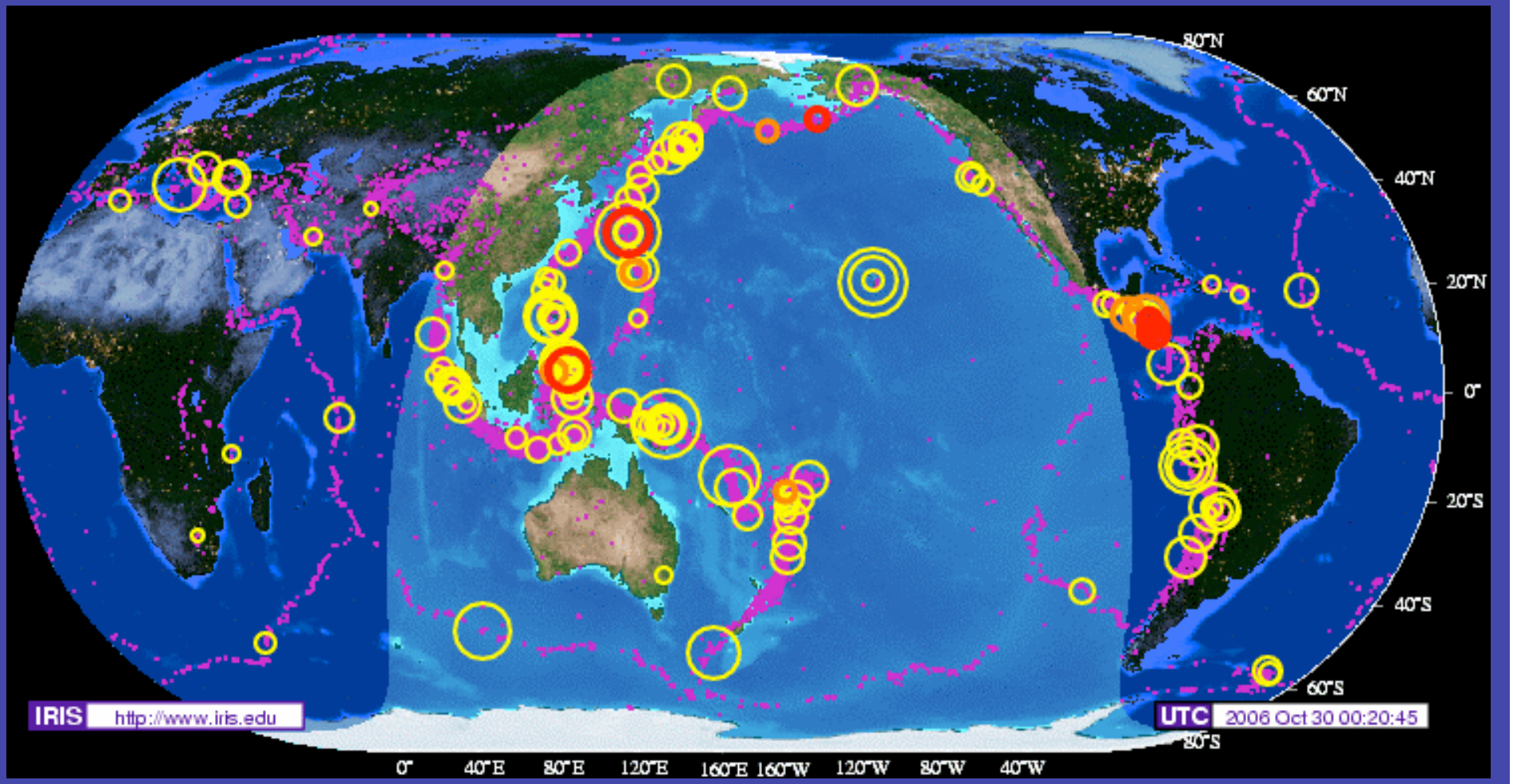
Where do the world's earthquakes occur?



What kinds of plate boundaries? What kinds of faults?

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

Equator

Middle America trench

Puerto Rico trench

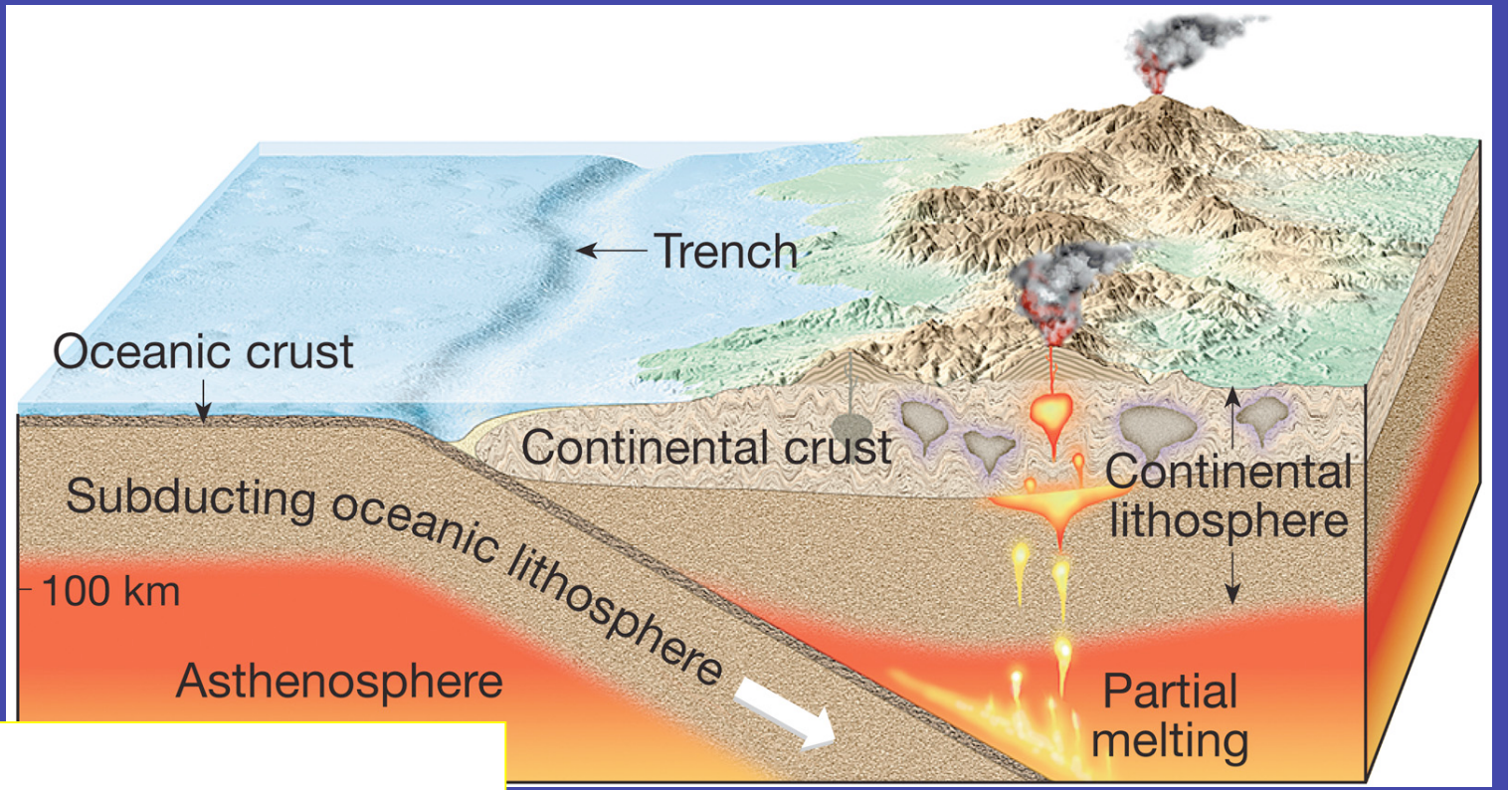
Peru-Chile trench

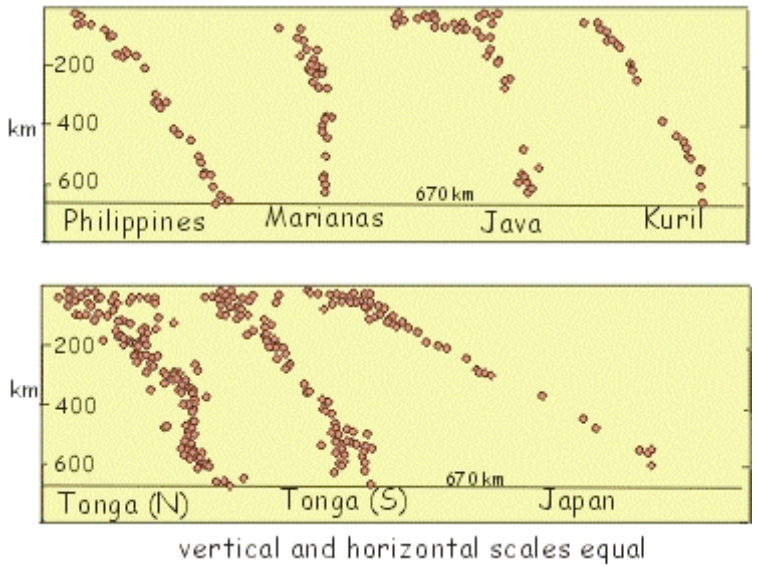
South Sandwich trench

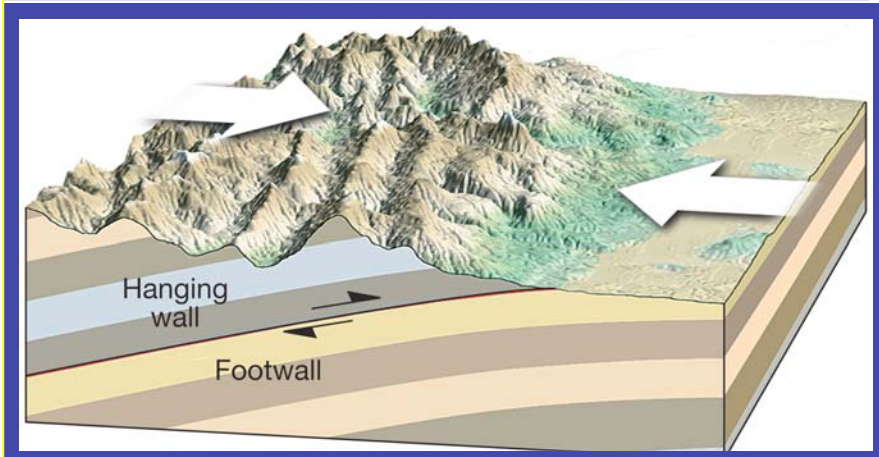
90% world’s earthquakes
81% of world’s largest earthquakes
Explosive volcanism

Convergence

Subduction zone earthquakes most common

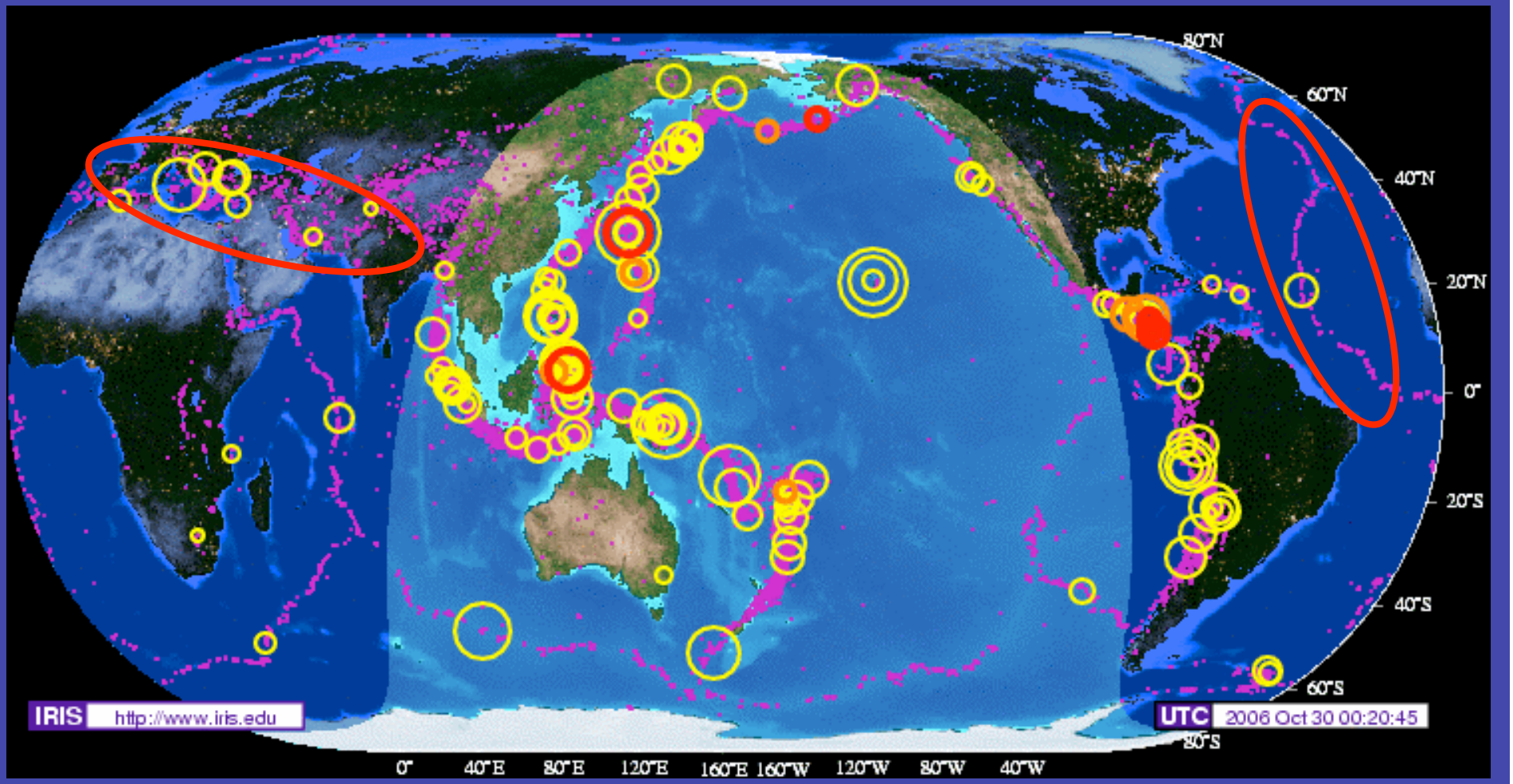






Thrust (reverse) faulting

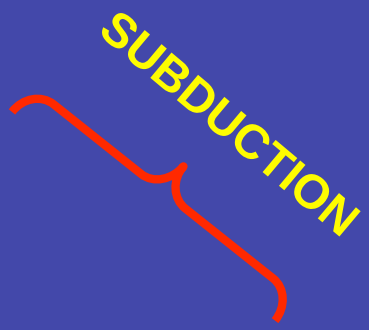
Where do the world's earthquakes occur?



What kinds of plate boundaries? What kinds of faults?

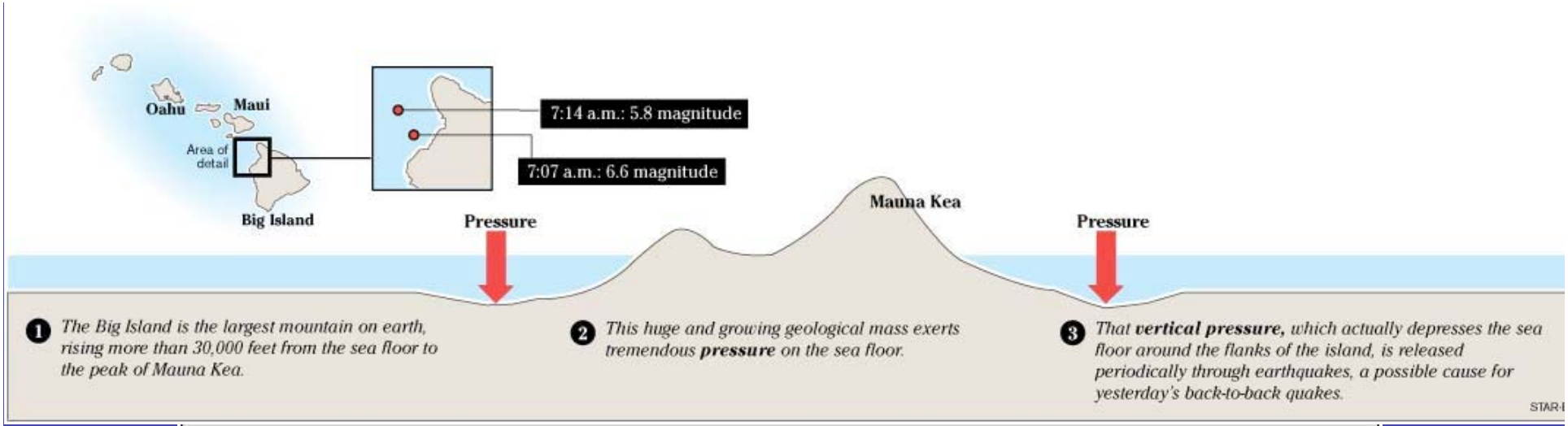
Where do the world's earthquakes occur?

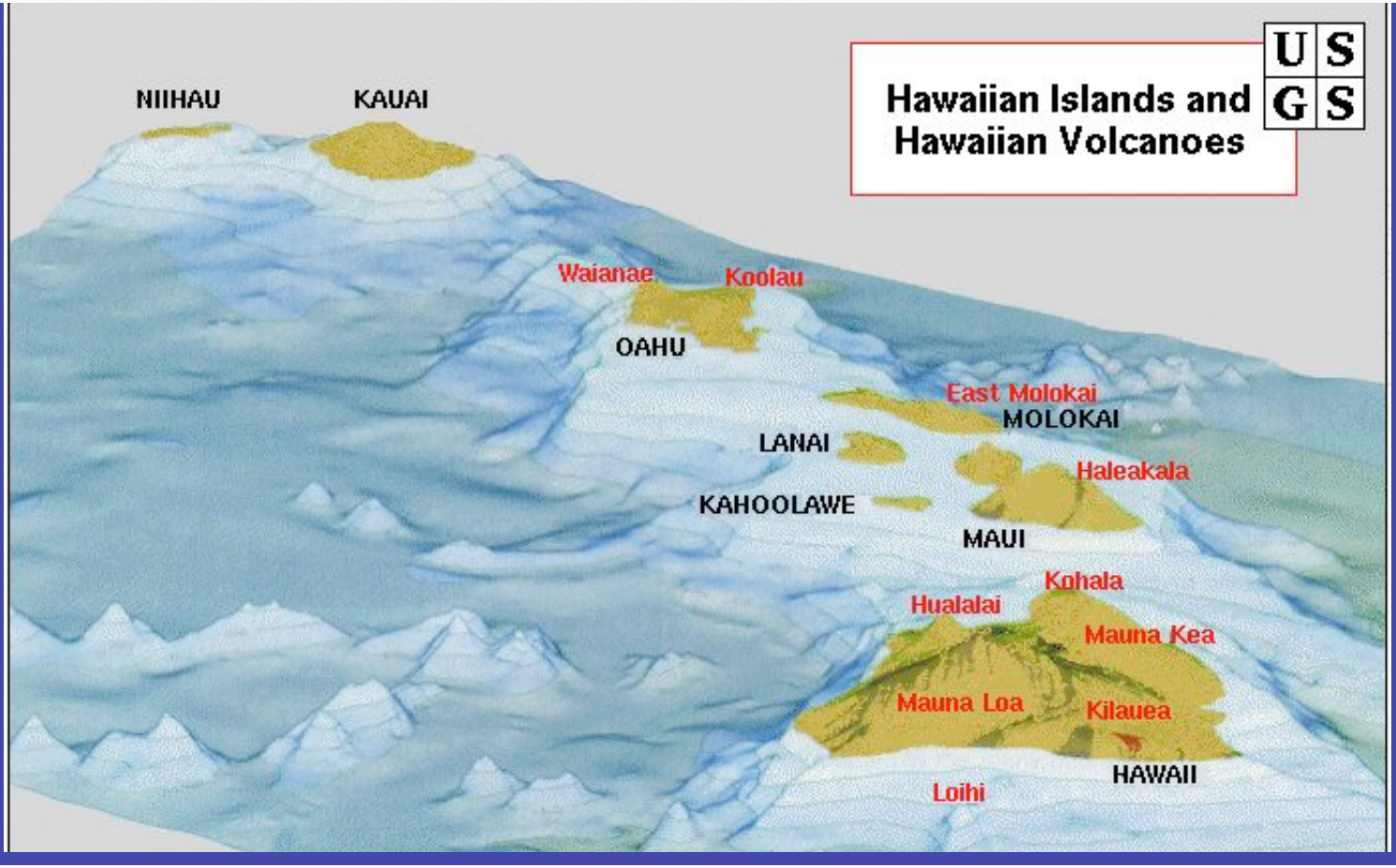
90% within Ring of Fire (convergence)
Thrust (reverse) faults



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

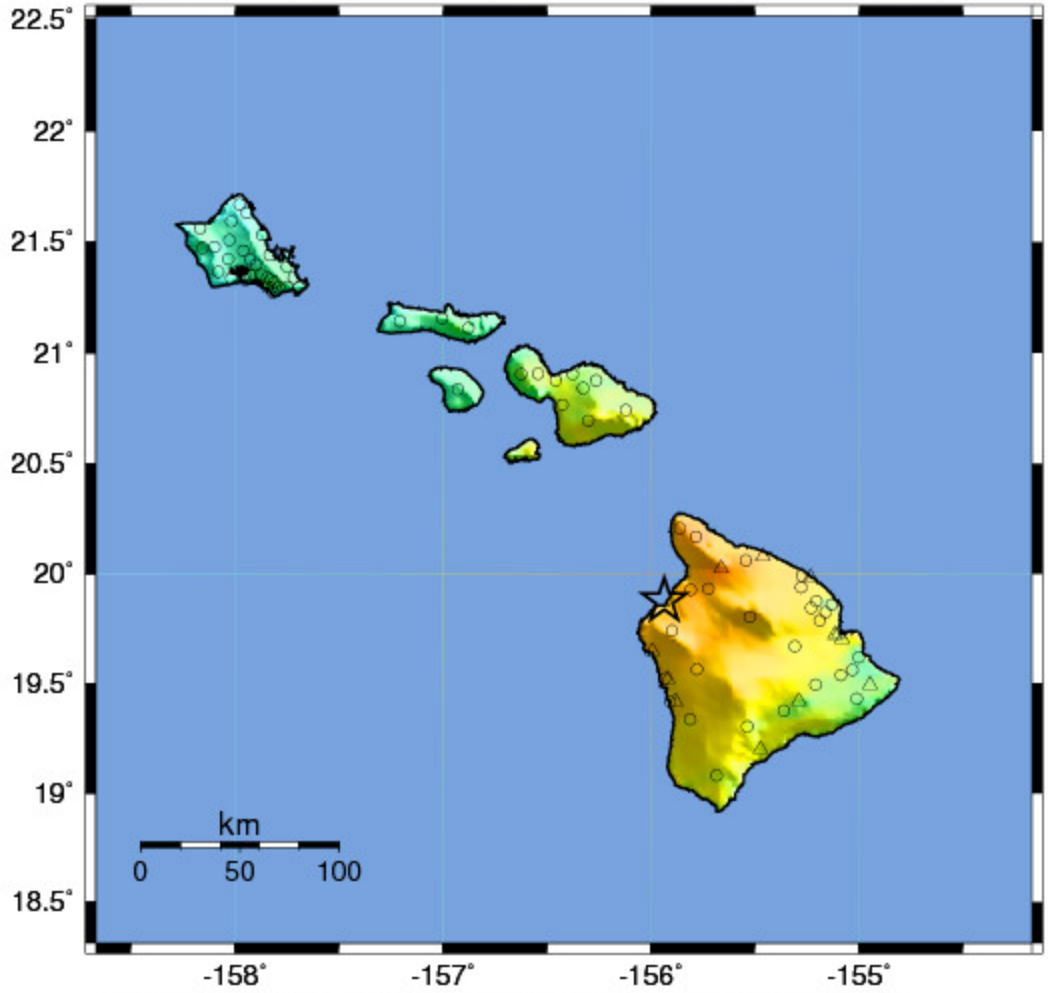
<4% along Mid-Atlantic Ridge ("divergence")
Strike-slip (transform) faults


