Earthquakes and Seismic Waves

Designed to meet South Carolina Department of Education 2005 Science Academic Standards

Department of Natural Resources

South Carolina Geological Survey

Table of Contents

Earthquakes: Folds and Faults

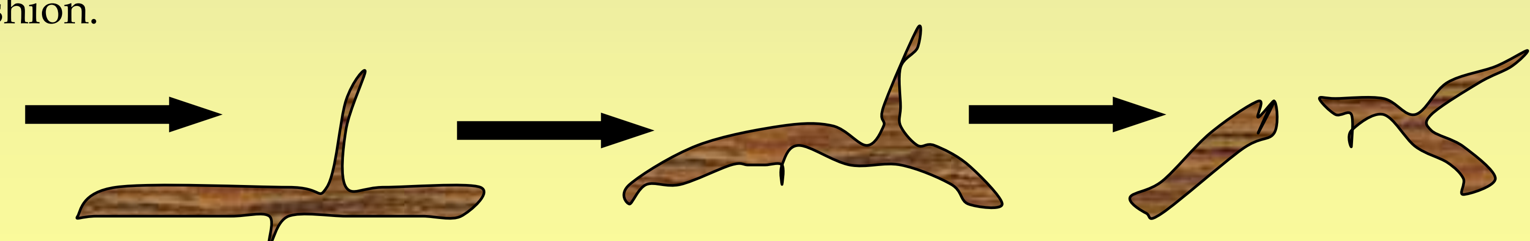
Standard 8-3.8: Explain how earthquakes result from forces inside Earth.

- Plate tectonics cause many of the physical features that we see on earth today like volcanoes and earthquakes, but also other geologic features like faults. **A geologic fault** is a fracture in the earth's crust causing loss of cohesion and accompanied by displacement along the fracture.

- At the Earth's surface, rock will break (brittle behavior) when put under large amounts of stress. Deep within the earth, however, rocks flow plastically (ductile behavior). The force, or *stress,* exerted on the rock may cause a change in shape or volume of the rock, called *strain*.

- Because rocks can "flow" when they are deep within the earth, they are considered ductile. They pass the point of ductile behavior closer to the earth's surface, where the rocks behave more brittle. When rocks pass from this ductile state to a brittle state, the rocks may break along a surface called a **fault**. The sudden release of stored strain energy causes an **earthquake.**

- For example, a dried tree branch is an example of brittle deformation. If you begin to bend a branch, it will only bend to a certain limit, or its elastic limit. Once it passes the elastic limit, it will break in a brittle fashion.



Tree branch

Tree branch bending elastically

Tree branch reaching it's elastic limit and breaking along a surface

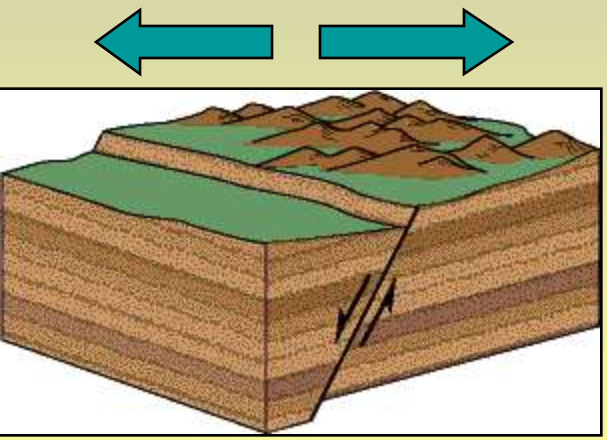
Table of Contents

Standard 8-3.8

Fault Types

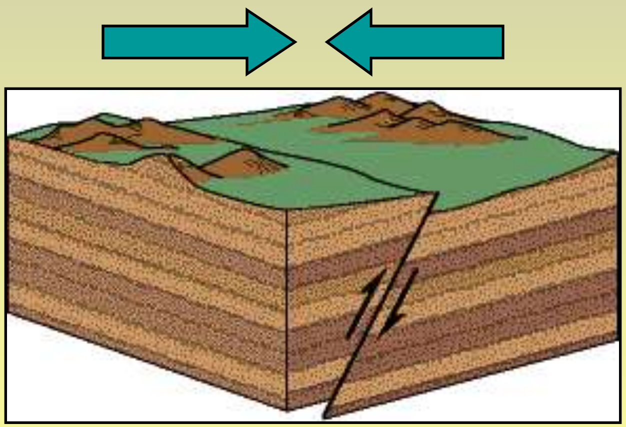
Fault surfaces are surfaces along which rocks move under, over, or past each other. Rocks may get "stuck" along the fault surface, causing a build-up of strain energy, and resulting in an earthquake when the rocks break free of each other. There are **3 types** of stress that can affect rocks, resulting in 3 different types of faults:

1. **Tension** pulls rocks apart resulting in normal faults



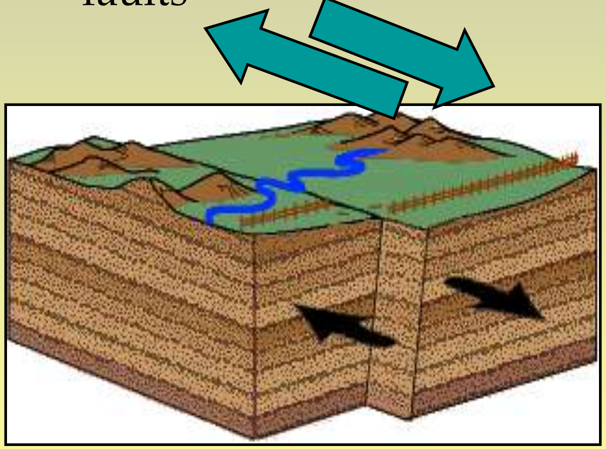
(Credit: U.S. Geological Survey Department of the Interior/USGS)

2. **Compression** squeezes rock together resulting in reverse faults



(Credit: U.S. Geological Survey Department of the Interior/USGS)

3. **Shear stress** causes rocks to slide past each other resulting in strike-slip faults



(Credit: U.S. Geological Survey Department of the Interior/USGS)

Table of Contents

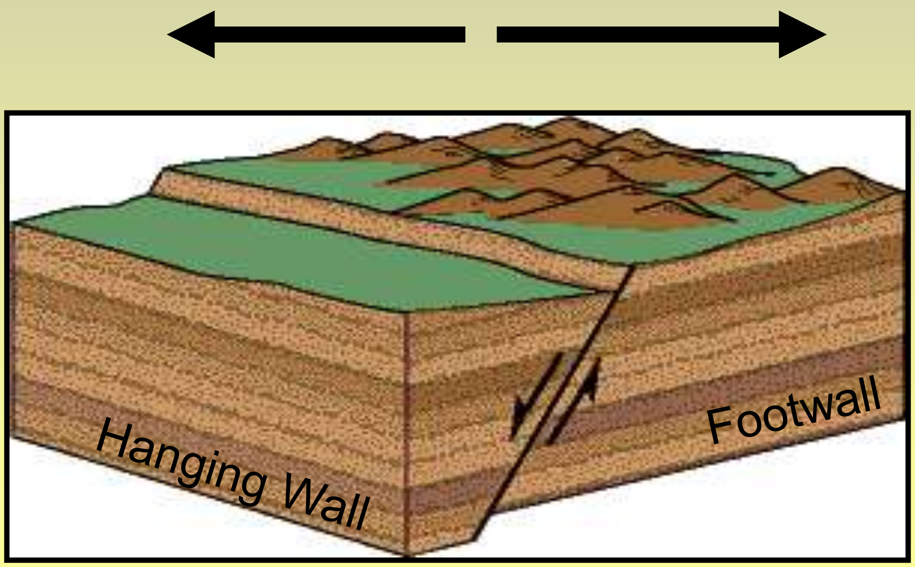
Faults: Normal Faults

❖ Faults caused by blocks of crust pulling apart under the forces of tension are called **<u>normal faults.</u>** Entire mountain ranges can form through these processes and are known as fault block mountains (examples: Basin and Range Province, Tetons).

