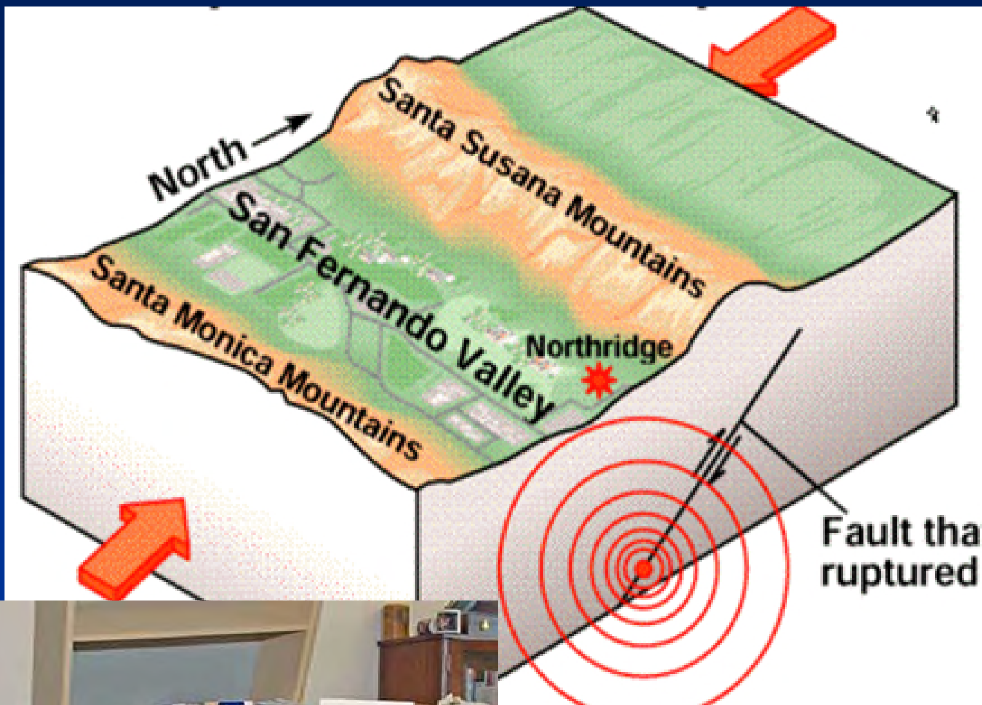
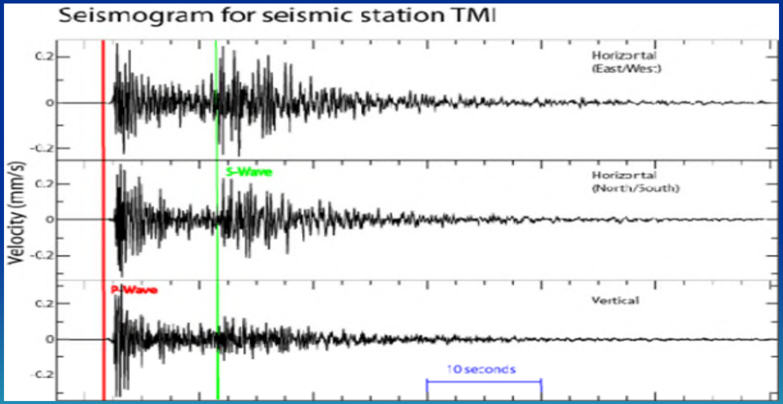
Earthquake!

Principles and Hazards





Physical Geology - GEOL 100

Ray Rector - Instructor

Earthquake Topics

What are Earthquakes?

Where and How do Earthquake Form?

What are the Types of Seismic Waves?

How are Earthquakes Measured?

What are the Effects of Earthquakes?

What are the Types of Seismic Hazards?

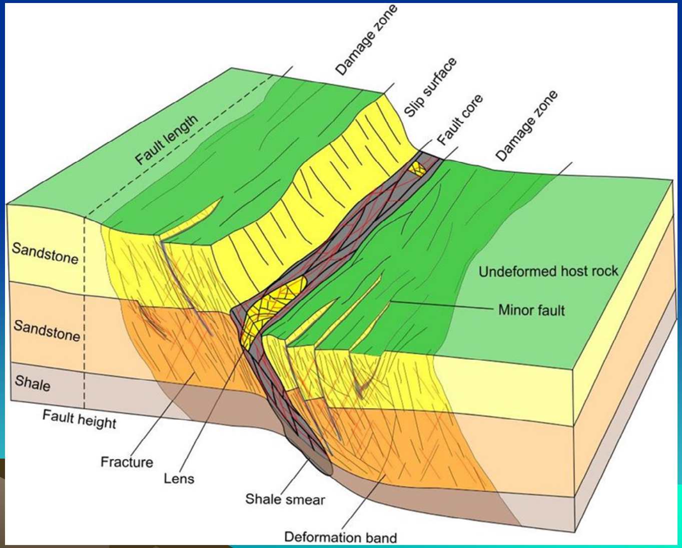
Can we Predict Earthquakes?

How Can We Prepare for an Earthquake?

Earthquakes Occur Along Active Fault Zones

1) Earthquakes are the instant release of built-up elastic strain energy (seismic waves) along faults in the crust as the result of fault rupture (rock fracture and offset)

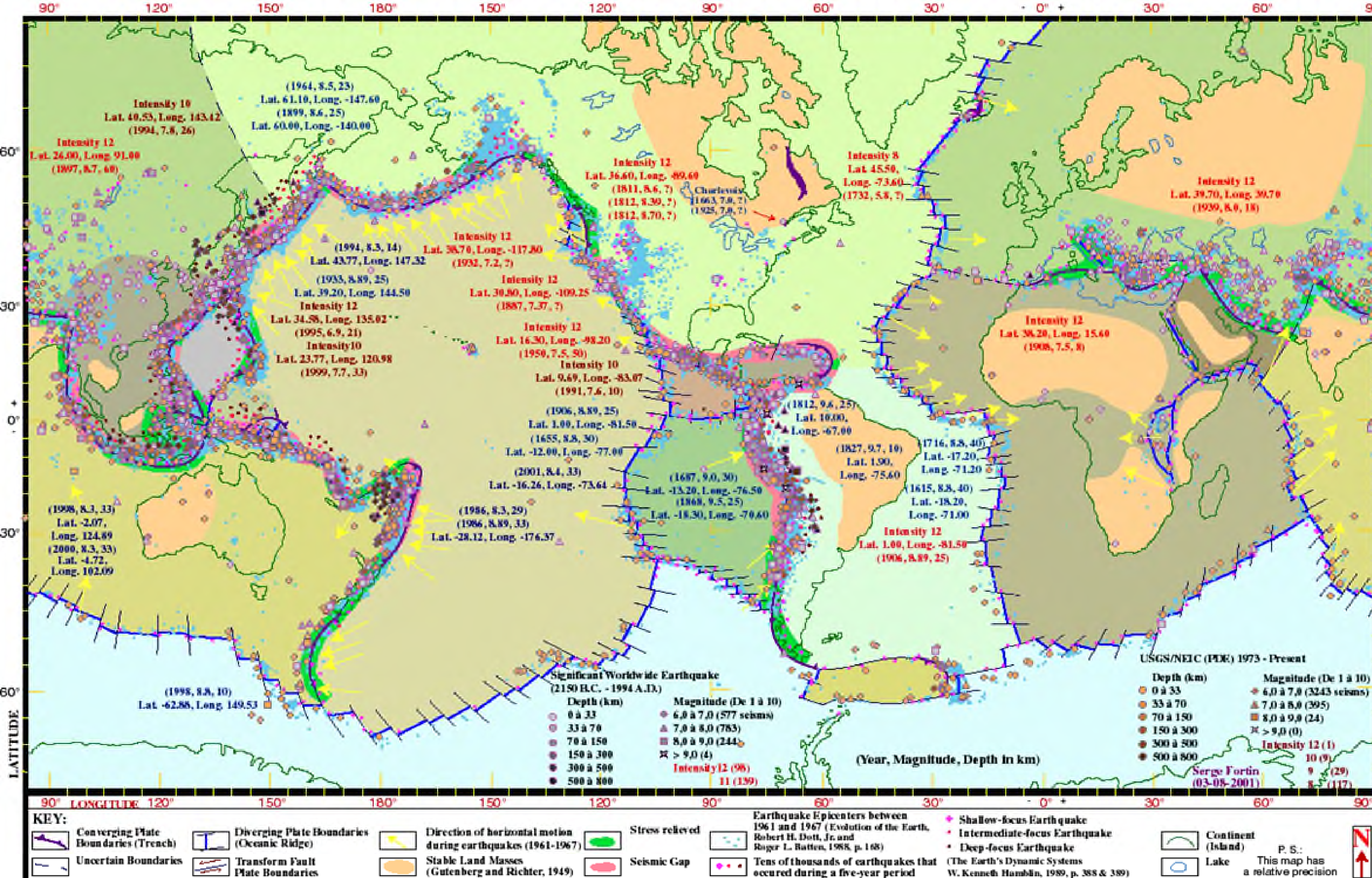
2) Faults are planar surfaces (zones of weakness) in the upper crust where brittle fracture and offset movement takes place between two crustal blocks



3) Faulting is caused when the built-up of tectonic, magmatic, or hydrologic stress/force in crustal rocks overcomes rock strength, resulting in rock failure.

4) Most active faults and quakes occur at or near tectonic plate boundaries

Major Earthquakes and Associated Fault Zones

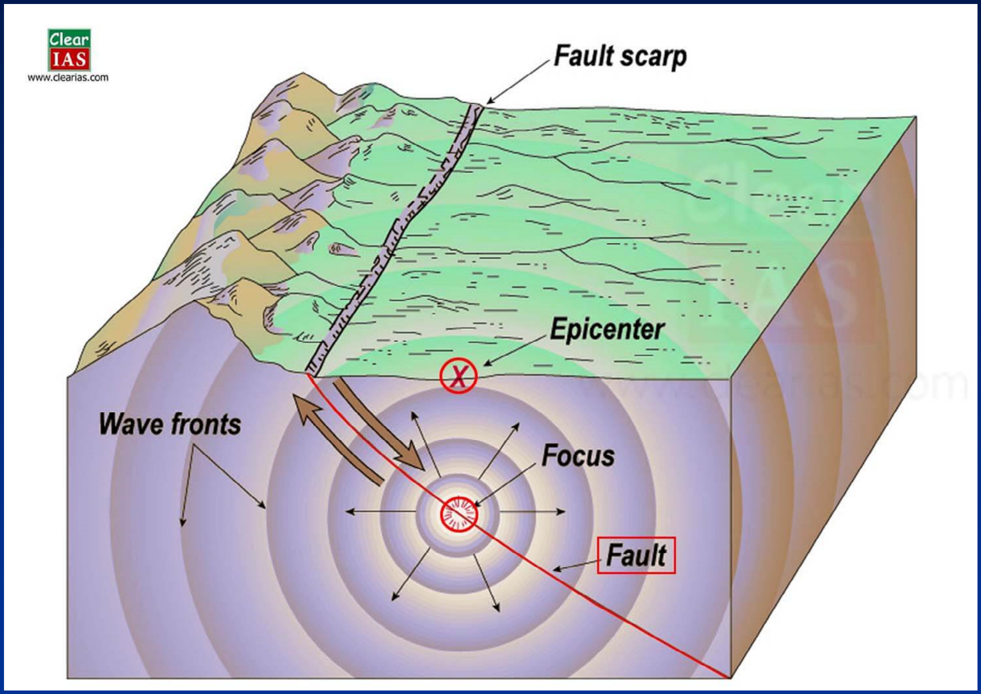


Most earthquakes and faulting occur at tectonic plate boundaries

Faulting and Earthquake Anatomy

Terminology

1) Fault
2) EQ Focus
3) EQ Epicenter
4) Seismic Waves
5) Fault Rupture Offset
6) Fault Line
7) Fault Scarp



- Earthquakes develop deep in the ground along a rupturing fault
- The site of origin of an earthquake on a fault is termed the ***focus***
- The ground surface location directly above the fault is termed the ***epicenter***
- Seismic energy waves are generated by the rupturing fault (at the focus)
- A fault line is where the fault is traced along the ground surface
- A fault scarp is where a cliff-like feature forms along the fault line

What Causes an Earthquake?

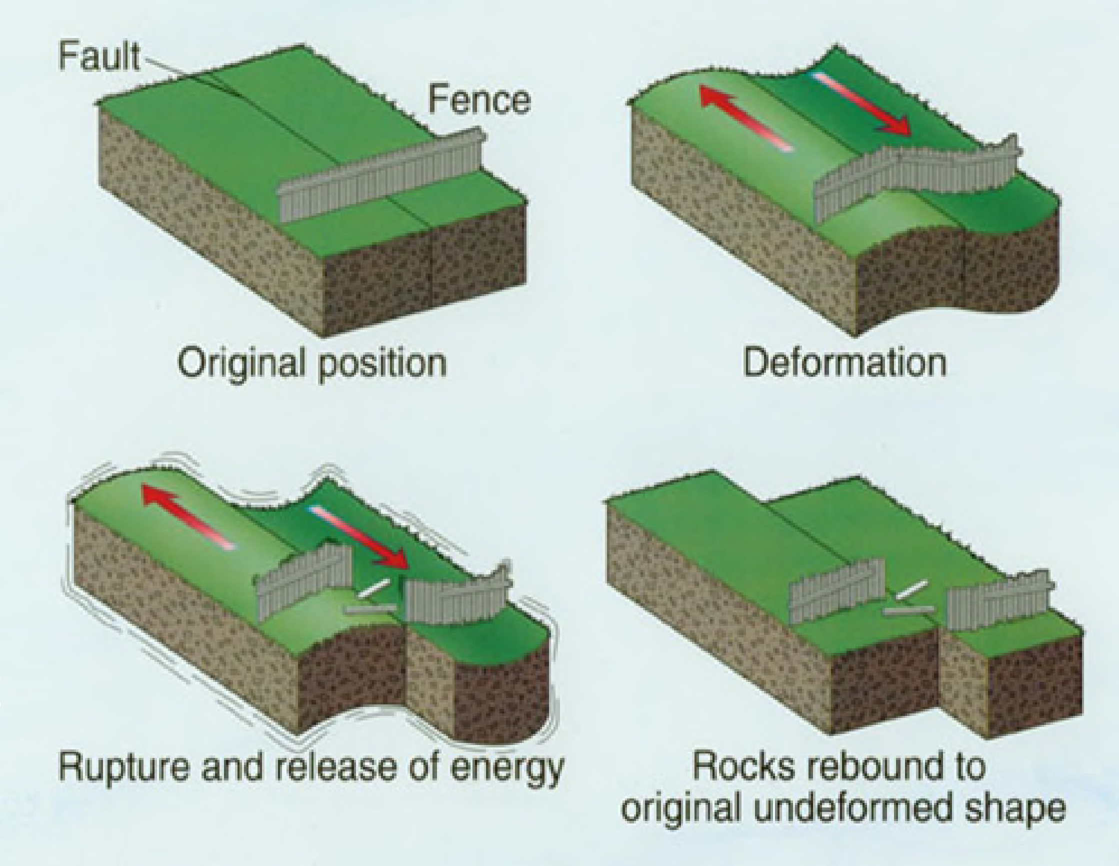
Reid's Elastic Rebound Theory

1) Pre-load Period
   - No Stress
   - No Deformation

2) Bending Period
   - Slow Stress Loading
   - Elastic Deformation

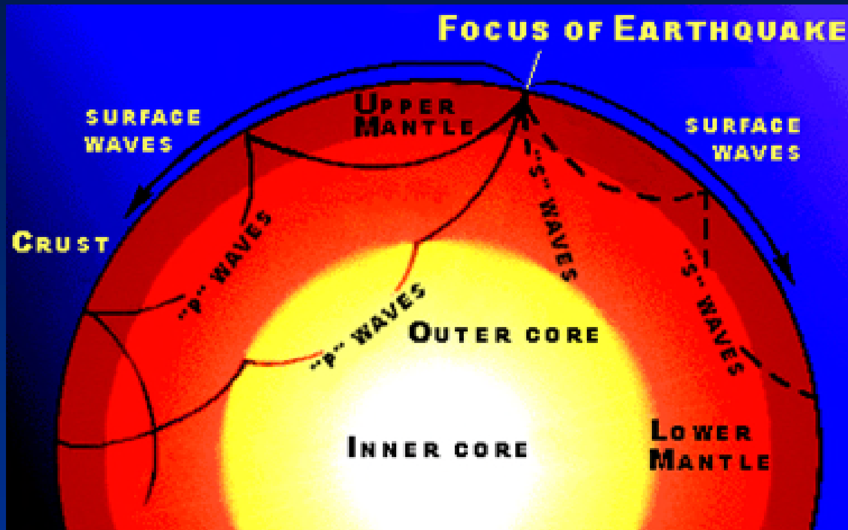
3) Rupture Period
   - Instant Stress Release
   - Brittle Deformation/Offset

