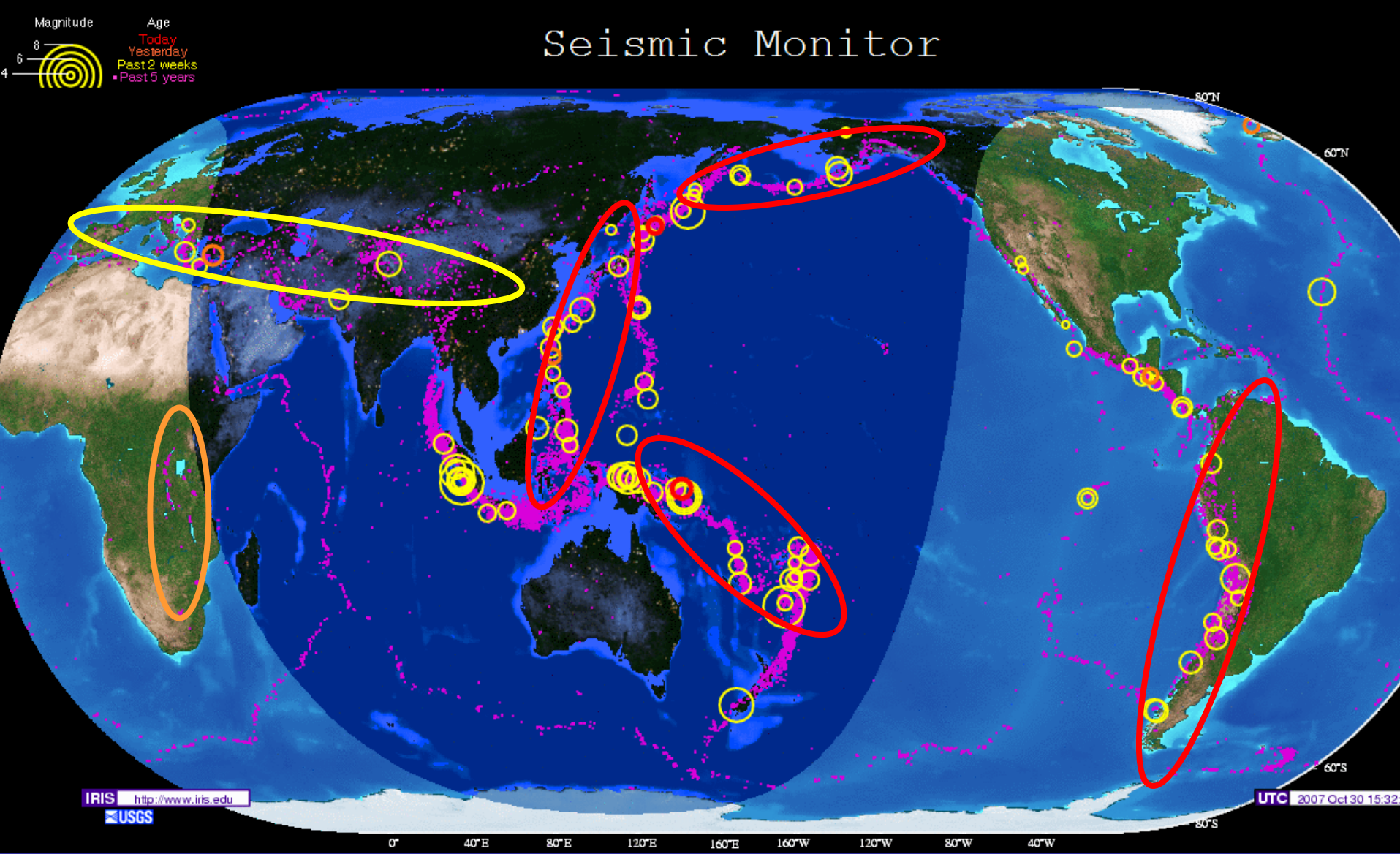


Where are most of the world's earthquakes?

A) Divergent, B) Convergent, C) Transform, D) Hotspot, E) Intracontinental

Convergent boundaries – “Ring of Fire”



RING OF FIRE

Aleutian trench

Kurile trench

Japan trench

Izu Bonin trench

Ryukyu trench

Philippine trench

Marianas trench

Challenger Deep

Bougainville trench

Java (Sunda) trench

Tonga trench

Kermadec trench

Puerto Rico trench

Middle America trench

Equator

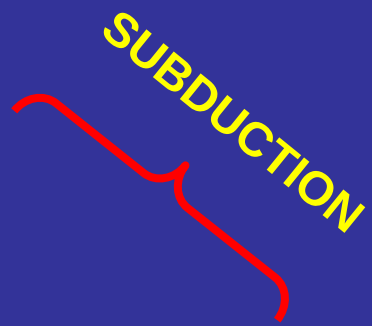
Peru-Chile trench

South Sandwich trench

90% world’s earthquakes
81% of world’s largest earthquakes
Explosive volcanism

Where do the world's earthquakes occur?

90% within Ring of Fire (convergence)
Thrust (reverse) faults



5-6% within Alpine-Himalayan belt (convergence)
Thrust (reverse) faults

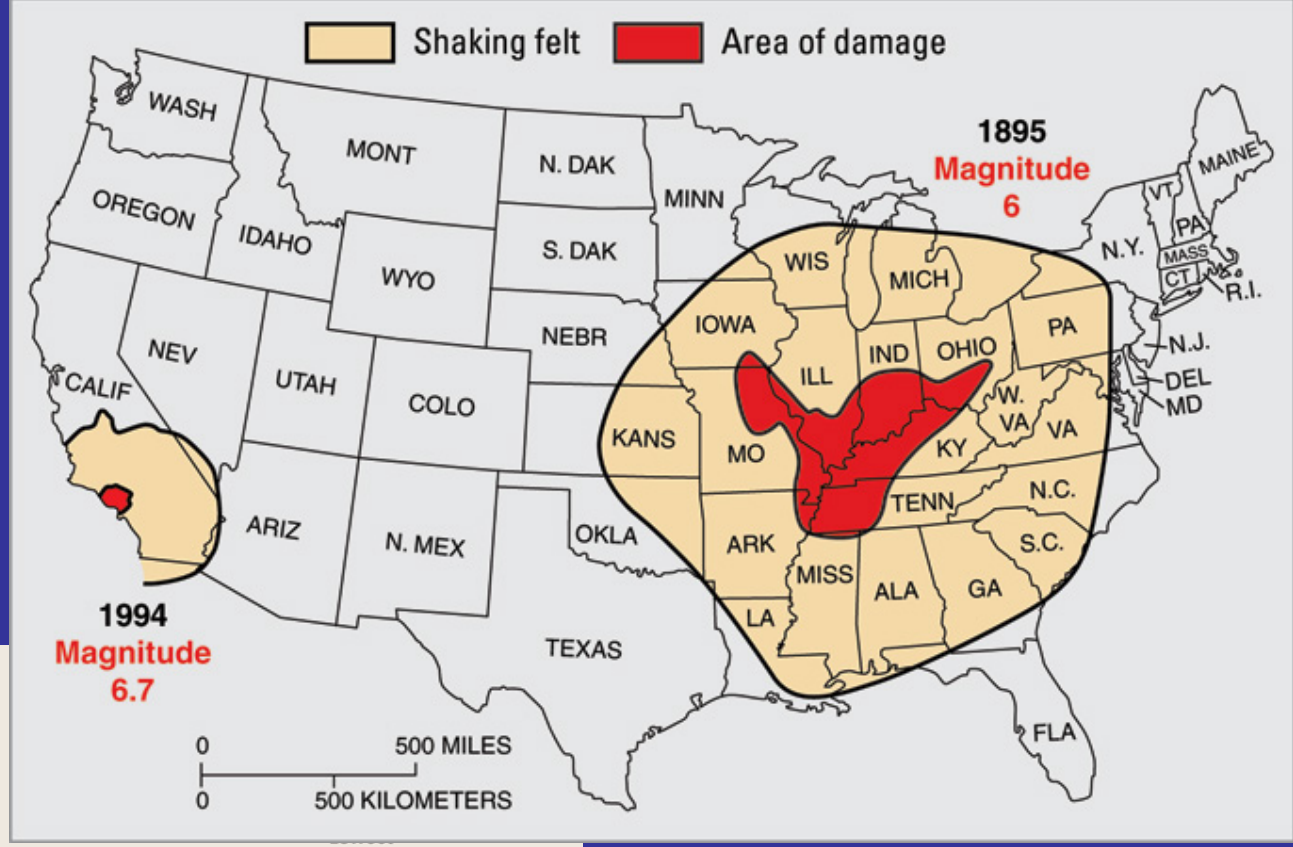
<4% along Mid-Atlantic Ridge (divergence)
Strike-slip (transform) faults

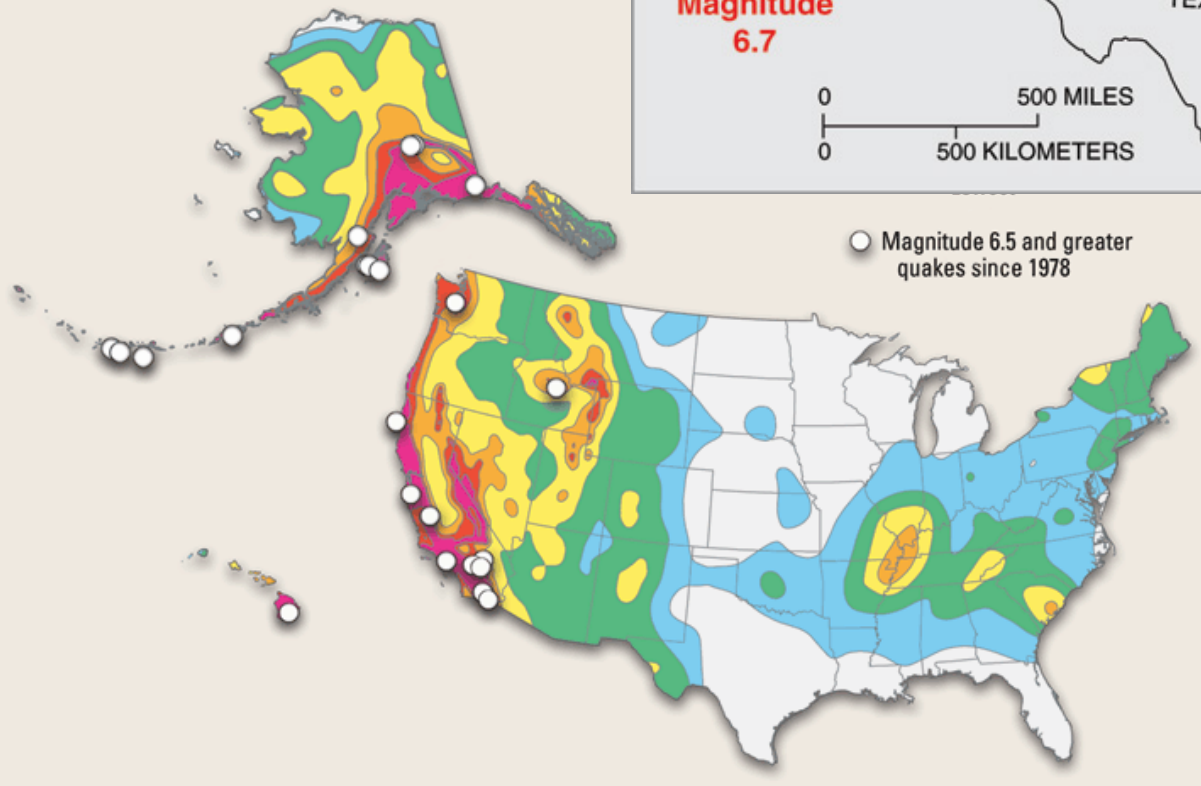
New Madrid Seismic Zone

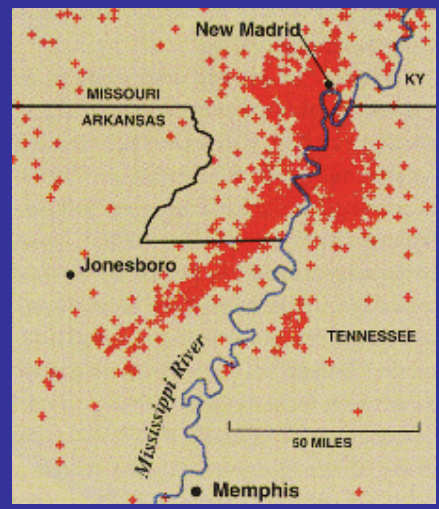
1) 12/16/1811 M 7.2-8.1

2) 1/23/1812 M 7.0-7.8

3) 2/4/1812 M 7.4-8.0

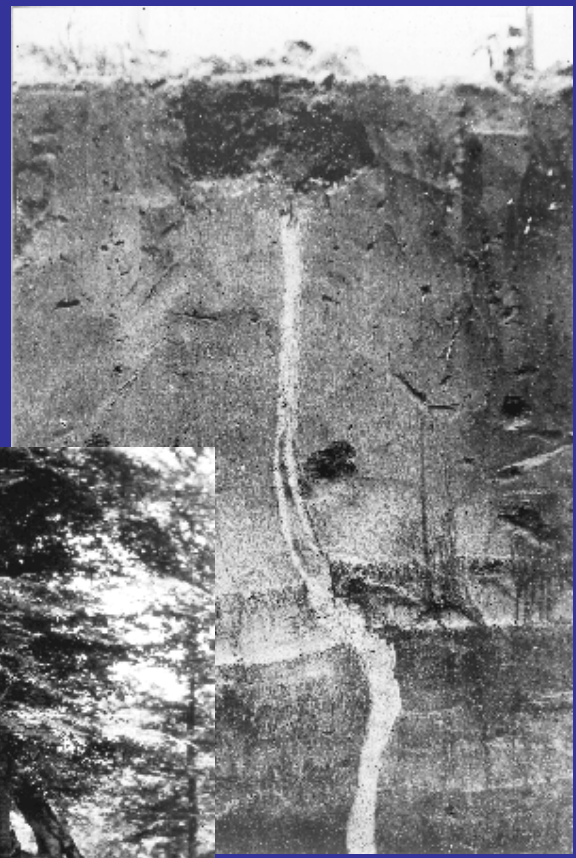






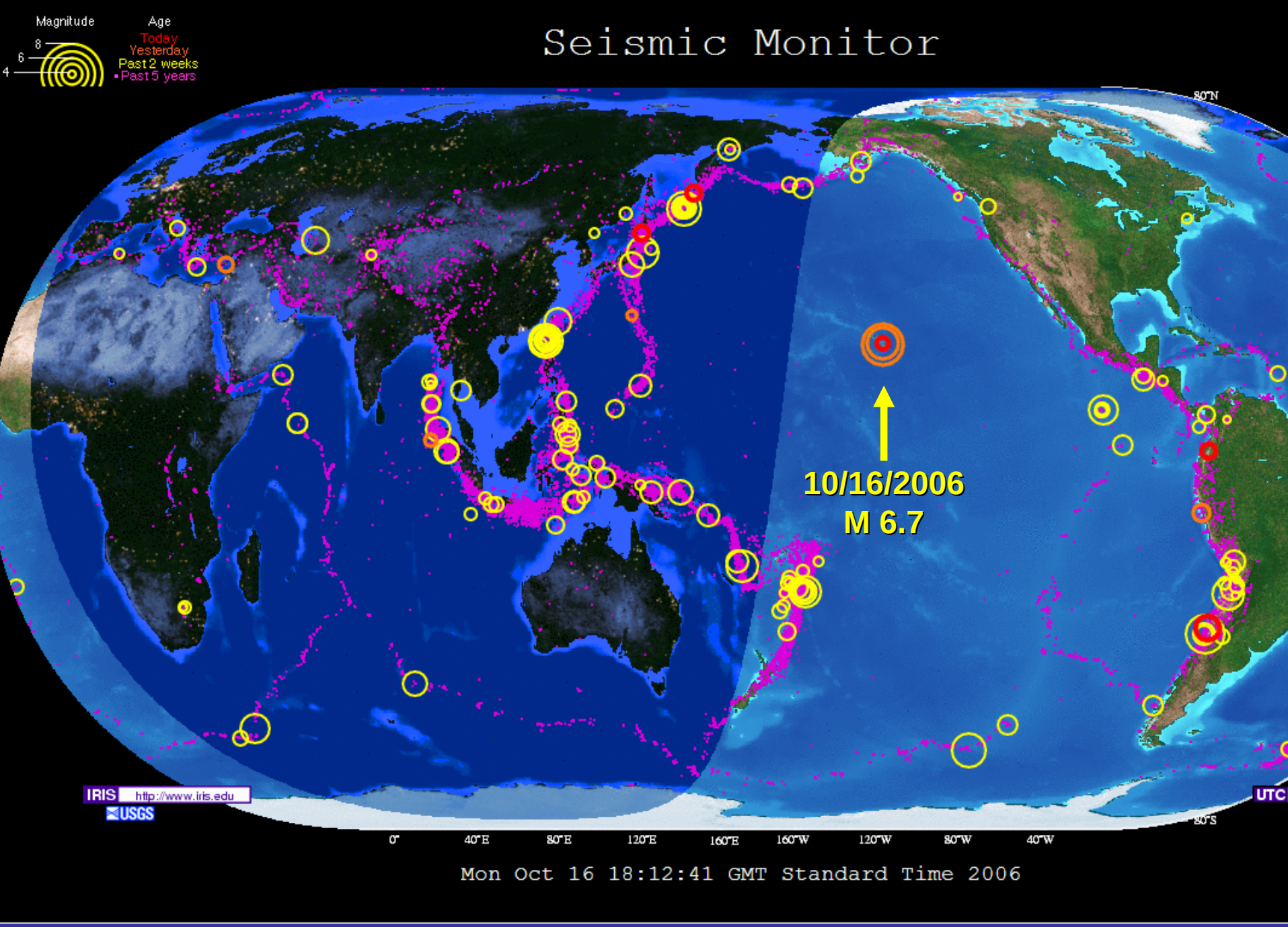
Quake Effects










Magnitude
8
6
4
Age
Today
Yesterday
Past 2 weeks
Past 5 years
Seismic Monitor
10/16/2006
M 6.7
IRIS
http://www.iris.edu
USGS
UTC
80°N
80°S
0°
40°E
80°E
120°E
160°E
160°W
120°W
80°W
40°W
Mon Oct 16 18:12:41 GMT Standard Time 2006







Structural Damage

Infrastructure Impacts











Road Damage





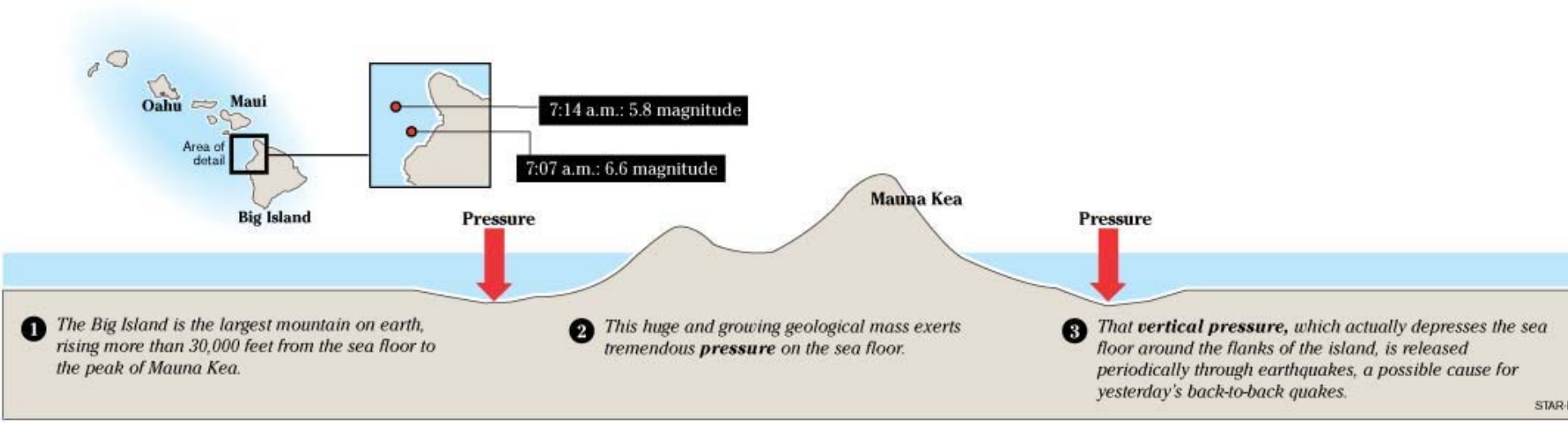


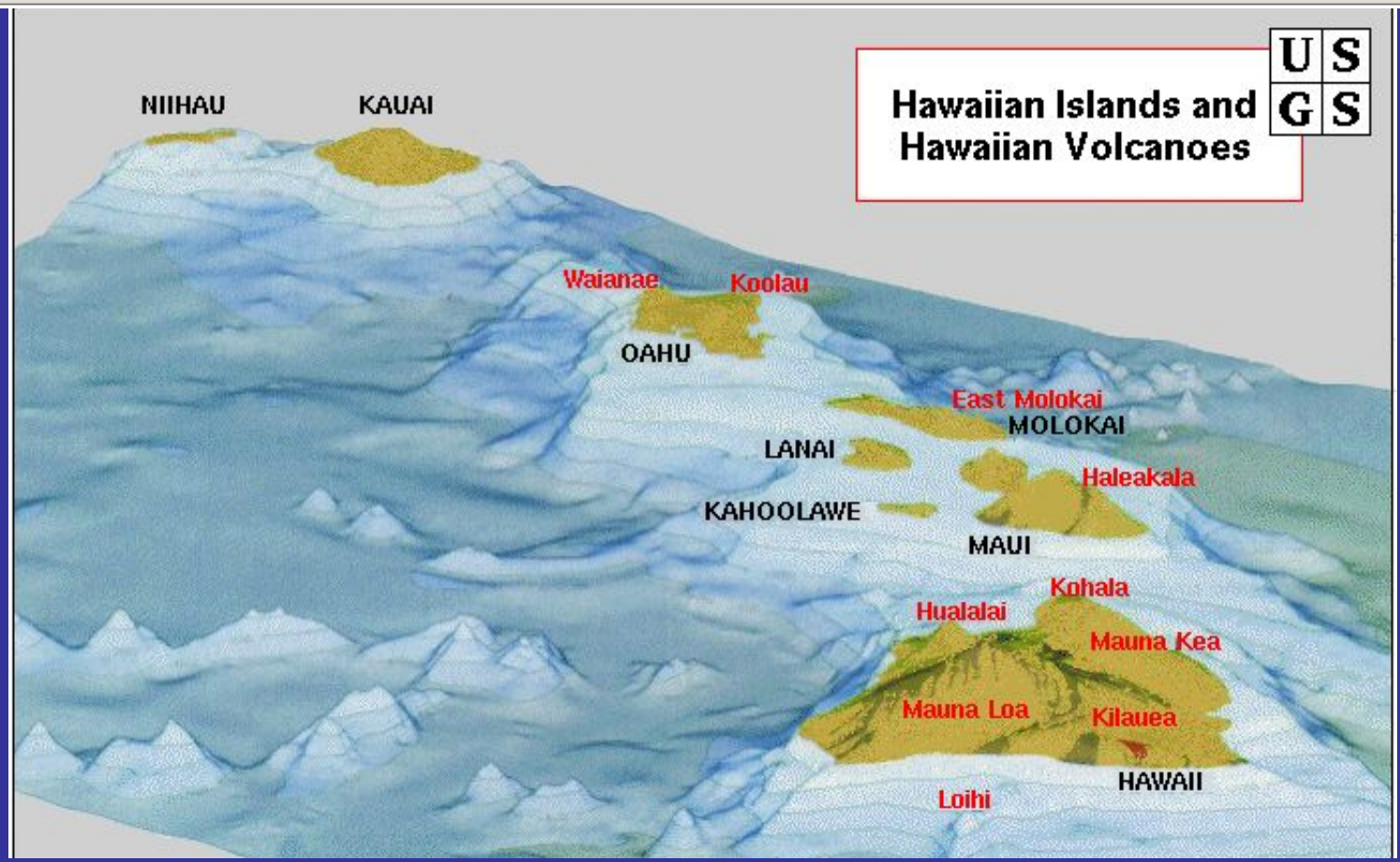
Food Distribution

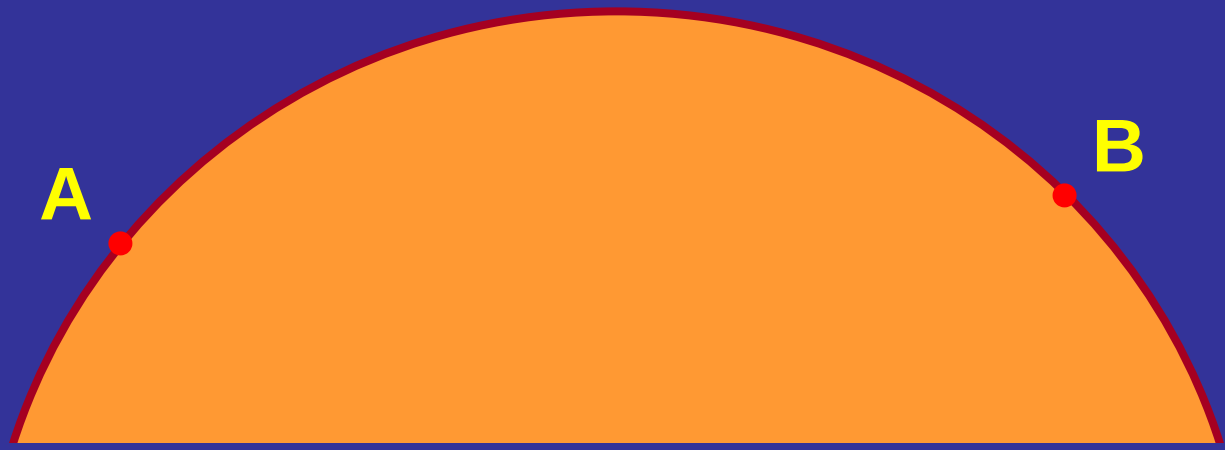
How much does lava weigh?



