedimentary rocks are very useful for deciphering the geological history of an area.

## Explore More

Use this resource to answer the questions that follow.



## MEDIA

Click image to the left for use the URL below.

URL: <http://gamma.ck12.org/flx/render/embeddedobject/1430>

1. What is the law of superposition?
2. How are the sediments laid down?
3. How can you determine the oldest rock?
4. What can happen to disturb the layers?
5. What does erosion do?
6. What is an intrusion?

### Explore More Answers

1. The oldest rock is on the bottom and the rocks get younger moving up the section.
2. horizontally
3. The oldest rock is on the bottom unless the section was overturned.
4. Geological processes that tilt or overturn the layers. A fault can lift some of the section but not all.
5. Erosion washes a lot of rock away.
6. Molten rock moves up and intrudes into other rock and hardens.

### Review

1. In the Grand Canyon section, what do you think happened to the rocks between layers 12 and 11?
2. For what reason are the rocks 16, 17 and 18 not layered?
3. What are the oldest rocks in the Grand Canyon and what type are they? What are the youngest rocks and what type are they?

### Review Answers

1. The 12+ rocks were tilted and eroded then the 11 layer 11 was deposited.
2. They are igneous intrusions or metamorphic.
3. The oldest are the Vishnu basement rocks and they are igneous or metamorphic.

## 1.3 Folds

- Identify and define types of folds and related structures.



### Can you see the anticline at Anticline Overlook?

Moving around the desert Southwest, we see a lot of folds. This view is from the Anticline Overlook at Canyonlands National Park. Look up what an anticline is below and then see if you can spot this one. Remember you may only be able to see part of it in the photo. All of the folds (not the basin) pictured below are found in the arid Southwest.

## Folds

Rocks deforming plastically under compressive stresses crumple into **folds**. They do not return to their original shape. If the rocks experience more stress, they may undergo more folding or even fracture.

You can see three types of folds.

### Monocline

A **monocline** is a simple bend in the rock layers so that they are no longer horizontal (see **Figure 1.5** for an example).



**FIGURE 1.5**

At Utah's Cockscomb, the rocks plunge downward in a monocline.

What you see in the image appears to be a monocline. Are you certain it is a monocline? What else might it be? What would you have to do to figure it out?

### Anticline

Anticline: An **anticline** is a fold that arches upward. The rocks dip away from the center of the fold ( **Figure 1.6**). The oldest rocks are at the center of an anticline and the youngest are draped over them.

When rocks arch upward to form a circular structure, that structure is called a **dome**. If the top of the dome is sliced off, where are the oldest rocks located?

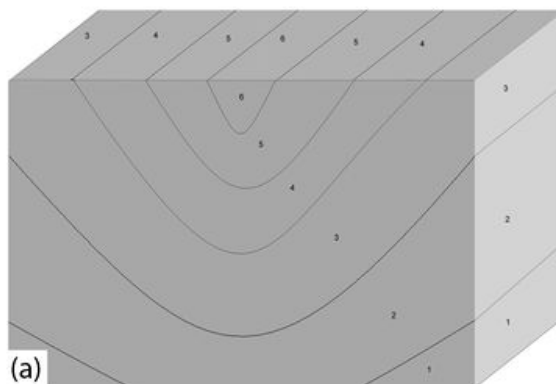
### Syncline

A **syncline** is a fold that bends downward. The youngest rocks are at the center and the oldest are at the outside ( **Figure 1.7**).

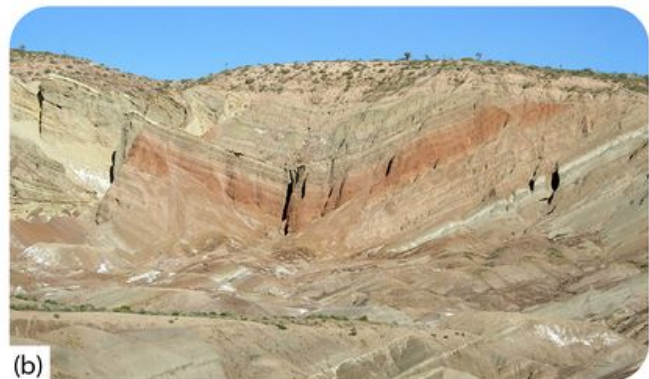
When rocks bend downward in a circular structure, that structure is called a **basin** ( **Figure 1.8**). If the rocks are exposed at the surface, where are the oldest rocks located?

**FIGURE 1.6**

Anticlines are formations that have folded rocks upward.



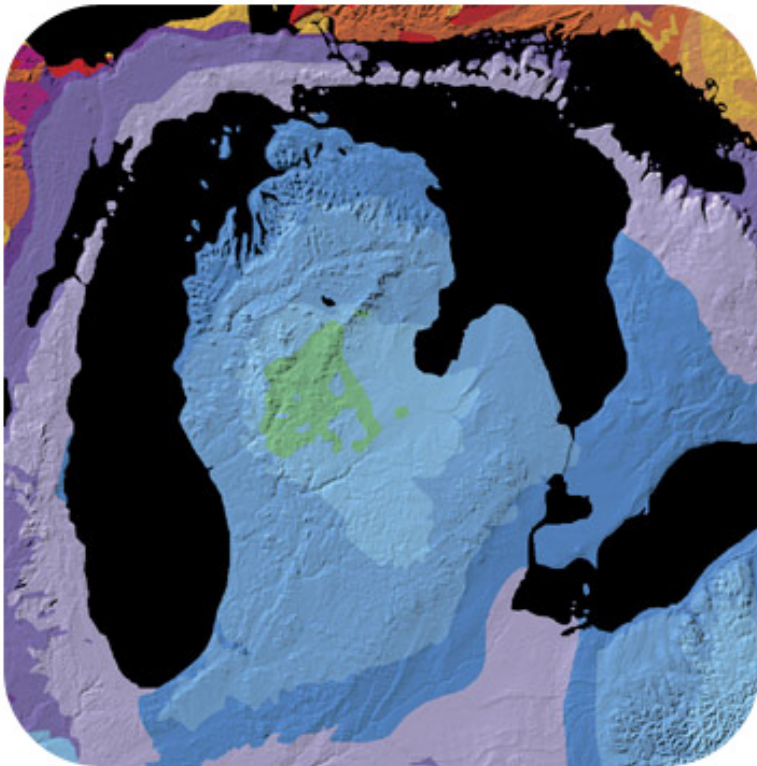
This drawing depicts a syncline and the numbers describe the order that the layers were laid down, 1 being the oldest.

**FIGURE 1.7**

(a) Schematic of a syncline. (b) This syncline is in Rainbow Basin, California.

## Summary

- Rocks deform by compressive stress into folds.
- A monocline is a simple bend.
- In anticline, rocks arch upward. A three-dimensional anticline is a dome.

**FIGURE 1.8**

Basins can be enormous. This is a geologic map of the Michigan Basin, which is centered in the state of Michigan but extends into four other states and a Canadian province.

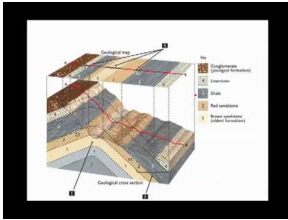
**FIGURE 1.9**

Some folding can be fairly complicated. What do you see in the photo above?

- In a syncline, rocks arch downward. A three-dimensional syncline is a basin.

## Explore More

Use this resource to answer the questions that follow.



### MEDIA

Click image to the left for use the URL below.

URL: <http://gamma.ck12.org/flx/render/embeddedobject/1410>

1. What causes folds?
2. What are the folds called?
3. What is dip? What is it measured from?
4. What is strike?
5. What does a block diagram show you?
6. What is the strike and dip symbol?
7. What do the arrows on the diagram tell you?
8. Describe the effects of erosion on how a rock layer looks on a map.

## Explore More Answers

1. stress
2. anticlines, synclines
3. The tilt of a rock layer measured from a horizontal surface.
4. The direction in which the rock layer is tilting. An imaginary line between the dipping rock and a horizontal plane.
5. The sides are cross-sections; the top is a geologic map.
6. The long line is the strike and the short line with the number is the dip angle.
7. The way the rock layers erode affect how thick the layers look. What appears at the surface also depends on the angle at which it has been eroded.

## Review

1. Draw a picture to show how compressive stresses lead to the formation of anticlines and synclines.
2. Do you think that anticlines and synclines are ordinarily found separately or adjacent to each other?
3. If you found a bulls-eye of rock on the flat ground with no structure to guide you, how could you tell if the structure had been a syncline or an anticline?



1. What folds can you find in this photo of Monument Valley in Arizona? Notice the rock layers at the top of the ridge. What is the geologic history of this region?

### Review Answers

1. Student must do this.
2. adjacent
3. You would need to look at the relative ages of the rocks. If the oldest is in the center, the structure is a dome. If the youngest is in the center, the structure is a basin.
4. The rocks were laid down horizontally and the region was eroded. Then the folded rocks were eroded and horizontal rocks were laid down on top of it. The geologic history looks more complicated than that.

## 1.4 Faults

- Describe the results of rocks fracturing under stress, forming joints or faults.
- Identify types of faults.



### Why is this called a fault?

The word "fault" refers to a defect. There may be no greater defect than the scar of the San Andreas Fault across California. Rocks on either side of the fault are estimated to have originated in locations about 350 miles apart! We're still in the arid western United States, but now our searching for geological features is more dangerous!

### Fractures

A rock under enough stress will fracture. There may or may not be movement along the fracture.

### Joints

If there is no movement on either side of a fracture, the fracture is called a **joint**. The rocks below show horizontal and vertical jointing. These joints formed when the confining stress was removed from the rocks as shown in (

Figure 1.10).



FIGURE 1.10

Joints in rocks at Joshua Tree National Park, in California.

## Faults

If the blocks of rock on one or both sides of a fracture move, the fracture is called a **fault** ( **Figure 1.11**). Stresses along faults cause rocks to break and move suddenly. The energy released is an earthquake.



FIGURE 1.11

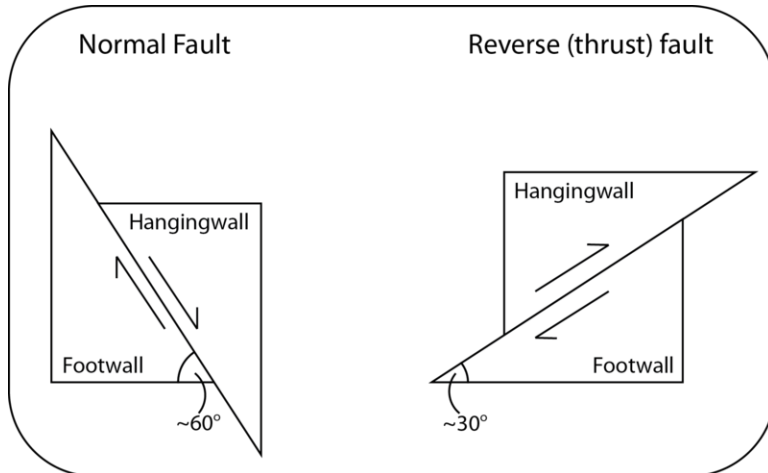
Faults are easy to recognize as they cut across bedded rocks.

How do you know there's a fault in this rock? Try to line up the same type of rock on either side of the lines that cut across them. One side moved relative to the other side, so you know the lines are a fault.

**Slip** is the distance rocks move along a fault. Slip can be up or down the fault plane. Slip is relative, because there is usually no way to know whether both sides moved or only one. Faults lie at an angle to the horizontal surface of the Earth. That angle is called the fault's **dip**. The dip defines which of two basic types a fault is. If the fault's dip is inclined relative to the horizontal, the fault is a **dip-slip fault** ( **Figure 1.12**).

## Dip-Slip Faults

There are two types of dip-slip faults. In a **normal fault**, the hanging wall drops down relative to the footwall. In a **reverse fault**, the footwall drops down relative to the hanging wall.



**FIGURE 1.12**

This diagram illustrates the two types of dip-slip faults: normal faults and reverse faults. Imagine miners extracting a resource along a fault. The hanging wall is where miners would have hung their lanterns. The footwall is where they would have walked.

An animation of a normal fault is seen here: [http://earthquake.usgs.gov/learn/animations/animation.php?flash\\_title=Normal+Fault&flash\\_file=normalfault&flash\\_width=220&flash\\_height=320](http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Normal+Fault&flash_file=normalfault&flash_width=220&flash_height=320) .

A **thrust fault** is a type of reverse fault in which the fault plane angle is nearly horizontal. Rocks can slip many miles along thrust faults ( **Figure 1.13**).

An animation of a thrust fault is seen here: [http://earthquake.usgs.gov/learn/animations/animation.php?flash\\_title=Thrust+Fault&flash\\_file=thrustfault&flash\\_width=220&flash\\_height=320](http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Thrust+Fault&flash_file=thrustfault&flash_width=220&flash_height=320) .



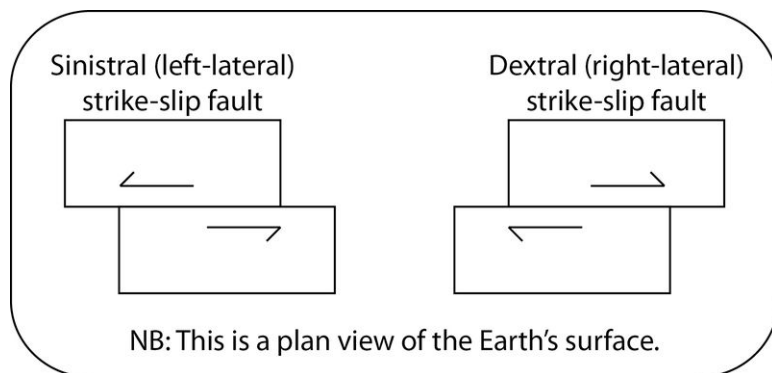
**FIGURE 1.13**

At Chief Mountain in Montana, the upper rocks at the Lewis Overthrust are more than 1 billion years older than the lower rocks. How could this happen?

Normal faults can be huge. They are responsible for uplifting mountain ranges in regions experiencing tensional stress.

## Strike-Slip Faults

A **strike-slip fault** is a dip-slip fault in which the dip of the fault plane is vertical. Strike-slip faults result from shear stresses. Imagine placing one foot on either side of a strike-slip fault. One block moves toward you. If that block moves toward your right foot, the fault is a right-lateral strike-slip fault; if that block moves toward your left foot, the fault is a left-lateral strike-slip fault ( **Figure 1.14**).



**FIGURE 1.14**

Strike-slip faults.

California's San Andreas Fault is the world's most famous strike-slip fault. It is a right-lateral strike slip fault (See opening image).

A strike-slip fault animation: [http://earthquake.usgs.gov/learn/animations/animation.php?flash\\_title=Strike-Slip+Fault&flash\\_file=strikeslip&flash\\_width=240&flash\\_height=310](http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Strike-Slip+Fault&flash_file=strikeslip&flash_width=240&flash_height=310) .

People sometimes say that California will fall into the ocean someday, which is not true. This animation shows movement on the San Andreas into the future: [http://visearth.ucsd.edu/VisE\\_Int/aralsea/bigone.html](http://visearth.ucsd.edu/VisE_Int/aralsea/bigone.html) .

## Summary

- A fracture with no movement on either side is a joint.
- Dip-slip faults show vertical movement. In a normal fault, the hanging wall drops down relative to the footwall. The reverse is true of a reverse fault.
- Strike-slip faults have horizontal motions due to shear stress.

## Explore More

Use this resource to answer the questions that follow.

<http://www.iris.edu/gifs/animations/faults.htm>

1. What causes normal fault motion?
2. What type of motion results from a normal fault?
3. Explain a reverse fault. What type of motion results from this fault?
4. Describe a strike-slip fault.
5. What causes an oblique-slip fault?

## Explore More Answers

1. tensional forces

2. extension
3. The block above the fault moves up relative to the block below the fault. Shortening results.
4. The blocks move past each other horizontally. There is no gain or loss of land.
5. Shearing and tension due to compressional forces.

### Review

1. Imagine you're looking at an outcrop. What features would you see to indicate a fault?
2. If the San Andreas Fault has had 350 miles of displacement, where did the rocks in San Francisco (on the west side of the fault) originate? How do scientists know?
3. How do you imagine the Grand Teton mountain range rose? In one earthquake? Along one fault? Or is there a more complex geological history?

### Review Answers

1. A rock layer is broken and in a different position from its other portion on the other side of the fault.
2. 350 miles south of where they are now
3. The Grand Tetons rose along a set of normal faults and it took millions of years for them to get where they are. The history is complex.

## 1.5 Mountain Building

- Explain how converging or diverging plates can create mountain ranges.



### How do plate motions create mountains?

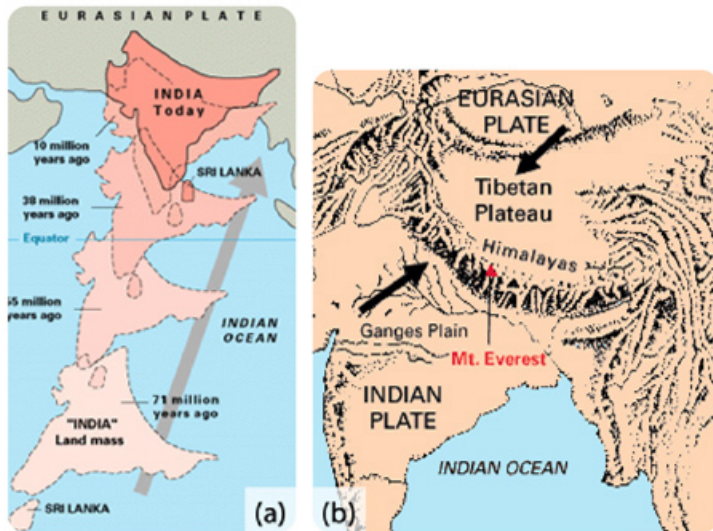
Plate tectonic processes create some of the world's most beautiful places. The North Cascades Mountains in Washington State are a continental volcanic arc. The mountains currently host some glaciers and there are many features left by the more abundant ice age glaciers. Changes in altitude make the range a habitable place for many living organisms.

### Converging Plates

Converging plates create the world's largest mountain ranges. Each combination of plate types —continent-continent, continent-ocean, and ocean-ocean —creates mountains.

### Converging Continental Plates

Two converging continental plates smash upwards to create gigantic mountain ranges ( **Figure 1.15**). Stresses from this **uplift** cause folds, reverse faults, and thrust faults, which allow the crust to rise upwards. As was stated previously there is currently no mountain range of this type in the western U.S., but we can find one where India is pushing into Eurasia.

**FIGURE 1.15**

(a) The world's highest mountain range, the Himalayas, is growing from the collision between the Indian and the Eurasian plates. (b) The crumpling of the Indian and Eurasian plates of continental crust creates the Himalayas.

### Subducting Oceanic Plates

Subduction of oceanic lithosphere at convergent plate boundaries also builds mountain ranges. This happens on continental crust, as in the Andes Mountains ( **Figure 1.16**), or on oceanic crust, as with the Aleutian Islands, which we visited earlier. The Cascades Mountains of the western U.S. are also created this way.

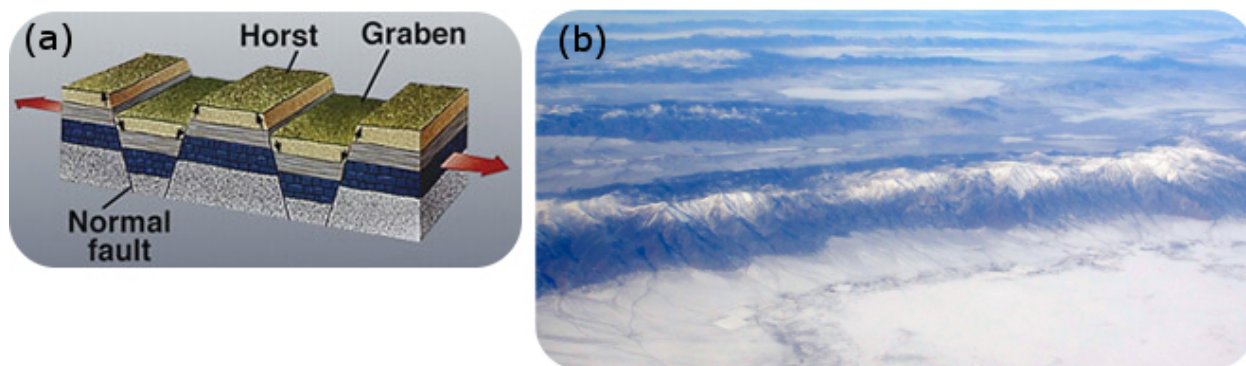
**FIGURE 1.16**

The Andes Mountains are a chain of continental arc volcanoes that build up as the Nazca Plate subducts beneath the South American Plate.

### Diverging Plates

Amazingly, even divergence can create mountain ranges. When tensional stresses pull crust apart, it breaks into blocks that slide up and drop down along normal faults. The result is alternating mountains and valleys, known as a basin-and-range ( **Figure 1.17**). In basin-and-range, some blocks are uplifted to form ranges, known as horsts, and some are down-dropped to form basins, known as grabens.

This is a very quick animation of movement of blocks in a basin-and-range setting: <http://earthquake.usgs.gov/learn>




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**FIGURE 1.17**

(a) Horsts and grabens. (b) Mountains in Nevada are of classic basin-and-range form.

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[/animations/animation.php?flash\\_title=Horst+%26amp%3B+Graben&flash\\_file=horstandgraben&flash\\_width=380&flash\\_height=210](/animations/animation.php?flash_title=Horst+%26amp%3B+Graben&flash_file=horstandgraben&flash_width=380&flash_height=210) .

