EOSC 114 - Earthquakes

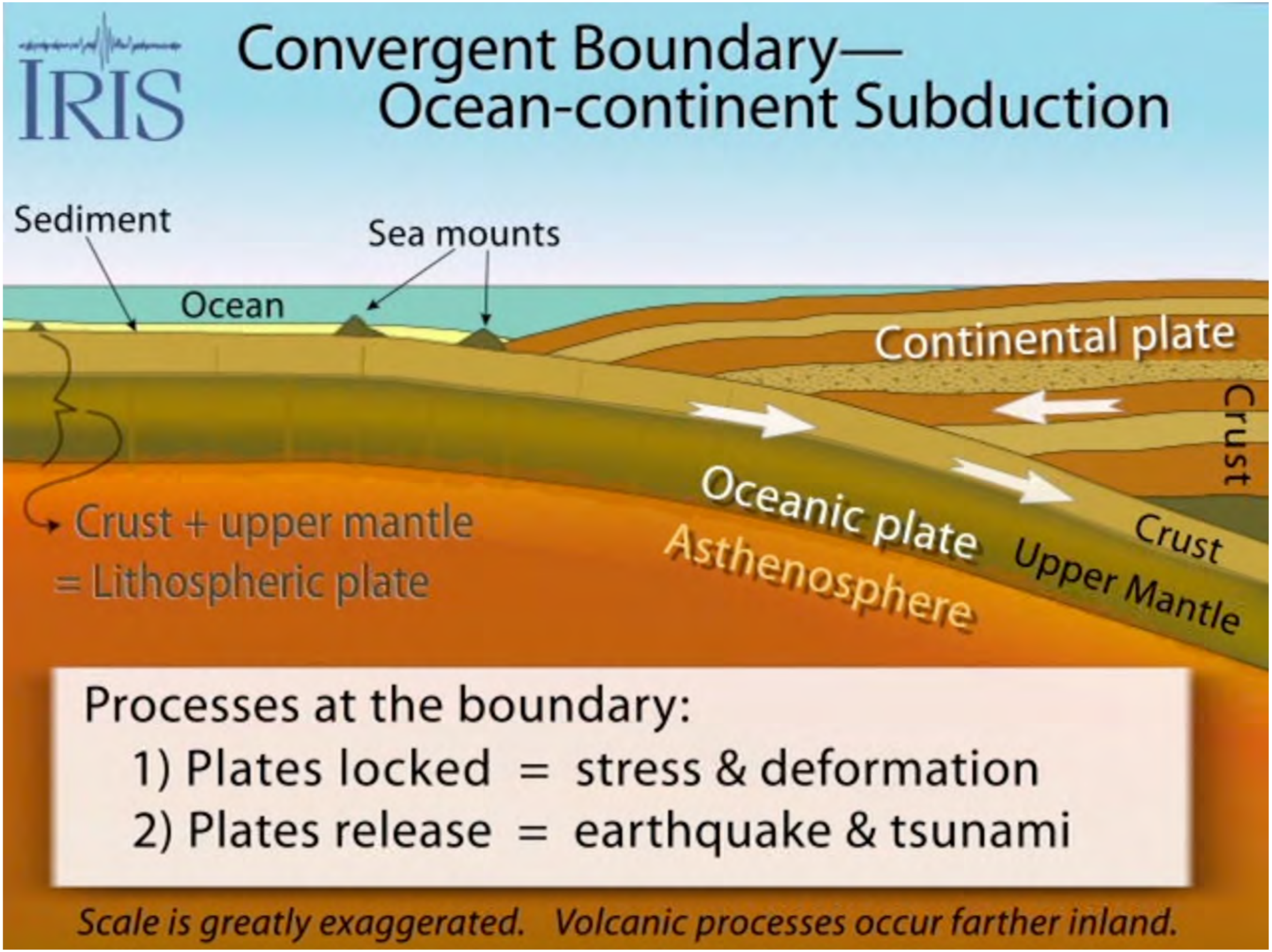
Earthquakes

- Lecture 1 – Why and how the Earth moves
- Lecture 2 - Plate tectonics, plate boundaries, faulting
- ***Lecture 3* - Seismology, earthquake magnitude/intensity**
- *Lecture 4* – Earthquake hazards and mitigation
- *Lecture 5* – Earthquake forecasting and survival

Clicker Question?

What are the dominant fault types at a convergent plate boundary?

A) Normal faults
B) Reverse (or thrust) faults
C) Strike-slip faults
D) Faulting does not occur at convergent plate margins



https://www.iris.edu/hq/inclass/animation/plate_boundary_convergent_margin

Learning Goals

- Explain what an earthquake is using the concept of elastic rebound
- Describe the motion and speed that different types of seismic waves travel through the Earth or along its surface:
  - Body waves [compression (P-waves) and shear (S-waves)]
  - Surface waves (Rayleigh and Love)
- Explain why shear waves cannot propagate through fluids while compressional waves can
- Determine the location of an earthquake using data from 3 or more seismograms
- Describe how we measure the size of an earthquake and the difference between earthquake magnitude and intensity

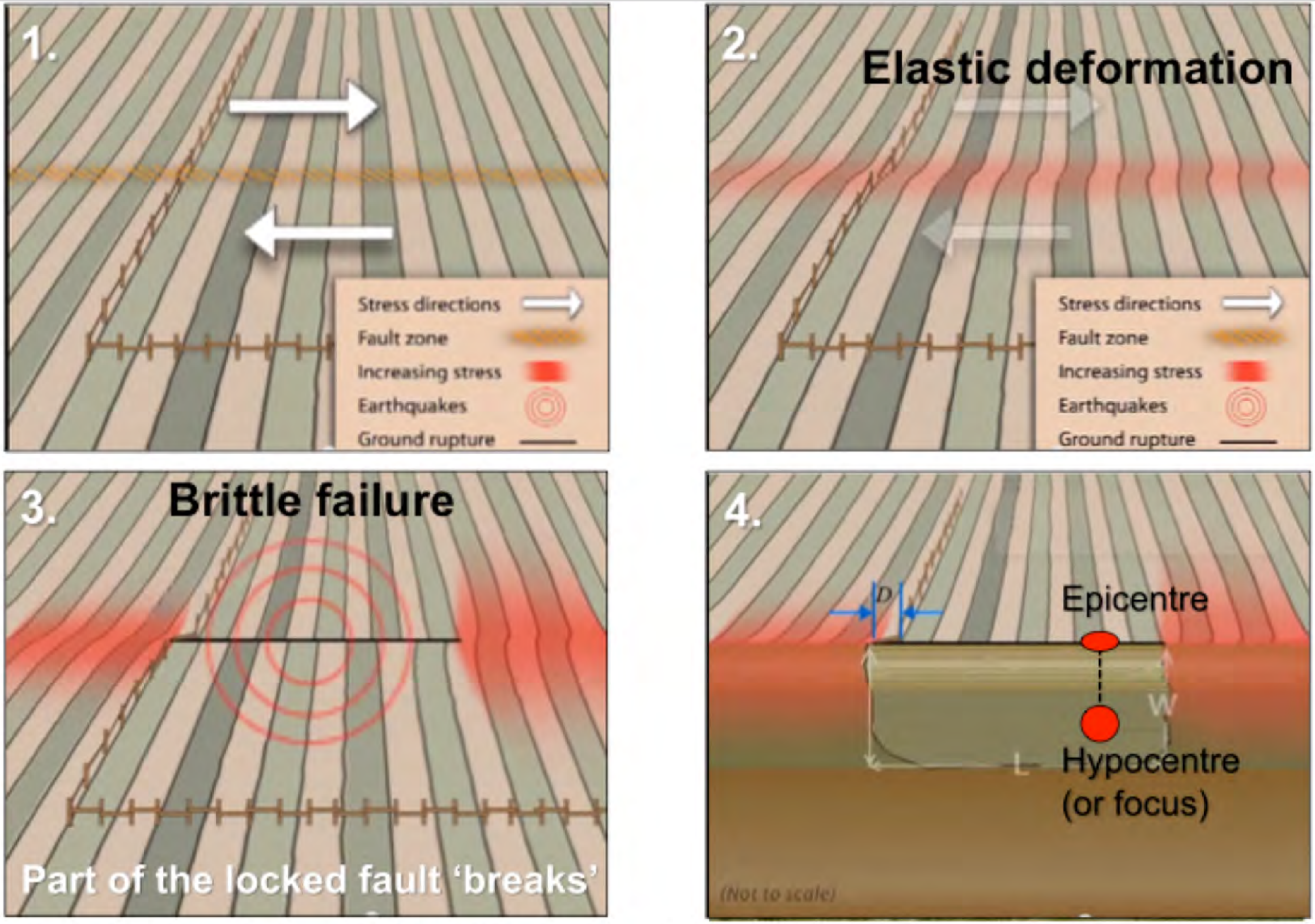
What is an earthquake?

What happens at the source?

What do we feel?

Mexico, 2017

What is an earthquake?



"Elastic Rebound" – how faults store and release energy

Earthquakes:

elastic rebound after cool, brittle rocks break

What is an Earthquake?

An **earthquake** is the sudden release of **elastic energy** in response to a buildup of stress.