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.
STAR-


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

USGS ShakeMap : HAWAII REGION, HAWAII

Sun Oct 15, 2006 17:07:48 GMT M 6.7 N19.88 W155.94 Depth: 38.9km ID:twbh_06



Map Version 10 Processed Mon Oct 16, 2006 09:45:46 AM MDT -- NOT REVIEWED BY HUMAN

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
POTENTIAL DAMAGE Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. 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*
ESTIMATED INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+







Structural Damage





Road Damage







Food Distribution

Infrastructure Impacts





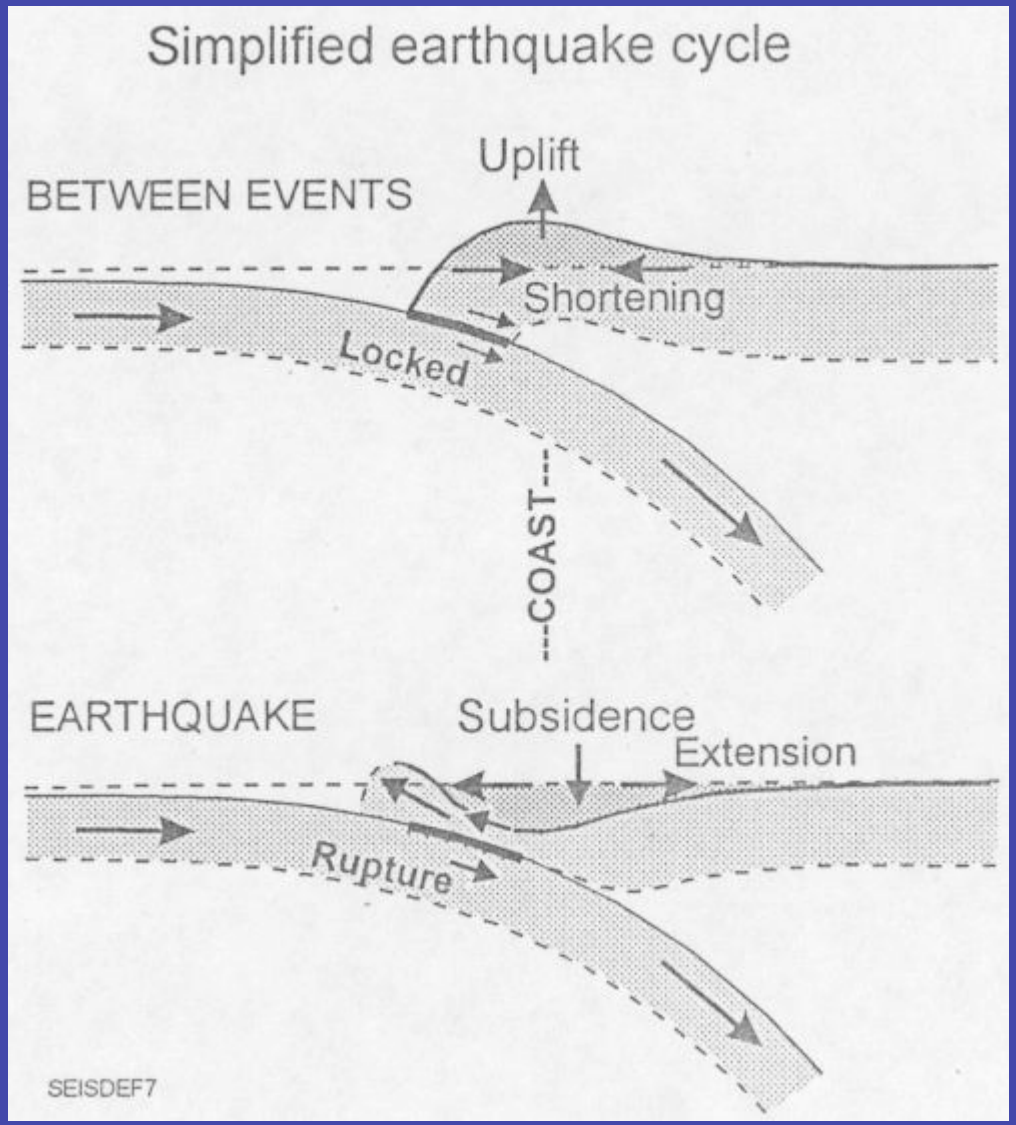


Hilo, 1946…triggered by Alaskan earthquake



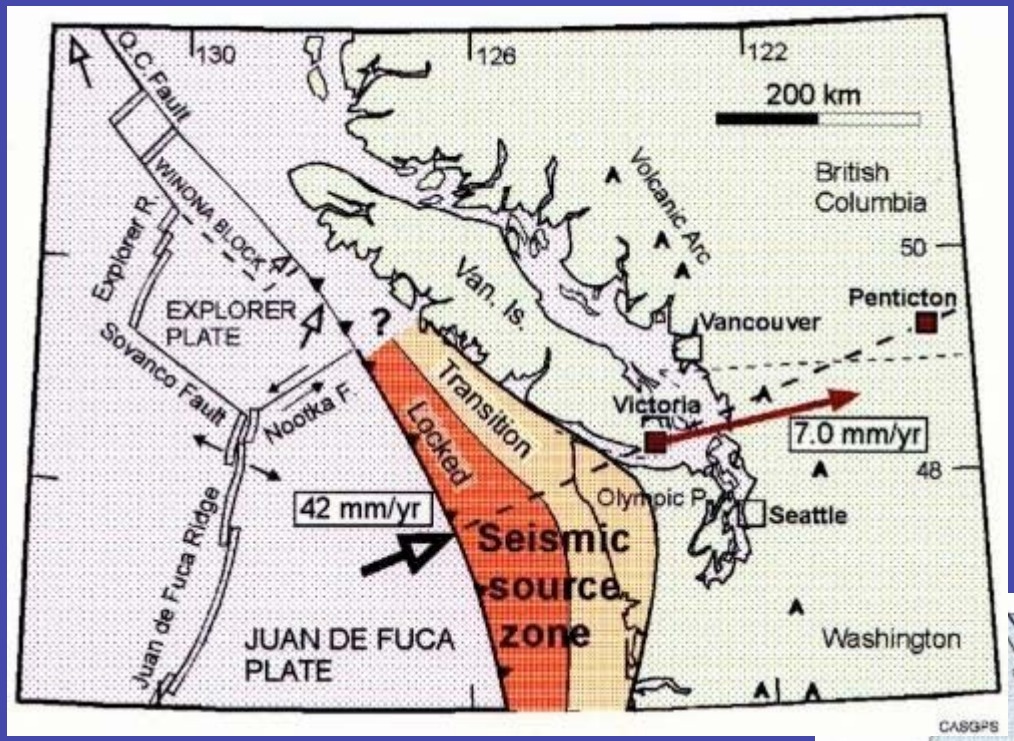
What happens during a subduction earthquake?

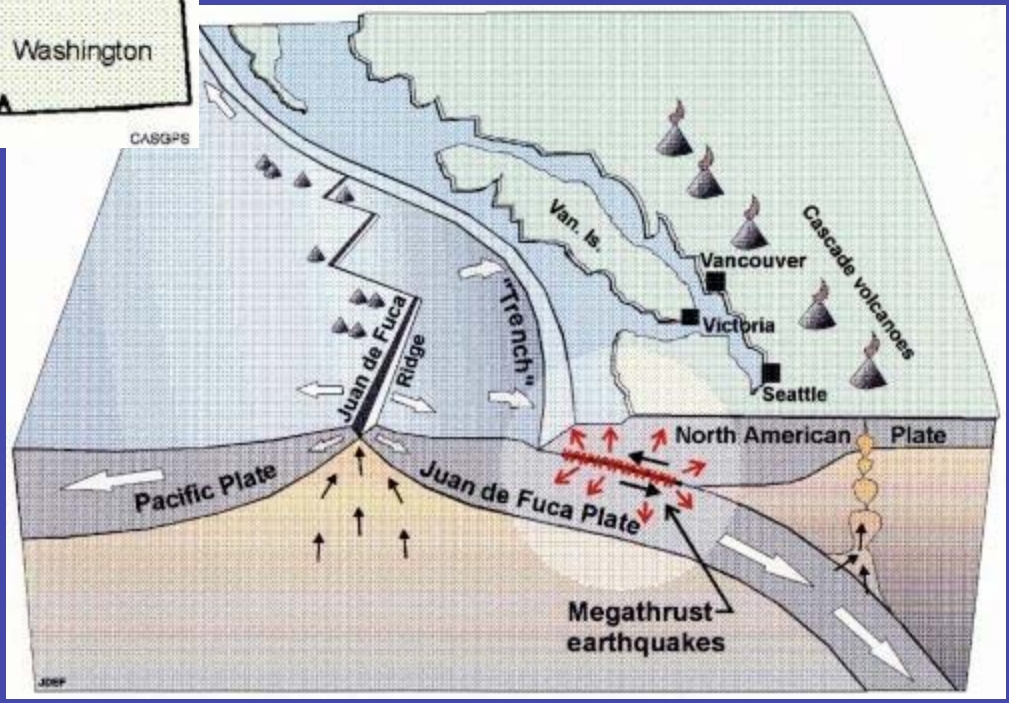
What happens during a subduction earthquake?



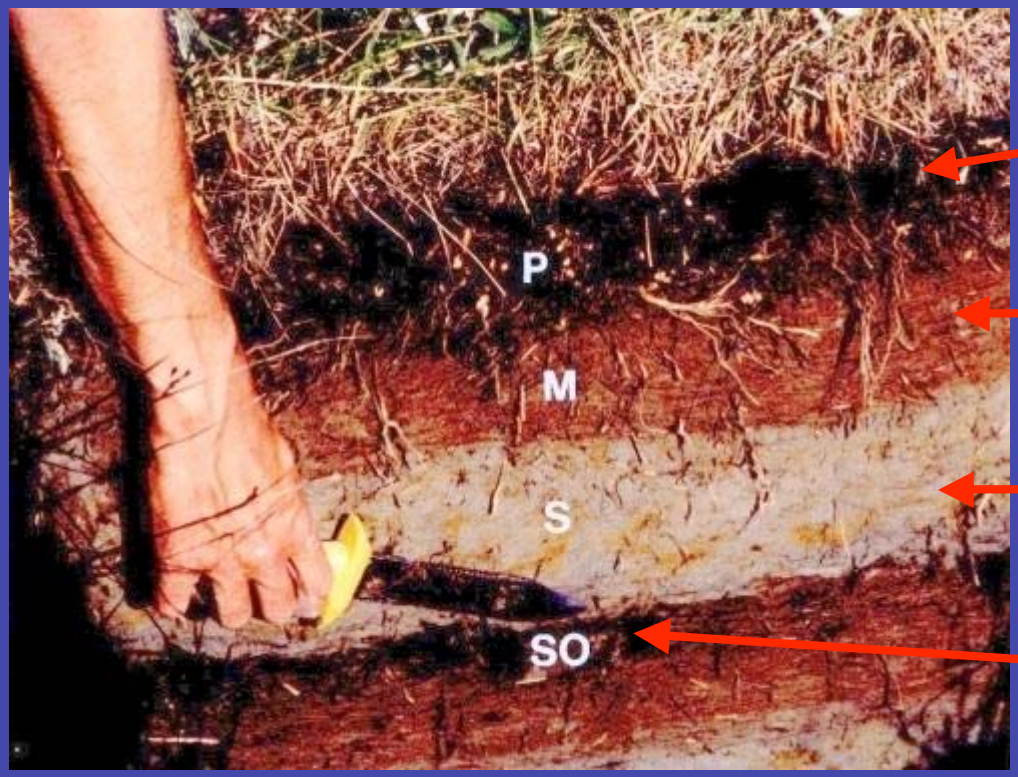
What type of deformation does each of these phases represent?

Great subduction earthquakes in the Pacific Northwest





Evidence for great subduction quake



Peat

Tidal Mud

Tsunami Sands

Peaty soil





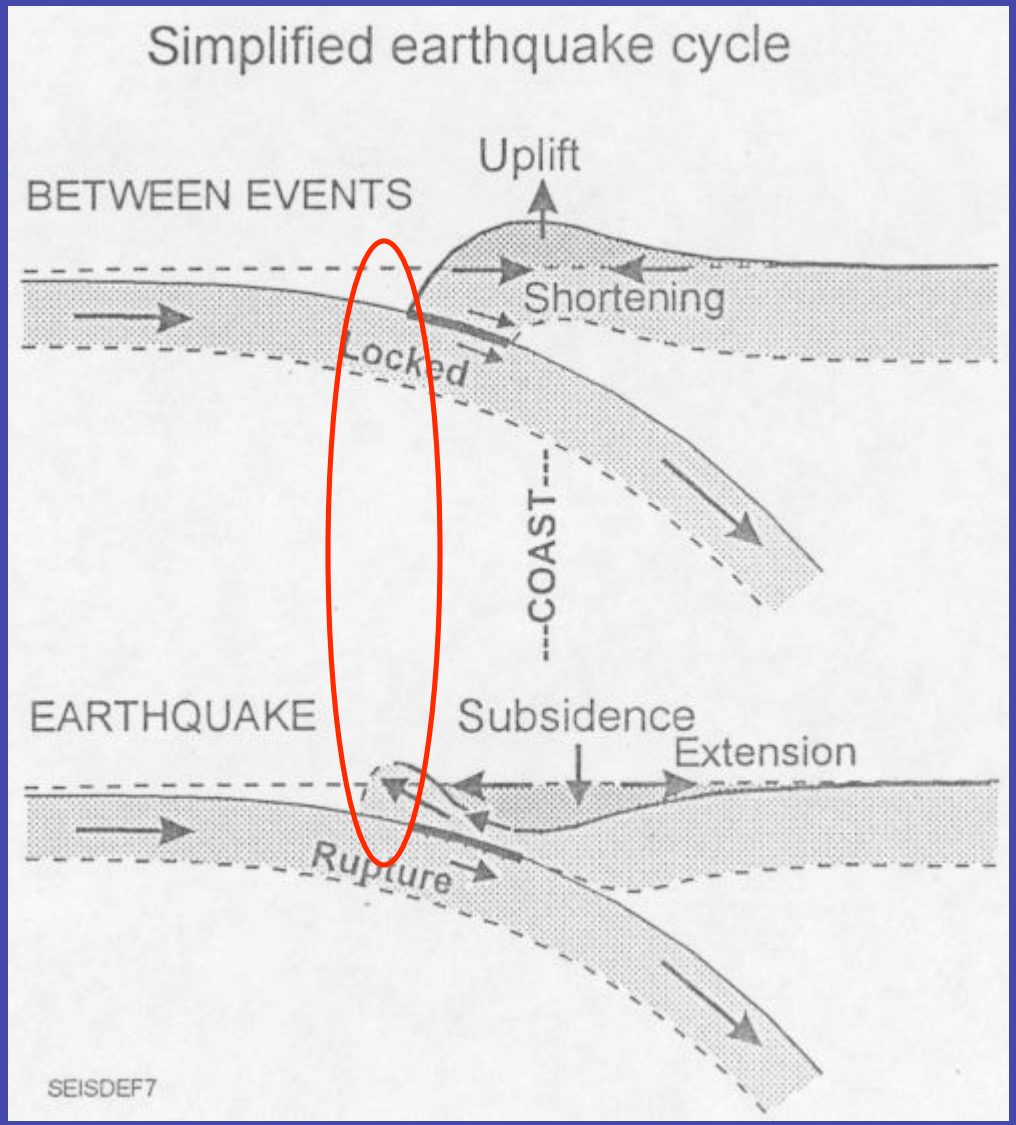


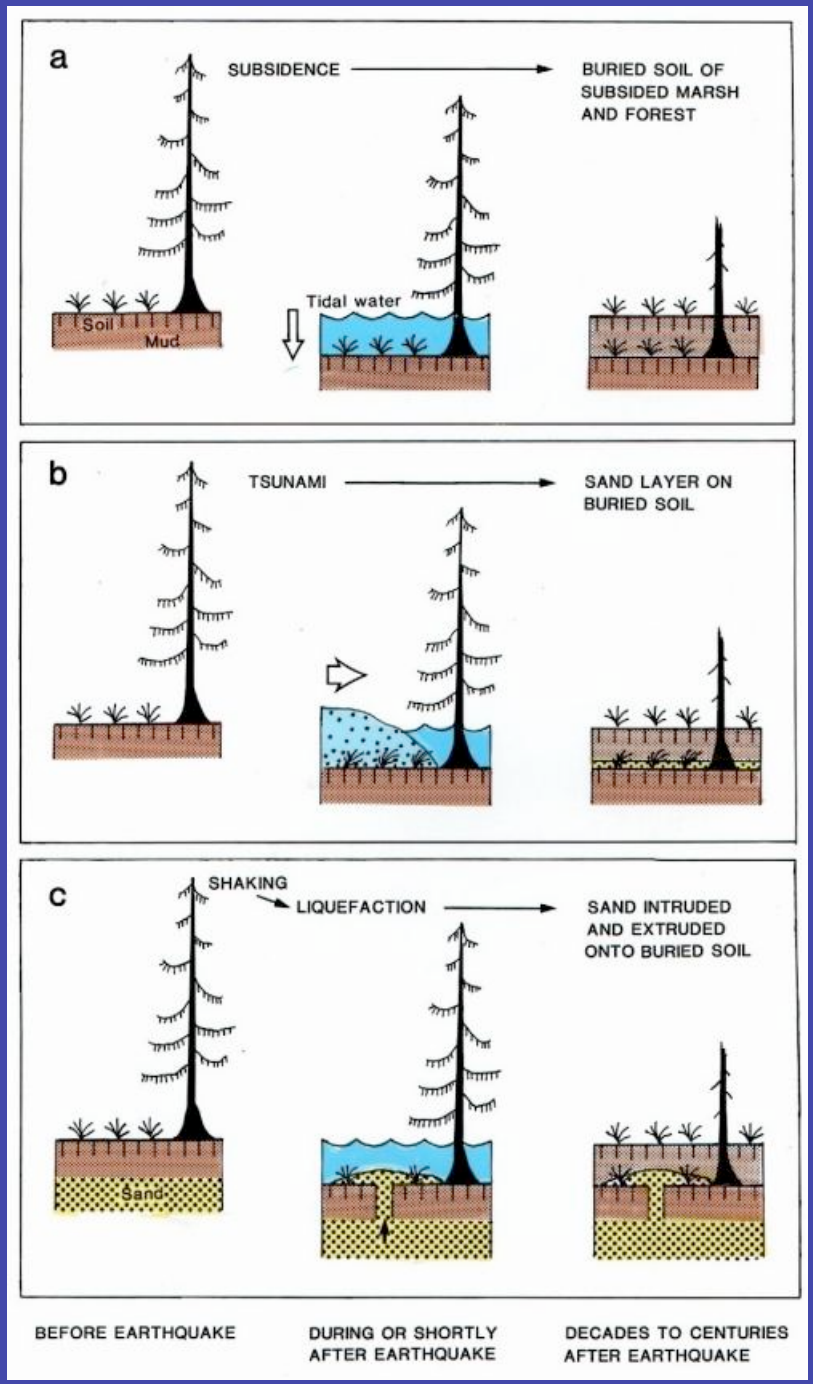
What happened to these trees?