### Summary

- Converging or diverging plates cause mountains to grow.
- Subduction of oceanic crust beneath a continental or oceanic plate creates a volcanic arc.
- Tensional forces bring about block faulting, which creates a basin-and-range topography.

### Explore More

Use this resource to answer the questions that follow. [http://www.tectonics.caltech.edu/outreach/animations/himalayas\\_small.html](http://www.tectonics.caltech.edu/outreach/animations/himalayas_small.html)

1. What are the four things that you can see at the surface at the beginning of the video? Be as specific as possible.
2. What is happening plate tectonically at the beginning of the video? What geological activity is visible on the video?
3. What happens to the oceanic crust in between when the two continents meet?
4. What happens as the continent on the left continues to collide with the continent on the right?

### Explore More Answers

1. Ocean, the Indian plate, ocean, the Eurasian plate.
2. An oceanic plate is subducting beneath the continental Eurasian plate. This is forming a continental volcanic arc that is erupting.
3. The ocean crust breaks off when the continent hits the other continent and it plunges into the mantle.
4. mountains rise

## Review

1. Describe how plate interactions create mountain ranges like the Himalayas.
2. Diagram how pulling apart continental crust could create mountains and basins. What are the mountains and basins called?
3. How are the Andes Mountains similar to the Aleutian Islands? How are they different?

## Review Answers

1. Two converging continental plates smash upwards, folding together in one giant mountain range.
2. This is the figure of the horsts and grabens created by tensional forces pulling the land apart.
3. They are both formed by subduction of oceanic crust beneath another crustal plate but in the Aleutians the plate is oceanic and in the Andes it is continental.

## 1.6 Earthquake Characteristics

- Define earthquakes, and explain how they occur.



### Does ground shaking cause the greatest damage in an earthquake?

This photo shows the Mission District of San Francisco burning after the 1906 earthquake. The greatest damage in earthquakes is often not from the ground shaking but from the effects of that shaking. In this earthquake, the shaking broke the gas mains and the water pipes so that when the gas caught fire there was no way to put it out. Do you wonder why the people standing in the street are looking toward the fire rather than running in the opposite direction?

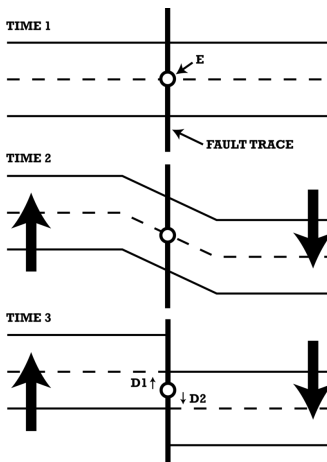
### Earthquake!

An **earthquake** is sudden ground movement caused by the sudden release of energy stored in rocks. Earthquakes happen when so much stress builds up in the rocks that the rocks rupture. The energy is transmitted by seismic waves. Earthquakes can be so small they go completely unnoticed, or so large that it can take years for a region to recover.

### Elastic Rebound Theory

The description of how earthquakes occur is called **elastic rebound theory** ( **Figure 1.18**).

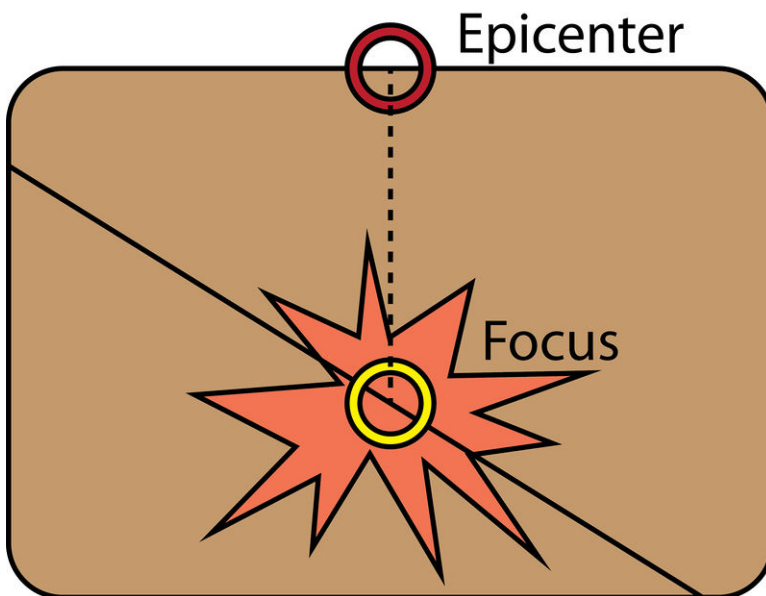
Elastic rebound theory in an animation: [http://earthquake.usgs.gov/learn/animations/animation.php?flash\\_title=Elastic+Rebound&flash\\_file=elasticrebound&flash\\_width=300&flash\\_height=350](http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Elastic+Rebound&flash_file=elasticrebound&flash_width=300&flash_height=350) .


**FIGURE 1.18**

Elastic rebound theory. Stresses build on both sides of a fault, causing the rocks to deform plastically (Time 2). When the stresses become too great, the rocks break and end up in a different location (Time 3). This releases the built up energy and creates an earthquake.

### Focus and Epicenter

In an earthquake, the initial point where the rocks rupture in the crust is called the **focus**. The **epicenter** is the point on the land surface that is directly above the focus ( **Figure 1.19**).


**FIGURE 1.19**

In the vertical cross section of crust, there are two features labeled - the focus and the epicenter, which is directly above the focus.

In about 75% of earthquakes, the focus is in the top 10 to 15 kilometers (6 to 9 miles) of the crust. Shallow earthquakes cause the most damage because the focus is near where people live. However, it is the epicenter of an earthquake that is reported by scientists and the media.

### Summary

- A sudden release of energy stored in rocks causes an earthquake.
- The focus is where the rocks rupture. The epicenter is the point on the ground directly above the focus.
- Most earthquakes are shallow; these do the most damage.

## Explore More

Use this resource to answer the questions that follow.

[https://www.youtube.com/watch?v=\\_YLjIvJXhpg](https://www.youtube.com/watch?v=_YLjIvJXhpg)

1. What is the San Andreas Fault?
2. What is the speed that this process along the San Andreas is happening?
3. What did Harry Fielding Reid base his elastic rebound theory on?
4. What is elastic rebound theory?
5. What happens at the time of the earthquake?
6. What happens in an earthquake that's large?
7. How likely is a large earthquake to happen in the Bay Area in the next 30 years?

## Explore More Answers

1. The major fault zone helping slide the North American Plate past the Pacific plate.
2. It is happening at about 2.5 inches per year.
3. Land surveys that measured changes in the land surface caused by the earthquake.
4. Forces accumulate along faults and are released in earthquakes.
5. A small piece of the high friction surface lets go and starts slipping. In the space of a few seconds the slippage speeds from an inch per year to 5000 miles per hour.
6. The event goes through several catches and releases of the earthquake.
7. twice as likely as not to happen

## Review

1. How does elastic rebound theory describe how an earthquake takes place?
2. Where is an earthquake's focus? Where is its epicenter?
3. Why do shallow earthquakes cause the most damage?

## Review Answers

1. Stresses on both sides of the fault build and cause the rocks to deform plastically. When the stresses are too great the rocks break and cause an earthquake.
2. The focus is where the rocks rupture. The epicenter is the point at the surface above the rupture.
3. The quake occurs near the surface, which is where people live.

## 1.7 Earthquake Zones

- Explain the relationship between plate boundaries and earthquakes.



### What caused the earthquake in Northridge, CA in 1994?

Northridge, California experienced a 6.7 magnitude earthquake in 1994. Roads, bridges and elevated highways, like this one, were damaged and 72 people died. Northridge lies on a blind thrust fault that was only discovered as a result of the quake. The fault is part of the San Andreas Fault system, which is part of the Pacific Ring of Fire (and ground shaking).

### Annual Earthquakes

In a single year, on average, more than 900,000 earthquakes are recorded and 150,000 of them are strong enough to be felt. Each year about 18 earthquakes are major, with a Richter magnitude of 7.0 to 7.9, and on average one earthquake has a magnitude of 8 to 8.9.

Magnitude 9 earthquakes are rare. The United States Geological Survey lists five since 1900 (see **Figure 1.20** and **Table 1.1**). All but the Great Indian Ocean Earthquake of 2004 occurred somewhere around the Pacific Ocean basin.

**TABLE 1.1: Earthquakes of magnitude 9 or greater**

Location	Year	Magnitude
Valdivia, Chile	1960	9.5
Prince William Sound, Alaska	1964	9.2
Great Indian Ocean Earthquake	2004	9.1
Kamchatka, Alaska	1952	9.0
Tōhoku, Japan	2011	9.0




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**FIGURE 1.20**

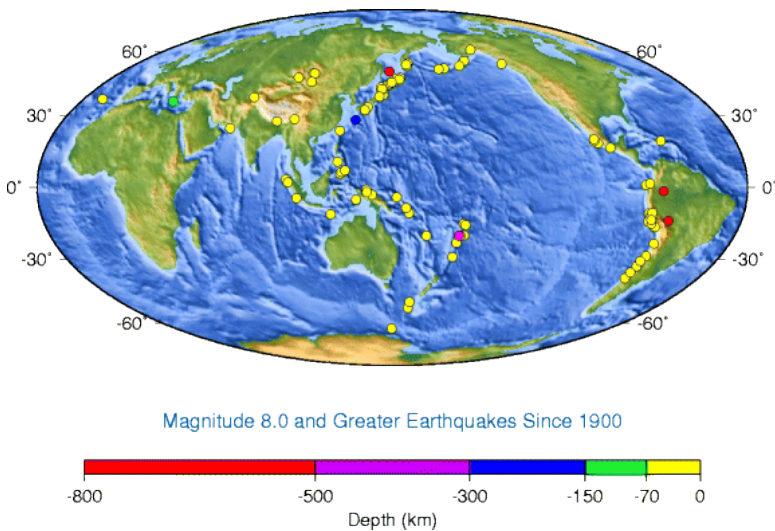
The 1964 Good Friday Earthquake centered in Prince William Sound, Alaska released the second most amount of energy of any earthquake in recorded history.

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## Earthquake Zones

Nearly 95% of all earthquakes take place along one of the three types of plate boundaries.

- About 80% of all earthquakes strike around the Pacific Ocean basin because it is lined with convergent and transform boundaries ( **Figure 1.21**).
- About 15% take place in the Mediterranean-Asiatic Belt, where convergence is causing the Indian Plate to run into the Eurasian Plate.
- The remaining 5% are scattered around other plate boundaries or are intraplate earthquakes.




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**FIGURE 1.21**

Earthquake epicenters for magnitude 8.0 and greater events since 1900. The earthquake depth shows that most large quakes are shallow focus, but some subducted plates cause deep focus quakes.

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## Summary

- Small earthquakes are extremely common, but the largest earthquakes are extremely rare.
- The vast majority of earthquakes happen at plate boundaries.
- The Pacific Ocean basin has the most earthquakes due to the plate boundaries that line it; the Himalaya region has the second most due to the convergence of India and Asia.

## Explore More

Use the resource below to answer the questions that follow.

- **Earthquake Zones Most at Risk** at <http://www.youtube.com/watch?v=73LNyVYD8Ig> (1:48)



### MEDIA

Click image to the left for use the URL below.

URL: <http://gamma.ck12.org/flx/render/embeddedobject/1414>

1. What was the magnitude of the Chilean earthquake?
2. What two plates are converging near Chile that caused the earthquake?
3. What is the Ring of Fire? What occurs along this Ring of Fire?
4. What was the strongest earthquake ever recorded? When did it occur?
5. Why are scientists urging Memphis to adopt building codes similar to Chile's?

## Explore More Answers

1. 8.8
2. The Nazca Plate is subducting beneath the South American Plate.
3. The Ring of Fire is a geologically active zone around the Pacific Ocean Basin, with many volcanoes and earthquakes.
4. 9.5; 1960 Chile
5. The New Madrid Fault produced a very large earthquake in the early 19th century. If one like that hit now there could be many fatalities since falling buildings are one of the things that kill people in a quake.

## Review

1. Why are most earthquakes at plate boundaries?
2. Why are some earthquakes away from plate boundaries?
3. What two types of plate motions occur along the Pacific Rim? Where would you find each type along western North America?
4. What type of plate motions cause the Mediterranean-Asiatic quakes?

## Review Answers

1. Plates are enormous slabs of lithosphere. When they interact there is the opportunity for lots of friction to build up until it is released with an earthquake.

2. There are other causes for earthquakes than plate interactions. Earth is a sphere and the movements of lithospheric slabs over a spherical surface causes earthquakes.
3. Convergent and transform. Convergent plate boundaries are found from Northern California through Alaska. The San Andreas Fault through California is a transform boundary.
4. convergent

## 1.8 Earthquakes at Transform Plate Boundaries

- Describe earthquakes that take place at transform plate boundaries.



### Would you like to live in San Francisco?

Lots of people live in California for the weather. Transplants from snowy climates think they've found paradise in the state's warm sunshine. What if you got your dream job in San Francisco? Would you take it? Are you afraid enough of the region's potential for large earthquakes that you wouldn't? Look at the map of faults in the Bay Area ( **Figure 1.22**) before you decide.

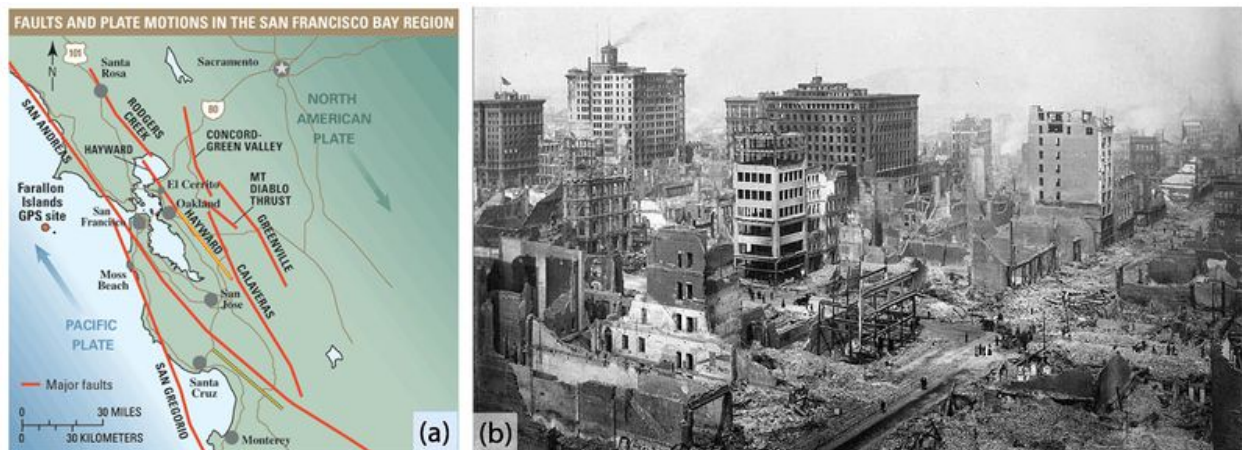
### Transform Plate Boundaries

Deadly earthquakes occur at transform plate boundaries. Transform faults have shallow focus earthquakes. Why do you think this is so?

## California

As you learned in the chapter Plate Tectonics, the boundary between the Pacific and North American plates runs through much of California as the San Andreas Fault zone. As you can see in the ( **Figure 1.22**), there is more than just one fault running through the area. There is really a fault zone. The San Andreas Fault runs from south to north up the peninsula, through San Francisco, gets through part of Marin north of the bay, and then goes out to sea. The other faults are part of the fault zone, and they too can be deadly.

The faults along the San Andreas Fault zone produce around 10,000 earthquakes a year. Most are tiny, but occasionally one is massive. In the San Francisco Bay Area, the Hayward Fault was the site of a magnitude 7.0 earthquake in 1868. The 1906 quake on the San Andreas Fault had a magnitude estimated at about 7.9 ( **Figure 1.22**). About 3,000 people died and 28,000 buildings were lost, mostly in the fire that followed the earthquake.



**FIGURE 1.22**

(a) The San Andreas Fault zone in the San Francisco Bay Area. (b) The 1906 San Francisco earthquake is still the most costly natural disaster in California history.

Recent California earthquakes occurred in:

- 1989: Loma Prieta earthquake near Santa Cruz, California. Magnitude 7.1 quake, 63 deaths, 3,756 injuries, 12,000+ people homeless, property damage about \$6 billion.
- 1994: Northridge earthquake on a blind thrust fault near Los Angeles. Magnitude 6.7, 72 deaths, 12,000 injuries, damage estimated at \$12.5 billion.

In this video, the boundaries between three different tectonic plates and the earthquakes that result from their interactions are explored: <http://www.youtube.com/watch?v=upEh-1DpLMg> (1:59).



### MEDIA

Click image to the left for use the URL below.

URL: <http://gamma.ck12.org/flx/render/embeddedobject/1420>

## New Zealand

New Zealand also has a transform fault with strike-slip motion, causing about 20,000 earthquakes a year! Only a small percentage of those are large enough to be felt. A 6.3 quake in Christchurch in February 2011 killed about 180 people.

### Summary

- Transform fault earthquakes have shallow focus because the plates meet near the surface.
- The San Andreas Fault is actually a fault zone made up of a number of other active faults.
- New Zealand also has a transform plate boundary.

### Explore More

Use these resources to answer the questions that follow.

<https://www.youtube.com/watch?v=DDtqbWgQQE>

1. Where does the San Andreas Fault go offshore in the north? Where does it begin in the south?
2. Where is the most dangerous part of the San Andreas?
3. What is the Carizzo Plain expression of the San Andreas Fault like? Why is it so visible there?
4. He says the largest oceanic plate in the world is stitched to the continental plate. Which plates is he referring to and what type of lithosphere meets on each side of the fault?
5. What does Wallace Creek do at the fault?
6. Why was Daly City a dangerous place to build houses?
7. In the Bay Area what does the fault do that's dangerous for the future?
8. How are scientists mapping the San Andreas in the northern region?
9. Did developers know where the San Andreas Fault went when they built the community of San Bruno?

### Explore More Answers

1. Daly City; in Salton Sea
2. the Coachella Valley from Palm Springs to San Bernadino
3. Large cracks in the ground, "like a suture that hasn't healed"; this region has not been bulldozed and there isn't much weathering and erosion.
4. The Pacific Plate and the North American Plate; although the Pacific Plate is the largest oceanic plate, at this location there is continental crust.
5. The two sides are offset by 400'.
6. It's a landslide on the San Andreas Fault.
7. The fault locks and it's impossible to say what's building up there?
8. They look at old photos and old topographic maps to locate the scarp.
9. yes

### Review

1. Why are earthquakes at convergent plate boundaries sometimes deep, while those at transform plate boundaries are always shallow?
2. Are the earthquakes that take place along the other faults in the San Andreas Fault Zone always smaller than the earthquakes that take place on the San Andreas Fault itself?

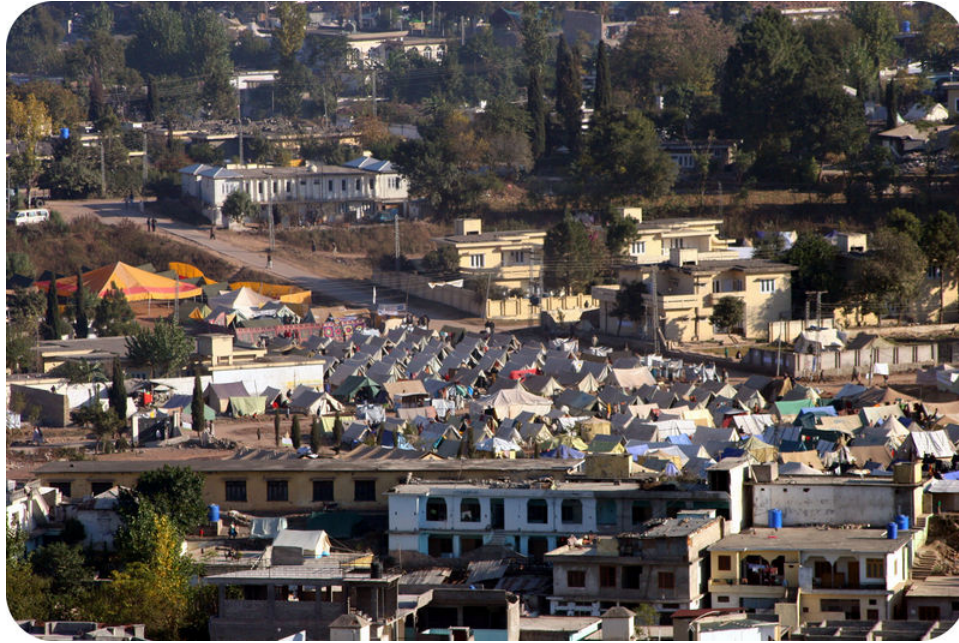
3. Do you expect that the quiet along the San Andreas Fault near San Francisco since 1906 means that earthquake activity is calming down along that plate boundary? What does it mean and why?

### Review Answers

1. Earthquakes at a convergent plate boundary occur along the subducted plate. It goes deep into the mantle and causes earthquakes all along. The quakes at a transform fault occur in lithosphere that is side-by-side and it doesn't go deep.
2. No they can be equally large.
3. No, it is probably building up tension and will burst in another quake like 1906. This part of the fault locks until so much tension builds up that it breaks.

## 1.9 Earthquakes at Convergent Plate Boundaries

- Describe earthquakes that take place at convergent plate boundaries.



### How do earthquakes create refugees?

People who've lost their homes in a large earthquake in Pakistan live in a refugee camp, which appears as tents in the photo. Despite suffering the loss of their homes, material possessions, and sometimes loved ones, refugees are often most damaged by the fear that another earthquake could strike. With many people, each aftershock brings renewed terror.