This energy is released when elastic stresses exceed the strength of the fault

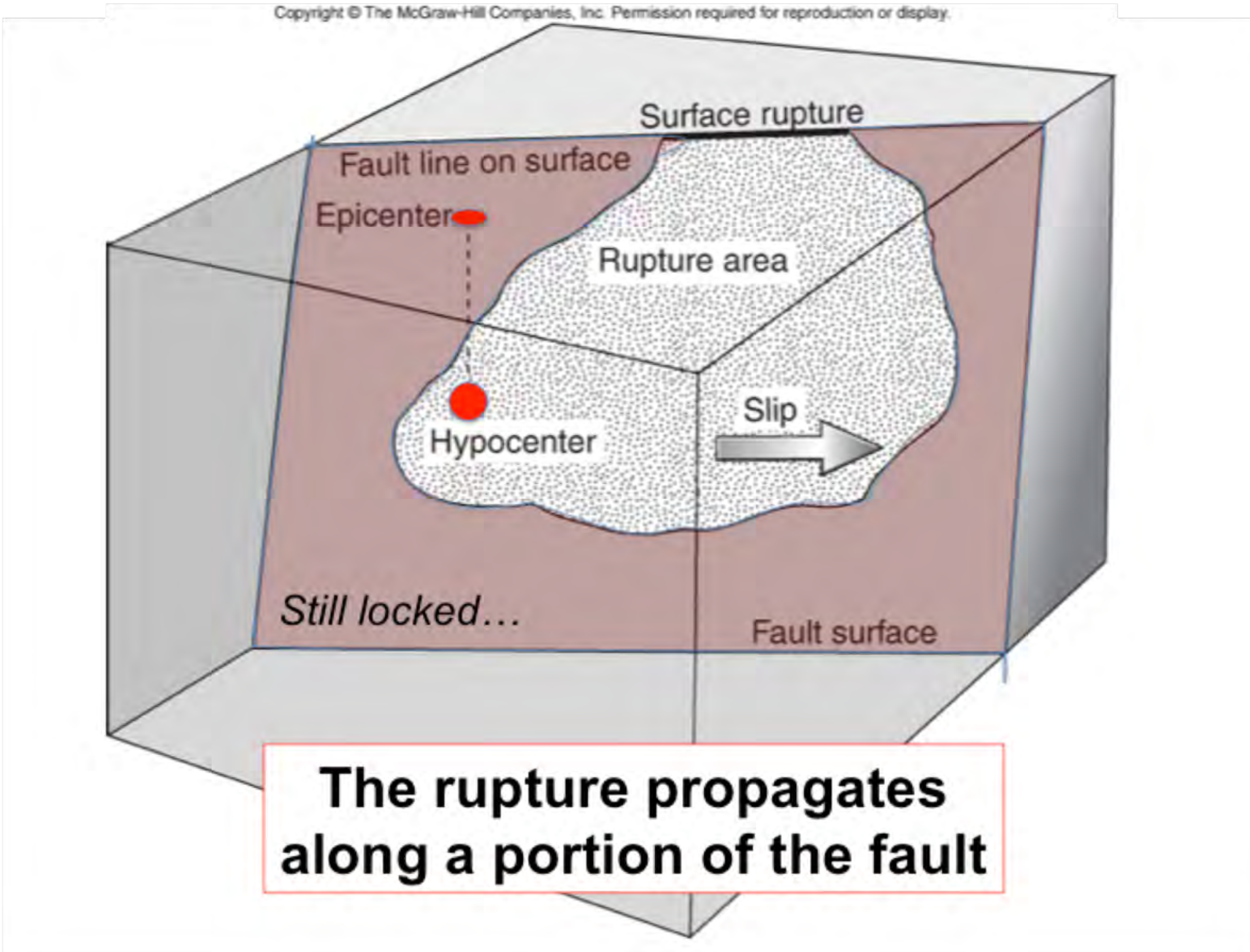
The energy is released as

- Seismic waves
- Displacement along the fault
- Heat and other energy

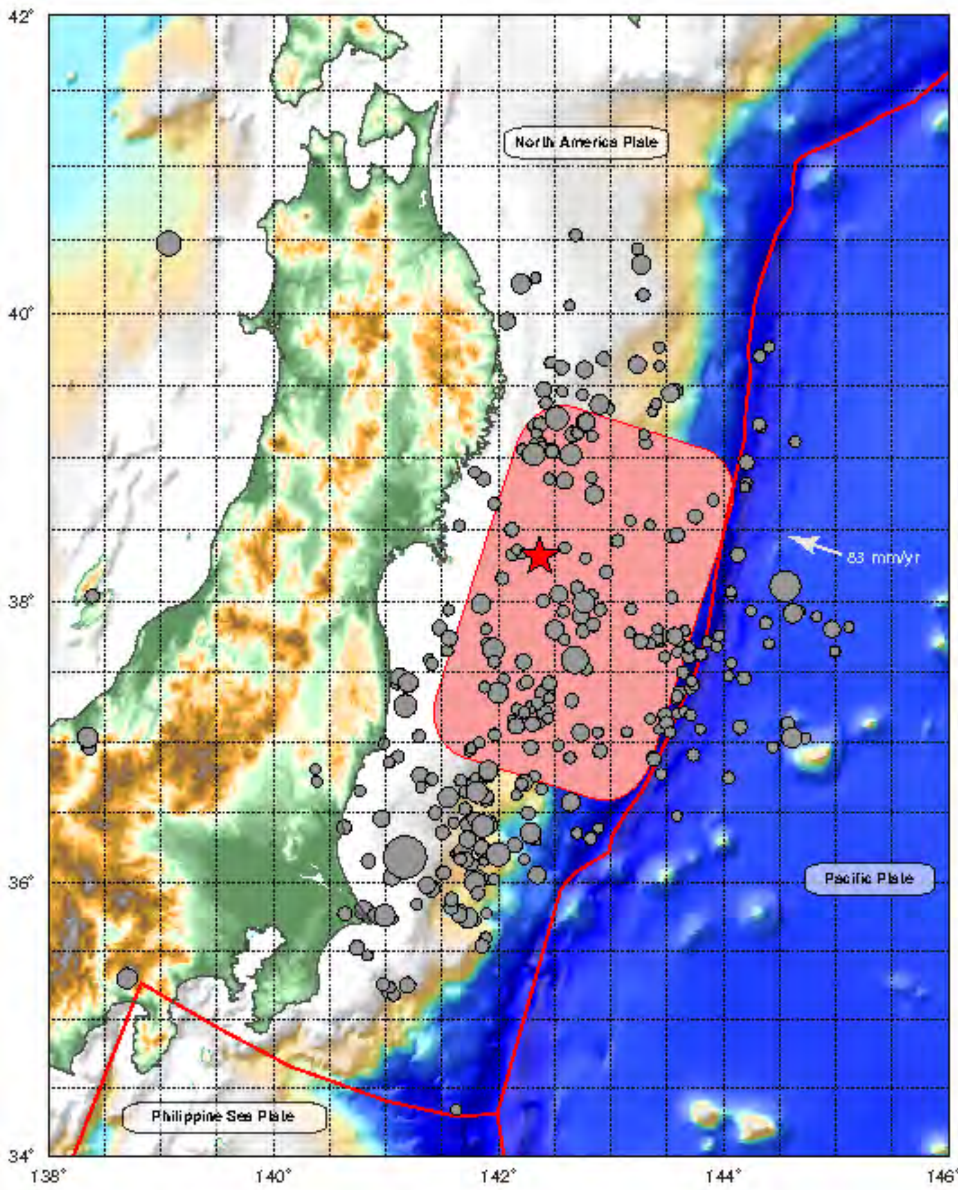
Earthquakes

- We feel the waves, or vibrations, produced by elastic rebound
- Plate tectonic forces stress the rocks causing them to deform or strain
- The lithosphere deforms elastically at first, but eventually breaks → brittle deformation
- Stored elastic energy is released and the deformed rocks rebound to their original state.....but the two sides of the fault have moved (slip along the fault)!

Fault rupture, epicenter, hypocenter



11 March 2011 Tohoku, Japan Earthquake

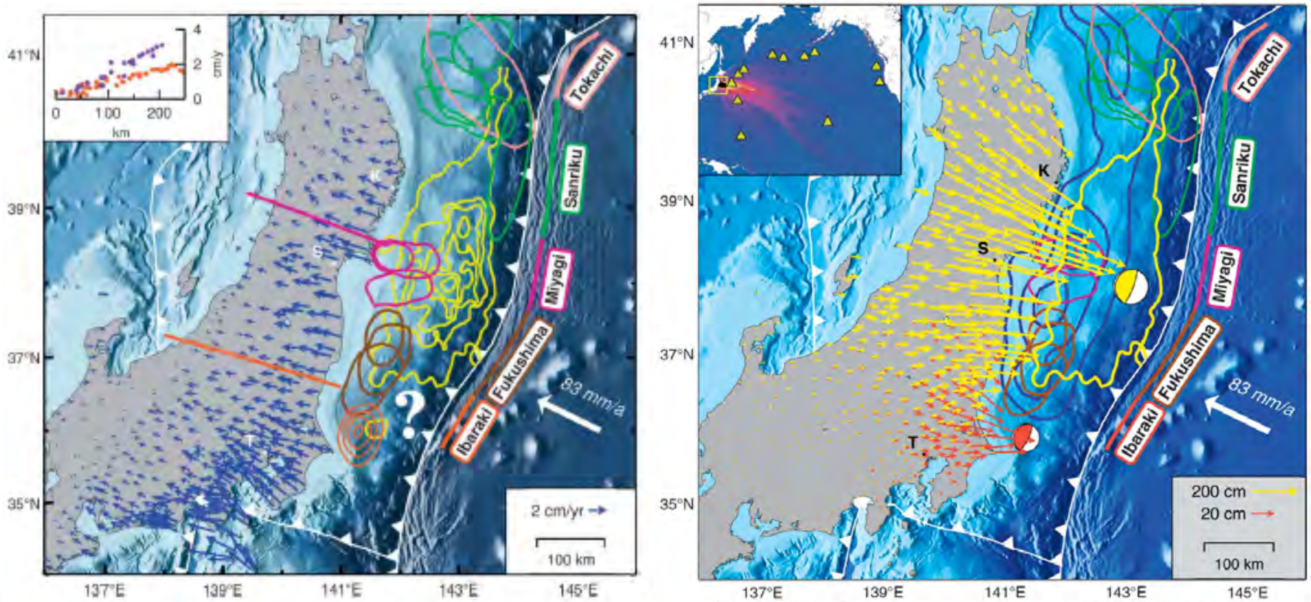


Approximate Rupture Zone

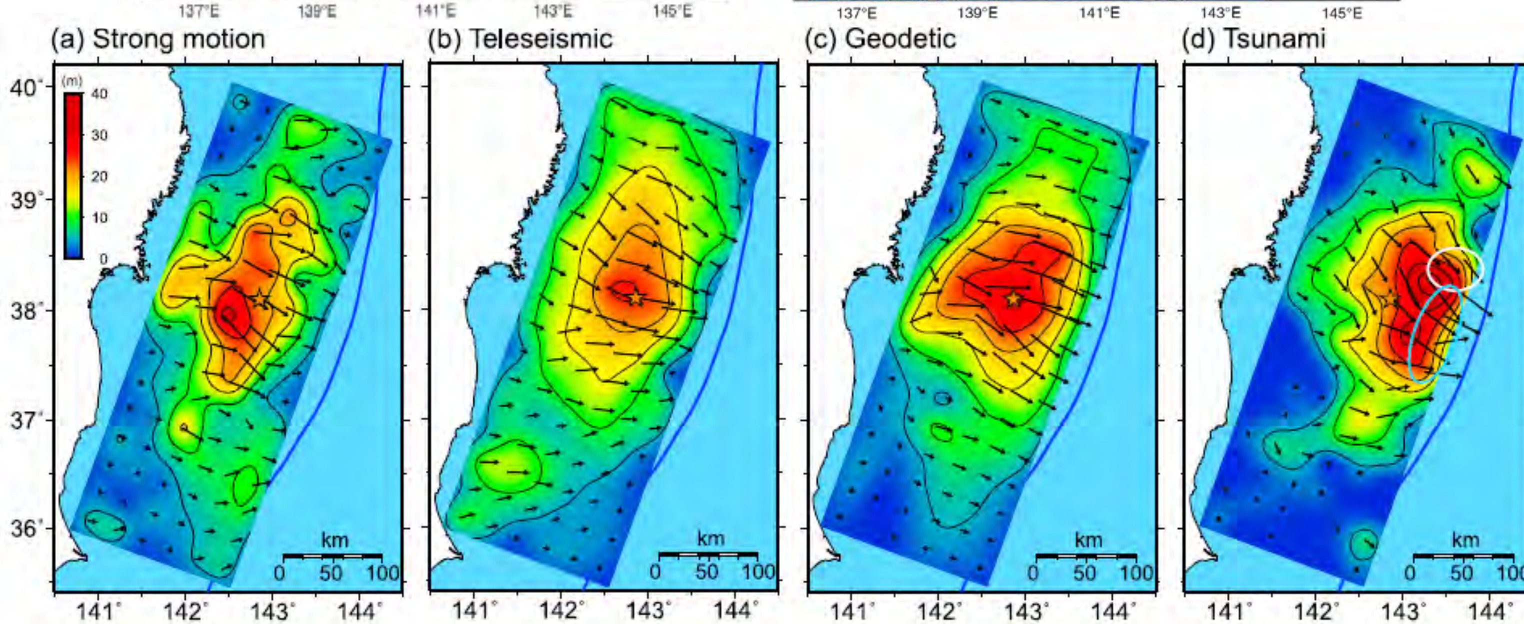
USGS

Pre-EQ GPS

After EQ



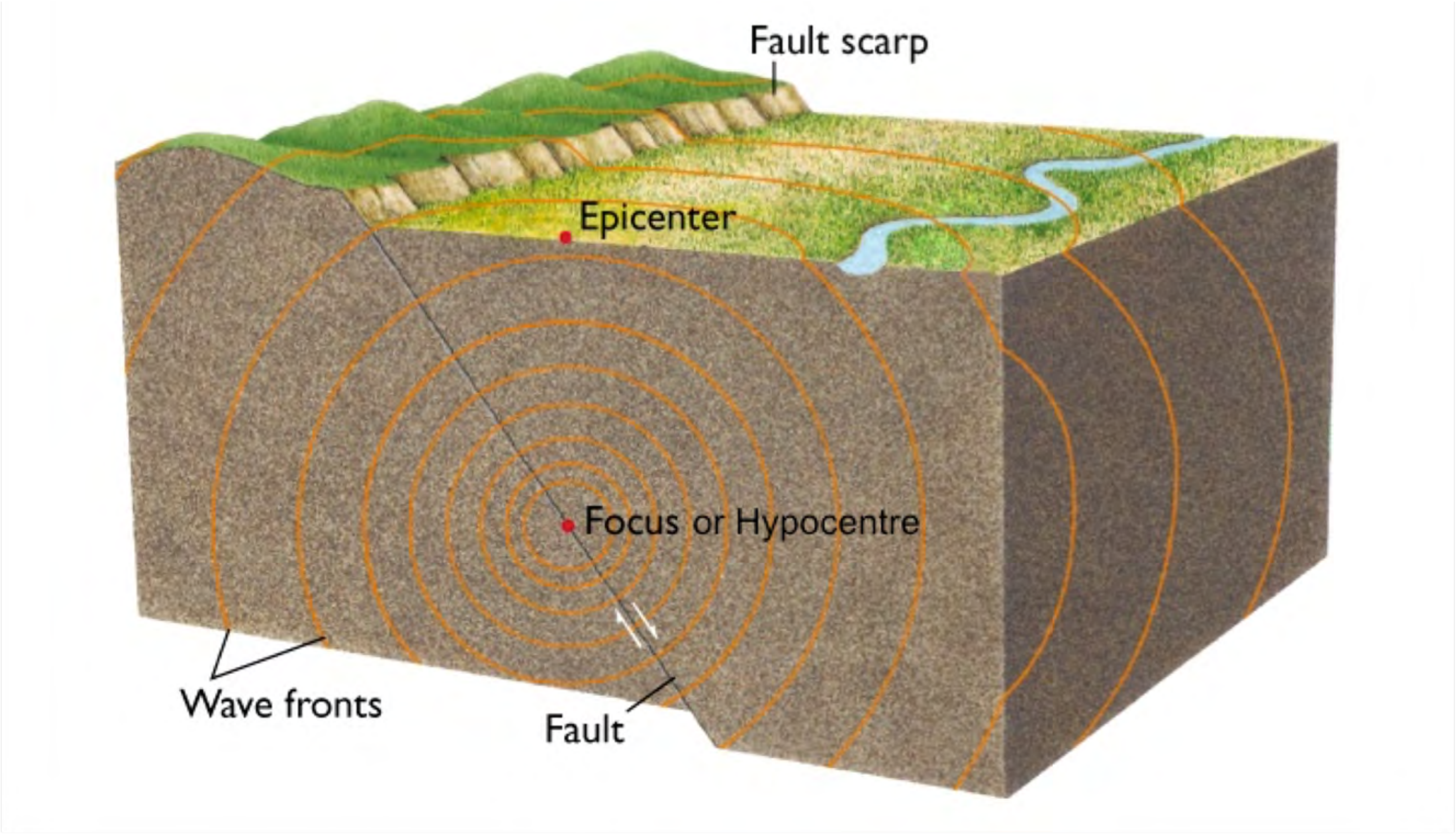
Simons et al. (2011)



Inferred distribution of slip for the great 11 March 2011 Tohoku Earthquake based on inverting four different data sets (Yokota et al., 2011)