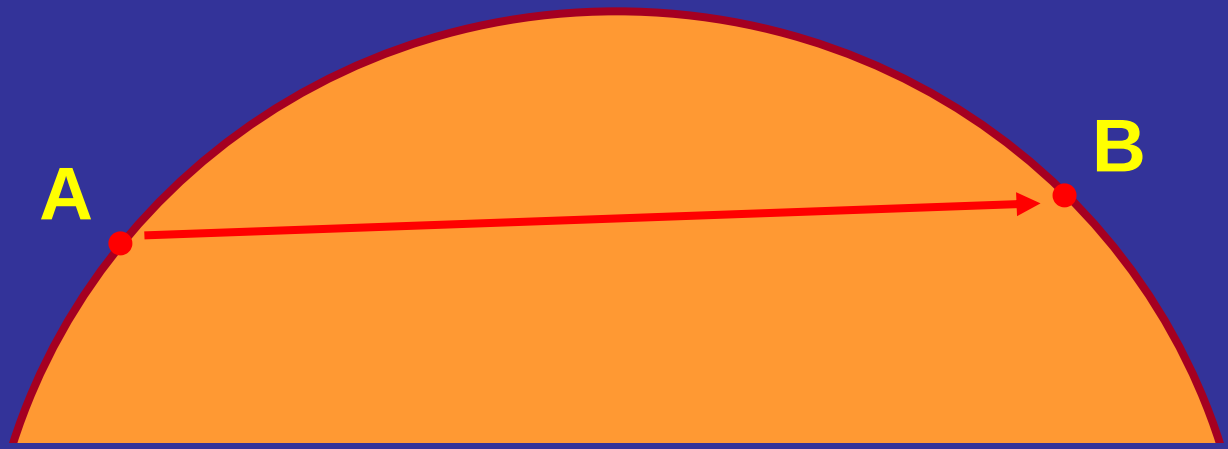



Oahu
Maui
Area of detail
Big Island
7:14 a.m.: 5.8 magnitude
7:07 a.m.: 6.6 magnitude
Pressure
Mauna Kea
Pressure
1 The Big Island is the largest mountain on earth, rising more than 30,000 feet from the sea floor to the peak of Mauna Kea.
2 This huge and growing geological mass exerts tremendous pressure on the sea floor.
3 That vertical pressure, which actually depresses the sea floor around the flanks of the island, is released periodically through earthquakes, a possible cause for yesterday's back-to-back quakes.


Hawaiian Islands and Hawaiian Volcanoes
USGS
NIIHAU
KAUAI
Waianae
Koolau
OAHU
East Molokai
MOLOKAI
LANAI
Haleakala
KAHOOLAWE
MAUI
Kohala
Hualalai
Mauna Kea
Mauna Loa
Kilauea
HAWAII
Loihi



What's the fastest way to get from point A to point B?



3 different types of seismic waves:

Body waves (travel through Earth):

1) Primary waves (P-waves)

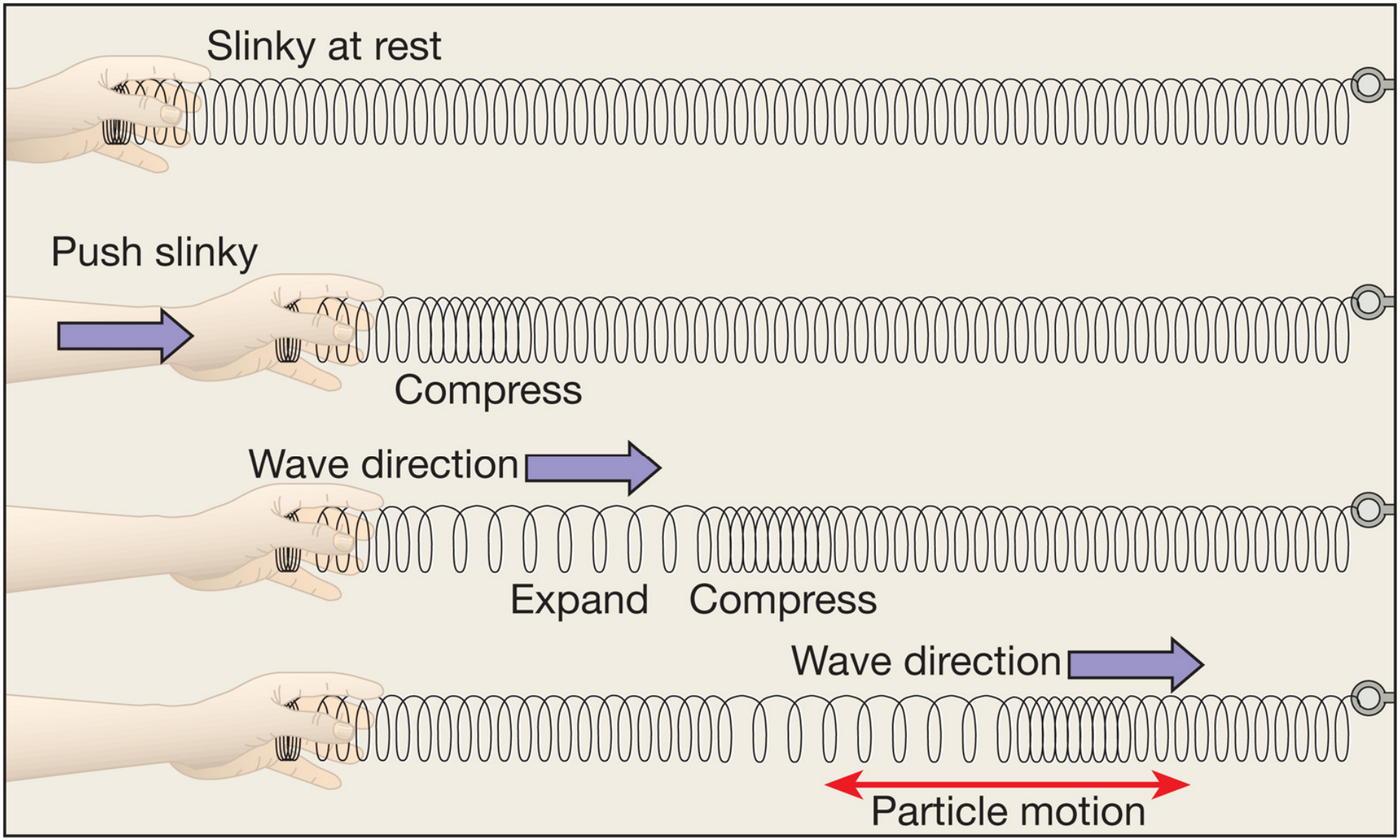
2) Secondary waves (S-waves)

(cannot travel through liquid)

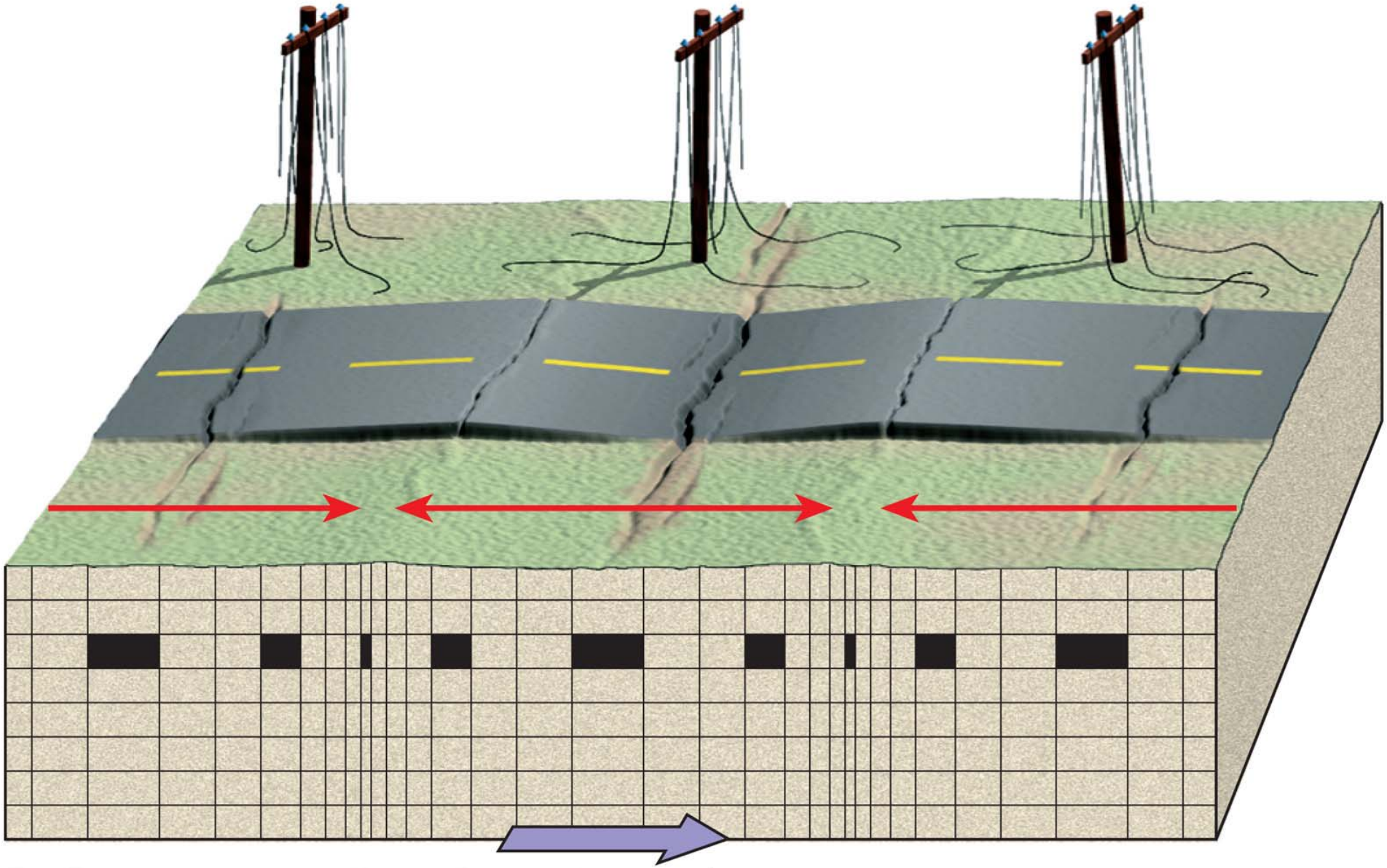
3) Surface waves (travel across surface)

FAST

SLOW



A. P waves generated using a slinky



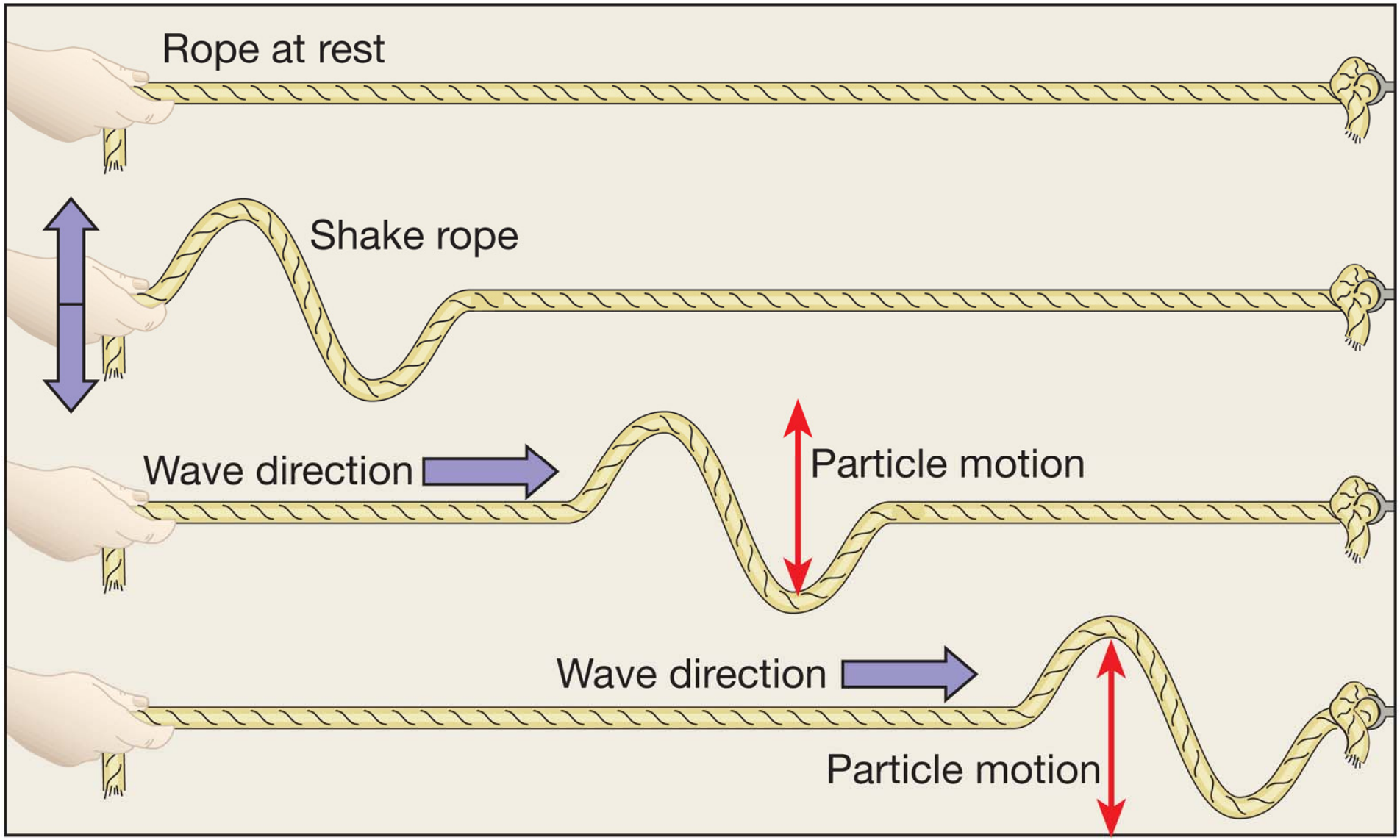
B. P waves traveling along the surface



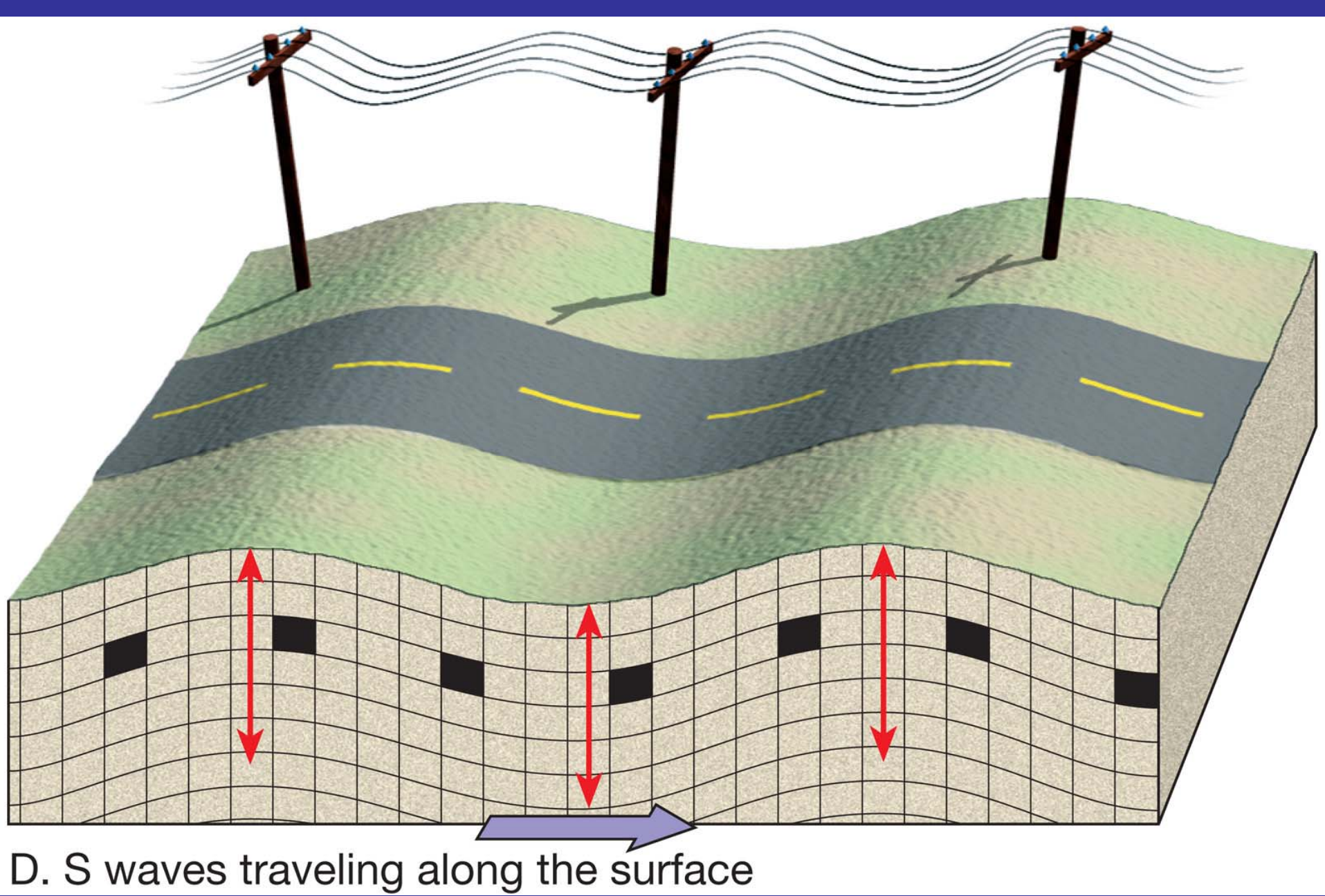




Fissuring (horizontal motion)



C. S waves generated using a rope

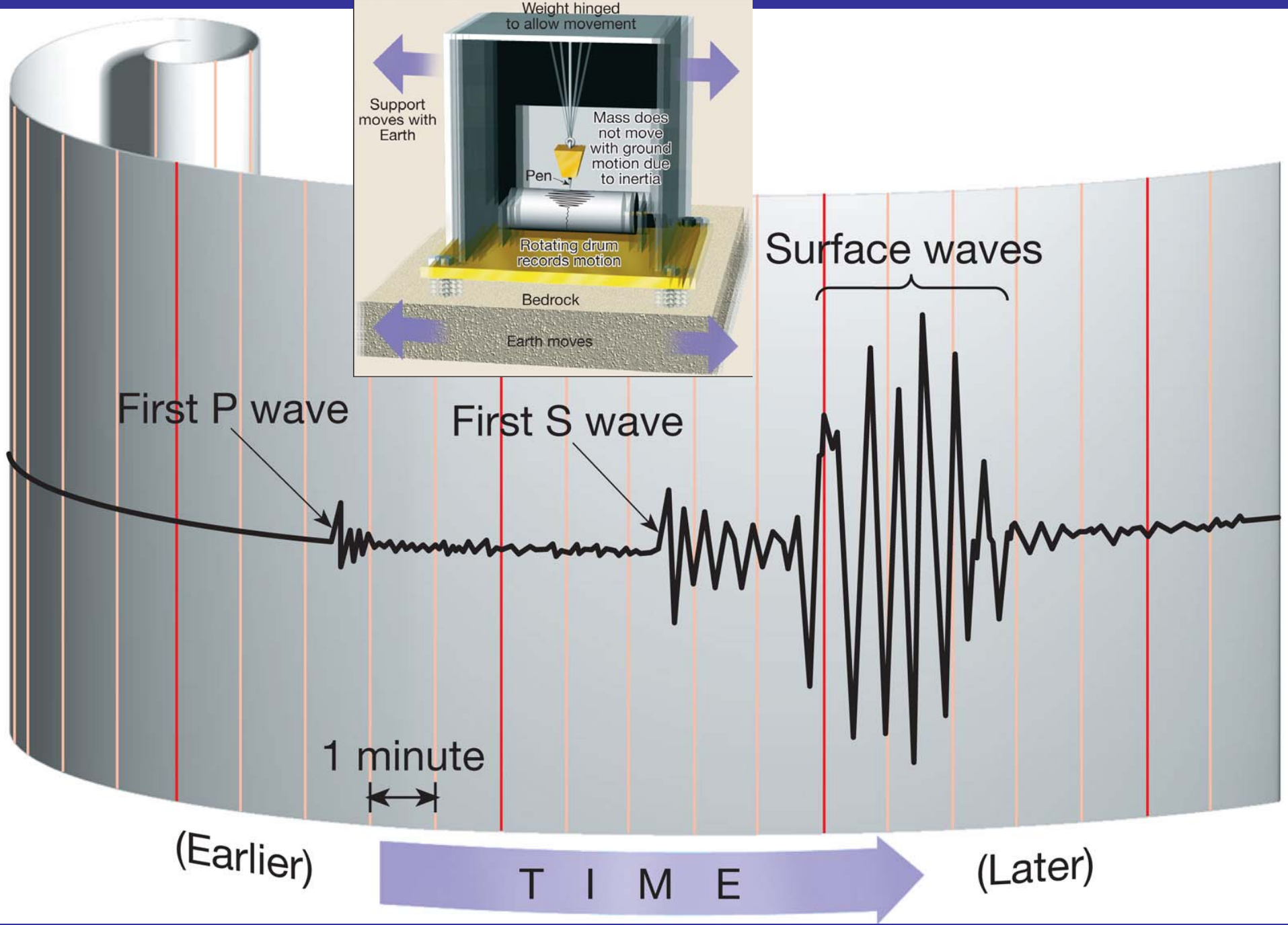


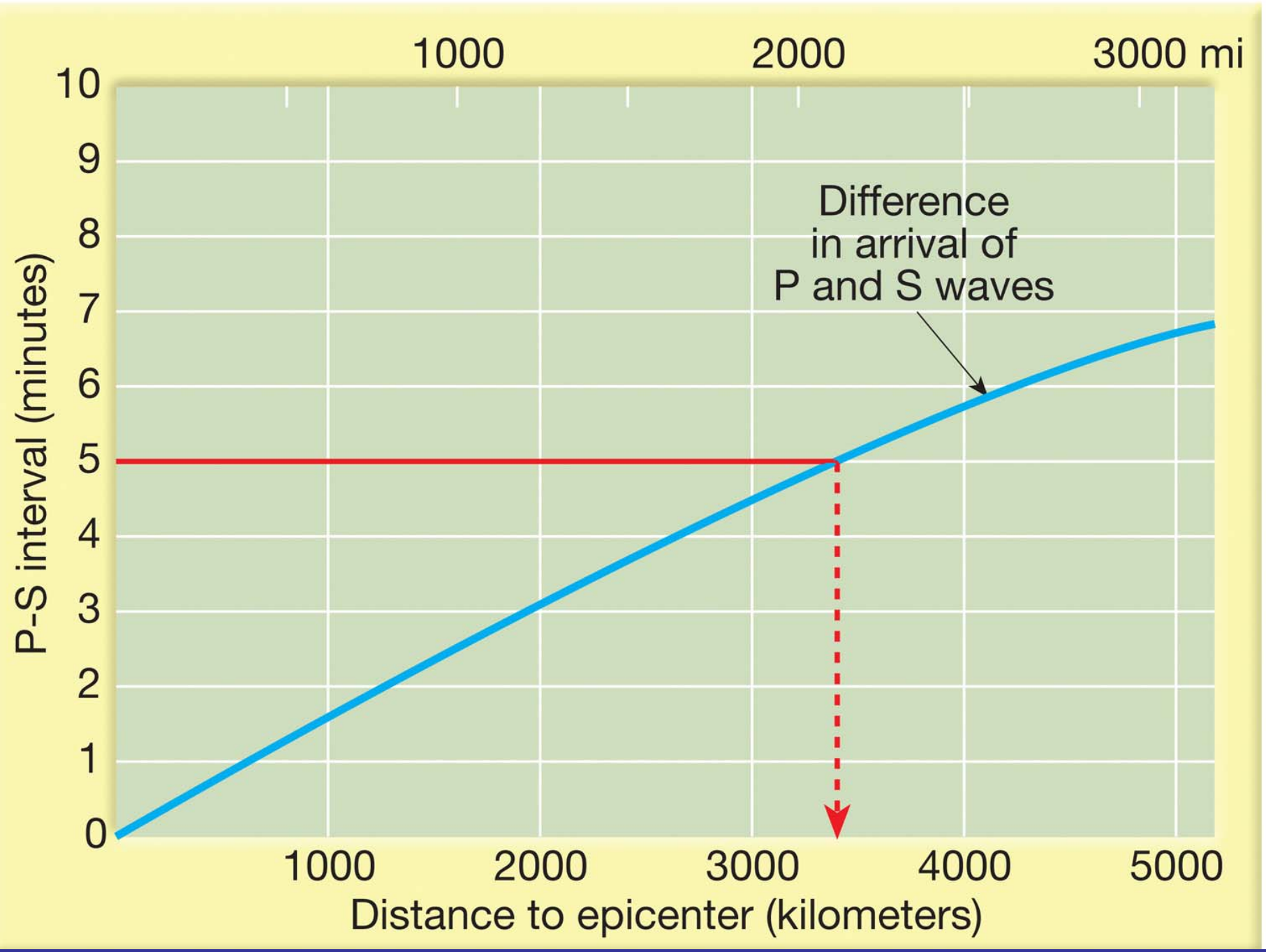
D. S waves traveling along the surface

Damage from flexure (vertical motion)






