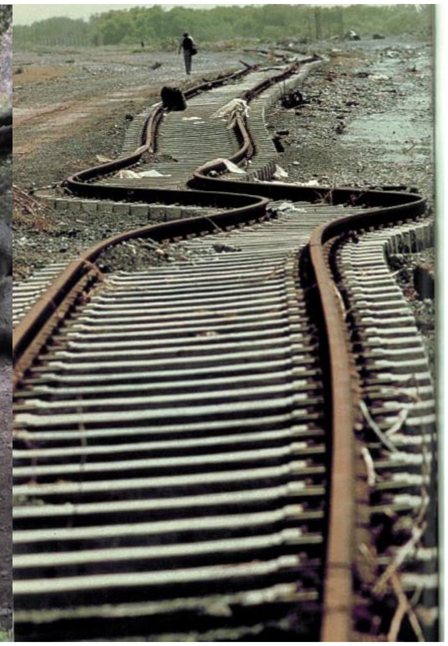
Ch 19 Earthquakes

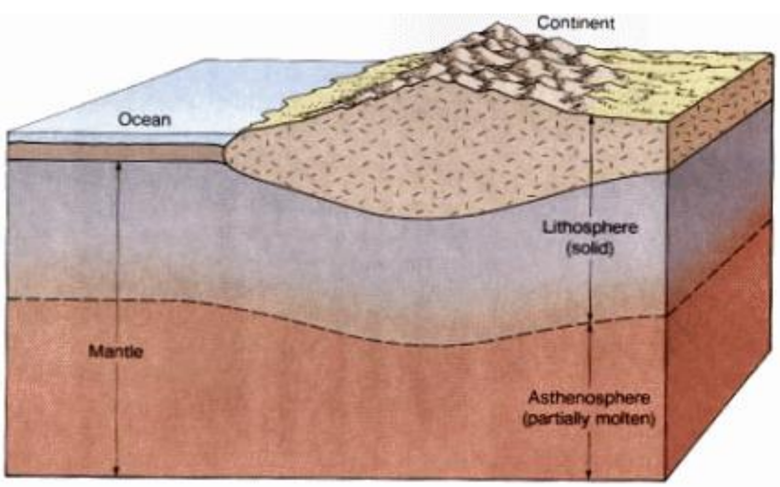



During the 1906 San Francisco earthquake, this fence in Marin County was displaced by almost 5 m. The fence has moved or been displaced due to a fault.

Objectives
- * Define stress and strain as they apply to rocks.
- * Distinguish among the three different fault types.
- * Contrast three types of seismic waves.

- What are Earthquakes?

- The shaking or trembling caused by the sudden release of energy
- Usually associated with faulting or breaking of rocks
- Continuing adjustment of position results in aftershocks



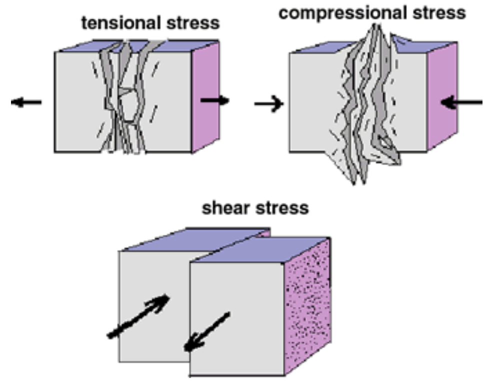
Review: Lithosphere

- Earth's **rigid** outer shell where the vast majority of earthquakes take place. Made up of the crust and the very upper part of the mantle.

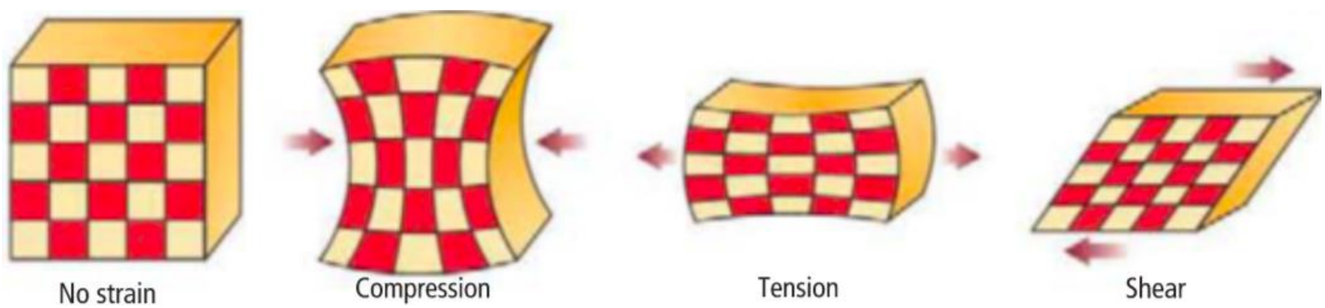
  - **rigid**: when stress is applied to a rock, it will break instead of bending.

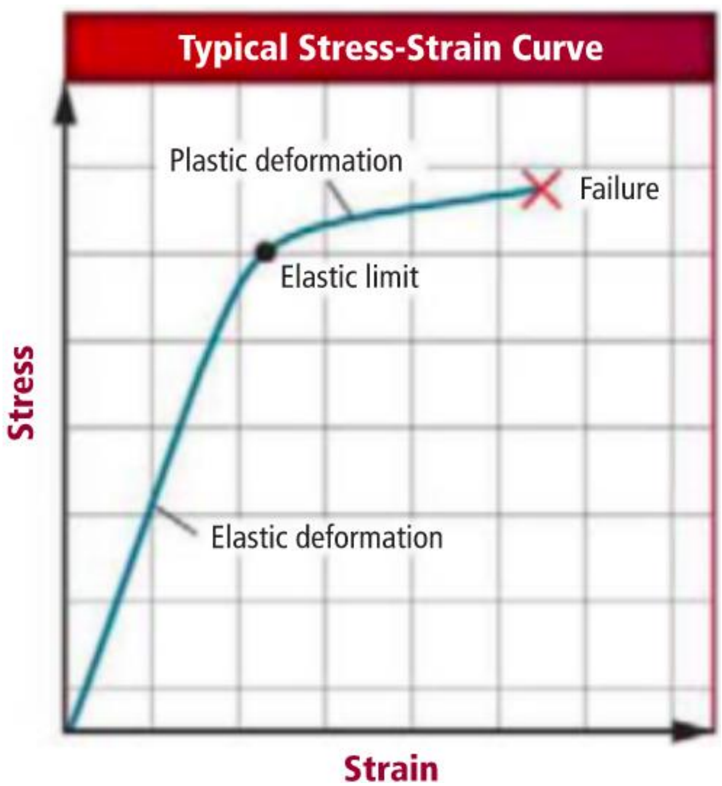
The Forces Within the Earth 19.1

- **Stress:** total force acting on the crustal rocks per unit of area; stress= force/area
  - when stress overcomes the strength of the rock, movement occurs
  - the vibrations are felt as earthquakes at the surface
  - 3 kinds of stress
    - tension: pulls material apart
    - compression: decreases volume
    - shear: causes material to twist
      rocks move past one another



Strain: deformation of material in response to stress



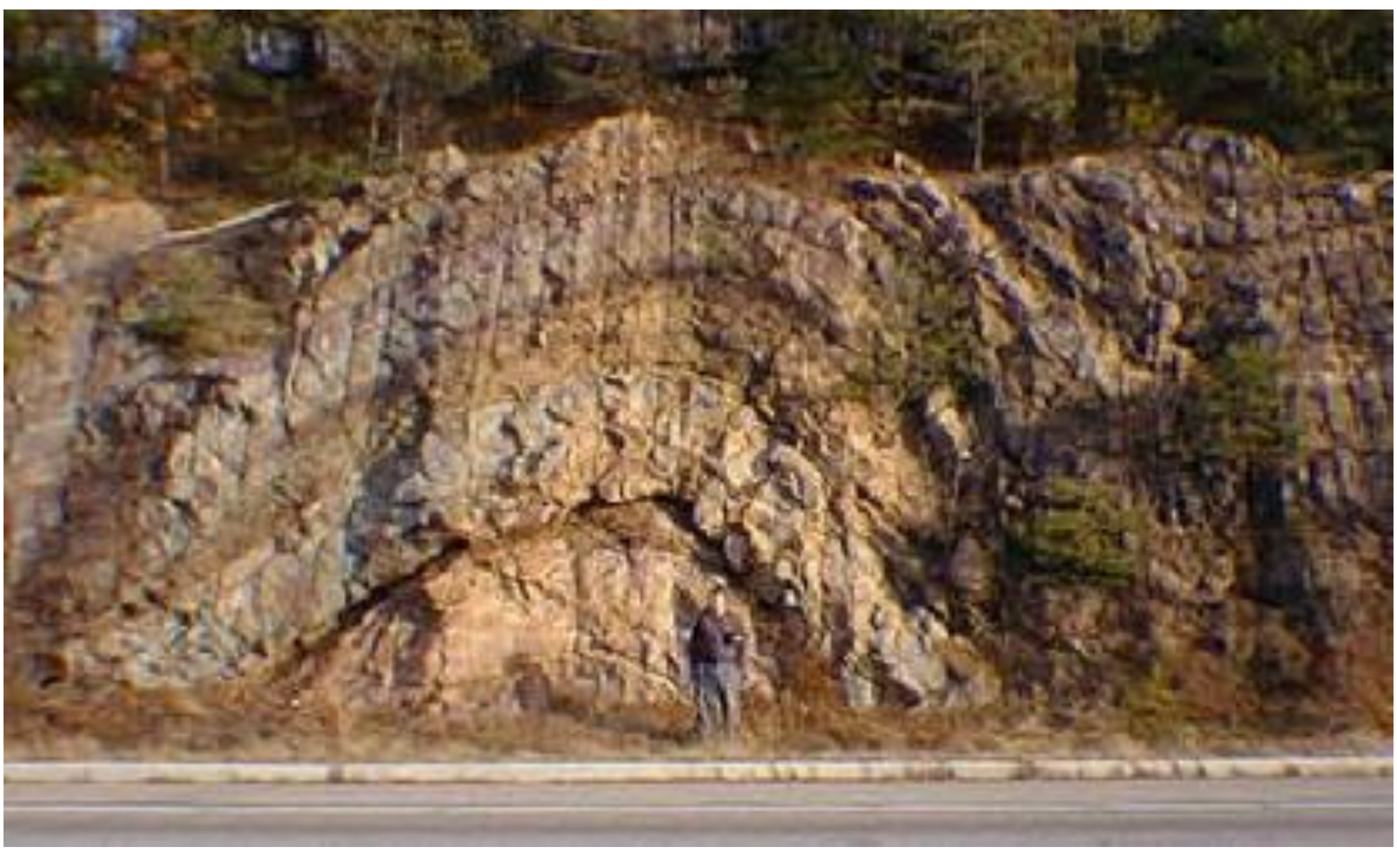


Stress-Strain Curve: shows the relationship between stress and strain. Has 2 parts to it.

- **Elastic deformation:** rock will return to its original shape when stress is removed. No permanent deformation.

- **Plastic deformation:** rock will NOT return to its original shape when stress is removed. There is permanent deformation.

