# Basic Earth Science - 1st nine weeks

# Creekside- 1st nine weeks- 6th grade Earth Science- 2014-15

Nancy B Sills
Dana Desonie, Ph.D.
Jessica Henze, M.Ed

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**AUTHORS**
Nancy B Sills
Dana Desonie, Ph.D.
Jessica Henze, M.Ed



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# Contents

# CONCEPT 1 Branches of Earth Science

- Identify and define the major branches of Earth Science.

**If science is the study of the natural world, what could be more obvious than to study the land, sky, water, and space surrounding us?**

Earth scientists seek to understand the beautiful sphere on which we live. Earth is a very large, complex system or set of systems, so most Earth scientists specialize in studying one aspect of the planet. Since all of the branches of Earth science are connected, these researchers work together to answer complicated questions. The major branches of Earth science are described below.

## Geology

Geology is the study of the Earth's solid material and structures and the processes that create them. Some ideas geologists might consider include how rocks and landforms are created or the composition of rocks, minerals, or various landforms. Geologists consider how natural processes create and destroy materials on Earth, and how humans can use Earth materials as resources, among other topics.

FIGURE 1.1
Geologists study rocks in the field to learn what they can from them.

### Oceanography

Oceanography is the study of everything in the ocean environment, which covers about 70% of the Earth's surface. Recent technology has allowed people and probes to venture to the deepest parts of the ocean, but much of the ocean remains unexplored. Marine geologists learn about the rocks and geologic processes of the ocean basins.

### Climatology and Meteorology

Meteorology includes the study of weather patterns, clouds, hurricanes, and tornadoes. Using modern technology such as radars and satellites, meteorologists are getting more accurate at forecasting the weather all the time.

Climatology is the study of the whole atmosphere, taking a long-range view. Climatologists can help us better understand how and why climate changes ( **Figure** 1.2).

FIGURE 1.2
Carbon dioxide released into the atmosphere is causing the global climate to change.

### Environmental Science

Environmental scientists study the effects people have on their environment, including the landscape, atmosphere, water, and living things. Climate change is part of climatology or environmental science.

### Astronomy

Astronomy is the study of outer space and the physical bodies beyond the Earth. Astronomers use telescopes to see things far beyond what the human eye can see. Astronomers help to design spacecraft that travel into space and send back information about faraway places or satellites ( **Figure** 1.3).

FIGURE 1.3
The Hubble Space Telescope.

### Summary

- The study of Earth science includes many different fields, including geology, meteorology, oceanography, and astronomy.
- Each type of Earth scientist investigates the processes and materials of the Earth and beyond as a system.
- Geology, climatology, meteorology, environmental science, and oceanography are important branches of Earth science.

### Making Connections


MEDIA
Click image to the left for more content.

### Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. What tools do geoscientists use?
2. Do all Earth scientists study Earth's past?
3. What is fundamental about the study of Earth science?
4. Why is it important for people to study Earth science?
5. Why is Earth science called a combined science?
6. What issues will Earth science need to address in the future?

### Review

1. What type of Earth scientist would be interested in understanding volcanic eruptions on the seafloor?
2. If it were to snow in Phoenix in July, which type of Earth scientist would be most surprised?
3. If people have been studying the natural world for centuries or even millennia, why are scientists learning so much about Earth science now?

## References

1. Flickr:miguelb. Geologist studying rocks in the field. CC BY 2.0
2. Walter Siegmund. Carbon dioxide released into the atmosphere by this factory is causing the global climate to change. CC BY 2.5
3. Courtesy of NASA. The Hubble Space Telescope. Public Domain

# CONCEPT 2 Earth's Outer Layers

- Identify Earth's layers and describe their characteristics.

**Does this look familiar?**

Gases, water, rock, and living organisms are all found at Earth's surface. These materials are also found above or below the surface. They interact with each other and in doing so alter each other. For example, the hydrosphere may cause some of the lithosphere to wash away.

## Spheres

Earth is made of layers. Since Earth is round, the layers all have the ending "-sphere" ( **Figure** 2.1).

Some of the different parts of the Earth are the:

- **Atmosphere**: The thin layer of air, mostly nitrogen and oxygen, that surrounds the Earth.
- **Hydrosphere**: All the water on Earth.
- **Biosphere**: All the living organisms on Earth.
- **Lithosphere**: The solid rock part of Earth, including mountains, valleys, continents, and all of the rock beneath the oceans.

All of Earth's layers interact. Therefore, Earth's surface is constantly undergoing changes.

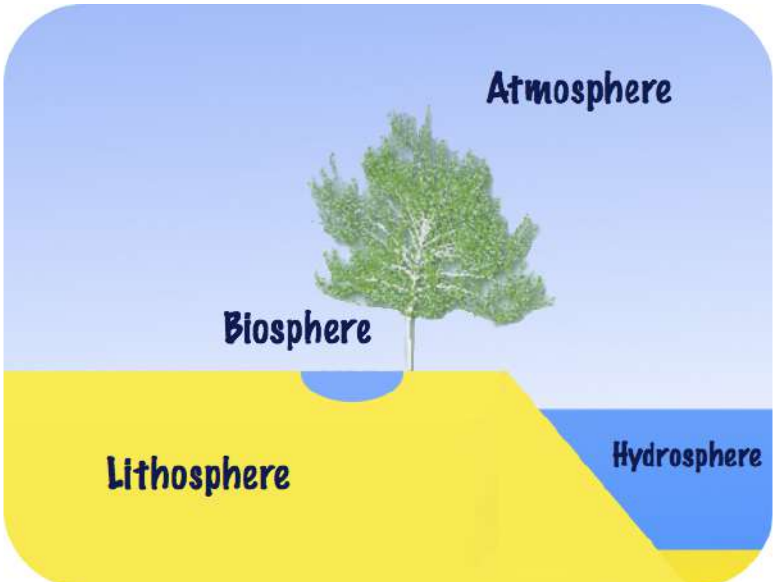



FIGURE 2.1
Earth has four layers: atmosphere, hydrosphere, biosphere, and lithosphere.

### Vocabulary

- **atmosphere**: Mixture of gases that surrounds a planet such as Earth.
- **biosphere**: All living organisms on Earth.
- **hydrosphere**: All the water on Earth.
- **lithosphere**: Solid, brittle rock; Earth's outermost rocky layer

### Summary

- Earth is made of layers. The names end in sphere because Earth is round.
- Some of the layers are: atmosphere, biosphere, hydrosphere, and lithosphere.
- The lithosphere is the brittle crust and uppermost mantle.

### Practice

Use the resource below to answer the questions that follow.

- **Big Ideas in Geoscience: Earth's Systems Interact** at http://www.youtube.com/watch?v=BnpF0ndXk-8 (5:49)

MEDIA
Click image to the left for more content.

1. What are the four major systems of Earth?

2. What are the components of the geosphere?
3. What is the hydrosphere?
4. Where does Earth's energy come from?
5. What are ecosystems?
6. What is feedback?

### Review

1. What is the atmosphere?
2. What is the lithosphere?
3. Where is the hydrosphere?
4. How do Earth's layers interact? Give an example.

## References

1. CK-12 Foundation. Earth has four layers: atmosphere, hydrosphere, biosphere, and lithosphere. CC BY-NC 3.0

# Concept 3 Earth's Shape

- Describe Earth's shape and explain how Earth's shape is related to its mass.

**Before spacecraft, how did people know that Earth is spherical?**

The ancient Greeks knew that Earth was round by observing the arc shape of the shadow on the Moon during a lunar eclipse. Was there other evidence of Earth's roundness available to people before spacecraft gave us a bird's eye view?

## Earth's Shape

Earth is a sphere or, more correctly, an oblate spheroid, which is a sphere that is a bit squished down at the poles and bulges a bit at the Equator. To be more technical, the minor axis (the diameter through the poles) is smaller than the major axis (the diameter through the Equator). Half of the sphere is a **hemisphere**. North of the Equator is the northern hemisphere and south of the Equator is the southern hemisphere. Eastern and western hemispheres are also designated.

What evidence is there that Earth is spherical? What evidence was there before spaceships and satellites?

Try to design an experiment involving a ship and the ocean to show Earth is round. If you are standing on the shore and a ship is going out to sea, the ship gets smaller as it moves further away from you. The ship's bottom also starts to disappear as the vessel goes around the arc of the planet ( **Figure** 3.1). There are many other ways that early scientists and mariners knew that Earth was not flat. Here is a summary of some: http://www.physlink.com/education/askexperts/ae535.cfm .

The Sun and the other planets of the solar system are also spherical. Larger satellites, those that have enough mass for their gravitational attraction to have made them round, are spherical as well.

## Summary

- Ancient Greeks knew that Earth was round because of the shadow the planet cast on the Moon during a lunar eclipse.
- A boat does not get smaller with distance but sinks below the horizon - more evidence for Earth's roundness.
- Earth is divided into hemispheres: northern, southern, eastern, and western.

FIGURE 3.1
Earth's curvature is noticeable when objects at a distance are below the arc.

### Interactive Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What was the first photo of Earth? What did it prove?
2. Why are bodies in space round?
3. How did the planets form?
4. What is the only shape in nature that looks the same from all directions?
5. Why are there odd-shaped objects in space?

### Review

1. Describe where you live in terms of hemispheres.
2. If you met up with someone who claimed that Earth is flat, what evidence would you present to them that their assertion is not true?
3. What evidence do you have that our planet is flat? Which of these ideas do you believe and why?

## References

1. Conan (Flickr:conanil). Earth's curvature can be seen when objects are below the horizon. CC BY 2.0

# CONCEPT 4 Earth's Interior

- Describe the ways in which scientists can learn about what's in Earth's interior.


**How deep can we go into Earth's interior?**

Not very deep, that's for sure! The deepest a drill hole has gotten was the Kola Superdeep Borehole. That hole got to 40,230 feet (12,262 m), about one-third of the way into the crust in that area. So learning about what's deeper requires less direct methods. A few of these methods will be described in this concept.

## Learning About Earth's Interior

If someone told you to figure out what is inside Earth, what would you do? How could you figure out what is inside our planet? How do scientists figure it out?

### Seismic Waves

Geologists study earthquake waves to "see" Earth's interior. Waves of energy radiate out from an earthquake's focus. These waves are called **seismic waves** ( **Figure** 4.1). Seismic waves go different speeds through different materials. They change speed when they go from one type of material to another. This causes them to bend. Some seismic waves do not travel through liquids or gases. They just stop. Scientists use information from seismic waves to understand what makes up the Earth's interior.

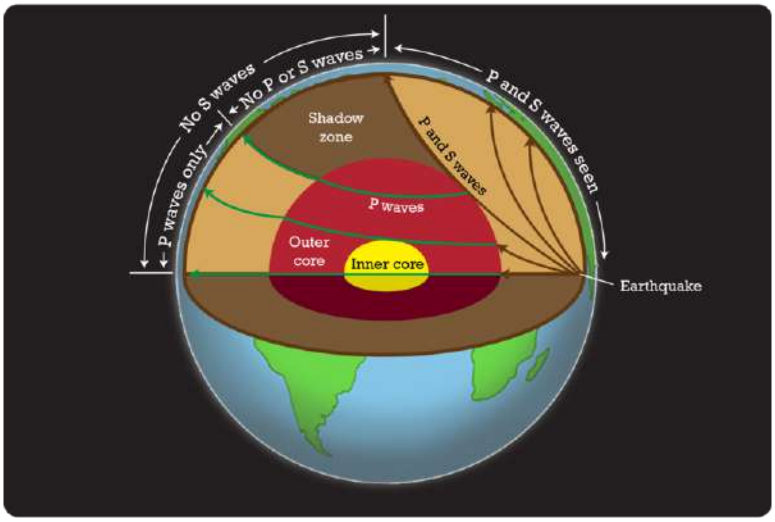



FIGURE 4.1
The properties of seismic waves allow scientists to understand the composition of Earth's interior.

### Meteorites

Scientists study **meteorites** to learn about Earth's interior. Meteorites formed in the early solar system. These objects represent early solar system materials ( **Figure** 4.2). Some meteorites are made of iron and nickel. They are thought to be very similar to Earth's core. An iron meteorite is the closest thing to a sample of the core that scientists can hold in their hands!

FIGURE 4.2
This meteorite contains the mafic minerals olivine and pyroxene. It also contains metal flakes, similar to the material that separated into Earth's core (metal) and mantle (ultramafic rock).

### Density

Earth's overall density is higher than the density of crustal rocks, so the core must be made of something dense, like metal.

### Magnetic Field

Since Earth has a magnetic field, there must be metal within the planet. Iron and nickel are both magnetic.

## Vocabulary

- **meteorite**: Fragment of planetary bodies, such as moons, planets, asteroids, and comets, that strike Earth.

- **seismic wave**: Waves of energy that come from earthquakes.

### Summary

- Different types of seismic waves behave differently in different materials. Their behavior can tell scientists about the material they travel through.
- Earth must contain metal. Its density, and the fact that it has a magnetic field, require it.
- Meteorites formed early in the solar system. They indicate something about Earth's interior.

### Practice

Use the resource below to answer the questions that follow.

- **Seismic Waves** at http://www.youtube.com/watch?v=yOGoKCK17a4 (1:39)

MEDIA

Click image to the left for more content.

1. What types of waves do earthquakes produce?
2. What are the fastest body waves?
3. What is the shadow zone?
4. What do S-waves do?
5. List and explain the two types of surface waves.

### Review

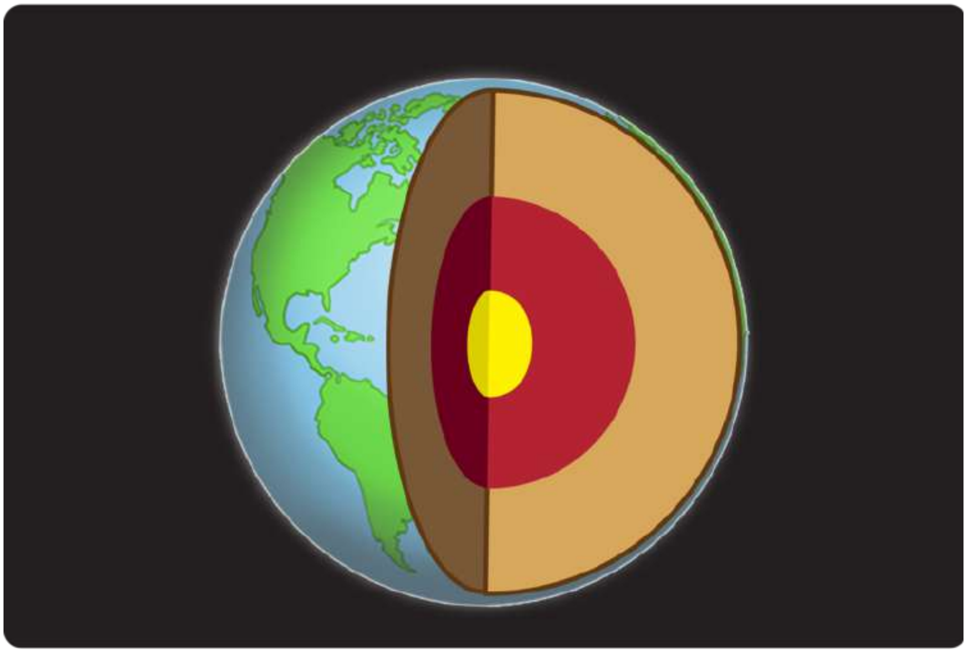
1. How do scientists know that Earth's interior contains metal?
2. What do meteorites tell us about Earth's interior?
3. How do scientists use seismic waves to learn about Earth's interior?

## References

1. Christopher Auyeung and Laura Guerin. The properties of seismic waves allow scientists to understand the composition of Earth's interior. CC BY-NC 3.0
2. Steve Jurvetson (Flickr: jurvetson). Meteorite containing the mafic minerals olivine and pyroxene, as well as metal flakes similar to the material that separated into the Earth's core and mantle. CC-BY 2.0

# CONCEPT 5 Earth's Inner Layers

- Identify Earth's internal layers in two different ways.
- Describe the characteristics of Earth's layers.



**What's below our feet? What's way below?**

If we could cut Earth open, we'd see the following layers from inside to outside: inner core, outer core, mantle, and crust. Alternatively, you can think of the brittle lithosphere riding on the plastic asthenosphere. Whew!

## Layers by Composition

The layers scientists recognize are pictured below ( **Figure** 6.3).

Core, mantle, and crust are divisions based on composition:

1. The **crust** is less than 1% of Earth by mass. The two types are oceanic crust and continental crust.
2. The **mantle** is hot, dense, dark (ultramafic) rock. It represents about 68% of Earth's mass.
3. The **core** is mostly iron metal. The core makes up about 31% of the Earth. Earth's metallic core has two layers: a solid inner layer and a liquid outer layer.

The terms core, mantle, and crust will be described in more detail in the next three concepts.

## Layers by Mechanical Properties

Lithosphere and asthenosphere are divisions based on mechanical properties:

1. The **lithosphere** is composed of both the crust and the uppermost mantle. The lithosphere is a brittle, rigid solid. It is easily cracked or broken.

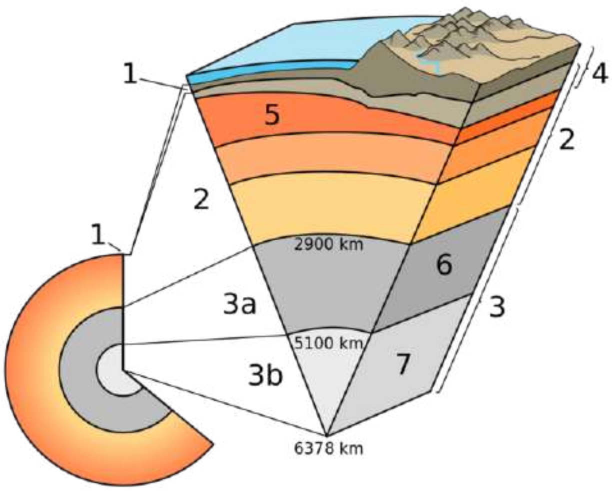



FIGURE 5.1
A cross section of Earth showing the following layers: (1) crust (2) mantle (3a) outer core (3b) inner core (4) lithosphere (5) asthenosphere (6) outer core (7) inner core.

2. The **asthenosphere** is below the lithosphere. The asthenosphere is also in the upper mantle. This layer is solid, but it can flow and bend. A solid that can flow is like silly putty.

This animation shows the layers by composition and by mechanical properties: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_layers.html .

## Vocabulary

- **asthenosphere**: Layer below the lithosphere, made of a portion of the upper mantle; the asthenosphere can flow.
- **core**: Innermost, densest layer of a celestial body.
- **crust**: Rocky outer layer of the Earth's surface.
- **lithosphere**: Layer of solid, brittle rock that makes up the Earth's surface.
- **mantle**: Middle layer of the Earth; made of hot rock.

## Summary

- By composition, Earth is divided into core, mantle, and crust.
- By mechanical properties, the crust and upper mantle are divided into lithosphere and asthenosphere.
- The core-mantle-crust divisions are based on composition.
- The lithosphere-asthensophere divisions are based on mechanical properties.

## Practice

Use the resource below to answer the questions that follow.

- **NASA SCI Files - Layers of the Earth** at http://www.youtube.com/watch?v=227okXKJpXA (3:51)

MEDIA

Click image to the left for more content.

1. What is the core?
2. Explain the core's structure.
3. What is the mantle?
4. What is the crust?
5. Why does the Earth have layers?

### Review

1. What are the the layers of Earth, based on composition? Where are they located?
2. What is the composition of the different layers?
3. How do the lithosphere and asthenosphere differ from each other?

## References

1. Courtesy of the US Geological Survey. Composition of Earth's layers. Public Domain

# CONCEPT 6 Earth's Composition

- Identify Earth's internal layers in two different ways.
- Describe the characteristics of Earth's layers.

Learning Objectives:

- Explain 2 ways scientists define the Earth's layers.
- Identify the five physical layers of the Earth.

FIGURE 6.1
Figure 1: Cross section of the Earth.

## Compositional Layers of the Earth

**As you look at the ground, you often see soil and rock and a variety of living things: plants, animals, and micro-organisms. However, if we could cut Earth open, we'd see the several distinct layers. In Figure 1, there appears to be 4 layers: inner core, outer core, mantle, and crust. Often people will combine the inner and outer core and just call it the core. This makes up the three compositional layers of the Earth.**

### The Crust

The crust is the outermost layer of the Earth. It can be 5 to 100 km thick depending on the location and surface features. As you can see in Figure 2 above, the areas where continents are located are much thicker than areas where there is ocean. Oceanic crust is typically more dense than continental crust due to the composition of the rock.

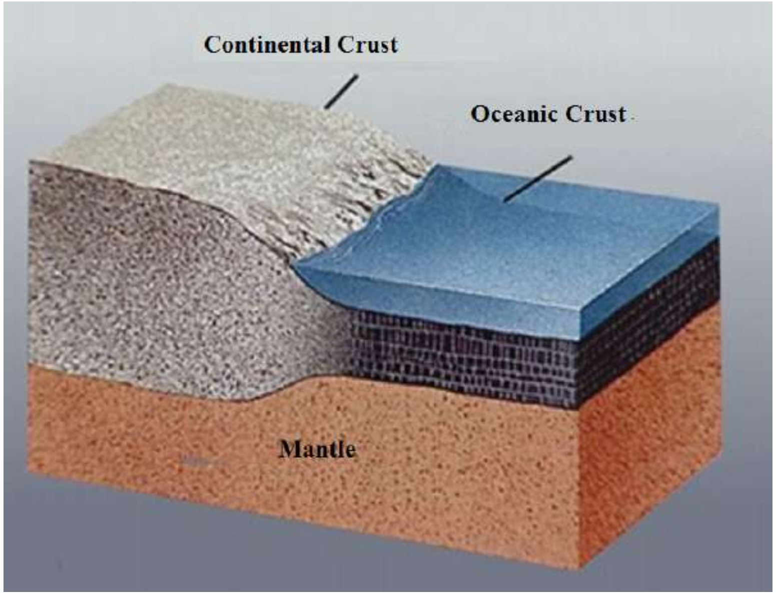



FIGURE 6.2
Figure 2

Continental crust usually ranges from 20-70 km thick. Oceanic crust usually ranges from 4-9 km thick. Most of the crust is composed of rock that is formed after molten rock has cooled. Despite these thicknesses, humans have never drilled all the way through the crust. The closest anyone has gotten was 1,415 m (1.4 km) into oceanic crust.

### The Mantle

As you saw in Figure 2 above, the mantle is below the crust. The approximate thickness of the mantle is 2,900 km. Even though we have never observed the mantle directly, scientists have been able to infer the composition of based on observations of volcanoes. It is in these locations that molten rock from the mantle flows to the surface. Scientists believe that the magma is composed of mostly iron and magnesium.

### The Core

The core is the innermost layer of the Earth. It is about 7,000km thick and goes all the way to the center of the earth. This layer is the most difficult to study since it cannot be reached. Scientists believe that the core is composed of mostly iron and nickel. They have used the data from how seismic waves (from earthquakes) travel through the core to determine this information.

## Layers by Physical Properties

Even though we've talked about the three compositional layers of the earth, scientists recognize a total of five physical layers as pictured below ( **Figure** 6.3 3).

The crust and upper part of the mantle comprises the **lithosphere** ( label 4 above). Because the average temperature of the lithosphere is about 0ºC, the material is brittle and solid. It is easily cracked or broken. The lithosphere is not able to flow or move easily, which is often what causes breaking to occur. The places where the lithosphere has broken, make up the boundaries of plates. These plates float atop the asthenosphere.

The **asthenosphere** (as THE nuh sfihr) makes up part of the upper mantle as well, and has an average temperature of 500ºC. While the lithosphere is solid and can't flow, the asthenosphere (label 5 above) is solid but can flow. Can

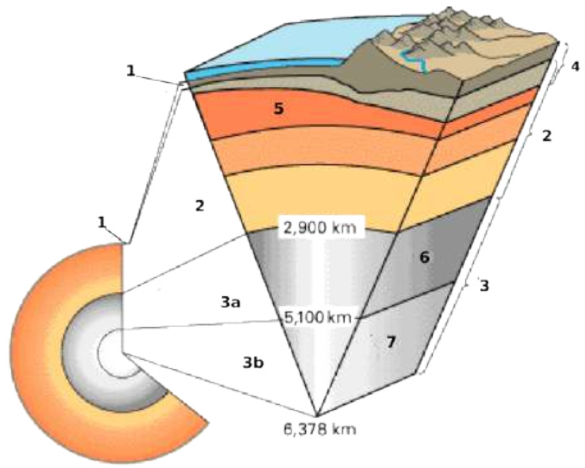



FIGURE 6.3

Figure 3: A cross section of Earth showing the following layers: (1) crust (2) mantle (3a) outer core (3b) inner core (4) lithosphere (5) asthenosphere (6) outer core (7) inner core.

you think of a solid that can flow? Consider toothpaste, silly putty, or hot plastic that hasn't melted. The plastic is really easy to bend, and the silly putty will take the shape of its container over time. Because of this property, the asthenosphere is classified differently than the lithosphere.

The lower mantle is also known as the **mesophere**. The average temperature of this layer is about 2000ºC. It is the bottom portion of the mantle that isn't included in the lithosphere or asthenosphere. The temperature of the mesosphere is significantly higher than that of the asthenosphere. Despite these higher temperatures, the mesophere is still solid because of the intense pressure from the weight of the earth.

The core is made up of the inner and the outer core. The outer core of the Earth is liquid iron and nickel. Scientists believe that this liquid outer core is responsible for Earth's magnetic field. The average temperature of the outer core is 5000ºC, which is definitely hot enough to melt iron and nickel.

The inner core is mostly made of iron. The extremely high temperatures (7000ºC) of the inner core would normally melt the metal, but it is under extreme pressure which prevents the molecules from moving much, causing it to remain solidified.

This animation shows the layers by composition and by mechanical properties: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_layers.html .

### Vocabulary

- **asthenosphere**: Layer below the lithosphere, made of a portion of the upper mantle; the asthenosphere can flow.
- **core**: Innermost, densest layer of a celestial body.
- **crust**: Rocky outer layer of the Earth's surface.
- **lithosphere**: Layer of solid, brittle rock that makes up the Earth's surface.
- **mantle**: Middle layer of the Earth; made of hot rock.
- **Mesosphere:** the lower portion of the mantle, between the asthenosphere and the outer core

### Summary

- By composition, Earth is divided into core, mantle, and crust.
- By physical properties, the crust and upper mantle are divided into lithosphere and asthenosphere with the mesosphere and outer core and inner core.

### Practice

Use the resource below to answer the questions that follow.

- **NASA SCI Files-Layers of the Earth** at http://www.youtube.com/watch?v=BnpF0ndXk-8 (3:51)

MEDIA
Click image to the left for more content.

1. What is the core?
2. Explain the core's structure.
3. What is the mantle?
4. What is the crust?
5. Why does the Earth have layers?

### Review

1. What are the the layers of Earth based on composition. Where are they located?
2. What is the composition of the different layers?
3. How do the lithosphere and asthenosphere differ from each other?
4. Create a concept map using the following terms: crust, mantle, core, lithosphere, asthenosphere, mesosphere, outer core, inner core.

## References

1. . . CC BY-NC-SA
2. . . CC BY-NC-SA
3. Courtesy of the US Geological Survey. . Public Domain

# Concept 7 Earth's Crust

- Describe the characteristics of Earth's two types of crust, oceanic and continental.


**How does a loaf of bread resemble Earth?**

A loaf of homemade bread could almost resemble Earth. The raised parts of the crust are the continents and the depressed parts are the oceans. The inside is gooier than the brittle exterior, but it's still solid. How is a loaf of bread not like Earth?

## Crust

Earth's outer surface is its crust, a cold, thin, brittle outer shell made of rock. The crust is very thin relative to the radius of the planet. There are two very different types of crust, each with its own distinctive physical and chemical properties, which are summarized in **Table** 7.1.

TABLE 7.1: **Oceanic and Continental Crust**

| Crust | Thickness | Density | Composition | Rock types |
|---|---|---|---|---|
| Oceanic | 5-12 km (3-8 mi) | 3.0 g/cm$^3$ | Mafic | Basalt and gabbro |
| Continental | Avg. 35 km (22 mi) | 2.7 g/cm$^3$ | Felsic | All types |

### Oceanic Crust

**Oceanic crust** is composed of mafic magma that erupts on the seafloor to create basalt lava flows or cools deeper down to create the intrusive igneous rock gabbro ( **Figure** 7.1).


FIGURE 7.1
Gabbro from ocean crust. The gabbro is deformed because of intense faulting at the eruption site.

Sediments, primarily mud and the shells of tiny sea creatures, coat the seafloor. Sediment is thickest near the shore, where it comes off the continents in rivers and on wind currents.

The oceanic crust is relatively thin and lies above the mantle. The cross section of oceanic crust in the **Figure** 7.2 shows the layers that grade from sediments at the top to extrusive basalt lava, to the sheeted dikes that feed lava to the surface, to deeper intrusive gabbro, and finally to the mantle.

