GreatHearts®

Earth Science 8

April 27 – May 1

Time Allotment:30 minutes per day

Student Name: ________________________________

Teacher Name: ________________________________

Packet Overview

Date	Objective(s)	Page Number
Monday, April 27	1. Students will be able to explain the different types of plate boundaries, their causes, and the geologic phenomena that occur at each boundary.	2
Tuesday, April 28	1.Students will be able to explain intraplate volcanism via hotspots and the supercontinent cycle	7
Wednesday, April 29	1. Students will be able to list the different stresses that cause different types of rock deformation, and compare the different types of folds and the conditions under which they form.	10
Thursday, April 30	1. Students will be able to explain the different types of faults found in the earth's crust.	14
Friday, May 1	Students will be able to explain the cause of earthquakes.	19

Additional Notes: Students are to designate a specific location in their home for their workspace to learn about Earth and Space.

This could be a table or desk anywhere in the home that could be labeled their school zone. By doing so, the students will have a stable work environment that they will keep all of their learning materials organized, they can visit, and take a rest from.

Academic Honesty

I certify that I completed this assignment independently in accordance with the GHNO Academy Honor Code.	I certify that my student completed this assignment independently in accordance with the GHNO Academy Honor Code.
Student signature:	*Parent signature:*
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Lesson 1: Monday, April 27

Back at the planet's surface, the edges where two plates meet are known as **plate boundaries**. Most geologic activity, including volcanoes, earthquakes, and mountain building, takes place at plate boundaries where two enormous pieces of solid lithosphere interact.

Think about two cars moving around a parking lot. In what three ways can those cars move relative to each other? They can move away from each other, they can move toward each other, or they can slide past each other. These three types of relative motion also define the three types of plate boundaries:

- **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.

What happens at plate boundaries depends on which direction the two plates are moving relative to each other. It also depends on whether the lithosphere on the two sides of the plate boundary is oceanic crust, continental crust, or one piece of each type. 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: earthquakes, volcanoes, or mountain building.

Divergent Plate Boundaries

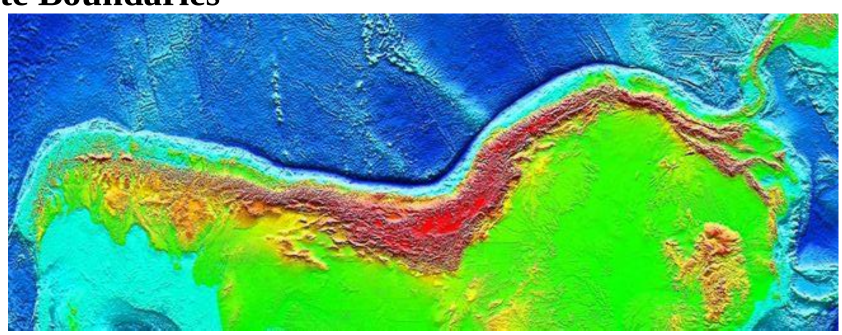
Plates move apart, or diverge, at mid-ocean ridges where seafloor spreading forms new oceanic lithosphere. At these mid-ocean ridges, lava rises, erupts, and cools. Magma cools more slowly beneath the lava mostly forming the igneous intrusive rock gabbro. The entire ridge system, then, is igneous. Earthquakes are also common at mid-ocean ridges since the movement of magma and oceanic crust result in crustal shaking. Although the vast majority of mid-ocean ridges are located deep below the sea, we can see where the Mid-Atlantic Ridge surfaces at the volcanic island of Iceland (below).

The Leif the Lucky Bridge straddles the Mid-Atlantic ridge separating the North American and Eurasian plates on Iceland.

The Arabian, Indian, and African plates are rifting apart, forming the Great Rift Valley in Africa. The Red Sea fills the rift with seawater.

Although it is uncommon, a divergent plate boundary can also occur within a continent. This is called **continental rifting** (above). Magma rises beneath the continent, causing it to thin, break, and ultimately split up. As the continental crust breaks apart, oceanic crust erupts in the void. This is how the Atlantic Ocean formed when Pangaea broke up. The East African Rift is currently splitting eastern Africa away from the African continent.

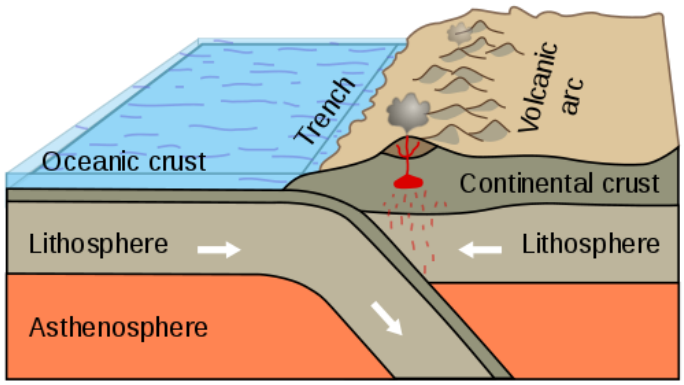
Convergent Plate Boundaries



This topographic map shows the trench lining the western margin of South America where the Nazca plate is subducting beneath the South American plate. The resulting Andes Mountains line western South America and are seen as brown and red uplands in this image. North is to the right.

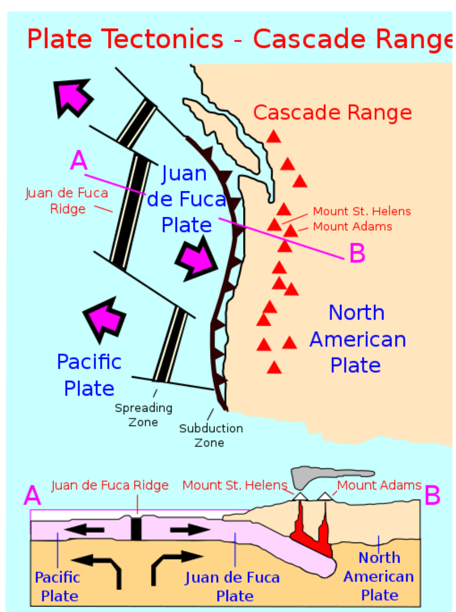
What happens when two plates **converge** depends on **the types of crust that are colliding.** Convergence can take place between two slabs of continental lithosphere, two slabs of oceanic lithosphere, or between one continental and one oceanic slab. Most often, when two plates collide, one or both are destroyed.