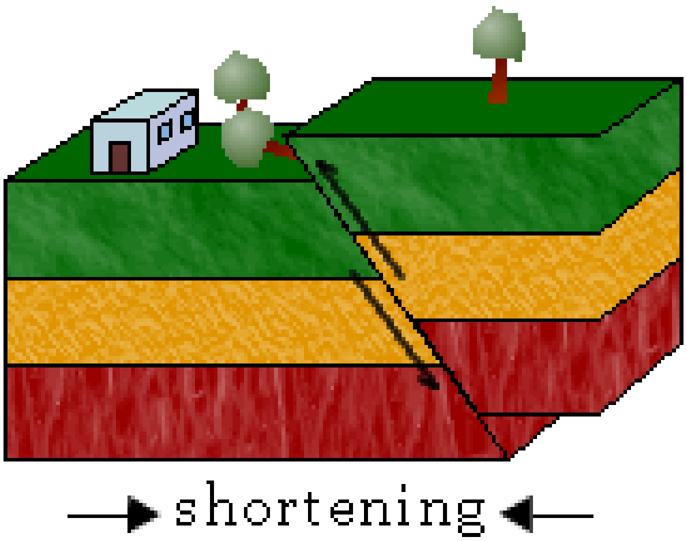
- **Failure:** when the rock breaks; earthquake occurs

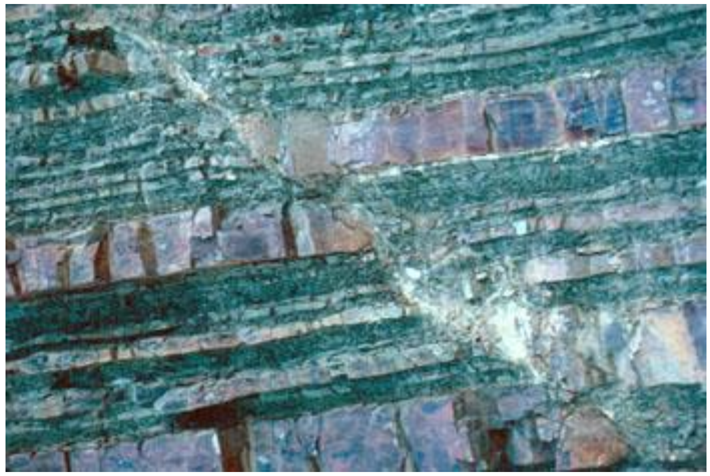


- **Fault:** the resulting movement, due to failure (breaking), that occurs in the rock

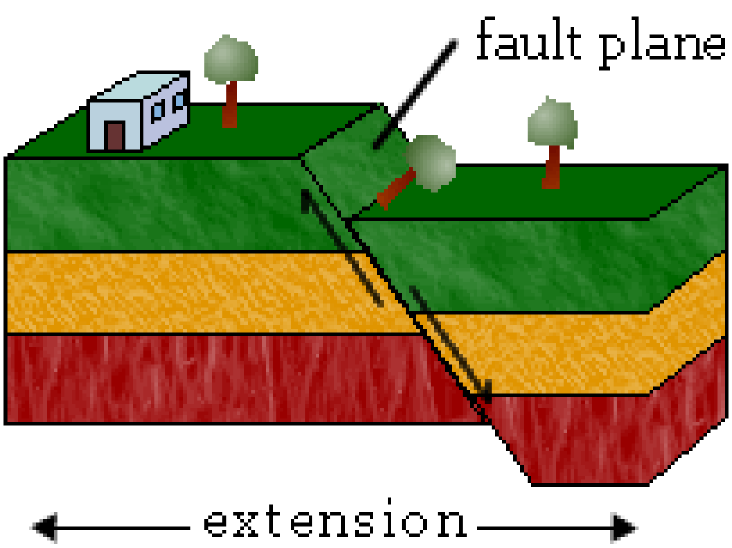
  - **Fault plane:** the surface along which fault movement takes place
  - There are 3 basic types of faults that are created from stress

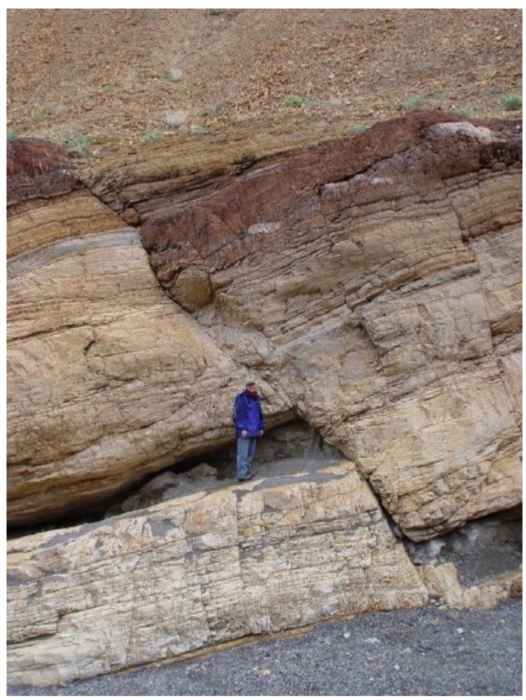
    1) Reverse Fault: forms as a result of horizontal compression and results in a *shortening* of the crust involved. One side is *pushed up* relative to the other side.



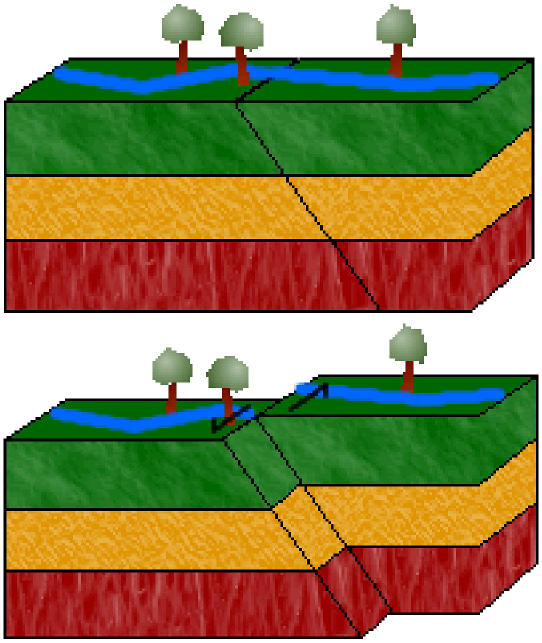


2) Normal Fault: movement is both horizontal and vertical, resulting in a lengthening of the crust involved. One side moves down relative to the other side. The rock is stretched.





3) Strick-slip Fault: the fracture is caused by horizontal shear and movement is mainly horizontal.



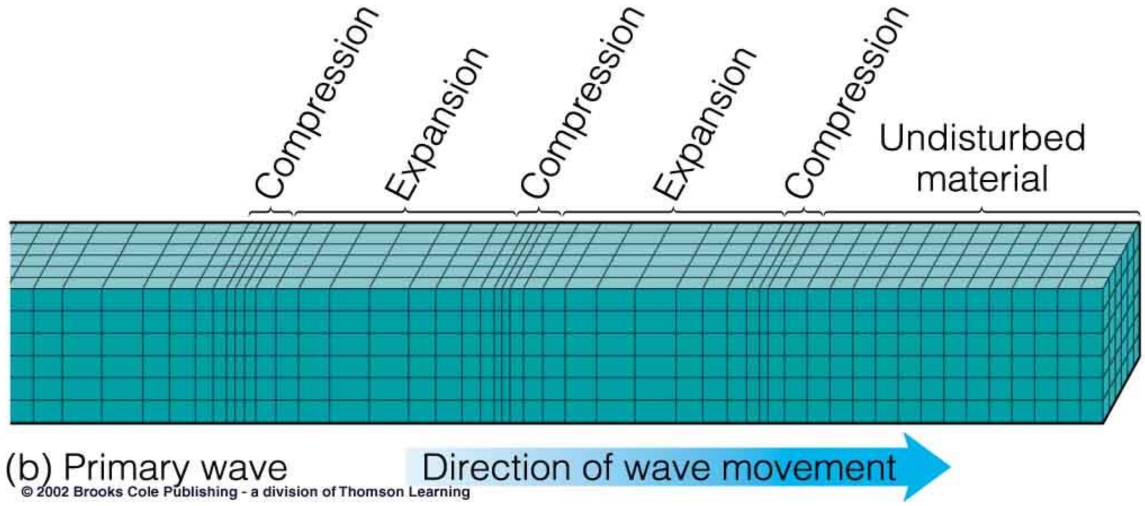
- What are Earthquake Waves?

- Response of material to the arrival of energy fronts released by rupture
- Waves are uniform through a homogeneous material
- Waves are *not* uniform through a heterogeneous material
  - The earth is not uniform! Therefore, waves do not travel in a uniform fashion. They are reflected or bent.
- **Two types** of waves: Body and Surface

- **Body waves**: two types; P and S

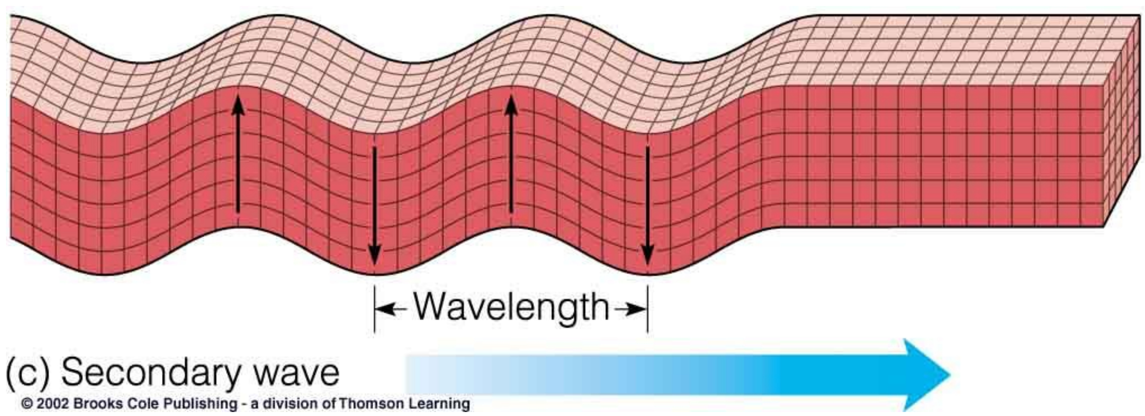
  - ***P-waves*** (primary waves or compression waves)
    - Energy moves parallel to waves
    - Squeeze and pull rocks in same direction as the wave travels
    - Fastest earthquake, 1st wave to reach you.
    - Travel: 5-7km per second in the crust
      8 km per sec in the mantle
      .34km per sec in sand
    - Travel through solids, liquids, or gases

http://www.youtube.com/watch?v=2rYjlVPU9U4&safe=active p waves: 18 sec



- **S-waves** (secondary waves)
    - Energy moves perpendicular which cause rocks to move at right angle in relation to the direction the waves are traveling
    - Travel 3-4 km per sec
    - slower than p-waves
    - arrive after p-wave
    - S-waves move only through solids! Not liquids!
    - Shear waves - move material perpendicular to wave movement

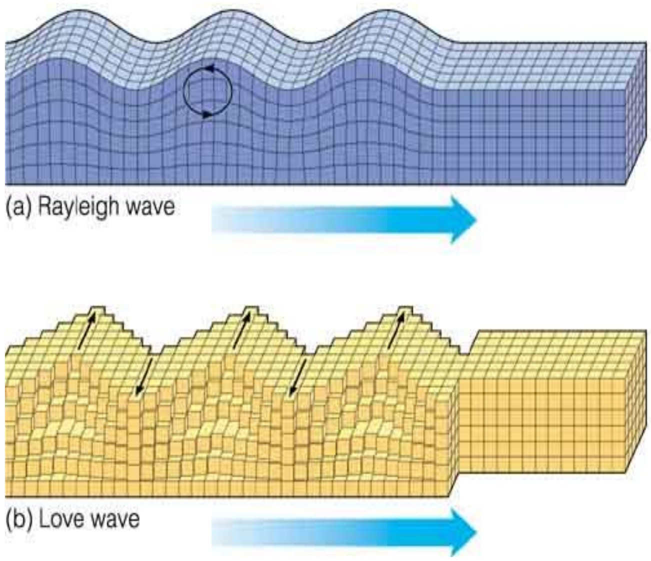
http://www.youtube.com/watch?v=en4HptC0mQ4&safety_mode=true
s waves: 18 sec
https://www.youtube.com/watch?v=jsVwVlU-qMQ&spfreload=10
s wave/p wave demo 4 min

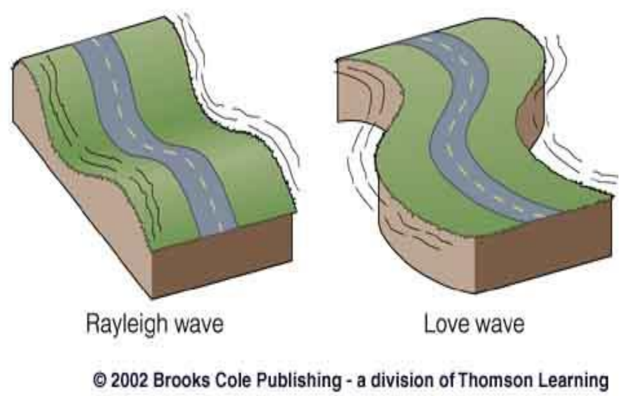


- **Surface waves**: two types, R and L; surface waves do not pass through Earth's interior at all.