### Convergent Plate Boundaries

Earthquakes at convergent plate boundaries mark the motions of subducting lithosphere as it plunges through the mantle ( **Figure 1.23**). Eventually the plate heats up enough deform plastically and earthquakes stop.

Convergent plate boundaries produce earthquakes all around the Pacific Ocean basin.

### Ocean-Ocean: Japan

Earthquakes in Japan are caused by ocean-ocean convergence. The Philippine Plate and the Pacific Plate subduct beneath oceanic crust on the North American or Eurasian plates. This complex plate tectonics situation creates a chain of volcanoes, the Japanese islands, and as many as 1,500 earthquakes annually.

In March 2011 an enormous 9.0 earthquake struck off of Sendai in northeastern Japan. This quake, called the 2011 Tōhoku earthquake, was the most powerful ever to strike Japan and one of the top five known in the world. Damage from the earthquake was nearly overshadowed by the tsunami it generated, which wiped out coastal cities and towns ( **Figure 1.24**). Several months after the earthquake, about 22,000 people were dead or missing, and 190,000 buildings had been damaged or destroyed. Aftershocks, some as large as major earthquakes, have continued to rock the region.

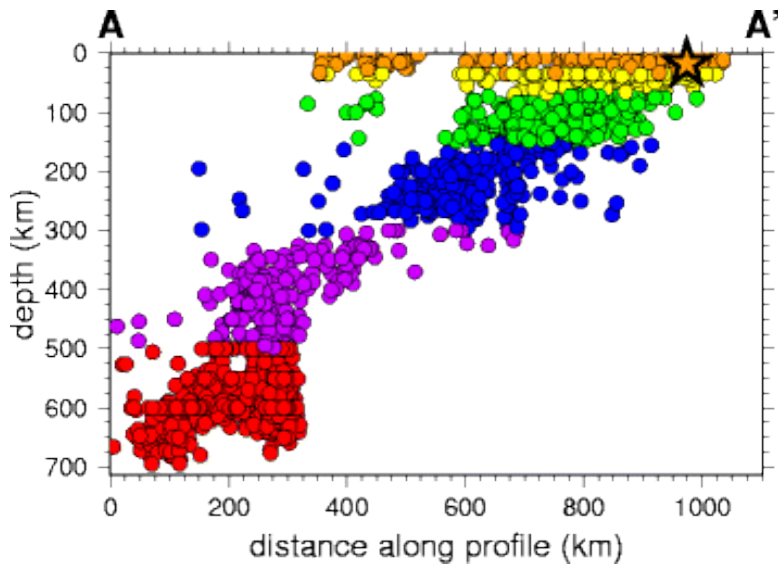


FIGURE 1.23

This cross section of earthquake epicenters with depth outlines the subducting plate with shallow, intermediate, and deep earthquakes.

A map of aftershocks is seen here: <http://earthquake.usgs.gov/earthquakes/seqs/events/usc0001xgp/> .

Here is an interactive feature article about the earthquake: <http://www.nytimes.com/interactive/2011/03/11/world/asia/maps-of-earthquake-and-tsunami-damage-in-japan.html> .



FIGURE 1.24

Destruction in Ofunato, Japan, from the 2011 Tōhoku Earthquake.

### Ocean-Continent: Cascades

The Pacific Northwest of the United States is at risk from a potentially massive earthquake that could strike any time. The subduction of three small plates beneath North America produces active volcanoes, the Cascades. As with an active subduction zone, there are also earthquakes. Surprisingly, large earthquakes only hit every 300 to 600 years. The last was in 1700, with an estimated magnitude of around 9. A quake of that magnitude today could produce an incredible amount of destruction and untold fatalities.

An image of earthquakes beneath the Pacific Northwest and the depth to the epicenter is shown here: <http://pubs.>

[usgs.gov/ds/91/](http://usgs.gov/ds/91/) .

Elastic rebound at a subduction zone generates an earthquake in this animation: [http://www.iris.edu/hq/files/programs/education\\_and\\_outreach/aotm/5/AOTF5\\_Subduction\\_ElasticRebound480.mov](http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/5/AOTF5_Subduction_ElasticRebound480.mov) .

### Continent-Continent: Asia

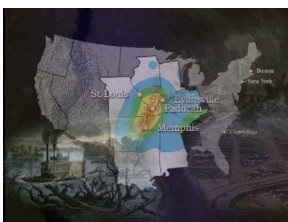
Massive earthquakes are the hallmark of the thrust faulting and folding when two continental plates converge ( **Figure 1.25**). The 2001 Gujarat earthquake in India was responsible for about 20,000 deaths, and many more people became injured or homeless.



**FIGURE 1.25**

Damage from the 2005 Kashmir earthquake.

In *Understanding Earthquakes: From Research to Resilience*, scientists try to understand the mechanisms that cause earthquakes and tsunamis and the ways that society can deal with them (**3d**): <http://www.youtube.com/watch?v=W5Qz-aZ2nUM> (8:06).



### MEDIA

Click image to the left for use the URL below.

URL: <http://gamma.ck12.org/flx/render/embeddedobject/1417>

### Summary

- Earthquakes occur all along the subducting plate as it plunges into the mantle.
- All three types of convergent plate boundaries produce massive earthquakes.
- Subduction zones around the Pacific Rim are responsible for many of the world's earthquakes.

## Explore More

Use the resource below to answer the questions that follow.

- **Convergent Plate Boundaries** at

<http://crack.seismo.unr.edu/ftp/pub/louie/class/100/plate-tectonics.html>

1. Earthquake epicenters delineate something important. What is that?
2. Why do earthquakes happen at divergent plate boundaries?
3. What occurs in and near subduction zones?
4. Why are earthquakes found at subduction zones?
5. Why are convergent plate boundary earthquakes at depths between surface to 700 km?
6. Why do you think the earthquakes stop at about 700 km?

## Explore More Answers

1. plate boundaries
2. Asthenosphere rises and plates move apart.
3. oceanic trenches with earthquakes and mountain belts
4. The plates are compressing. Subduction takes place between the two.
5. The subducting plate causes earthquakes all along its length.
6. The plate gets so hot that it deforms plastically and doesn't break.

## Review

1. Why does a subducting plate produce so many earthquakes and what type of quakes does it produce?
2. What caused the most destruction from the 2011 Japan earthquake and why?
3. Why do you think the Pacific Northwest has such infrequent but exceptionally massive earthquakes? There are several possible reasons.

## Review Answers

1. The plate plunges through the mantle and moves material aside. This causes earthquakes. Convergent plate boundaries can produce shallow intermediate and deep quakes.
2. The tsunami caused more destruction and overshadowed the damage from the earthquake.
3. The plates could lock together so that so much pressure must build up along the fault that when it does release it causes a massive earthquake.

## 1.10 Intraplate Earthquakes

- Identify the causes of intraplate earthquakes.



### **What caused an earthquake in Virginia? It's not near a plate boundary.**

Everyone expects earthquakes in California, but no one expects a large (okay, medium) earthquake in Virginia, but that's what happened in August 2011. This earthquake was one of the intraplate earthquakes that do not occur along plate boundaries but within plates. This crack is in the Washington Monument in the District of Columbia. The monument reopened in May 2014 after being closed nearly three years for repairs.

## Intraplate Earthquakes

Intraplate earthquakes are the result of stresses caused by plate motions acting in solid slabs of lithosphere. The earthquakes take place along ancient faults or rift zones that have been weakened by activity that may have taken place hundreds of millions of years ago.

### 2011 Virginia Earthquake

In August 2011 the eastern seaboard of the U.S. was rocked by a magnitude 5.8 earthquake. While not huge, most of the residents had never experienced a quake and many didn't know what it was. Some people thought the shaking might have been the result of a terrorist attack.

This region is no longer part of an active plate boundary. But if you went back in time to the late Paleozoic, you would find the region being uplifted into the ancestral Appalachian mountains as continent-continent convergence brought Pangaea together. The Piedmont Seismic Zone is an area of several hundred million year-old faults that sometimes reactivate.

### New Madrid Earthquake

In 1812, a magnitude 7.5 earthquake struck near New Madrid, Missouri. The earthquake was strongly felt over approximately 50,000 square miles and altered the course of the Mississippi River. Because very few people lived there at the time, only 20 people died. Many more people live there today ( **Figure 1.26**). A similar earthquake today would undoubtedly kill many people and cause a great deal of property damage.

Like the Piedmont Seismic Zone, the New Madrid Seismic Zone is a set of reactivated faults. These faults are left from the rifting apart of the supercontinent Rodinia about 750 million years ago. The plates did not rift apart here but left a weakness in the lithosphere that makes the region vulnerable to earthquakes.

## Summary

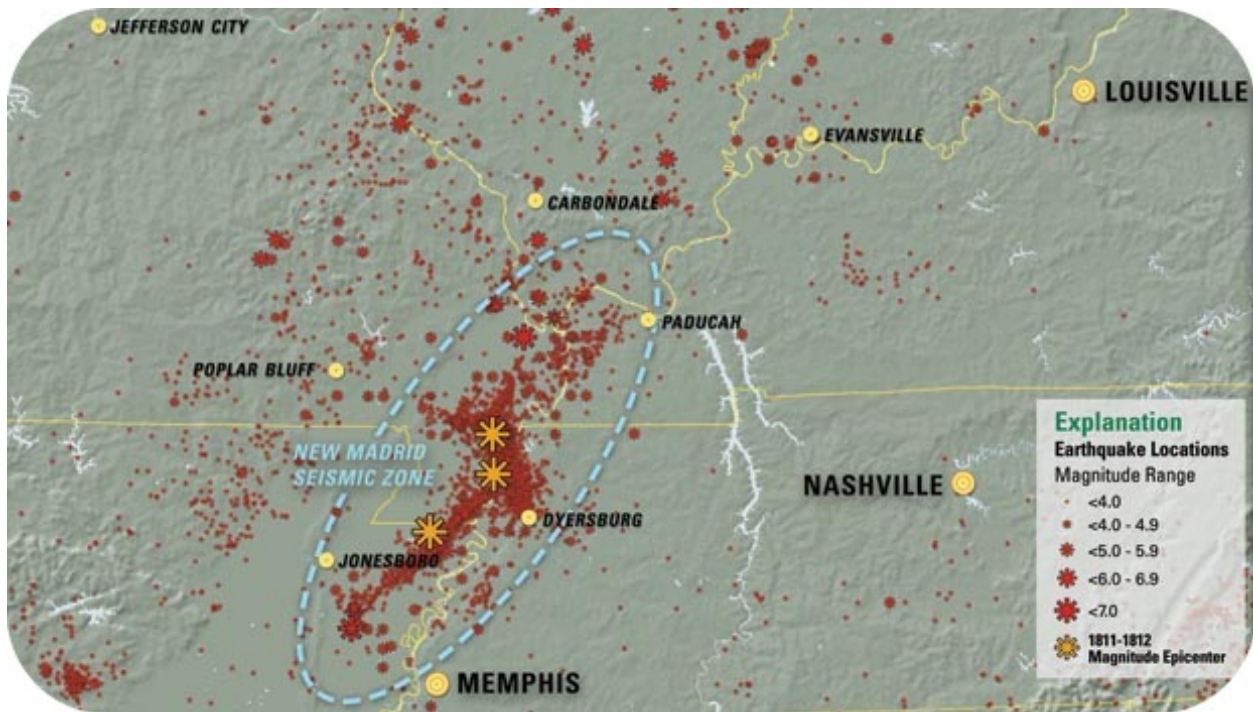
- Intraplate earthquakes occur because solid slabs of lithosphere traveling on a round planet must make some adjustments.
- Intraplate earthquakes strike at ancient fault or rift zones that are reactivated.
- Intraplate earthquakes can do a great deal of damage even though they are not usually as large as quakes along plate boundaries.

## Explore More

Use this resource to answer the questions that follow.

[http://earthquake.usgs.gov/earthquakes/states/events/1811\\_overview.php](http://earthquake.usgs.gov/earthquakes/states/events/1811_overview.php)

1. How many large earthquakes made up the New Madrid Earthquakes of 1811-1812? Which was the largest?
2. What was the effect of the earthquakes on the lake of the St. Francis River?
3. How did the quakes negatively impact farming in the region?
4. What happened in the rivers?
5. Why was the death toll from such large earthquakes so small?
6. Why was the New Madrid quake set felt so much farther from the epicenter than the 1906 San Francisco quake?
7. Will a large earthquake happen again in the region? How big will it be and when will it happen?
8. What would be the effect of such a large quake today?



**FIGURE 1.26**

The New Madrid seismic zone is located in the interior of the North American plate (near Missouri, Arkansas, Tennessee, Kentucky, and Illinois), but many earthquakes occur there.

### Explore More Answers

- 3, the 2nd one on Feb 7
- Water was replaced by sand and dead fish were found in the former lake bottom.
- Large fissures couldn't be crossed by horseback; land subsided and turned to swamps; sand and mud covered the ground.
- Islands disappeared; banks caved in; fissures opened and closed; water from the fissures produced large waves; new channels were opened and old channels were cut off; boats capsized.
- Not many people lived in the area and log cabins withstood shaking very well.
- Rock in the western US absorbs earthquake energy, but in the eastern US the seismic energy is not absorbed so it spreads.
- Yes, a large earthquake will happen, but when and how large are unknown.
- There would be lots of property damage and many deaths.

### Review

- Why do intraplate earthquakes tend to be less frequent and smaller than earthquakes at plate boundaries?
- Why do intraplate earthquakes take place at all?
- Along what sorts of features do intraplate earthquakes take place?

**Review Answers**

1. Intraplate earthquakes are not the result of giant slabs of lithosphere meeting at a plate boundary so there is less motion to take up along the fault.
2. Solid slabs of lithosphere traveling on a round planet need to make adjustments.
3. They reactivate an ancient fault or rift zone.

## 1.11 Predicting Earthquakes

- Explain how scientists attempt to predict earthquakes.



### What if you could predict an earthquake?

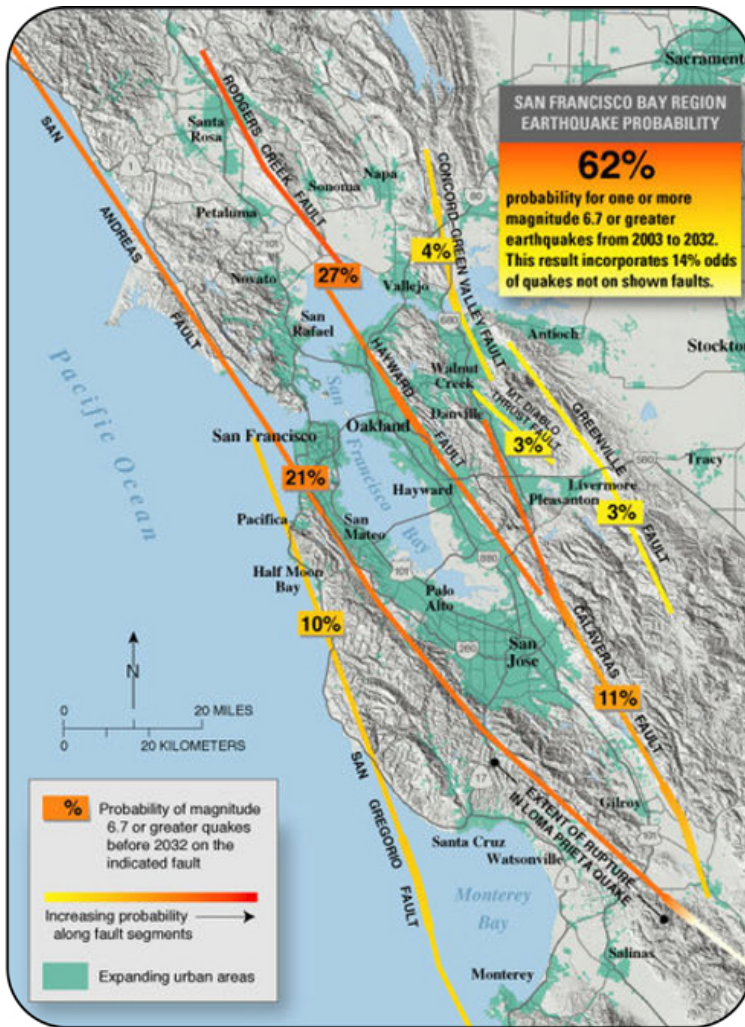
What would make a good prediction? Knowing where, when, and the magnitude of the quake would make it possible for people to evacuate.

### A Good Prediction

Scientists are a long way from being able to predict earthquakes. A good prediction must be detailed and accurate. Where will the earthquake occur? When will it occur? What will be the magnitude of the quake? With a good prediction authorities could get people to evacuate. An unnecessary evacuation is expensive and causes people not to believe authorities the next time an evacuation is ordered.

### Where?

Where an earthquake will occur is the easiest feature to predict. How would you predict this? Scientists know that earthquakes take place at plate boundaries and tend to happen where they've occurred before ( **Figure 1.27**). Fault segments behave consistently. A segment with frequent small earthquakes or one with infrequent huge earthquakes will likely do the same thing in the future.



**FIGURE 1.27**

The probabilities of earthquakes striking along various faults in the San Francisco area between 2003 (when the work was done) and 2032.

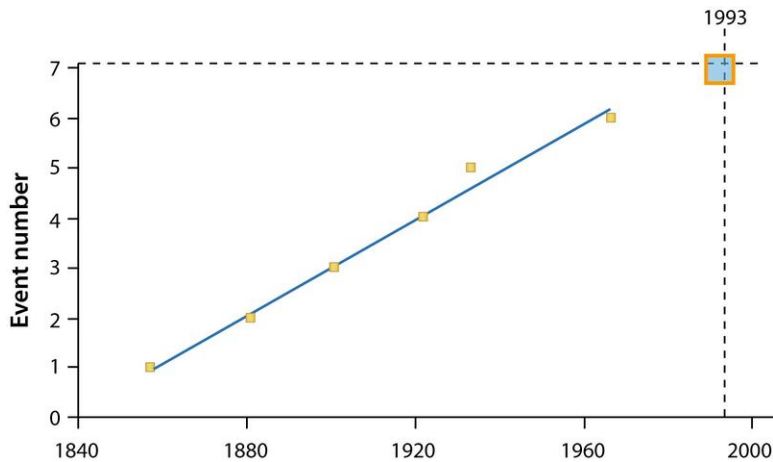
**When?**

When an earthquake will occur is much more difficult to predict. Since stress on a fault builds up at the same rate over time, earthquakes should occur at regular intervals ( **Figure 1.28**). But so far scientists cannot predict when quakes will occur even to within a few years.

**Earthquake Signs**

Signs sometimes come before a large earthquake. Small quakes, called **foreshocks**, sometimes occur a few seconds to a few weeks before a major quake. However, many earthquakes do not have foreshocks, and small earthquakes are not necessarily followed by a large earthquake. Ground tilting, caused by the buildup of stress in the rocks, may precede a large earthquake, but not always. Water levels in wells fluctuate as water moves into or out of fractures before an earthquake. This is also an uncertain predictor of large earthquakes. The relative arrival times of P-waves and S-waves also decreases just before an earthquake occurs.

Folklore tells of animals behaving erratically just before an earthquake. Mostly, these anecdotes are told after the earthquake. If indeed animals sense danger from earthquakes or tsunamis, scientists do not know what it is they could be sensing, but they would like to find out.

**FIGURE 1.28**

Around Parkfield, California, an earthquake of magnitude 6.0 or higher occurs about every 22 years. So seismologists predicted that one would strike in 1993, but that quake came in 2004 - 11 years late.

Earthquake prediction is very difficult and not very successful, but scientists are looking for a variety of clues in a variety of locations and to try to advance the field.

See more at <http://science.kqed.org/quest/video/earthquakes-breaking-new-ground/> .

**MEDIA**

Click image to the left for use the URL below.

URL: <http://gamma.ck12.org/flx/render/embeddedobject/59205>

It's been twenty years since the Loma Prieta Earthquake ravaged downtown Santa Cruz and damaged San Francisco's Marina District and the Bay Bridge. QUEST looks at the dramatic improvements in earthquake prediction technology since 1989. But what can be done with ten seconds of warning?

Find out more by listening to this audio report at <http://science.kqed.org/quest/audio/predicting-the-next-big-one/> .

**MEDIA**

Click image to the left for use the URL below.

URL: <http://gamma.ck12.org/flx/render/embeddedobject/59206>

**Summary**

- A good prediction must indicate when and where an earthquake will take place with detail and accuracy.
- Fault segments tend to behave the same way over time.
- Signs that an earthquakes may occur include foreshocks, ground tilting, water levels in wells and the relative arrival times of P and S waves.

## Explore More

Use this resource to answer the questions that follow.

[http://authors2.ck12.org/wiki/index.php/Earthquakes\\_VI:\\_Predicting\\_Earthquakes#Practice](http://authors2.ck12.org/wiki/index.php/Earthquakes_VI:_Predicting_Earthquakes#Practice)

1. What can scientists predict about future earthquakes? What can't they predict?
2. Which plates does the Enriquillo-Plantain Garden Fault separate? Which islands does it pass through?
3. How large was the recent Haiti earthquake?
4. What did scientists predict about a quake on the Enriquillo-Plantain Garden Fault?
5. How did scientists measure the amount of strain that was accumulating?
6. How is the Hayward Fault like the Enriquillo-Plantain Garden Fault?
7. What is the prediction for the Hayward Fault? What can't scientists predict?
8. What is the value of predictions like this?