When oceanic crust converges with continental crust, the denser oceanic plate plunges beneath the continental plate. This process occurs at the oceanic trenches and is called **subduction** (below). 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. The magma rises and erupts, creating volcanoes. These volcanoes are found in a line above the subducting plate. The volcanoes are known as a **continental arc**. The movement of crust and magma causes earthquakes. The Andes Mountains, which line the western edge of South America, are a continental arc. The volcanoes are the result of the Nazca plate subducting beneath the South American plate (image above).



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

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 (below). Mount St. Helens, which erupted explosively on May 18, 1980, is the most famous and currently the most active of the Cascades volcanoes.

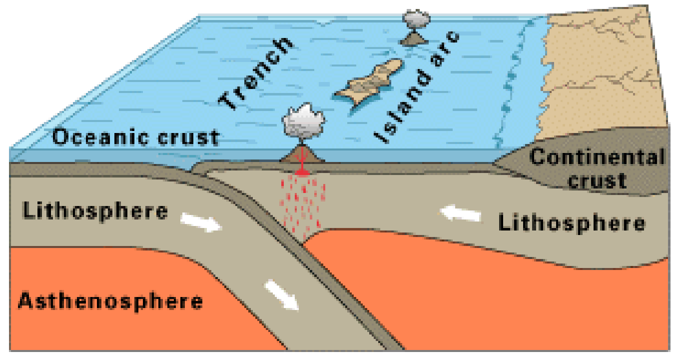


The Cascade Mountains of the Pacific Northwest are formed by the subduction of the Juan de Fuca plate beneath the North American plate. The Juan de Fuca plate forms near the shoreline at the Juan de Fuca ridge.

Sometimes the magma does not rise all the way through the continental crust beneath a volcanic arc. This usually happens if the magma is rich in silica. These viscous magmas form large areas of intrusive igneous rock, called **batholiths**, which may someday be uplifted to form a mountain range. The Sierra

Nevada batholith cooled beneath a volcanic arc roughly 200 million years ago (below) Similar batholiths are likely forming beneath the Andes and Cascades today.

The granite batholith of the Sierra Nevada Mountain range is well exposed here at Mount Whitney, the highest mountain in the range at 14,505 feet and the second highest mountain in North America.

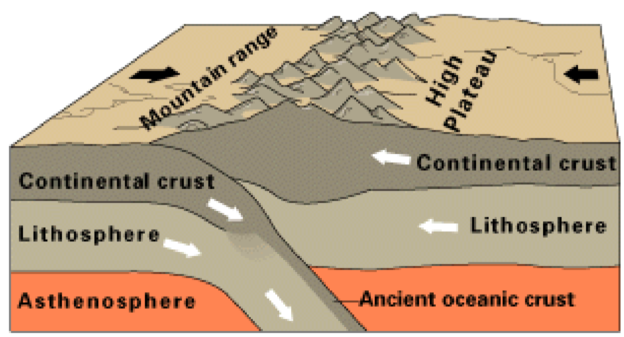


Oceanic-oceanic convergence
A convergent plate boundary subduction zone between two plates of oceanic lithosphere. Melting of the subducting plate causes volcanic activity and earthquakes.

When two oceanic plates converge, the older, denser plate will sink beneath the other plate and plunge into the mantle. As the plate is pushed deeper into the mantle, it melts, which forms magma. As the magma rises it forms volcanoes in a line known as an **island arc**, which is a line of volcanic islands (above).

The Japanese, Indonesian, and Philippine islands are examples of island arc volcanoes. The volcanic islands are set off from the mainland in an arc shape as seen in this satellite image of Japan (below.

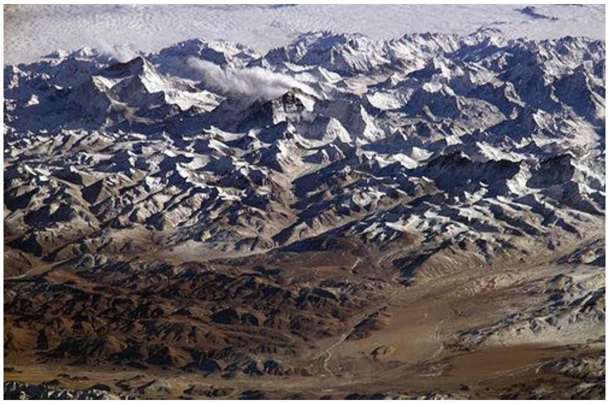
Japan is an island arc composed of volcanoes off the Asian mainland, as seen in this satellite image. North is to the right.



Continental-continental convergence
When two plates of continental crust collide, the material pushes upward forming a high mountain range. The remnants of subducted oceanic crust remain beneath the continental convergence zone.

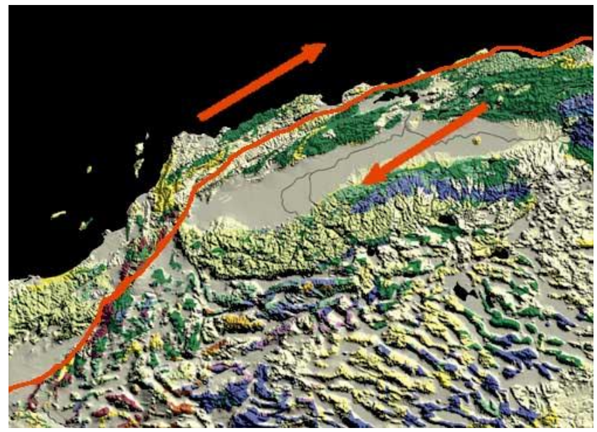
When two continental plates collide, they are too thick to subduct. Just like if you put your hands on two sides of a sheet of paper and bring your hands together, the material has nowhere to go but up (above)! **Some of the world's largest mountains ranges are created at continent-continent convergent plate boundaries**. In these locations, the crust is too thick for magma to penetrate so there are no volcanoes, but there may be magma. Metamorphic rocks are common due to the stress the continental crust experiences. As you might think, with enormous slabs of crust smashing together, continent-continent collisions bring on numerous earthquakes.

