Earthquakes and Earth's Interior

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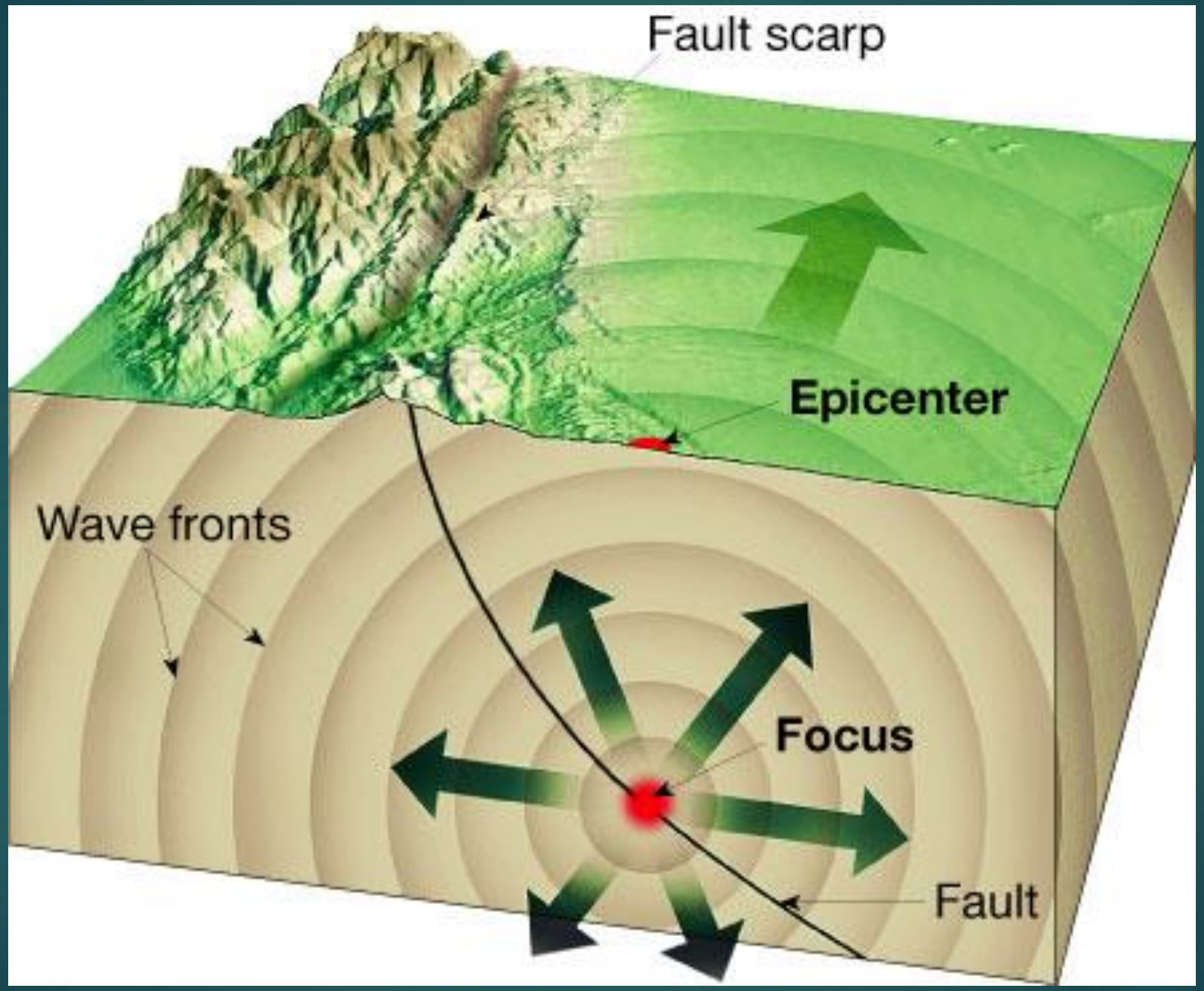
EARTH SCIENCE

What is an Earthquake?