4) Rebound Period
   - Removal of Bending
   - Stress Relieved



Four Stages

Types of Seismic Waves

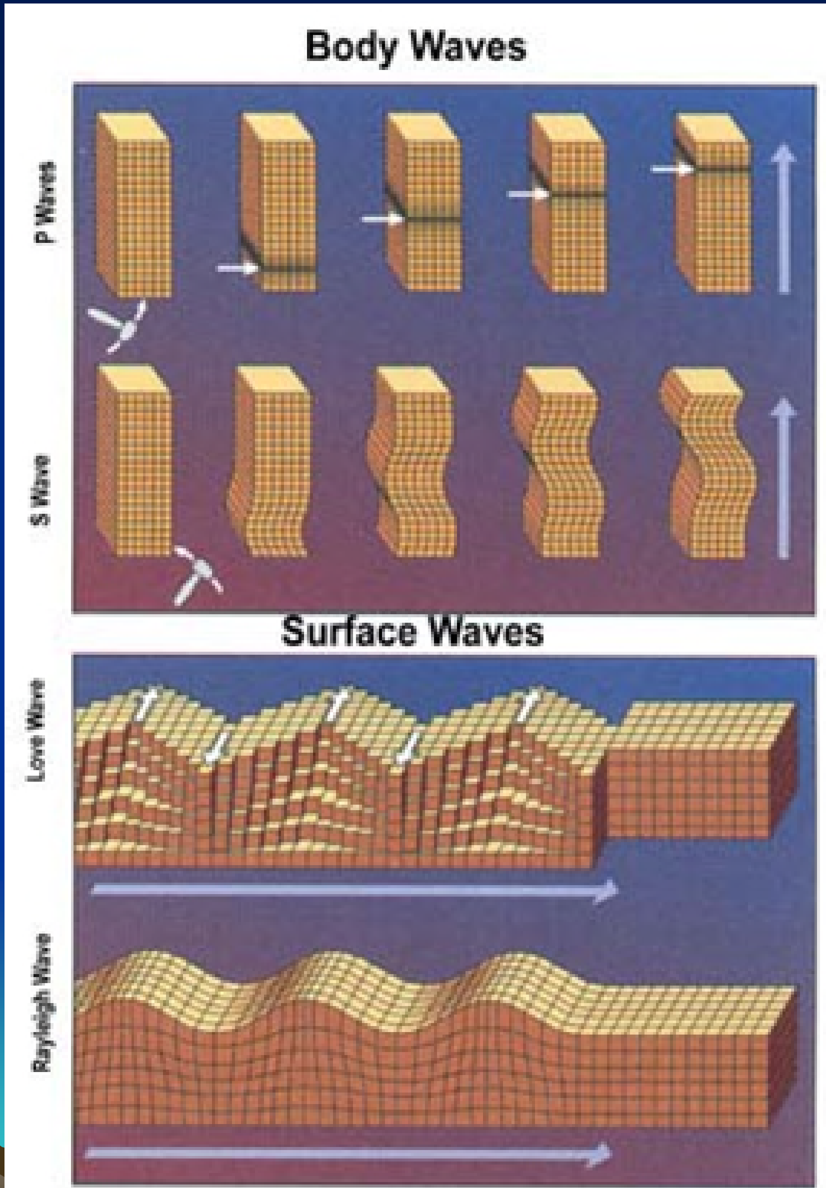


Body Waves – Formed at Focus

1) P-waves
2) S-waves

Surface Waves – Formed at Surface

1) Love-waves
2) Raleigh-waves



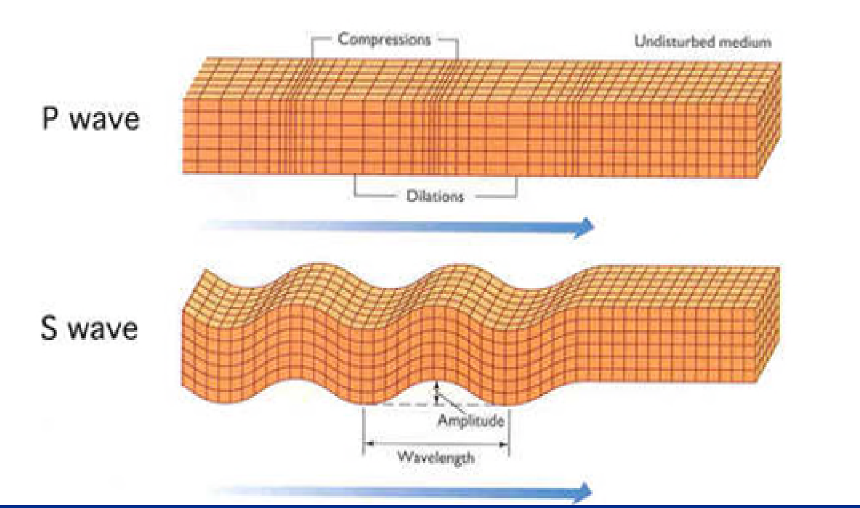
Two Types of Seismic Body Waves

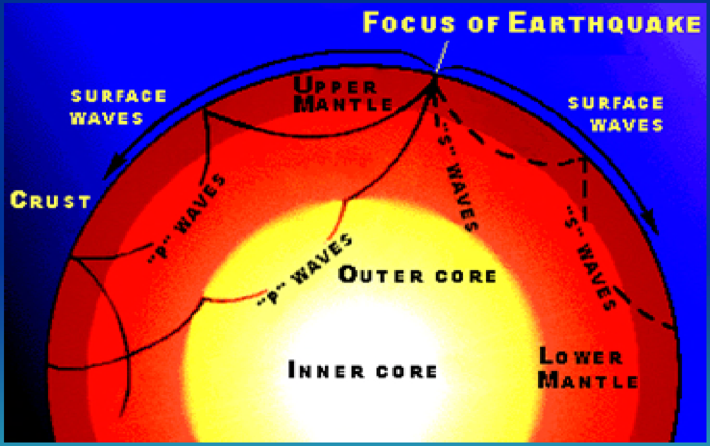
P-waves

- Compression-dilation behavior of ground when wave passes through
- Relatively Fast

S-waves

- Up-down shearing behavior of ground when wave passes through
- Relatively Slow

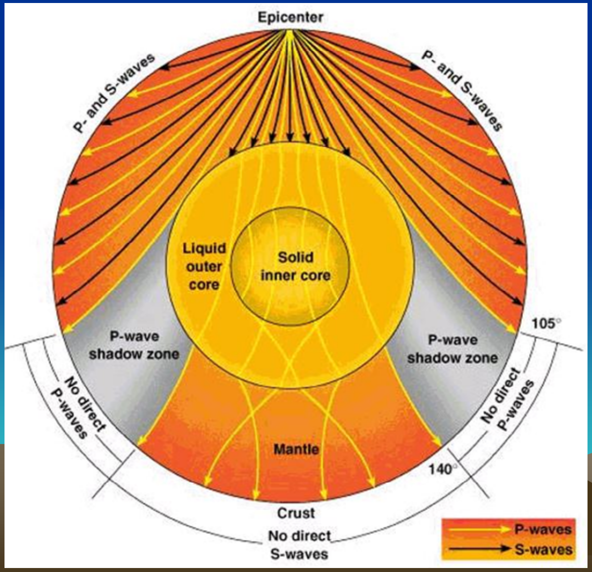


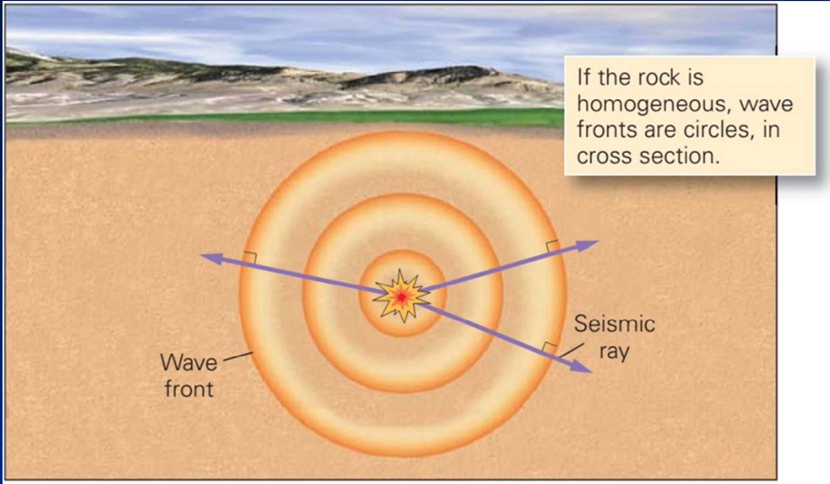


- P- and S-waves form at the site of fault rupture deep in the Earth (quake foci zones)
- Body waves bend when travelling down through the Earth due to changes in rock density which affects seismic wave speed
- P-waves travel nearly twice as fast as the S-waves
- P-waves travel through solid and molten rock; S-waves cannot travel through liquid

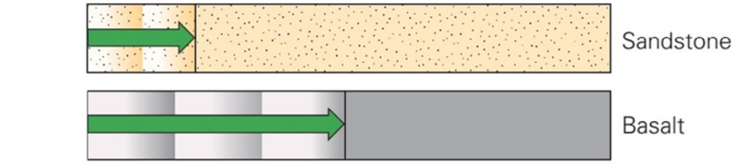
Body Wave Motion Through the Earth

- P- and S-waves travel perpendicular to their wave fronts in al directions from their origin (earthquake foci)
- Body waves change speed when moving from one rock type to another, travelling faster through denser, more solid rock.
- P-waves travel through the entire Earth, whereas S-waves stop at the core - not being able to travel through liquids

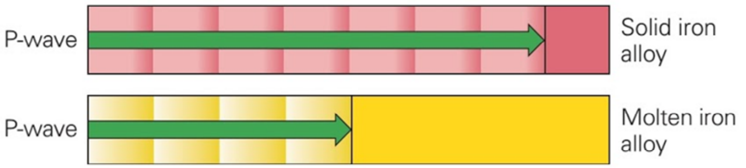




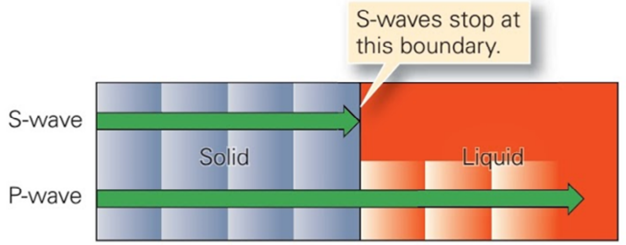
(a) An earthquake sends out waves in all directions. Seismic rays are perpendicular to wave fronts.



(b) Seismic waves travel at different velocities in different rock types. After a given time, the wave will have traveled farther in basalt than in sandstone.



(c) P-waves travel faster in solid iron alloy than in liquid, such as molten iron alloy.

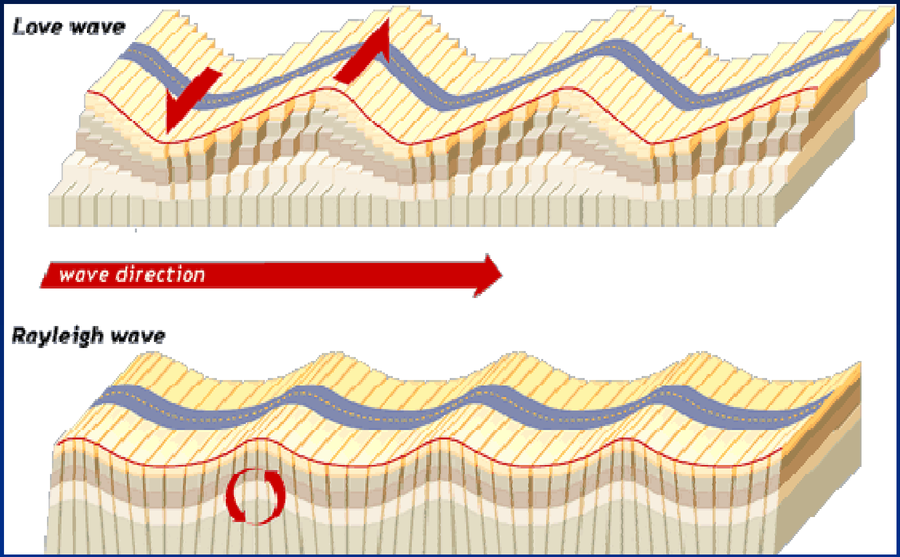


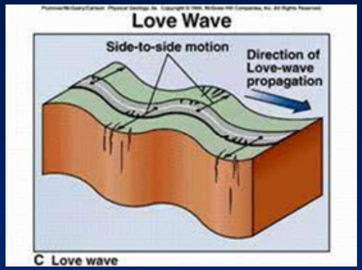
(d) Both P-waves and S-waves can travel through a solid, but only P-waves can travel through a liquid.

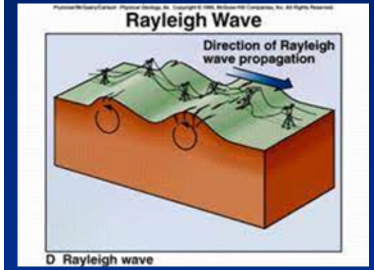
Two Types of Seismic Surface Waves

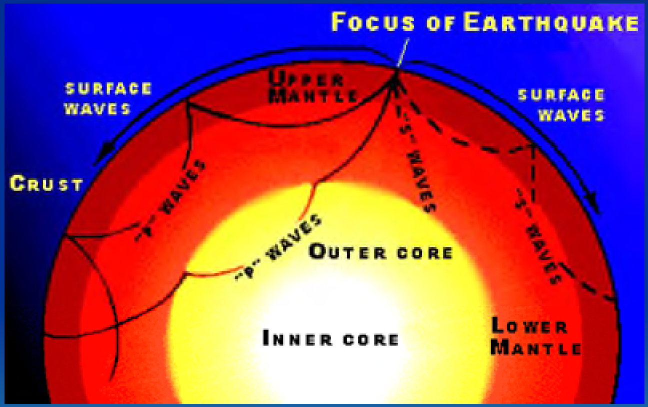
1) **Love-waves**
   - Side-to-side shear motion of ground

2) **Raleigh-waves**
   - Orbital rolling motion of ground



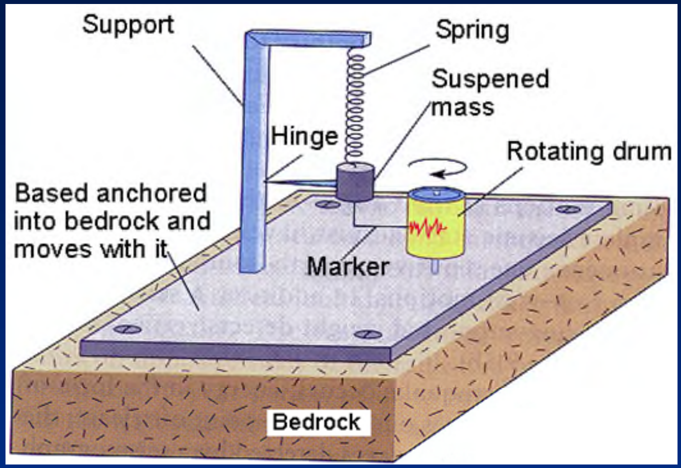




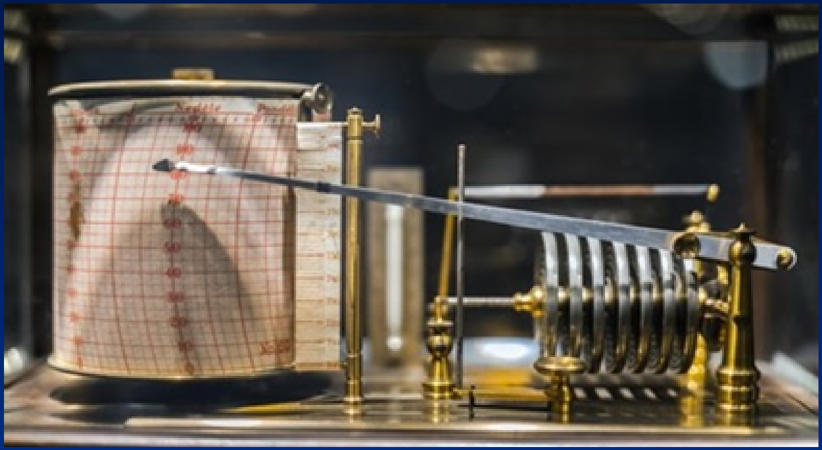


- Love- and Raleigh-waves form at the ground surface as the result of P- and S- body waves striking the ground surface from depth
- Surface waves only travel through the shallow surface layers of the crust
- Surface waves have larger wavelengths and amplitudes than the body waves
- Surface waves are more destructive to building and other structures than body waves

Recording Seismic Activity with a Seismometer



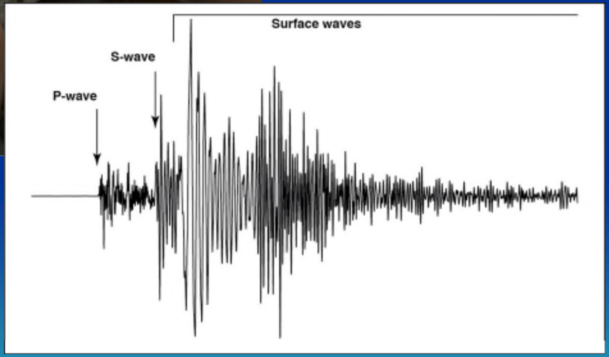
A Simplified Seismometer



Examples of Seismometers

- A seismometer measures and records ground shaking
- A seismometer measures back-and-forth, side-to-side, and up-and-down ground motion
- A seismometer records seismic wave energy on a rolling drum
- Both body and surface waves of a quake are recorded as a seismogram

A Seismogram

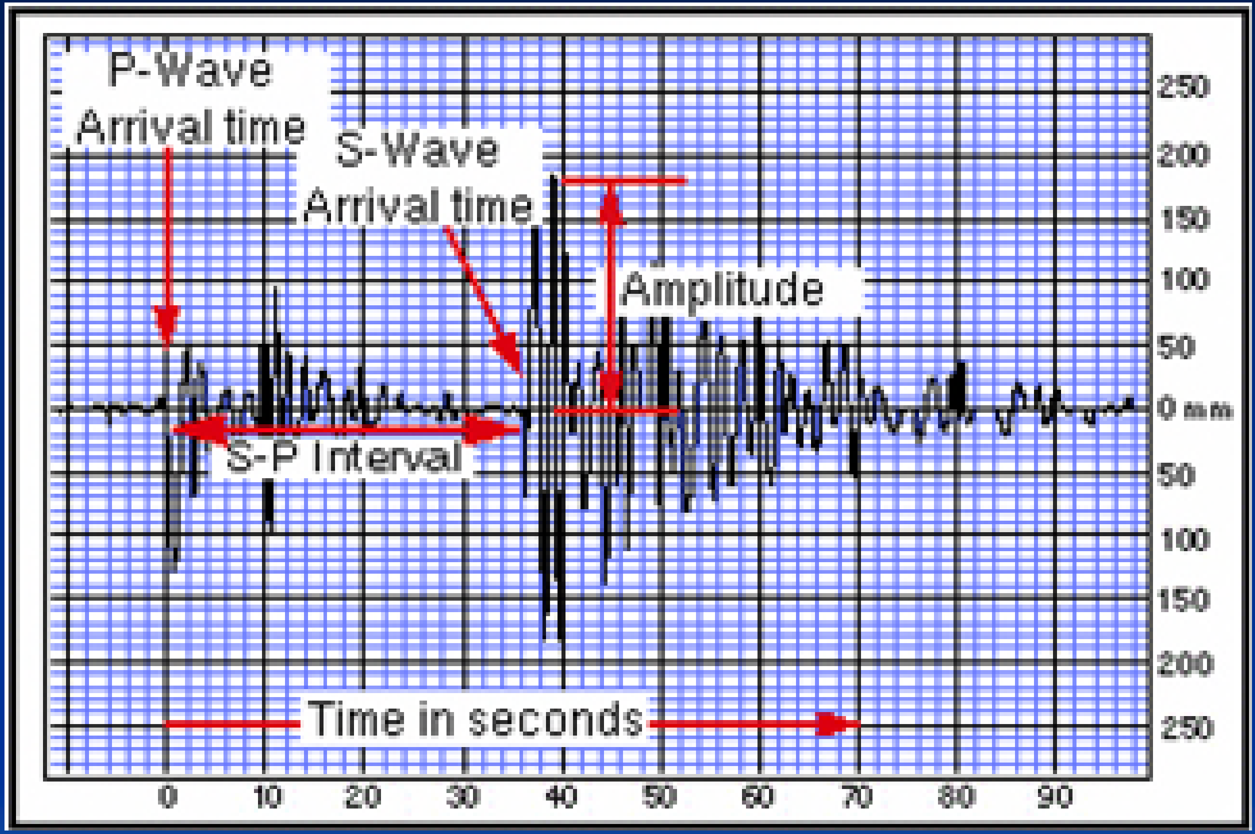


How does a seismometer work?

