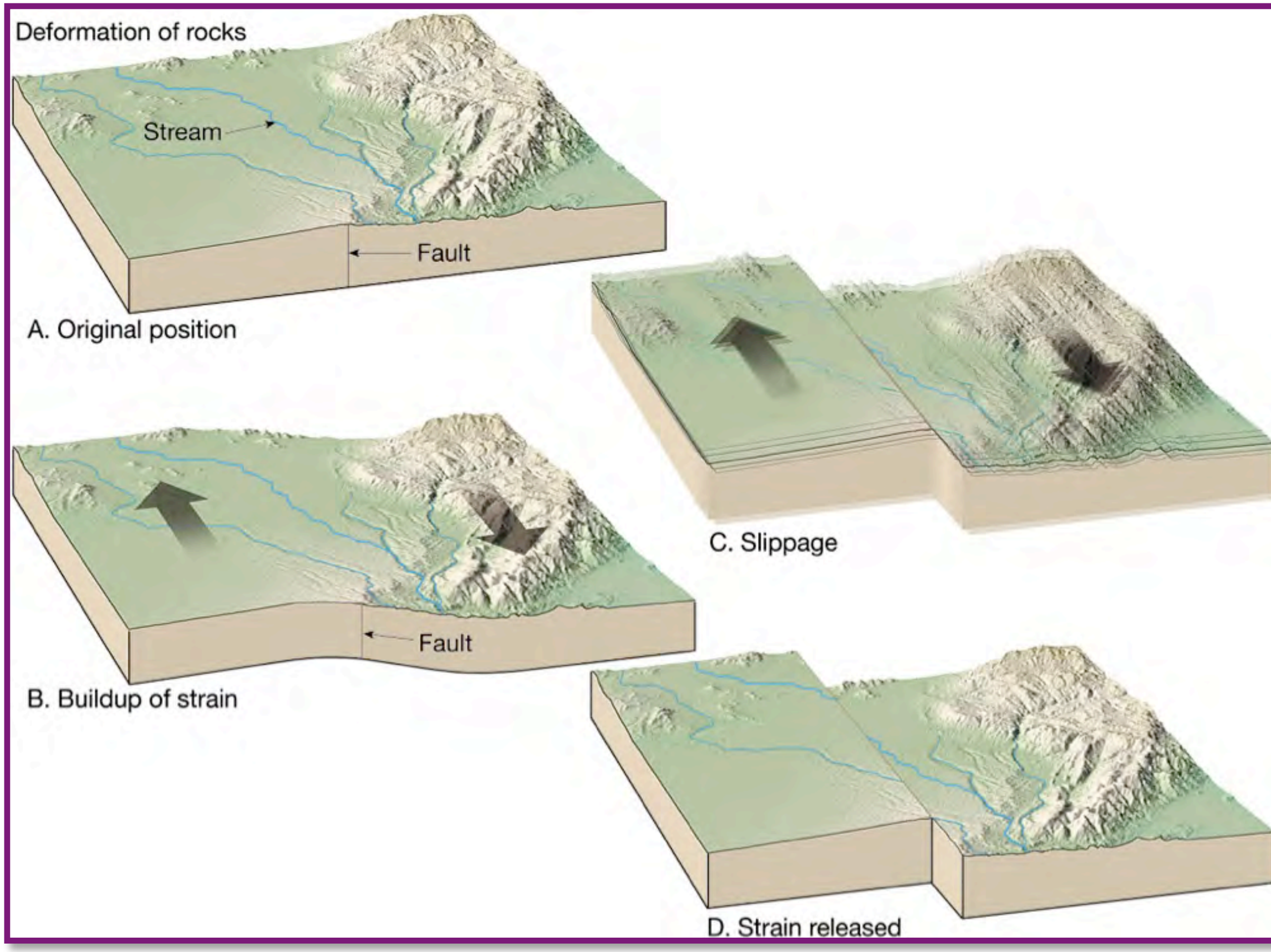
Stick-slip: Elastic Rebound Theory
Jerky motions on faults produce EQs

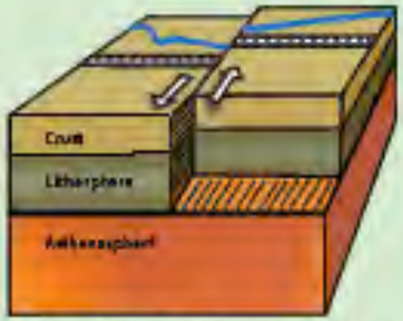


Three Fs of earthquakes: forces, faults, and friction.

Slow accumulation and rapid release of elastic energy.

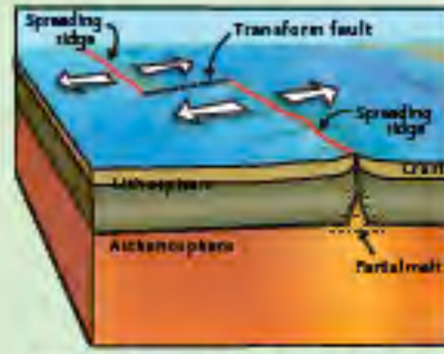
Three Basic Types of Plate Boundaries

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.



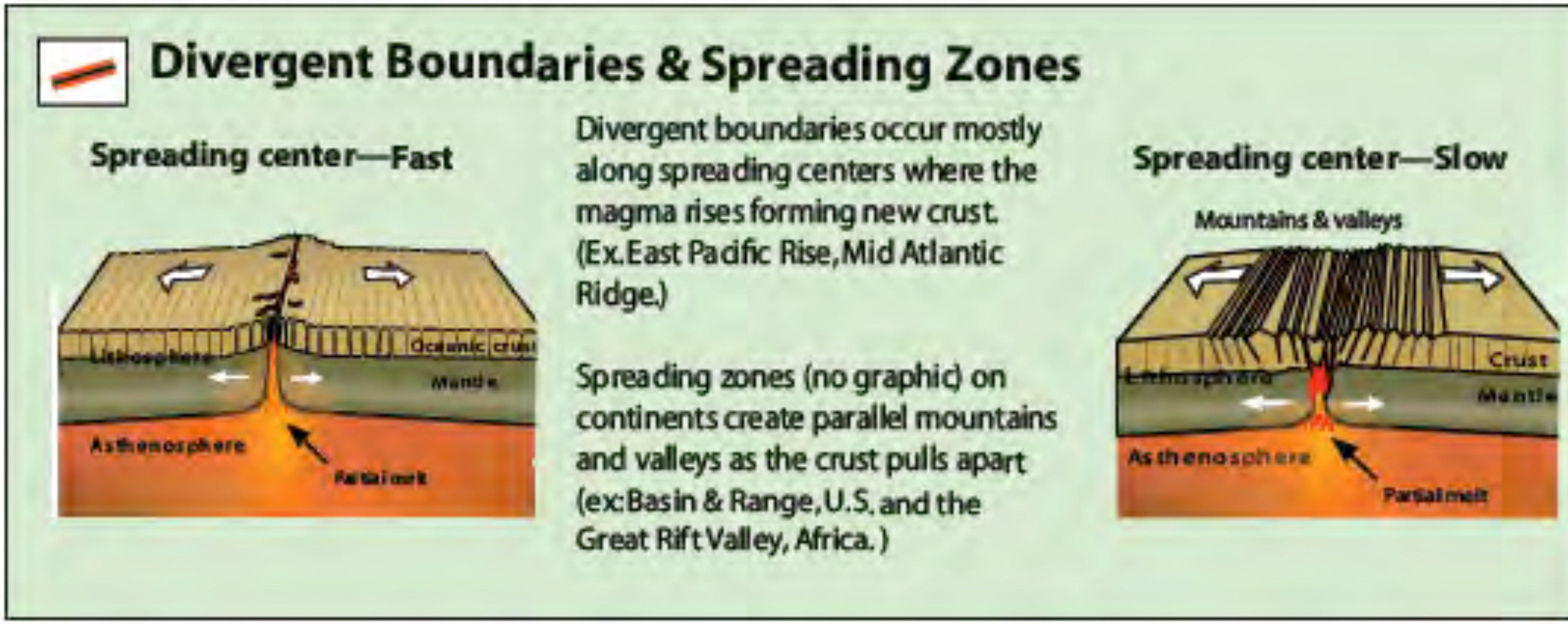
Transform faults are where two plates are moving away from a spreading ridge and fracture zones develop (ex: ocean floor)

Transform (e.g. San Andreas Fault)