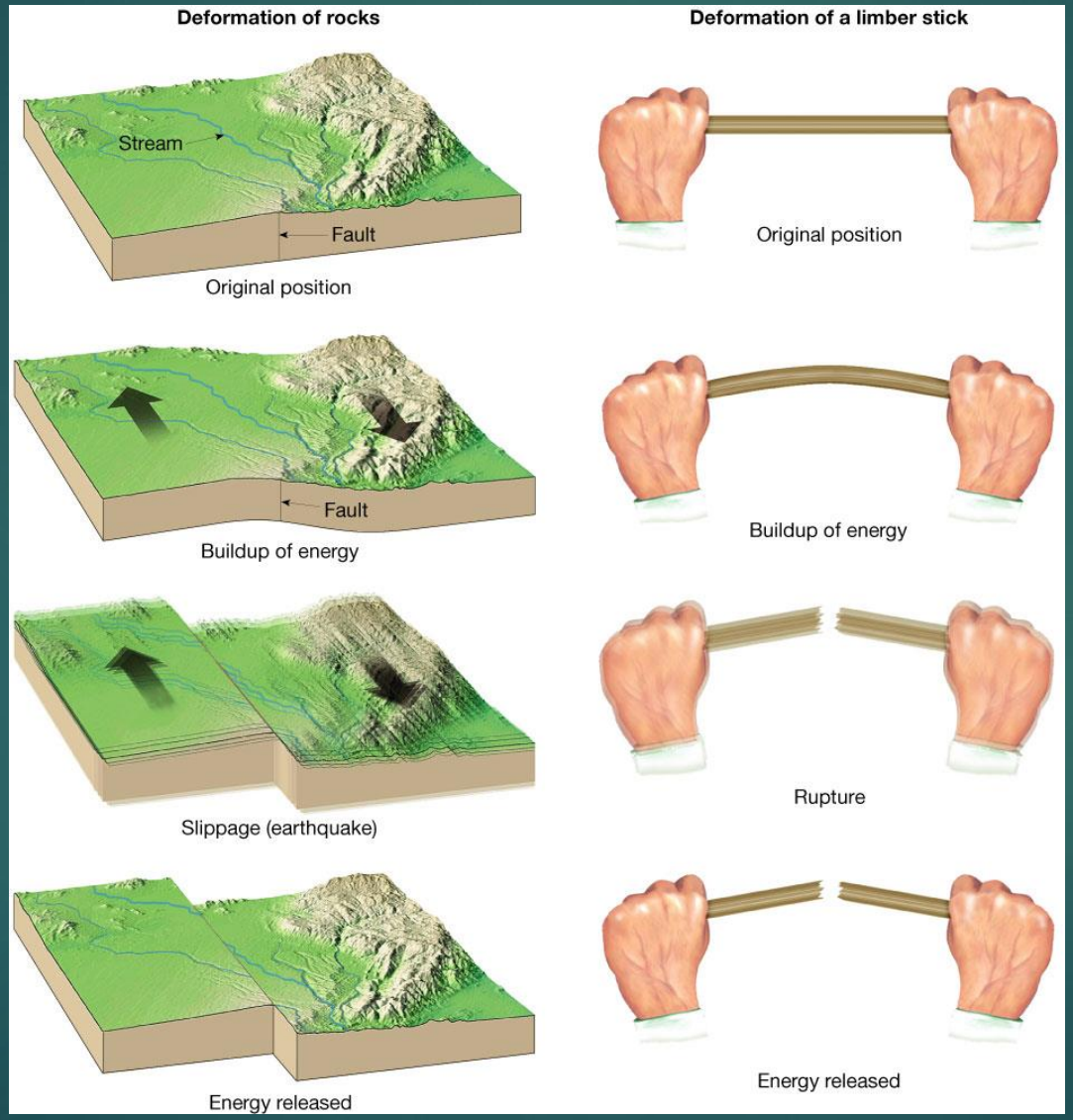
- An **earthquake** is the vibration of Earth produced by the rapid release of energy
- Focus and Epicenter
  - **Focus** is the point within Earth where the earthquake starts
  - **Epicenter** is the location of the surface directly above the focus
- Faults
  - **Faults** are fracture in Earth where movement has occurred.


Fault scarp
Epicenter
Wave fronts
Focus
Fault

Cause of Earthquakes

- Elastic Rebound Hypothesis
  - Most earthquakes are produced by the rapid release of elastic energy stored in rock that has been subjected to great forces.
  - When the strength of the rock is exceeded, it suddenly breaks, causing the vibrations of an earthquake.

Elastic Rebound Hypothesis



Aftershocks and Foreshocks

- A **foreshock** is a small earthquake that often precedes an earthquake
- An **aftershock** is a small earthquake that follows the main earthquake

Earthquake Waves

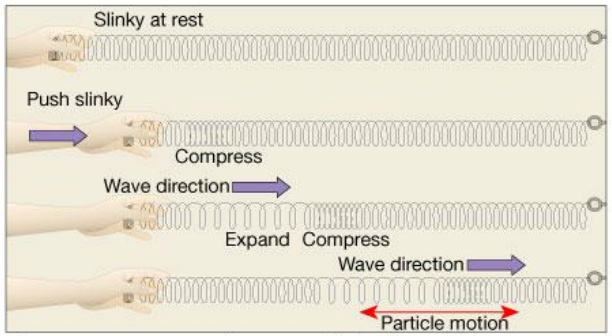
- Surface Waves are seismic waves that travel along Earth's outer layer
  - Move up and down and side to side
  - Side to side is most damaging to buildings.
  - Most destructive type of earthquake wave

Earthquake Waves

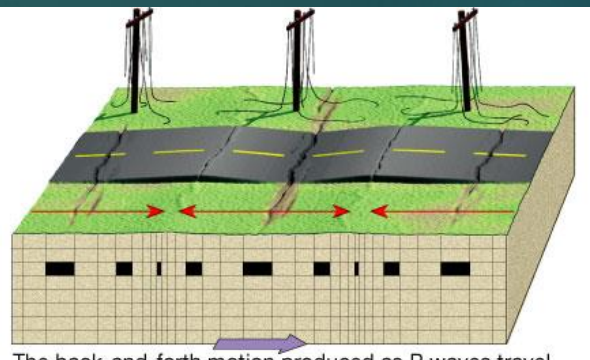
- Body Waves
  - Identified as P waves or S waves
    - P waves
      - Are push-pull waves that push (compress) and pull (expand) in the direction that the waves travel
      - Travel through solids, liquids, and gases
      - Have the greatest velocity of all earthquake waves

