



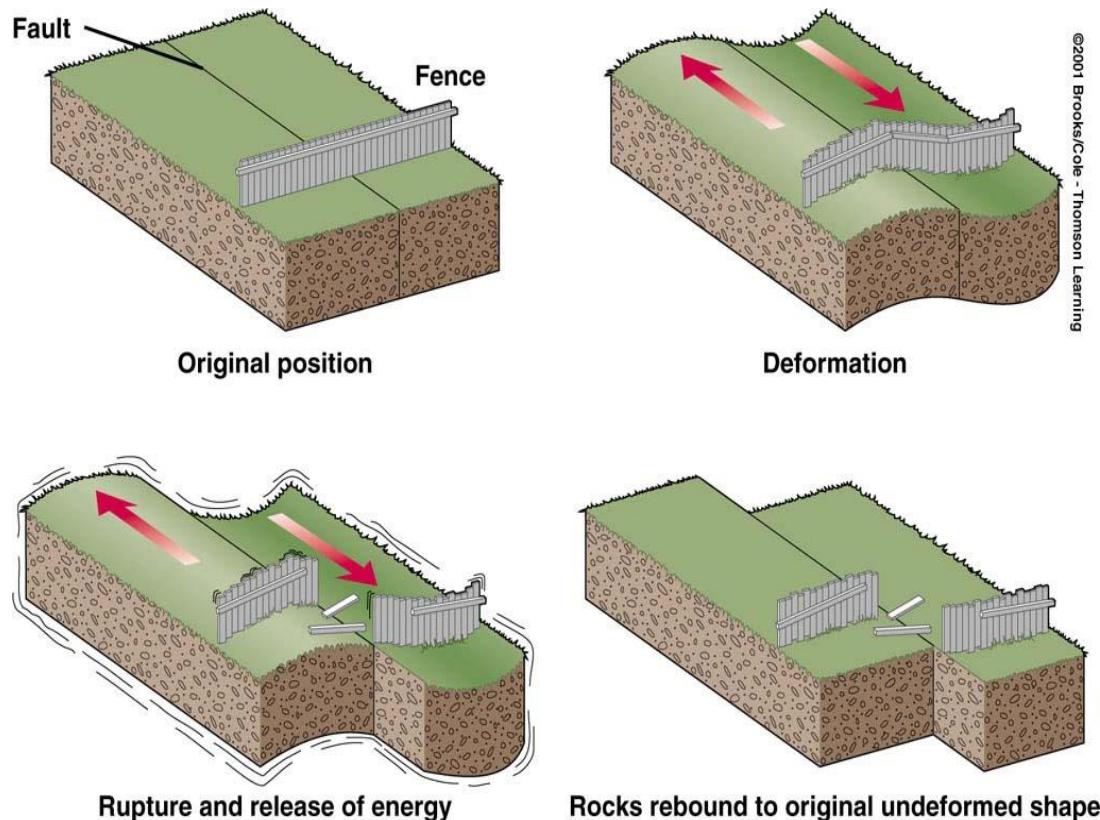
Earth quakes

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

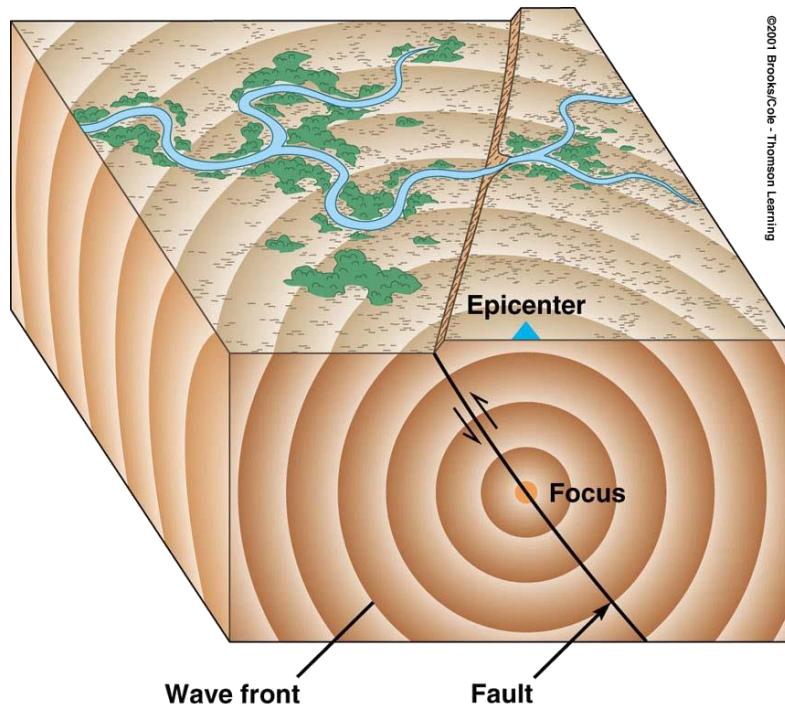
What is the Elastic Rebound Theory?

- ▶ Explains how energy is stored in rocks
 - Rocks bend until the strength of the rock is exceeded
 - Rupture occurs and the rocks quickly rebound to an undeformed shape
 - Energy is released in waves that radiate outward from the fault

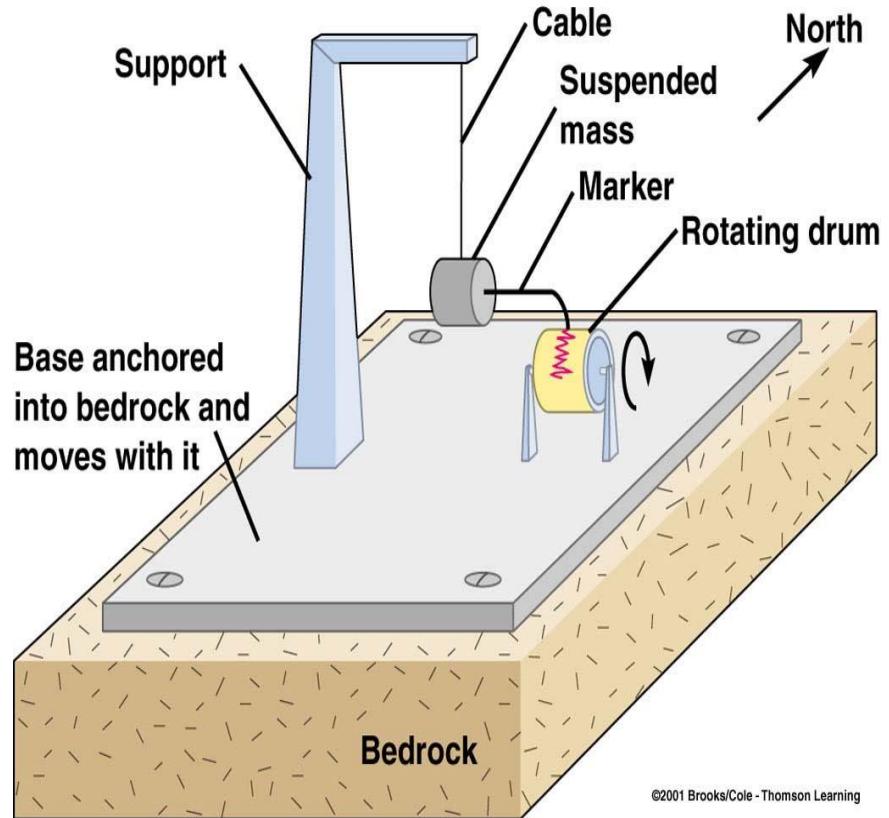


The Focus and Epicenter of an Earthquake

- The point within Earth where faulting begins is the **focus, or hypocenter**
- The point directly above the focus on the surface is the **epicenter**



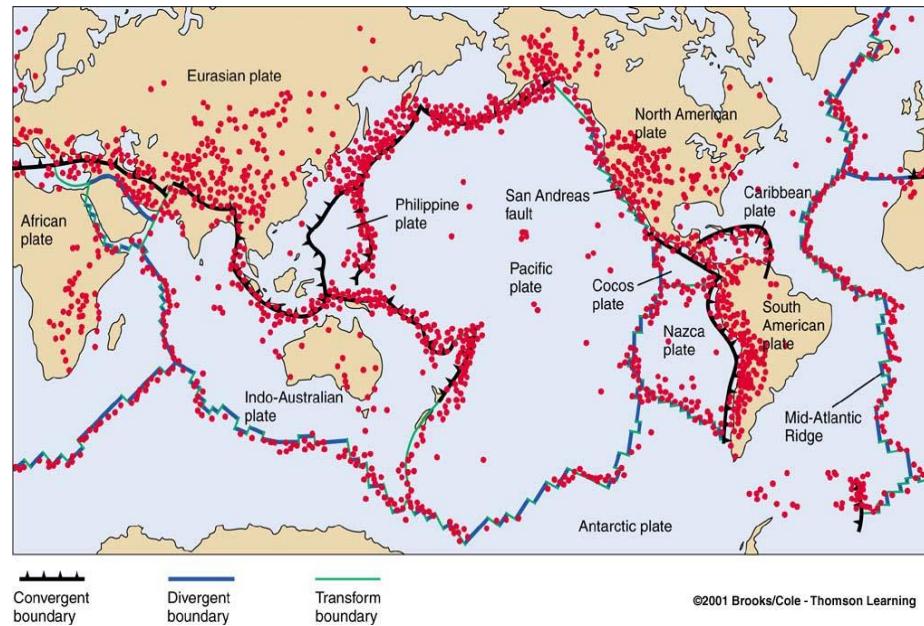
**Seismographs record
earthquake events.
Records are seismograms.**



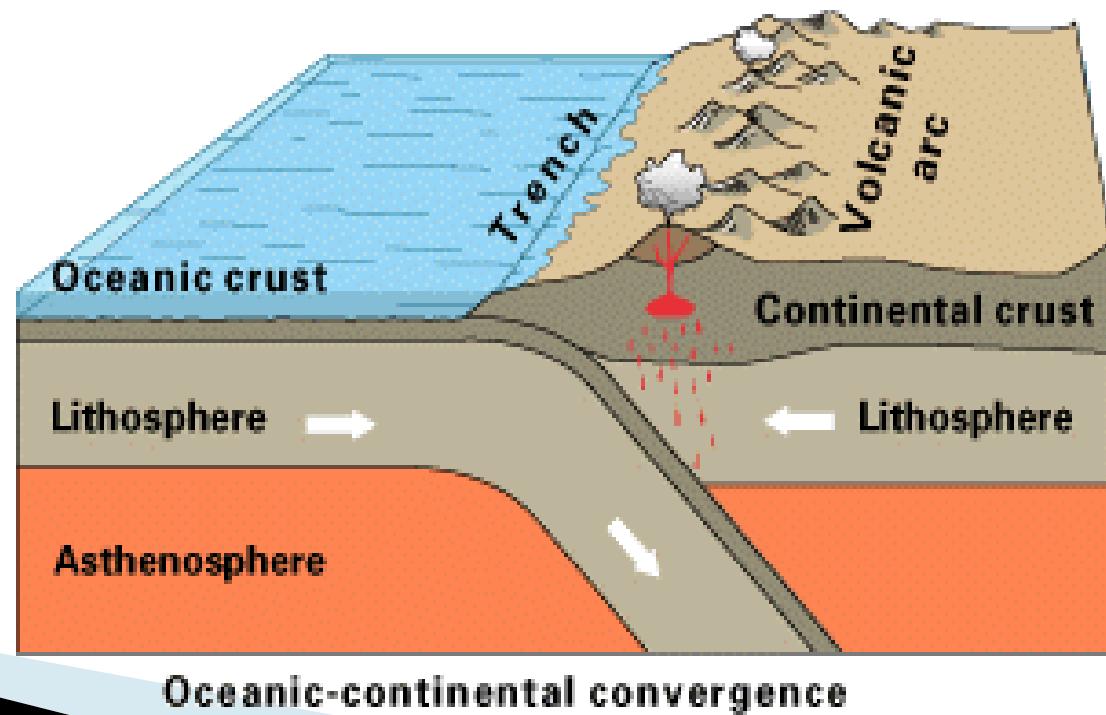
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Where Do Earthquakes Occur and How Often?

- ~80% of all earthquakes occur in the circum-Pacific belt
 - most of these result from convergent margin activity
 - ~15% occur in the Mediterranean-Asiatic belt
 - remaining 5% occur in the interiors of plates and on spreading ridge centers
 - more than 150,000 quakes strong enough to be felt are recorded each year



When one plate dives below another plate, it creates a subduction zone as the diving plate is crushed and melted. This process often creates volcanoes as the magma (molten rock) rises up to the surface.



Seismic Wave

- ▶ **Seismic waves** are the waves of energy caused by the sudden breaking of rock within the earth or an explosion. They are the energy that travels through the earth and is recorded on seismographs.
- ▶ There are several different kinds of seismic waves, and they all move in different ways. The two main types of waves are **body waves** and **surface waves**.

Types of Seismic Waves

► Body waves

Travel through the earth's interior

► Surface Waves

Travel along the earth's surface – similar to ocean waves

Types of seismic Waves

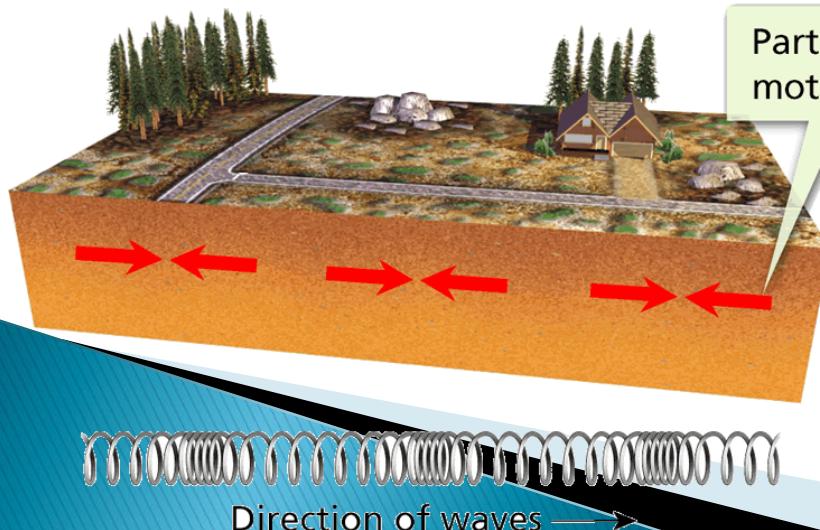
- **Body Waves**
 - Primary or p-wave
 - Compression wave
 - Secondary or s-wave
 - Transverse wave
- **Surface**
 - Love wave
 - Rayleigh wave

Types of Seismic Waves

- P waves are seismic waves that compress and expand the ground like an accordion. S waves are seismic waves that vibrate from side to side as well as up and down.

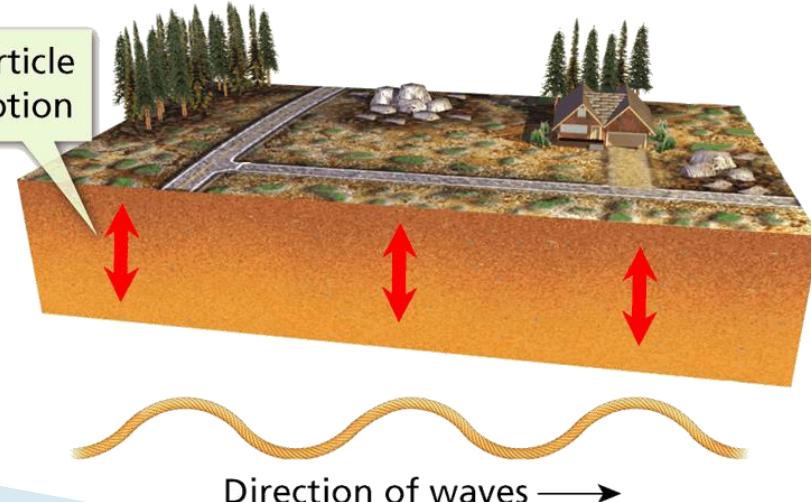
P waves

The crust vibrates forward and back along the path of the wave.



S waves

The crust vibrates from side to side and up and down.



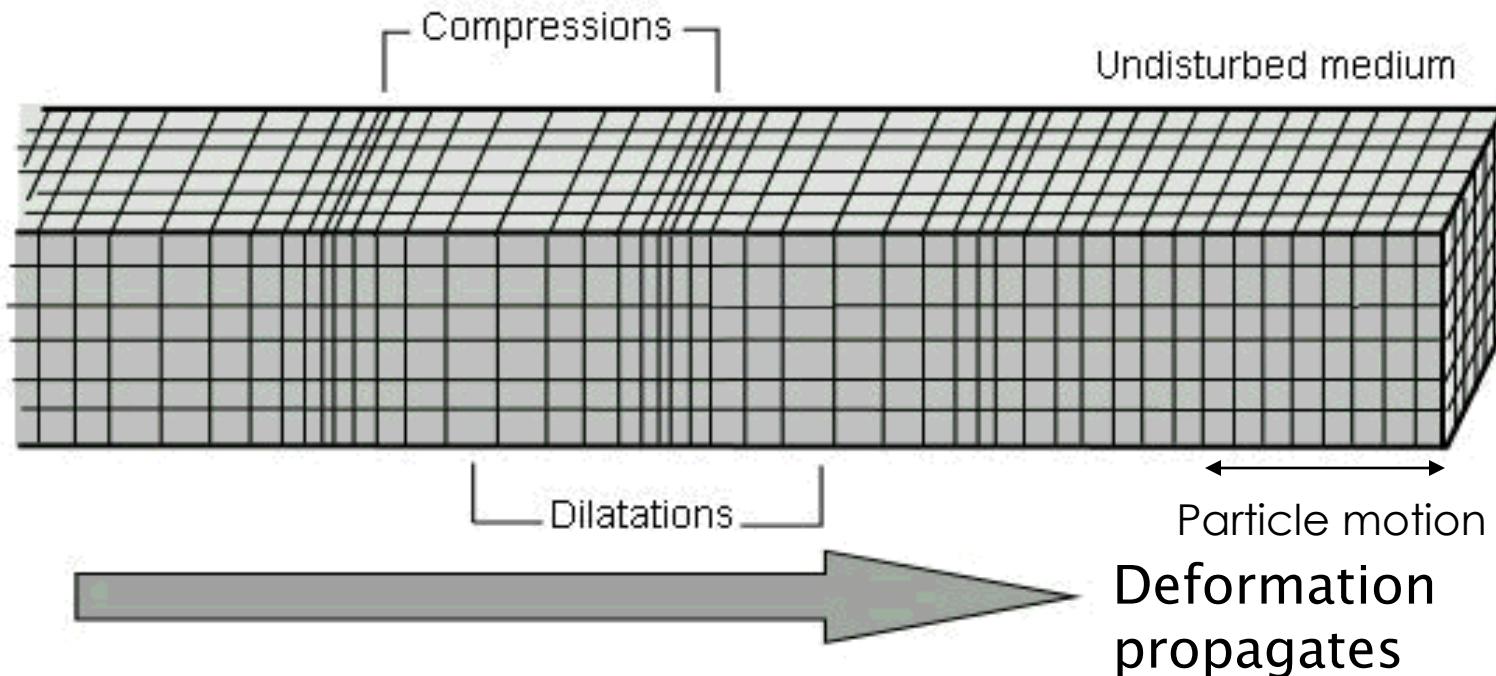
P-Wave(Body Wave)

Primary or compressional (P) waves

- The first kind of body wave is the **P wave or primary wave**. This is the fastest kind of seismic wave.
- The P wave can move through solid rock and fluids, like water or the liquid layers of the earth.
- It pushes and pulls the rock it moves through just like sound waves push and pull the air.
- Highest velocity (6 km/sec in the crust)

P-Wave

P Wave



Particle motion consists of alternating compression and dilation.
Particle motion is parallel to the direction of propagation
(longitudinal). Material returns to its original shape after wave passes.