https://www.youtube.com/watch?v=geNiqkgZDXA

Fundamentals of a Seismogram

1) P-wave Arrival time
2) S-wave Arrival time
3) S-P Interval
4) Amplitude



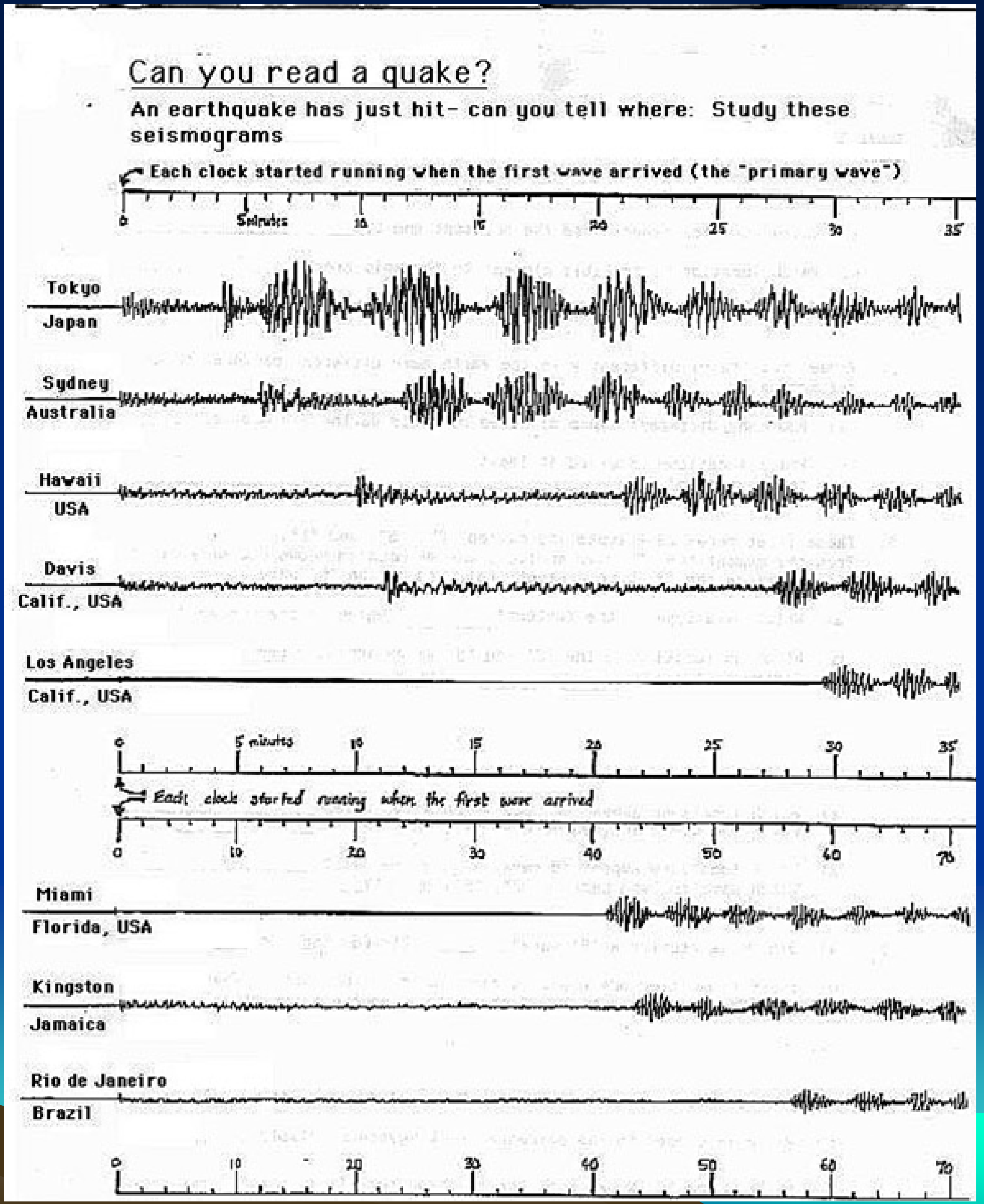
Reading a Seismogram

1) P-wave Arrival time

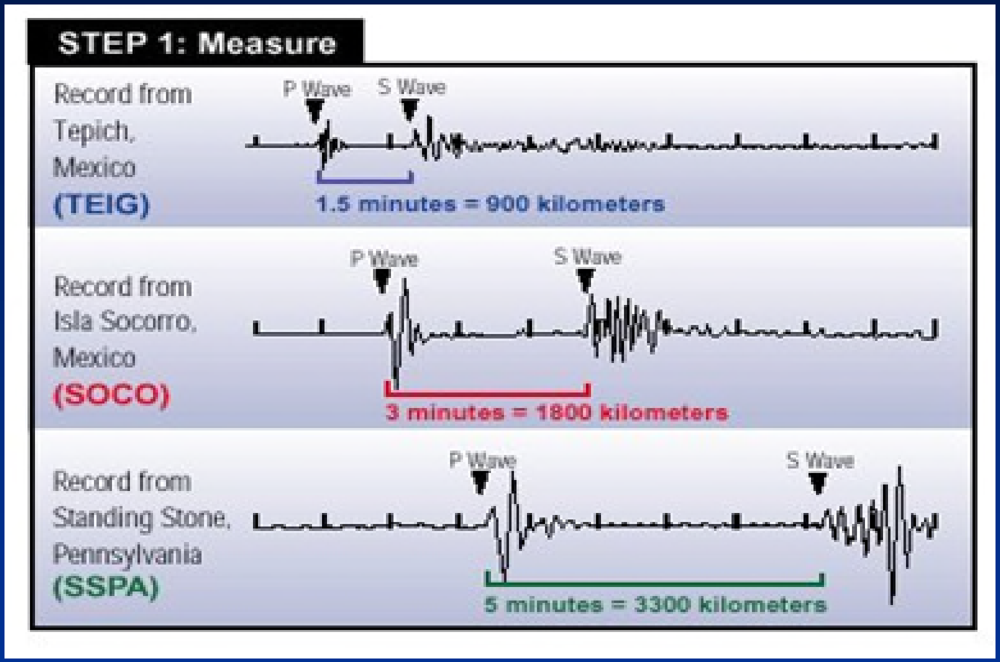
2) S-wave Arrival time

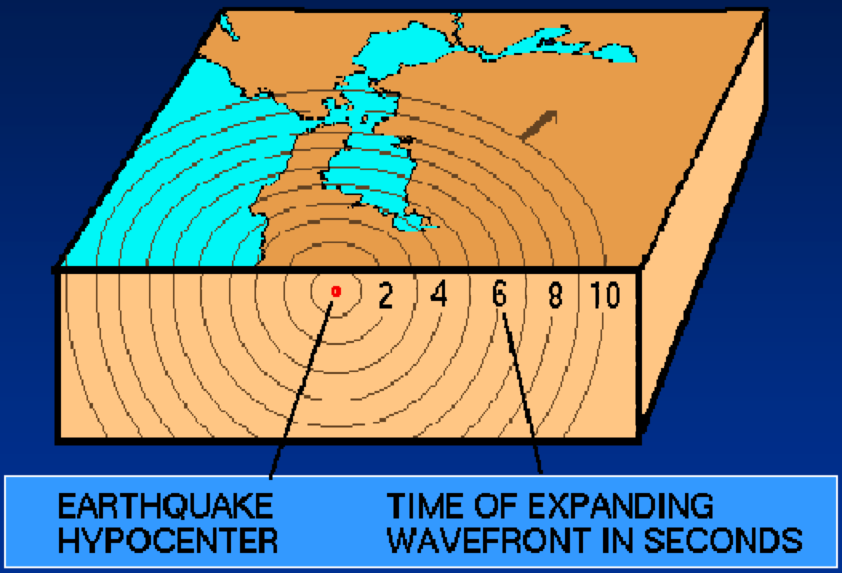
3) S-P Interval

4) Amplitude



Determining Distance to Epicenter

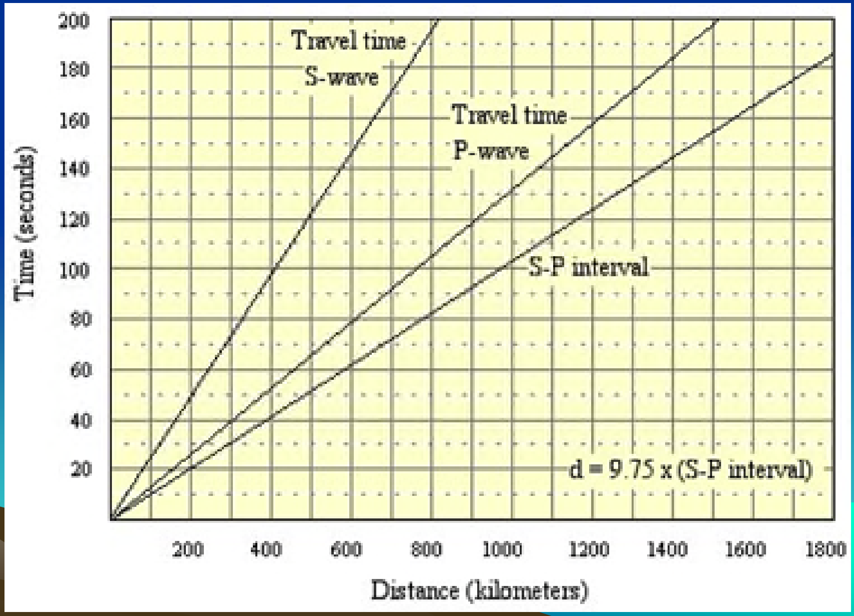




1) Measure S-P Interval for each station

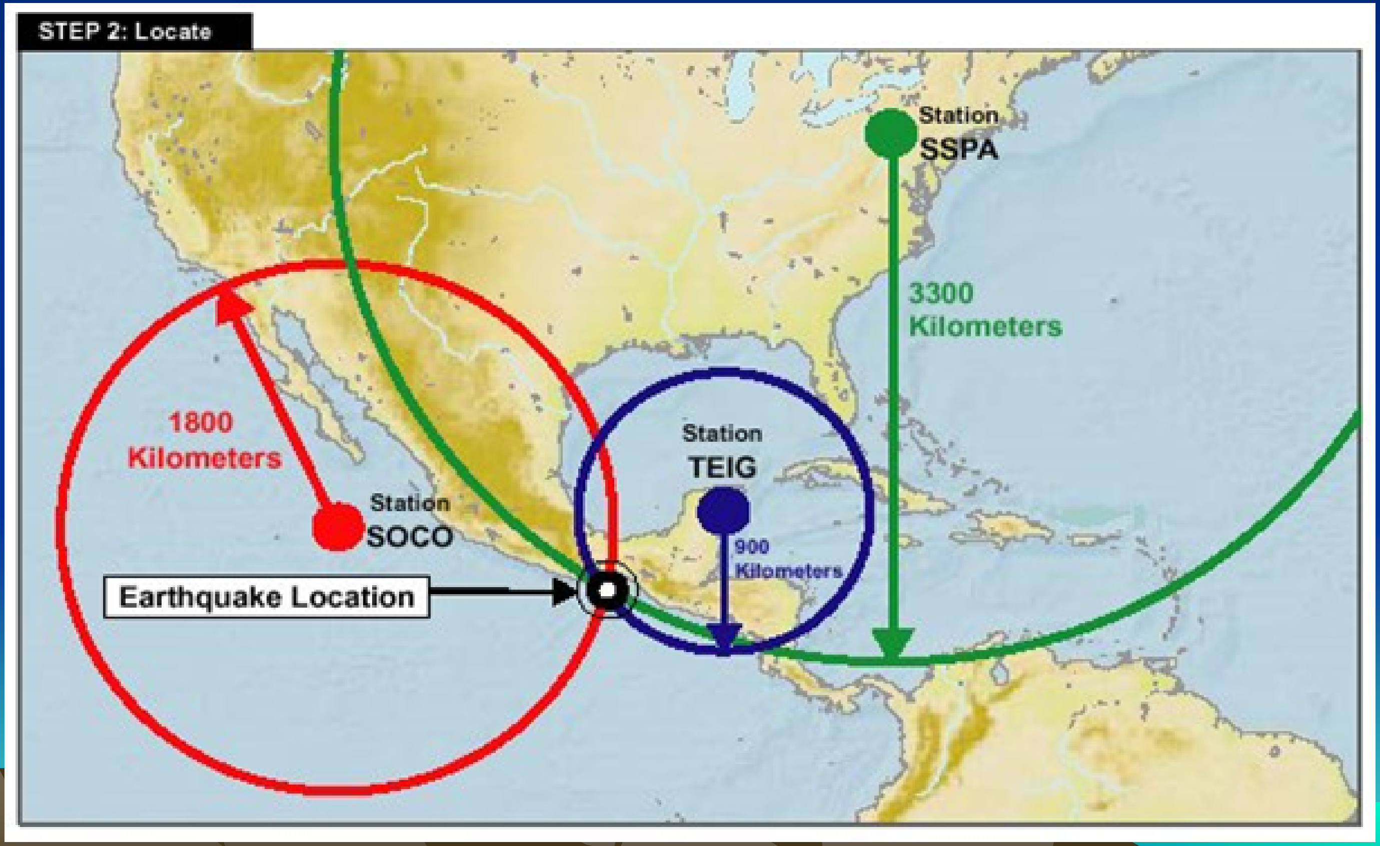
2) Convert S-P Interval time into ground distance from epicenter using the S-P conversion chart

3) Location of epicenter from seismic station is found somewhere along a circle drawn around station with a radius equal to epicenter distance



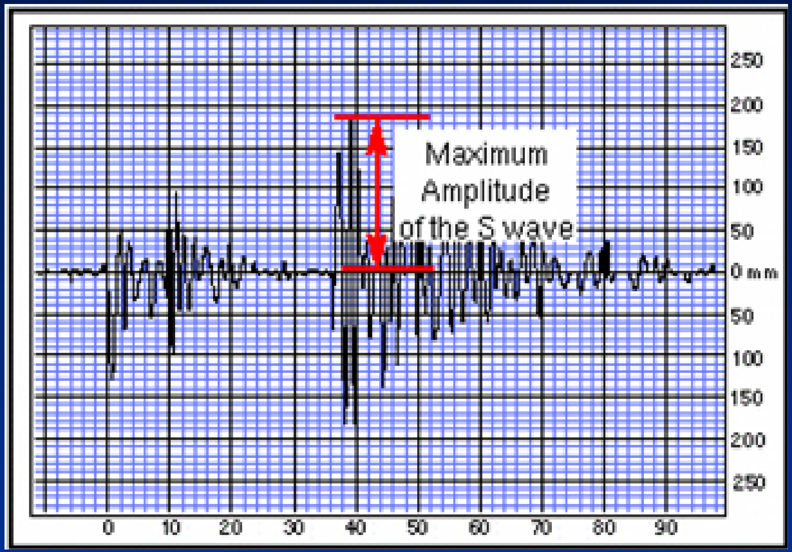
Determining Earthquake Epicenter

1) Need at least three seismograph stations
2) Find distance from station to epicenter for each station
3) Plot distance circles for each station
4) Epicenter located where all three circles intersect

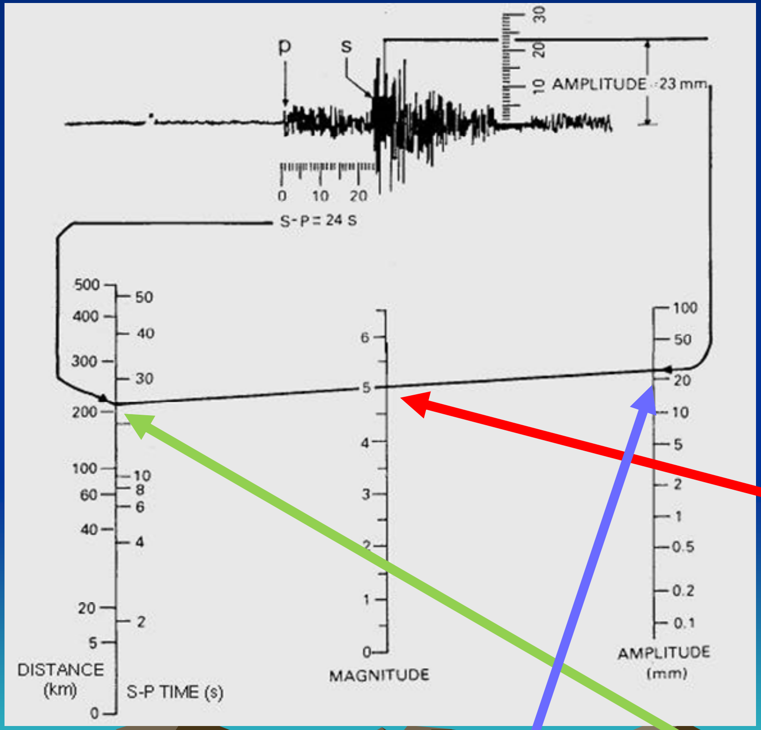


Determining Earthquake Magnitude

1) Measure amplitude of largest S-wave
2) Plot line from distance to amplitude
3) Magnitude is read from center scale
4) Only need 1 station for determination