- ***R-waves*:** (Rayleigh waves)
  - particles move in an elliptical path within a vertical plane, up and down, while the direction of the wave moves horizontal.
    http://www.youtube.com/watch?v=6yXgfYHAS7c&safe=active r waves: 15 sec

- ***L-waves*:** (Love waves)
  - particles move material back and forth in a horizontal plane, side to side, while the direction of the wave moves horizontal.
    http://www.youtube.com/watch?v=B-8H4GmSNO8&NR=1&safe=active l waves: 6 sec

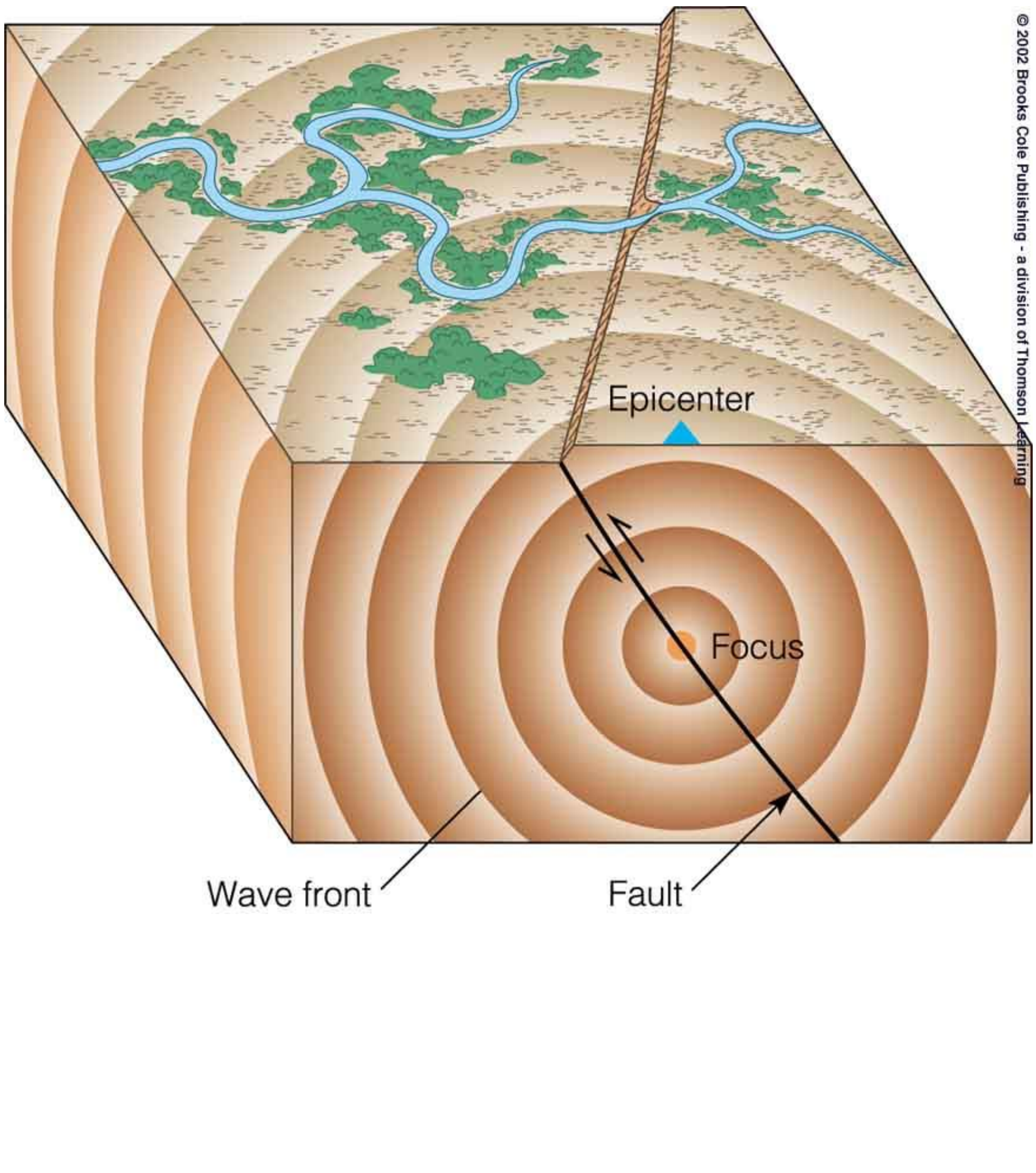




- Caused when S & P waves reach the surface
- Travel just below or along the ground's surface
- Slower than body waves; rolling and side-to-side movement
- Especially damaging to buildings; severe ground movement

- **Generation of Seismic Waves:** Focus & Epicenter

  - **Focus:** The point within Earth where faulting begins. Earthquake waves originate here.
    - Three categories based on focus depth
      - Shallow-focus earthquake: 0-70 km deep
        - most destructive
      - Intermediate-focus: 70-300 km deep
      - Deep-focus: 300km plus
    - Most are less than100km
  - **Epicenter:** The point directly above the focus on the surface.



The epicenter of the magnitude 7.0 January 12, 2010,earthquake that devastated Haiti was located approximately 25 km west-southwest of Port-au-Prince, and had a focal depth of 13 km.

The 7.0-magnitude earthquake that struck the island nation of Haiti on January 12, 2010, destroyed its capital city, Port-au-Prince, and devastated the surrounding areas, killing more than 222,500 people.

TABLE 9.1 **Some Significant Earthquakes**

Year	Location	Magnitude (estimated before 1935)	Deaths (estimated)
1556	China (Shanxi Province)	8.0	1,000,000
1755	Portugal (Lisbon)	8.6	70,000
1906	U.S.A. (San Francisco, California)	8.3	3,000
1923	Japan (Tokyo)	8.3	143,000
1960	Chile	9.5	5,700
1964	U.S.A. (Anchorage, Alaska)	8.6	131
1976	China (Tangshan)	8.0	242,000
1985	Mexico (Mexico City)	8.1	9,500
1988	Armenia	6.9	25,000
1990	Iran	7.3	50,000
1993	India	6.4	30,000
1995	Japan (Kobe)	7.2	>6,000
1999	Turkey	7.4	17,000
2001	India	7.9	>14,000
2003	Iran	6.6	43,000
2004	Indonesia	9.0	>230,000
2005	Pakistan	7.6	>86,000
2006	Indonesia	6.3	>6,200
2008	China (Sichuan Province)	7.9	>69,000
2010	Haiti	7.0	>222,500
2011	New Zealand	6.3	181
2011	Japan	9.0	>20,000
2012	Iran	6.4	>300

Earthquakes per year	Magnitude on the Richter scale*	Severity
1	8.0 and higher	great
18	7.0–7.9	major
120	6.0–6.9	strong
800	5.0–5.9	moderate
6200	4.0–4.9	light
49,000	3.0–3.9	minor

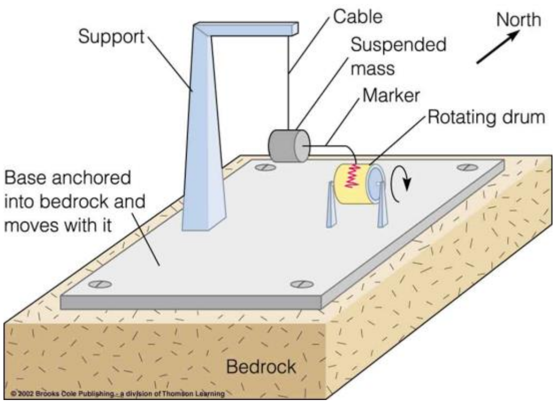
*Earthquakes measuring less than 3.0 are not included because approximately 9000 occur daily.

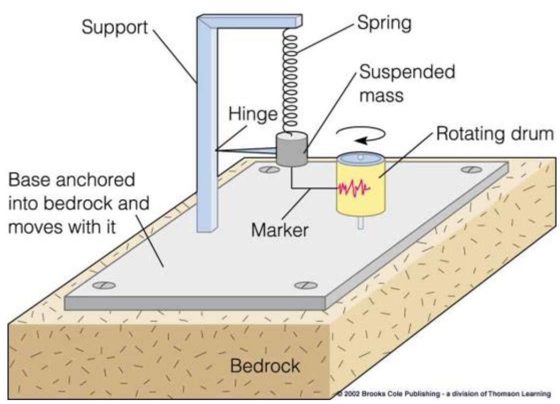
https://www.cnn.com/2021/03/04/world/new-zealand-quake-tsunami-warning-intl/index.html

Seismic Waves and Earth's Interior 19.2

Objectives
* Describe how a seismometer works
* Explain how seismic waves have been used to determine the structure and composition of the Earth's interior.

- **Seismometer/Seismograph:** Instrument used to measure horizontal and vertical motions of an earthquake. Used to record earthquake waves.



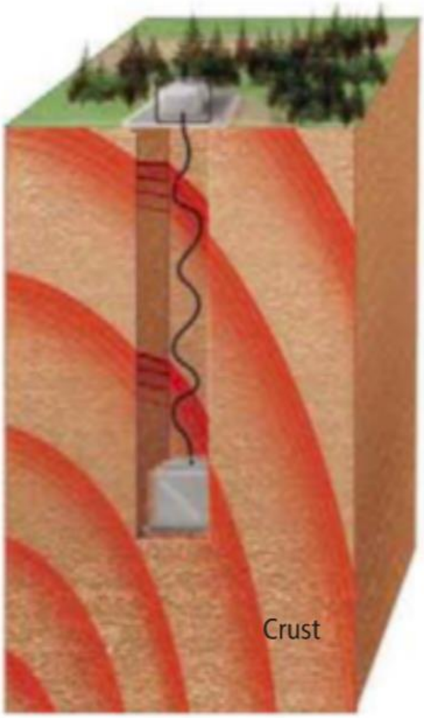


Horizontal-motion seismograph
http://www.youtube.com/watch?v=83GOKn7kWXM&safety_mode=true&safe=active 11 sec
Because of its inertia, the suspended mass that contains the marker remains stationary, while the rest of the structure moves along with the ground during an earthquake. The marker will record the earthquake waves on the rotating drum. This seismograph would record waves from west or east, but to record waves from the north or south, another seismograph, at right angles to this one, is needed.

Vertical-motion seismograph
http://www.youtube.com/watch?v=DX5VXGmdnAg&safety_mode=true&safe=active 13 sec

This seismograph operates on the same principle as the horizontal-motion instrument and records vertical ground movement.

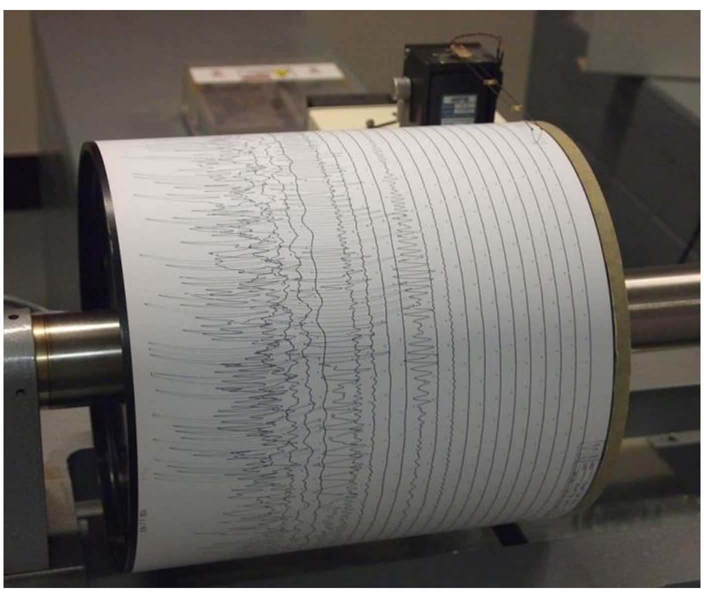
- Modern seismographs will have the ability to measure horizontal east-west and horizontal north-south and the vertical motion. That is three directions of motion