Earthquake Waves

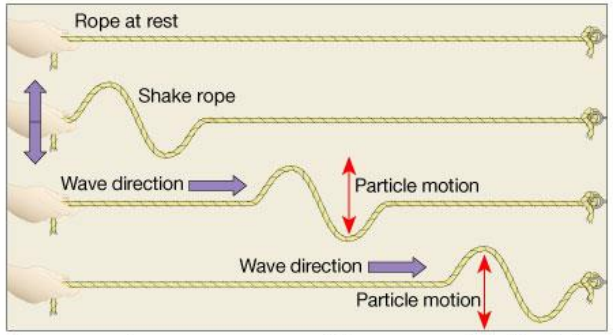
- S waves
  - Seismic waves that travel along Earth's outer layer
  - Shake particles at right angles to the direction they travel
  - Travel only through solids
  - Slower velocity than P waves
- A seismogram shows all three types of seismic waves– surface waves, P waves, and S waves



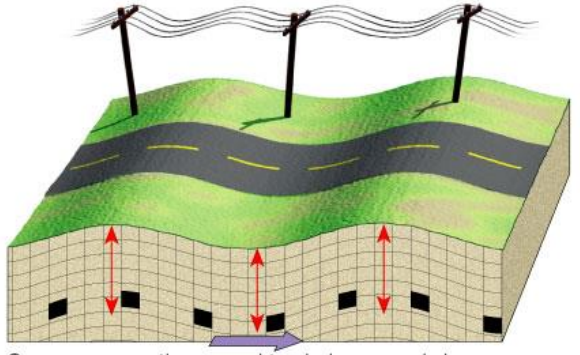
P waves are compression waves that alternately compress and expand the material through which they pass.



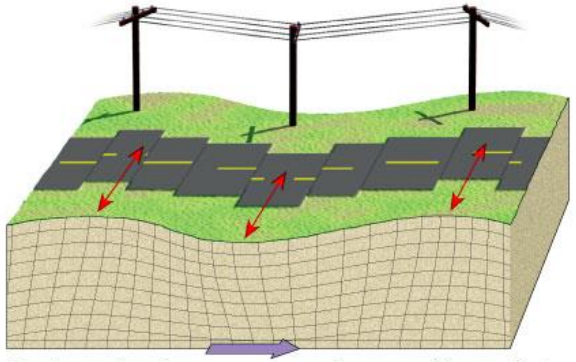
The back-and-forth motion produced as P waves travel along the surface can cause the ground to buckle and fracture.



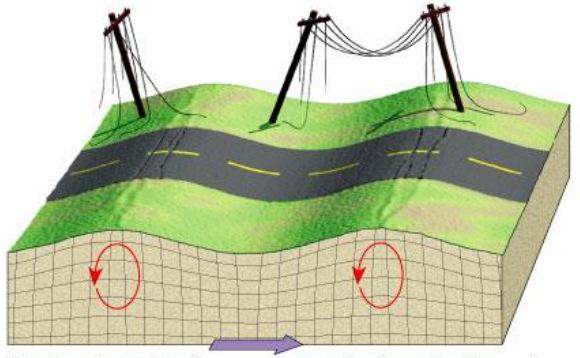
S waves are transverse waves which cause material to shake at right angles to the direction of wave motion. The length of the red arrow is the displacement, or amplitude, of the S wave.



S waves cause the ground to shake up-and-down and sideways.