Subsidence/tsunami bury old coastline



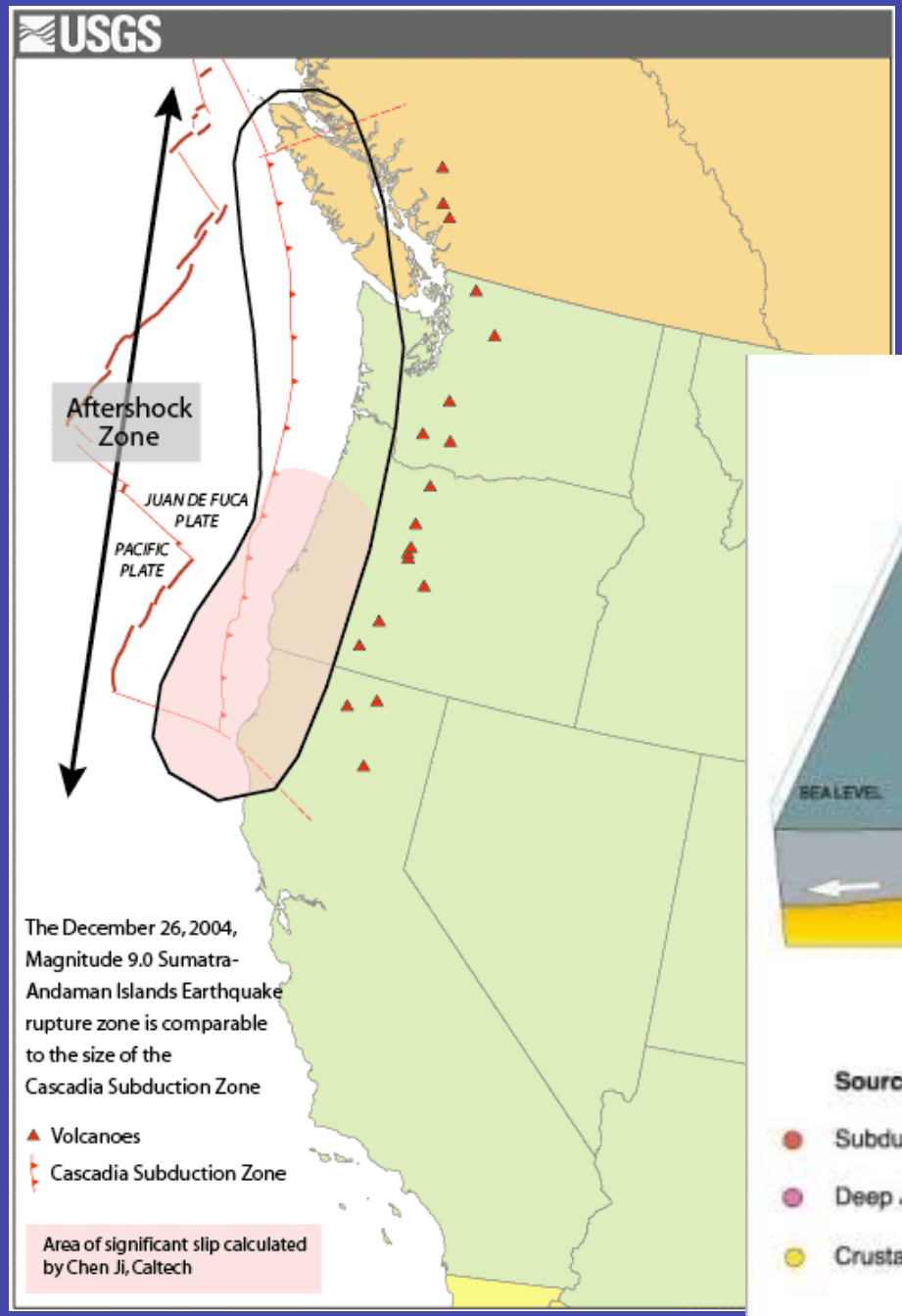


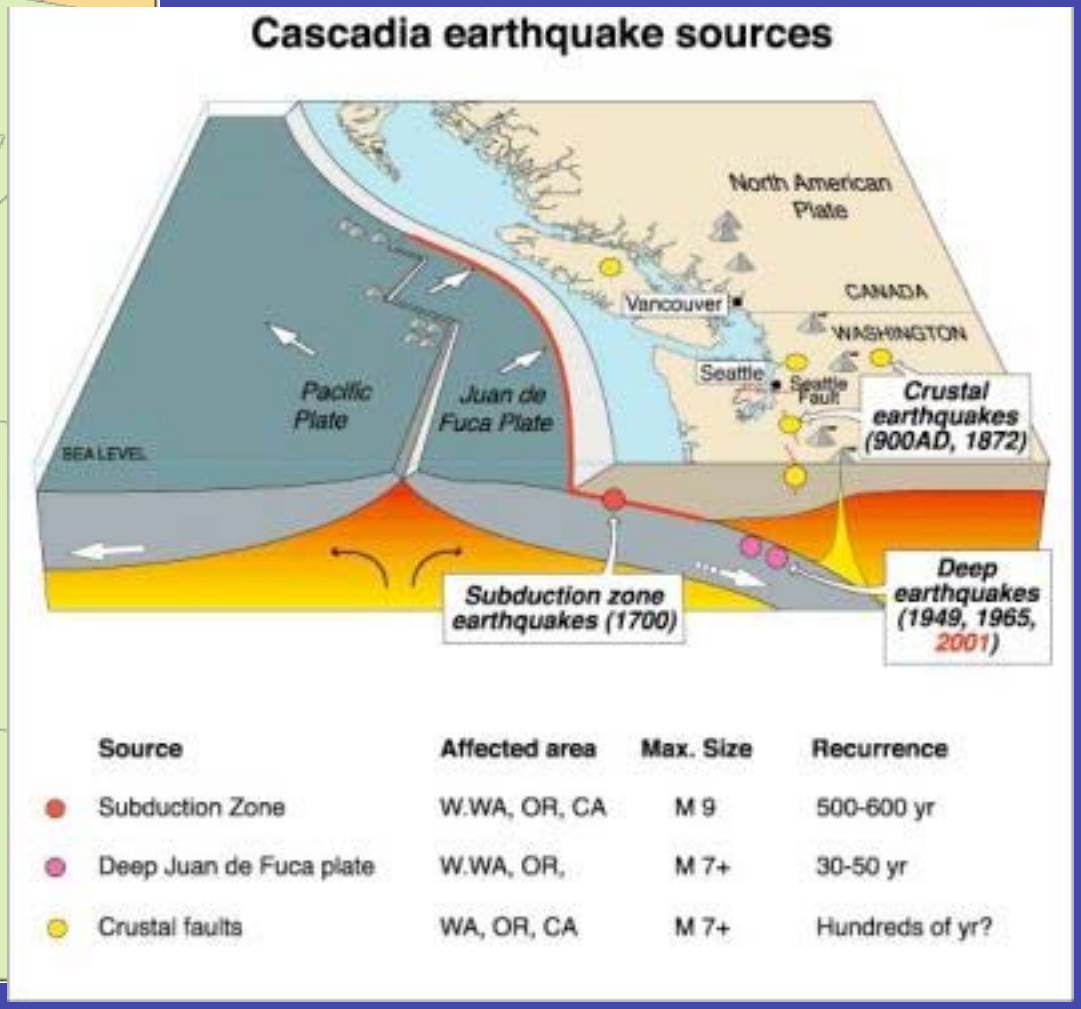
Last great subduction quake in Cascadia occurred in 1700

(M 9.0, tsunami in Japan)

Recurrence interval ~500 yrs

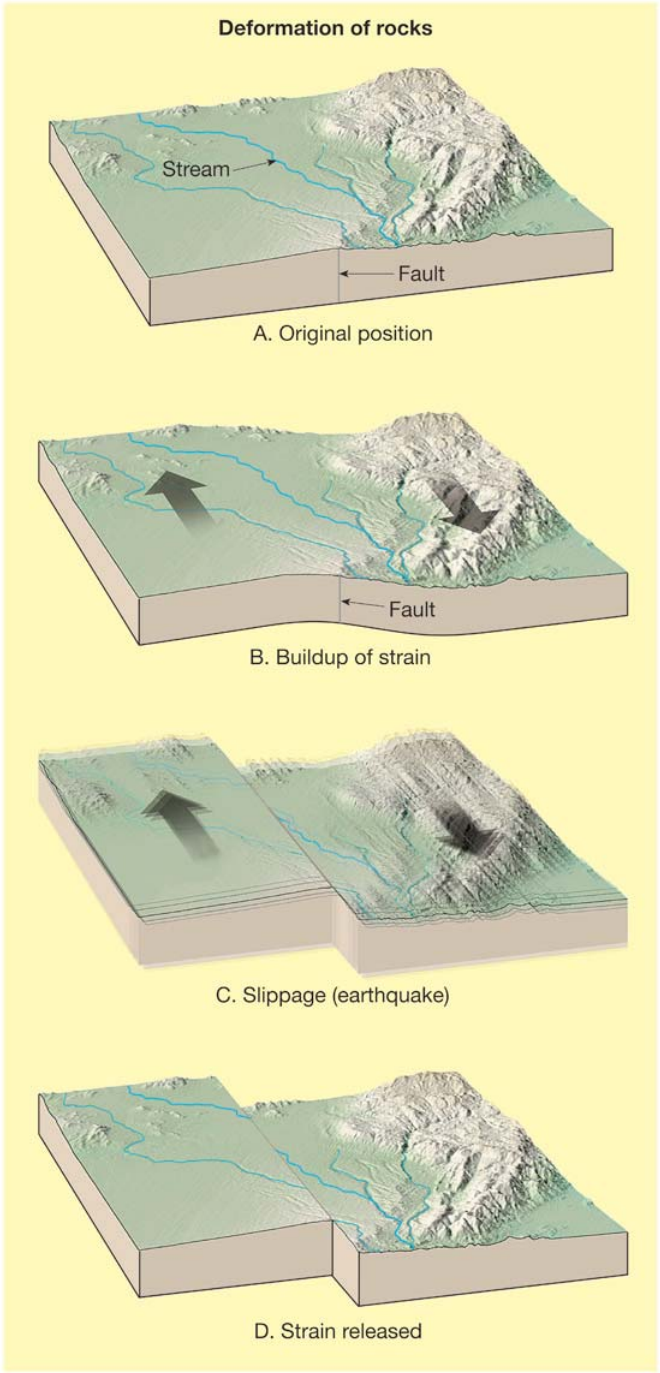
(13 previous events, 300-900 year spacing)

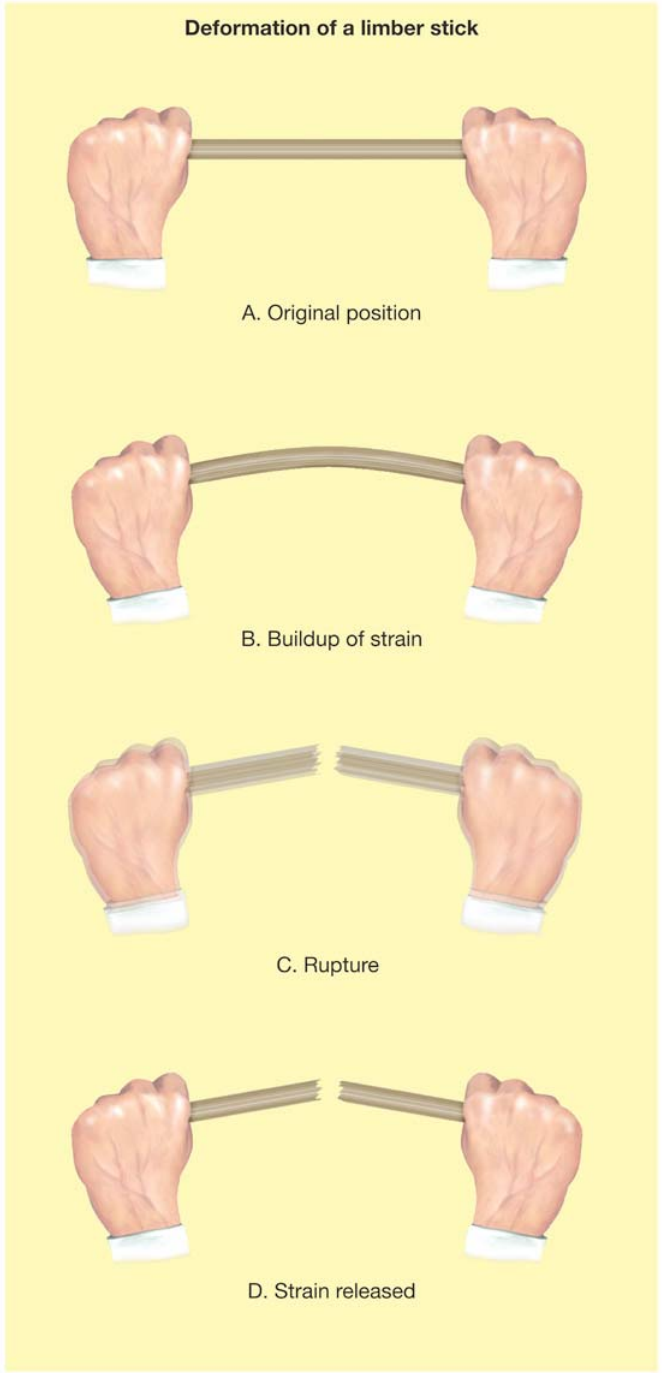




Source	Affected area	Max. Size	Recurrence
Subduction Zone	W.WA, OR, CA	M 9	500-600 yr
Deep Juan de Fuca plate	W.WA, OR,	M 7+	30-50 yr
Crustal faults	WA, OR, CA	M 7+	Hundreds of yr?

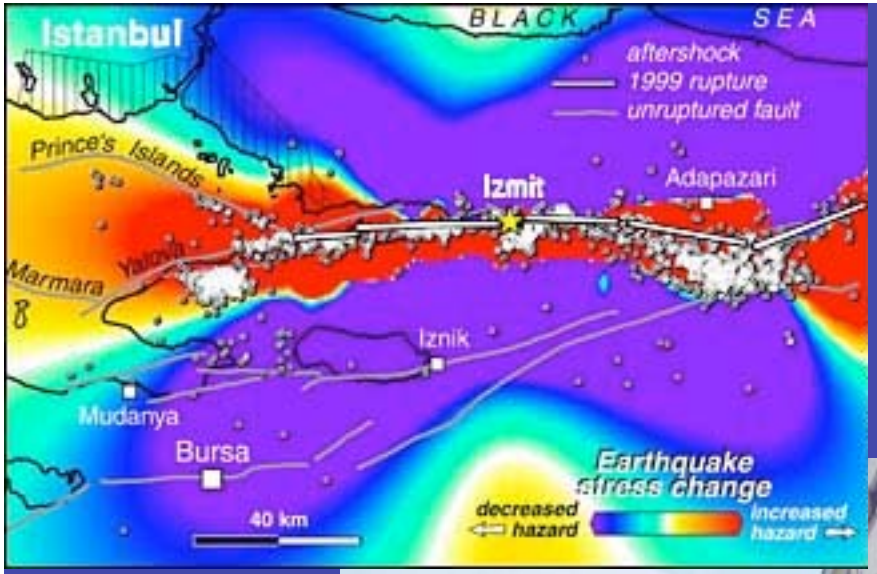
What happens during a strike-slip earthquake?



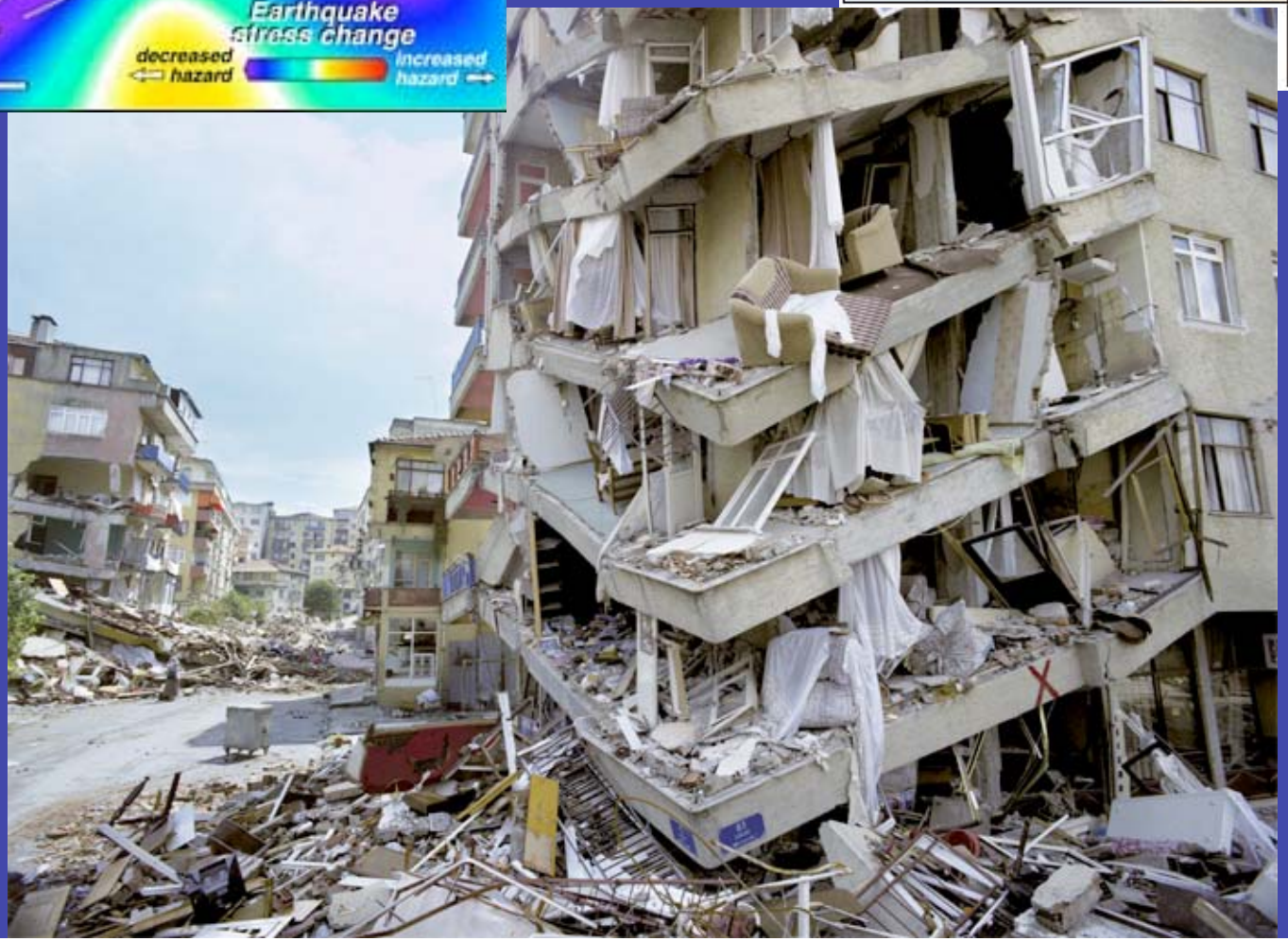


What type of deformation does each of these phases represent?

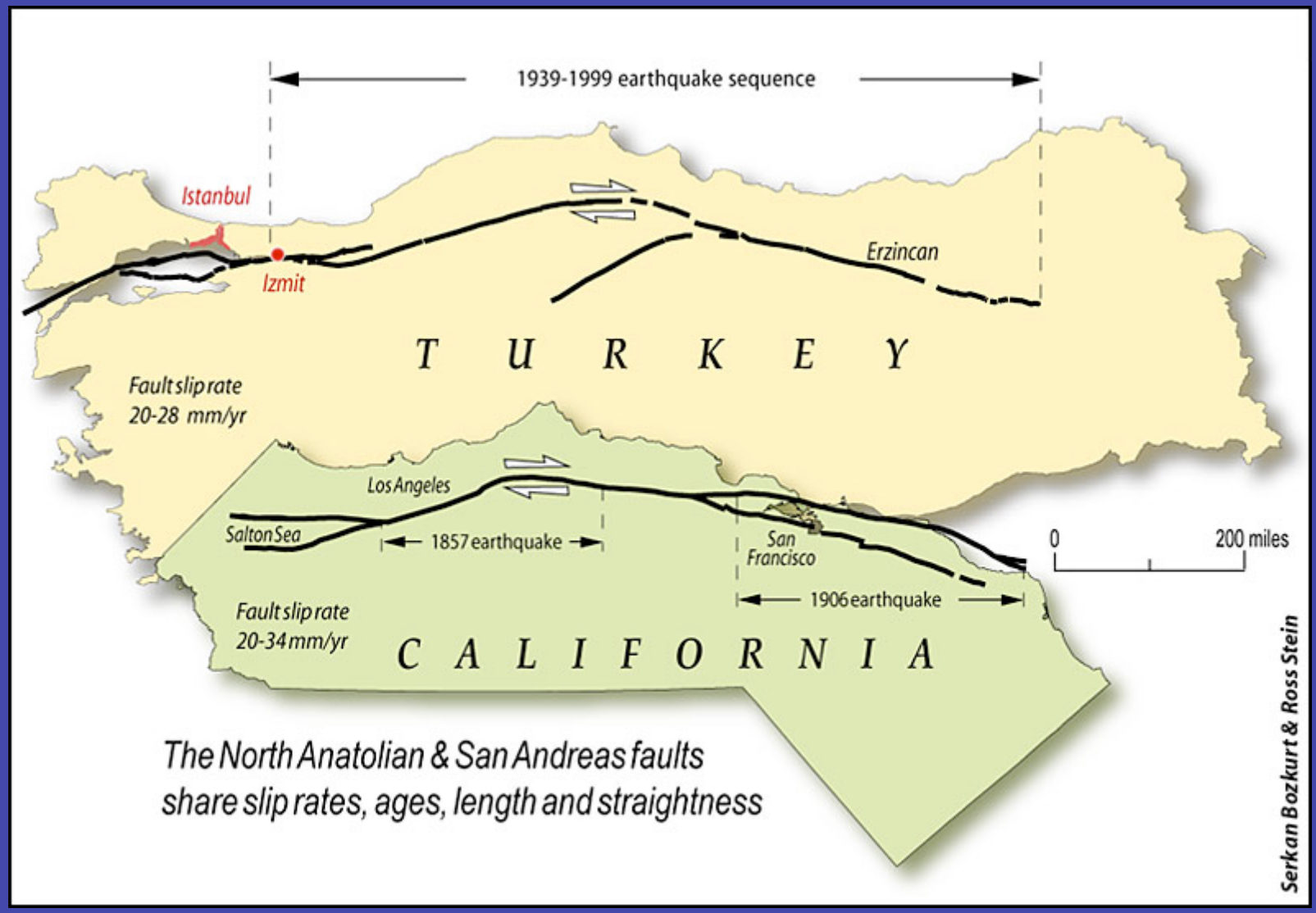
Izmit Turkey 1999



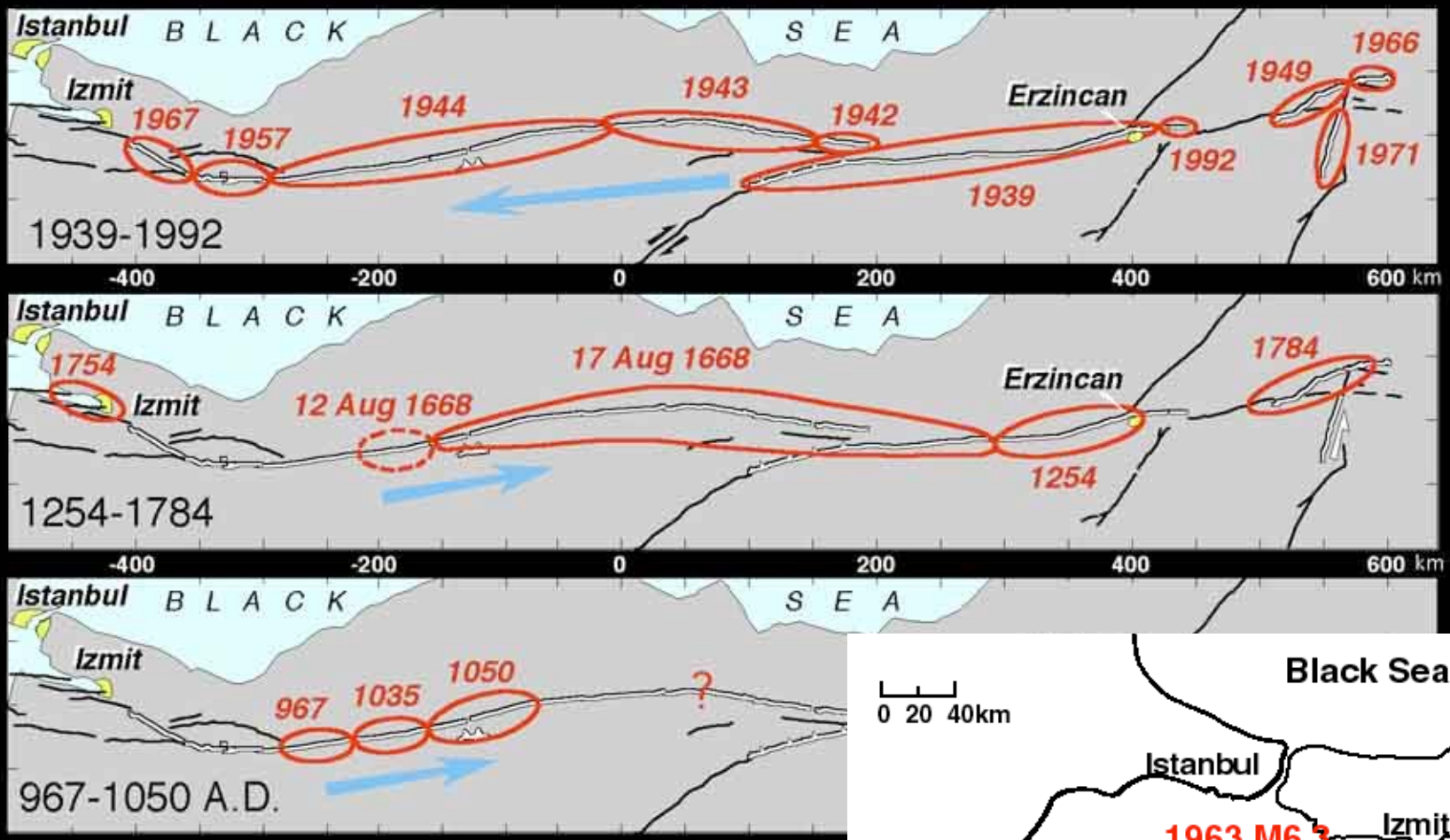




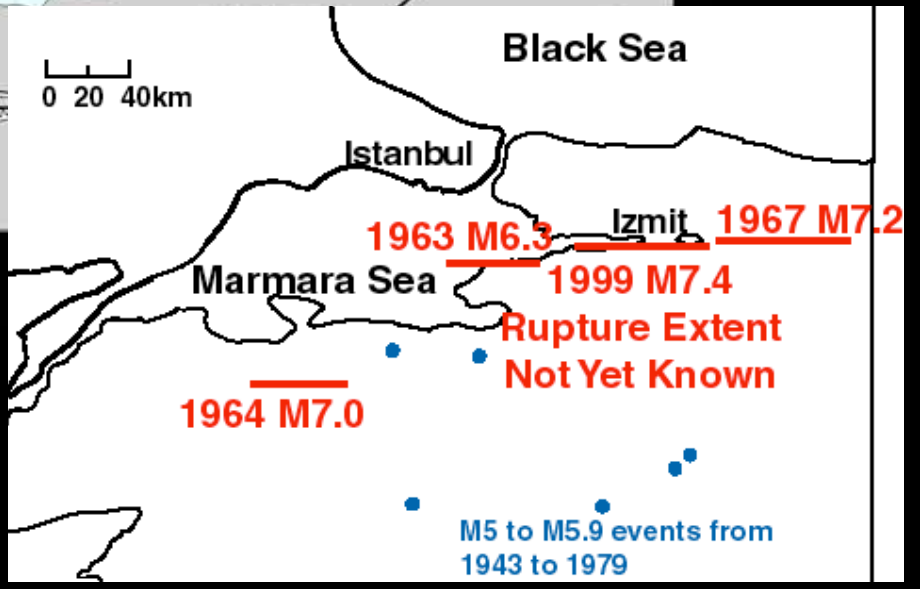
North Anatolian Fault resembles San Andreas Fault



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



Progressive Rupture Pattern



Why do some structures survive?