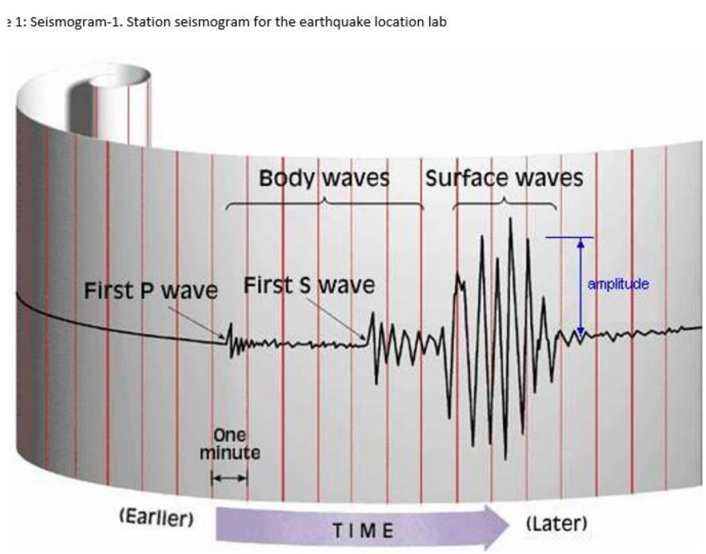


Modern

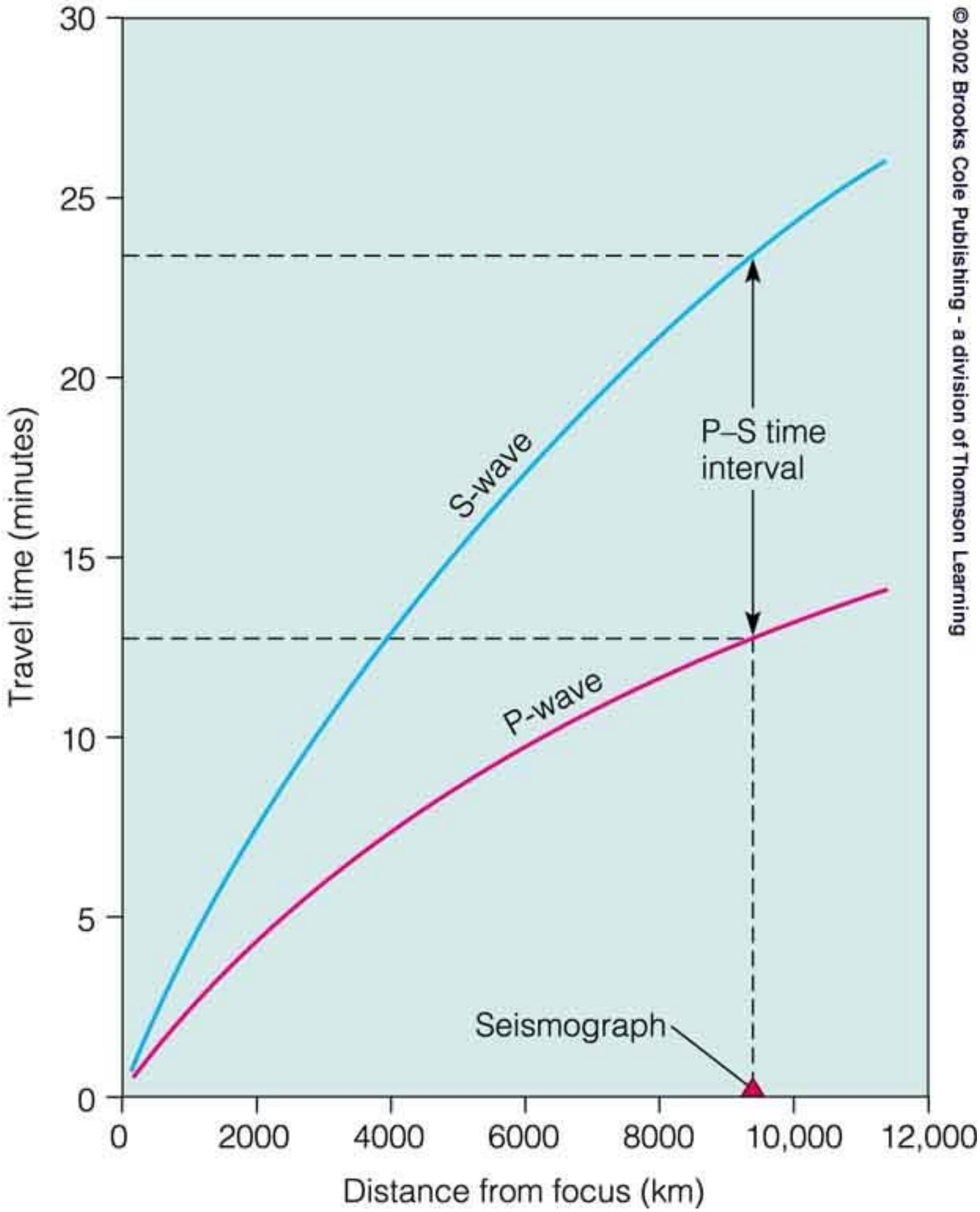
This seismograph records earthquakes on a strip of paper attached to a rotating drum.

- **Seismogram:** a record produced by the seismometer
    - can provide individual tracking of each type of seismic wave





- **Travel-time curves** (also referred to as time-distance graphs) : show how long it takes for P-waves and S-waves to reach seismic stations.
  - Graph shows the average travel times for P- and S-waves.
  - The farther away a seismograph is from the focus of an earthquake, the longer the interval between the arrivals of the P- and S- waves.
  - * we will use this to figure out the distance to the epicenter in section 3*

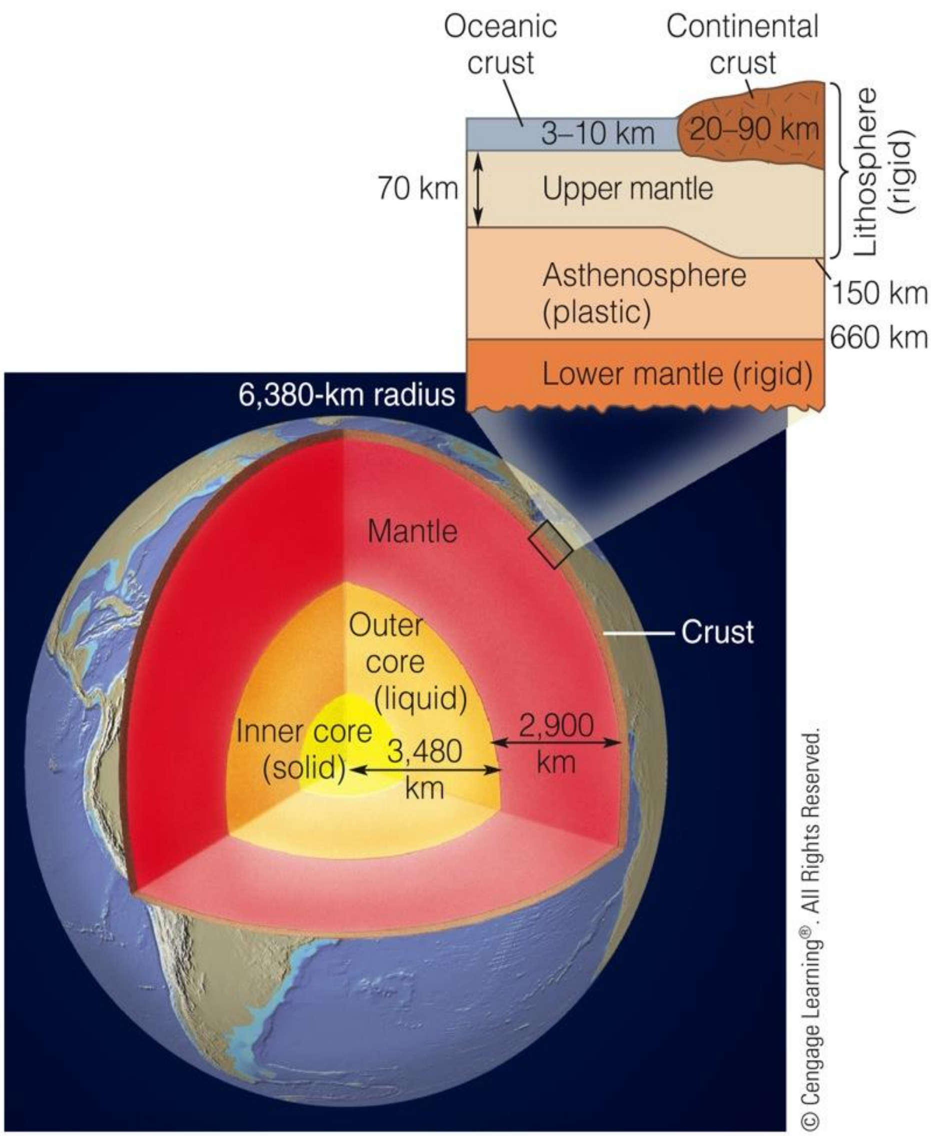


What is Earth's Interior Like?

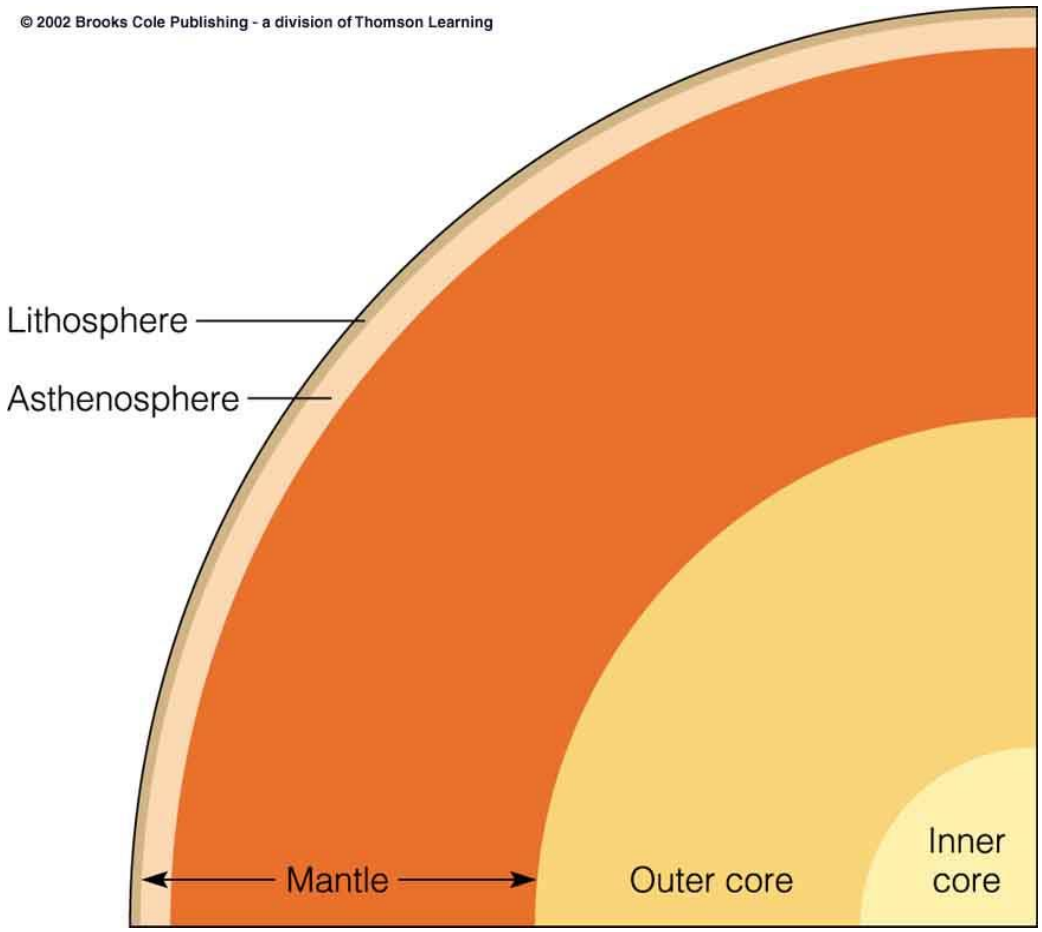
- Clues to Earth's Interior

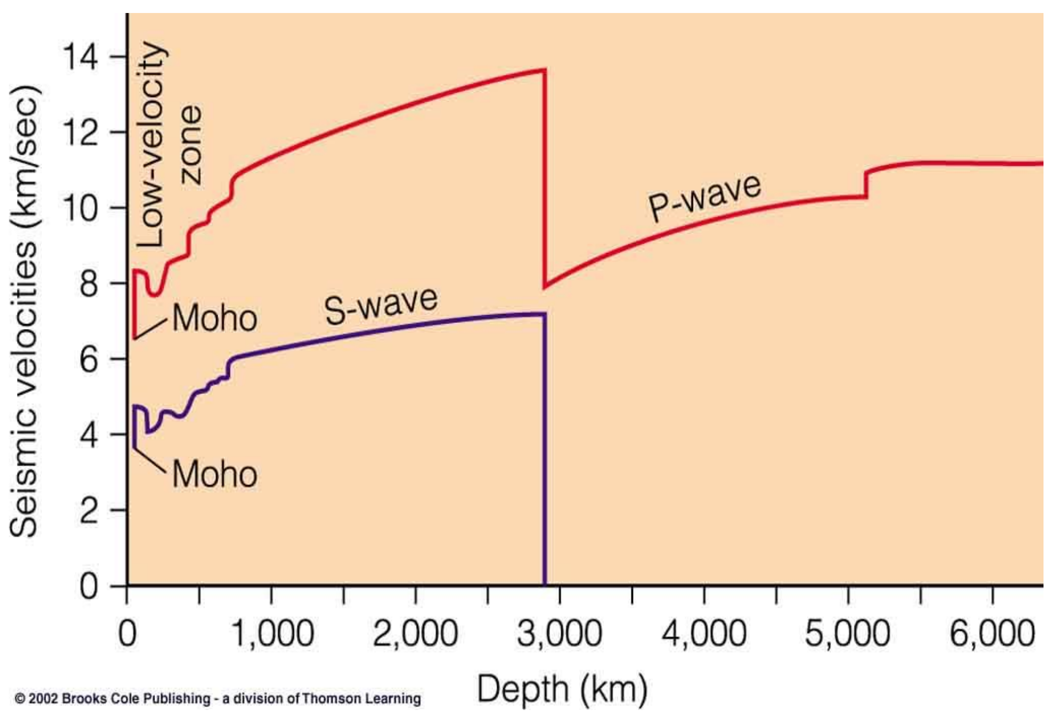
- behavior and travel times of P and S waves helps define interior structure
- speed of waves is dependent on the density and elasticity of material they travel through
- waves are bent (refracted) or bounced (reflected) as they pass through different materials in Earth

The change in speed and direction of the waves mark the boundaries between the different layers of the Earth!!!