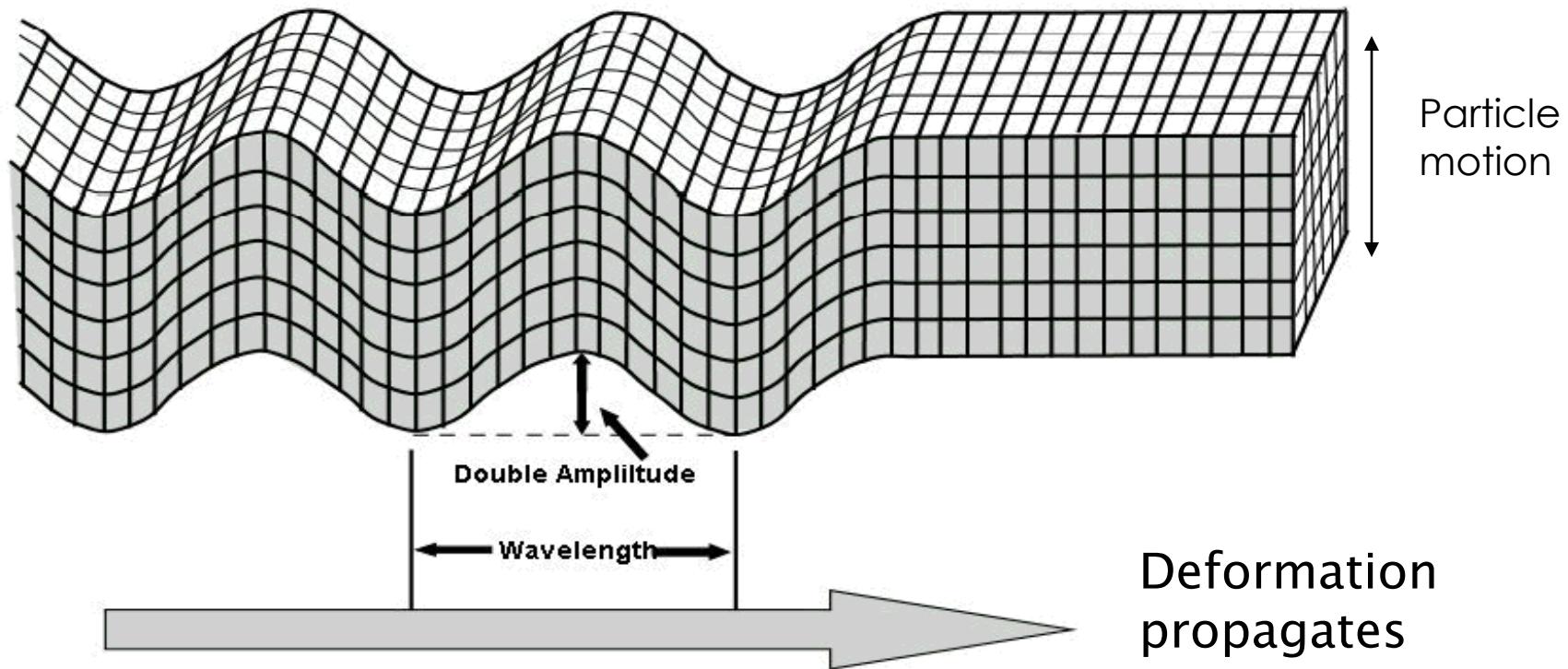
Secondary Wave (S Wave)

Secondary or shear (S) waves

- The second type of body wave is the **S wave** or **secondary wave**, which is the second wave you feel in an earthquake.
- An S wave is slower than a P wave and can only move through solid rock. (3.6 km/sec in the crust)
- This wave moves rock up and down, or side-to-side.

S-Wave

S Wave



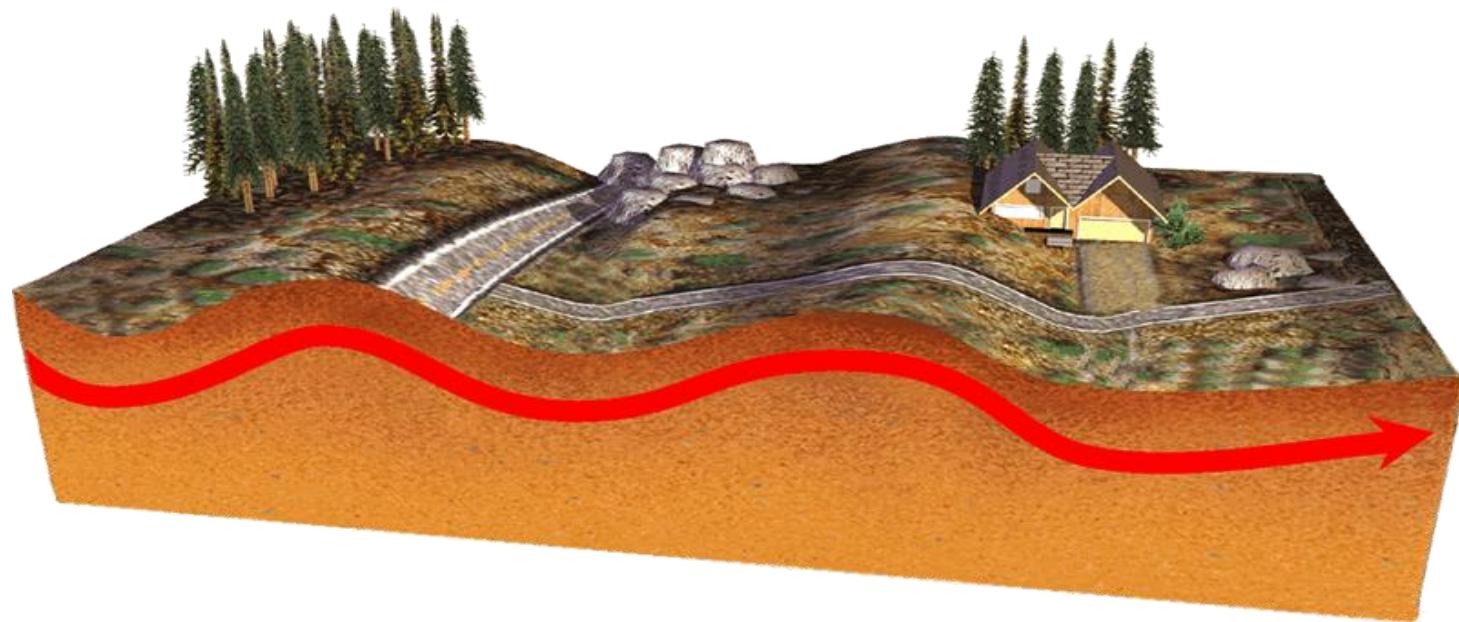
Particle motion consists of alternating transverse motion. Particle motion is perpendicular to the direction of propagation (transverse). Transverse particle motion shown here is vertical but can be in any direction. Material returns to its original shape after wave passes.

Types of Seismic Waves

Surface waves move more slowly than P waves and S waves, but they produce the most severe ground movements.

Surface waves

The ground surface rolls with a wavelike motion.



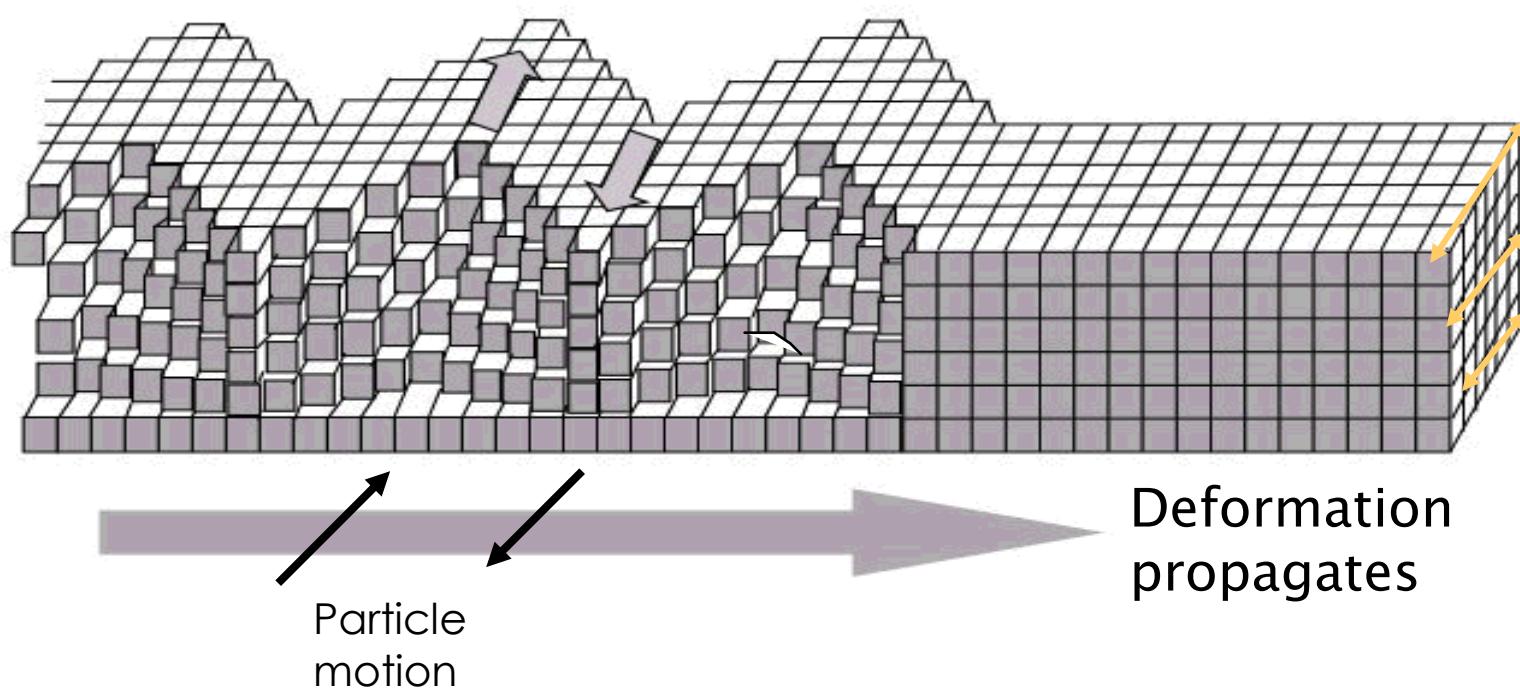
L-Wave

Love Waves

- ▶ The first kind of surface wave is called a **Love wave**, named after A.E.H. Love, a British mathematician who worked out the mathematical model for this kind of wave in 1911.
- ▶ It's the fastest surface wave and moves the ground from side-to-side.

L-Wave

Love Wave



Particle motion consists of alternating transverse motions. Particle motion is horizontal and perpendicular to the direction of propagation (transverse). Particle motion is purely horizontal.

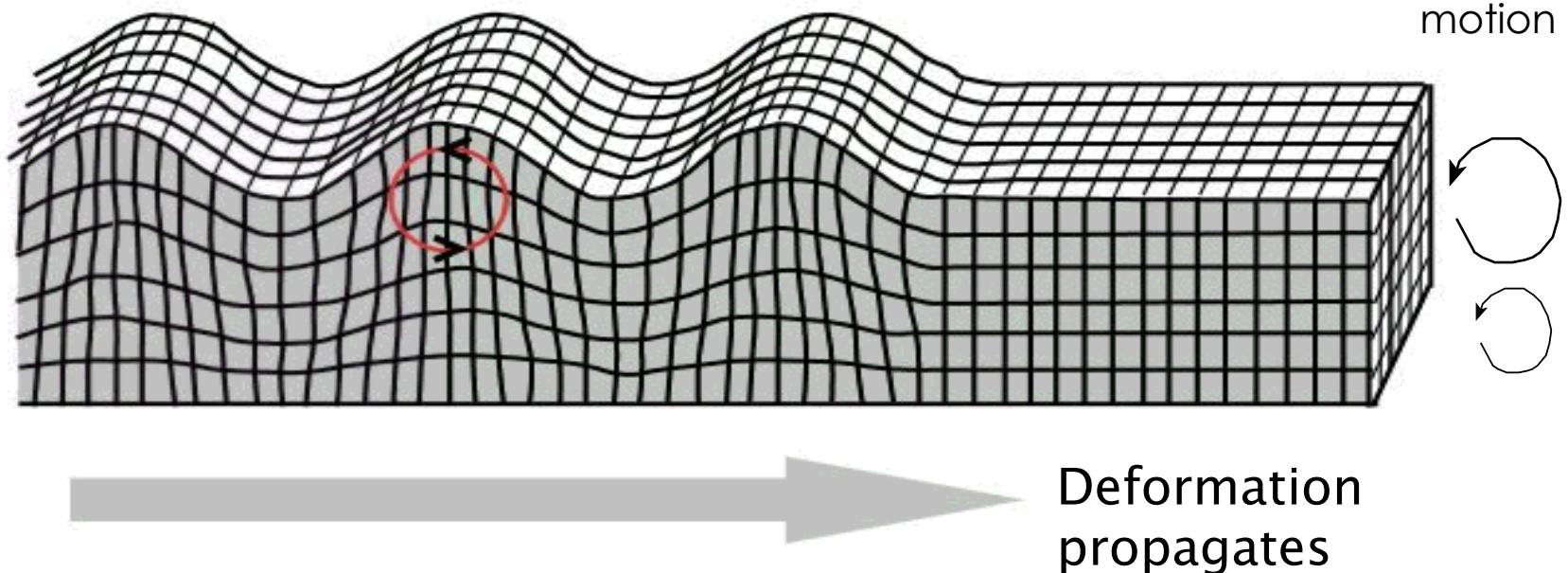
Rayleigh Waves

Rayleigh Waves

- ▶ The other kind of surface wave is the **Rayleigh wave**, named for John William Strutt, Lord Rayleigh, who mathematically predicted the existence of this kind of wave in 1885.
- ▶ A Rayleigh wave rolls along the ground just like a wave rolls across a lake or an ocean.
- ▶ Because it rolls, it moves the ground up and down, and side-to-side in the same direction that the wave is moving.
- ▶ Most of the shaking felt from an earthquake is due to the Rayleigh wave, which can be much larger than the other waves.

Rayleigh Waves

Rayleigh Wave



Particle motion consists of elliptical motions (generally retrograde elliptical) in the vertical plane and parallel to the direction of propagation. Amplitude decreases with depth.

Seismic Wave Speeds

$$V_p = \sqrt{\frac{\left(\frac{4}{3}\mu + k\right)}{\rho}}$$

$$V_s = \sqrt{\frac{\mu}{\rho}}$$

The **bulk modulus (K)** of a substance essentially measures the substance's resistance to uniform compression.

Shear modulus, μ , sometimes referred to as the modulus of rigidity, is the ratio of shear stress to the shear strain.

μ = shear modulus

ρ = density

K = modulus of compressibility (bulk modulus)

Seismic Wave Speeds

$$V_p = \sqrt{\frac{\left(\frac{4}{3}\mu + k\right)}{\rho}}$$

$$V_s = \sqrt{\frac{\mu}{\rho}}$$

Material	P wave Velocity (m/s)	S wave Velocity (m/s)
Air	332	
Water	1400-1500	
Petroleum	1300-1400	
Steel	6100	3500
Concrete	3600	2000
Granite	5500-5900	2800-3000
Basalt	6400	3200
Sandstone	1400-4300	700-2800
Limestone	5900-6100	2800-3000
Sand (Unsaturated)	200-1000	80-400
Sand (Saturated)	800-2200	320-880
Clay	1000-2500	400-1000
Glacial Till (Saturated)	1500-2500	600-1000

μ = modulus of rigidity ρ = density

K = modulus of compressibility (bulk modulus)

How are Earthquakes Measured?

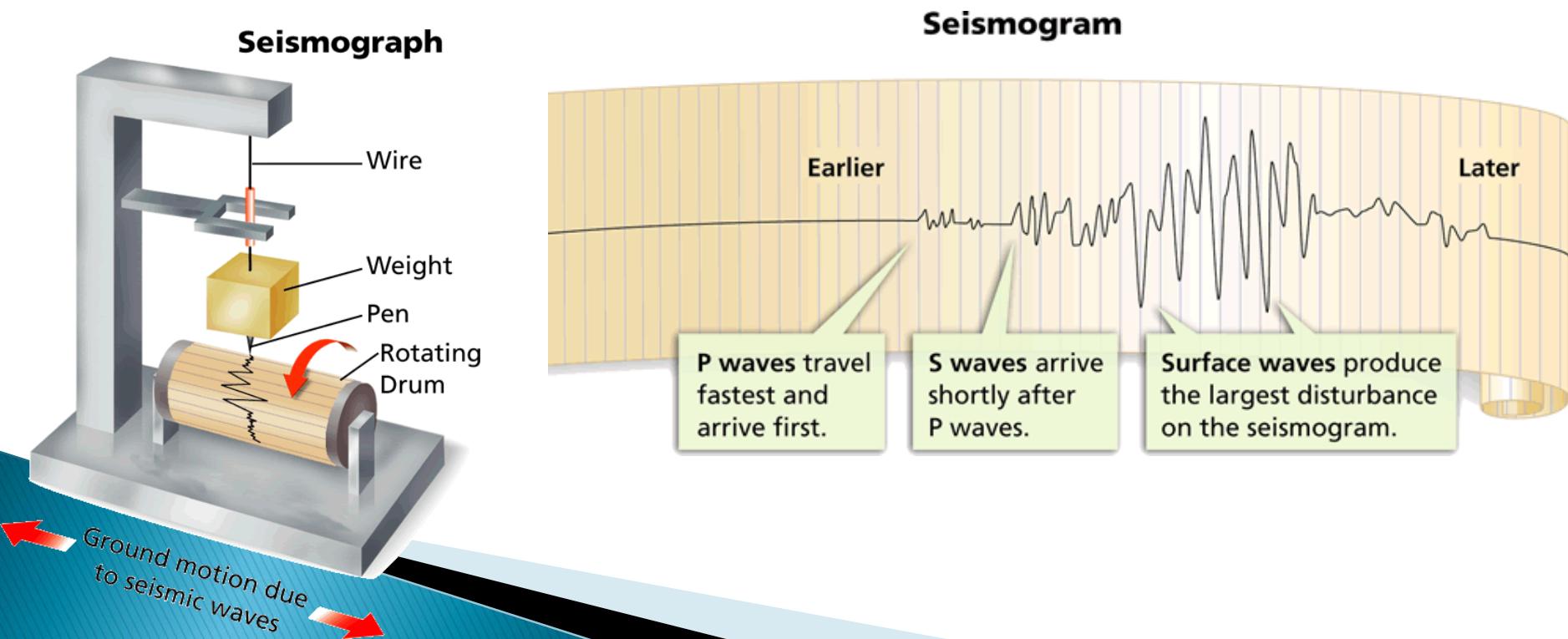
- ▶ Earthquakes are measured based on three different scales.
- ▶ The first measures the actual size or magnitude of the quake.
- ▶ The second measures the effects or damage of the quake.
- ▶ The third measures the total energy of the quake.

How is the Size of Earthquakes Measured?

- ▶ A seismograph is the tool used to measure the strength of an earthquakes
- ▶ The seismograph prints out a seismogram that scientists read to determine the strength of the quake.
- ▶ The data from the seismogram is translated into a 1–10 rating on the Richter Scale. Each step in the scale represents a tenfold increase in the size of the quake!

What is a Seismograph

- ▶ The Modern Seismograph
- ▶ Seismic waves cause the seismograph's drum to vibrate. But the suspended weight with the pen attached moves very little. Therefore, the pen stays in place and records the drum's vibrations.



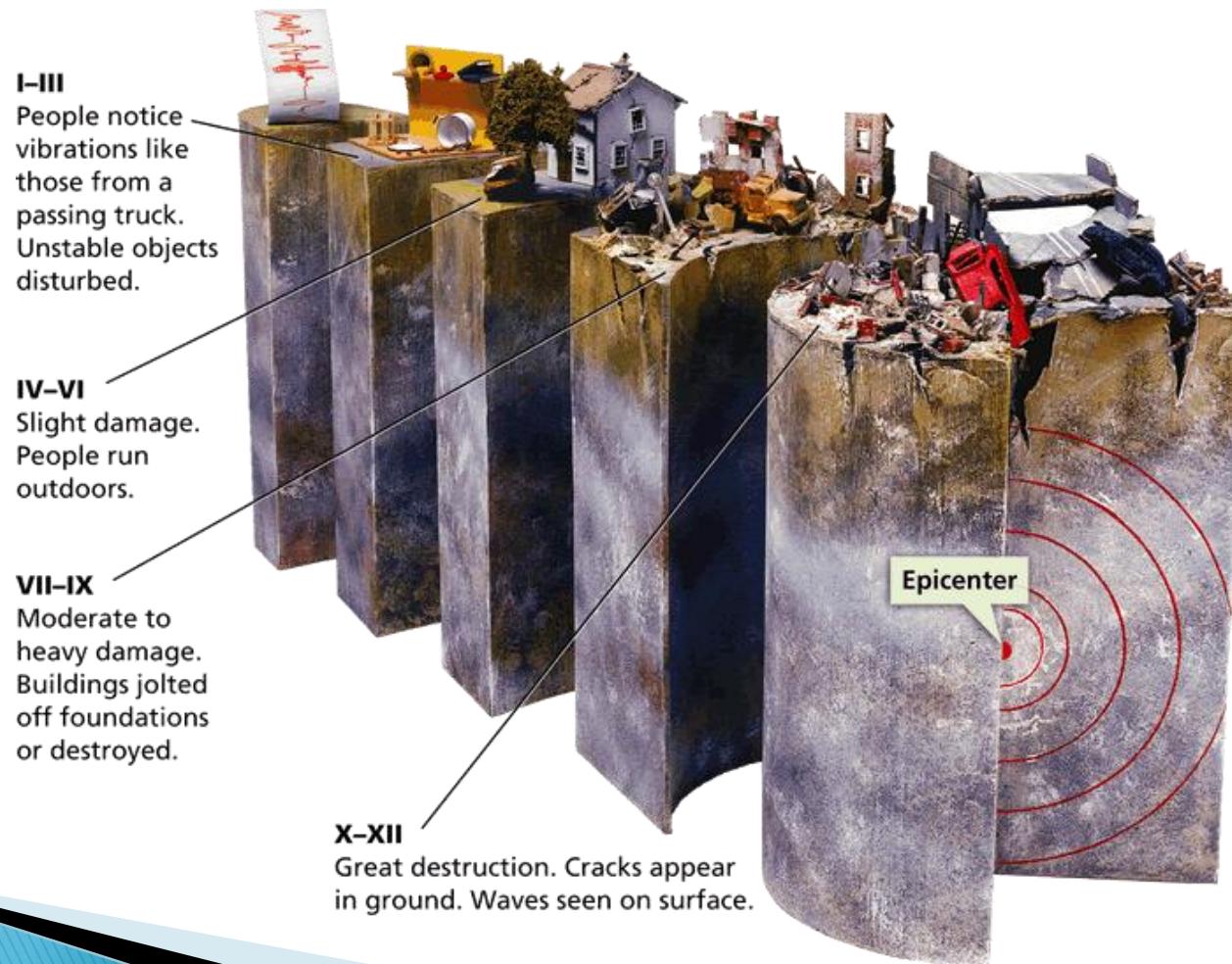


How are the Effects Measured?