The world's highest mountains, the Himalayas, are being created by a collision between the Indian and Eurasian plates (below). The Appalachian Mountains are the remnants of a large mountain range that was created when North America rammed into Eurasia about 250 million years ago.



The Himalaya Mountains are the result of the collision of the Indian Plate with the Eurasian Plate, seen in this photo from the International Space Station. The high peak in the center is world's tallest mountain, Mount Everest (29,035 feet).

Transform Plate Boundaries



At the San Andreas Fault in California, the Pacific Plate is sliding northeast relative to the North American plate, which is moving southwest. North is to the right.

Transform plate boundaries are seen as **transform faults**. At these earthquake faults, two plates move past each other in opposite directions. Where transform faults bisect continents, there are massive earthquakes. The world's most notorious transform fault is the 800 mile)long San Andreas Fault in California (above). This is where the Pacific and North American plates grind past each other, sometimes with disastrous consequences.

California is very geologically active. A transform plate boundary creates the San Andreas Fault. A convergent plate boundary between an oceanic plate and a continental plate creates the Cascades volcanoes. Just offshore, the Juan de Fuca ridge is subducting beneath the North American plate at a divergent plate boundary.

Key Terms:

batholith
An enormous body of granitic rock that is formed from a large number of plutons.

continental arc
A line of volcanoes sitting on a continental plate and aligned above a subducting oceanic plate near a deep sea trench.

continental rifting
A divergent plate boundary that forms in the middle of a continent.

convergent plate boundary
A location where two lithospheric plates come together.

divergent plate boundary
A location where two lithospheric plates spread apart.

fault
A fracture along which there has been movement of rock on one or both sides.

plate boundary
A location where two plates come together.

plate tectonics
The theory that the Earth's surface is divided into lithospheric plates that move on the planet's surface. The driving force behind plate tectonics is mantle convection.

subduction
The sinking of one lithospheric plate beneath another.

transform plate boundary
The type of plate boundary where two plates slide past one another.

Review Questions

1. What are the three types of plate boundaries? For each type, what sort of geologic activity do you find?

2. As a working geologist, you come across a landscape with a massive fault zone that produces lots of large earthquakes, but has no volcanoes. What type of plate boundary have you come across?

<u>Lesson 2: Tuesday, April 28</u>

Earth's Changing Surface

Geologists now know that Wegener was right when he said that the continents had once been joined into the supercontinent Pangaea and are now moving apart. Most of the geologic activity that we see on the planet today is due to the interactions of the moving plates. Where plates come apart at a divergent boundary, there is volcanic activity and small earthquakes. If the plates meet at a convergent boundary, and at least one is oceanic, there is a chain of volcanoes and many earthquakes. If both plates at a convergent boundary are continental, mountain ranges grow. If the plates meet at a transform boundary, there is a transform fault. These faults do not have volcanic activity but they have massive earthquakes.

If you look at a map showing the locations of volcanoes and earthquakes in North America, you will see that the plate boundaries are now along the western edge. This geologically active area makes up part of the Pacific Ring of Fire. California, with its volcanoes and earthquakes, is an important part of this region. The eastern edge of North America is currently mostly quiet, although mountain ranges line the area. If there is no plate boundary there today, where did those mountains come from?

Remember that Wegener used the similarity of the mountains in eastern North America, on the west side of the Atlantic, and the mountains in Great Britain, on the eastern side of the Atlantic, as evidence for his continental drift hypothesis. These mountains were formed at a convergent plate boundary as the continents that made up Pangaea came together. So about 200 million years ago these mountains were similar to the Himalaya today (below)!

The Appalachian Mountains of eastern North America were probably once as high as the Himalaya, but they have aged since the breakup of Pangaea.

Before the continents collided they were separated by an ocean, just as the continents rimming the Pacific are now. That ocean crust had to subduct beneath the continents just as the oceanic crust around the Pacific is being subducted today. Subduction along the eastern margin of North America produced continental arc volcanoes. Ancient lava from those volcanoes can be found in the region.

Currently, Earth's most geologically active area is around the Pacific. The Pacific is shrinking at the same time the Atlantic is growing. But hundreds of millions of years ago, that was reversed: the Atlantic was shrinking as the Pacific was growing. What we've just identified is a cycle, known as the **supercontinent cycle**, which is responsible for most of the geologic features that we see and many more that are long gone. Scientists think that the creation and breakup of a supercontinent takes place about every 500 million years.

Intraplate Activity

While it is true that most geological activity takes place along plate boundaries, some is found away from the edges of plates. This is known as **intraplate activity**. The most common intraplate volcanoes are above hotspots that lie beneath oceanic plates. Hotspot volcanoes arise because plumes of hot material that come from deep in the mantle rise through the overlying mantle and crust. When the magma reaches the plate above, it erupts, forming a volcano. Since the hotspot is stable, when the oceanic plate moves over it, and it erupts again, another volcano is created in line with the first. With time, there is a line of volcanoes; the youngest is directly above the hot spot and the oldest is furthest away. Recent research suggests that hotspots are not as stable as scientists once thought, but some larger ones still appear to be.

The Hawaiian Islands are a beautiful example of a chain of hotspot volcanoes. Kilauea volcano on the south side of the Big Island of Hawaii lies above the Hawaiian hot spot. The Big Island is on the southeastern end of the Hawaiian chain. Mauna Loa volcano, to the northwest, is older than Kilauea and is still erupting, but at a lower rate. Hawaii is the youngest island in the chain. As you follow the chain to the west, the islands get progressively older because they are further from the hotspot (below).