Measure the Tallest S-Wave on a Seismogram

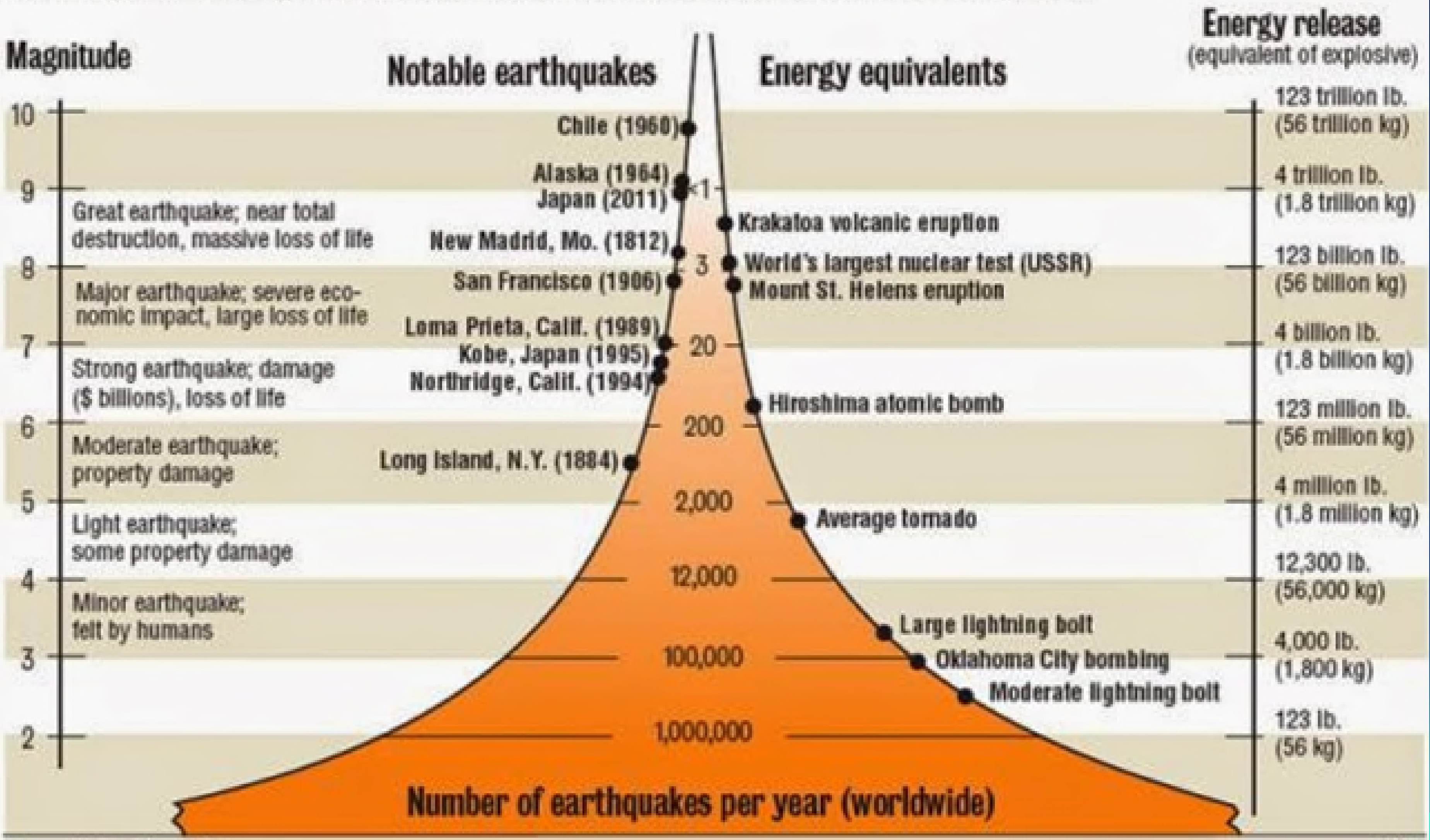


Richter Magnitude is found by drawing a line between plotted left and right column points

Plot the distance to epicenter on **left column** and the height of S-wave on right column of Richter Chart

Earthquake frequency and destructive power

The left side of the chart shows the magnitude of the earthquake and the right side represents the amount of high explosive required to produce the energy released by the earthquake. The middle of the chart shows the relative frequencies.



Source: U.S. Geological Survey

MCT

Measuring Ground Shaking

Modified Mercalli Intensity Scale

I	Not felt
II	Felt only by persons at rest
III–IV	Felt by persons indoors only
V–VI	Felt by all; some damage to plaster, chimneys
VII	People run outdoors, damage to poorly built structures
VIII	Well-built structures slightly damaged; poorly built structures suffer major damage
IX	Buildings shifted off foundations
X	Some well-built structures destroyed
XI	Few masonry structures remain standing; bridges destroyed
XII	Damage total; waves seen on ground; objects thrown into air

Seismic Hazards

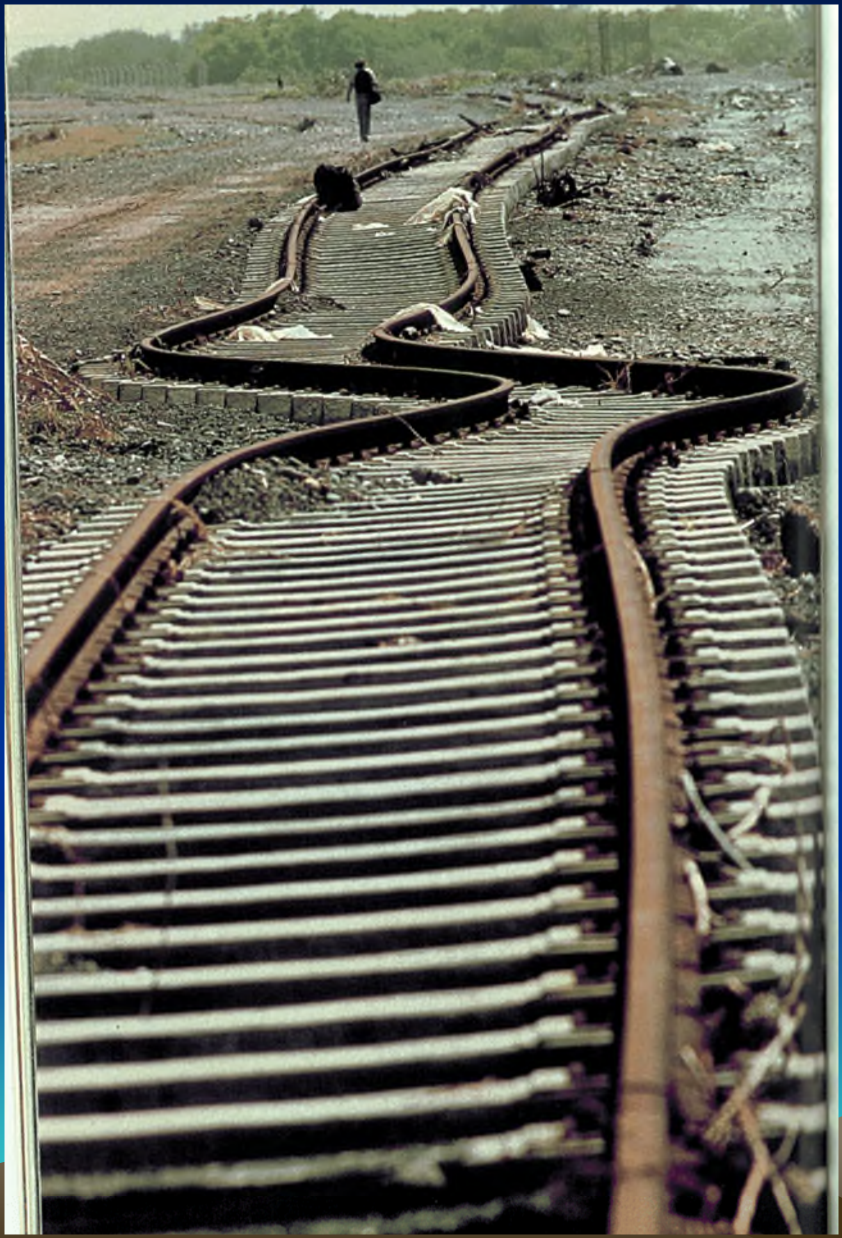
1) Ground shaking
2) Ground displacement
3) Liquefaction
4) Landslides
5) Building collapse
6) Tsunami
7) Fires
8) Flooding

Ground Shaking and Building Motion

Japan Earthquake - Building Shaking

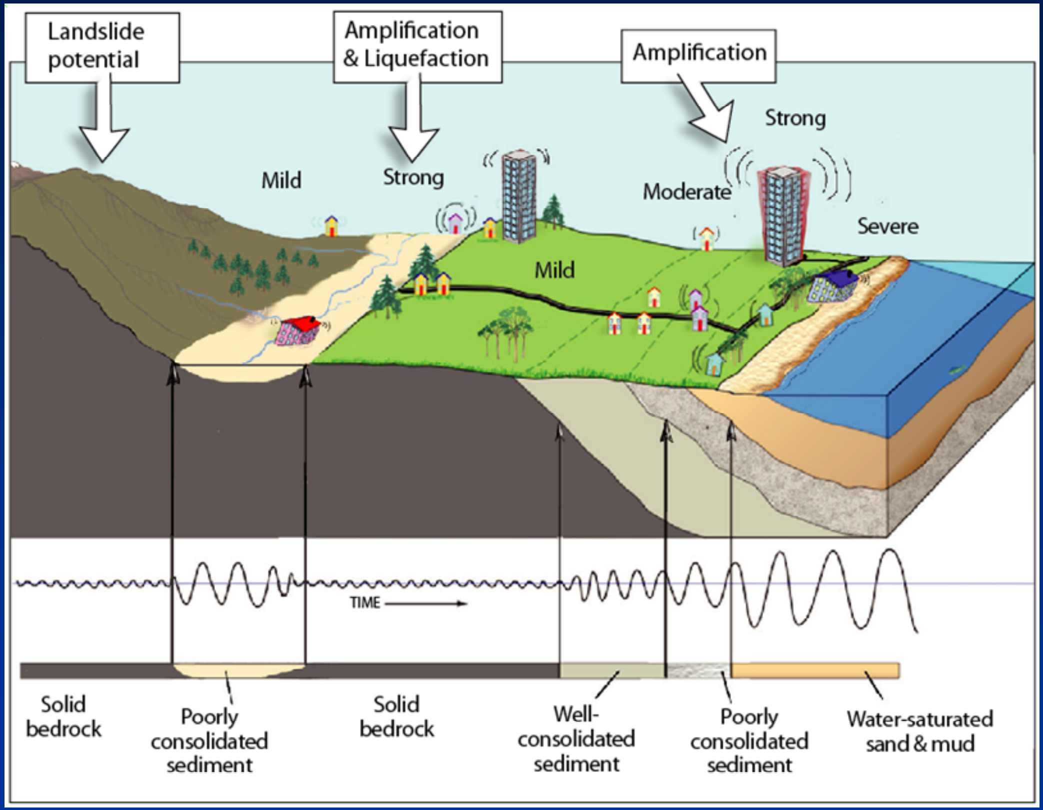
Alaska Earhquake - Modeled Building Motion

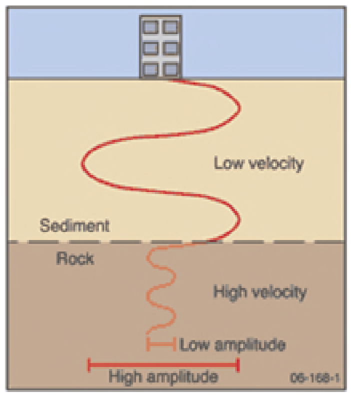
Surface Displacement Along Active Faults



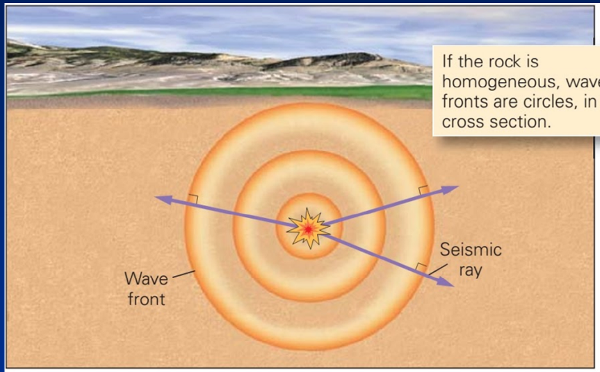
Earthquake Ground Shaking:
Variations in Substrate

1) Different types of ground materials behave differently to seismic waves
2) The softer the material, the greater the shaking
3) Solid rock is less shaken than consolidated sediment
4) Well-consolidated sediment is less shaken than poorly-consolidated sediment
5) Dry sediment is more stable than water-saturated sediment





How Ground Shaking Affects Buildings



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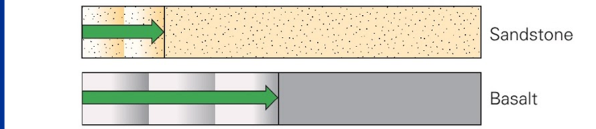
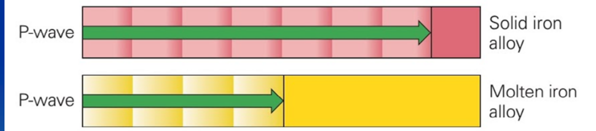
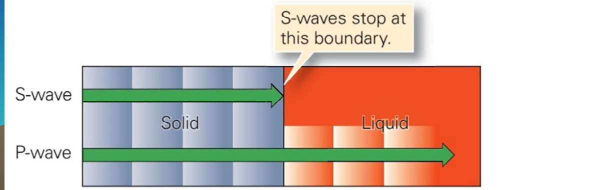


(b) Seismic waves travel at different velocities in different rock types. After a given time, the wave will have traveled farther in basalt than in sandstone.



(c) P-waves travel faster in solid iron alloy than in liquid, such as molten iron alloy.



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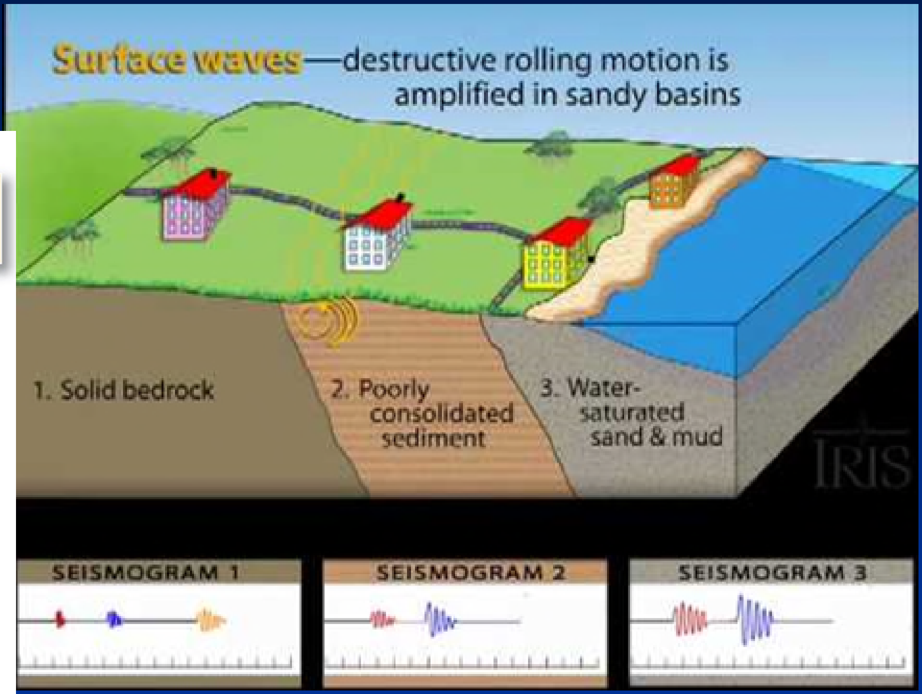
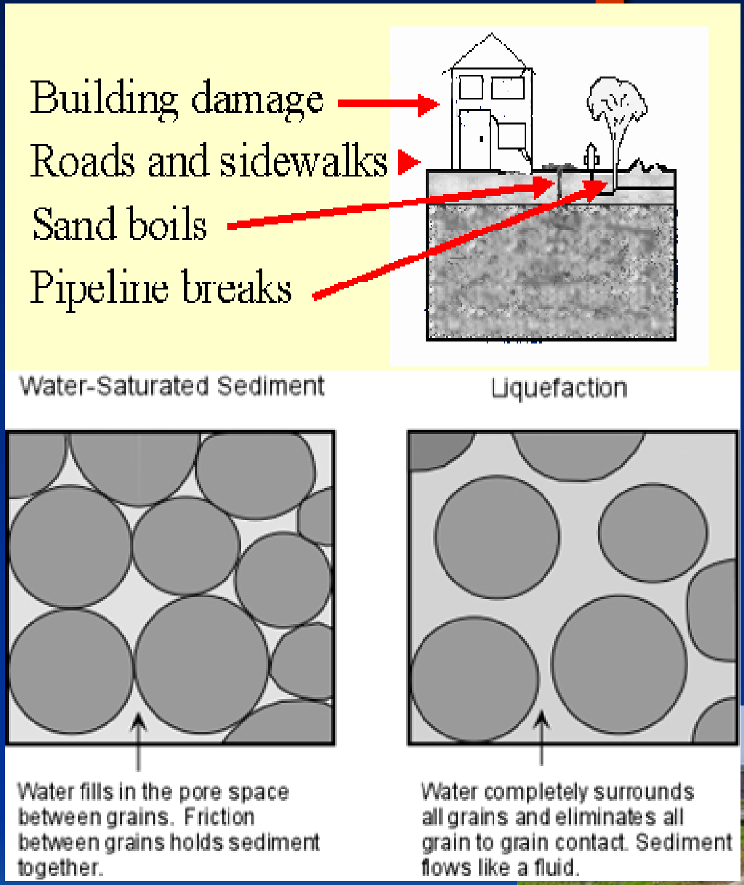


Liquifaction!

Liquifaction!