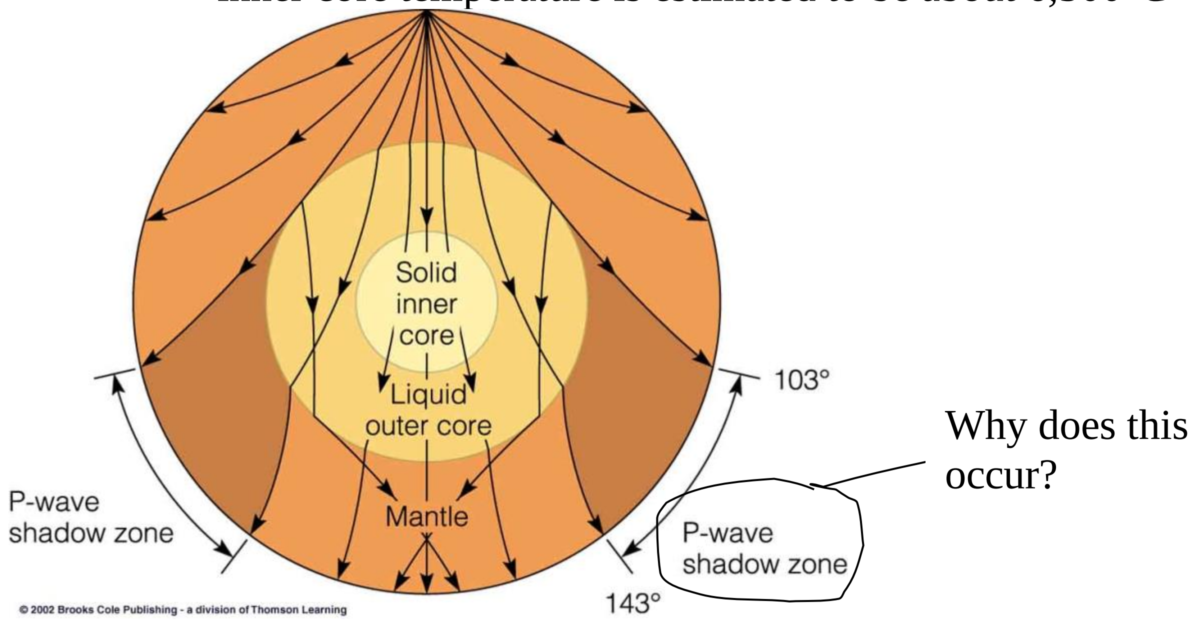
Here is a profile showing P & S wave speeds versus depth. The changes in speed indicate changes in Earth materials or their properties and is the basis for subdividing Earth's interior into concentric layers



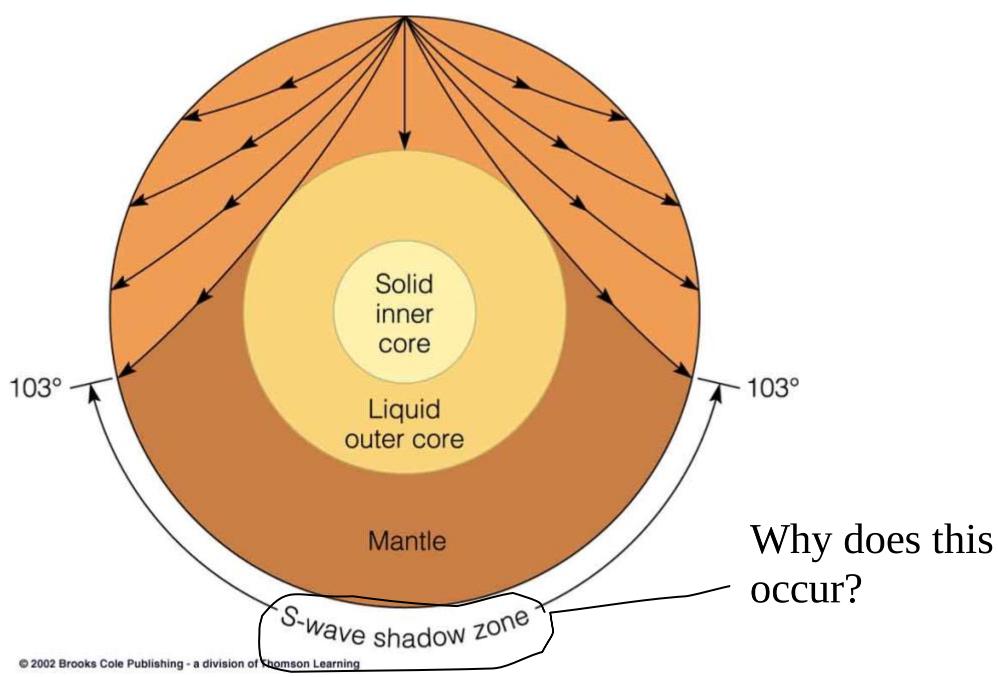


- The Core

- behavior of P and S waves indicates a solid inner and liquid outer core
- inner core is iron/nickel, rotates more rapidly than outer core
- produces earth's magnetic poles?
- outer core is iron mixed with sulfur, density of 9.9 to 12.3 gm/cm^3
- 3.5 million atmospheres of pressure; approximately 52 million psi
- inner core temperature is estimated to be about 6,500°C



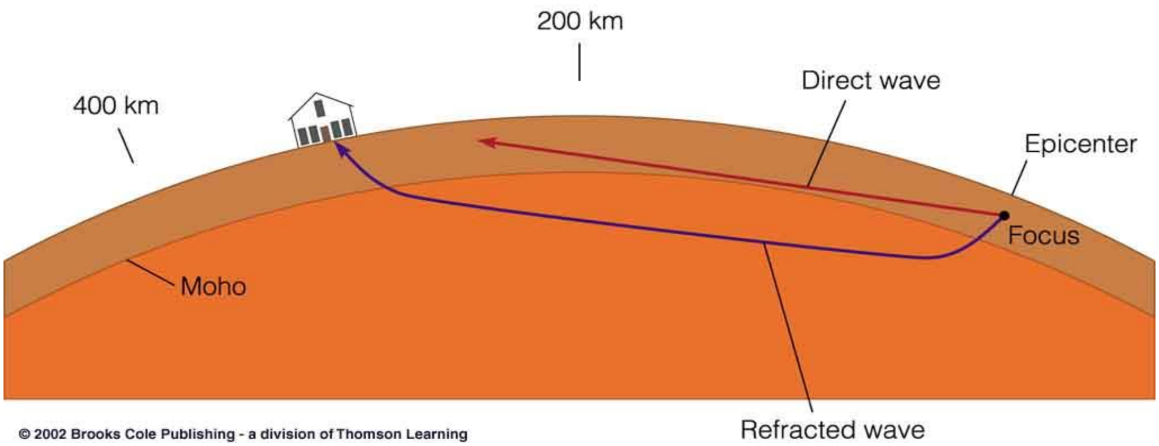
P-waves are refracted so that no direct P-wave energy reaches the surface in the P-wave shadow zone.



The presence of an S-wave shadow zone indicates that S-waves are being blocked within Earth

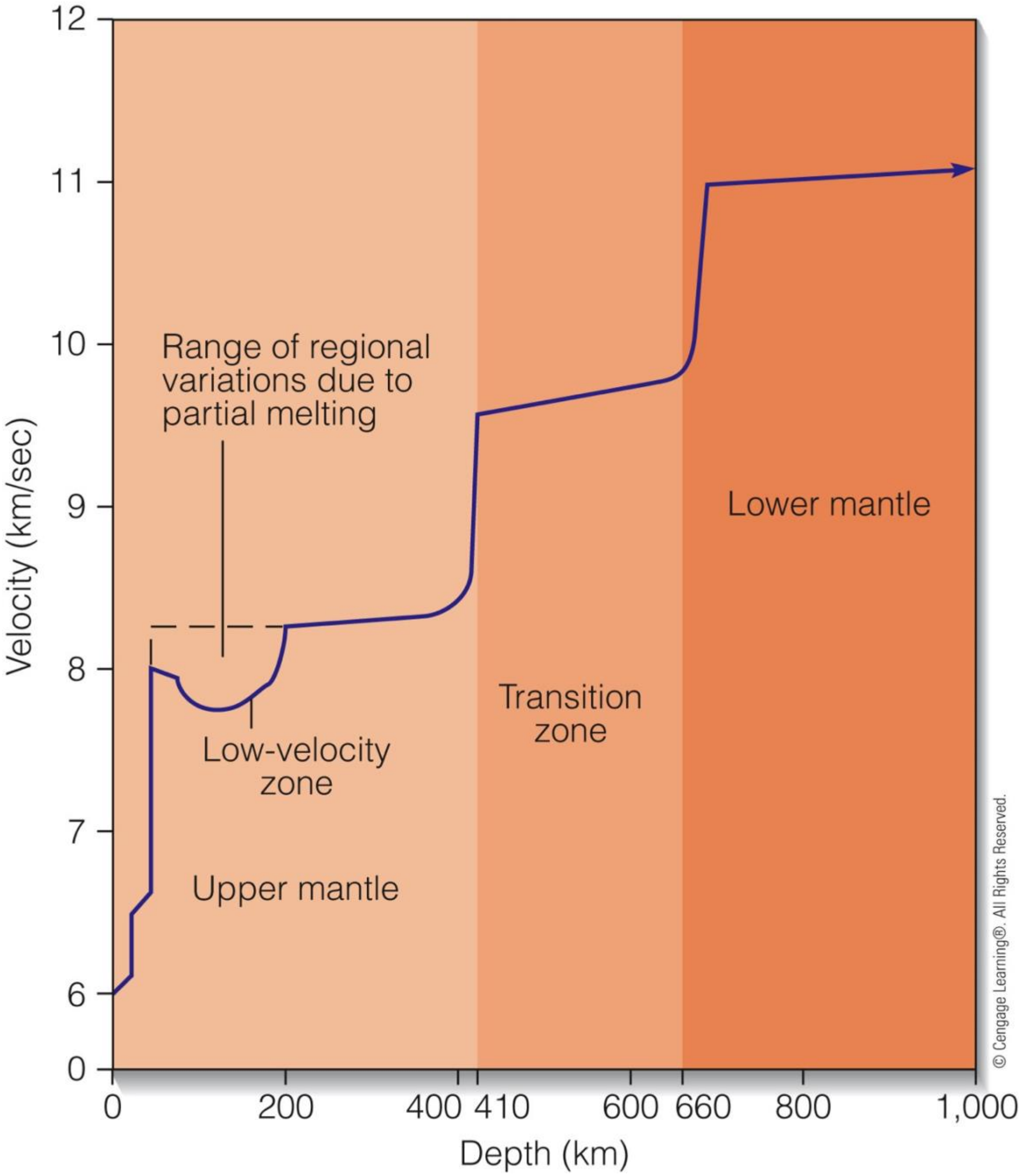
- **The Mantle**

  - Seismic wave velocities generally increase with depth, but several irregularities or discontinuities exist
    - Sharp velocity increase in wave travel times at a depth of about 30km - called the ***Moho***



Seismic Discontinuity: Andrija Mohorovic´icˆ studied seismic waves and detected a seismic discontinuity at a depth of about 30 km. The deeper, faster seismic waves arrive at seismic stations first, even though they travel farther. This discontinuity, now known as the Moho, is between the crust and mantle.

    - The Moho separates the crust from the mantle
    - The low-velocity zone is inferred to represent zones of partial melting in the asthenosphere
      - 1-2% melted
      - somewhat plastic
    - Composition believed to be that of the igneous rock peridotite



Variations in P-wave velocity in the upper mantle and transition zone.

https://www.youtube.com/watch?v=aY6SG7GPAlo **Earth's Interior - Seismic Evidence Explanation 14:30 min**

- The Crust

- Continental crust
    - Overall composition similar to granite
    - Low density (2-3gm/cm^3)
    - Averages 35km thick, more under mountain ranges

- Oceanic crust
    - Basalt/gabbro composition
    - Higher density (3gm/cm^3)
    - Between 5 and 10km thick

Earth's Composition and Density

	Composition	Density (g/cm^3)
Continental crust	Average composition of granodiorite	≈2.7
Oceanic crust	Upper part basalt, lower part gabbro	≈3.0
Mantle	Peridotite (made up of ferromagnesian silicates)	3.3–5.7
Outer core	Iron with perhaps 12% sulfur, silicon, oxygen, nickel, and potassium	9.9–12.2
Inner core	Iron with 10%–20% nickel	12.6–13.0
Earth		5.5