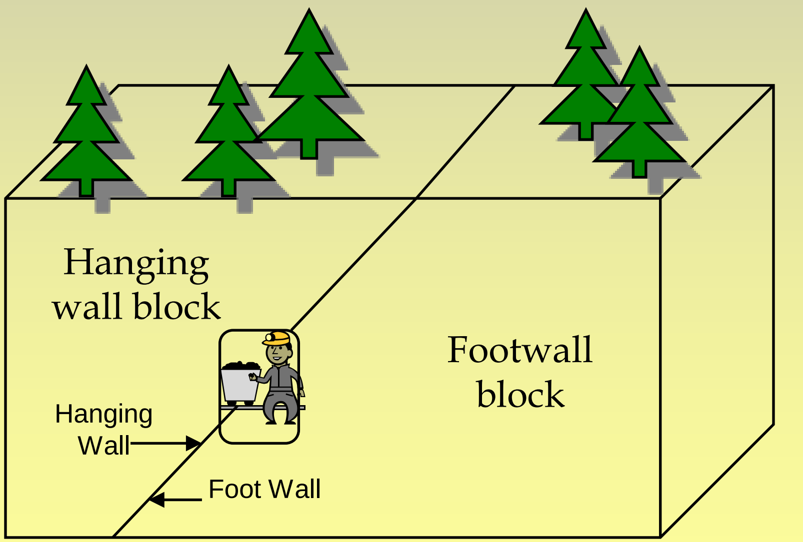
❖ In a normal fault, the hanging-wall block moves down relative to the foot-wall block.

❖ The footwall is the <u>underlying</u> surface of an inclined fault plane.

❖ The hanging wall is the <u>overlying</u> surface of an inclined fault plane.



Relative movement of two blocks indicating a normal fault. *(Credit: Modified after U.S. Geological Survey Department of the Interior/USGS)*



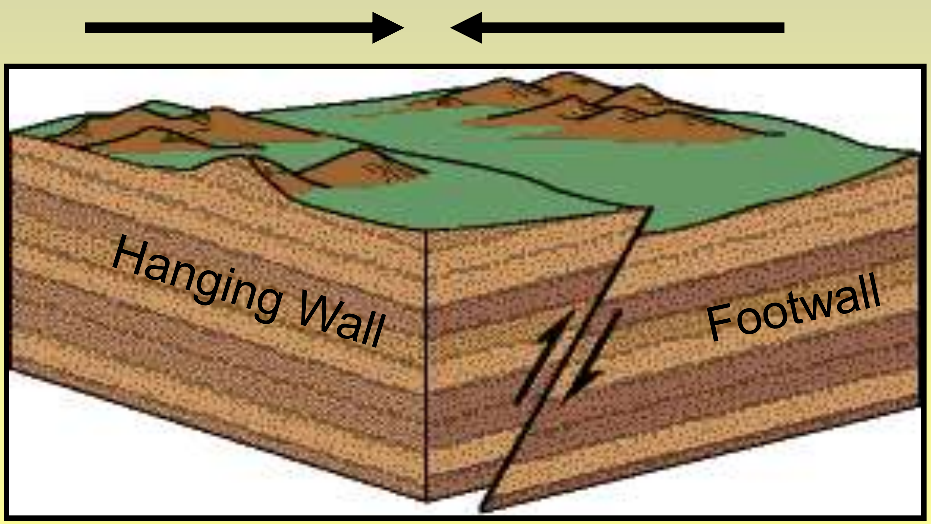
Diagrammatic sketch of the two types of blocks used in identifying normal faults.

Faults: Reverse Faults

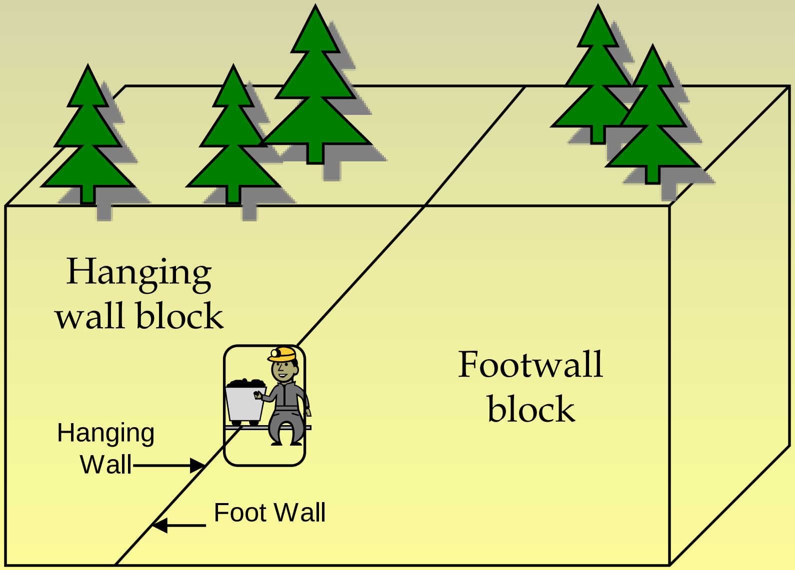
❖ Faults caused by blocks of crust colliding under the forces of compression are called reverse faults.

❖ Reverse faults are a prevalent feature in continent-continent collisions. Usually, there is also accompanying folding of rocks.

❖ During reverse faulting, the hanging wall block moves upward (and over) relative to the footwall block.



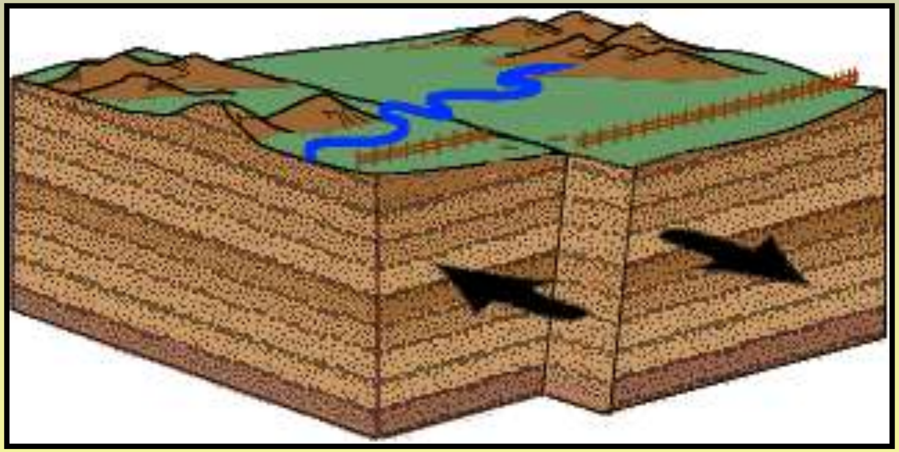
Relative movement of two blocks indicating a reverse fault. *(Credit: U.S. Geological Survey Department of the Interior/USGS)*



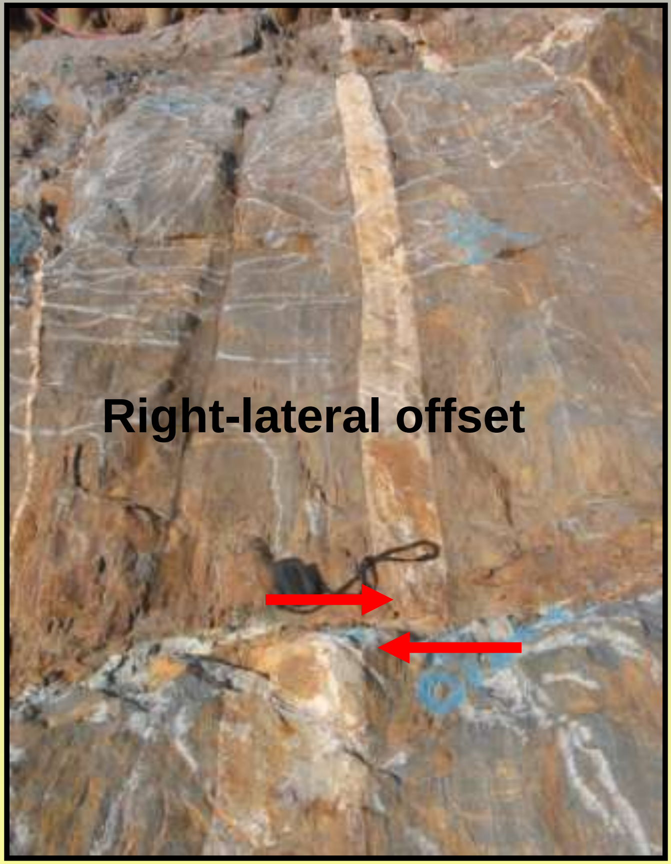
Diagrammatic sketch of the two types of blocks used in identifying reverse faults.