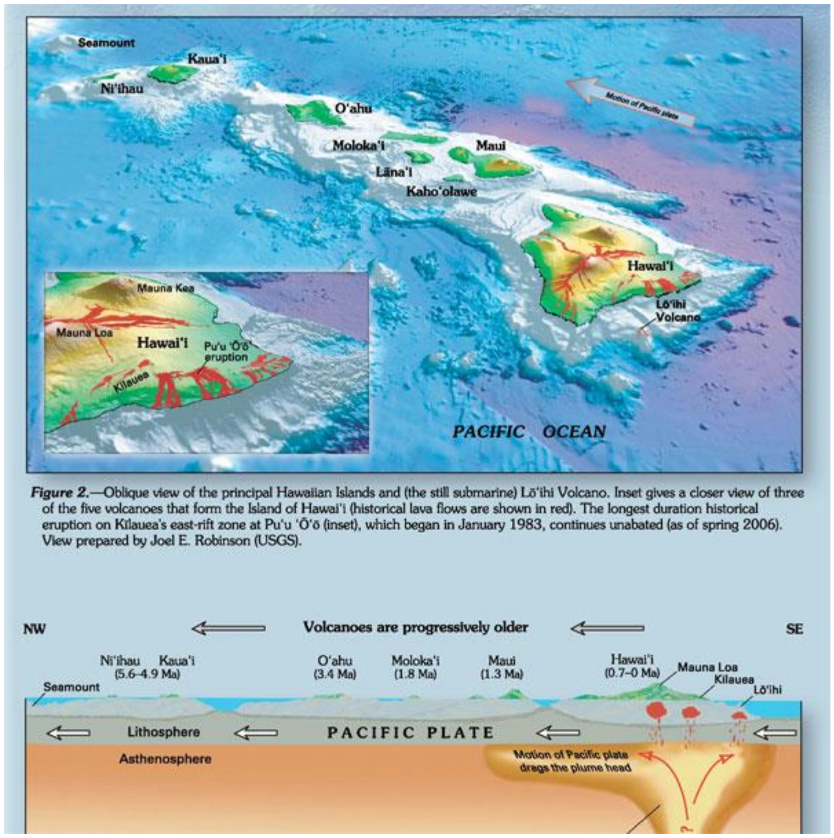
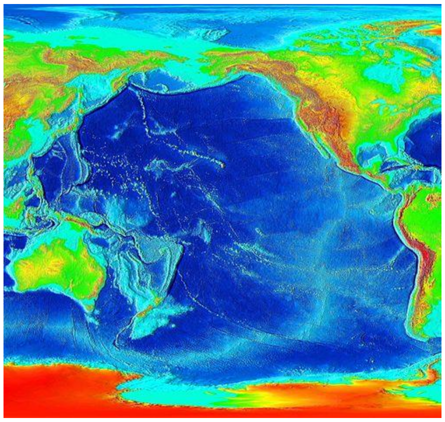


Figure 2.—Oblique view of the principal Hawaiian Islands and (the still submarine) Lō'ihi Volcano. Inset gives a closer view of three of the five volcanoes that form the Island of Hawai'i (historical lava flows are shown in red). The longest duration historical eruption on Kīlauea's east-rift zone at Pu'u 'Ō'ō (inset), which began in January 1983, continues unabated (as of spring 2006). View prepared by Joel E. Robinson (USGS).

This view of the Hawaiian islands shows that the youngest islands are in the southeast and the oldest in the northwest. Kilauea volcano, which makes up the southeastern side of the Big Island of Hawaiian, is located above the Hawaiian hotspot. (https://pubs.usgs.gov/imap/2800/)

The chain continues into the Emperor Seamounts, which are so old they no longer reach above sea level. The oldest of the Emperor seamounts is about to subduct into the Aleutian trench off of Alaska; no one knows how many older volcanoes have already subducted. It's obvious from looking at the Emperor seamounts that the Pacific plate took a large turn. Radiometric dating has shown that turn to have taken place about 43 million years ago (below). The Hawaii hotspot may also have been moving southward during this time. Still, geologists can use some hotspot chains to tell not only the direction but the speed a plate is moving.



The Hawaii-Emperor chain creates a large angular gash across the Pacific basin in this satellite image. The bend in the chain is due to a change in the direction of motion of the Pacific plate 43 million years ago.

Hot spots are also found under the continental crust, although it is more difficult for the magma to make it through the thick crust and there are few eruptions. One exception is Yellowstone, which creates the activity at the Yellowstone hotspot. In the past, the hotspot produced enormous volcanic eruptions, but now its activity is best seen in the region's famous geysers.

Key Terms:

intraplate activity
Geologic activity such as volcanic eruptions and earthquakes that takes place away from plate boundaries.

supercontinent cycle
The cycle in which the continents join into one supercontinent on one side of the planet and then break apart.

Review Questions

1. What is the driving force behind the movement of lithospheric plates on the Earth's surface? About how fast do the plates move?

2. How does the theory of plate tectonics explain the locations of volcanoes, earthquakes and mountain belts on Earth?

<u>Lesson 3: Wednesday, April 29</u>

Stress in the Earth's Crust

When you think about an enormous plates of lithosphere traveling around on the planet's surface, you can probably imagine that the process is not smooth**. Most geological activity takes place where two plates meet, at plate boundaries. Nearly all earthquakes, volcanic eruptions, and mountain building occur at plate boundaries**.

When plates are pushed or pulled, the rock is subjected to **stress**. Stress can cause a rock to change shape or to break. When a rock bends without breaking, it folds. When the rock breaks, it fractures. Mountain building and earthquakes are some of the ways rock responds to stress.

Causes and Types of Stress

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

- A deeply buried rock is pushed down by the weight of all the material above it. Since the rock is trapped in a single spot, it is as if the rock is being pushed in from all sides. This pushing causes the rock to become compressed, but it cannot deform because there is no place for it to move. This is called **confining stress**.
- **Compression** is the stress that squeezes rocks together. Compression causes rocks to fold or fracture (or break)(below). When cars driving around a parking lot collide, compression causes the cars to crumple. Compression is the most common stress at convergent plate boundaries.