### Continental Crust

**Continental crust** is made up of many different types of igneous, metamorphic, and sedimentary rocks. The average composition is granite, which is much less dense than the mafic rocks of the oceanic crust ( **Figure** 7.3). Because it is thick and has relatively low density, continental crust rises higher on the mantle than oceanic crust, which sinks into the mantle to form basins. When filled with water, these basins form the planet's oceans.

## Summary

- Oceanic crust is thinner and denser than continental crust.
- Oceanic crust is more mafic, continental crust is more felsic.
- Crust is very thin relative to Earth's radius.

## Interactive Practice

Use these resources to answer the questions that follow.

http://www.learner.org/interactives/dynamicearth/structure.html

Click on the crust to answer the questions below:

1. Describe the crust.

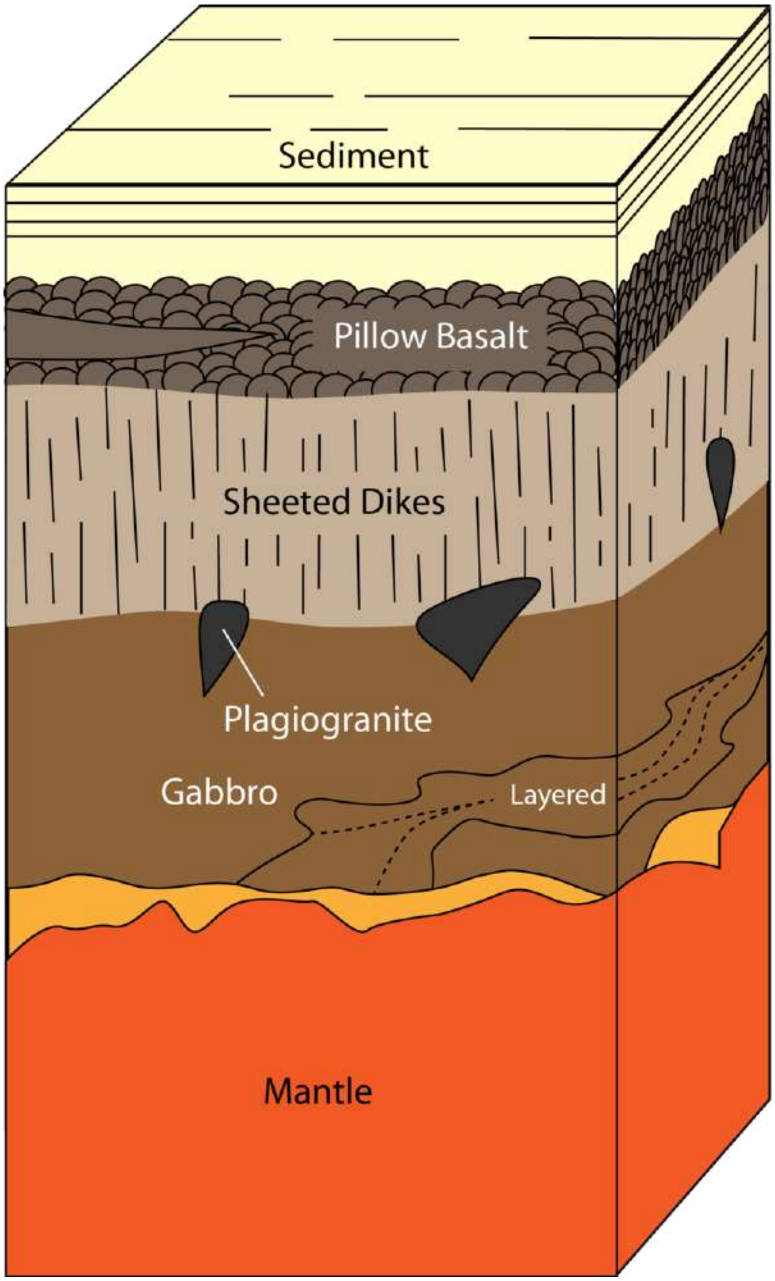



FIGURE 7.2
A cross-section of oceanic crust.

2. Where is the crust the thickest?

http://www.scec.org/education/k12/learn/plate1.htm

3. How thick is continental crust?

4. How thick is oceanic crust?

5. Compare the thickness of the crust in comparison with the rest of the layers of the earth.

## Review

1. Describe the properties of oceanic crust.

FIGURE 7.3
This granite from Missouri is more than 1 billion years old.

2. Describe the properties of continental crust.
3. What type of rock makes up each of the types of crust?

## References

1. Courtesy of National Oceanic and Atmospheric Administration/University of Washington. Gabbro from ocean crust. Public Domain
2. Christopher Auyeung. A cross-section of oceanic crust. CC BY-NC 3.0
3. Courtesy of US Geological Survey. Granite from Missouri, and part of the continental crust. Public Domain

# CONCEPT 8 Earth's Mantle

- Describe Earth's mantle and explain its relationship to conduction and convection.

**What is a diamond delivery system?**

Some events happened when Earth was younger and hotter that do not happen any more. **Kimberlite pipes** shot up from deep in the mantle. These pipes are the most important source of diamonds, which form at very high pressure. Most kimberlites surfaced long ago.

## Mantle

The two most important things about the mantle are: (1) it is made of solid rock, and (2) it is hot.

### Solid Rock

Scientists know that the mantle is made of rock based on evidence from seismic waves, heat flow, and meteorites. The properties fit the ultramafic rock **peridotite**, which is made of the iron- and magnesium-rich silicate minerals ( **Figure** 8.1). Peridotite is rarely found at Earth's surface.

### Heat Flow

Scientists know that the mantle is extremely hot because of the heat flowing outward from it and because of its physical properties.

Heat flows in two different ways within the Earth:

1. **Conduction**: Heat is transferred through rapid collisions of atoms, which can only happen if the material is solid. Heat flows from warmer to cooler places until all are the same temperature. The mantle is hot mostly because of heat conducted from the core.

FIGURE 8.1
Peridotite is formed of crystals of olivine (green) and pyroxene (black).

2. **Convection**: If a material is able to move, even if it moves very slowly, convection currents can form.

Convection in the mantle is the same as convection in a pot of water on a stove. Convection currents within Earth's mantle form as material near the core heats up. As the core heats the bottom layer of mantle material, particles move more rapidly, decreasing its density and causing it to rise. The rising material begins the convection current. When the warm material reaches the surface, it spreads horizontally. The material cools because it is no longer near the core. It eventually becomes cool and dense enough to sink back down into the mantle. At the bottom of the mantle, the material travels horizontally and is heated by the core. It reaches the location where warm mantle material rises, and the mantle **convection cell** is complete ( **Figure** 8.2).

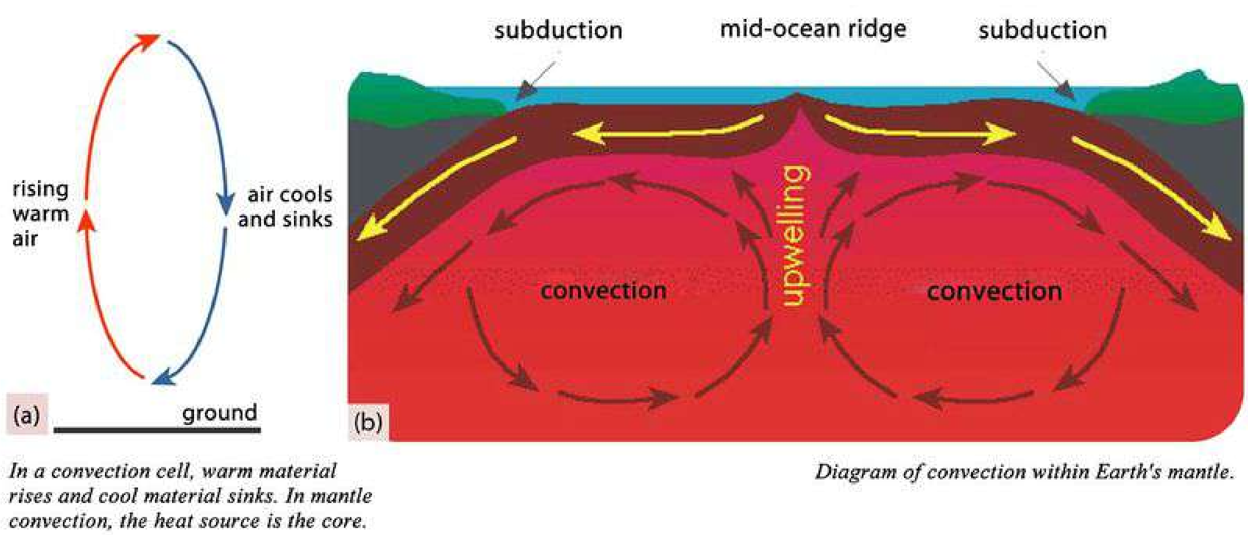


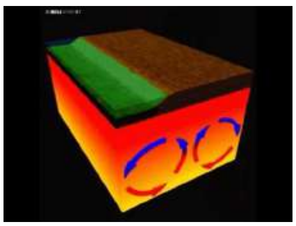

FIGURE 8.2
Convection.

## Summary


- The mantle is composed of solid peridotite.
- Conduction from the core heats the lower mantle.
- Mantle convection cells bring hot material up toward the surface and cooler material down toward the core.


## Practice

Use these resources to answer the questions that follow.



MEDIA
Click image to the left for more content.

1. What incorrect statement does this video make about the asthenosphere?
2. What causes plate movement?
3. What is convection?

http://www.youtube.com/watch?v=yt_K_bfKxTc

MEDIA
Click image to the left for more content.

4. What happens to the denser material?
5. What happens to the less dense material?
6. Where are convection currents found?

http://www.learner.org/interactives/dynamicearth/structure.html

7. Explain the structure of the mantle.

## Review

1. What is the composition of the mantle and how do scientists know this?
2. What is conduction?
3. How does convection work in the mantle?

## References


1. Image copyright Marcin Ciesielski / Sylwia Cisek, 2013. Peridotite is formed of crystals of olivine and pyroxene. Used under license from Shutterstock.com
2. Hana Zavadska. Illustration of convection within the Earth. CC BY-NC 3.0

# CONCEPT 9 Earth's Core

- Describe the characteristics of Earth's inner core and outer core.

**Do you want to take a journey to the center of the earth?**

Jules Verne's imagined core was fiery. But we know that the outer core is molten metal, as seen above. As hot as a journey to Verne's center of the earth might have been, a visit to the real location would be worse.

## Core

At the planet's center lies a dense metallic core. Scientists know that the core is metal because:

1. The density of Earth's surface layers is much less than the overall density of the planet, as calculated from the planet's rotation. If the surface layers are less dense than average, then the interior must be denser than average. Calculations indicate that the core is about 85% iron metal with nickel metal making up much of the remaining 15%.
2. Metallic meteorites are thought to be representative of the core. The 85% iron/15% nickel calculation above is also seen in metallic meteorites ( **Figure** 9.1).

If Earth's core were not metal, the planet would not have a magnetic field. Metals such as iron are magnetic, but rock, which makes up the mantle and crust, is not.

Scientists know that the outer core is liquid and the inner core is solid because:

1. S-waves do not go through the outer core.
2. The strong magnetic field is caused by convection in the liquid outer core. Convection currents in the outer core are due to heat from the even hotter inner core.

FIGURE 9.1

An iron meteorite is the closest thing to the Earth's core that we can hold in our hands.

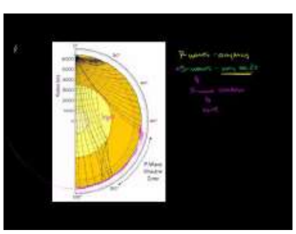
The heat that keeps the outer core from solidifying is produced by the breakdown of radioactive elements in the inner core.

## Summary

- Earth's core is dense metal.
- The inner core is solid and the outer core is liquid, as indicated by seismic waves.
- Metallic meteorites, density calculations, and the magnetic field are all clues that about the composition of Earth's inner and outer core.

## Interactive Practice

Use this resource to answer the questions that follow.



MEDIA

Click image to the left for more content.

1. What materials can P-waves travel through?
2. What materials can S-waves travel through?
3. How do we know the outer core is liquid?
4. What happens to P-waves when they go through a liquid?
5. What do P-waves tell about the inner core?

### Review

1. Why is there convection in the outer core and what is the result of this?

2. If scientists discovered a major mistake in their calculations and Earth's crust turned out to be much denser than they'd thought, what would this say about the material that makes up the core?

3. What is the outer core so hot?

## References

1. Kevin Walsh. An iron meteorite is the closest thing to the Earth's core. CC BY 2.0

# CONCEPT 10 Wegener and the Continental Drift Hypothesis

- Define the continental drift hypothesis.
- Describe what was wrong with it.

**What is continental drift?**

Wegener put together a tremendous amount of evidence that the continents had been joined. He advanced a great idea. But other scientists didn't accept it.

## Wegener's Continental Drift Hypothesis

Wegener put his idea and his evidence together in his book, *The Origin of Continents and Oceans*. The book was first published in 1915. He included evidence that the continents had been joined. New editions of the book containing additional evidence were published later.

In his book he said that around 300 million years ago, the continents had all been joined. They created a single landmass he called Pangaea, meaning "all earth" in ancient Greek. The supercontinent later broke apart. Since then the continents have been moving into their current positions. He called his hypothesis **continental drift**.

### The Problem with the Hypothesis

Wegener had a lot of evidence to support his hypothesis. But he had a problem. The problem was that he could not explain how the continents could move through the oceans. He suggested that continental drift occurred like an icebreaker plows through sea ice ( **Figure** 10.1). He thought the continents could cut through the ocean floor.

FIGURE 10.1
An icebreaking ship.

Other scientists didn't buy his idea. They thought that the continents would be much more deformed than they are.

Wegener believed that Africa and South America had once been joined. He had the evidence. But very few scientists accepted his idea. He needed a mechanism that they would accept.

Alfred Wegener died in 1930 on an expedition on the Greenland icecap. The continental drift hypothesis was put to rest for a few decades. It was when technology could provide even more evidence for continental drift that scientists looked into the idea again. Technology also helped scientists to develop a mechanism for how continents could drift.

### Vocabulary

- **continental drift**: Early 20th century hypothesis, made by Alfred Wegener, that the continents move about on Earth's surface.

### Summary

- Alfred Wegener said that the continents had been joined as a single landmass, which he called Pangaea.
- Wegener thought that Pangaea was together about 300 million years ago.
- Wegener could not develop a mechanism for continents moving through oceanic crust that other scientists would accept.

### Practice

Use the resource below to answer the questions that follow.

- **Continental Drift: Planet of Man** at http://www.youtube.com/watch?v=bVdrg5ZId1M at (9:47)

MEDIA

Click image to the left for more content.

1. What is uniformatarianism?
2. What did Wegener write about in his book?
3. What did Wegener think caused continental drift?
4. Give specific examples of the response to Wegener's continental drift hypothesis.
5. What did scientists learn after the war?

### Review

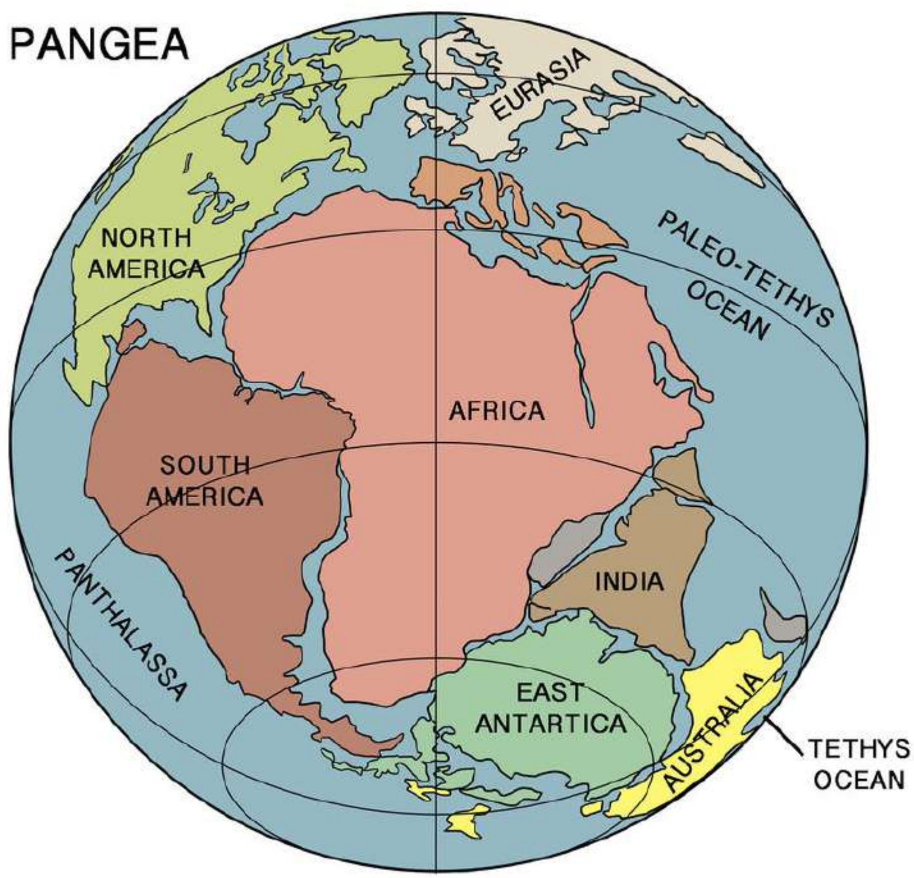
1. Describe the continental drift hypothesis.
2. Why did scientists reject Wegener's idea? What was needed for them to accept it?
3. What was Wegener's mechanism for drifting continents?

## References

1. Patrick Kelley, US Coast Guard. Wegener thought continental drift occurred as continents cut through the ocean floor, in the same way as this icebreaker plows through sea ice. CC BY 2.0

# CONCEPT 11 Continental Drift

- Identify the evidence Wegener had in support of his continental drift hypothesis.
- Apply the steps of scientific method to Wegener's scientific investigation.




**"Doesn't the east coast of South America fit exactly against the west coast of Africa, as if they had once been joined? This is an idea I'll have to pursue."** - Alfred Wegener to his future wife, December, 1910.

We can't really get into Alfred Wegner's head, but we can imagine that he started his investigations by trying to answer this question: Why do the continents of Africa and South America appear to fit together so well? Is it an accident that they do, or is there some geological reason?

### Wegener's Idea

Alfred Wegener, born in 1880, was a meteorologist and explorer. In 1911, Wegener found a scientific paper that listed identical plant and animal fossils on opposite sides of the Atlantic Ocean. Intrigued, he then searched for and found other cases of identical fossils on opposite sides of oceans. The explanation put out by the scientists of the day was that land bridges had once stretched between these continents.

Instead, Wegener pondered the way Africa and South America appeared to fit together like puzzle pieces. Other scientists had suggested that Africa and South America had once been joined, but Wegener was the idea's most dogged supporter. Wegener amassed a tremendous amount of evidence to support his hypothesis that the continents had once been joined.

Imagine that you're Wegener's colleague. What sort of evidence would you look for to see if the continents had actually been joined and had moved apart?

### Wegener's Evidence

Here is the main evidence that Wegener and his supporters collected for the continental drift hypothesis:

- The continents appear to fit together.
- Ancient fossils of the same species of extinct plants and animals are found in rocks of the same age but are on continents that are now widely separated ( **Figure** 11.1). Wegener proposed that the organisms had lived side by side, but that the lands had moved apart after they were dead and fossilized. His critics suggested that the organisms moved over long-gone land bridges, but Wegener thought that the organisms could not have been able to travel across the oceans.
  - Fossils of the seed fern *Glossopteris* were too heavy to be carried so far by wind.
  - *Mesosaurus* was a swimming reptile, but could only swim in fresh water.
  - *Cynognathus* and *Lystrosaurus* were land reptiles and were unable to swim.

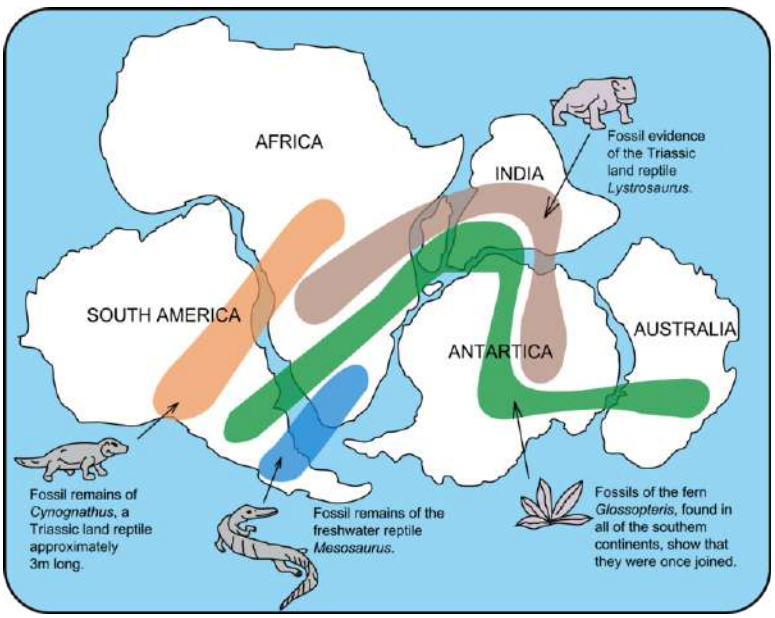



FIGURE 11.1
Wegener used fossil evidence to support his continental drift hypothesis. The fossils of these organisms are found on lands that are now far apart.

- Identical rocks, of the same type and age, are found on both sides of the Atlantic Ocean. Wegener said the rocks had formed side by side and that the land had since moved apart.
- Mountain ranges with the same rock types, structures, and ages are now on opposite sides of the Atlantic Ocean. The Appalachians of the eastern United States and Canada, for example, are just like mountain ranges in eastern Greenland, Ireland, Great Britain, and Norway ( **Figure** 11.2). Wegener concluded that they formed as a single mountain range that was separated as the continents drifted.

- Grooves and rock deposits left by ancient glaciers are found today on different continents very close to the Equator. This would indicate that the glaciers either formed in the middle of the ocean and/or covered most of the Earth. Today, glaciers only form on land and nearer the poles. Wegener thought that the glaciers were centered over the southern land mass close to the South Pole and the continents moved to their present positions later on.


FIGURE 11.2
The similarities between the Appalachian and the eastern Greenland mountain ranges are evidences for the continental drift hypothesis.

- Coral reefs and coal-forming swamps are found in tropical and subtropical environments, but ancient coal seams and coral reefs are found in locations where it is much too cold today. Wegener suggested that these creatures were alive in warm climate zones and that the fossils and coal later drifted to new locations on the continents. An animation showing that Earth's climate belts remain in roughly the same position while the continents move is seen here: http://www.scotese.com/paleocli.htm .
- Wegener thought that mountains formed as continents ran into each other. This got around the problem of the leading hypothesis of the day, which was that Earth had been a molten ball that bulked up in spots as it cooled (the problem with this idea was that the mountains should all be the same age and they were known not to be). An animation showing how the continents split up can be found here: http://www.exploratorium.edu/origins/antarctica/ideas/gondwana2.html .

## Summary

- Alfred Wegener did some background reading and made an observation.
- Wegener then asked an important question and set about to answer it.
- He collected a great deal of evidence to support his idea. Wegener's evidence included the fit of the continents, the distribution of ancient fossils, the placement of similar rocks and structures on the opposite sides of oceans, and indicators of ancient climate found in locations where those climates do not exist today.

## Practice

Use these resources to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. Who was Alfred Wegener?
2. What evidence did Wegener find for Pangaea?
3. What was the response to Wegener's hypothesis?

MEDIA

Click image to the left for more content.

4. What is the continental drift hypothesis?
5. What do the continental plates consist of?
6. What were formed when Pangaea broke apart?
7. How long ago did the continents reach their present position?

### Review

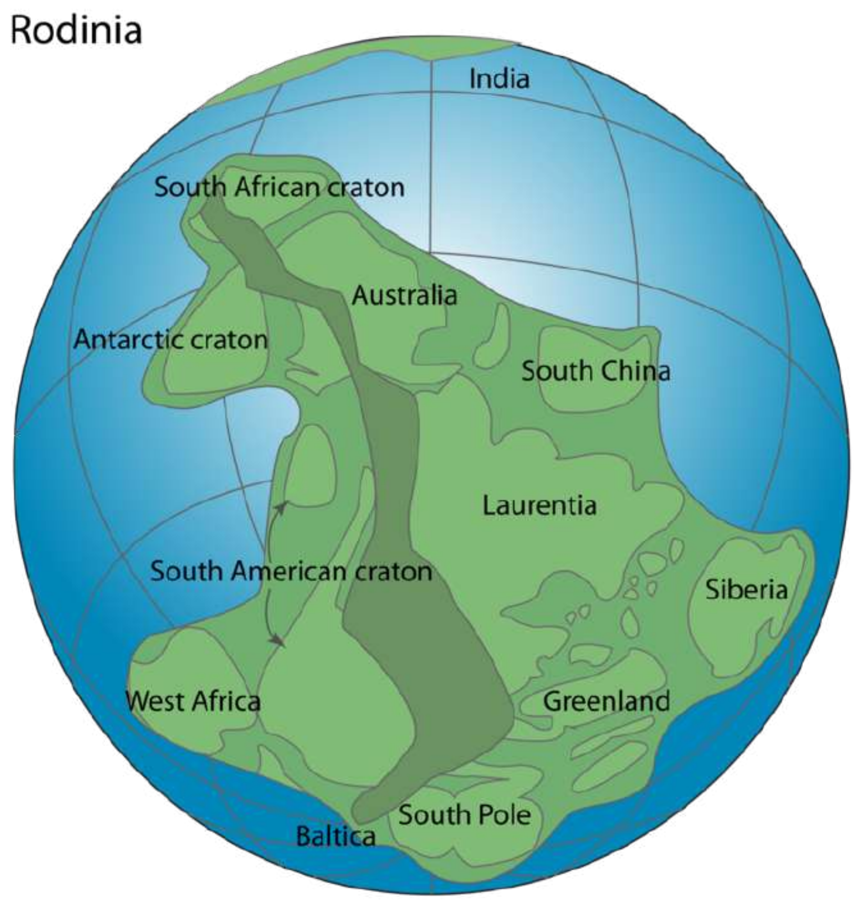
1. How did Wegener become interested in the idea that continents could move?
2. What did he need to do to explore the question and make it into a reasonable hypothesis?
3. How did Wegener use fossil evidence to support his hypothesis?
4. How did Wegener use climate evidence from rocks to support his hypothesis?

## References

1. Courtesy of the US Geological Survey, User:Osvaldocangaspadilla/Wikimedia Commons. Fossil remains of organisms on South America and Africa. Public Domain
2. Appalachian mountain image copyright Geir Olav Lyngfjell, 2014 and eastern Greenland mountain image copyright TTstudio, 2014. The Appalachian Mountains are similar to the eastern Greenland mountain ranges. Used under licenses from Shutterstock.com

# CONCEPT 12 Theory of Plate Tectonics

- Explain the theory of plate tectonics theory.
- Describe how plate tectonics leads to existence of supercontinents such as Pangaea.




**What would Wegener think?**

Like any great theory, plate tectonics makes a tremendous amount of sense. The whole story fits together so perfectly. Wegener had so much evidence that the continents had once been joined. Seafloor spreading is a perfect mechanism for moving those continents. It's really too bad that Alfred Wegener is not here to learn about the theory of plate tectonics. It seems certain that he would be ecstatic!

## Plate Tectonics Theory

The theory of plate tectonics is what brings together continental drift and seafloor spreading. Plates are made of lithosphere topped with oceanic and/or continental crust. The plates are moved around on Earth's surface by seafloor spreading. Convection in the mantle drives seafloor spreading. Oceanic crust is created at mid-ocean ridges. The crust moves outward from the ridge over time. The crust may eventually sink into the mantle and be destroyed. If a continent sits on a plate with a mid-ocean ridge, the continent will be pushed along.

### Plate Boundaries

Two plates meet at a **plate boundary**. There are three types of plate boundaries since there are three ways that plates can meet. Plates can move away from each other. They can move toward each other. Finally, they can slide past each other. The three types of plate boundaries are divergent, convergent, and transform. They are described in the following three concepts.

Most geological activity takes place at plate boundaries. This activity includes volcanoes, earthquakes, and mountain building. The activity occurs as plates interact. Giant slabs of lithosphere moving around can create a lot of activity! The features seen at a plate boundary are determined by the direction of plate motion and by the type of crust found at the boundary.

### What the Theory Explains

The theory of plate tectonics explains most of the features of Earth's surface. It explains why earthquakes, volcanoes and mountain ranges are where they are. It explains where to find some mineral resources. Plate tectonics is the key that unlocks many of the mysteries of our amazing planet. Plate tectonics theory explains why:

- Earth's geography has changed over time and continues to change today.
- some places are prone to earthquakes while others are not.
- certain regions may have deadly, mild, or no volcanic eruptions.
- mountain ranges are located where they are.
- many ore deposits are located where they are.
- living and fossil species of plants and animals are found where they are.
- some continental margins have a lot of geological activity, and some have none.

Plate tectonic motions affect Earth's rock cycle, climate, and the evolution of life.

### Vocabulary

- **plate boundary**: Location at which two plates come together.