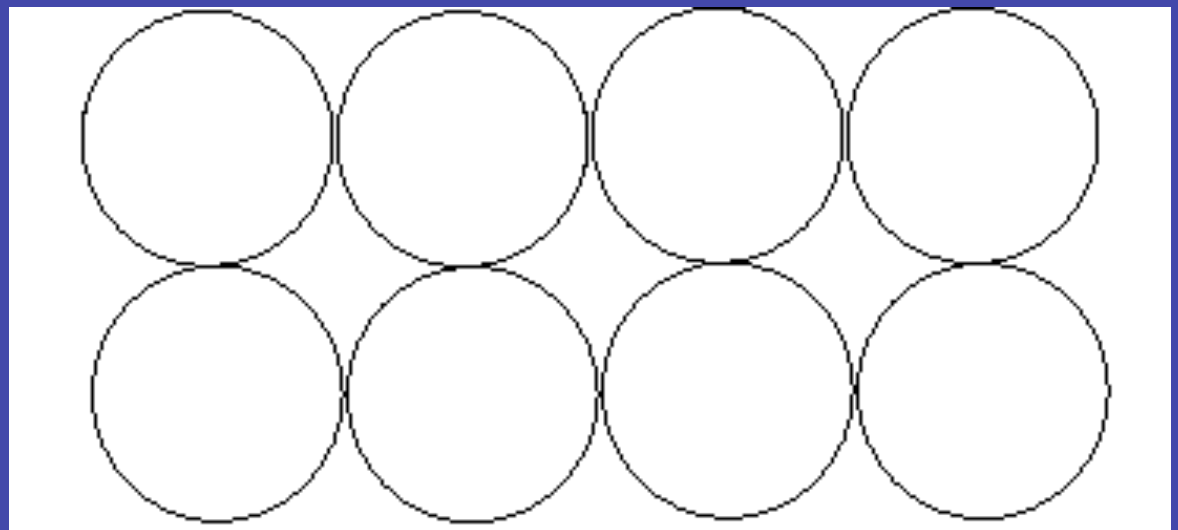
Why did these buildings fall over?

How do these form?

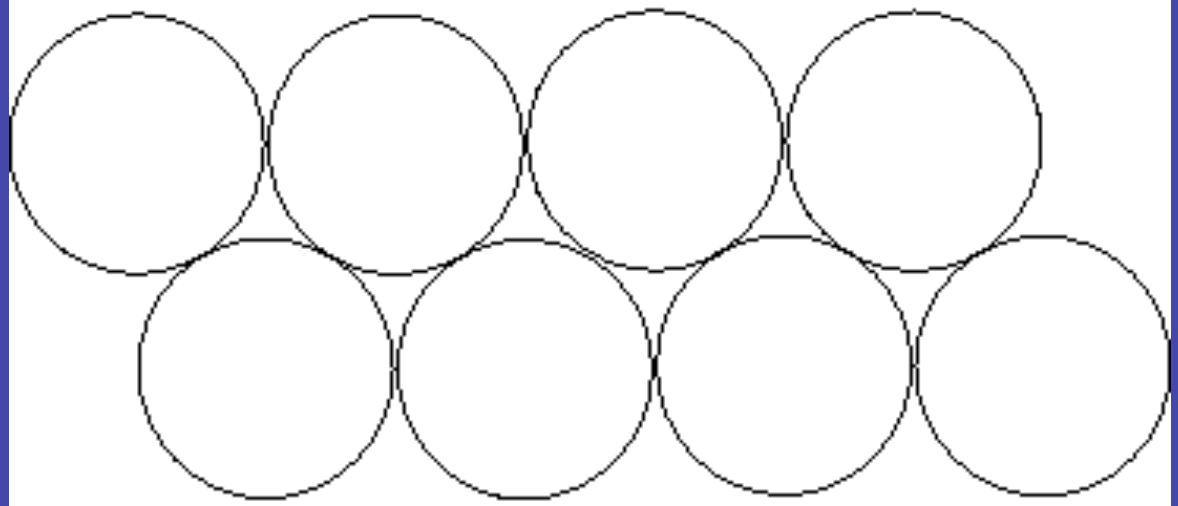








Loose packing of sand grains



More compact packing

Loosely packed grains form slurry during earthquake

LIQUEFACTION

After earthquake they settle into more compact configuration

Liquefaction undermines foundations - Niigata, 1964





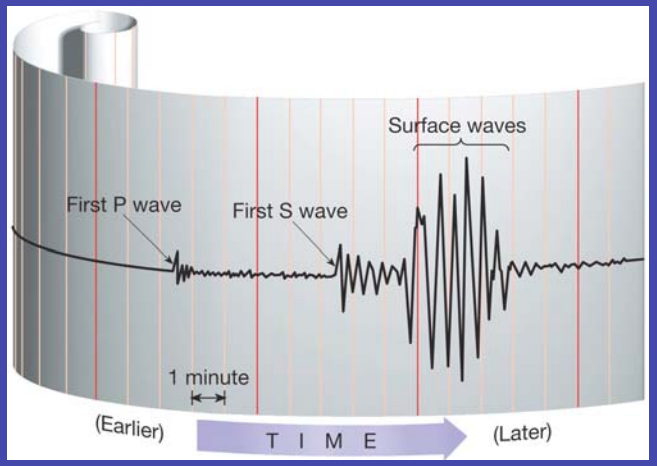
The first seismograph (Chinese)

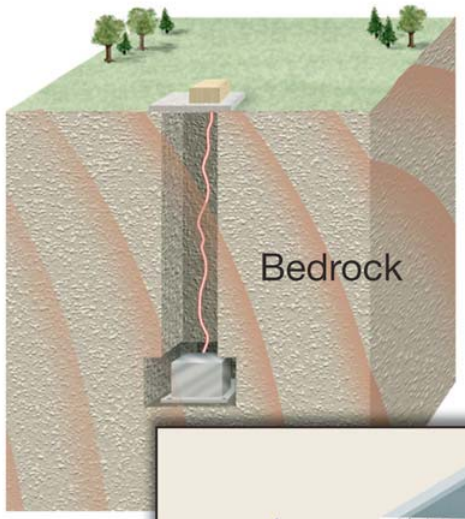


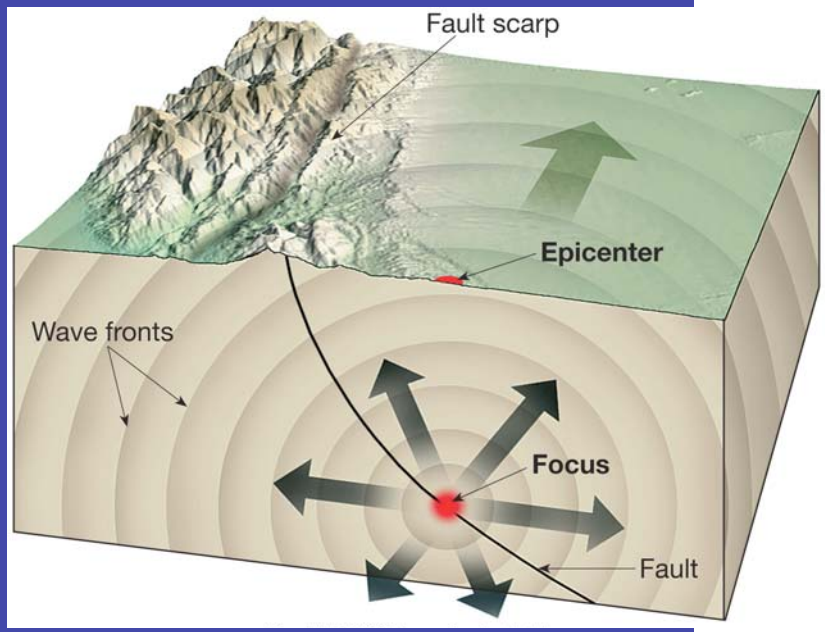
Central pendulum knocks ball from mouth of dragon into mouth of frog towards direction of epicenter

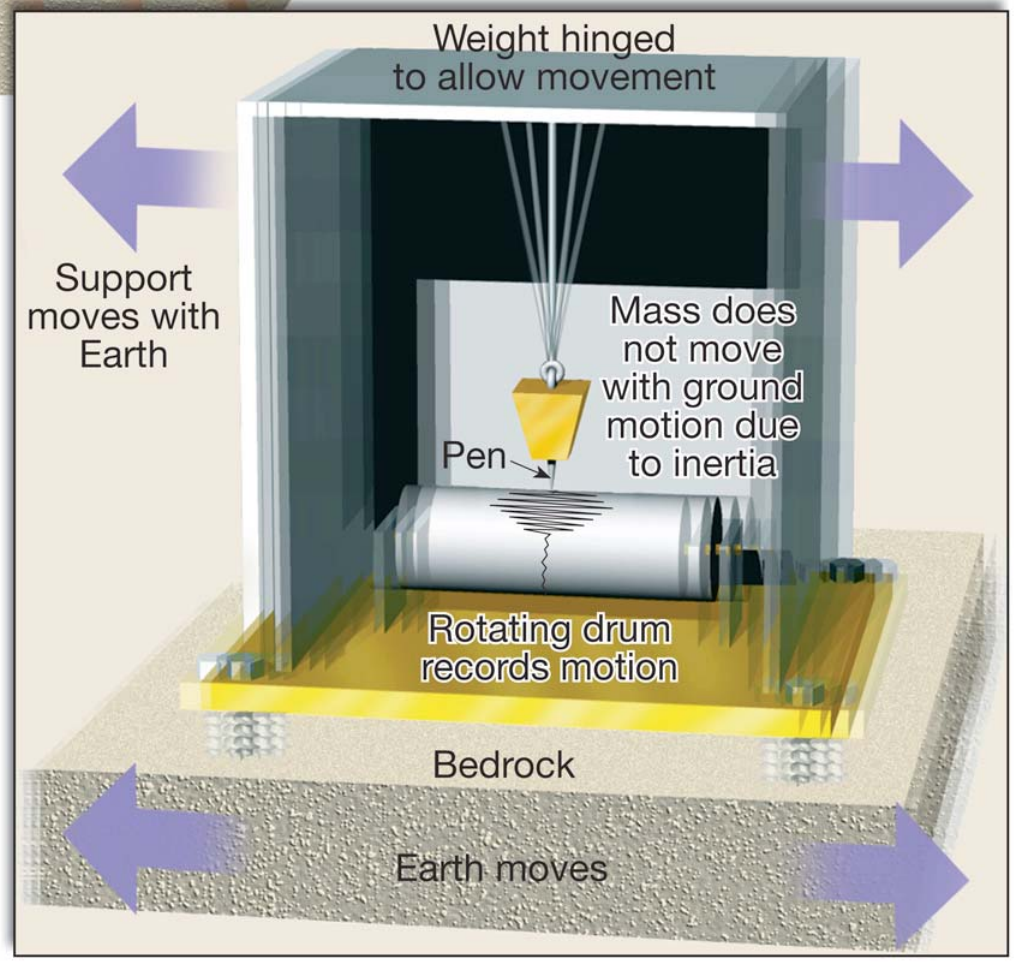


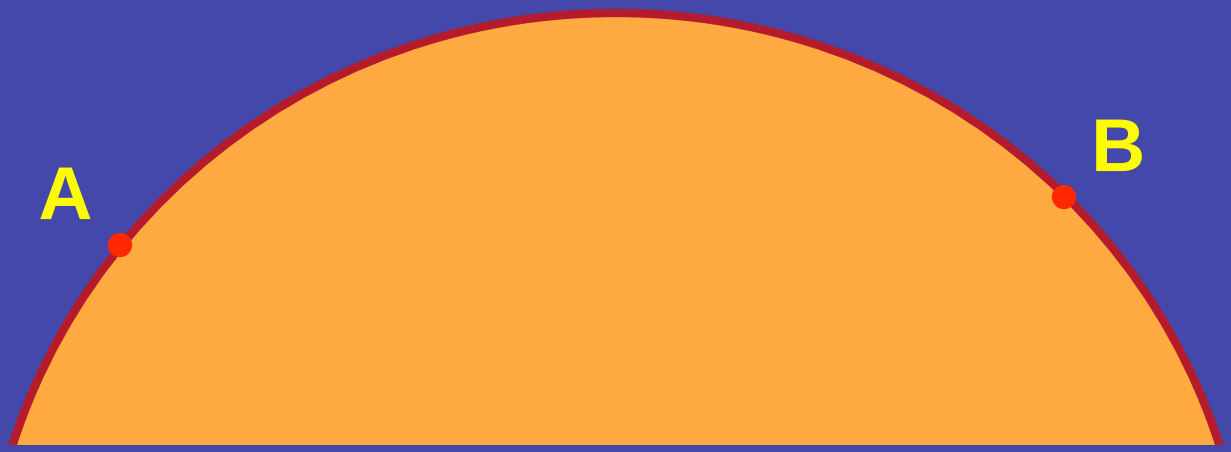
Modern Seismograph











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

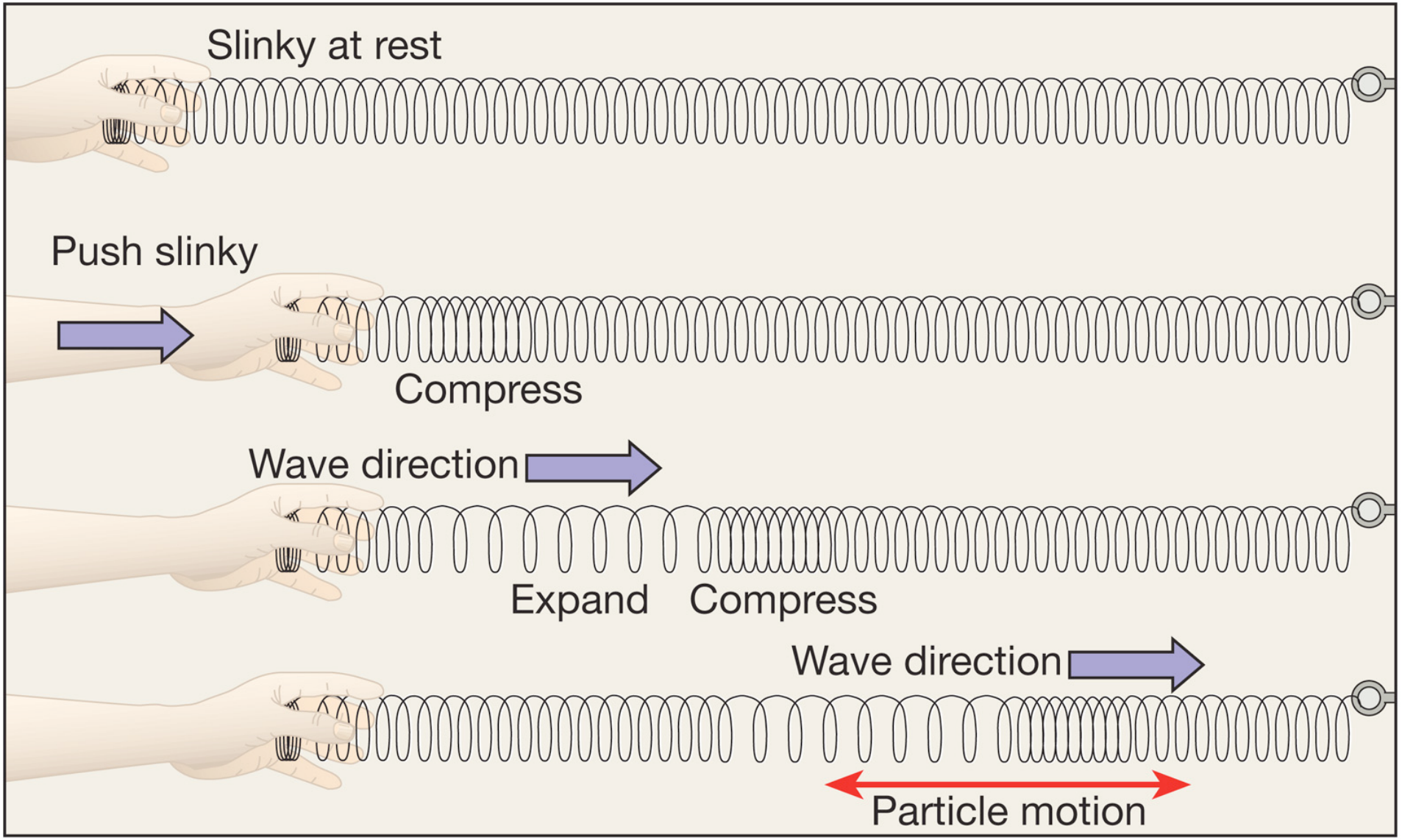
3 different types of seismic waves:

Body waves (travel through Earth):

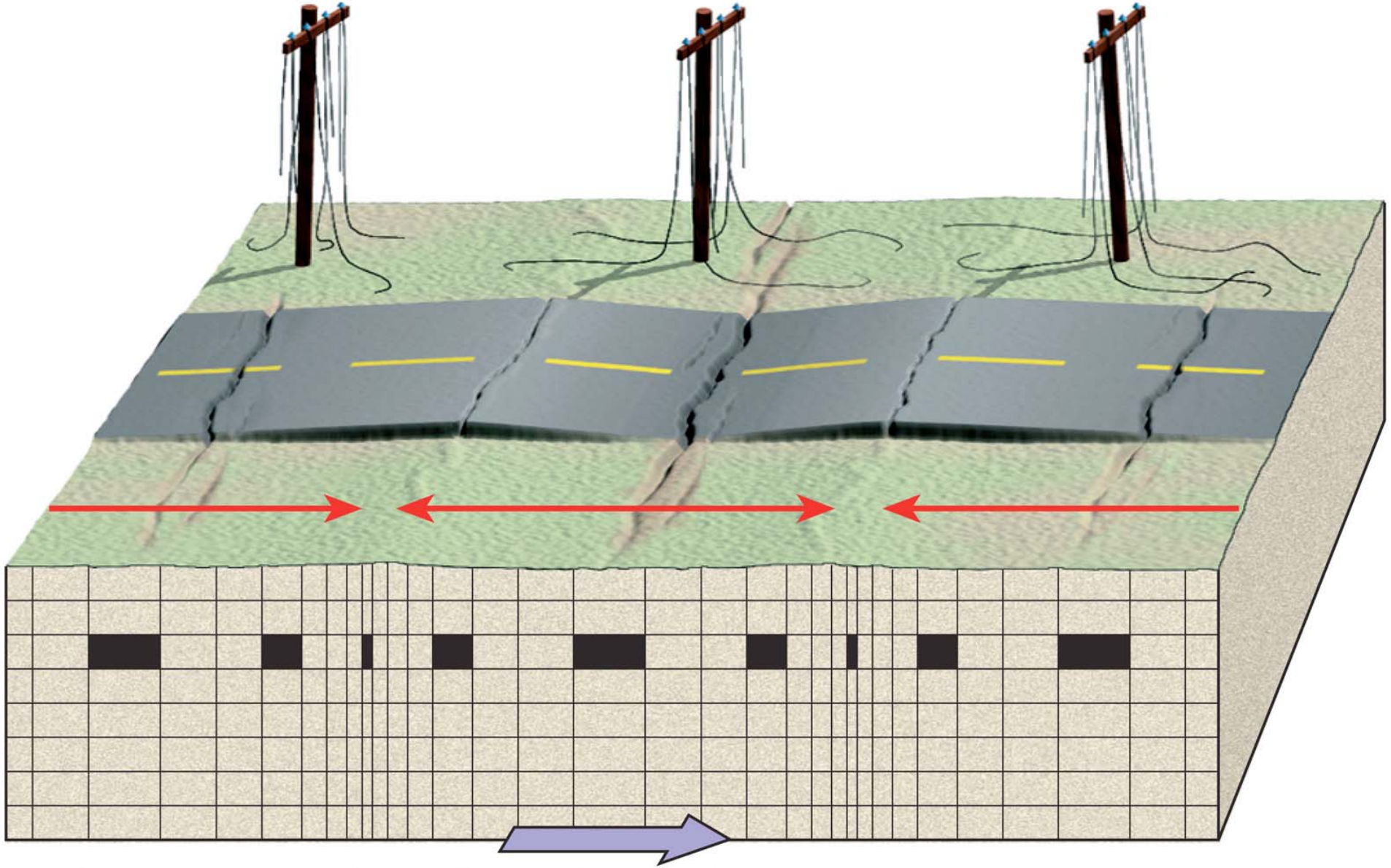
1) Primary waves (P-waves)

2) Secondary waves (S-waves)

3) Surface waves (travel across surface)