- Rocks that are being pulled apart are under **tension** (also called extension). Tension causes rocks to lengthen or break apart. Tension is the major type of stress found at divergent plate boundaries.
- When forces act parallel to each other but in opposite directions, the stress is called **shear** (below). Shear stress causes two planes of material to slide past each other. This is the most common stress found at transform plate boundaries.

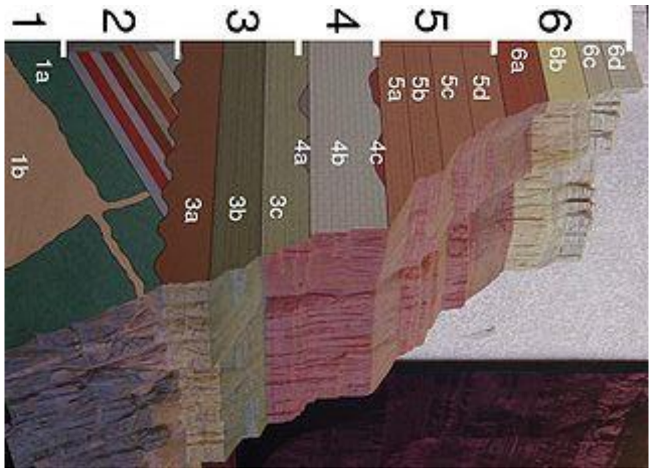
Stress caused these rocks to fracture.

Rocks showing shear. Pen for scale. The stress has caused a fracture (break or crack) just below the pen. The rock above the fracture is moving in the opposite direction as the rock below the fracture.

If the amount of stress on a rock is greater than the rock's internal strength, the rock bends elastically. This type of change is called elastic because when the stress is eliminated the rock goes back to its original shape, like a squeezed rubber ball. If more stress is applied to the rock, it will eventually bend plastically. In this instance, the rock bends, but does not return to its original shape when the stress is removed. If the stress continues, the rock will **fracture**; that is, it breaks. When a material changes shape, it has undergone **deformation**. Deformed rocks are common in geologically active areas

Geologic Structures

Sedimentary rocks are often found in layers. This is most magnificently displayed at the Grand Canyon, where the rock layers are exposed like a layer cake (below). Each layer is made of sediments that were deposited (laid down) in a particular environment, perhaps a lake bed, shallow offshore region, or a sand dune. Sediments are deposited horizontally, the lowest layers are the oldest and the highest layers are the youngest. Some volcanic rocks, like ash falls, resemble sedimentary rocks because they are laid down horizontally as well.

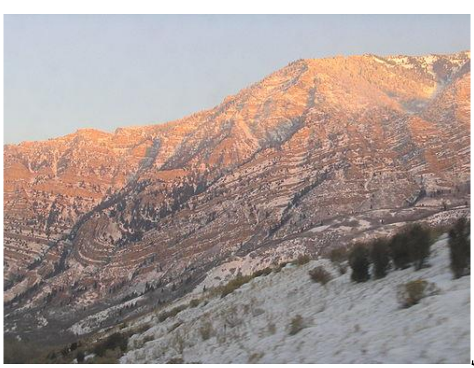


Geologic column of the Grand Canyon. The sedimentary rocks of groups 3 through 6 were deposited horizontally and remain horizontal. Group 2 rocks were deposited horizontally but have been tilted. Group 1 rocks are not sedimentary. The rock layers at the bottom of the stack are the oldest while the ones at the top are the youngest.

It's important to remember that sediments are deposited horizontally when thinking about geologic structures. This is because you can trace the deformation the rock has experienced by seeing how it differs from its original horizontal, oldest-on-bottom, position. Geologic structures are the folds, joints, and faults that are caused by stresses.

Folds

When rocks experiencing compressive stress deform plastically, the rocks crumple into **folds**. Folds are just bends in the rock. You can easily make folds by placing your hands on opposite edges of a piece of cloth and pushing the cloth together. In layered sedimentary rocks, you can trace the folding of the layers with your eyes (Figure 7.6).

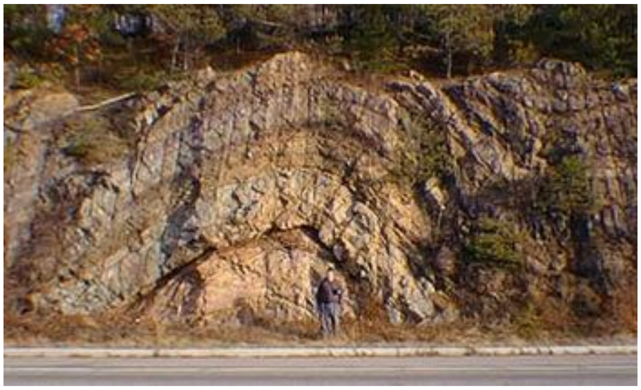


Snow accentuates the fold exposed in these rocks in Utah.

Once rocks are folded, they do not return to their original shape. If the rocks experience more stress, they may undergo more folding, or even fracture. Folds often occur in groups.

There are **three types of folds**: monoclines, anticlines, and synclines. A **monocline** is a simple bend in the rock layers so that they are no longer horizontal but are inclined (below In a monocline, the oldest rocks are at the bottom and the youngest are at the top. In the Grand Canyon geologic column, the rocks in group 2 have been folded into a monocline.

A monocline can be spotted in the photo taken at Colorado National Monument where the rocks plunge toward the ground.



An anticline exposed in a road cut in New Jersey.

An **anticline** is a fold that arches upward. The rocks dip away from the center of the fold (above).

The oldest rocks are found at the center of an anticline and the youngest ones are draped over them at the top of the structure.

When rocks arch upward to form a circular structure, that structure is called a **dome**. If the top of the dome is eroded off, the oldest rocks will be exposed at the center.