Faults: Strike-slip faults

- Strike-slip faults occur when two blocks move in horizontal but opposite directions of each other.
- Depending on the direction of offset, it can be a "right-lateral offset" or a "left-lateral offset."



In the example above, the fence has been offset to the right, therefore it is called a right lateral strike-slip fault. *(Credit: U.S. Geological Survey Department of the Interior/USGS)*



The photograph above displays a light-colored pegmatite vein offset to the right in a schistose matrix. ***Photo courtesy of K. McCarney-Castle.***

Folding

- During mountain building processes rocks can undergo folding as well as faulting.
- Sometimes rocks deform ductilely, particularly if they are subjected to heat and pressure. At elevated temperature and pressure within the crust, folds can form from compressional forces.
- Entire mountain rages, like the Appalachians, have extensive fold systems.
- The conditions of whether a rock faults or folds vary with temperature, pressure, rock composition, and strain rate. In the same location, some rocks can fold while others fault. Often folding is just a precursor to faulting.

Z-fold in schist with white felsic dike (hammer for scale). Near Lake Murray, S.C.   *Photo courtesy of K. McCarney-Castle*

Large fold in outcrop (geologists for scale). Near Oakridge, Tennessee, Appalachian Mtns. *Photo courtesy of K. McCarney-Castle.*

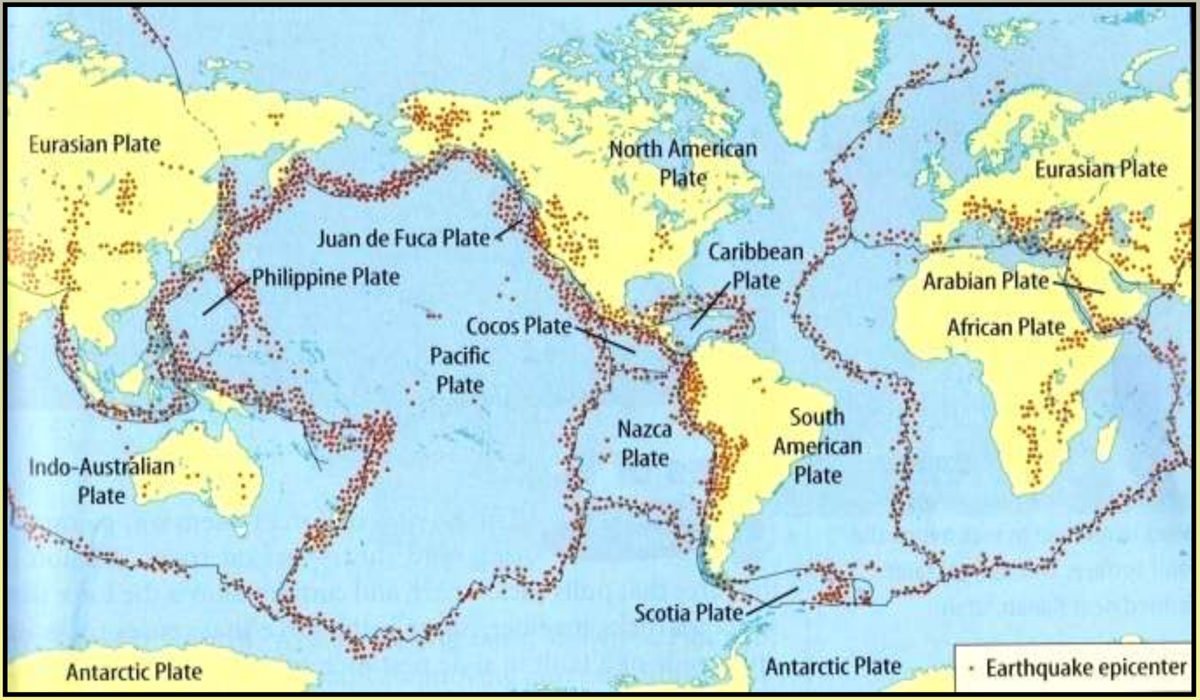
Table of Contents

What is an earthquake?

- Earthquakes occur within the Earth's crust along faults that suddenly release large amounts of energy that have built up over long periods of time.

- The shaking during an **earthquake** is caused by seismic waves. **Seismic waves** are generated when rock within the crust breaks, producing a tremendous amount of energy. The energy released moves out in all directions as waves, much like ripples radiating outward when you drop a pebble in a pond.

- The Earth's crust near tectonic plate edges are forced to bend, compress, and stretch due to the internal forces within the earth, causing earthquakes.



Earthquake locations around the world and their correlation to plate boundaries. Plate boundaries are outlined by red circles, which indicate past earthquake epicenters. *Credit: McGraw Hill/Glencoe, 1st ed., pg. 143.*

- Nearly all earthquakes occur at plate boundaries.

Seismic Waves

Standard 8-3.2: Explain how scientists use seismic waves – primary, secondary, and surface waves – and Earth's magnetic fields to determine the internal structure of Earth

- Seismic waves are generated by the release of energy during an earthquake. They travel through the earth like waves travel through water.
- The location within the Earth where the rock actually breaks is called the **focus** of the earthquake. Most foci are located within 65 km of the Earth's surface; however, some have been recorded at depths of 700 km. The location on the Earth's surface directly above the focus is called the **epicenter**.
- The study of seismic waves and earthquakes is called seismology, which is a branch of geophysics.

Two types of seismic waves are generated at the earthquake focus:

1. **Body waves** spread outward from the focus in all directions.
2. **Surface waves** spread outward from the epicenter to the Earth's surface, similar to ripples on a pond. These waves can move rock particles in a rolling motion that very few structures can withstand. These waves move slower than body waves.

Standard 8-3.2

Seismic Waves, continued

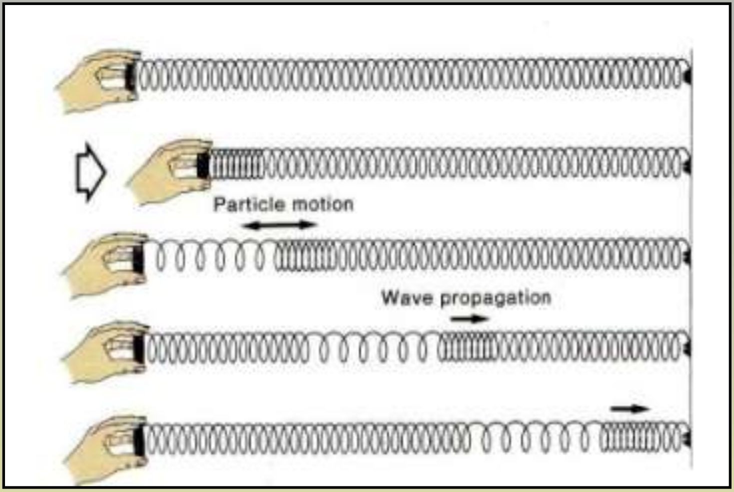
There are two types of Body Waves:

1. **<u>Primary Wave (P wave):</u>** Compressional wave (travels in the same direction the waves move). Example: A slinky.

   * Very fast (4-7 km/second)

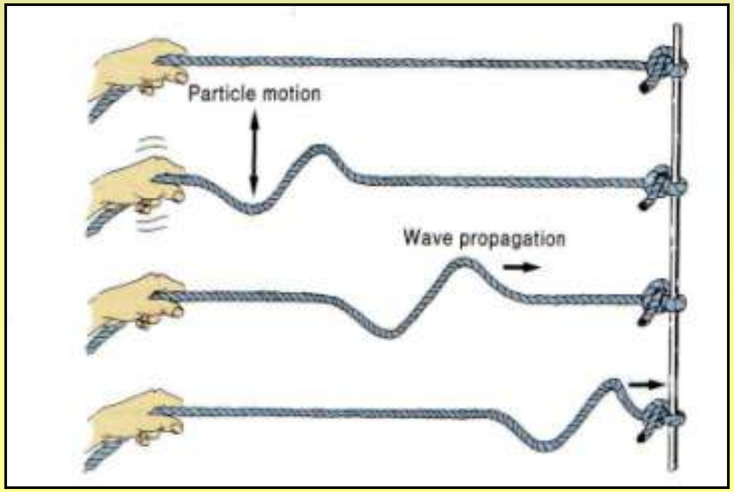
   * Can pass through a fluid (gas or liquid)

   * Arrives at recording station first



2. **<u>Secondary Wave (S wave):</u>** Transverse wave (travels perpendicular to the wave movement). Example: Shaking a rope.