Strike-slip faulting

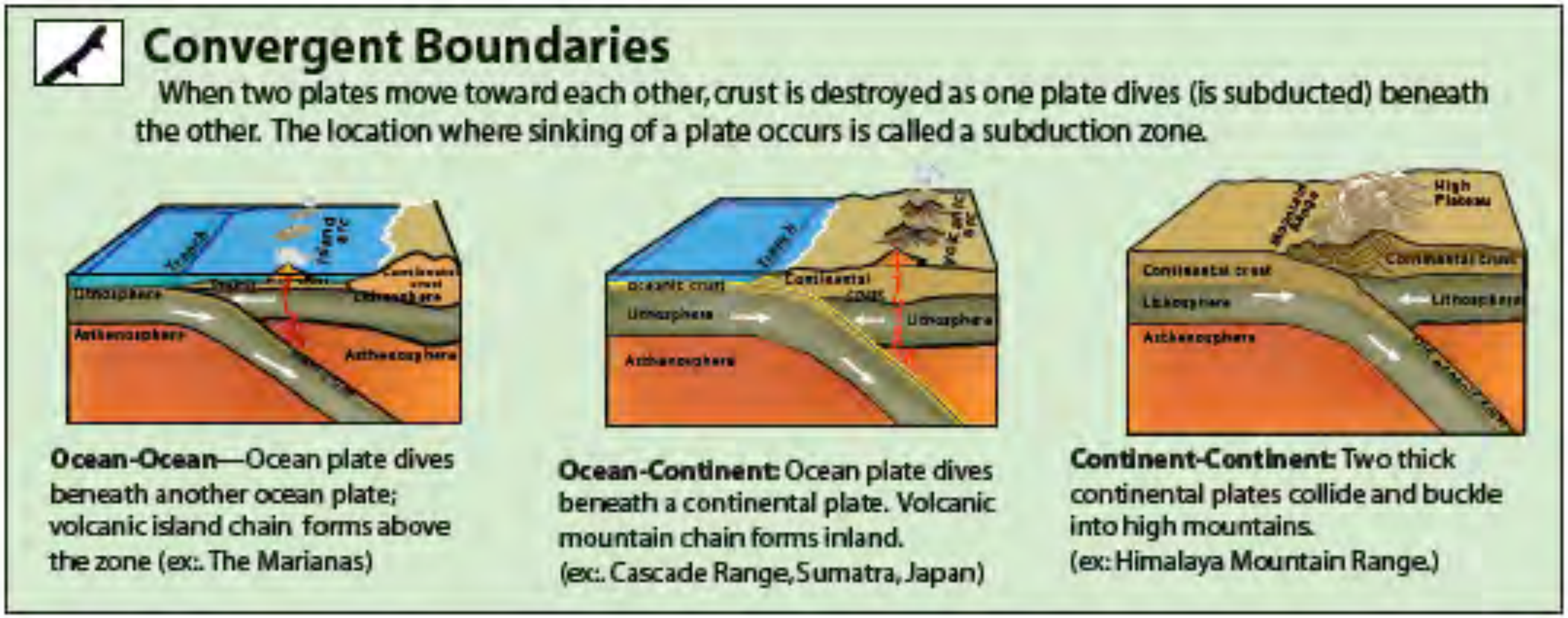
Magnitudes generally ≤ 7

Three Basic Types of Plate Boundaries



Divergent (e.g. spreading ocean ridge)
Normal faulting   Magnitudes $\leq$ 6

Three Basic Types of Plate Boundaries

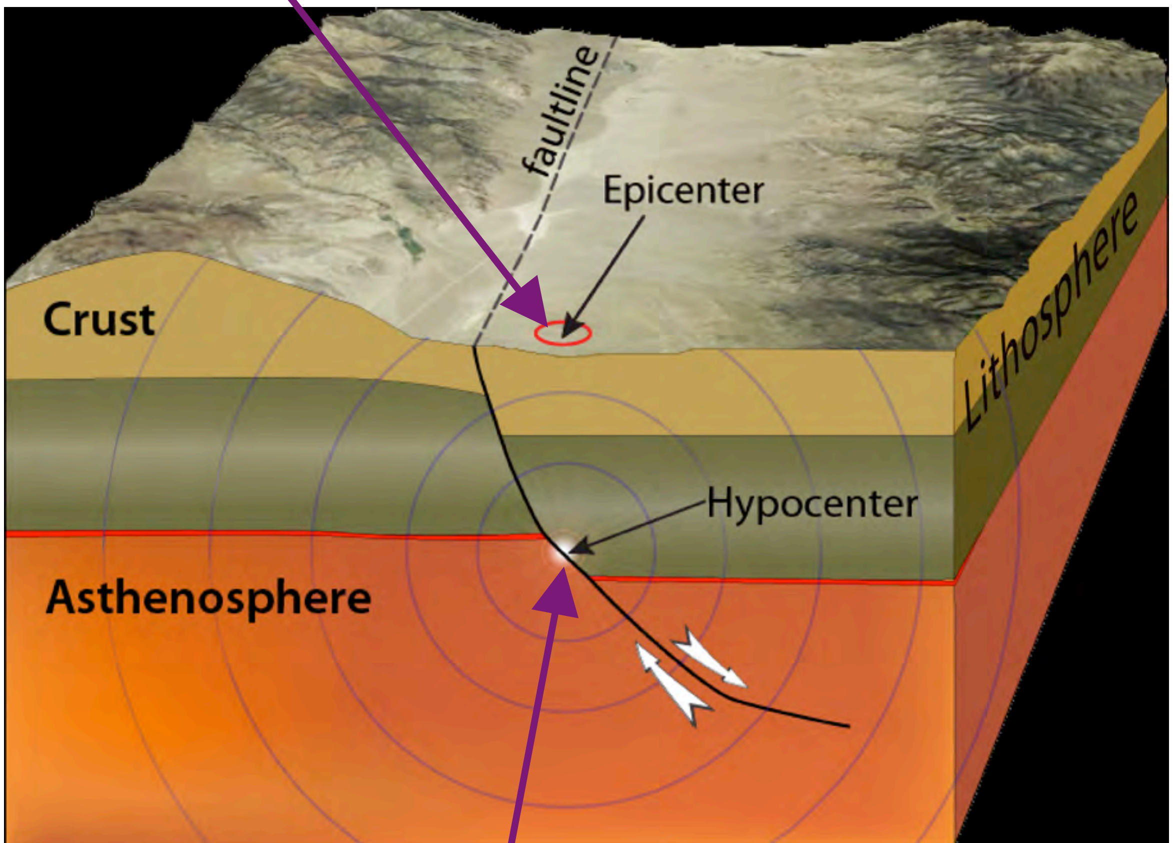


Convergent (e.g. subduction zone)

Magnitudes up to 9 or larger

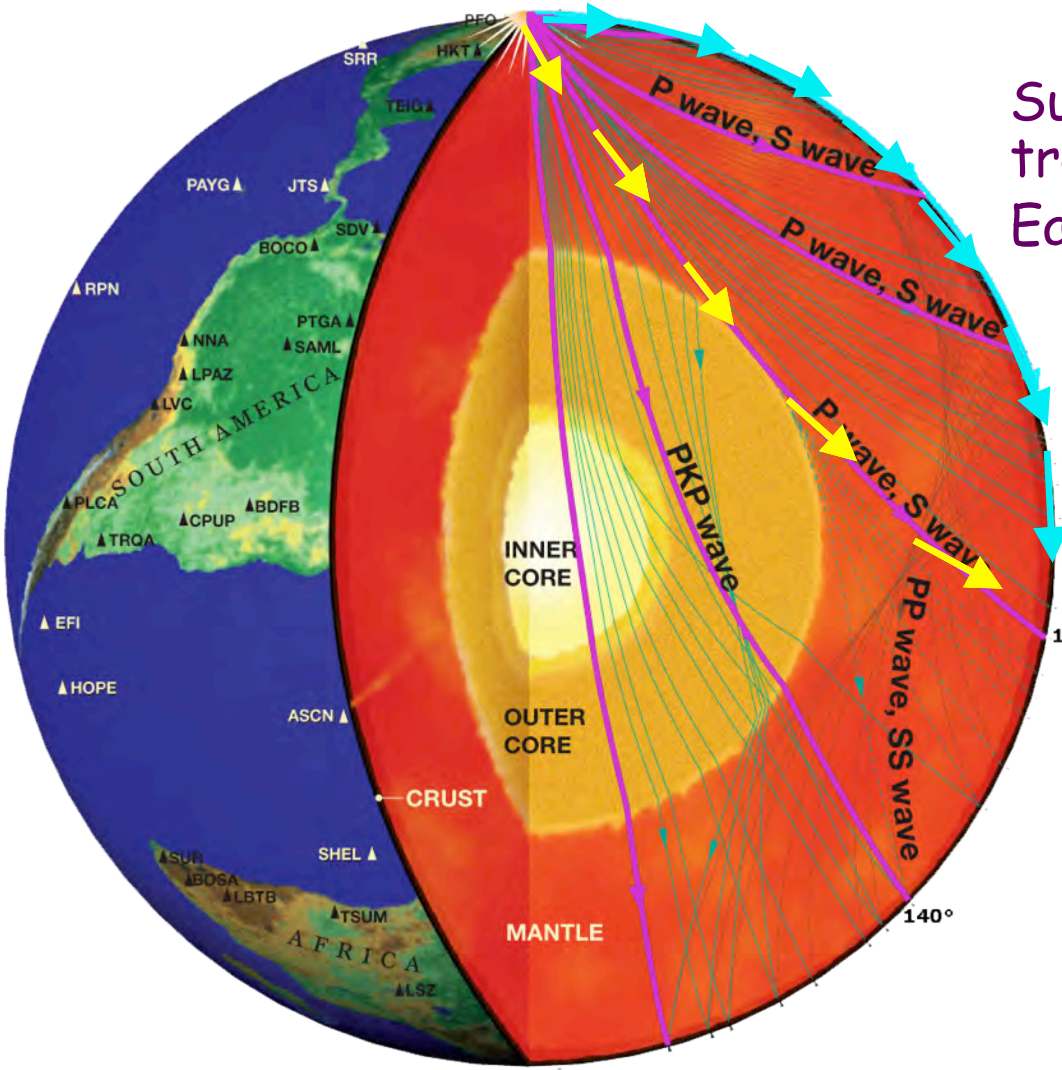
Depths to 700 km

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



Hypocenter or Focus: Point WITHIN Earth where EQ occurred.

Body Waves and Surface Waves

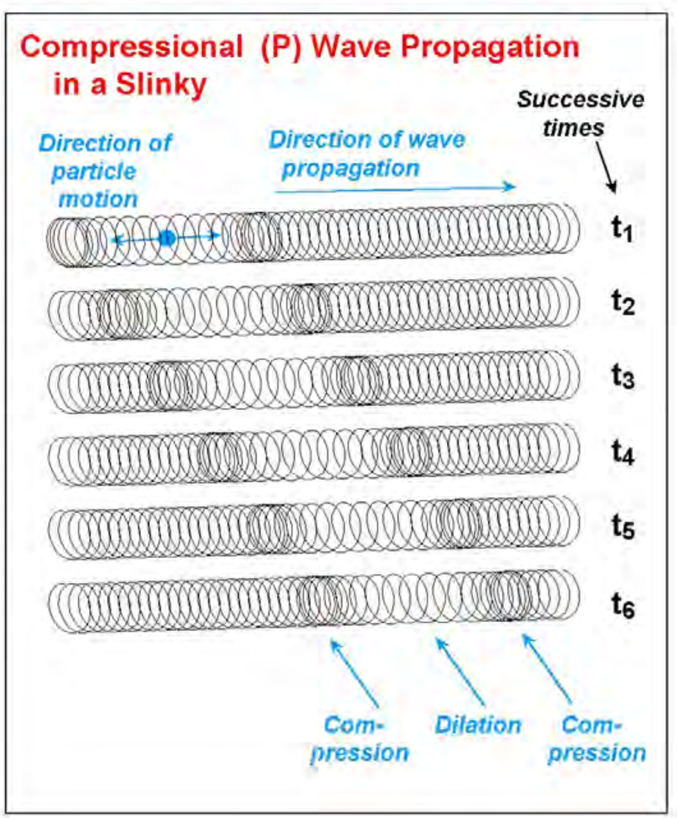


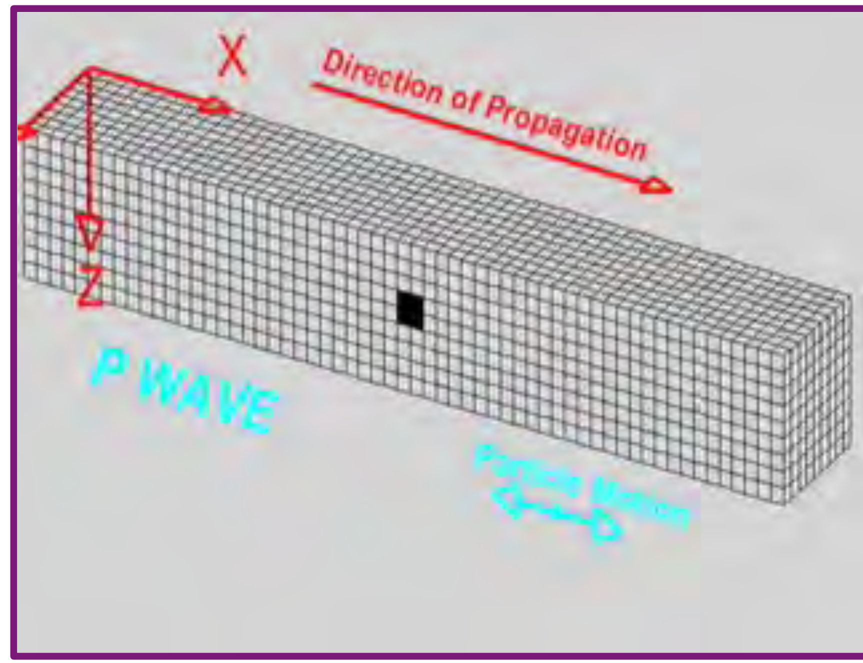
Surface waves travel along Earth's surface.

Body waves (P and S) travel inside Earth.

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.

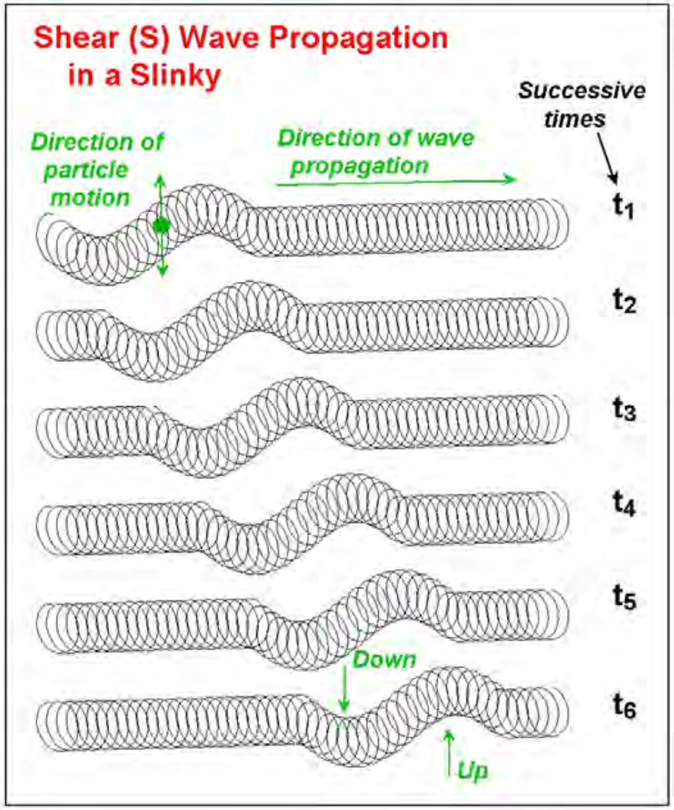
P Waves Are Pressure Waves

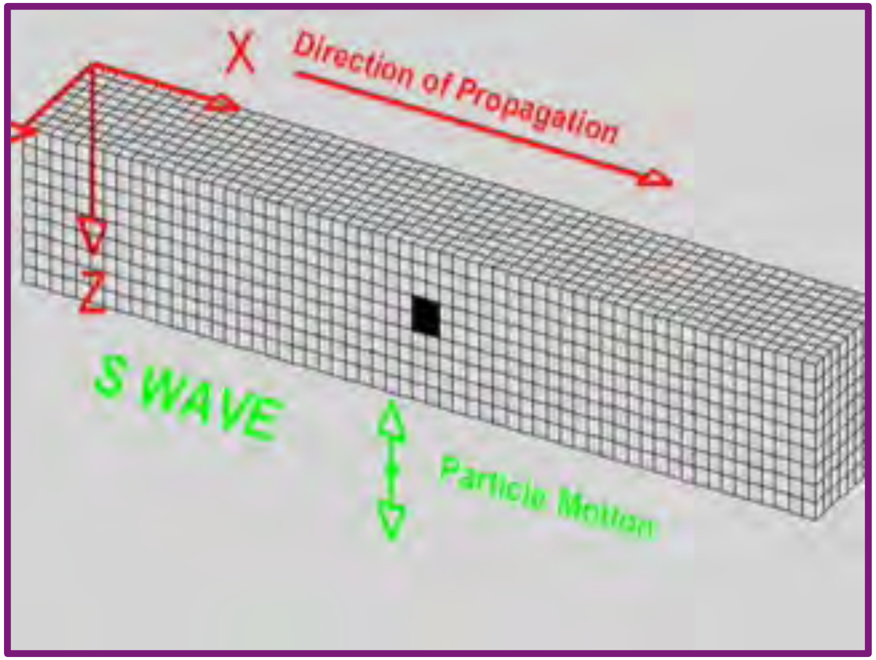




P waves are fastest seismic waves.