A **syncline** is a fold that bends downward. The rocks curve down to a center (below).

A syncline in Rainbow Basin in California.

In a syncline, the youngest rocks are at the center and the oldest at the outsides.

Key Terms

anticline
A fold that arches upward, in which the older rocks are in the center and the younger rocks are at the outside.

compression
Stresses that push toward each other. This causes a decrease in the space a rock takes up.

confining stress
The stress due to the weight of material above a buried object. Confining stress reduces volume but causes no deformation.

deformation
The change of shape that a rock undergoes when it has been altered by stresses. Also called strain.

monocline
A bend in a set of rocks that causes them to be inclined relative to the horizontal.

shear
Stresses that pushed past each other in opposite directions.

syncline
A fold in rocks that bends downward, in which the youngest rocks are at the center.

Review Questions

1. What type of stress is shear and at what type of plate boundary is it found?

2. You are a geologist walking around in the field when you spot a monocline. You inspect the fossils in each layer of the rock- where would you expect to find the oldest fossils and where would expect to find the youngest?

<u>Lesson 4: Thursday, April 30</u>

Faults

A rock under enough stress will fracture, or break. When there is a block of rock still standing on either side of a fracture line, as shown in the image below, the fracture is called a **joint**. One example of how joints form is when confining stress is removed from an underlying granite.

Granite rocks showing horizontal and vertical jointing. Over millions of years, wind and water have broken down the granite, enlarging the joints and making the pattern of jointing more obvious.

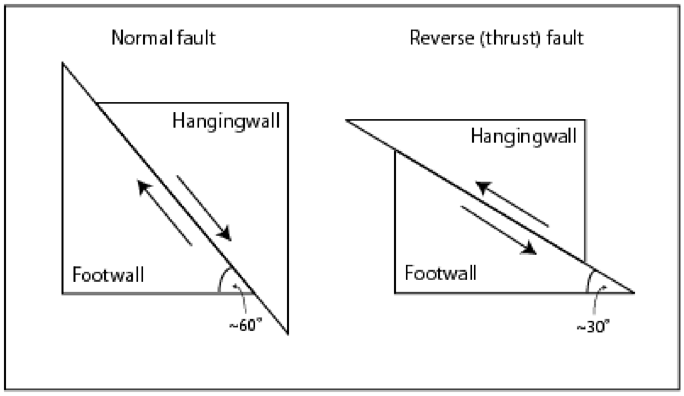
If the blocks of rock on one or both sides of a fracture move, the fracture is called a **fault**. **Earthquakes** happen when there are sudden motions along faults. When rocks break and move suddenly, the energy released causes an earthquake. Faults may occur at the Earth's surface or deeper in the crust. Faults are found alone or in clusters, creating a **fault zone**.

A small fault visible cutting through the rock from the bottom left towards the upper right.

Slip is the distance rocks move along a fault. Slip is said to be relative, because there is usually no way to know whether both sides moved or only one. The only thing we can say for sure, is that one block of rock moved passed the other. 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. Slip can be up or down the fault plane.

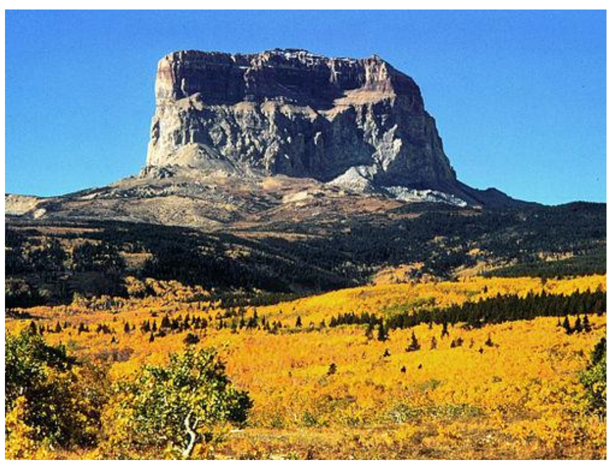
In the following images, you are looking at the fault straight on, as if you are standing on a road and the fault is exposed in the road cut. The hanging wall is the rock that overlies the fault, while the **footwall** is beneath the fault. You can remember which part is the hanging wall and which is the footwall by imagining you are walking along a fault. The hanging wall is above you and the footwall is where your feet would be. Miners often extract mineral resources along faults. They used to hang their lanterns above their heads. That is why these layers were called the hanging wall.

In **normal faults**, the hanging wall drops down relative to the footwall. Normal faults are caused by tensional stress that pulls the crust apart, causing the hanging wall to slide down relative to the footwall. When compression squeezes the crust into a smaller space, the hanging wall pushes up relative to the footwall. This creates a **reverse fault** (below).



The two types of dip-slip faults. In normal faults the hanging wall drops down relative to the footwall. In reverse faults, the footwall drops down relative to the hanging wall.

A type of reverse fault is called a **thrust fault**. At a thrust fault, the fault plane angle is nearly horizontal and rocks can slip many miles along thrust faults.

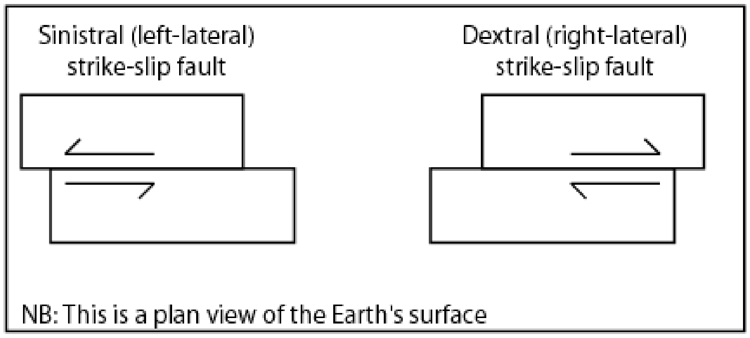


The result of a thrust fault. Stresses in the lithosphere caused ancient crust to be thrust more than 50 miles over much younger Cretaceous rocks. The result is that the upper rocks at the Lewis Overthrust are more than 1 billion years older than the lower rocks.