## Explore More Answers

1. They can't predict date and time; they know a fault is under stress and strain.
2. North American and Caribbean, Espanola to Jamaica
3. magnitude 7.0
4. If all the energy stored in the fault zone were released at once, a large quake of 7.2 magnitude would hit the region.
5. very accurate GPA measurements
6. They are both accomodating plate motion and they are both strike-slip.
7. A magnitude 7.0 will happen sometime but they don't know when.
8. Communities can prepare for that magnitude of quake.

## Review

1. Why are earthquakes so hard to predict?
2. Why is it easier to predict where a quake will occur than when?
3. Describe some of the signs that scientists use to predict earthquakes.
4. It's now more than a decade after the map of earthquake probabilities in the San Francisco Bay area was made. What do you think the fact that no large earthquakes have struck those faults yet does to the probability that one will strike by 2032?

## Review Answers

1. Faults build up stress but no one can know when enough stress will build up that the fault will break.
2. There are lots of indications that a region is seismically active. Besides historical records there are lots of geological indicators.
3. Some signs are foreshocks that may occur a few weeks early, but not all small quakes precede larger quakes; ground tilting caused by stress buildup; water levels fluctuate as water moves in and out of fractures; the behavior of seismic waves.
4. The probability is still the same but the probability increases beyond 2032 if it doesn't happen.

## 1.12 Tsunami

- Describe the wave features of tsunami.



### What is a tsunami?

"Tsunami" is a Japanese word meaning "harbor wave." Some people call them tidal waves. But these deadly waves are not related to tides and they are not restricted to harbors. Few words can express the horror these waves can bring.

### Tsunami as Waves

**Tsunami** are deadly ocean waves from the sharp jolt of an undersea earthquake. Less frequently, these waves can be generated by other shocks to the sea, like a meteorite impact. Fortunately, few undersea earthquakes, and even fewer meteorite impacts, generate tsunami.

### Wave Height

Tsunami waves have small wave heights relative to their long wavelengths, so they are usually unnoticed at sea. When traveling up a slope onto a shoreline, the wave is pushed upward. As with wind waves, the speed of the

bottom of the wave is slowed by friction. This causes the wavelength to decrease and the wave to become unstable. These factors can create an enormous and deadly wave.

Landslides, meteorite impacts, or any other jolt to ocean water may form a tsunami. Tsunami can travel at speeds of 800 kilometers per hour (500 miles per hour).

A video explanation of tsunami is here: <http://www.youtube.com/watch?v=StdqGoezNrY> .

## Wavelength

Since tsunami are long-wavelength waves, a long time can pass between crests or troughs. Any part of the wave can make landfall first.

In 1755 in Lisbon, Portugal, a tsunami trough hit land first. A large offshore earthquake did a great deal of damage on land. People rushed out to the open space of the shore. Once there, they discovered that the water was flowing seaward fast and some of them went out to observe. What do you think happened next? The people on the open beach drowned when the crest of the wave came up the beach.

Large tsunami in the Indian Ocean and more recently Japan have killed hundreds of thousands of people in recent years. The west coast is vulnerable to tsunami since it sits on the Pacific Ring of Fire. Scientists are trying to learn everything they can about predicting tsunamis before a massive one strikes a little closer to home.

Although most places around the Indian Ocean did not have warning systems in 2005, there is a tsunami warning system in that region now. Tsunami warning systems have been placed in most locations where tsunami are possible.

See more at <http://science.kqed.org/quest/video/scary-tsunamis/> .



### MEDIA

Click image to the left for use the URL below.

URL: <http://gamma.ck12.org/flx/render/embeddedobject/114946>

## Summary

- Tsunami have relatively low wave heights, so they are not noticeable until they move up a shore.
- Tsunami have long wavelengths. The time between two crests or two troughs can be many minutes.
- Tsunami warning systems have been placed in most locations where tsunami are possible.

## Explore More

Use this resource to answer the questions that follow.



### MEDIA

Click image to the left for use the URL below.

URL: <http://gamma.ck12.org/flx/render/embeddedobject/116521>

1. What does the word tsunami mean in Japanese?

2. Why has Japan had so many tsunamis?
3. What causes a tsunami?
4. How fast do the waves travel?
5. What happens to the tsunami as it reaches the continental shelf?
6. How do tsunamis differ from regular waves?
7. What was the deadliest tsunami ever recorded? How many people died?
8. What does the Pacific Tsunami Warning Center do?

### Explore More Answers

1. harbor wave
2. Japan lies across the edges of four tectonic plates where most earthquakes happen.
3. Two tectonic plates push together and create an earthquake that displaces lots of water and creating a series of waves that expanding in all directions.
4. In deep water the waves travel up to 500 mph, but in shallow water friction with the bottom lowers the wave's speed.
5. Friction with the bottom slows the wave but the shallower depth raises the height of the water.
6. A tsunami hits like a wall of water, crashing into everything up to a mile inland. It drags everything in it out to sea.
7. December 2004 Indian Ocean; more than 200,000 people died
8. Monitor quakes from around the globe, alert the coastlines, tell people to move to higher ground and be ready to deal with the ruins left behind.

### Review

1. Why is a wave that is so powerful and tall on land unnoticeable at sea?
2. What should you do if you are at the beach and the water suddenly is sucked offshore?
3. Describe tsunami as waves in the way they travel up a shoreline and may strike as crests or troughs.

### Review Answers

1. Tsunami waves have small wave heights compared to long wavelengths so they are not noticeable if the bottom is deep.
2. Run for higher ground. In the western United States, signs indicate elevation when you are out of the tsunami hazard zone.
3. As they move onshore the wavelength decreases and the bottom is slowed by friction. If the crest of the wave hits first, there will be no warning. If the trough hits first the water will rush out to sea and there will be some warning.

## 1.13 21st Century Tsunami

- Describe the consequences of major 21st-century tsunami.



### Why should you pay attention in school?

Tilly Smith, an 11-year old English schoolgirl, was vacationing with her family in Phuket, Thailand on December 26, 2004. Walking along the beach Tilly noticed that the bubbling sea in Phuket resembled a video taken just before a tsunami in Hawaii in 1946. She'd seen the video in geography class two weeks earlier and insisted to her parents that a tsunami was coming. Her warning saved the approximately 100 tourists and others who were on that beach.

### Boxing Day Tsunami 2004

Not everyone had the same warning the people on Tilly's beach had. The Boxing Day Tsunami of December 26, 2004 was by far the deadliest of all time ( **Figure 1.29**). The tsunami was caused by the 2004 Indian Ocean Earthquake. With a magnitude of 9.2, it was the second largest earthquake ever recorded.

The extreme movement of the crust displaced trillions of tons of water along the entire length of the rupture. Several tsunami waves were created with about 30 minutes between the peaks of each one. The waves that struck nearby Sumatra 15 minutes after the quake reached more than 10 meters (33 feet) in height. The size of the waves decreased with distance from the earthquake and were about 4 meters (13 feet) high in Somalia.

The tsunami did so much damage because it traveled throughout the Indian Ocean. About 230,000 people died in eight countries. There were fatalities even as far away as South Africa, nearly 8,000 kilometers (5,000 miles) from the earthquake epicenter. More than 1.2 million people lost their homes and many more lost their ways of making a living.

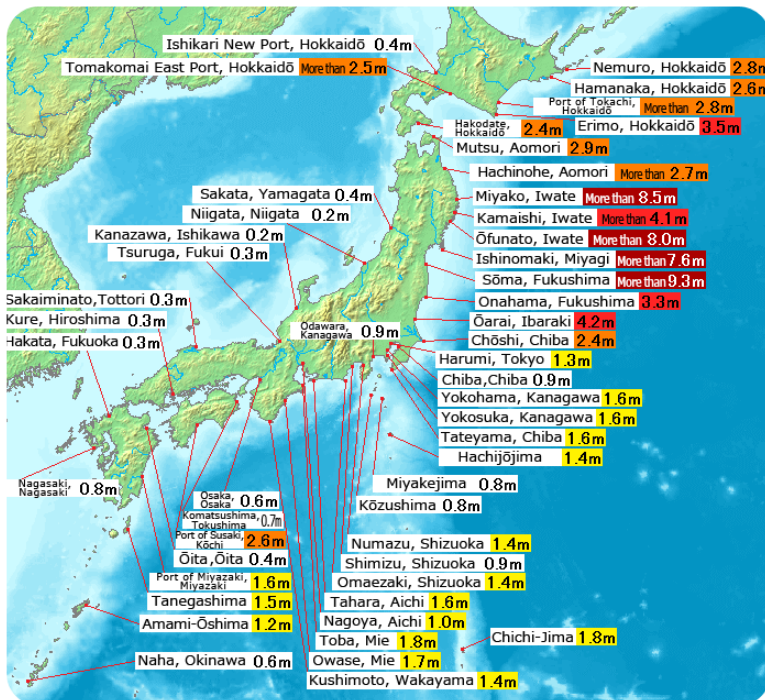


**FIGURE 1.29**

The countries that were most affected by the 2004 Boxing Day tsunami.

### Japan Tsunami 2011

The Japanese received a one-two punch in March 2011. The 2011 Tōhoku earthquake offshore was a magnitude 9.0 and damage from the quake was extensive. People didn't have time to recover before massive tsunami waves hit the island nation. As seen in **Figure 1.30**, waves in some regions topped 9 meters (27 feet).



**FIGURE 1.30**

This map shows the peak tsunami wave heights.

The tsunami did much more damage than the massive earthquake ( **Figure 1.31**).

**FIGURE 1.31**

An aerial view shows the damage to Sendai, Japan caused by the earthquake and tsunami. The black smoke is coming from an oil refinery, which was set on fire by the earthquake. The tsunami prevented efforts to extinguish the fire until several days after the earthquake.

Worst was the damage done to nuclear power plants along the northeastern coast. Eleven reactors were automatically shut down. Power and backup power were lost at the Fukushima plant, leading to equipment failures, meltdowns, and the release of radioactive materials. Control and cleanup of the disabled plants will go on for many years.

### Tsunami Warning Systems

As a result of the 2004 tsunami, an Indian Ocean warning system was put into operation in June 2006. Prior to 2004, no one had thought a large tsunami was possible in the Indian Ocean.

**FIGURE 1.32**

A sign in Thailand shows an evacuation route.

In comparison, a warning system has been in effect around the Pacific Ocean for more than 50 years. The system was used to warn of possible tsunami waves after the Tōhoku earthquake, but most were too close to the quake to get to high ground in time. Further away, people were evacuated along many Pacific coastlines, but the waves were not that large.

## Summary

- The Boxing Day Tsunami of 2004 came from a massive earthquake and traveled across the Indian Ocean, causing death and destruction in 12 nations.
- In Japan, the tsunami struck very quickly after the 9.0 earthquake in the subduction zone offshore. Many more people died from the tsunami than the quake.
- Tsunami warning systems are important but are not useful in locations that are very close to the earthquake that generated them.

## Explore More

Use this resource to answer the questions that follow.



### MEDIA

Click image to the left for use the URL below.

URL: <http://gamma.ck12.org/flx/render/embeddedobject/116523>

1. What was the magnitude of the Japan Tsunami?
2. How tall was the world's deepest and largest sea wall?
3. How many people died or were missing?
4. How does a tsunami move in deep water?
5. How far inland did some waves reach?
6. How fast were the waves moving on land?

## Explore More Answers

1. 9.0 magnitude
2. 18'
3. 28,000
4. Reaches a height of a few feet.
5. as much as 3 miles
6. as fast as 5 miles per second

## Review

1. How does an earthquake generate a tsunami?
2. Why did so many people die in the Indian Ocean tsunami?
3. Why do you think there was more damage from the tsunami in Japan than from the earthquake that caused it?

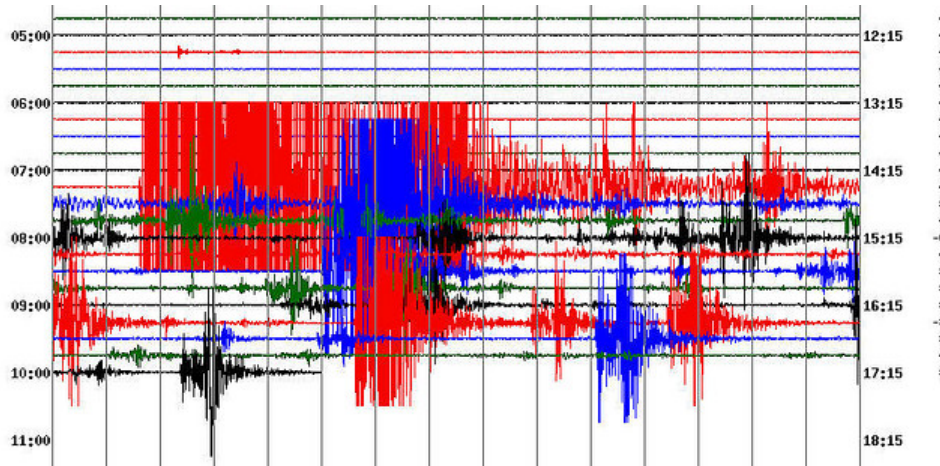
## Review Answers

1. Extreme movement of the crust underwater displaces tons of water along the length of the rupture.
2. The tsunami went all around the Indian Ocean basin. Many people live near the sea because they fish for a living. Tourists also flock to the seaside and so tourist hotels and the communities that serve them were vulnerable.

- 
- 
3. The wave of water wiped out everything. It wasn't even possible to see the earthquake damage because the tsunami damage ruined it.

## 1.14 Measuring Earthquake Magnitude

- Describe instruments scientists use to measure earthquakes.



### Can you read a seismogram?

What information can you pick out of this seismograph? Can you see arrival of the P- and S-waves? How many earthquakes were there? Were there foreshocks or aftershocks? At what times do all of these things happen?

### Measuring Magnitude

A **seismograph** produces a graph-like representation of the seismic waves it receives and records them onto a **seismogram** ( **Figure 1.33**). Seismograms contain information that can be used to determine how strong an earthquake was, how long it lasted, and how far away it was. Modern **seismometers** record ground motions using electronic motion detectors. The data are then kept digitally on a computer.

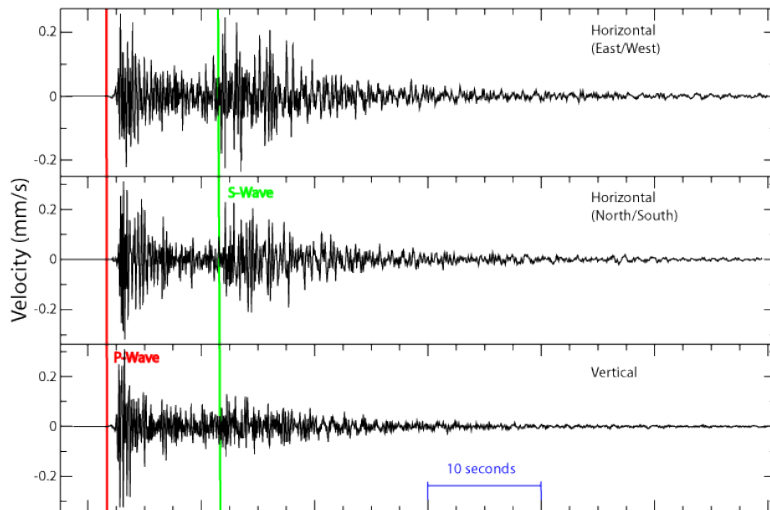
If a seismogram records P-waves and surface waves but not S-waves, the seismograph was on the other side of the Earth from the earthquake. The amplitude of the waves can be used to determine the magnitude of the earthquake, which will be discussed in a later section.

- A seismograph records an earthquake 50 miles away: [http://www.iris.edu/hq/files/programs/education\\_and\\_outreach/aotm/17/Seismogram\\_RegionalEarthquake.mov](http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/17/Seismogram_RegionalEarthquake.mov) .
- This animation shows three different stations picking up seismic waves: [http://www.iris.edu/hq/files/program/education\\_and\\_outreach/aotm/10/4StationSeismoNetwork480.mov](http://www.iris.edu/hq/files/program/education_and_outreach/aotm/10/4StationSeismoNetwork480.mov) .

### Interpreting a Seismogram

The seismogram in the introduction shows:

- foreshocks.
- the arrival of the P-waves.
- the arrival of the S-waves.
- the arrival of the surface waves (very hard to pick out).




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**FIGURE 1.33**

These seismograms show the arrival of P-waves and S-waves. The surface waves arrive just after the S-waves and are difficult to distinguish. Time is indicated on the horizontal portion (or x-axis) of the graph.

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- aftershocks.
- the times when all of these things occur.

### Summary

- A seismograph records seismic waves on a seismogram. A seismometer is a digital seismic wave recorder.
- Since S-waves do not travel through liquids, a seismogram with no S-waves is on the other side of the planet.
- Seismographs yield a tremendous amount of information about an earthquake.

### Explore More

Use this resource to answer the questions that follow.

<http://www.youtube.com/watch?v=U6cRzDddAFI> Start at 06:30.

1. What is the Mercalli Scale?
2. What happens at level IX?
3. What does the Richter Scale measure?
4. What is the most damaging quake on this scale?
5. What does each step of the Richter scale represent in energy increase.
6. In our historical experience what releases the most energy: earthquakes, volcanic eruptions or atomic bombs?
7. How often do we have earthquake of magnitude 8 and above?
8. What does the Moment Magnitude scale measure?
9. Where is the epicenter of an earthquake?
10. How do you calculate the epicenter of an earthquake?

### Explore More Answers

1. A 12 step measure of intensity with 12 measurements, from I to XII.
2. Ruinous damage, ground cracks, buildings collapse.
3. Movement on the fault and the seismic waves, from 1 to 10.
4. 9 to 10

5. A 30-fold increase in energy per one whole number increase.
6. earthquakes
7. About once in every 5 to 10 years.
8. the total energy released
9. where the rock breaks
10. Calculate the difference in arrival time of P and S waves and figure the distance to the quake from each of the seismic stations.

### Review

1. Define seismograph, seismogram, and seismometer.
2. What does a seismogram with P-waves but not S-waves mean?
3. How can you tell a main earthquake from foreshocks and aftershocks?

### Review Answers

1. A seismograph is the machine that records earthquakes on a seismogram. A seismometer is a machine that records ground motions electronically.
2. It means that the earthquake is at the other side of the world because the S-waves couldn't go through the outer core.
3. They are smaller than the main event but it's not clear what is happening without the other earthquakes being recorded. For example a small quake may stand alone or it may be a foreshock.

## 1.15 Locating Earthquake Epicenters

- Explain how to find an earthquake epicenter.



### Can you find an earthquake epicenter?

The epicenter of the 2011 Japan earthquake was just offshore of Sendai where the Pacific Plate plunges into a subduction zone. The quake had a relatively shallow depth of 20 miles (32 km). Remember that shallow quakes typically cause the most damage. How do scientists find an earthquake epicenter?

### Finding the Epicenter

Here are the steps to finding an earthquake epicenter using three seismograms:

1. Determine the epicenter distance from three different seismographs. The longer the time between the arrival of the P-wave and S-wave, the farther away is the epicenter. So the difference in the P- and S-wave arrival times determines the distance between the epicenter and a seismometer.

This animation shows how to determine distance using P, S, and surface waves: [http://www.iris.edu/hq/files/program\\_s/education\\_and\\_outreach/aotm/12/IRIStravelTime\\_Bounce\\_480.mov](http://www.iris.edu/hq/files/program_s/education_and_outreach/aotm/12/IRIStravelTime_Bounce_480.mov) .

2. Draw a circle with a radius equal to the distance from the epicenter for that seismograph. The epicenter is somewhere along that circle. Do this for three locations. Using data from two seismographs, the two circles will intercept at two points. A third circle will intercept the other two circles at a single point. This point is the earthquake epicenter ( **Figure 1.34**).

Seismic stations record ten earthquakes in this animation: [http://www.iris.edu/hq/files/programs/education\\_and\\_outreach/aotm/12/TravelTime\\_Sphere\\_10Stn\\_480.mov](http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/12/TravelTime_Sphere_10Stn_480.mov) .

**FIGURE 1.34**

Three circles drawn from three seismic stations each equal to the radius from the station to the epicenter of the quake will intercept at the actual epicenter.

Of course, it's been a long time since scientists drew circles to locate an earthquake epicenter. This is all done digitally now. but it's a great way to learn the basics of how locating an epicenter works.

### Summary

- To find an earthquake epicenter you need at least three seismographs.
- Find the distance from each seismograph to the earthquake epicenter.
- The intersection of the three circles is the epicenter.

### Explore More

Use this resource to answer the questions that follow.

<http://www.youtube.com/watch?v=694yaY2yITg>

1. What is the difference in P- and S-wave arrival times at Salt Lake City?
2. How do you find out how far away the epicenter of the quake was from SLC?

3. What is the distance to the epicenter from Salt Lake City? So where is the epicenter?
4. When you know the distance from SLC and from Houston, where is the epicenter?
5. When you have three circles around three cities, how do you know where the epicenter is?

### Explore More Answers

1. 3 minutes
2. Where 3 minutes fits between arrival on the P-and S-wave chart.
3. 1800 km; it is somewhere on a circle around SLC that has a radius of 1800 km.
4. It is where the two circles intersect, but we don't know between the two points where that happens.
5. It is where all three circles intersect.

### Review

1. How do you determine the distance from the seismograph to the earthquake epicenter?
2. How do you find the epicenter from three seismographs? What if you have more seismographs involved?
3. In what circumstance would three seismographs not give you enough information to find an earthquake epicenter?

### Review Answers

1. It is the difference in arrival time between the P-wave and the S-wave. Once you have the time difference you look at the P and S wave curve to see the distance from the epicenter that corresponds with that time difference.
2. You find the distance to the epicenter for all three seismic stations. You draw a circle around each station that it the correct distance from each. The point where all three circles intersect is the epicenter. If you have more then the result will be more accurate.
3. If the seismic stations were too close to the epicenter it might be hard to figure this out.

