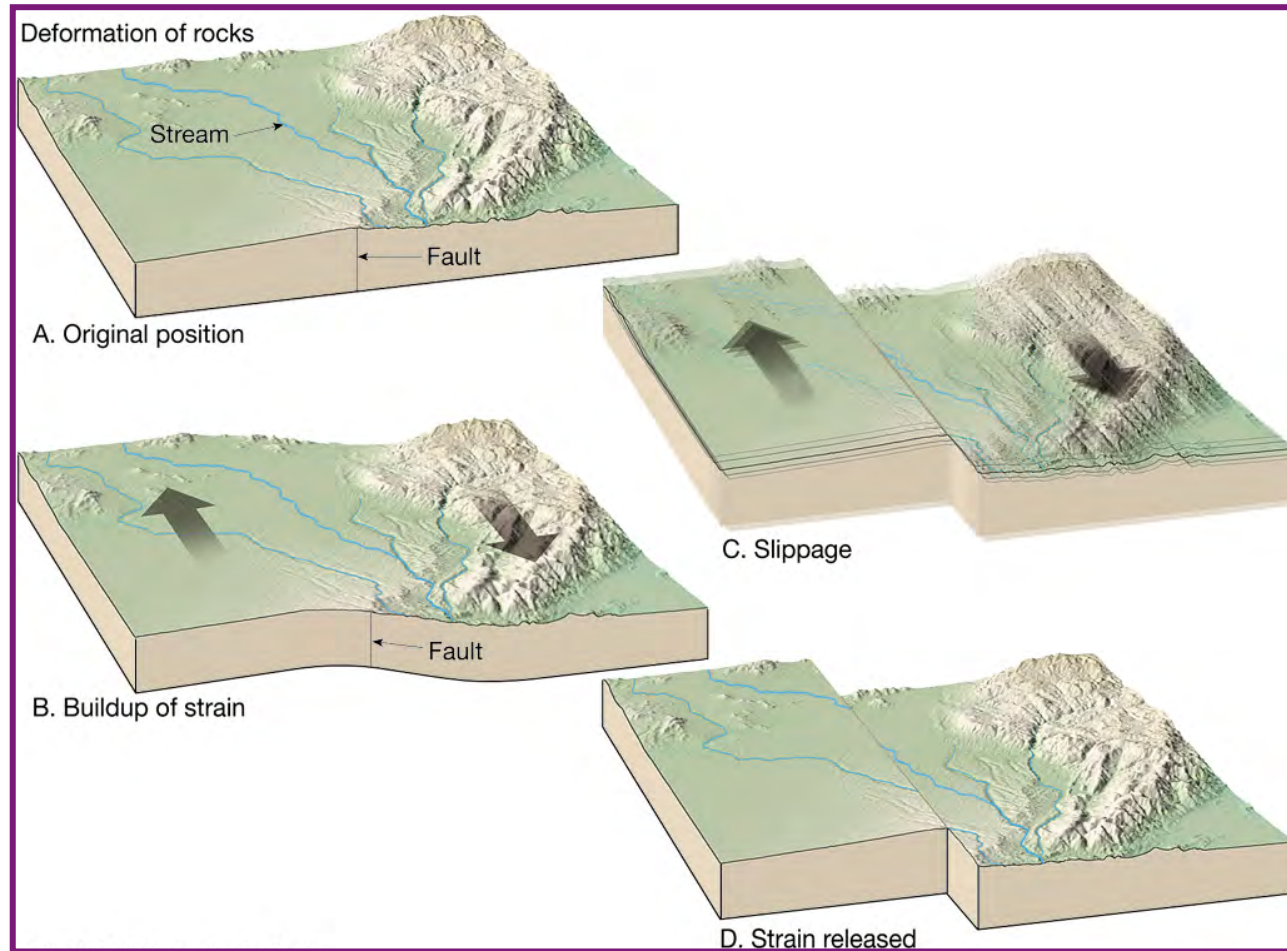


Earthquake Machine

Stick-slip: Elastic Rebound Theory Jerky motions on faults produce EQs

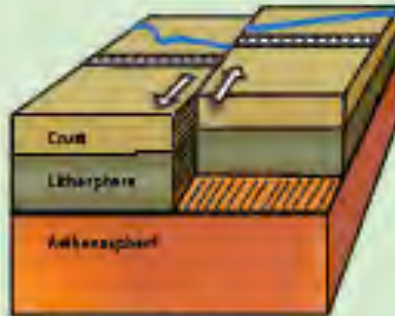


Three Fs of earthquakes: forces, faults, and friction.
Slow accumulation and rapid release of elastic energy.

Three Basic Types of Plate Boundaries

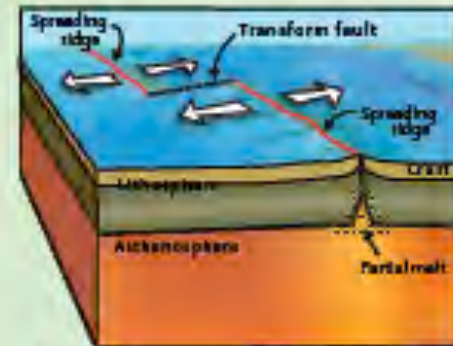


Transform Boundaries



Strike slip faults result from two plates moving horizontally in opposite directions (ex: San Andreas Fault, California).

As surrounding plates are driven by deep forces to move apart or crunch together, the in-between areas are pushed around on the surface. This forces them to slide past each other horizontally.



Transform faults are where two plates are moving away from a spreading ridge and fracture zones develop (ex: ocean floor)

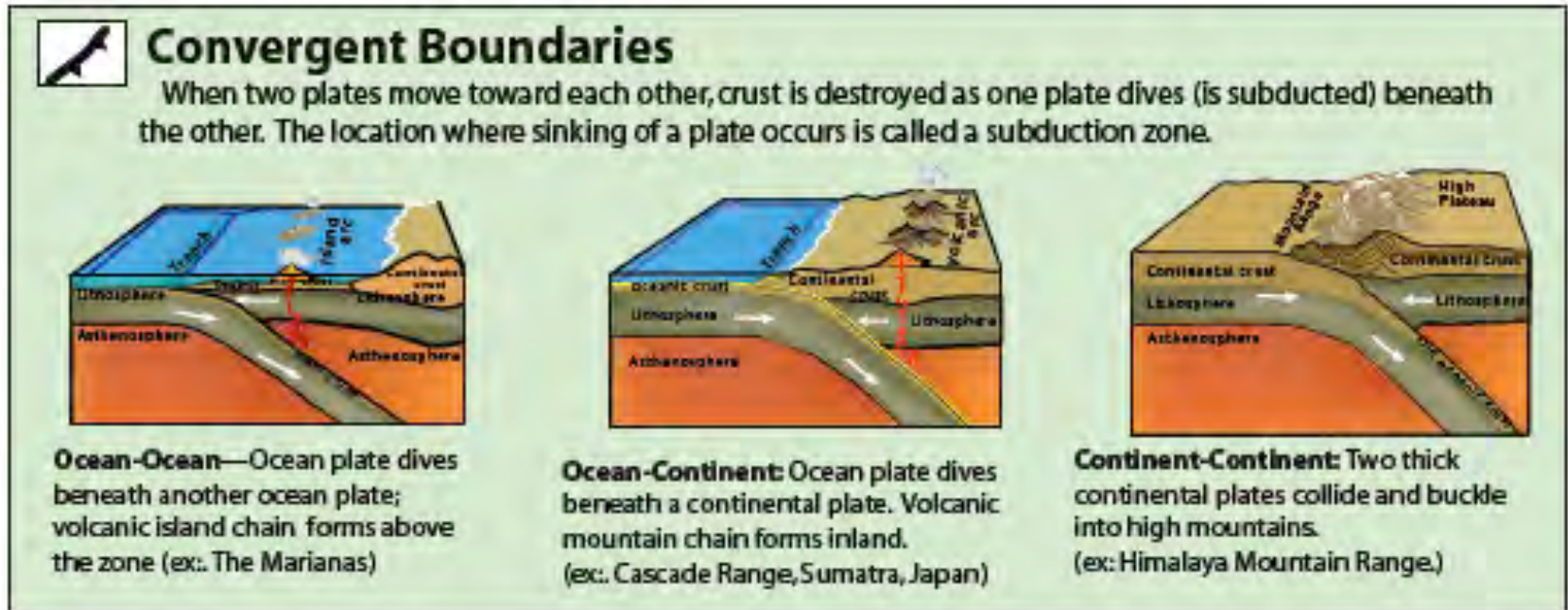
Transform (e.g. San Andreas Fault)
Strike-slip faulting
Magnitudes generally ≤ 7

Three Basic Types of Plate Boundaries



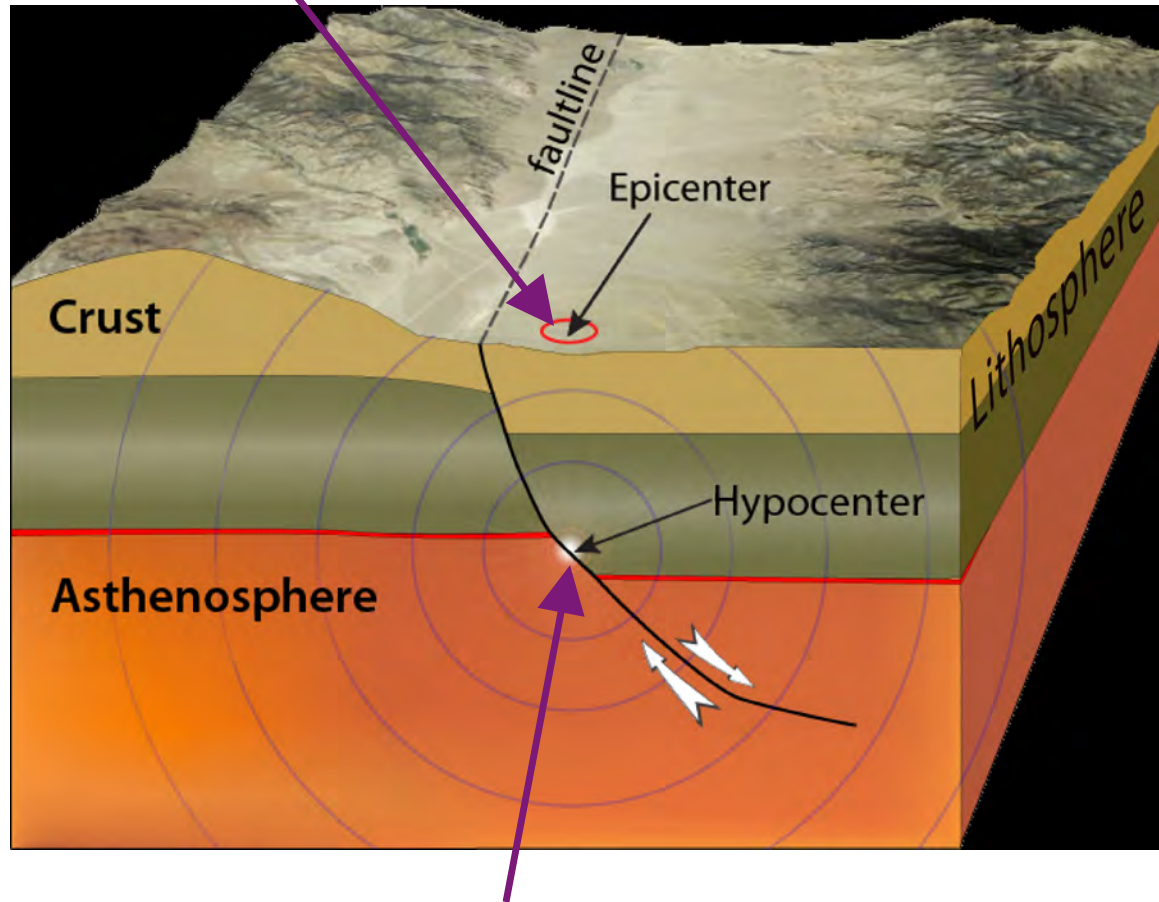
Divergent (e.g. spreading ocean ridge)
Normal faulting Magnitudes ≤ 6