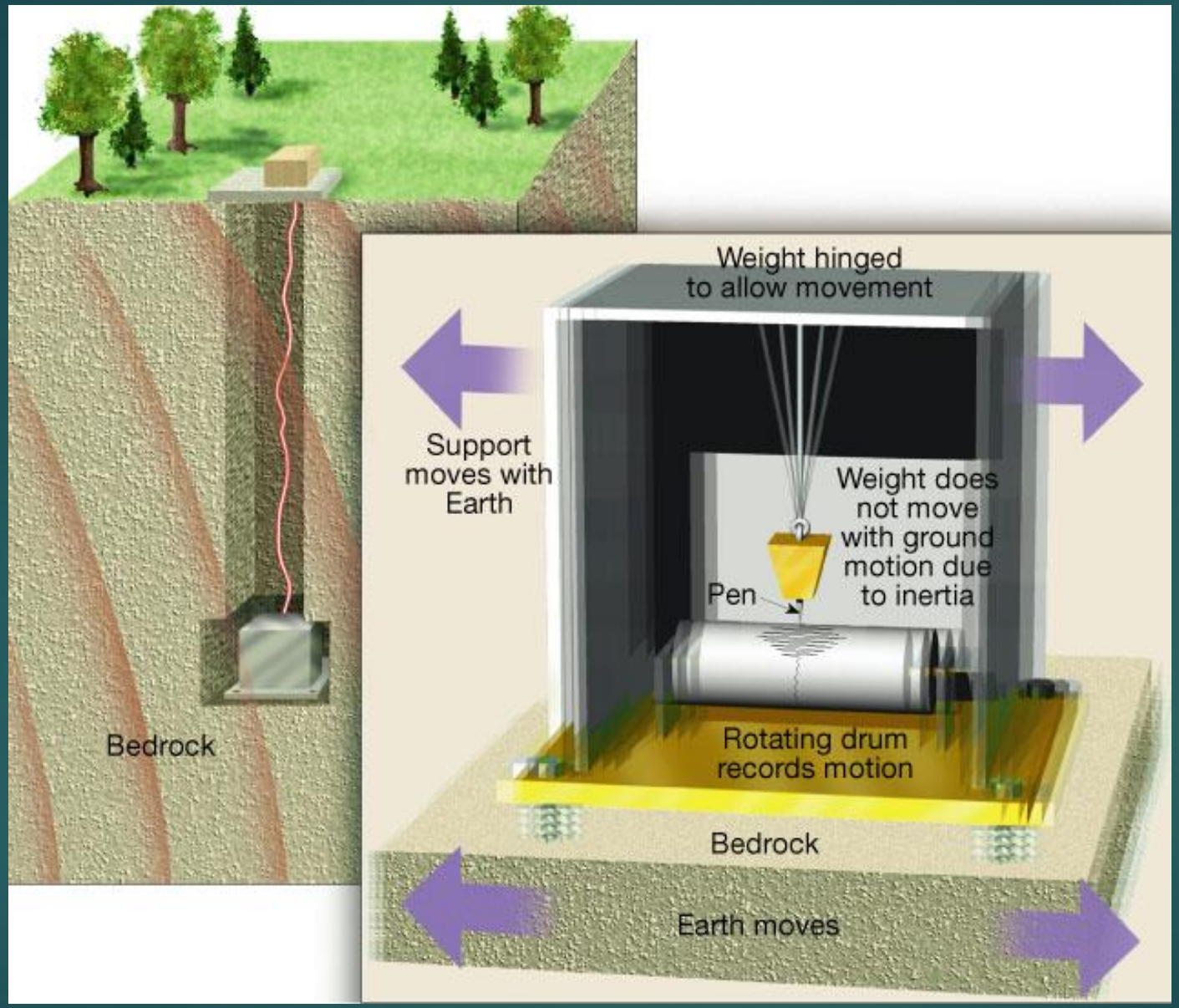
One type of surface wave moves the ground from side to side and can damage the foundations of buildings.