### Summary

- The theory of plate tectonics brings together continental drift and seafloor spreading.
- At a plate boundary, two plates can be moving apart, together or past each other.
- Plate tectonics theory explains many things in geology, such as where volcanoes, earthquakes, mountain ranges, ore deposits, and other features are located.

### Practice

Use the resource below to answer the questions that follow.

- **Plate Tectonics** at http://www.youtube.com/watch?v=nfziy_860GU (3:27)

MEDIA

Click image to the left for more content.

1. Where is the Cascade Range found?
2. What does the Cascade Range include?
3. What formed the Cascade mountains?
4. What is a plate boundary?
5. List the three ways plates interact.
6. What is subduction?
7. What is the Ring of Fire?
8. What do colliding plates form?

## Review

1. What is a plate boundary?
2. What three interactions can plates have? These are the three major types of plate boundaries.
3. In general, what does the theory of plate tectonics explain?

# CONCEPT 13 Tectonic Plate Motions

- Describe how plates move.


**What is tectonics?**

Dividing the lithosphere into plates is one thing. Having the plates move around on the planet is another! A conveyor belt is a good analogy for how a plate moves. How the plates move and where they move is the "tectonics" part of plate tectonics.

## Plate Motions

Scientists have determined the direction that each plate is moving ( **Figure** 13.1). Plates move around the Earth's surface at a rate of a few centimeters a year. This is about the same rate that fingernails grow.

## How Plates Move

Convection within the Earth's mantle causes the plates to move. Mantle material is heated above the core. The hot mantle rises up toward the surface ( **Figure** 13.2). As the mantle rises, it cools. At the surface, the material moves horizontally away from a mid-ocean ridge crest. The material continues to cool. It sinks back down into the mantle at a deep sea trench. The material sinks back down to the core. It moves horizontally again, completing a **convection cell**.

**Seafloor spreading** takes place as plates move apart from each other at a mid-ocean ridge. Mantle convection drives seafloor spreading.

## Vocabulary

- **convection cell**: Hot material rises and cool material sinks in a circular pattern.

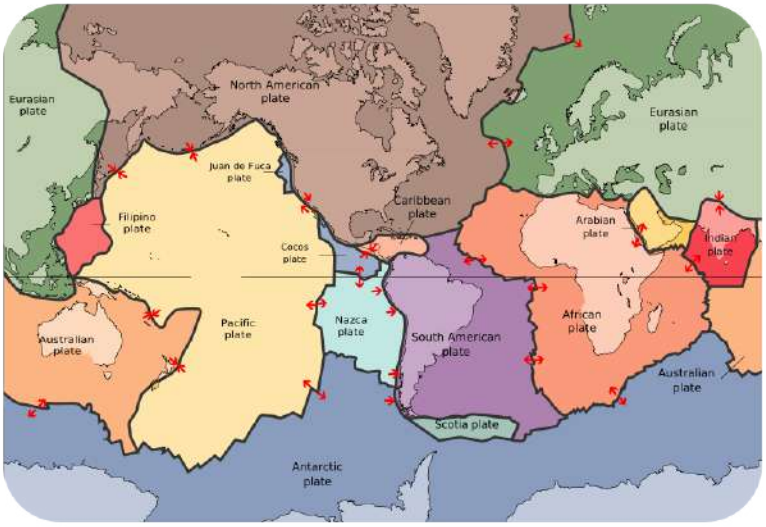



FIGURE 13.1
Earth's plates are shown in different colors. Arrows show the direction the plate is moving.

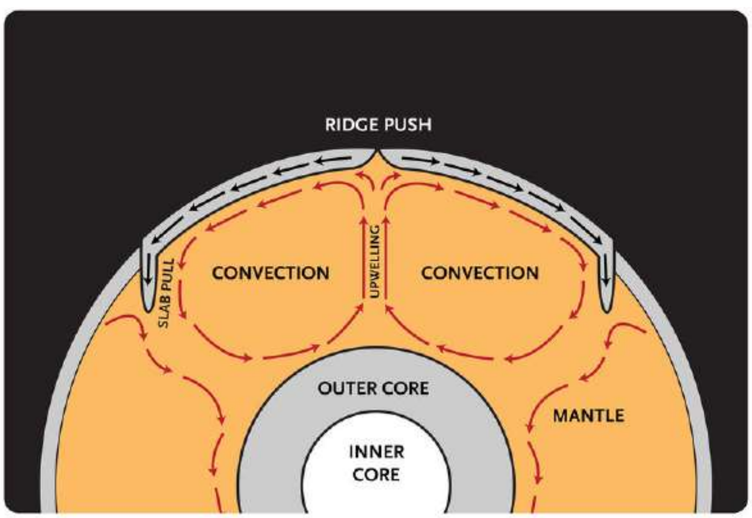



FIGURE 13.2
Plates move for two reasons. Upwelling mantle at the mid-ocean ridge pushes plates outward. Cold lithosphere sinking into the mantle at a subduction zone pulls the rest of the plate down with it.

- **seafloor spreading**: Mechanism for moving continents. The formation of new seafloor at spreading ridges pushes lithospheric plates on the Earth's surface.

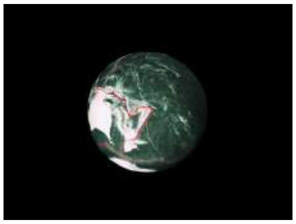
## Summary

- Plates move by seafloor spreading
- Seafloor spreading is driven by mantle convection.
- Plates move as if on a conveyor belt.

## Practice

Use the resource below to answer the questions that follow.

- **Tectonic Plate Movement** at http://www.youtube.com/watch?v=prfgw8uKXA8 (3:18)



MEDIA

Click image to the left for more content.

1. What would the Earth look like without the biosphere and atmosphere?
2. What are plates?
3. How fast are the plates moving?
4. What happens at the ridges?
5. What are subduction zones?
6. What heats Earth's interior?

### Review

1. Describe how convection takes place in the mantle.
2. How does mantle convection cause seafloor spreading?
3. How does seafloor spreading move plates?

## References

1. Courtesy of the US Geological Survey. Map of Earth's tectonic plates. Public Domain
2. Christopher Auyeung. Convection cells move plates. CC BY-NC 3.0

# CONCEPT 14 Rocks and Processes of the Rock Cycle

- Explain the processes of the rock cycle.

**Is this what geologists mean by the rock cycle?**

Okay, very punny. The rock cycle shows how any type of rock can become any other type of rock. Some rocks may stay the same type for a long time, for example, if they're at the base of the crust, but other rocks may relatively rapidly change from one type to another.

## The Rock Cycle

The **rock cycle**, illustrated in **Figure** 14.1, depicts how the three major rock types – igneous, sedimentary, and metamorphic - convert from one to another. Arrows connecting the rock types represent the processes that accomplish these changes.

Rocks change as a result of natural processes that are taking place all the time. Most changes happen very slowly. Rocks deep within the Earth are right now becoming other types of rocks. Rocks at the surface are lying in place before they are next exposed to a process that will change them. Even at the surface, we may not notice the changes. The rock cycle has no beginning or end.

## The Three Rock Types

Rocks are classified into three major groups according to how they form. These three types are described in more detail in other concepts in this chapter, but here is a summary.

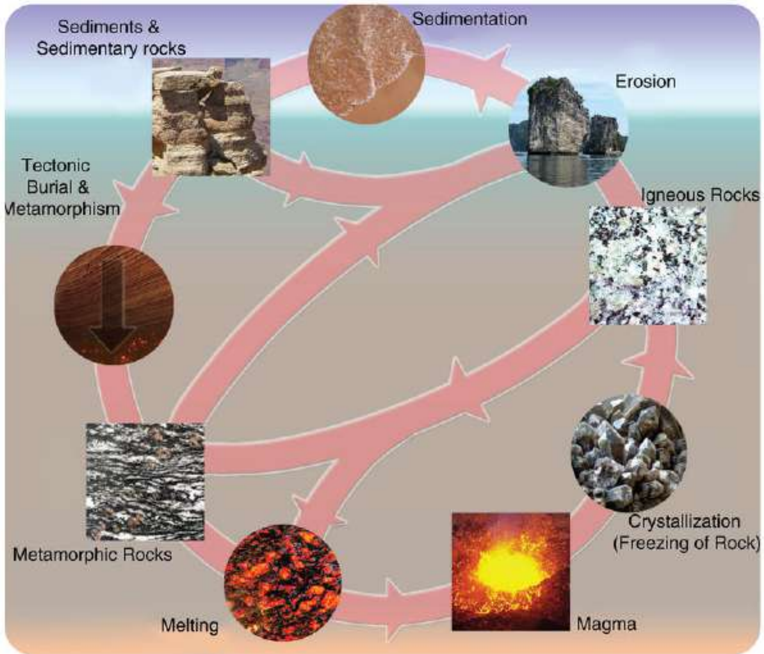



FIGURE 14.1
The Rock Cycle.

- **Igneous rocks** form from the cooling and hardening of molten magma in many different environments. The chemical composition of the magma and the rate at which it cools determine what rock forms. Igneous rocks can cool slowly beneath the surface or rapidly at the surface. These rocks are identified by their composition and texture. More than 700 different types of igneous rocks are known.
- **Sedimentary rocks** form by the compaction and cementing together of **sediments**, broken pieces of rock-like gravel, sand, silt, or clay. Those sediments can be formed from the weathering and erosion of preexisting rocks. Sedimentary rocks also include chemical **precipitates**, the solid materials left behind after a liquid evaporates.
- **Metamorphic rocks** form when the minerals in an existing rock are changed by heat or pressure below the surface.

A simple explanation of the three rock types and how to identify them can be seen in this video: http://www.youtube.com/watch?v=tQUe9C40NEE .

This video discusses how to identify igneous rocks: http://www.youtube.com/watch?v=Q0XtLjE3siE .

This video discusses how to identify a metamorphic rocks: http://www.youtube.com/watch?v=qs9x_bTCiew .

## The Processes of the Rock Cycle

Several processes can turn one type of rock into another type of rock. The key processes of the rock cycle are crystallization, erosion and sedimentation, and metamorphism.

### Crystallization

Magma cools either underground or on the surface and hardens into an igneous rock. As the magma cools, different crystals form at different temperatures, undergoing **crystallization**. For example, the mineral olivine crystallizes out of magma at much higher temperatures than quartz. The rate of cooling determines how much time the crystals will have to form. Slow cooling produces larger crystals.

### Erosion and Sedimentation

**Weathering** wears rocks at the Earth's surface down into smaller pieces. The small fragments are called sediments. Running water, ice, and gravity all transport these sediments from one place to another by **erosion**. During **sedimentation**, the sediments are laid down or deposited. In order to form a sedimentary rock, the accumulated sediment must become compacted and cemented together.

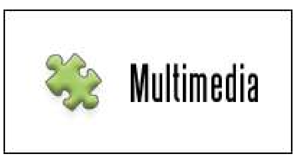
### Metamorphism

When a rock is exposed to extreme heat and pressure within the Earth but does not melt, the rock becomes metamorphosed. **Metamorphism** may change the mineral composition and the texture of the rock. For that reason, a metamorphic rock may have a new mineral composition and/or texture.

## Summary

- The three main rock types are igneous, metamorphic and sedimentary.
- The three processes that change one rock to another are crystallization, metamorphism, and erosion and sedimentation.
- Any rock can transform into any other rock by passing through one or more of these processes. This creates the rock cycle.

## Making Connections




MEDIA
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## Practice

Use these resources to answer the questions that follow.

This *Science Made Fun* video discusses the conditions under which the three main rock types form **(3c)**: http://www.youtube.com/watch?v=G7AWGhQynTY (3:41).

MEDIA
Click image to the left for more content.

1. How do igneous rocks form?

2. What are the two types of igneous rocks and how do they differ?

3. What are metamorphic rocks?

4. How do metamorphic rocks form?

5. How do sedimentary rocks form?

6. List three examples of igneous rocks.

7. List three examples of sedimentary rocks.

8. What forms coal?

9. List three examples of metamorphic rocks.

10. Can an igneous rock become an igneous rock? Can a sedimentary rock become a sedimentary rock? Can a metamorphic rock become a metamorphic rock?

11. Draw an diagram of the rock cycle and include the processes that transform rocks from one type to another.

Review the rock cycle - click a rock to begin.

http://www.phschool.com/atschool/phsciexp/active_art/rock_cycle/index.html

Test your rock identification skills with this activity:

**Name that Rock** - http://library.thinkquest.org/J002289/rocks.html

### Review

1. What processes must a metamorphic rock go through to become an igneous rock?
2. What processes must a sedimentary rock go through to become a metamorphic rock?
3. What types of rocks can become sedimentary rocks and how does that happen?

## References

1. User:Woudloper/Woodwalker; modified by CK-12 Foundation. The rock cycle. Public Domain

# CONCEPT 15 Earth's Tectonic Plates

- Describe tectonic plates and how they move.

**"With such wisdom has nature ordered things in the economy of this world, that the destruction of one continent is not brought about without the renovation of the earth in the production of another."** — James Hutton, *Theory of the Earth, with Proofs and Illustrations, Vol. 1*, 1795.

Hutton's quote predates plate tectonics theory by about one-and-a-half centuries, but it seems as if he was talking about divergent and convergent plate boundaries. The next step in understanding the development of plate tectonics theory is to learn what it is that moves around on Earth's surface. It's not really a continent; it's a plate. What is a plate?

## What is a Plate?

What portion of Earth makes up the "plates" in plate tectonics? Again, the answer came about in part due to war. In this case, the Cold War.

During the 1950s and early 1960s, scientists set up seismograph networks to see if enemy nations were testing atomic bombs. These seismographs also recorded all of the earthquakes around the planet. The seismic records were used to locate an earthquake's **epicenter**, the point on Earth's surface directly above the place where the earthquake occurs.

Why is this relevant? It turns out that earthquake epicenters outline the plates. This is because earthquakes occur everywhere plates come into contact with each other.

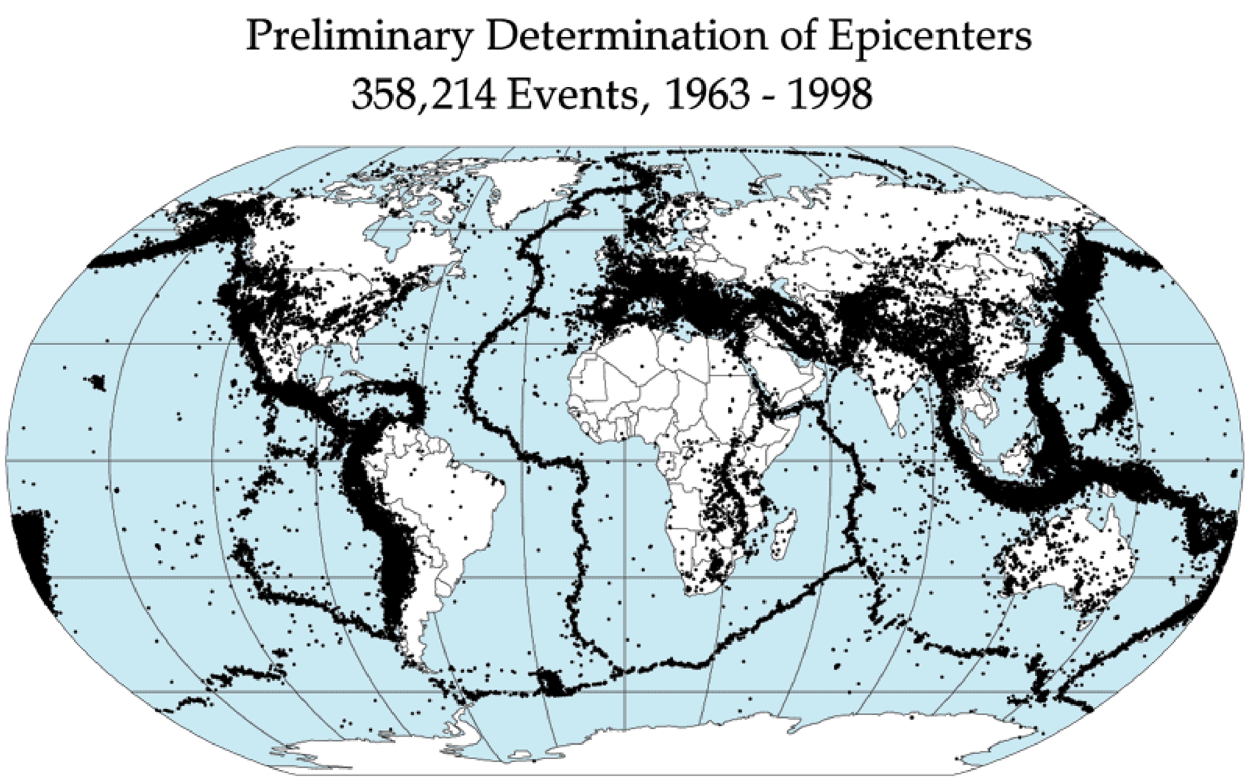



FIGURE 15.1

Earthquakes outline the plates.

The lithosphere is divided into a dozen major and several minor plates ( **Figure** 15.1). A single plate can be made of all oceanic lithosphere or all continental lithosphere, but nearly all plates are made of a combination of both.

The movement of the plates over Earth's surface is termed **plate tectonics**. Plates move at a rate of a few centimeters a year, about the same rate fingernails grow.

### How Plates Move

If seafloor spreading drives the plates, what drives seafloor spreading?

This goes back to Arthur Holmes' idea of mantle convection. Picture two convection cells side by side in the mantle, similar to the illustration in **Figure** 15.2.

1. Hot mantle from the two adjacent cells rises at the ridge axis, creating new ocean crust.
2. The top limb of the convection cell moves horizontally away from the ridge crest, as does the new seafloor.

3. The outer limbs of the convection cells plunge down into the deeper mantle, dragging oceanic crust as well. This takes place at the deep sea trenches.
4. The material sinks to the core and moves horizontally.
5. The material heats up and reaches the zone where it rises again.

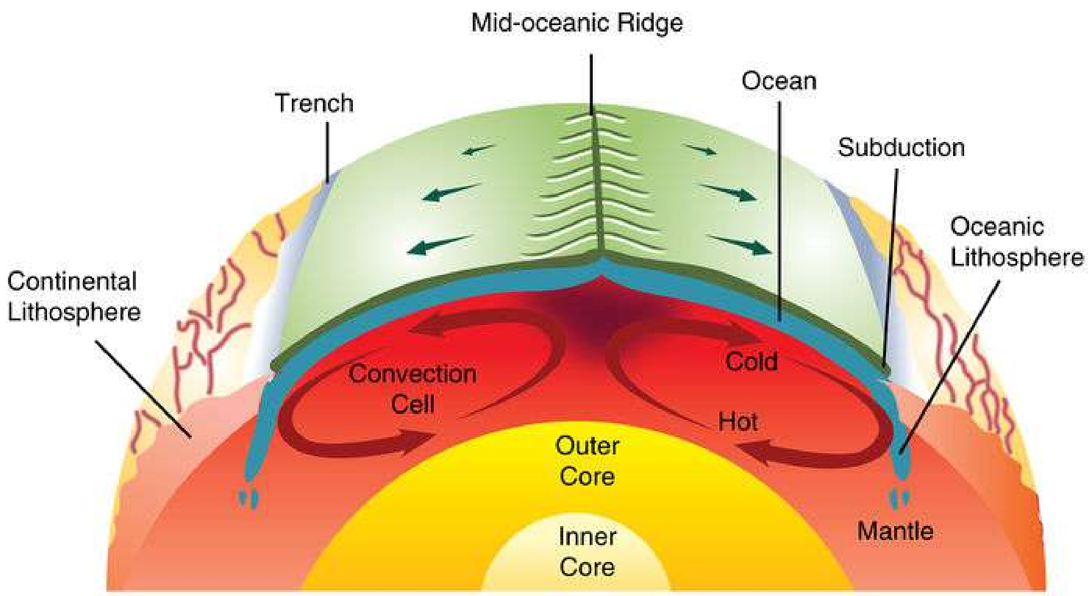



FIGURE 15.2
Mantle convection drives plate tectonics. Hot material rises at mid-ocean ridges and sinks at deep sea trenches, which keeps the plates moving along the Earth's surface.

Mantle convection is shown in these animations:

- http://www.youtube.com/watch?v=p0dWF_3PYh4
- http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_convection2.html

## Plate Boundaries

**Plate boundaries** are the edges where two plates meet. How can two plates move relative to each other? Most geologic activities, including volcanoes, earthquakes, and mountain building, take place at plate boundaries. The features found at these plate boundaries are the mid-ocean ridges, trenches, and large transform faults ( **Figure** 15.3).

- **Divergent plate boundaries**: the two plates move away from each other.
- **Convergent plate boundaries**: the two plates move towards each other.
- **Transform plate boundaries**: the two plates slip past each other.

The type of plate boundary and the type of crust found on each side of the boundary determines what sort of geologic activity will be found there. We can visit each of these types of plate boundaries on land or at sea.

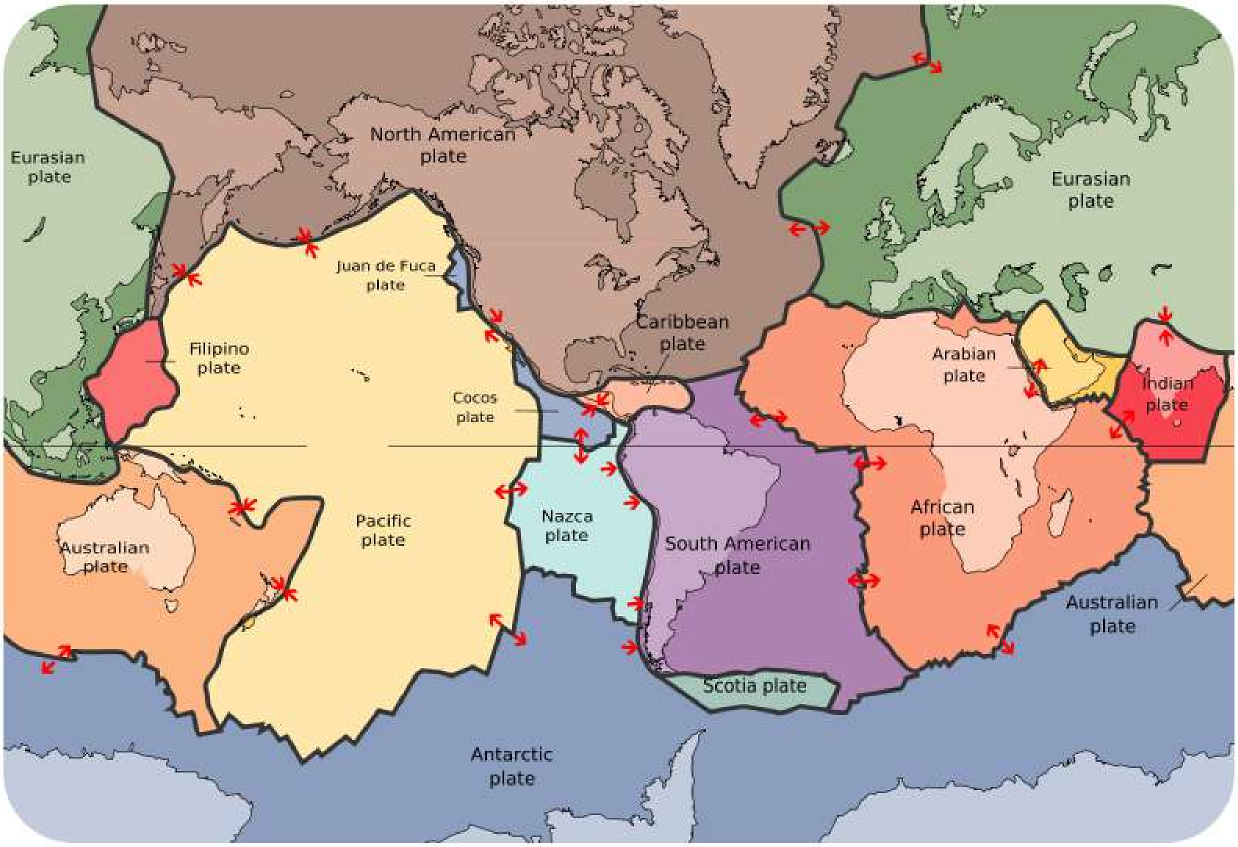



FIGURE 15.3

The lithospheric plates and their names. The arrows show whether the plates are moving apart, moving together, or sliding past each other.

## Summary

- The plate in plate tectonics is a large chunk of lithosphere that can carry continental crust, oceanic crust, or some of each.
- Plates can be identified by the locations of earthquake epicenters. At the boundaries of plates are mid-ocean ridges, trenches, and large faults.
- Plates move by seafloor spreading, which is driven by mantle convection.
- Plates meet at plate boundaries. The three types are divergent, convergent, and transform.

## Making Connections

MEDIA

Click image to the left for more content.

### Practice

Use this resource to answer the questions that follow.

http://science.discovery.com/videos/100-greatest-discoveries-shorts-plate-tectonics.html

1. Which two plates meet in California?
2. What occurs where two plates meet?
3. What is an ocean ridge?
4. What is a strike-slip fault?
5. What occurs at strike-slip faults?
6. What evidence can be seen in California of the movement of the plates?

### Review

1. How does the topography of the seafloor give evidence for seafloor spreading?
2. How does seafloor spreading fit into the idea that continents move about on Earth's surface?
3. How do convection cells drive the plates around Earth's surface?
4. What are the three types of plate boundaries?

## References

1. Courtesy of NASA. A map of earthquake epicenters, which outline the plates. Public Domain
2. CK-12 Foundation. Mantle convection drives plate tectonics. CC BY-NC 3.0
3. Courtesy of the US Geological Survey. The lithospheric plates and their names. Public Domain

# CONCEPT 16 Minerals

- Describe the characteristics that define minerals.

**Are you a mineral?**

There used to be a TV commercial that said "you are what you eat." If that's true - and to some extent it is - then you are a mineral. Nearly all of our food is salted, and what is salt but the mineral halite? You also wear minerals, play with and on minerals, and admire the beauty of minerals. However, a mineral by definition cannot be organic, so despite what you heard on TV, you aren't what you eat!

## What is a Mineral?

Minerals are everywhere! Scientists have identified more than 4,000 minerals in Earth's crust, although the bulk of the planet is composed of just a few.

A **mineral** possesses the following qualities:

- It must be solid.
- It must be crystalline, meaning it has a repeating arrangement of atoms.
- It must be naturally occurring.
- It must be inorganic.
- It must have a specific chemical composition.

Minerals can be identified by their physical properties, such as hardness, color, luster (shininess), and odor. The most common laboratory technique used to identify a mineral is X-ray diffraction (XRD), a technique that involves shining an X-ray light on a sample, and observing how the light exiting the sample is bent. XRD is not useful in the field, however.

The definition of a mineral is more restricted than you might think at first. For example, glass is made of sand, which is rich in the mineral quartz. But glass is not a mineral, because it is not crystalline. Instead, glass has a random assemblage of molecules. What about steel? Steel is made by mixing different metal minerals like iron, cobalt, chromium, vanadium, and molybdenum, but steel is not a mineral because it is made by humans and therefore is not naturally occurring. However, almost any rock you pick up is composed of minerals. Below we explore the qualities of minerals in more detail.

### Crystalline Solid

Minerals are "crystalline" solids. A **crystal** is a solid in which the atoms are arranged in a regular, repeating pattern. Notice that in **Figure** 16.1 the green and purple spheres, representing sodium and chlorine, form a repeating pattern. In this case, they alternate in all directions.

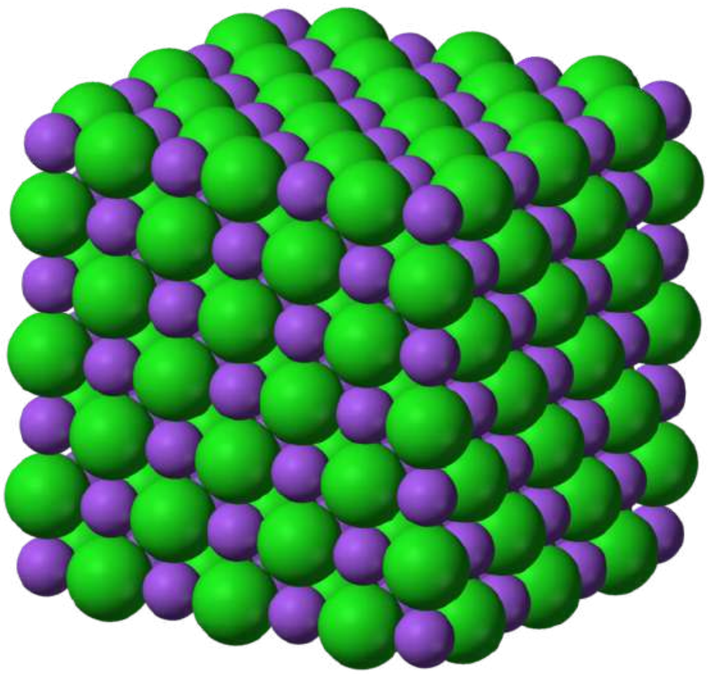


FIGURE 16.1
Sodium ions (purple balls) bond with chloride ions (green balls) to make table salt (halite). All of the grains of salt that are in a salt shaker have this crystalline structure.