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

Strike-slip fault

A **strike-slip fault** is a dip-slip fault where the dip of the fault plane is vertical. Strike-slip faults result from shear stresses. If you stand with one foot on one side and one foot on the other side of a strike-slip fault, the block on one side will be moving toward you and the block on the other side will be moving away from you. If the block moving toward you is the block that your right foot is on, the fault is known as a right-lateral strike-slip fault. If the block moving toward you is the one your left foot is on, the fault is a left-lateral strike-slip fault .



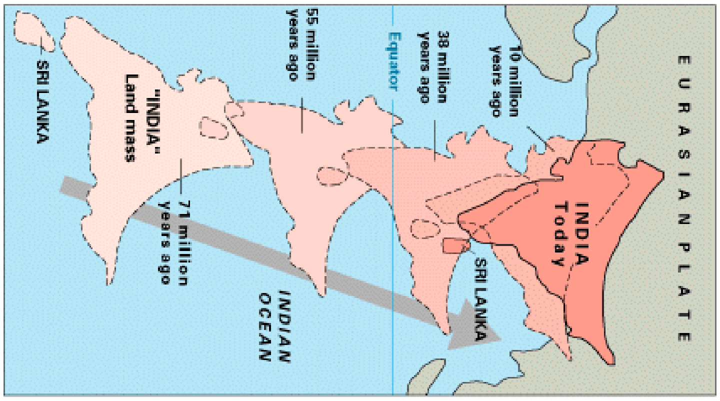
The two types of strike slip faults. Note the Latin roots of the names.

The world's most famous strike-slip fault is the San Andreas Fault in California, which is a right-lateral strike slip fault. Because the San Andreas is a plate boundary, it is also called a transform fault. The portion west of the San Andreas Fault is moving northeastward and someday Los Angeles and San Francisco will be side by side, but not for millions and millions of years.

The San Andreas is a transform fault separating the Pacific from North American Plates. The fault creates a scar on the land.

A fault may have broken and moved only once, but most faults are active repeatedly. There are two reasons for this. One is that plate tectonic processes continue in the same locations. The other is that a fault is a zone of weakness in the crust, and it is easier for movement to take place along an existing fault than for a new fault to be created in solid crust.

Stress and Mountain Building



The Indian plate collides with the Eurasian plate to form the world's largest mountain range, the Himalayas. North is to the right

Most of the world's largest mountains result from compression at convergent plate boundaries. The largest mountains arise when two continental plates smash together. Continental lithosphere is too buoyant to get pushed down into the mantle or subduct, so when the plates smash together, the crust crumples upwards, causing **uplift**. The stresses cause folds, reverse faults, and thrust faults, all of which allow the crust to grow thicker and rise upwards.

The world's highest mountain range, the Himalayas, is growing from the collision between the Indian and the Eurasian plates. About 80 million years ago, the Indian plate was separated from the Eurasian plate by an ocean (image above). As the Indian plate moved northward, a subduction zone formed beneath Eurasia. The seafloor was subducted and caused the formation of a set of continental arc volcanoes. When the oceanic lithosphere was completely subducted, about 40 million years ago, the Indian plate began to collide with the Eurasian plate. Some of the Indian plate was thrust beneath Asia and some of Asia was thrust onto India. Rock also folded, which thickened the crust and formed the mountains. In places, the old seafloor that was between the two slabs of continental crust have been thrust over the Asian continent and are found high in the Himalayas.

Key Terms

dip-slip fault
A fault in which the dip of the fault plane is inclined relative to the horizontal.

fault zone
A network of related faults.

footwall
The block of rock that is beneath a dip-slip fault.

joint
A break in rock caused by stresses along which there is no movement.

normal fault
A dip-slip fault in which the hanging wall drops down relative to the footwall.

reverse fault
A dip-slip fault in which the hanging wall pushes up relative to the footwall.

slip

The distance rocks move along a fault.

strike-slip fault

A fault in which the dip of the fault plane is vertical.

thrust fault

A reverse fault in which the dip of the fault plane is nearly horizontal.

uplift

The upward rise of rock material.

Review Questions

1. California is plagued by earthquakes along the San Andreas Fault zone. Why are there so many earthquakes and why are they so severe?

2. Describe the plate tectonics processes and associated stresses that have led to the formation of the Himalayas, the world's largest mountain range.

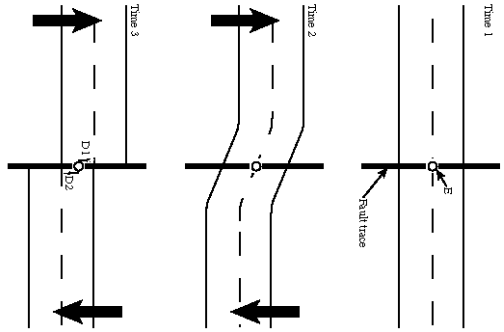
Lesson 4: Friday, May 1

Earthquakes

An **earthquake** is sudden ground movement caused by the sudden release of energy stored in rocks. The earthquake happens when so much stress builds up in the rocks that the rocks rupture. An earthquake's energy is transmitted by seismic waves. Each year there are more than 150,000 earthquakes strong enough to be felt by people and 900,000 recorded by seismometers.