Measuring and Locating Earthquakes 19.3

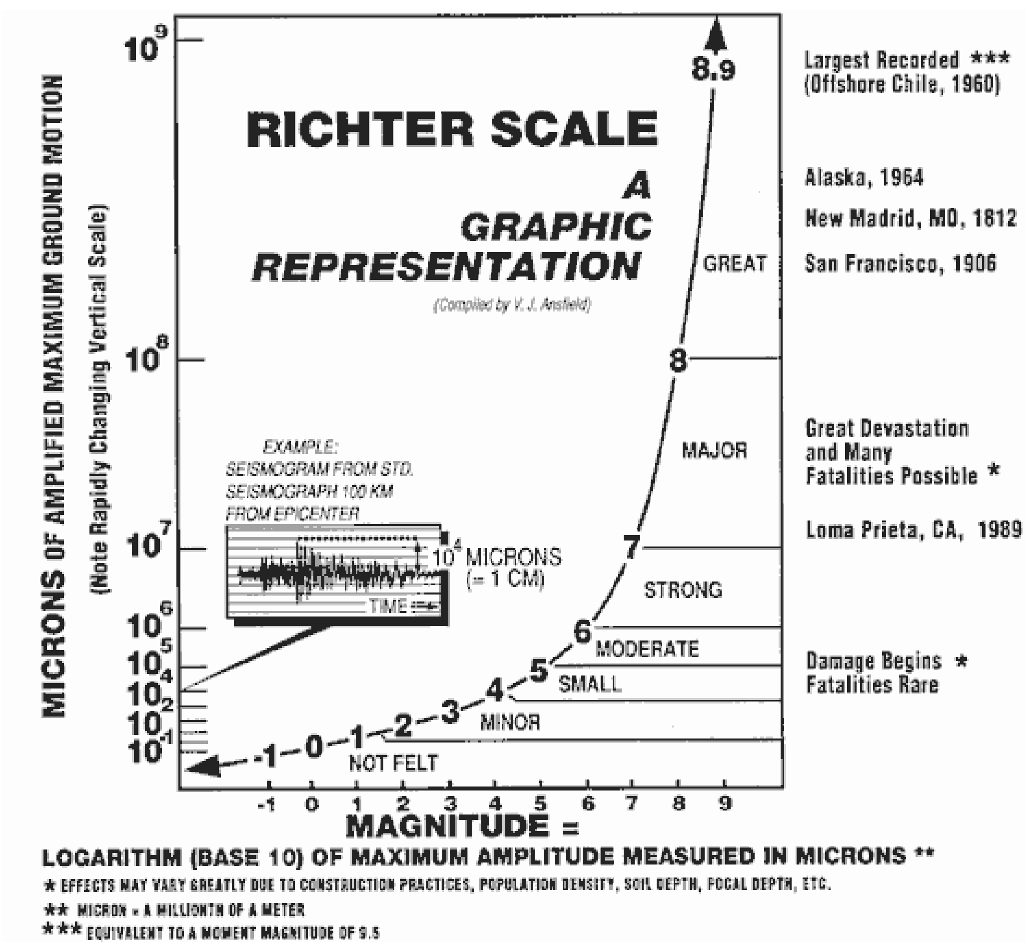
Objectives

* Compare and contrast earthquake magnitude and intensity and the scales used to measure each.
* Explain why data from at least three seismic stations are needed to locate an earthquake's epicenter.
* Describe the Earth's seismic belts.

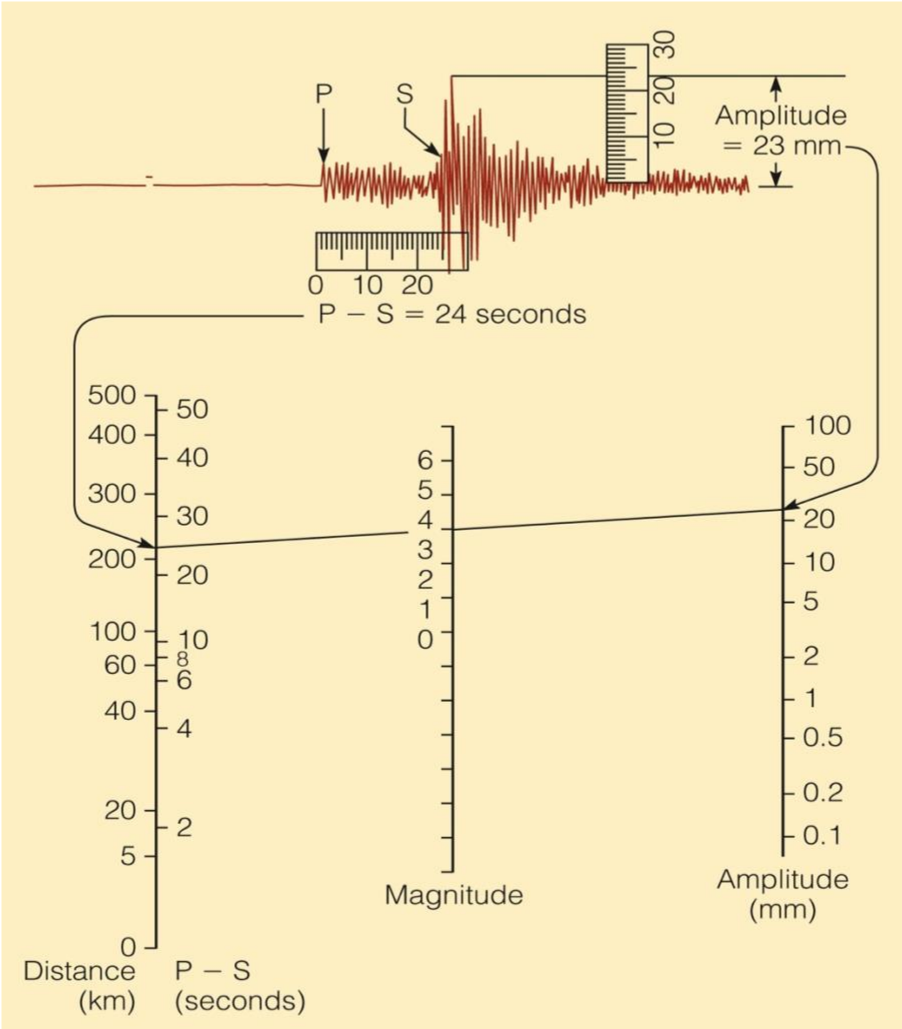
- How is the Size and Strength of an Earthquake Measured?

- **Magnitude:** measure of the amount of energy released during an earthquake
- **Movement Magnitude Scale:** measures the energy **and** the size of the fault rupture

  - **Richter Scale:** This scale was developed in the 1930's. This scale is a rating of the size of seismic waves measured by the seismograph. This scale measures mostly shaking. This scale provides accurate measurements for small, nearby earthquakes but the scale does not work well for large or distant earthquakes. This scale is based on a logarithmic scale by 10's.



- Richter scale measures total amount of energy released by an earthquake, independent of intensity
- **Amplitude** of the largest wave produced by an event is corrected for distance and assigned a value on a logarithmic scale



The Richter Magnitude Scale measures the total amount of energy released by an earthquake at its source. The magnitude is determined by measuring the maximum amplitude of the largest seismic wave and marking it on the right-hand scale. The difference between the arrival times of the P- and S-waves (recorded in seconds) is marked on the left-hand scale. When a line is drawn between the two points, the magnitude of the earthquake is the point at which the line crosses the center scale.

- Intensity

- ***Mercalli Scale***- This scale was developed in the early 20th century to rates the types of damage and the intensity of an earthquake. The Mercalli scale is a 12 step scale that describes how earthquakes affect people, buildings, and the lands surface. This scale is not a precise measurement.

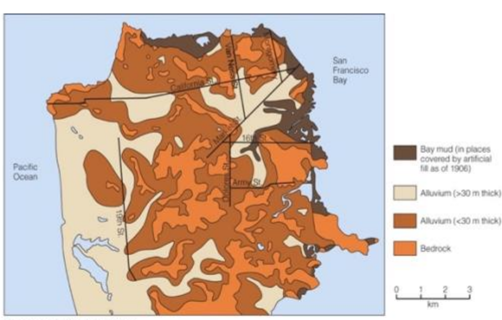
- subjective measure of the kind of damage done and people's reactions to it

- isoseismal lines identify areas of equal intensity

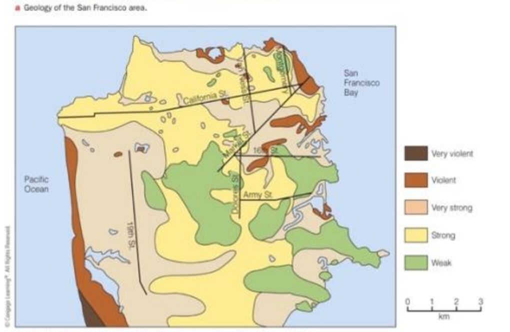
Table 2 Modified Mercalli Scale

I	Not felt except under unusual conditions
II	Felt only by a few persons; suspended objects might swing.
III	Quite noticeable indoors; vibrations are like the passing of a truck.
IV	Felt indoors by many, outdoors by few; dishes and windows rattle; standing cars rock noticeably.
V	Felt by nearly everyone; some dishes and windows break and some plaster cracks.
VI	Felt by all; furniture moves; some plaster falls and some chimneys are damaged.
VII	Difficult to stand; some chimneys break; damage is slight in well-built structures but considerable in weak structures.
VIII	Chimneys, smokestacks, and walls fall; heavy furniture is overturned; partial collapse of ordinary buildings occurs.
IX	Great general damage occurs; buildings shift off foundations; ground cracks; underground pipes break.
X	Most ordinary structures are destroyed; rails are bent; landslides are common.
XI	Few structures remain standing; bridges are destroyed; railroad ties are greatly bent; broad fissures form in the ground.
XII	Damage is total; objects are thrown upward into the air.

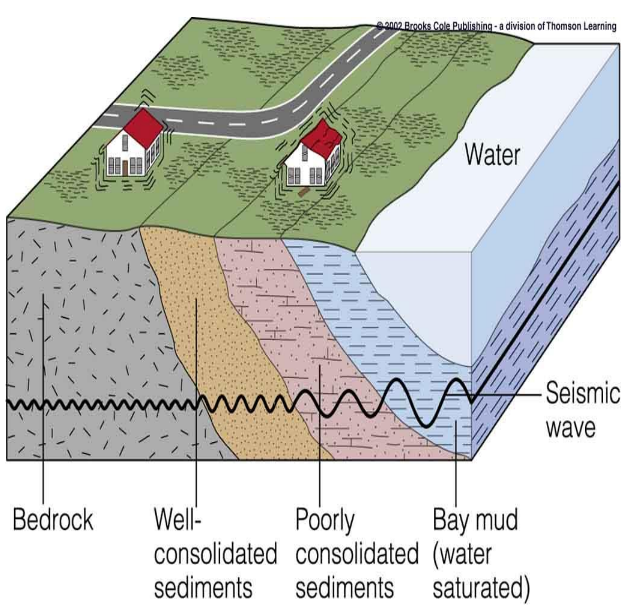
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	***<0.02***	***0.1***	***1.4***	***4.7***	***9.6***	***20***	***41***	***86***	***>178***
INSTRUMENTAL INTENSITY	**I**	**II–III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X+**



a Geology of the San Francisco area.

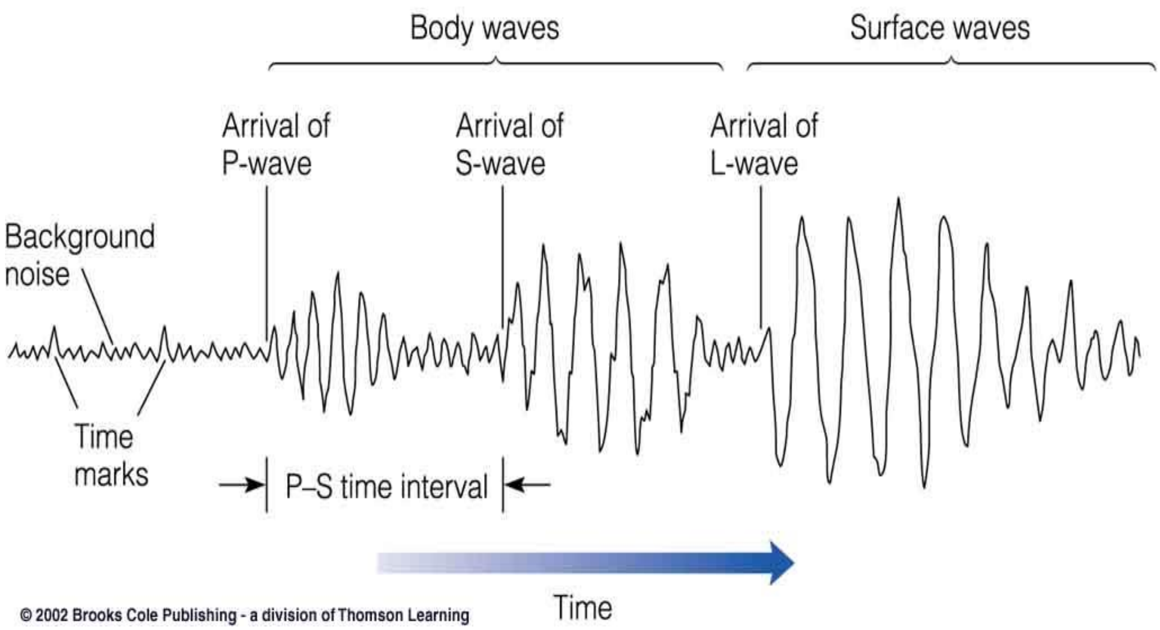


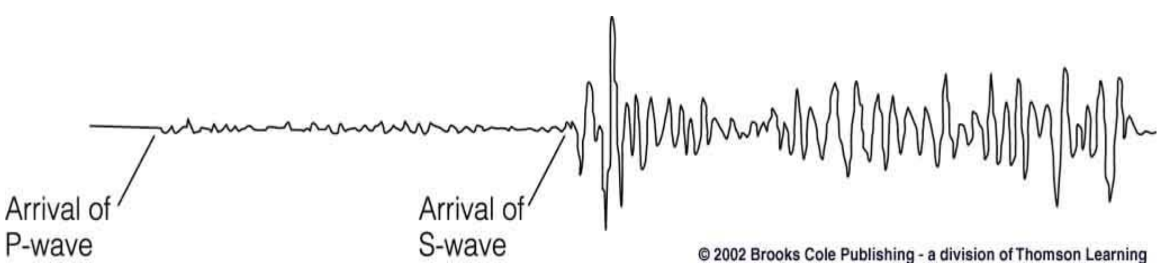
b Intensity of ground shaking in the San Francisco area during the 1906 earthquake.