Weight hinged
to allow movement
Support
moves with
Earth
Mass does
not move
with ground
motion due
to inertia
Pen
Rotating drum
records motion
Bedrock
Earth moves
Surface waves
First P wave
First S wave
1 minute
(Earlier)
T I M E
(Later)

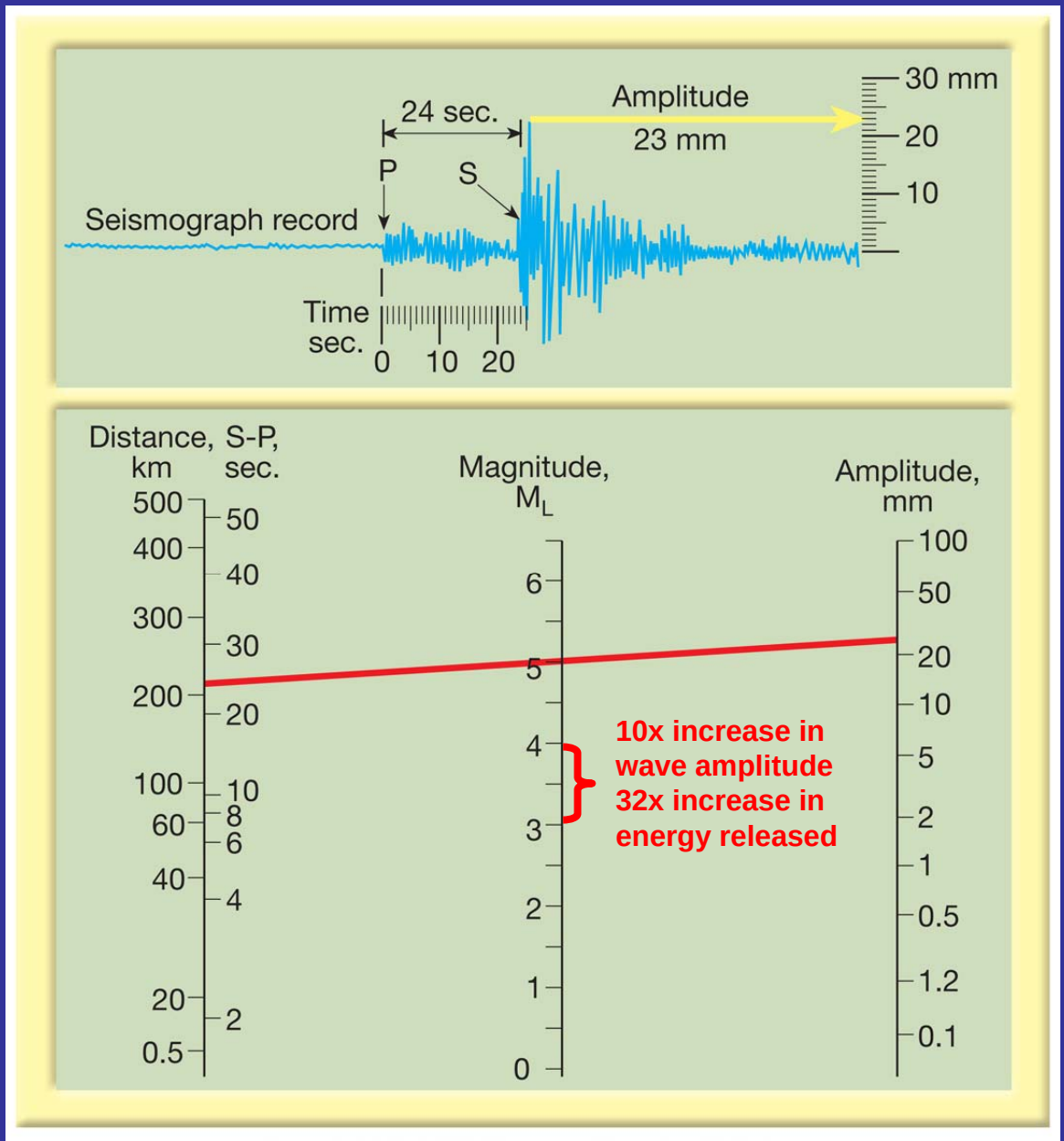

1000
2000
3000 mi
10
9
8
7
6
5
4
3
2
1
0
P-S interval (minutes)
Difference
in arrival of
P and S waves
1000
2000
3000
4000
5000
Distance to epicenter (kilometers)



Triangulation

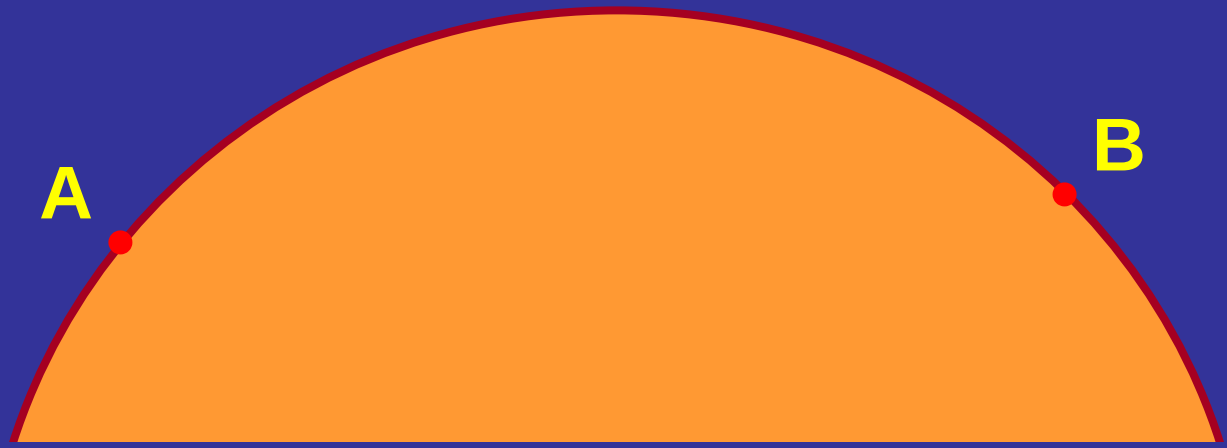
Overlapping distance calculations from 3 points

How do you measure the intensity of an earthquake?



Richter Magnitude Scale (1935)

Uses amplitudes of waves recorded on seismographs and distance from epicenter



What's the fastest-moving seismic wave?

A) Primary Wave (P-wave)
B) Body Wave
C) Secondary Wave (S-wave)
D) Surface Wave
E) Sound Wave



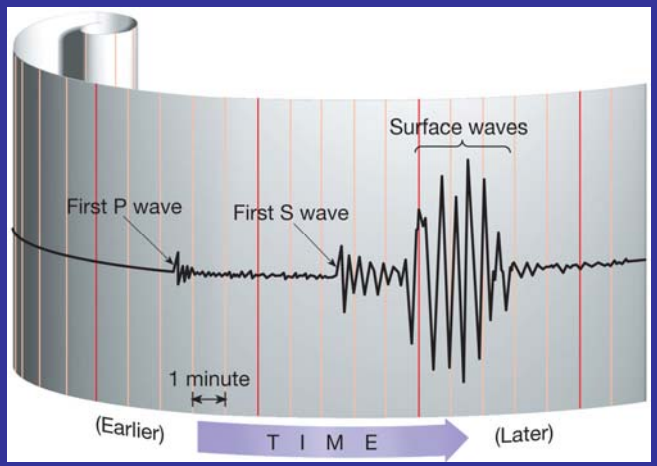
The first seismograph (Chinese), 132 AD

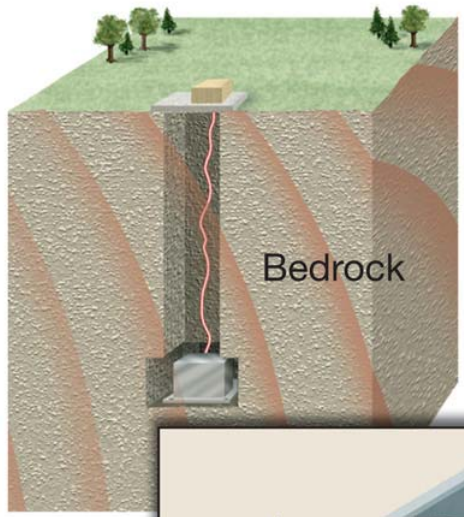


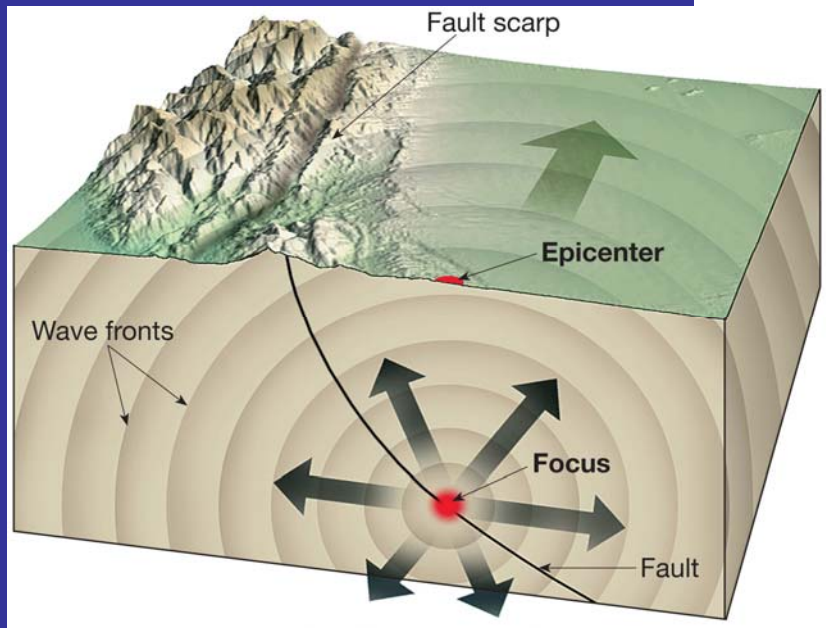
Central pendulum knocks ball from mouth of dragon into mouth of frog towards direction of first motion