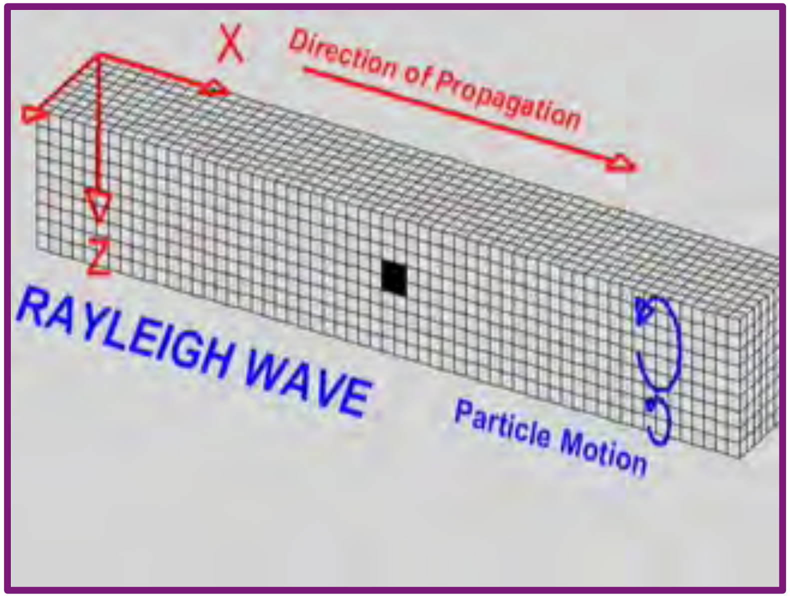
S Waves Are Shear Waves





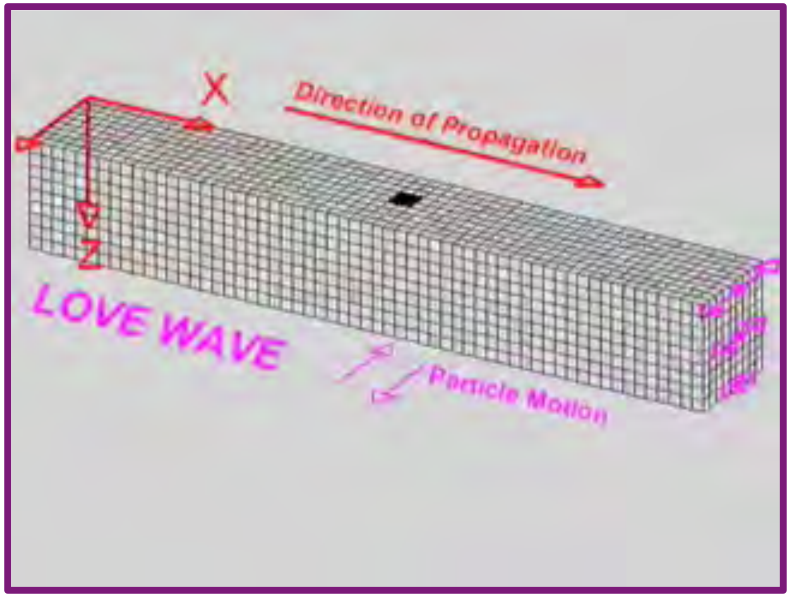
S waves are slower than P waves but faster than surface waves.

Surface Waves



Amplitude greatest at surface, decreasing with depth.

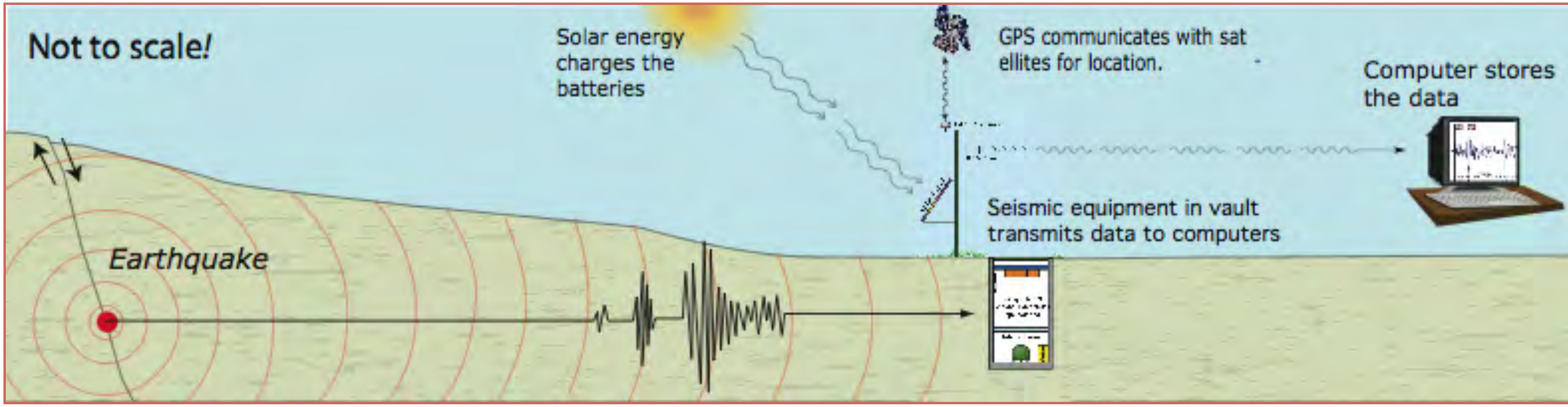
Slower than P or S waves.



Often are largest amplitude and most damaging seismic waves.

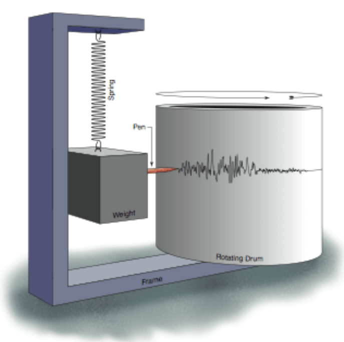
Human Waves
Modeling P, S, and Surface Waves

How do scientists detect earthquakes?

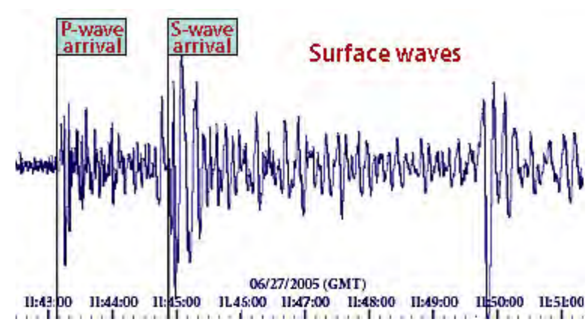


When an earthquake occurs the seismic waves travel through the Earth to the seismic station where the information is transmitted to distant computers.

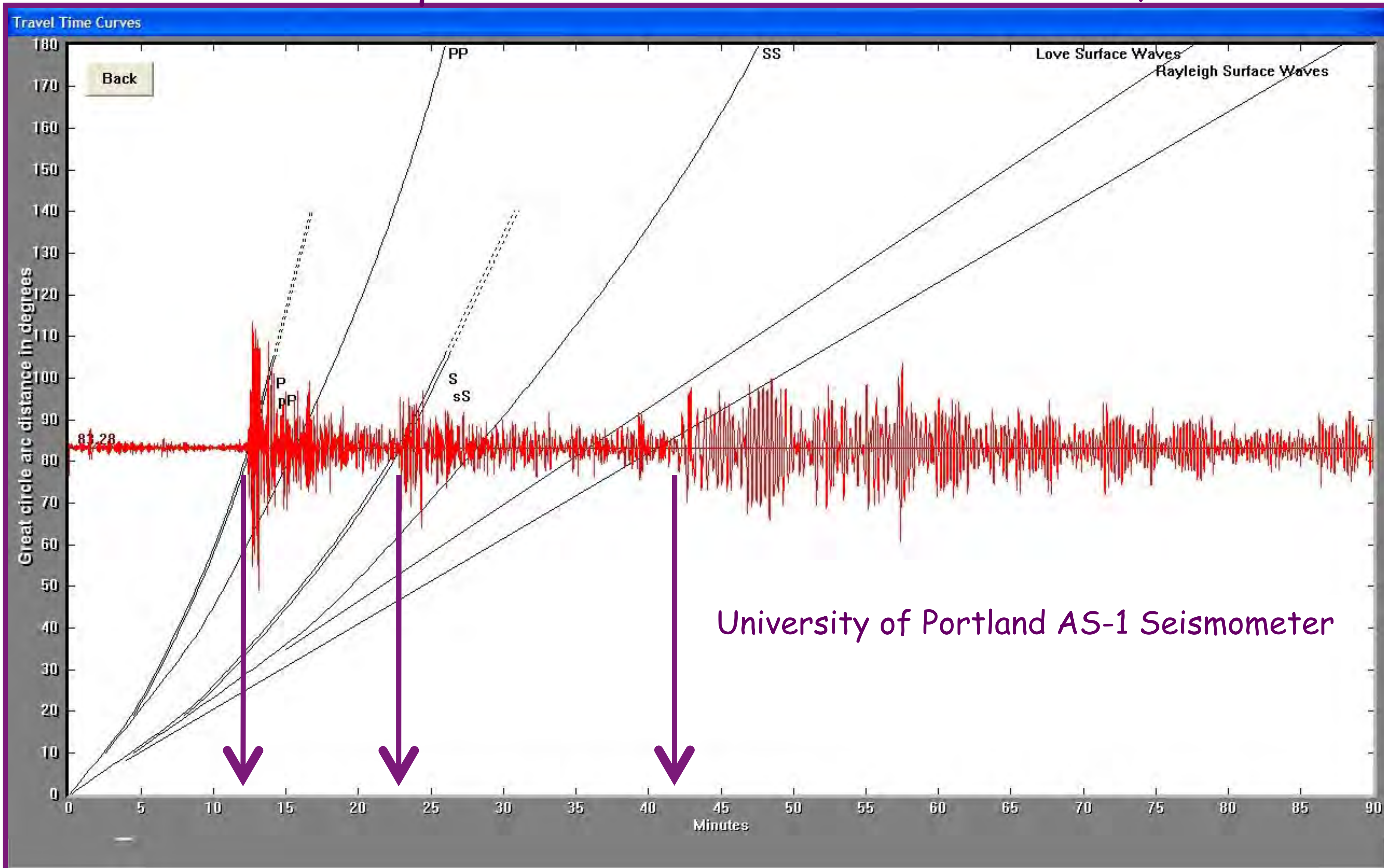
A seismograph detects and records EQs.



A seismogram is the EQ record.