Three Basic Types of Plate Boundaries



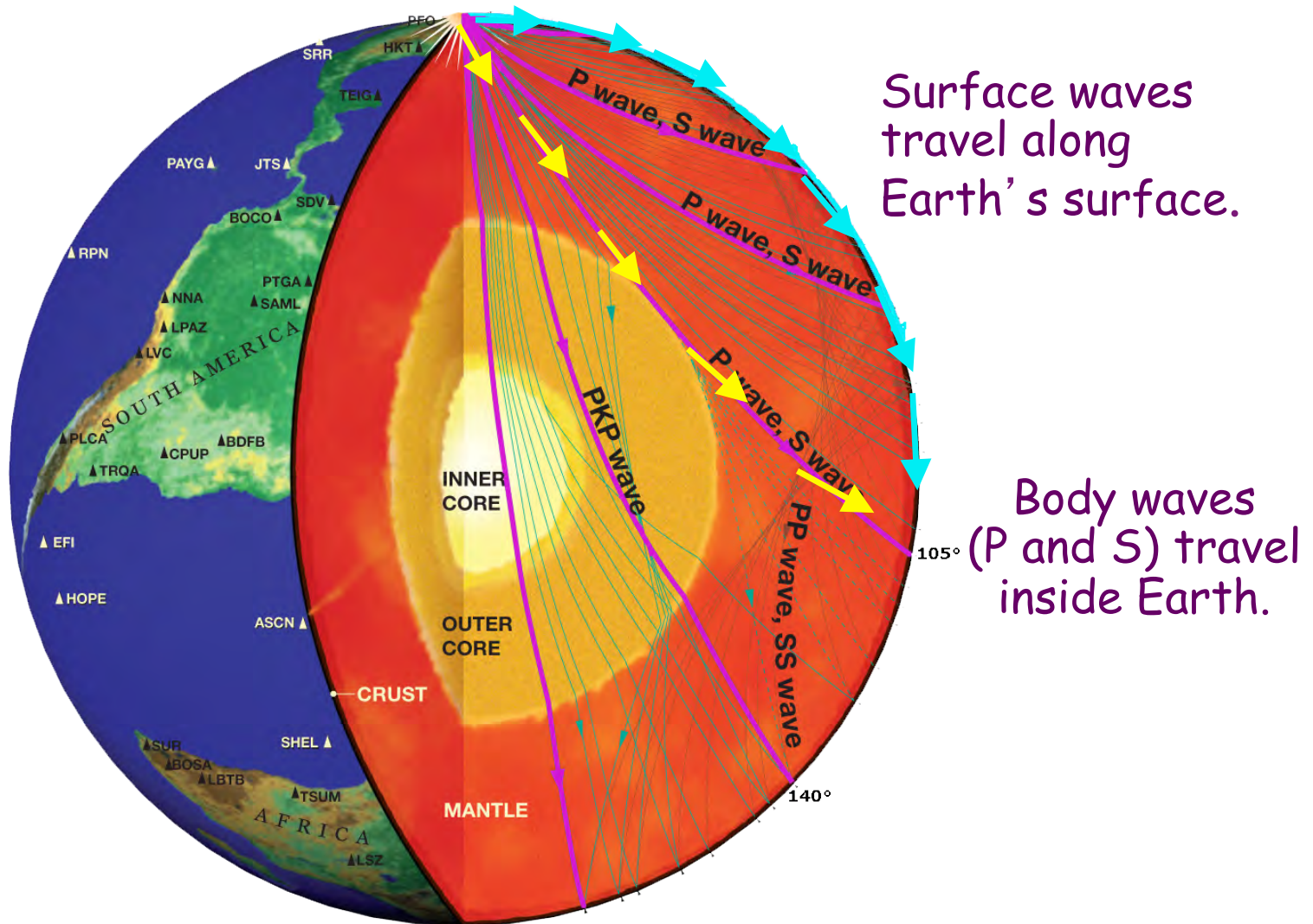
Convergent (e.g. subduction zone)
Magnitudes up to 9
Depths to 700 km

Epicenter: Location on Earth's surface directly ABOVE the EQ.



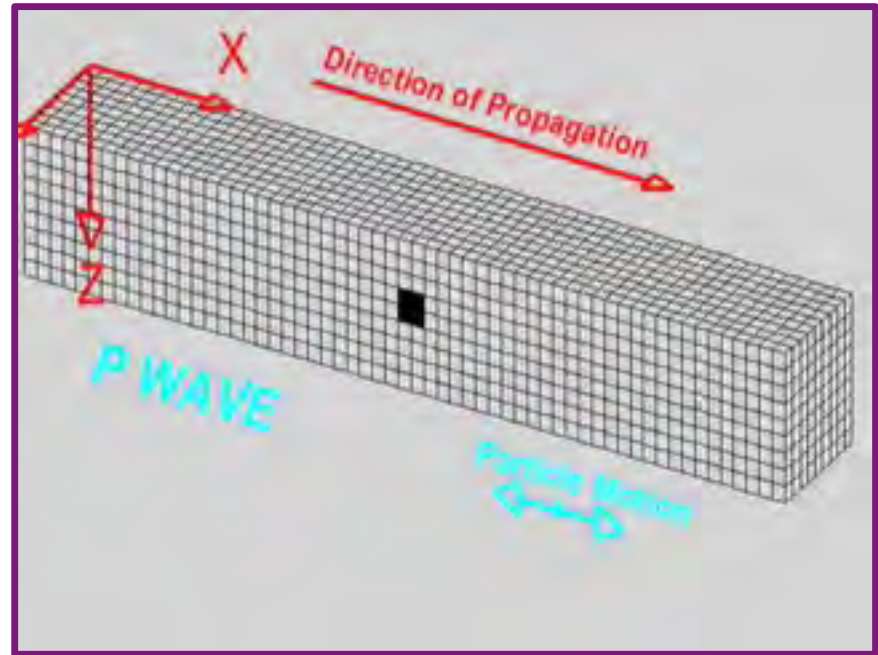
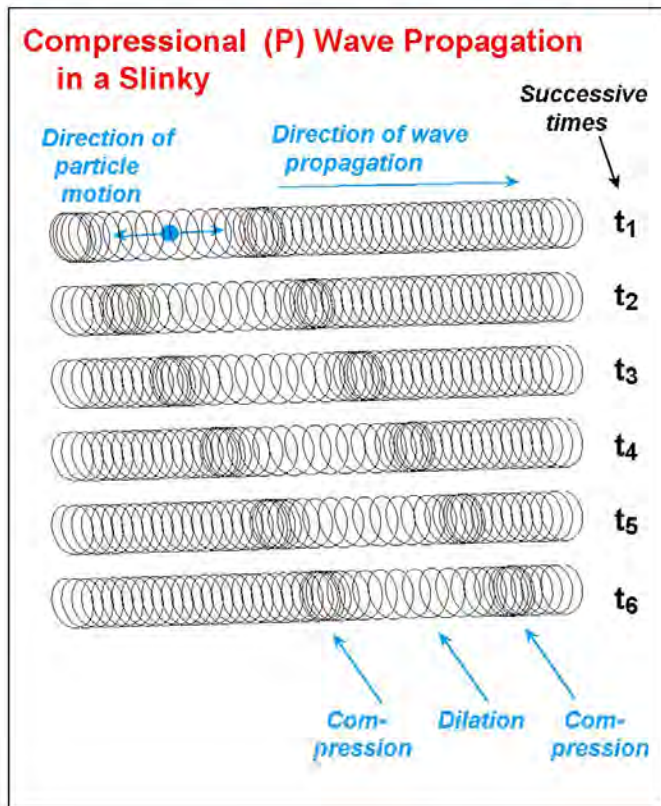
Hypocenter or Focus: Point WITHIN Earth where EQ occurred.

Body Waves and Surface Waves



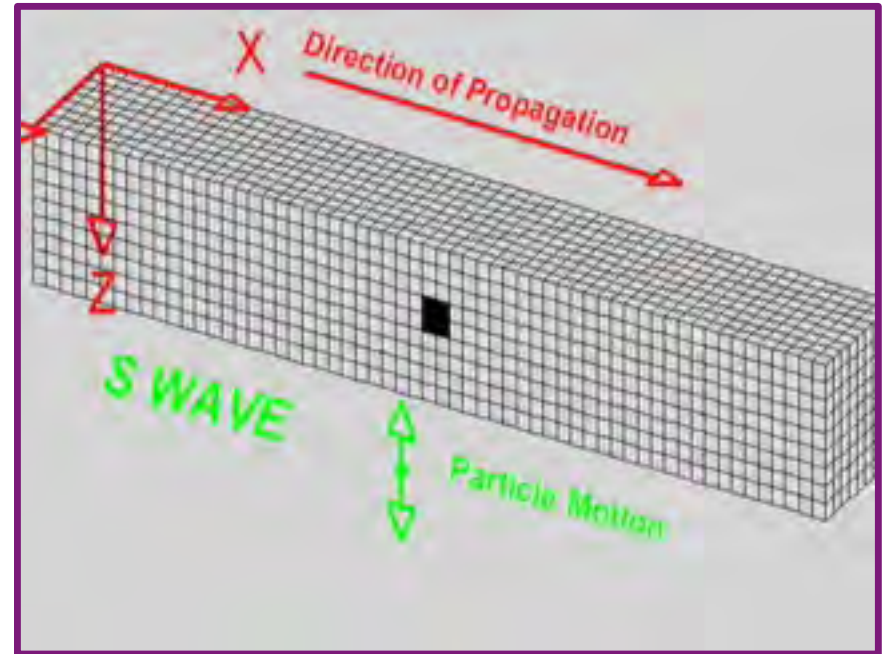
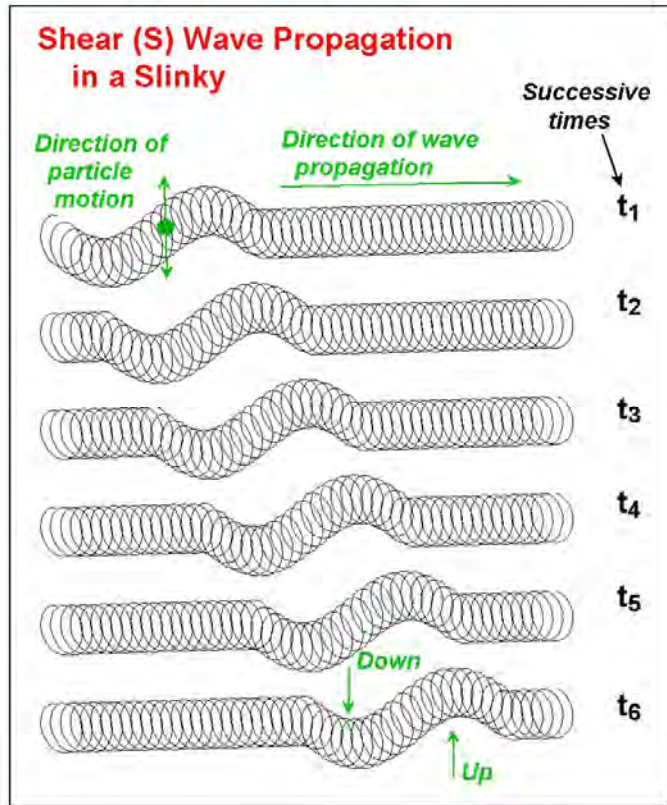
While P- and S- waves radiate outward in all directions, surface waves travel along the surface of the earth and decrease in amplitude with depth.