- ▶ The Mercalli Scale measures the earthquake's effects on a scale of 1–12 (in Roman Numerals). This is determined by scientists surveying the damage and then rating it on the scale. *This scale is VERY subjective!*
 - ▶ I: only detected by seismographs.
 - ▶ VI: felt by all, but very little damage
 - ▶ XII: causes total destruction.

Measuring Earthquakes

The Mercalli scale was developed to rate earthquakes according to the amount of damage at a given place.



Moment Magnitude Scale

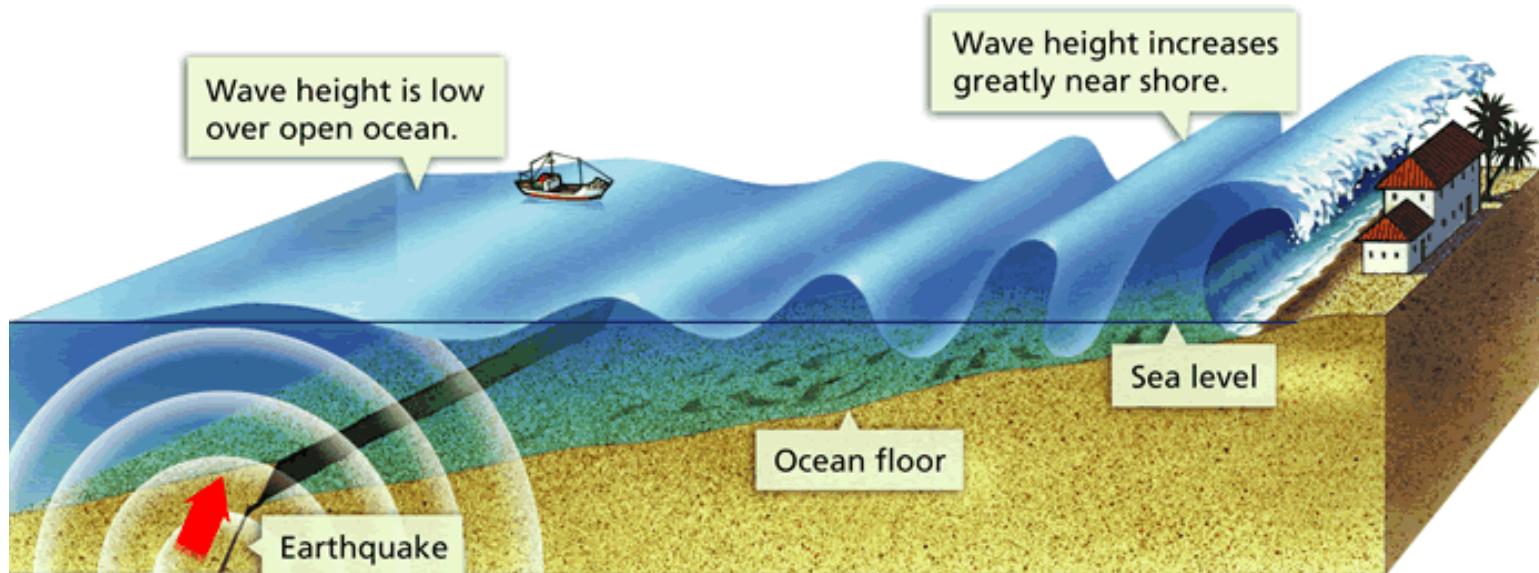
- ▶ Preferred by scientists and seismologists to the Richter scale because moment magnitude is more precise.
- ▶ not based on instrumental recordings of a quake, but is *based on the area of the fault that ruptured in the quake.*
 - calculated by multiplying the area of the fault's rupture surface by the distance the earth moves along the fault....this calculation is more precise than a tool or scientist opinion!

Comparison between the Richter and Moment Magnitude Scales

Earthquake	Richter Scale	Moment Magnitude Scale
New Madrid, MO, 1812	8.7	8.1
San Francisco, CA, 1906	8.3	7.7
Prince William, AK, 1964	8.4	9.2
Northridge, CA, 1994	6.4	6.7

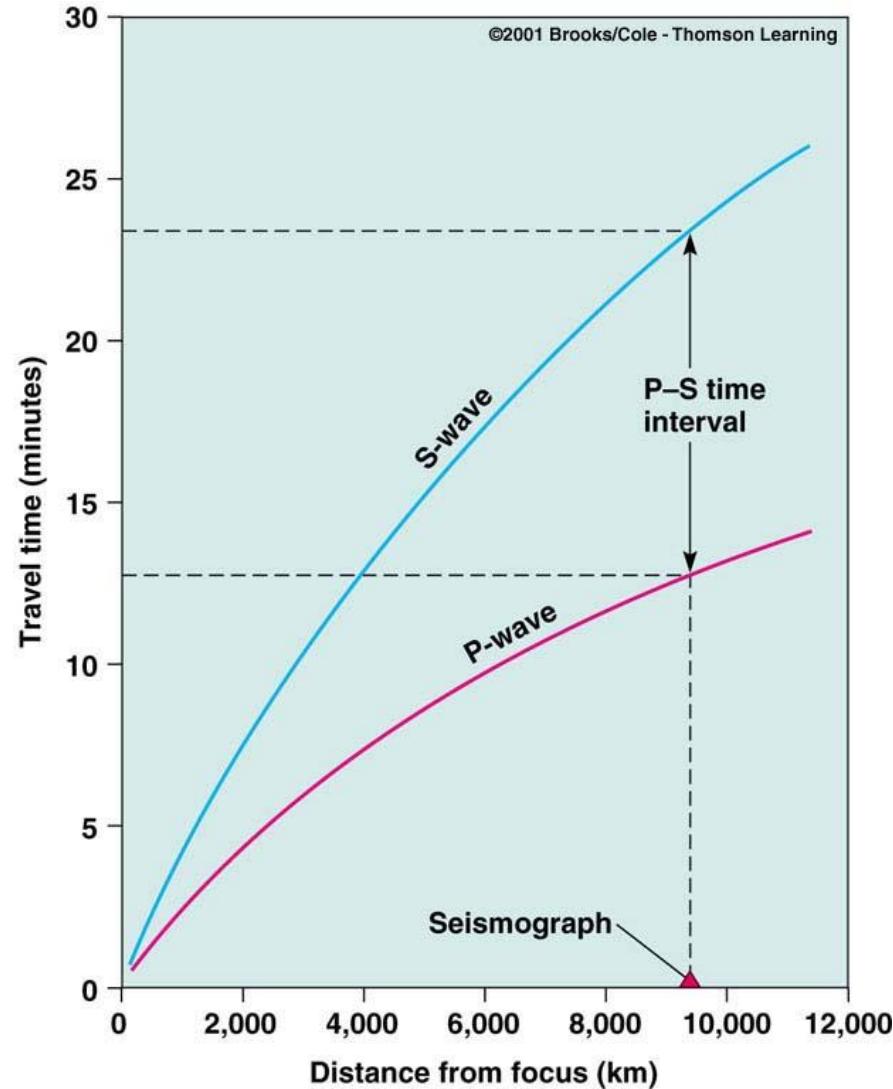
Damage

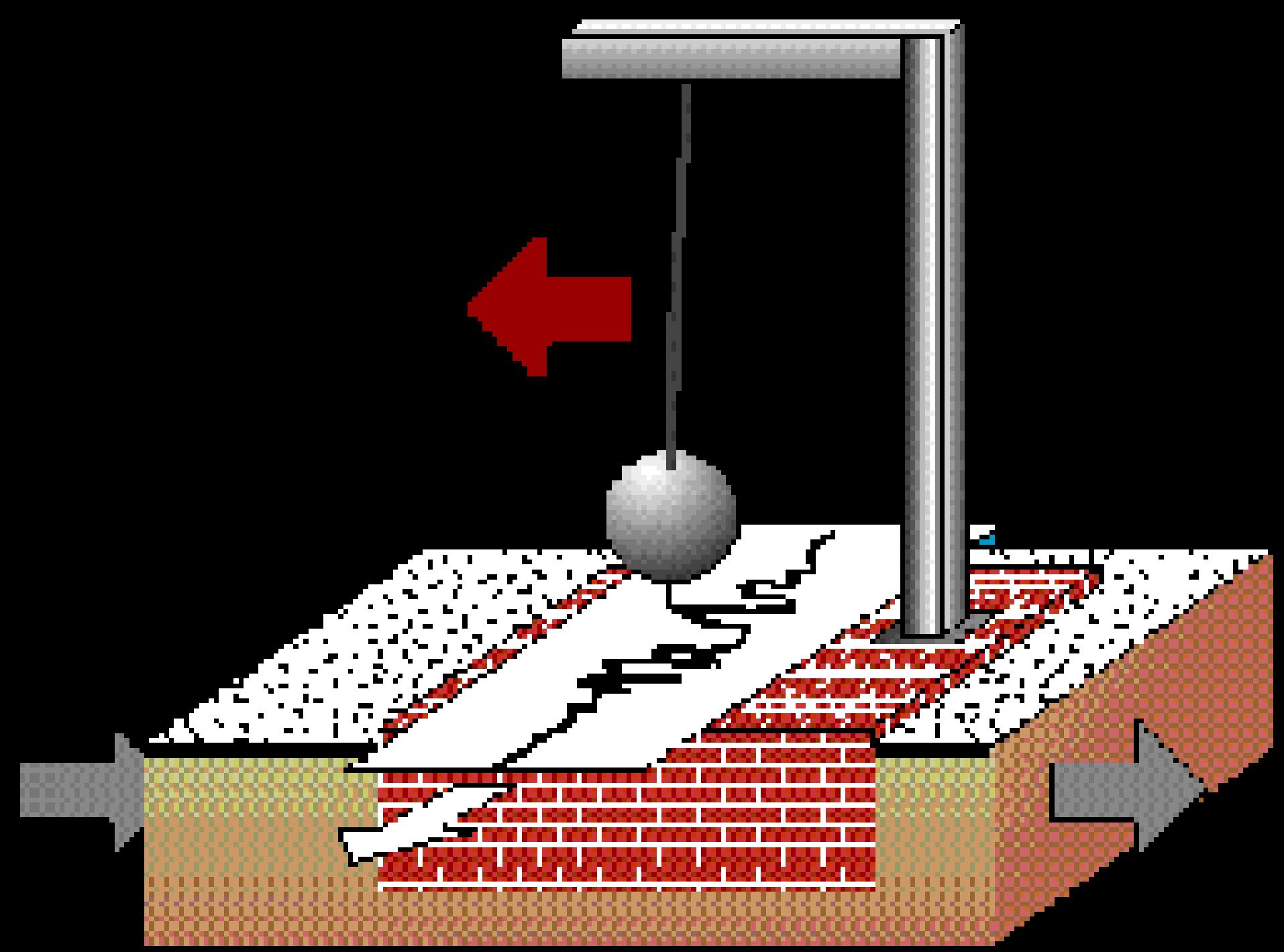
A tsunami spreads out from an earthquake's epicenter and speeds across the ocean.



How is an Earthquake's Epicenter Located?

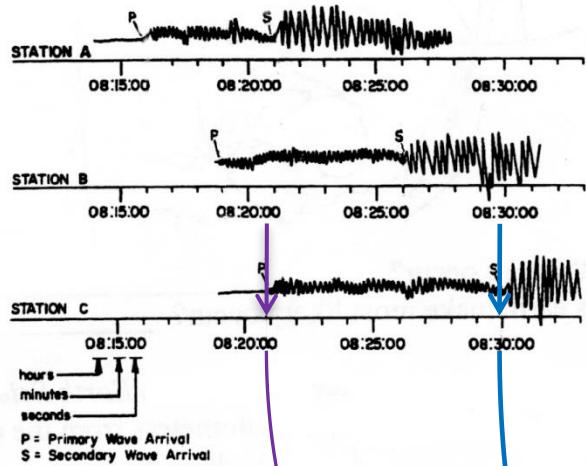
Time-distance graph showing the average travel times for P- and S-waves. The farther away a seismograph is from the focus of an earthquake, the longer the interval between the arrivals of the P- and S-waves



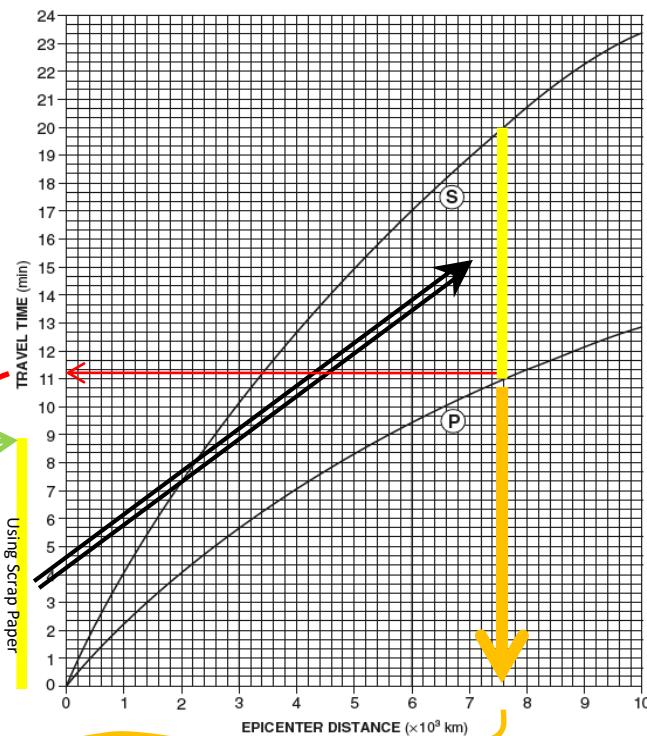


Finding the epicenter of an
earthquake using the difference
in time between P and S wave.

Earthquake P-Wave and S-Wave Travel Time

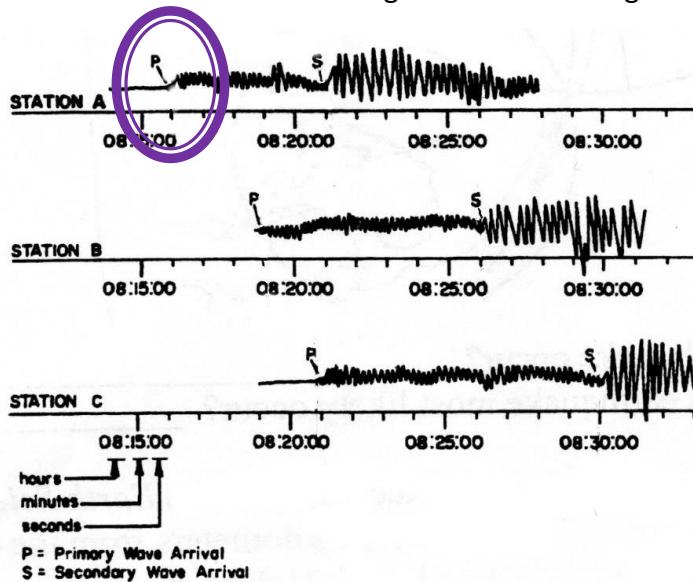


Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km	00:06:20	08:09:40
B	08:19:00	08:26:00	00:07:00	5.0×10^3 km	00:08:20	08:10:40
C	08:21:00	08:30:00	00:09:00	7.6×10^3 km	00:10:20	08:11:40



The Completed Process

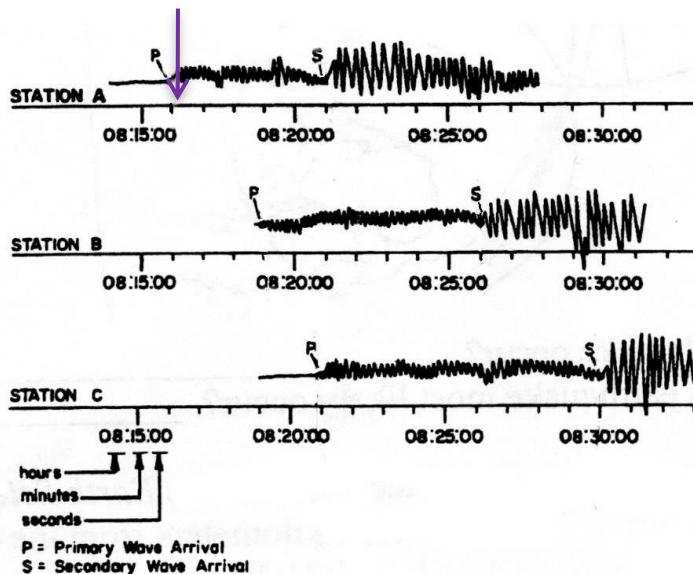
Fill out the chart below using the three seismograms and the chart on Page 11 of the Earth Science Reference Tables.



Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A						
B						
C						

Start Simple – Draw a Line Down From the P-Wave to the Time Scale

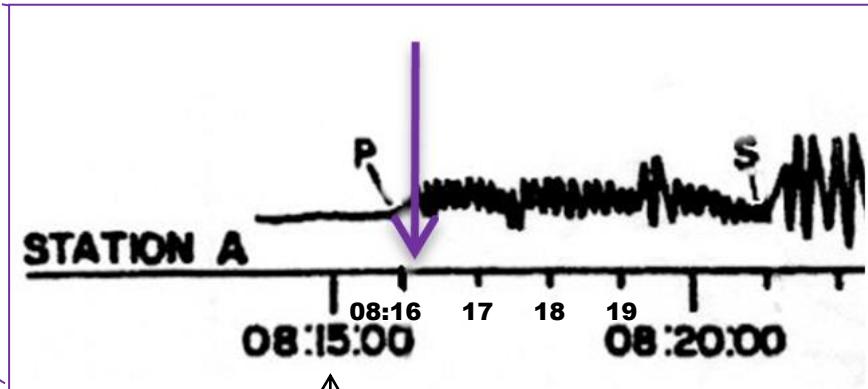
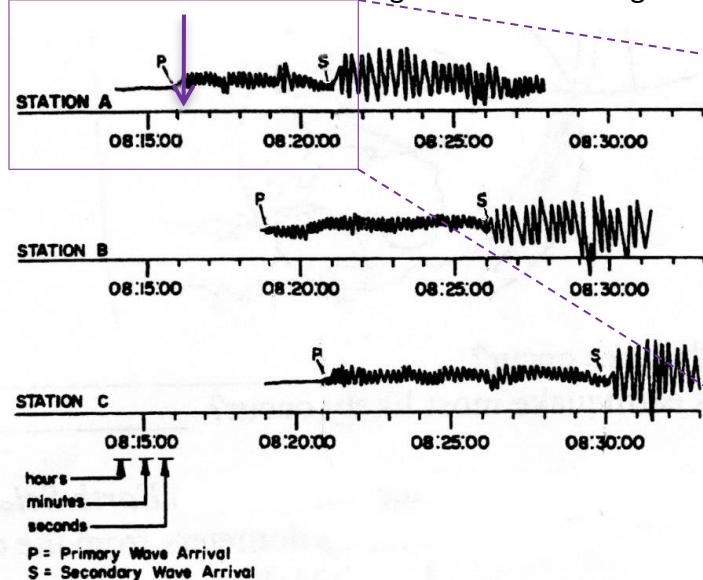
Fill out the chart below using the three seismograms and the chart on Page 11 of the Earth Science Reference Tables.



Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A						
B						
C						

Judge what time the P-wave starts

Fill out the chart below using the three seismograms and the chart on Page 11 of the Earth Science Reference Tables.