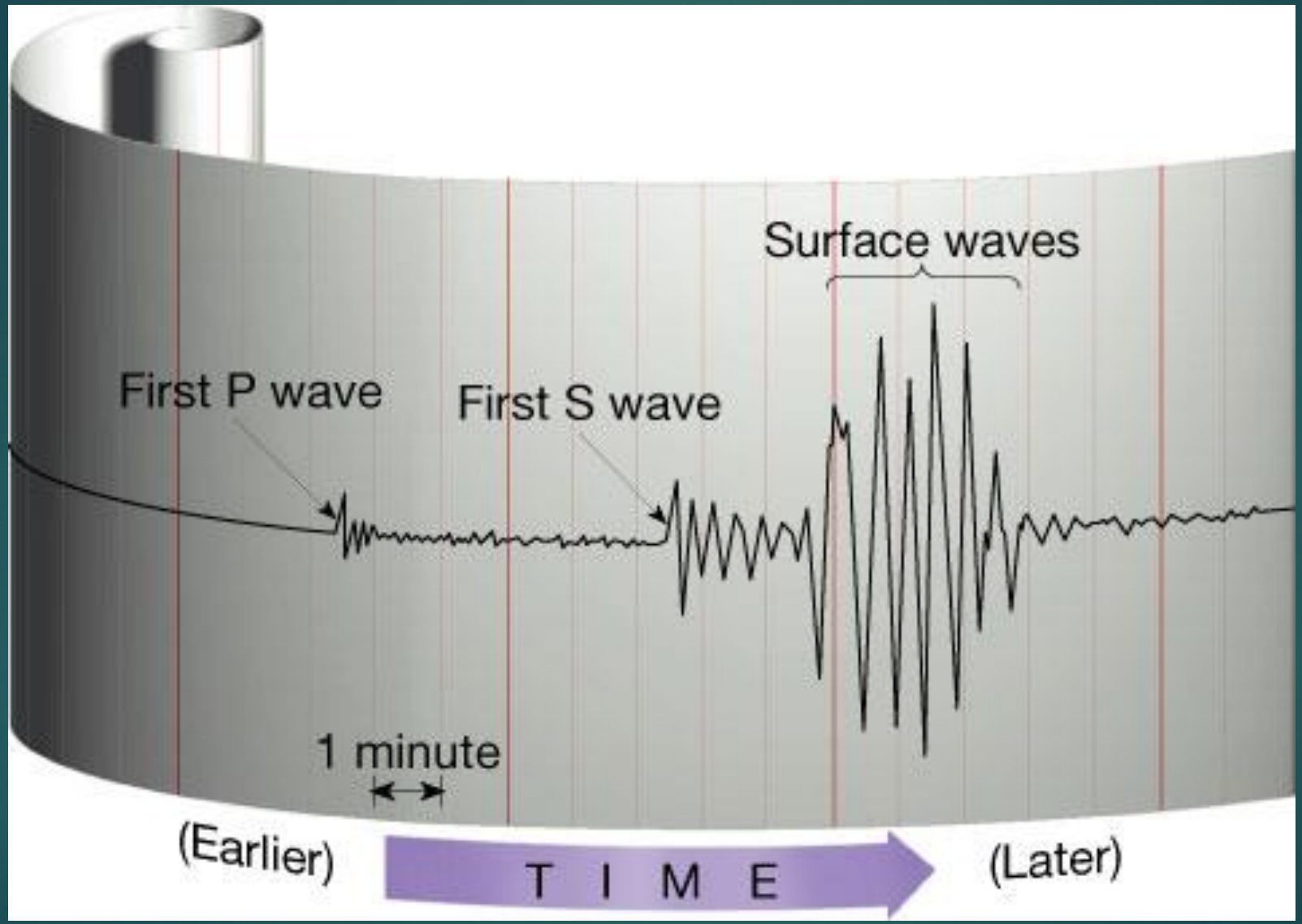


Another type of surface wave travels along Earth's surface much like rolling ocean waves. The arrows show the movement of rock as the wave passes. The motion follows the shape of an ellipse.

Measuring Earthquakes

- Earthquake waves
  - **Seismographs** are instruments that record earthquake waves.
  - **Seismograms** are traces of amplified electronically recorded ground motion make by seismographs
  - **Surface waves** are seismic waves that travel along Earth's outer layer.


Weight hinged
to allow movement
Support
moves with
Earth
Weight does
not move
with ground
motion due
to inertia
Pen
Rotating drum
records motion
Bedrock
Earth moves
Bedrock


Surface waves
First P wave
First S wave
1 minute
(Earlier)
T I M E
(Later)