M7.7 Earthquake off Northern Chile Nov 14, 2007

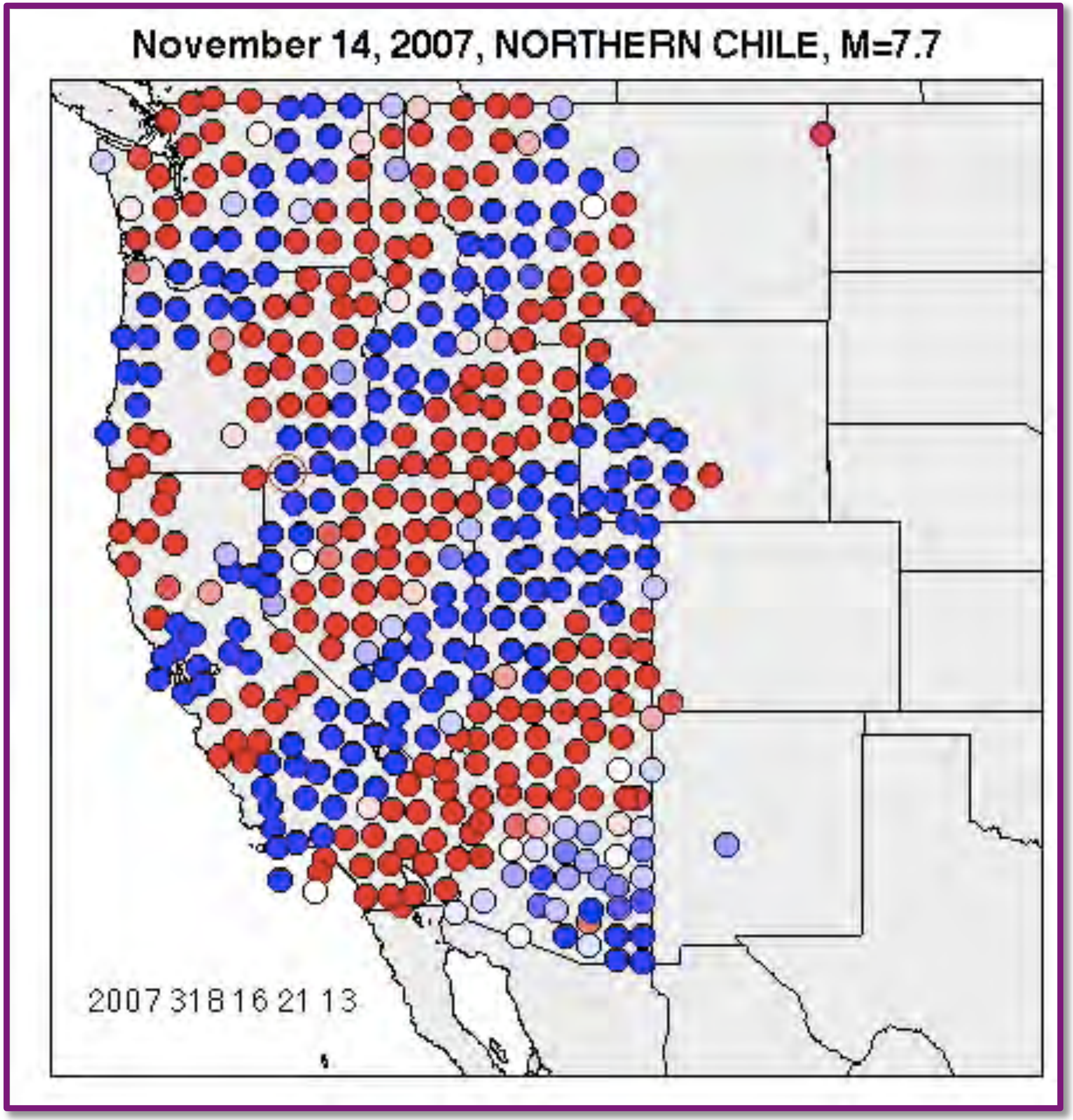


P waves
~12 min
~720 sec

S waves
~22 min
~1320 sec

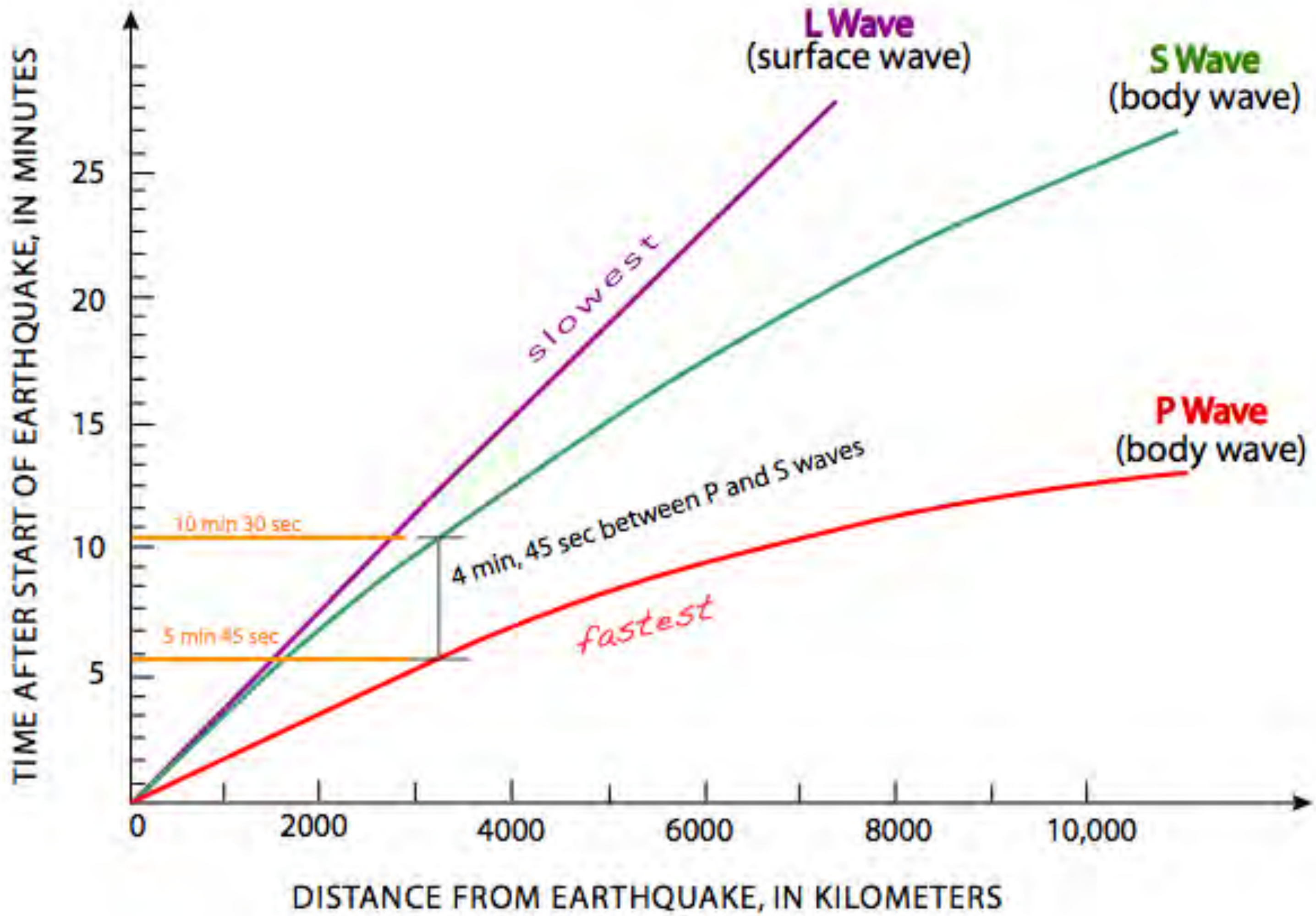
Surface waves
~42 min
~2500 sec

USArray Animations



Seismic Waves from Chile Earthquake

Distance of EQ from seismometer?

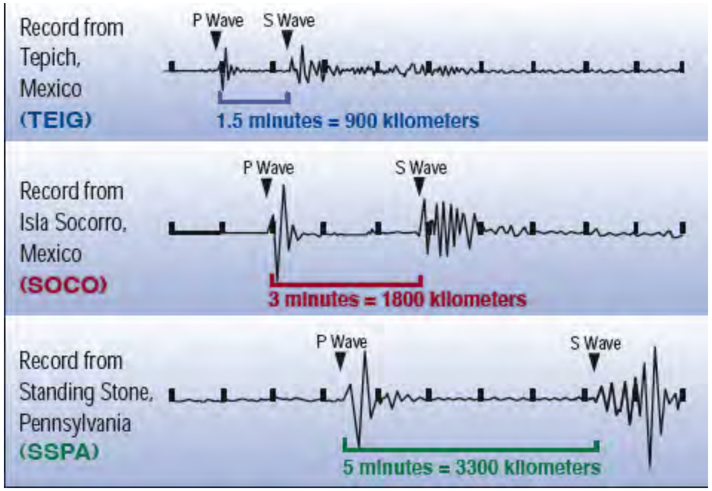


Determined from S arrival time - P arrival time.

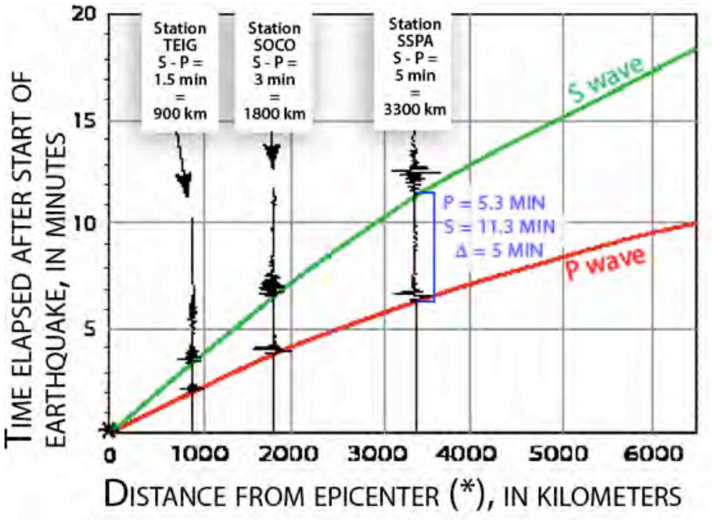
Locating an Earthquake

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.