### Inorganic

Organic substances are the carbon-based compounds made by living creatures and include proteins, carbohydrates, and oils. Inorganic substances have a structure that is not characteristic of living bodies. Coal is made of plant and animal remains. Is it a mineral? Coal is a classified as a sedimentary rock, but is not a mineral.

### Naturally Occurring

Minerals are made by natural processes, those that occur in or on Earth. A diamond created deep in Earth's crust is a mineral, but a diamond made in a laboratory by humans is not. Be careful about buying a laboratory-made "diamond" for jewelry. It may look pretty, but it's not a diamond and is not technically a mineral.

### Chemical Composition

Nearly all (98.5%) of Earth's crust is made up of only eight elements – oxygen, silicon, aluminum, iron, calcium, sodium, potassium, and magnesium – and these are the elements that make up most minerals.

All minerals have a specific chemical composition. The mineral silver is made up of only silver atoms and diamond is made only of carbon atoms, but most minerals are made up of **chemical compounds**. Each mineral has its own chemical formula. Table salt (also known as halite), pictured in **Figure** 16.1, is NaCl (sodium chloride). Quartz is always made of two oxygen atoms (red) bonded to a silicon atom (grey), represented by the chemical formula $SiO_2$ ( **Figure** 16.2).

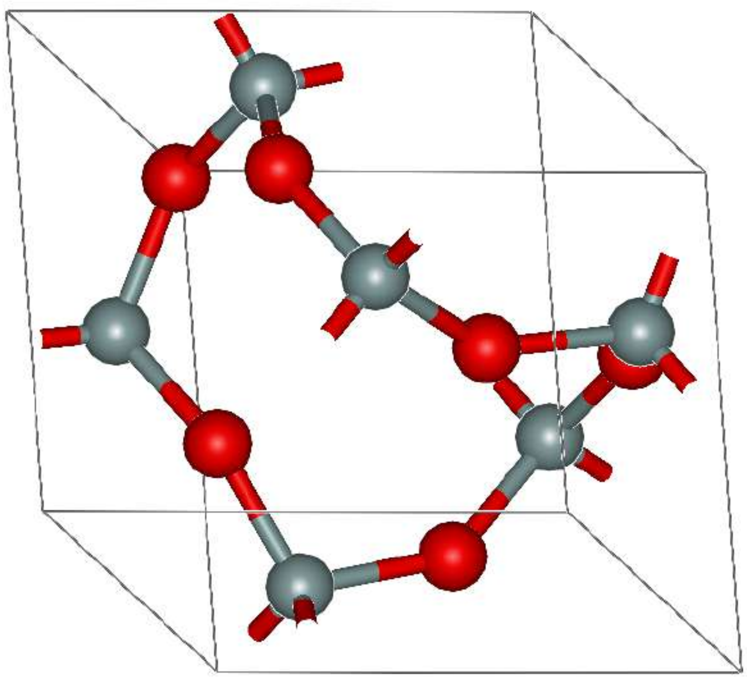


FIGURE 16.2

Quartz is made of two oxygen atoms (red) bonded to a silicon atom (grey).

In nature, things are rarely as simple as in the lab, and so it should not come as a surprise that some minerals have a range of chemical compositions. One important example in Earth science is olivine, which always has silicon and oxygen as well as some iron and magnesium, $(Mg, Fe)_2SiO_4$.

### Physical Properties

Some minerals can be identified with little more than the naked eye. We do this by examining the physical properties of the mineral in question, which include:

- Color: the color of the mineral.
- Streak: the color of the mineral's powder (this is often different from the color of the whole mineral).
- Luster: shininess.
- Density: mass per volume, typically reported in "specific gravity," which is the density relative to water.
- Cleavage: the mineral's tendency to break along planes of weakness.
- Fracture: the pattern in which a mineral breaks.
- Hardness: which minerals it can scratch and which minerals can scratch it.

How physical properties are used to identify minerals is described in the concept "Mineral Identification."

### Summary


- A mineral is an inorganic, crystalline solid.
- A mineral is formed through natural processes and has a definite chemical composition.
- Minerals can be identified by their characteristic physical properties, such as crystalline structure, hardness, density, breakage, and color.


### Practice

Use this resource to answer the questions that follow.

http://library.thinkquest.org/J002289/minerals.html

1. What are minerals?

2. How many minerals have been found?

3. List three examples of gems.

4. How are minerals identified?

5. What is the hardest mineral?

6. What is slate used for?

### Review

1. Is coal a mineral? Why or why not?

2. Is a diamond made in a laboratory a mineral? Why or why not?

3. How does the internal structure of a mineral reflect in its physical appearance?

## References


1. Ben Mills (User:Benjah-bmm27/Wikimedia Commons). Halite crystals form from sodium and chloride ions. Public Domain
2. User:Materialscientist/Wikipedia. Quartz is made of two oxygen atoms bonded to a silicon atom. Public Domain

# CONCEPT 17 Mineral Identification

- Explain how minerals are identified by their physical characteristics.

**Can you identify this mineral?**

Check out the mineral above. How would you figure out what kind of mineral it is? By color? Shape? Whether it's shiny or dull? Are there lines (striations) running across the minerals? This mineral has shiny, gold, cubic crystals with striations, and smells like sulfur. What is it? In this concept, we will discuss how to identify a mineral as one would "in the field," that is, without using fancy lab equipment.

## How Are Minerals Identified?

There are a multitude of laboratory and field techniques for identifying minerals. While a mineralogist might use a high-powered microscope to identify some minerals, or even techniques like x-ray diffraction, most are recognizable using physical properties.

The most common field techniques put the observer in the shoes of a detective, whose goal it is to determine, by process of elimination, what the mineral in question is. The process of elimination usually includes observing things like color, hardness, smell, solubility in acid, streak, striations and/or cleavage.

Check out the mineral in the opening image. What is the mineral's color? What is its shape? Are the individual crystals shiny or dull? Are there lines (striations) running across the minerals? In this concept, the properties used to identify minerals are described in more detail.

## Color, Streak, and Luster

### Color

Color may be the first feature you notice about a mineral, but color is not often important for mineral identification. For example, quartz can be colorless, purple (amethyst), or a variety of other colors depending on chemical impurities **Figure** 17.1.

FIGURE 17.1
Purple quartz, known as amethyst, and clear quartz are the same mineral despite the different colors.

### Streak

Streak is the color of a mineral's powder, which often is not the same color as the mineral itself. Many minerals, such as the quartz in the **Figure** 17.1, do not have streak.

Hematite is an example of a mineral that displays a certain color in hand sample (typically black to steel gray, sometimes reddish), and a different streak color (red/brown).

FIGURE 17.2
The streak of hematite across an unglazed porcelain plate is red-brown.

### Luster

**Luster** describes the reflection of light off a mineral's surface. Mineralogists have special terms to describe luster. One simple way to classify luster is based on whether the mineral is metallic or non-metallic. Minerals that are opaque and shiny, such as pyrite, have a metallic luster. Minerals such as quartz have a non-metallic luster. Different types of non-metallic luster are described in **Table** 17.1.

**TABLE 17.1: Six types of non-metallic luster.**

| Luster | Appearance |
| --- | --- |
| Adamantine | Sparkly |
| Earthy | Dull, clay-like |
| Pearly | Pearl-like |
| Resinous | Like resins, such as tree sap |
| Silky | Soft-looking with long fibers |
| Vitreous | Glassy |

### Specific Gravity

**Density** describes how much matter is in a certain amount of space: density = mass/volume.

Mass is a measure of the amount of matter in an object. The amount of space an object takes up is described by its volume. The density of an object depends on its mass and its volume. For example, the water in a drinking glass has the same density as the water in the same volume of a swimming pool.

Gold has a density of about 19 $g/cm^3$; pyrite has a density of about 5 $g/cm^3$ - that's another way to tell pyrite from gold. Quartz is even less dense than pyrite and has a density of 2.7 $g/cm^3$.

The specific gravity of a substance compares its density to that of water. Substances that are more dense have higher specific gravity.

### Hardness

**Hardness** is a measure of whether a mineral will scratch or be scratched. Mohs Hardness Scale, shown in **Table** 17.2, is a reference for mineral hardness.

**TABLE 17.2: Mohs Hardness Scale: 1 (softest) to 10 (hardest).**

| Hardness | Mineral |
| --- | --- |
| 1 | Talc |
| 2 | Gypsum |
| 3 | Calcite |
| 4 | Fluorite |
| 5 | Apatite |
| 6 | Feldspar |
| 7 | Quartz |
| 8 | Topaz |
| 9 | Corundum |
| 10 | Diamond |

With a Mohs scale, anyone can test an unknown mineral for its hardness. Imagine you have an unknown mineral. You find that it can scratch fluorite or even apatite, but feldspar scratches it. You know then that the mineral's hardness is between 5 and 6. Note that no other mineral can scratch diamond.

### Cleavage and Fracture

Breaking a mineral breaks its chemical bonds. Since some bonds are weaker than other bonds, each type of mineral is likely to break where the bonds between the atoms are weaker. For that reason, minerals break apart in characteristic ways.

**Cleavage** is the tendency of a mineral to break along certain planes to make smooth surfaces. Halite ( **Figure** 17.3) breaks between layers of sodium and chlorine to form cubes with smooth surfaces.

FIGURE 17.3
Halite has cubic cleavage.

Mica has cleavage in one direction and forms sheets ( **Figure** 17.4).

FIGURE 17.4
Sheets of mica.

Minerals can cleave into polygons. Magnetite forms octahedrons ( **Figure** 17.5).

One reason gemstones are beautiful is that the cleavage planes make an attractive crystal shape with smooth faces.

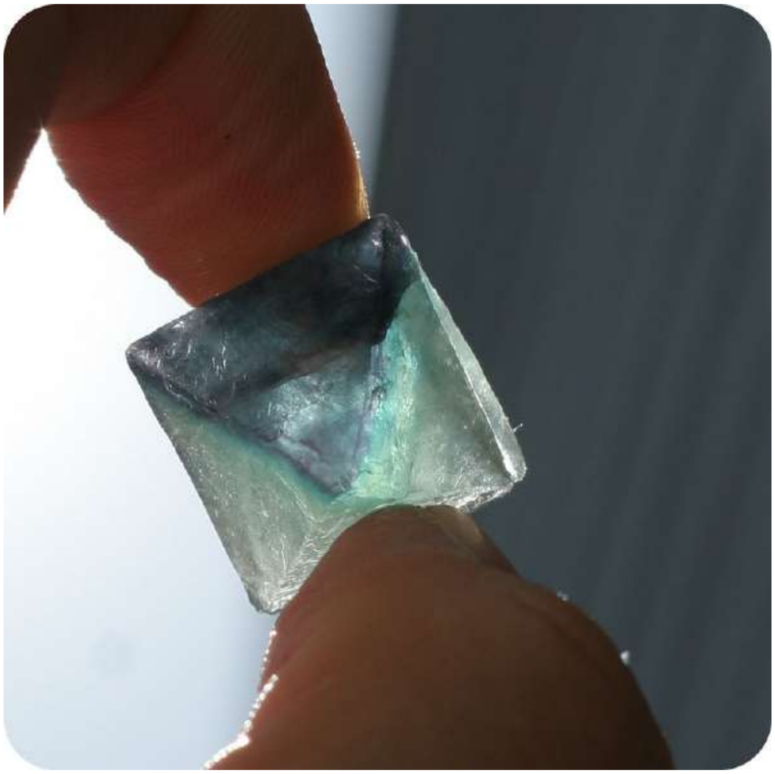


FIGURE 17.5
Fluorite has octahedral cleavage.

**Fracture** is a break in a mineral that is not along a cleavage plane. Fracture is not always the same in the same mineral because fracture is not determined by the structure of the mineral.

Minerals may have characteristic fractures ( **Figure** 17.6). Metals usually fracture into jagged edges. If a mineral splinters like wood, it may be fibrous. Some minerals, such as quartz, form smooth curved surfaces when they fracture.

FIGURE 17.6
Chrysotile has splintery fracture.

### Other Identifying Characteristics

Some minerals have other unique properties, some of which are listed in **Table** 17.3. Can you name a unique property that would allow you to instantly identify a mineral that's been described quite a bit in this concept? (Hint: It is most likely found on your dinner table.)

**TABLE 17.3: Some minerals have unusual properties that can be used for identification.**

| Property | Description | Example of Mineral |
|---|---|---|
| Fluorescence | Mineral glows under ultraviolet light | Fluorite |
| Magnetism | Mineral is attracted to a magnet | Magnetite |
| Radioactivity | Mineral gives off radiation that can be measured with Geiger counter | Uraninite |
| Reactivity | Bubbles form when mineral is exposed to a weak acid | Calcite |
| Smell | Some minerals have a distinctive smell | Sulfur (smells like rotten eggs) |
| Taste | Some minerals taste salty | Halite |

A simple lesson on how to identify minerals is seen in this video: http://www.youtube.com/watch?v=JeFVwqBuYl4 .

## Summary

- Some minerals have a unique property that makes them fairly easy to identify, such as high specific gravity or salty taste.
- Color is not a reliable indicator of mineral type for most minerals, but streak is for certain minerals.
- Cleavage can be a unique and beautiful indicator of mineral type.

## Practice

Use this resource to answer the questions that follow.


MEDIA
Click image to the left for more content.

1. What color streak will pyrite leave on sandpaper?
2. What color streak would real gold leave on sandpaper?
3. List some examples of the different types of quartz.
4. What characteristic do all types of quartz share?
5. What is unique about mica?
6. What is mica used for?

7. What was azurite used for in ancient times?

8. In what colors can calcite be found?

9. What color does green calcite streak?

10. What is galena?

11. How can you tell that fluorite is not a calcite mineral?

12. How many sides does garnet have?

### Review

1. How does color differ from streak and luster?

2. How does cleavage differ from fracture?

3. What's the first thing you should do when trying to identify a mineral? What do you do if you still can't identify it?

## References

1. Left: Stephanie Clifford; Right: Mauro Cateb. . CC BY 2.0
2. CK-12 Foundation. . CC BY-NC 3.0
3. Image copyright Nadezda Boltaca, 2014. . Used under license from Shutterstock.com
4. User: /Wikimedia Commons. . Public Domain
5. Bruce. . CC BY 2.0
6. Courtesy of Andrew Silver, USGS. . Public Domain

# CONCEPT 18 Mineral Formation

- Explain how different types of minerals form.

**Is carbon a girl's best friend?**

Yes! (At least if you think that diamond is a girl's best friend, anyway.) When people think of carbon they think of black dust left over from a fire, but the diamond is just carbon that was squeezed very hard at extremely high pressure. Formed at lower pressure, the carbon mineral is graphite, the mineral that is pencil "lead." Graphite would make a very different sort of ring.

## Mineral Formation

Minerals form in a variety of ways:

- crystallization from magma
- precipitation from ions in solution
- biological activity
- a change to a more stable state as in metamorphism
- precipitation from vapor

### Formation from Magma

Imagine a rock that becomes so hot it melts. Many minerals start out in liquids that are hot enough to melt rocks. **Magma** is melted rock inside Earth, a molten mixture of substances that can be hotter than 1,000°C. Magma cools slowly inside Earth, which gives mineral crystals time to grow large enough to be seen clearly ( **Figure** 18.1).

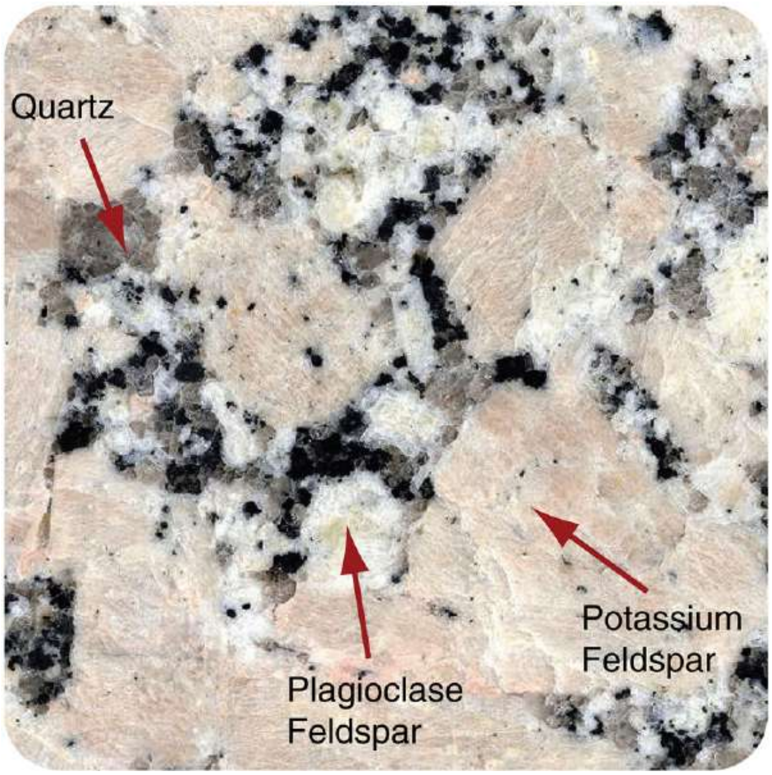



FIGURE 18.1
Granite is rock that forms from slowly cooled magma, containing the minerals quartz (clear), plagioclase feldspar (shiny white), potassium feldspar (pink), and biotite (black).

When magma erupts onto Earth's surface, it is called **lava**. Lava cools much more rapidly than magma. Crystals do not have time to form and are very small. The chemical composition between minerals that form rapidly or slowly is often the same, only their size differs.

Existing rocks may be heated enough so that the molecules are released from their structure and can move around. The molecules may match up with different molecules to form new minerals as the rock cools. This occurs during metamorphism, which will be discussed in the "Metamorphic Rocks" concept.

### Formation from Solutions

Water on Earth, such as the water in the oceans, contains chemical elements mixed into a solution. Various processes can cause these elements to combine to form solid mineral deposits.

#### Minerals from Salt Water

When water evaporates, it leaves behind a solid precipitate of minerals, as shown in **Figure** 18.2.

Water can only hold a certain amount of dissolved minerals and salts. When the amount is too great to stay dissolved in the water, the particles come together to form mineral solids, which sink. Halite easily precipitates out of water, as does calcite. Some lakes, such as Mono Lake in California ( **Figure** 18.3) or The Great Salt Lake in Utah, contain many mineral precipitates.

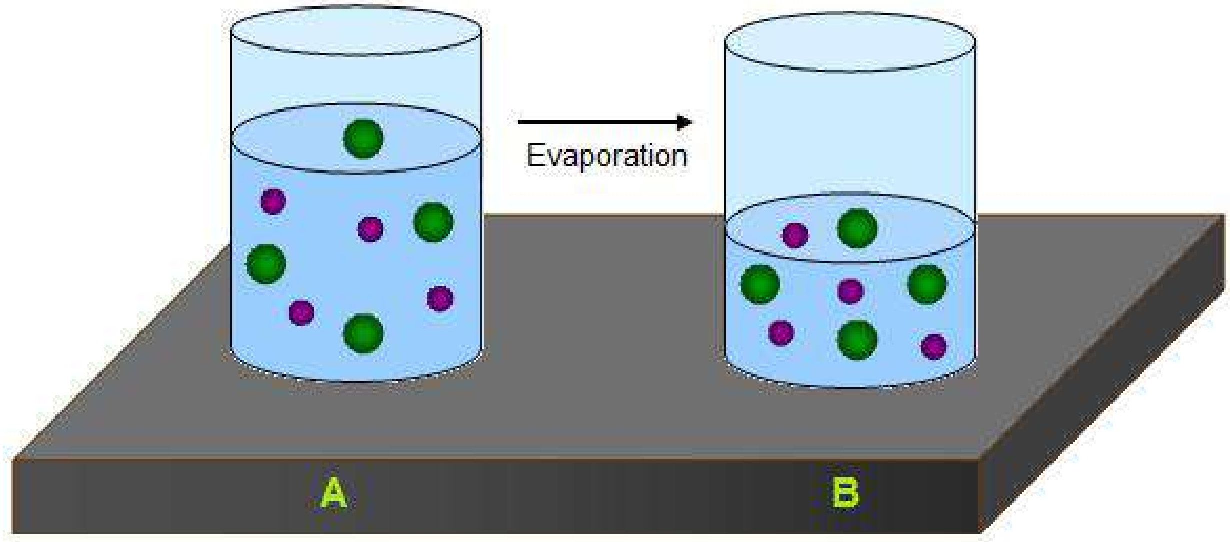



FIGURE 18.2
When the water in glass A evaporates, the dissolved mineral particles are left behind.

FIGURE 18.3
Tufa towers form when calcium-rich spring water at the bottom of Mono Lake bubbles up into the alkaline lake. The tufa towers appear when lake level drops.

### Minerals from Hot Underground Water

Magma heats nearby underground water, which reacts with the rocks around it to pick up dissolved particles. As the water flows through open spaces in the rock and cools, it deposits solid minerals. The mineral deposits that form when a mineral fills cracks in rocks are called **veins** ( **Figure** 18.4).

When minerals are deposited in open spaces, large crystals form ( **Figure** 18.5).

FIGURE 18.4
Quartz veins formed in this rock.

FIGURE 18.5
Amethyst formed when large crystals grew in open spaces inside the rock. These special rocks are called geodes.

### Minerals Under Pressure

In the last several years, many incredible discoveries have been made exploring how minerals behave under high pressure, like rocks experience inside the Earth. If a mineral is placed in a special machine and then squeezed, eventually it may convert into a different mineral. Ice is a classic example of a material that undergoes solid-solid "phase transitions" as pressure and/or temperature is changed. A "phase diagram" is a graph which plots the stability of phases of a compound as a function of pressure and temperature.

A phase diagram for water (ice) is included in the **Figure** 18.6. The phase diagram is split up into 3 main areas for the solid crystalline phase (ice), the liquid phase (water), and the gas phase (water vapor). Notice that increasing pressure lowers the freezing point and raises the boiling point of water. What does that do to the stability conditions of the liquid phase?

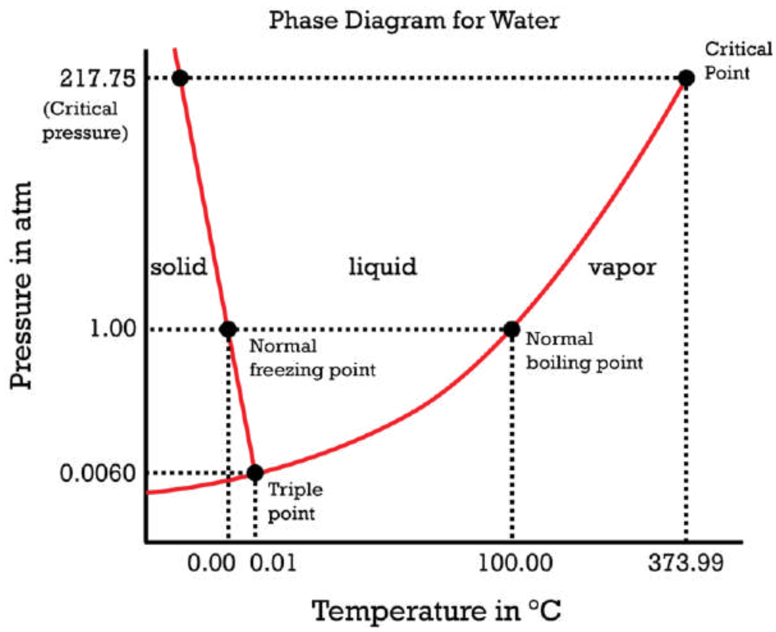



FIGURE 18.6
A sample phase diagram for water.

## Summary

- Minerals form as magma cools.
- Minerals form when they precipitate from hot fluids that have cooled down.
- Minerals form when the concentration of ions gets too great in a fluid.

## Practice

Use this resource to answer the questions that follow.

http://nature.berkeley.edu/classes/eps2//wisc/Lect3.html

1. How do minerals form in water?
2. What crystals are formed from silica-based minerals?
3. What crystals are formed from copper-based minerals?
4. What is a pegmatite?
5. What can magma rich in boron crystallize into?
6. What other gems can be found in magma?

## Review

1. How do minerals form in veins?
2. How do minerals form from cool water?
3. When do large crystals form from magma? When do small crystals form from magma?

## References


1. Kevin Walsh, modified by CK-12 Foundation. Granite is formed from magma, and contains quartz, feldspar, and biotite. CC BY 2.0
2. Rebecca Calhoun. Crystals form when water evaporates. CC BY-NC 3.0
3. Flickr:Zengame. Tufa towers in Mono Lake. CC BY 2.0
4. Image copyright Phon Promwisate, 2014. Picture of a quartz vein in rock. Used under license from Shutterstock.com
5. User:Pseudopanax/Wikipedia. An amethyst geode inside a rock. Public Domain
6. Christopher Auyeung. A phase diagram for water. CC BY-NC 3.0

# CONCEPT 19 Rocks

- Define rock.

**How many different rock types are in this photo?**

A beach or river bed is a good place to see a lot of different rock types since the rocks there represent the entire drainage system. How could you tell how many different rock types were in the photo? What characteristics would you look for?

## What Are Rocks?

A **rock** is a naturally formed, non-living Earth material. Rocks are made of collections of mineral grains that are held together in a firm, solid mass ( **Figure** 19.1).

How is a rock different from a mineral? Rocks are made of minerals. The mineral grains in a rock may be so tiny that you can only see them with a microscope, or they may be as big as your fingernail or even your finger ( **Figure** 19.2).

Rocks are identified primarily by the minerals they contain and by their texture. Each type of rock has a distinctive set of minerals. A rock may be made of grains of all one mineral type, such as quartzite. Much more commonly, rocks are made of a mixture of different minerals. Texture is a description of the size, shape, and arrangement of mineral grains. Are the two samples in **Figure** 19.3 the same rock type? Do they have the same minerals? The same texture?

TABLE 19.1: Properties of Sample 1 and Sample 2

| Sample | Minerals | Texture | Formation | Rock type |
|---|---|---|---|---|

**TABLE 19.1:** (continued)

| Sample | Minerals | Texture | Formation | Rock type |
|---|---|---|---|---|
| Sample 1 | plagioclase, quartz, hornblende, pyroxene | Crystals, visible to naked eye | Magma cooled slowly | Diorite |
| Sample 2 | plagioclase, hornblende, pyroxene | Crystals are tiny or microscopic | Magma erupted and cooled quickly | Andesite |

FIGURE 19.1
The different colors and textures seen in this rock are caused by the presence of different minerals.

FIGURE 19.2
A pegmatite from South Dakota with crystals of lepidolite, tourmaline, and quartz (1 cm scale on the upper left).


FIGURE 19.3
Rock samples.

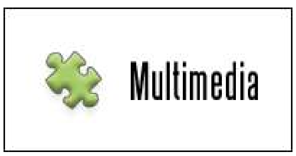
As seen in **Table** 19.1, these two rocks have the same chemical composition and contain mostly the same minerals, but they do not have the same texture. Sample 1 has visible mineral grains, but Sample 2 has very tiny or invisible grains. The two different textures indicate different histories. Sample 1 is a diorite, a rock that cooled slowly from magma (molten rock) underground. Sample 2 is an andesite, a rock that cooled rapidly from a very similar magma that erupted onto Earth's surface.

A few rocks are not made of minerals because the material they are made of does not fit the definition of a mineral. Coal, for example, is made of organic material, which is not a mineral. Can you think of other rocks that are not made of minerals?

## Summary

- Nearly all rocks are made of minerals. A few are made of materials that do not fit the definition of minerals.
- Rocks are typically identified by the minerals they contain and their textures.
- The texture of a rock describes the size, shape, and arrangement of mineral grains and is a reflection of how the rock formed.

## Making Connections

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## Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What is a rock?
2. What type of rock is this?
3. What mineral produces the pink pieces?
4. What mineral produces the white pieces?
5. What mineral produces the black pieces?
6. What is a mineral?

## Review

1. Name a rock type that is not made of minerals and state how a rock could not be made of minerals.

2. Can a rock be made of only one type of mineral, or do rocks need to be made of at least two minerals?
3. Why is texture so important in classifying rock types?

## References


1. User:Woudloper/Wikimedia Commons. Different minerals cause the different colors and textures in this rock. Public Domain
2. James Stuby (User:Jstuby/Wikipedia). This pegmatite contains lepidolite, tourmaline, and quartz. Public Domain
3. (a) User:Roll-Stone/De.Wikipedia; (b) Beatrice Murch. Two different rock samples to be analyzed. (a) Public Domain; (b) CC BY 2.0

# CONCEPT 20 Igneous Rocks

- Describe igneous rocks.
- Learn igneous rock compositions.

**Have you seen igneous rocks in the field?**

Igneous rocks are everywhere! One of the most common igneous rocks that make up the crust is granite. Many mountain ranges are made of granite. The spectacular features of Yosemite Valley, like Half Dome, are granitic. Volcanoes are made of igneous rocks, such as basalt. Igneous rocks are also found where you can't see them. Oceanic crust is mostly basalt and gabbro. The mantle is peridotite.