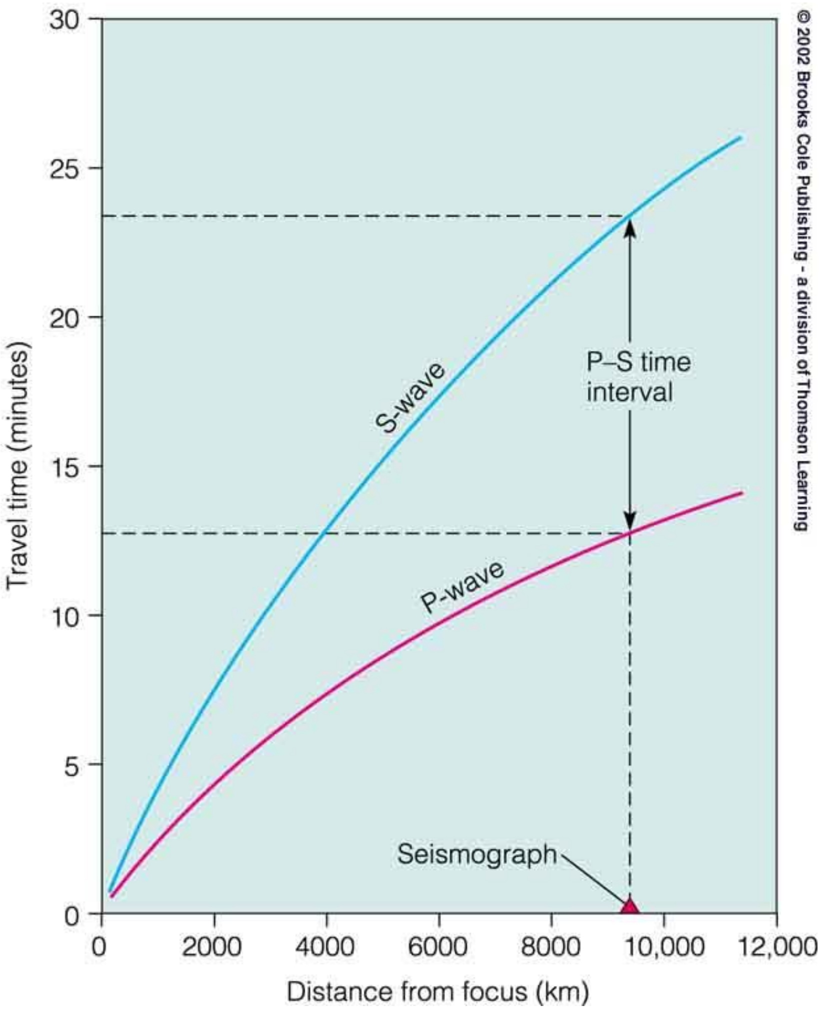
- How is an Earthquake's Epicenter Located?

- P waves arrive first, then S waves, then L and R
- Average speeds for all these waves is known
- After an earthquake, the difference in arrival times at a seismograph station can be used to calculate the distance from the seismograph to the epicenter.





- Time-distance graph showing the average travel times for *P- and S-waves. The farther away a seismograph is from the* focus of an earthquake, the longer the interval between the arrivals of the P- and S- waves.



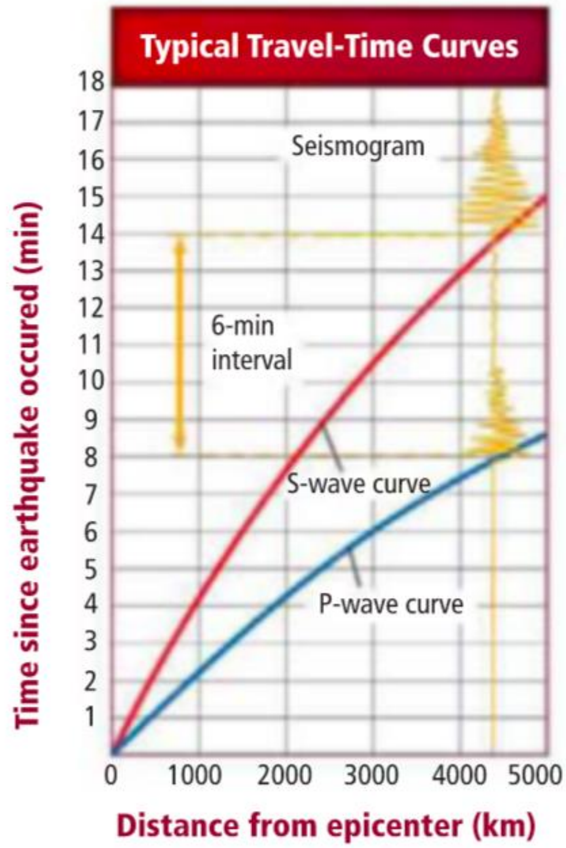


Figure 16 This travel-time curve also shows seismographic data for an earthquake event.

- Three seismograph stations are needed to locate the epicenter of an earthquake
- A circle where the radius equals the distance to the epicenter is drawn
- The intersection of the circles locates the epicenter

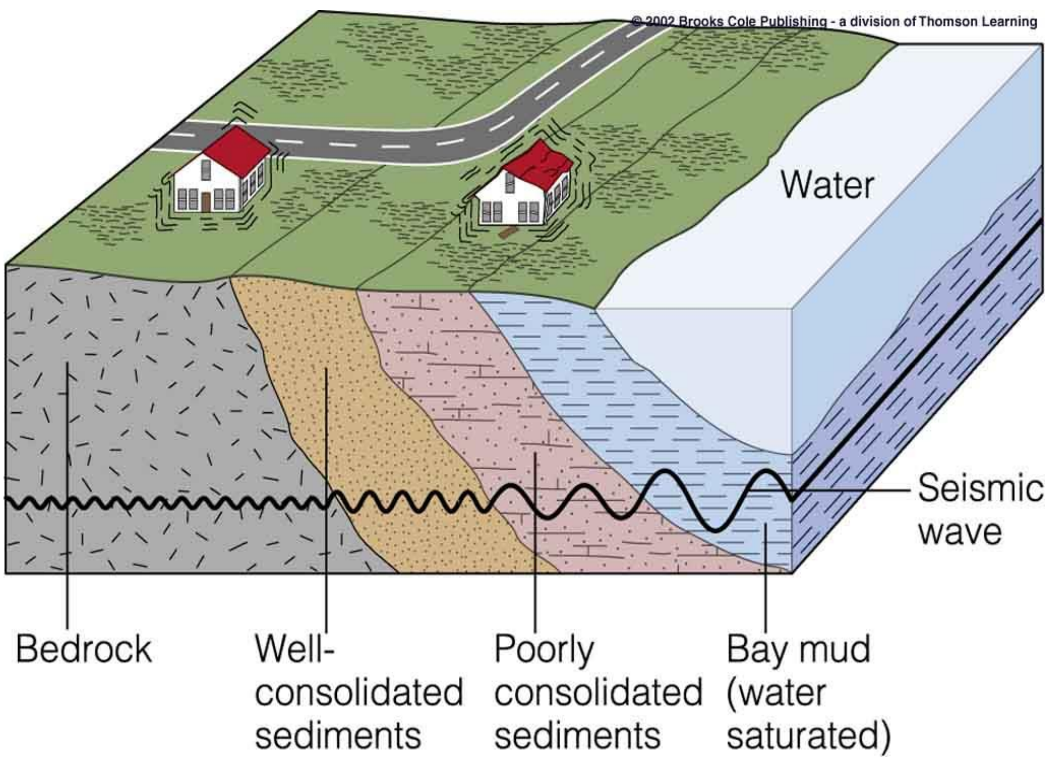
https://www.youtube.com/watch?v=694yaY2ylTg
4 min
https://www.youtube.com/watch?v=TBss68oBmmk
10 min 18 sec

Earthquakes & Society 19.4

Objectives
* Discuss factors that affect the amount of damage done by an earthquake.
* Explain some of the factors considered in earthquake probability studies.
* Define seismic gaps

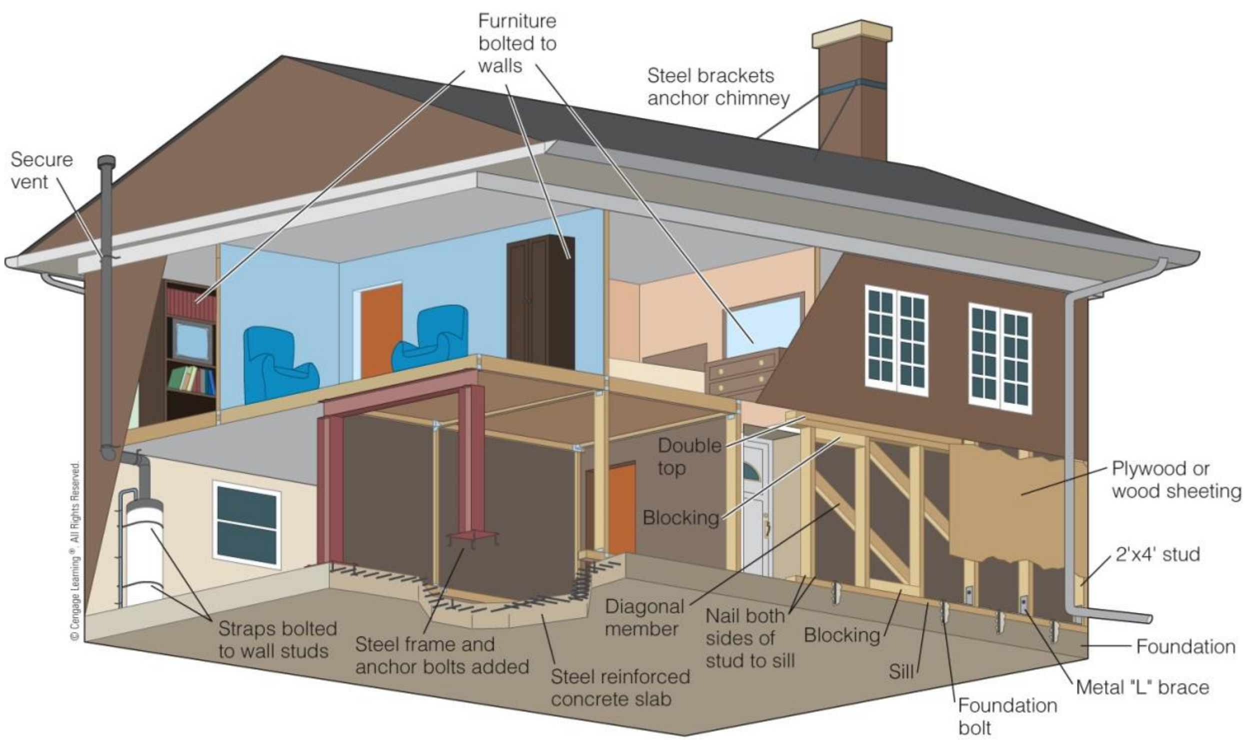
- Earthquake Hazards

- Ground Shaking
  - amplitude, duration, and damage increases in poorly consolidated rocks
    - structures built on weaker material typically suffer greater damage
- Structural failure
- Fire
- Tsunami
- Ground failure



Relationship Between Seismic Wave Amplitude and Underlying Geology: The amplitude and duration of seismic waves generally increase as the waves pass from bedrock into poorly consolidated or water-saturated material. Thus, structures built on weaker material typically suffer greater damage than similar structures built on bedrock because the shaking lasts longer.

Liquefaction: The effects of ground shaking on water saturated soil are dramatically illustrated by the collapse of these buildings in Niigata, Japan, during a 1964 earthquake. The buildings were designed to be earthquake resistant and fell over on their sides intact when the ground below them underwent liquefaction.



Some of the useful things a homeowner can do to reduce damage to a building because of ground shaking during an earthquake. Notice that the structure must be solidly attached to its foundation and bracing the walls helps prevent damage from horizontal motion.