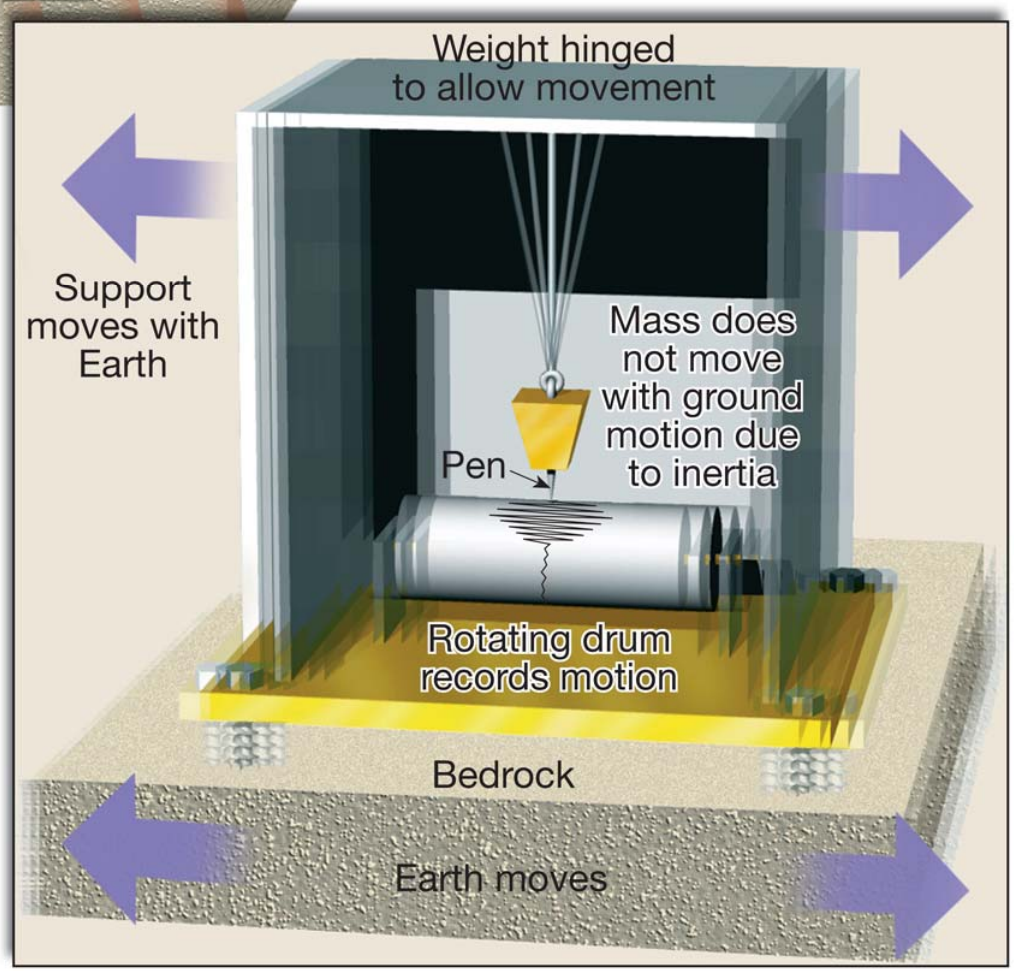


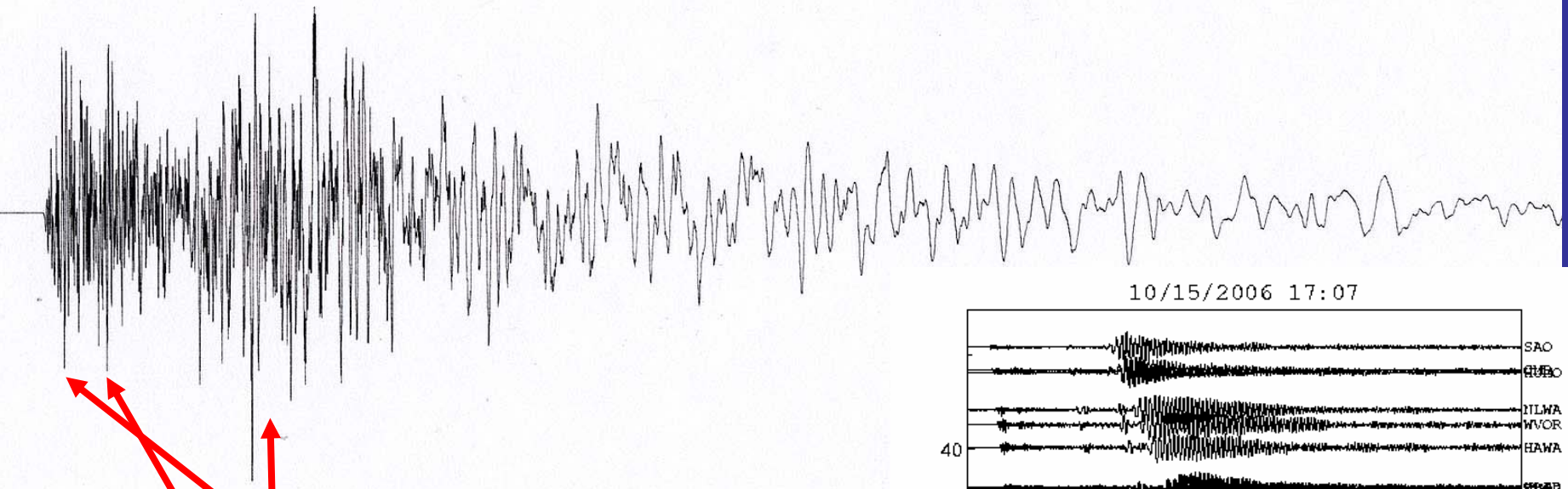
Modern Seismograph







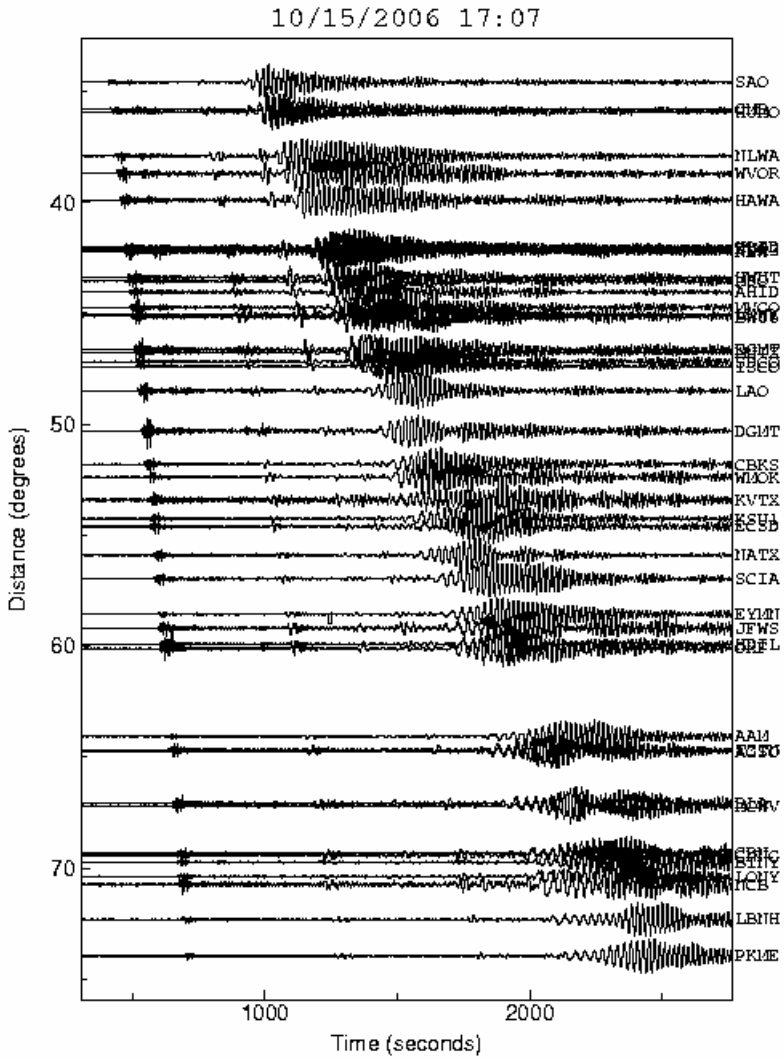


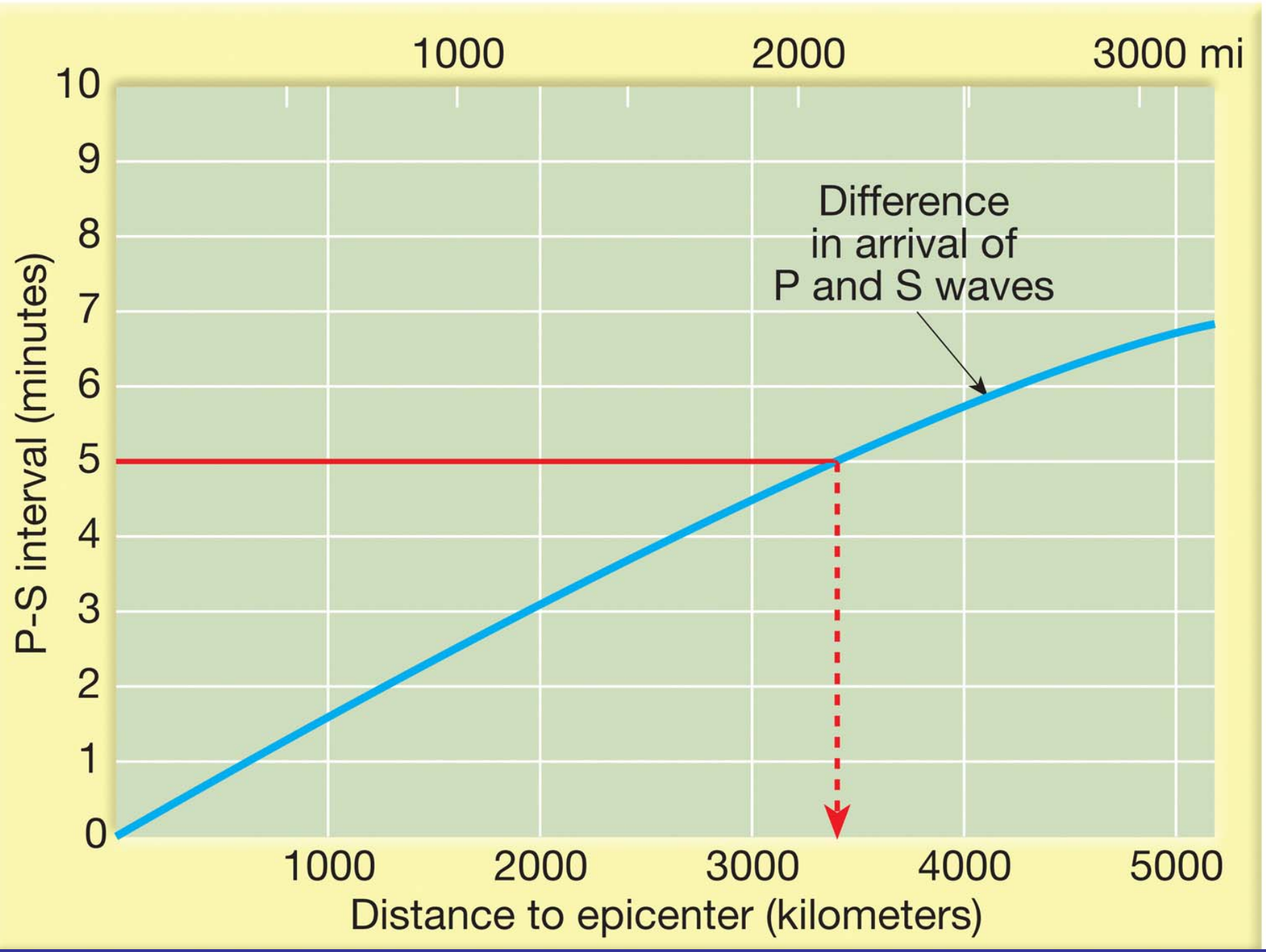


First P-waves

First S-waves

Surface Waves

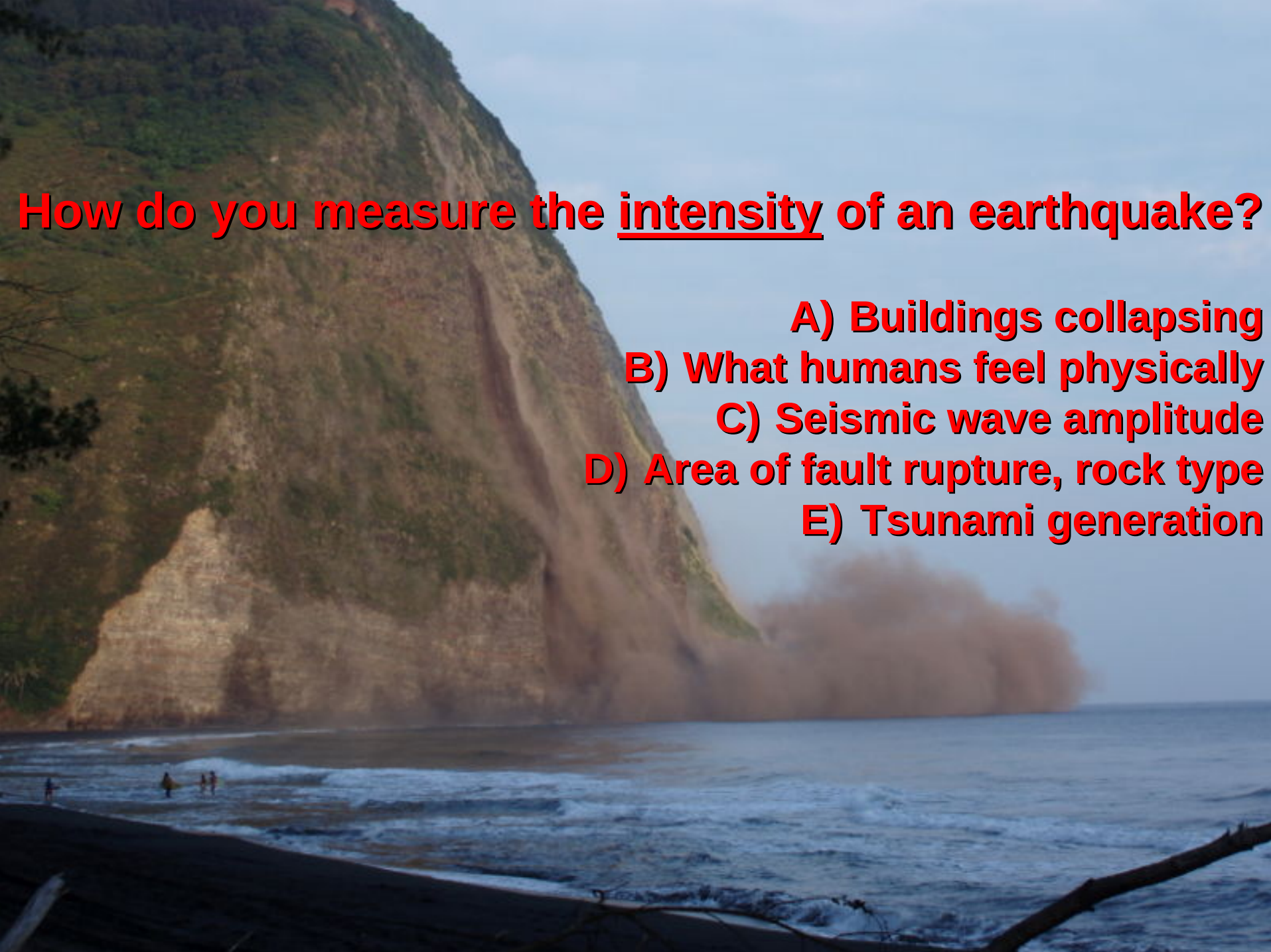



1000
2000
3000 mi
10
9
8
7
6
5
4
3
2
1
0
P-S interval (minutes)
Difference
in arrival of
P and S waves
1000
2000
3000
4000
5000
Distance to epicenter (kilometers)



Triangulation

Overlapping distance calculations from 3 points



How do you measure the intensity of an earthquake?

A) Buildings collapsing
B) What humans feel physically
C) Seismic wave amplitude
D) Area of fault rupture, rock type
E) Tsunami generation

1) Modified Mercalli Intensity Scale

I	Not felt except by a very few under especially favorable circumstances.
II	Felt only by a few persons at rest, especially on upper floors of buildings.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake.
IV	During the day felt indoors by many, outdoors by few. Sensation like heavy truck striking building.
V	Felt by nearly everyone, many awakened. Disturbances of trees, poles, and other tall objects sometimes noticed.
VI	Felt by all; many frightened and run outdoors. Some heavy furniture moved; few instances of fallen plaster or damaged chimneys. Damage slight.
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight-to-moderate in well-built ordinary structures; considerable in poorly built or badly designed structures.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. (Fall of chimneys, factory stacks, columns, monuments, walls.)
IX	Damage considerable in specially designed structures. Buildings shifted off foundations. Ground cracked conspicuously.
X	Some well-built wooden structures destroyed. Most masonry and frame structures destroyed. Ground badly cracked.
XI	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground.
XII	Damage total. Waves seen on ground surfaces. Objects thrown upward into air.

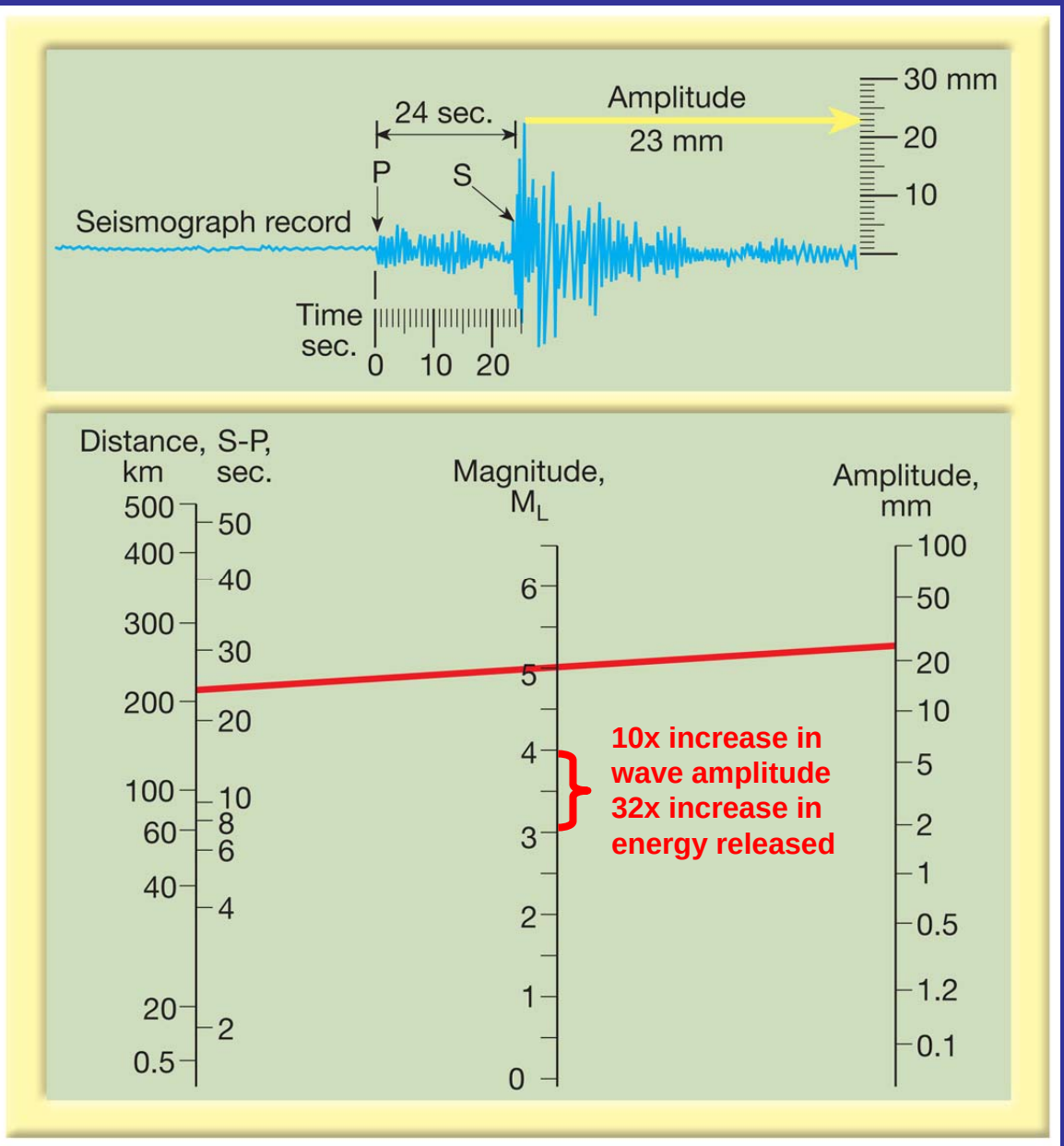
Created by Guiseppe Mercalli in 1902

What's wrong with this scale?

Anchorage, Alaska 1964, Richter magnitude 8.3



How do you measure the intensity of an earthquake?



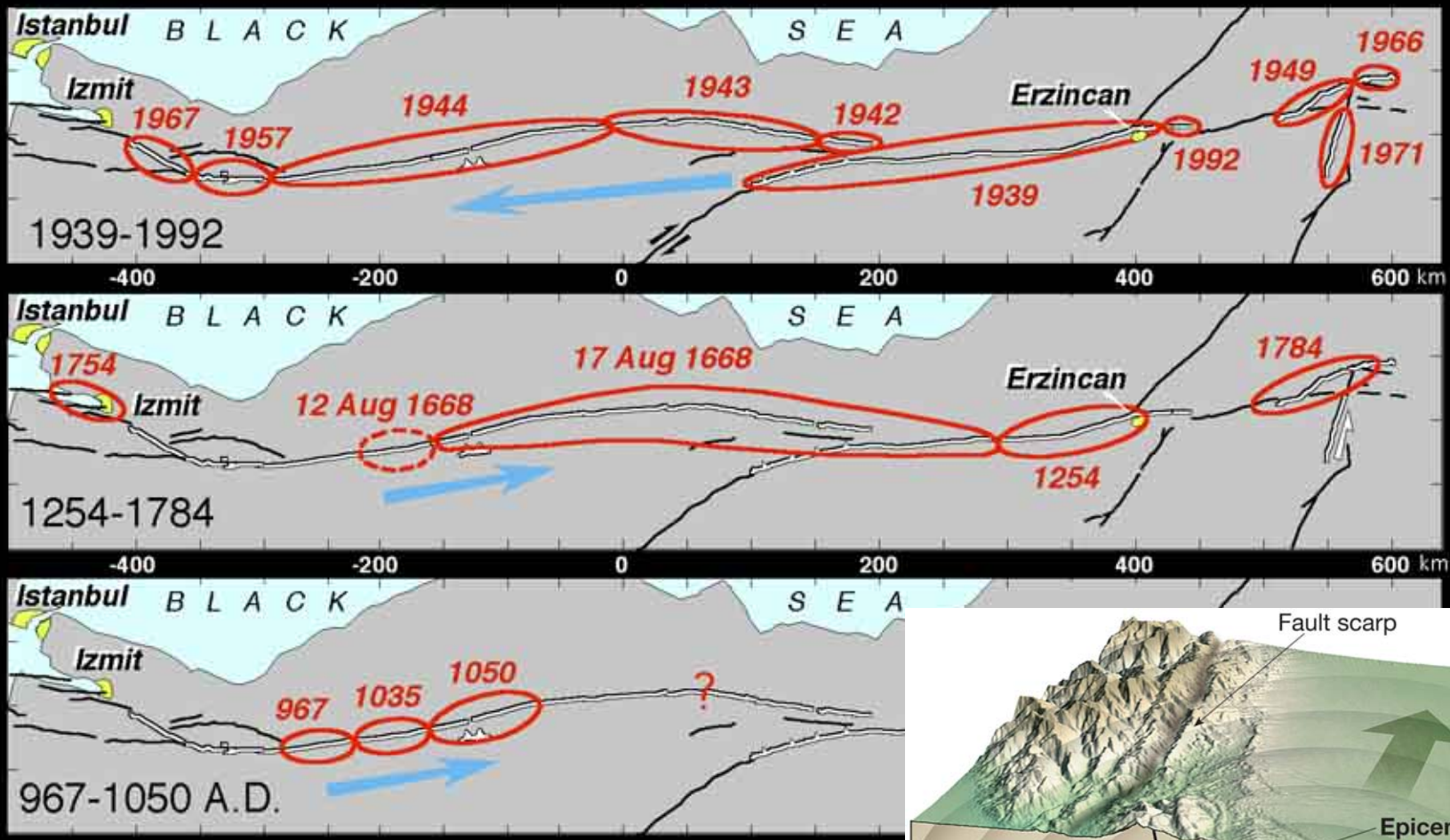
2) Richter Magnitude Scale (1935)

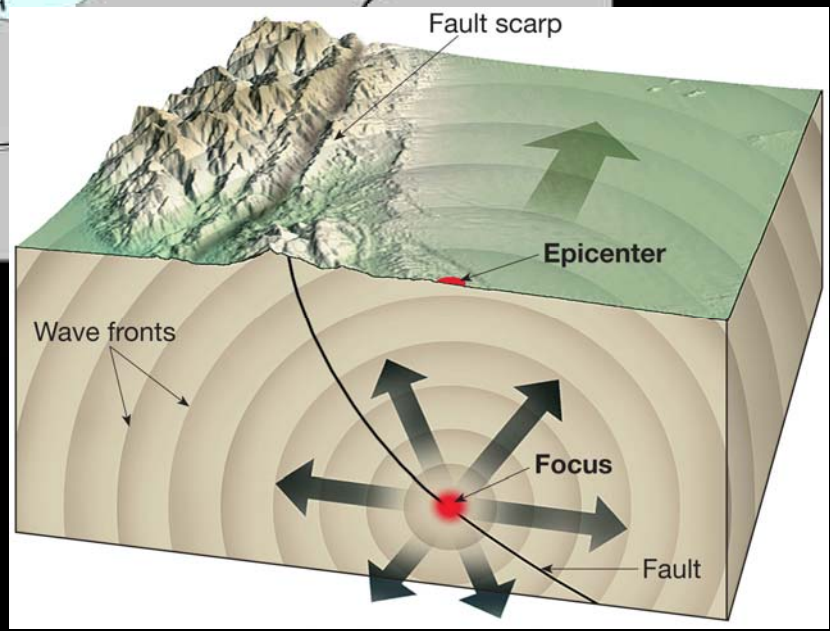
Uses 1) amplitudes of waves recorded on seismographs and 2) distance from epicenter



San Francisco 1906
Anchorage 1964
Both 8.3 on Richter Scale

North Anatolian fault often ruptures in progressive earthquakes Mean repeat time ~450±220 yr





Rupture <u>area</u> important to total energy released by earthquake

How do you measure the intensity of an earthquake?

Richter magnitude (M_L) can't distinguish largest quakes

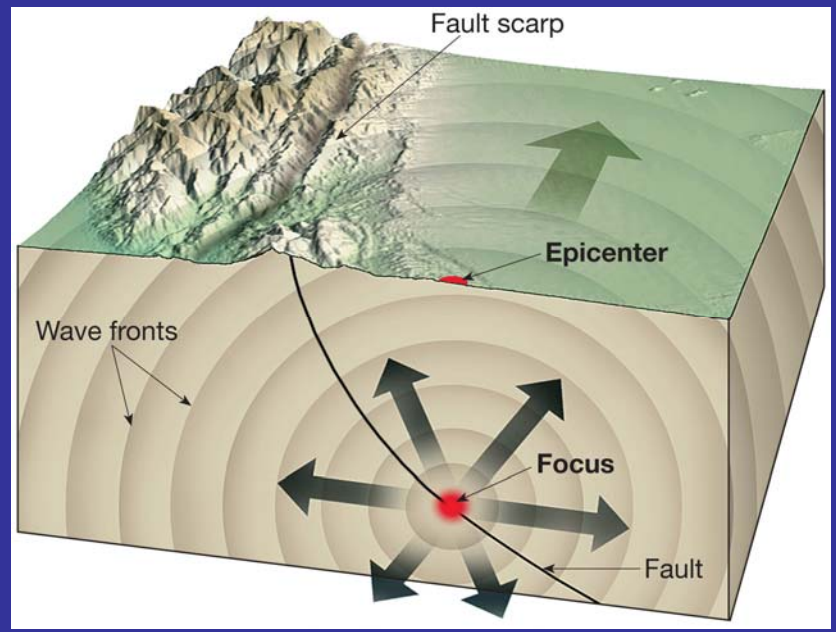
3) Moment magnitude (M_W) measures:

1) Average displacement along fault

2) Area of rupture surface

3) Shear strength of faulted rock

To give an accurate measure of earthquake energy



Anchorage, Alaska 1964, Richter magnitude 8.3, Moment magnitude 9.2
San Francisco, 1906, Richter magnitude 8.3, Moment magnitude 7.8



164 killed

High population density
Poor earthquake infrastructure

~3,000 killed

How do you measure the intensity of an earthquake?

1) (Modified) Mercalli Intensity Scale

can't account for differences in construction, population density, rock types

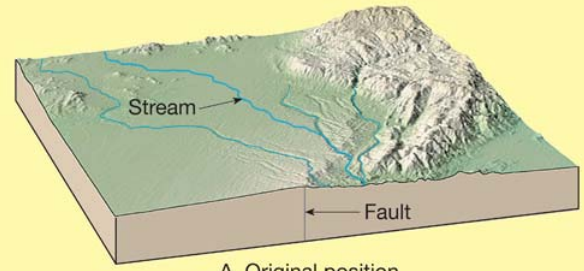
2) Richter Magnitude Scale (M_L)

can't distinguish largest earthquakes

3) Moment Magnitude Scale (M_W)

best tool for determining earthquake energy

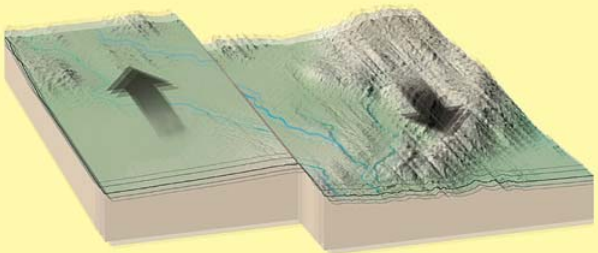
What happens during a strike-slip earthquake?

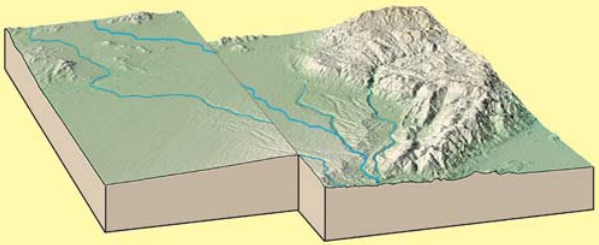


A. Original position



B. Buildup of strain

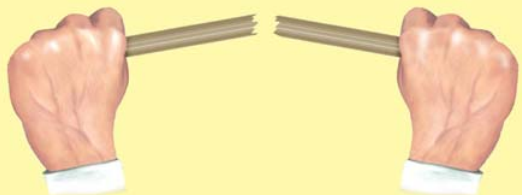

C. Slippage (earthquake)


D. Strain released


A. Original position


B. Buildup of strain


C. Rupture


D. Strain released

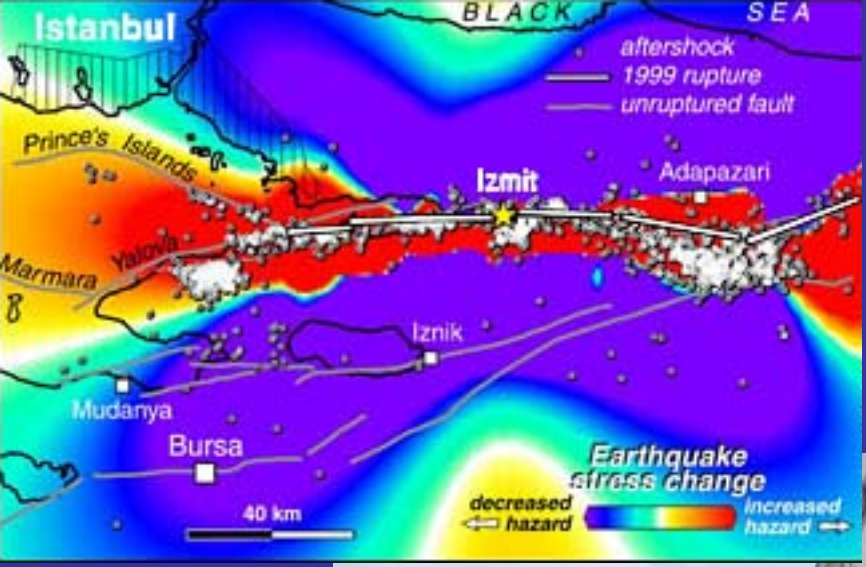
What type of deformation does each of these phases represent:

Ductile

or

Brittle?