   - Slower moving (2-5 km/second)
   - Caused by a shearing motion
   - Cannot pass through a fluid (gas or liquid)



Standard 8-3.2

Seismic Waves, continued

- **Surfaces waves** are produced when earthquake energy reaches the Earth's surface. Surface waves moves rock particles in a rolling and swaying motion, so that the earth moves in different directions.
- These are the slowest moving waves, but are the most destructive for structures on earth.

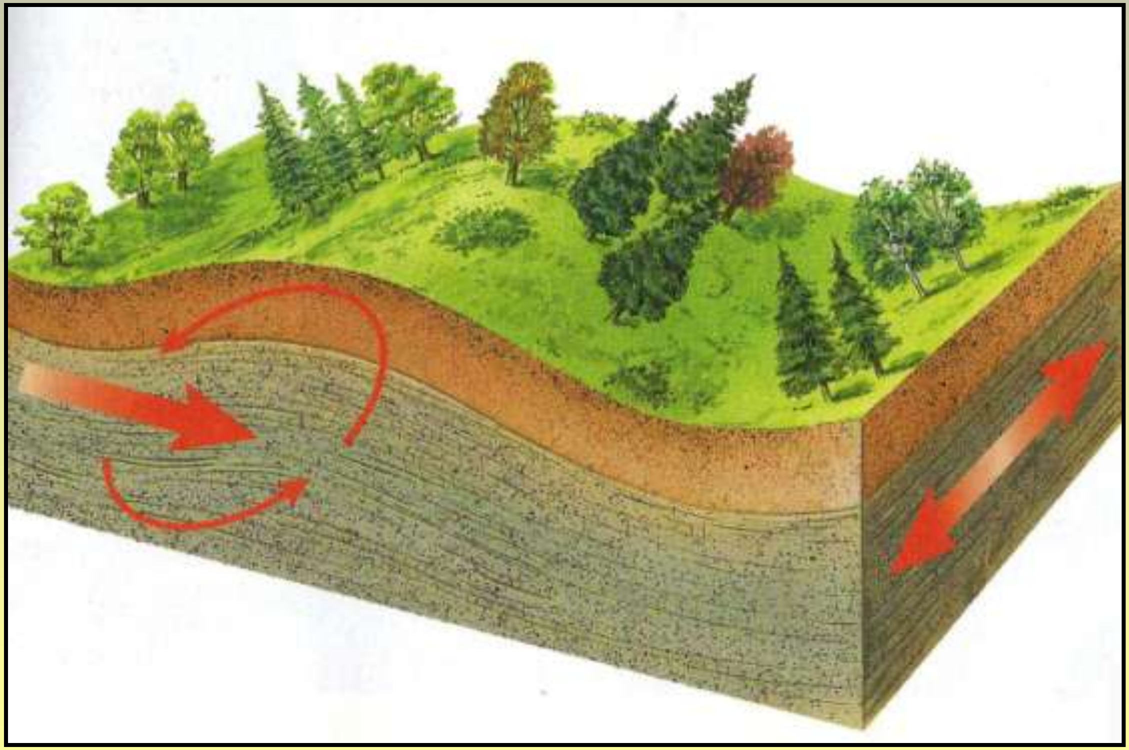


Diagram representing the damaging back-and-forth motion of a surface wave. (*Credit: McGraw Hill/Glencoe, 1st ed., pg. 163)*

Standard 8-3.2

Mapping the earth: Seismic waves

- The deepest well ever drilled was 12 kilometers in Russia. The Earth's radius is 6,370 km, so drilling can barely "scratch the surface."
- A branch of geology called seismology lets us obtain information about the interior of the Earth without directly observing it. Seismologists apply principles and laws of physics to study the internal structure of the earth.
- Geophysics includes the study of seismic waves and the Earth's magnetic and gravity fields and heat flow. Because we cannot directly observe the Earth's interior, geophysical methods allow us to investigate the interior of the Earth by making measurements at the surface. Without studying these things, we would know nothing of the Earth's internal structure.
- Keeping in mind that seismic waves have similar properties to other types of waves (e.g. light waves), the wave properties of reflection and refraction are useful for learning about the Earth's interior. Results of early studies showed that the internal structure of the Earth consists of distinct layers:

1. **Seismic reflection:** Seismic waves bounce (reflect) off rock boundaries of different rock type, and their travel times are recorded on a seismogram. The seismogram records the time it took for the waves to travel to the boundary, reflect off of it and return to the surface. Seismologists can measure the time this takes and calculate the depth to the boundary.

Seismic waves reflect off of a rock boundary in the earth and return to a seismograph station on the surface.

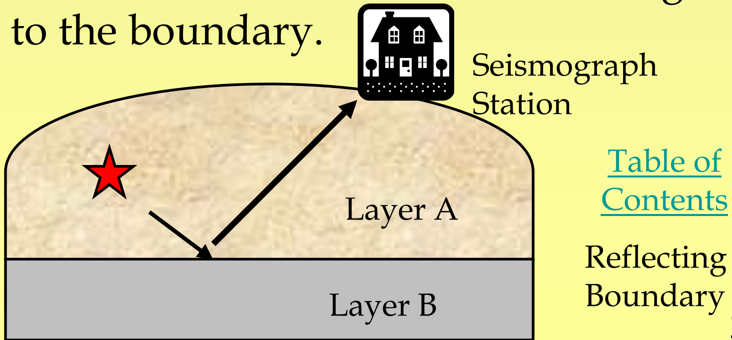
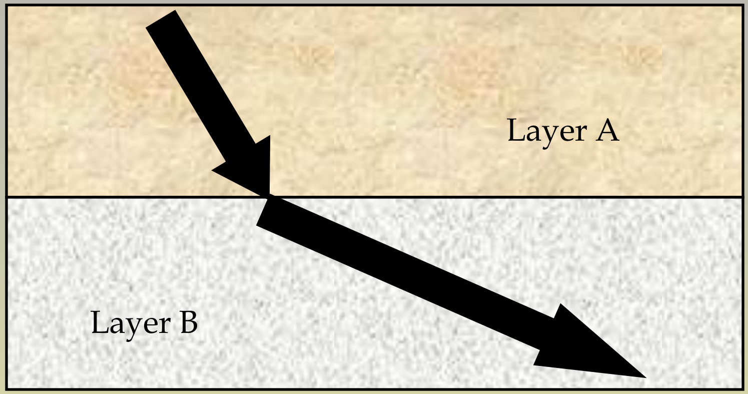


Table of Contents

2. **Seismic refraction:** Waves change velocity and direction (refract) when they enter a medium of different density than the one they just passed through.



Low-velocity layer: Seismic wave travels slow.

Example: Granite

High-velocity layer: Seismic wave travels fast.

Example: Gabbro

Research from seismic reflection and refraction has led to many important discoveries such as:

1. There are three main layers of the Earth: The crust, mantle, and core.
2. The continental crust is thicker than oceanic crust and seismic waves travel slower in the continental crust meaning that they are made up of different kinds of rock (granite/basalt).
3. There is a distinct boundary between the crust and the mantle called the Mohorovicic discontinuity, or, simply, the Moho. At this boundary, seismic waves are refracted.
4. There is a layer within the mantle up to 70 km thick beneath the ocean and up to 250 km thick beneath the continents where waves travel slower than in more shallow layers. This layer is called the low-velocity zone, and scientists have concluded that this zone is at least partially liquid. In plate-tectonic theory, it is called the asthenosphere, which is the semi-molten region of the earths' interior just below the earth's rigid crust that allows for tectonic plate movement.
5. P-waves can pass through the outer core but S-waves cannot. The outer core is a molten liquid.