## 1.16 Scales that Represent Earthquake Magnitude

- Describe how scientists express the size and intensity of an earthquake.



### How do scientists measure earthquakes?

This 6.3 magnitude earthquake in Christchurch, New Zealand in 2011 caused 181 deaths and thousands of injuries. Earthquakes and the damage they cause can be measured in a few different ways based on the damage they cause or the energy of the quake.

### Measuring Earthquakes

People have always tried to quantify the size of and damage done by earthquakes. Since early in the 20<sup>th</sup> century, there have been three methods. What are the strengths and weaknesses of each?

#### Mercalli Intensity Scale

Earthquakes are described in terms of what nearby residents felt and the damage that was done to nearby structures. What factors would go into determining the damage that was done and what the residents felt in a region?

#### Richter Magnitude Scale

Developed in 1935 by Charles Richter, this scale uses a seismometer to measure the magnitude of the largest jolt of energy released by an earthquake.

## Moment Magnitude Scale

This scale measures the total energy released by an earthquake. Moment magnitude is calculated from the area of the fault that is ruptured and the distance the ground moved along the fault.

## Log Scales

The Richter scale and the moment magnitude scale are **logarithmic scales**.

- The amplitude of the largest wave increases ten times from one integer to the next.
- An increase in one integer means that thirty times more energy was released.
- These two scales often give very similar measurements.

How does the amplitude of the largest seismic wave of a magnitude 5 earthquake compare with the largest wave of a magnitude 4 earthquake? How does it compare with a magnitude 3 quake? The amplitude of the largest seismic wave of a magnitude 5 quake is 10 times that of a magnitude 4 quake and 100 times that of a magnitude 3 quake.

How does an increase in two integers on the moment magnitude scale compare in terms of the amount of energy released? Two integers equals a 900-fold increase in released energy.

## Moment Magnitude Scale is Best

Which scale do you think is best? With the Richter scale, a single sharp jolt measures higher than a very long intense earthquake that releases more energy. The moment magnitude scale more accurately reflects the energy released and the damage caused. Most seismologists now use the moment magnitude scale.

The way scientists measure earthquake intensity and the two most common scales, Richter and moment magnitude, are described along with a discussion of the 1906 San Francisco earthquake in *Measuring Earthquakes* video (**3d**): [http://www.youtube.com/watch?v=wtl\\_uADteCA](http://www.youtube.com/watch?v=wtl_uADteCA) (2:54).



### MEDIA

Click image to the left for use the URL below.

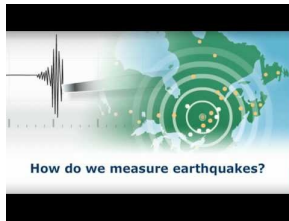
URL: <http://gamma.ck12.org/flx/render/embeddedobject/1428>

## Summary

- Mercalli Intensity Scale depends on many factors besides the amount of energy released in the earthquake including the type of basement rock and the quality of the structures built in the area.
- The Richter scale is a logarithmic scale that measures the largest jolt of energy released by an earthquake.
- The moment magnitude scale is a logarithmic scale that measures the total amount of energy released by an earthquake.

## Explore More

Use this resource to answer the questions that follow.

**MEDIA**

Click image to the left for use the URL below.

URL: <http://gamma.ck12.org/flx/render/embeddedobject/1429>

1. How is earthquake strength measured?
2. What is magnitude?
3. What do scientists use to measure earthquakes?
4. How is magnitude calculated?
5. How much does ground motion increase for each unit of increase in magnitude?
6. What is intensity?
7. What does intensity depend upon?
8. How does geology affect intensity?

**Explore More Answers**

1. magnitude, intensity
2. The energy released at the earthquake's source.
3. A network of seismometers records earthquakes.
4. The ground motion recorded by each seismometer and the distance of each from the earthquake.
5. 10-times
6. Intensity is the strength of shaking we feel.
7. The magnitude of the quake and the distance from the epicenter, plus our circumstances.
8. Soft soil shakes longer and more than bedrock or stiff soil.

**Review**

1. Under what circumstances might the Mercalli Intensity Scale be useful today? Why was it replaced by the Richter and then the moment magnitude scales?
2. Why do scientists prefer the moment magnitude scale to the Richter scale?
3. How much difference is there between the 5.8 magnitude quake that struck Virginia and the 9.0 quake that struck Japan, both in 2011, in their energy released and largest wave amplitude?

**Review Answers**

1. In a quake that happened a long time ago, before scientists had seismometers, they can use the reports of people at the time to determine the intensity of a quake. Planners also use it to determine what types of structures might be best for certain areas.
2. It is the total energy released by the quake rather than one large jolt. It is a more realistic view of the magnitude of the quake.
3. The amplitude of a 9 quake is 10 times greater than an 8, 100 times greater than a 7 so it is 1000 times greater than a 6 and even greater for a 5.8. The energy released is 30 times greater for a 8 than an 8 and 900 times greater than a 7 and 2700 times greater than a 6 so more than 2700 times.

## 1.17 Earthquake Damage

- Identify factors that make an earthquake damaging and deadly.



### Is magnitude all that matters for determining earthquake damage?

The type and quality of construction has a tremendous effect on what happens during an earthquake. Damage and fatalities are directly affected by the construction in an earthquake. For example, many more people died in the 1988 Armenia earthquake, where people live in mud houses, than in the 1989 earthquake in Loma Prieta. Most buildings in California's earthquake country are designed to be earthquake-safe.

### Damage from Earthquakes

We know that earthquakes kill lots of people. However, the ground shaking almost never kills people, and the ground does not swallow someone up. Fatalities depend somewhat on an earthquake's size and the type of ground people inhabit. But much of what determines the number of fatalities depends on the quality of structures. People are killed when structures fall on them. More damage is done and more people are killed by the fires that follow an earthquake than the earthquake itself.

### What Makes an Earthquake Deadly?

- Population density. The magnitude 9.2 Great Alaska Earthquake, near Anchorage, of 1964 resulted in only 131 deaths. At the time few people lived in the area ( **Figure 1.35**).
- Not size. Only about 2,000 people died in the 1960 Great Chilean earthquake, the largest earthquake ever recorded. The Indian Ocean earthquake of 2004 was one of the largest ever, but most of the 230,000 fatalities were caused by the tsunami, not the earthquake itself.




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**FIGURE 1.35**

A landslide in a neighborhood in Anchorage, Alaska, after the 1964 Great Alaska earthquake.

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- Ground type. Solid bedrock vibrates less than soft sediments, so there is less damage on bedrock. Sediments that are saturated with water undergo **liquefaction** and become like quicksand ( **Figure 1.36**). Soil on a hillside may become a landslide.




---

**FIGURE 1.36**

Liquefaction of sediments in Mexico City caused the collapse of many buildings in the 1985 earthquake.

---

Earthquake effects on buildings are seen in this animation: [http://www.iris.edu/hq/files/programs/education\\_and\\_outreach/aotm/6/SeismicBuilding-Narrated480.mov](http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/6/SeismicBuilding-Narrated480.mov) .

## City Planning

In earthquake-prone areas, city planners try to reduce hazards. For example, in the San Francisco Bay Area, maps show how much shaking is expected for different ground types ( **Figure 1.37**). This allows planners to locate new hospitals and schools more safely.

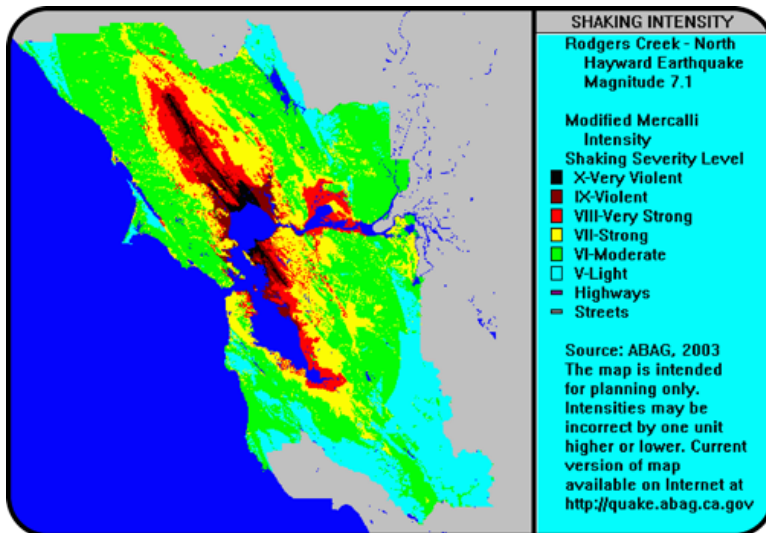


FIGURE 1.37

The expected Modified Mercalli Intensity Scale for an earthquake of magnitude 7.1 on the northern portion of the Hayward Fault.

## Summary

- Seismic waves rarely kill anyone. Structures falling on people and fires or tsunamis after the earthquake cause many more fatalities.
- City planning can lessen the damage done by earthquakes.
- Population density and ground type affect the number of fatalities.

## Explore More

Use this resource to answer the questions that follow.

Earthquake Destruction <https://www.youtube.com/watch?v=CtBXTvtFaCU>

1. What is one reason that earthquakes are so scary?
2. On an average day, how many earthquakes take place around the world? How many large earthquakes take place?
3. What causes earthquakes?
4. What happens when plates can't move for long periods of time?
5. What would happen if Earth didn't have internal heat?

## Explore More Answers

1. There is no warning.
2. hundreds; none
3. Heat from the core causes plate tectonics and most quakes occur at plate boundaries.
4. The plates break, the fault gives way, the energy is released and an earthquake occurs.
5. There would be no earthquakes, but the planet would be dead and flat.

## Review

1. In the map of expected Modified Mercalli Intensity for the Bay Area of a hypothetical earthquake on the Hayward Fault, why do you think there is red and black north of the bay and up the Sacramento River? Why

do you think there are much safer areas in rings around the bay?

2. What causes liquefaction and why is it damaging?
3. If a 9.2 earthquake struck near Anchorage, Alaska today, what do you think the fatalities would be compared with the quake in 1964?

### Review Answers

1. The region with red may be topped with material that moves more during a quake. A river would bring in sediment, which might shake more than bedrock.
2. Sediments become saturated with water and become like quicksand. Buildings and other things maybe swallowed up or fall over.
3. There would be so much more damage and so many more fatalities it would be night and day. The damage would be huge and intense.

## 1.18 Earthquake Safe Structures

- Identify steps that can be taken to make buildings safer and avoid fires in earthquake-prone areas.



### Why is California Memorial Stadium called a "tectonic time bomb"?

The Hayward Fault passes directly beneath both end zones at California Memorial Stadium, the home of football at the University of California, Berkeley. The site probably looked flat and easy to build on in 1922 before knowledge of earthquake faults was very advanced. Now, in the over-built East Bay, the land is worth an incredible amount of money. To make the stadium safe for workers, players, and fans, the stadium is being renovated in a \$321 million project involving 10 miles of steel cables, silicone fluid-filled shock absorbers, concrete piers, 3 feet of sand, plastic sheeting, and stone columns. Go Bears!

### New Construction

New construction can be made safer in many ways:

- Skyscrapers and other large structures built on soft ground must be anchored to bedrock, even if it lies hundreds of meters below the ground surface.
- The correct building materials must be used. Houses should bend and sway. Wood and steel are better than brick, stone, and adobe, which are brittle and will break.
- Larger buildings must sway, but not so much that they touch nearby buildings. Counterweights and diagonal steel beams are used to hold down sway.
- Large buildings can be placed on rollers so that they move with the ground.
- Buildings may be placed on layers of steel and rubber to absorb the shock of the waves.
- Connections, such as where the walls meet the foundation, must be made strong.
- In a multi-story building, the first story must be well supported ( **Figure 1.38**).




---

**FIGURE 1.38**

The first floor of this San Francisco building is collapsing after the 1989 Loma Prieta earthquake.

---

### Retrofitting

To make older buildings more earthquake safe, **retrofitting** with steel or wood can reinforce a building's structure and its connections. Elevated freeways and bridges can also be retrofitted so that they do not collapse.




---

**FIGURE 1.39**

Steel trusses were built diagonally and horizontally across windows to retrofit a building at Stanford University in Palo Alto, California. The San Andreas Fault passes just west of the university.

---

### Preventing Fire Damage

Fires often cause more damage than the earthquake. Fires start because seismic waves rupture gas and electrical lines, and breaks in water mains make it difficult to fight the fires ( **Figure 1.40**). Builders zigzag pipes so that they bend and flex when the ground shakes. In San Francisco, water and gas pipelines are separated by valves so that areas can be isolated if one segment breaks.

### Cost Considerations

Why aren't all structures in earthquakes zones constructed for maximum safety? Cost, of course. More sturdy structures are much more expensive to build. So communities must weigh how great the hazard is, what different

**FIGURE 1.40**

In the 1906 San Francisco earthquake, fire was much more destructive than the ground shaking.

building strategies cost, and make an informed decision.

In 1868 marked the Hayward Fault erupted in what would be a disastrous earthquake today. Since the fault erupts every 140 years on average, East Bay residents and geologists are working to prepare for the inevitable event.

See more at <http://science.kqed.org/quest/video/the-hayward-fault-predictable-peril/> .

**MEDIA**

Click image to the left for use the URL below.

URL: <http://gamma.ck12.org/flx/render/embeddedobject/114947>

**Summary**

- New structures that are built to meet earthquake safety codes do much better in earthquakes.
- Old buildings can be retrofitted for better safety.
- Cost is an important factor in deciding how safe to make the structures in an area.

**Explore More**

Use this resource to answer the questions that follow. <https://www.youtube.com/watch?v=I9g4tLcghPM>

1. What is the goal of the scientists engineers from the three universities?
2. What do they use as examples of these types of structures?
3. What is pre-cast concrete?
4. Why do builders use pre-cast concrete?
5. What are the tests designed to do to make the concrete structures more earthquake safe?
6. What is one thing the building will do to release energy?
7. How is this research useful to society?
8. What happened in past earthquakes that they want to avoid?

### Explore More Answers

1. Create new designs for pre-cast buildings that can withstand major earthquakes.
2. parking garages
3. It is concrete that is made in a plant in fixed forms.
4. It is a durable design material for structures.
5. They are testing the connections to see which hold the concrete structures together best.
6. Doors open and close to release energy rather than having the energy move up the building.
7. The scientists determine the most earthquake safe building forms and get codes changed so that communities build buildings that are more earthquake safe.
8. The collapse of concrete buildings such as roadways and parking structures.

### Review

1. Why do people build structures in earthquake-prone areas like the San Francisco or Los Angeles areas?
2. Why do fires do so much damage after an earthquake?
3. How do people weigh the costs and benefits to determining how earthquake safe to make structures in an area?

### Review Answers

1. Cities have built up in these areas and so instead of moving the city engineers try to build safer buildings.
2. Fires start because the earthquake waves rupture gas and electrical lines. They also break water mains so the fires can't be put out.
3. Communicates must look at the projected risk and how much that risk can be mitigated with new earthquake-safe structures versus the cost of those new structures.

## 1.19 Staying Safe in an Earthquake

- Identify the preparations for and actions during and after an earthquake that increase safety.



### How can you prepare for an earthquake?

If you live in earthquake country the actions you take before, during, and after a quake could make the difference in your comfort for several days or even your survival.

### Protecting Yourself in an Earthquake

There are many things you can do to protect yourself before, during, and after an earthquake.

#### Before the Earthquake

- Have an engineer evaluate the house for structural integrity. Make sure the separate pieces —floor, walls, roof, and foundation —are all well-attached to each other.
- Bracket or brace brick chimneys to the roof.
- Be sure that heavy objects are not stored in high places.
- Secure water heaters all around and at the top and bottom.
- Bolt heavy furniture onto walls with bolts, screws, or strap hinges.
- Replace halogen and incandescent light bulbs with fluorescent bulbs to lessen fire risk.

- Check to see that gas lines are made of flexible material so that they do not rupture. Any equipment that uses gas should be well secured.
- Everyone in the household should know how to shut off the gas line.
- Prepare an earthquake kit with three days supply of water and food, a radio, and batteries.
- Place flashlights all over the house and in the glove box of your car.
- Keep several fire extinguishers around the house to fight small fires.
- Be sure to have a first aid kit. Everyone should know basic first aid and CPR.
- Plan in advance how you will evacuate and where you will go. Do not plan on driving, as roadways will likely be damaged.

### During the Earthquake

- If you are in a building, get beneath a sturdy table, cover your head, and hold on.
- Stay away from windows, mirrors, and large furniture.
- If the building is structurally unsound, get outside as fast as possible.
- If you are outside, run to an open area away from buildings and power lines that may fall.
- If you are in a car, stay in the car and stay away from structures that might collapse, such as overpasses, bridges, or buildings.

### After the Earthquake

- Be aware that aftershocks are likely.
- Avoid dangerous areas like hillsides that may experience a landslide.
- Turn off water and power to your home.
- Use your phone only if there is an emergency. Many people will be trying to get through to emergency services.
- Be prepared to wait for help or instructions. Assist others as necessary.

### Summary

- Before an earthquake, be sure that your home is secure and that you have supplies to last a few days.
- During an earthquake, get to a safe place.
- After an earthquake, avoid dangerous situations, wait for instructions, and assist as necessary.

### Explore More

Use these resources to answer the questions that follow.

**Earthquake Safety** at [http://www.youtube.com/watch?v=piZ\\_tfbUp2E](http://www.youtube.com/watch?v=piZ_tfbUp2E)



#### MEDIA

Click image to the left for use the URL below.

URL: <http://gamma.ck12.org/flx/render/embeddedobject/116800>

1. What should you do when an earthquake hits and you are in your home?
2. Why is a doorway the second choice?

3. What should you do if you are outside when an earthquake hits?
4. How should you organize your home?

### Explore More Answers

1. Seek shelter under something substantial if the roof caves in, like a heavy desk.
2. Doorways are more substantial than ceilings.
3. Get into open away from things that will fall on you.
4. Don't have heavy things high on shelf. Be aware of things that could fall on you.

### Review

1. What should you do to prepare for an earthquake?
2. What should you do during an earthquake?
3. What should you do after an earthquake?

### Review Answers

1. Be sure that things will not fly or fall and hurt someone. Have an emergency kit ready. Know where to meet up with people and what you plan to do.
2. Stay away from anything that might fall on you whether you're inside or outside.
3. Be careful of aftershocks, turn off your utilities, avoid dangerous situations.

## 1.20 Volcano Characteristics

- Define volcanoes, their locations, and their stages.



### Do you think volcanoes are cool?

Active volcanoes are found on all continents except Australia. Volcanoes even erupt under the ice on Antarctica! Do you live near a volcano? What are the chances that it will erupt in your lifetime? If you don't live near one, could a volcanic eruption elsewhere cloud the skies above where you live?

### Volcanoes

A volcano is a vent from which the material from a magma chamber escapes. Volcanic eruptions can come from peaky volcanic cones, fractured domes, a vent in the ground, or many other types of structures.

### Where They Are

Volcanoes are a vibrant manifestation of plate tectonics processes. Volcanoes are common along convergent and divergent plate boundaries. Volcanoes are also found within lithospheric plates away from plate boundaries. Wherever mantle is able to melt, volcanoes may be the result.

What is the geological reason for the locations of all the volcanoes in the figure? Does it resemble the map of earthquake epicenters? Are all of the volcanoes located along plate boundaries? Why are the Hawaiian volcanoes located away from any plate boundaries?

## Active Volcanoes, Plate Tectonics, and the "Ring of Fire"

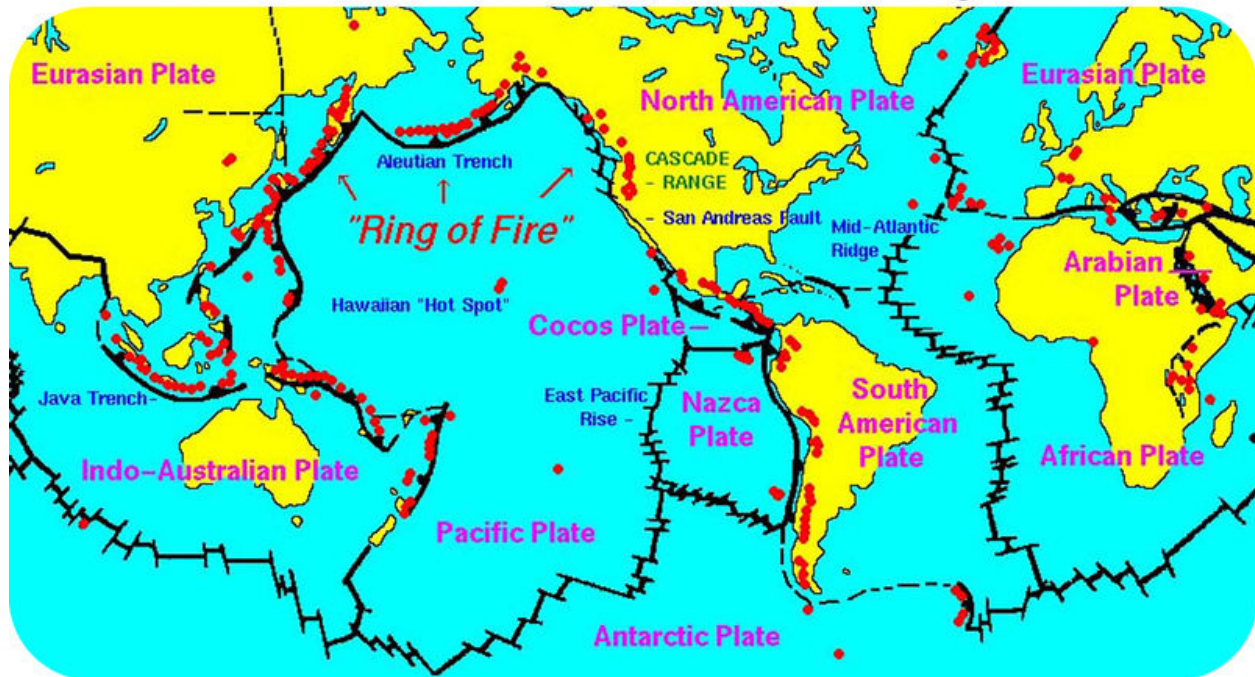


FIGURE 1.41

World map of active volcanoes (red dots).