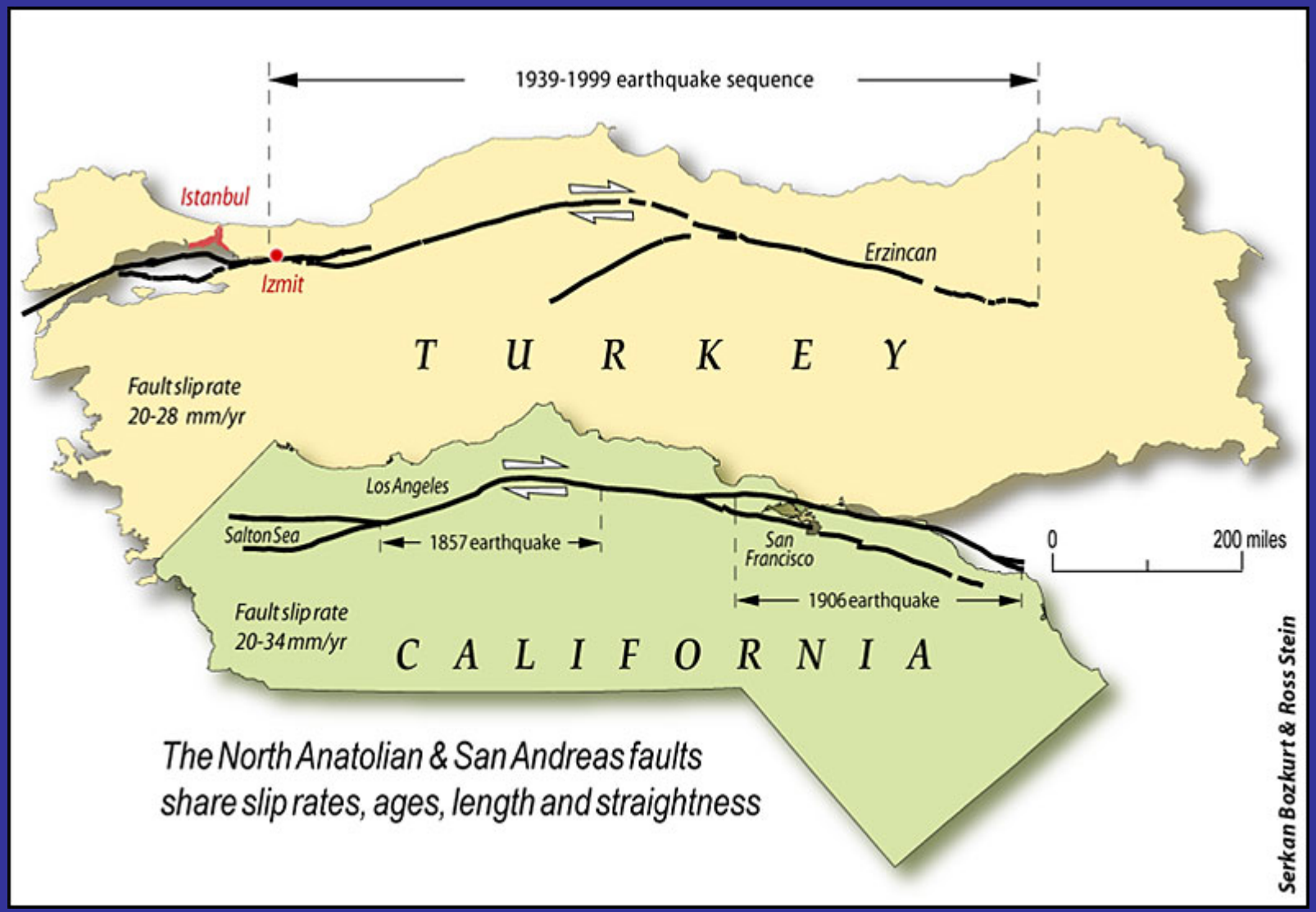
Izmit Turkey 1999 M7.6



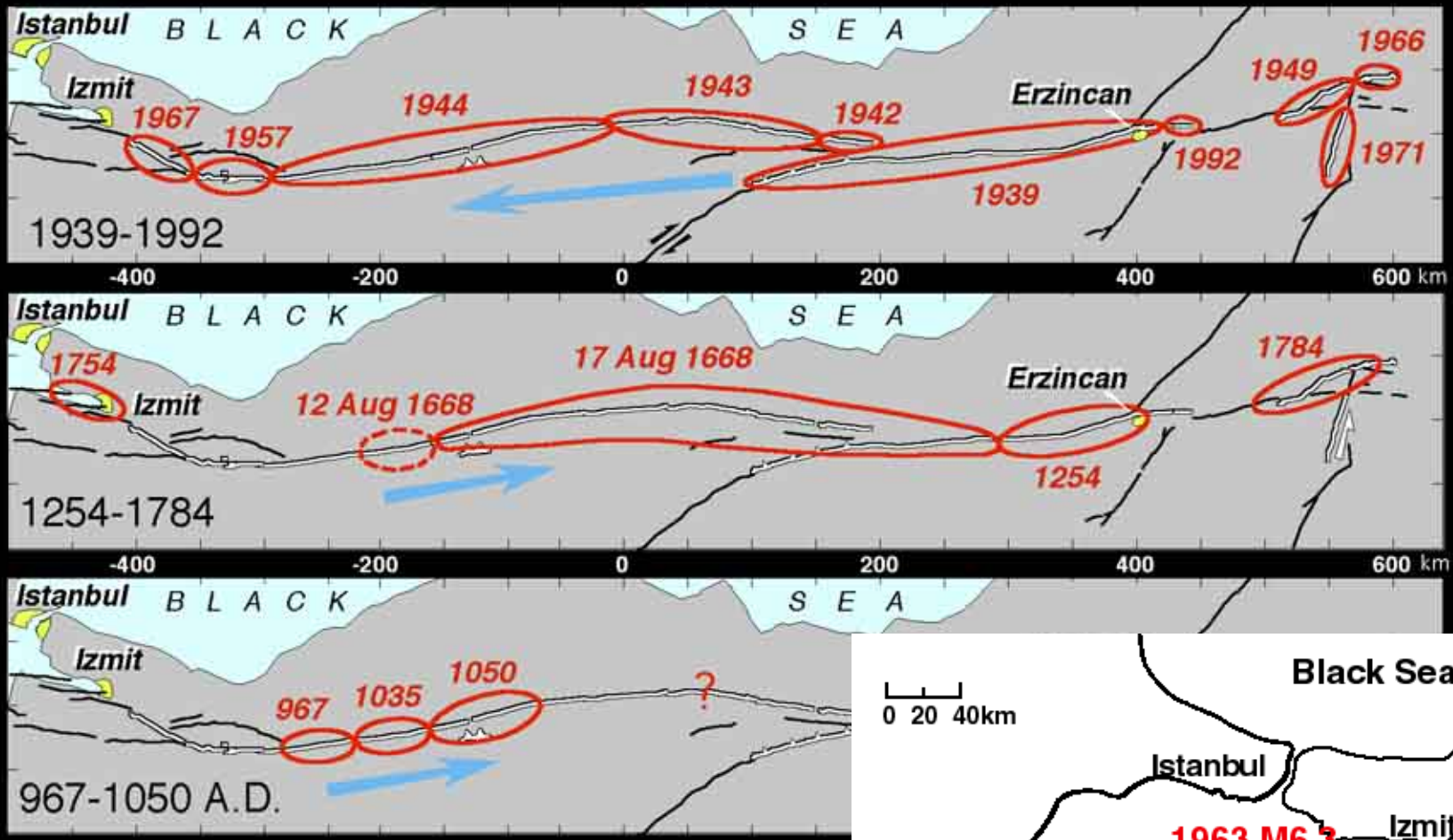




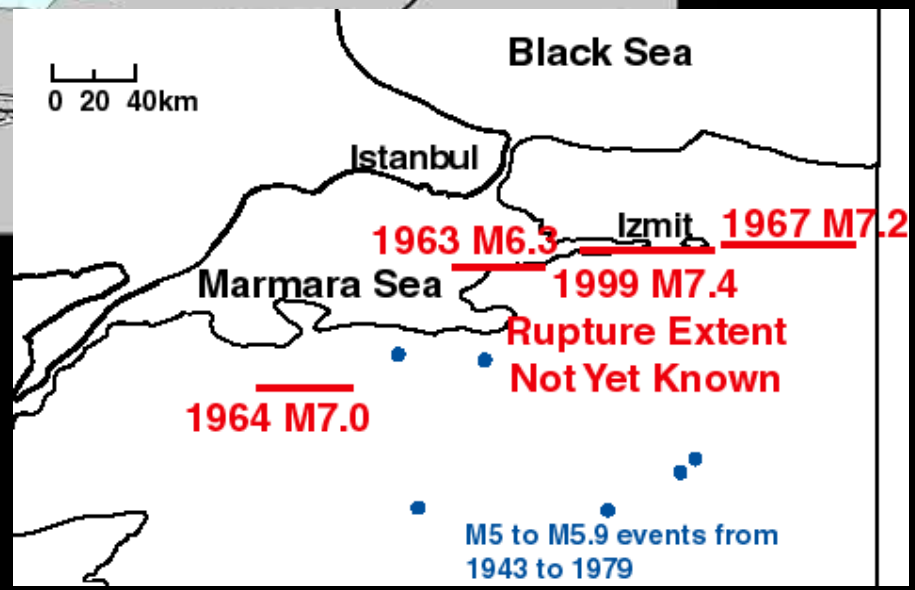
North Anatolian Fault resembles San Andreas Fault



North Anatolian fault often ruptures in progressive earthquakes Mean repeat time ~450±220 yr



Progressive Rupture Pattern



Why do some structures survive?











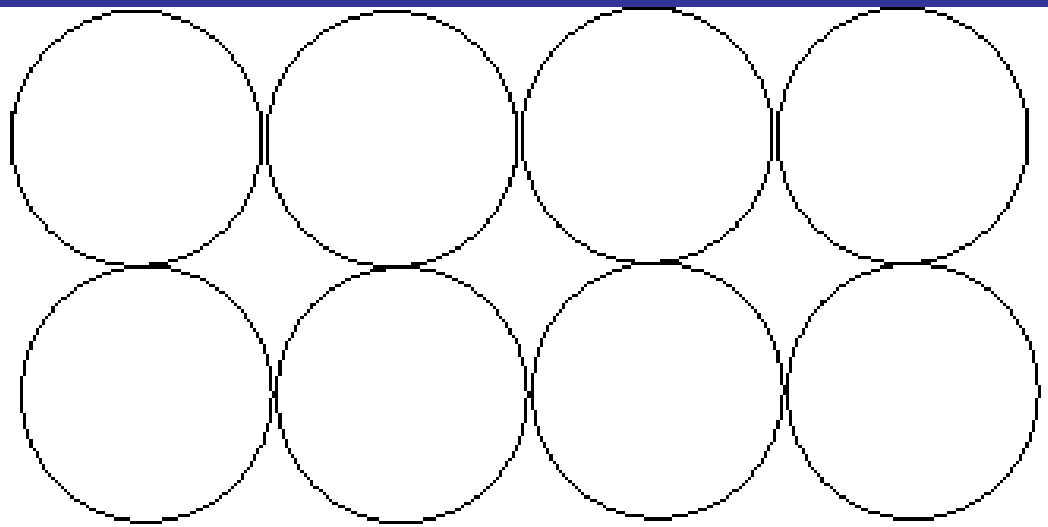
Why did these buildings fall over?

How do these form?

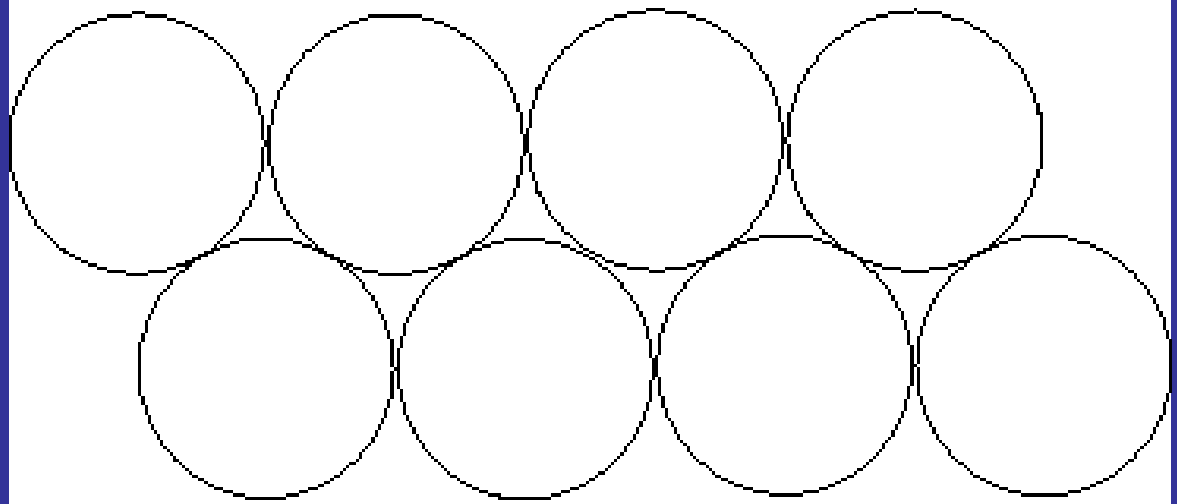








Loose packing of sand grains



More compact packing

Loosely packed grains form slurry during earthquake

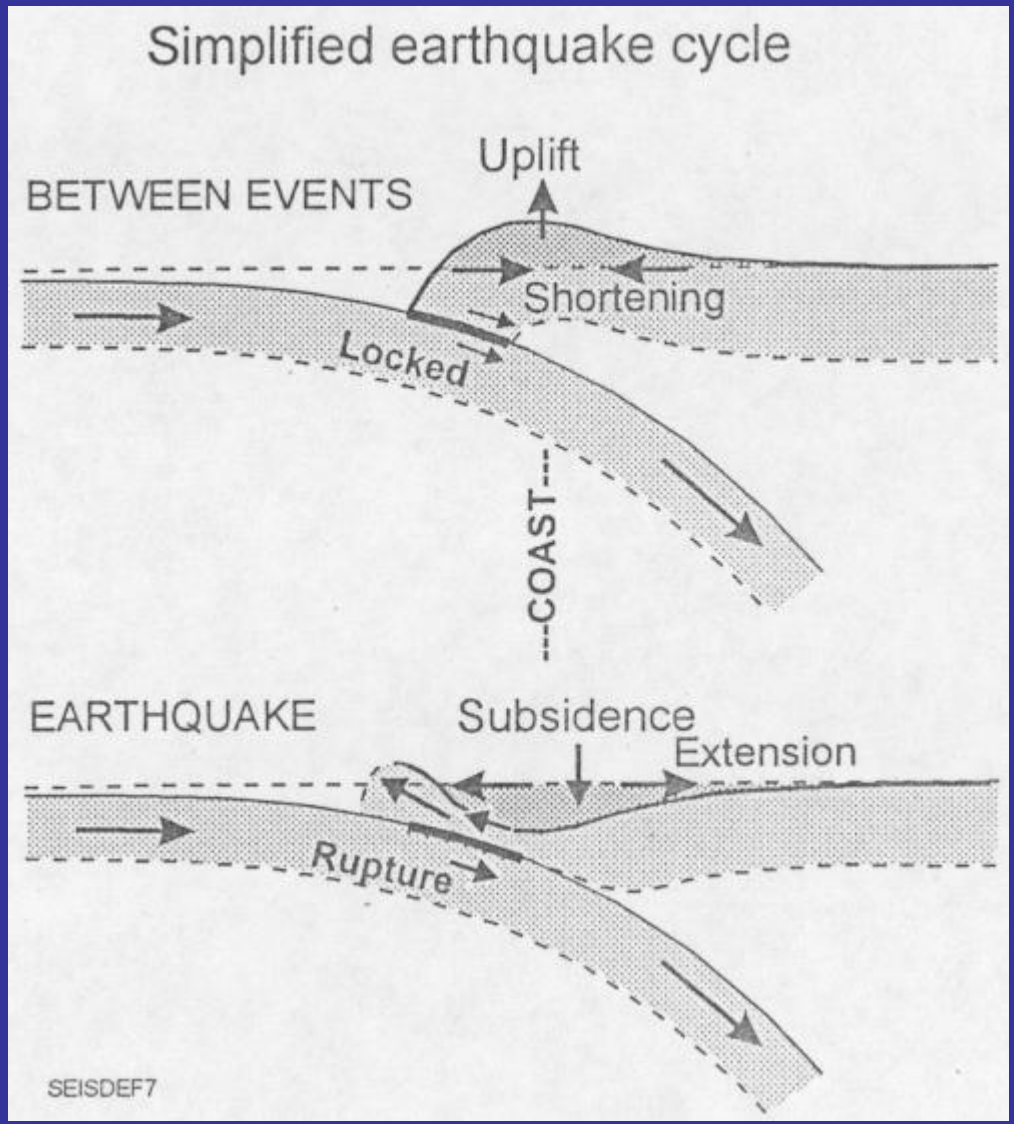
LIQUEFACTION

After earthquake they settle into more compact configuration

Liquefaction undermines foundation – Mexico City, 1985



What happens during a subduction earthquake?



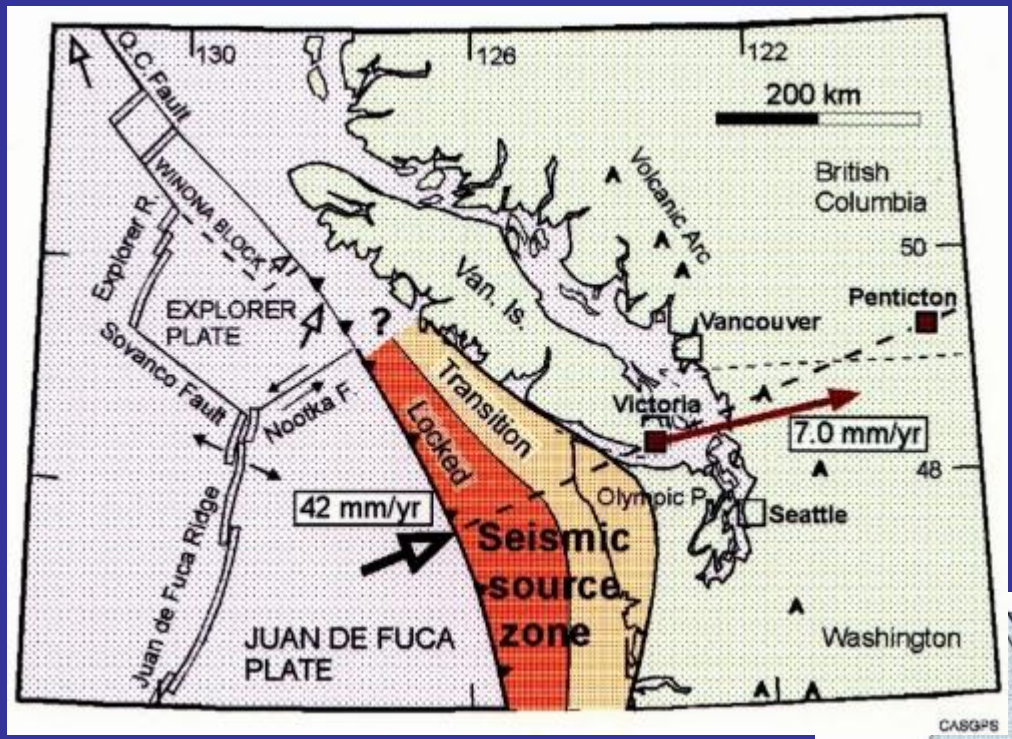
What type of deformation does each of these phases represent:

Brittle

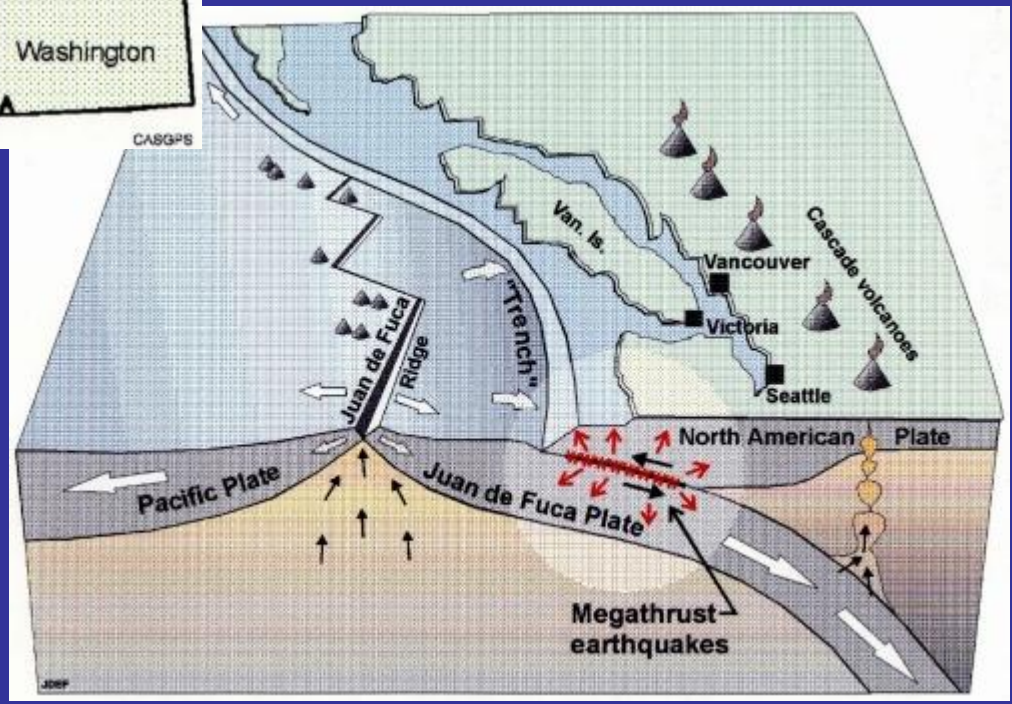
or

Ductile?

Great subduction earthquakes in the Pacific Northwest



"Great" = M8.0 +







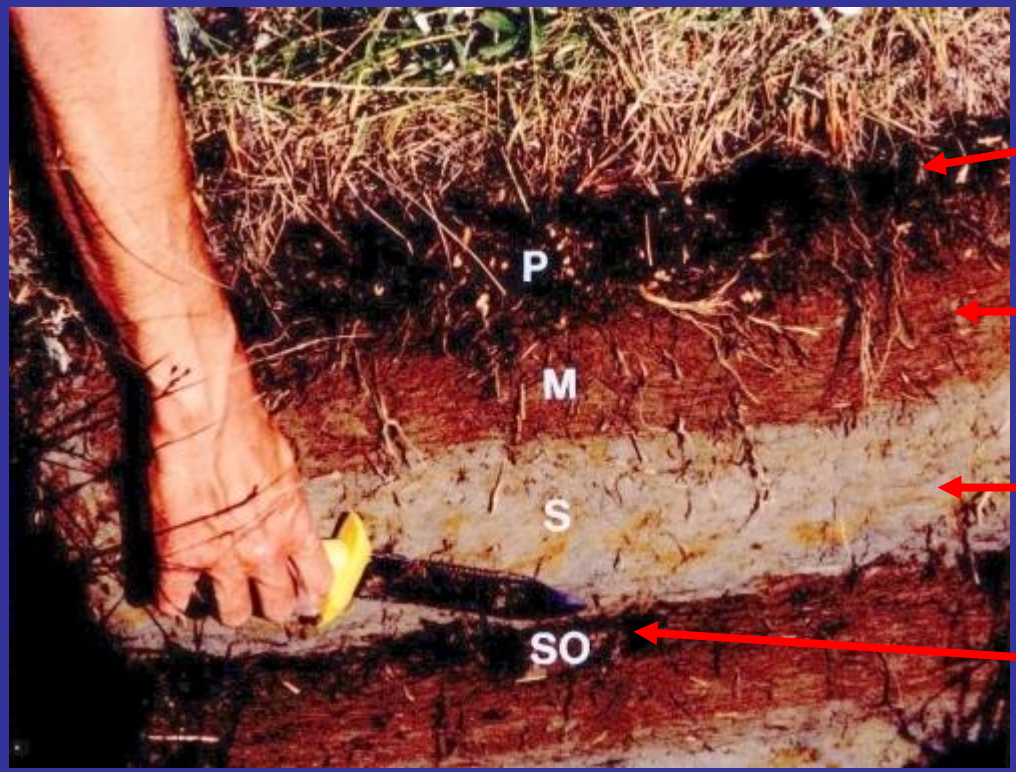


What happened to these trees?