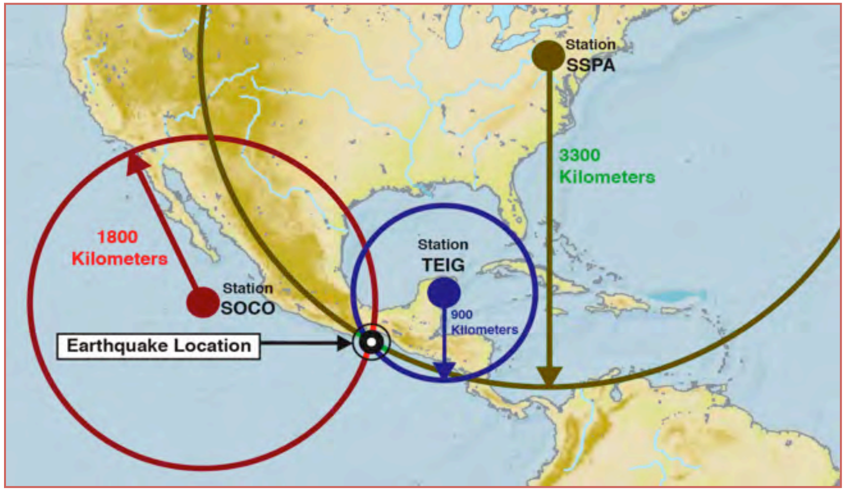
1



2

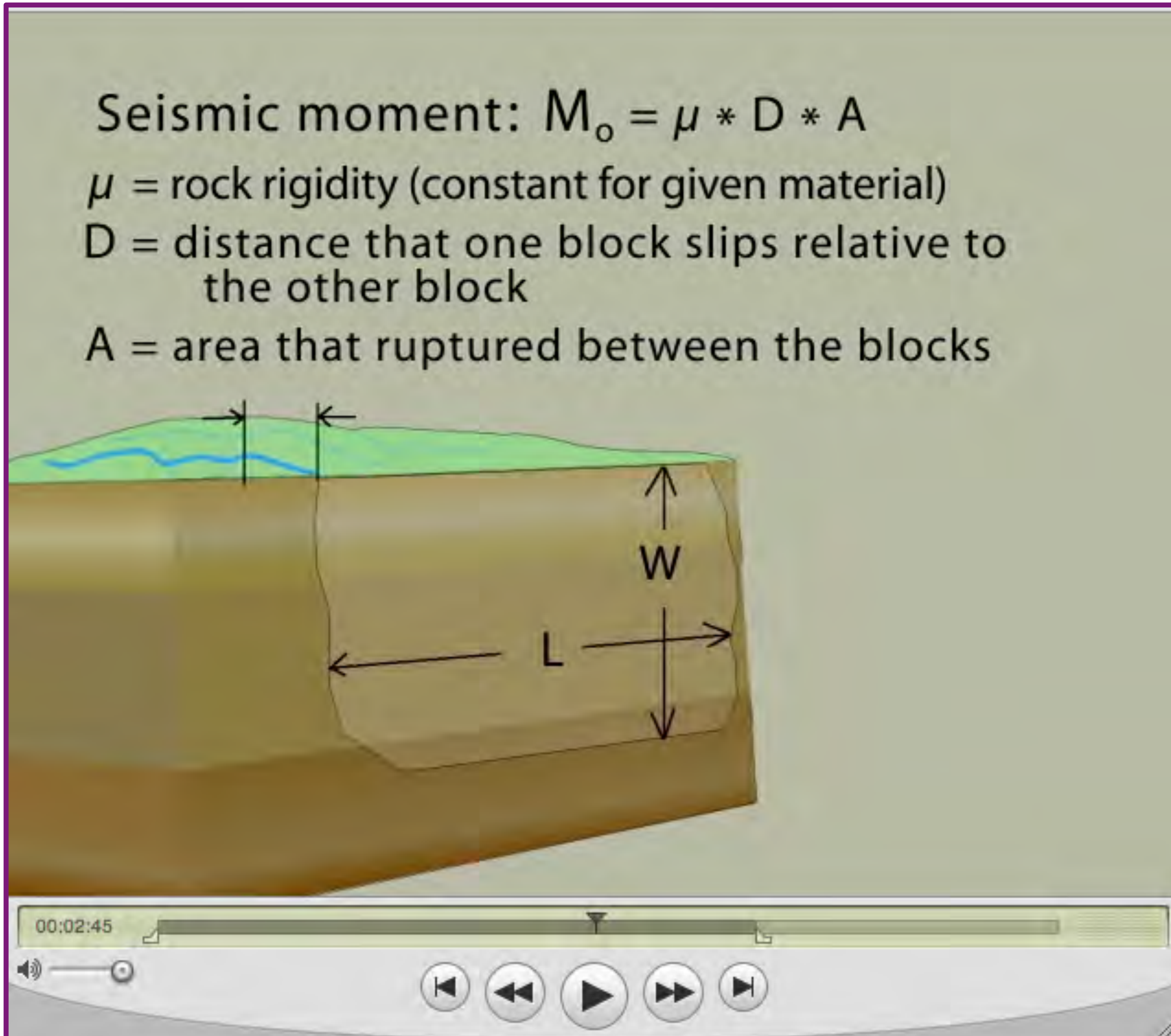


3



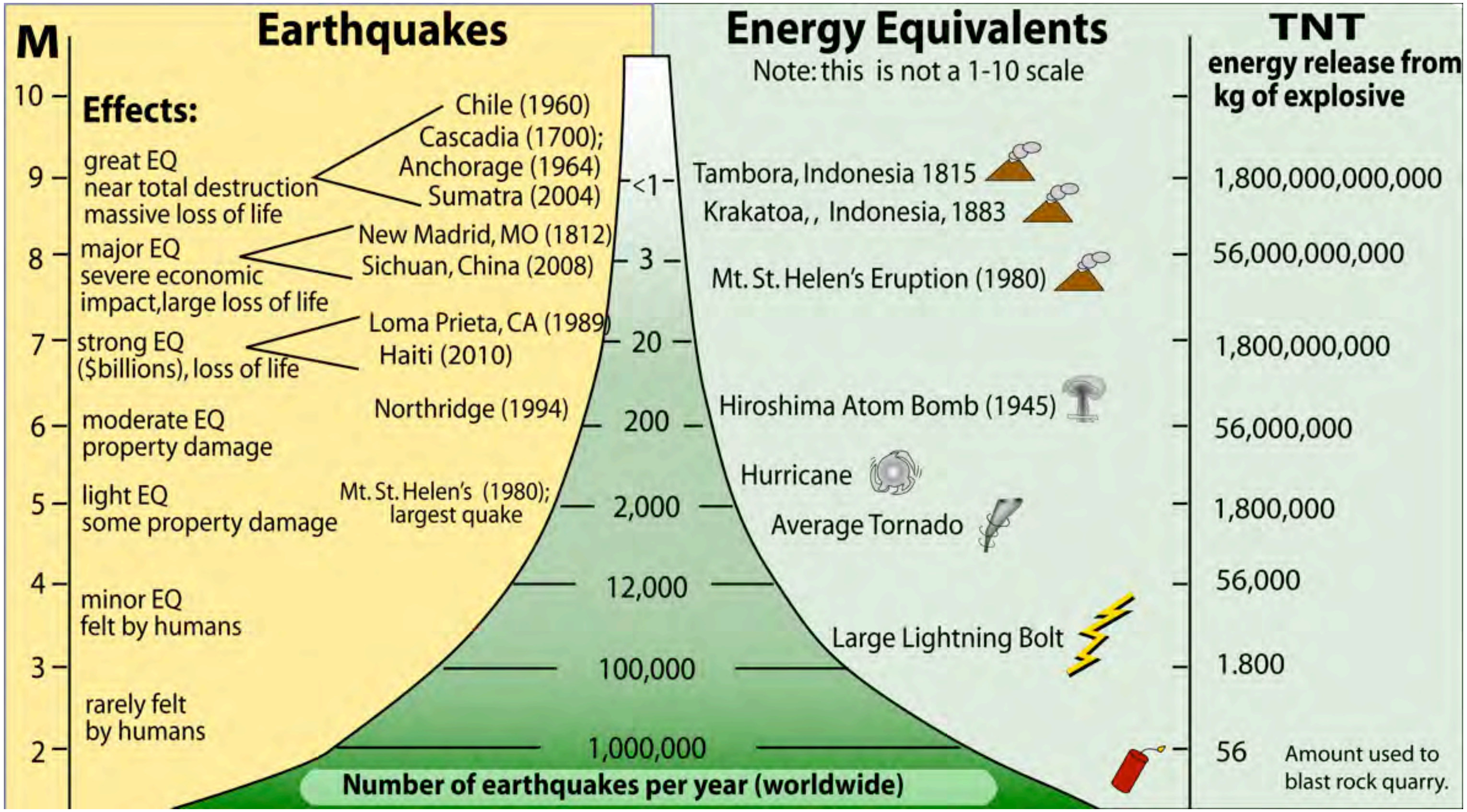
Moment Magnitude

Pasta Quake



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	[illegible]	[illegible]

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.

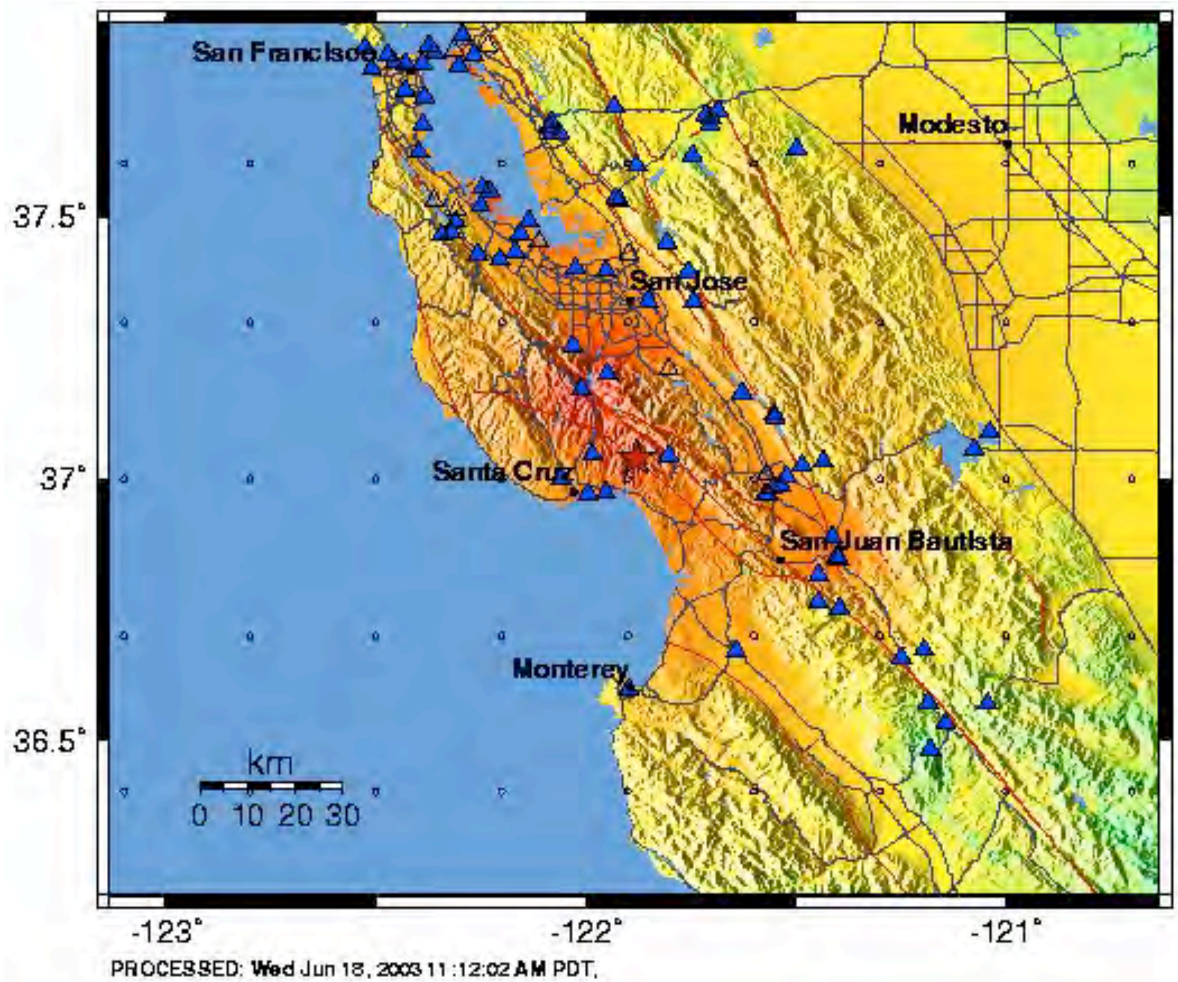
Distance—Shaking decays with distance.

Depth—Deeper EQ yields less shaking at the surface.

Geology—Weak sediments can amplify shaking.

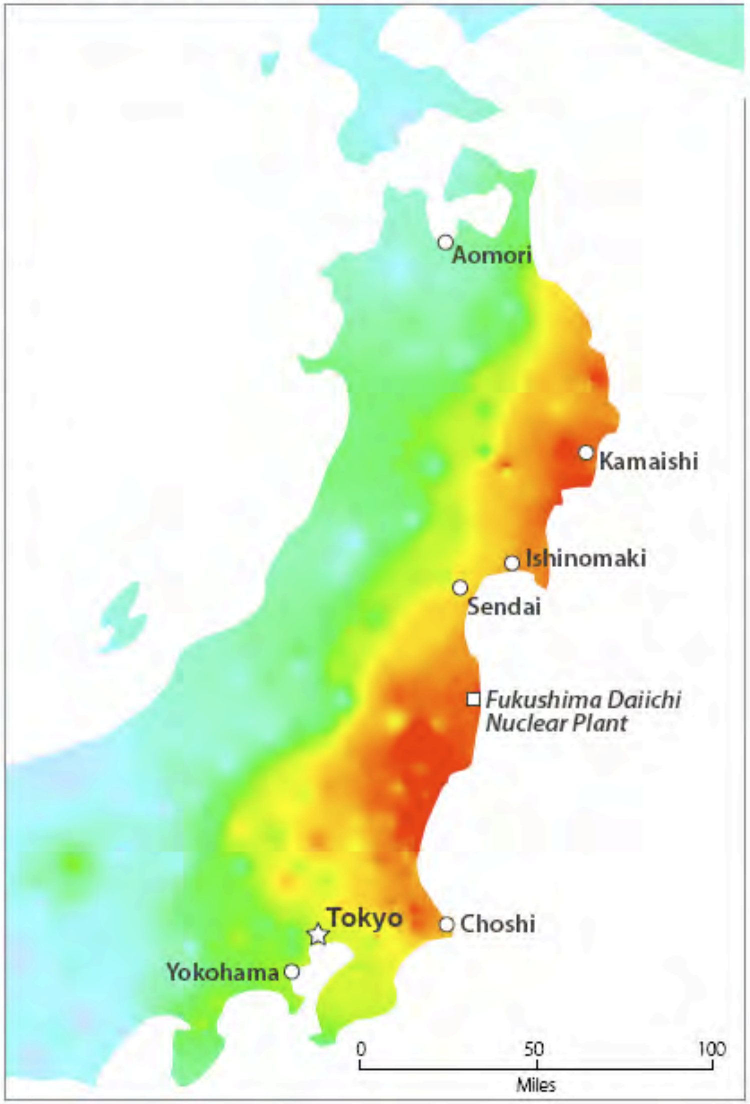
Building style

Duration of shaking.