### Creating Magma

Volcanoes erupt because mantle rock melts. This is the first stage in creating a volcano. Remember from the chapter Materials of Earth's Crust that mantle may melt if temperature rises, pressure lowers, or water is added. Be sure to think about how and why melting occurs in the settings where there is volcanism mentioned in the next few concepts.

### Stages

Of all the volcanoes in the world, very few are erupting at any given time. Scientists question whether a volcano that is not erupting will ever erupt again and then describe it as active, dormant, or extinct.

- **Active:** currently erupting or showing signs of erupting soon.
- **Dormant:** no current activity, but has erupted recently.
- **Extinct:** no activity for some time; will probably not erupt again.

### Summary

- Volcanoes are located along convergent and divergent plate boundaries.
- Magma can be created when temperature rises, pressure lowers, or water is added.

**FIGURE 1.42**

Volcanoes can be active, dormant, or extinct.

- Volcanoes may be active, dormant, or extinct depending on whether there is the possibility of magma in their magma chambers.

### Making Connections



#### MEDIA

Click image to the left for use the URL below.

URL: <http://gamma.ck12.org/flx/render/embeddedobject/54942>

### Explore More

Use this resource to answer the questions that follow. <https://www.youtube.com/watch?v=WgkTM2luLok>

1. Where do volcanoes mostly occur?
2. Why does magma come out of a volcano?
3. What is magma that reaches the surface called? What happens when it cools?
4. What does magma collect in beneath the volcano? How does it go onto the surface?
5. When does an eruption occur?
6. How are fast-moving mudflows created?
7. How are volcanoes essential for life on our planet?
8. When will an extinct volcano erupt next?

### Explore More Answers

1. Destructive or constructive plate boundaries.

2. Pressure builds up and when it gets too high the magma explodes from the volcano.
3. Magma on the surface is called lava; it cools to form new rock that builds up to form a volcano.
4. A magma chamber; from the main or secondary vents.
5. When pressure builds up enough that it forces the magma up the main vent.
6. Ash mixes with rainwater or snow melt.
7. They created the first atmosphere and they are crucial to the carbon cycle.
8. Never

### Review

1. Where do most volcanoes occur? Why?
2. What is needed for magma to form?
3. If a volcano is dormant, can it become active? Can it become extinct?

### Review Answers

1. Most volcanoes are found at convergent and divergent plate boundaries. This is because it is where magma can reach the surface due to melting in the mantle. Convergent plate boundaries have melting due to the subducting plate. Divergent plate boundaries have melting as the new plates move apart.
2. Magma forms if temperature increases, pressure decreases or water is added.
3. A dormant volcano can become active or extinct.

## 1.21 Volcanoes at Plate Boundaries

- Describe volcanic activity at convergent and divergent plate boundaries and explain why it occurs.



### Climb a volcano... are you mad?

Volcanoes are fun (and difficult) to climb. Climbing in the Cascades ranges in difficulty from a non-technical hike, like on South Sister, to a technical climb on Mount Baker in which an ice axe, crampons, and experience are needed.

### Convergent Plate Boundaries

Converging plates can be oceanic, continental, or one of each. If both are continental they will smash together and form a mountain range. If at least one is oceanic, it will subduct. A subducting plate creates volcanoes.

In the chapter Plate Tectonics we moved up western North America to visit the different types of plate boundaries there. Locations with converging in which at least one plate is oceanic at the boundary have volcanoes.

## Melting

Melting at convergent plate boundaries has many causes. The subducting plate heats up as it sinks into the mantle. Also, water is mixed in with the sediments lying on top of the subducting plate. As the sediments subduct, the water rises into the overlying mantle material and lowers its melting point. Melting in the mantle above the subducting plate leads to volcanoes within an island or continental arc.

## Pacific Rim

Volcanoes at convergent plate boundaries are found all along the Pacific Ocean basin, primarily at the edges of the Pacific, Cocos, and Nazca plates. Trenches mark subduction zones, although only the Aleutian Trench and the Java Trench appear on the map in the previous concept, "Volcano Characteristics."

The Cascades are a chain of volcanoes at a convergent boundary where an oceanic plate is subducting beneath a continental plate. Specifically the volcanoes are the result of subduction of the Juan de Fuca, Gorda, and Explorer Plates beneath North America. The volcanoes are located just above where the subducting plate is at the right depth in the mantle for there to be melting ( **Figure 1.43**).

The Cascades have been active for 27 million years, although the current peaks are no more than 2 million years old. The volcanoes are far enough north and are in a region where storms are common, so many are covered by glaciers.

The Cascades are shown on this interactive map with photos and descriptions of each of the volcanoes: [http://www.iris.edu/hq/files/programs/education\\_and\\_outreach/aotm/interactive/6.Volcanoes4Rollover.swf](http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/interactive/6.Volcanoes4Rollover.swf) .

## Divergent plate boundaries

At divergent plate boundaries hot mantle rock rises into the space where the plates are moving apart. As the hot mantle rock convects upward it rises higher in the mantle. The rock is under lower pressure; this lowers the melting temperature of the rock and so it melts. Lava erupts through long cracks in the ground, or **fissures**.

## Mid-Ocean Ridges

Volcanoes erupt at mid-ocean ridges, such as the Mid-Atlantic ridge, where seafloor spreading creates new seafloor in the rift valleys. Where a hotspot is located along the ridge, such as at Iceland, volcanoes grow high enough to create islands ( **Figure 1.45**).

## Continental Rifting

Eruptions are found at divergent plate boundaries as continents break apart. The volcanoes in **Figure 1.46** are in the East African Rift between the African and Arabian plates. Remember from the chapter Plate Tectonics that Baja California is being broken apart from mainland Mexico as another example of continental rifting.

## Summary

- Melting is common at convergent plate boundaries.
- Convergent plate boundaries line the Pacific Ocean basin so that volcanic arcs line the region.
- Melting at divergent plate boundaries is due to pressure release.
- At mid-ocean ridges seafloor is pulled apart and new seafloor is created.




---

**FIGURE 1.43**

The Cascade Range is formed by volcanoes created from subduction of oceanic crust beneath the North American continent.

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### Explore More

Use this resource to answer the questions that follow.

<https://www.youtube.com/watch?v=uw7Uq137YJQ> End at 11:02

1. What percent of volcanoes and earthquakes occur on the Pacific Ring of Fire?
2. How long is the arc of volcanoes along the Pacific Rim?
3. How has Augustine built up so high? Does it have high or low silica?
4. What type of volcanoes are found along the ring of fire? What happens to the gas in the magma?
5. what kills so many people?
6. What does water do in hot rock below the surface?
7. What does carbon-12 indicate?
8. What process brings the sediments and water into the mantle?



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**FIGURE 1.44**

Mt. Baker, Washington.

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**FIGURE 1.45**

A volcanic eruption at Surtsey, a small island near Iceland.

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### Explore More Answers

1. 75% of volcanoes and 90% of earthquakes
2. 25,000 miles
3. The lava is viscous and it builds up near the vent. Viscous lava has high silica.
4. Stratovolcanoes; The gases get trapped and the eruption explodes.
5. Plumes of ash go up for tens of miles; they collapse in super-heated avalanche of ash and gas. They race through the region.
6. It lowers the melting temperature and causes melting with plumes of magma reaching the surface.
7. Sea organisms in the ocean take in carbon 12 that they transfer to the seafloor. This indicates that seafloor sediments enter the mantle and get into volcanoes.
8. Subduction brings the seafloor with sediments and water into the mantle.

**FIGURE 1.46**

Mount Gahinga in the East African Rift valley.

### Review

1. What causes melting at convergent plate boundaries?
2. Why are there so many volcanoes around the Pacific Ocean basin?
3. What causes melting at divergent plate boundaries?
4. How does a rifting within a continent lead to seafloor spreading?

### Review Answers

1. The subducting plate heats up in the hot mantle. Water mixed into the sediments lowers the melting point so the mantle melts.
2. The Pacific basin is surrounded by convergent plate boundaries.
3. The mantle rises and the release of pressure lowers the melting temperature and produces magma.
4. Continents rift apart so that seafloor forms in between. It starts with the continent spreading in both directions and then seafloor spreading begins.

## 1.22 Volcanoes at Hotspots

- Explain the relationship between hotspots and volcanic activity away from plate boundaries.



### Hawaii is a hotspot, or is it a hot spot?

Both, actually. Hawaii is definitely a hot vacation spot, particularly for honeymooners. The Hawaiian Islands are formed from a hotspot beneath the Pacific Ocean. Volcanoes grow above the hotspot. Lava flows down the hillsides and some of it reaches the ocean, causing the islands to grow. Too hot now, but a great place in the future for beach lovers!

### Intraplate Volcanoes

Although most volcanoes are found at convergent or divergent plate boundaries, intraplate volcanoes may be found in the middle of a tectonic plate. These volcanoes rise at a hotspot above a **mantle plume**. Melting at a hotspot is due to pressure release as the plume rises through the mantle.

Earth is home to about 50 known hotspots. Most of these are in the oceans because they are better able to penetrate oceanic lithosphere to create volcanoes. But there are some large ones in the continents. Yellowstone is a good example of a mantle plume erupting within a continent.

### Pacific Hotspots

The South Pacific has many hotspot volcanic chains. The hotspot is beneath the youngest volcano in the chain and older volcanoes are found to the northwest. A volcano forms above the hotspot, but as the Pacific Plate moves, that volcano moves off the hotspot. Without its source of volcanism, it no longer erupts. The crust gets cooler and the volcano erodes. The result is a chain of volcanoes and seamounts trending northwest from the hotspot.

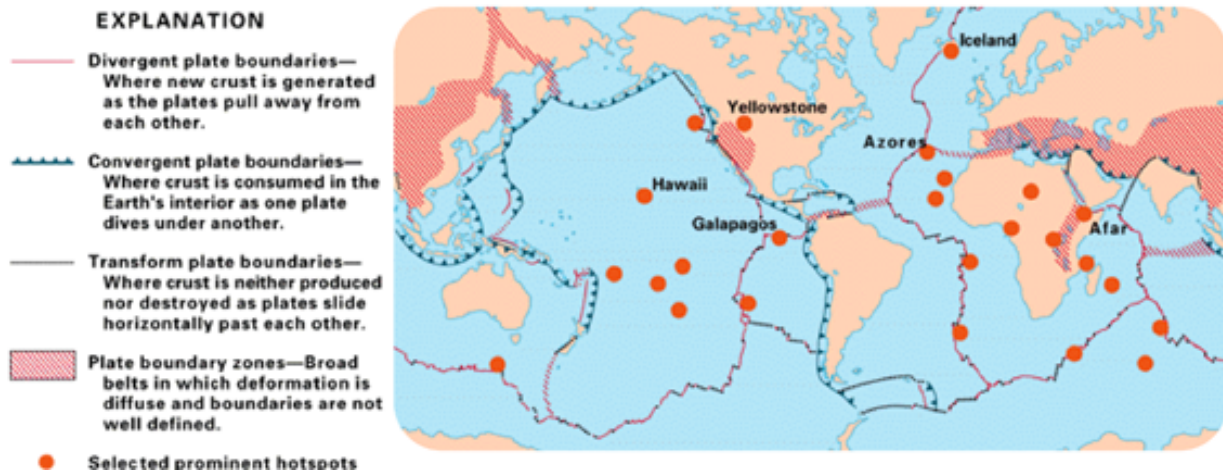


FIGURE 1.47

Prominent hotspots of the world.

The Society Islands are the exposed peaks of a great chain of volcanoes that lie on the Pacific Plate. The youngest island sits directly above the Society hotspot ( **Figure 1.48**).

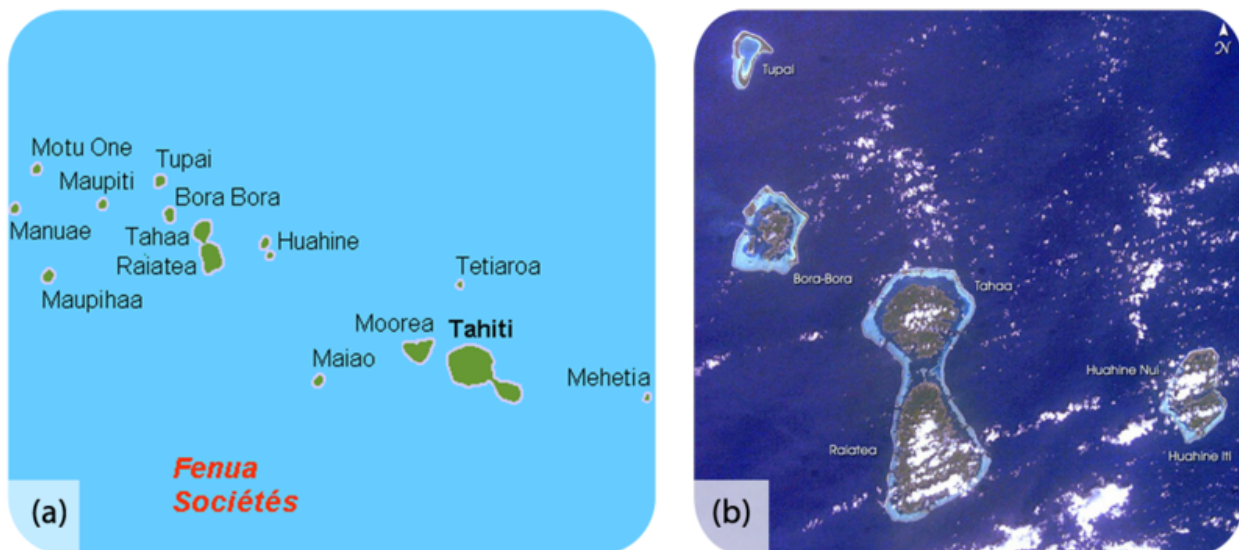


FIGURE 1.48

(a) The Society Islands formed above a hotspot that is now beneath Mehetia and two submarine volcanoes. (b) The satellite image shows how the islands become smaller and coral reefs became more developed as the volcanoes move off the hotspot and grow older.

The most famous example of a hotspot in the oceans is the Hawaiian Islands. Forming above the hotspot are massive shield volcanoes that together create the islands. The lavas are mafic and have low viscosity. These lavas produce beautiful ropy flows of pāhoehoe and clinkery flows of a’ā, which will be described in more detail in Effusive Eruptions.

A hot spot beneath Hawaii, the origin of the voluminous lava produced by the shield volcano Kilauea can be viewed here: <http://www.youtube.com/watch?v=byJp5o49IF4> (2:06).



#### MEDIA

Click image to the left for use the URL below.

URL: <http://gamma.ck12.org/flx/render/embeddedobject/1426>

## Continental Hotspots

The hotspots that are known beneath continents are extremely large. The reason is that it takes a massive mantle plume to generate enough heat to penetrate through the relatively thick continental crust. The eruptions that come from these hotspots are infrequent but massive, often felsic and explosive. All that’s left at Yellowstone at the moment is a giant caldera and a very hot spot beneath.

## Hotspot Versus Island Arc Volcanoes

How would you be able to tell hotspot volcanoes from island arc volcanoes? At island arcs, the volcanoes are all about the same age. By contrast, at hotspots the volcanoes are youngest at one end of the chain and oldest at the other.

## Summary

- Volcanoes grow above hotspots, which are zones of melting above a mantle plume.
- Hotspot volcanoes are better able to penetrate oceanic crust, so there are more chains of hotspot volcanoes in the oceans.
- Shield volcanoes commonly form above hotspots in the oceans.

## Explore More

<https://www.youtube.com/watch?v=bYv6V5EJAKc>

1. How far is Hawaii from the nearest convergent plate boundary?
2. How does a hotspot get through the Pacific plate?
3. How do scientists know that the hotspot doesn’t move?
4. Why does an older volcano cease volcanic activity?
5. What has happened to Oahu? How much was lost?

## Explore More Answers

1. 2,000 miles

2. It melts a hole in it.
3. the plate moves over the hotspot so older volcanoes move off the hotspot and new volcanoes form over the hotspot.
4. The volcano is cut off from the magma source.
5. It is eroding away. I extended out about 20 miles at that area.

### Review

1. What causes melting at a hotspot?
2. Why are there a relatively large number of hotspots in the Pacific Ocean basin?
3. Why do you think there are so many hotspots at mid-ocean ridges; e.g. four along the Mid-Atlantic Ridge and two at the East Pacific Rise?

### Review Answers

1. Pressure release as the plume rises through the mantle.
2. Hotspots can penetrate oceanic crust better than continental crust. The Pacific is large so there's room for a lot of hotspots.
3. The hotspots can penetrate easily there because there is no crust to puncture. The hotspot may also get caught up in processes of upwelling at the ridge.

## 1.23 Magma Composition at Volcanoes

- Describe types of magma composition and explain their effect on types of eruptions.



### What's more viscous, water or honey?

Honey, of course! The composition of magma determines its viscosity, which affects how a lava flows and what kind of volcano forms from the lava.

### Magma Composition

There are as many types of volcanic eruptions as there are eruptions. Actually more since an eruption can change character as it progresses. Each volcanic **eruption** is unique, differing in size, style, and composition of erupted material.

One key to what makes the eruption unique is the chemical composition of the magma that feeds a volcano, which determines (1) the eruption style, (2) the type of volcanic cone that forms, and (3) the composition of rocks that are found at the volcano.

Different minerals within a rock melt at different temperatures. The amount of partial melting and the composition of the original rock determine the composition of the magma.

The words that describe composition of igneous rocks also describe magma composition.

- Mafic magmas are low in silica and contain more dark, magnesium- and iron-rich mafic minerals, such as olivine and pyroxene.

- Felsic magmas are higher in silica and contain lighter colored minerals such as quartz and orthoclase feldspar. The higher the amount of silica in the magma, the higher is its **viscosity**. Viscosity is a liquid's resistance to flow.

Viscosity determines what the magma will do. Mafic magma is not viscous and will flow easily to the surface. Felsic magma is viscous and does not flow easily. Most felsic magma will stay deeper in the crust and will cool to form igneous intrusive rocks such as granite and granodiorite. If felsic magma rises into a magma chamber, it may be too viscous to move, so it gets stuck. Dissolved gases become trapped by thick magma. The magma churns in the chamber and the pressure builds.

Magma collects in **magma chambers** in the crust at 160 kilometers (100 miles) beneath the surface.

## Summary

- Magmas differ in composition, which affects viscosity. Magma composition has a large effect on how a volcano erupts.
- Felsic lavas are more viscous and erupt explosively or do not erupt.
- Mafic lavas are less viscous and erupt effusively.

## Making Connections



### MEDIA

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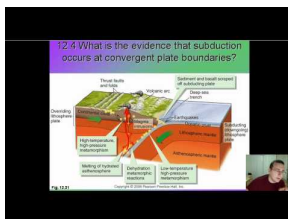
URL: <http://gamma.ck12.org/flx/render/embeddedobject/53801>

## Explore More

Use this resource to answer the questions that follow.

Magma Factors

<http://www.youtube.com/watch?v=R0GT-C6BddA>



### MEDIA

Click image to the left for use the URL below.

URL: <http://gamma.ck12.org/flx/render/embeddedobject/4792>

Go to 6:00

1. What are the two categories of magma?
2. What is mafic lava rich in?
3. Where is mafic lava eruptions more common?
4. What is felsic lava rich in?

5. Where is felsic lava found?
6. What are the characteristics of felsic lava?
7. List the characteristics of mafic lava.
8. What is most felsic material? What does that mean?
9. What is most mafic material?

### Explore More Answers

1. felsic-mafic in a spectrum
2. Mafic lava is rich in magnesium.
3. Oceans at collisions and divergent boundaries.
4. Silicon oxide.
5. continental crust
6. Melts at a lower temperature, erupts at cooler because it goes through more crust. Stickier, crystallizes more before eruption. More gas because it gets trapped in the more viscous magma; eruptions more explosive.
7. Basaltic eruptions, crystallizes less before eruption; less gas; eruptions less explosive.
8. pyroclastic: fire rock; lava domes
9. runny lavas

### Review

1. Why do felsic lavas erupt explosively?
2. Why do mafic lavas erupt effusively?
3. How is magma composition related to viscosity?

### Review Answers

1. Felsic magmas erupt explosively because they are higher in silica so they are more viscous. This sticky material has a harder time flowing and it traps more gas. For it to escape the volcano it has more pressure to overcome.
2. Mafic lavas are lower in silica so they flow more easily. Not much gas builds up so they create rivers of lava.
3. Silica determines viscosity: high silica = high viscosity, low silica = low viscosity.

## 1.24 Explosive Eruptions

- Describe the causes and effects of explosive volcanic eruptions.



### Why do we still talk about Pompeii, 79 AD?

Nearly 2,000 years later, the explosive eruption of Mt. Vesuvius remains one of the most talked about eruptions in history. It began with a column of ash that blanketed the area, which was followed by fast-moving, dense, and scorching-hot pyroclastic flows. People suffocated or burnt, and structures in two thriving Roman cities were destroyed. Remains of some of the dead can be seen at Pompeii, where people were entombed in scorching ash. The eruption type was named plinian, after Pliny the Younger, who watched from offshore.