Evidence for great subduction quake



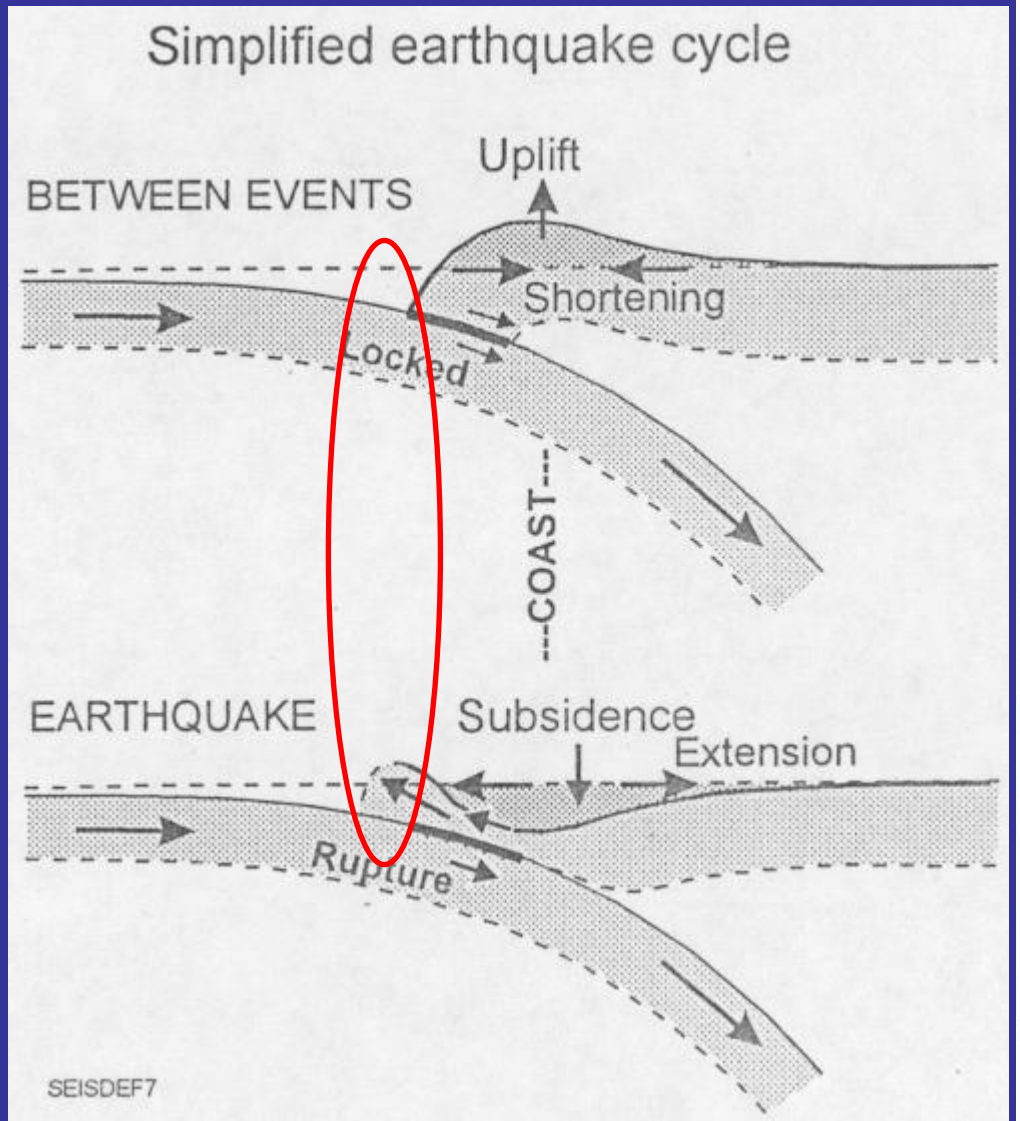
Peat

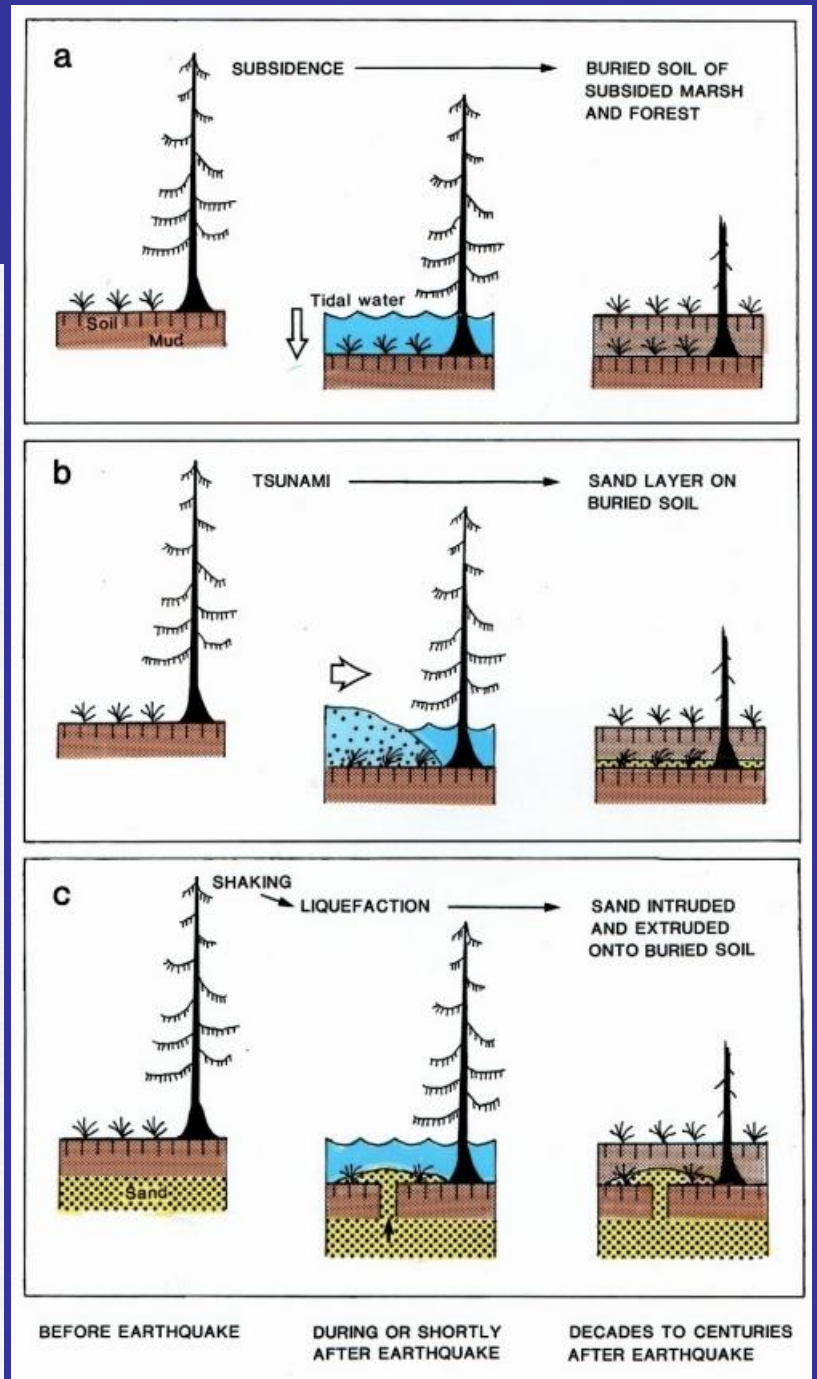
Tidal Mud

Tsunami Sands

Peaty soil

Subsidence/tsunami bury old coastline



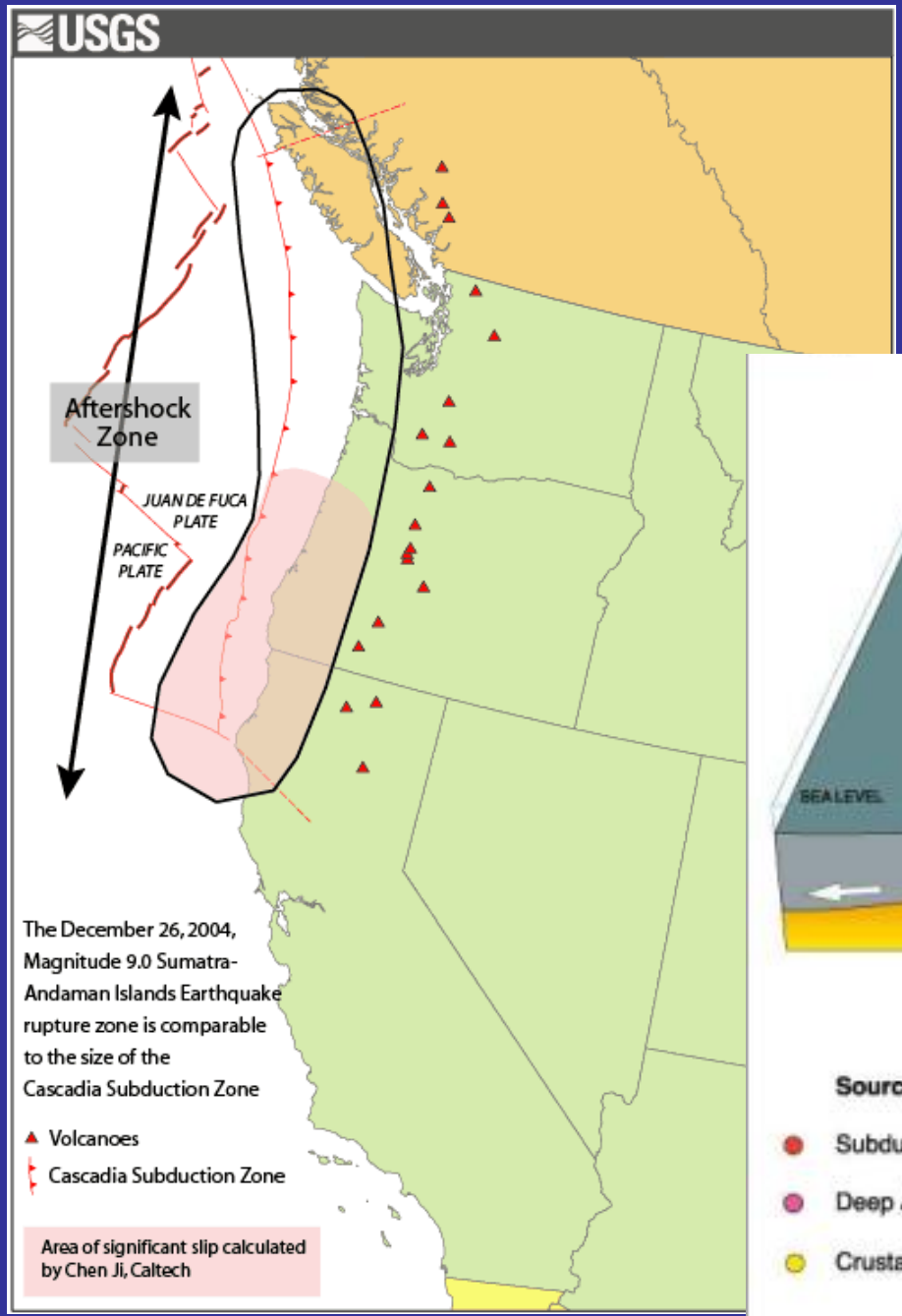


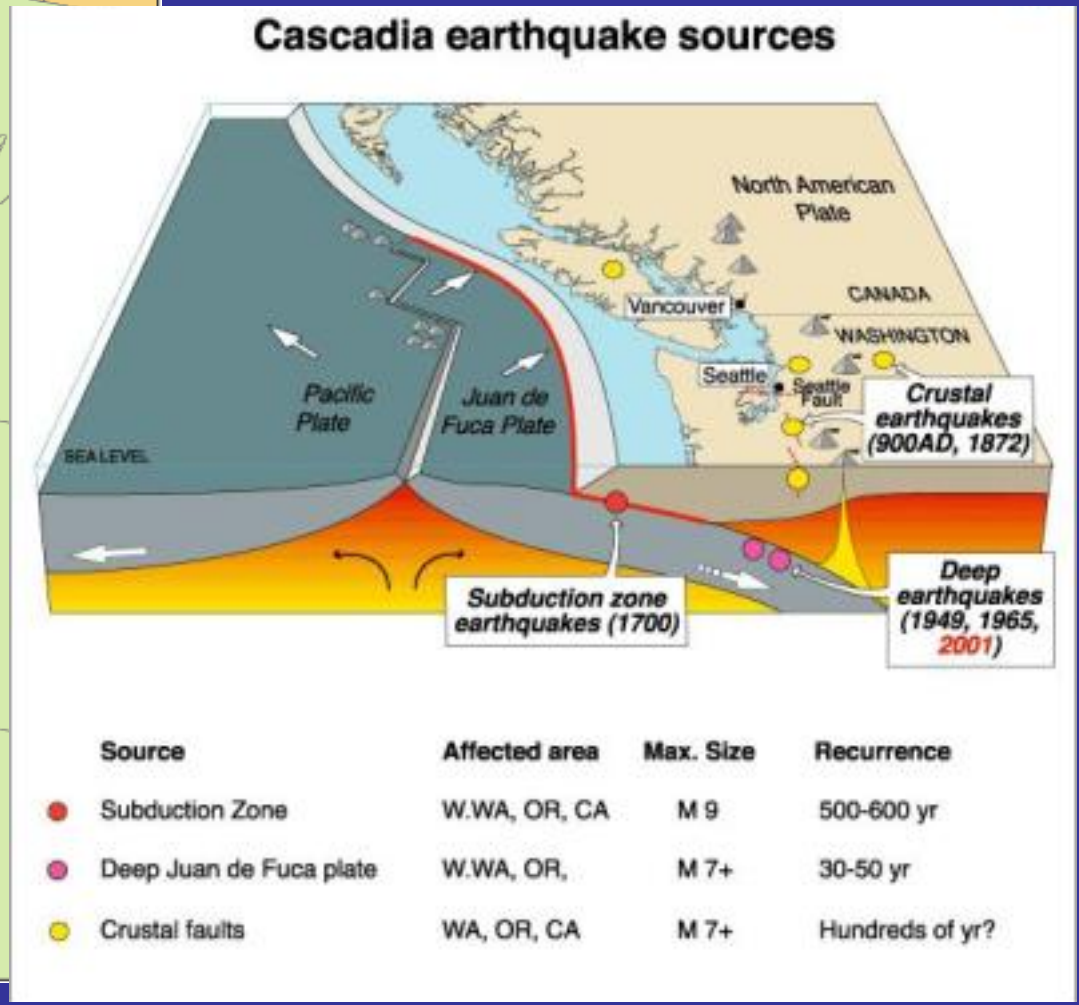
Last great subduction quake in Cascadia occurred in 1700

(M 9.0, tsunami in Japan)

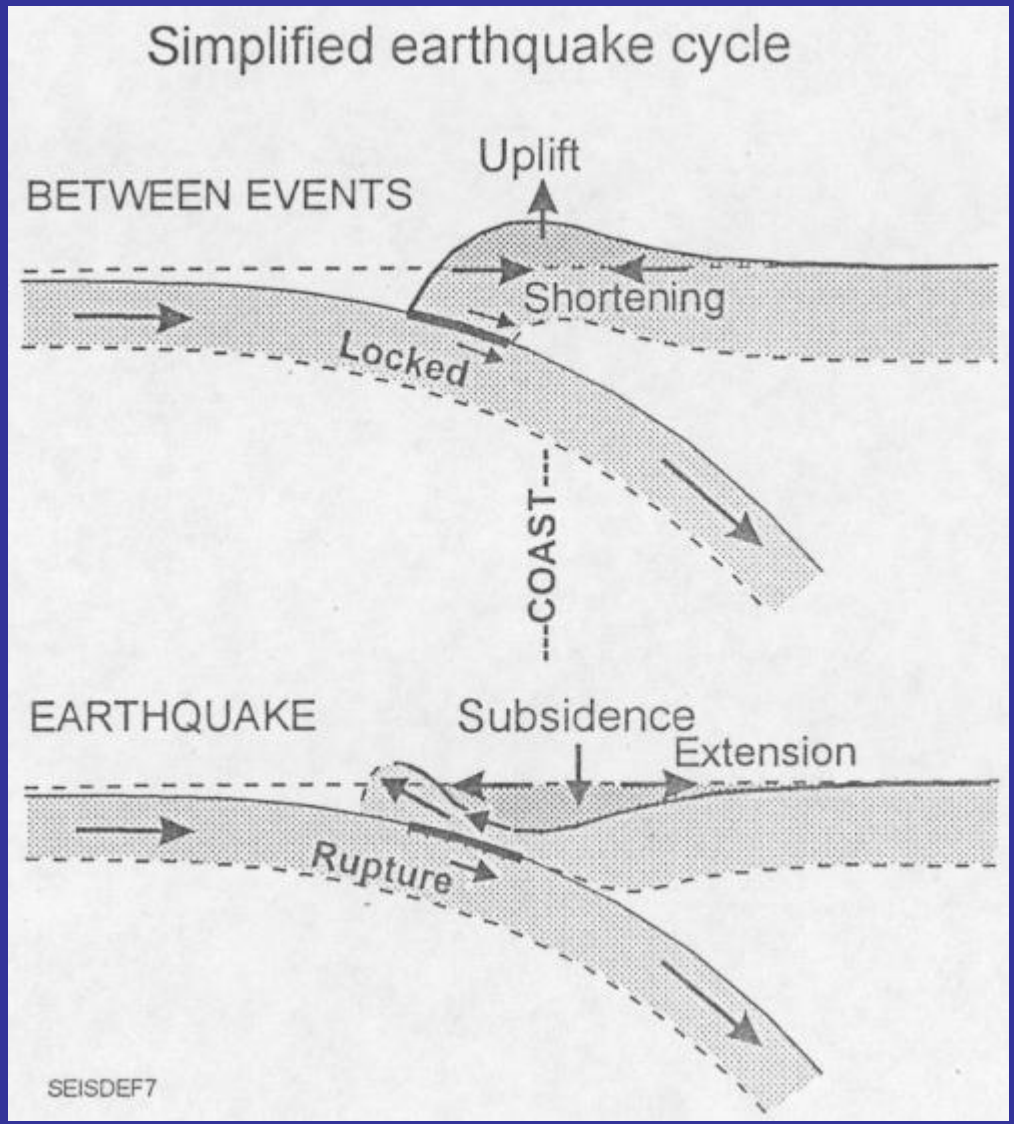
Recurrence interval ~500 yrs

(13 previous events, 300-900 year spacing)



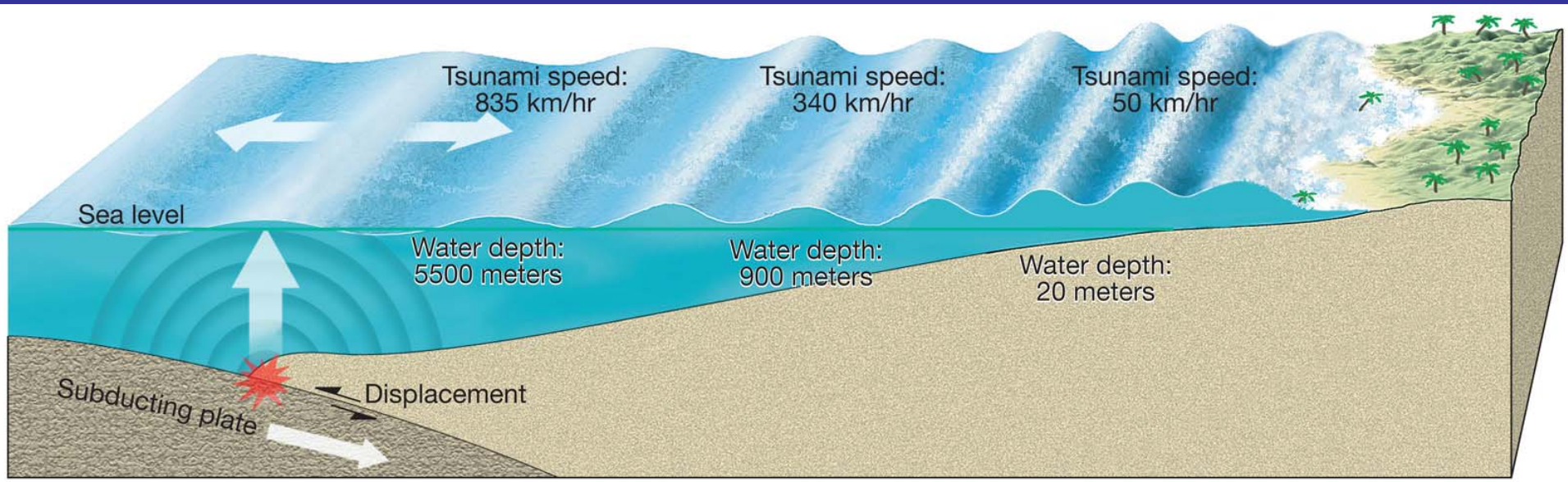


During a subduction earthquake…

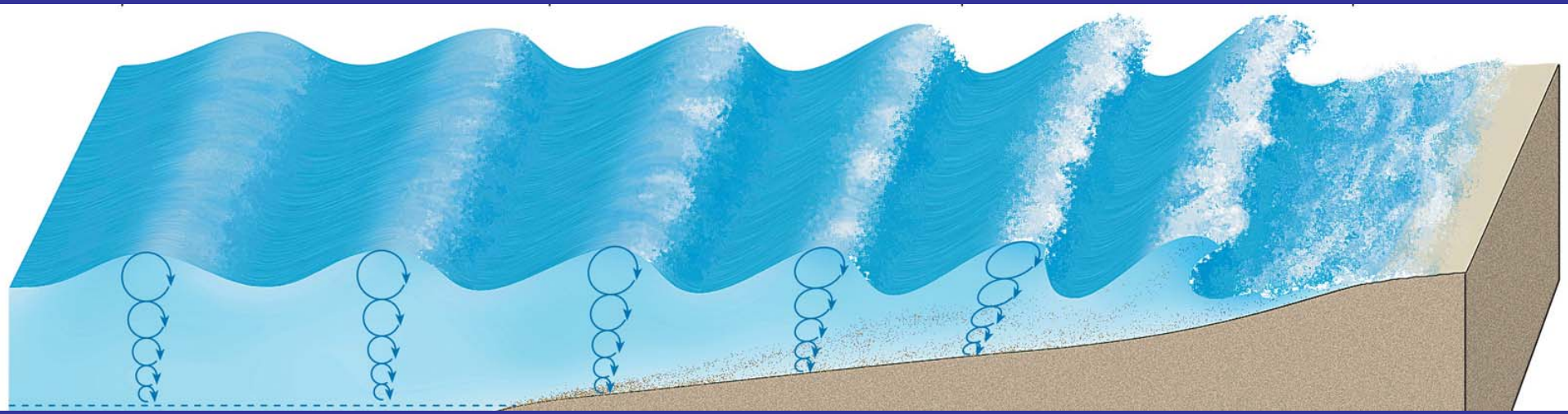


What triggers the tsunami wave?