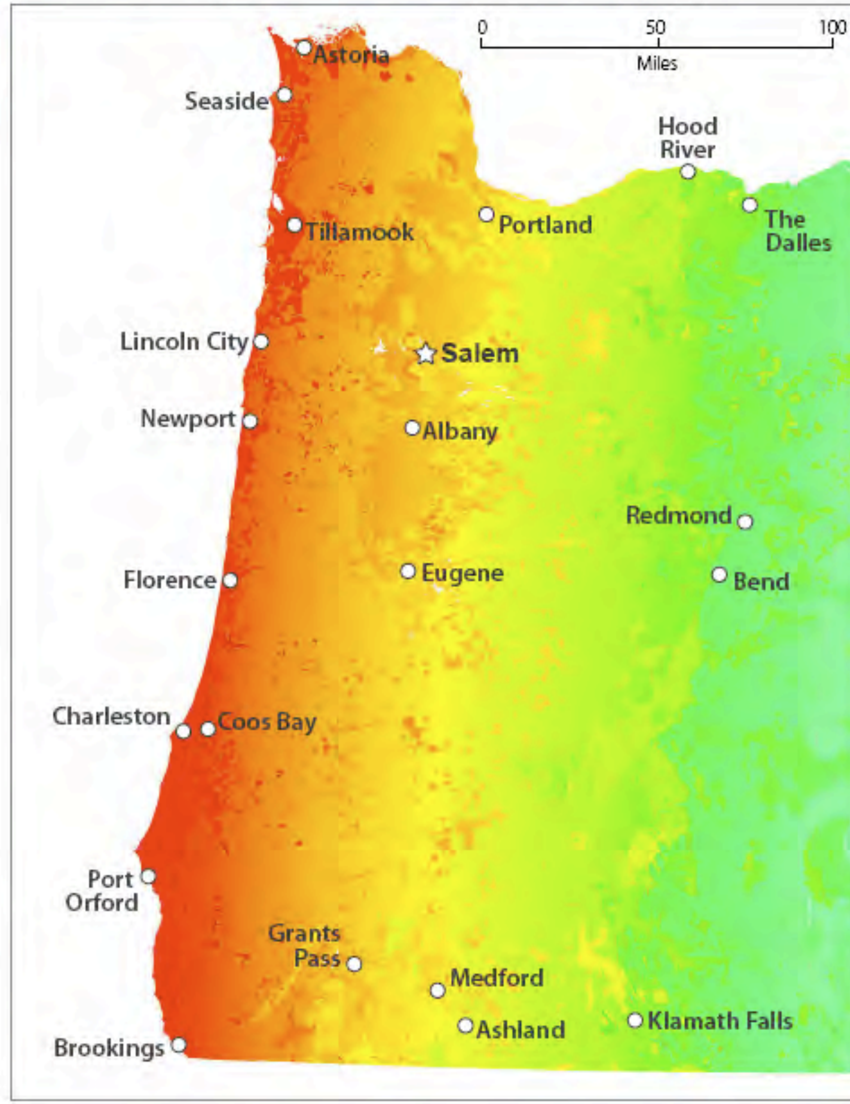


PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	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



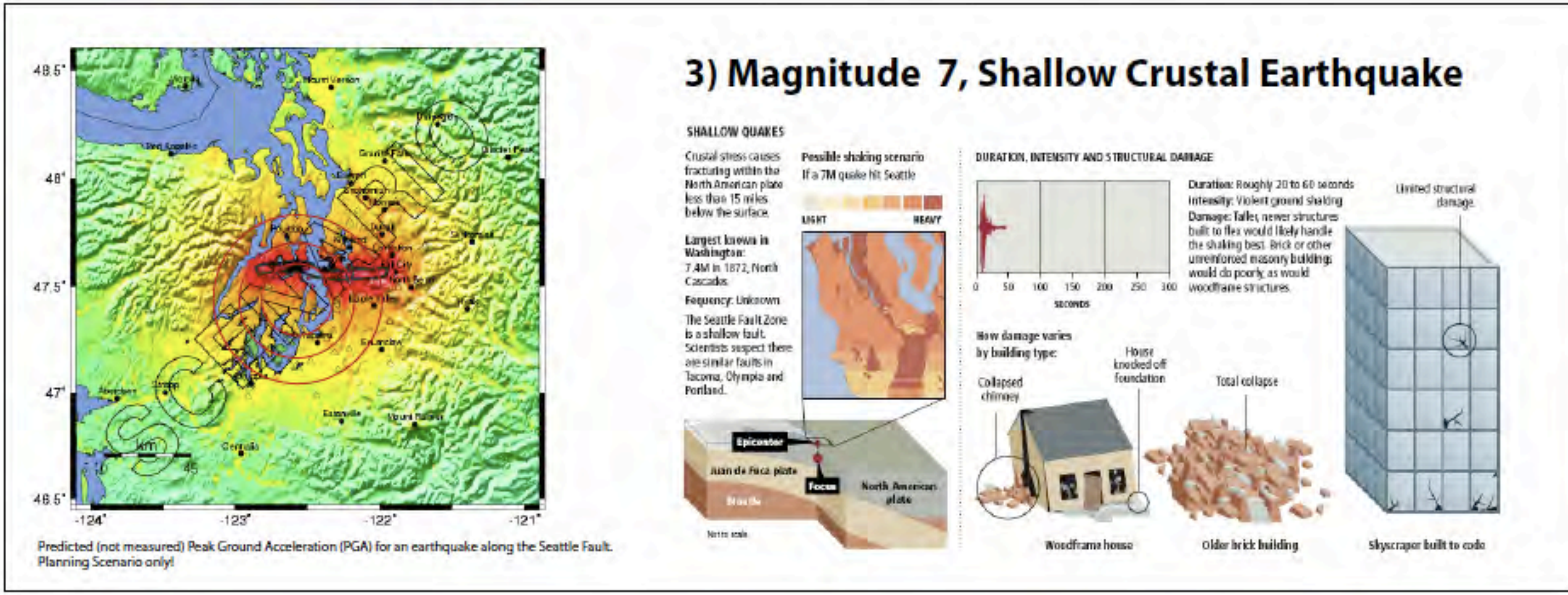
ShakeMap for SIMULATED M9 Cascadia earthquake



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+

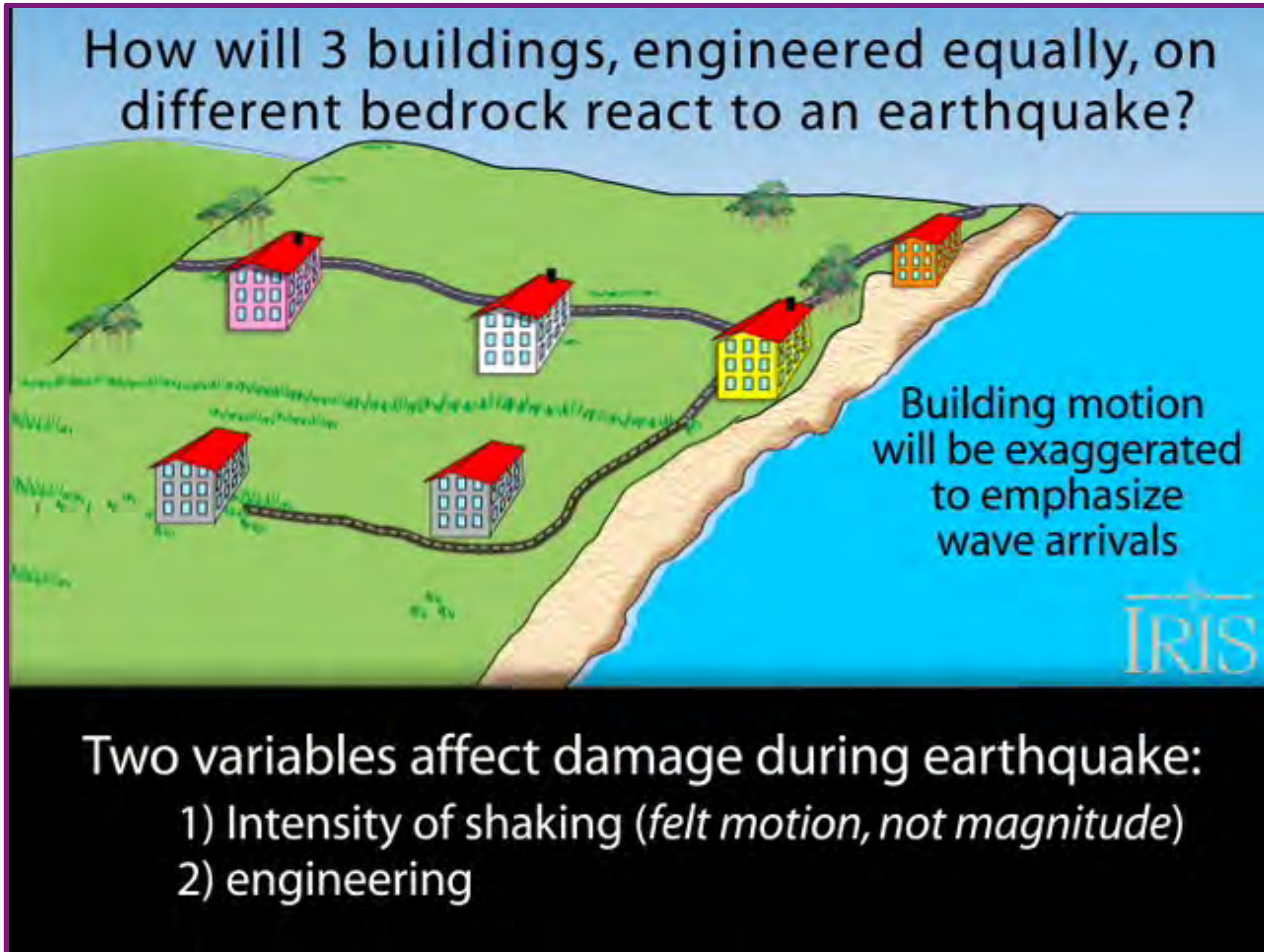
Three kinds of Cascadia EQs = Triple Trouble



Magnitude 9 Subduction Zone Earthquake
Magnitude 6.5 "Deep" Earthquake
Magnitude 7 "Crustal" Earthquake

20 - 30 seconds of shaking
Ground shaking for 4 - 6 minutes.