## Igneous Rocks

Igneous rocks form when **magma** cools and forms crystals. Magma is melted rock. What an igneous rock looks like is determined by two things. One is the composition of the magma. The other is how fast the magma cools. The rate of cooling determines the texture of the rock.

### Composition

Different igneous rocks contain minerals with different compositions. **Mafic** igneous rocks contain mafic minerals. Mafic minerals are dense and dark in color. They typically contain iron and magnesium; they are low in silica. Olivine and pyroxene are mafic minerals.

**Felsic** igneous rocks contain felsic minerals. They typically contain aluminum and sodium; they are high in silica. Quartz and potassium feldspar are felsic minerals. Minerals and rocks with a composition in between mafic and felsic are called intermediate.

## Vocabulary

- **felsic**: Minerals that are light in color and relatively low in density.
- **mafic**: Minerals that are dark in color and relatively dense.
- **magma**: Melted rock.

## Summary

- Magma cools to form igneous rocks. Two factors determine what type of rock forms.
- The composition of the magma determines if the rock is mafic, felsic, or intermediate.
- The rate the magma cools determines the texture of the rock.

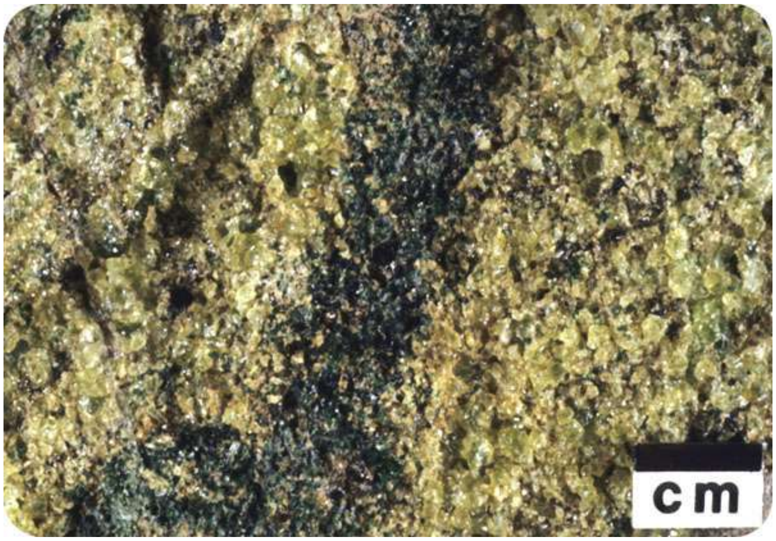



FIGURE 20.1
Olivine is the green mineral, pyroxene is the black mineral.

FIGURE 20.2
Potassium feldspar is the pink mineral, plagioclase feldspar is the white mineral, and quartz is the gray mineral.

## Practice

Use the resource below to answer the questions that follow.

- **What are Igneous Rocks?** at http://video.about.com/geology/What-Are-Igneous-Rocks-.htm (2:24)

1. How do igneous rocks form?
2. What is magma?

3. What are plutonic rocks?
4. How are extrusive rocks formed?
5. How are igneous rocks classified?
6. What is granite? Where is it used?

### Review

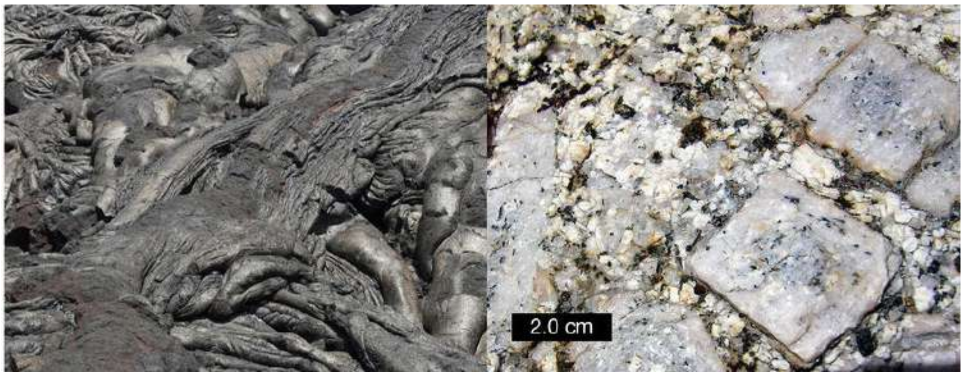
1. How does an igneous rock form?
2. How do mafic and felsic minerals and rocks differ from each other?
3. What two factors determine what type of rock a magma will form?

## References

1. User:Omphacite/Wikimedia Commons. Olivine and pyroxene are mafic igneous rocks. Public Domain
2. Kevin Walsh. Feldspar and quartz are felsic igneous rocks. CC BY 2.0

# CONCEPT 21 Intrusive and Extrusive Igneous Rocks

- Compare and contrast intrusive and extrusive igneous rock.




**Are these both igneous rocks?**

These rocks don't even look like they're the same type! They are, at least in the same way that fish and mice are both vertebrates. They both cooled from magma, but the similarities end there. Can you tell what's different?

## Cooling

Igneous rocks cool from magma. The appearance of the rock is created by the composition of the magma. It is also determined by the rate that the magma cools. If the magma cools deep underground, it cools slowly. If the magma cools at or very near the surface, it cools quickly. This results in two different rock types. The rock types can be told apart by the size of their crystals. The size of the crystals creates the texture of the rock.

### Intrusive Igneous Rocks

**Intrusive** igneous rocks cool underground. Deep in the crust, magma cools slowly. Slow cooling gives crystals a chance to grow. Intrusive igneous rocks have relatively large crystals that are easy to see. Intrusive igneous rocks are also called plutonic. A **pluton** is an igneous rock body that forms within the crust.

Granite is the most common intrusive igneous rock. Pictured below are four types of intrusive rocks ( **Figure** 21.1).

Geological processes have brought some igneous rocks to the surface. Pictured below is a landscape in California's Sierra Nevada Mountains made of granite that has been raised to create mountains ( **Figure** 21.2).

### Extrusive Igneous Rocks

**Extrusive** igneous rocks form above the surface. The lava cools quickly as it pours out onto the surface ( **Figure** 21.3). Extrusive igneous rocks cool much more rapidly than intrusive rocks. The rapid cooling time does not allow time for large crystals to form. So igneous extrusive rocks have smaller crystals than igneous intrusive rocks. Extrusive igneous rocks are also called **volcanic rocks**.

Some extrusive igneous rocks cool so rapidly that crystals do not develop at all. These form a glass, such as obsidian. Others, such as pumice, contain holes where gas bubbles were trapped in the lava. The holes make pumice so light


FIGURE 21.1
(A) This granite has more plagioclase feldspar than many granites. (B) Diorite has more dark-colored minerals than granite. (C) Gabbro. (D) Peridotite contains olivine and other mafic minerals.

FIGURE 21.2
California's Sierra Nevada Mountains are intrusive igneous rock exposed at Earth's surface.


FIGURE 21.3
(A) Lava cools to form extrusive igneous rock. The rocks here are basalts. (B) The strange rock formations of Chiricahua National Monument in Arizona are formed of the extrusive igneous rock rhyolite.

that it actually floats in water. The most common extrusive igneous rock is basalt. It is the rock that makes up the ocean floor. Shown below are three types of extrusive igneous rocks ( **Figure** 21.4).


(a) Obsidian is lava that cools so rapidly crystals do not form, creating natural glass.

(b) Pumice contains holes where gas bubbles were trapped in the molten lava, creating vesicular texture. The holes make pumice so light that it can float on water.

(c) The most common extrusive igneous rock is basalt because it makes up most of the seafloor. These are examples of basalt below the South Pacific Ocean.

FIGURE 21.4

Different cooling rate and gas content resulted in these different textures.

## Vocabulary

- **extrusive**: Igneous rocks that form at Earth's surface from rapidly cooling lava.
- **intrusive**: Igneous rocks that form inside the Earth from slowly cooling magma.
- **pluton**: Igneous intrusive rock body that has cooled in the crust.
- **volcanic rock**: Rock that originates in a volcano or volcanic feature.

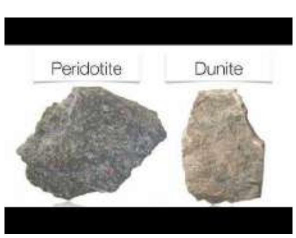
## Summary

- Intrusive igneous rocks cool from magma slowly in the crust. They have large crystals.
- Extrusive igneous rocks cool from lava rapidly at the surface. They have small crystals.
- Texture reflects how an igneous rock formed.

## Practice

Use the resource below to answer the questions that follow.

- **Igneous Rocks** at http://www.youtube.com/watch?v=deC5af9AW6w (5:06)




MEDIA

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1. How are intrusive rocks formed?
2. What size are the crystals in very coarse rocks? Why are they that size?
3. What are the most common coarse rocks?
4. How are extrusive rocks formed?
5. List the three textures for extrusive rocks.
6. Describe rhyolite.
7. Describe pumice.
8. Explain why obsidian appears black.

### Review

1. How do intrusive igneous rocks form? What is another name for these rocks?
2. How do extrusive igneous rocks form? What is another name for these rocks?
3. How can you use texture to determine whether an igneous rock is intrusive or extrusive?

## References

1. (A) Image copyright MARGRIT HIRSCH, 2013; (B) Image copyright Tyler Boyes, 2013; (C) Mark A. Wilson (Department of Geology, The College of Wooster); (D) Image copyright Marcin Sylwia Ciesielski, 2013. Granite, diorite, gabbro, and peridotite are all intrusive igneous rocks. (A, B, D) Used under licenses from Shutterstock.com; (C) Public domain
2. User:Dcrjsr/Wikimedia Commons. The Sierra Nevada Mountains are made of intrusive igneous rock. CC BY 3.0
3. (A) Courtesy of J.D. Griggs, US Geological Survey; (B) Flickr:SonoranDesertNPS. Lava cools to form extrusive igneous rock, and rhyolite formations in Chiricahua National Monument. (A) Public Domain; (B) CC BY 2.0
4. (a) Kevin Walsh (Flickr: kevinzim); (b) User:deltalimatrieste/Wikimedia Commons; (c) Courtesy of the National Oceanic and Atmospheric Administration. Obsidian, pumice, and basalt are extrusive igneous rocks that cool at different rates. (a) CC BY 2.0; (b) Public Domain; (c) Public Domain

# CONCEPT 22 Sedimentary Rocks

- Describe factors that determine the composition of sedimentary rocks.

**What is this material and what created the ripples?**

If you've walked on a sandy beach or on a sand dune, you may have seen ripples like this formed from wind or waves. Sand is small broken pieces of rock that can be moved around. They can also be lithified to become a rock known as sandstone.

## Sediments

Sandstone is one of the common types of sedimentary rocks that form from sediments. There are many other types. Sediments may include:

- fragments of other rocks that often have been worn down into small pieces, such as sand, silt, or clay.
- **organic** materials, or the remains of once-living organisms.
- chemical precipitates, which are materials that get left behind after the water evaporates from a solution.

Rocks at the surface undergo mechanical and chemical weathering. These physical and chemical processes break rock into smaller pieces. Mechanical weathering simply breaks the rocks apart. Chemical weathering dissolves the less stable minerals. These original elements of the minerals end up in solution and new minerals may form. Sediments are removed and transported by water, wind, ice, or gravity in a process called erosion ( **Figure** 22.1). Much more information about weathering and erosion can be found in the chapter Surface Processes and Landforms.

Streams carry huge amounts of sediment ( **Figure** 22.2). The more energy the water has, the larger the particle it can carry. A rushing river on a steep slope might be able to carry boulders. As this stream slows down, it no longer has the energy to carry large sediments and will drop them. A slower moving stream will only carry smaller particles.

FIGURE 22.1
Water erodes the land surface in Alaska's Valley of Ten Thousand Smokes.

FIGURE 22.2
A river dumps sediments along its bed and on its banks.

Sediments are deposited on beaches and deserts, at the bottom of oceans, and in lakes, ponds, rivers, marshes, and swamps. Landslides drop large piles of sediment. Glaciers leave large piles of sediments, too. Wind can only transport sand and smaller particles. The type of sediment that is deposited will determine the type of sedimentary rock that can form. Different colors of sedimentary rock are determined by the environment where they are deposited. Red rocks form where oxygen is present. Darker sediments form when the environment is oxygen poor.

### Summary

- Rocks undergo chemical or mechanical weathering to form smaller pieces.
- Sediments range in size from tiny bits of silt or clay to enormous boulders.
- Sediments are transported by wind, water, ice, or gravity into different environments.

## Practice

Use these resources to answer the questions that follow.

http://www.windows2universe.org/earth/geology/sed_intro.html

1. What percentage of rocks are sedimentary?
2. Where are sedimentary rocks found?
3. What can scientists learn from sedimentary rocks?
4. List and explain each of the types of sedimentary rocks?

http://www.windows2universe.org/earth/geology/sed_clastic.html

5. How is clastic sedimentary rock formed?
6. What holds the sediment together?
7. What is Cathedral Rocked made of?

## Review

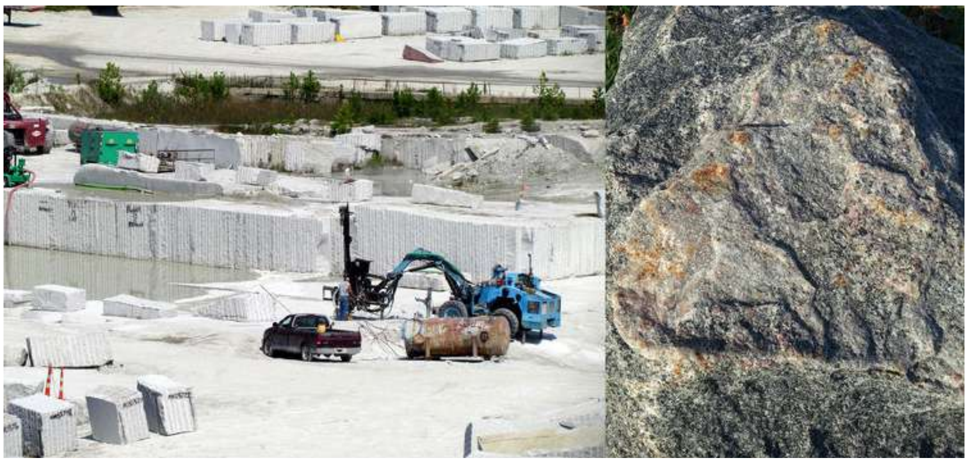
1. What does sediment size indicate about the history of that sediment?
2. How are chemical precipitates different from rocks that form from sediment particles?
3. Why are organic materials considered sediments but not minerals?

# References

1. Courtesy of the National Oceanic and Atmospheric Administration. Water erosion in Alaska's Valley of Ten Thousand Smokes. Public Domain
2. User:ZackClark/Wikimedia Commons. A river dumps sediments along its bed and on its banks. Public Domain

# CONCEPT 23 Weathering and Erosion

- Weathering breaks rocks apart or alters them.
- Erosion moves the pieces of broken rock.



**Why are these rocks different?**

The rock seen on the left is being mined in a quarry. What are the features of the rock? The rock seen on the right is exposed in an outcrop. How do the features of these rocks differ? The rock in the quarry is being exposed to the elements for the first time. It is not weathered. The rock in the outcrop has been weathering for many thousands of years. Can you identify the weathering features?

## Weathering

**Weathering** changes solid rock into pieces. These pieces are called sediments. Sediments are described in the chapter *Earth's Materials and Crust*. Sediments are different sizes of rock particles. Boulders are sediments; so is gravel. At the other end, silt and clay are also sediments. Weathering may also cause the minerals at the Earth's surface to change form. The new minerals that form are stable at the Earth's surface. There are two types of weathering, mechanical and chemical. These are discussed in the next two concepts.

### Weathering Takes Time

No one can watch for millions of years as mountains are built. And no one can watch as those same mountains gradually are worn away. But imagine a new sidewalk or road. The new road is smooth and even. Over hundreds of years, it will completely disappear. What happens to that road over one or two years? What changes would you see ( **Figure** 23.1)? What forces of weathering wear down that road, or rocks or mountains over time?

- Animations of different types of weathering processes can be found here: http://www.geography.ndo.co.uk/animationsweathering.htm# .

FIGURE 23.1
One bad winter can cause a road to weather. The potholes in this road will need to be fixed.

## Erosion

**Erosion** moves sediments after they have formed. The sediments are transported away from the place where they form. There are several agents of erosion. Flowing water moves and deposits sediments. Water erodes far more material than any other erosional agent. Wind is important as an agent of erosion. This is especially true in arid climates. Ice, in glaciers, can erode enormous quantities of sediments. Gravity as a force of erosion pulls material downhill.

Many types of landforms are created by the erosion of sediments. Some are described later in this chapter.

## Deposition

Sediments are deposited in an environment of deposition. This can be a sand dune, beach, lake, river bend, or a great number of other locations. Scientists can figure out the environment of deposition of a sedimentary rock by looking at the size of sediments and the sedimentary features in the rock.

Many types of landforms are created by the deposition of sediments. Some are described later in this chapter.

## Changing Landscapes

Plate tectonics forces work to build huge mountains and other landscapes. Conversely, the forces of weathering gradually wear down those rocks and landscapes. Together with erosion, tall mountains turn into hills and even plains. The Appalachian Mountains along the east coast of North America were once as tall as the Himalayas.

## Vocabulary

- **erosion**: Transport of weathered materials and sediments by water, wind, ice, or gravity.
- **weathering**: Chemical or physical breakdown of rocks, soils, or minerals at Earth's surface.

## Summary

- Weathering breaks down Earth's materials into smaller pieces.
- Erosion transports those pieces to other locations.
- Weathering and erosion modify Earth's surface landscapes over time.

## Practice

Use the resource below to answer the questions that follow.

- **Weathering and Erosion Revision** at http://www.youtube.com/watch?v=HjVSiuj7Lxk (11:02)

MEDIA
Click image to the left for more content.

1. What is erosion?
2. What does erosion require?
3. What happens to water when it freezes? What can this do to rocks?
4. List other causes of erosion.
5. What are lichen? How do they aid weathering?
6. How fast does erosion occur? Why does erosion have such a big effect on landscapes?
7. What do waves do to rock? How does that contribute to erosion?
8. What are sea stacks?
9. As rocks continue to be pounded by waves on a beach what happens to them?
10. How can trees affect erosion?
11. What is weathering? What are the things that cause weathering?
12. What do weathering and erosion work together to do?

### Review

1. What is weathering?
2. How is weathering different from erosion?
3. Why does weathering take so much time?
4. What are some of the agents of erosion?

## References

1. Warren Flick. Weathering leads to potholes in roads. CC BY 2.0

# CONCEPT 24 Metamorphic Rocks

- Explain how metamorphic rocks form.

**Can you decipher the history of this rock?**

The rock in this photo is a banded gneiss. The bands are of different composition, more felsic and more mafic, that separated as a result of heat and pressure. The waviness of the bands also shows how the rock was hot enough to alter but not to melt all the way.

## Metamorphism

Any type of rock – igneous, sedimentary, or metamorphic — can become a metamorphic rock. All that is needed is enough heat and/or pressure to alter the existing rock's physical or chemical makeup without melting the rock entirely. Rocks change during metamorphism because the minerals need to be stable under the new temperature and pressure conditions. The need for stability may cause the structure of minerals to rearrange and form new minerals. Ions may move between minerals to create minerals of different chemical composition. Hornfels, with its alternating bands of dark and light crystals, is a good example of how minerals rearrange themselves during metamorphism. Hornfels is shown in the table for the "Metamorphic Rock Classification" concept.

### Texture

Extreme pressure may also lead to **foliation**, the flat layers that form in rocks as the rocks are squeezed by pressure ( **Figure** 24.1). Foliation normally forms when pressure is exerted in only one direction. Metamorphic rocks may also be non-foliated. Quartzite and marble, shown in the concept "Metamorphic Rock Classification," are non-foliated.

### Types of Metamorphism

The two main types of metamorphism are both related to heat within Earth:

FIGURE 24.1
A foliated metamorphic rock.

1. **Regional metamorphism**: Changes in enormous quantities of rock over a wide area caused by the extreme pressure from overlying rock or from compression caused by geologic processes. Deep burial exposes the rock to high temperatures.
2. **Contact metamorphism**: Changes in a rock that is in contact with magma. The changes occur because of the magma's extreme heat.

## Summary

- Any type of rock - igneous, sedimentary or metamorphic - can become a metamorphic rock.
- Foliated rocks form when rocks being metamorphosed are exposed to pressure in one direction.
- Regional metamorphism occurs over a large area but contact metamorphism occurs when a rock is altered by a nearby magma.

## Practice

Use this resource to answer the questions that follow.

http://library.thinkquest.org/J002289/meta.html

1. How do metamorphic rocks form?

2. Where does the heat come from to change these rocks?

3. What produces the pressure to change these rocks?

4. List the characteristics of metamorphic rocks.

5. List examples of metamorphic rocks.

## Review

1. Why do changes in temperature or pressure cause rocks to change?

2. What are the similarities and differences in conditions that cause regional versus contact metamorphism?

3. What causes foliation in a metamorphic rock? Under what circumstances would you expect this to happen?

## References

1. Steven Coutts. A foliated metamorphic rock. CC BY 2.0

# CONCEPT 25 Divergent Plate Boundaries

- Describe the activity and features of divergent plate boundaries on land.


**What can we see in Western North America?**

When we got off the Atlantis in Iceland a new batch of scientists got on for a different scientific investigation. We're now going to fly to western North America to see a different set of plate tectonic features. Western North America has all three of the different types of plate boundaries and the features that are seen at them.

## Tectonic Features of Western North America

We're on a new trip now. We will start in Mexico, in the region surrounding the Gulf of California, where a divergent plate boundary is rifting Baja California and mainland Mexico apart. Then we will move up into California, where plates on both sides of a transform boundary are sliding past each other. Finally we'll end up off of the Pacific Northwest, where a divergent plate boundary is very near a subduction zone just offshore.

In the **Figure** 25.1 a red bar where seafloor spreading is taking place. A long black line is a transform fault and a black line with hatch marks is a trench where subduction is taking place. Notice how one type of plate boundary transitions into another.

## Plate Divergence on Land

A divergent plate boundary on land rips apart continents ( **Figure** 25.2).

In **continental rifting**, magma rises beneath the continent, causing it to become thinner, break, and ultimately split apart. New ocean crust erupts in the void, ultimately creating an ocean between continents. On either side of the ocean are now two different lithospheric plates. This is how continents split apart.

These features are well displayed in the East African Rift, where rifting has begun, and in the Red Sea, where water is filling up the basin created by seafloor spreading. The Atlantic Ocean is the final stage, where rifting is now separating two plates of oceanic crust.


FIGURE 25.1
This map shows the three major plate boundaries in or near California.

### Baja California

Baja California is a state in Mexico just south of California. In the **Figure** 25.3, Baja California is the long, skinny land mass on the left. You can see that the Pacific Ocean is growing in between Baja California and mainland Mexico. This body of water is called the Gulf of California or, more romantically, the Sea of Cortez. Baja is on the Pacific Plate and the rest of Mexico is on the North American Plate. Extension is causing the two plates to move apart and will eventually break Baja and the westernmost part of California off of North America. The Gulf of California will expand into a larger sea.

Rifting has caused volcanic activity on the Baja California peninsula as seen in the **Figure** 25.4.

Can you relate what is happening at this plate boundary to what happened when Pangaea broke apart?

### Summary

- Where continental rifting takes place, continents are split apart and an ocean may grow or be created between the two new plates.
- Baja California is rifting apart from mainland Mexico.
- Continental rifting can create major ocean basins, like the Atlantic.

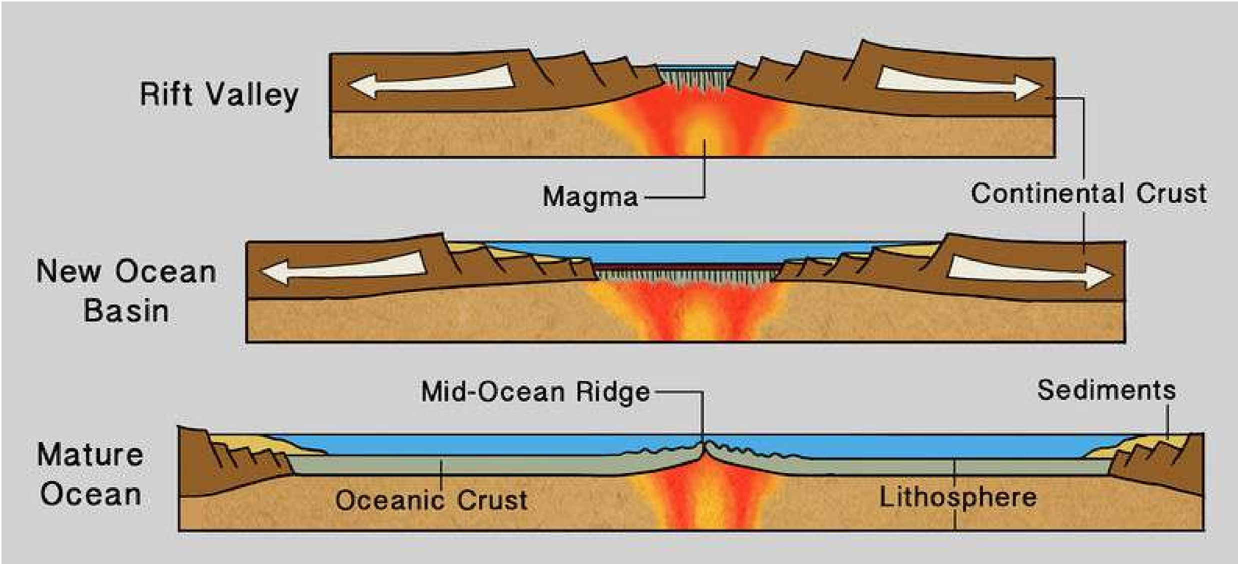



FIGURE 25.2

When plate divergence occurs on land, the continental crust rifts, or splits. This effectively creates a new ocean basin as the pieces of the continent move apart.

## Making Connections


MEDIA

Click image to the left for more content.

## Practice

Use this resource to answer the questions that follow.

http://www.cotf.edu/ete/modules/msese/earthsysflr/plates3.html

1. What are divergent boundaries?
2. What layer is pulled apart?
3. What occurs along the faults on land?
4. What results when the magma reaches the surface?
5. List examples of rift valleys on land.

## Review

1. How is a divergent plate boundary on land different from one in the ocean?

FIGURE 25.3
Baja California is rifting apart from mainland Mexico, as seen in this satellite image.

2. What is happening to the Baja California peninsula?
3. How did continental rifting play into the breakup of Pangaea?

## References


1. Courtesy of US Geological Survey, modified by CK-12 Foundation. Map showing three major plate boundaries around California. Public Domain
2. Laura Guerin. Plate divergence creates a rift valley or a new ocean basin. CC BY-NC 3.0
3. Courtesy of NASA. Baja California is rifting apart from Mainland Mexico. Public Domain
4. Courtesy of NASA. Volcanism in Baja California is evidence of rifting. Public Domain


FIGURE 25.4

Volcanism in Baja California is evidence of rifting.

# CONCEPT 26 Divergent Plate Boundaries in the Oceans

- Describe the activity and features of divergent plate boundaries in the ocean and on land.

**How could you walk between two plates?**

On a bridge! Let's get off the Atlantis in Iceland. It's good to feel solid ground beneath our feet again! While in Iceland we'll take a walk on Leif the Lucky Bridge. Why did we sail across the ocean for this? Iceland is one place where a mid-ocean ridge is found above sea level.

## Plate Divergence in the Ocean

Iceland provides us with a fabulous view of a mid-ocean ridge above sea level ( **Figure** 26.1) As you can see, where plates diverge at a mid-ocean ridge is a rift valley that marks the boundary between the two plates. Basalt lava erupts into that rift valley and forms new seafloor. Seafloor on one side of the rift is part of one plate and seafloor on the other side is part of another plate.

Leif the Lucky Bridge straddles the divergent plate boundary. Look back at the photo at the top. You may think that the rock on the left side of the valley looks pretty much like the rock on the right side. That's true – it's all basalt and it even all has the same magnetic polarity. The rocks on both sides are extremely young. What's different is that the rock one side of the bridge is the youngest rock of the North American Plate while the rock on the other side is the youngest rock on the Eurasian plate.

This is a block diagram of a divergent plate boundary. Remember that most of these are on the seafloor and only in Iceland do we get such a good view of a divergent plate boundary in the ocean.