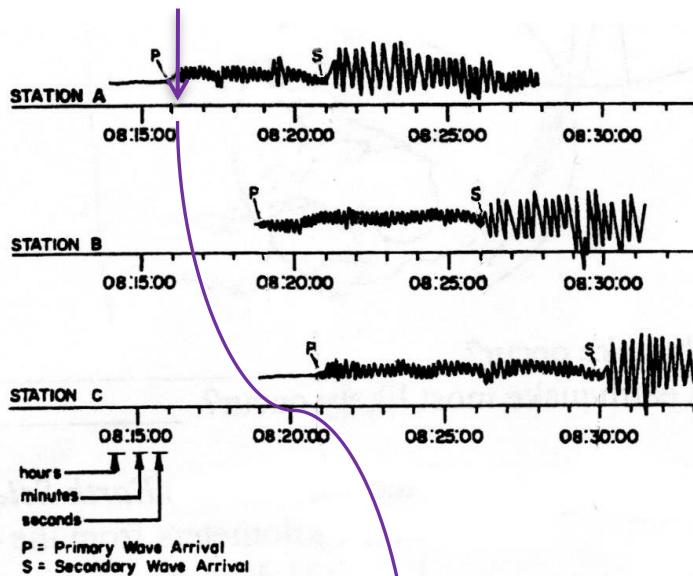


A Quarter after 8 O'Clock! And No Seconds!

Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A						
B						
C						

A zoom-in shows P-wave starting at approximately 08:16:00

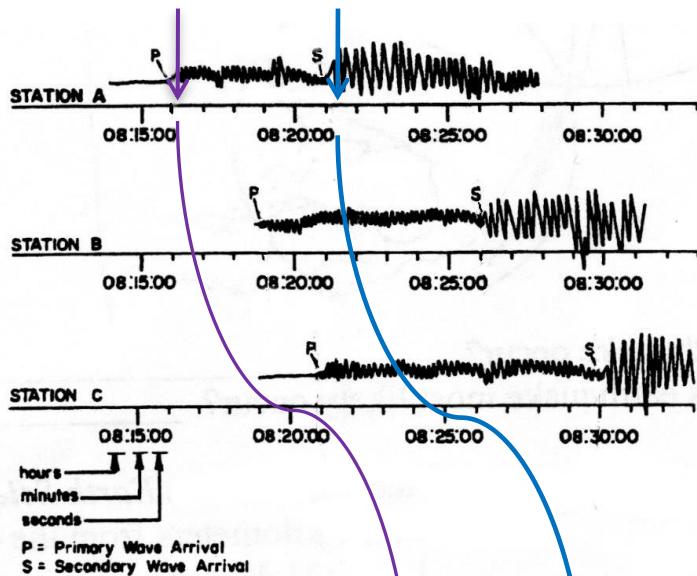
Fill out the chart below using the three seismograms and the chart on Page 11 of the Earth Science Reference Tables.



Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00					
B						
C						

Put that value in the appropriate box

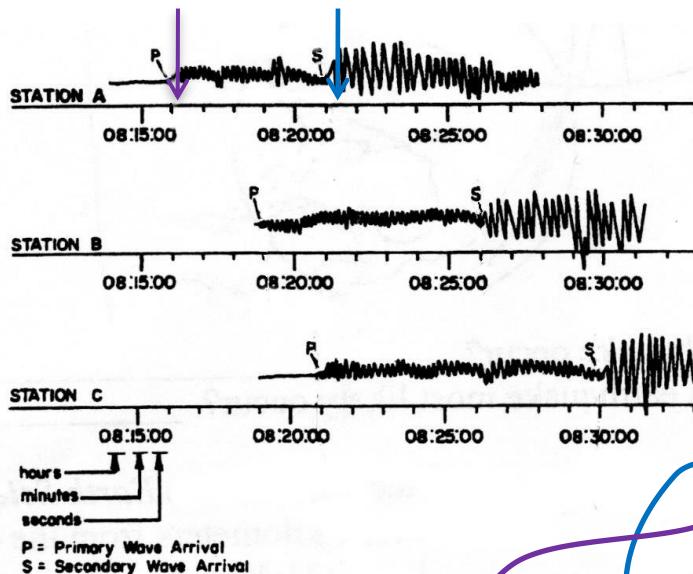
Fill out the chart below using the three seismograms and the chart on Page 11 of the Earth Science Reference Tables.



Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00				
B						
C						

Repeat the same process for the S-wave.

Fill out the chart below using the three seismograms and the chart on Page 11 of the Earth Science Reference Tables.

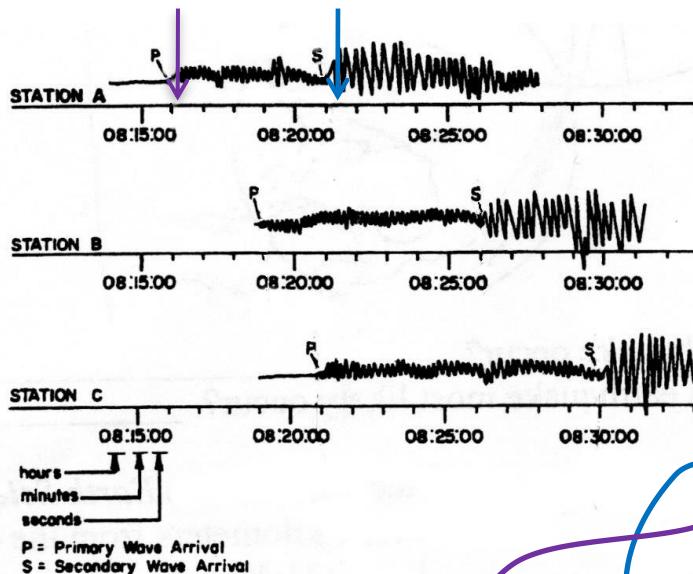


08:21:00 (S-Wave Time)
-08:16:00 (P-Wave Time)

Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00				
B						
C						

Calculate the interval between the two wave arrivals at the seismograph

Fill out the chart below using the three seismograms and the chart on Page 11 of the Earth Science Reference Tables.

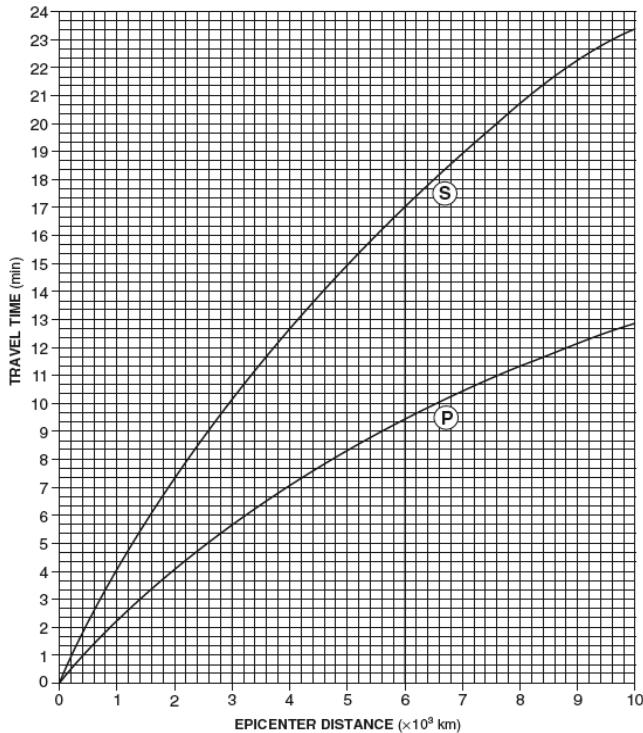


08:21:00 (S-Wave Time)
-08:16:00 (P-Wave Time)
00:05:00 (Time Difference)
(0 Hours, 5 Minutes, 0 Seconds)

Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00			
B						
C						

Enter that time in the appropriate box

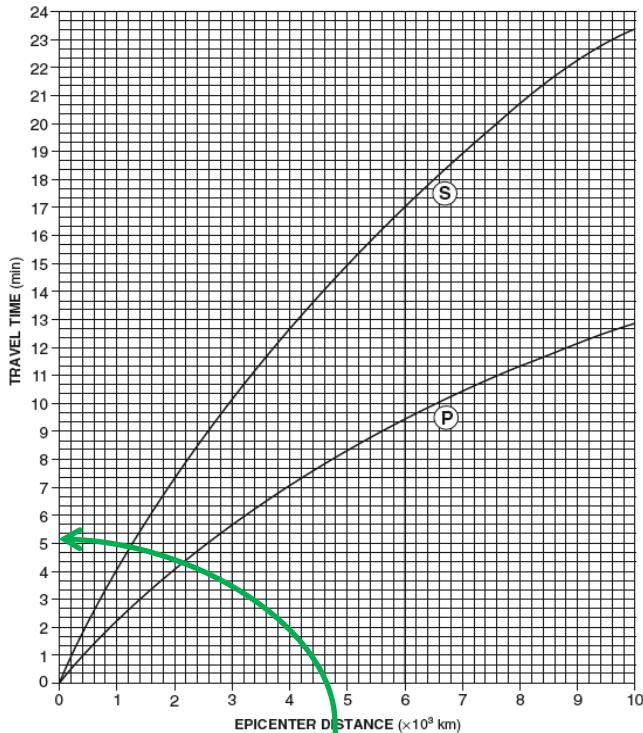
Earthquake P-Wave and S-Wave Travel Time



Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00			
B						
C						

Go to page 11 of your Earth Science Reference Tables for the chart shown above

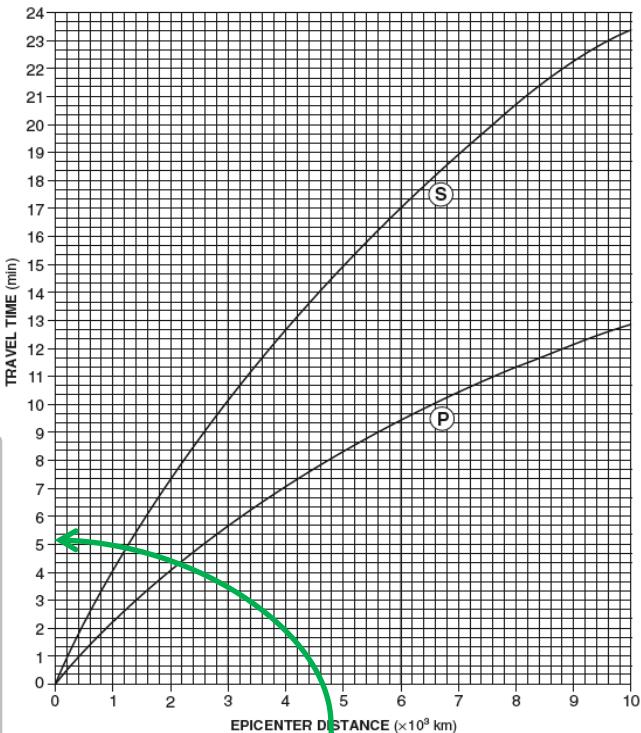
Earthquake P-Wave and S-Wave Travel Time



Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00			
B						
C						

Use the P-S Wave time interval to figure out the distance to the epicenter

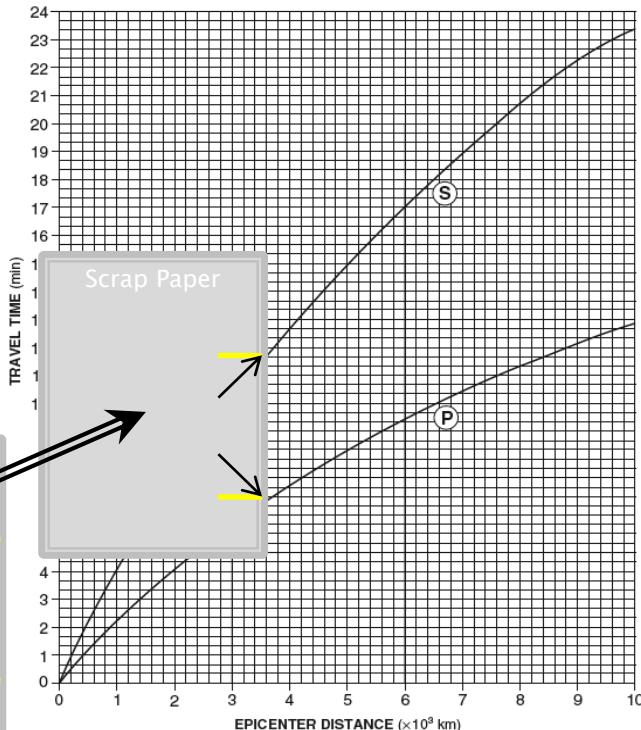
Earthquake P-Wave and S-Wave Travel Time



Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00			
B						
C						

Create a reference measurement using scrap paper and the P-S Wave value

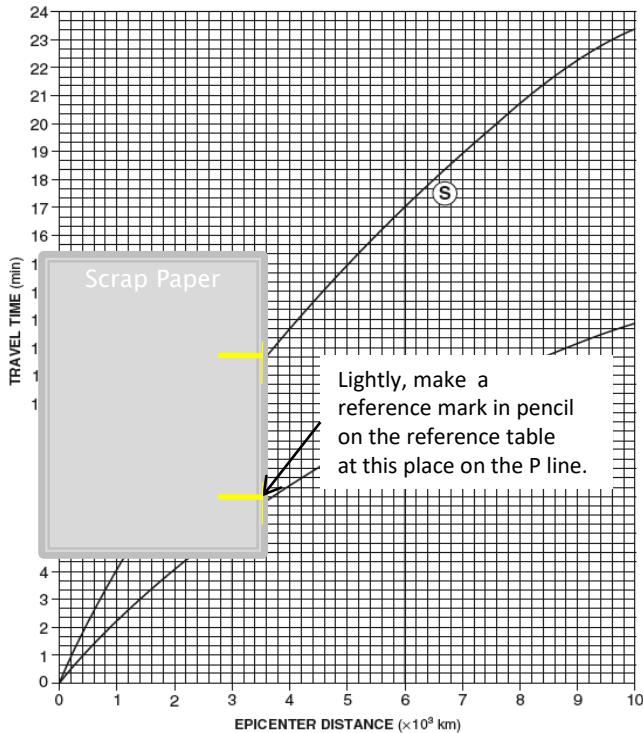
Earthquake P-Wave and S-Wave Travel Time



Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00			
B						
C						

Find the proper place where the reference marks match the P and S Lines.

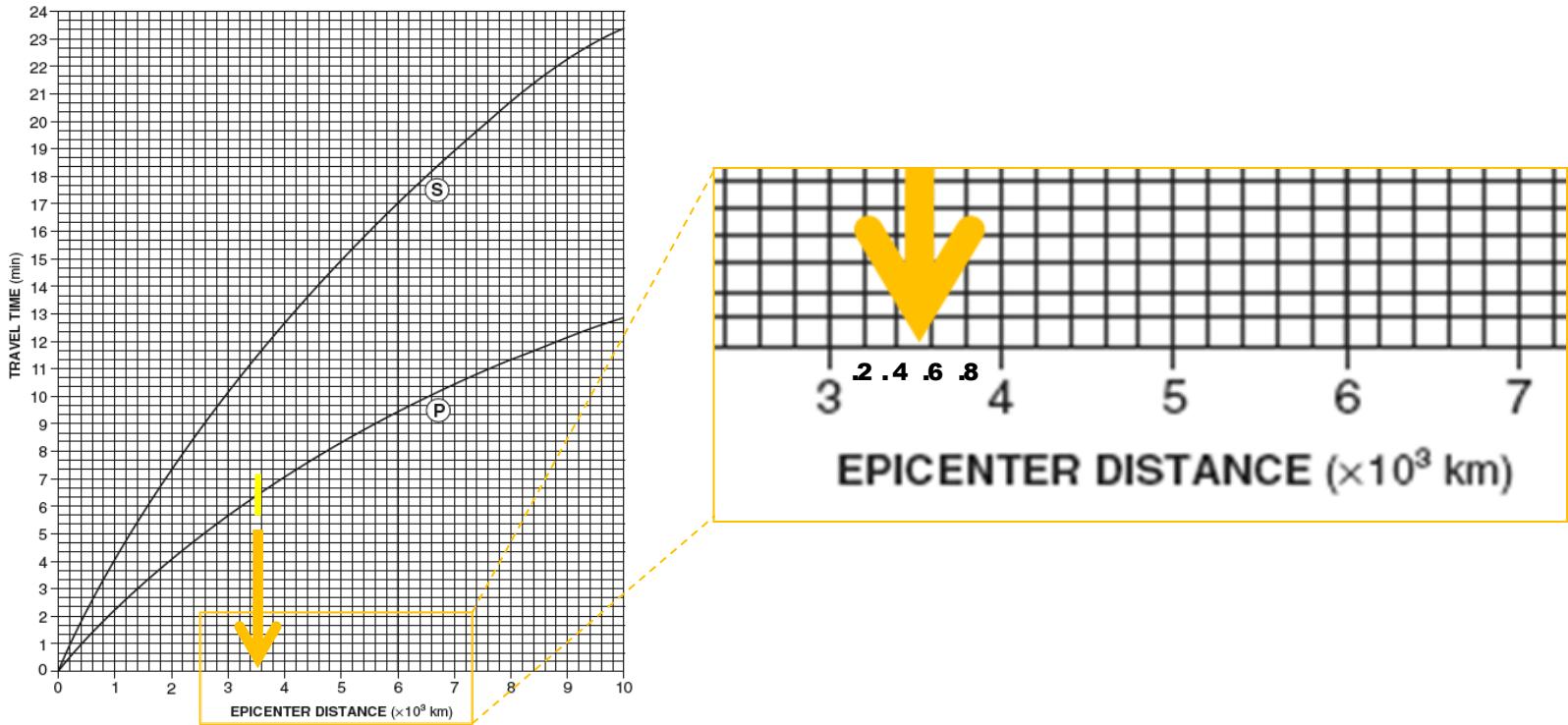
Earthquake P-Wave and S-Wave Travel Time



Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00			
B						
C						

For convenience, make a light pencil mark on the P line for use in the next step

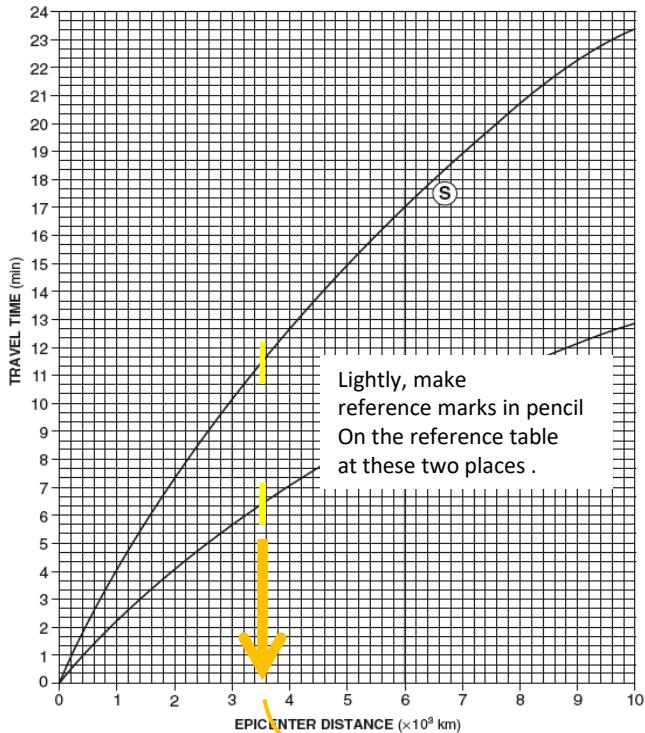
Earthquake P-Wave and S-Wave Travel Time



Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00			
B						
C						

Look straight down from the P line pencil mark and judge the epicenter distance.

Earthquake P-Wave and S-Wave Travel Time

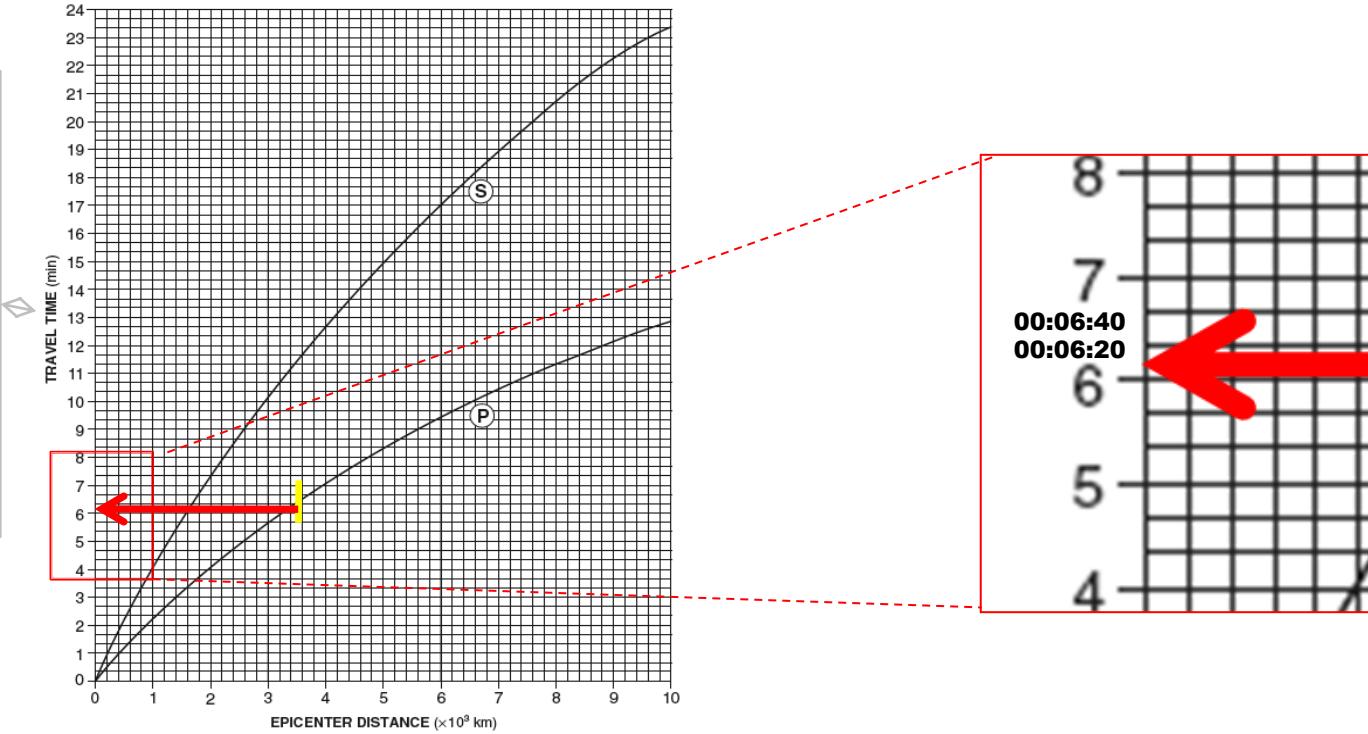


Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km		
B						
C						

Enter that value for the epicenter distance with proper units.