P Waves Are Pressure Waves



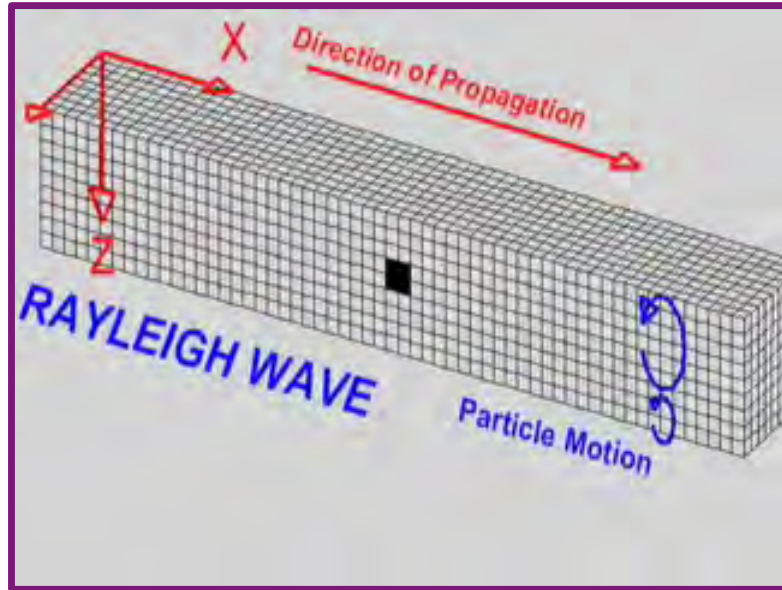
P waves are fastest seismic waves.

S Waves Are Shear Waves



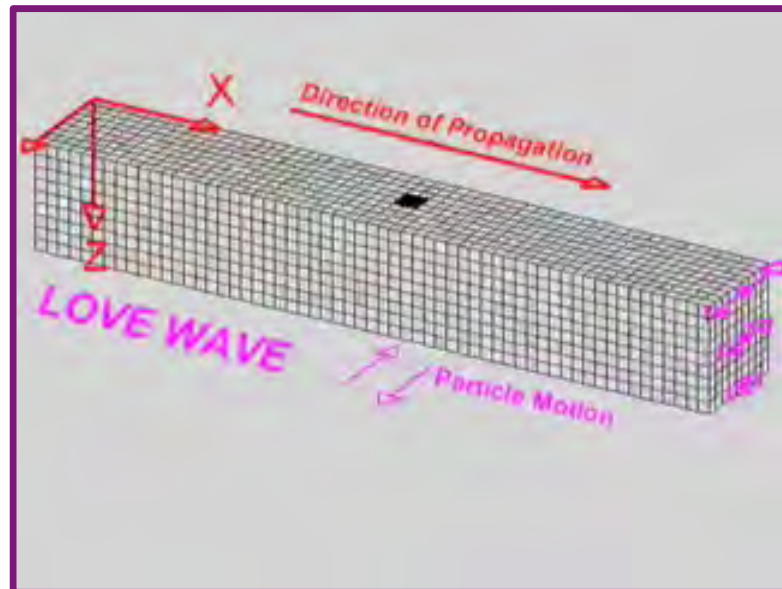
S waves are slower than P waves but faster than surface waves.

Surface Waves



Amplitude greatest at surface, decreasing with depth.

Slower than P or S waves.

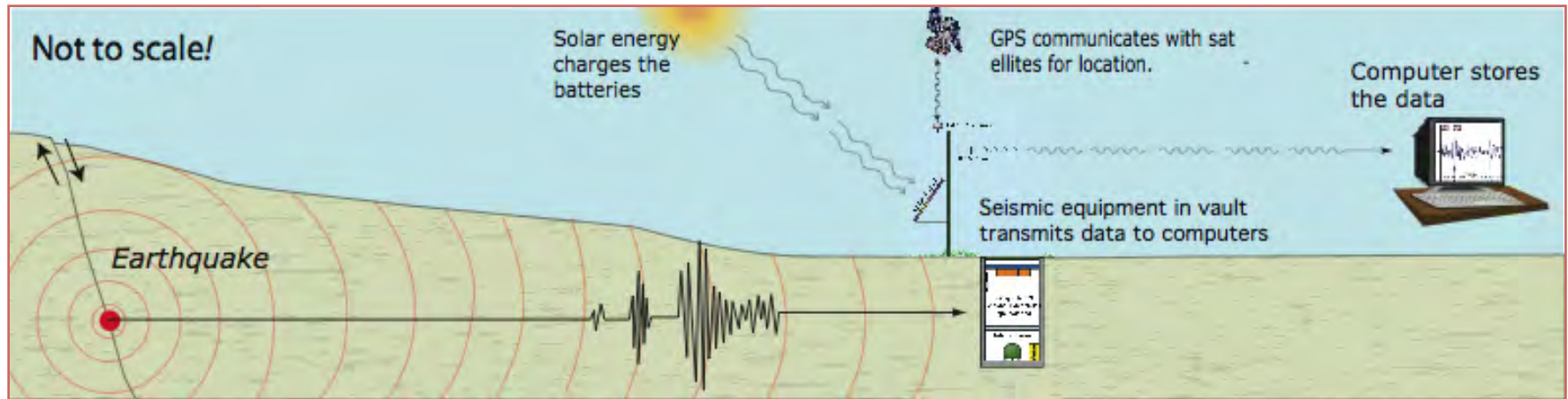


Often are largest amplitude and most damaging seismic waves.

Human Waves
Modeling P and S Waves

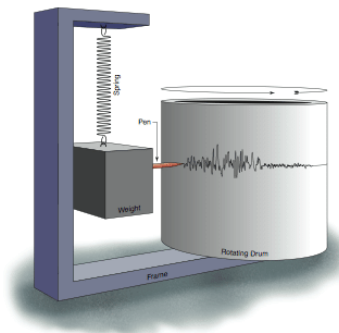
THEN Seismic Slinky

How do scientists detect earthquakes?

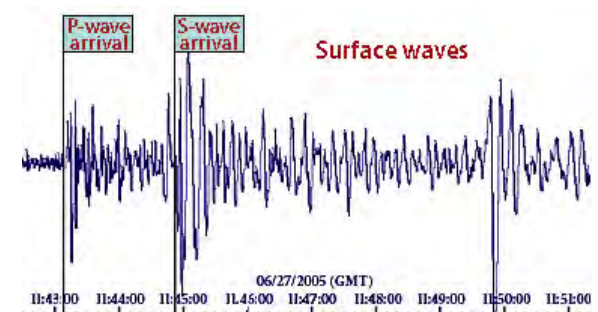


When an earthquake occurs the seismic waves travel through the Earth to the seismic station where the information is transmitted to distant computers.

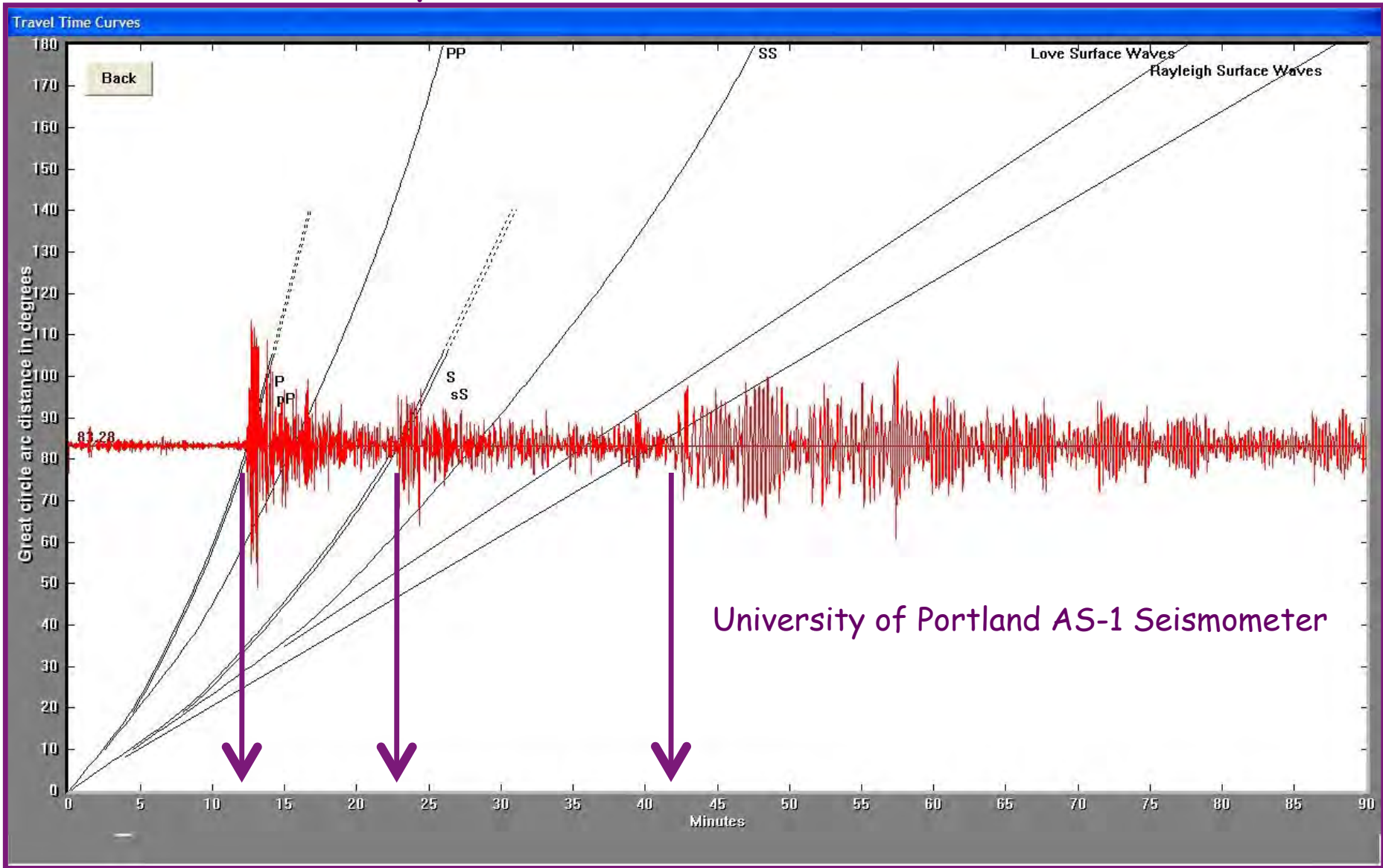
A seismograph detects and records EQs.



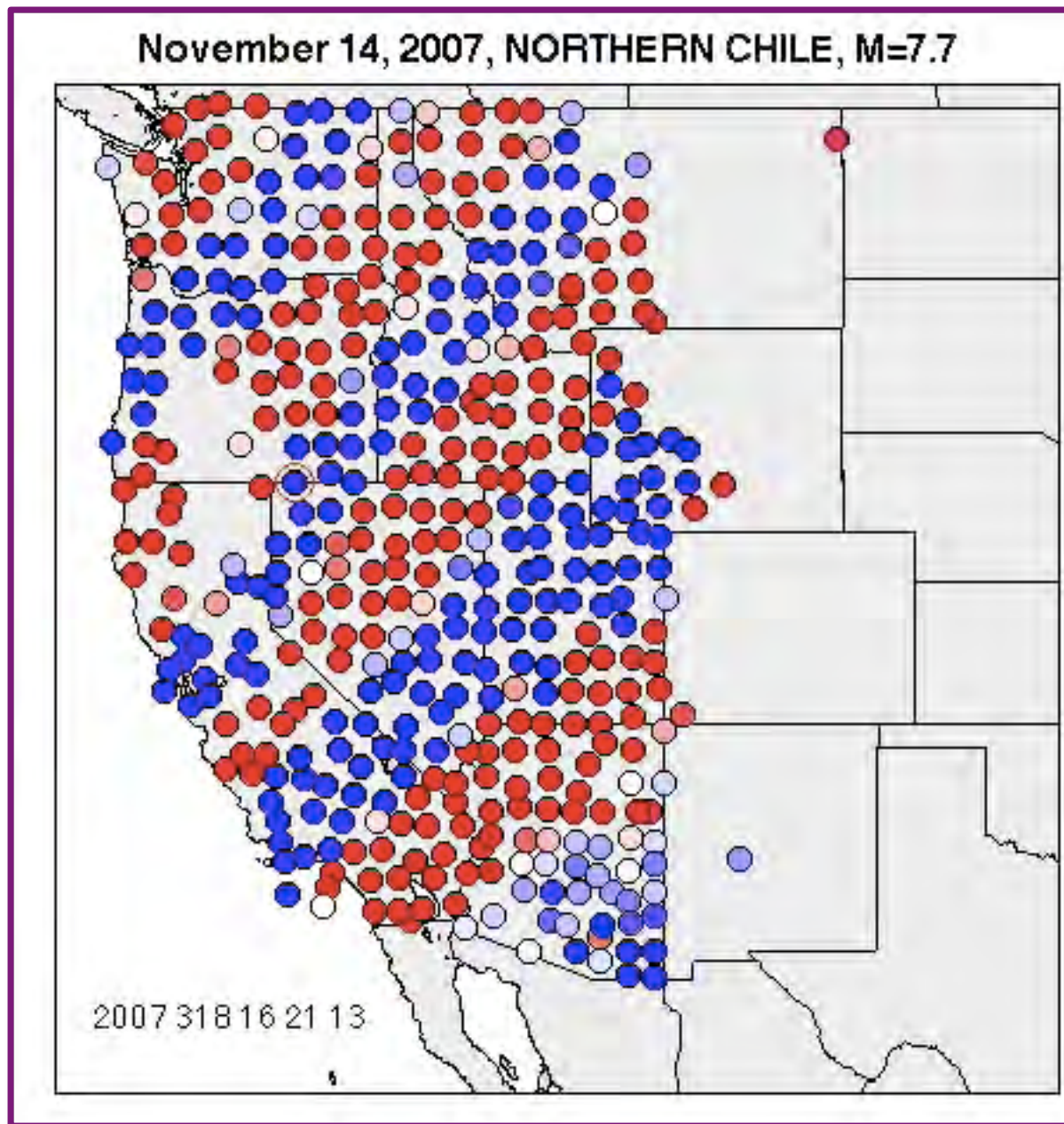
A seismogram is the EQ record.