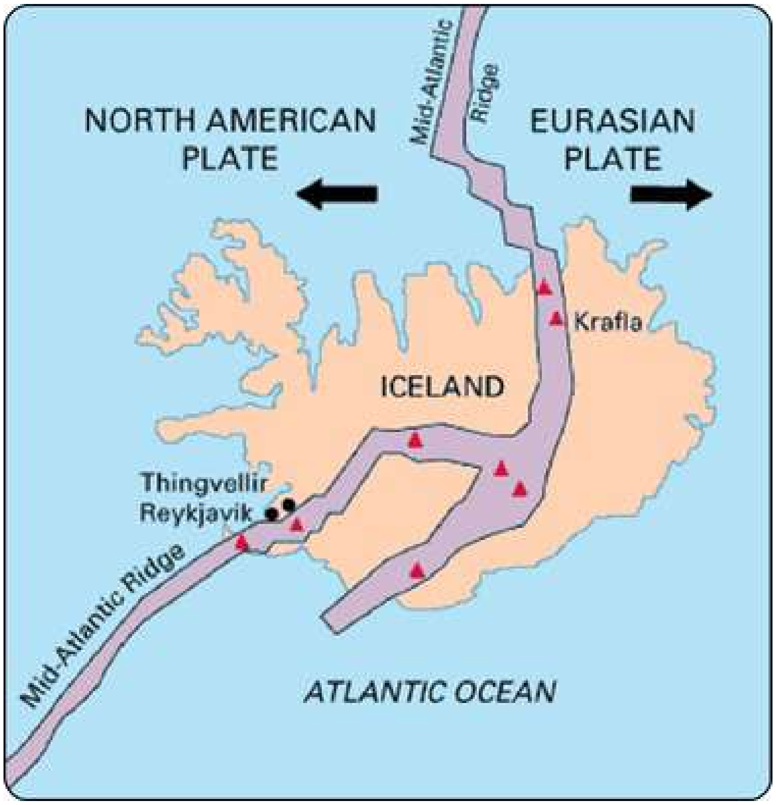



FIGURE 26.1
Iceland is the one location where the ridge is located on land: the Mid-Atlantic Ridge separates the North American and Eurasian plates

### Convection Cells at Divergent Plate Boundaries

Remember that the mid-ocean ridge is where hot mantle material upwells in a convection cell. The upwelling mantle melts due to pressure release to form lava. Lava flows at the surface cool rapidly to become basalt, but deeper in the crust, magma cools more slowly to form gabbro. The entire ridge system is made up of igneous rock that is either extrusive or intrusive. The seafloor is also igneous rock with some sediment that has fallen onto it.

Earthquakes are common at mid-ocean ridges since the movement of magma and oceanic crust results in crustal shaking.

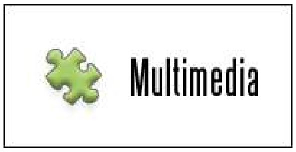
USGS animation of divergent plate boundary at mid-ocean ridge: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Divergent+Boundary&flash_file=divergent&flash_width=500&flash_height=200 .

Divergent plate boundary animation: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/11/AOTM_09_01_Divergent_480.mov .

### Summary

- Oceanic plates diverge at mid-ocean ridges. New seafloor is created in the rift valley between the two plates.
- Lava cools to form basalt at the top of the seafloor. Deeper in the crust the magma cools more slowly to form gabbro.
- Iceland is a location where we can see a mid-ocean ridge above sea level.

### Making Connections




MEDIA
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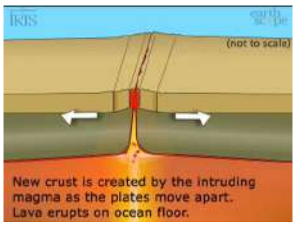
## Practice

Use this resource to answer the questions that follow.




MEDIA
Click image to the left for more content.

1. What causes divergence?
2. How is new crust created?
3. What erupts on the ocean floor?
4. How fast does divergence occur?
5. What is formed at a divergent boundary?

## Review

1. What is the direction of plate motion at a divergent plate boundary?
2. Describe the relationship between the convection cell and volcanism at the mid-ocean ridge.
3. Why is the Leif the Lucky bridge so interesting?

# References

1. Courtesy of US Geological Survey. Iceland is the one location where the Mid-Atlantic Ridge is located on land. Public Domain

# CONCEPT 27 Transform Plate Boundaries

- Describe the activity and features of transform plate boundaries on land and in the ocean.

**What could cause such an enormous scar on the land?**

A transform plate boundary! As we continue up the West Coast, we move from a divergent plate boundary to a transform plate boundary. As in Iceland, where we could walk across a short bridge connecting two continental plates, we could walk from the Pacific Plate to the North American plate across this transform plate boundary. In this image, the San Andreas Fault across central California is the gash that indicates the plate boundary.

## Transform Plate Boundaries

With transform plate boundaries, the two slabs of lithosphere are sliding past each other in opposite directions. The boundary between the two plates is a **transform fault**.

### Transform Faults On Land

Transform faults on continents separate two massive plates of lithosphere. As they slide past each other, they may have massive earthquakes.

The San Andreas Fault in California is perhaps the world's most famous transform fault. Land on the west side is moving northward relative to land on the east side. This means that Los Angeles is moving northward relative to Palm Springs. The San Andreas Fault is famous because it is the site of many earthquakes, large and small. ( **Figure** 27.1).

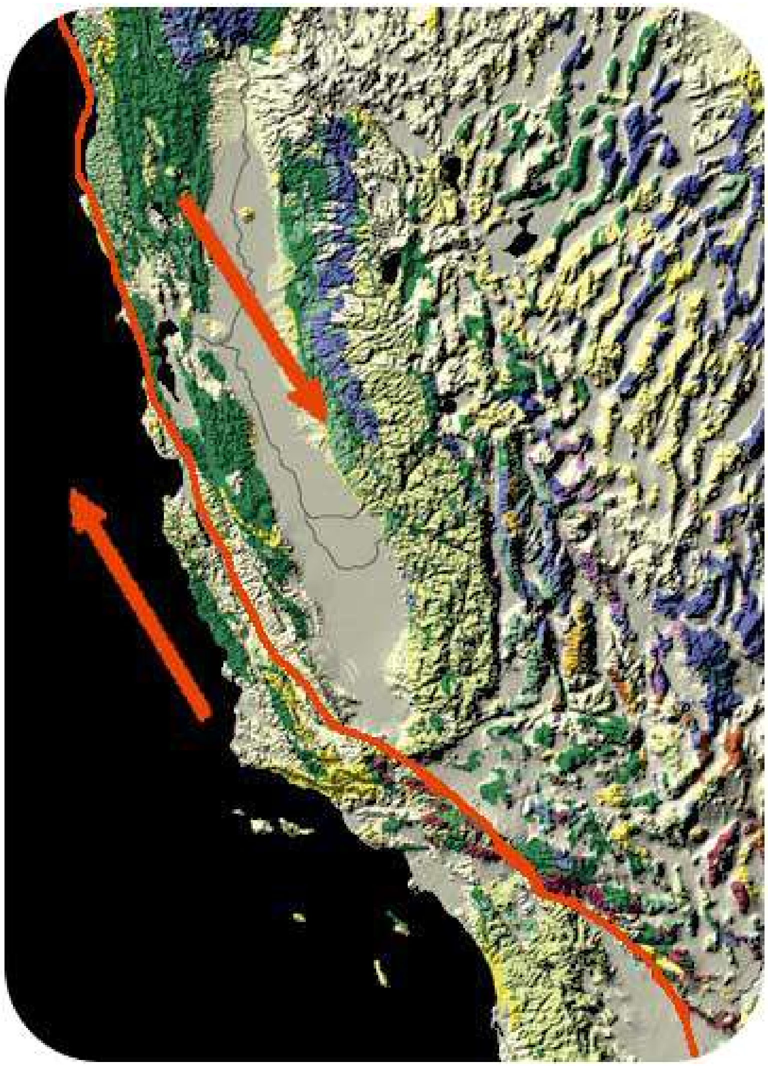


FIGURE 27.1
At the San Andreas Fault in California, the Pacific Plate is sliding northeast relative to the North American plate, which is moving southwest. At the northern end of the picture, the transform boundary turns into a subduction zone.

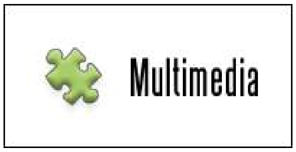
Transform plate boundaries are also found in the oceans. They divide mid-ocean ridges into segments. In the diagram of western North America, the mid-ocean ridge up at the top, labeled the Juan de Fuca Ridge, is broken apart by a transform fault in the oceans. A careful look will show that different plates are found on each side of the ridge: the Juan de Fuca plate on the east side and the Pacific Plate on the west side.

### Summary

- A transform plate boundary divides two plates that are moving in opposite direction from each other.

- On land, transform faults are the site of massive earthquakes because they are where large slabs of lithosphere slide past each other.
- Transform faults in the oceans break mid-ocean ridges into segments.

### Making Connections




MEDIA

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### Practice

Use this resource to answer the questions that follow.

http://www.learner.org/interactives/dynamicearth/slip3.html

1. Describe the motion of transform boundaries.
2. What is a fault?
3. What do transform boundaries produce?
4. Explain a strike-slip fault.
5. What is the best studied fault?
6. What two plates make this boundary?
7. Which direction are each of these plates moving?

### Review

1. What is the direction of plate motion at a transform plate boundary?
2. Why are transform faults on continents prone to massive earthquakes?
3. How do transform faults in the oceans compare with those on land?

## References

1. Courtesy of Kate Barton, David Howell, and Joe Vigil/US Geological Survey. Map of the San Andreas Fault. Public Domain

# CONCEPT 28 Ocean-Continent Convergent Plate Boundaries

- Describe the activity and features of convergent plate boundaries where an oceanic plate meets a continental plate.


**What do you see at an ocean-continent convergent boundary?**

We continue our field trip up the West Coast. Just offshore from Washington, Oregon, and Northern California is a subduction zone, where the Juan de Fuca Plate is sinking into the mantle. The Juan de Fuca Plate is being created at a spreading center, the Juan de Fuca Ridge. Let's see the results of subduction of the Juan de Fuca Plate.

## Convergent Plate Boundaries

When two plates converge, what happens depends on the types of lithosphere that meet. The three possibilities are oceanic crust to oceanic crust, oceanic crust to continental crust, or continental crust to continental crust. If at least one of the slabs of lithosphere is oceanic, that oceanic plate will plunge into the trench and back into the mantle. The meeting of two enormous slabs of lithosphere and subduction of one results in magma generation and earthquakes. If both plates meet with continental crust, there will be mountain building. Each of the three possibilities is discussed in a different concept.

In this concept we look at subduction of an oceanic plate beneath a continental plate in the Pacific Northwest.

## Ocean-Continent Convergence

When oceanic crust converges with continental crust, the denser oceanic plate plunges beneath the continental plate. This process, called **subduction**, occurs at the oceanic trenches. The entire region is known as a **subduction zone**. Subduction zones have a lot of intense earthquakes and volcanic eruptions. The subducting plate causes melting in the mantle above the plate. The magma rises and erupts, creating volcanoes. These coastal volcanic mountains are found in a line above the subducting plate ( **Figure** 28.1). The volcanoes are known as a **continental arc**.

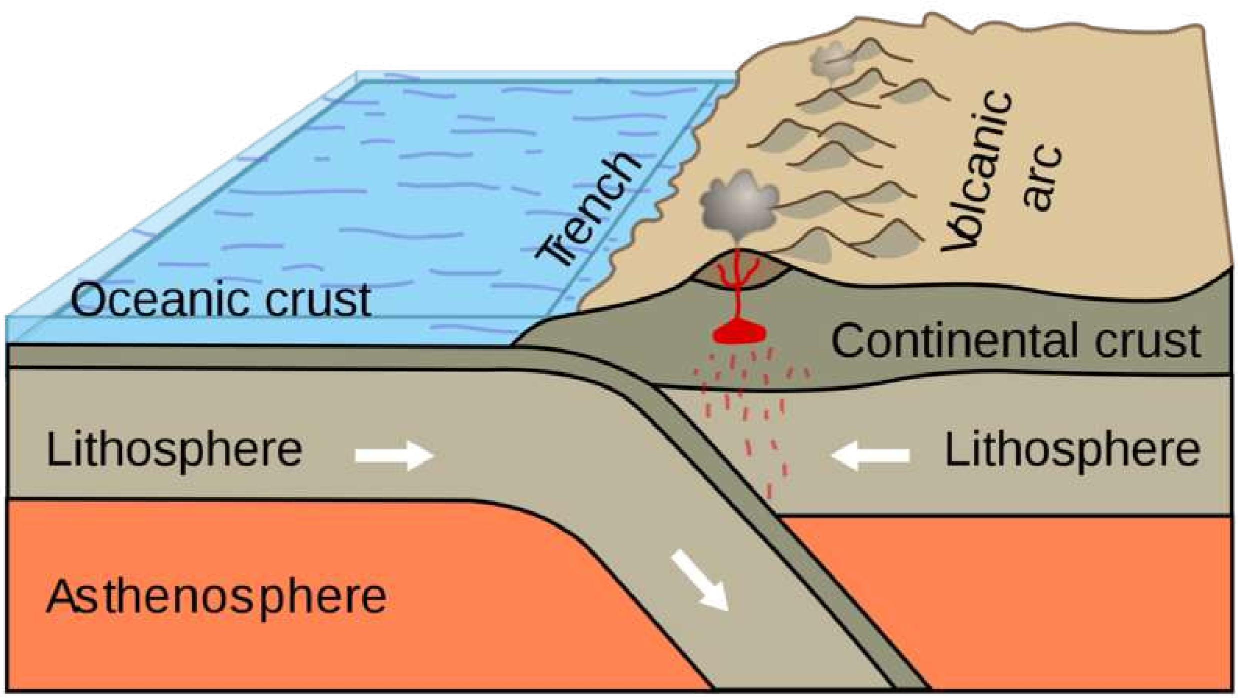



FIGURE 28.1

Subduction of an oceanic plate beneath a continental plate causes earthquakes and forms a line of volcanoes known as a continental arc.

The movement of crust and magma causes earthquakes. A map of earthquake epicenters at subduction zones is found here: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_earthquakessubduction.html .

This animation shows the relationship between subduction of the lithosphere and creation of a volcanic arc: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_subduction.html .

Remember that the mid-ocean ridge is where hot mantle material upwells in a convection cell. The upwelling mantle melts due to pressure release to form lava. Lava flows at the surface cool rapidly to become basalt, but deeper in the crust, magma cools more slowly to form gabbro. The entire ridge system is made up of igneous rock that is either extrusive or intrusive. The seafloor is also igneous rock with some sediment that has fallen onto it.

### Cascades Volcanoes

The volcanoes of northeastern California — Lassen Peak, Mount Shasta, and Medicine Lake volcano — along with the rest of the Cascade Mountains of the Pacific Northwest, are the result of subduction of the Juan de Fuca plate beneath the North American plate ( **Figure** 28.2). The Juan de Fuca plate is created by seafloor spreading just offshore at the Juan de Fuca ridge.

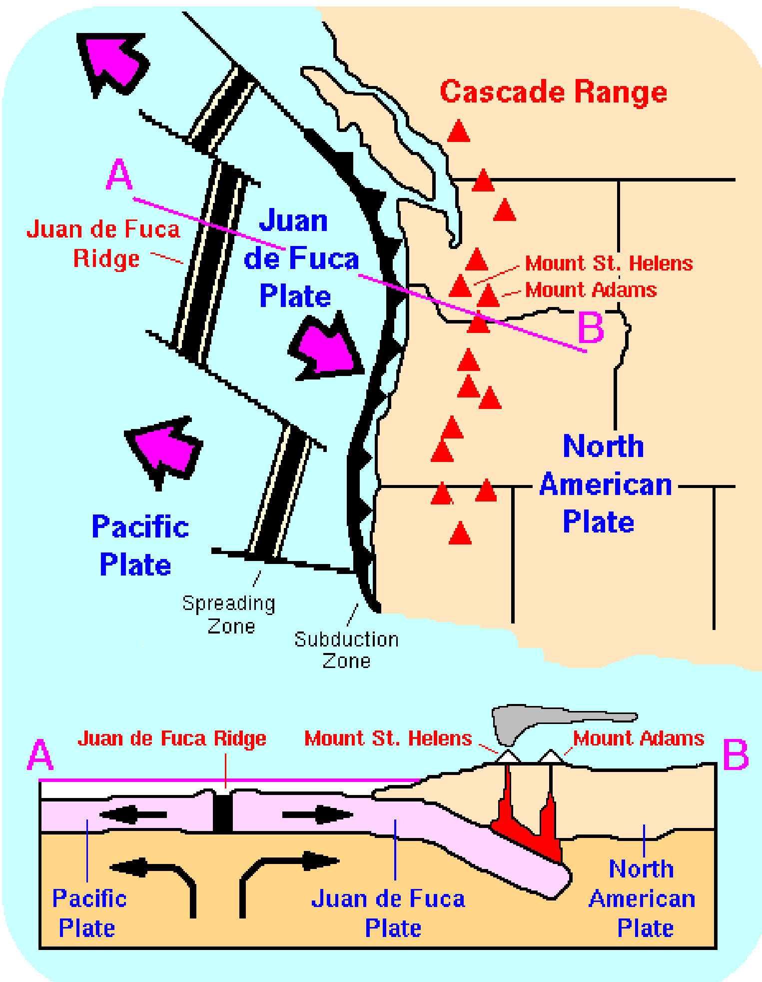



FIGURE 28.2
The Cascade Mountains of the Pacific Northwest are a continental arc.

### Intrusions at a Convergent Boundary

If the magma at a continental arc is felsic, it may be too viscous (thick) to rise through the crust. The magma will cool slowly to form granite or granodiorite. These large bodies of intrusive igneous rocks are called **batholiths**, which may someday be uplifted to form a mountain range. California has an ancient set of batholiths that make up the Sierra Nevada mountains ( **Figure** 28.3).

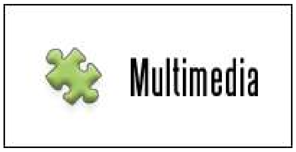
FIGURE 28.3
The Sierra Nevada batholith cooled beneath a volcanic arc roughly 200 million years ago. The rock is well exposed here at Mount Whitney. Similar batholiths are likely forming beneath the Andes and Cascades today.

An animation of an ocean continent plate boundary is seen here: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/11/AOTM_09_01_Convergent_480.mov .

### Summary

- When two plates come towards each other they create a convergent plate boundary.
- The plates can meet where both have oceanic crust or both have continental crust, or they can meet where one has oceanic and one has continental.
- Dense oceanic crust will subduct beneath continental crust or a less dense slab of oceanic crust.
- The oceanic plate subducts into a trench, resulting in earthquakes. Melting of mantle material creates volcanoes at the subduction zone.
- If the magma is too viscous to rise to the surface it will become stuck in the crust to create intrusive igneous rocks.

### Making Connections




MEDIA
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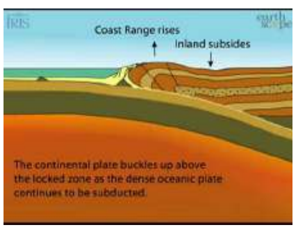
## Practice

Use these resources to answer the questions that follow.

http://www.nature.nps.gov/geology/usgsnps/pltec/converge.html

1. Describe a subduction zone.
2. What forms this subduction zone?
3. How far does the subducting oceanic plate descend?
4. What is formed on the continental plate?
5. Where can an example of this plate boundary be found?

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6. What is a locked zone?
7. What is produced when the locked zone is released?

## Review

1. What is the direction of plate motion at a convergent plate boundary?
2. Describe the relationship between the convection cell and subduction at a trench.
3. Subduction is sometimes called crustal recycling. Why do you think this is the case?
4. What happens if magma is too viscous to rise through the crust to erupt at the surface?

# References

1. User:Booyabazooka/Wikipedia. Subduction of an oceanic plate beneath a continental plate causes earthquakes and forms a line of volcanoes known as a continental arc. Public Domain
2. Courtesy of US Geological Survey. The Cascade Mountains of the Pacific Northwest are a continental arc. Public Domain
3. User:Geographer/Wikipedia. Picture of Mount Whitney, which formed from the Sierra Nevada batholith cooling beneath a volcanic arc. CC BY 1.0

# CONCEPT 29 Continent-Continent Convergent Plate Boundaries

- Describe the activity and features of convergent plate boundaries where two continental plates come together.

**What do you see at a continent-continent convergent plate boundary?**

Nowhere along the west coast of North America is there a convergent plate boundary of this type at this time. Why are there no continent-continent convergent boundaries in western North America? The best place to see two continental plates converging is in the Himalaya Mountains, the mountains that are the highest above sea level on Earth.

## Continent-Continent Convergence

Continental plates are too buoyant to subduct. What happens to continental material when it collides? It has nowhere to go but up!

Continent-continent convergence creates some of the world's largest mountains ranges. Magma cannot penetrate this thick crust, so there are no volcanoes, although the magma stays in the crust. Metamorphic rocks are common because of the stress the continental crust experiences. With enormous slabs of crust smashing together, continent-continent collisions bring on numerous and large earthquakes.

A short animation of the Indian Plate colliding with the Eurasian Plate: http://www.scotese.com/indianim.htm .

An animation of the Himalayas rising: http://www.youtube.com/watch?v=ep2_axAA9Mw .

The Appalachian Mountains along the eastern United States are the remnants of a large mountain range that was created when North America rammed into Eurasia about 250 million years ago. This was part of the formation of Pangaea.

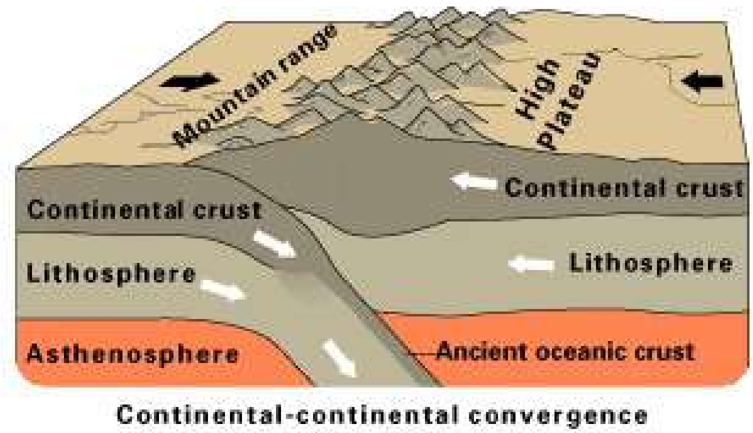


FIGURE 29.1
A diagram of two sections of continental crust converging.

## Summary

- Continental crust is too buoyant to subduct. If the two plates that meet at a convergent plate boundary both consist of continental crust, they will smash together and push upwards to create mountains.
- Large slabs of lithosphere smashing together create large earthquakes.
- The activity at continent-continent convergences does not take place in the mantle, so there is no melting and therefore no volcanism.
- The amazing Himalaya Mountains are the result of this type of convergent plate boundary.
- Old mountain ranges, such as the Appalachian Mountains, resulted from ancient convergence when Pangaea came together.

## Practice

Use these resources to answer the questions that follow.

http://www.nature.nps.gov/geology/usgsnps/pltec/converge.html

1. What happens when two continental plates converge?

2. What is the result of this convergence?

http://pubs.usgs.gov/gip/dynamic/himalaya.html

3. Where are the Himalaya Mountains?

4. When were the Himalayas formed?

5. When did India ram into Asia?

6. How fast are the Himalayas rising?

## Review

1. Compare and contrast the features of a continent-continent convergent plate boundary with the features of an ocean-continent convergent plate boundary.

2. What causes mountain ranges to rise in this type of plate boundary?

3. Why are there earthquakes but not volcanoes in this type of plate boundary?

## References

1. Courtesy of the US Geological Survey. Diagram of continent-continent convergence. Public Domain

# CONCEPT 30 Intraplate Activity

- Describe and explain volcanic activity that occurs within oceanic and continental plates.


**What would you think if you heard that all geological activity does NOT take place at plate boundaries?**

These photos of fabulous geological activity are going to rock your world. Why? After all of these concepts in which you learned that volcanoes and earthquakes are located around plate boundaries, this last concept in Plate Tectonics doesn't quite fit. These volcanoes are located away from plate boundaries. Two such locations are Hawaii and Yellowstone. Yellowstone is in the western U.S. and Hawaii is in the central Pacific.

## Intraplate Activity

A small amount of geologic activity, known as **intraplate activity**, does not take place at plate boundaries but within a plate instead. Mantle plumes are pipes of hot rock that rise through the mantle. The release of pressure causes melting near the surface to form a **hotspot**. Eruptions at the hotspot create a volcano.

Hotspot volcanoes are found in a line ( **Figure** 30.1). Can you figure out why? *Hint*: The youngest volcano sits above the hotspot and volcanoes become older with distance from the hotspot.

An animation of the creation of a hotspot chain is seen here: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_hawaii.html .

### Intraplate Activity in the Oceans

The first photo above is of a volcanic eruption in Hawaii. Hawaii is not in western North America, but is in the central Pacific ocean, near the middle of the Pacific Plate.

The Hawaiian Islands are a beautiful example of a hotspot chain in the Pacific Ocean. Kilauea volcano lies above the Hawaiian hotspot. Mauna Loa volcano is older than Kilauea and is still erupting, but at a slower rate. The islands get progressively older to the northwest because they are further from the hotspot. This is because the Pacific Plate is moving toward the northwest over the hotspot. Loihi, the youngest volcano, is still below the sea surface.

Since many hotspots are stationary in the mantle, geologists can use some hotspot chains to tell the direction and the speed a plate is moving ( **Figure** 30.2). The Hawaiian chain continues into the Emperor Seamounts. The bend in the chain was caused by a change in the direction of the Pacific Plate 43 million years ago. Using the age and distance of the bend, geologists can figure out the speed of the Pacific Plate over the hotspot.

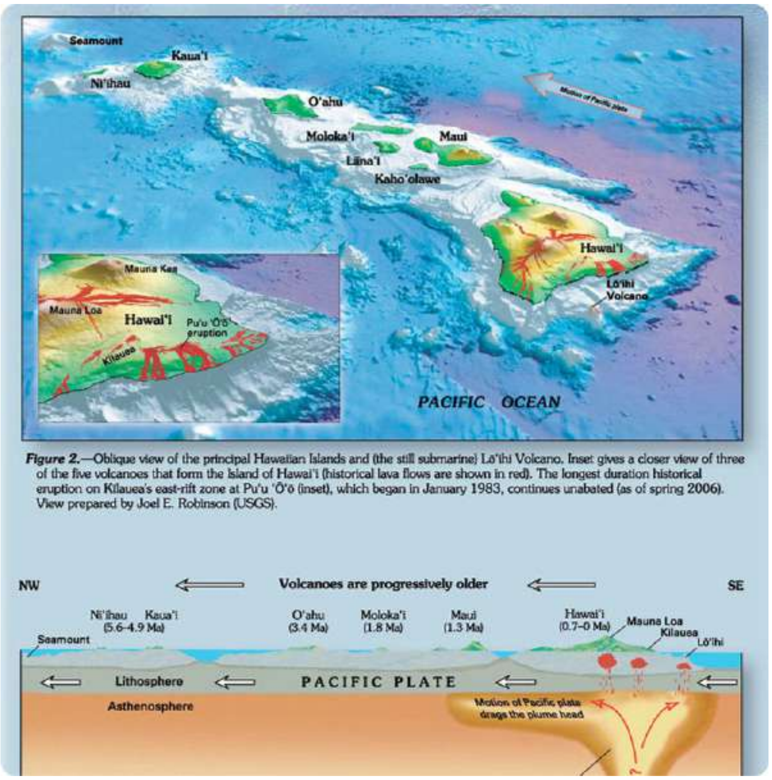


FIGURE 30.1

The Hawaiian Islands have formed from volcanic eruptions above the Hawaii hotspot.

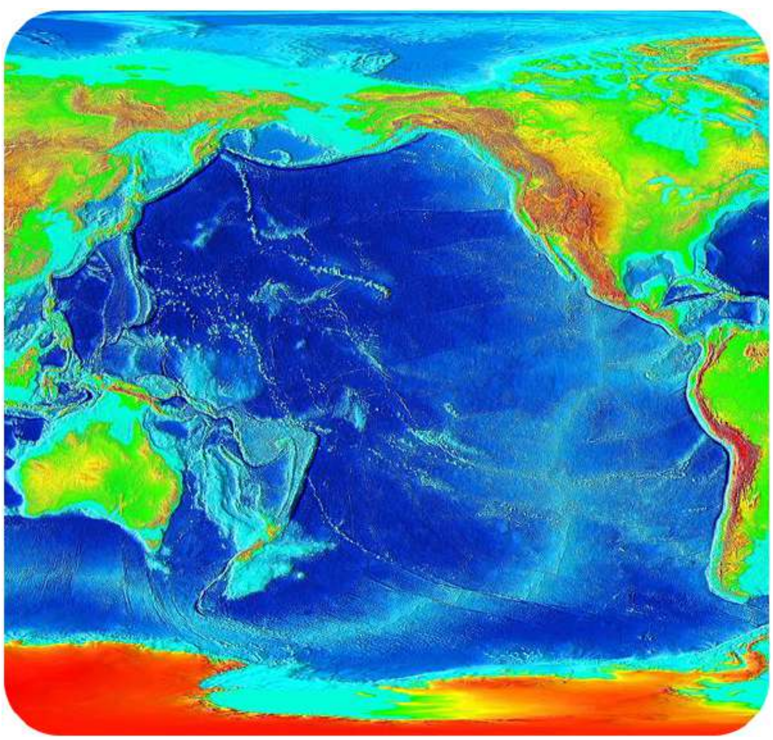

FIGURE 30.2

The Hawaiian-Emperor chain can be traced from Hawaii in the central Pacific north of the Equator into the Aleutian trench, where the oldest of the volcanoes is being subducted. It looks like a skewed "L".