Travel Time
(minutes)

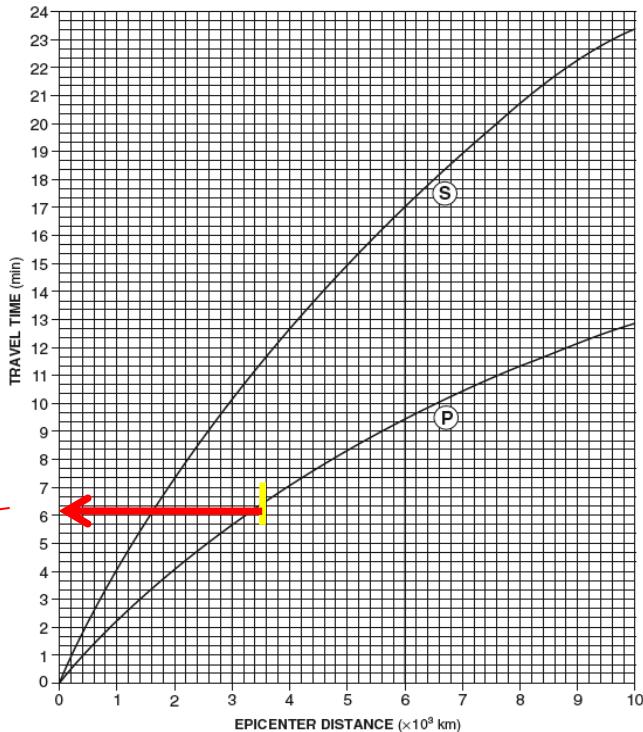
Earthquake P-Wave and S-Wave Travel Time



Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km		
B						
C						

Look across at the y-axis to Judge the time value

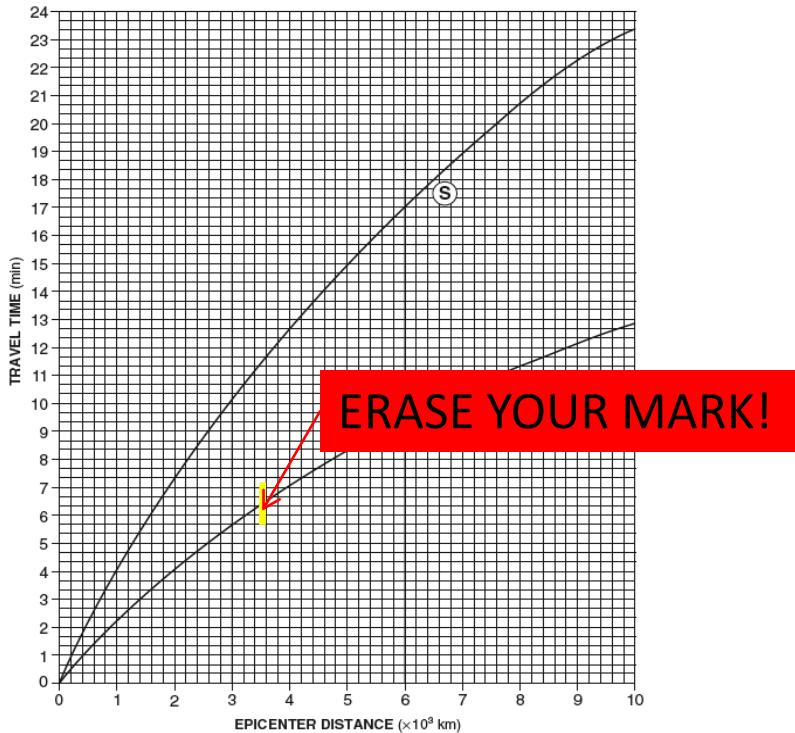
Earthquake P-Wave and S-Wave Travel Time



Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km	00:06:20	
B						
C						

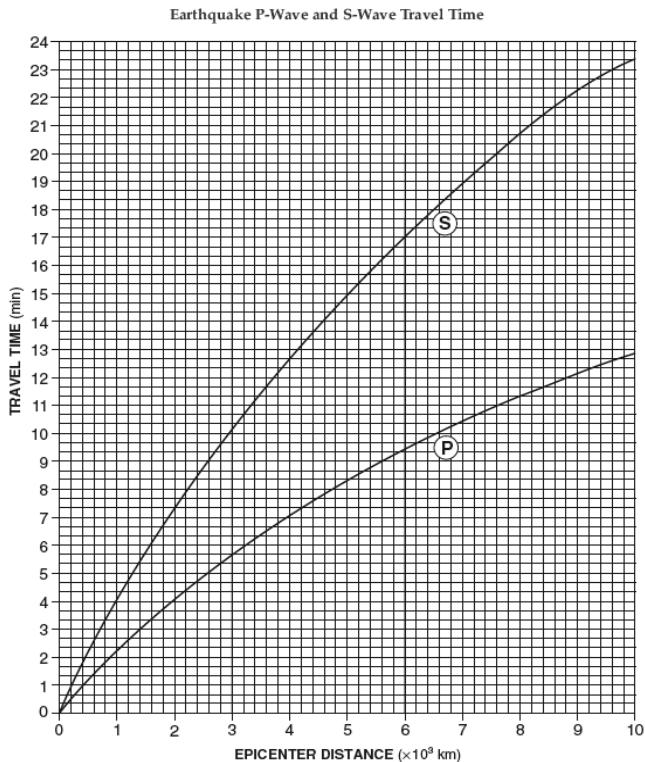
Enter that value for the epicenter distance with proper units.

Earthquake P-Wave and S-Wave Travel Time



Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km	00:06:20	
B						
C						

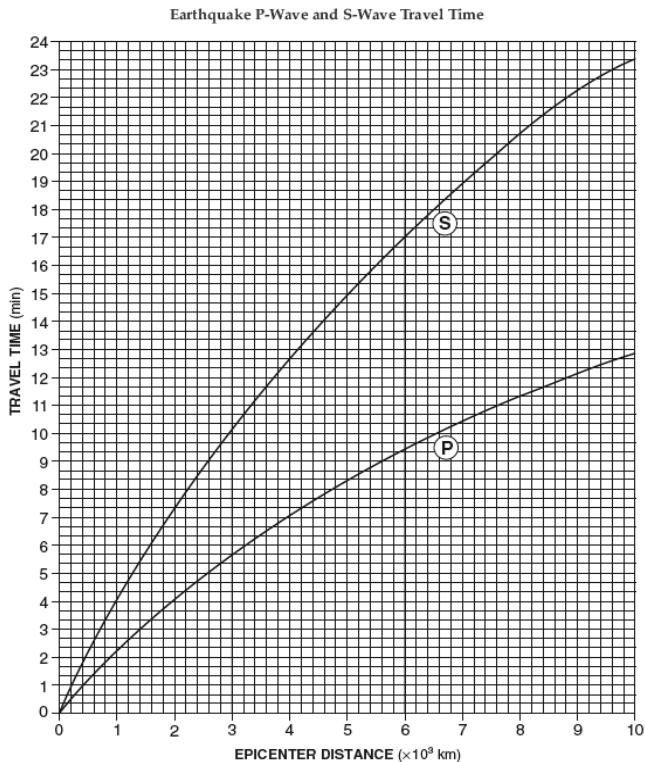
Erase your pencil mark on the P-wave to keep your reference table clean



08:16:00 (P Arrival
Time)
00:06:20 (P Travel
Time)

Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km	00:06:20	
B						
C						

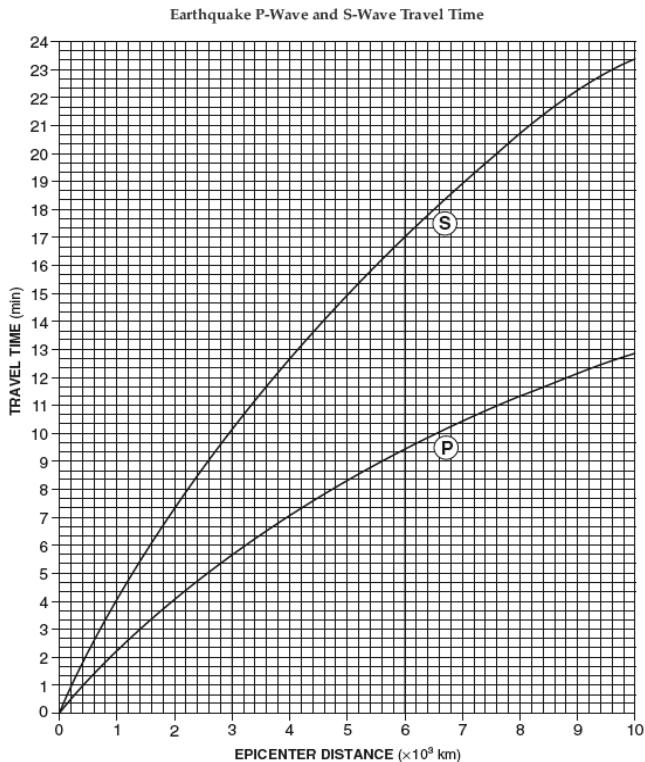
Calculate what time the earthquake happened using the Arrival and travel times



08:16:00 (P Arrival
MINUS! → Time)
- 00:06:20 (P Travel
Time)

Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km	00:06:20	
B						
C						

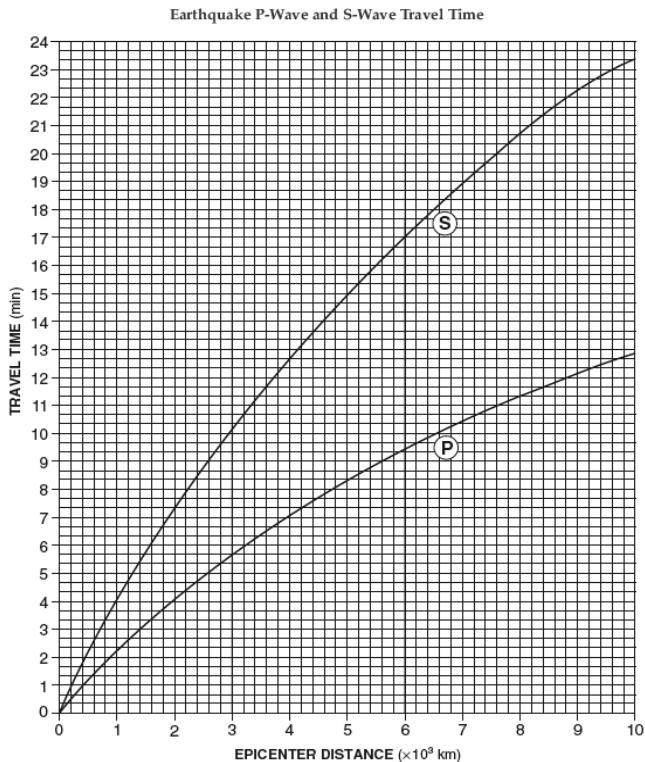
Obviously, the earthquake happened earlier than when it was felt miles away



08:15:60 (1 min. is 60 sec)
08:16:00 (P Arrival Time)
- 00:06:20 (P Travel Time)

Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km	00:06:20	
B						
C						

Convert hours to minutes or minutes to seconds when necessary



08:15:60 (1 min. is 60 sec)

08:16:00 (P Arrival Time)

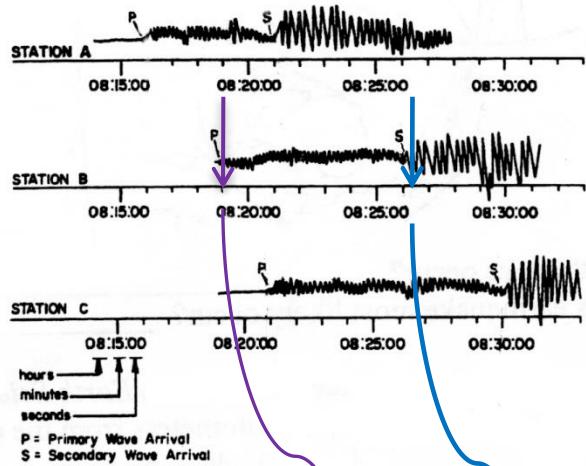
- 00:06:20 (P Travel Time)

08:09:40 (Time at Origin)

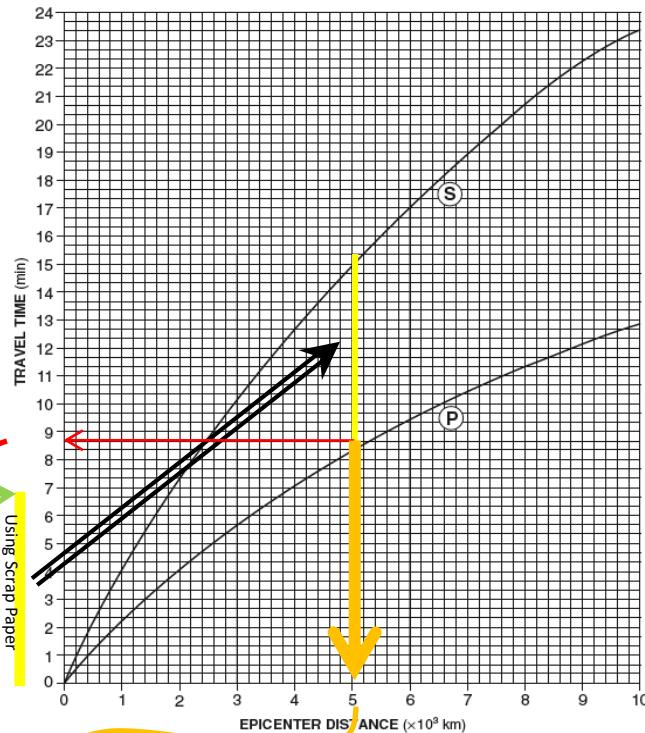
Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km	00:06:20	08:09:40
B						
C						

Put the calculated time of earthquake in the proper box

Earthquake P-Wave and S-Wave Travel Time

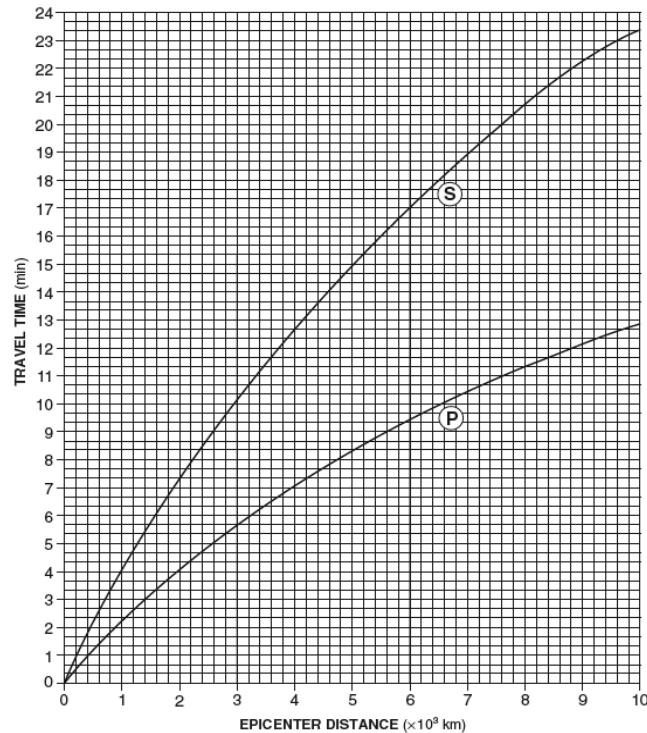
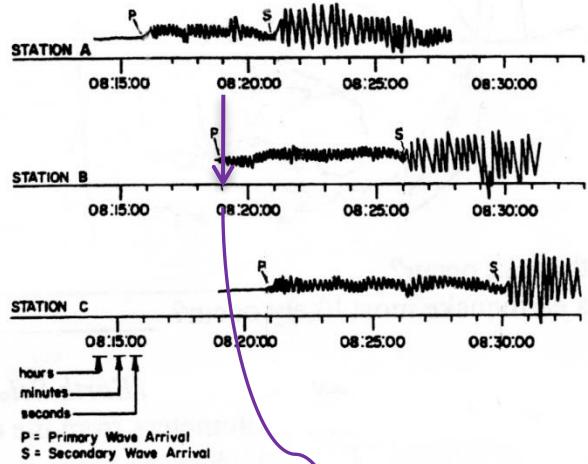


Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km	00:08:20	08:09:40
B	08:19:00	08:26:00	00:07:00	5.0×10^3 km	00:08:20	08:10:40
C						



Anything complex is easier when broken into smaller steps

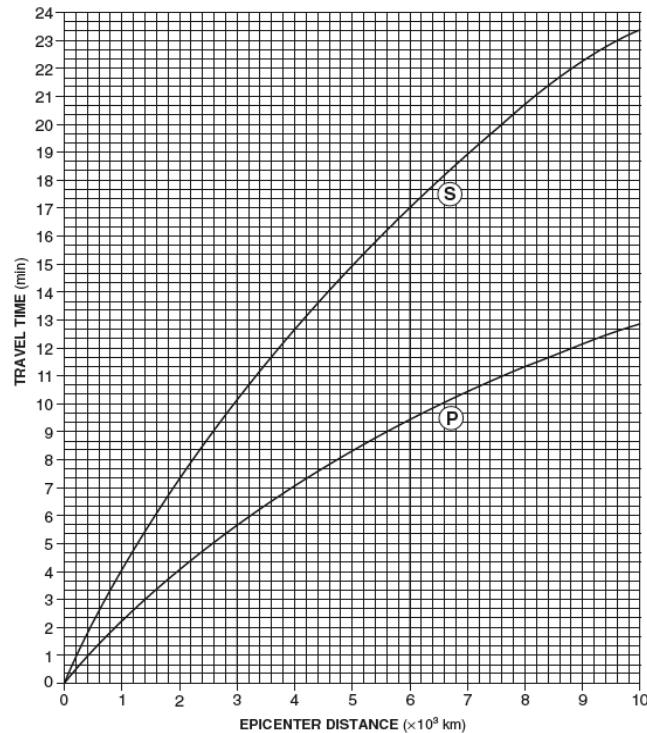
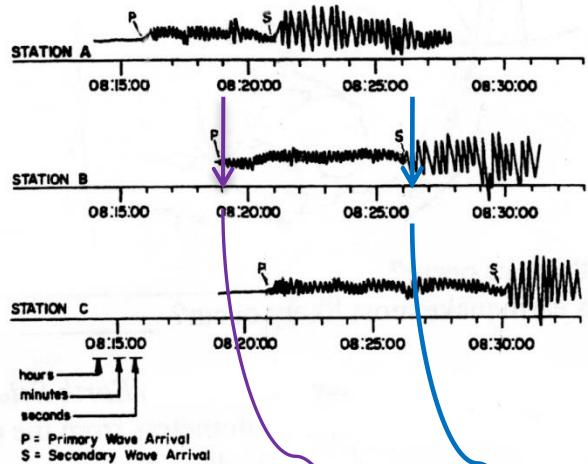
Earthquake P-Wave and S-Wave Travel Time



Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km	00:06:20	08:09:40
B	08:19:00					
C						

Judge what time the P-wave starts and enter it in the box

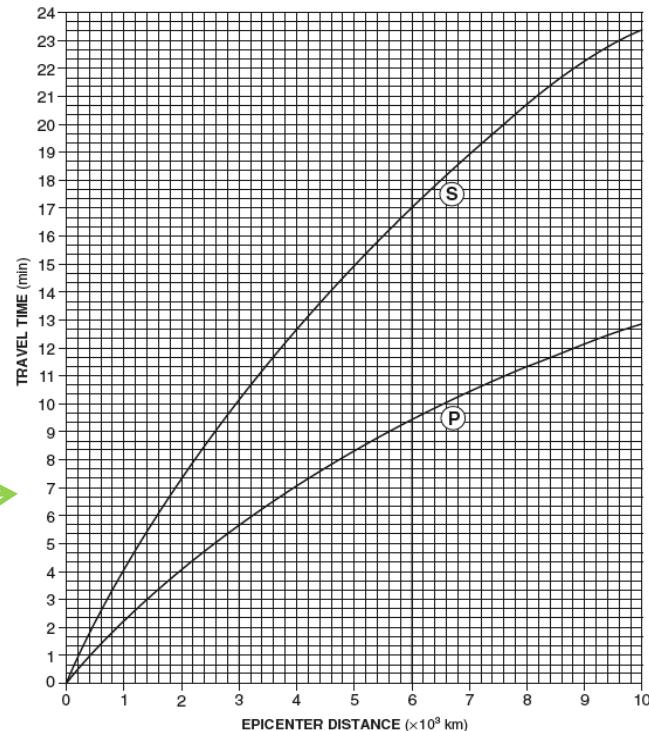
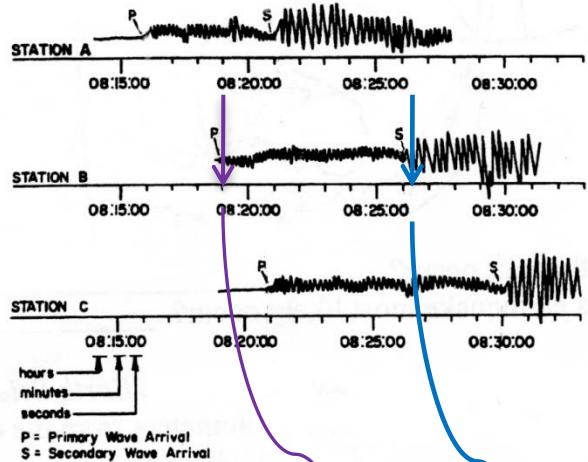
Earthquake P-Wave and S-Wave Travel Time



Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km	00:06:20	08:09:40
B	08:19:00	08:26:00				
C						

Repeat the same process for the S-wave.