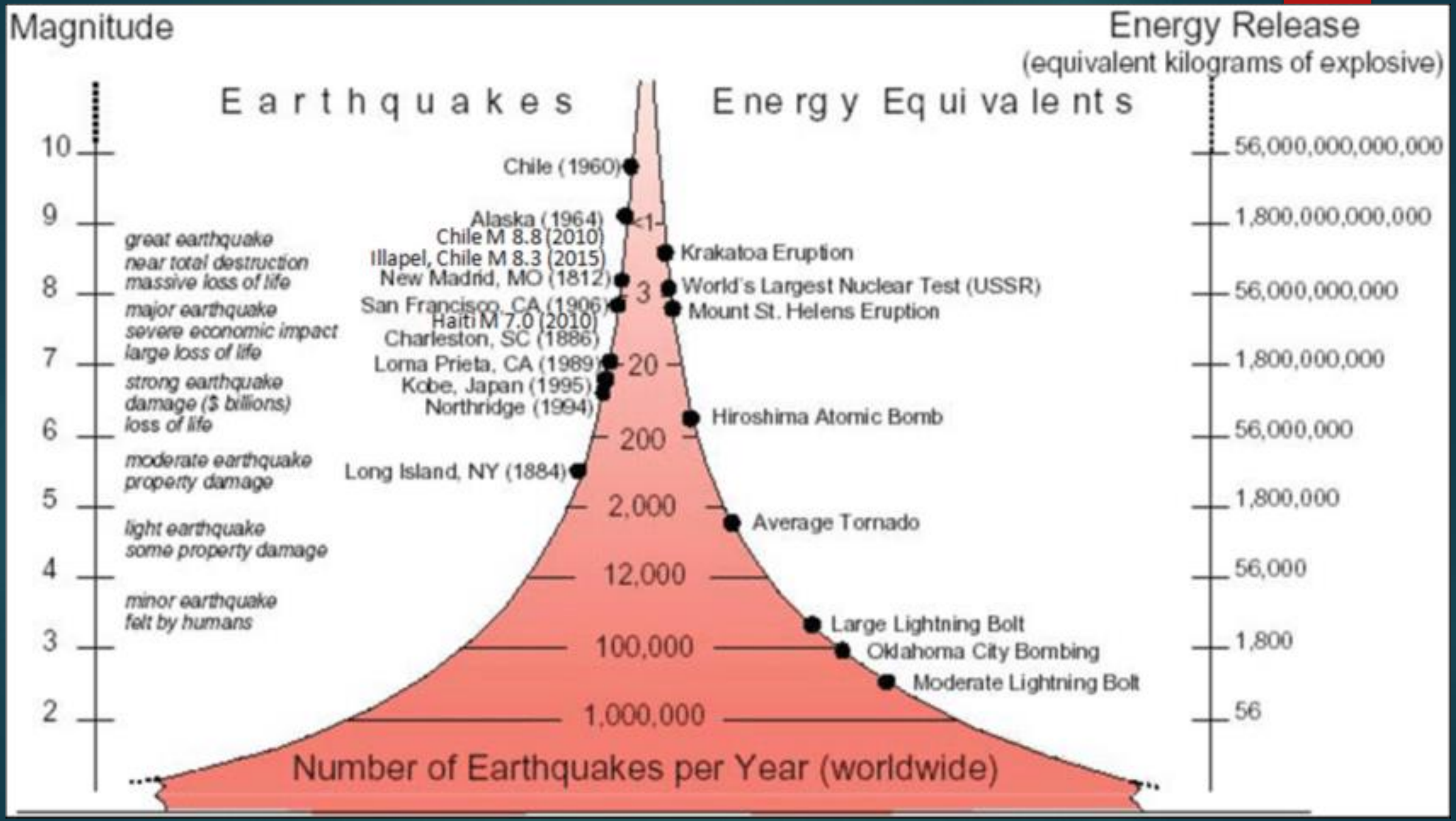
Measuring Earthquakes

- Historically, scientists have used two different types of measurements to describe the size of an earthquake – intensity and magnitude
- Richter scale
  - Based on the amplitude of the largest seismic wave
  - Each unit of Richter magnitude equates to roughly a 32-fold energy increase
  - Does not estimate adequately the size of very large earthquakes

- Moment Magnitude
  - Derived from the amount of displacement that occurs along the fault zone
  - Moment magnitude is the most widely used measurement for earthquakes because it is the only magnitude scale that estimates the energy released by earthquakes
  - Measures very large earthquakes

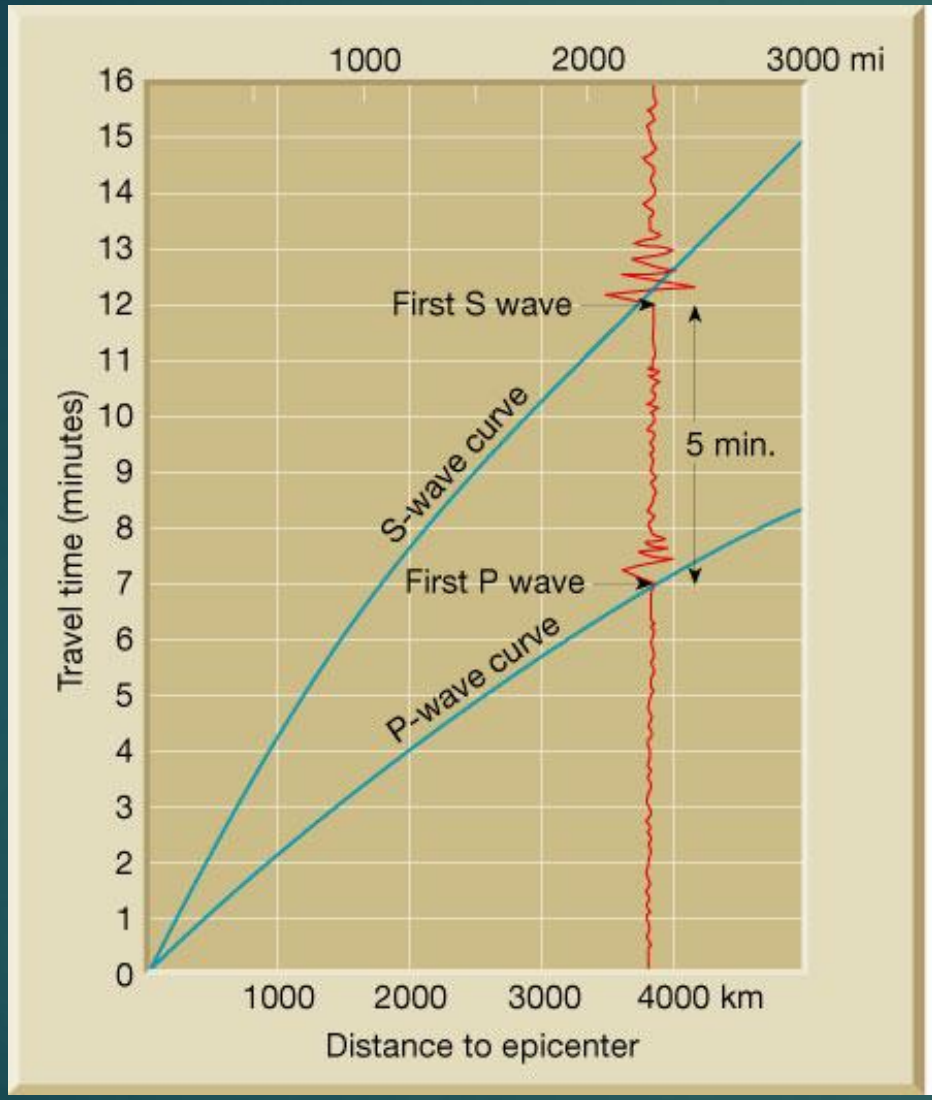
Table 1 Earthquake Magnitudes and Expected World Incidence