Sinking Building

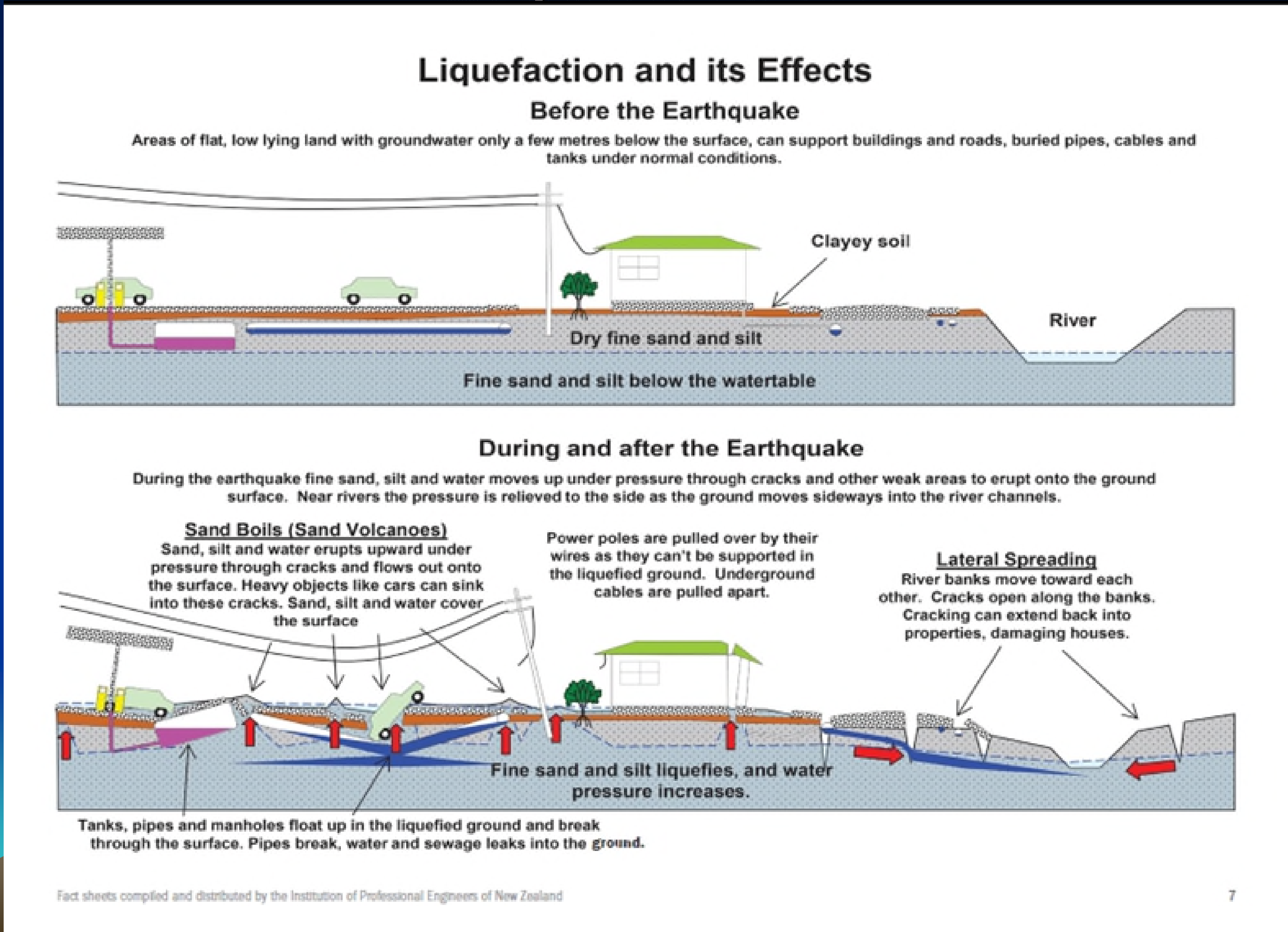
Exhumed pipes

Sand volcanoes

Video 1

Video 2

Liquifaction



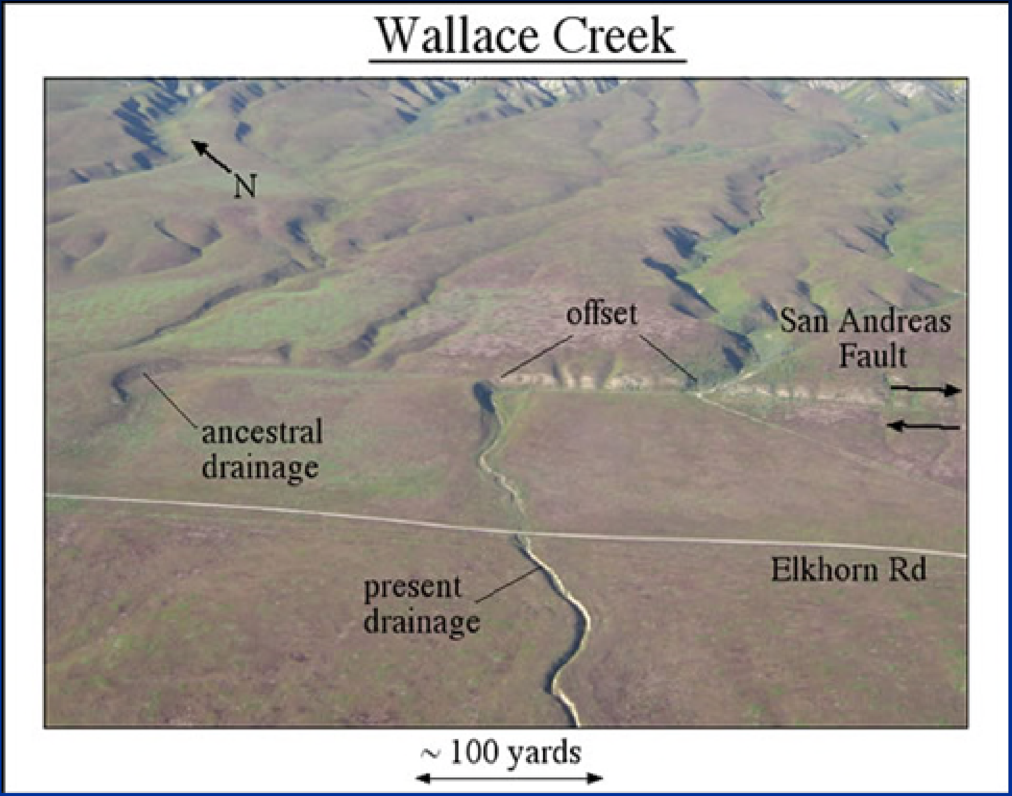
Using Aerial Photos to Interpret Fault Movement

1) Recognizing the offset of linear surface features

- ✓ Drainage channels
- ✓ Ridgelines
- ✓ Geologic formations

2) Relative direction of offset feature shows the relative movement direction

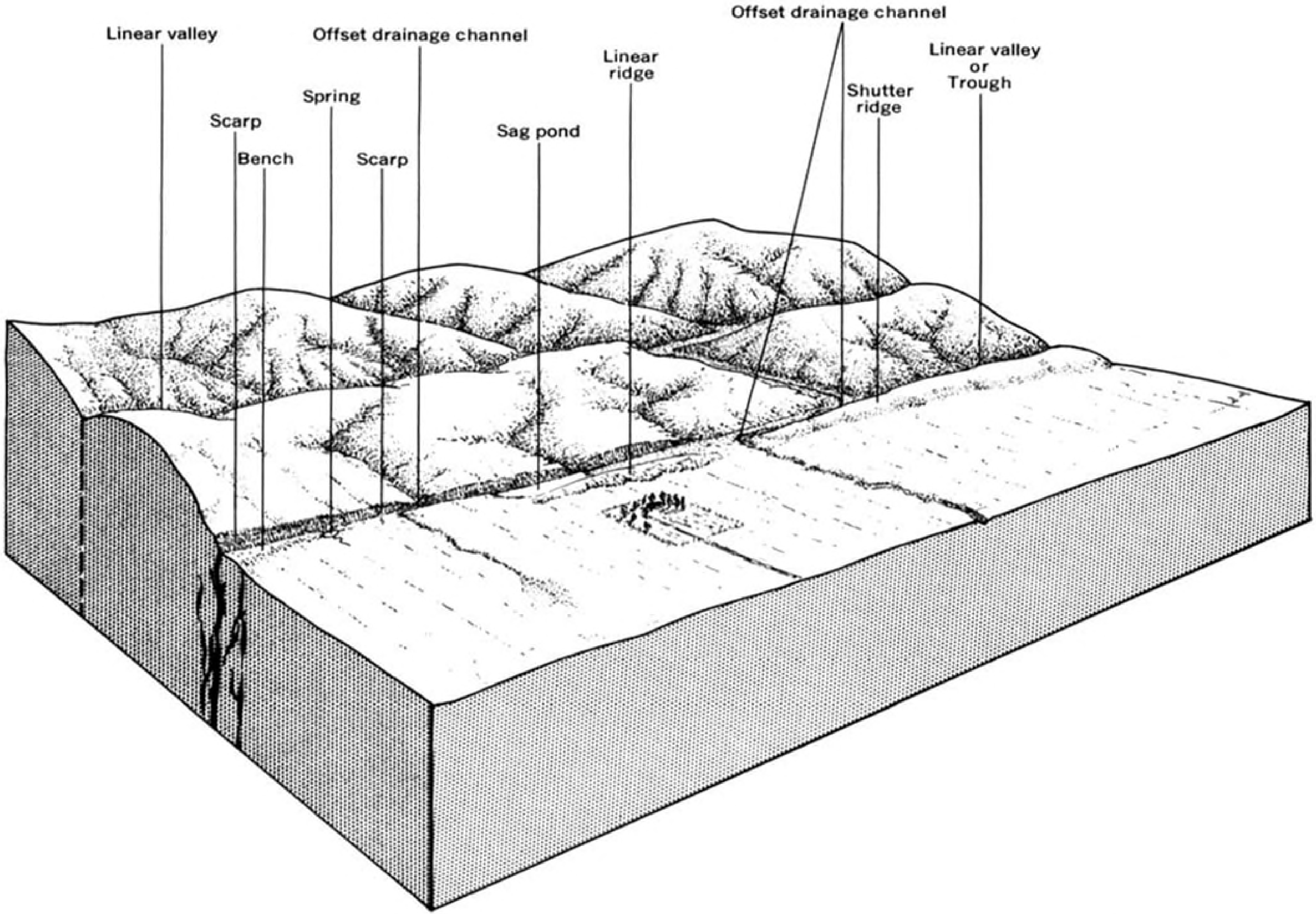
3) Amount of offset along disturbed feature shows the amount of fault movement



Surface Displacement Along San Andreas Fault

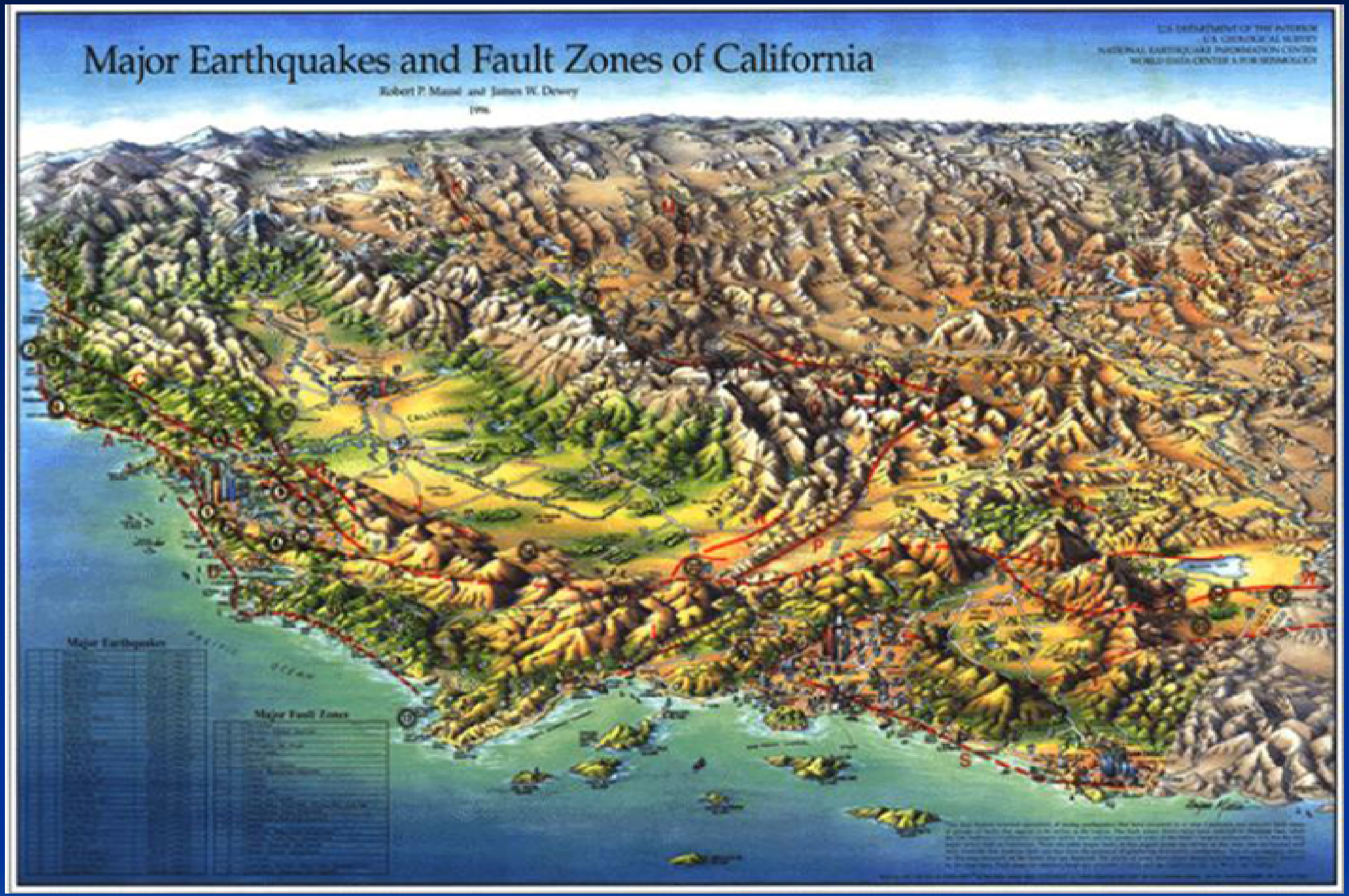
4) Age of offset feature gives averaged rate of displacement

Active Fault Features



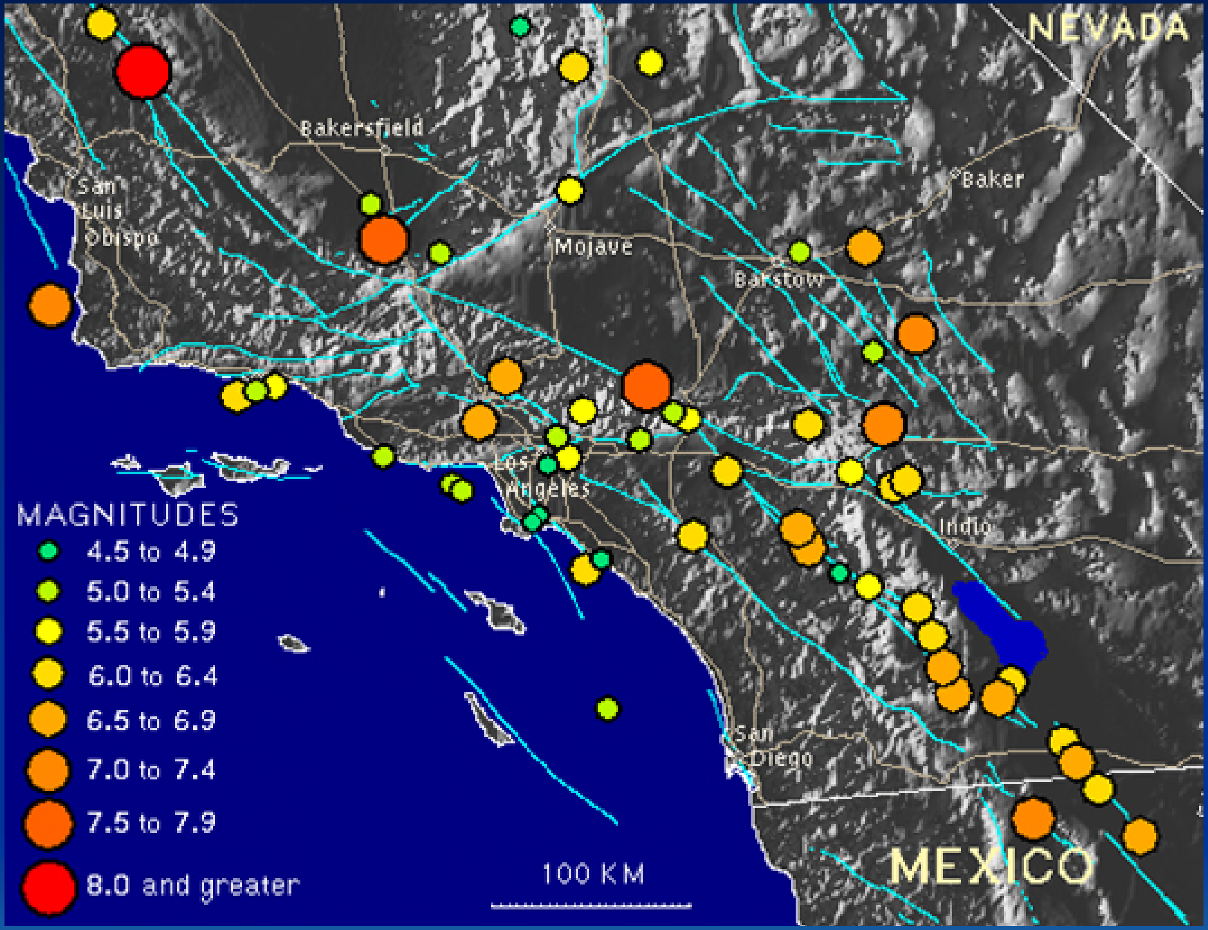
BLOCK DIAGRAM SHOWING LANDFORMS PRODUCED ALONG RECENTLY ACTIVE FAULTS

Major Fault Zones of California



The majority of California’s abundance of faults are part of the San Andreas Fault Zone – a transform boundary fault system

Largest Earthquakes of Southern California



The San Andreas Fault is capable of up to 8.0 M earthquakes.
The most active fault in So Cal is the San Jacinto Fault

Most Recent Earthquakes in California

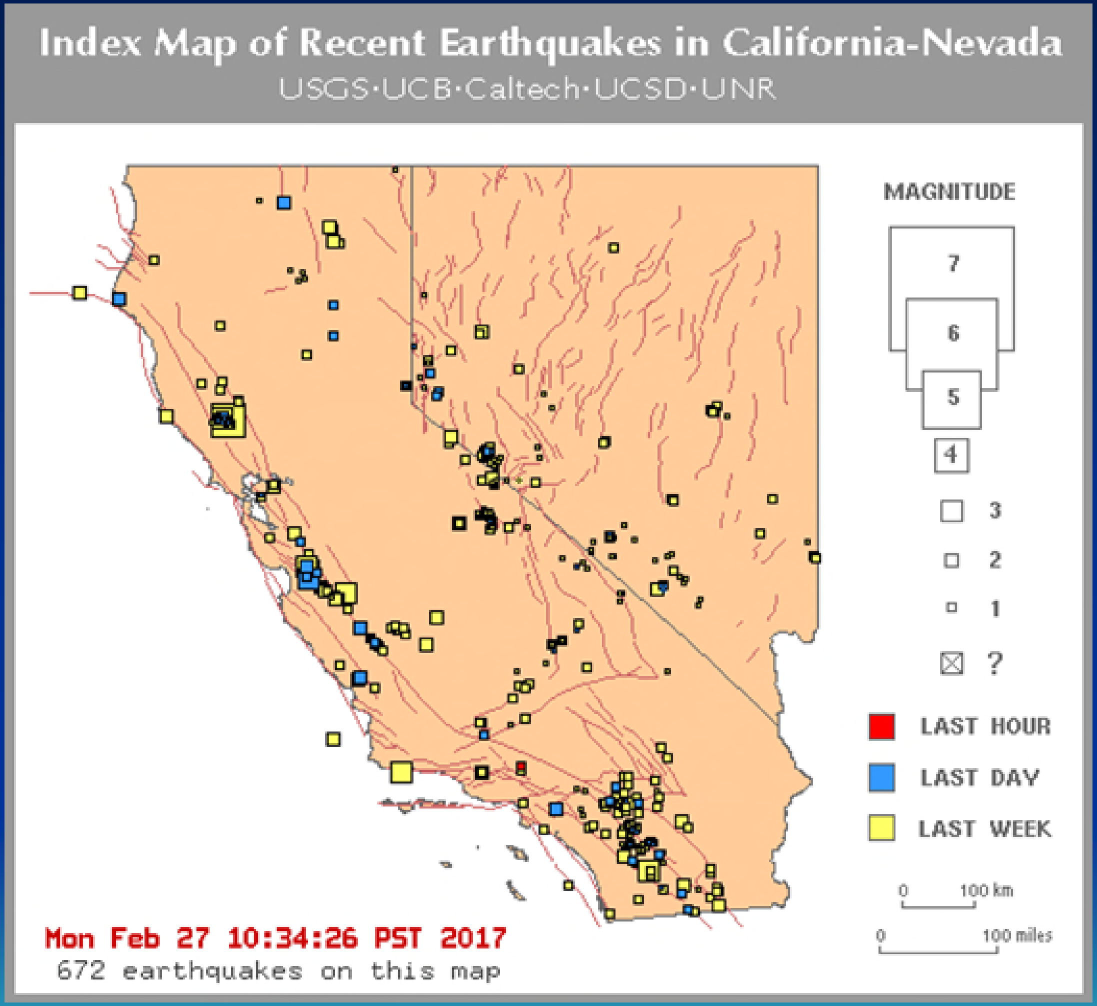
1) Most fault activity is associated with the San Andreas Fault Zone

2) The other zone is the Eastern Sierra region

3) The most active in Southern California are the San Jacinto and Elsinore faults

4) Short range quake prediction does not exist at this time

5) Where will the next "Big One" (> 7.5M) hit?