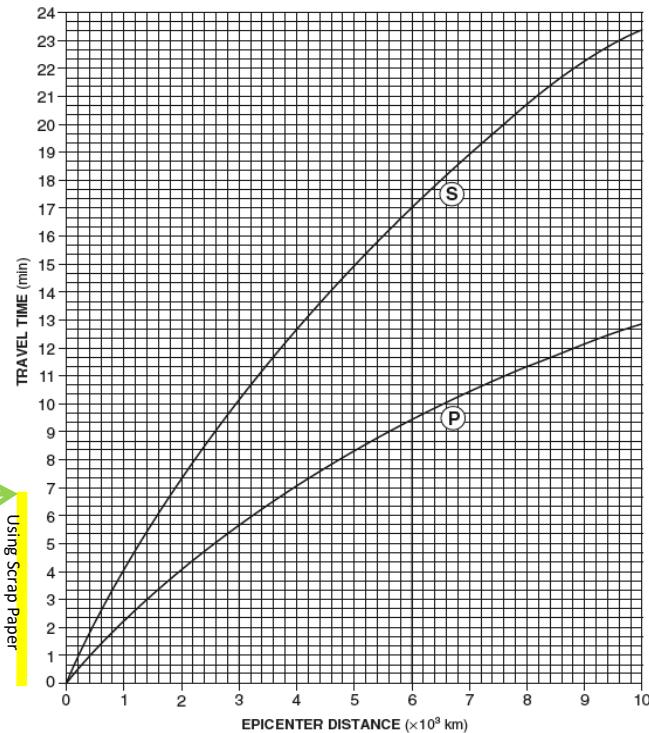
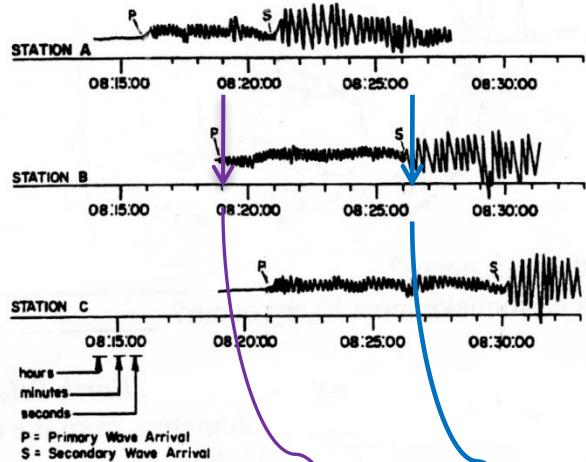
Earthquake P-Wave and S-Wave Travel Time



Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km	00:06:20	08:09:40
B	08:19:00	08:26:00	00:07:00			
C						

Use the P-S Wave time interval to set reference marks for the sliding step

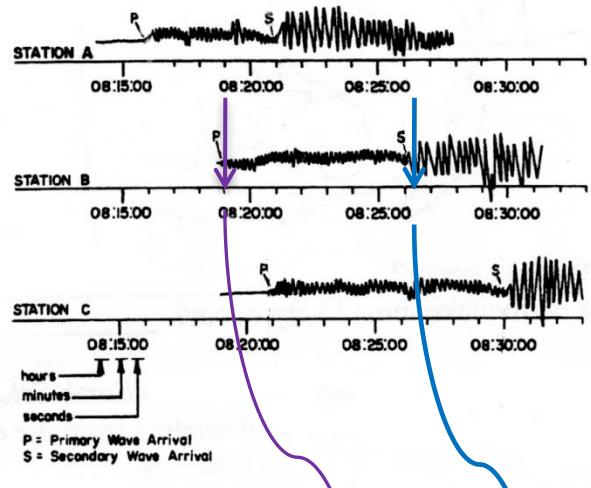
Earthquake P-Wave and S-Wave Travel Time



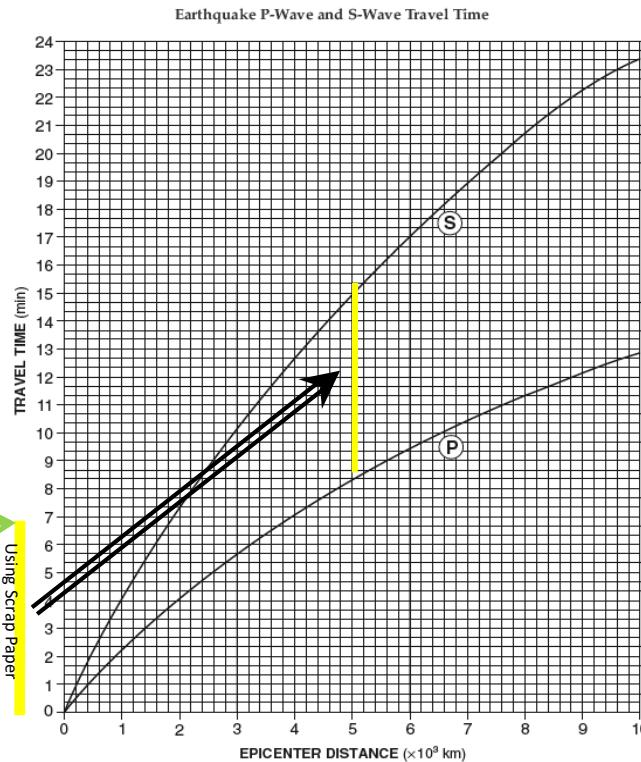
Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km	00:06:20	08:09:40
B	08:19:00	08:26:00	00:07:00			
C						

Create a reference measurement using scrap paper and the P-S Wave value

Earthquake Using the Difference in Time Between the P and the S Wave

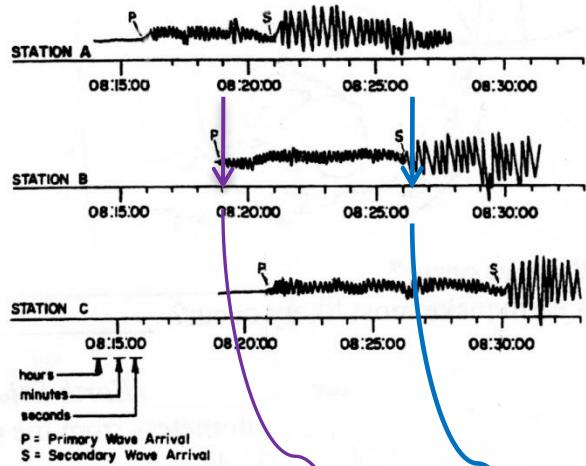


Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km	00:06:20	08:09:40
B	08:19:00	08:26:00	00:07:00			
C						

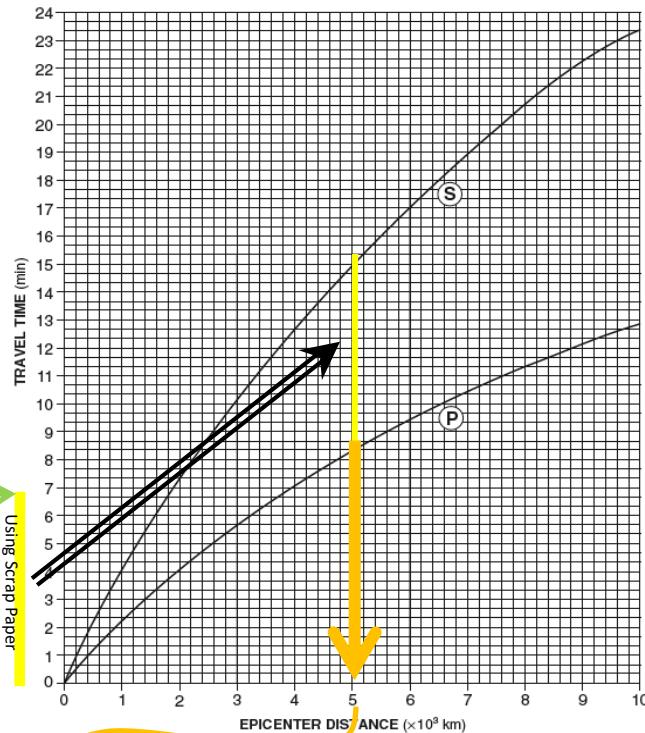


Find the proper place where the reference marks match the P and S Lines.

Earthquake P-Wave and S-Wave Travel Time

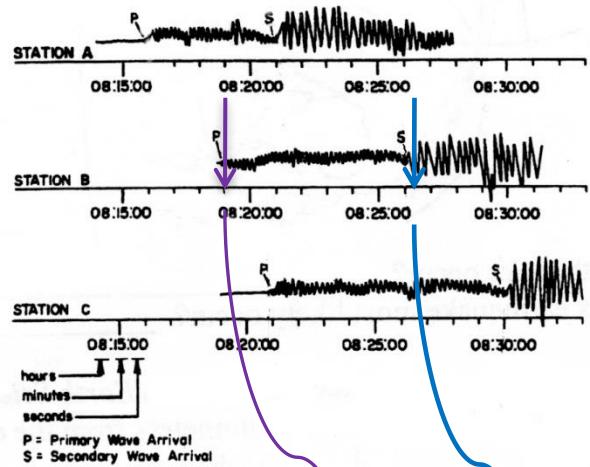


Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km	00:06:20	08:09:40
B	08:19:00	08:26:00	00:07:00	5.0×10^3 km		
C						

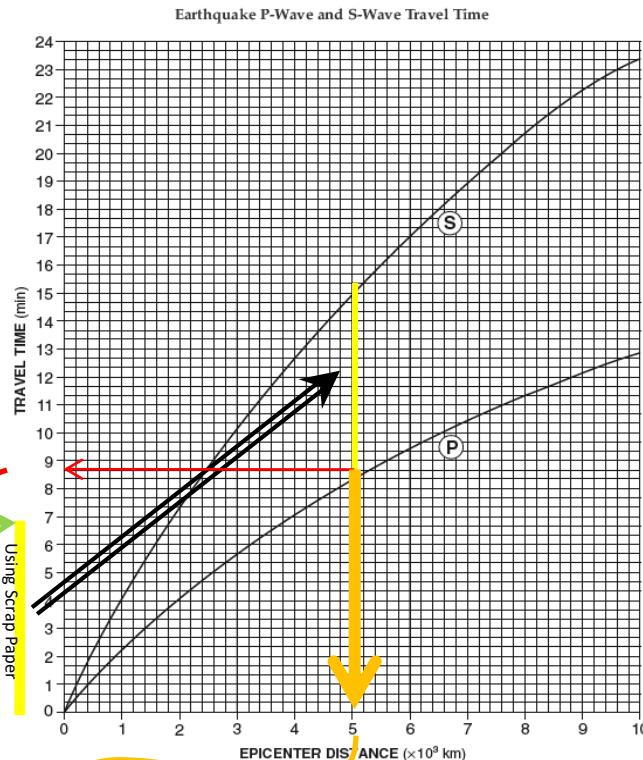


Look straight down from the P line pencil mark and judge the epicenter distance.

Earthquake Using the Difference in Time Between the P and the S Wave

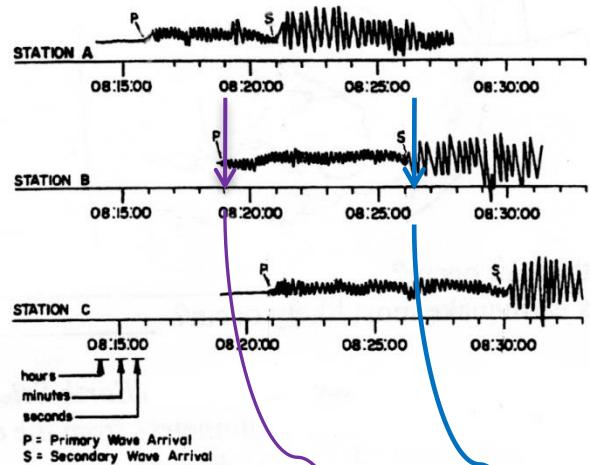


Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km	00:08:20	08:09:40
B	08:19:00	08:26:00	00:07:00	5.0×10^3 km	00:08:20	
C						

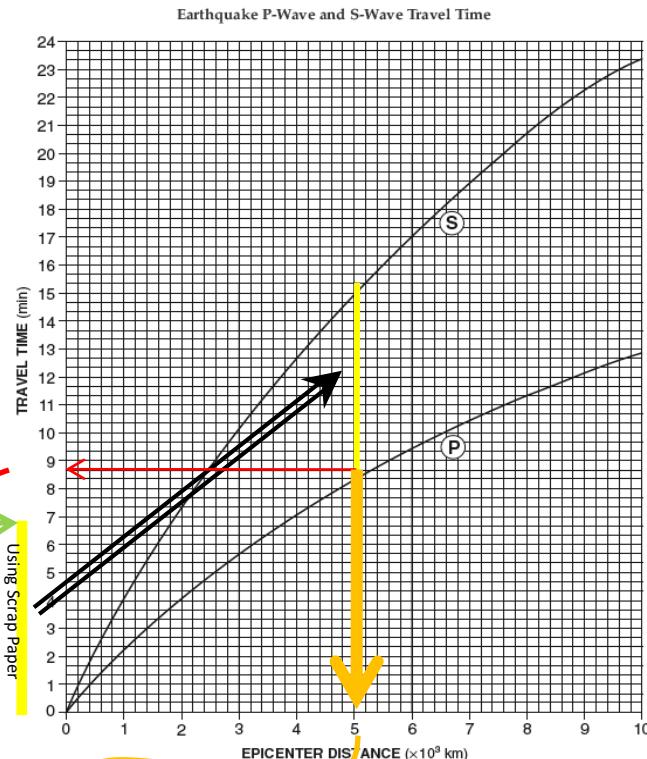


Look across at the y-axis to Judge the time value

Earthquake Using the Difference in Time Between the P and the S Wave

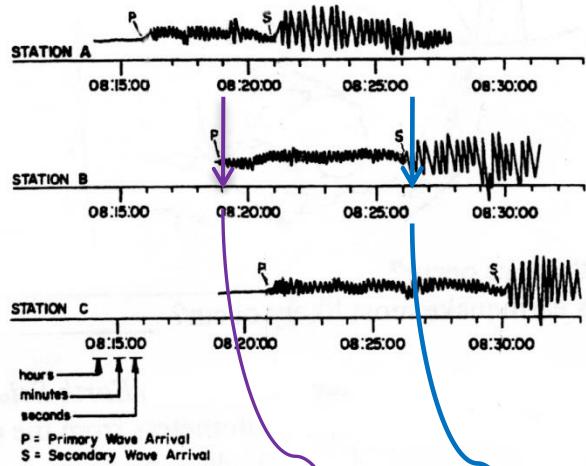


Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km	00:06:20	08:09:40
B	08:19:00	08:26:00	00:07:00	5.0×10^3 km	00:08:20	08:10:40
C						

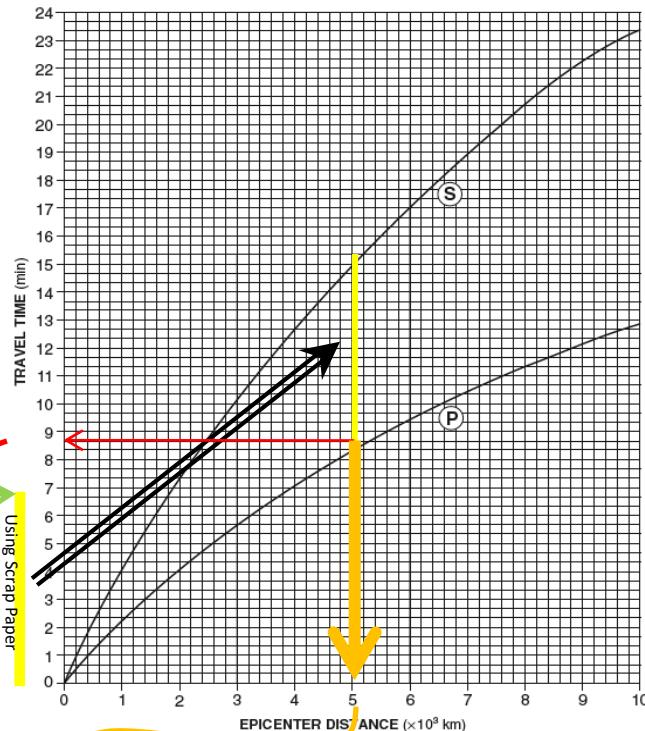


Put the calculated time of earthquake in the proper box

Earthquake P-Wave and S-Wave Travel Time

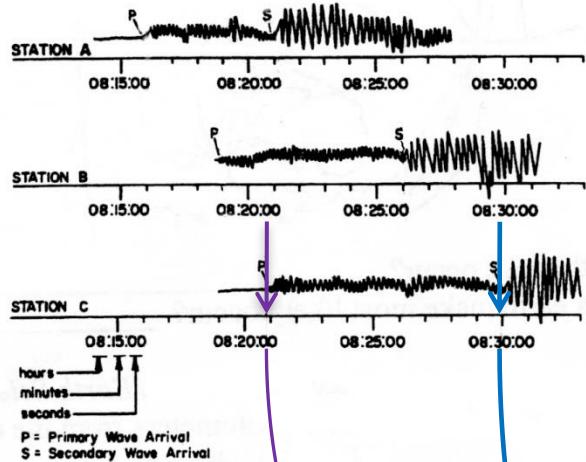


Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km	00:08:20	08:09:40
B	08:19:00	08:26:00	00:07:00	5.0×10^3 km	00:08:20	08:10:40
C						

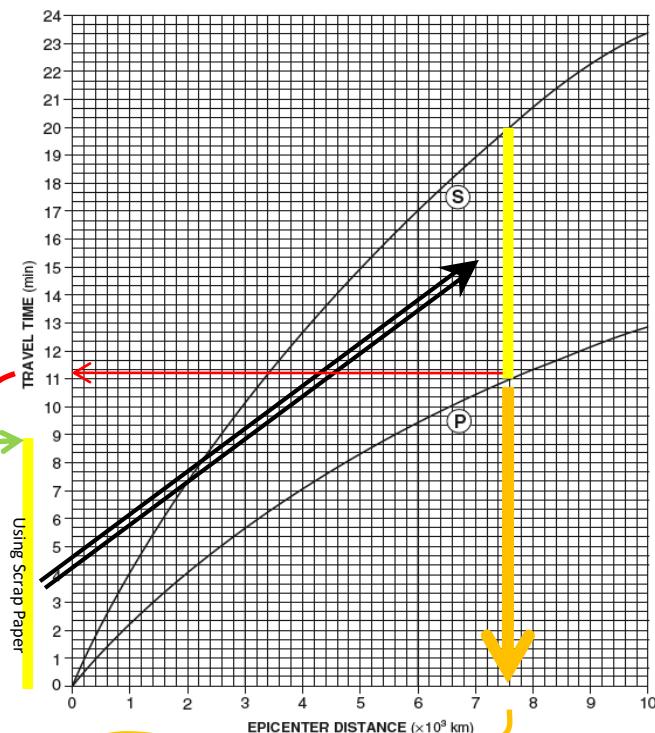


Anything complex is easier when broken into smaller steps

Earthquake P-Wave and S-Wave Travel Time

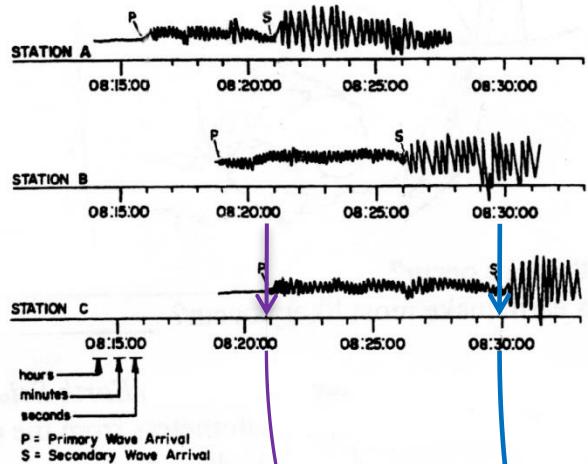


Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km	00:06:20	08:09:40
B	08:19:00	08:26:00	00:07:00	5.0×10^3 km	00:08:20	08:10:40
C	08:21:00	08:30:00	00:09:00	7.6×10^3 km	00:10:20	08:11:40