A. P waves generated using a slinky



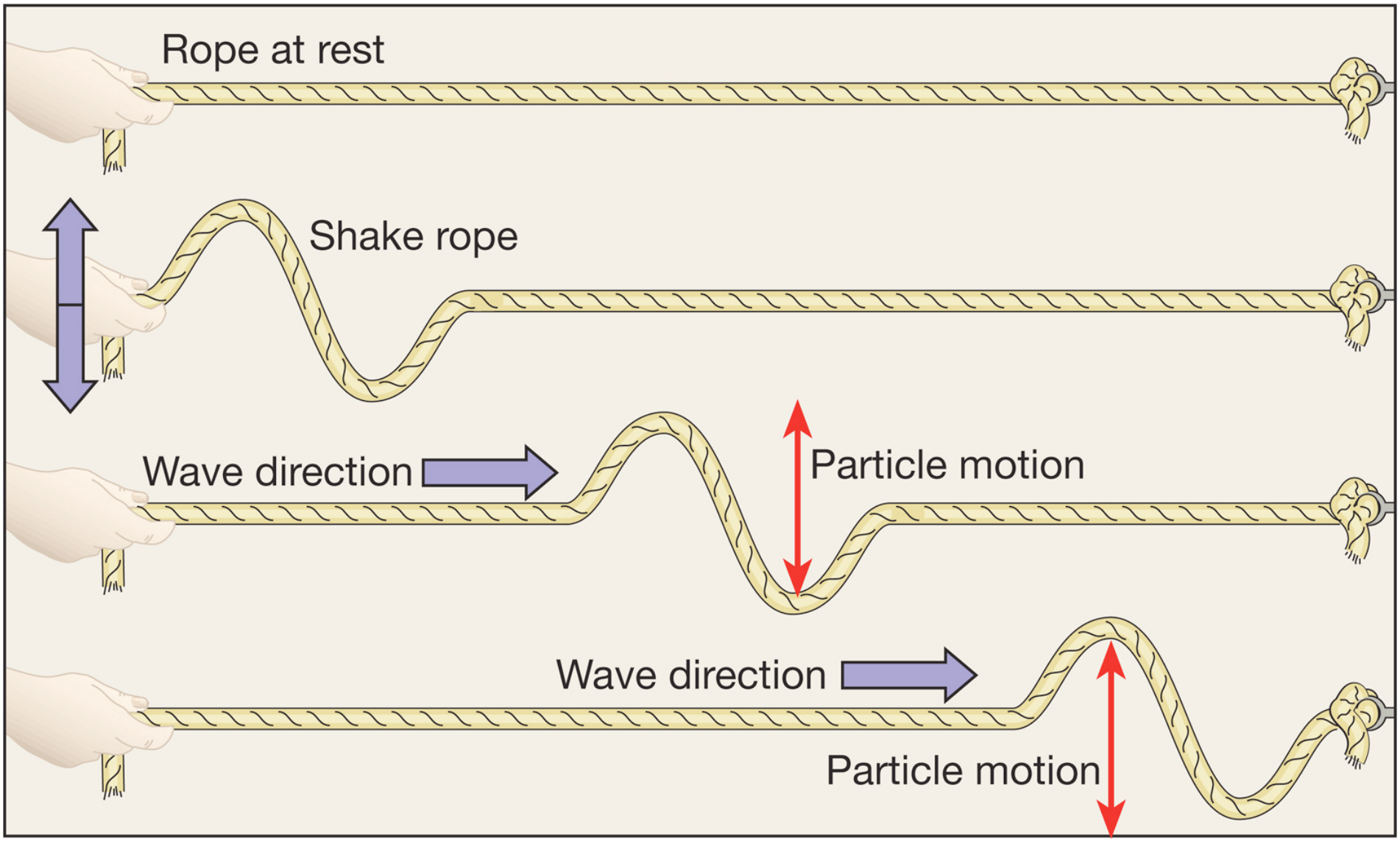
B. P waves traveling along the surface



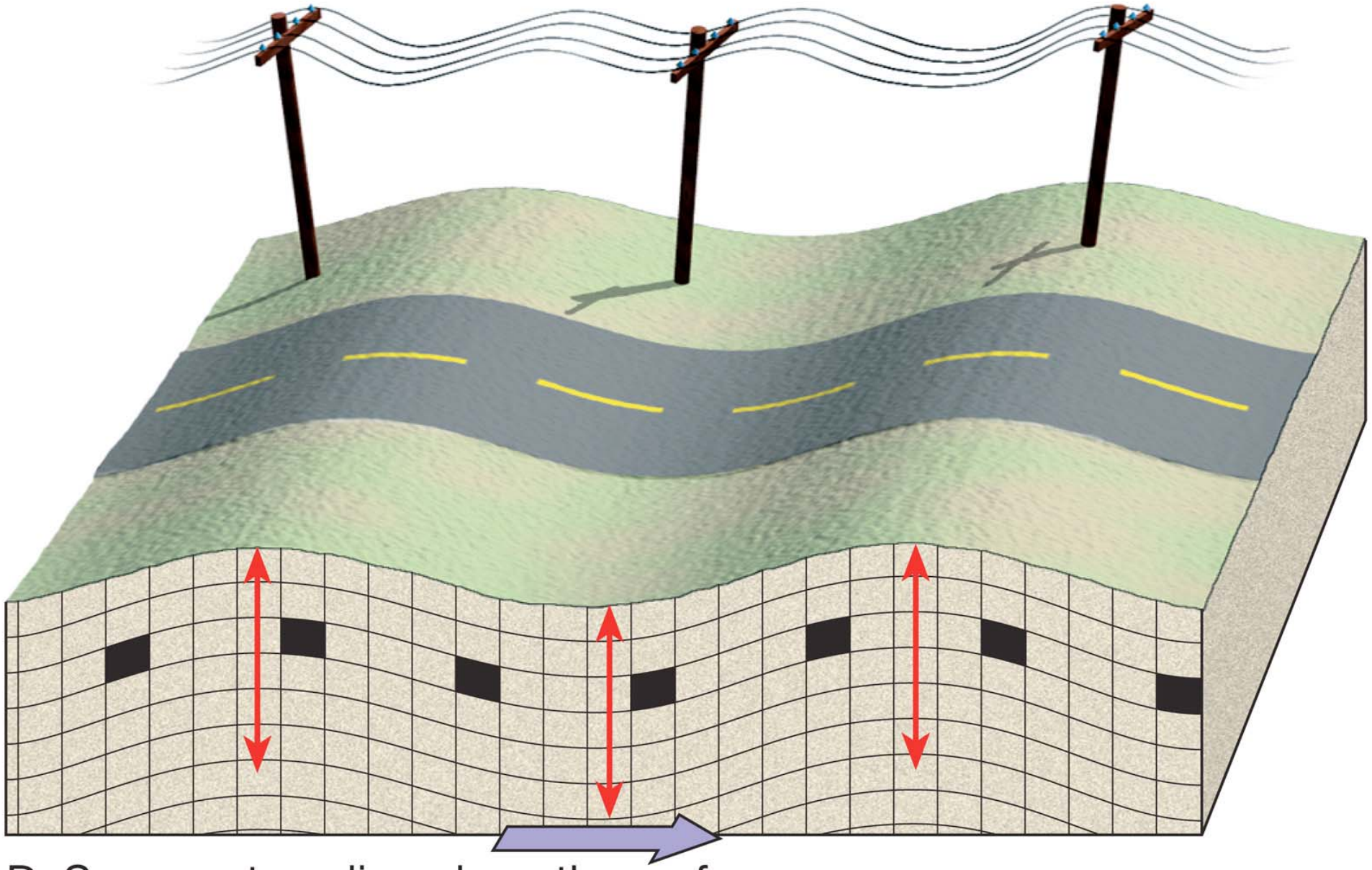




Fissuring (horizontal motion)



C. S waves generated using a rope

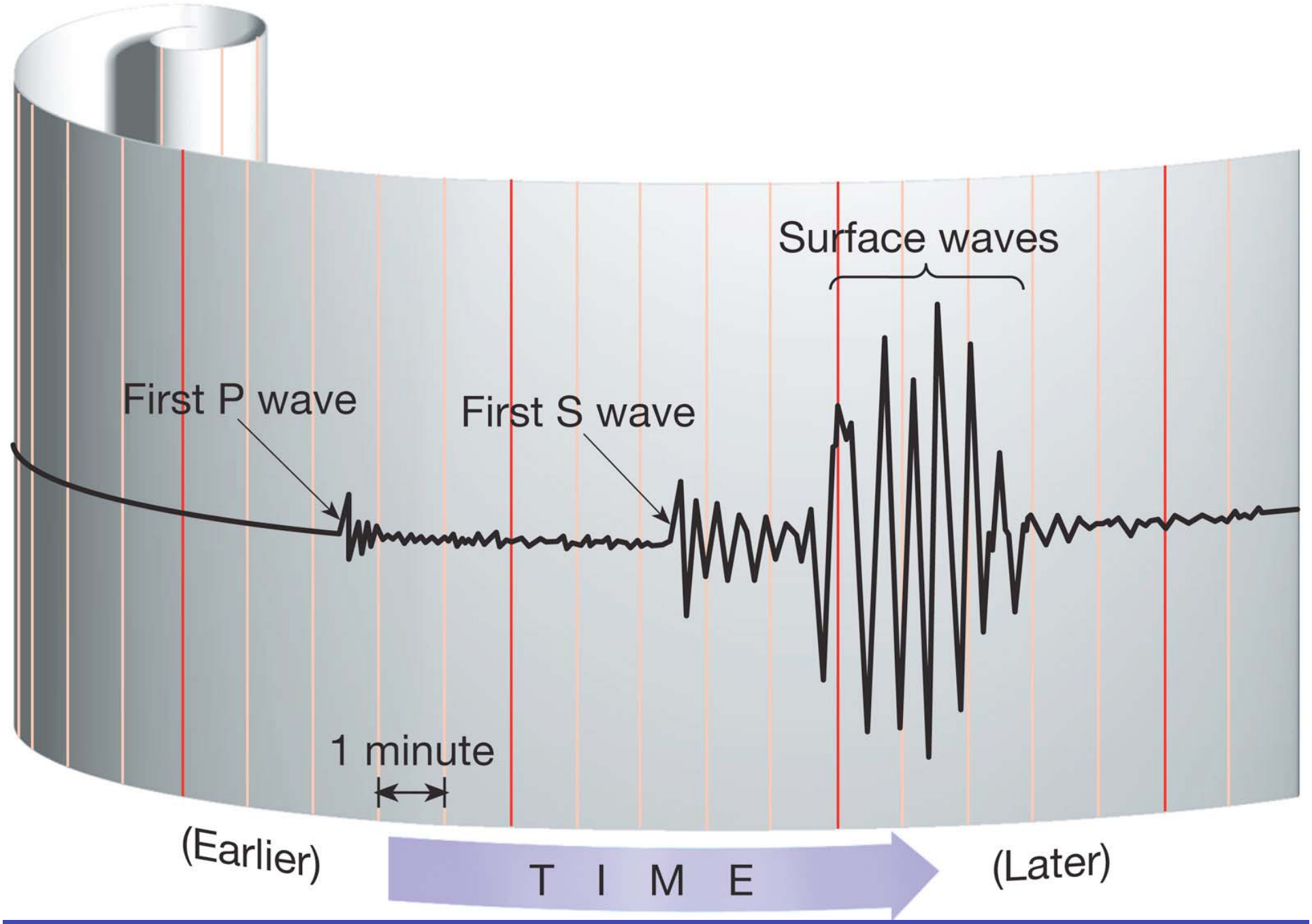


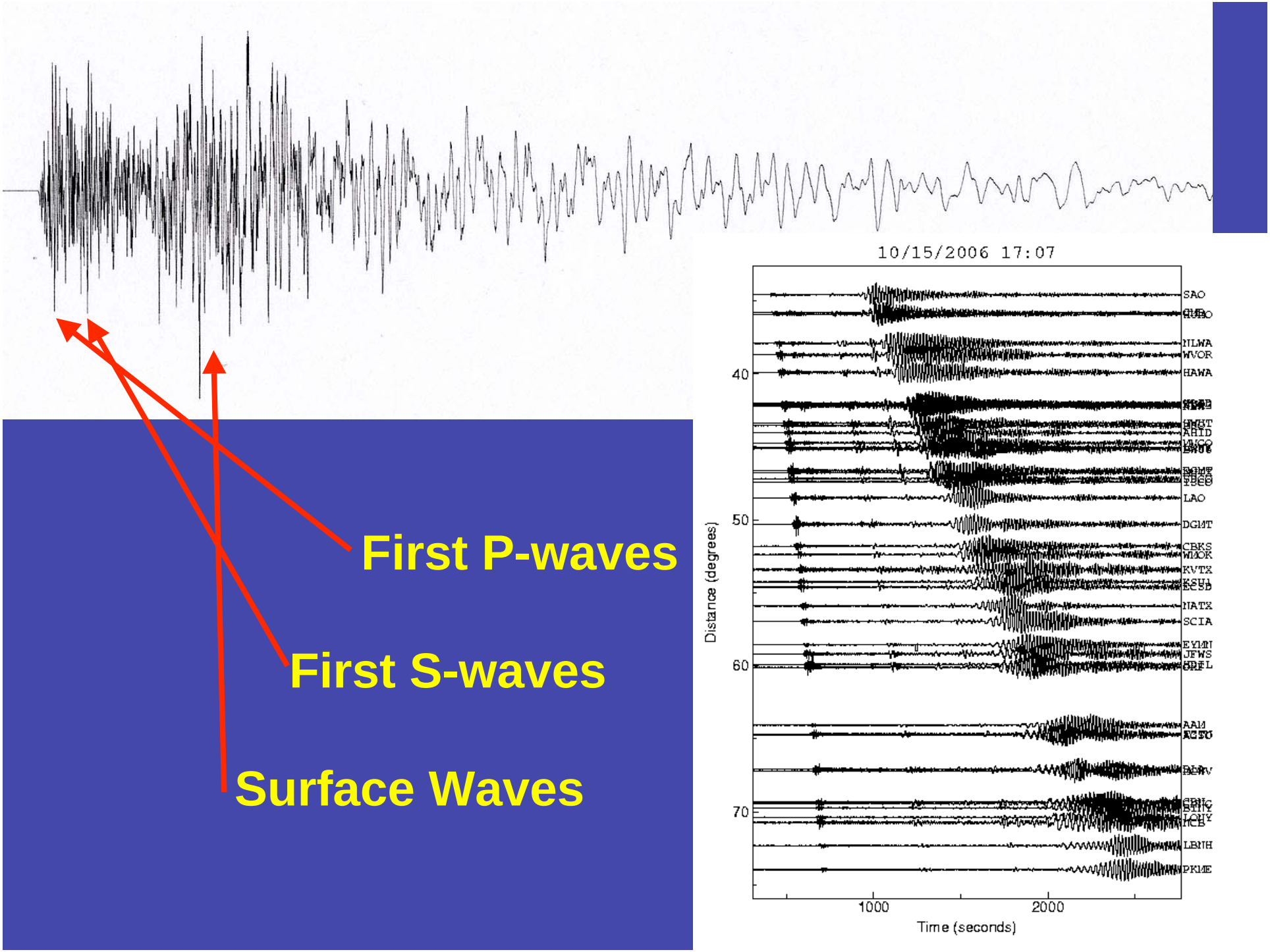
D. S waves traveling along the surface

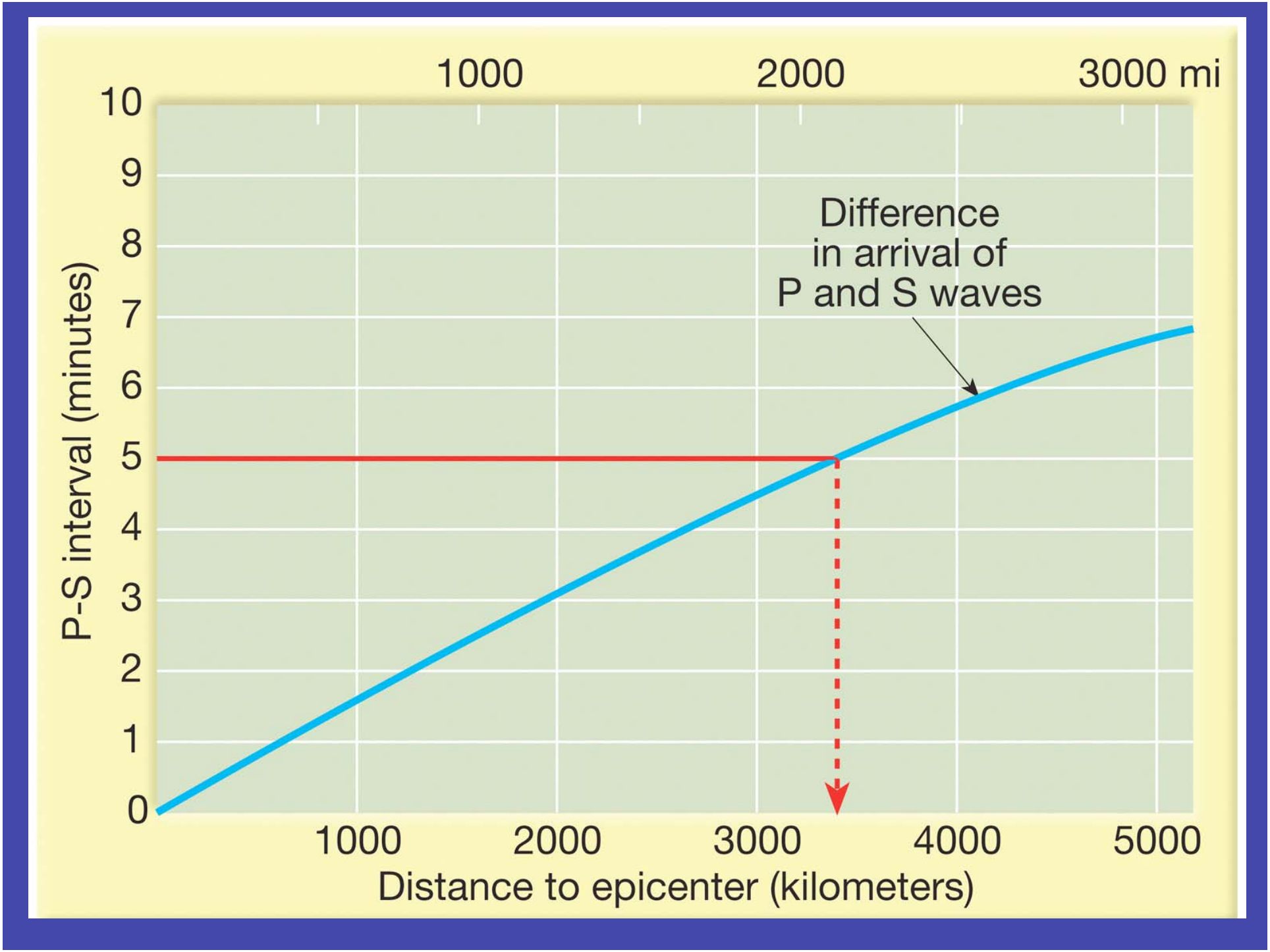
Damage from flexure (vertical motion)






Surface waves
First P wave
First S wave
1 minute
(Earlier)
T I M E
(Later)


First P-waves
First S-waves
Surface Waves
10/15/2006 17:07
Distance (degrees)
40
50
60
70
1000
2000
Time (seconds)
SAO
HAWA
LAO
SCIA


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

Table 14.3 Some notable earthquakes

Year	Location	Deaths (est.)	Magnitude†	Comments
1556	Shensi, China	830,000		Possibly the greatest natural disaster.
1755	Lisbon, Portugal	70,000		Tsunami damage extensive.
*1811–1812	New Madrid, Missouri	Few	7.9	Three major earthquakes.
*1886	Charleston, South Carolina	60		Greatest historical earthquake in the eastern United States.
*1906	San Francisco, California	1500	7.8	Fires caused extensive damage.
1908	Messina, Italy	120,000		
1923	Tokyo, Japan	143,000	7.9	Fire caused extensive destruction.
1960	Southern Chile	5700	9.5	Possibly the largest-magnitude earthquake ever recorded.
*1964	Alaska	131	9.2	Greatest North American earthquake ever recorded.
1970	Peru	66,000	7.8	Great rock avalanche.
*1971	San Fernando, California	65	6.5	Damage exceeded $1 billion.
1975	Liaoning Province, China	1328	7.5	First major earthquake to be predicted.
1976	Tangshan, China	240,000	7.6	Not predicted.
1985	Mexico City	9500	8.1	Major damage occurred 400 km from epicenter.
1988	Armenia	25,000	6.9	Poor construction practices.
*1989	Loma Prieta	62	6.9	Damages exceeded $6 billion.
1990	Iran	50,000	7.3	Landslides and poor construction practices caused great damage.
1993	Latur, India	10,000	6.4	Located in stable continental interior.
*1994	Northridge, California	57	6.7	Damages in excess of $40 billion.
1995	Kobe, Japan	5472	6.9	Damage estimated to exceed $100 billion.
1999	Izmit, Turkey	17,127	7.4	Nearly 44,000 injured and more than 250,000 displaced.
1999	Chi-Chi, Taiwan	2300	7.6	Severe destruction; 8700 injuries.
2001	El Salvador	1000	7.6	Triggered many landslides.
2001	Bhuj, India	20,000	7.9	1 million or more homeless.
2003	Bam, Iran	41,000	6.6	Ancient city with poor construction.
2004	Indian Ocean	200,000	9.0	Devastating tsunami damage.

*U.S. earthquakes.

†Widely differing magnitudes have been estimated for some of these earthquakes. When available, moment magnitudes are used.

Source: U.S. Geological Survey.

Shensi, China





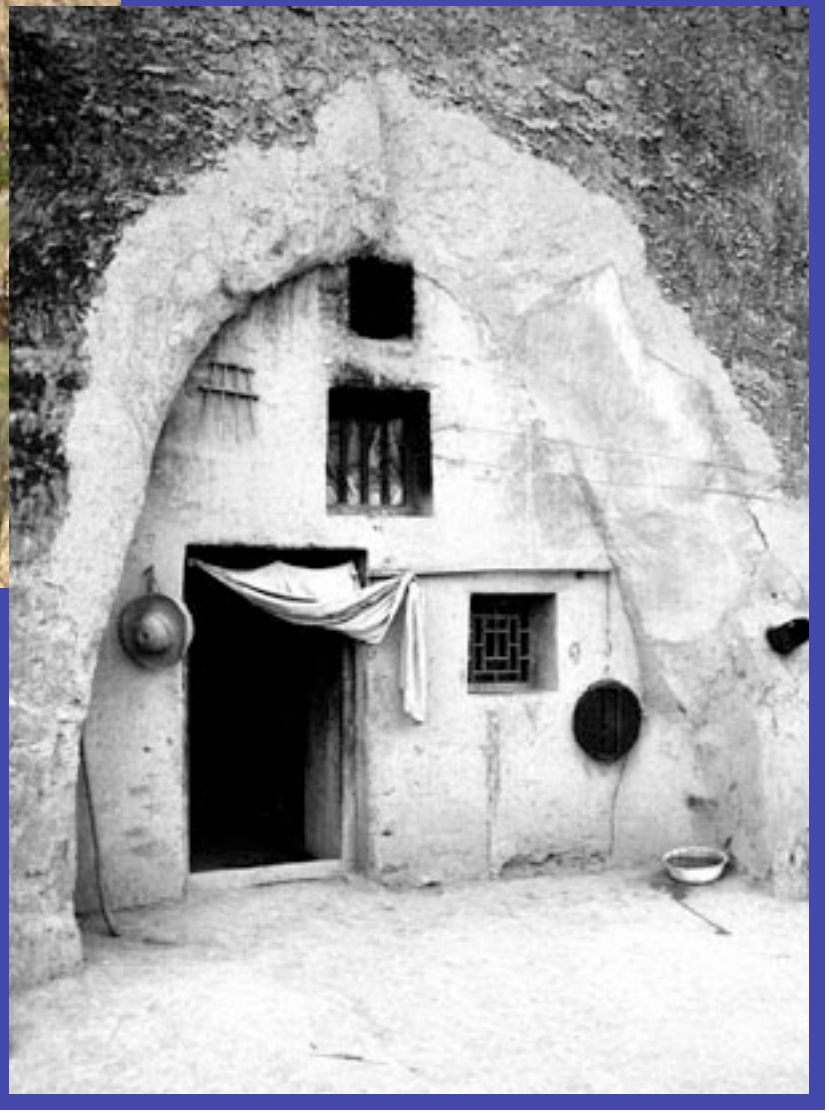
Loess – wind-transported glacial flour



Terracing in Shensi province



Shensi China Earthquake, 1556 830,000 killed



Yaodong – cave dwellings built into loess soils, collapsed



How do you measure the intensity of an earthquake?

How do you measure the intensity of an earthquake?