M7.7 Earthquake off Northern Chile Nov 14, 2007

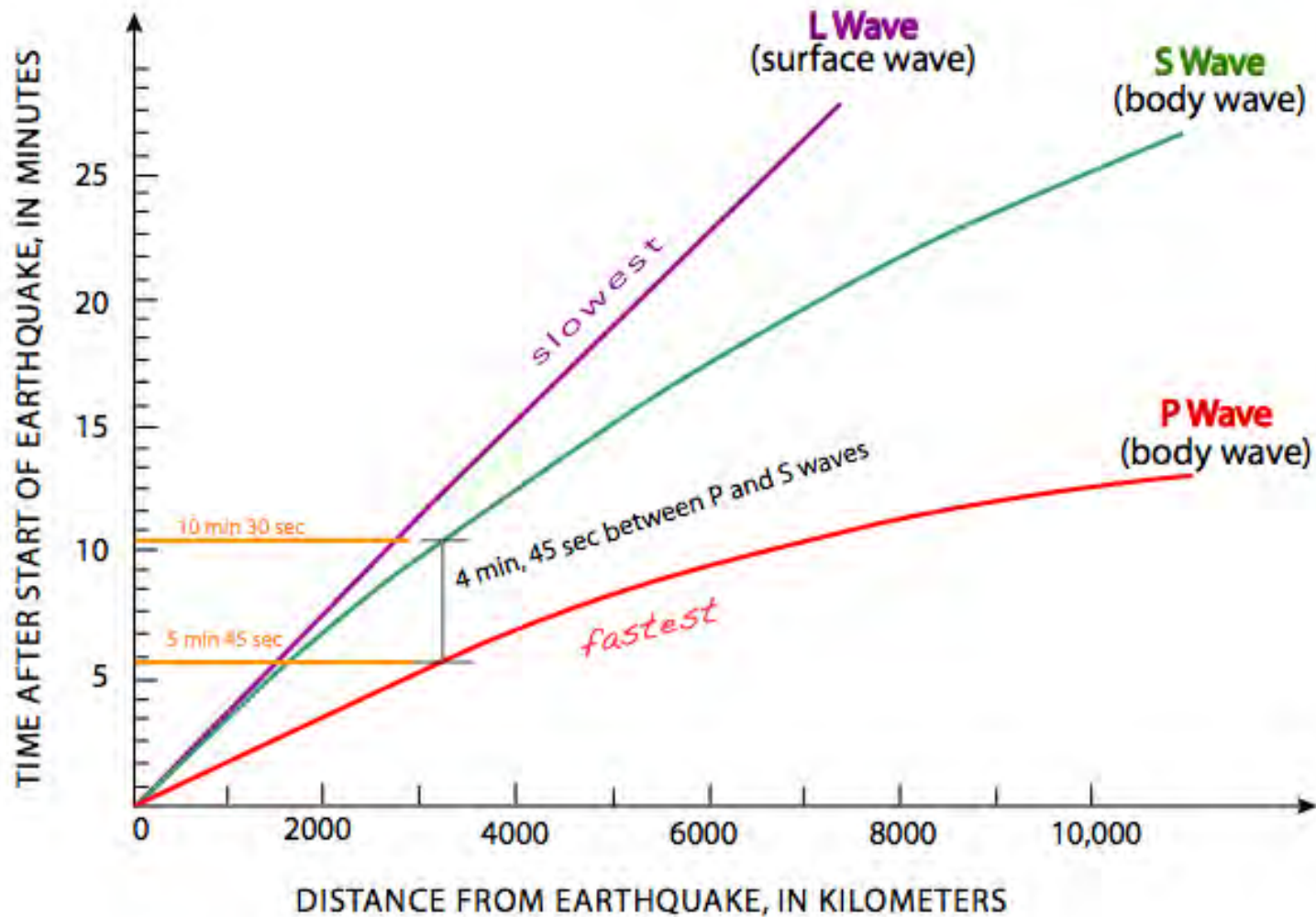


P waves	S waves	Surface waves
~12 min	~22 min	~42 min
~720 sec	~1320 sec	~2500 sec



Seismic Waves from Chile Earthquake

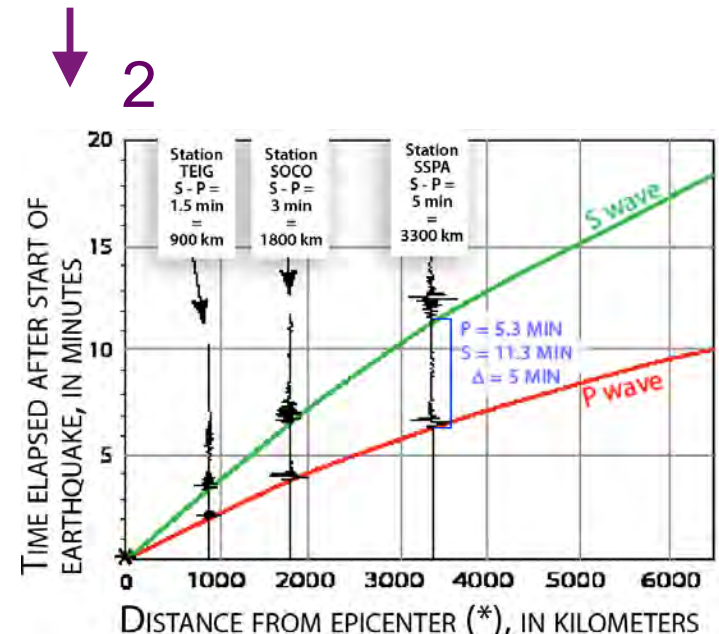
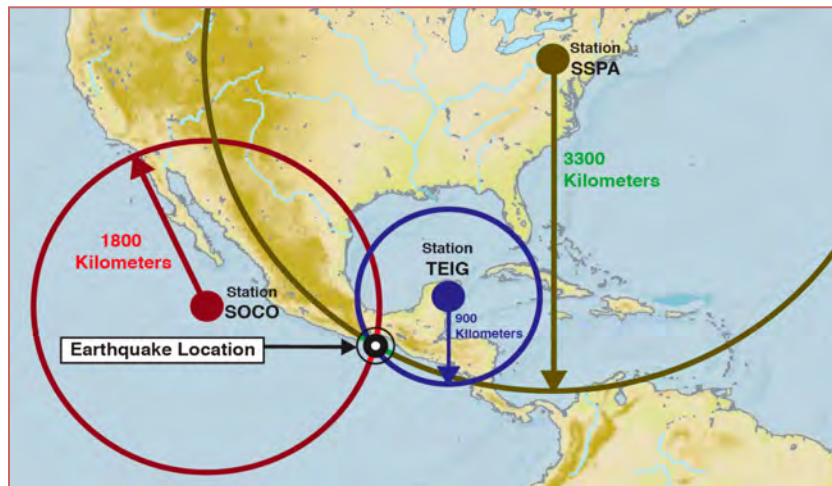
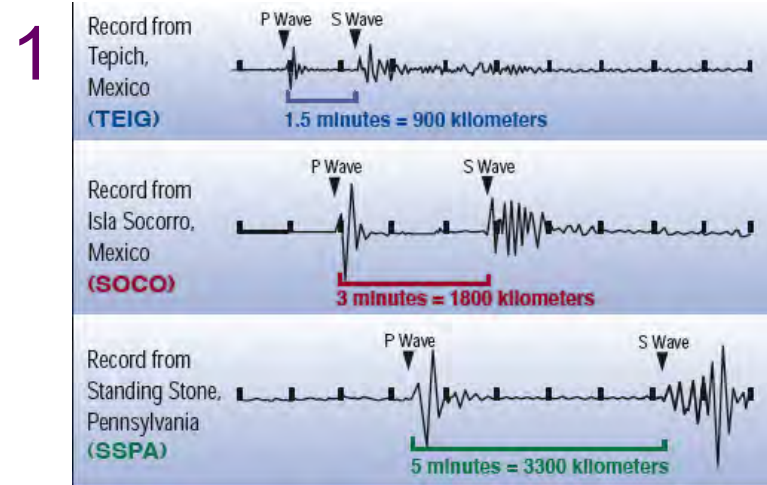
Distance of EQ from seismometer?



Determined from S arrival time - P arrival time.

Locating an Earthquake

- 1) Determine distance of EQ from three seismic stations by calculating the S minus P arrival times.
- 2) Plot them on the travel-time graph.
- 3) Intersection of the circles gives the location.



Moment Magnitude

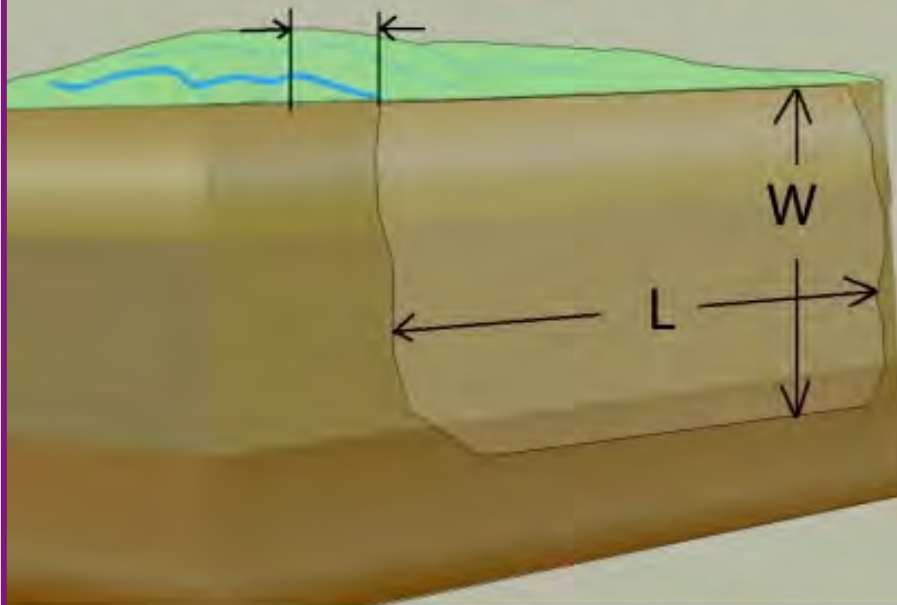
Pasta Quake

Seismic moment: $M_o = \mu * D * A$

μ = rock rigidity (constant for given material)