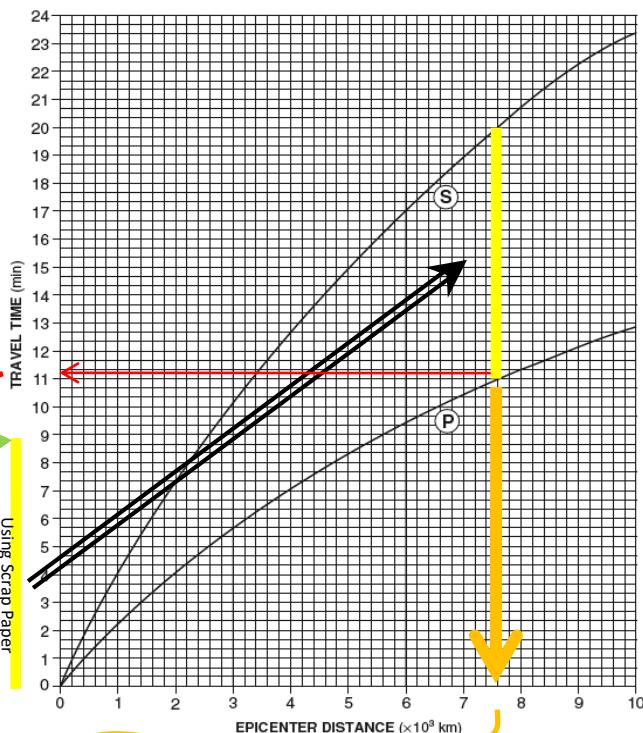


Follow the same overall process for Station C

Earthquake P-Wave and S-Wave Travel Time

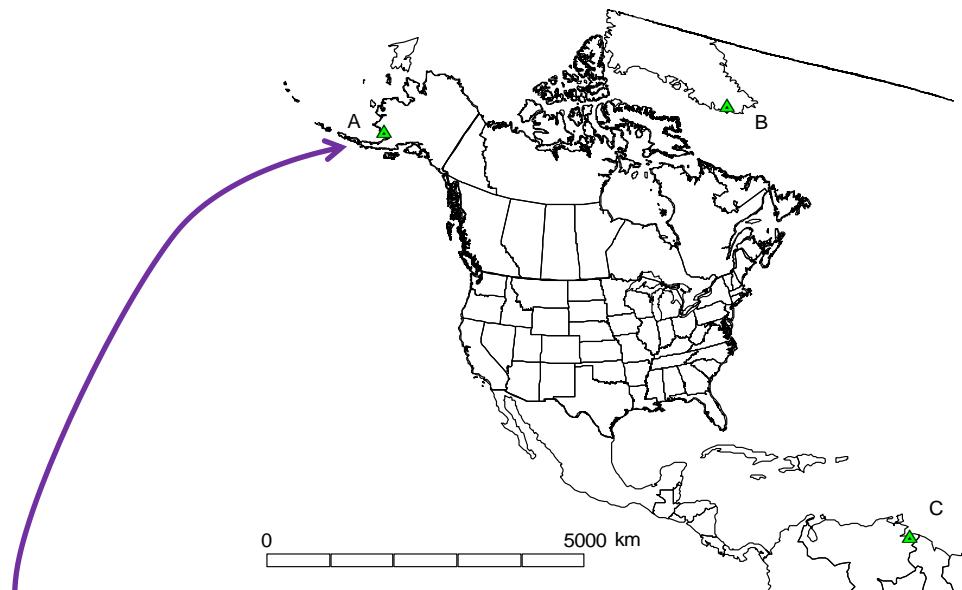


Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km	00:06:20	08:09:40
B	08:19:00	08:26:00	00:07:00	5.0×10^3 km	00:08:20	08:10:40
C	08:21:00	08:30:00	00:09:00	7.6×10^3 km	00:10:20	08:11:40



Calculate and place the time of earthquake in the proper box

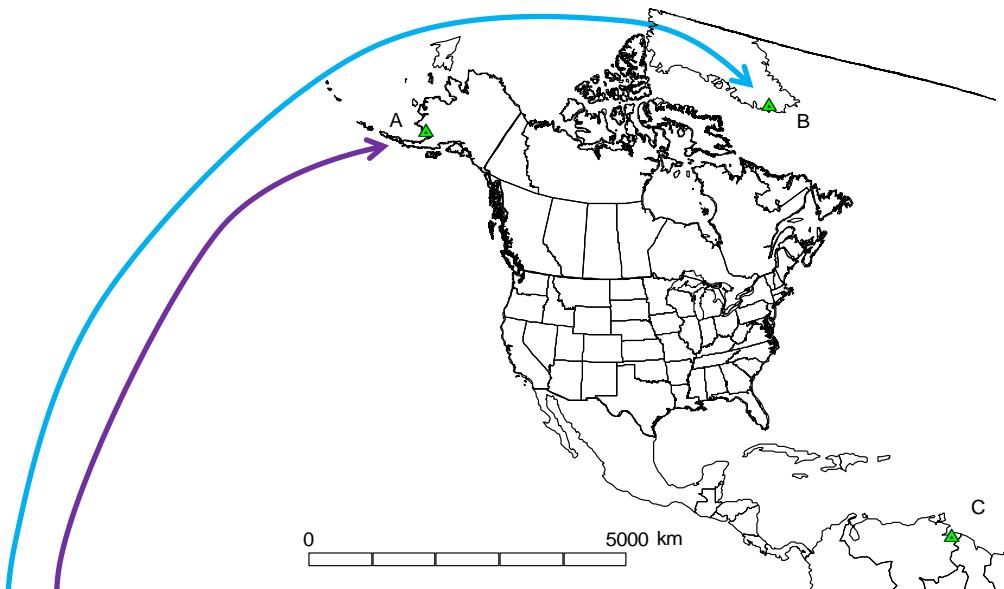
Finding the Epicenter of an Earthquake Using the Difference in Time Between the P and the S Wave



Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km	00:06:20	08:09:40
B	08:19:00	08:26:00	00:07:00	5.0×10^3 km	00:08:20	08:10:40
C	08:21:00	08:30:00	00:09:00	7.6×10^3 km	00:10:20	08:11:40

On the Station Map, Find Station A

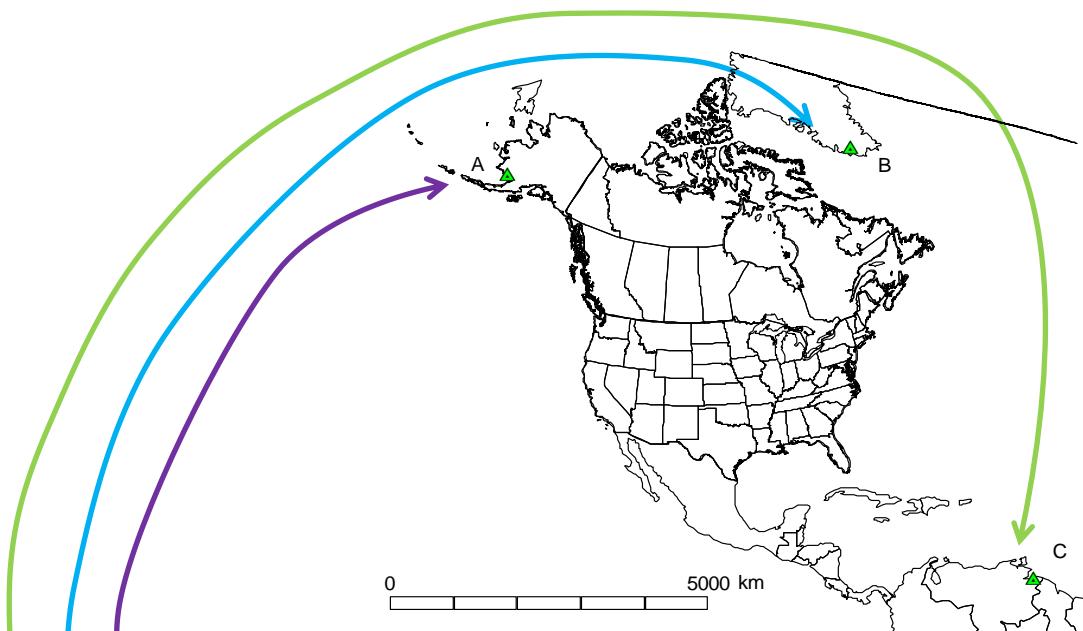
Finding the Epicenter of an Earthquake Using the Difference in Time Between the P and the S Wave



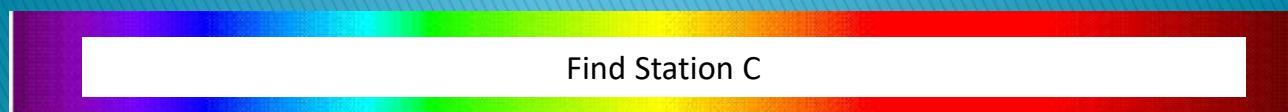
Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
A	08:16:00	08:21:00	00:05:00	3.6×10^3 km	00:06:20	08:09:40
B	08:19:00	08:26:00	00:07:00	5.0×10^3 km	00:08:20	08:10:40
C	08:21:00	08:30:00	00:09:00	7.6×10^3 km	00:10:20	08:11:40

Find Station B

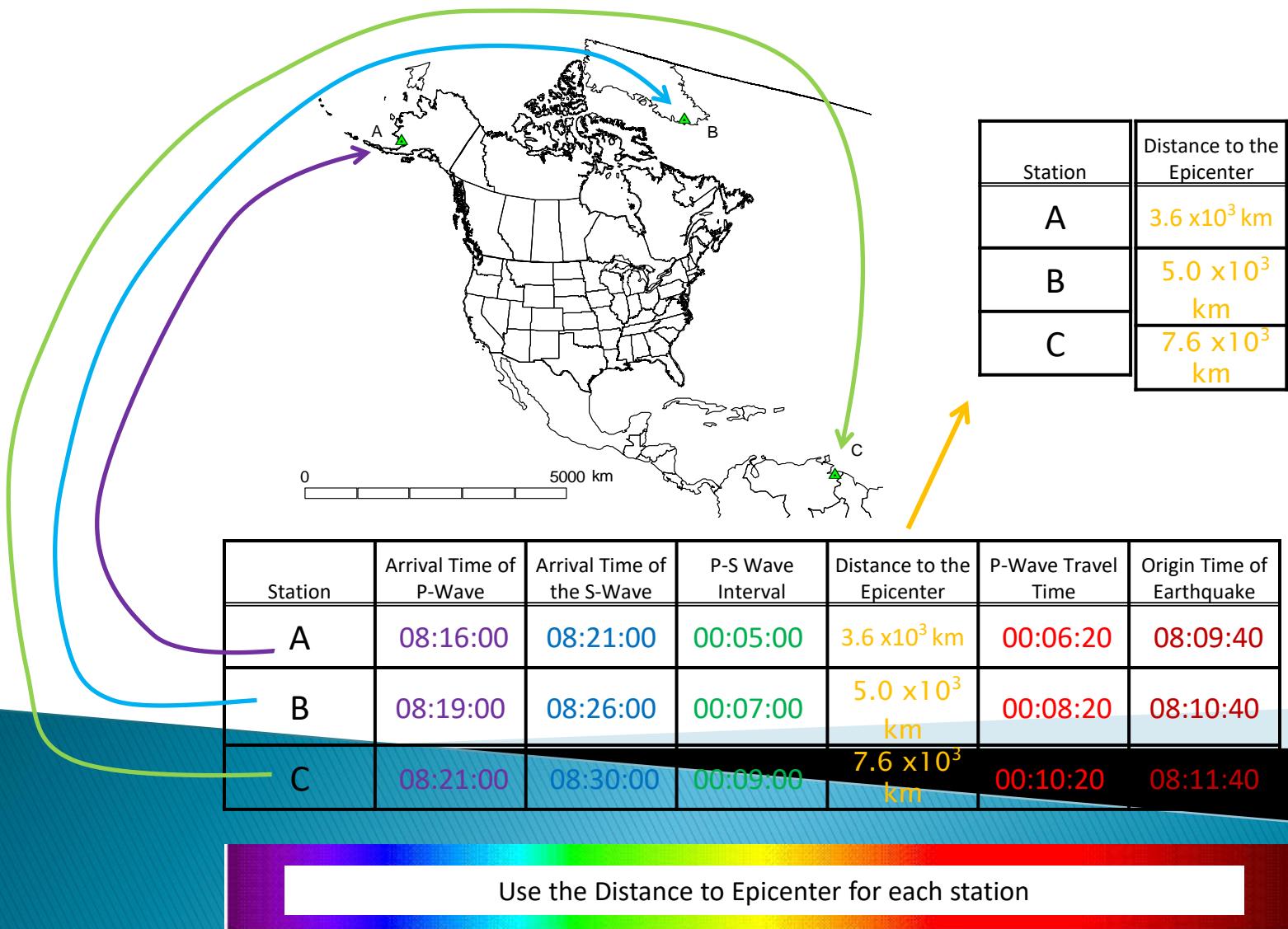
Finding the Epicenter of an Earthquake Using the Difference in Time Between the P and the S Wave



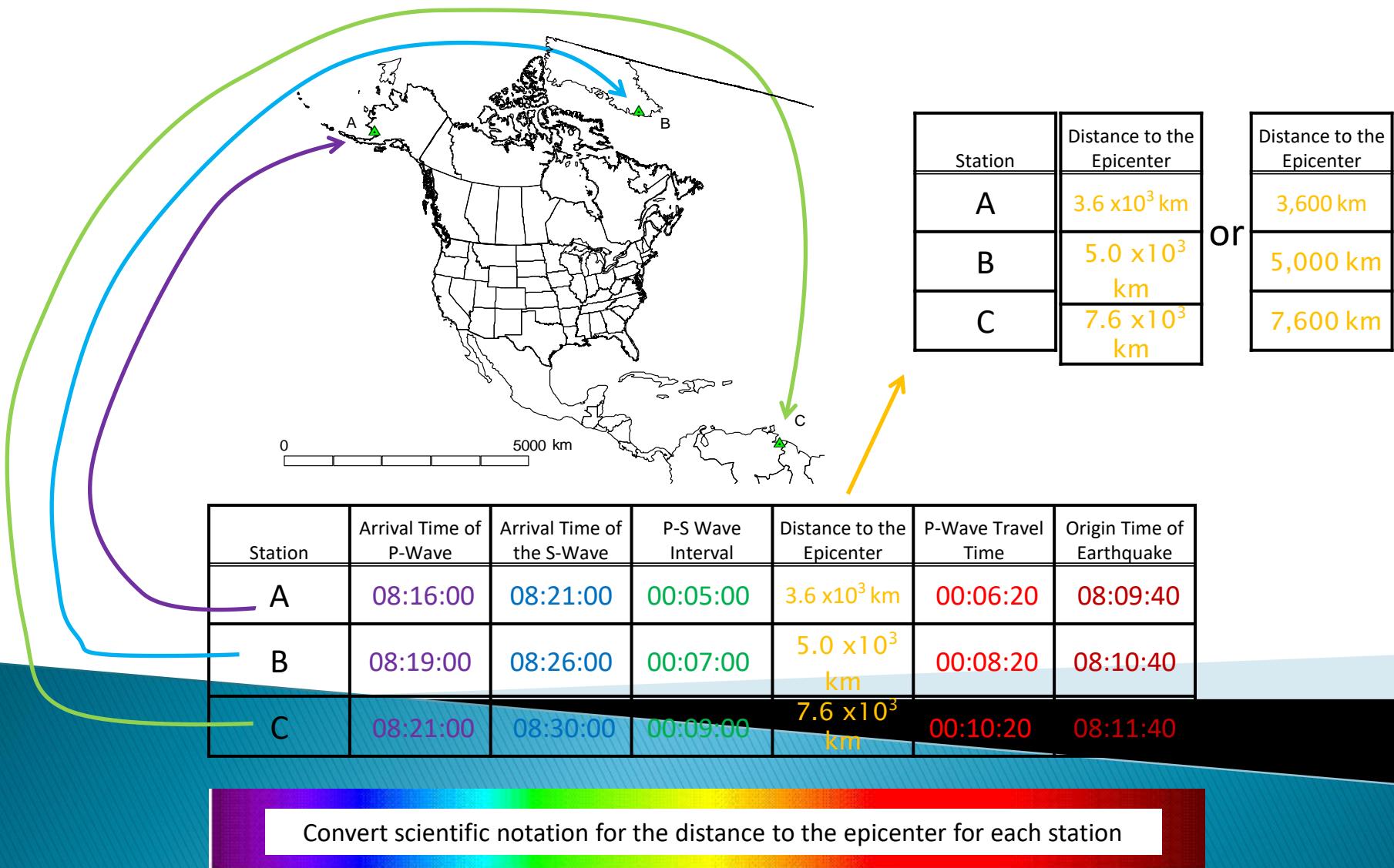
Station	Arrival Time of P-Wave	Arrival Time of the S-Wave	P-S Wave Interval	Distance to the Epicenter	P-Wave Travel Time	Origin Time of Earthquake
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B	08:19:00	08:26:00	00:07:00	5.0×10^3 km	00:08:20	08:10:40
C	08:21:00	08:30:00	00:09:00	7.6×10^3 km	00:10:20	08:11:40



Finding the Epicenter of an Earthquake Using the Difference in Time Between the P and the S Wave

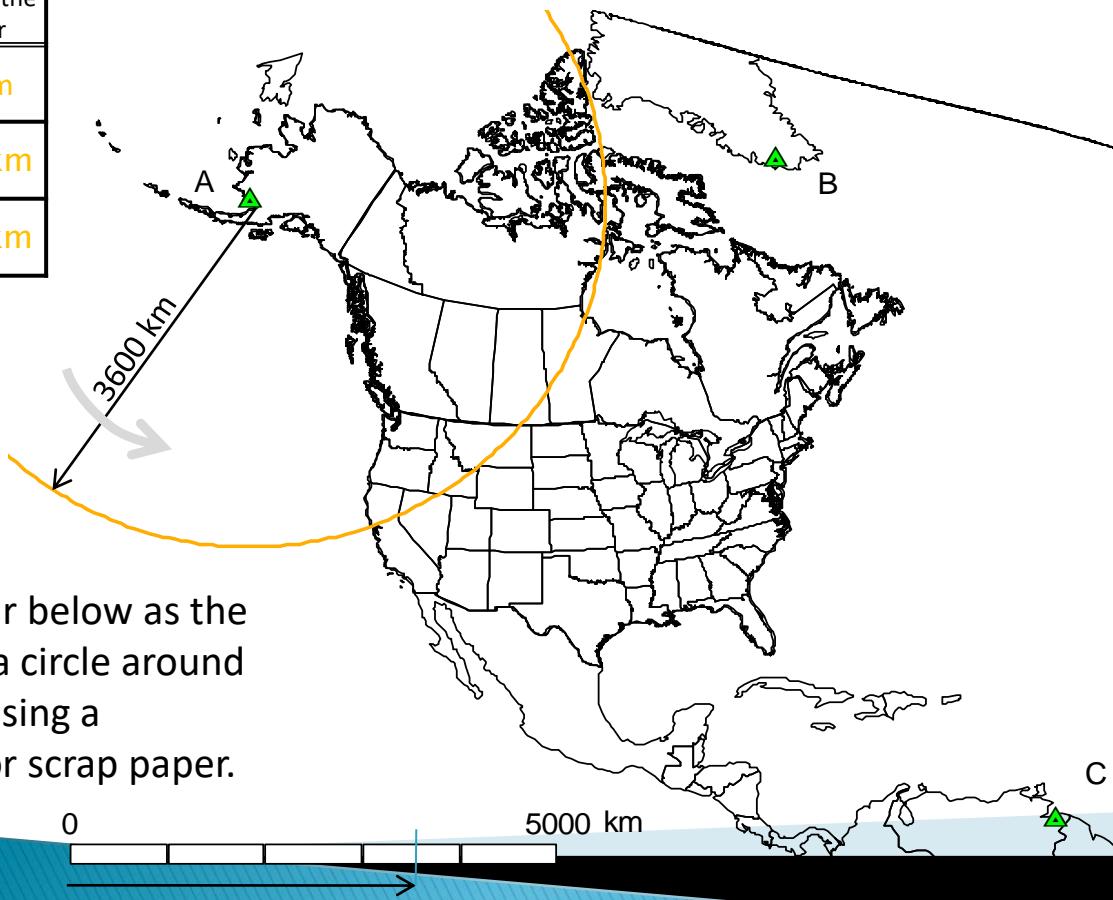


Finding the Epicenter of an Earthquake Using the Difference in Time Between the P and the S Wave