Table 14.1 Modified Mercalli Intensity Scale

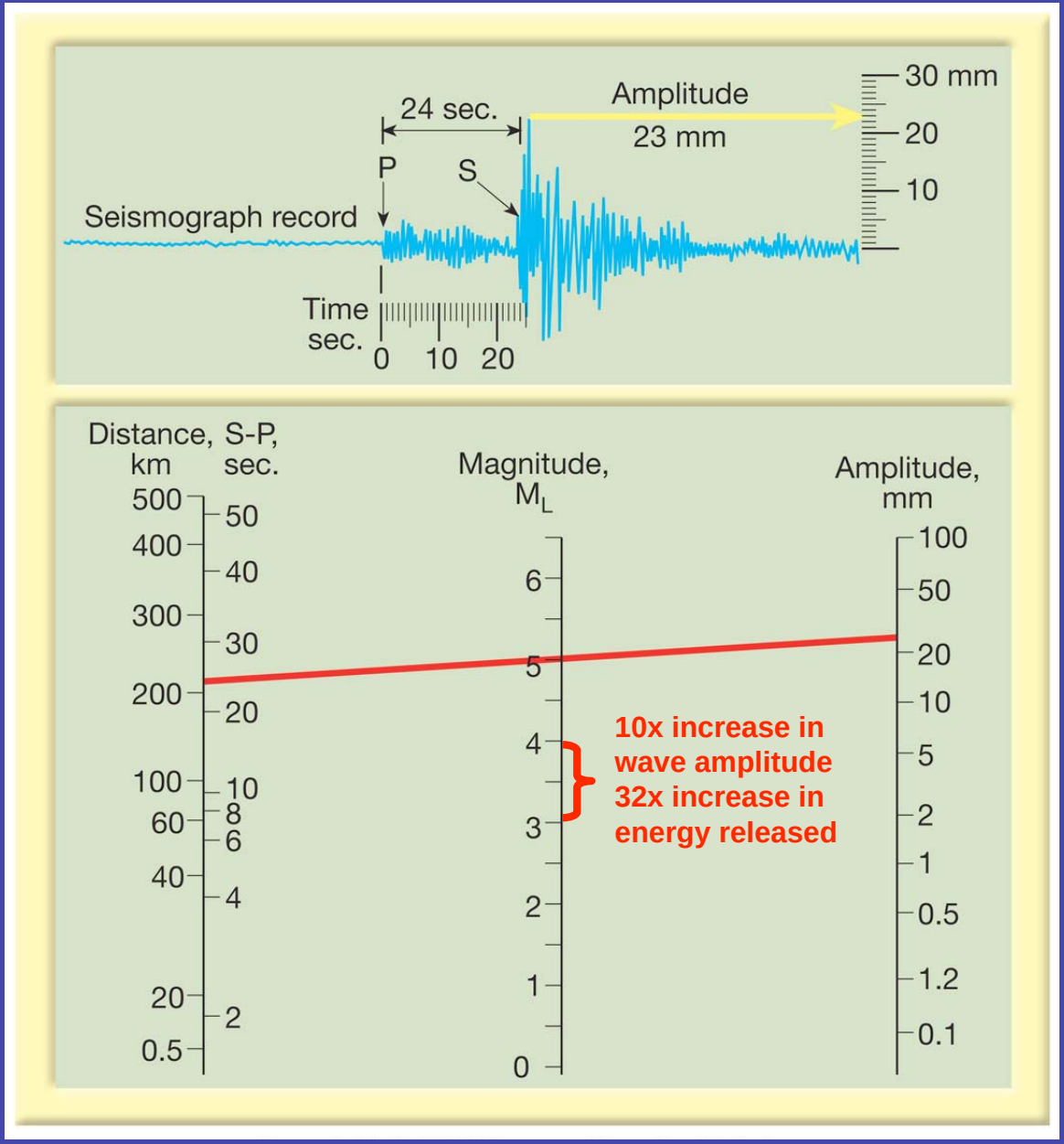
I	Not felt except by a very few under especially favorable circumstances.
II	Felt only by a few persons at rest, especially on upper floors of buildings.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake.
IV	During the day 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?

What happened to this building, Mexico City, 1985?



How do you measure the intensity of an earthquake?



Richter Magnitude Scale (1935)

Uses amplitudes of waves recorded on seismographs and distance from epicenter

Anchorage, Alaska 1964, Richter magnitude 8.3

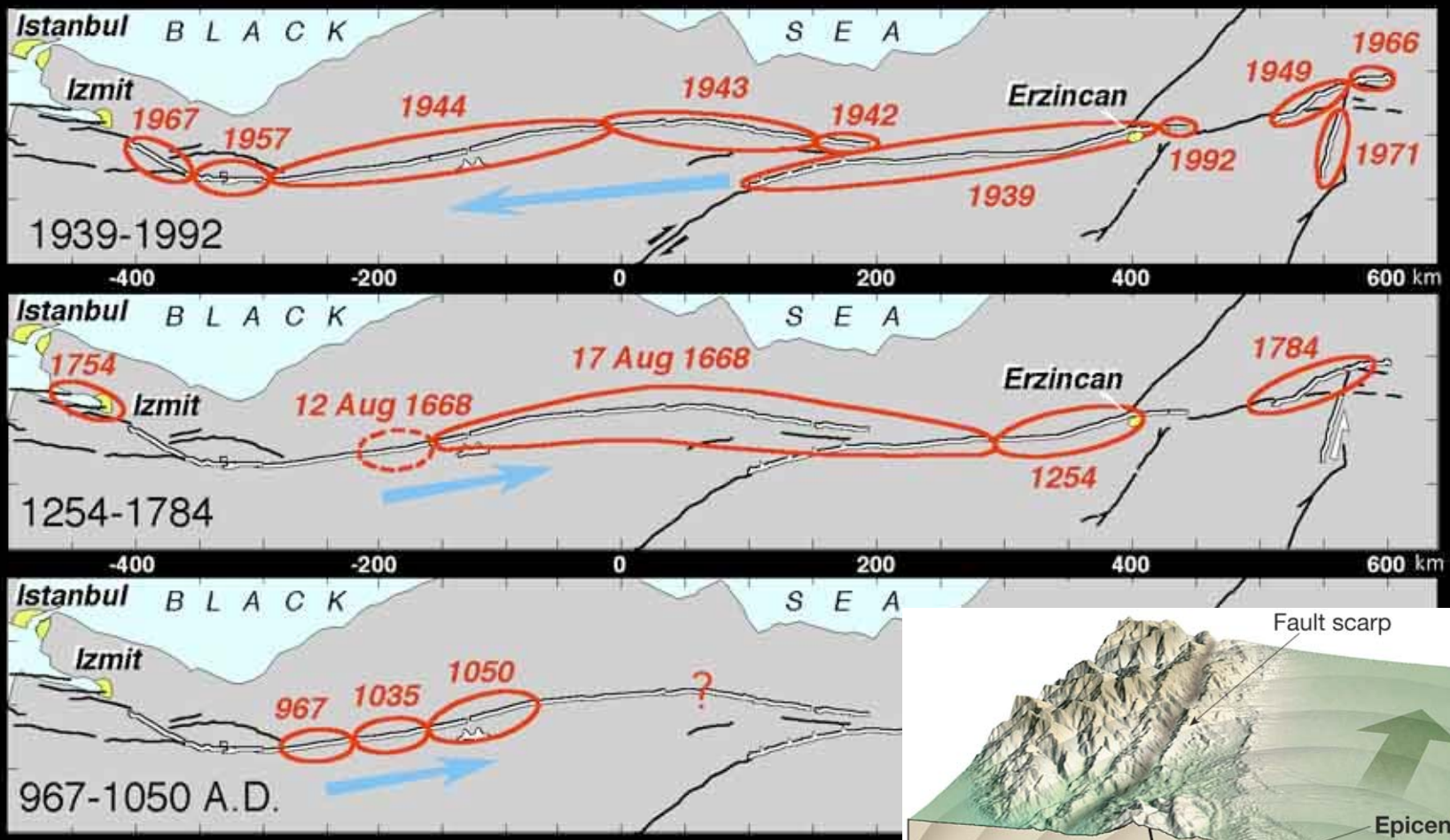


Differences in construction not important to magnitude calculation

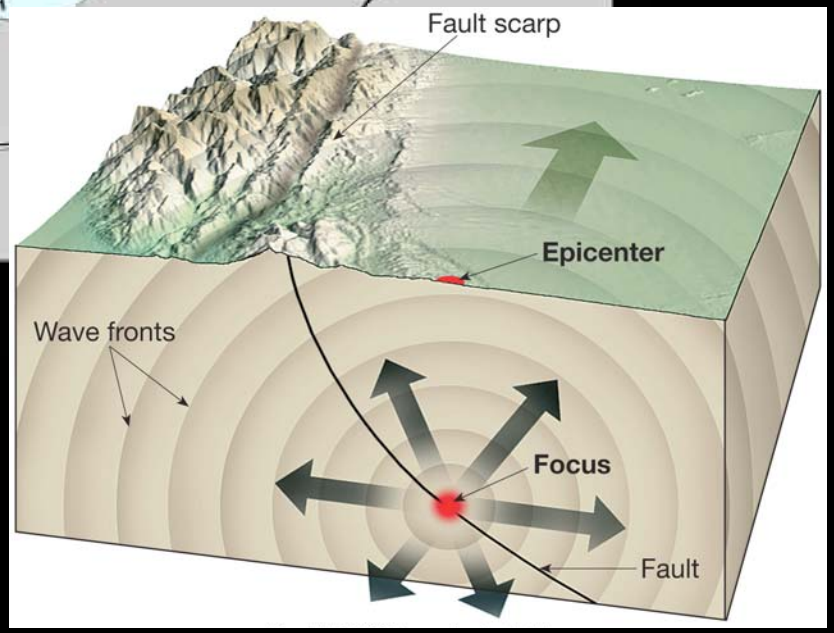


San Francisco 1906
Anchorage 1964
Both 8.3 on Richter Scale

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

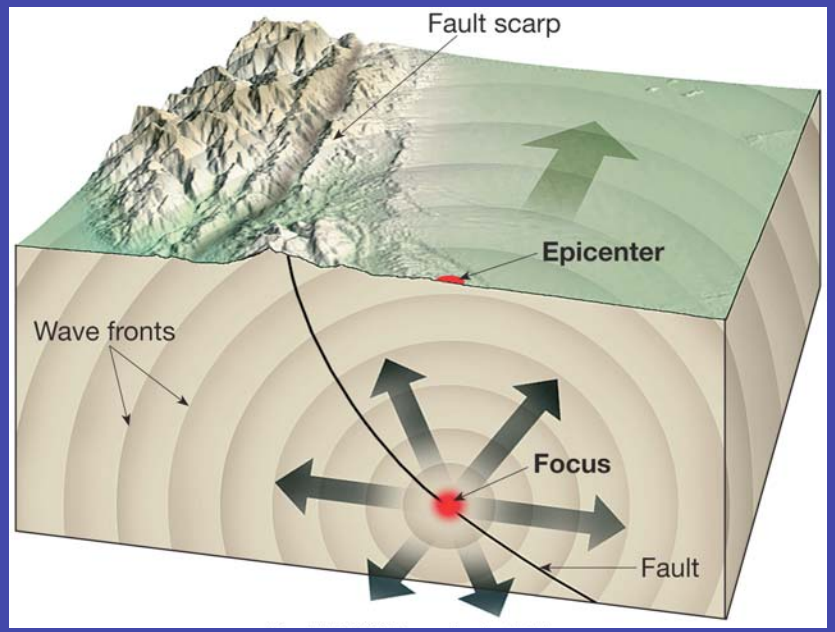
Moment magnitude (M_W) measures:

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

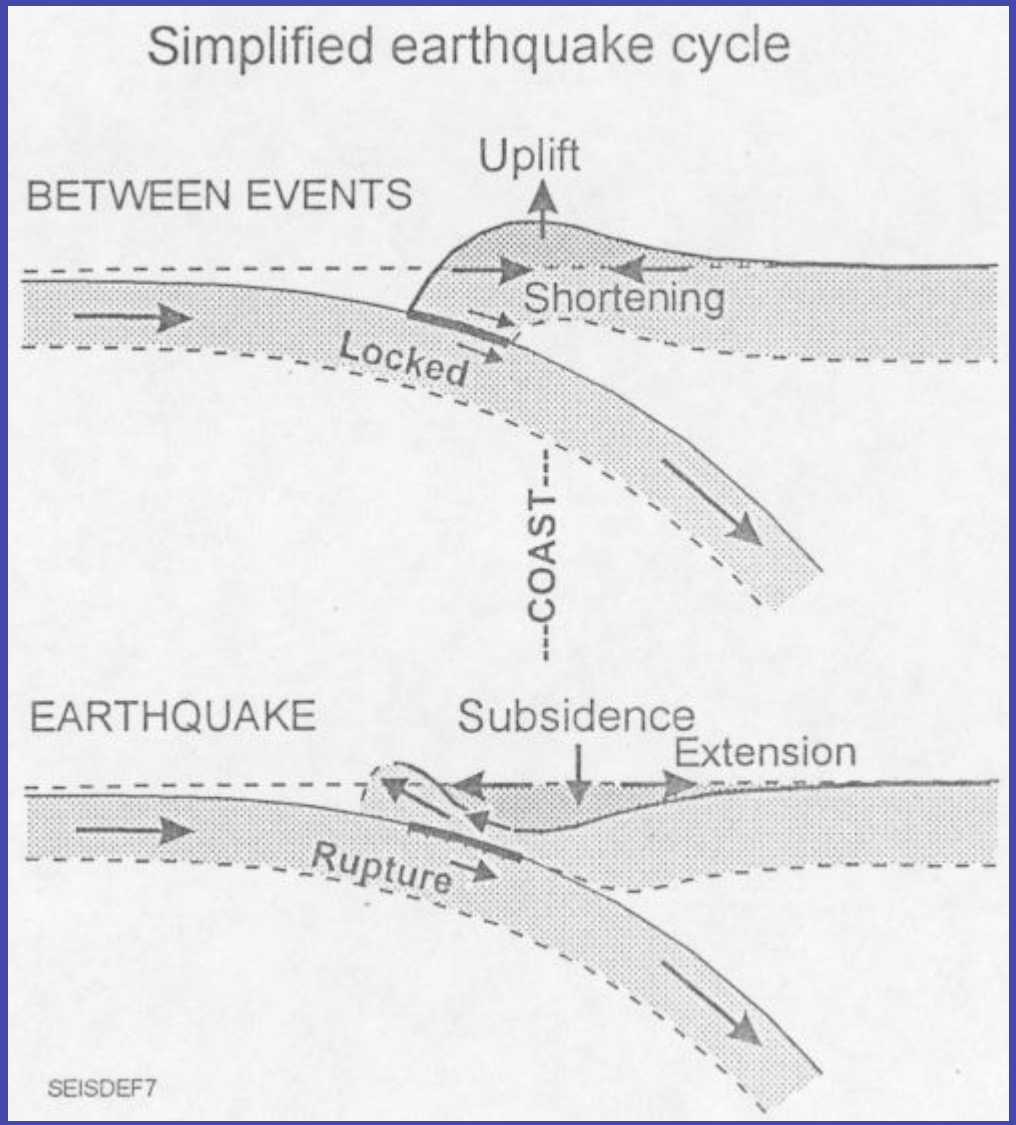
2) Richter Magnitude Scale (M_L)

can't distinguish largest earthquakes

3) Moment Magnitude Scale (M_W)

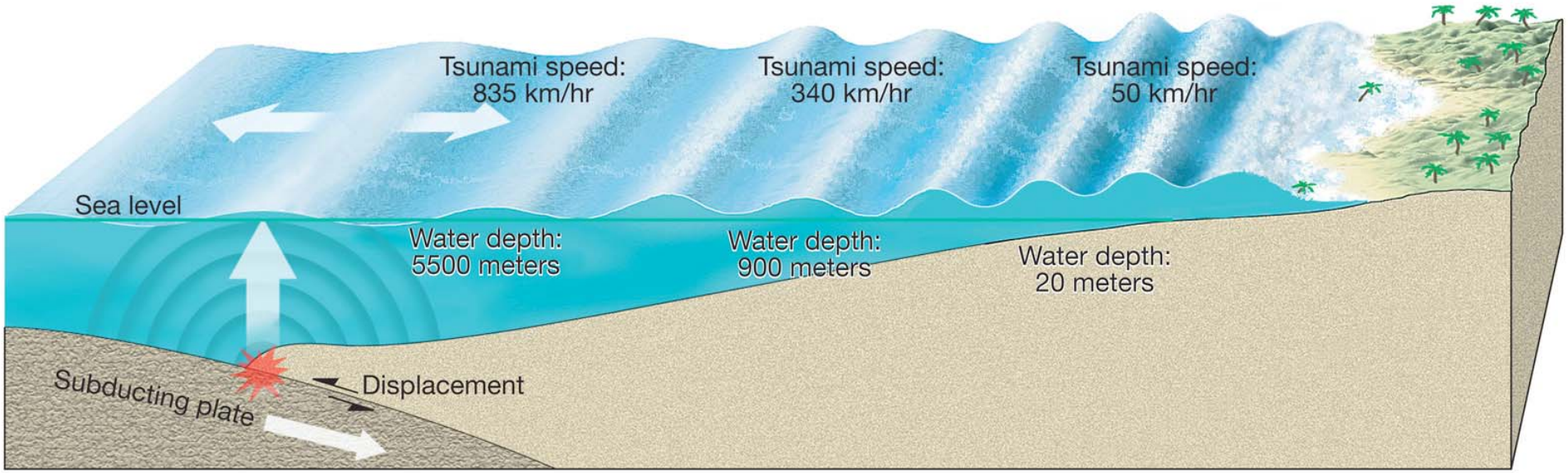
best tool for determining earthquake energy

What happens during a subduction earthquake?

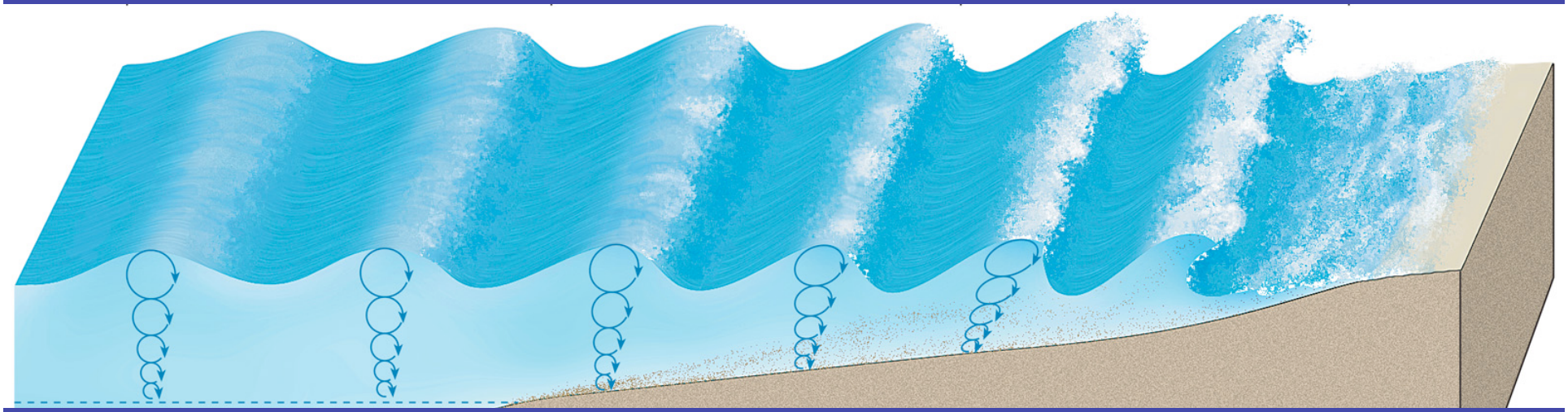


What triggers the tsunami wave?

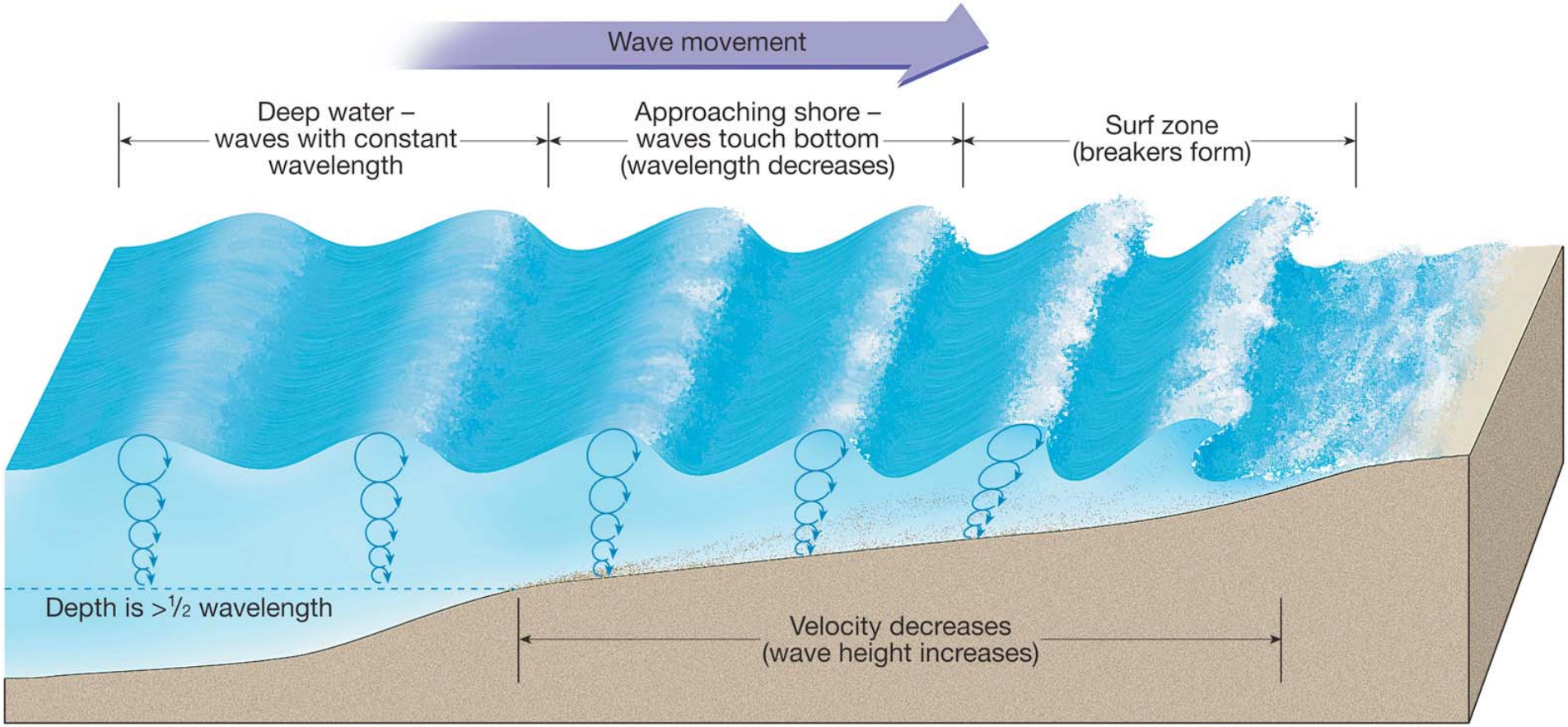
Shock wave propagates based on water depth



depth , wavelength , velocity , wave height



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




Jaws, Maui



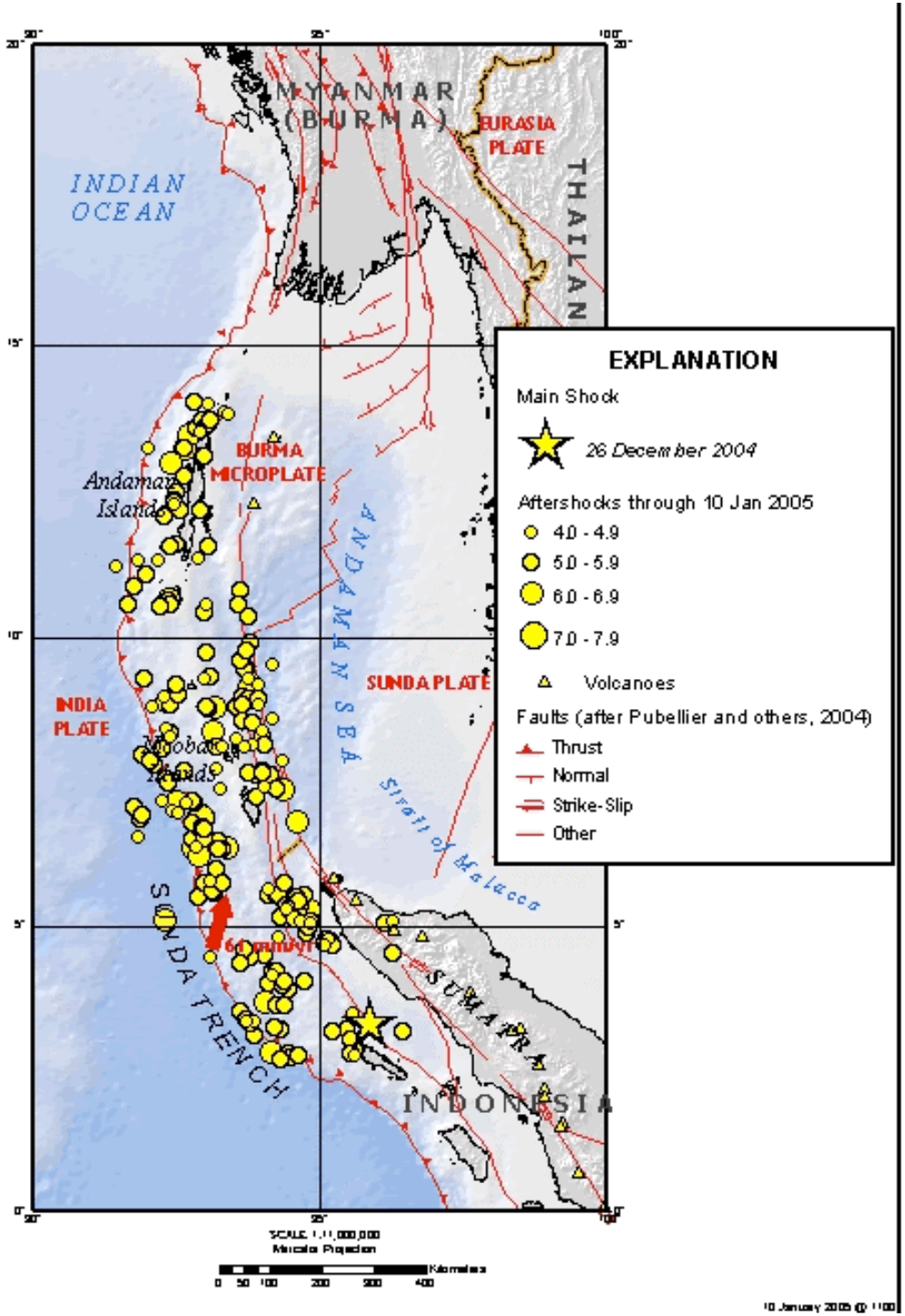
Indonesian Tsunami
December 2004
283,100 killed