D = distance that one block slips relative to the other block

A = area that ruptured between the blocks

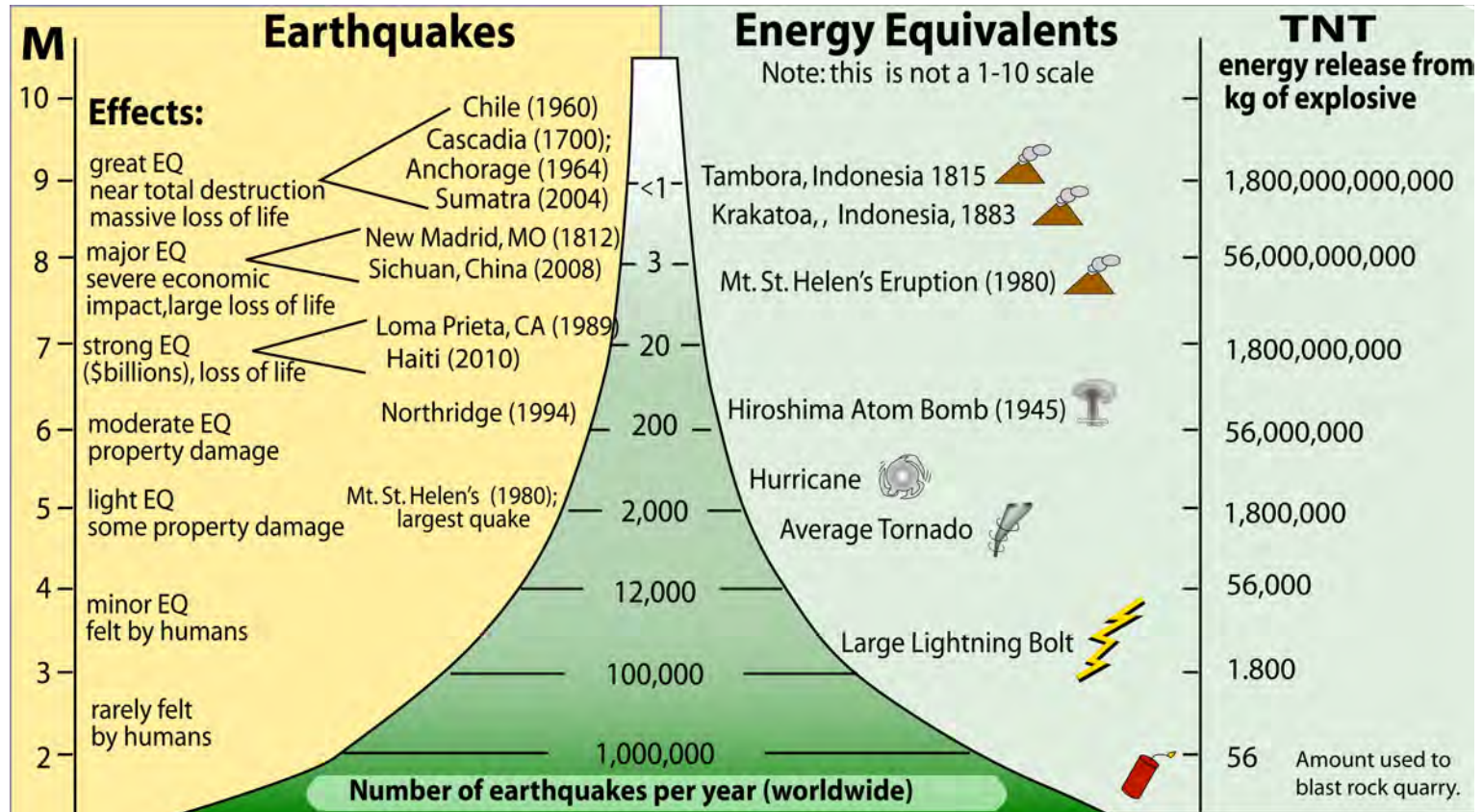


00:02:45



Magnitudes and Energy of Earthquakes

Annual Numbers of EQs



MOST of the energy is released by around 20 magnitude-7 and larger EQs every year.

Earthquake Intensity: Violence and Effects of Ground Shaking.

- I. Not felt.
- II. Felt only by a few people.
- III. Felt noticeably by people indoors.
- IV. Felt indoors by many, outdoors by few people.
- V. Felt by nearly everyone; many awakened.
Some dishes, windows broken.
- VI. Felt by all; some heavy furniture moved.
- VII. Considerable damage in poorly-built structures; No damage to well-built structures.
- VIII. Great damage to poorly-built structures; considerable damage to ordinary buildings.
- IX. Damage great in substantial buildings, with partial collapse.
- X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed.
- XI. Few masonry structures remain standing; Bridges destroyed.
- XII. Damage total.

Magnitude/Intensity Comparison

Intensities typically observed at locations near epicenter.

Magnitude	Typical Maximum Modified Mercalli Intensity
1.0 - 3.0	I
3.0 - 3.9	II - III
4.0 - 4.9	IV - V
5.0 - 5.9	VI - VII
6.0 - 6.9	VII - IX
7.0 and higher	VIII or higher

Earthquake Intensity: Violence and Effects of Ground Shaking.

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC (%g)	<17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL (cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X

A table of intensity descriptions with the corresponding peak ground acceleration (PGA) and peak ground velocity (PGV) values used in USGS ShakeMaps.

USGS ShakeMap Scientific Background

<http://earthquake.usgs.gov/earthquakes/shakemap/background.php>

Earthquake Intensity: Violence and Effects of Ground Shaking.

What controls Intensity?

Magnitude—More energy released.

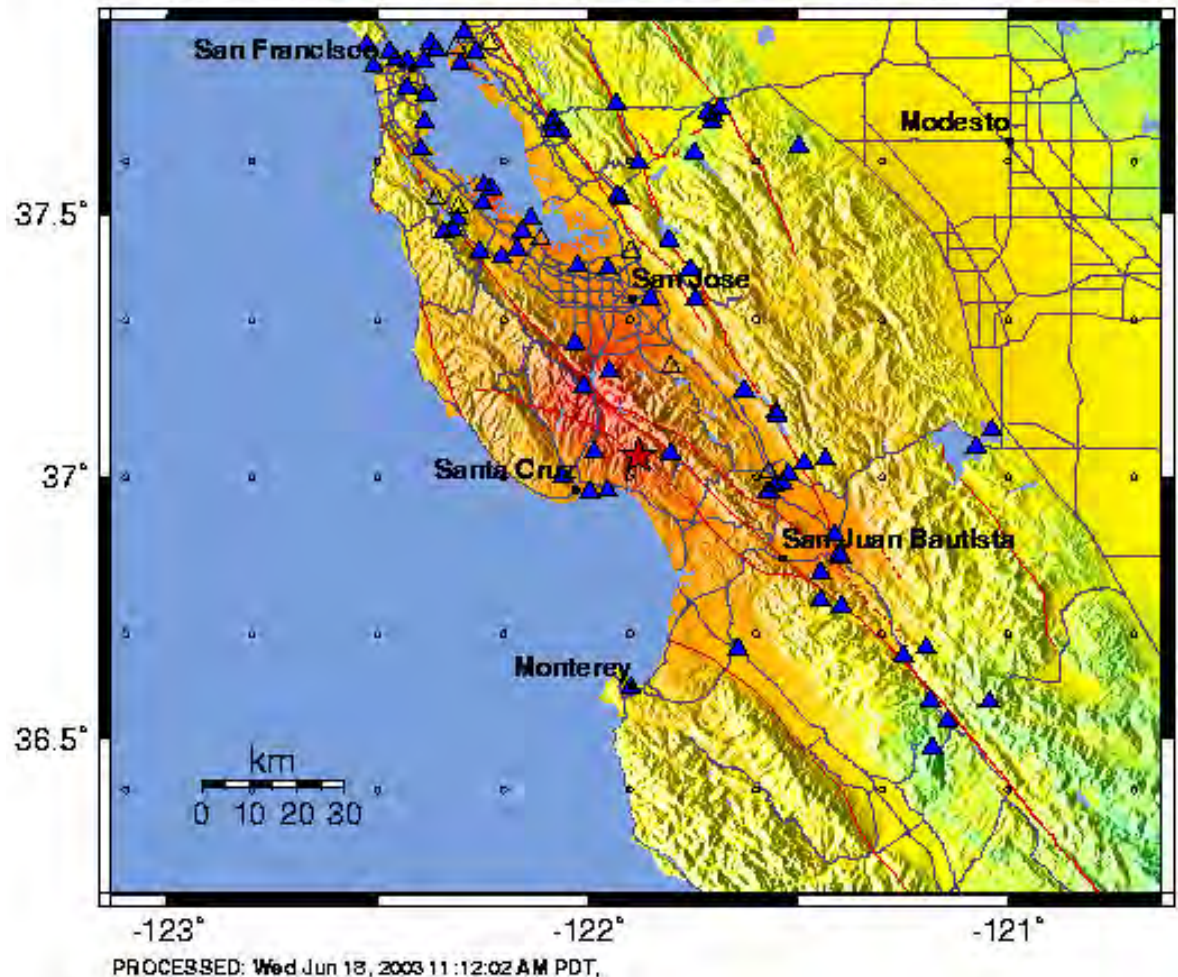
Distance—Shaking decays with distance.

Depth—Deeper EQ yields less shaking at the surface.

Geology—Weak sediments can amplify shaking.

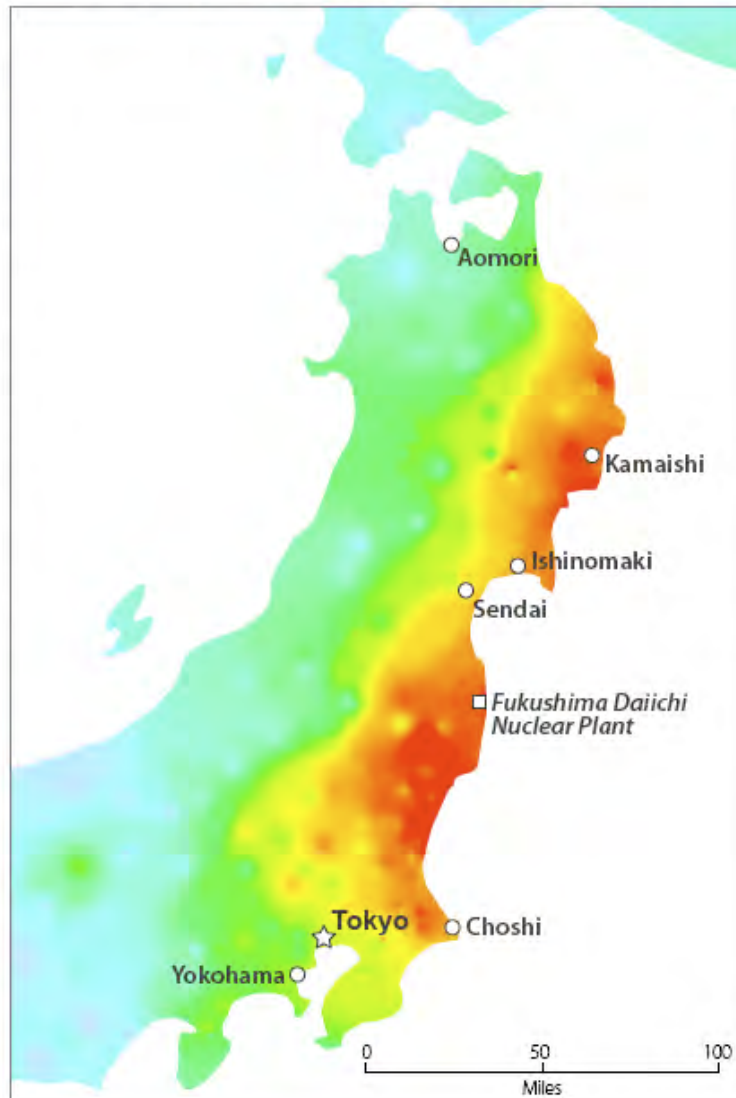
Building style

Duration of shaking.