Finding the Epicenter of an Earthquake Using the Difference in Time Between the P and the S Wave

Station	Distance to the Epicenter
A	3,600 km
B	5,000 km
C	7,600 km

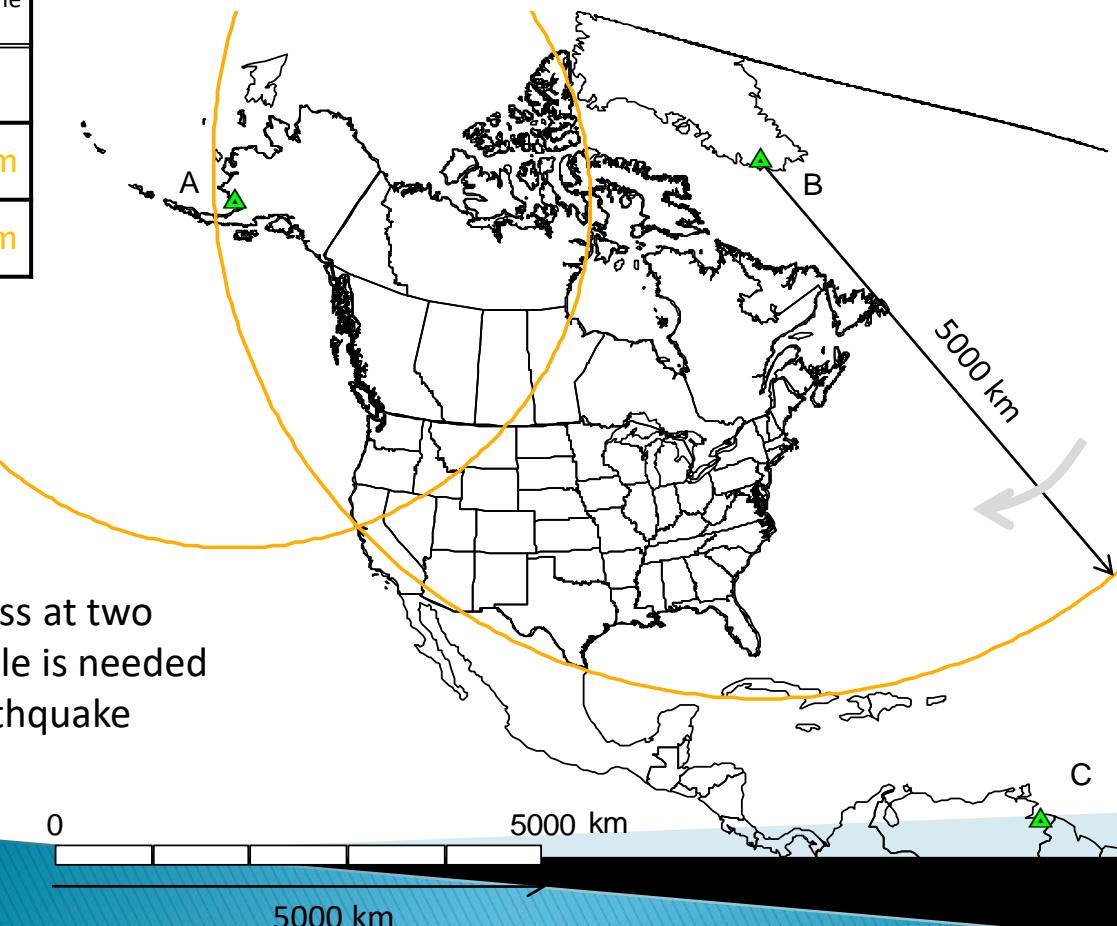


Using the scale bar below as the reference, scribe a circle around the three points using a compass, string, or scrap paper.

Scribe the arc for Station A using the map scale distance

Finding the Epicenter of an Earthquake Using the Difference in Time Between the P and the S Wave

Station	Distance to the Epicenter
A	3,600 km
B	5,000 km
C	7,600 km



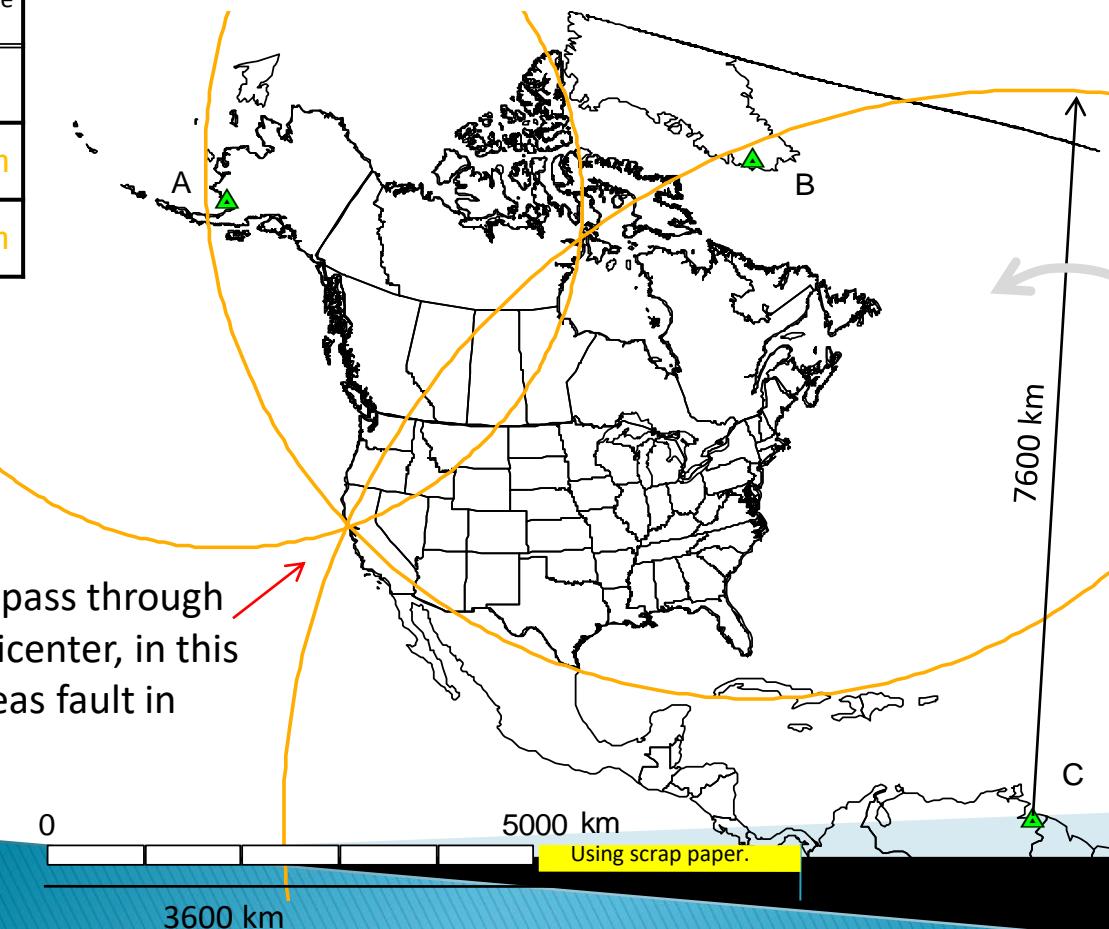
The two circles cross at two points. A third circle is needed to confirm the earthquake epicenter.

Scribe the arc for Station B using the map scale distance

Finding the Epicenter of an Earthquake Using the Difference in Time Between the P and the S Wave

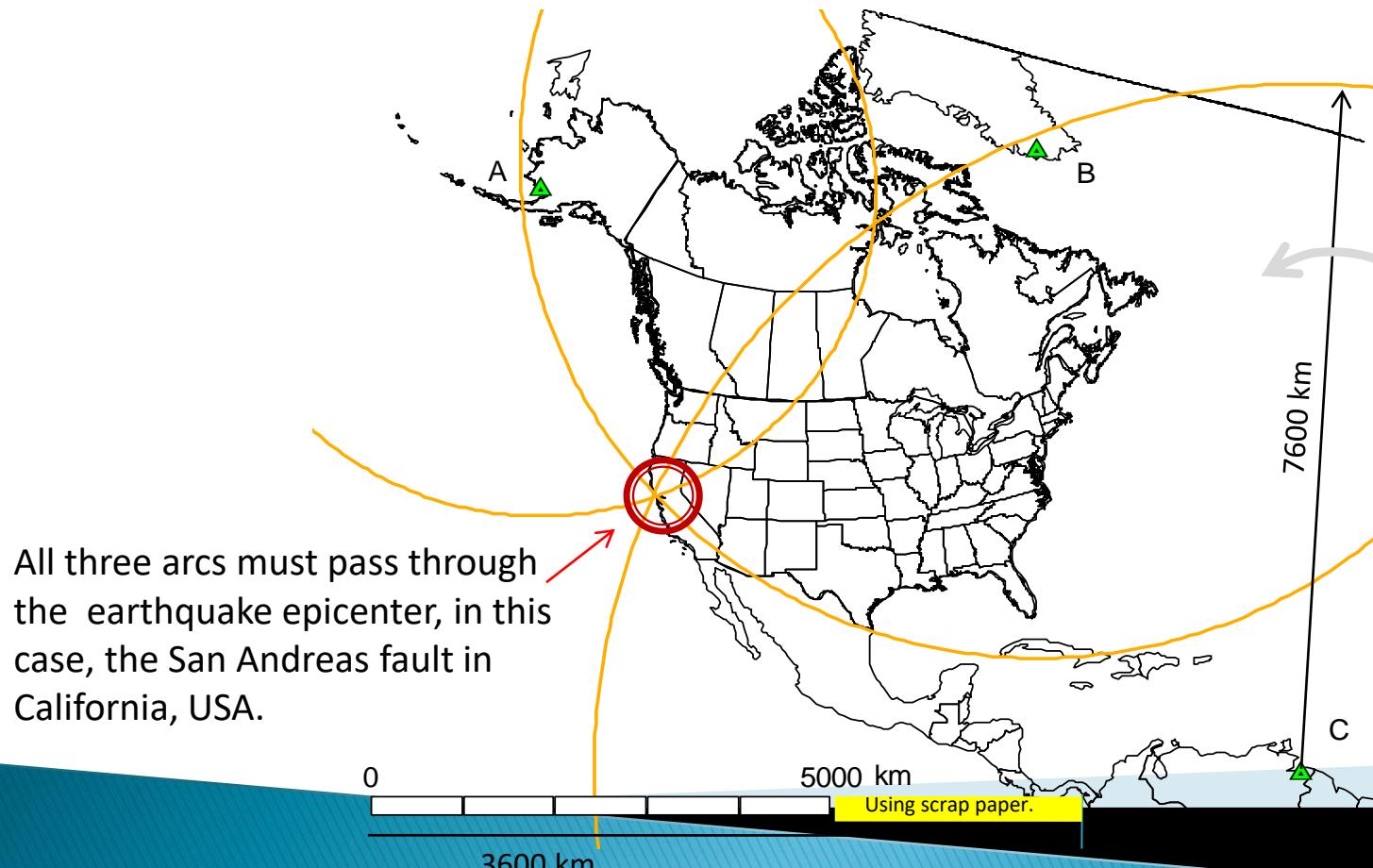
Station	Distance to the Epicenter
A	3,600 km
B	5,000 km
C	7,600 km

All three arcs must pass through the earthquake epicenter, in this case, the San Andreas fault in California, USA.



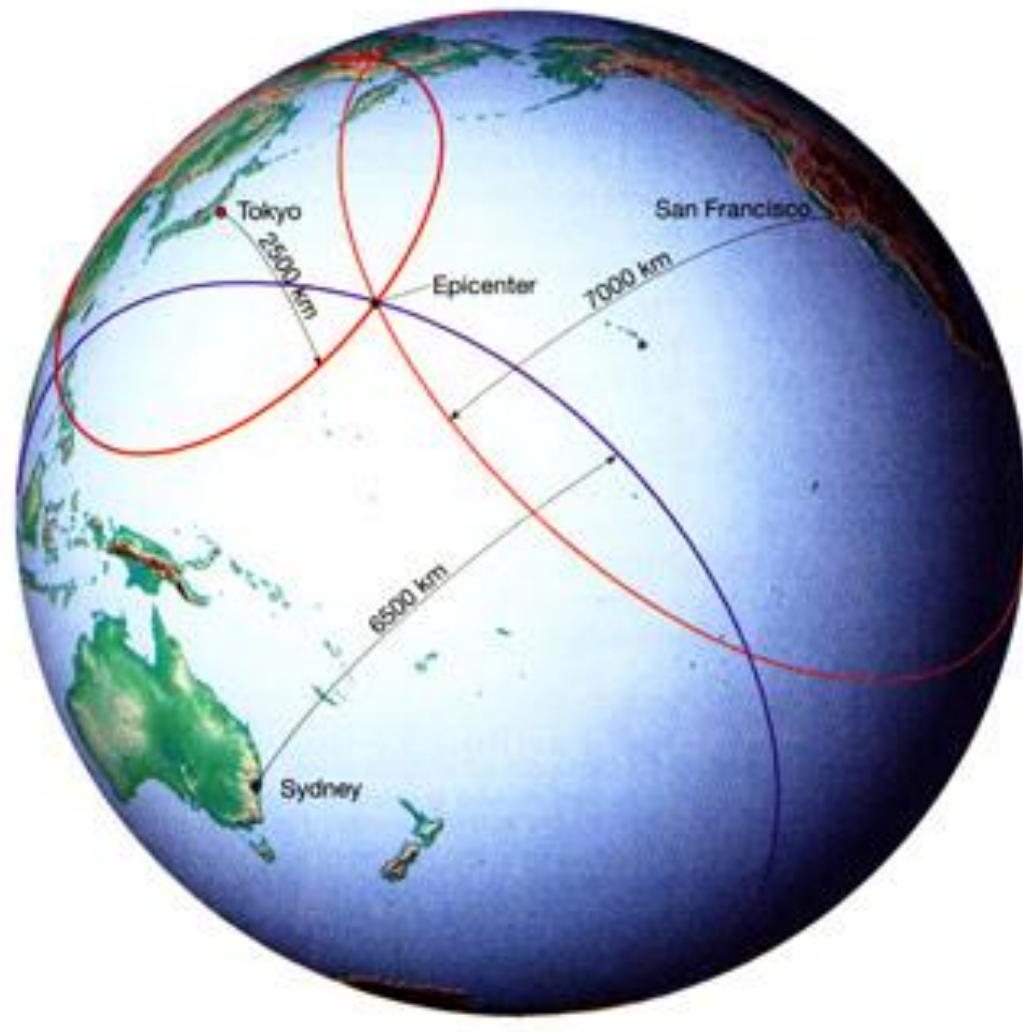
If the distance is longer than the scale, use scrap paper to extend the scale.

Finding the Epicenter of an Earthquake Using the Difference in Time Between the P and the S Wave



Where the three arcs cross is the epicenter – Circle it!

Locating the Earthquake



Figure

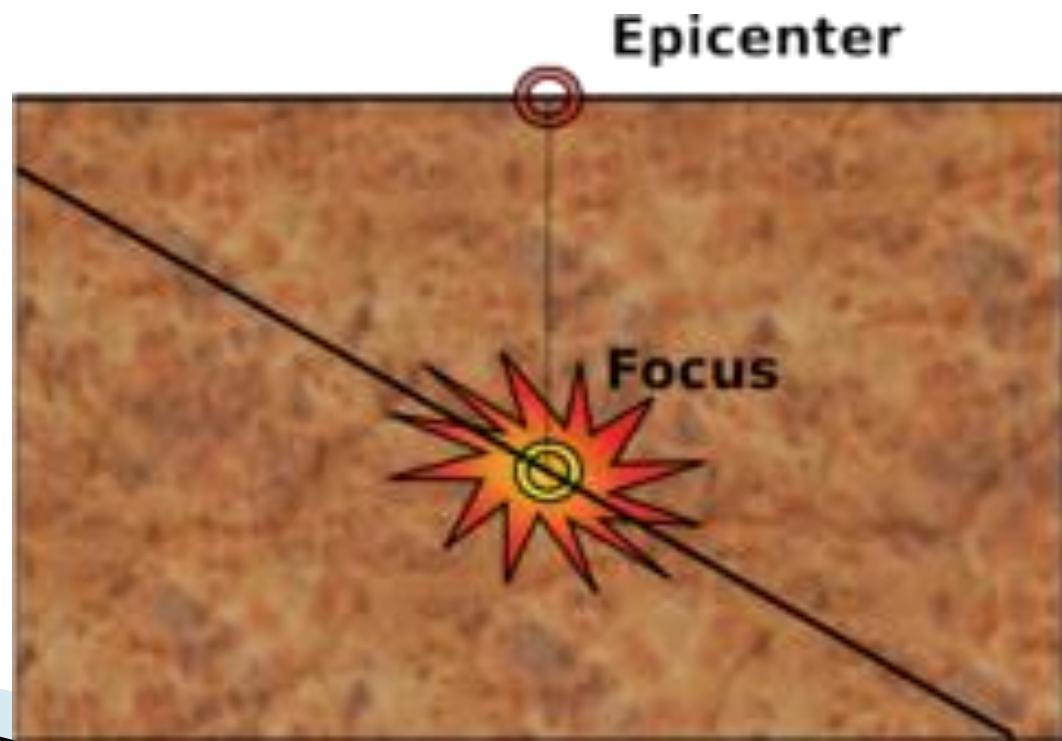


What is an Epicenter?

- ▶ A point on the surface of the Earth directly above the FOCUS of the earthquake.



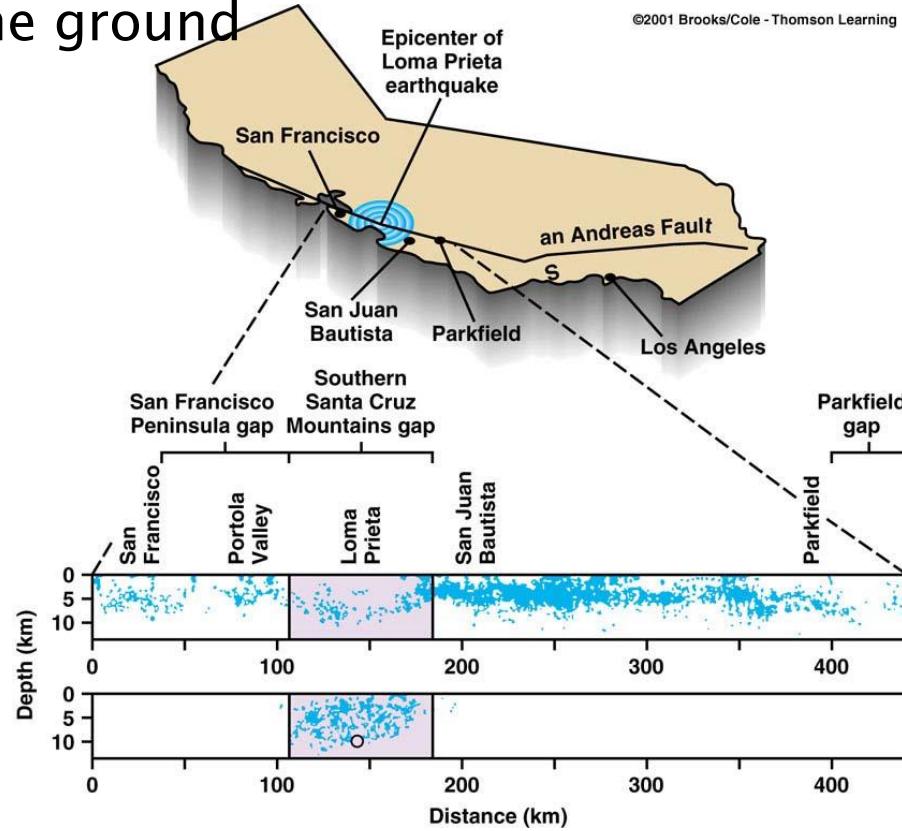
- The point within the Earth from which earthquake waves originate.



Can Earthquakes be Predicted?

Earthquake Precursors

1. changes in elevation or tilting of land surface
2. fluctuations in groundwater levels
3. magnetic field
4. electrical resistance of the ground
5. Release of gases



EVERY
CHILD IS A
different KIND OF flower,
AND ALL TOGETHER,
MAKE THIS WORLD
A *Beautiful* GARDEN.