Earthquakes

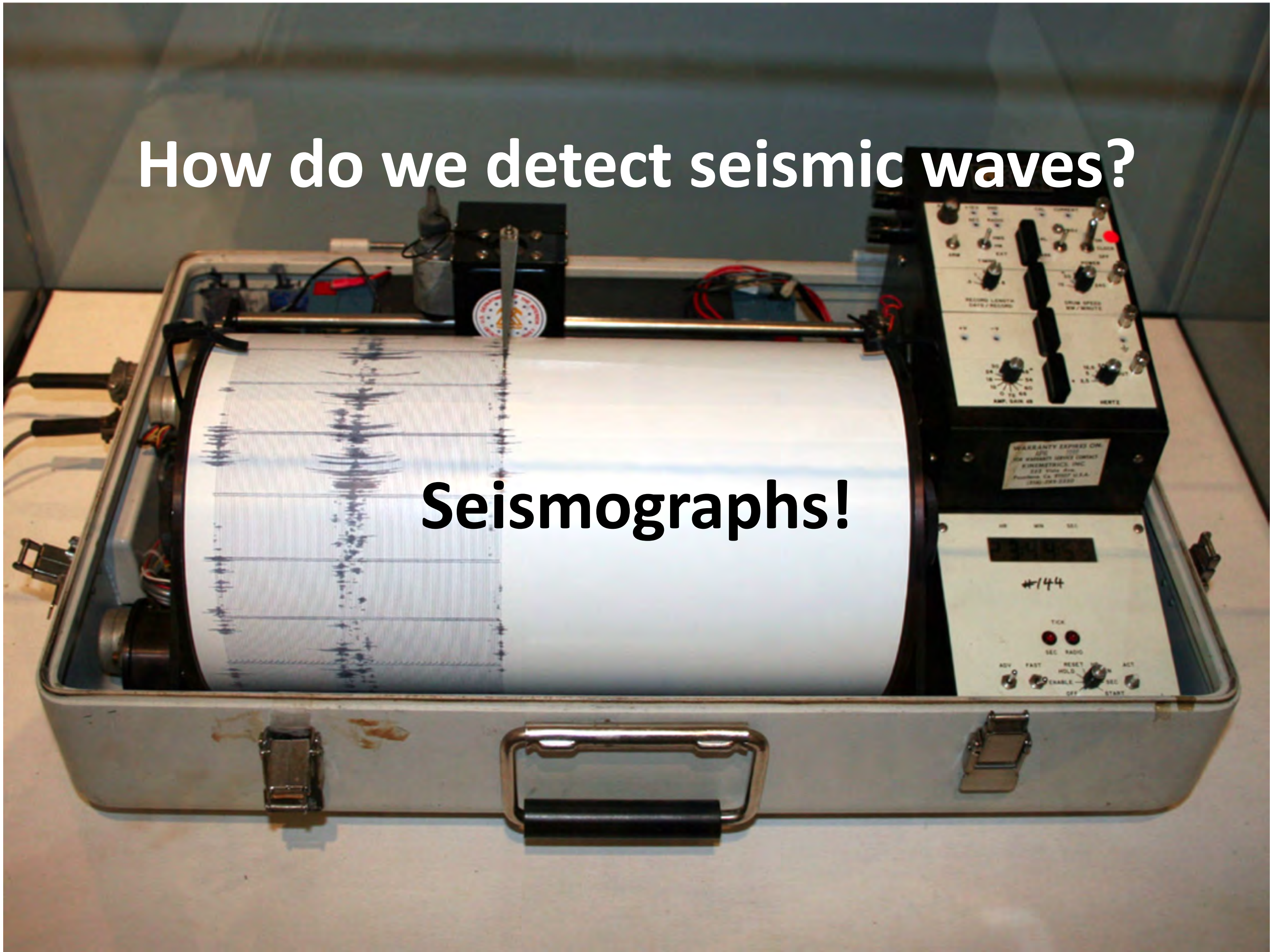
Brittle crust ruptures at the hypocentre
Elastically deformed crust rebounds and vibrates
Waves propagate in all directions (approximately spherical wave fronts)



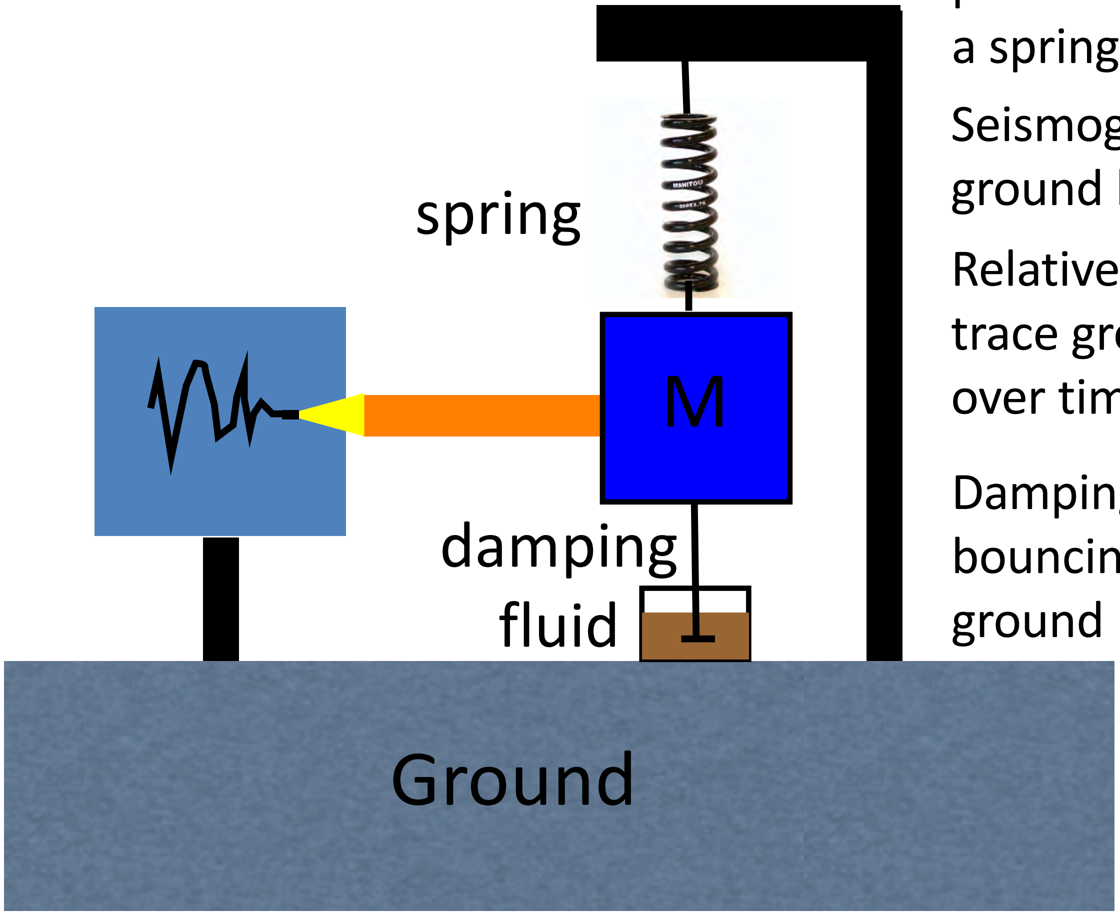
Earthquakes

- Rupture of rocks (usually along a pre-existing fault plane)
- Waves (energy) propagate away from the rupture point
- We feel the seismic waves
- Different types of seismic waves

Utility of Seismic Waves



Seismographs: the basic idea



Vertical seismograph

Heavy mass (shown here with pencil attached) is suspended by a spring.

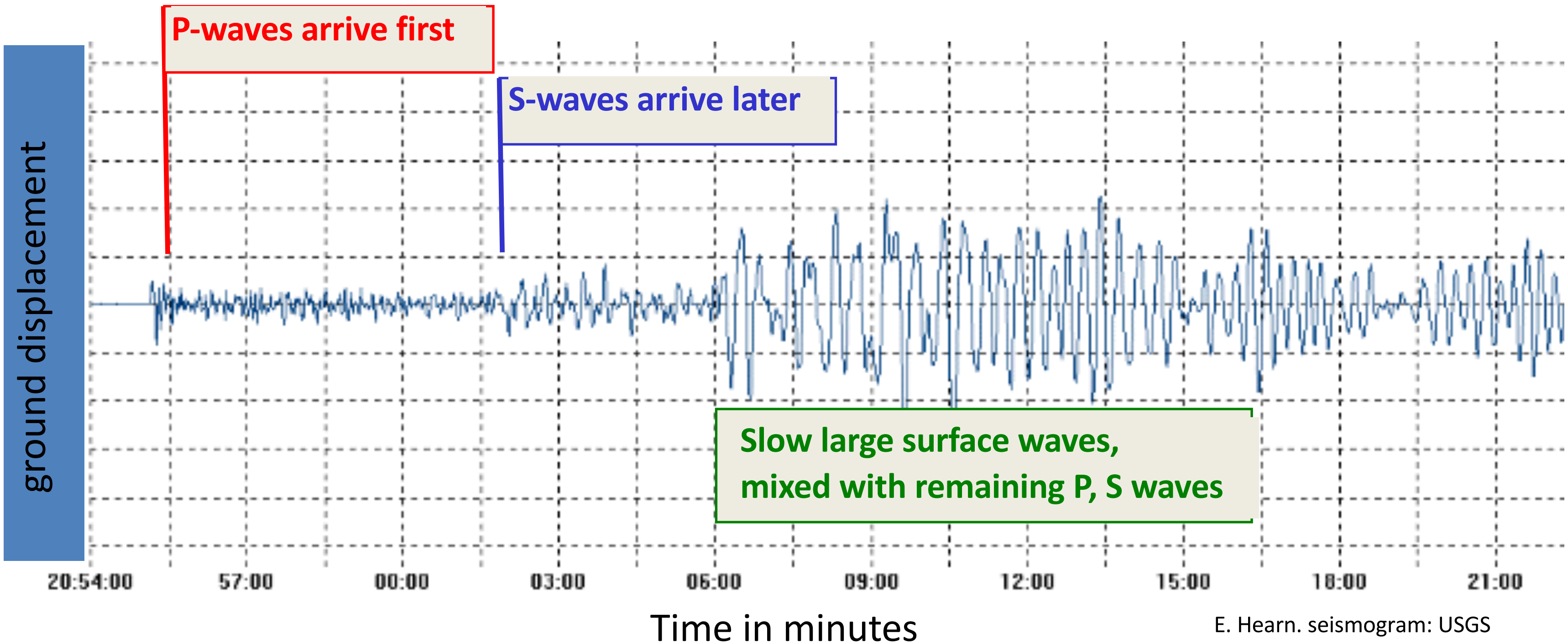
Seismograph moves with the ground but the mass stays put.

Relative motion causes pen to trace ground displacement over time.

Damping fluid stops mass from bouncing around after the ground has stopped shaking.

http://www.youtube.com/watch?v=DX5VXGmdnAg&NR=1

Analyzing a seismogram

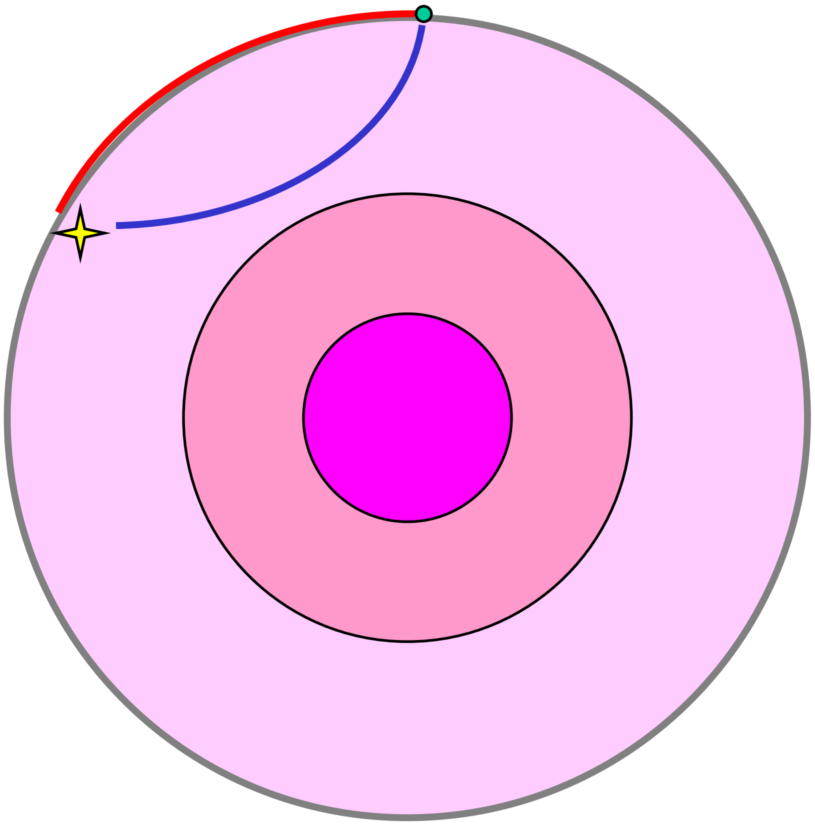


E. Hearn. seismogram: USGS

Seismic Waves

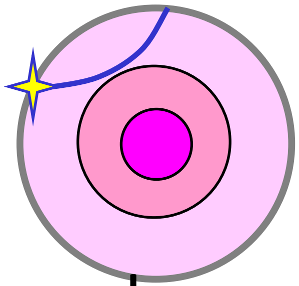
Body waves travel inside materials (the Earth)