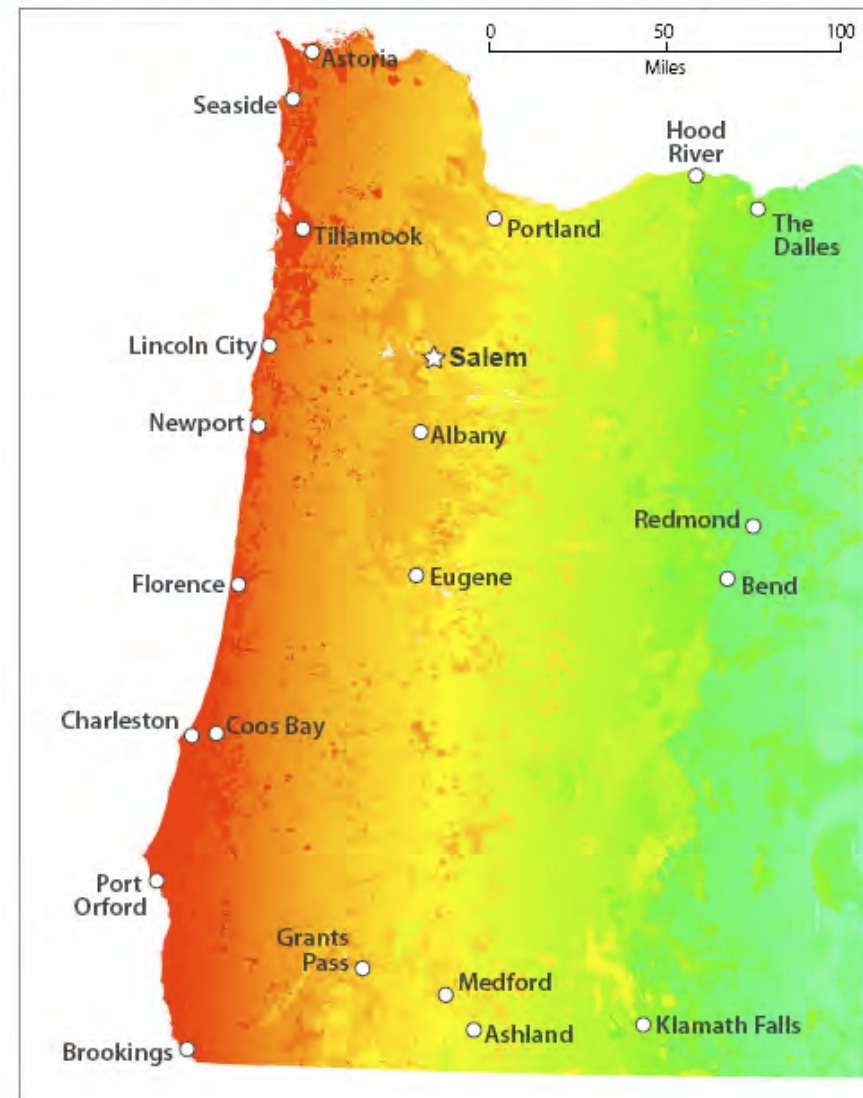


PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC (%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL (cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

ShakeMap for March 11, 2011 Tōhoku M9 earthquake



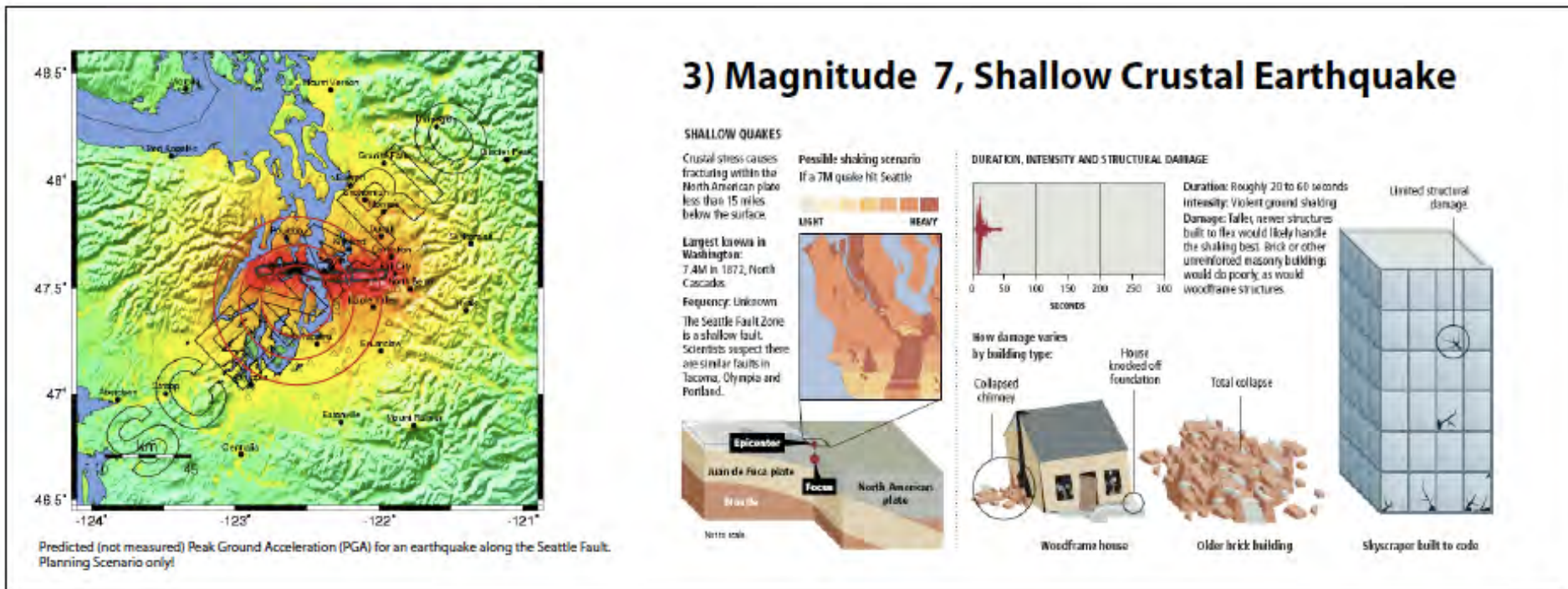
ShakeMap for SIMULATED M9 Cascadia earthquake



ShakeMaps
(<http://earthquake.usgs.gov/earthquakes/shakemap>)
are designed as rapid response tools to portray the extent and variation of ground shaking throughout the affected region immediately following significant earthquakes. The maps shown here do not take into account liquefaction and ground failure, which can significantly increase damage.

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

Three kinds of Cascadia EQs = Triple Trouble



Magnitude 7.0 or 7.5 Cascadia Fault Earthquake

20-60 seconds of ground shaking.

Effects of Near-Surface Geology

How will 3 buildings, engineered equally, on different bedrock react to an earthquake?



Two variables affect damage during earthquake:

- 1) Intensity of shaking (*felt motion, not magnitude*)
- 2) engineering

Amplitude of oscillation increasing

Liquefaction

Liquefaction

What happens to a structure built on a weak foundation when an earthquake strikes?

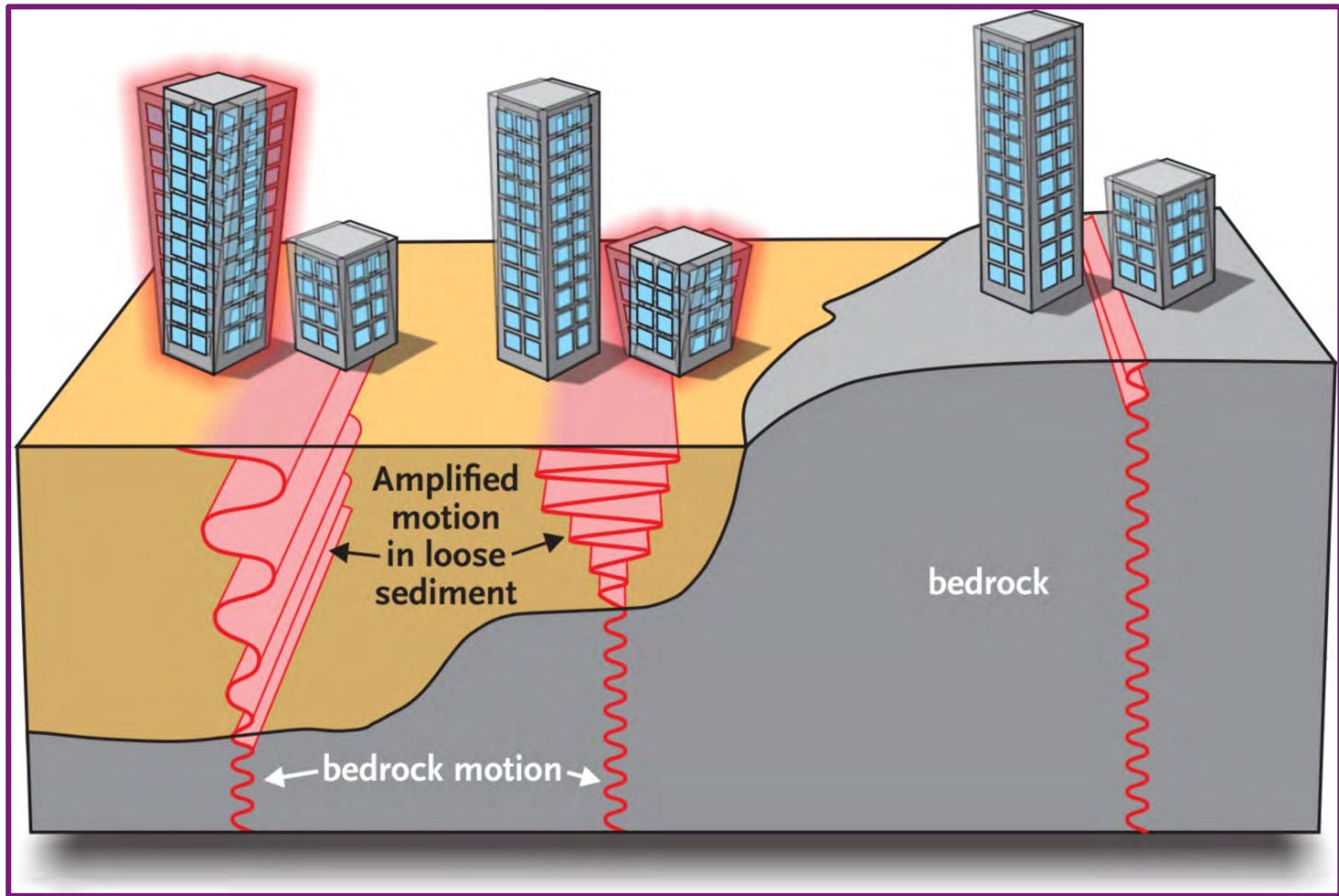


M7.4 Niigata, Japan 1964

Source: National Geophysical Data Center



Ground Shaking Amplification



Seismic waves are amplified as they pass from bedrock into basins filled with sedimentary rock.