### Intraplate Activity on the Continents

The second photo in the introduction is of a geyser at Yellowstone National Park in Wyoming. Yellowstone is in the western U.S. but is inland from the plate boundaries offshore.

Hotspot magmas rarely penetrate through thick continental crust, so hotspot activity on continents is rare. One exception is the Yellowstone hotspot ( **Figure** 30.3). Volcanic activity above the Yellowstone hotspot on can be traced from 15 million years ago to its present location on the North American Plate.

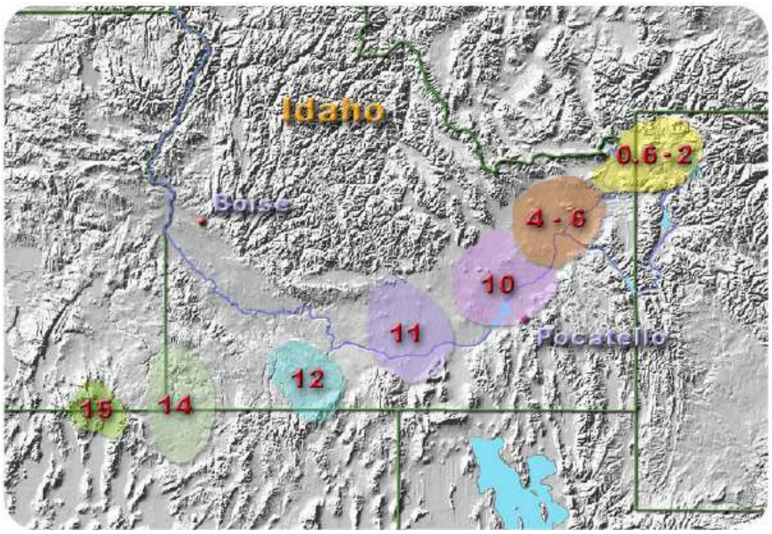


FIGURE 30.3
The ages of volcanic activity attributed to the Yellowstone hotspot.

## Summary

- Not all geological activity is found at plate boundaries. Some volcanic activity, with accompanying earthquakes, is located within a plate. This is called intraplate activity.
- Intraplate activity occurs above mantle plumes that cause melting at a hotspot.
- Hotspots erupt mostly on oceanic crust. Hawaii is an example. A few hotspots, like Yellowstone, erupt on continental crust. The difference is due to the thickness of the crust.
- Hotspots can be used to tell the speed and direction that a plate is moving, since the hotspots are stationary within the mantle.

## Practice

Use these resources to answer the questions that follow.

http://www.youtube.com/watch?v=D1eibbfAEVk

MEDIA
Click image to the left for more content.

1. Where are the Hawaiian islands located in relation to plate boundaries?
2. What are hotspots?
3. How do hotspots form volcanoes?
4. What evidence supports the theory that hotspots are stationary?
5. Why is Kauai older than the big island?
6. Why is the big island bigger than Kauai?

http://www.nps.gov/yell/naturescience/tracking_hotspot.htm

8. What direction is the North American Plate moving? How fast is it moving?
9. When did the McDermmit Volcanic Field erupt?
10. What was the most recent eruption of this hotspot? Where?

### Review

1. What is a mantle plume and how is it related to a hotspot?
2. How do scientists use hotspot volcanism to tell the direction and speed of a plate?
3. Why are hotspot volcanoes much more common in the oceans than on continents?

## References

1. Courtesy of Joel E. Robinson, Will R. Stettner, US Geological Survey. Map of the Hawaiian island chain. Public Domain
2. Courtesy of National Oceanic and Atmospheric Administration. Map of the Pacific and the Hawaiian-Emperor chain. Public Domain
3. User:Metrodyne/Wikipedia. Volcanic activity attributed to the Yellowstone hotspot. Public Domain

# CONCEPT 31 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** 31.1). 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.

### 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** 31.2), or on oceanic crust, as with the Aleutian Islands, which

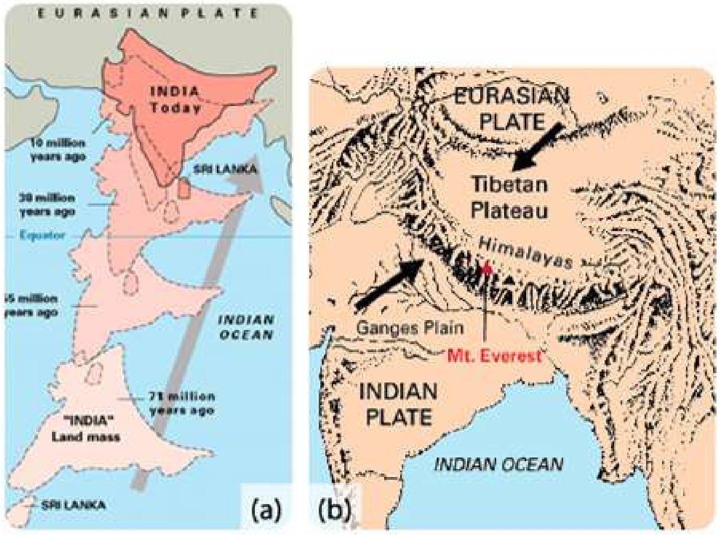


FIGURE 31.1
(a) The world's highest mountain range, the Himalayas, is growing from the collision between the Indian and the Eurasian plates. (b) The crumpling of the Indian and Eurasian plates of continental crust creates the Himalayas.

we visited earlier. The Cascades Mountains of the western U.S. are also created this way.

FIGURE 31.2
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** 31.3). 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/animations/animation.php?flash_title=Horst+%26amp%3B+Graben&flash_file=horstandgraben&flash_width=380&flash_height=210 .

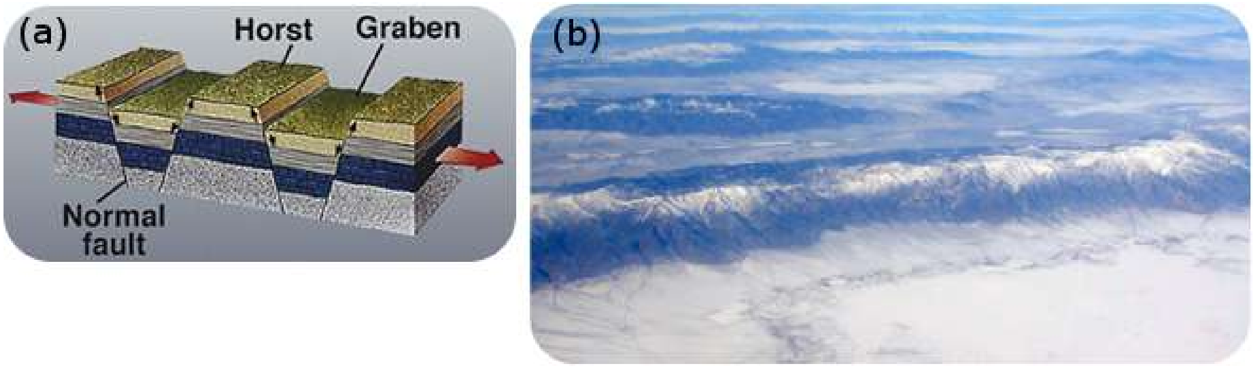


FIGURE 31.3

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

## 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.

## Practice

Use this resource to answer the questions that follow.


MEDIA

Click image to the left for more content.

1. What created the landscape we see today on Earth?
2. What can cause mountains to form?
3. How tall are the Alps?
4. How were the Alps formed?
5. Explain the forces that caused the Alps to form.

## 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?

## References

1. Courtesy of the US Geological Survey. The Himalaya Mountains rise as India rams into Eurasia. Public Domain
2. Courtesy of NASA. The Andes Mountains formed due to oceanic plate subduction. Public Domain
3. (a) Courtesy of the US Geological Survey; (b) Miguel Vieira. Diagram and picture of basin-and-range. (a) Public Domain; (b) CC BY 2.0

# CONCEPT 32 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** 32.1).

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 .

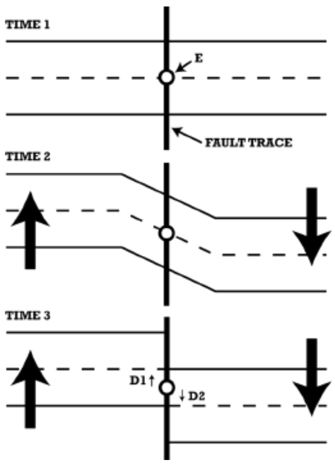


FIGURE 32.1
Elastic rebound theory. Stresses build on both sides of a fault, causing the rocks to deform plastically (Time 2). When the stresses become too great, the rocks break and end up in a different location (Time 3). This releases the built up energy and creates an earthquake.

### 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** 32.2).

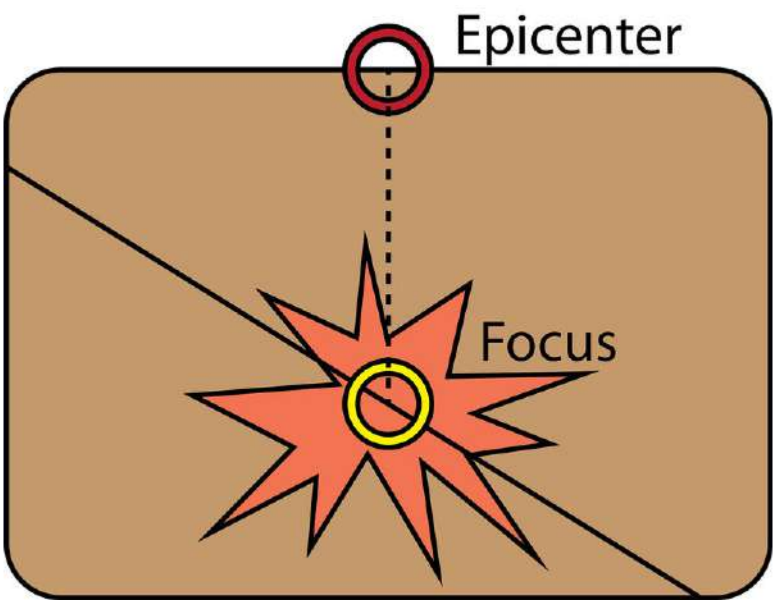


FIGURE 32.2
In the vertical cross section of crust, there are two features labeled - the focus and the epicenter, which is directly above the focus.

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.

### Practice

Use this resource to answer the questions that follow.

http://www.pbs.org/wnet/savageearth/animations/earthquakes/main.html

1. What causes an earthquake?
2. What is the focus?
3. Which waves travel the fastest?
4. Which waves cannot travel through the core?
5. What happens to the waves as distance increases?

### 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?

## References

1. Christopher Auyeung. Diagram of the elastic rebound theory. CC BY-NC 3.0
2. Jodi So. The epicenter and focus of an earthquake. CC BY-NC 3.0

# CONCEPT 33 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** 33.1) 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** 33.1), 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** 33.1). About 3,000 people died and 28,000 buildings were lost, mostly in the fire that followed the earthquake.

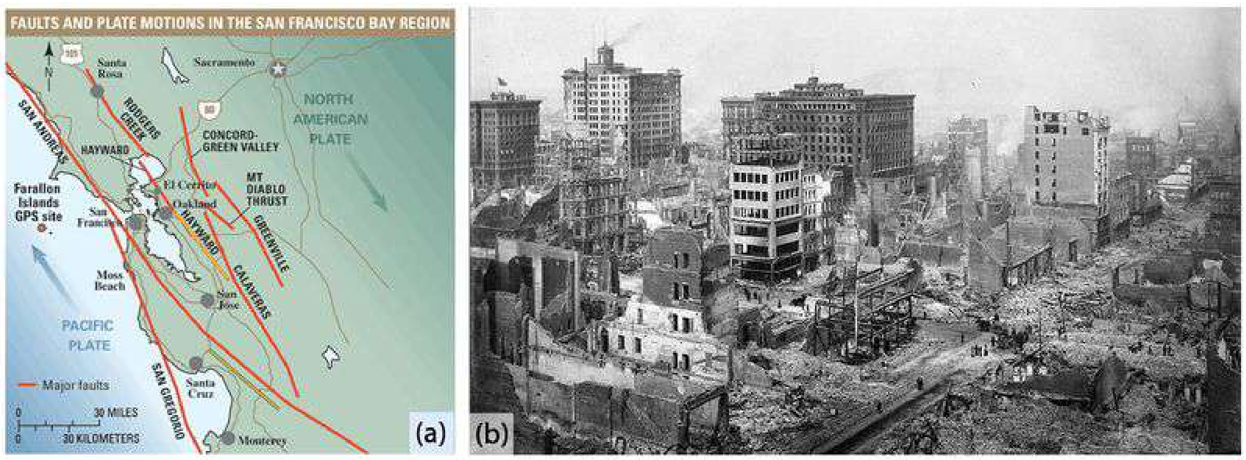


FIGURE 33.1

(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

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### 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.

## Practice

Use these resources to answer the questions that follow.

- http://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Transform Plates**

1. What is a transform boundary?
2. Give an example of where a transform boundary is found.

MEDIA

Click image to the left for more content.

3. How far does the San Andreas Fault extend?
4. What two plates form the fault?
5. What type of fault is it?
6. What causes an earthquake?
7. What is a creepmeter?
8. How many earthquakes occur at the San Andreas fault each year?

## Review

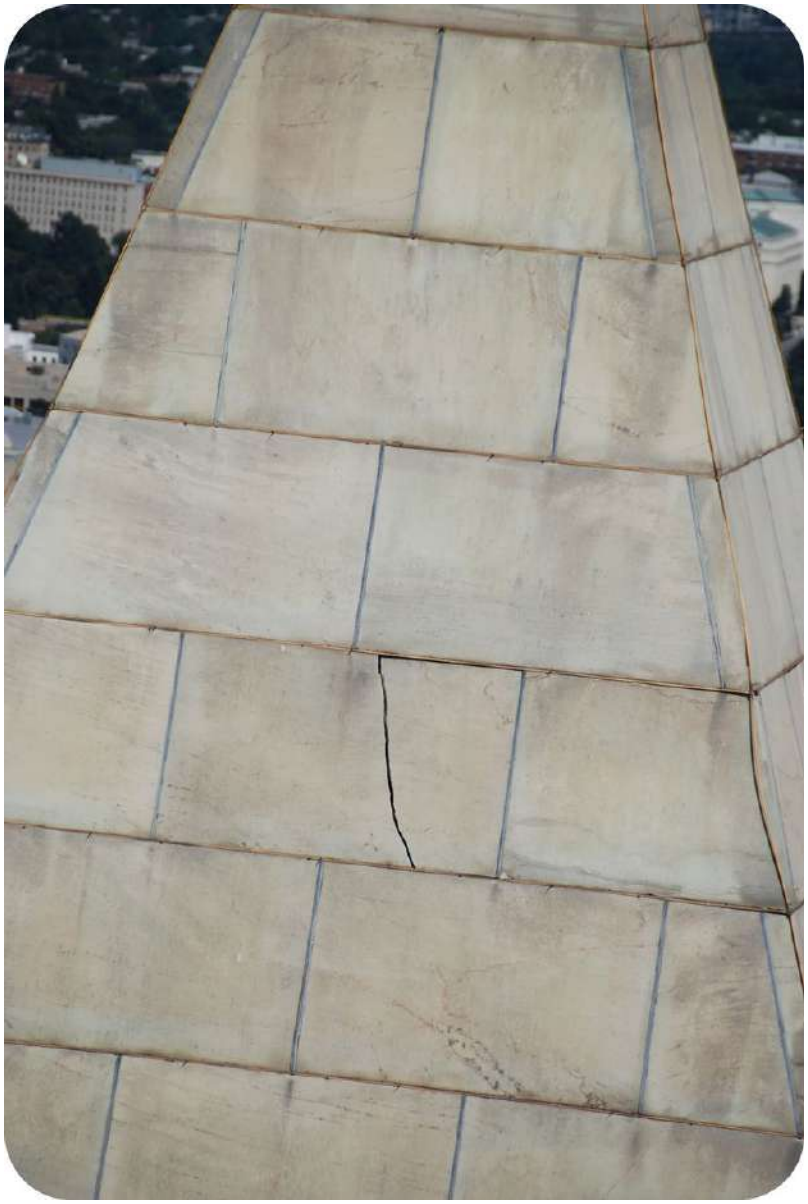
1. Why are earthquakes at convergent plate boundaries sometimes deep, while those at transform plate boundaries are always shallow?
2. Are the earthquakes that take place along the other faults in the San Andreas Fault Zone always smaller than the earthquakes that take place on the San Andreas Fault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

## References

1. (a) Courtesy of US Geological Survey; (b) Photographed by HD Chadwick and courtesy of National Archives and Records Administration. Map of faults in the San Francisco Bay Area. Public Domain

# CONCEPT 34 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** 34.1). A similar earthquake today would undoubtedly kill many people and cause a great deal of property damage.

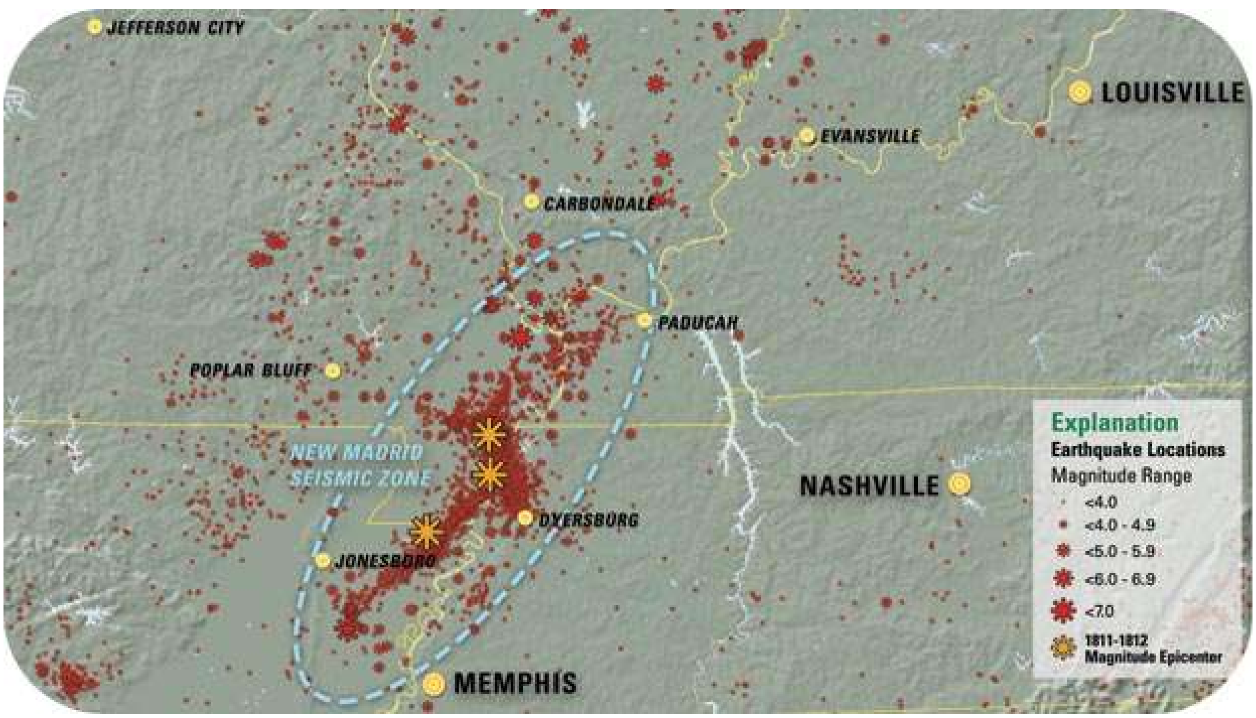



FIGURE 34.1
The New Madrid seismic zone is located in the interior of the North American plate (near Missouri, Arkansas, Tennessee, Kentucky, and Illinois), but many earthquakes occur there.

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.

### Practice

Use this resource to answer the questions that follow.


MEDIA

Click image to the left for more content.

1. How many earthquakes are there in the United States?
2. What is the second most active fault in the United States?
3. When did the New Madrid earthquake occur?
4. What was the magnitude of the New Madrid earthquake?
5. How many aftershocks occurred?
6. How long is the New Madrid fault?
7. How many people would be affected by another quake?
8. Where is the Ramapo fault?

### Review

1. Why do intraplate earthquakes tend to be less frequent and smaller than earthquakes at plate boundaries?
2. Why do intraplate earthquakes take place at all?
3. What causes intraplate earthquakes?

## References

1. Courtesy of US Geological Survey. The map of the New Madrid seismic zone. Public Domain

# CONCEPT 35 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** 35.1).

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 .

## 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** 35.3).

### Continental Rifting

Eruptions are found at divergent plate boundaries as continents break apart. The volcanoes in **Figure** 35.4 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 35.1
The Cascade Range is formed by volcanoes created from subduction of oceanic crust beneath the North American continent.

## Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. Why does the melted rock rise?
2. What does spreading cause?
3. What happens at plate convergence?

FIGURE 35.2
Mt. Baker, Washington.

FIGURE 35.3
A volcanic eruption at Surtsey, a small island near Iceland.

4. How is carbon dioxide released from the rock?
5. How is carbon dioxide returned to the atmosphere?

### 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?

FIGURE 35.4
Mount Gahinga in the East African Rift valley.

## References


1. Courtesy of NASA, modified by User:Black Tusk/Wikimedia Commons. Map of volcanoes on the Cascade Range. Public Domain
2. Curt Smith. Picture of Mt. Baker in Washington. CC BY 2.0
3. Courtesy of the U.S. National Oceanic and Atmospheric Administration. A volcanic eruption at Surtsey, a small island near Iceland. Public Domain
4. Image copyright PRILL, 2013. Mount Gahinga in the East African Rift valley. Used under license from Shutterstock.com

# CONCEPT 36 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?

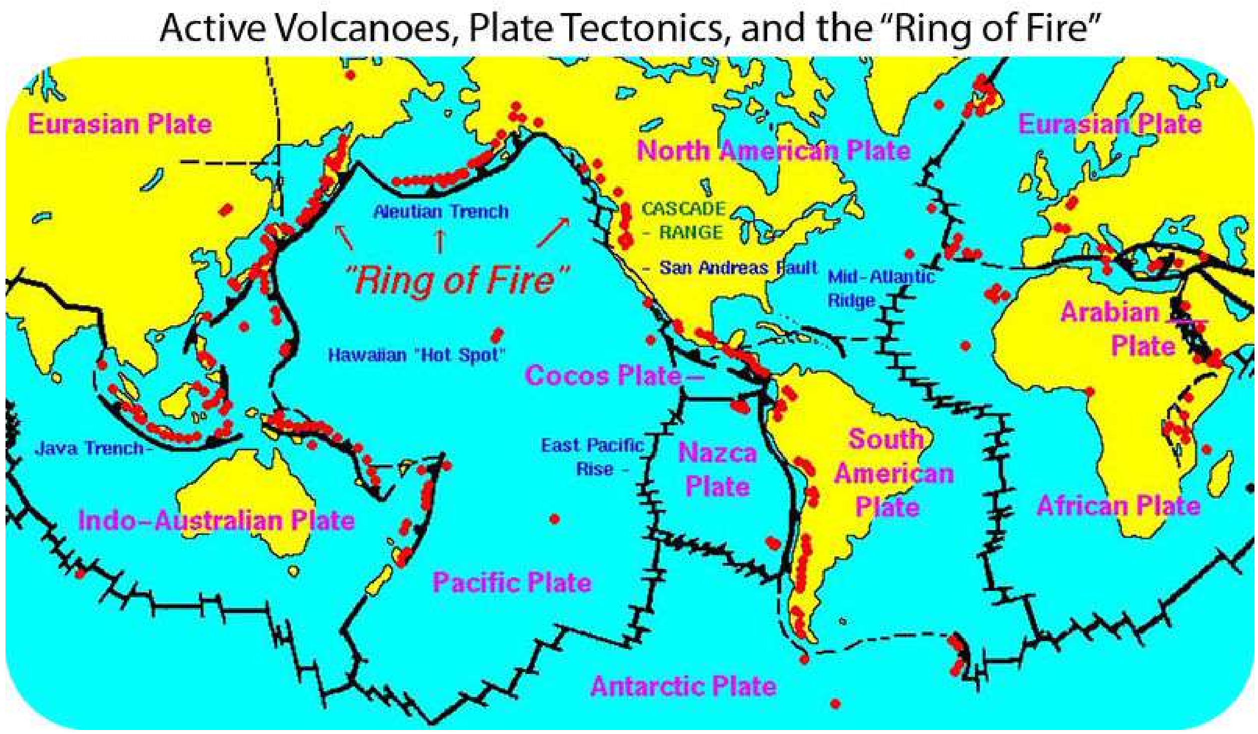



FIGURE 36.1

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 36.2
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 more content.

## Practice

Use this resource to answer the questions that follow.

http://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Volcanoes**

1. How are volcanoes formed?
2. Where do volcanoes occur?
3. What is the Ring of Fire? Where is it located?
4. Where is Mount St. Helen's located?
5. Where is Mount Pinatubo located?

## 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?

## References

1. Courtesy of US Geological Survey/Cascades Volcano Observatory. Map of active volcanos around the world. Public Domain
2. Zappy's. Volcanoes can be active, dormant, or extinct. CC BY-NC 3.0

# CONCEPT 37 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.

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** 37.2).

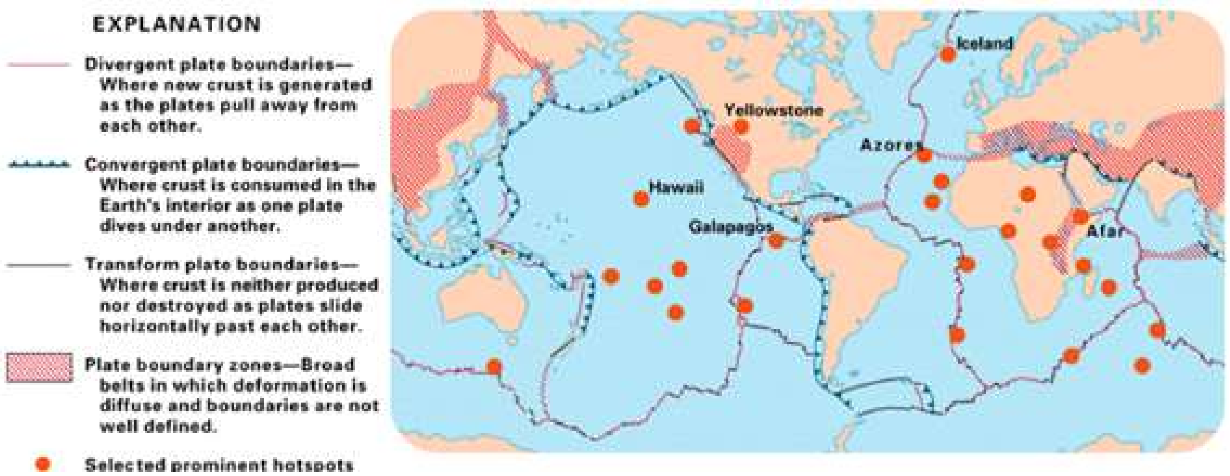



FIGURE 37.1

Prominent hotspots of the world.

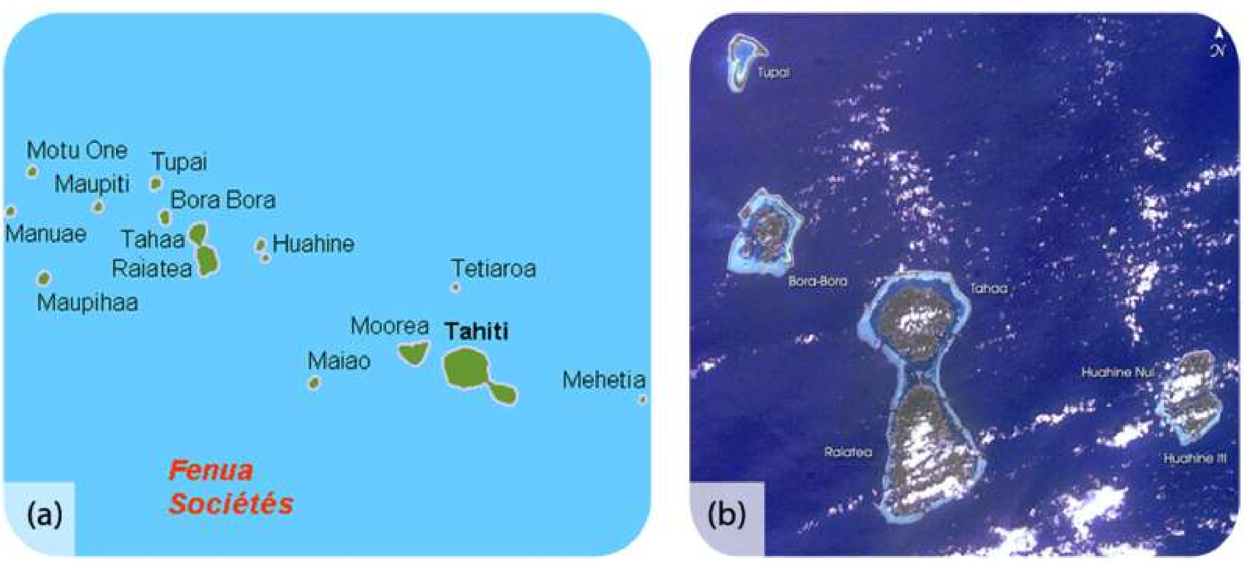



FIGURE 37.2

(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'a, 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 more content.