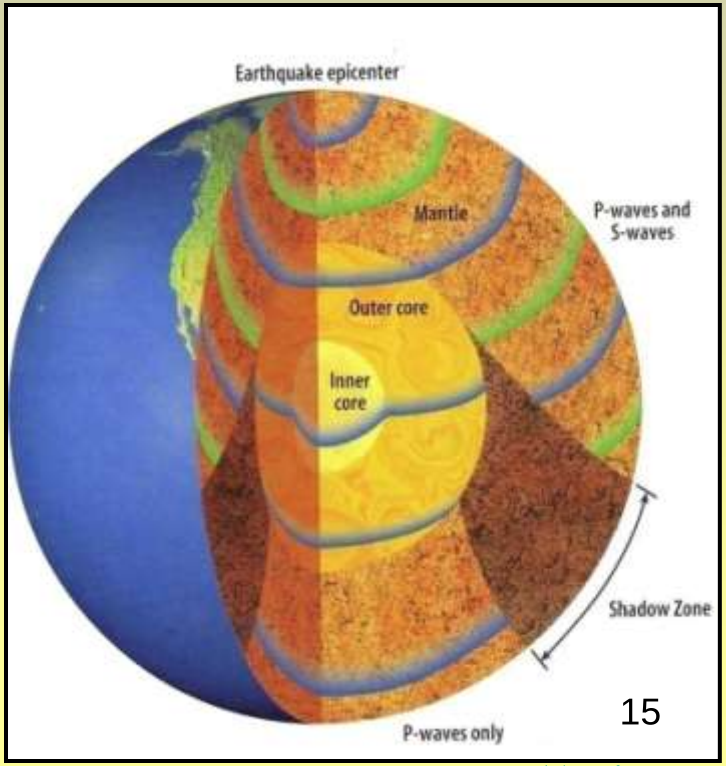
Standard 8-3.2

- In the early 1900's scientists discovered that parts of the Earth's surface did not receive direct earthquake waves.

- Scientists found that direct P-waves "disappear" from seismograms in a region between 104 and 140 degrees away from an epicenter. The seismic waves are bent, or refracted, upon encountering the core-mantle boundary, casting a shadow called the P-wave shadow zone.

- Direct S-waves are not recorded in the entire region more than 104 degrees away from an epicenter, and this is referred to as the S-wave shadow zone. The S-wave shadow zone, together with the knowledge that liquids do not transmit S-waves, is evidence that the outer core is liquid (or behaves as liquid).

- S-waves cannot travel through liquids because they are shear waves, which attempt to change the shape of what they pass through. Simply put, a liquid "doesn't care" what shape it's in—for example, you can empty a bottle of water into an empty box, and it will change shape with the shape of container. Liquids cannot support shear stresses, so shearing has no effect on them. Therefore, a liquid will not propagate shears waves.



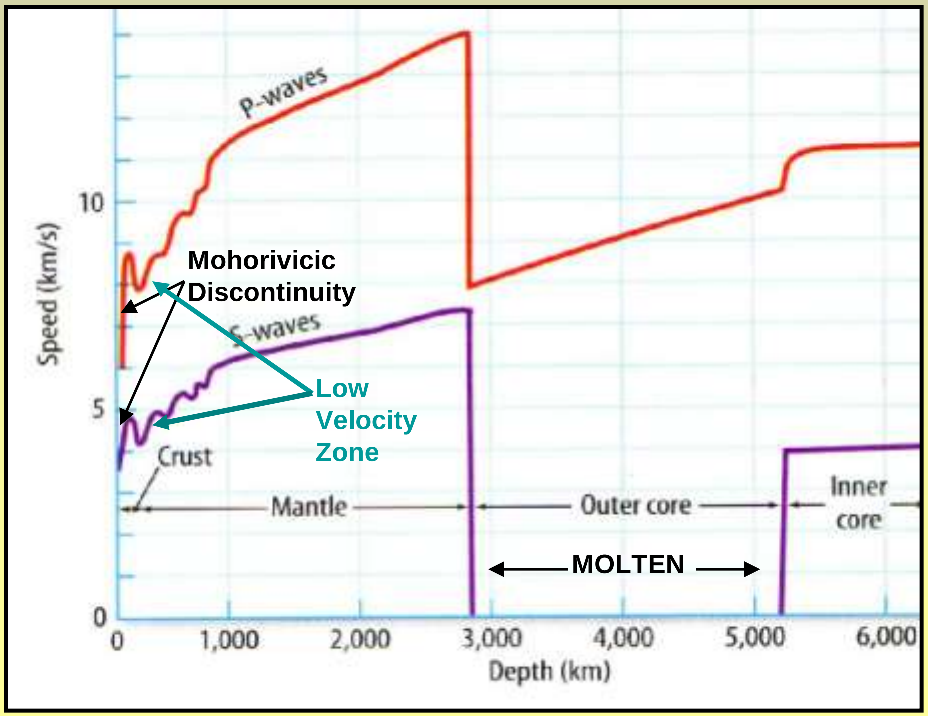
A cross-sectional figure of the layers of the earth with P- and S-wave propagation. *McGraw Hill/Glencoe, 1st ed., pg. 172*

Table of Contents

Standard 8-3.2

Seismic Waves: Mapping the earth

- Both P- and S-waves slow down when they reach the asthenosphere. Because of this, scientists know that the asthenosphere is partially liquid.
- The asthenosphere (Greek: weak) is the uppermost part of the mantle, which is partially molten. Lithospheric, or tectonic, plates are able to "slide" in different directions on top of the asthenosphere. Because seismic waves travel slowly here, it is also called the "low velocity" zone.
- The boundary between the crust and the mantle is distinguished by jump in seismic wave velocity. This feature is known as the Mohorovicic Discontinuity.



- Changes in velocity (km/s) of P- and S-waves allow seismologists to identify the locations of boundaries within the earth such as the Mohorovicic boundary near the earth's surface and the boundary between the mantle and outer core.

Modified after McGraw Hill/Glencoe, 1st ed., pg. 173

Seismic Waves: Epicenter location

Standard 8-3.3: Infer an earthquake's epicenter from seismographic data.

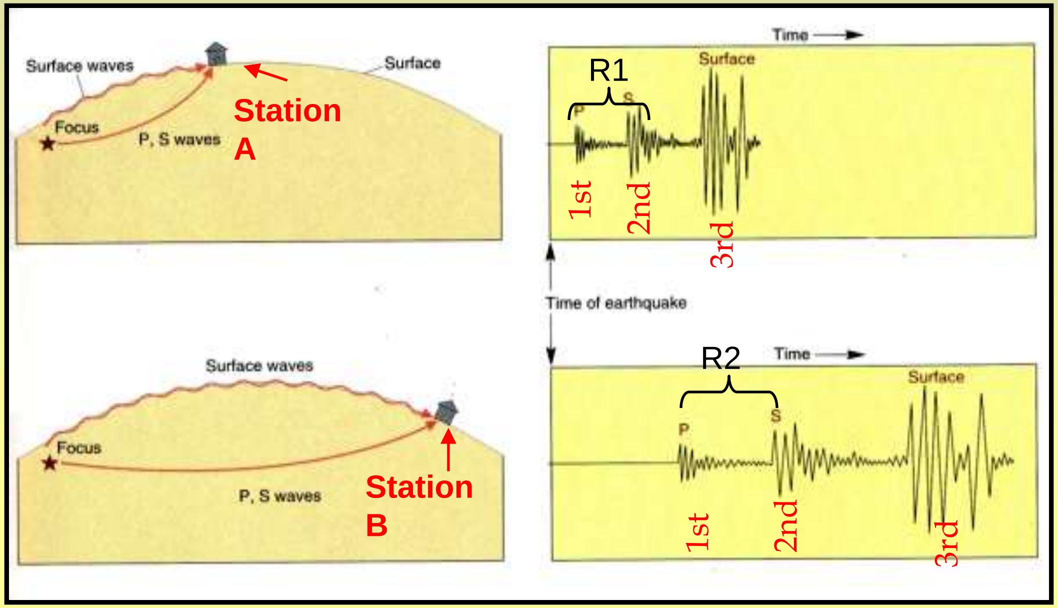
- Although S-waves, P-waves and surface waves all start out at the same time, they travel at different speeds. The speed of a traveling seismic wave can be used to determine the location of an earthquake epicenter.