Earthquake-Induced Landslides



El Salvador January 2001 M7.6

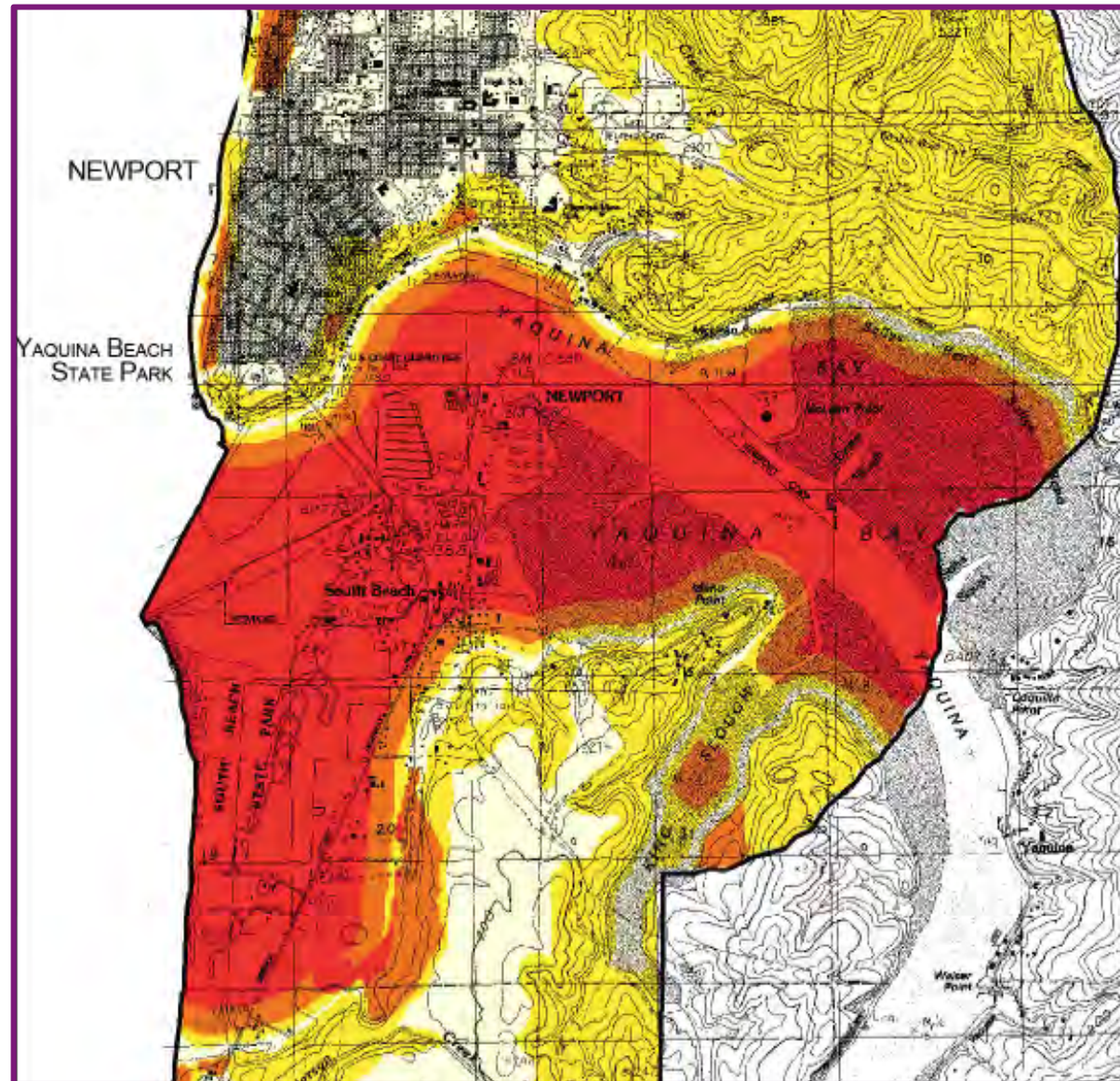
Relative Earthquake Hazards

Relative EQ Hazard

= Seismic Wave
Amplification

+ Liquefaction
Potential

+ Earthquake-
induced
Landslide
Hazard



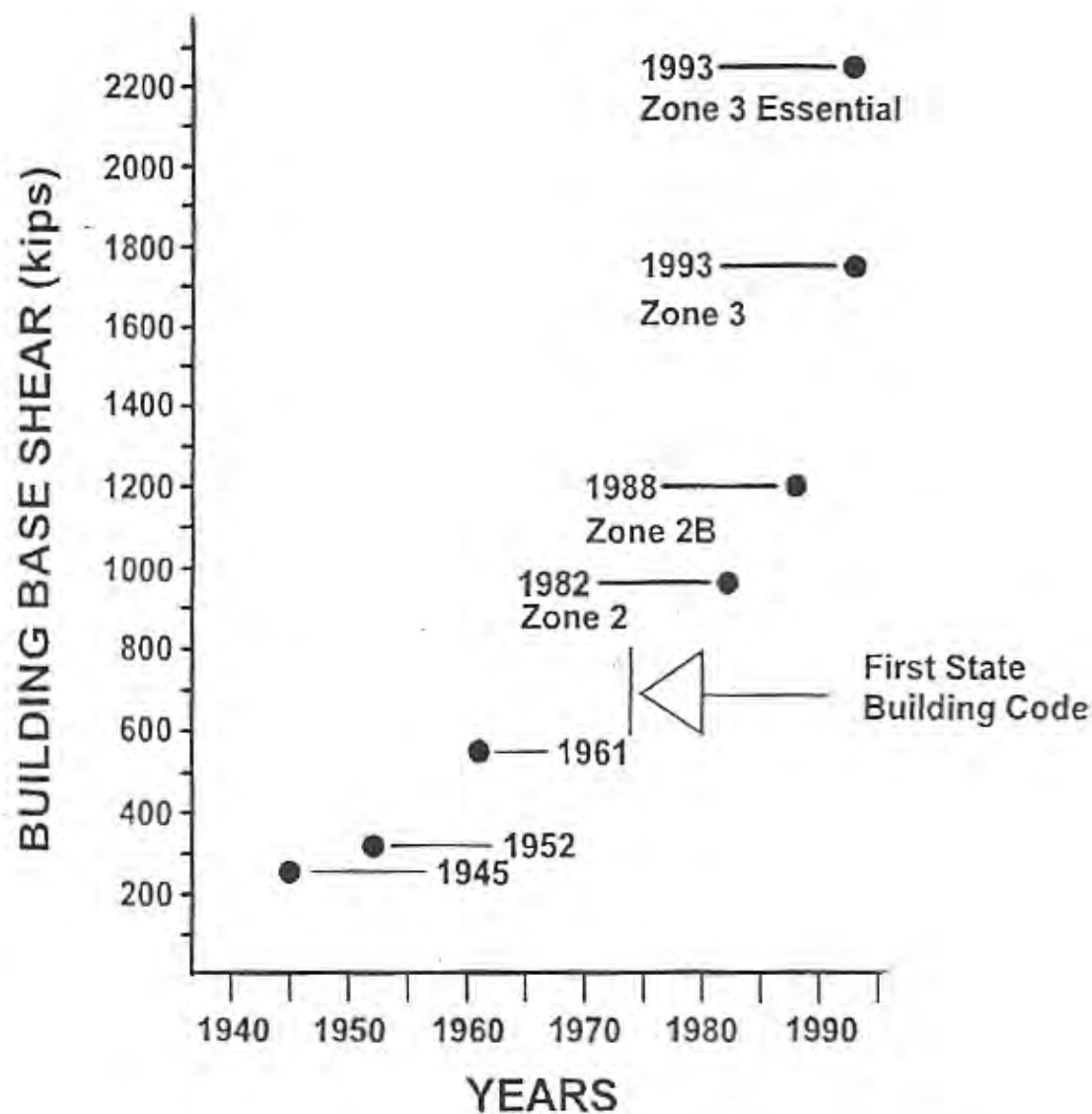
Build a Better Wall

Build a Better Wall



"Earthquakes don't kill people buildings that collapse during earthquake ground shaking kill people."

Oregon EQ Building Codes



Seismic Retrofit



1942 North Portland House
Wood frame NOT attached to foundation.

Seismic Retrofit



Bolting frame to foundation on exterior.

Seismic Retrofit

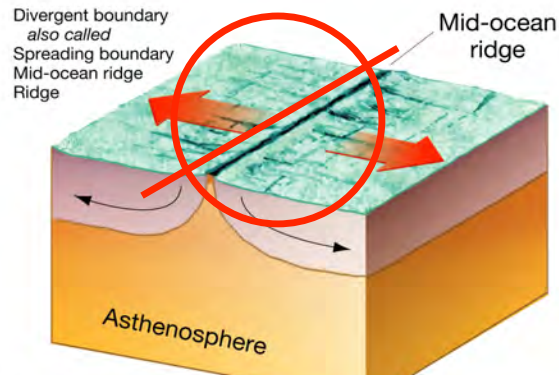


Post & beam reinforcement.

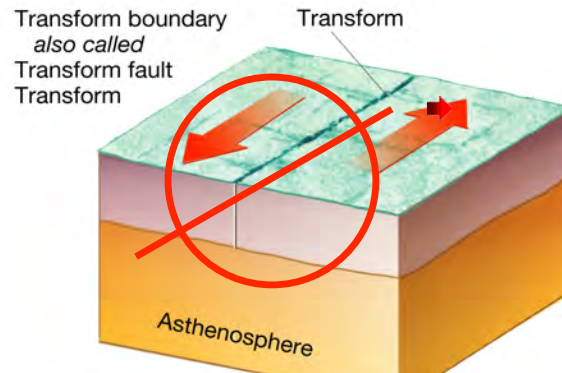
Drop, Cover, and Hold On!



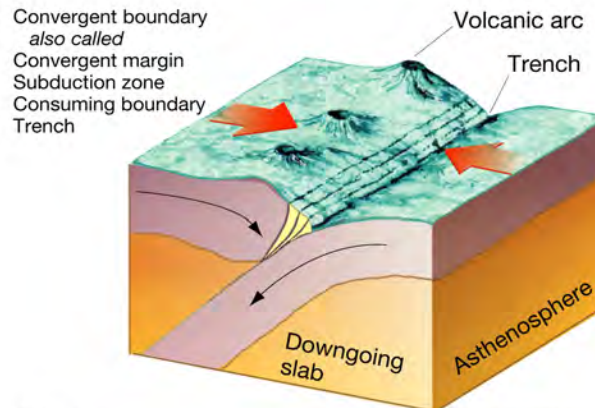
Three Types of Plate Boundaries



- Divergent



- Transform



- Convergent
(subduction zones)

Tsunami

2011 Tohoku Earthquake and Tsunami



15,883 people killed; 6,145 missing; 2,671 injured;
Recovery, Cleanup, and Rebuilding Cost = \$235 Billion.

Tohoku Earthquake Fault Displacement Model

Modeling of seismic
waveform
fault s

Maximum
the surface
hypocenter

Such large
surface
displacement
floor to
large t

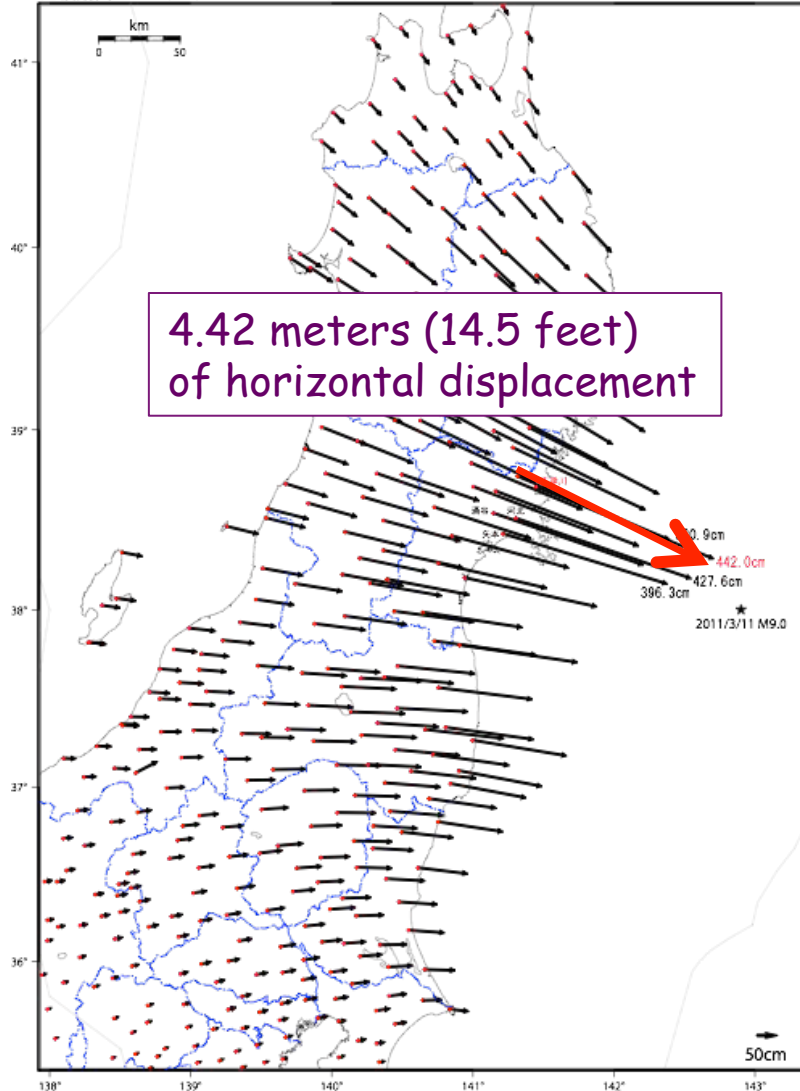


GPS Displacements During the Earthquake

変動ベクトル図（水平）

暫定

基準期間：2011/03/01 21:00 - 2011/03/09 21:00
比較期間：2011/03/11 18:00 - 2011/03/13 03:00