### Explosive Eruptions

A large **explosive eruption** creates even more devastation than the force of the atom bomb dropped on Nagasaki at the end of World War II, in which more than 40,000 people died. A large explosive volcanic eruption is 10,000 times as powerful. Explosive eruptions are found at the convergent plate boundaries that line parts of western North America, resulting in the Cascades in the Pacific Northwest and the Aleutians in Alaska.

### Causes of the Explosion

Explosive eruptions are caused by gas-rich, felsic magmas that churn within the magma chamber. When the pressure becomes too great the magma breaks through the rock above the chamber and explodes, just like when a cork is released from a bottle of champagne. Magma, rock, and ash burst upward in an enormous explosion ( **Figure 1.49**).

**FIGURE 1.49**

Ash and gases create a mushroom cloud above Mt. Redoubt in Alaska, 1989. The cloud reached 45,000 feet and caught a Boeing 747 in its plume.

### Pyroclastic Material

The erupted rock fragments are called **tephra**. Ash and gas also explode from the volcano. Scorching hot tephra, ash, and gas may speed down the volcano's slopes at 700 km/h (450 mph) as a **pyroclastic flow**. Pyroclastic means fire rock ( **Figure 1.50**).

**FIGURE 1.50**

Left: An explosive eruption from the Mayon Volcano in the Philippines in 1984. Ash flies upward into the sky and pyroclastic flows pour down the mountainside. Right: The end of a pyroclastic flow at Mount St. Helens.

Pyroclastic flows knock down everything in their path. The temperature inside a pyroclastic flow may be as high as 1,000°C (1,800°F).

A pyroclastic flow at Montserrat volcano is seen in this video: <http://faculty.gg.uwyo.edu/heller/SedMovs/Sed%20Movie%20files/PyroclasticFlow.MOV> .




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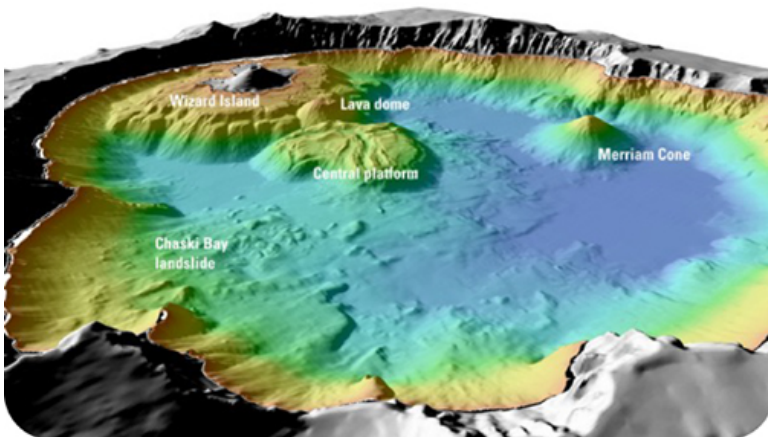
**FIGURE 1.51**

Blowdown of trees near Mount St. Helens shows the direction of the blast and pyroclastic flow.

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### Cascades Volcanoes

Prior to the Mount St. Helens eruption in 1980, the Lassen Peak eruption on May 22, 1915, was the most recent Cascades eruption. A column of ash and gas shot 30,000 feet into the air. This triggered a high-speed pyroclastic flow, which melted snow and created a volcanic mudflow known as a **lahar**. Lassen Peak currently has geothermal activity and could erupt explosively again. Mt. Shasta, the other active volcano in California, erupts every 600 to 800 years. An eruption would most likely create a large pyroclastic flow, and probably a lahar. Of course, Mt. Shasta could explode and collapse like Mt. Mazama in Oregon ( **Figure 1.52**).




---

**FIGURE 1.52**

Crater Lake fills the caldera of the collapsed Mt. Mazama, which erupted with 42 times more power than Mount St. Helens in 1980. The bathymetry of the lake shows volcanic features such as cinder cones.

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### Volcanic Gases

Volcanic gases can form poisonous and invisible clouds in the atmosphere. These gases may contribute to environmental problems such as acid rain and ozone destruction. Particles of dust and ash may stay in the atmosphere for years, disrupting weather patterns and blocking sunlight ( **Figure 1.53**).

**FIGURE 1.53**

The ash plume from Eyjafjallajökull volcano in Iceland disrupted air travel across Europe for six days in April 2010.

## Summary

- Felsic magmas erupt explosively, creating pyroclastic eruptions.
- Pyroclastic eruption types include tephra, ash, and lahars.
- Mt. Mazama blew its top off and then collapsed, creating Crater Lake in Oregon.

## Making Connections



### MEDIA

Click image to the left for use the URL below.

URL: <http://gamma.ck12.org/flx/render/embeddedobject/54946>

## Explore More

Use this resource to answer the questions that follow.

<http://www.volcanodiscovery.com/stromboli.html>

1. On what date and time was the large eruption of Mount St. Helens?
2. What was the damage in dollars? How many human lives were lost?
3. Where was the deformation before the eruption?
4. What was the cause of the activity before the eruption?

5. What caused the bulge on the north side of the volcano? How much was the bulge increasing each day?
6. What was the first indication each of the two scientists interviewed had that the big eruption had come?
7. Why did the eruption happen when it did?
8. What is the evidence that some of the eruption was a directed blast?
9. Why did the eruption increase the visibility of volcanology as a science?

### Explore More Answers

1. May 18, 1980; 8:32 AM
2. hundreds of millions; 57
3. On the north side of the mountain.
4. Magma was moving from a deep reservoir into the volcano itself.
5. Accumulating magma made the bulge grow about 6' per day.
6. The one could see a mushroom cloud above the mountain and the other found the largest earthquake yet on the seismograph.
7. The landslide uncorked a pressurized body of magma that then could explode upwards very rapidly. The explosion was horizontally directed.
8. The trees are pointing in the direction the blast was moving.
9. The public was very interested and the news media's attention was on the mountain.

### Review

1. Why do convergent plate boundaries have explosive eruptions?
2. Why do felsic magmas erupt explosively?
3. How do volcanic gases affect the atmosphere?

### Review Answers

1. Magmas at convergent boundaries are felsic and gas rich. The viscous magma traps gases that erupt when pressure builds very high.
2. The silica in the felsic magma is sticky and gases collect without being able to get out easily.
3. Volcanic gases can be poisonous in the vicinity of the eruption. Dust and ash may enter the atmosphere and stay aloft for years.

## 1.25 Effusive Eruptions

- Describe the causes and effects of effusive volcanic eruptions.



### Is Stromboli just a rolled-up pizza?

For most people a stromboli is a rolled sandwich of dough, cheeses, and meats. For volcanologists, Stromboli is a volcano for which a type of eruption was named. Strombolian eruptions spew lava into the air but do not explode as massively as in the plinian eruptions in the previous concept. Still, the power of a volcano is easily seen in this eruption on Mt. Stromboli in Italy.

### Effusive Eruptions

Mafic magma creates gentler **effusive eruptions**. Although the pressure builds enough for the magma to erupt, it does not erupt with the same explosive force as felsic magma. Magma pushes toward the surface through fissures. Eventually, the magma reaches the surface and erupts through a vent ( **Figure 1.54**). Effusive eruptions are common in Hawaii, where lavas are mafic.

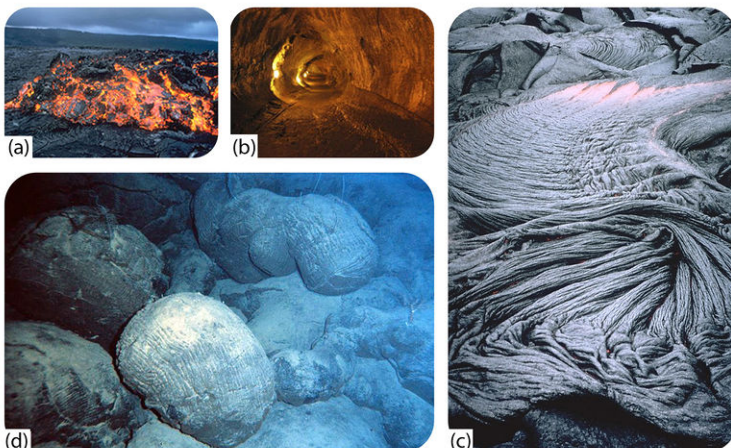
**FIGURE 1.54**

In effusive eruptions, lava flows readily, producing rivers of molten rock.

- The Kilauea volcanic eruption in 2008 is seen in this short video: <http://www.youtube.com/watch?v=BtH79yxBIJI> .
- A Quicktime movie with thermal camera of a lava stream within the vent of a Hawaiian volcano is seen here: [http://hvo.wr.usgs.gov/kilauea/update/archive/2009/Nov/OverflightFLIR\\_13Jan2010.mov](http://hvo.wr.usgs.gov/kilauea/update/archive/2009/Nov/OverflightFLIR_13Jan2010.mov) .

### Types of Lava

Low-viscosity lava flows down mountainsides. Differences in composition and where the lavas erupt result in three types of lava flow coming from effusive eruptions. A'a lava forms a thick and brittle crust that is torn into rough and jagged pieces. A'a lava can spread over large areas as the lava continues to flow underneath the crust's surface. Pāhoehoe lava forms lava tubes where fluid lava flows through the outer cooled rock crust. Pāhoehoe lava is less viscous than a'a lava, so its surface looks smooth and ropy. Mafic lava that erupts underwater creates pillow lava. The lava cools very quickly, forming roughly spherical rocks. Pillow lava is common at mid-ocean ridges ( **Figure 1.55**).

**FIGURE 1.55**

(a) A'a lava spread over large areas. (b) Pāhoehoe lava tubes where at the Thurston Lava Tube in Hawai'i Volcanoes National Park. (c) Pāhoehoe lava is less viscous than a'a lava so its surface looks smooth and ropy. (d) Pillow lava.

- Undersea eruption videos are seen here <http://news.discovery.com/videos/earth-undersea-eruption-now-in-ster eo.html> and here <http://news.discovery.com/videos/earth-underwater-volcano-caught-on-video.html> .

### Effusive Eruptions Damage

People can usually be evacuated before an effusive eruption, so they are much less deadly. Although effusive eruptions rarely kill anyone, they can be destructive. Even when people know that a lava flow is approaching, there is not much anyone can do to stop it from destroying a building or road ( **Figure 1.56**).



**FIGURE 1.56**

A road is overrun by an eruption at Kilauea volcano in Hawaii.

### Summary

- Mafic magma creates effusive eruptions. The pressure builds but the lava does not explode so violently from the vent.
- Effusive eruptions cause damage but usually people can be evacuated, so there are few or no fatalities.
- Mafic magma cools into different types of flows like a'a, pāhoehoe, and pillow lava.

### Making Connections



#### MEDIA

Click image to the left for use the URL below.

URL: <http://gamma.ck12.org/flx/render/embeddedobject/84185>

### Explore More

Use these resources to answer the questions that follow.

<https://www.youtube.com/watch?v=6uFvNJCpl14>

1. What are you viewing early in the video?
2. What is the source of the thunder-like cracking and booming?
3. What is causing the rise in the lava lake?
4. How does a fissure eruption differ from a lava lake eruption?
5. How does the eruption in this video differ from the eruption in the Mount St. Helens video in the previous concept?

### Explore More Answers

1. Lava in a lava lake that is growing toward the surface.
2. The walls of the vent above the lava surface expand and fracture.
3. A modest uplift and expansion of Kilauea's summit area, although they don't know what is causing that.
4. The fissure eruption is spread along a line; the lake eruption is in a pool.
5. This one is relatively quiet with lots of hot lava. The St. Helens eruption shows ash and explosions in a very different eruption type.

### Review

1. Why do mafic lavas flow rather than explode?
2. Compare and contrast a'a and pāhoehoe lavas.
3. How do pillow lavas form?

### Review Answers

1. Mafic lavas do not have as much silica so they are less viscous and flow more easily. Also they trap less gas before the eruption occurs.
2. Both types of lava form from lavas of similar mafic composition, but a'a is more viscous so flows are thicker and rough. Pāhoehoe is so smooth it looks ropy.
3. Pillow lavas form when liquid lava hits cold seawater and cools very quickly.

## 1.26 Predicting Volcanic Eruptions

- Explain how scientists attempt to predict volcanic eruptions.



### Can she see your future?

No one can predict exactly when a volcanic eruption will take place. Scientists do a bit better forecasting volcanic eruptions than earthquakes. Still, volcanologists have a high fatality rate because forecasting eruptions is so difficult.

### Predicting Volcanic Eruptions

Many pieces of evidence can mean that a volcano is about to erupt, but the time and magnitude of the eruption are difficult to pin down. This evidence includes the history of previous volcanic activity, earthquakes, slope

deformation, and gas emissions.

## History of Volcanic Activity

A volcano's history —how long since its last eruption and the time span between its previous eruptions —is a good first step to predicting eruptions. Active and dormant volcanoes are heavily monitored, especially in populated areas.

## Earthquakes

Moving magma shakes the ground, so the number and size of earthquakes increases before an eruption. A volcano that is about to erupt may produce a sequence of earthquakes. Scientists use seismographs that record the length and strength of each earthquake to try to determine if an eruption is imminent.

## Slope Deformation

Magma and gas can push the volcano's slope upward. Most ground deformation is subtle and can only be detected by tiltmeters, which are instruments that measure the angle of the slope of a volcano. But ground swelling may sometimes create huge changes in the shape of a volcano. Mount St. Helens grew a bulge on its north side before its 1980 eruption. Ground swelling may also increase rock falls and landslides.

## Gas Emissions

Gases may be able to escape a volcano before magma reaches the surface. Scientists measure gas emissions in vents on or around the volcano. Gases, such as sulfur dioxide ( $\text{SO}_2$ ), carbon dioxide ( $\text{CO}_2$ ), hydrochloric acid ( $\text{HCl}$ ), and even water vapor can be measured at the site ( **Figure 1.57**) or, in some cases, from a distance using satellites. The amounts of gases and their ratios are calculated to help predict eruptions.

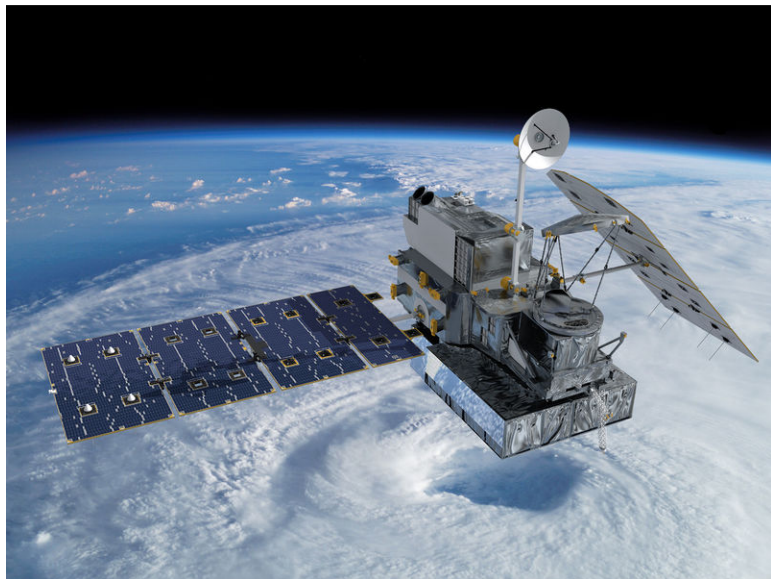


**FIGURE 1.57**

Scientists monitoring gas emissions at Mount St. Helens.

## Remote Monitoring

Some gases can be monitored using satellite technology ( **Figure 1.58**). Satellites also monitor temperature readings and deformation. As technology improves, scientists are better able to detect changes in a volcano accurately and safely.



**FIGURE 1.58**

An earth observation satellite.

## Evacuate?

Since volcanologists are usually uncertain about an eruption, officials may not know whether to require an evacuation. If people are evacuated and the eruption doesn't happen, the people will be displeased and less likely to evacuate the next time there is a threat of an eruption. The costs of disrupting business are great. However, scientists continue to work to improve the accuracy of their predictions.

## Summary

- Volcanologists use several lines of evidence to try to forecast volcanic eruptions.
- Magma moving beneath a volcano will cause earthquakes and slope deformation. Gases may be released from the magma out of the volcano vent.
- Deciding whether to call for an evacuation is very tricky.

## Explore More

Use this resource to answer the questions that follow.

Mount Pinatubo: Predicting a Volcanic Eruption

[http://www.teachersdomain.org/asset/ess05\\_vid\\_pinatubo/](http://www.teachersdomain.org/asset/ess05_vid_pinatubo/)

1. What brought scientific attention to Pinatubo?
2. What does the measurement of sulfur dioxide tell scientists?
3. What did the seismic stations measure?

4. What evidence was there for a potential eruption?
5. What finally triggered the evacuation from the island?
6. When did the first eruption occur? How soon after the evacuation?
7. What was the big eruption like?
8. What was the effect of the prediction?

### Explore More Answers

1. Several large explosions.
2. If magma is rising, SO<sub>2</sub> and other gases escape through the overlying rocks to the atmosphere.
3. They record earthquakes 5 miles beneath the surface. The quakes were spread over a large area.
4. Magma rising into the volcano and earthquakes; an increase in earthquake activity.
5. Discovery of the dome.
6. 48 hours after evacuation the volcano erupts.
7. A massive explosion sending ash high into the air. The eruption was continuous and had massive explosion that released ash.
8. The death toll was kept to under 500.

### Review

1. What are the detectable signs that magma is moving beneath a volcano?
2. What are the consequences of incorrectly predicting a volcanic eruption?
3. How would a successful prediction of a volcanic eruption resemble a successful prediction of an earthquake?

### Review Answers

1. Earthquakes, gases, such as sulfur oxides; and slope deformation are among the signs of an eruption.
2. A false prediction costs a lot of money and loses the good will of the evacuees so they are less likely to evacuate next time.
3. It would give the time and place, plus the size. This is closer with volcanoes than with earthquakes.

## 1.27 Types of Volcanoes

- Describe the magma compositions and characteristics of different types of volcanoes.



### What does an active volcano look like?

Climbing up Mount St. Helens and looking into the crater at the steaming dome is an incredible experience. The slope is steep and the landscape is like something from another planet. Nothing's alive up there, except maybe a bird. When you're standing on the top you can see off to others of the Cascades volcanoes: Mt. Adams, Rainier, Hood, Jefferson, and sometimes more.

### Volcanoes

A volcano is a vent through which molten rock and gas escape from a magma chamber. Volcanoes differ in many features, such as height, shape, and slope steepness. Some volcanoes are tall cones and others are just cracks in the ground ( **Figure 1.59**). As you might expect, the shape of a volcano is related to the composition of its magma.

### Composite Volcanoes

**Composite volcanoes** are constructed of felsic to intermediate rock. The viscosity of the lava means that eruptions at these volcanoes are often explosive.

### Eruptions at Composite Volcanoes

Viscous lava cannot travel far down the sides of the volcano before it solidifies, which creates the steep slopes of a composite volcano. In some eruptions the pressure builds up so much that the material explodes as ash and small rocks. The volcano is constructed layer by layer, as ash and lava solidify, one upon the other ( **Figure 1.61**). The result is the classic cone shape of composite volcanoes.

**FIGURE 1.59**

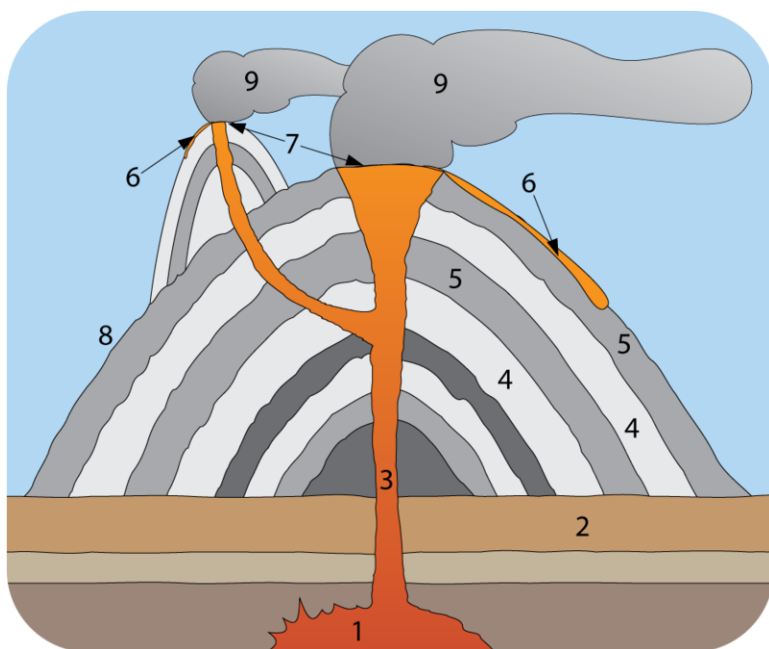
Mount St. Helens was a beautiful, classic, cone-shaped volcano. In May 1980 the volcano blew its top off in an explosive eruption, losing 1,300 feet off its summit.

**FIGURE 1.60**

Mt. Fuji in Japan is one of the world's most easily recognized composite volcanoes.

## Shield Volcanoes

**Shield volcanoes** get their name from their shape. Although shield volcanoes are not steep, they may be very large. Shield volcanoes are common at spreading centers or intraplate hot spots ( **Figure 1.62**). Hawaii has some spectacular shield volcanoes including Mauna Kea, which is the largest mountain on Earth from base to top. The mountain stands 33,500 ft high, about 4,000 feet greater than the tallest mountain above sea level, Mt. Everest.

**FIGURE 1.61**

A cross section of a composite volcano reveals alternating layers of rock and ash: (1) magma chamber, (2) bedrock, (3) pipe, (4) ash layers, (5) lava layers, (6) lava flow, (7) vent, (8) lava, (9) ash cloud. Frequently there is a large crater at the top from the last eruption.