Effects of Near-Surface Geology



Amplitude of oscillation increasing

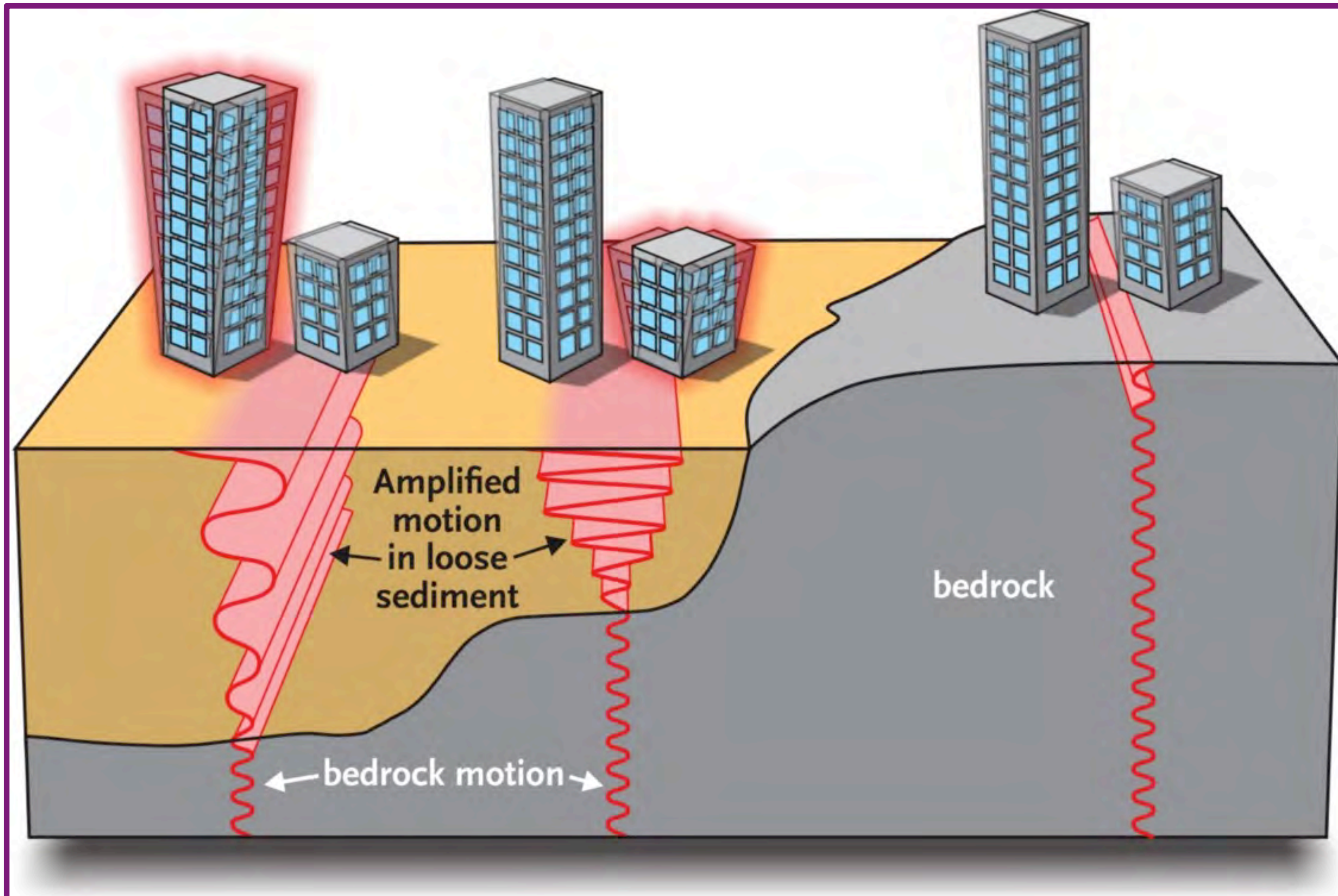
Liquefaction

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

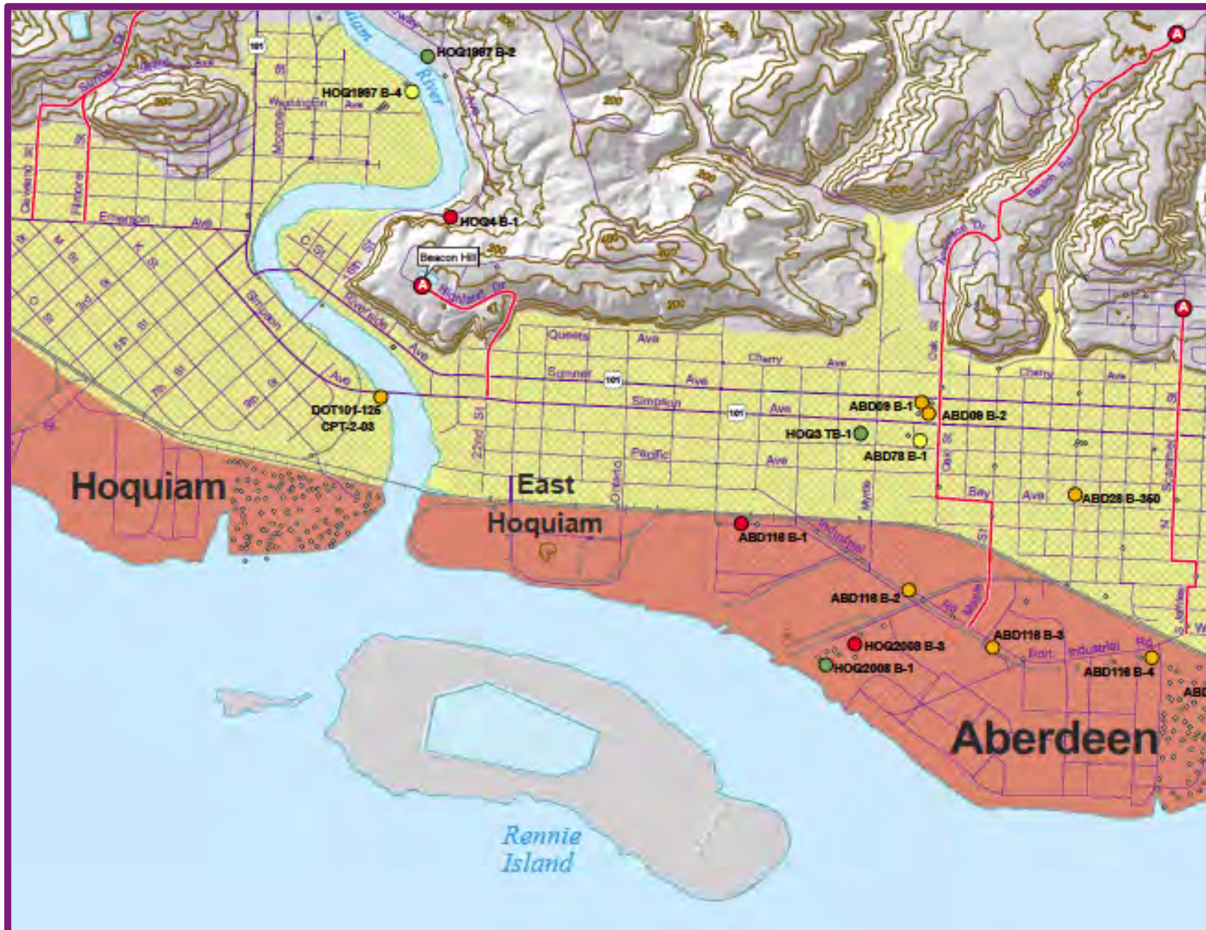
Relative Earthquake Hazards

Relative EQ Hazard

Seismic Wave Amplification

Liquefaction Potential

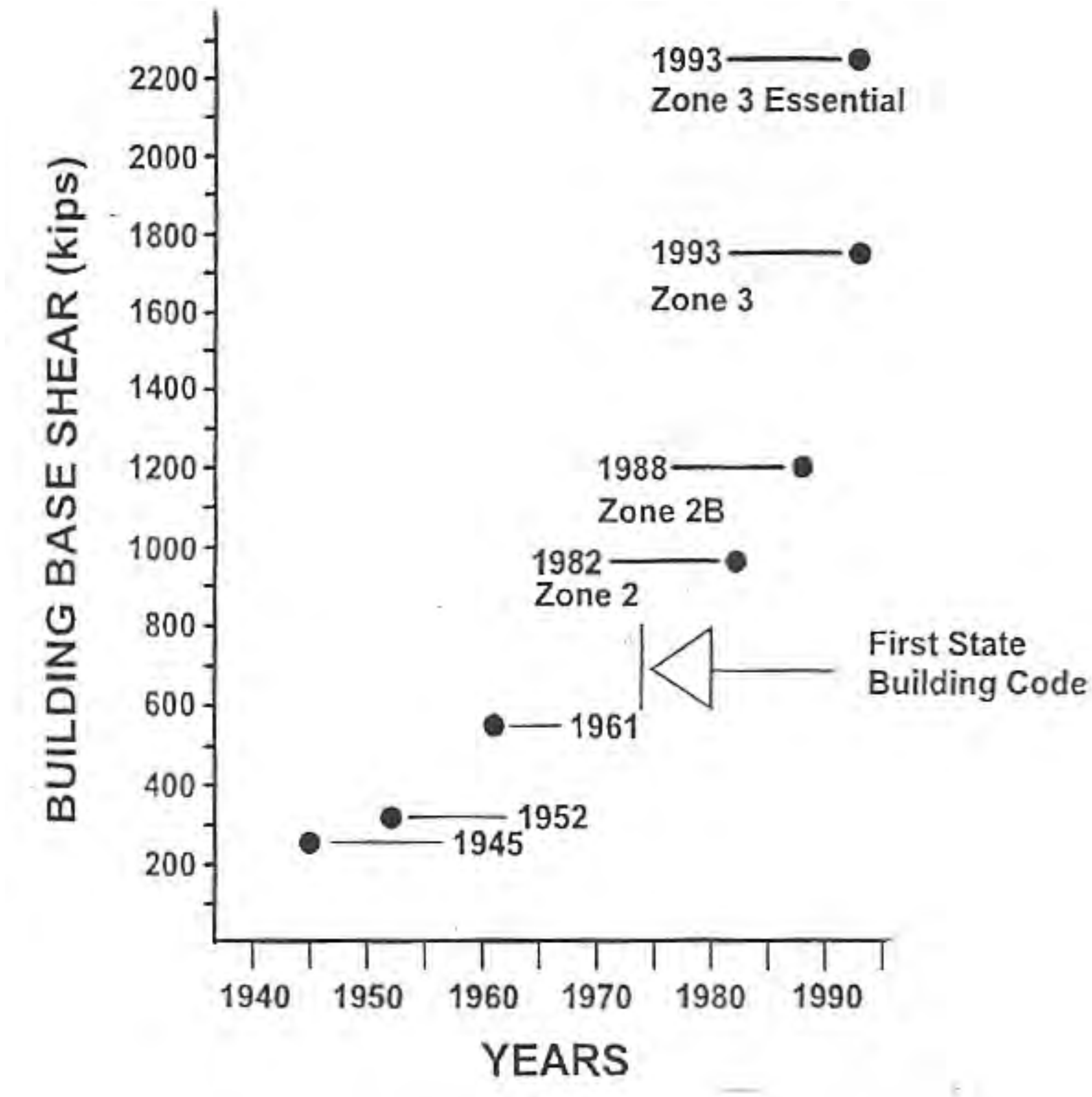
Earthquake-induced Landslide Hazard



Build a Better Wall

“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

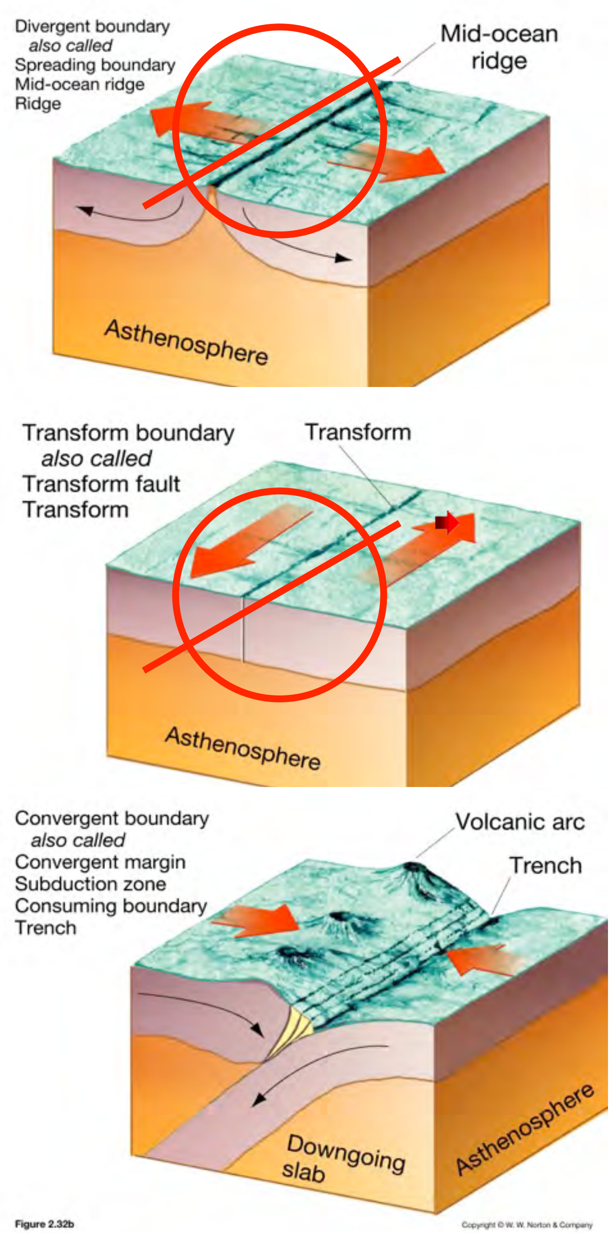
Bolting frame to foundation on exterior.

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.

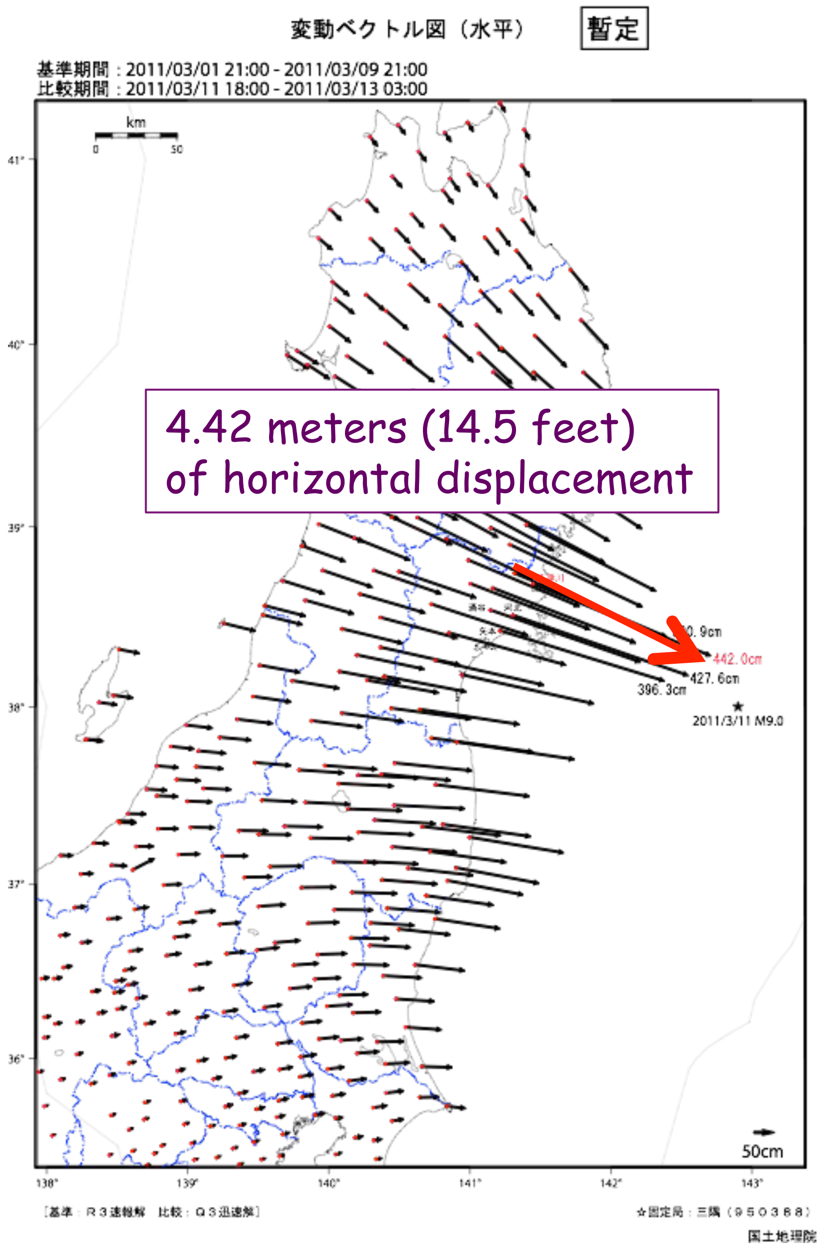
Tohoku Earthquake Fault Displacement Model