- A seismograph records the arrival time and the magnitude of horizontal and vertical movements caused by an earthquake. The arrival time between different seismic waves is used to calculate the travel time and the distance from the epicenter.

- The difference in arrival time between primary waves and secondary waves is used to calculate the distance from the seismograph station to the epicenter.

- It is crucial that seismic waves are recorded by three different seismograph stations in order to estimate the location of the epicenter (see next slide.)

This example shows seismic waves arriving at different times at two seismograph stations. Station B is farther away from Station A so the waves take longer to reach Station B. Primary waves arrive first, followed by secondary waves, and then surface waves. *Credit: Modified after Plummer/McGeary, 7th ed., pg.*



Standard 8-3.2
Standard 8-3.3

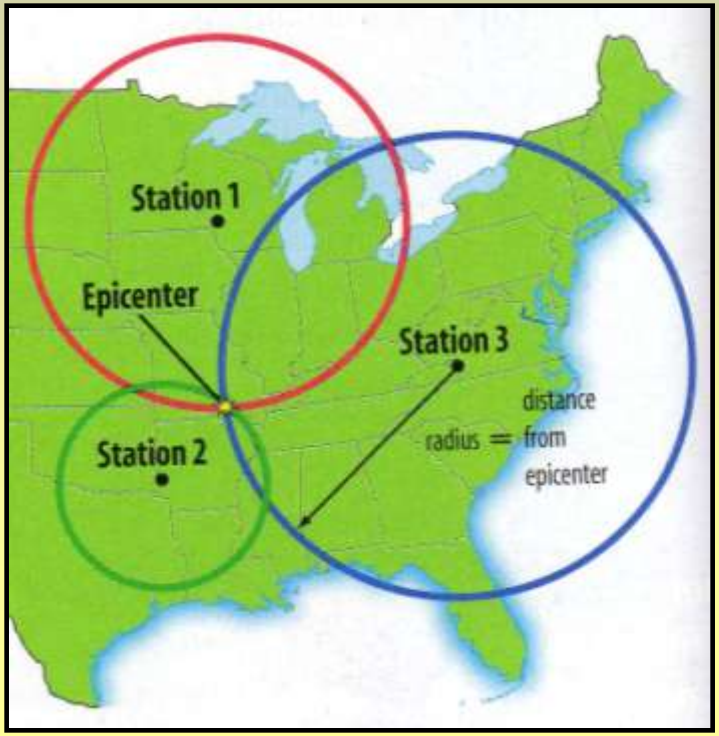
Seismic Waves: Epicenter location

- Earthquake scientists, or seismologists, can locate the epicenter of an earthquake as long as the vibrations are felt at three different seismograph stations.

1. Locate at least 3 stations on a map that recorded the seismic waves

2. Calculate the time difference between arrival of P-waves and arrival of S-waves from a seismogram. The time difference is proportional to the distance from the epicenter. Because the direction to the epicenter is unknown, the distance defines a circle around the receiving station. The radius of each circle equals that station's distance from the earthquake epicenter.

3. The epicenter is where the circles intersect.



Epicenter location using three stations.

McGraw Hill/ Glencoe, 1st ed., pg 170

Earthquake nomenclature based on proximity to the epicenter:

- Local event: Epicenter of felt earthquake < 100km away
- Regional event: Epicenter of felt earthquake is 100 to 1400 km away
- Teleseismic event: Epicenter of felt earthquake > than 1400 km away

Table of Contents

Mapping the earth: Magnetic anomalies

*Standard 8-3.2: Explain how scientists use seismic waves – primary, secondary, and surface waves – and **Earth's magnetic fields** to determine the internal structure of Earth*

- The Earth's magnetic field is used along with seismic waves to help understand the interior of the Earth. The geomagnetic field surrounds the Earth in a south to north direction and has been studied for many years due to its importance in navigation.

- The current hypothesis for the origin of geomagnetic field is that it is created by electrical currents generated within the liquid outer core. The heat of the outer core (5000-6000° C) drives convection of the molten material. The convection of a metallic liquid creates electric currents, which, in turn, creates a magnetic field. This is a dynamo model, where mechanical energy of convection generates an electrical energy and a magnetic field.

- Magnetism has two important components: intensity and direction. Most rocks differ in their magnetism, depending upon their content of iron-bearing minerals, i.e. magnetic susceptibility. For example, a body of magnetite or gabbro is strongly magnetic, and their magnetic signature makes them stand out from other rocks. Additionally, when rocks form, they acquire the direction (polarity) of the magnetic field existing at that time.

- Magnetic anomalies are deviations from the normal magnetic direction (i.e. today's), or they are exceptionally large differences (positive or negative) in magnetic intensity relative to average values of surrounding rocks. Anomalies occur all over the earth and are sometimes indicative of different rock types under the earth's surface.

- Magnetic intensity anomalies can be measured by magnetometers, which are often towed behind ships or flown over land surfaces to aid in mapping deposits in the earth.

Earthquake classification scales

- Earthquakes can be very destructive at the Earth's surface. The magnitude of an earthquake is a measure of how destructive it is. Basically the magnitude corresponds to how much energy is released.
- The Richter Scale is used to express earthquake magnitude on the basis of the height (amplitude) of the largest line (seismic wave, P or S) on a seismogram. The Richter scale was originally developed for earthquakes in Southern California. The utility of this scale was its ability to account for decreased wave amplitude with increased distance from the epicenter. Richter's scale is also a logarithmic scale.
- Today, a standard magnitude scale is used, Seismic Moment, which more accurately represents the energy released in an earthquake, especially large magnitude events.
- The majority of earthquakes are minor and have magnitudes of 3-4.9 on the Richter scale. These can be felt, but cause little or no damage, and there are about 55,000 of these earthquakes each year.
- Thousands of earthquakes are recorded every day with magnitudes < 3.0 but are almost never felt.
- The Mercalli scale is different from the Richter scale because it measures the intensity of how people and structures are affected by the seismic event. In essence, it measures damage. It is much more subjective and uses numbers ranging from 1 (no damage) to 12 (total destruction).

The Richter Scale

Richter Magnitudes	Description	Earthquake Effects	Frequency of Occurrence
Less than 2.0	Micro	Micro-earthquakes, not felt.	About 8,000 per day
2.0-2.9	Minor	Generally not felt, but recorded.	About 1,000 per day
3.0-3.9	Minor	Often felt, but rarely causes damage.	49,000 per year (est.)
4.0-4.9	Light	Noticeable shaking of indoor items, rattling noises. Significant damage unlikely.	6,200 per year (est.)
5.0-5.9	Moderate	Can cause major damage to poorly constructed buildings over small regions. At most slight damage to well-designed buildings.	800 per year
6.0-6.9	Strong	Can be destructive in areas up to about 100 miles across in populated areas.	120 per year
7.0-7.9	Major	Can cause serious damage over larger areas.	18 per year
8.0-8.9	Great	Can cause serious damage in areas several hundred miles across.	1 per year
9.0-9.9	Great	Devastating in areas several thousand miles across.	1 per 20 years
10.0+	Great	Never recorded; see below for equivalent seismic energy yield.	Extremely rare (Unknown)

Complications of the Richter scale include:

1. The Richter scale originally only applied to shallow-focus earthquakes in southern California so now must be modified.
2. Magnitudes calculated from seismograms above 7 tend to be inaccurate.

The Mercalli scale of earthquake intensity *Credit: USGS*

I. Not felt except by a very few under especially favorable conditions.

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III. Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration similar to the passing of a truck. Duration estimated.

IV. Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.

V. Felt by nearly everyone; many awakened. some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.

VI. Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.

VII. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.

VIII. Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chmineys, factory stacks, columns, monuments, walls. Heavy furniture overturned.

IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rail bent.

XI. Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.

XII. Damage total. Lines of sight and level are distorted. Objects thrown into the air.

Table of Contents

The Big Ones: Earthquakes from around the world

- Charleston Earthquake: The Charleston Earthquake struck this eastern South Carolina city on August 31, 1886. East Coast earthquakes are felt over a much larger area than earthquakes occurring on the West Coast, because the eastern half of the country is mainly composed of older rock that has not been fractured and cracked by frequent earthquake activity in the recent geologic past. Rock that is highly fractured and crushed absorbs more seismic energy than rock that is less fractured. The Charleston earthquake, with an estimated magnitude of about 7.0, was felt as far away as Chicago, more than 1,300 km to the northwest, whereas the 7.1-magnitude Loma Prieta earthquakes was felt no farther than Los Angeles, about 500 km south. Approximately 60 people were killed as a result of this historic earthquake.