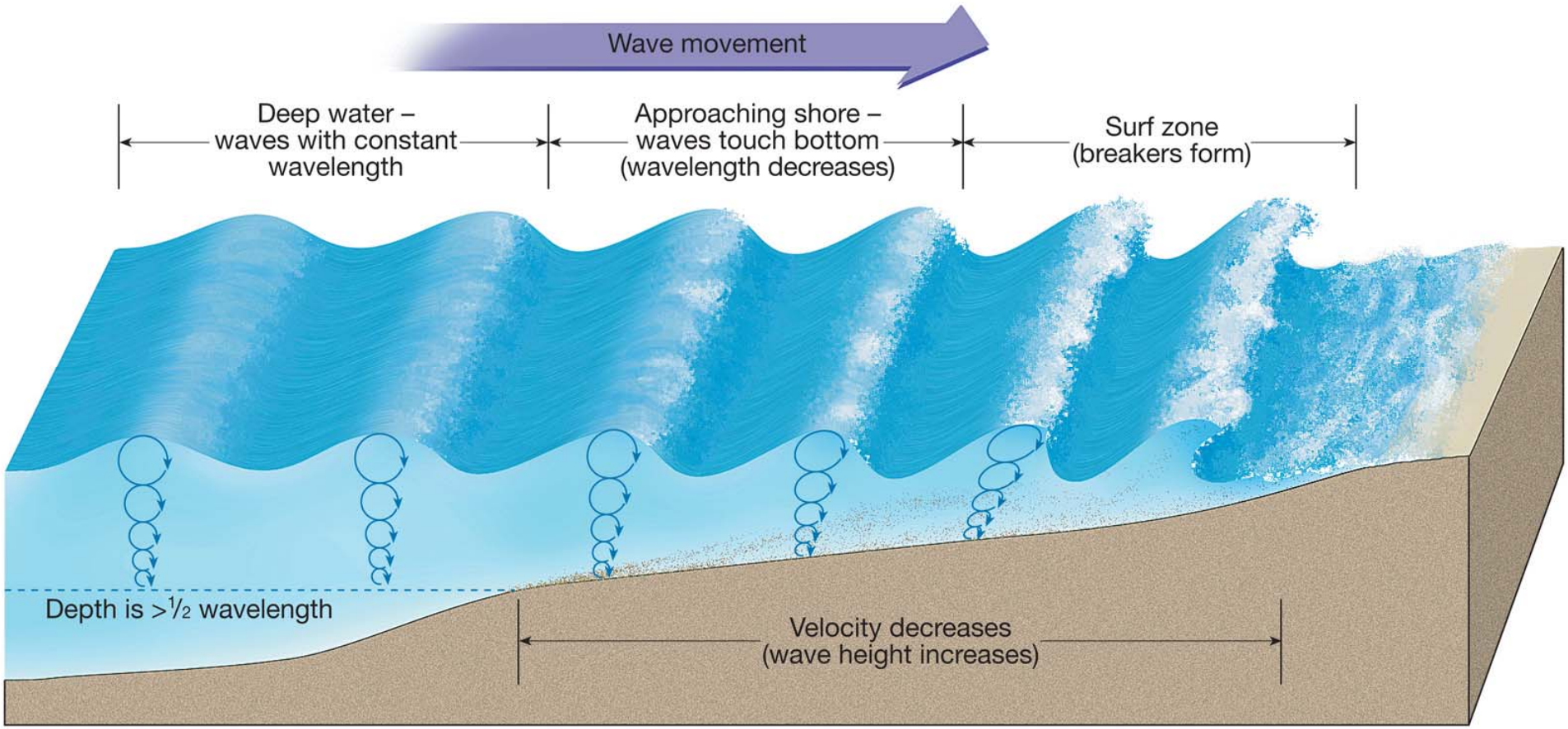
Shock wave propagates based on water depth



depth , wavelength , velocity , wave height



depth ↓, wavelength ↓, velocity ↓, wave height ↑




Jaws, Maui

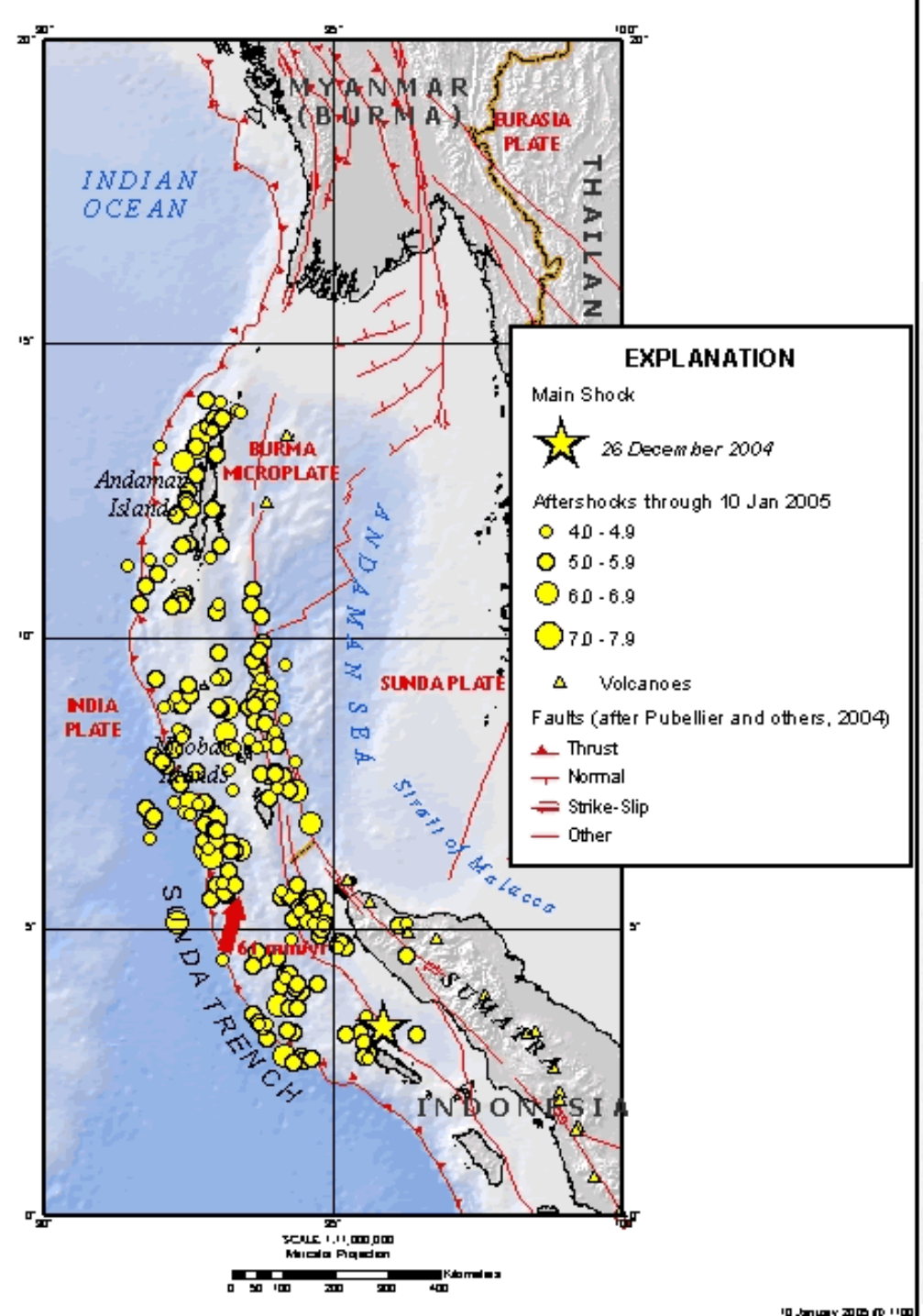


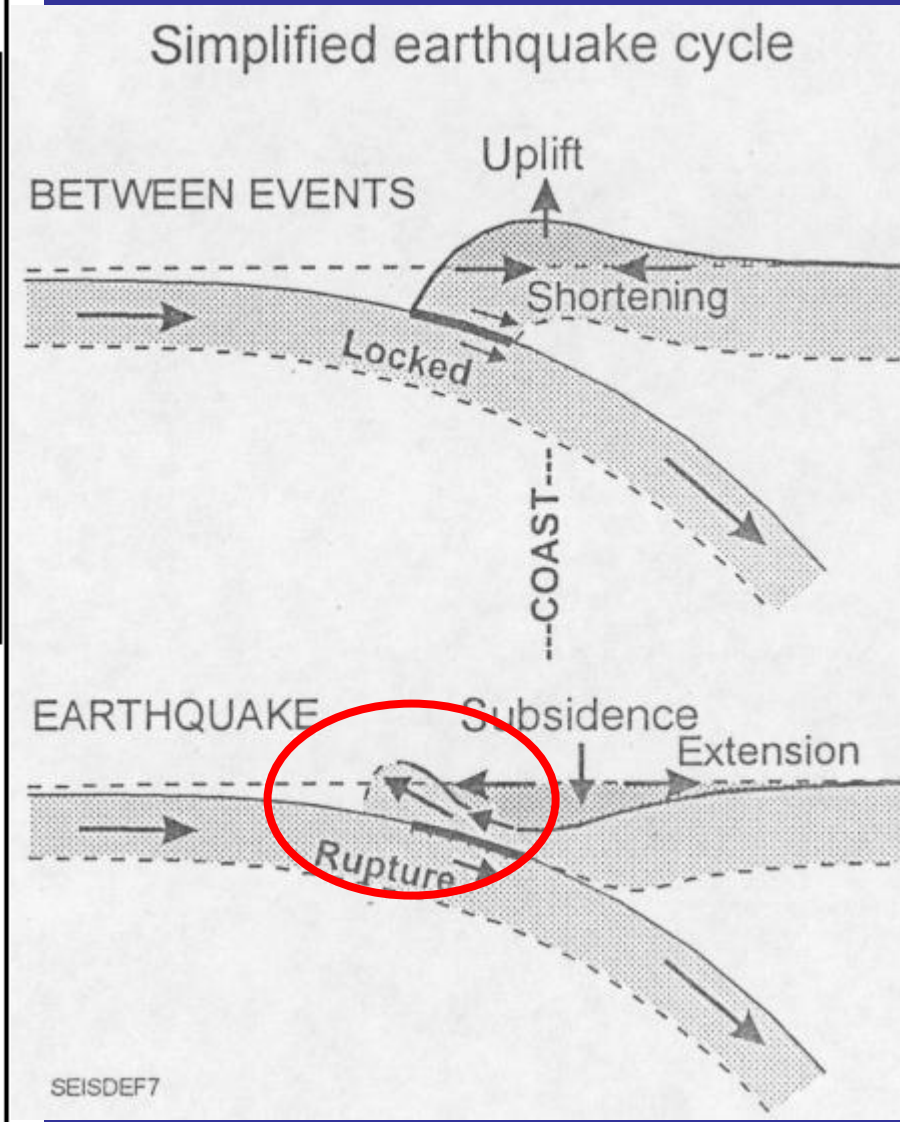
Indonesian Tsunami
December 2004
283,100 killed



M_W 9.0+ Earthquake

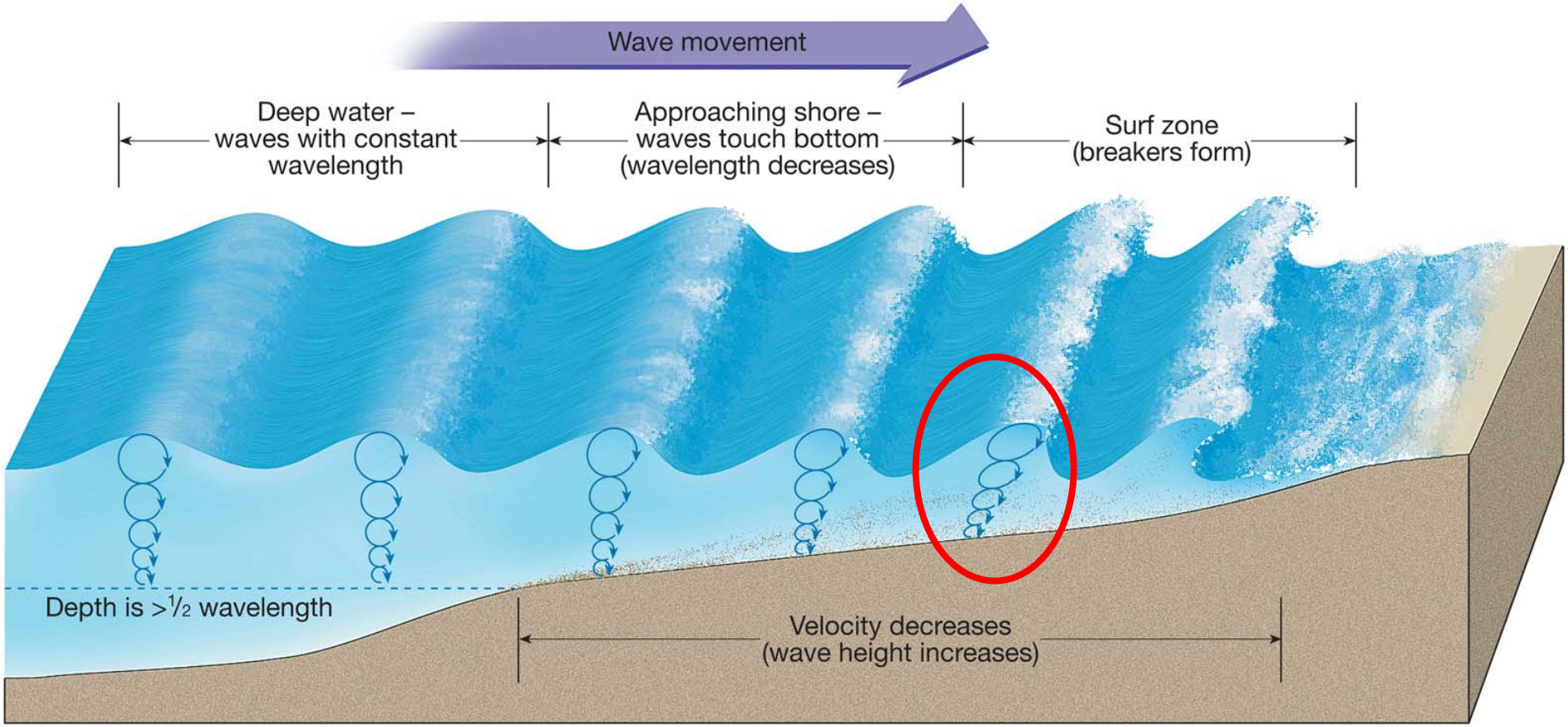
Strain release causes earthquake/tsunami






BANGLADESH
INDIA
MYANMAR
(BURMA)
THAILAND
SRI
LANKA
SOMALIA
MALAYSIA
MALDIVES
KENYA
INDONESIA
TANZANIA
SEYCHELLES
Indian
Ocean
MADAGASCAR
SOUTH
AFRICA

Why are tsunami waves so dangerous?



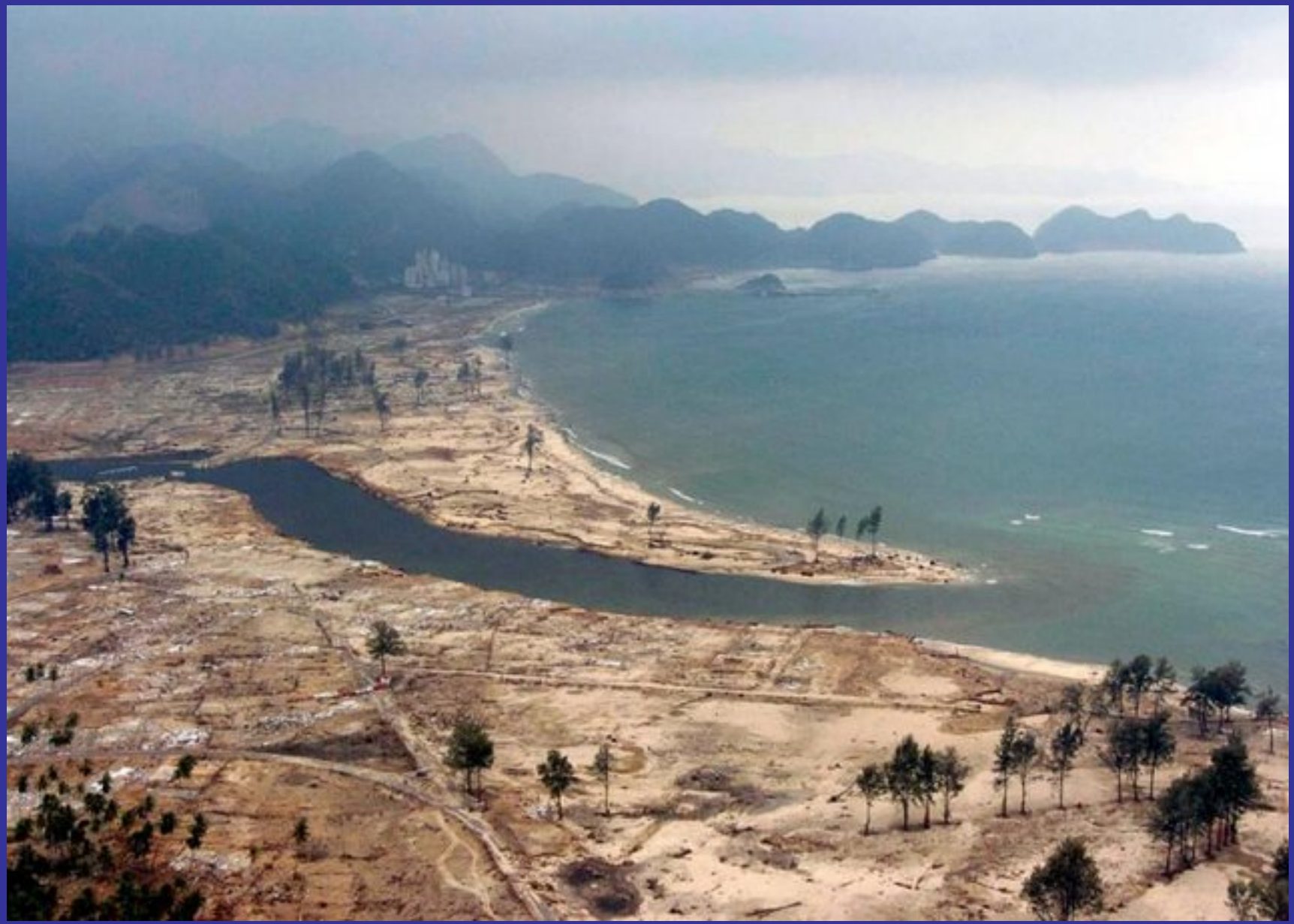
Drawdown precedes tsunami - Thailand





What should you do when you observe beach drawdown?
A) Go investigate, B) Pick up dying fish, C) Sunbathe
D) Get ready for big surf! E) Run uphill as fast as you can

Phuket, Thailand

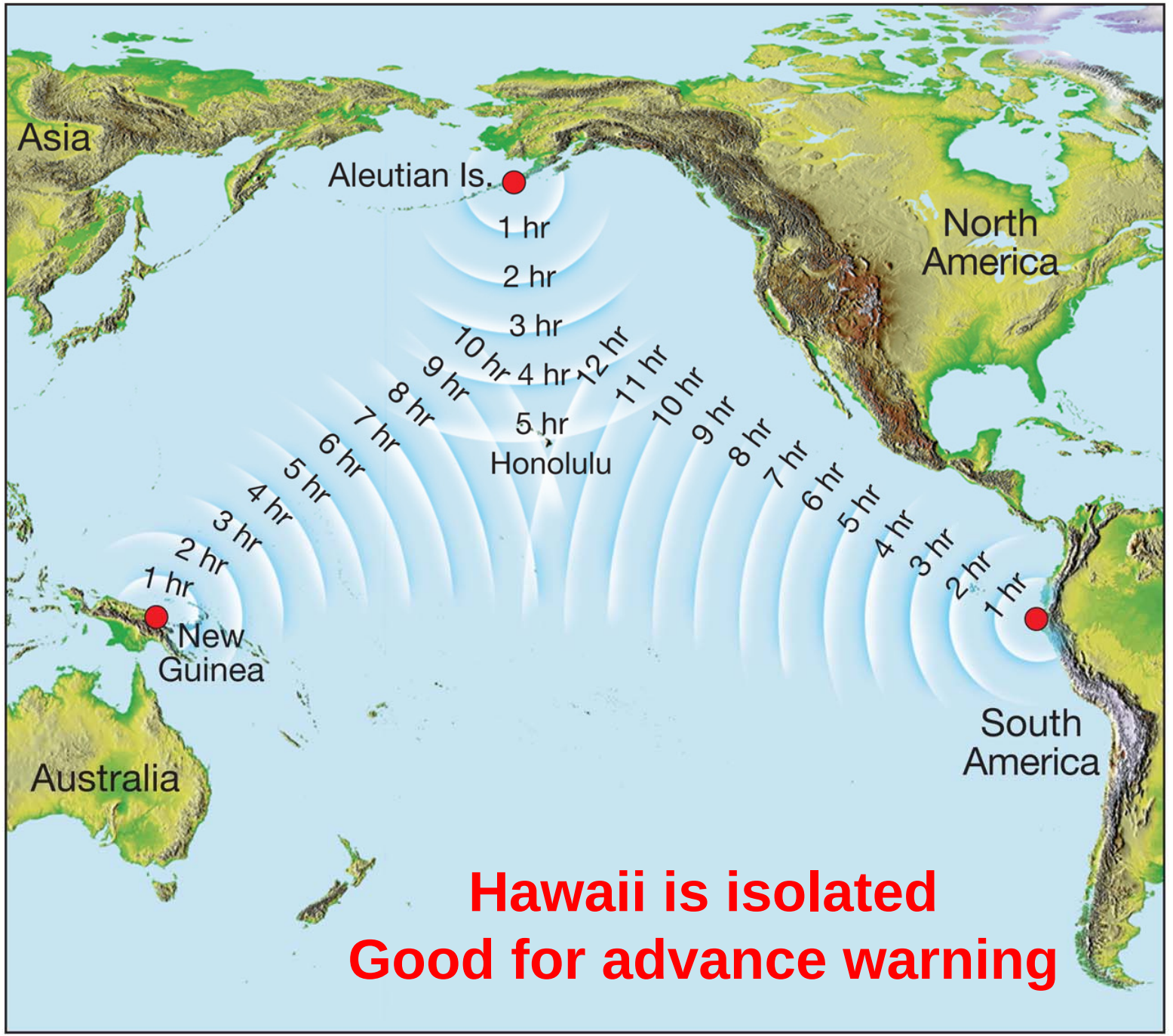


Sumatra, Indonesia



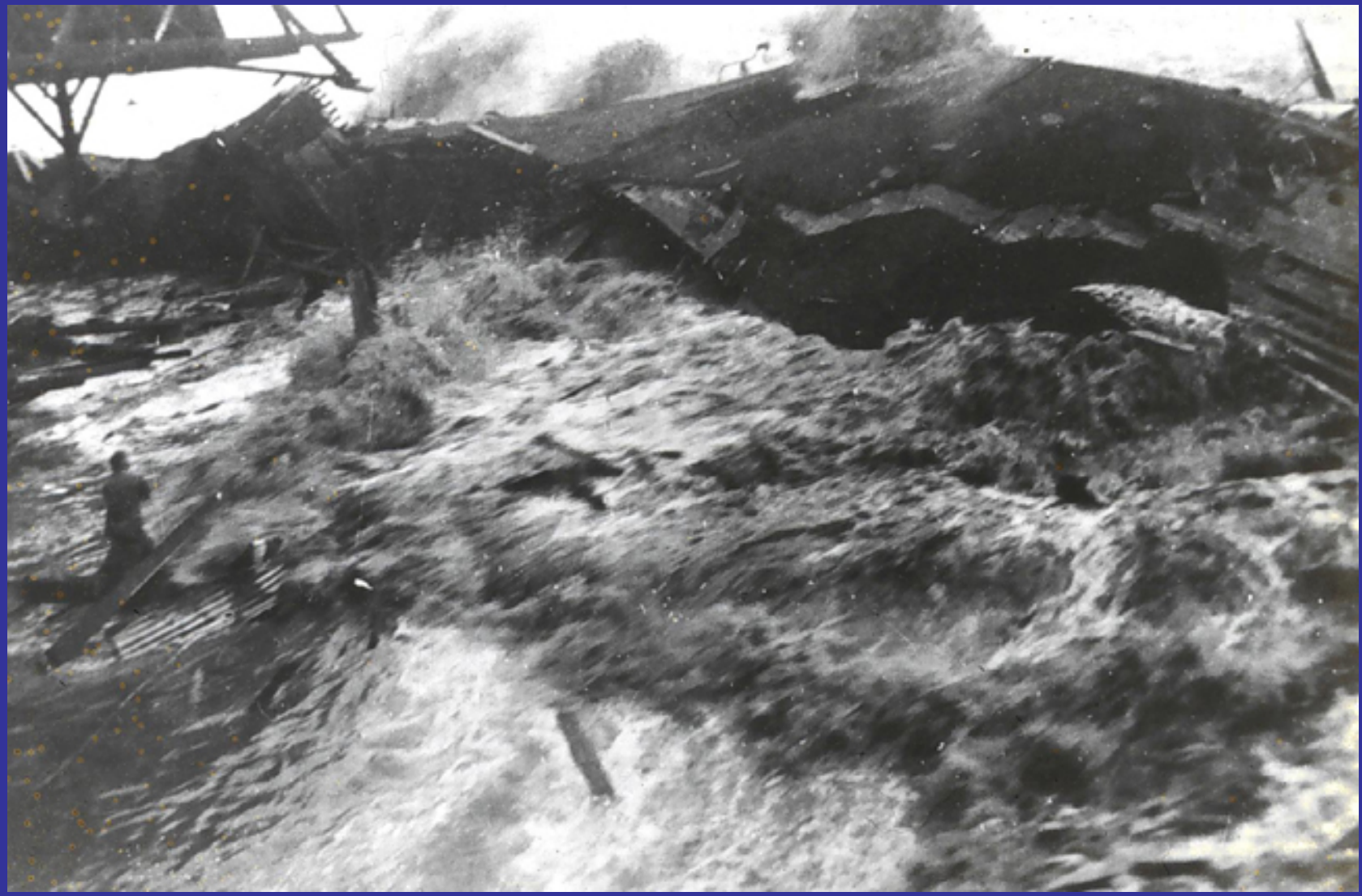
Aceh, Indonesia




Asia
Aleutian Is.
North America
1 hr
2 hr
3 hr
4 hr
5 hr
Honolulu
10 hr
9 hr
8 hr
7 hr
6 hr
5 hr
4 hr
3 hr
2 hr
1 hr
12 hr
11 hr
10 hr
9 hr
8 hr
7 hr
6 hr
5 hr
4 hr
3 hr
2 hr
1 hr
New Guinea
Australia
South America
Hawaii is isolated
Good for advance warning