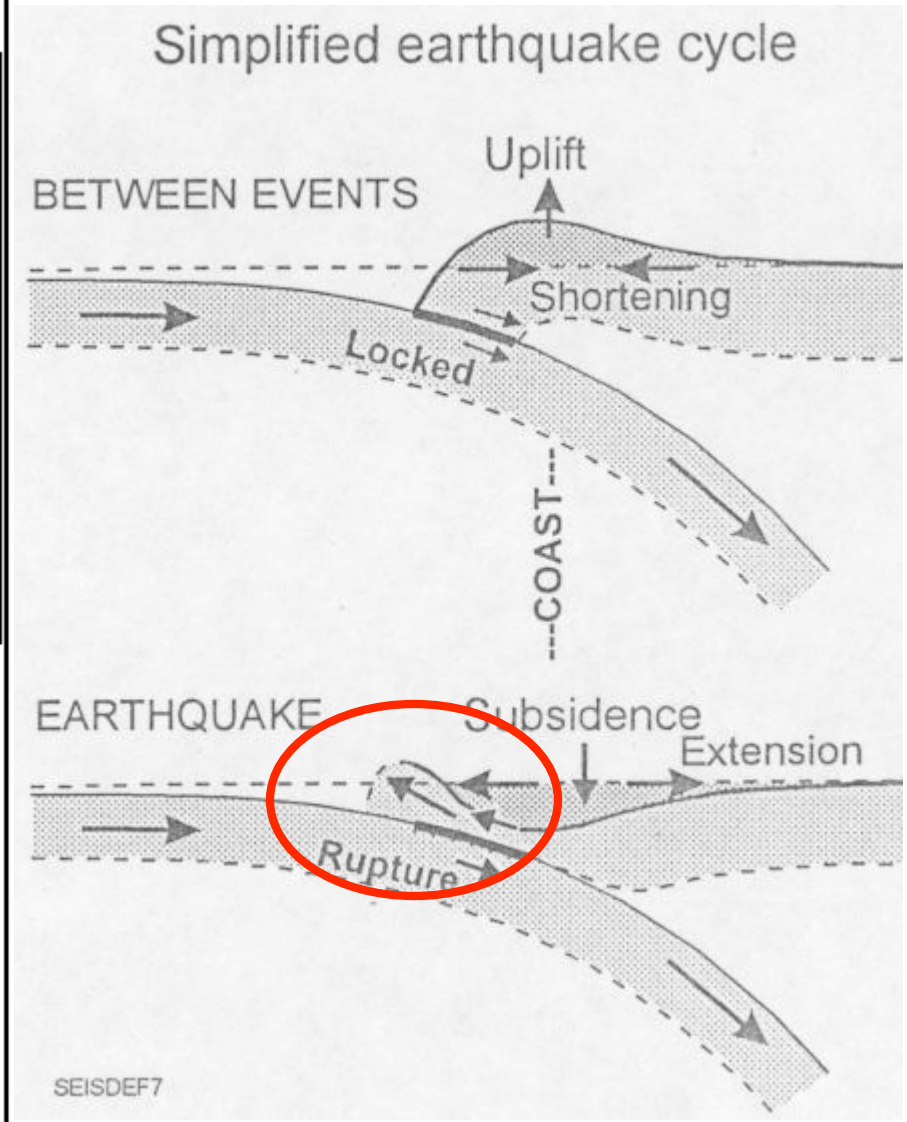


M_W 9.0 Earthquake

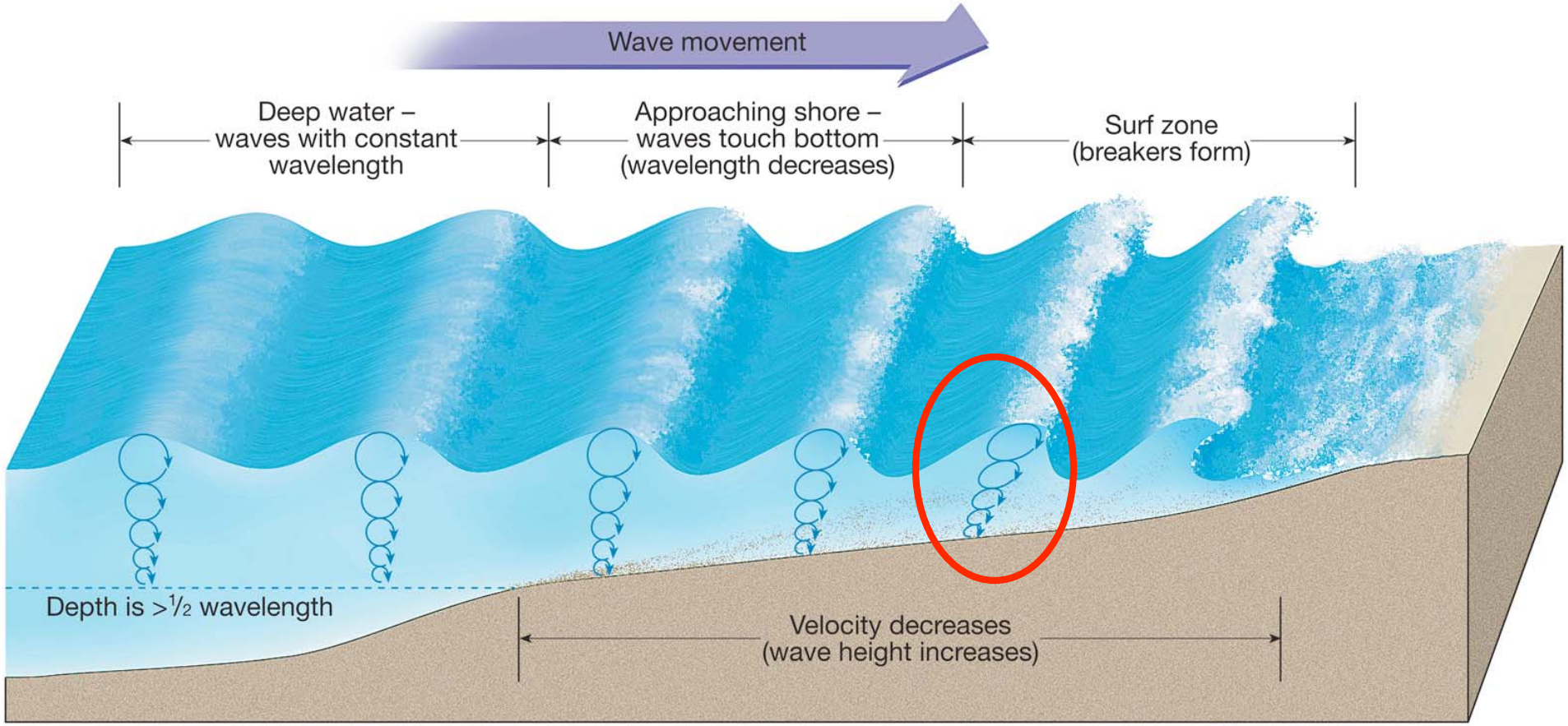

BANGLADESH
INDIA
MYANMAR
(BURMA)
THAILAND
SRI
LANKA
MALAYSIA
SOMALIA
MALDIVES
KENYA
INDONESIA
TANZANIA
SEYCHELLES
Indian
Ocean
MADAGASCAR
SOUTH
AFRICA

Strain release causes earthquake





Why are tsunami waves so dangerous?

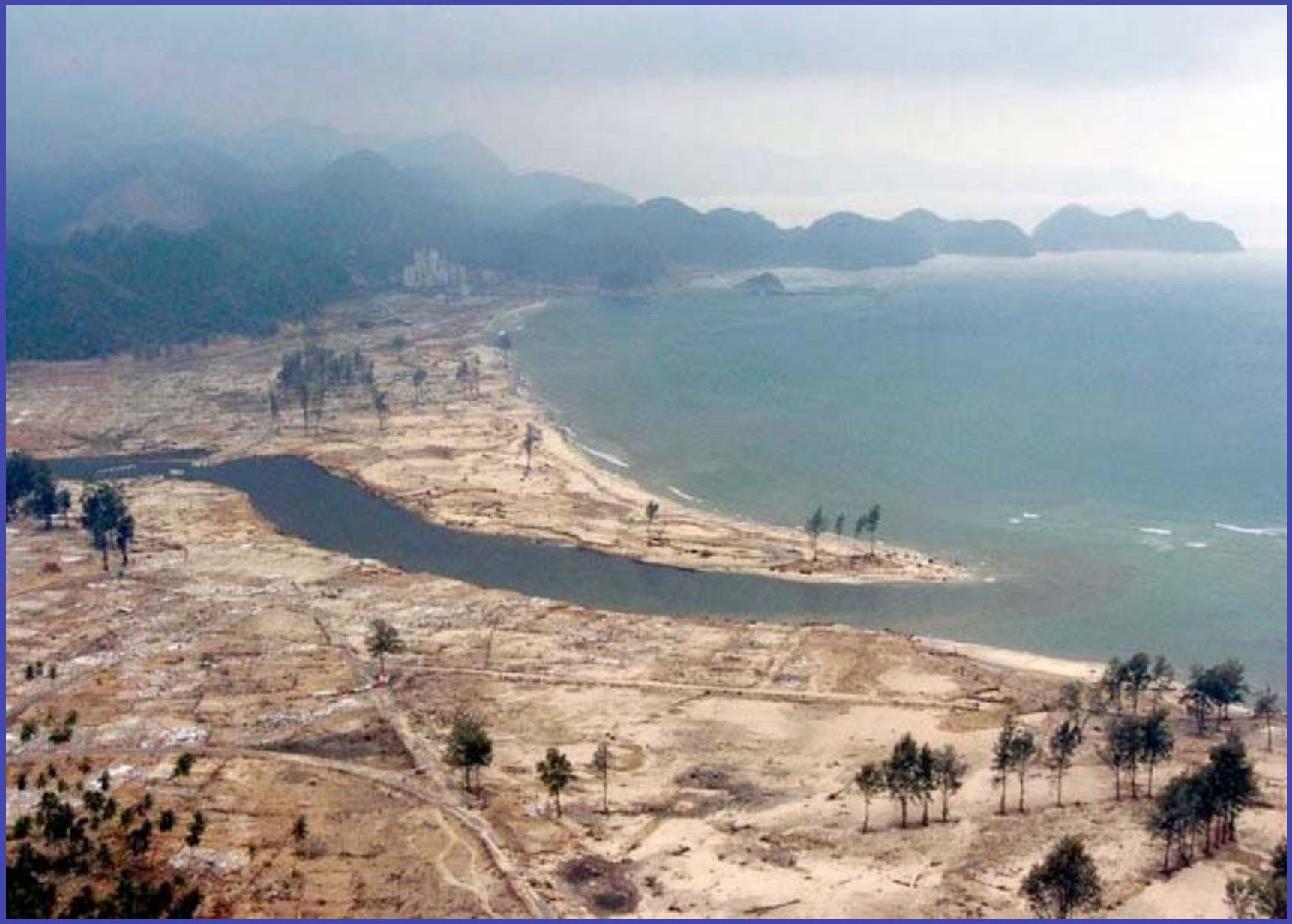


Drawdown precedes tsunami - Thailand





Phuket, Thailand

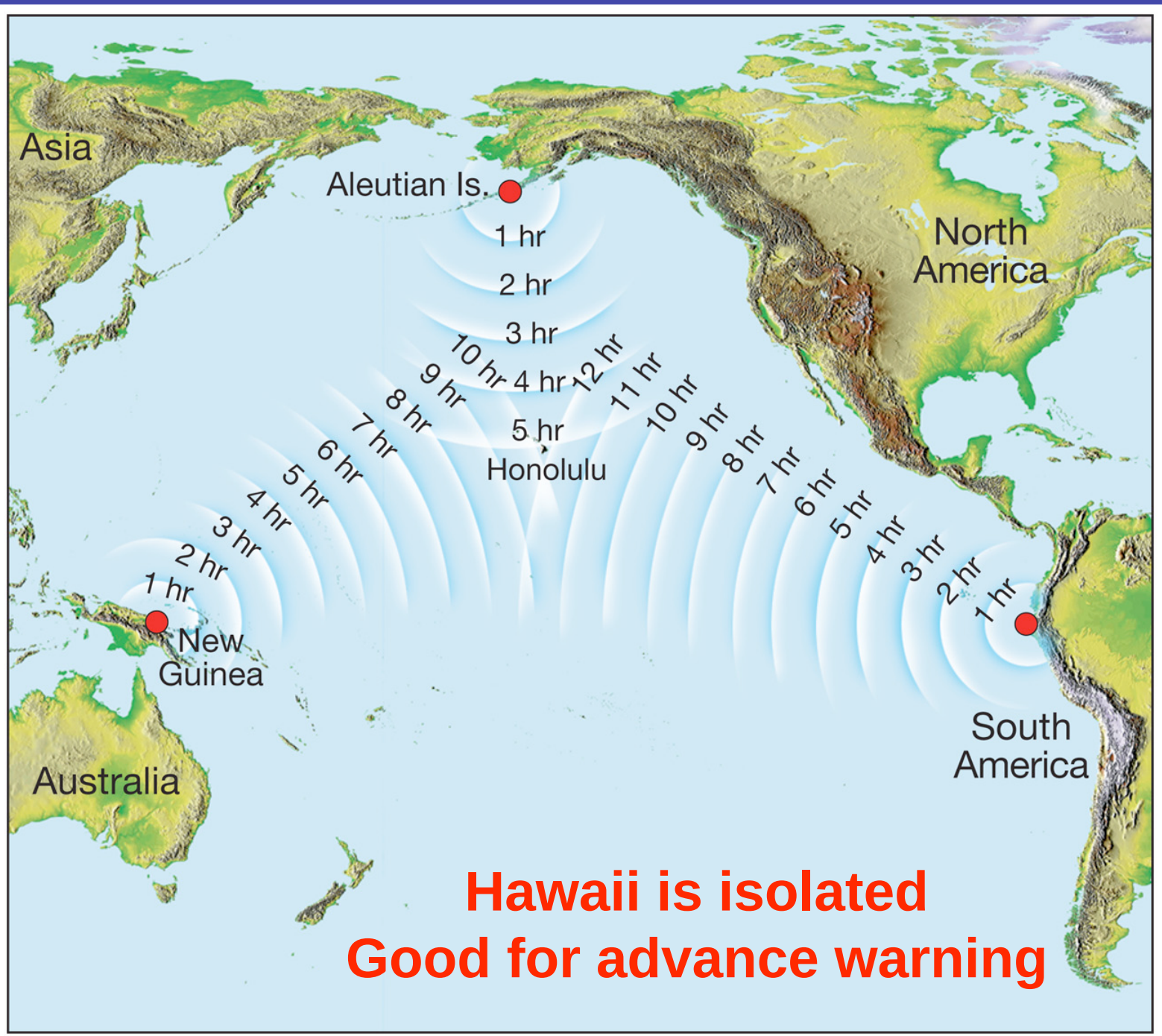


Sumatra, Indonesia

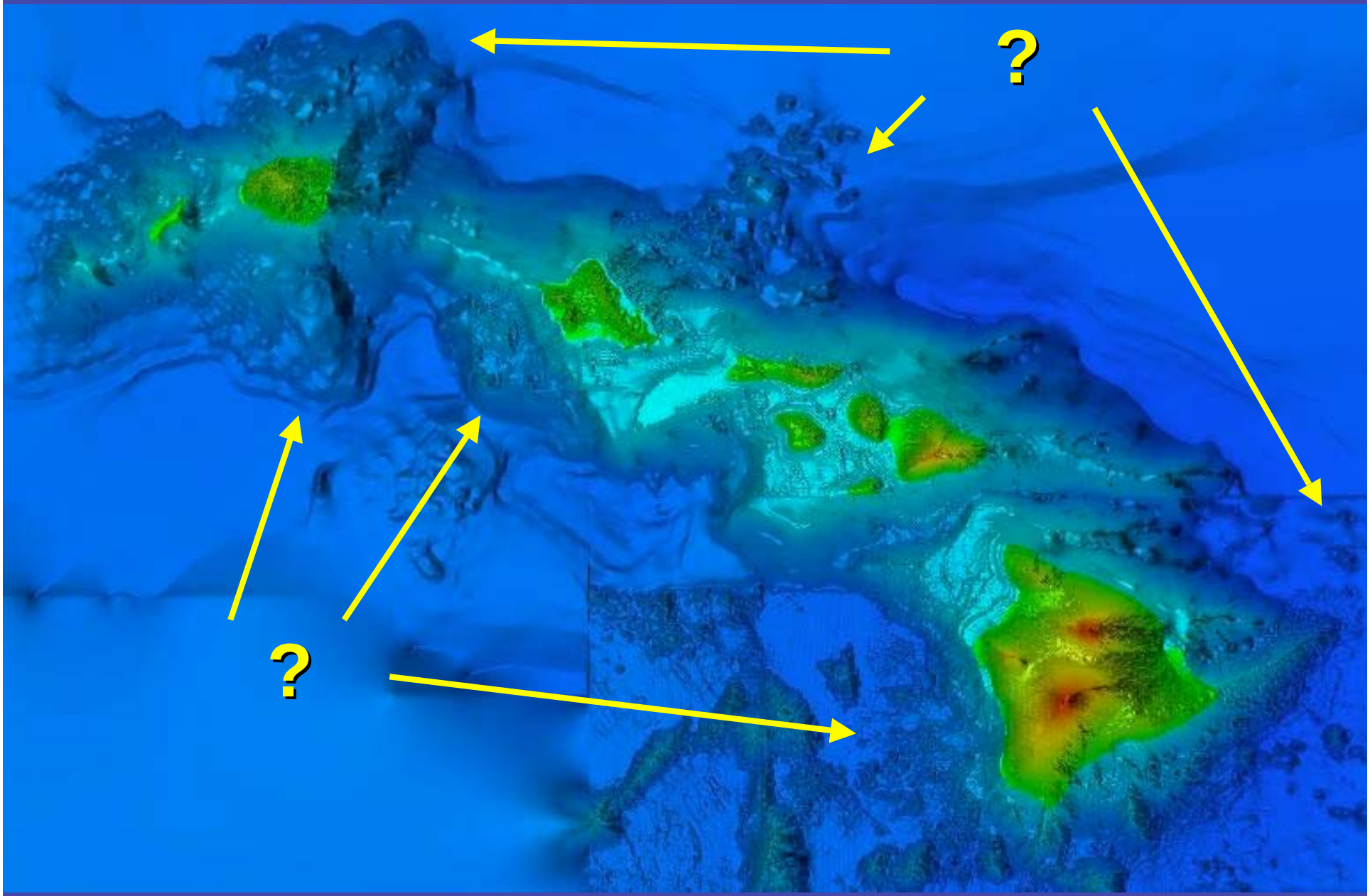


Aceh, Indonesia

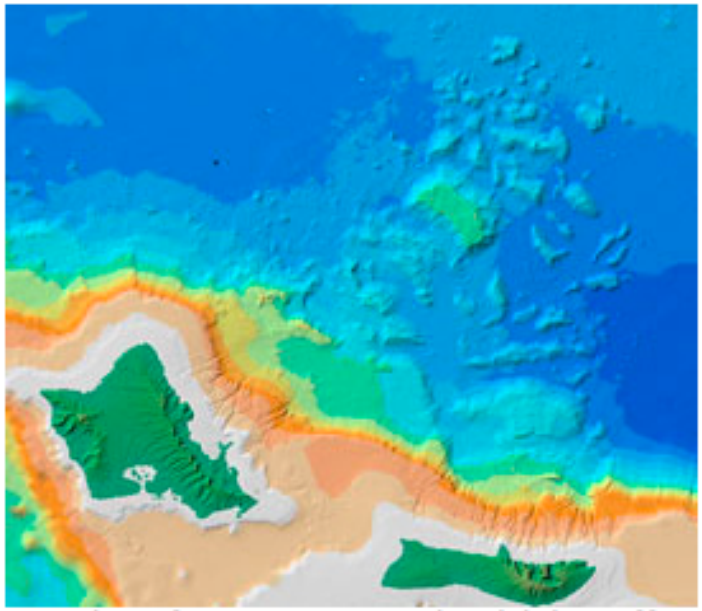



Asia
Aleutian Is.
North America
1 hr
2 hr
3 hr
4 hr
5 hr
Honolulu
6 hr
7 hr
8 hr
9 hr
10 hr
11 hr
12 hr
New Guinea
Australia
South America
Hawaii is isolated
Good for advance warning

What are the piles of debris on the seafloor from?