- New Madrid Earthquake: Three quakes over 8.0 occurred from Dec 16, 1811 to February 7, 1812. This was an unusual place for an earthquake, and seemed to represent a weak point in the North American tectonic plate. Survivors reported that they saw the ground rolling in waves. Scientists estimate that the possibility of another earthquake at the New Madrid fault zone in the next 50 years is higher than 90 percent. The most widely felt earthquakes ever to strike the United States were centered near the town of New Madrid, Missouri, in 1811 and 1812. Three earthquakes, felt as far away as Washington D.C., were each estimated to be above 8.0 in magnitude.

- San Francisco Earthquake (April 18, 1906, 5:12am): Occurred along the San Andreas Fault. The total population at the time was 400,000, the death toll was 3,000 and 225,000 were left homeless. 28,000 buildings were destroyed and damages were estimated at $400 million from the earthquake plus fire, but only $80 million from the earthquake alone. Horizontal displacement was 15 feet with a visible scar 280 miles long. Fires caused by broken gas lines raged for 3 days until buildings were destroyed to create a firebreak. The vast percentage of damage was done by fires.

Damage to Stanford University. Source USGS: http://earthquake.usgs.gov/regional/nca/1906/18april/casualties.php

Table of Contents

▪ The Loma Prieta Earthquake (5:04pm October 17, 1989) occurred along the San Andreas Fault Zone with the epicenter located in the Santa Cruz Mountains, 70 miles south of the San Franciso earthquake. It registered 6.9 on the Richter Scale with a final death toll of 63 people and damages of $6 billion. Resulting fires were hard to manage due to broken water lines. The total tremor time lasted approximately 15 seconds.

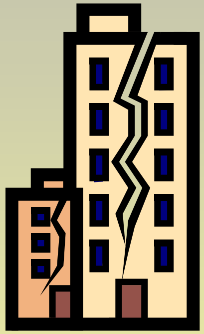
Photo left: Cypress Freeway collapsed- 42 people killed at this section. Right: Bay bridge section collapse. Source:http://www.olympus.net/personal/gofamily/quake/famous/prieta.html

▪ The Good Friday Earthquake (March 27, 1964 at 5:36pm): At 9.2 on the Richter Scale, this was the largest earthquake to occur in the U.S. in recorded history. The death toll was only 115 due to the scarcity of people in this area. Damages were approximately $300 million. A 30 mile x 125 mile block of land was raised 40 ft, and a similar block dropped 3-6 feet. The tremor, which lasted 3 minutes, created a tsunami that drowned 100 people in Alaska, Oregon and California. Landslides destroyed parts of Anchorage, 90 miles away.

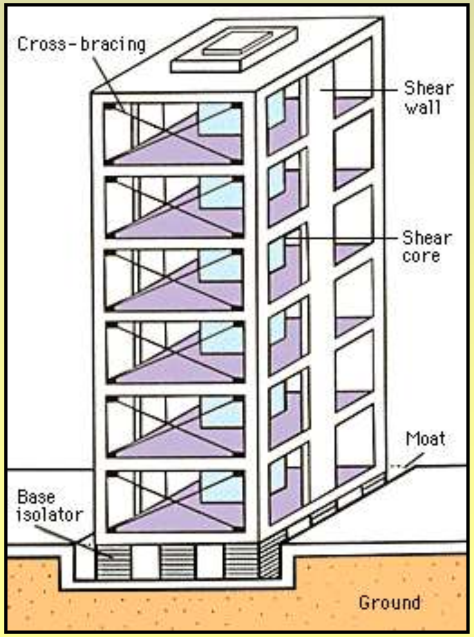
▪Lisbon, Portugal: November 1, 1755. 9:40 am on All Souls Day. The quake triggered a tsunami with a wave 50-ft high, which crashed through the city. Buildings collapsed of killing many people, and waves swept thousands more away. Fires ran unchecked for 3 days, completing the destruction of the capitol. Over 60,000 people died in the city alone and thousands more in surrounding areas.

Quake-resistant Structures

- While it is not possible to accurately predict earthquakes, measures can be taken to reduce the devastation by constructing earthquake-resistant structures. Earthquakes have the ability to level entire office buildings and homes, destroy bridges and overpasses, roads, and break underground water lines. In some cases, building practices are not up to code, and in the event of an earthquake, the loss of life is catastrophic.
- In earthquake-prone areas, buildings are now being constructed with moorings filled with alternating layers of rubber and steel. These are called base isolators. The rubber acts as an "earthquake absorber." Buildings with these types of moorings are designed to withstand a magnitude 8.3 earthquake.
- In attempts to reduce damage to structures, engineers try to
  1. Increase the natural period of the structure through "base isolation."
  2. Install "energy dissipating devices" to dampen the system.



Cited from http://www.architectjaved.com/equake_resistant.html



World Book illustration by Dan Swanson, Van Garde Imagery

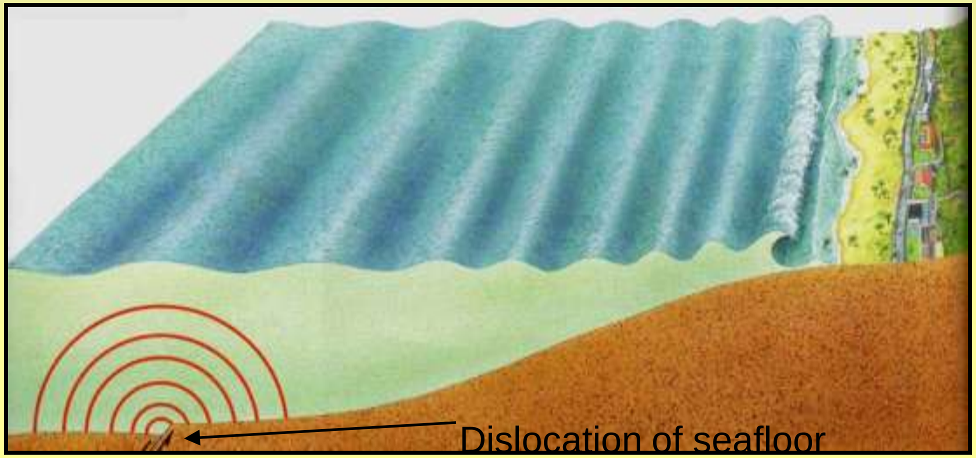
- Simple reinforcement methods used by engineers include using large bolts to secure buildings to their foundations, as well as providing supporting walls, or shear walls, made of reinforced concrete. This can help to reduce the rocking effect of a building during and after a seismic event.
- Shear walls at the center of the building (around an elevator shaft) can form a shear core.
- Employing cross-braces, where walls are built with diagonal steel beams, adds extra support.

(*http://www.worldbook.com/wb/Students?content_spotlight/earthquakes/damage_reducing)*

Earthquakes: Tsunamis

*Standard 5-3.1: Explain how natural processes (including weathering, erosion, deposition, landslides, volcanic eruptions, **earthquakes**, and floods) affect Earth's oceans and land in constructive and destructive ways.*

- An underwater earthquake with a magnitude of 8 or higher on the Richter scale can affect the earth's oceans by causing a tsunami. Less commonly, tsunamis are also caused by submarine landslides or volcanic explosions.
- Tsunamis are sometimes called seismic sea waves. They can destroy everything in the coastal zone, but they occur as small unnoticeable waves out at sea.
- This is because the earthquake generates a rolling wave out in the open water; however, as the waves approach shore, they start to "feel" the bottom of the sea floor. The waves slow down near the bottom, causing a huge wave to build up on top as the top is still moving at its original speed. This is the same as the way regular waves form in the surf zone. The tsunami, however, can be a one-hundred foot high wall of water moving at 450 miles per hour.