### 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

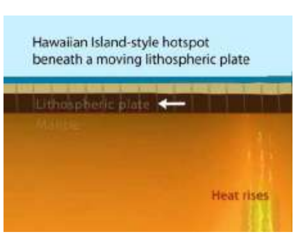
How would you be able to tell hotspot volcanoes from island arc volcanoes? At island arcs, the volcanoes are all about the same age. By contrast, at hotspots the volcanoes are youngest at one end of the chain and oldest at the other.

## 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.

## Practice

Use this resource to answer the questions that follow.




MEDIA
Click image to the left for more content.

1. What is a hotspot?

2. What does a thermal plume allow for?
3. What causes convection?
4. What does the volcano build?
5. What carries the volcanoes away from a hotspot?

### Review

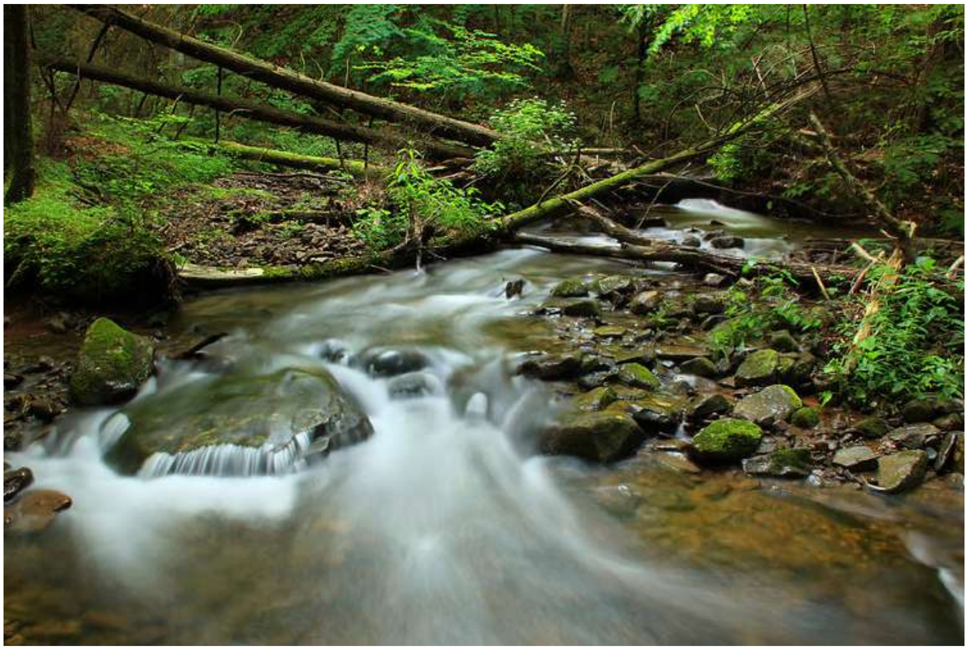
1. What causes melting at a hotspot?
2. Why are there a relatively large number of hotspots in the Pacific Ocean basin?
3. Why do you think there are so many hotspots at mid-ocean ridges; e.g. four along the Mid-Atlantic Ridge and two at the East Pacific Rise?

## References

1. Courtesy of US Geological Survey. Map of hotspots around the world. Public Domain
2. (a) Holger Behr (User:Hobe/Wikimedia Commons); (b) Courtesy of Johnson Space Center/NASA's Earth Observatory. Map of the Society Islands. Public Domain

# CONCEPT 38 Soil Characteristics

- Describe the characteristics of soil.



**"Land, then, is not merely soil; it is a fountain of energy flowing through a circuit of soils, plants, and animals."**
— Aldo Leopold, *A Sand County Almanac*, 1949

Even though soil is only a very thin layer on Earth's surface over the solid rocks below, it is the where the atmosphere, hydrosphere, biosphere, and lithosphere meet. We should appreciate soil more.

## Characteristics of Soil

**Soil** is a complex mixture of different materials.

- About half of most soils are **inorganic** materials, such as the products of weathered rock, including pebbles, sand, silt, and clay particles.
- About half of all soils are **organic** materials, formed from the partial breakdown and decomposition of plants and animals. The organic materials are necessary for a soil to be fertile. The organic portion provides the nutrients, such as nitrogen, needed for strong plant growth.
- In between the solid pieces, there are tiny spaces filled with air and water.

Within the soil layer, important reactions between solid rock, liquid water, air, and living things take place.

In some soils, the organic portion could be missing, as in desert sand. Or a soil could be completely organic, such as the materials that make up peat in a bog or swamp ( **Figure** 38.1).

## Soil Texture

The inorganic portion of soil is made of many different size particles, and these different size particles are present in different proportions. The combination of these two factors determines some of the properties of the soil.

FIGURE 38.1
Peat is so rich in organic material, it can be burned for energy.

- A **permeable** soil allows water to flow through it easily because the spaces between the inorganic particles are large and well connected. Sandy or silty soils are considered "light" soils because they are permeable, water-draining types of soils.
- Soils that have lots of very small spaces are water-holding soils. For example, when clay is present in a soil, the soil is heavier, holds together more tightly, and holds water.
- When a soil contains a mixture of grain sizes, the soil is called a **loam** ( **Figure** 38.2).

FIGURE 38.2
A loam field.

### Classification

When soil scientists want to precisely determine soil type, they measure the percentage of sand, silt, and clay. They plot this information on a triangular diagram, with each size particle at one corner ( **Figure** 38.3). The soil type can then be determined from the location on the diagram. At the top, a soil would be clay; at the left corner, it would be sand; at the right corner, it would be silt. Soils in the lower middle with less than 50% clay are loams.

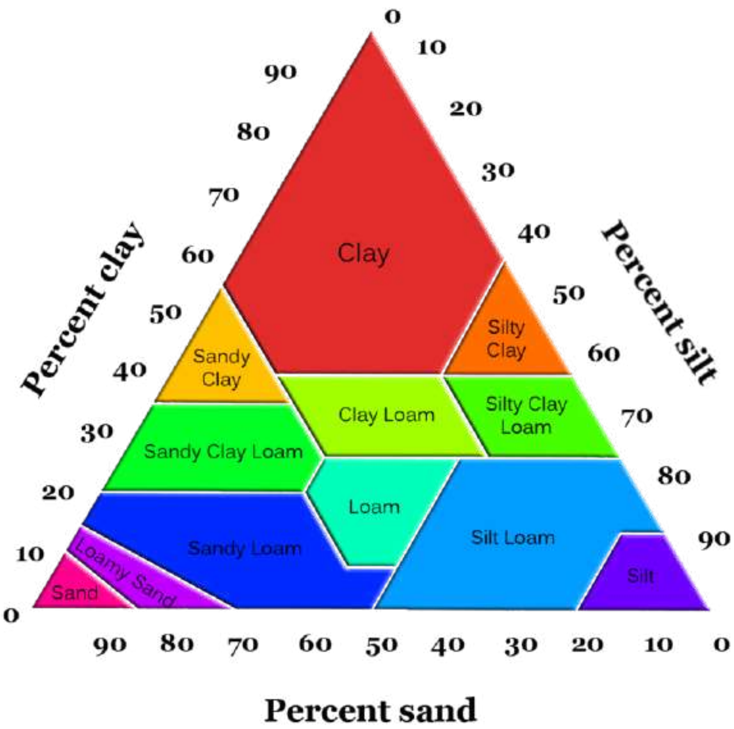



FIGURE 38.3
Soil types by particle size.

### Soil, the Ecosystem

Soil is an ecosystem unto itself. In the spaces of soil, there are thousands or even millions of living organisms. Those organisms could include earthworms, ants, bacteria, or fungi ( **Figure** 38.4).

FIGURE 38.4
Earthworms and insects are important residents of soils.

## Summary

- Soil reflects the interactions between the lithosphere, atmosphere, hydrosphere and biosphere.

- Permeable soils allow water to flow through.
- The proportions of silt, clay, and sand allow scientists to classify soil type.

### Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. Why is soil important?
2. How many different types of soils are there?
3. Explain the composition of average soil.
4. What is humus?
5. What does the amount of humus determine?
6. What is texture?
7. How can texture effect plant growth?
8. What type of soil do farmers prefer?
9. How is soil being lost each year?
10. List the different types of erosion.

### Review

1. What is the inorganic material that makes up a soil?
2. What is the organic material that makes up a soil?
3. If a soil has equal amounts of silt, clay, and sand, what type of soil is it?

## References

1. Flickr:Kecko. Peat is soil that is so rich in organic material, it can be burned for energy. CC BY 2.0
2. User:Otto Normalverbraucher/De.Wikipedia. Picture of a loam field. The copyright holder of this file allows anyone to use it for any purpose, provided that the copyright holder is properly attributed
3. Courtesy of the USDA Natural Resources Conservation Service, modified by Sam McCabe (CK-12 Foundation). Categorizing soil types by particle size. Public Domain
4. S Shepherd (Flickr:schizoform). Earthworms and insects are important residents of soils. CC BY 2.0

# CONCEPT 39 Soil Horizons and Profiles

- Describe the characteristics of the three major types of soil horizon.
- Explain the relationship of each type of soil to weathering processes.

**What's beneath your car tires?**

Beneath an asphalt road is this incredible soil profile. Can you identify the horizons? There are some clues in the photo that can help you identify the climate type. What type of climate would produce this soil?

## Soil Horizons and Profiles

Soil develops over time and forms soil horizons. **Soil horizons** are different layers of soil with depth. The most weathering occurs in the top layer. This layer is most exposed to weather! It is where fresh water comes into contact with the soil. Each layer lower is weathered just a little bit less than the layer above. As water moves down through the layers, it is able to do less work to change the soil. This is because the chemical reactions have already occurred.

If you dig a deep hole in the ground, you may see each of the different layers of soil. All together, the layers are a **soil profile**. Each horizon has its own set of characteristics ( **Figure** 39.1). In the simplest soil profile, a soil has three horizons.

### Topsoil

The first horizon is the "A" horizon. It is more commonly called the **topsoil**. The topsoil is usually the darkest layer of the soil. It is the layer with the most organic material. Humus forms from all the plant and animal debris that falls to or grows on the ground. The topsoil is also the region with the most biological activity. Many organisms live within this layer. Plant roots stretch down into this layer. The roots help to hold the topsoil in place. Topsoil is needed to grow most crops ( **Figure** 39.2).

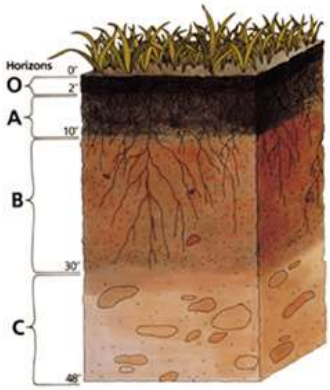



FIGURE 39.1
In this diagram, a cut through soil shows different soil layers.

FIGURE 39.2
Good topsoil is great for growing plants.

Topsoil usually does not have very small particles like clay. Clay-sized particles are carried to lower layers as water seeps down into the ground. Many minerals dissolve in the fresh water that moves through the topsoil. These minerals are carried down to the lower layers of soil.

### Subsoil

Below the topsoil is the "B" horizon. This is also called the **subsoil**. Soluble minerals and clays accumulate in the subsoil. Because it has less organic material, this layer is lighter brown in color than topsoil. It also holds more water due to the presence of iron and clay. There is less organic material in this layer.

### C-horizon

The next layer down is the "C" horizon. The **C horizon** is made of partially altered bedrock. There is evidence of weathering in this layer. Still, it is possible to identify the original rock type from which this soil formed ( **Figure** 39.3).

Not all climate regions develop soils. Arid regions are poor at soil development. Not all regions develop the same soil horizons. Some areas develop as many as five or six distinct layers. Others develop only a few.

- An animation of soil profile development can be viewed here: http://courses.soil.ncsu.edu/resources/soil_classification_genesis/soil_formation/soil_transform.swf .

## Vocabulary

- **C-horizon**: Lowest layer of soil; partially altered bedrock.
- **soil horizon**: Individual layer of a complete soil profile; examples include A, B C horizons.

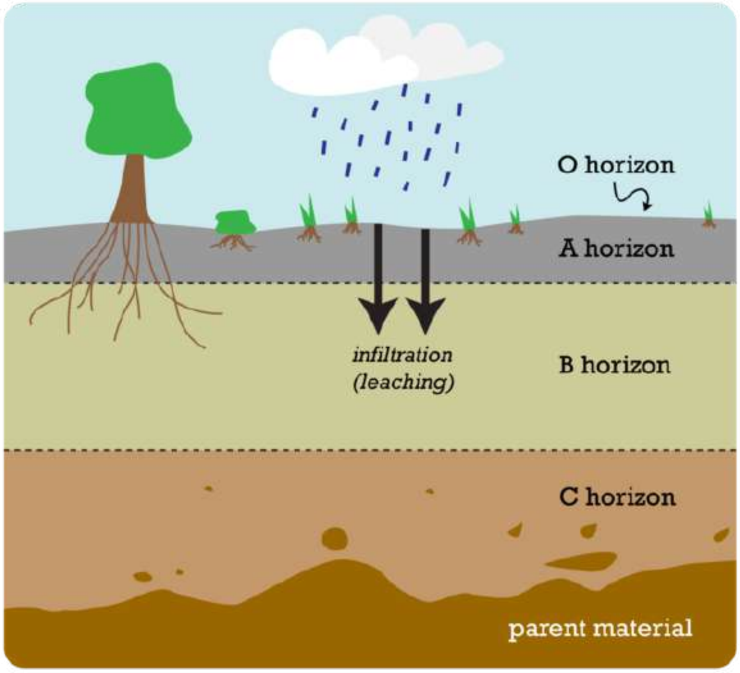



FIGURE 39.3
This image shows the various soil horizons.

- **soil profile**: Entire set of soil layers or horizons for a particular soil.
- **subsoil (B-horizon)**: Subsoil; the zone where iron oxides and clay minerals accumulate.
- **topsoil (A-horizon)**: The A horizon; the most fertile layer with humus, plant roots and living organisms.

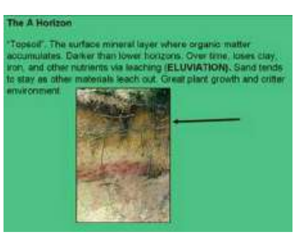
## Summary

- Soil horizons are layers within a soil. Different soil horizons show different amounts of alteration.
- Soil profiles reveal the different layers of soil.
- Soil layers include topsoil, subsoil, and the C horizon.
- Topsoil has the highest proportion of organic material. Topsoil is essential for farming.

## Practice

Use the resource below to answer the questions that follow.

- **Soil Horizons** at http://www.youtube.com/watch?v=YQhyMsisRD8 (4:33)




MEDIA
Click image to the left for more content.

1. What are the two main components of the A horizon and what is different about them?

2. What is in the O-horizon? What is its more common name?
3. What distinguishes the E-horizon from the horizons above and below?
4. In what regions do soils have an E-horizon?
5. What are the characteristics of the B-horizon?
6. How does the C-horizon differ from the other horizons?
7. What is below the C-horizon?

### Review

1. What is topsoil? Why is topsoil so important for growing plants?
2. How does weathering produce soil?
3. Why does the C horizon most resemble the parent material?

## References

1. Courtesy of the US Department of Agriculture. Diagram of the soil horizons. Public Domain
2. Southern Foodways Alliance. Picture of rich topsoil. CC BY 2.0
3. Christopher Auyeung. This image shows the various soil horizons. CC BY-NC 3.0

# CONCEPT 40 Principle of Horizontality

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

**What is the pattern of the Grand Canyon rock layers?**

If you go to the Grand Canyon, you'll see layers of sedimentary rocks. These rocks are extremely well exposed for viewing. Some people call this "layer cake geology." It looks like a layer cake, but not as tasty. Just like a cake, the bottom layer is put down first. Subsequent layers are deposited next. Where the layers are not horizontal, there was deformation.

## Sedimentary Rock Rules

Sedimentary rocks follow certain rules.

1. Sedimentary rocks form with the oldest layers on the bottom and the youngest on top.
2. Sediments are deposited horizontally so sedimentary rock layers are originally horizontal.
3. Sedimentary rock layers that are not horizontal are deformed.

Sedimentary rocks start out horizontal with the oldest on the bottom. Sedimentary rocks that are not horizontal must be deformed. This deformation produces geologic structures such as folds, joints, and faults that are caused by stresses. We can look at the deformation and structures out the deformation history of the rock.

## Geologic Structures

Sedimentary rocks are formed in horizontal layers. This is magnificently displayed around the southwestern United States. The arid climate allows rock layers to be well exposed ( **Figure** 40.1). The lowest layers are the oldest, and the higher layers are younger. This concept is called **superposition** since it deals with the positions of rock layers.

Folds, joints, and faults are caused by stresses. If a sedimentary rock is tilted or folded, we know that stresses have changed the rock.

FIGURE 40.1
Layers of different types of rocks are exposed in this photo from Grand Staircase-Escalante National Monument. White layers of limestone are hard and form cliffs. Red layers of shale are flakier and form slopes.

## Vocabulary

- **superposition**: The law in geology that states that the oldest rocks are on the bottom of a section unless there has been overturning.

## Summary

- Sedimentary rocks are laid down horizontally with the oldest at the bottom.
- Sedimentary rocks that are not horizontal have been deformed.
- Sedimentary rocks are very useful for determining the deformation history of an area.

## Practice

Use the resource below to answer the questions that follow.

- **Law of Superposition** at http://www.youtube.com/watch?v=EadTLGMu3LI (6:22)


MEDIA
Click image to the left for more content.

1. How is rock laid down?
2. What is the law of superposition?
3. Why is the law of superposition important?
4. Where is the oldest rock found?
5. Where is the youngest rock found?
6. Why do we know that the fault is younger than the three rock layers?
7. Is the intrusion the youngest rock in the section? How do you know?

### Review

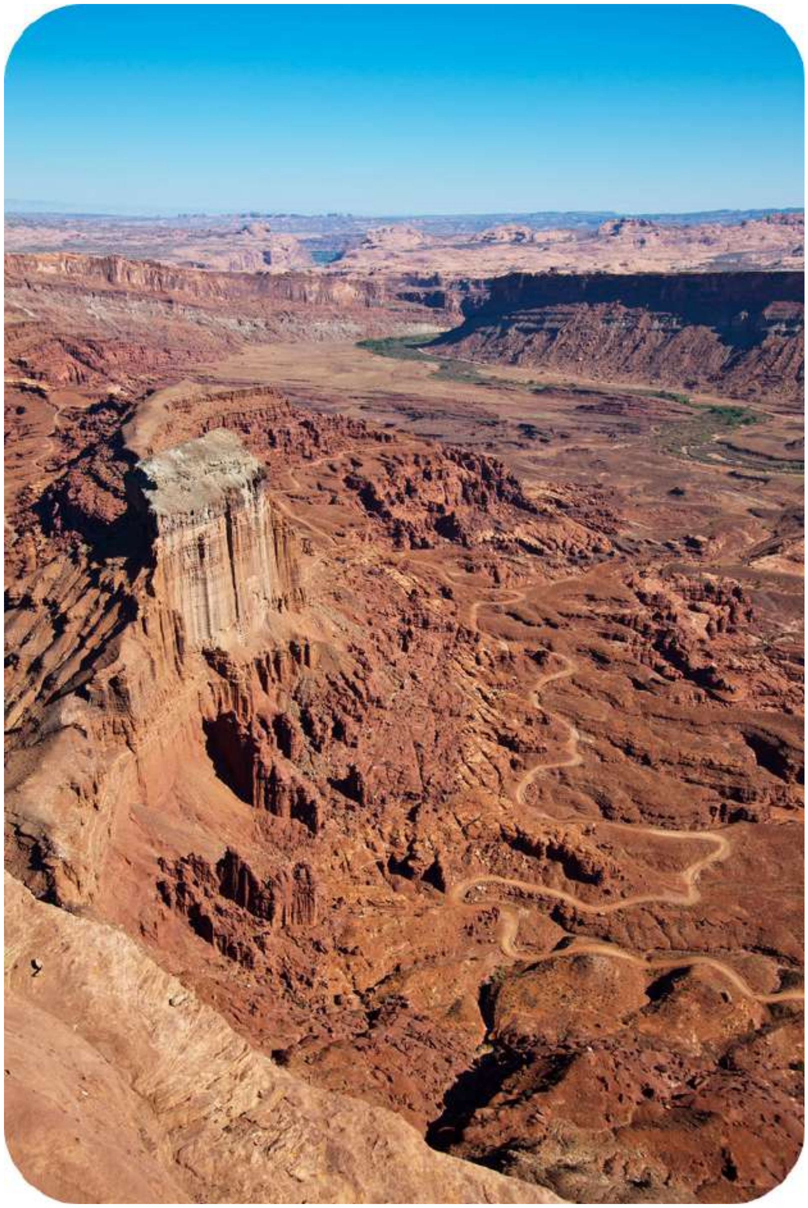
1. Why are sediments laid down horizontally?
2. Why are sediments laid down from oldest to youngest?
3. Why are sedimentary rocks so good for studying the geology of a region?

## References

1. Wolfgang Staudt. Layers of different types of rocks are exposed in this photo from Grand Staircase-Escalante National Monument. CC BY 2.0

# CONCEPT 41 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** 41.1 for an example).

FIGURE 41.1
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** 41.2). 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** 41.3).

When rocks bend downward in a circular structure, that structure is called a **basin** ( **Figure** 41.4). If the rocks are exposed at the surface, where are the oldest rocks located?

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

FIGURE 41.2

Anticlines are formations that have folded rocks upward.

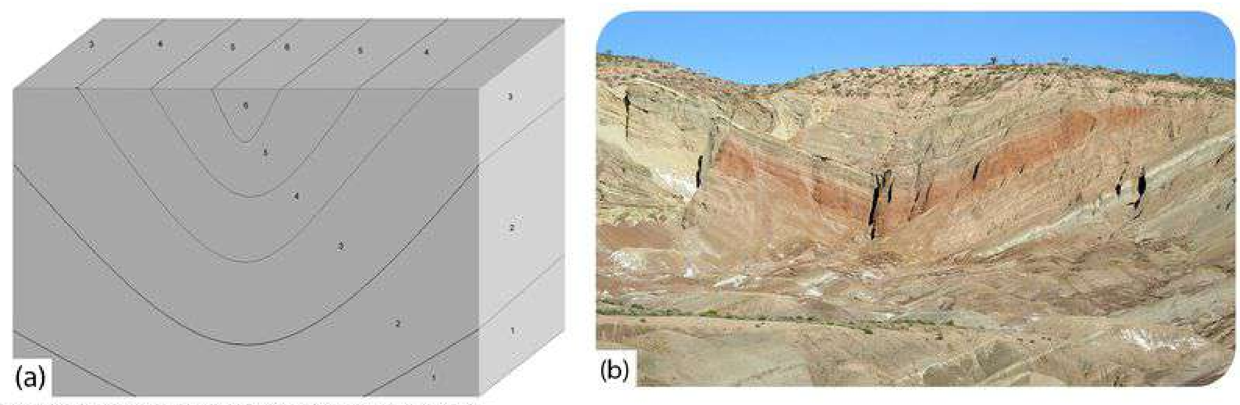



FIGURE 41.3

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

## Practice

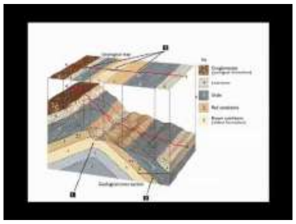
Use this resource to answer the questions that follow.

FIGURE 41.4

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 41.5

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



MEDIA
Click image to the left for more content.

1. What causes folds?
2. What are the folds called?
3. What is a dip?
4. What is a 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.

### 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?

4. 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?

## References


1. Image copyright Scott Prokop, 2014. Picture of a monocline. Used under license from Shutterstock.com
2. Flickr:woosh2007. Picture of an anticline. CC BY 2.0
3. (A) User:Jonathan3784/Wikipedia; (B) Mark A. Wilson (User:Wilson44691/Wikipedia). Picture of a syncline. Public Domain

4. Courtesy of Nation Atlas of the United States. Map of the Michigan Basin. Public Domain
5. Image copyright Darren J. Bradley, 2013. Folding in rock. Used under license from Shutterstock.com

# CONCEPT 42 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** 42.1).

FIGURE 42.1
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** 42.2). Stresses along faults cause rocks to break and move suddenly. The energy released is an earthquake.

FIGURE 42.2
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** 42.3).

### 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.

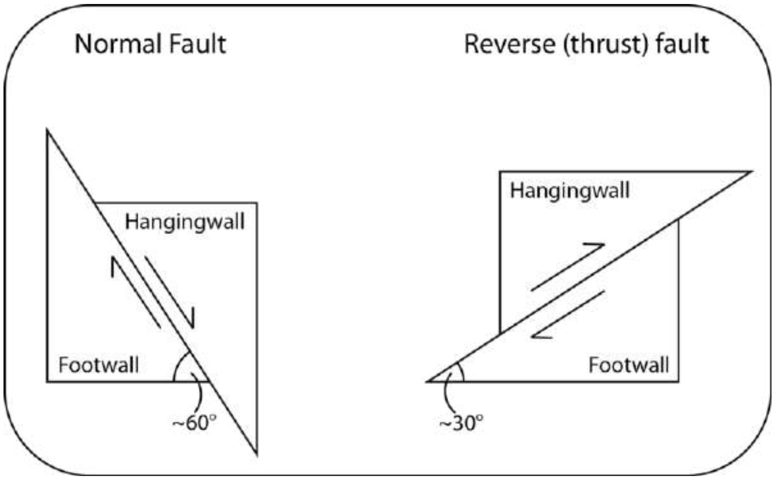



FIGURE 42.3
This diagram illustrates the two types of dip-slip faults: normal faults and reverse faults. Imagine miners extracting a resource along a fault. The hanging wall is where miners would have hung their lanterns. The footwall is where they would have walked.

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 .

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** 42.4).

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 .

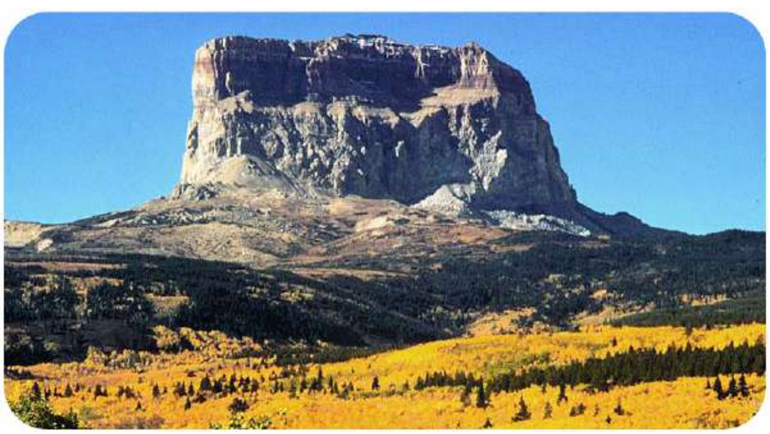


FIGURE 42.4
At Chief Mountain in Montana, the upper rocks at the Lewis Overthrust are more than 1 billion years older than the lower rocks. How could this happen?

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** 42.5).

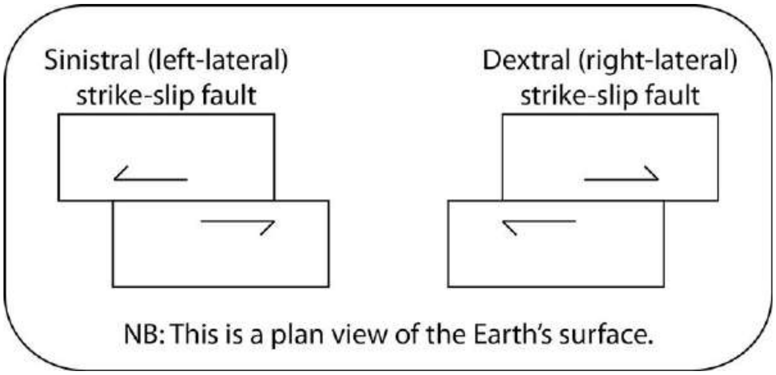



FIGURE 42.5
Strike-slip faults.

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 .

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 .

## 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.

## Practice

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?

## 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?

## References

1. Flickr:Tscherno. Joints in rocks at Joshua Tree National Park, in California. CC BY 2.0
2. Roy Luck. A fault cutting across bedded rocks. CC BY 2.0
3. Jodi So. Diagram of a reverse and normal fault. CC BY-NC 3.0
4. Courtesy of the National Park Service. Chief Mountain in Montana formed due to a thrust fault. Public Domain
5. Jodi So. Diagram of a strike-slip fault. CC BY-NC 3.0