Surface waves travel along boundaries between materials

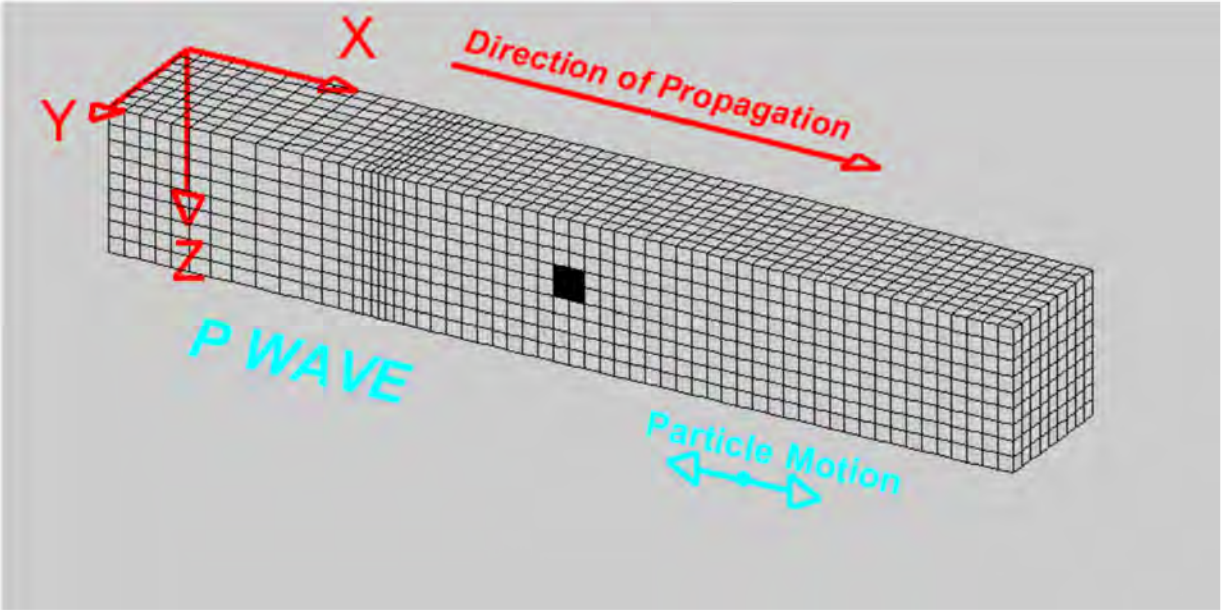


P wave (Primary wave)

body waves



- Compression and extension of the solid (or fluid), like a sound wave
- Particles move in same direction wave propagates
- Fastest type of seismic wave: about 6 km/second in continental crust



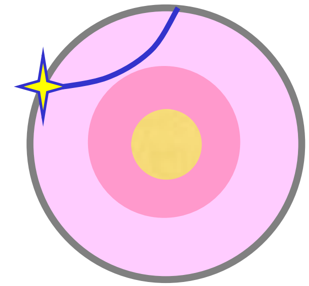
http://web.ics.purdue.edu/~braile/edumod/waves/WaveDemo.htm

Larry Braile

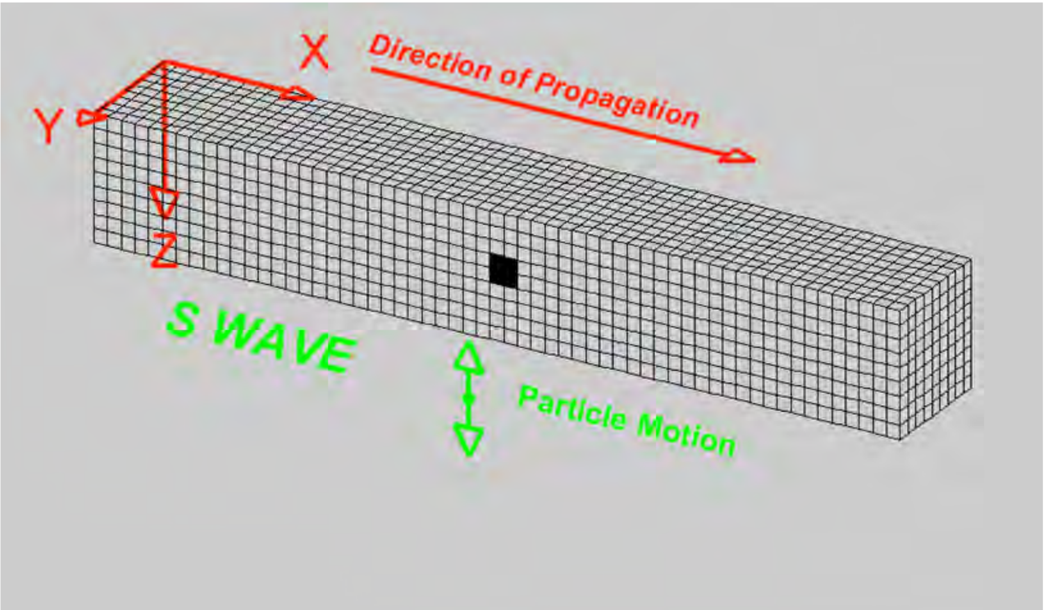
http://web.ics.purdue.edu/~braile/edumod/waves/Pwave.htm

S wave (Secondary wave)

body waves



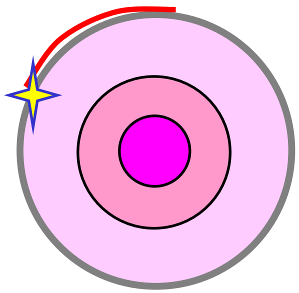
- Shearing distortion of the solid
- Particles move perpendicular to the direction of wave propagation
- Slower than P wave: about 3.5 km/second in continental crust. Cannot pass through fluids!



Larry Braile

http://web.ics.purdue.edu/~braile/edumod/waves/Swave.htm

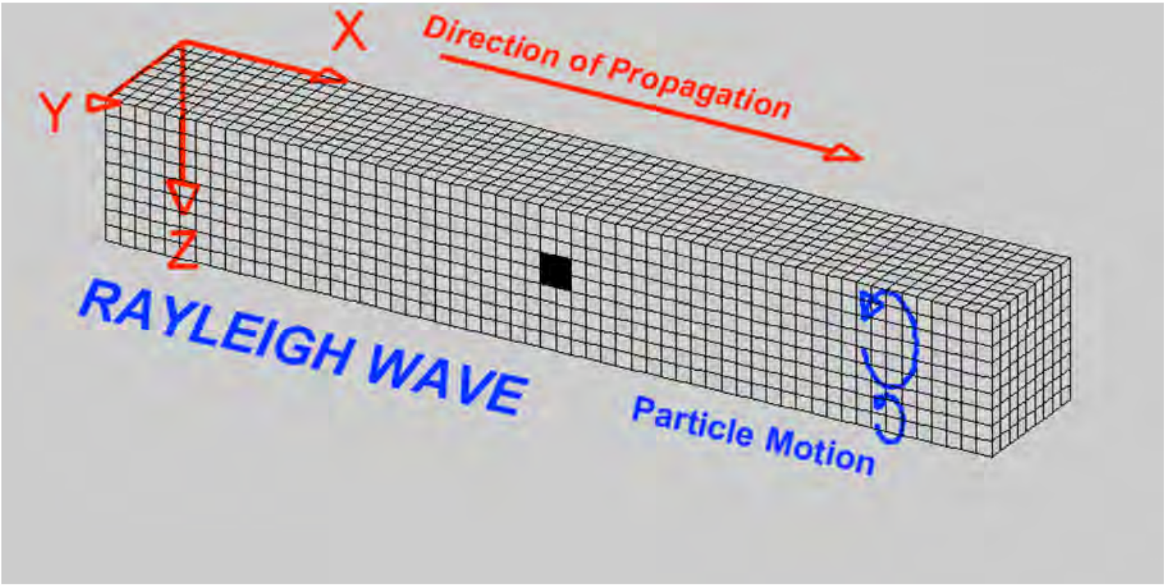
Surface waves - 1



- Require an interface: ground-air, water-air, mantle-liquid outer core

- Slower than body waves

- **Rayleigh wave**: vertical and horizontal motion parallel to wave travel direction (like an ocean wave)



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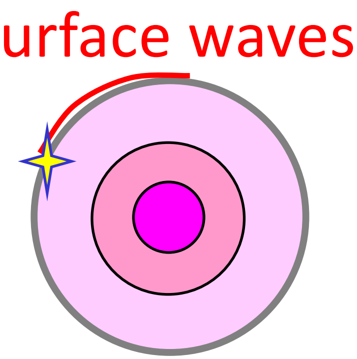
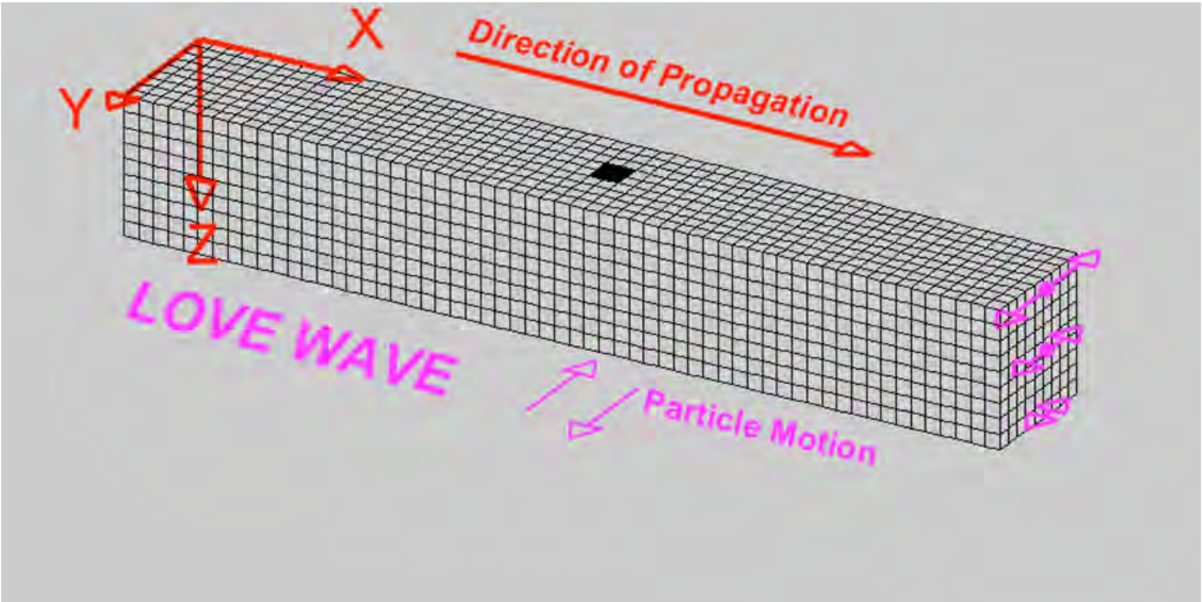
http://web.ics.purdue.edu/~braile/edumod/waves/Rwave.htm

Surface waves - 2



- **Love wave**: horizontal movement perpendicular to wave travel direction•



Larry Braile

http://web.ics.purdue.edu/~braile/edumod/waves/Lwave.htm

Activity – seismicity race!

- Everyone in an aisle seat stand up
- Work as a team
- First be P-wave
- Now be a S-wave
- Now for the race!!!