**FIGURE 1.62**

Mauna Kea on the Big Island of Hawaii is a classic shield volcano.

### Eruptions at Shield Volcanoes

The lava that creates shield volcanoes is fluid and flows easily. The spreading lava creates the shield shape. Shield volcanoes are built by many layers over time and the layers are usually of very similar composition. The low viscosity also means that shield eruptions are non-explosive.

This "Volcanoes 101" video from National Geographic discusses where volcanoes are found and what their properties come from: <http://www.youtube.com/watch?v=uZp1dNybfc> (3:05).

**MEDIA**

Click image to the left for use the URL below.

URL: <http://gamma.ck12.org/flx/render/embeddedobject/1405>

## Cinder Cones

**Cinder cones** are the most common type of volcano. A cinder cone has a cone shape, but is much smaller than a composite volcano. Cinder cones rarely reach 300 meters in height, but they have steep sides. Cinder cones grow rapidly, usually from a single eruption cycle. These volcanoes usually flank shield or composite volcanoes. Many cinder cones are found in Hawaii.

**FIGURE 1.63**

A lava fountain erupts from Pu'u O'o, a cinder cone on Kilauea.

## Eruptions at Cinder Cones

Cinder cones are composed of small fragments of rock, such as pumice, piled on top of one another. The rock shoots up in the air and doesn't fall far from the vent. The exact composition of a cinder cone depends on the composition of the lava ejected from the volcano. Cinder cones usually have a crater at the summit. Most cinder cones are active only for a single eruption.

## Summary

- Magma composition determines both eruption type and volcano type.
- Composite cones are built of felsic to intermediate lava and shield volcanoes of mafic lava.
- Cinder cones are made of small fragments of a variety of compositions usually from a single eruption.

## Making Connections

**MEDIA**

Click image to the left for use the URL below.

URL: <http://gamma.ck12.org/flx/render/embeddedobject/63617>

**Explore More**

Use these resources to answer the questions that follow.

<https://www.youtube.com/watch?v=DnBggrCdkN0>

1. What determines the type of eruption a volcano will have?
2. Where are the most violent volcanoes formed?
3. What type of layering do these volcanoes have? What is their name?
4. What fuels the volcanoes at Hawaii?
5. What types of volcanoes are the result of non-explosive eruptions like at Hawaii?
6. What are cinder cones? How do they erupt?
7. What determines the shape of the cinder cone?

**Explore More Answers**

1. It's origin.
2. Subduction zones.
3. Alternating layers of ash, cinder and lava make up a composite cone.
4. Hotspots; a pool of magma breaks through the crust as the crust moves over it.
5. Shield.
6. They are small but can produce violent eruptions.
7. The size of the ejected material.

**Review**

1. Why do mafic lavas produce shield-shaped volcanoes and felsic lavas produce cone-shaped volcanoes?
2. From what does a composite volcano get its name?
3. Describe how a cinder cone forms.

**Review Answers**

1. Mafic lavas can flow so they spread out to create a larger edifice, a shield. Felsic lavas explode to create ash. Felsic lavas create domes and other features that grow upward into a composite cone.
2. It is made of several types of material deposited in the same edifice.
3. A cinder cone is usually the result of only one eruption. The cinders it produces pile on top of each other near the vent to create the cone.

## 1.28 Supervolcanoes

- Describe the characteristics of supervolcanoes and their eruptions.



### What would cause such a giant caldera?

You can stand on the rim and view the enormous Yellowstone Caldera, but it's hard to visualize a volcano or a set of eruptions that enormous. Supervolcanoes are a fairly new idea in volcanology. Although their eruptions are unbelievably massive, they are exceedingly rare. The power of Yellowstone, even 640,000 years after the most recent eruption, is seen in its fantastic geysers.

### Supervolcanoes

**Supervolcano** eruptions are extremely rare in Earth's history. It's a good thing because they are unimaginably large. A supervolcano must erupt more than 1,000 cubic km (240 cubic miles) of material, compared with 1.2 km<sup>3</sup> for Mount St. Helens or 25 km<sup>3</sup> for Mount Pinatubo, a large eruption in the Philippines in 1991. Not surprisingly, supervolcanoes are the most dangerous type of volcano.

## Supervolcano Eruptions

The exact cause of supervolcano eruptions is still debated. However, scientists think that a very large magma chamber erupts entirely in one catastrophic explosion. This creates a huge hole or **caldera** into which the surface collapses ( **Figure 1.64**).



**FIGURE 1.64**

The caldera at Santorini in Greece is so large that it can only be seen by satellite.

## Yellowstone Caldera

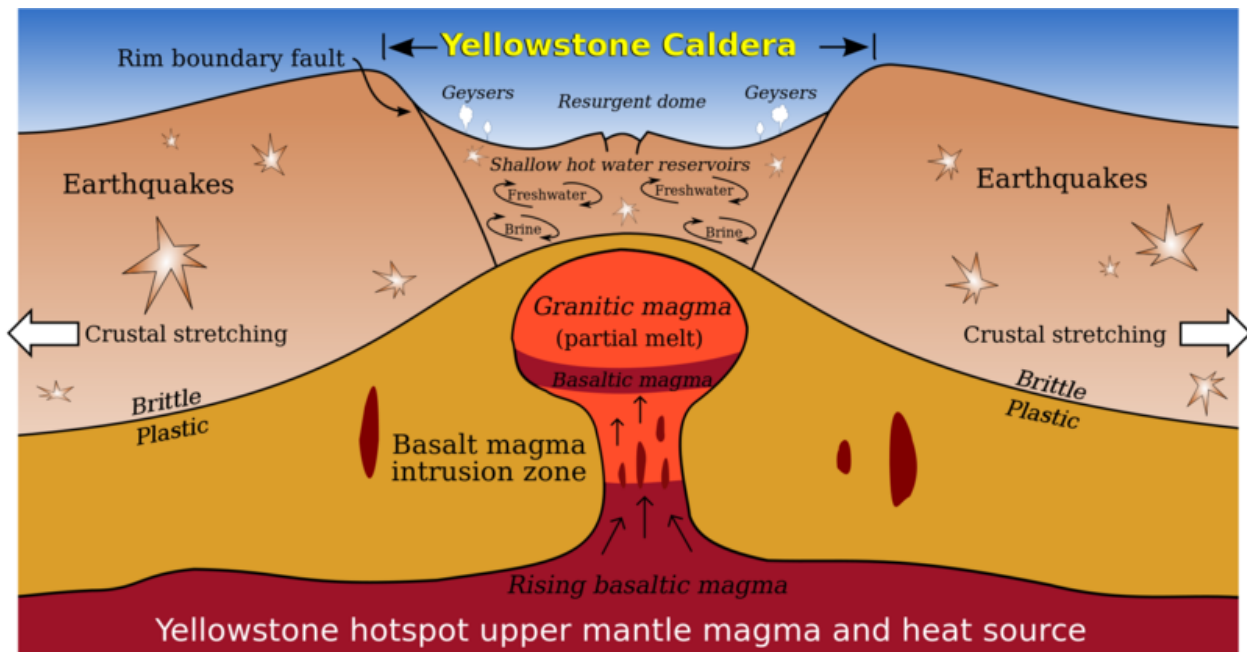
The largest supervolcano in North America is beneath Yellowstone National Park in Wyoming. Yellowstone sits above a hotspot that has erupted catastrophically three times: 2.1 million, 1.3 million, and 640,000 years ago. Yellowstone has produced many smaller (but still enormous) eruptions more recently ( **Figure 1.65**). Fortunately, current activity at Yellowstone is limited to the region’s famous geysers.

The Old Faithful web cam shows periodic eruptions of Yellowstone’s famous geyser in real time: <http://www.nps.gov/features/yell/live/live4.htm> .

## Supervolcano Eruptions and Life on Earth

A supervolcano could change life on Earth as we know it. Ash could block sunlight so much that photosynthesis would be reduced and global temperatures would plummet. Volcanic eruptions could have contributed to some of the mass extinctions in our planet’s history. No one knows when the next super eruption will be.

Interesting volcano videos are seen on National Geographic Videos, Environment Video, Natural Disasters, Earthquakes: <http://video.nationalgeographic.com/video/player/environment/> . One interesting one is “Mammoth Mountain,” which explores Hot Creek and the volcanic area it is a part of in California.



**FIGURE 1.65**

The Yellowstone hotspot has produced enormous felsic eruptions. The Yellowstone caldera collapsed in the most recent super eruption.

### Summary

- Supervolcano eruptions are rare but massive and deadly.
- Yellowstone Caldera is a supervolcano that has erupted catastrophically three times.
- Supervolcano eruptions can change the course of life on Earth.

### Explore More

Use this resource to answer the questions that follow.

<http://www.discovery.com/tv-shows/curiosity/topics/yellowstone-super-eruptions.htm>

1. How many super eruptions has Yellowstone had?
2. What would a super eruption at Yellowstone do today?
3. What are scientists monitoring at Yellowstone?
4. How do scientists use radon gas to predict eruptions?
5. What do scientists learn from radon gas?

### Explore More Answers

1. 3
2. It would bury western North America, a sulfur haze would dim the sun and the eruption would plunge the world into a volcanic winter.

3. They are monitoring ground deformation, gas eruptions, and earthquakes.
4. Small amounts of radon gas escape from active magma chambers. As the radon decays, it forms radioactive isotopes that can be measured.
5. The radon can be a clock to understand how fast the magma is rising deep down and coming to the surface.

### Review

1. What is the composition of supervolcano eruptions?
2. Why are these eruptions so massive?
3. What is the source of volcanism for the supervolcano at Yellowstone?
4. How does a supervolcano eruption potentially change the course of life on Earth?

### Review Answers

1. Since they are so large they must be felsic.
2. These eruptions are so massive because they are above a hotspot that is so large that it can penetrate continental crust beneath the region.
3. A large hotspot
4. Ash could block sunlight and reduce photosynthesis, plus global temperatures would go down very low and make many environments difficult for the creatures that live there. It could cause a mass extinction.

## 1.29 Volcanic Landforms

- Identify and describe landforms created by volcanic activity.



### Why is the Republic of Indonesia made of 17,508 islands?

Around the Pacific Rim is Indonesia, a nation built from the dotted volcanoes of an island arc. Indonesia is distinctive for its rich volcanic soil, tropical climate, tremendous biodiversity, and volcanoes. These volcanoes are in Java, Indonesia.

### Landforms from Lava

#### Volcanoes and Vents

The most obvious landforms created by lava are volcanoes, most commonly as cinder cones, composite volcanoes, and shield volcanoes. Eruptions also take place through other types of vents, commonly from fissures ( **Figure 1.66**). The eruptions that created the entire ocean floor are essentially fissure eruptions.

#### Lava Domes

Viscous lava flows slowly. If there is not enough magma or enough pressure to create an explosive eruption, the magma may form a **lava dome**. Because it is so thick, the lava does not flow far from the vent. ( **Figure 1.67**).

Lava flows often make mounds right in the middle of craters at the top of volcanoes, as seen in the **Figure 1.68**.



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**FIGURE 1.66**

A fissure eruption on Mauna Loa in Hawaii travels toward Mauna Kea on the Big Island.

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**FIGURE 1.67**

Lava domes are large, round landforms created by thick lava that does not travel far from the vent.

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**FIGURE 1.68**

Lava domes may form in the crater of composite volcanoes as at Mount St. Helens.

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## Lava Plateaus

A **lava plateau** forms when large amounts of fluid lava flow over an extensive area ( **Figure 1.69**). When the lava solidifies, it creates a large, flat surface of igneous rock.



**FIGURE 1.69**

Layer upon layer of basalt have created the Columbia Plateau, which covers more than 161,000 square kilometers (63,000 square miles) in Washington, Oregon, and Idaho.

## Land

Lava creates new land as it solidifies on the coast or emerges from beneath the water ( **Figure 1.70**).



**FIGURE 1.70**

Lava flowing into the sea creates new land in Hawaii.

Over time the eruptions can create whole islands. The Hawaiian Islands are formed from shield volcano eruptions that have grown over the last 5 million years ( **Figure 1.71**).

**FIGURE 1.71**

The island of Hawaii was created by hotspot volcanism. You can see some of the volcanoes (both active and extinct) in this mosaic of false-color composite satellite images.

### Landforms from Magma

Magma intrusions can create landforms. Shiprock in New Mexico is the neck of an old volcano that has eroded away ( **Figure 1.72**). The volcanic neck is the remnant of the conduit the magma traveled up to feed an eruption.

**FIGURE 1.72**

The aptly named Shiprock in New Mexico.

## Summary

- Landforms created by lava include volcanoes, domes, and plateaus.
- New land can be created by volcanic eruptions.
- Landforms created by magma include volcanic necks and domes.

## Explore More

Use this resource to answer the questions that follow.

<https://www.youtube.com/watch?v=9UBFSXu9UHY>

1. How many separate eruptions created the basalts at Quincy, Washington?
2. How thick is the basalt?
3. When did the lavas begin to erupt?
4. How do scientists know that the Cascade volcanoes didn't erupt these lavas?
5. What type of volcanic vent did the eruptions come from?
6. What is the origin of all this volcanism?
7. How are the flows in eastern Washington different from those in Hawaii today?

## Explore More Answers

1. more than 300
2. 2 miles in some places
3. From 17 million years ago
4. Their chemistry is not the same.
5. A deep crack
6. The Yellowstone Hotspot!
7. The Washington flows were much larger and thicker.

## Review

1. What is Shiprock and how did it form?
2. How do lava plateaus form?
3. What types of landforms are created by very viscous magma?

## Review Answers

1. Shiprock is the neck of an old volcano the rest of which has eroded away.
2. Large amounts of fluid lava flow over a large area.
3. lava domes

## 1.30 Hot Springs and Geysers

- Define hot springs and geysers, and explain how they work.



### Hot spring, anyone?

Even some animals enjoy relaxing in nature's hot tubs. Care to join them?

### Hot Springs and Geysers

Water sometimes comes into contact with hot rock. The water may emerge at the surface as either a hot spring or a geyser.

### Hot Springs

Water heated below ground that rises through a crack to the surface creates a **hot spring**. The water in hot springs may reach temperatures in the hundreds of degrees Celsius beneath the surface, although most hot springs are much cooler.

**FIGURE 1.73**

Even in winter, the water in this hot spring in Yellowstone doesn't freeze.

## Geysers

**Geysers** are also created by water that is heated beneath the Earth's surface, but geysers do not bubble to the surface—they erupt.

When water is both superheated by magma and flows through a narrow passageway underground, the environment is ideal for a geyser. The passageway traps the heated water underground, so that heat and pressure can build. Eventually, the pressure grows so great that the superheated water bursts out onto the surface to create a geyser. **Figure 1.74.**

Conditions are right for the formation of geysers in only a few places on Earth. Of the roughly 1,000 geysers worldwide, about half are found in the United States.

**FIGURE 1.74**

Castle Geyser is one of the many geysers at Yellowstone National Park. Castle erupts regularly, but not as frequently or predictably as Old Faithful.

Yellowstone isn't the only place in the continental U.S. with hot springs and geysers. Hot Creek in California deserves its name; Like Yellowstone, it is above a supervolcano.

## Summary

- When magma heats groundwater it may come to the surface as a hot spring or a geyser.
- Geysers erupt because the water is trapped and becomes superheated until finally the pressure builds enough for it to break the seal.
- Yellowstone is famous for its geysers. Hot Creek in California is also above a supervolcano.

## Explore More

Use the resources below to answer the questions that follow.

- **Geysers** at [http://www.nps.gov/yell/naturescience/geysers\\_work.htm](http://www.nps.gov/yell/naturescience/geysers_work.htm)

1. What is required for a geyser to erupt?
2. What provides the heat?
3. What supplies the water?

- **Hot Springs** at <http://www.unmuseum.org/flash/geyflash.htm>

4. How is a hot spring created?
5. What creates a fumerole?
6. How is a mud pot created?

## Explore More Answers

1. A constriction holds the pressure in, the water rises, as the pressure decreases and flashes into steam and explodes.
2. magma chamber
3. Rain and snow filter in through fractures.
4. Water seeps into the ground and is heated from the volcanic source below. The water pools below ground.
5. There is not enough hot water to reach the surface so it stays in the ground and flashes to steam and erupts.
6. A steam vent emerges underground; chemicals in the water react to make sulfuric acid. This alters the surrounding rock to make clay and the water and mud become a bubbling pool.

## Review

1. What creates a hot spring?
2. Why do geysers erupt rather than just bubble to the surface like a hot spring?
3. Are hot springs and geysers always found where there is active volcanism? What is the source of the heat?

## Review Answers

1. Water is heated below the surface and then travels on a crack to the surface.
2. In geysers the water is trapped and can't get to the surface until so much pressure builds up that it can erupt out.
3. There is a magma chamber nearby and the volcano is not dead, but sometimes the volcano may not be actively erupting.

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## Summary

Most earthquakes and volcanoes are located along plate boundaries. Plate tectonic processes can explain why we see these types of geological activity where we do. Stresses build up in some locations and may cause folding or faulting. Earthquakes strike along all three types of plate boundaries. The most damaging earthquakes are shallow and people in earthquake-prone regions must be aware of the potential damage from earthquakes. Seismologists have scales for measuring earthquake intensity and magnitude and work with designers to create earthquake-safe structures and guidelines for being safe in earthquakes. Earthquakes are often associated with volcanoes. Volcanoes erupt at all types of plate boundaries except transform. Volcanic eruptions can be quiet or explosive and the volcanoes they form range from large shields, to classic peaks, to small cones. Volcanic activity creates unique landforms. Some geological activity, both earthquakes and volcanic eruptions, are located away from plate boundaries.

## 1.31 References

1. Giulio Callegaro. Stress caused these rocks to fracture. CC BY 2.0
2. Roland Gotthard. Rock that has undergone shearing. Public Domain
3. Jodi So. Graph of stress, going from elastic deformation to plastic deformation to fracture. CC BY-NC 3.0
4. (a) Kyle Simourd; (b) Courtesy of the US Department of the Interior. Graph showing the ages of the layers of the Grand Canyon. (a) CC BY 2.0; (b) Public Domain
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23. Courtesy of the US Geological Survey. A cross section of earthquake epicenters. Public Domain
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26. Courtesy of US Geological Survey. The map of the New Madrid seismic zone. Public Domain
27. Courtesy of the US Geological Survey. Map of probabilities of earthquake along faults in the San Francisco Bay Area. Public Domain
28. Hana Zavadska. Graph of earthquake years in Parkfield, California. CC BY-NC 3.0
29. Zachary Wilson. Map of the area hit by the Boxing Day Tsunami. CC BY-NC 3.0
30. User:Pekachu/Wikimedia Commons and User:Eastwind41/Wikimedia Commons. Peak tsunami heights from the 2011 tsunami. Public Domain
31. Courtesy of the US Navy. Damage caused by the 2011 earthquake and tsunami. Public Domain
32. Esme Vos. Picture of a tsunami warning sign. CC BY 2.0
33. User:Crickett/Wikipedia. These seismograms show the arrival of P-waves and S-waves. Public Domain
34. CK-12 Foundation. Finding an earthquake epicenter using 3 seismographs. CC-BY-NC 3.0
35. Courtesy of US Geological Survey. A landslide in a neighborhood in Anchorage, Alaska, after the 1964 Great

- Alaska earthquake. Public Domain
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  37. Courtesy of Association of Bay Area Governments. The expected Modified Mercalli Intensity Scale for an earthquake of magnitude 7.1 on the northern portion of the Hayward Fault. Public Domain
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  39. Matthew Lew. Building retrofitted to meet earthquake safety standards. CC BY-NC 3.0
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  41. Courtesy of US Geological Survey/Cascades Volcano Observatory. Map of active volcanos around the world. Public Domain
  42. Zappy's. Volcanoes can be active, dormant, or extinct. CC BY-NC 3.0
  43. Courtesy of NASA, modified by User:Black Tusk/Wikimedia Commons. Map of volcanoes on the Cascade Range. Public Domain
  44. Curt Smith. Picture of Mt. Baker in Washington. CC BY 2.0
  45. Courtesy of the U.S. National Oceanic and Atmospheric Administration. A volcanic eruption at Surtsey, a small island near Iceland. Public Domain
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  47. Courtesy of US Geological Survey. Map of hotspots around the world. Public Domain
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  49. Courtesy of the US Geological Survey. Eruption of Mt. Redoubt in Alaska in 1989. Public Domain
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  54. Paul Bica. In effusive eruptions, lava flows readily, producing rivers of molten rock. CC BY 2.0
  55. (a) Courtesy of US Geological Survey; (b) Michael Oswald; (c) Courtesy of TN Mattox/US Geological Survey; (d) Courtesy of OAR/National Undersea Research Program. Pictures of A'a, pahoehoe, and pillow lava. Public Domain
  56. Courtesy of the US Geological Survey. Road covered by lava from an eruption at Kilauea in Hawaii. Public Domain
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  58. Courtesy of the NASA's Goddard Space Flight Center. Picture of an Earth observation satellite. Public Domain
  59. Left: Courtesy of DR Mullineaux/US Geological Survey; Right: Courtesy of Lyn Topinka/US Geological Survey. Mount St. Helens was a cone-shaped volcano, then it erupted and blew off its top. Public Domain
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  64. Courtesy of NASA. The caldera at Santorini in Greece is so large that it can only be seen by satellite. Public Domain

65. User:Kbh3rd/Wikimedia Commons. Diagram of the Yellowstone hotspot and caldera. Public Domain
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68. Courtesy of Willie Scott/US Geological Survey. Lava domes forming in the crater of Mount St. Helens. Public Domain
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