Moment Magnitudes	Effects Near Epicenter	Estimated Number per Year
< 2.0	Generally not felt, but can be recorded	> 600,000
2.0–2.9	Potentially perceptible	> 300,000
3.0–3.9	Rarely felt	> 100,000
4.0–4.9	Can be strongly felt	13,500
5.0–5.9	Can be damaging shocks	1,400
6.0–6.9	Destructive in populous regions	110
7.0–7.9	Major earthquakes; inflict serious damage	12
8.0 and above	Great earthquakes; destroy communities near epicenter	0–1


Magnitude
Energy Release
(equivalent kilograms of explosive)
Earthquakes
Energy Equivalents
10
9
8
7
6
5
4
3
2
great earthquake
near total destruction
massive loss of life
major earthquake
severe economic impact
large loss of life
strong earthquake
damage ($ billions)
loss of life
moderate earthquake
property damage
light earthquake
some property damage
minor earthquake
felt by humans
Chile (1960)
Alaska (1964)
Chile M 8.8 (2010)
Illapel, Chile M 8.3 (2015)
New Madrid, MO (1812)
San Francisco, CA (1906)
Haiti M 7.0 (2010)
Charleston, SC (1886)
Loma Prieta, CA (1989)
Kobe, Japan (1995)
Northridge (1994)
Long Island, NY (1884)
1
3
20
200
2,000
12,000
100,000
1,000,000
Krakatoa Eruption
World's Largest Nuclear Test (USSR)
Mount St. Helens Eruption
Hiroshima Atomic Bomb
Average Tornado
Large Lightning Bolt
Oklahoma City Bombing
Moderate Lightning Bolt
56,000,000,000,000
1,800,000,000,000
56,000,000,000
1,800,000,000
56,000,000
1,800,000
56,000
1,800
56
Number of Earthquakes per Year (worldwide)

Locating an Earthquake

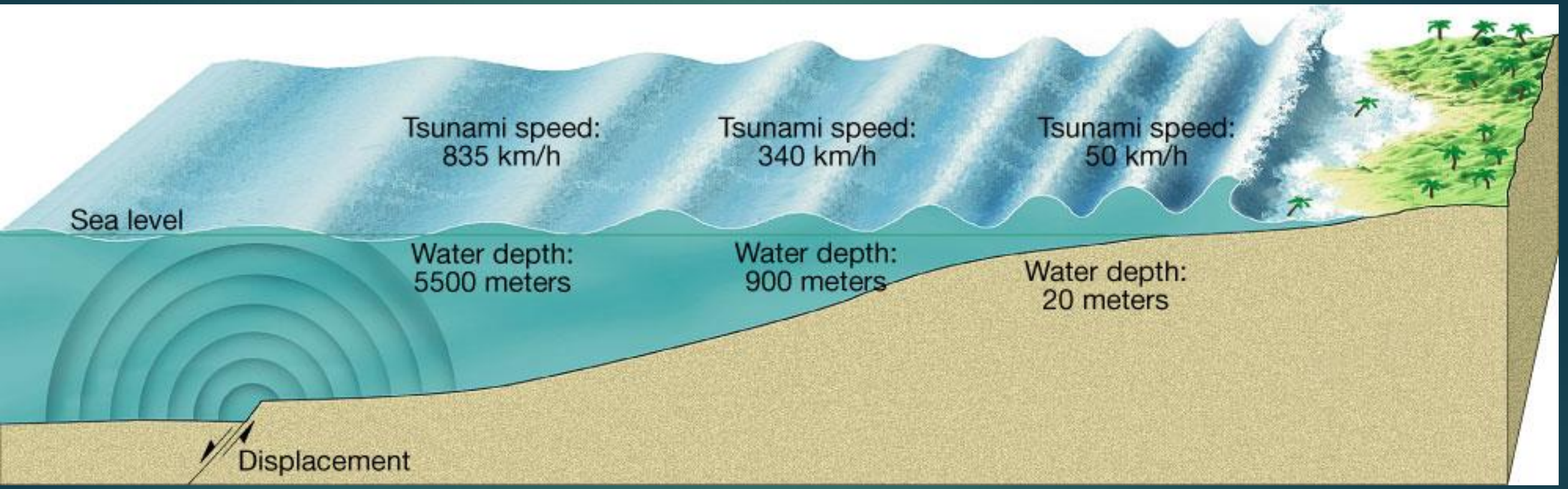
- Earthquake Distance
  - The epicenter is located using the difference in arrival times between P and S wave recordings, which are related to distance.
- Earthquake Direction
  - Travel-time graphs from three or more seismographs can be used to find the exact location of an earthquake epicenter.
- Earthquake Zones
  - About 95% of the major earthquakes occur in a few narrow zones.