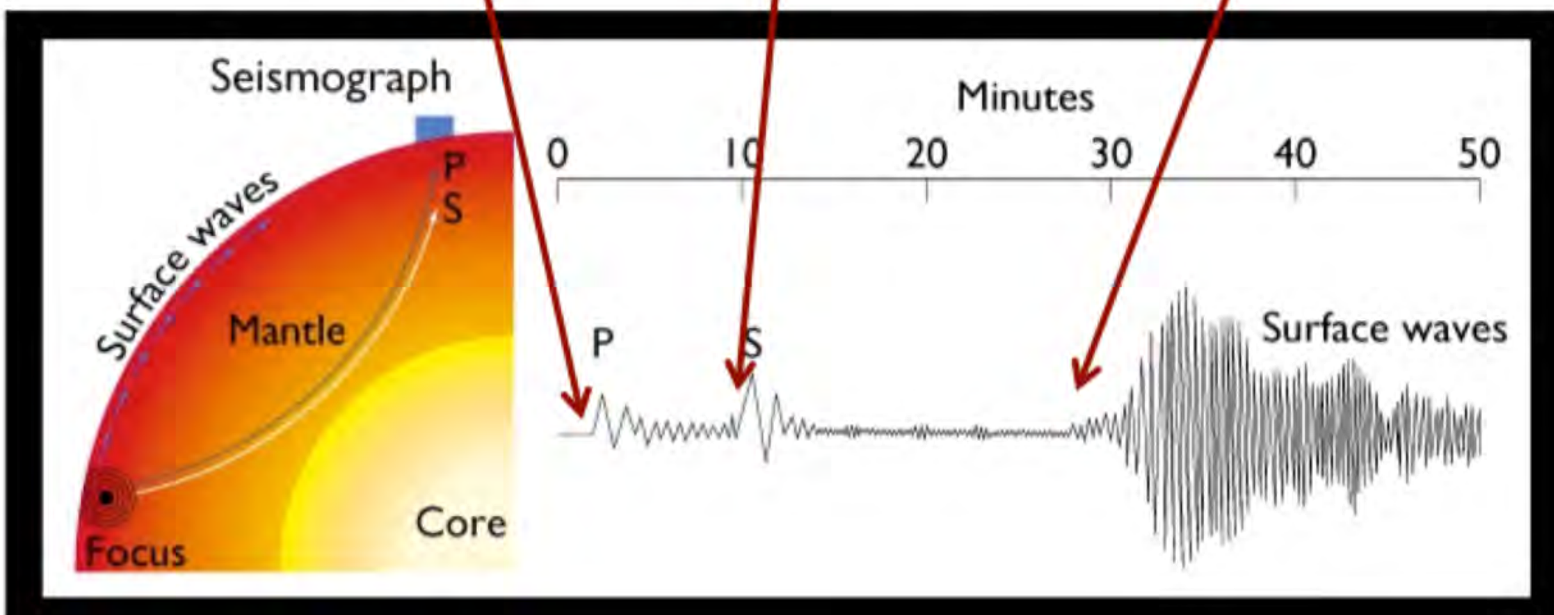
Seismic Waves

Seismic wave speeds

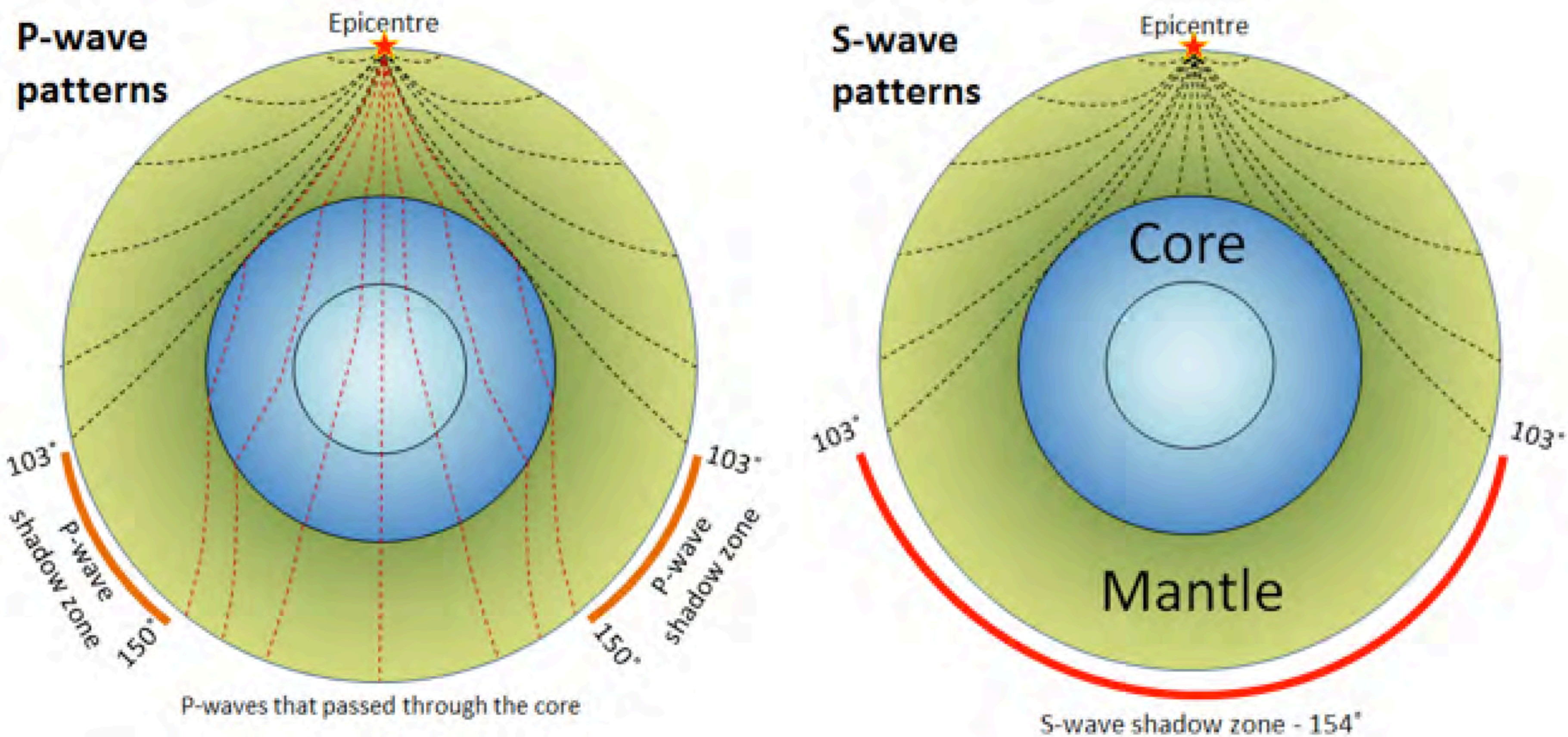
P waves fastest
~6 km/s in upper crust

S waves slower
~3.5 km/s in upper crust

Surface waves
Even slower
~2-3 km/s



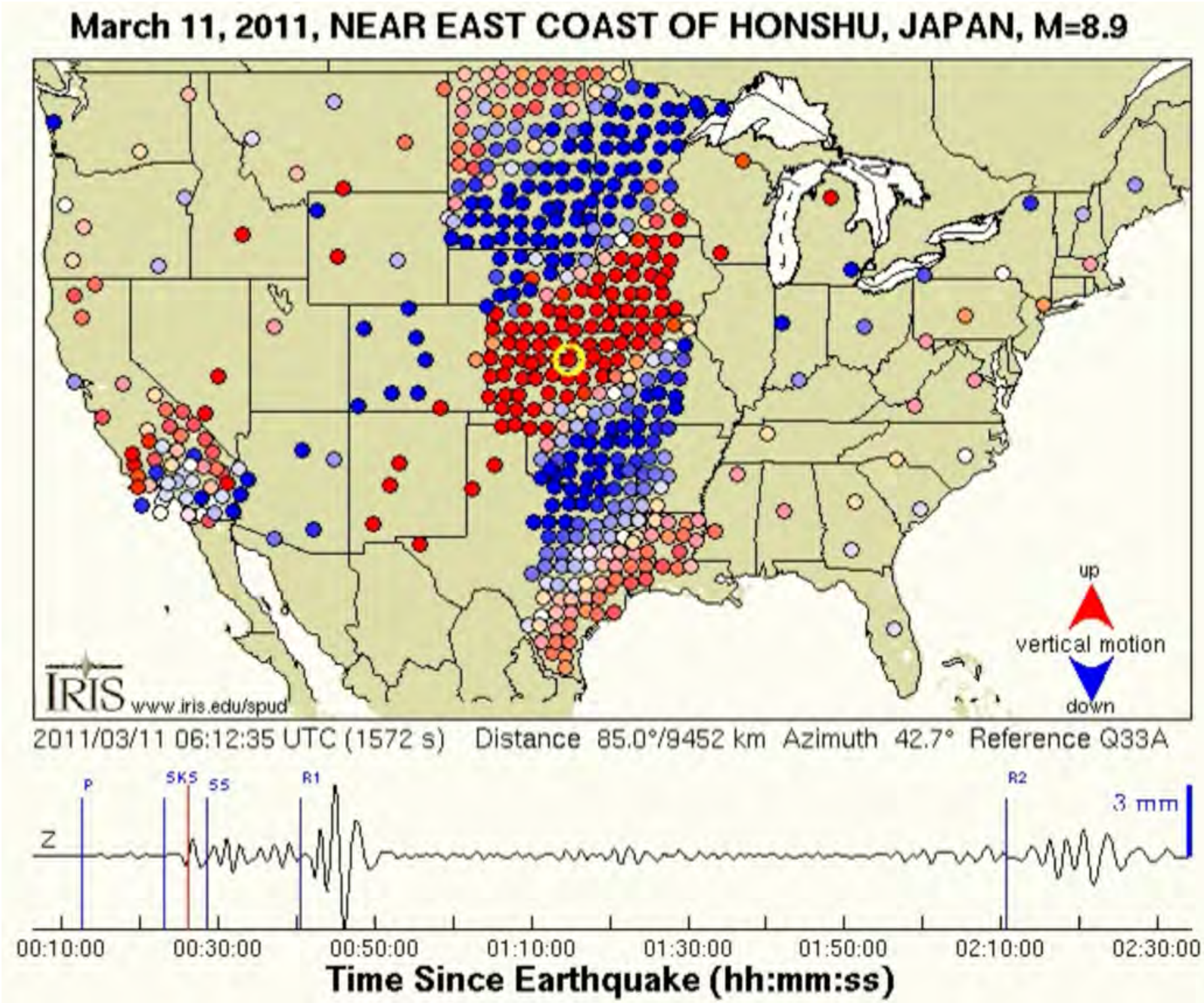
S-waves do not travel through liquid



→ Outer core must be liquid!

Source: Panchuk (2019) Textbook
Earle (2016) CC BY 4.0

Actual ground movement



http://ds.iris.edu/spud/gmv/4841

For those who like equations (we won't ask this on an exam)

The factors that control why P and S waves travel at different speeds and why S waves can't travel through liquids

Speed depends on the material properties

1) compressibility (K) ← volume change
2) rigidity (μ) ← bending
3) density (ρ) ← related to temperature and pressure

P Waves
Compression and Bending

$$V_p = \left(\frac{K + \frac{4}{3}\mu}{\rho} \right)^{\frac{1}{2}}$$

S Waves
Bending

$$V_s = \left(\frac{\mu}{\rho} \right)^{\frac{1}{2}}$$

$\mu = 0$ **for fluids**

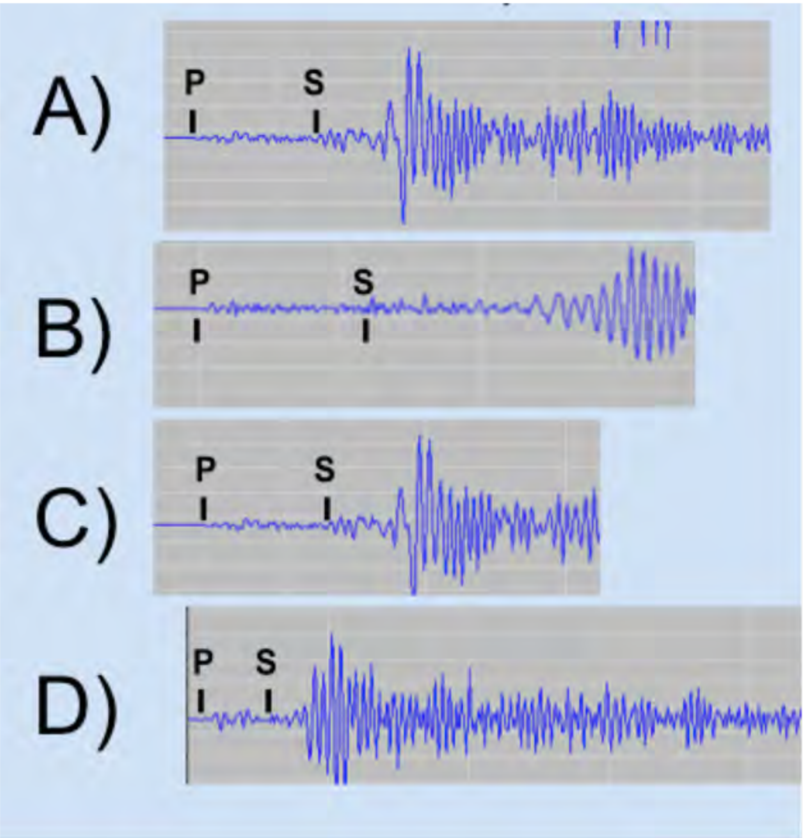
Can't 'bend' a liquid!

$$V_p > V_s$$

fastest slowest

Clicker Question?

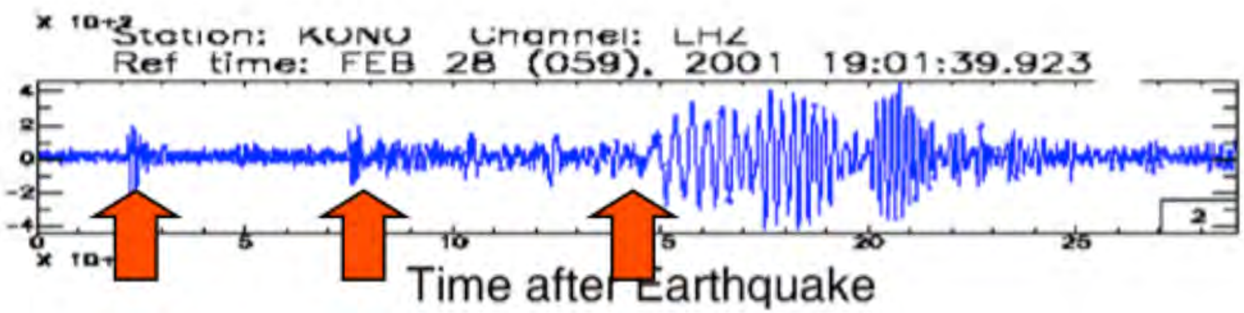
Seismic waves can travel through and around the entire planet. Take a look at these seismographs all recording the same earthquake.
Which of these was recorded at a location furthest from the earthquake hypocentre?



Understanding Seismic Waves

Nisqually Earthquake (Feb. 28, 2001)
Magnitude 6.8, Depth 52.4 km

The S waves come well after P waves…
Then the slower surface waves roll in.



P **S** **Surface**

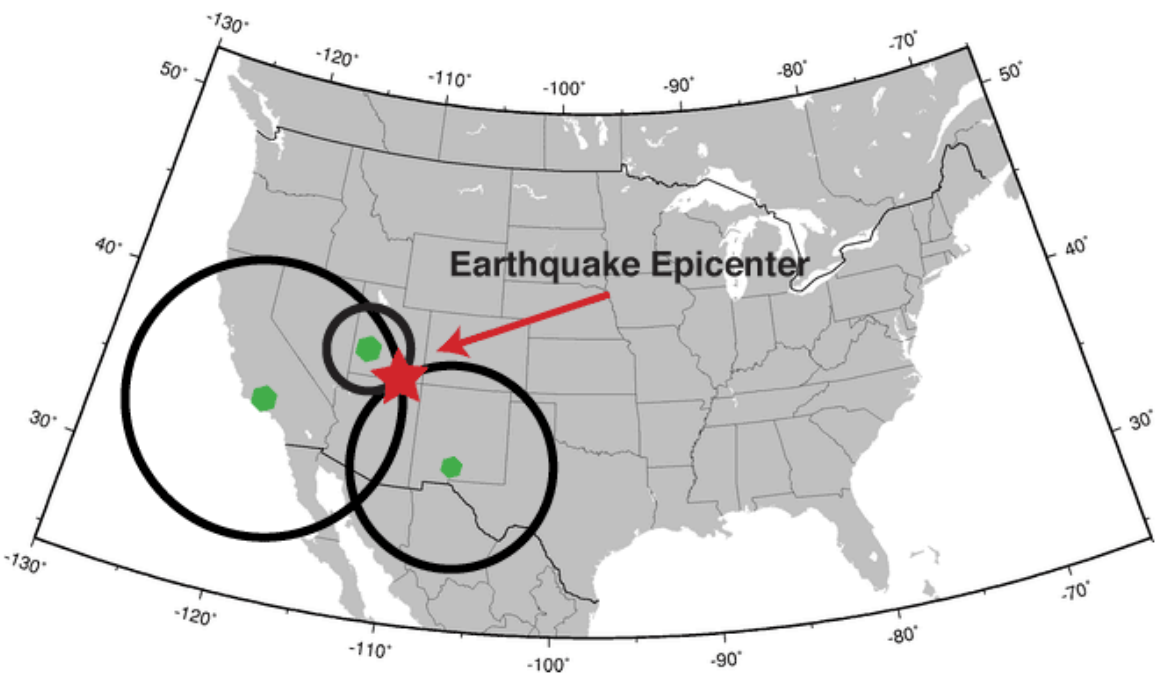
A big quake off our coast may have a ~50 second gap between the arrival of the P and S waves

Locating earthquakes

P waves travel faster than S waves

P-S ***lag*** time→ distance from seismograph to earthquake

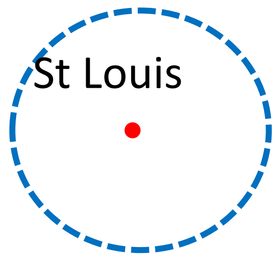
Three seismograph stations allow us to triangulate earthquake epicenter!