[基準：R3速観解 比較：Q3速観解]

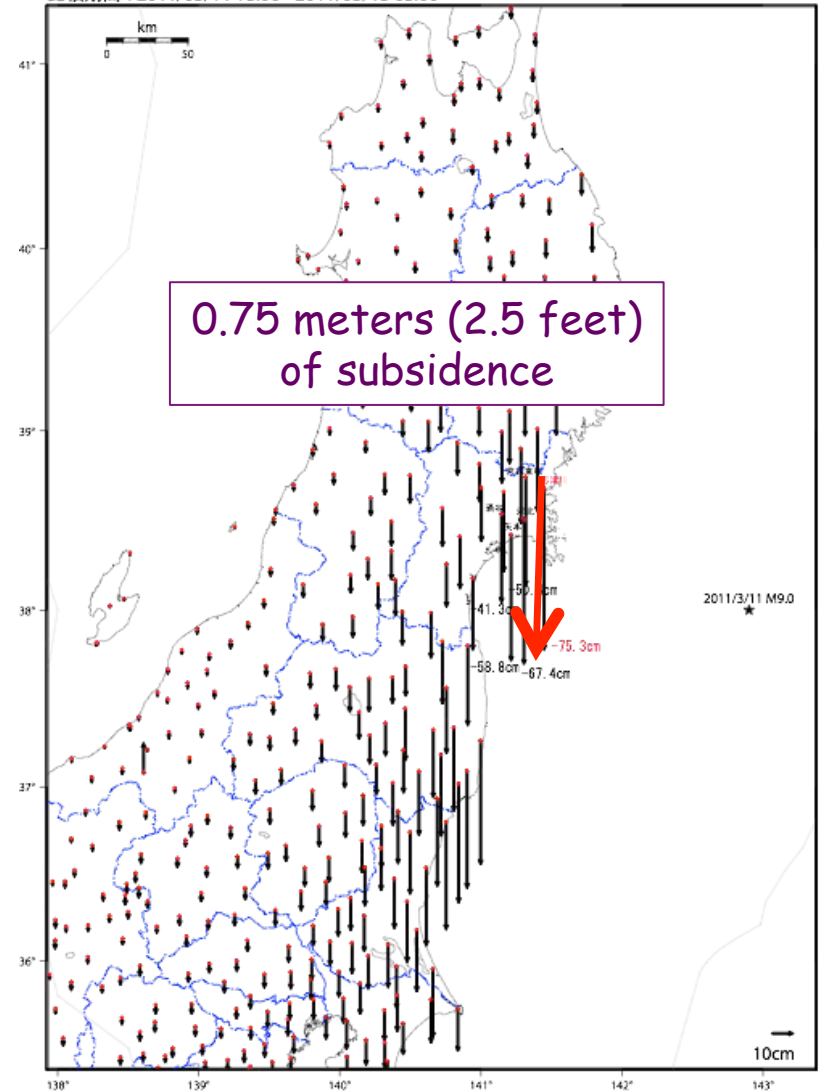
☆固定局：三隅 (950368)

国土地理院

変動ベクトル図（上下）

暫定

基準期間：2011/03/01 21:00 - 2011/03/09 21:00
比較期間：2011/03/11 18:00 - 2011/03/13 03:00



[基準：R3速観解 比較：Q3速観解]

☆固定局：三隅 (950368)

国土地理院

Some Coast Areas Now Below Sea Level Yuriage



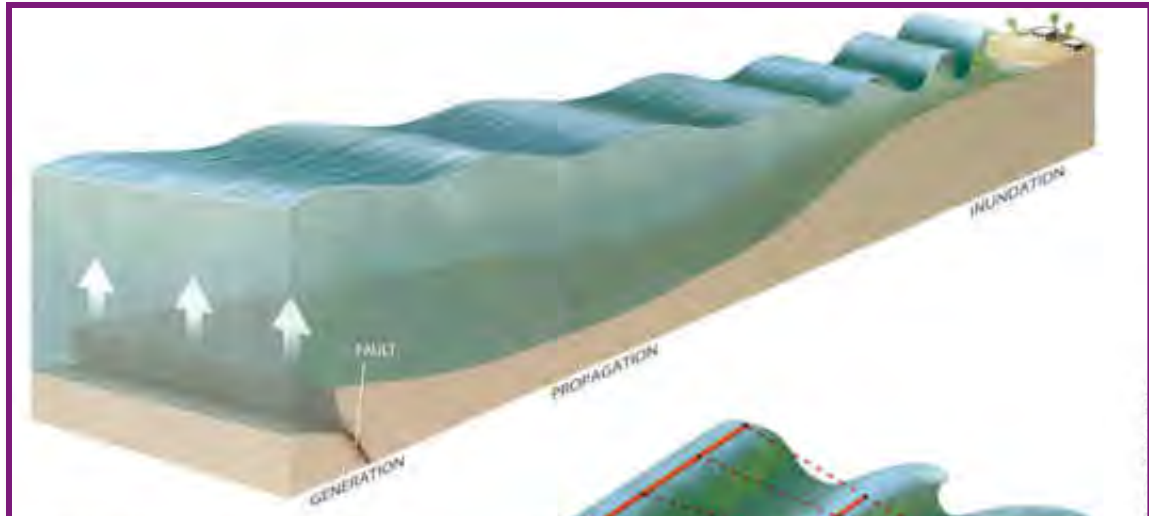
Before



After

- Some areas that were above sea level on march 10 dropped below sea level on March 11, 2011.
- This also happened along the Washington - Oregon coast during the 1700 AD great Cascadia earthquake.

Tsunami Produced by Earthquake



Important points:

LONG period: 20 - 60 minutes.

Can flood on shore for 10 - 15 minutes.

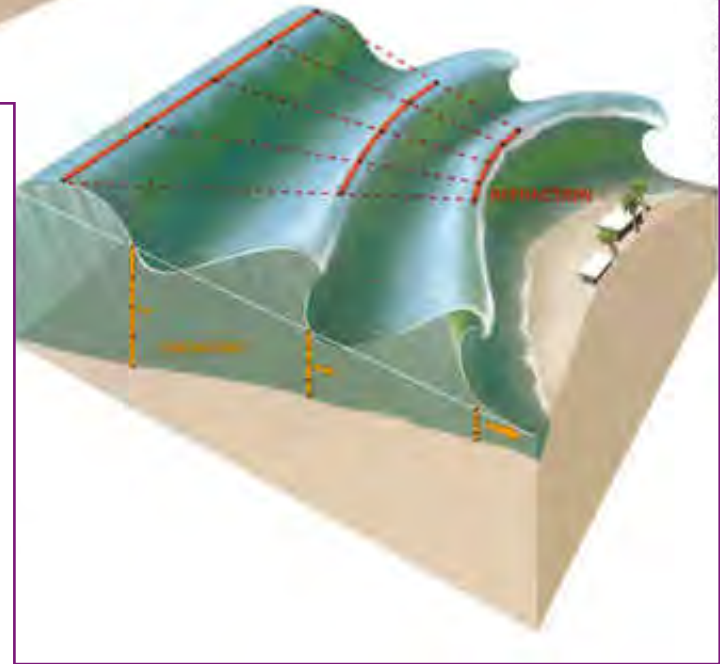
LONG wavelength: >800 kilometers (520 miles)

Moves seawater all the way to floor of ocean.

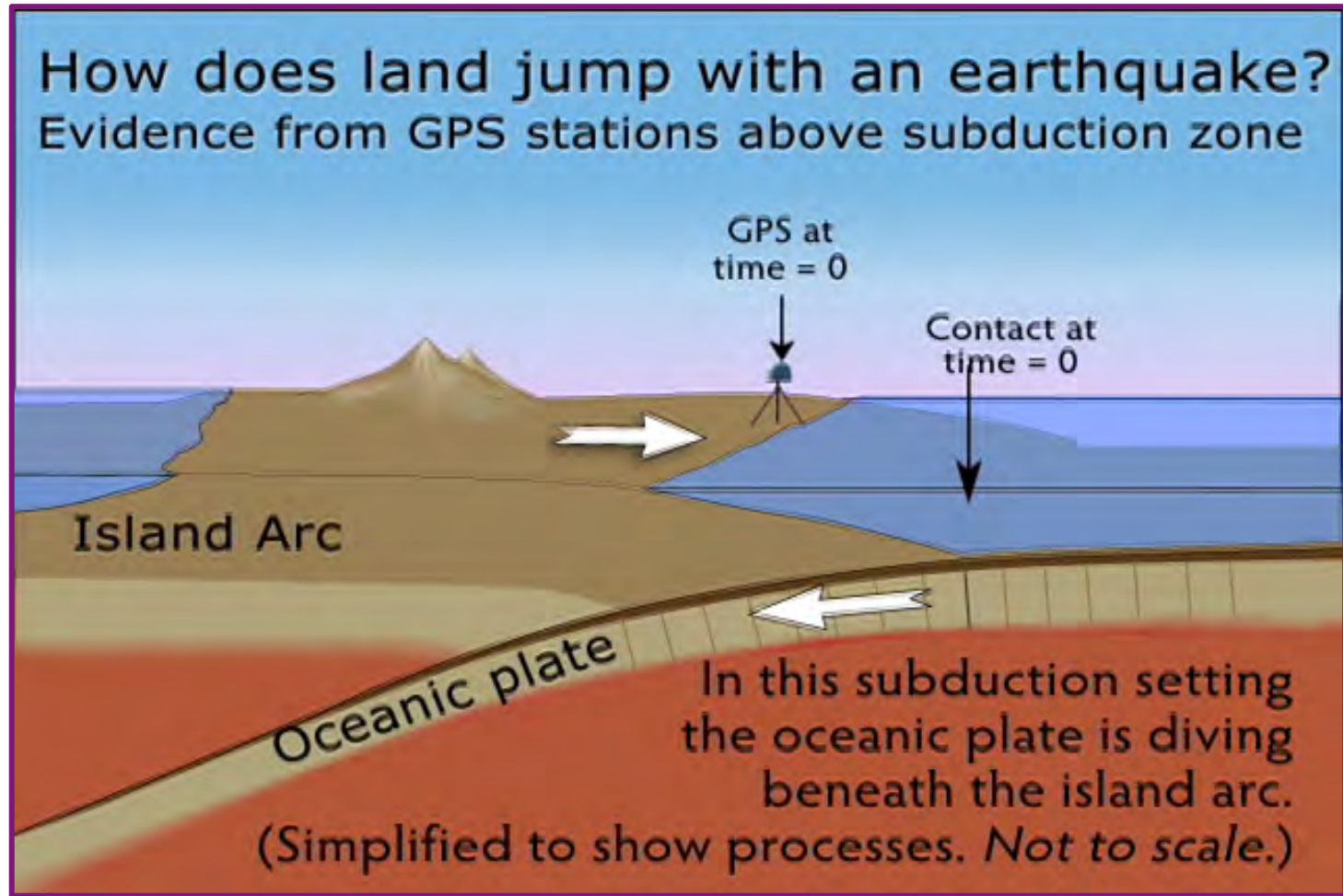
In deep ocean, tsunami has small amplitude and travels with speed of jet airliner.

When approaching land, speed slows and amplitude increases dramatically.

A tsunami is a SERIES of waves, not a single wave.



Tsunami Produced by Subduction Zone Earthquake



Why are tsunamis rarely produced by earthquakes along divergent and transform plate boundaries?

Lessons from Tohoku, Japan

- **Earthquake engineering works.**
Few buildings collapsed during the Tohoku earthquake.
Cascadia must construct earthquake-resilient built environment.
- **Earthquake and tsunami hazards education improves public safety.**
Tohoku tsunami inundation zone had 95% survival rate while
Banda Aceh inundation zone had 10% survival rate.



Cascadia Great Earthquakes and Tsunamis After Field Trip