Causes of Earthquakes

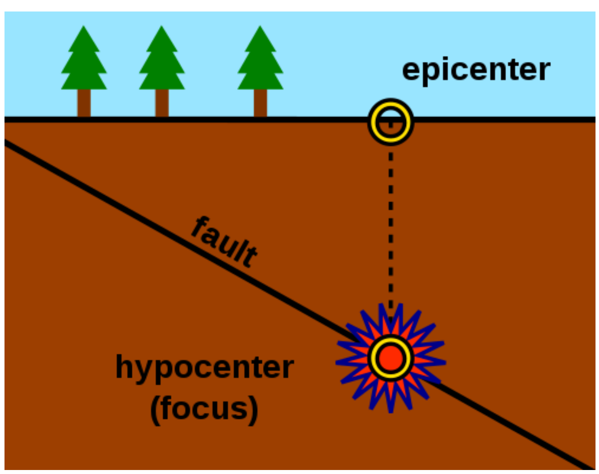
Almost all earthquakes occur at plate boundaries. All three boundary types—divergent, convergent and transform—are prone to earthquake activity. Plate tectonics causes the lithospheric plates to move. As you might imagine, having giant slabs of lithosphere moving about on a spherical shape is not smooth. When stresses build, they first cause the rocks to bend elastically. If the stresses persist, energy continues to build in the rocks. When the stresses are greater than the internal strength of the rocks, the rocks snap. Although they return to their original shape, the stresses cause the rocks to move to a new position. This movement releases the energy that was stored in the rocks, which creates an earthquake. During an earthquake the rocks usually move several centimeters or maybe as much as a few meters. This description of how earthquakes occur is called **elastic rebound theory.**



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 return to their original shape but they move (Time 3). This motion releases the energy that creates an earthquake.

The point where the rock ruptures is usually below the Earth’s surface. The point of rupture is called the earthquake's **focus**. The focus of an earthquake can be shallow - less than 70 kilometers intermediate - 70 to 300 kilometers deep - greater than 300 kilometers. About 75% of earthquakes have a focus 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 the Earth's surface where people live.

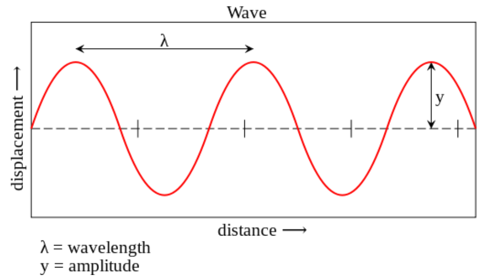
Just above the focus on the land surface is the earthquake's **epicenter**.



A vertical cross section through the crust shows an earthquake's focus below ground and its epicenter at the ground surface.

Seismic Waves

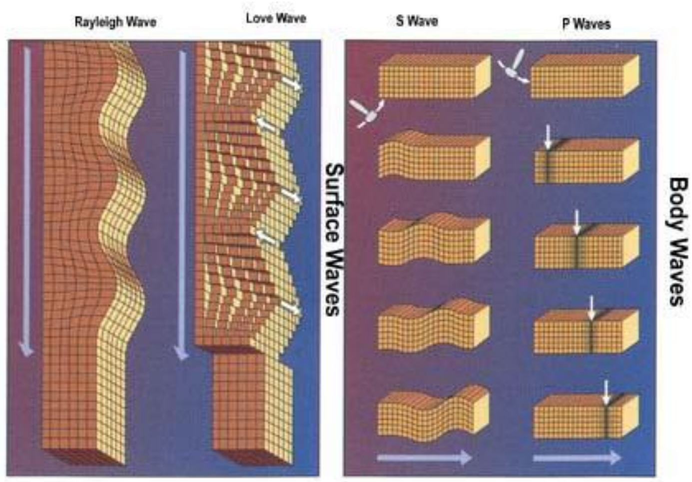
Energy is transmitted in waves. Every wave has a high point called a **crest** and a low point called a **trough**. The height of a wave from the center line to its crest is its **amplitude**. The distance between waves from crest to crest (or trough to trough) is its **wavelength**.



The energy from earthquakes (and also from explosions) travels in waves called **seismic waves**. Other types of waves transmit other types of energy; for example, sound waves transmit a child's laughter and other sounds. The study of seismic waves is known as **seismology**. Seismologists use seismic waves to learn about earthquakes and also about the Earth's interior.

Seismic waves move outward in all directions away from their source. There are two major types of seismic waves. **Body waves** travel through the solid body of the Earth from the earthquake's focus throughout the Earth's interior and to the surface. **Surface waves** just travel along the ground surface. The different types of seismic waves travel at different speeds in different materials. All seismic waves travel through rock, but not all travel through liquid or gas. In an earthquake, body waves are responsible for sharp jolts. Surface waves are responsible for rolling motions. Surface waves do most of the damage in an earthquake.

Body Waves



The top figure shows how body waves, including P-waves and S-waves, move through a grid. The bottom figure shows how surface waves move. The two types of surface waves are Love waves and Rayleigh waves.

There are two types of body waves – **primary waves (P-waves)** and **secondary waves (S-waves)**. These waves travel through the Earth's interior. P-waves are the fastest at about 6 to 7 kilometers (about 4 miles) per second. They are named primary waves because they are the first waves to reach a seismometer. S-waves are slower and so are the second waves to reach a seismometer. Body waves move at different speeds depending on the type of material they are passing through.

P-waves are **longitudinal** waves. They move material forward and backward in the same direction that they are traveling. This motion resembles a spring squeezing and unsqueezing. The material returns to its original size and shape after the P-wave goes by. For this reason, P-waves are not the most damaging earthquake waves. P waves can travel through solids, liquids and gases.

S-waves are transverse waves, that move up and down. Their oscillations are perpendicular to the direction the wave is traveling. In a rock, this motion produces shear stresses. S-waves are about half as fast as P-waves, traveling at about 3.5 km (2 miles) per second. S-waves can only move through solids because liquids and gases have no shear strength.

Surface Waves

Surface waves travel along the ground outward from an earthquake's epicenter. Surface waves are the slowest of all seismic waves, traveling at 2.5 km (1.5 miles) per second. There are two types of surface waves. **Love waves** move side-to-side much like a snake. **Rayleigh waves** move in rolls, like ocean swells. These waves cause objects to fall and rise, while swaying back and forth. These motions cause damage to rigid structures during an earthquake.

Minor Assessment:

Using this week's lessons, pick 3 Geological phenomena (Earthquakes/Faults/Anticlines/convergent plate boundaries, etc.) and explain how each one ultimately connects to the theory of plate tectonics. (4-6 sentences)