USGS

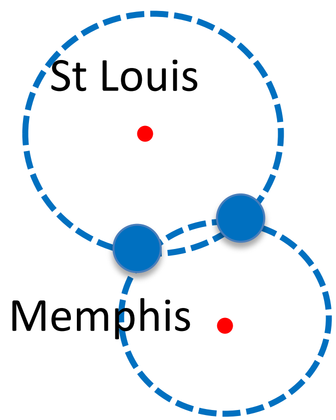
Locating earthquakes

With one seismograph station we know how far away the quake is but not where it is or even what direction the waves came from



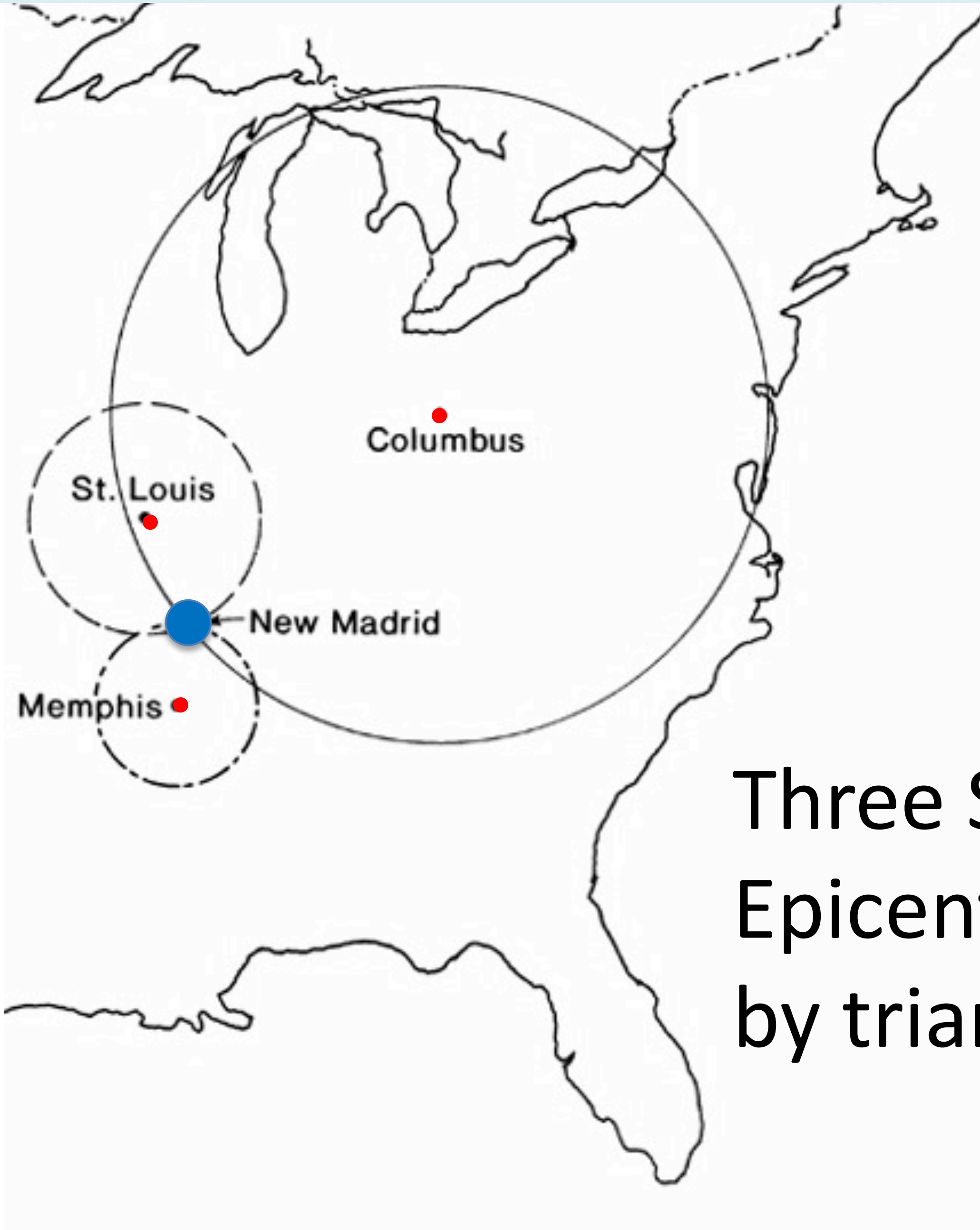
Epicentre could be anywhere on blue circle

Distances calculated from two stations will give us two possible points:



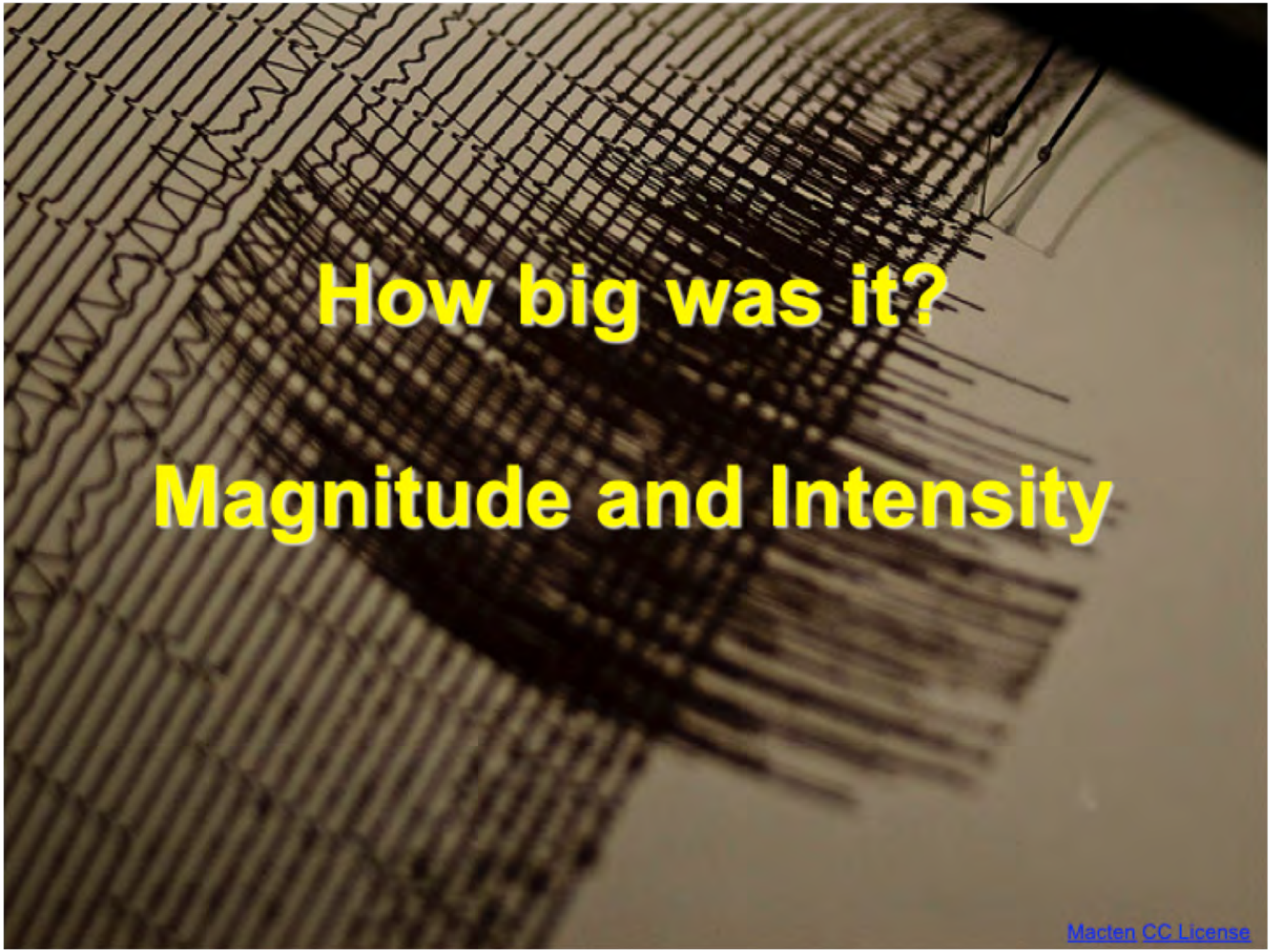
Epicenter could be at either blue dot

Where was the epicenter?



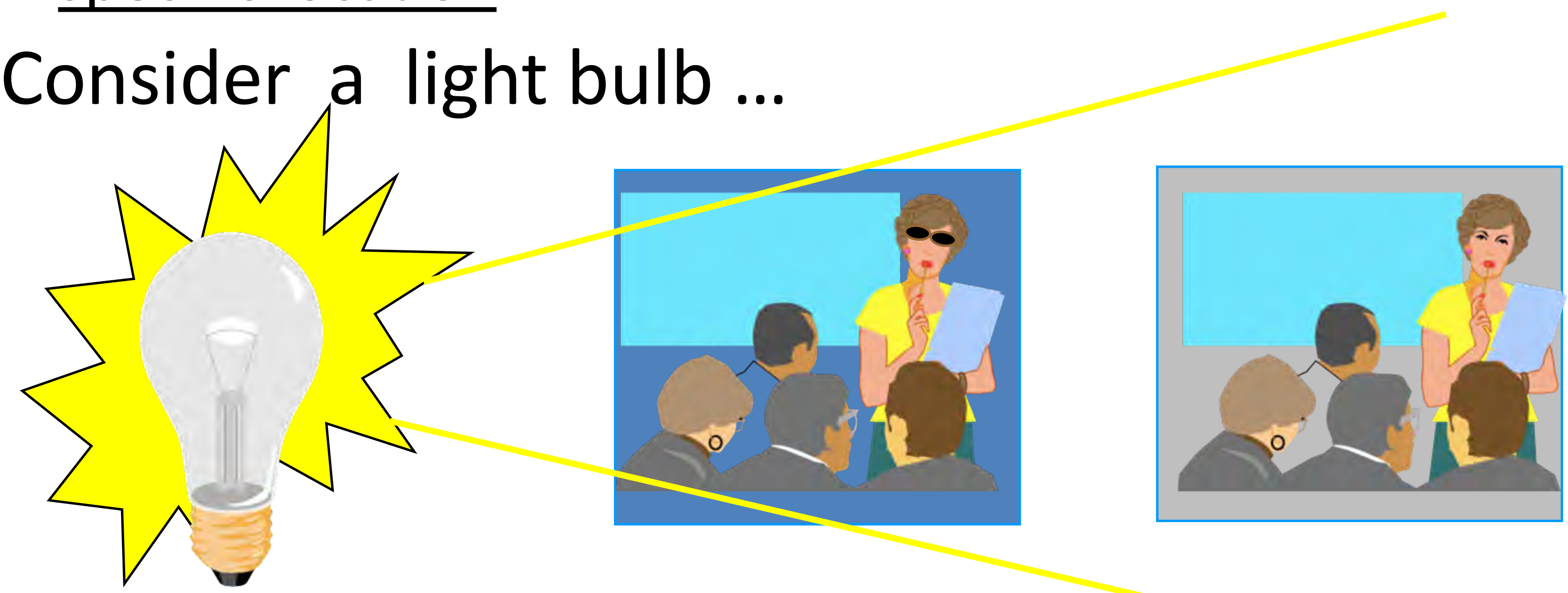
Three Stations =
Epicenter location
by triangulation!

Earthquake “size”



How big was the earthquake?

- Distinguish between *magnitude* and *intensity*
  - **Magnitude** = how much energy was released.
  - **Intensity** = how strong the ground motion is <u>at a specific location</u>.
- Consider a light bulb ...