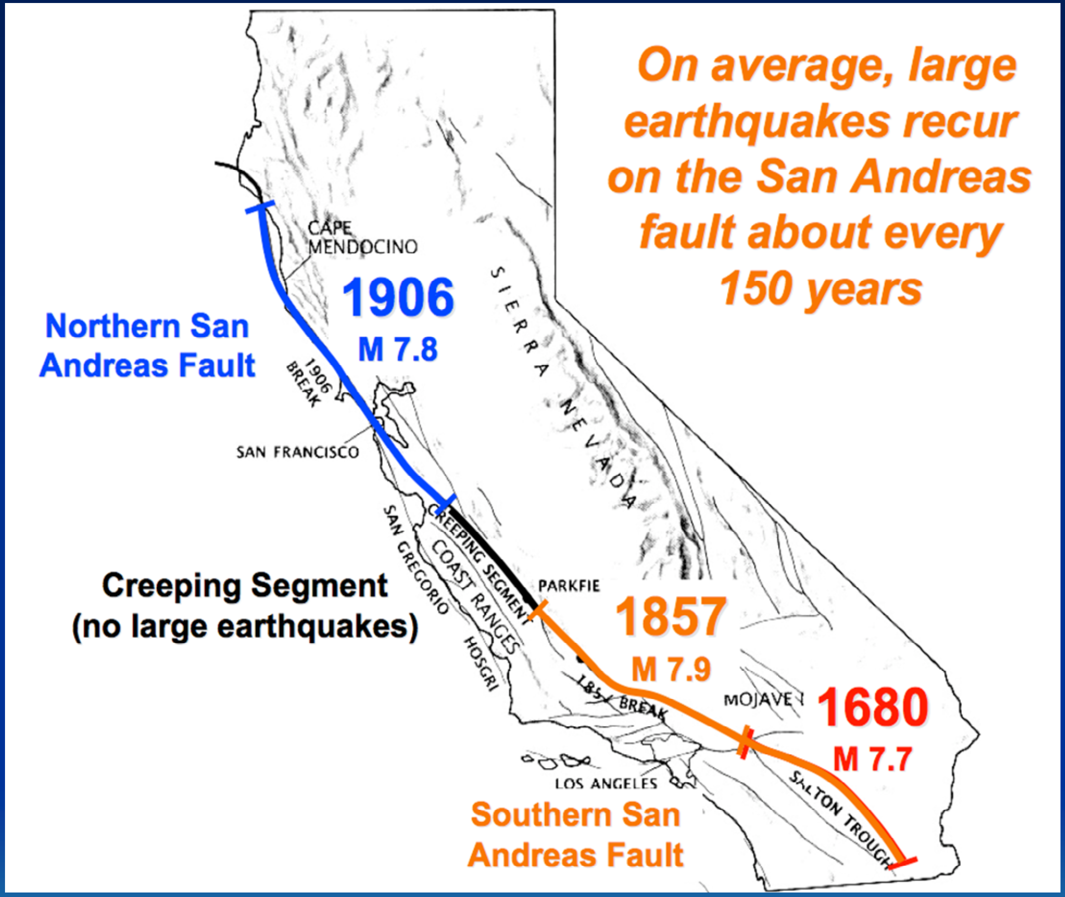
“Big Ones” on the San Andreas

1) Three Big Ones in the last 500 years on the SAF

2) Last Big One was on the Northern California segment in 1906

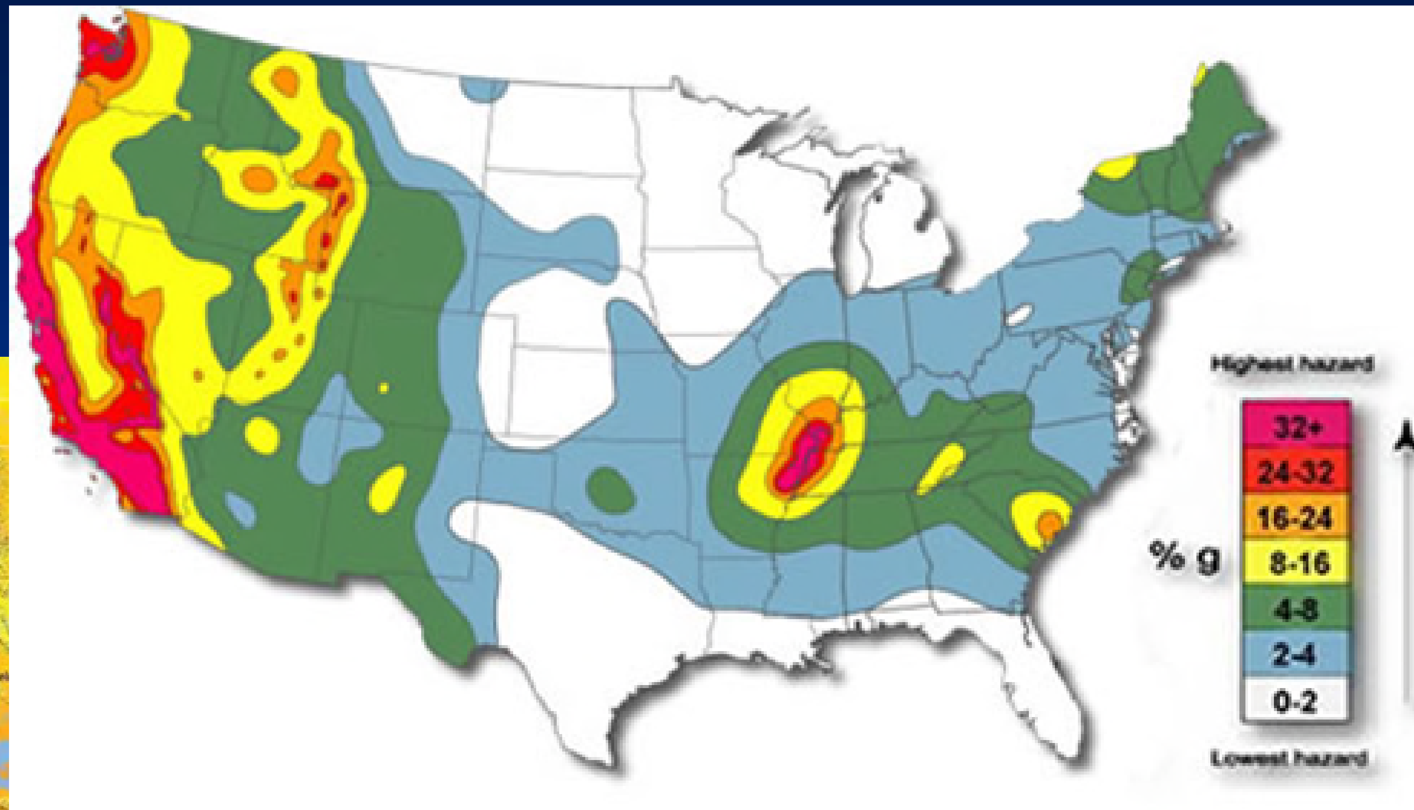
3) Last Big One on the Southern California segment was in 1680

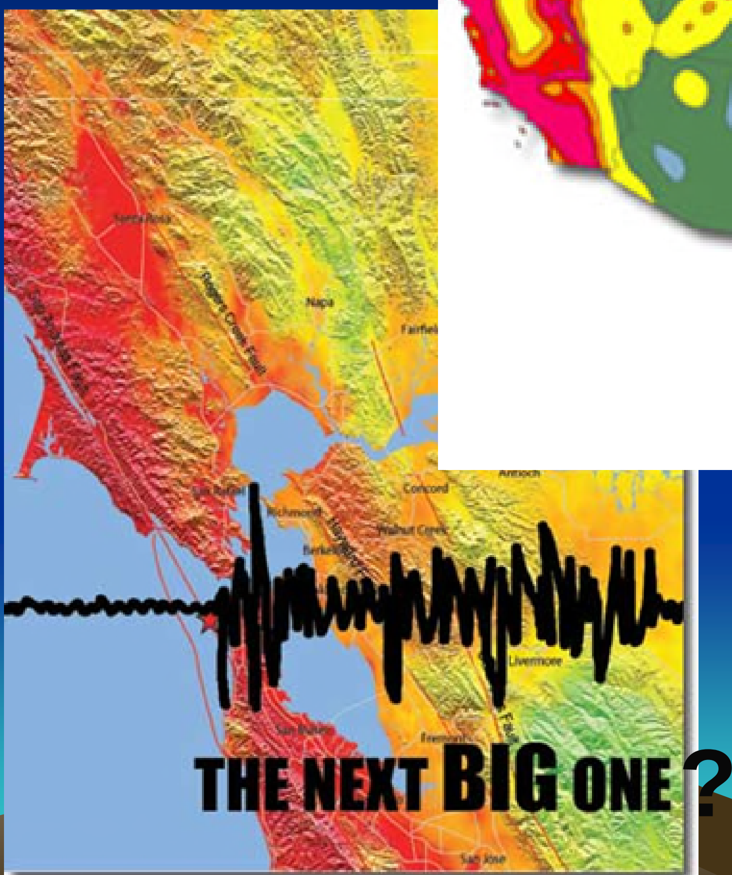
4) A “Big One” occurs about every 400 years on each of the SAF segments



5) Based on this map, where will the next “Big One” on the SAF most likely strike?

Earthquake Probability in USA

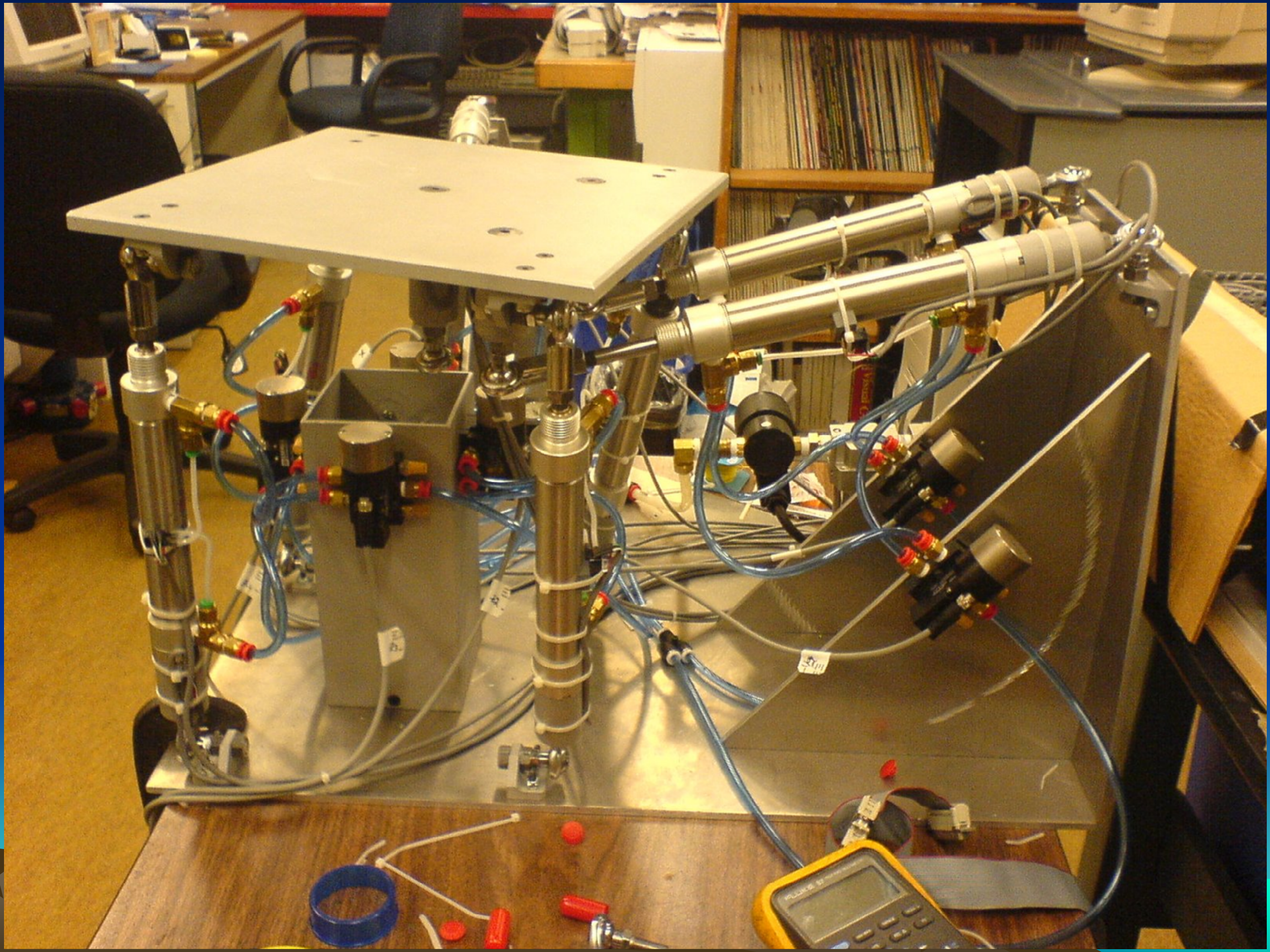




1) Geologists cannot predict an earthquake at the present time

2) Geologists can make statistically-based probability estimates for a given faults's chances of rupture