Sketch showing the generation of a Tsunami from an underwater earthquake. *Credit: McGraw Hill/Glencoe, 1st ed., pg. 178*

Standard 5-3.1

The Great Sumatra-Andaman Earthquake/Tsunami

- Since 1945, more people have been killed by tsunamis than earthquakes. A tsunami event that occurred recently and received global news coverage was the catastrophic tsunami that was generated in the Indian Ocean on December 26, 2004. The epicenter of the earthquake that triggered the series of tsunami's was located off the west coast of Sumatra, Indonesia. More than 225,000 people in 11 countries were killed. The waves were up to 100 feet high.
- The earthquake was the 2nd largest ever recorded on a seismograph at ~9.2 on the Richter scale and it cause the entire planet to vibrate up to 1 centimeter, causing smaller earthquakes in other parts of the world.
- The tsunami took anywhere from 15 minutes to 7 hours to reach the various coastlines that were devastated. In the minutes preceding the tsunami wave, the sea withdrew from the shores by nearly 2 miles, attracting people to the beach with fatal consequences.
- Tsunami warning systems are now in place in the Indian Ocean; however, it is only in the aftermath of such a horrific catastrophe.

Total destruction- Band Aceh

Photos USGS: http://walrus.wr.usgs.gov/tsunami/sumatra05/photos.html

Earthquakes: Seiches

- A seiche is a large wave occurring in an enclosed body of water such as a lake and is sometimes referred to as a 'slosh.' Small rhythmic waves are always present on larger lakes. In French, the word means "to sway back and forth." You have probably created seiche-like phenomena in your own bath.

- The wave has a very long wavelength. If you are in a boat in the middle of a lake, you would not notice the seiche wave, much like a tsunami wave in the deep ocean. Also the speed of the wave depends on the depth of the water.

- Seiches can be caused by meterological phenomena and the effects are similar to a storm surge with extreme wave heights that oscillate from one side of the lake to the other for extended periods of time.

- In 1959, a 7.3 magnitude earthquake occurred in Montana. As a result of faulting near Hebgen Lake, the bedrock beneath the lake was permanently warped, causing the lake floor to drop and generate a seiche. Maximum subsidence was 6.7 meters in Hebgen Lake Basin. About 130 square kilometers subsided more than 3 meters, and about 500 square kilometers subsided more than 0.3 meters.

Photo; USGS- Damaged and collapsed buildings at the Blarneystone Ranch, near Hebgen Lake, Montana, caused by the August 18, 1959, earthquake. (Photograph by I.J. Witkind.)

- Consequently, in Yellowstone National Park, new geysers erupted, and massive slumping caused large cracks in the ground, which emitted steam, and many hot springs became muddy.

Earthquakes: Turbidity Current

➢ Turbidity currents are huge masses of sediment-laden water that flow down the continental slope (usually in a submarine canyon) due to gravity and density differences between the ocean water and the more dense sediment-laden water. They are sometimes referred to as density currents and are usually triggered by underwater earthquakes, although strong surface storms and floods from sediment-rich rivers can also trigger a current.

➢ Recent evidence for these catastrophic events comes from broken submarine cables on the ocean floor. The fact that large cables can be snapped by a turbidity current is a good indication of their size, speed, and energy.

➢ **Example:** After the 1929 earthquake in the Grand Banks region occurred, a string of underwater telephone cables on the Atlantic sea floor began breaking and continued to break up to 13 hours after the initial earthquake. The last cable to snap was 700 km from the epicenter. It has been estimated that the currents were traveling at 15-60 km/hr.

➢ Sediment deposited by turbidity currents are called turbidites and are geologically unique and recognizable by their layering (graded bedding and Bouma Sequences).

To see the formation of a turbidity current in a laboratory flume, follow this link:

http://faculty.gg.uwyo.edu/heller/SedMovs/middletonturb.htm

Image Courtesy United States Geological Survey; Image source: Earth Science World Image Bank http://www.earthsciencewor ld.org/images

Example of graded bedding/ Bouma Sequences

Liquefaction of an Earthen Dam: A South Carolina case study

➢ Liquefaction is a common phenomenon and is defined as the point where a water-saturated soil turns from a solid into a liquid due to loss of cohesion. Whenever a loose material like soil or sand is saturated with water and then undergoes some external pressure or vibration, it loses its "strength" and begins to liquefy because all of the water that was trapped in the pores between the material is released almost instantly.

Niigata earthquake, from the Earthquake Engineering Research Center Library, University of California at Berkeley

➢ Liquefaction may occur several minutes after an earthquake. It can cause buildings to sink, underground tanks to float to the surface, and dams to collapse as once-solid sediment flows like water.

➢ When you are walking along the beach and your feet sink into the wet sand with every step that you take, you are actually liquefying the sand that you are stepping on. Because the sand is saturated and you are exerting pressure on the sand, you are effectively pushing the pore water trapped in the spaces of the sand out (i.e. raising pore-water pressure), thereby causing it to "flow" around your foot.

- Dams, especially earthen dams, pose a significant risk of failing via liquefaction, flooding everything for miles downstream with a slurry of water and sediment.
- While concrete dams will fail through cracking under intense, local seismic activity, earthen dams, can fail from a relatively small tremor occurring a hundred miles away.
- Any saturated soil can liquefy, causing landslides and soils underneath buildings to liquefy.

★ Class Activity: Simulating an earthen dam failure due to liquefaction

The process of liquefaction can be demonstrated very easily in the classroom. Below are the steps for simulating the failure of a dam similar to the Lake Murray Dam:

1. Fill up a small beach pail or plastic cup with sand and water.
2. Mix until it is the consistency of thick, wet concrete. You may need to add more sand, so make sure you have extra on hand. It is recommended to do a test run before class. Depending on the grade of sand you use, you will need more or less water.
3. Turn the bucket upside down (very quickly) onto a plastic plate or inside a clear tupper-ware bowl. You should now have a free-standing "sand castle."
4. Pick up the dish and show it to the class. Explain that it represents an earthen dam.
5. Take a small vibratory machine (a small shoulder/hand massager from Walmart works well- approx. $9.00) and hold it to the BOTTOM of the dish.
6. The sand castle will begin to liquefy with the application of vibration, mimicking what would happen to an earthen dam if subjected to an earthquake tremor. Total liquefaction should take a just under a minute (or less depending on how much water you use).

Note: It is advised to carry this demonstration out on top of a large plastic garbage bag for easy clean-up, especially if the students are experimenting.

Table of Contents

- Here in South Carolina and all over the U.S., many earthen dams are undergoing or have undergone remediation of some type to safeguard downstream areas. Near Columbia, the Saluda Dam, also called the Lake Murray Dam, was built in the 1930's and was the largest earthen dam in the world for years. It is nearly 1.5 miles long, 200 feet high and made of compacted silt, sand, and clay. The dam lies just 20 miles north of Columbia, and, if it were to fail, the entire downstream region, including the downtown area, would be under water within minutes to hours.

Lake Murray dam above Columbia, SC.
Photo courtesy of K. McCarney-Castle.

- The city of Charleston, approximately 100 miles southeast of Columbia, experienced an earthquake that registered an 8 on the Richter Scale in 1886 known as the great "Charleston Earthquake." If another earthquake of this scale were to strike Charleston, the tremor would be felt in Columbia. Consequently, the people of Columbia would be in peril due to a potential failure of Saluda Dam. Because of this risk factor, a concrete "back-up" dam was built directly downstream of the original earthen dam from 2002 to 2006.

Newly constructed concrete backup dam, Lake Murray, SC

South Carolina Science Academic Standards: Grade 5

Landforms and Oceans:

Standard 5-3:
The student will demonstrate an understanding of features, processes, and changes in Earth's land and oceans. (Earth Science)

Indicators:

5-3.1: Explain how natural processes (including weathering, erosion, deposition, landslides, volcanic eruptions, **earthquakes**, and floods) affect Earth's oceans and land in constructive and destructive ways.

South Carolina Science Academic Standards: Grade 8

Earth's Structure and Processes:

Standard 8-3:
The student will demonstrate an understanding of materials that determine the structure of Earth and the processes that have altered this structure. (Earth Science)

<u>Indicators:</u>

8-3.2 Explain how scientists use seismic waves—primary, secondary, and surface waves—and Earth's magnetic fields to determine the internal structure of Earth.
8-3.3 Infer an earthquake's epicenter from seismographic data.
8-3.8 Explain how earthquakes result from forces inside Earth.