Fixed magnitude

Close to light bulb
High intensity

Far from light bulb
Low intensity

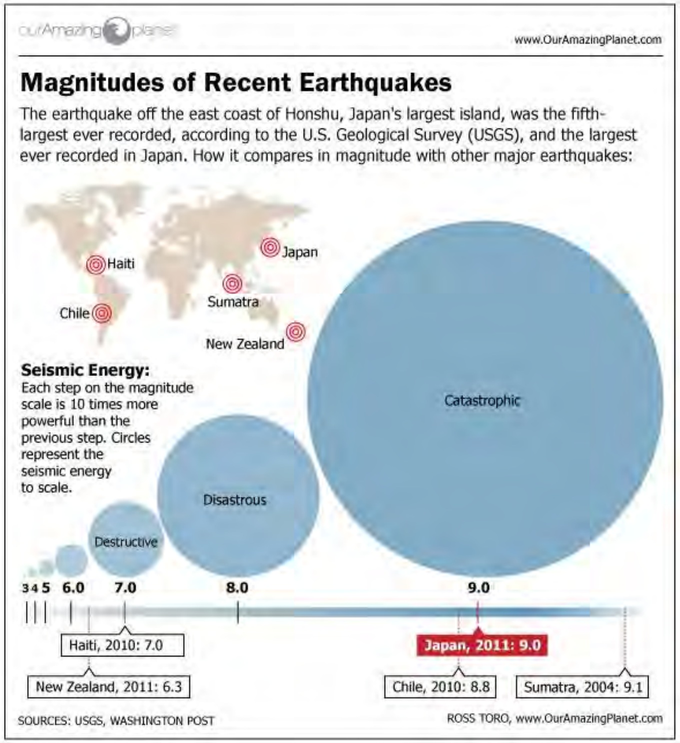
Earthquake Magnitude

A **quantitative** measure of the energy release by the earthquake

Richter Magnitude has been replaced by
Moment Magnitude Scale (Mw)

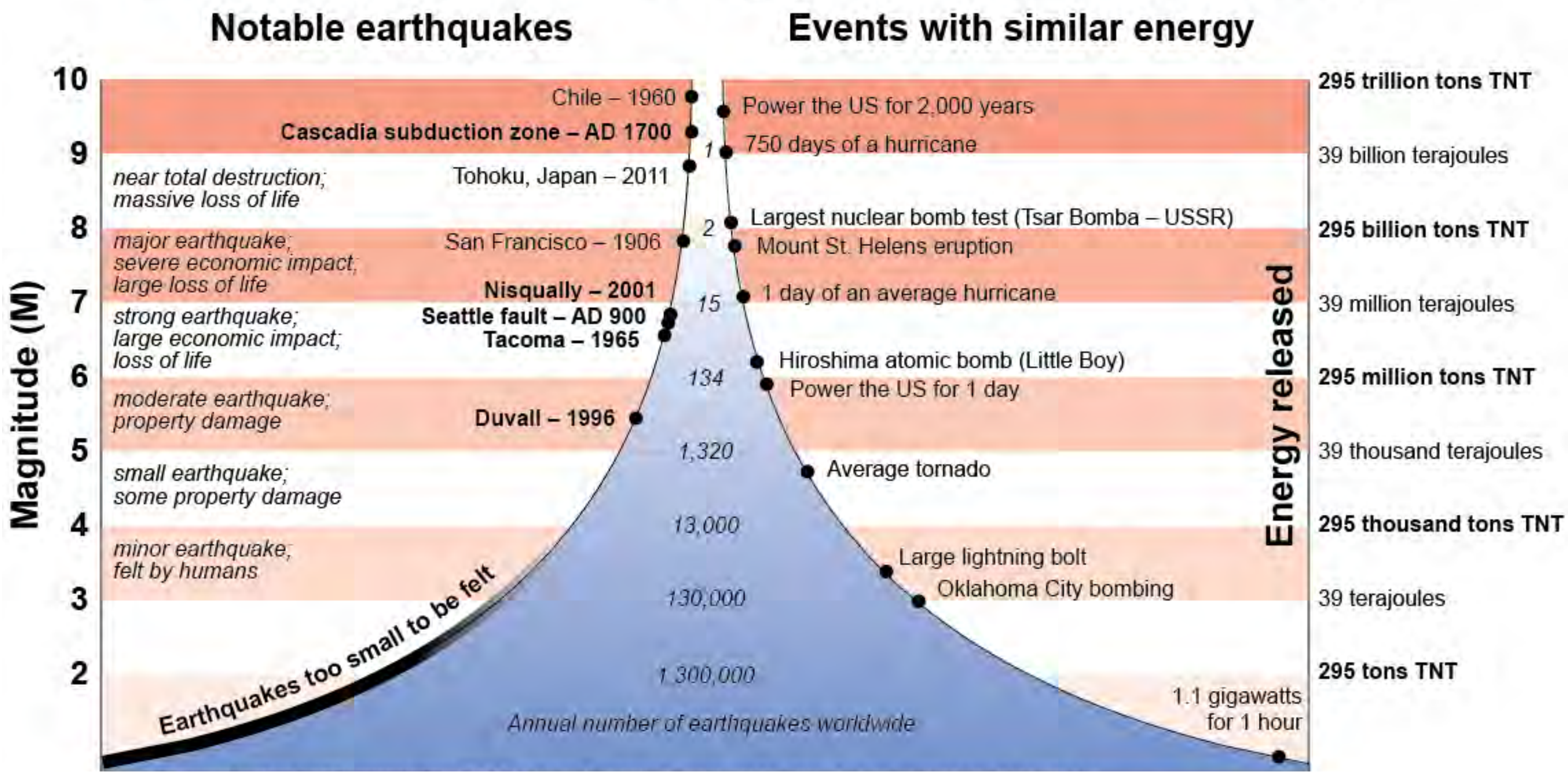
energy released =
strength of rock
x area of fault that moved
x how much it moved

As Mw increases, the earthquake:
- Affects a broader region
- Shakes the ground for longer
- Causes more damage!



Log scale – An increase of one unit on the Magnitude (Mw) scale equates to 10 times more **shaking** (10^1) and about 32 times more **energy released** ($10^{1.5}$)

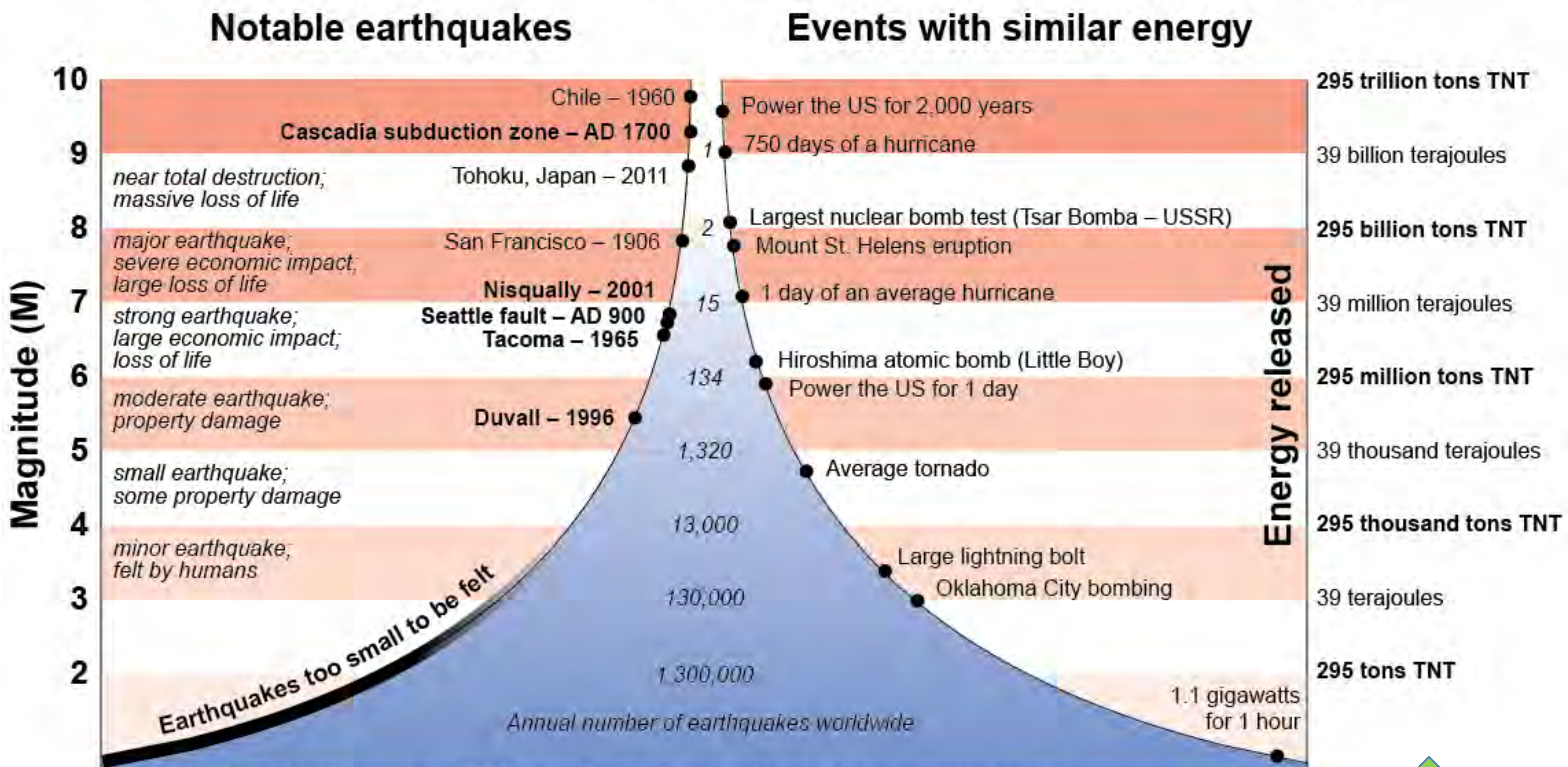
Earthquake energy and frequency



- Huge range in energy released requires using a logarithmic scale
- Very few large earthquakes, huge number of small earthquakes

http://www.dnr.wa.gov

Earthquake energy and frequency



10-fold increase in ground shaking for every step in magnitude

32-fold increase in energy released for every step in magnitude

Top 10 Deadliest Earthquakes since 2000

Rank	Fatalities	Magnitude	Location	Event	Date
1	227,898	9.1–9.3	Indonesia, Indian Ocean	2004 Indian Ocean earthquake and tsunami	December 26, 2004
2	160,000[3]	7.0	Haiti	2010 Haiti earthquake	January 12, 2010
3	87,587	7.9	China	2008 Sichuan earthquake	May 12, 2008
4	87,351	7.6	Pakistan	2005 Kashmir earthquake	October 8, 2005
5	59,259	7.8	Turkey, Syria	2023 Turkey–Syria earthquakes	February 6, 2023
6	34,000[4]	6.6	Iran	2003 Bam earthquake	December 26, 2003
7	20,085	7.7	India	2001 Gujarat earthquake	January 26, 2001
8	19,759	9.0–9.1	Japan	2011 Tōhoku earthquake and tsunami	March 11, 2011
9	8,964	7.8	Nepal	2015 Nepal earthquake	April 25, 2015
10	5,782	6.4	Indonesia	2006 Yogyakarta earthquake	May 26, 2006

Wikipedia

Clicker Question?

How much more ground motion (shaking side-side or up-down) does a Mw = 9 earthquake cause when compared to a Mw = 7 earthquake?

A) 0.1 times
B) 1 times
C) 10 times
D) 100 times
E) 1000 times

Clicker Question?

A Mw = 8 earthquake releases approximately how much more **energy** than a Mw = 6 earthquake?

A) 2 times
B) 64 times
C) 100 times
D) 1000 times
E) 10,000 times

Clicker Question?

Which of the following affects the amount of damage to buildings during an earthquake?

A) Proximity to the earthquake hypocentre
B) Magnitude of the earthquake
C) Local geology
D) Design of the buildings
E) All of the above

Earthquake Intensity

Qualitative description of the impact of ground shaking on people and their surroundings.

We use the **Modified Mercali Scale** for earthquake intensity

Ranges from I (felt by very few or not at all) to XII (total destruction)

INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy

Earthquake Intensity

Earthquake intensity depends upon several factors:

1) **Earthquake Magnitude**

Lower magnitude = less intense

- Less energy, less powerful seismic waves

2) **Distance from epicentre**

Further away = less intense

- Seismic waves weaken with distance from earthquake

Modified Mercali Scale

Approximate Magnitude (Mw)

Intensity	**Effects**	
I	Felt by very few people	
II	Felt by only a few people at rest, especially on upper floors of buildings.	2
III	Felt noticeably. Vibration feels like the passing of a truck	3
IV	Sensation of a heavy truck striking a building	
V	Felt by nearly everyone; many people awakened	4
VI	Felt by all. Damage is slight	
VII	Almost everybody runs outdoors. Damage is negligible/moderate/considerable	5
VIII	Damage is slight/considerable	6
IX	Damage is considerable	
X	Most of buildings are destroyed. Underground pipes are broken.	7
XI	Few structures remain standing. Bridges are destroyed.	8
XII	Damage is total. Waves are seen on the ground surface.	