Advanced Earthquake Modeling



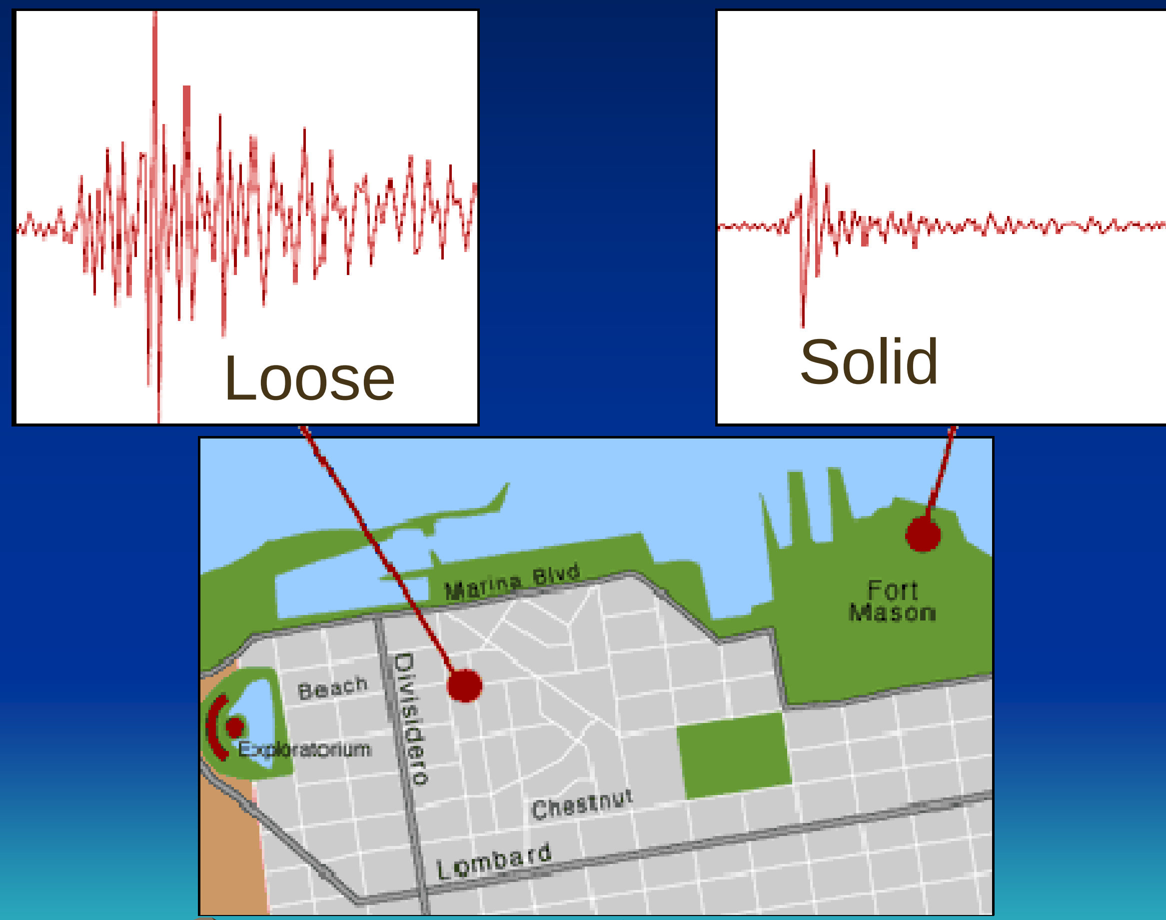
Bay Area Earthquake Analysis

Comparing Substrate Type with Observed Ground Motion

1) Solid Rock

2) Dry Loose Sediment

3) Water-saturated Loose Sediment



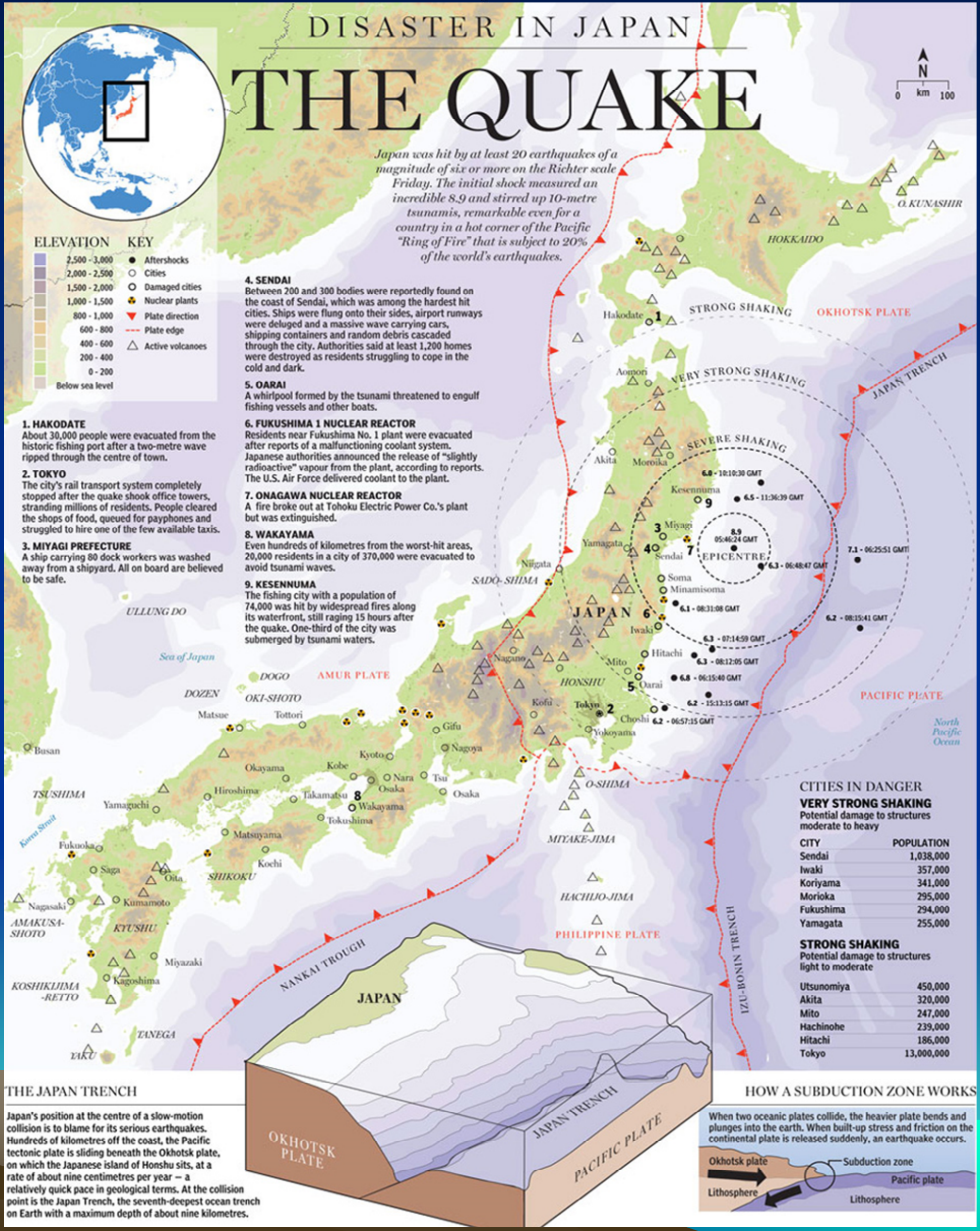
Recent Earthquake in Japan

1) Measured 9.0 on Richter Scale and lasted for over 4 minutes

2) One of the largest earthquakes ever recorded – biggest ever measured in Japan

3) Centered offshore along subduction zone thrust fault

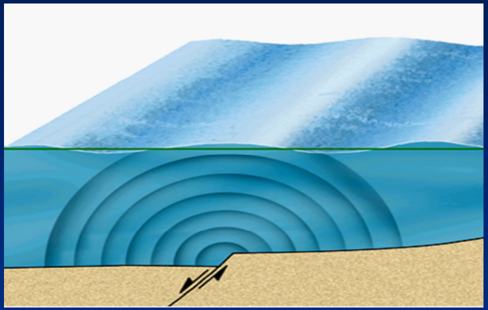
4) Caused super destructive tsunami waves

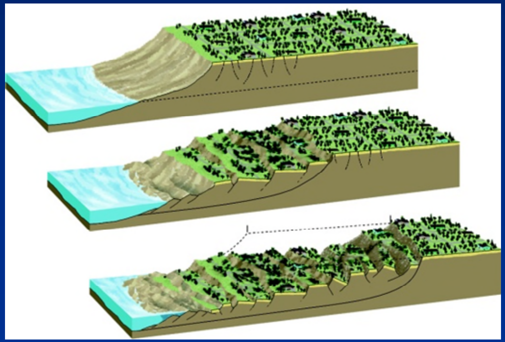


Origin of Tsunami

Tsunami can be generated by several means:

1) Seismic event





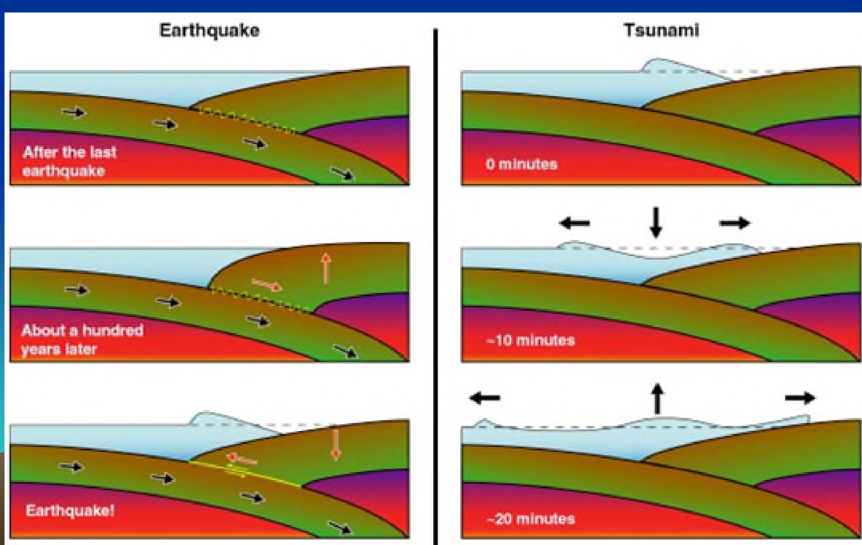
2) Coastal landslide

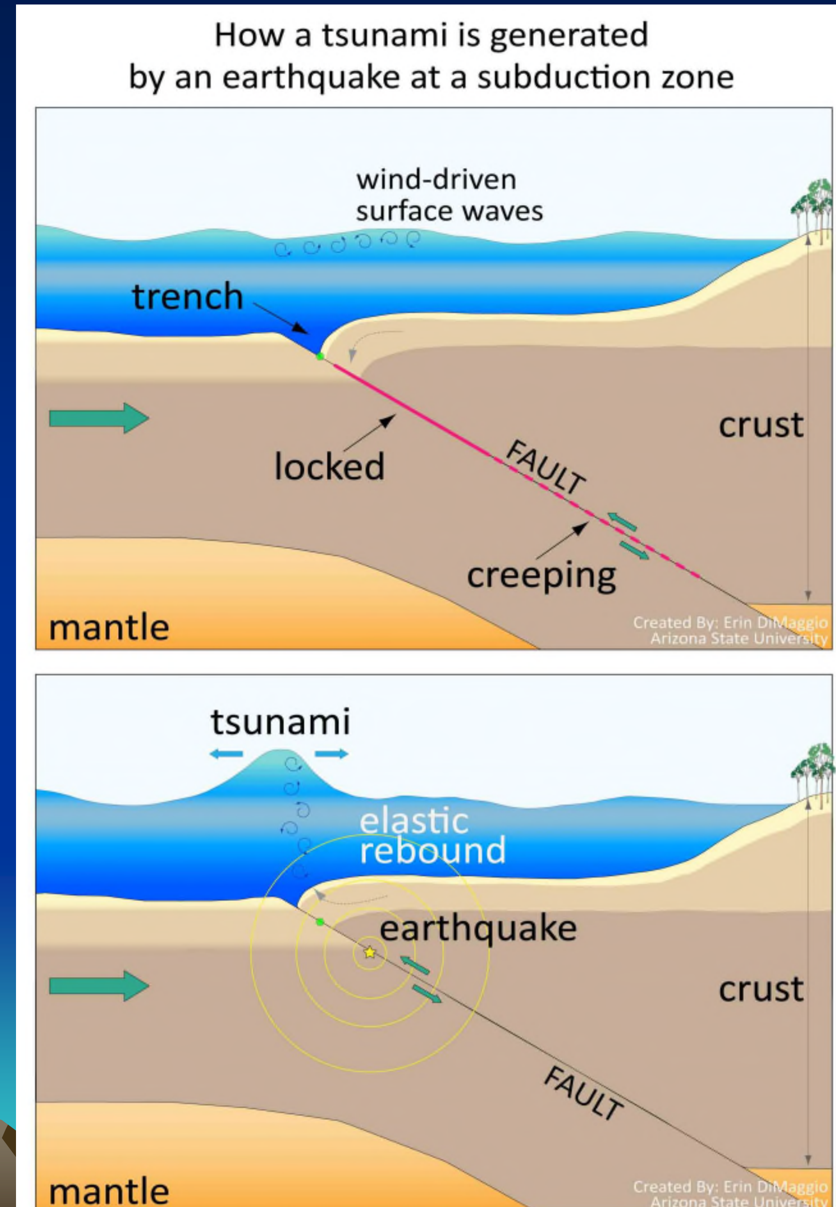
3) Volcanic eruption

4) Bolide ocean impact

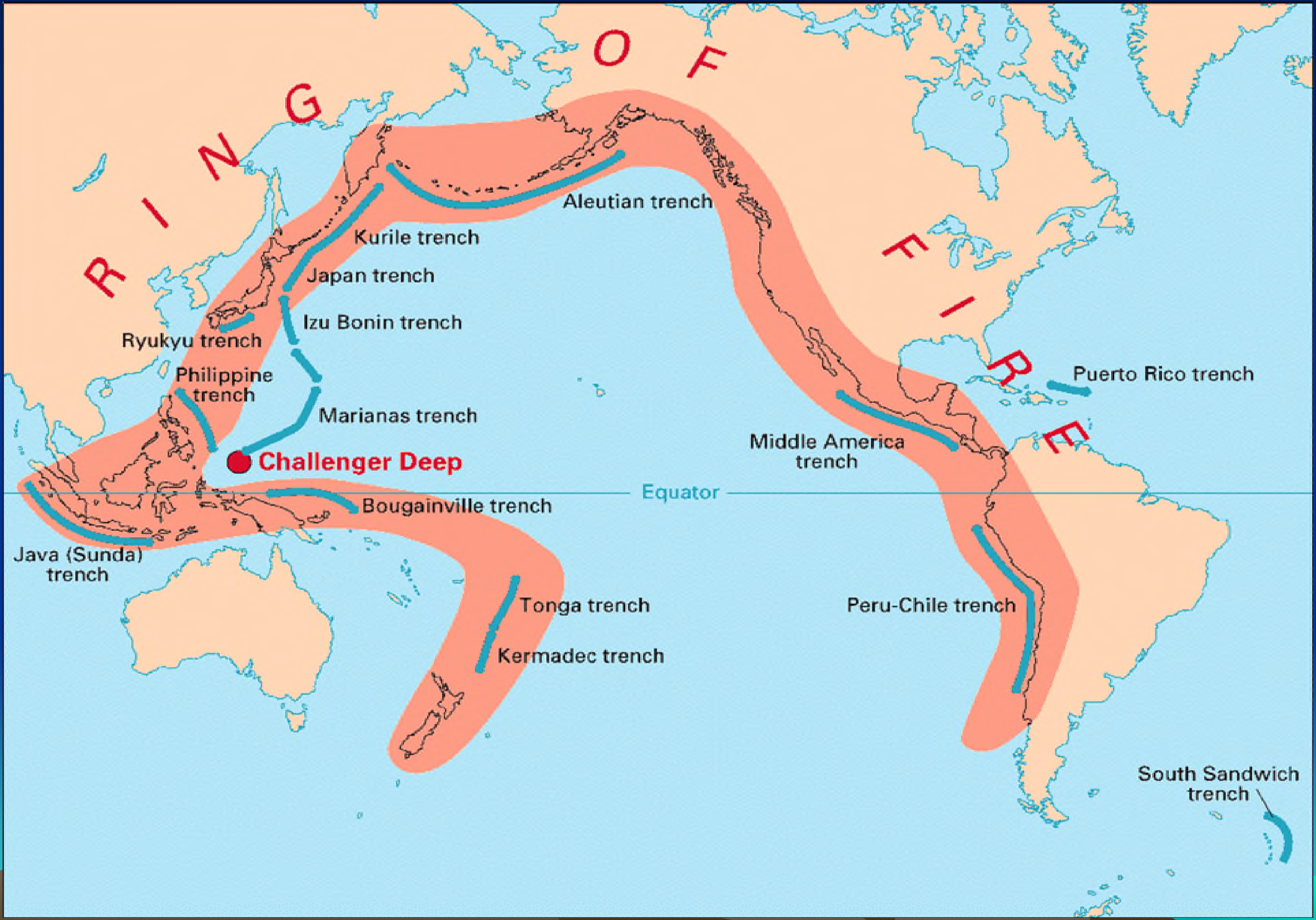
Formation of Seismic Sea Waves

- A seismic sea wave is generated by a rapid vertical displacement of the sea bottom during an earthquake
- Overlying water column is equally displaced, either up or down, depending on direction of the ruptured seafloor
- The influence of gravity on the ocean surface anomaly will cause water column oscillation resulting in a set of outwardly moving concentric tsunami waves



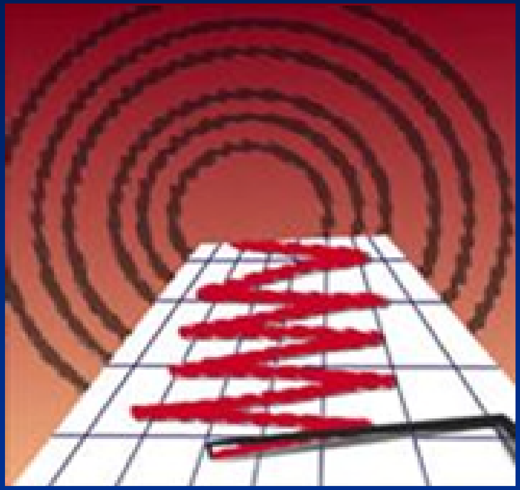


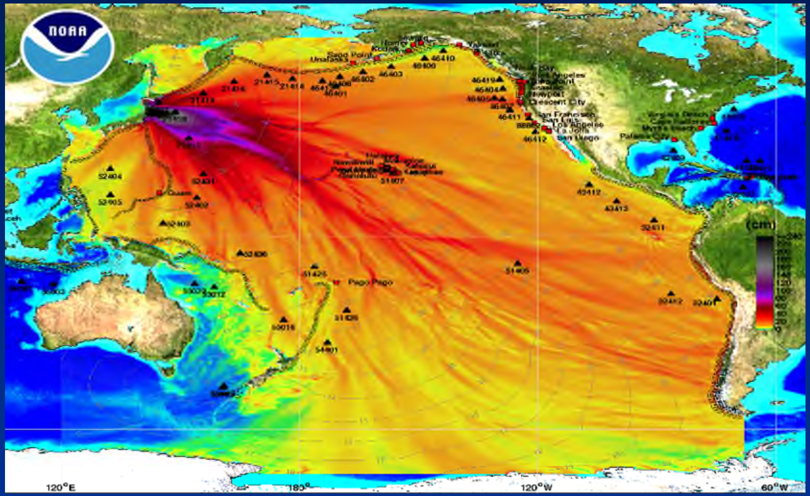
Pacific Rim – Tsunami Factory



Earthquake-Tsunami Combo

The Deadly One-Two Punch





Tsunami = Godzilla Wave?