Hilo Tsunami, 1946 - triggered by Alaskan quake - 170 dead



1837, 1841, 1868, 1869, 1877, 1883, 1906, 1918, 1923, 1933, 1946, 1957, 1960
Locally-generated damaging tsunami in 1868, 1872, and 1975



Hilo Tsunami, 1960 - triggered by Chile quake - 61 dead
200 dead in Japan

National Weather Service

Pacific Tsunami Warning Center

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DOC > NOAA > NWS > PTWC

Local forecast by "City, State" or Zip

City, St or Zip | Go

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All Regions | Pacific Ocean | Hawai`i | Indian Ocean | Caribbean Sea

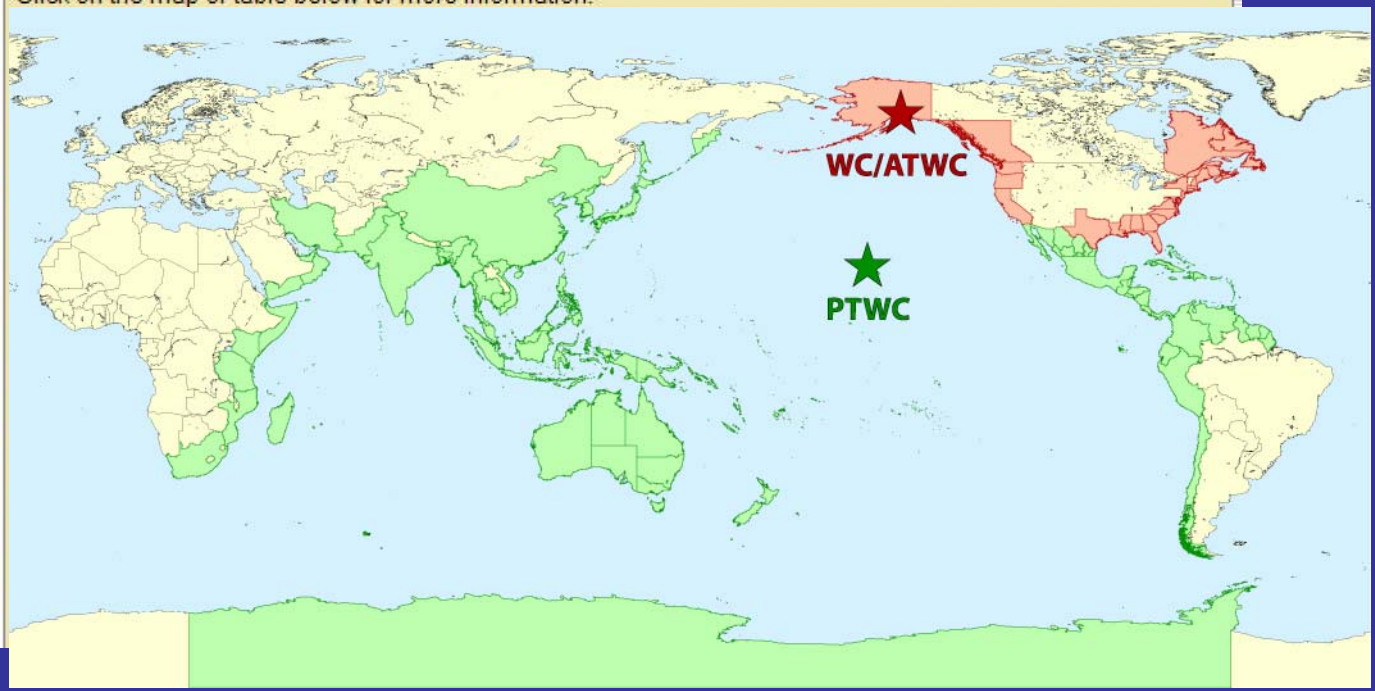
low

No Current Warning, Watch, or Advisory in Effect

Click here to read the latest tsunami message.

Tsunami Messages for All Regions (Past 90 Days)

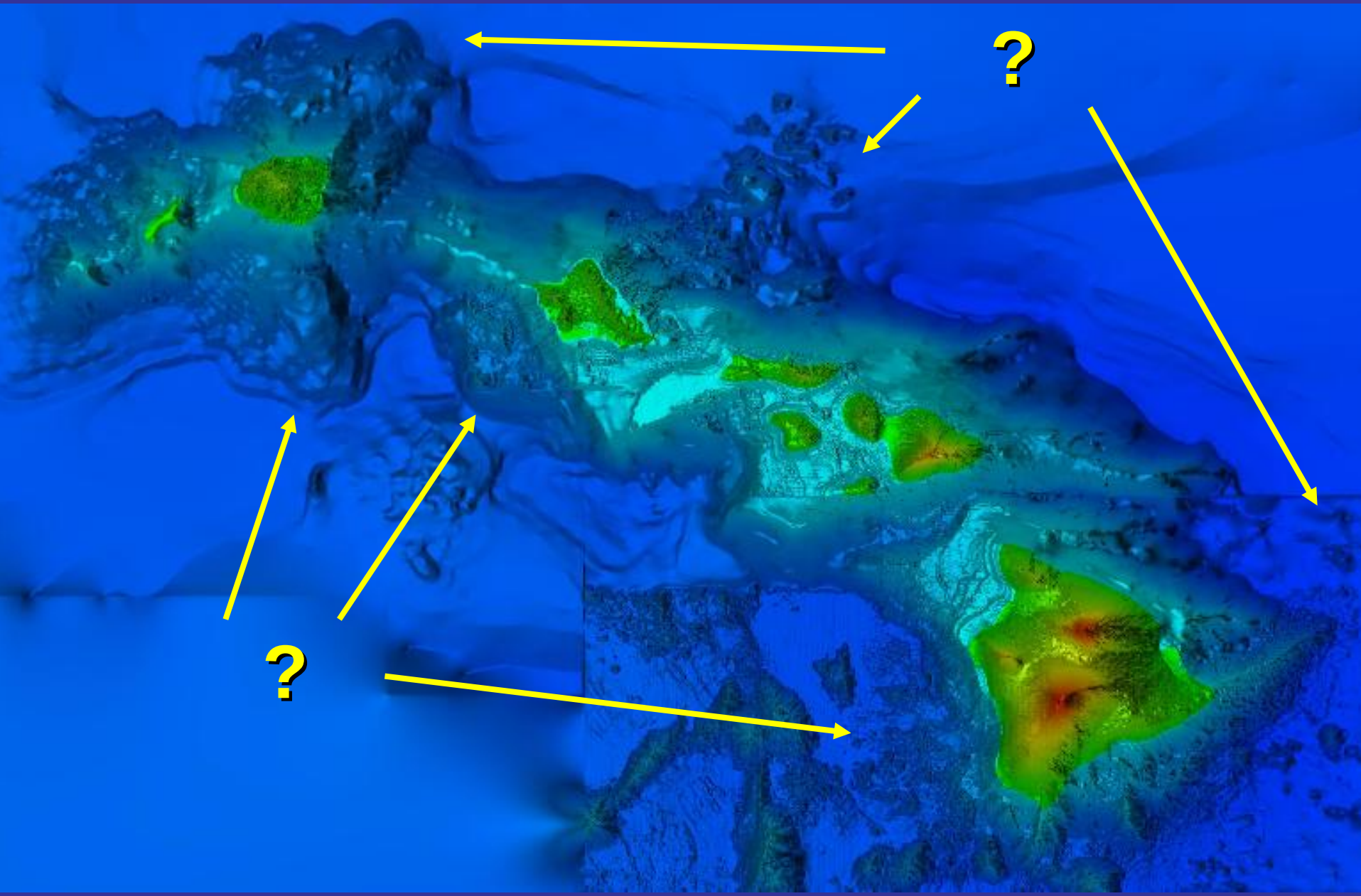
Click on the map or table below for more information.

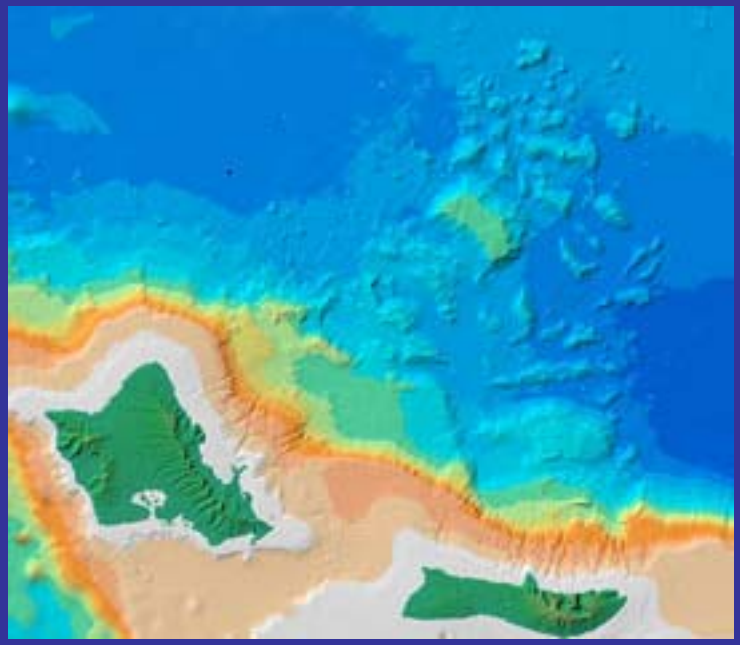


Pacific Tsunami Warning Center

Founded 1949

What are the piles of debris on the seafloor from?





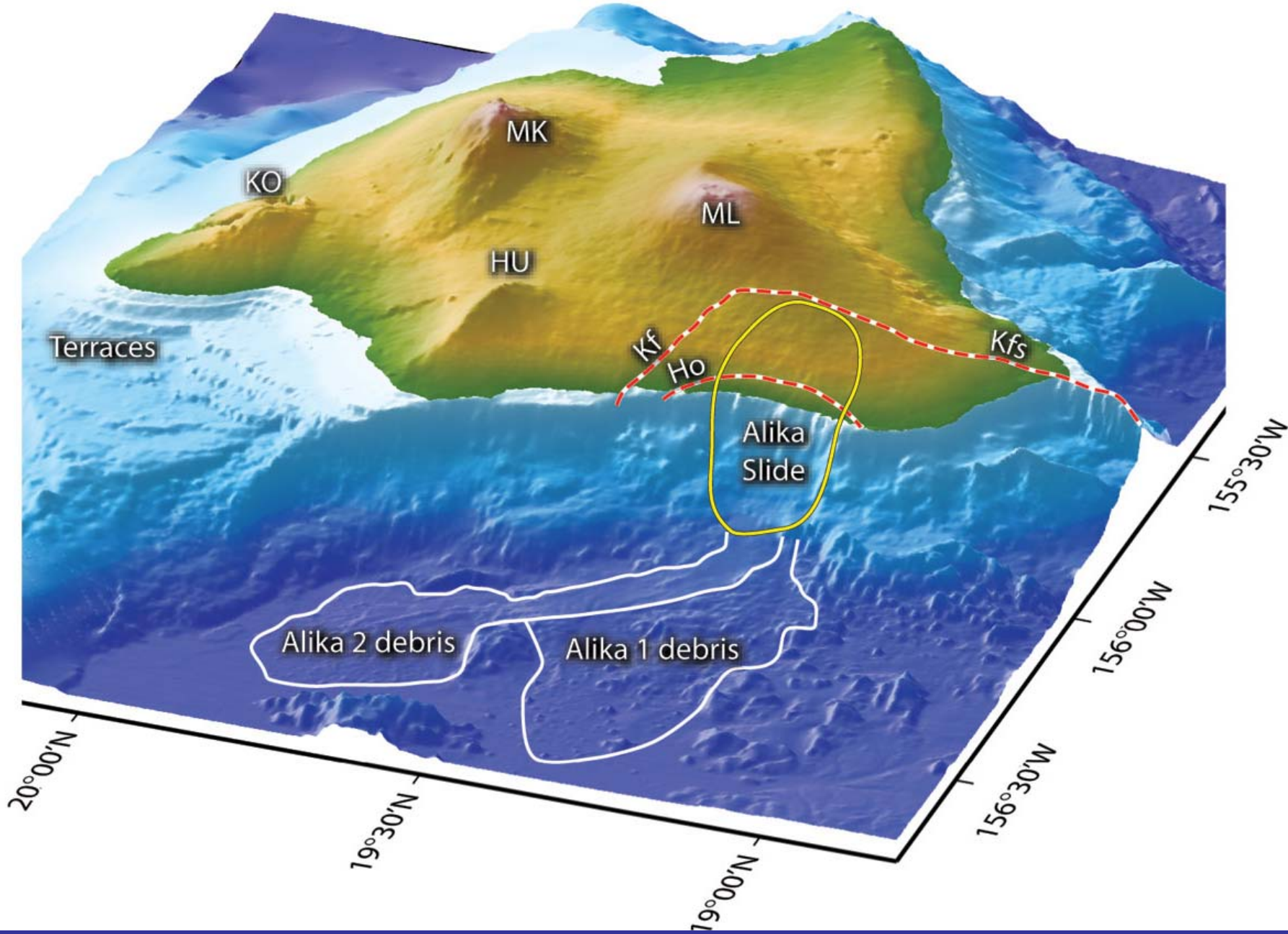


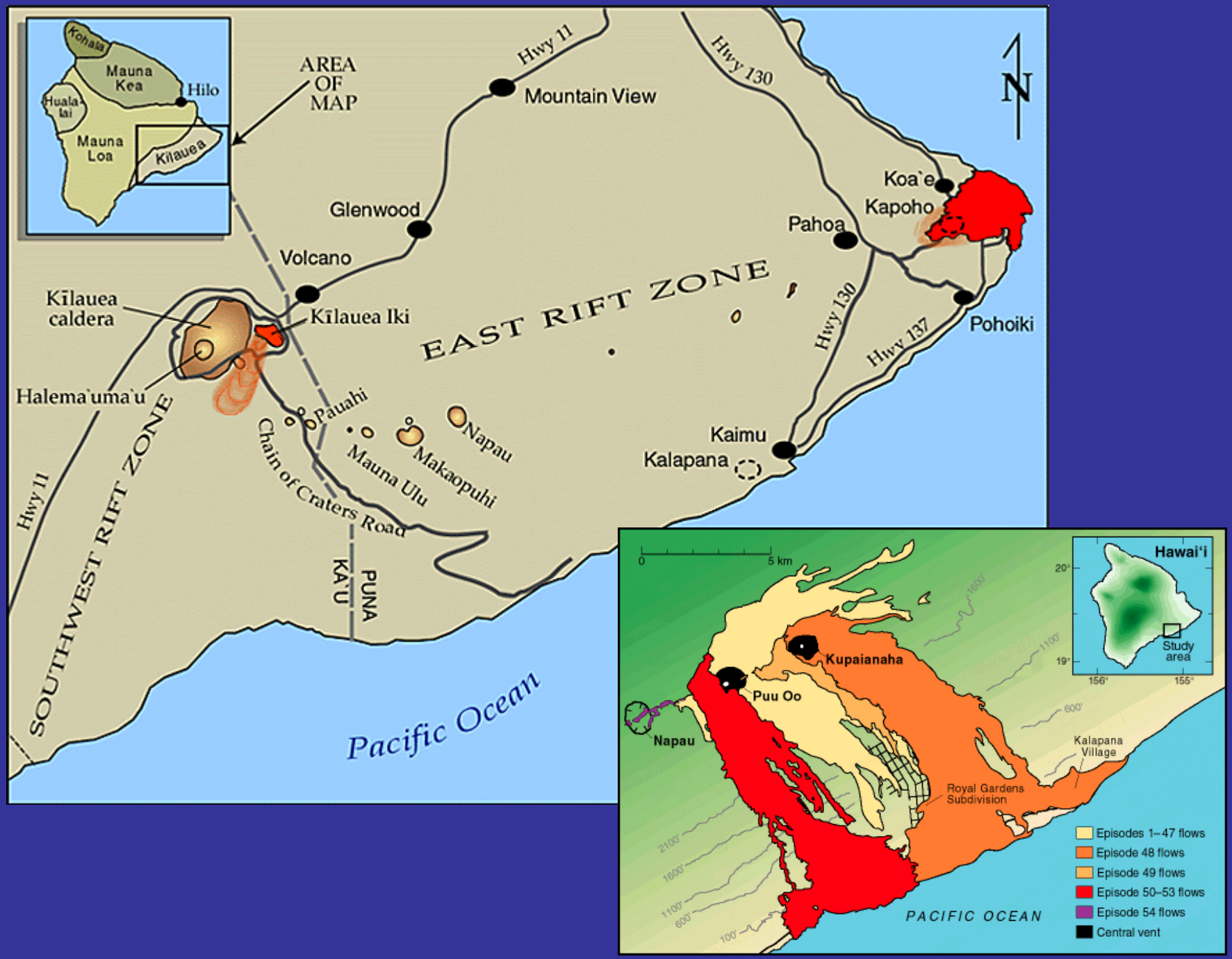


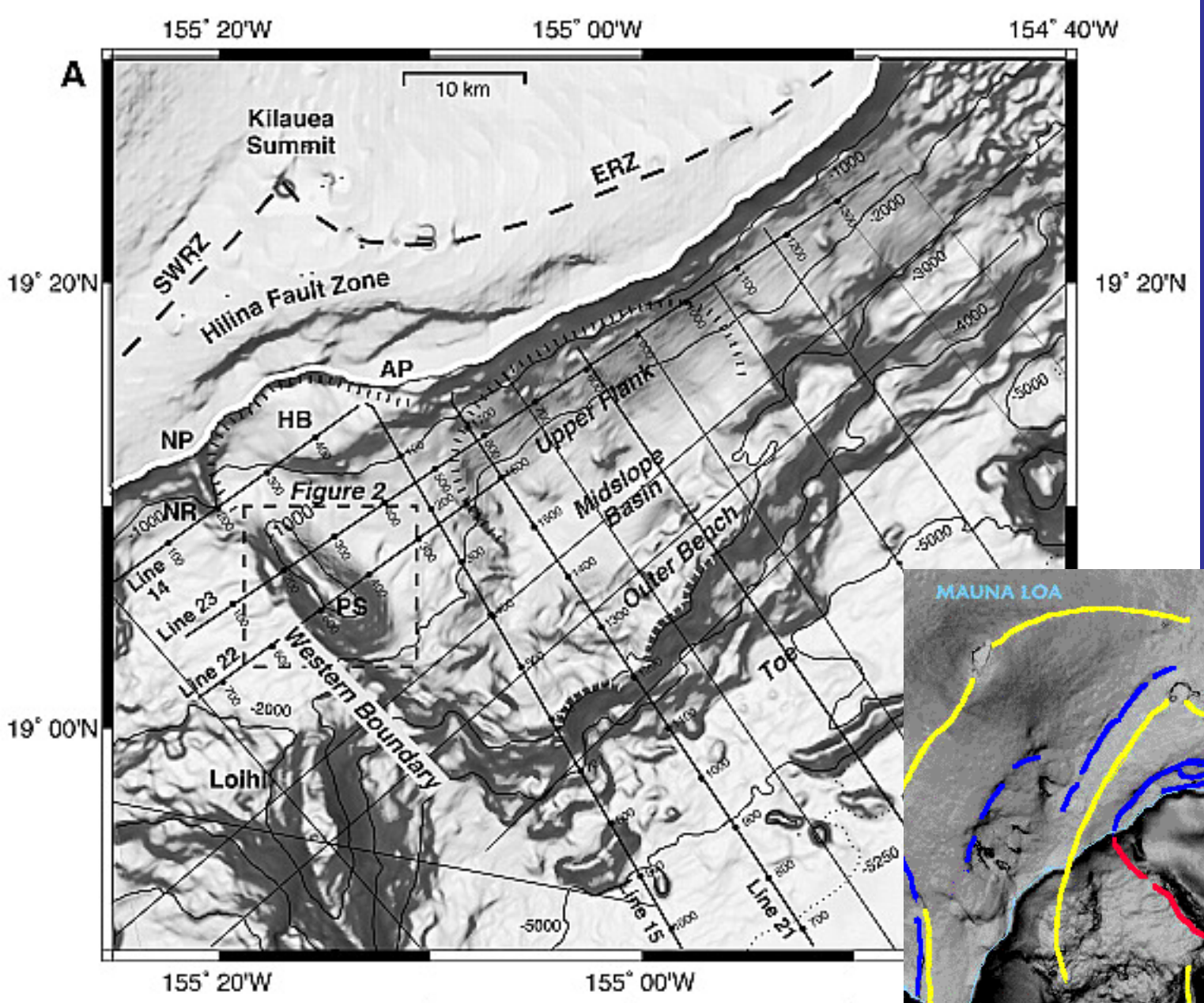
Nuuanu / Wailau Landslides

Bisected Oahu / Molokai

Alika Slide, 120,000 years ago - Tsunami 1,600 feet high!

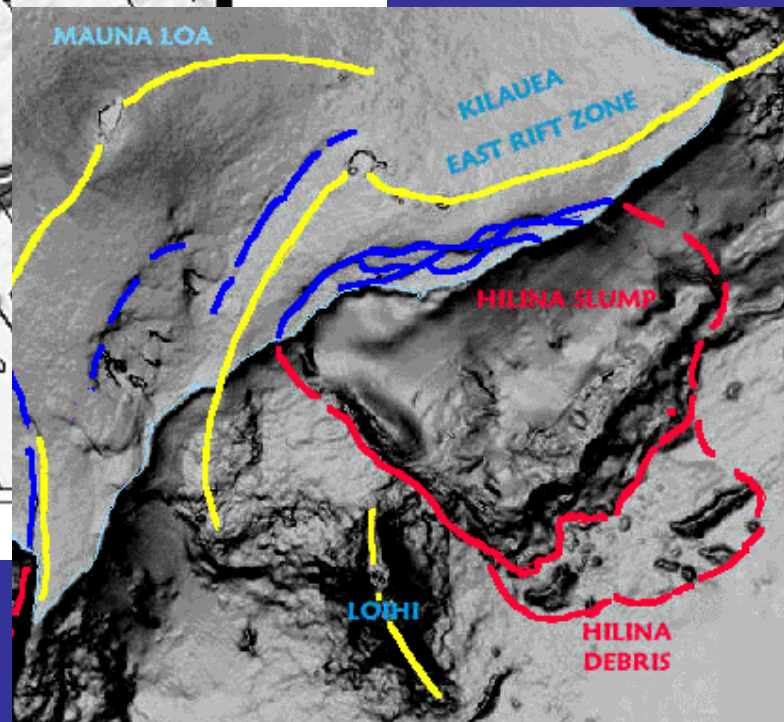



Kohala
Mauna Kea
Hilo
Hualalai
Mauna Loa
Kīlauea
AREA OF MAP
Hwy 11
Mountain View
Hwy 130
N
Koa`e
Kapoho
Pahoa
Glenwood
Volcano
EAST RIFT ZONE
Kīlauea caldera
Kīlauea Iki
Hwy 130
Hwy 137
Pohoiki
Halema`uma`u
Pauahi
Napau
Makaopuhi
Mauna Ulu
Chain of Craters Road
Kaimu
Kalapana
SOUTHWEST RIFT ZONE
Hwy 11
KA`U
PUNA
Pacific Ocean
0
5 km
Hawai'i
Study area
20°
19°
156°
155°
Kupaianaha
Puu Oo
Napau
Kalapana Village
Royal Gardens Subdivision
1600'
1100'
600'
2100'
100'
PACIFIC OCEAN
Episodes 1–47 flows
Episode 48 flows
Episode 49 flows
Episode 50–53 flows
Episode 54 flows
Central vent



Slump rate = 4 inches/year

Catastrophic landslide would trigger M 9.0 quake, 300m high tsunami



Hilina Slump

In the next big Hawaii quake, don’t wait for tsunami warning!