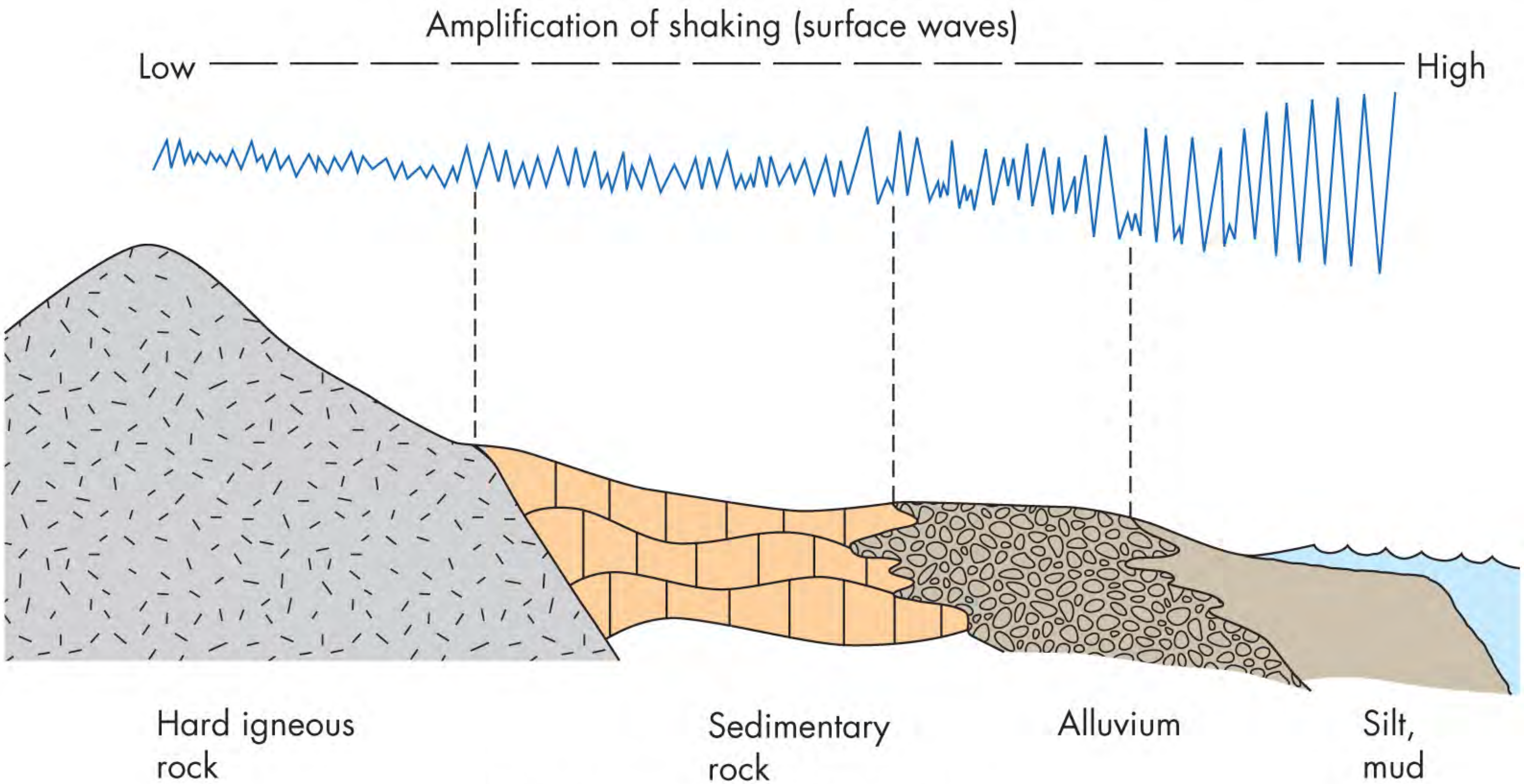
Earthquake Intensity

3) **Underlying geology / soil**

Bedrock = low amplification

Well compacted sediment = Moderate amplification

Water saturated sediment = ___________?



Earthquake Intensity

4) **Structural Resistance**

The resistance of a building or structure to ground motion

Building design

More resistant = less intense

5) **Duration**

How long does the ground shaking last?

Short duration = less intense

Long duration = more intense

- Shaking from a Mw 9 earthquake will last 4-5 minutes!

Central Italy
August 24, 2016
Mw 6.2

294 fatalities
Town of Amatrice destroyed

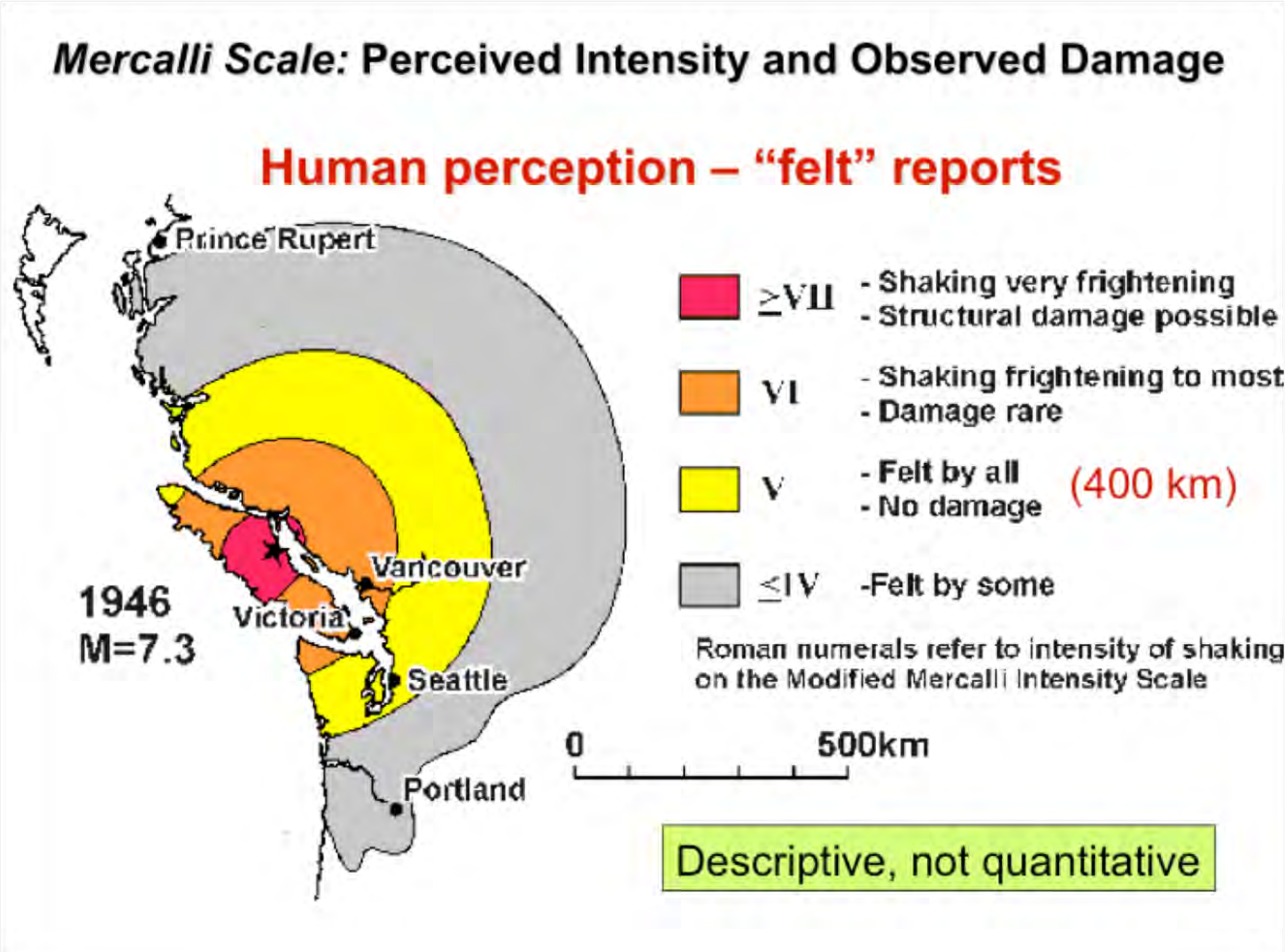
Estimated $11 billion
economic cost

Nisqually earthquake, Seattle - February, 2001 Mw = 6.8
Watch this and describe the intensity.

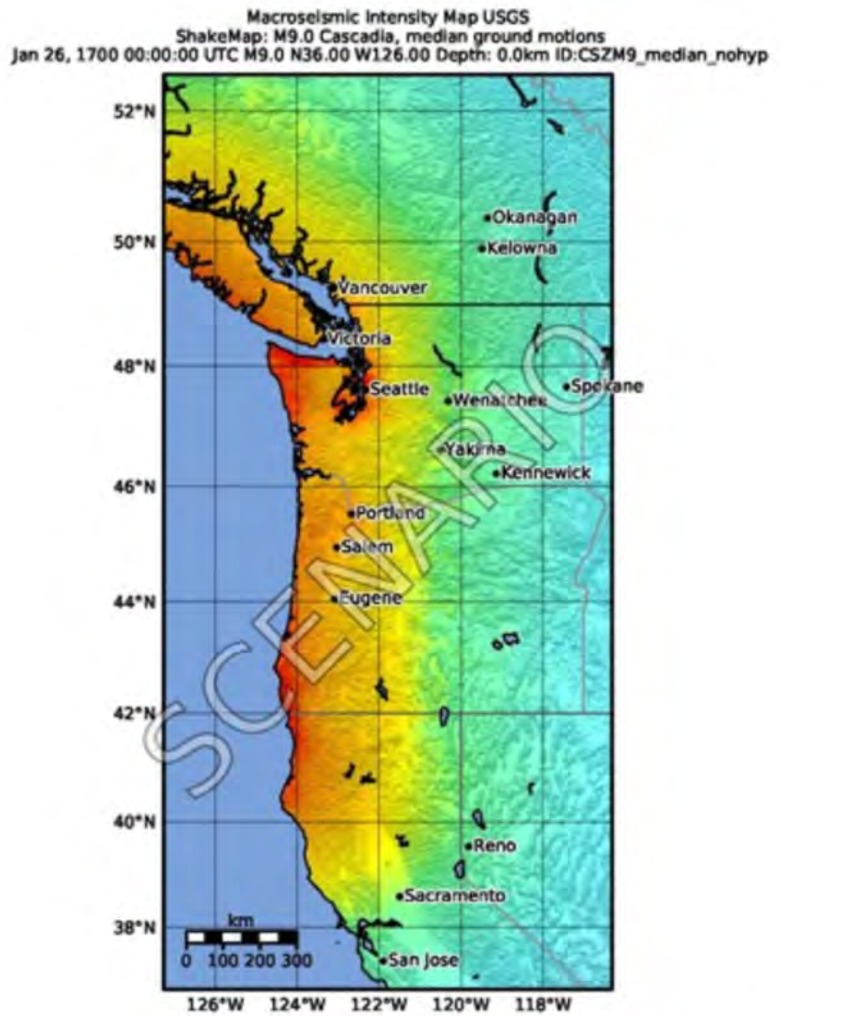
Seattle Quake | National Geographic

http://www.youtube.com/watch?v=V0WuSCaTYI0&hl

Earthquake Intensity



Earthquake Intensity – Mag 9



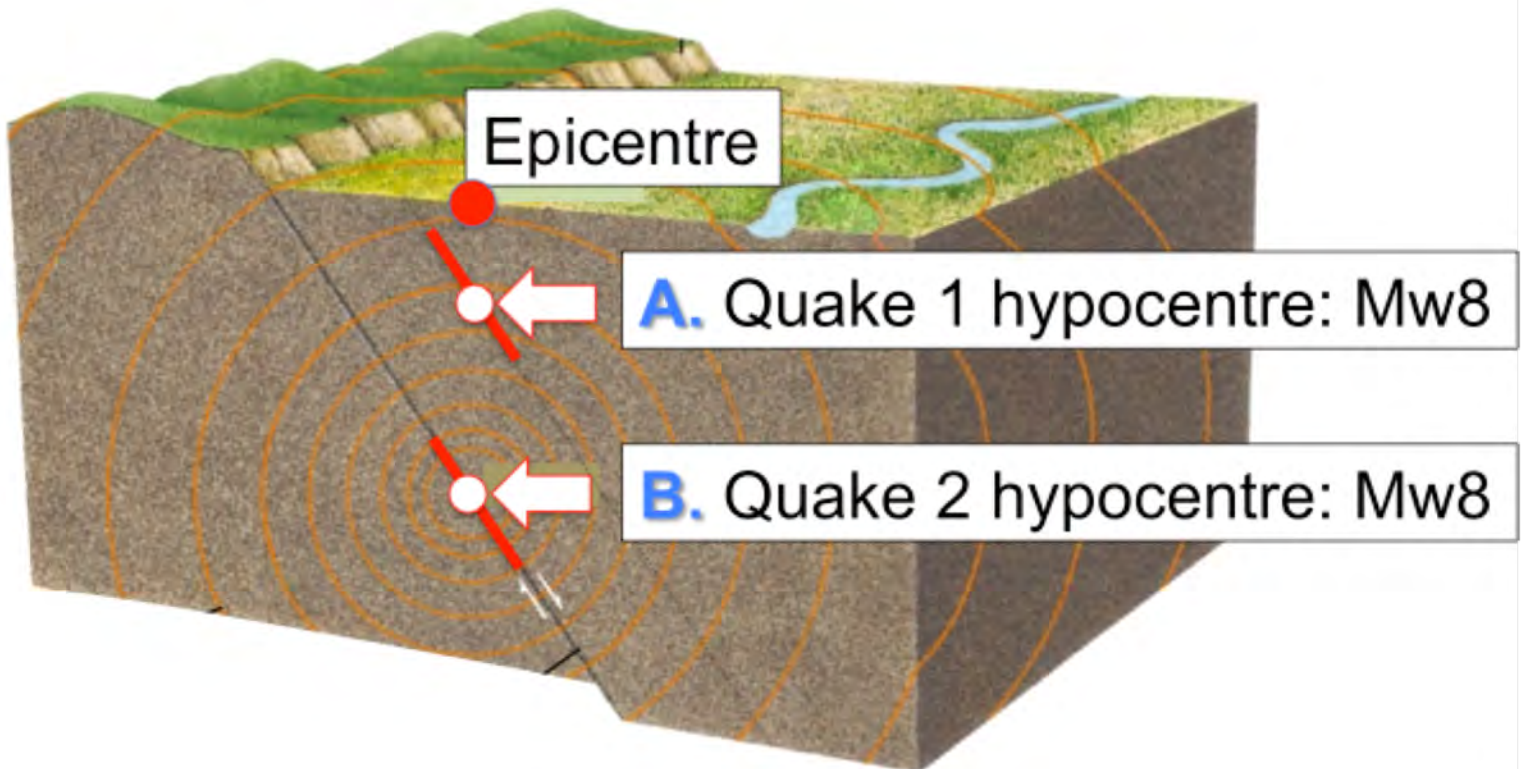
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.00661	0.0795	0.954	4.99	8.76	15.4	27	47.4	>83.2
PGV(cm/s)	<0.00280	0.0383	0.524	3.03	6.48	13.9	29.6	63.4	>136
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based on Atkinson and Kaka (2007)
Version 1: Processed 2020-11-15T02:19:47Z

Δ Seismic Instrument ○ Reported Intensity ★ Epicenter

Clicker Question?

Which earthquake would have a higher Mercalli 'Intensity'?



Next class:

Earthquake hazards and the situation here in Vancouver