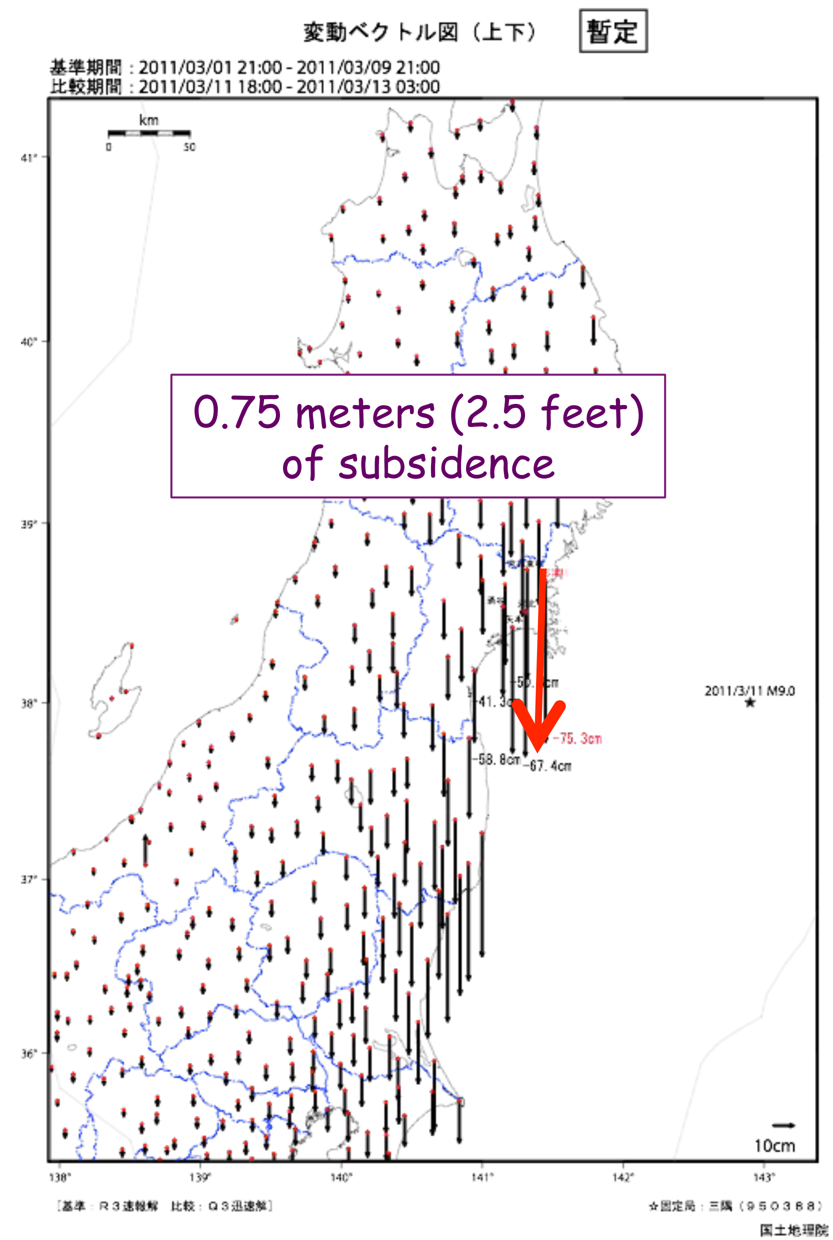
Modeling of seismic
wavef
fault s

Maxim
the su
hypoce

Such l
surfac
displac
floor t
large t

GPS Displacements During the Earthquake





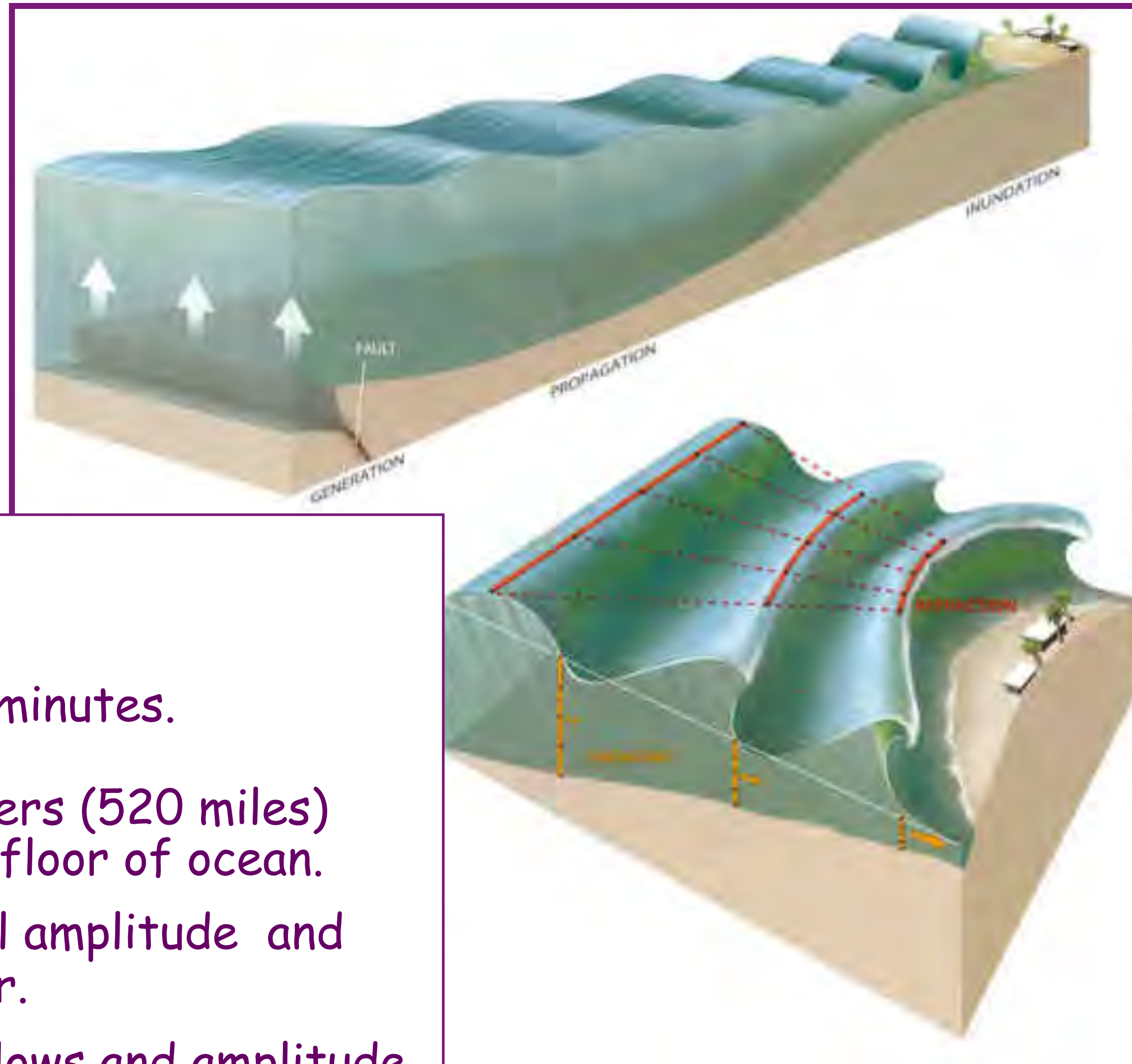
Some Coast Areas Now Below Sea Level
Yuriage

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.

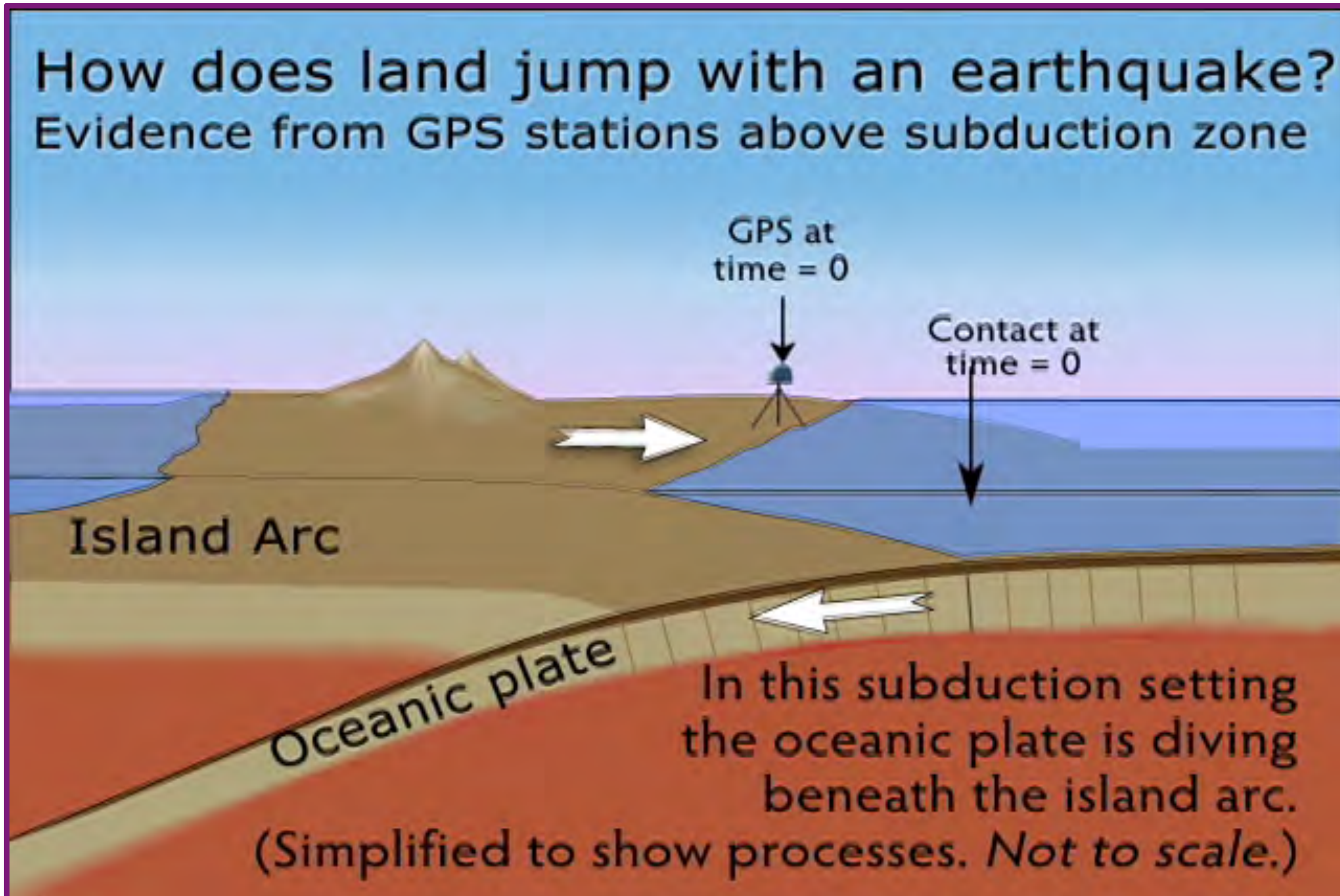
LONG wavelength: >800 kilometers (520 miles)
Moves seawater all the way to floor of ocean.

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.

Tsunami Stones on Hillsides
Message: "Do not build below this level."

Cascadia Great Earthquakes and Tsunamis After Field Trip

Relative Earthquake Hazards

Relative EQ Hazard

= Seismic Wave Amplification

+ Liquefaction Potential

+ Earthquake-induced Landslide Hazard