1000
2000
3000 mi
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Travel time (minutes)
First S wave
S-wave curve
5 min.
First P wave
P-wave curve
1000
2000
3000
4000 km
Distance to epicenter


Montréal
Paris
8400 km
6700 km
Epicenter
5500 km
São Paulo

Tsunamis

- A **Tsunami** triggered by an earthquake occurs where a slab of the ocean floor is displaced vertically along a fault.
- A tsunami also can occur when the vibration of a quake sets an underwater landslide into motion


Tsunami speed:
835 km/h
Tsunami speed:
340 km/h
Tsunami speed:
50 km/h
Sea level
Water depth:
5500 meters
Water depth:
900 meters
Water depth:
20 meters
Displacement

Other dangers from Earthquakes

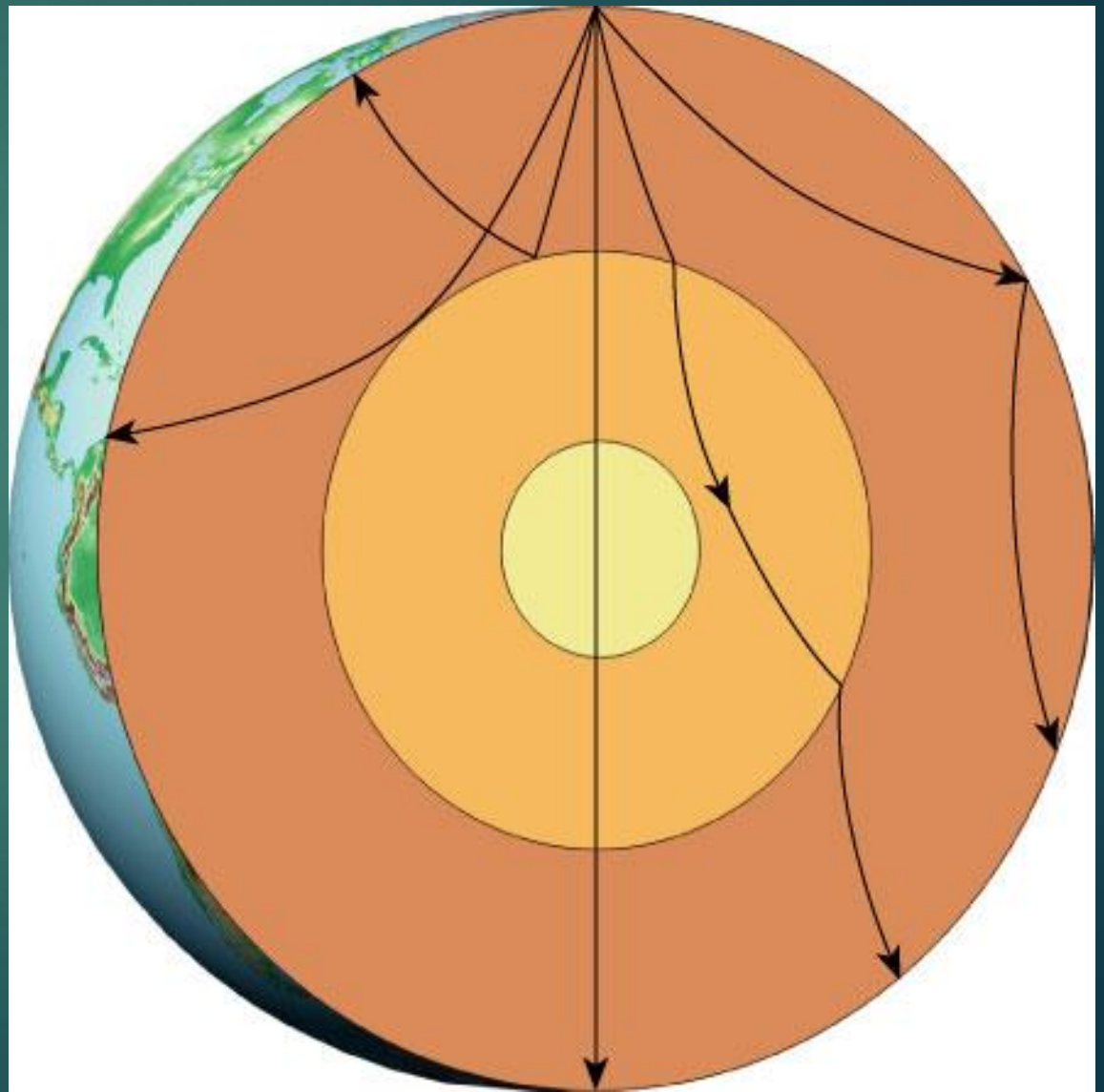
- Landslides
  - With many earthquakes, the greatest damage
    to structures is from landslides and ground subsidence, or the sinking of the ground triggered by vibrations.
- Fire
  - In the San Francisco earthquake of 1906, most of the destruction was caused by fires that started when gas and electrical lines were cut

Predicting Earthquakes

- Short Range Predictions
  - So far, methods for short-range predictions of earthquakes have not been successful.
- Long Range Forecasts
  - Scientists don't yet understand enough about how and where earthquakes will occur to make accurate long-term predictions.
  - A **seismic gap** is an area along a fault where there has not been any earthquake activity for a long period of time.

How can we use Earthquakes for science?

- Seismic waves Paths through the Earth



Discovering Earth's Layers

- **Moho**
  - **Velocity of seismic waves increases abruptly below 50 km of depth**
  - **Separates crust from underlying mantle**
- **Shadow Zone**
  - **Absence of P waves from about 105 degrees to 140 degrees around the globe from an earthquake**
  - **Can be explained if Earth contains a core composed of materials unlike the overlying mantle**

- Earth's Interior showing P and S wave Paths