University of California at Berkeley

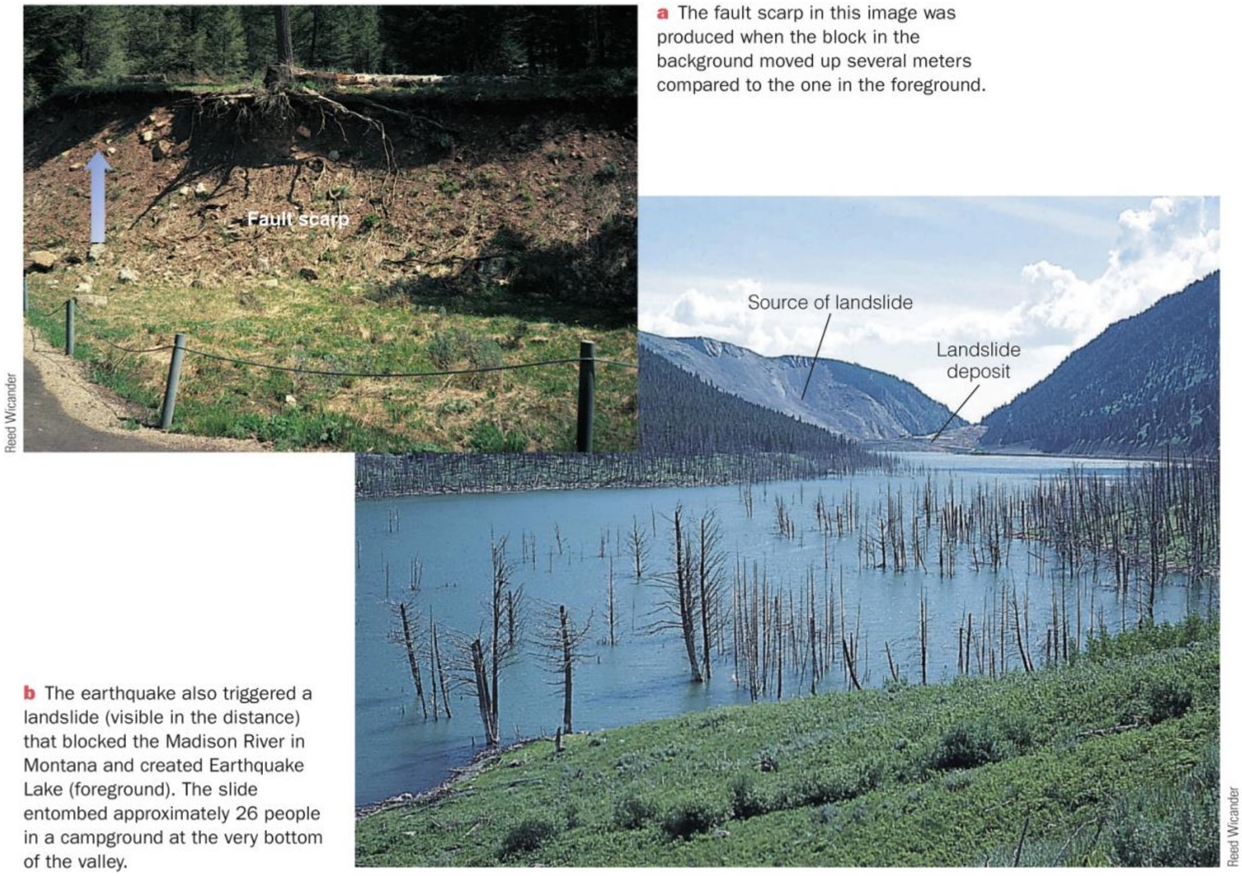
a San Francisco following the 1906 earthquake. This view along Sacramento Street shows damaged buildings and the approaching fire. It is estimated that about 3,000 people died, and approximately 28,000 buildings were destroyed, many of them by the three-day fire that raged out of control.

The Marin Independent Journal

b San Francisco Marina district fire caused by broken gas lines during the 1989 Loma Prieta earthquake. Because of the system of valves throughout San Francisco's gas and water pipeline network, this fire was quickly contained before it could spread and do potentially greater damage.

Kein Wang, Pacific Geoscoence Center, Canada

During the 2008 Sichuan, China earthquake, structures of masonry construction, coupled with little or no reinforcing collapsed, leading to tremendous damage and loss of life.



a The fault scarp in this image was produced when the block in the background moved up several meters compared to the one in the foreground.

b The earthquake also triggered a landslide (visible in the distance) that blocked the Madison River in Montana and created Earthquake Lake (foreground). The slide entombed approximately 26 people in a campground at the very bottom of the valley.

http://www.youtube.com/watch?v=tF204Pgf-eo&safety_mode=true&safe=active
eathquake proof: 2:22 min

http://www.youtube.com/watch?v=IjPiujuF0TA&safety_mode=true&safe=active
Smart earthquake protection with vibration control: 1:06 min

http://www.youtube.com/watch?v=ChaqMDc4ces&safety_mode=true&safe=active
Earthquake Protective Foundation - base isolation video: 27 sec

http://www.youtube.com/watch?v=xp2pGxFzrzI&NR=1&feature=endscreen&safety_mode=true
Dampers for earthquake protection: 30 sec

TABLE 9.3 What You Can Do to Prepare for an Earthquake

Anyone who lives in an area that is subject to earthquakes or who will be visiting or moving to such an area can take certain precautions to reduce the risks and losses resulting from an earthquake.

Before an earthquake:

1. Become familiar with the geologic hazards of the area where you live and work.
2. Make sure your house is securely attached to the foundation by anchor bolts and that the walls, floors, and roof are all firmly connected together.
3. Heavy furniture such as bookcases should be bolted to the walls; semiflexible natural gas lines should be used so that they can give without breaking; water heaters and furnaces should be strapped and the straps bolted to wall studs to prevent gas-line rupture and fire. Brick chimneys should have a bracket or brace that can be anchored to the roof.
4. Maintain a several-day supply of fresh water and canned foods, and keep a fresh supply of flashlight and radio batteries, as well as a fire extinguisher.
5. Maintain a basic first-aid kit and have a working knowledge of first-aid procedures.
6. Learn how to turn off the various utilities at your house.
7. Above all, have a planned course of action for when an earthquake strikes.

During an earthquake:

1. Remain calm and avoid panic.
2. If you are indoors, get under a desk or table if possible, or stand in a room corner as that is the structurally strongest part of a room; avoid windows and falling debris.
3. In a tall building, do not rush for the stairwells or elevators.
4. In an unreinforced or other hazardous building, it may be better to get out of the building rather than to stay in it. Be on the alert for fallen power lines and the possibility of falling debris.
5. If you are outside, get to an open area away from buildings if possible.
6. If you are in an automobile, stay in the car, and avoid tall buildings, overpasses, and bridges if possible.

After an earthquake:

1. If you are uninjured, remain calm and assess the situation.
2. Help anyone who is injured.
3. Make sure there are no fires or fire hazards.
4. Check for damage to utilities and turn off gas valves if you smell gas.
5. Use your telephone only for emergencies.
6. Do not go sightseeing or move around the streets unnecessarily.
7. Avoid landslide and beach areas.
8. Be prepared for aftershocks.

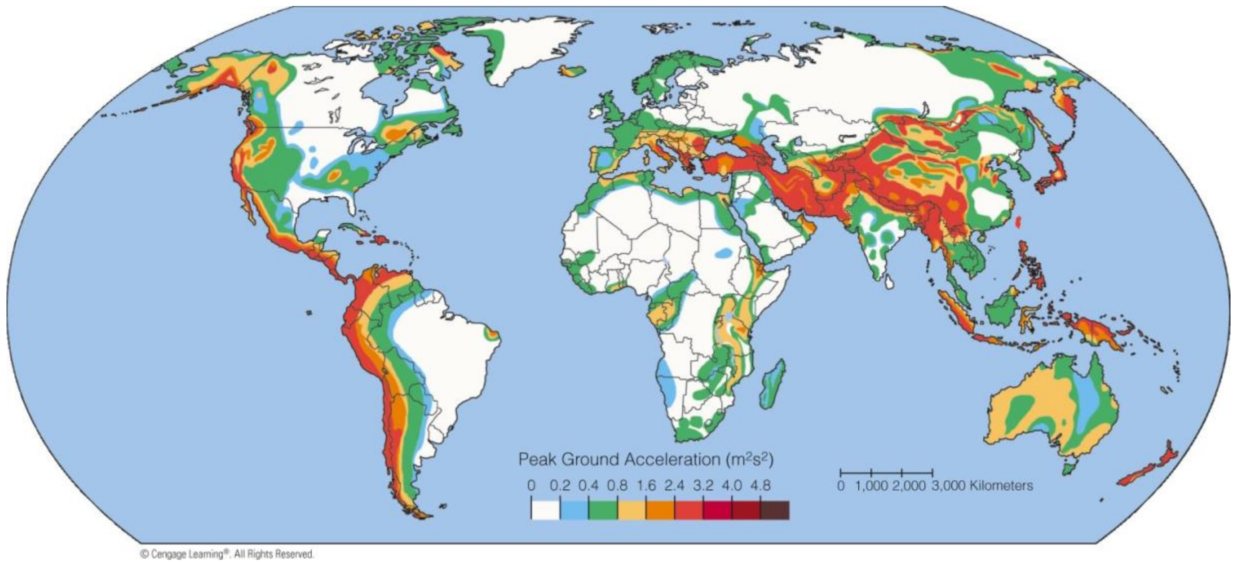
- Can Earthquakes be Predicted?

- Earthquake Precursors

    - changes in elevation or tilting of land surface, fluctuations in groundwater levels, magnetic field, electrical resistance of the ground
    - seismic dilatancy model
        - based on changes in rock when subjected to high pressure; increase in volume
    - **seismic gaps**: areas of prior earthquake activity

- Earthquake Prediction Programs

    - include laboratory and field studies of rocks before, during, and after earthquakes
    - monitor activity along major faults
    - produce risk assessments

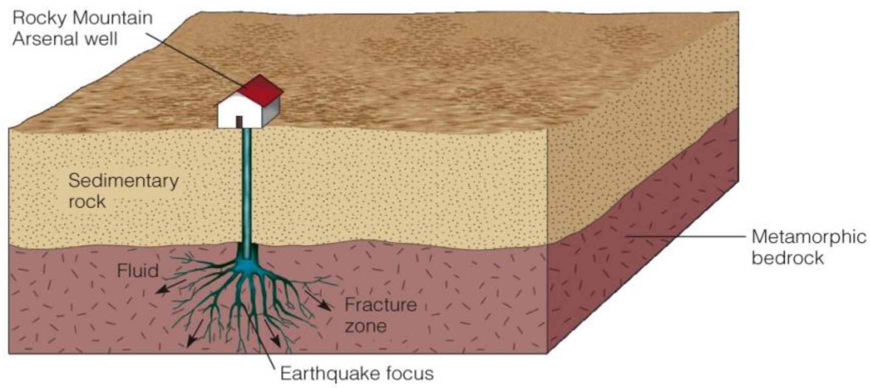


Global Seismic Hazard Assessment Map The Global Seismic Hazard Assessment Program published this seismic hazard map showing peak ground accelerations. The values are based on a 90% probability that the indicated horizontal ground acceleration during an earthquake is not likely to be exceeded in 50 years. The higher the number, the greater the hazard. As expected, the greatest seismic risks are in the circum-Pacific belt and the Mediterranean–Asiatic belt.

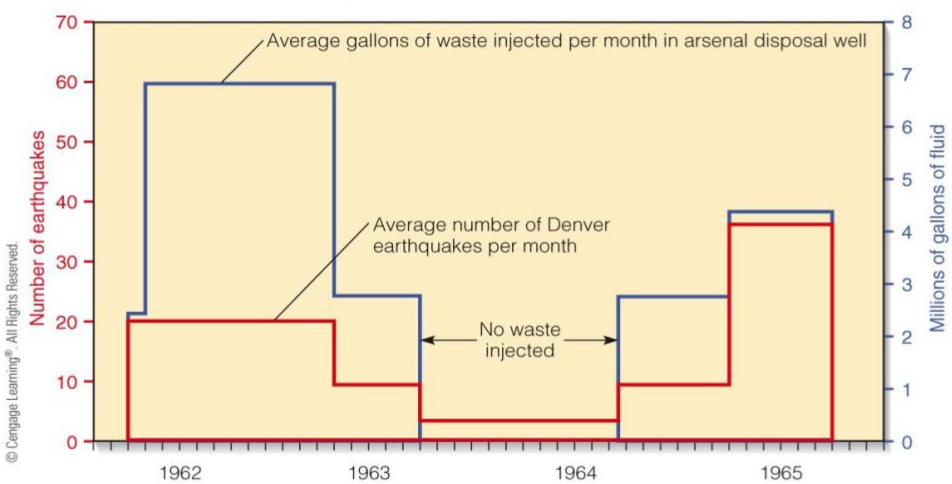
Geologists examine a trench across an active fault in California to determine possible seismic hazards. Excavating trenches is a common method used by geologists to gather information about ancient earthquakes in a region and to help assess the potential for future earthquakes and the damage that they might cause.

- Can Earthquakes be Controlled?

- Graph showing the relationship between the amount of waste injected into wells per month and the average number of Denver earthquakes per month
- Some have suggested that pumping fluids into seismic gaps will cause small earthquakes while preventing large ones



a A block diagram of the Rocky Mountain Arsenal well and the underlying geology.



b A graph showing the relationship between the amount of wastewater injected into the well per month and the average number of Denver earthquakes per month. There have been no significant earthquakes in Denver since injection of wastewater into the disposal well ceased in 1965.