ゴジラウェーブ

https://www.youtube.com/watch?v=23VflsU3kZE

https://www.youtube.com/watch?v=F1ZewAPl7L0

https://www.youtube.com/watch?v=k8IAqUNr6x4

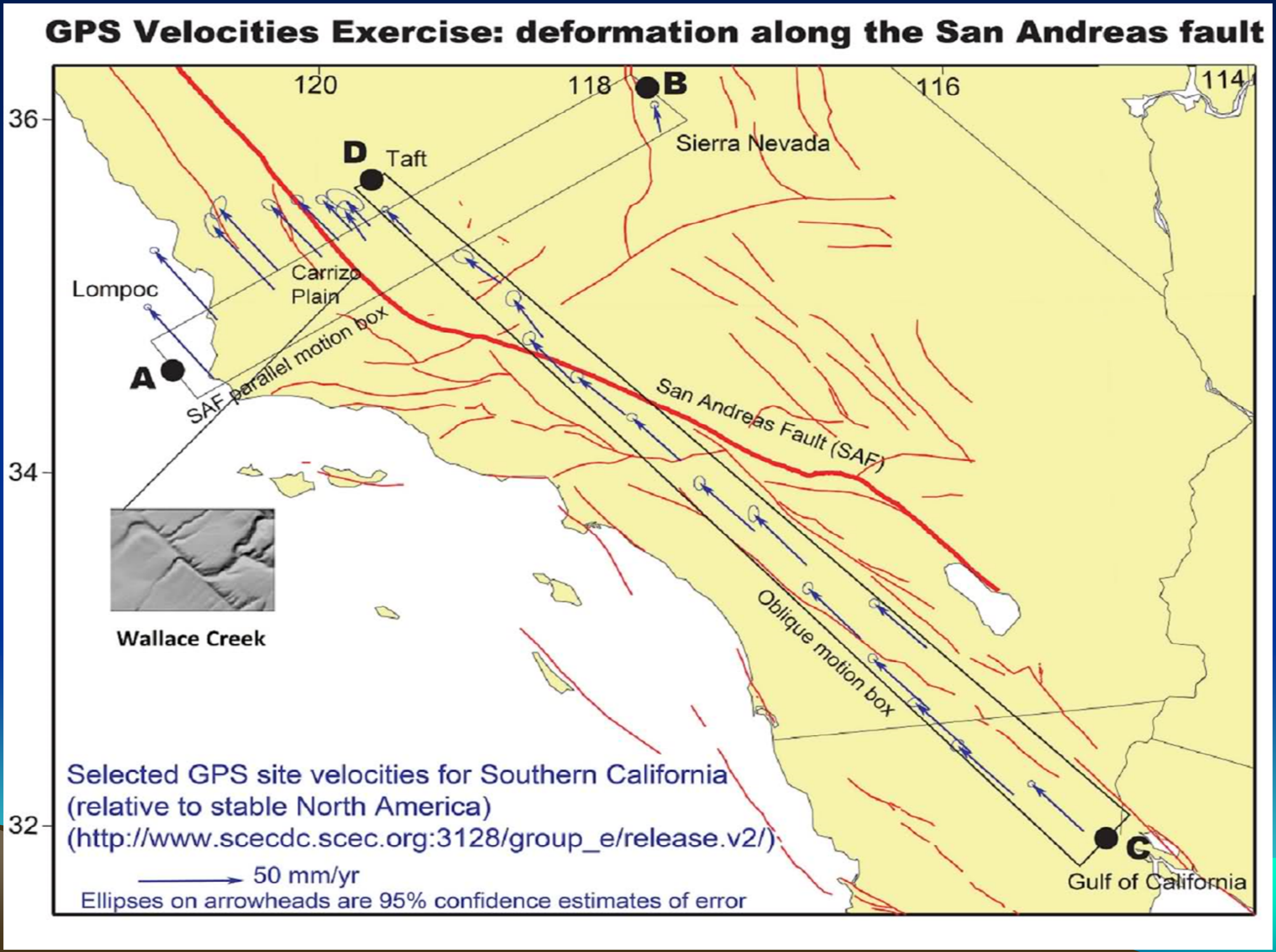
Earthquake Preparation and Mitagation

Earthquake Epicenter and Magnitude Internet Exercise

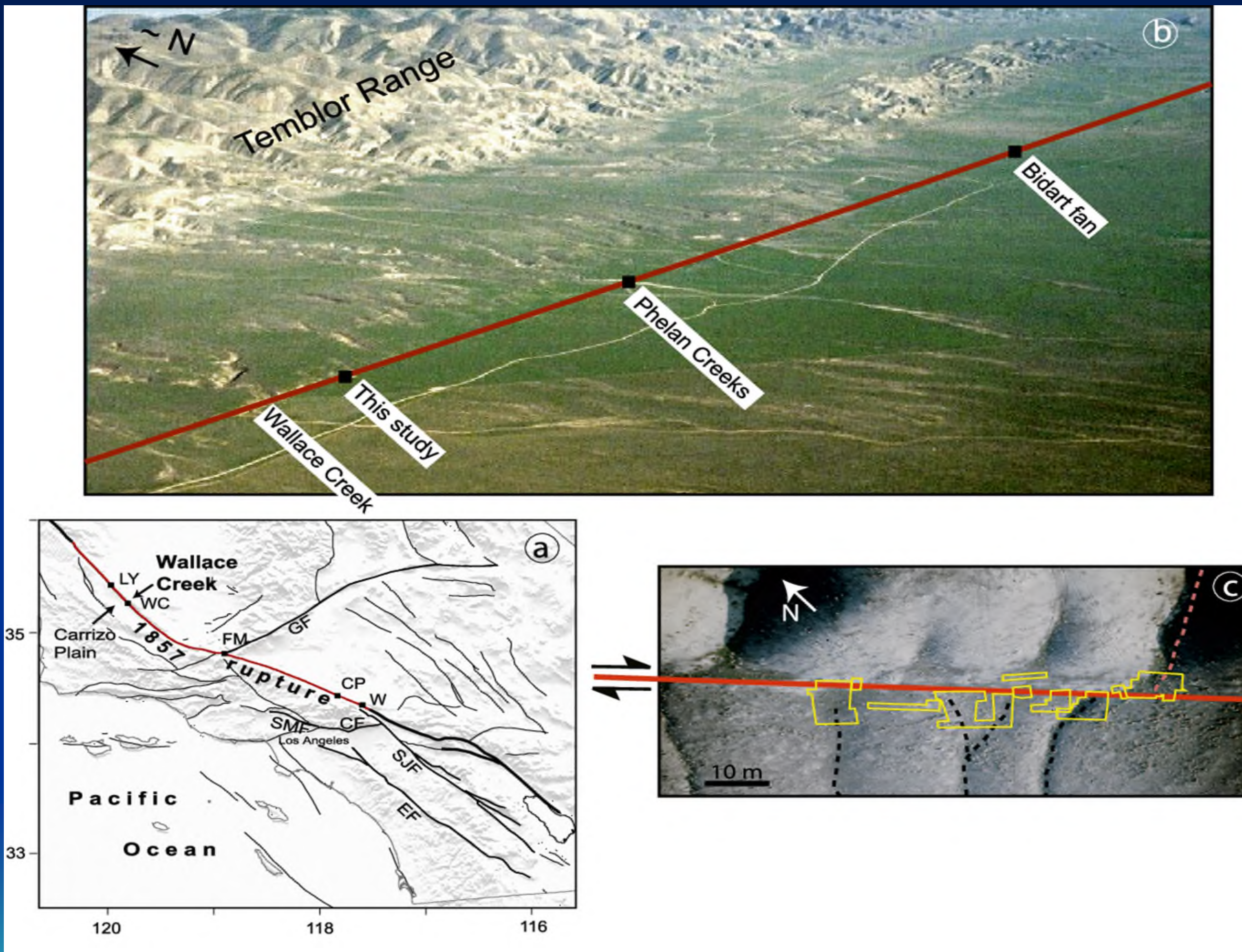
[Virtual Earthquake Internet Exercises]

Virtual EQ Certificate

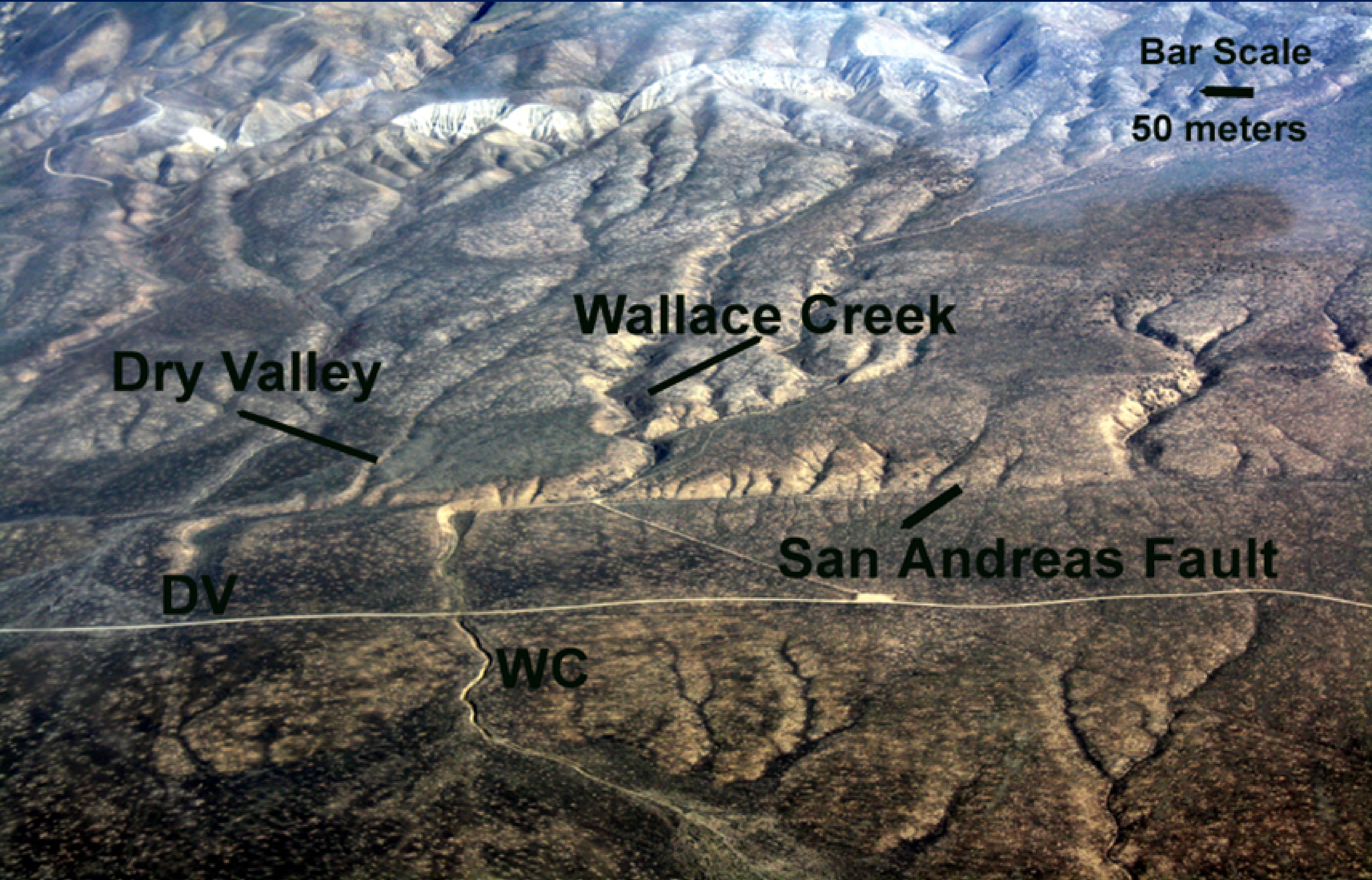
San Andreas Fault – Wallace Creek



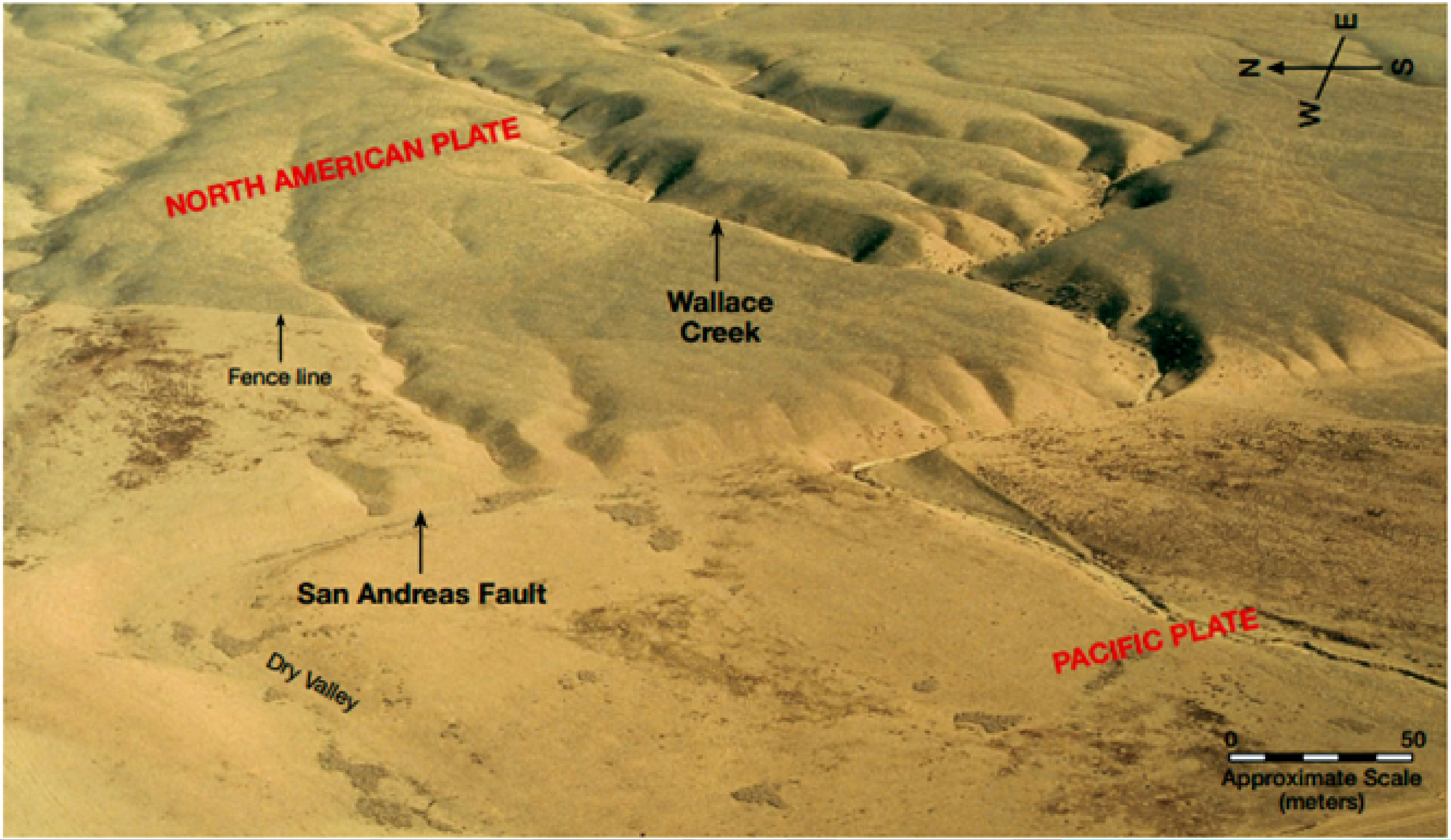
San Andreas Fault – Wallace Creek



San Andreas Fault – Wallace Creek

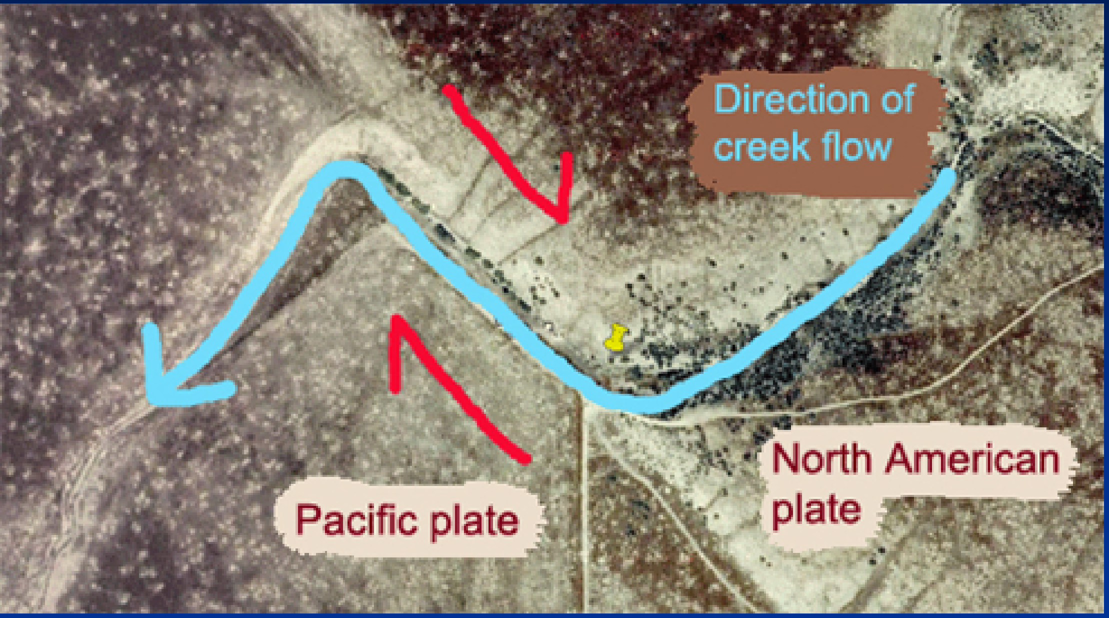


San Andreas Fault – Wallace Creek



San Andreas Fault – Wallace Creek

San Andreas Fault – Wallace Creek



Dextral Fault Movement as Shown by Apparent Creek Offset

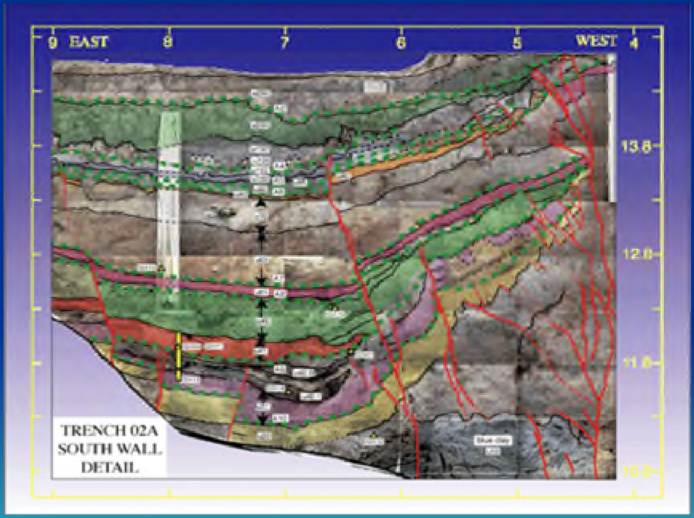
Using Trenching to Interpret Faulting History

1) Trench perpendicular to active fault zone along a stream channel

2) Trace and record all rupture surfaces and offset bedding and rock units

3) Date ruptured stream deposits using carbon 14 method on charcoal grains

4) Correlate offset events to ruptured layers using cross-cutting principle and C-14 dates.



Fault Trenching Studies

Head's-Up for Next Week's Lab

Structural Geology and Geologic Maps

Next Week's Lab Activities

1) Analyze structural block diagrams
2) Construct structural diagrams
3) Take compass bearing

Preparation

Recommended Pre-Lab Web Activities (Click on Link)

1) Construction of topographic and bathymetric profiles
2) Plotting map locations and taking bearings
3) World ocean bottom features and Tectonic plate boundaries