Hawaiian landslides



Debris from enormous landslides off Oahu and Molokai extends hundreds of kilometers

Map © 2001 MBARI



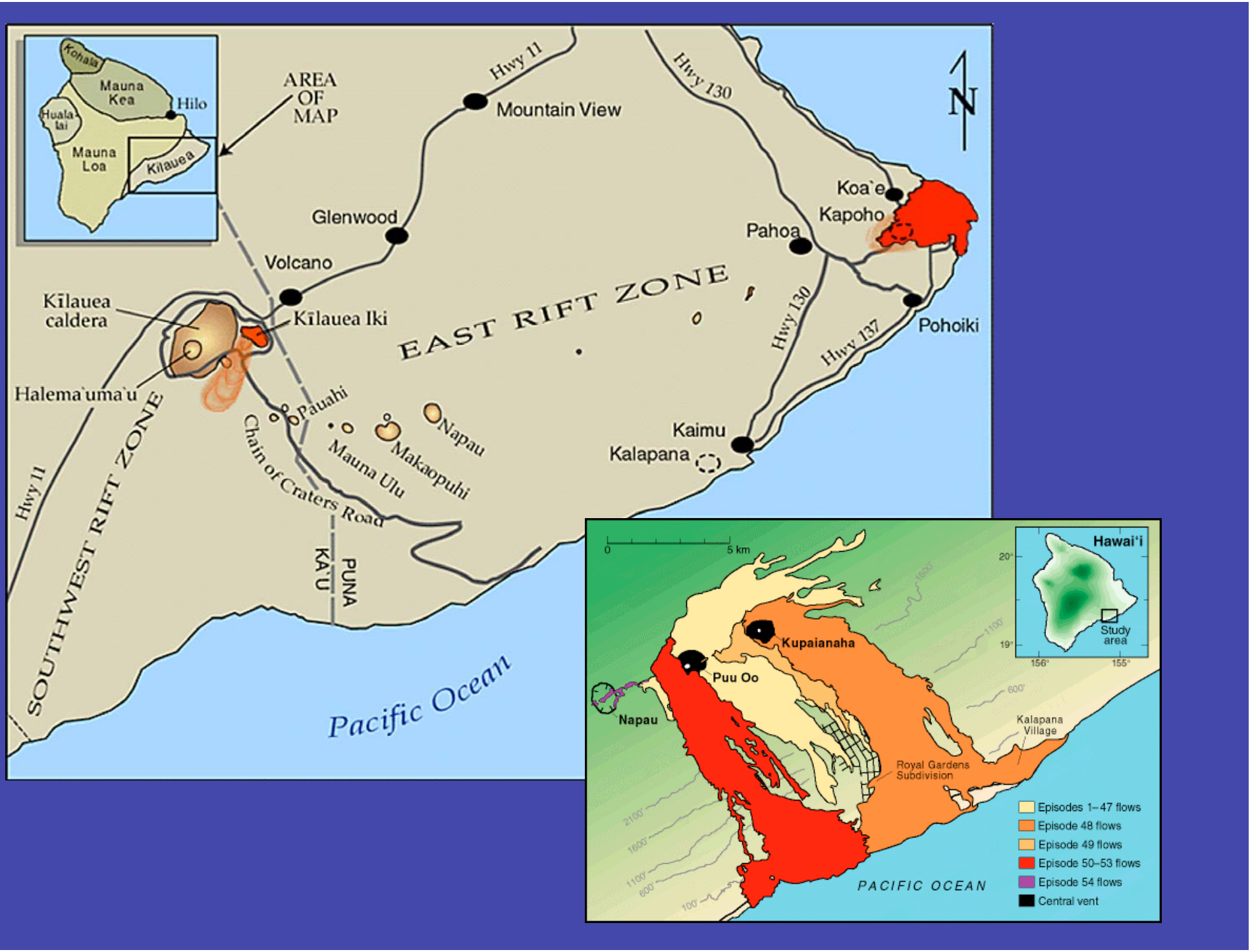
Larger version

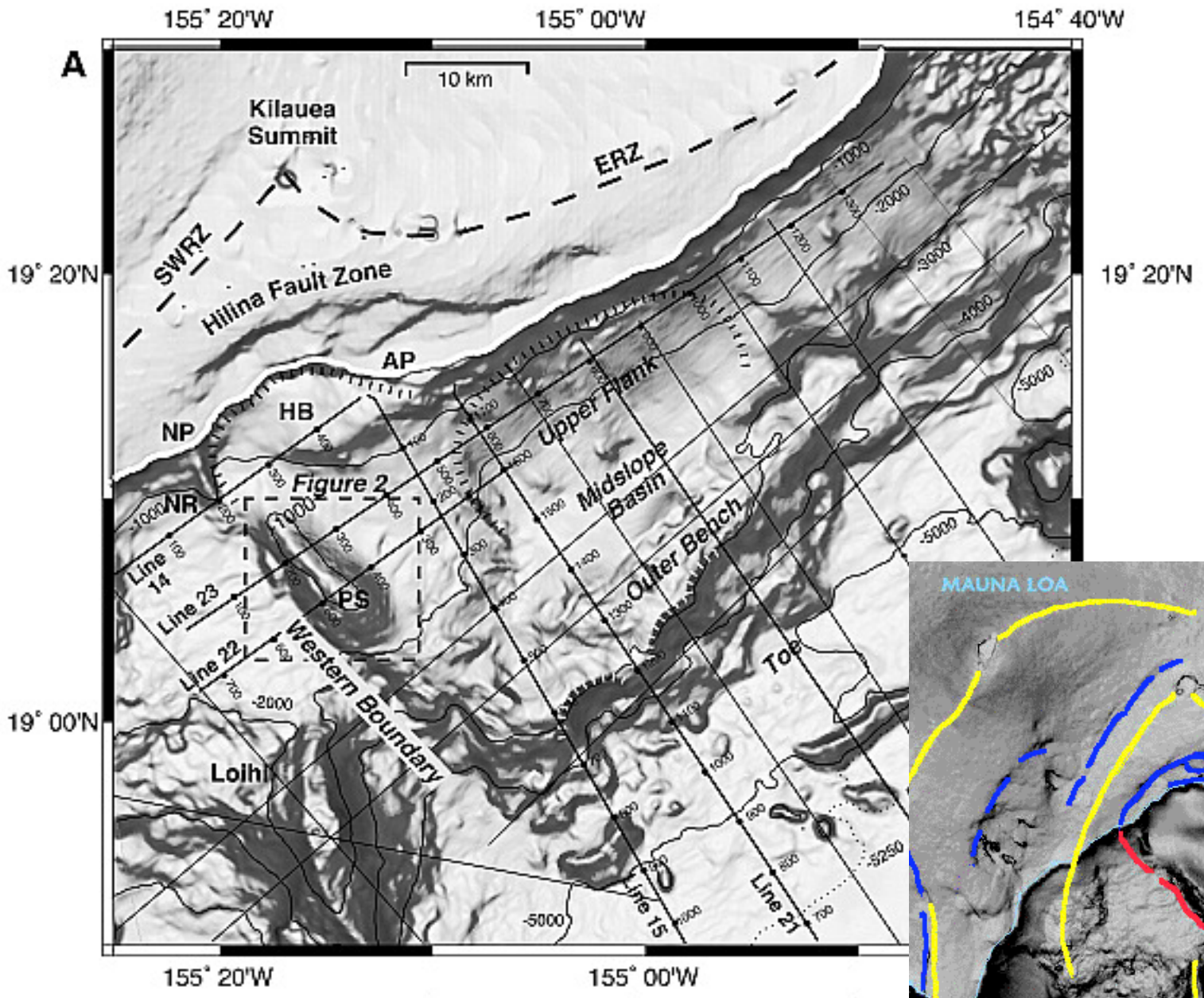
Pali above Kane'ohe Bay on Oahu: the slide-scarp of the Nuuanu landslide

Photo © 2004 J.B. Paduan

Hawaiian landslides have been catastrophic

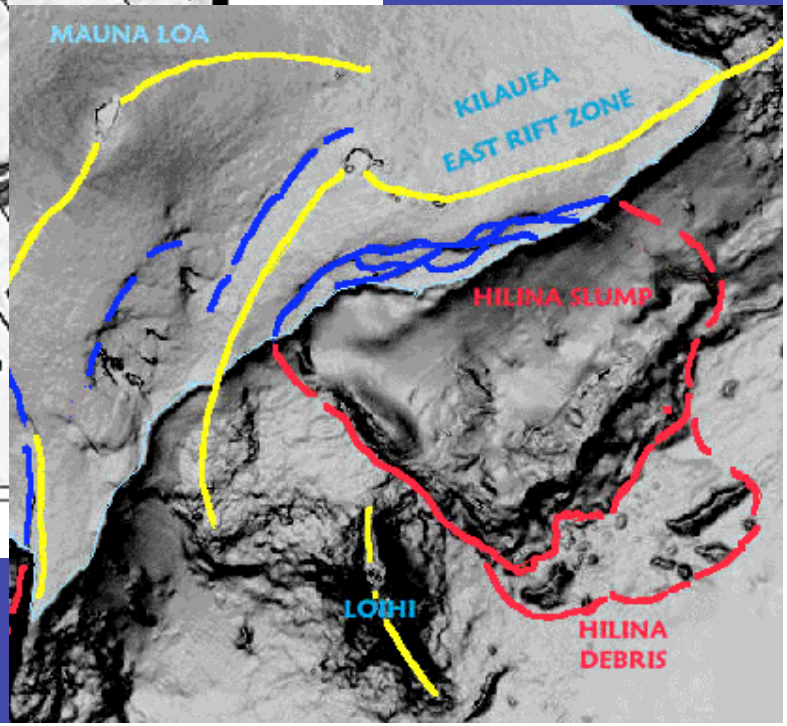
Volcanic activity and gentle erosion have not been the only forces to shape the Hawaiian islands. Landslide debris has now been mapped off of all the islands. Enormous amounts of material have traveled great distances, indicating that the slides were truly catastrophic. The Nuuanu and Wailau landslides, shown in the map, tore the volcanoes forming eastern Oahu and northern Molokai, respectively, in half, and deposited blocks large enough to have been given names as seamounts. Tsunamis generated during these slides would have been devastating around the entire Pacific Basin.


Kohala
Mauna Kea
Hilo
Hualalai
Mauna Loa
Kilauea
AREA OF MAP
Hwy 11
Mountain View
Hwy 130
N
Koa`e
Kapoho
Glenwood
Pahoa
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
Hwy 11
SOUTHWEST RIFT ZONE
KA`U
PUNA
Pacific Ocean
0
5 km
Hawai`i
Study area
Kupaianaha
Puu Oo
Napau
Kalapana Village
Royal Gardens Subdivision
PACIFIC OCEAN
Episodes 1–47 flows
Episode 48 flows
Episode 49 flows
Episode 50–53 flows
Episode 54 flows
Central vent



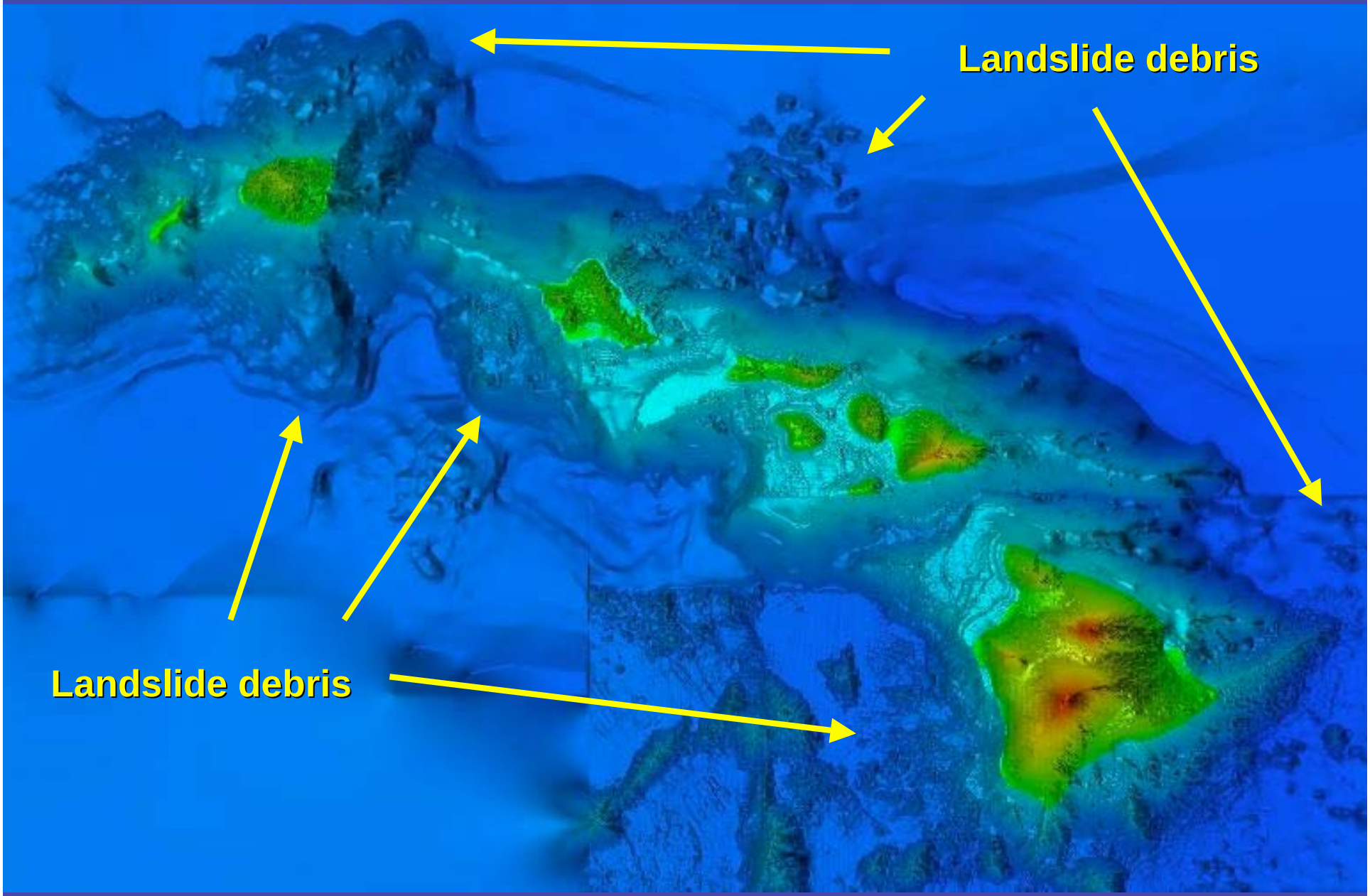
Slump rate = 4 inches/year

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!

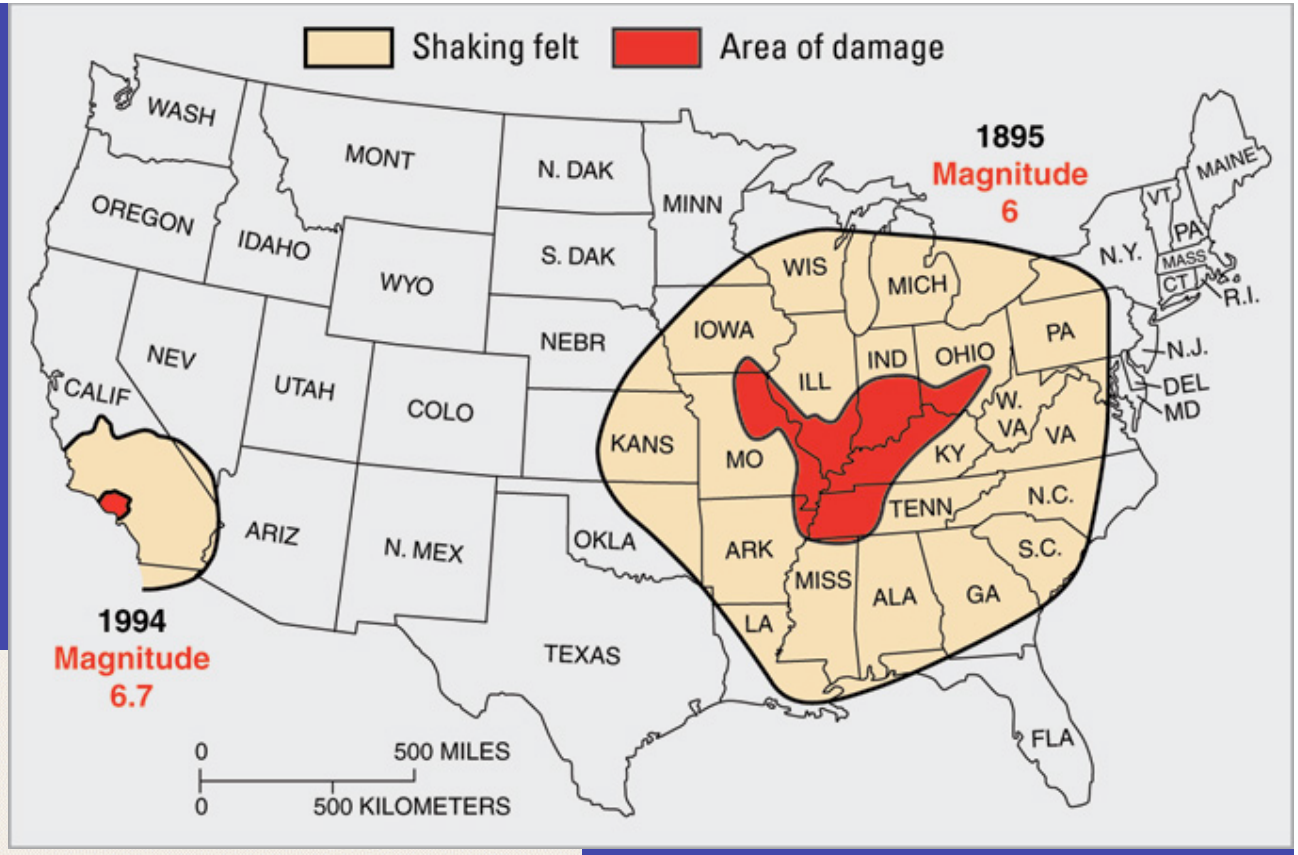


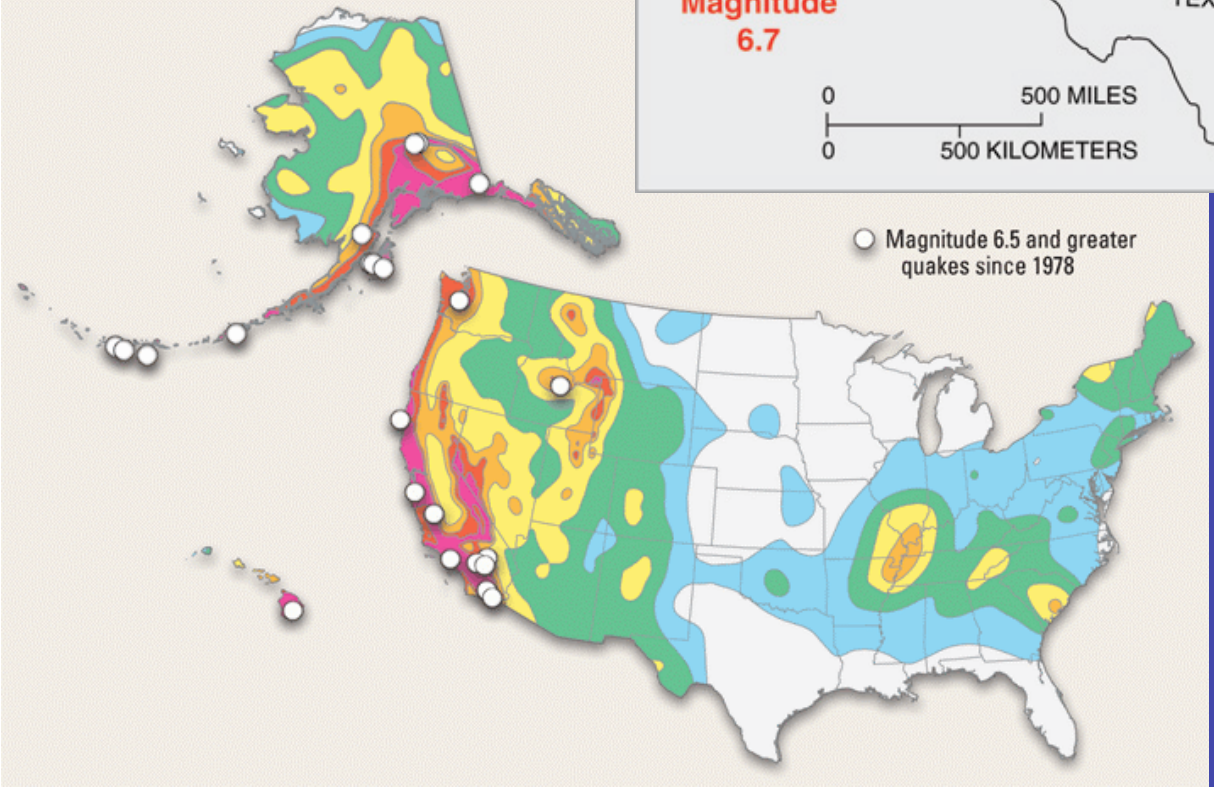
New Madrid Seismic Zone

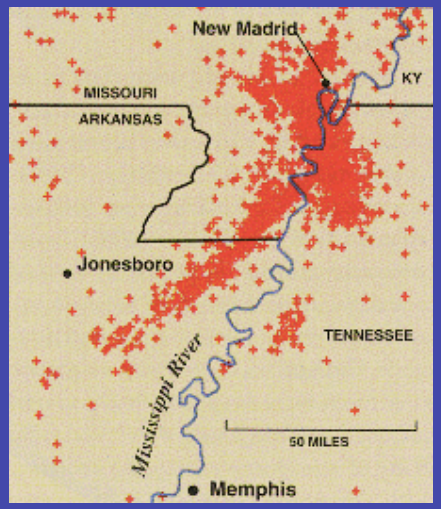
1) 12/16/1811 M 7.2-8.1

2) 1/23/1812 M 7.0-7.8

3) 2/4/1812 M 7.4-8.0

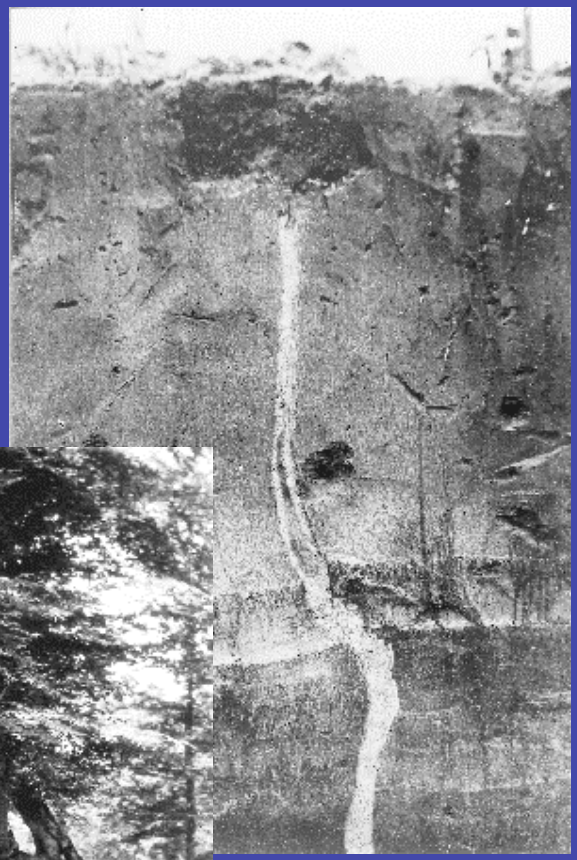






Quake Effects

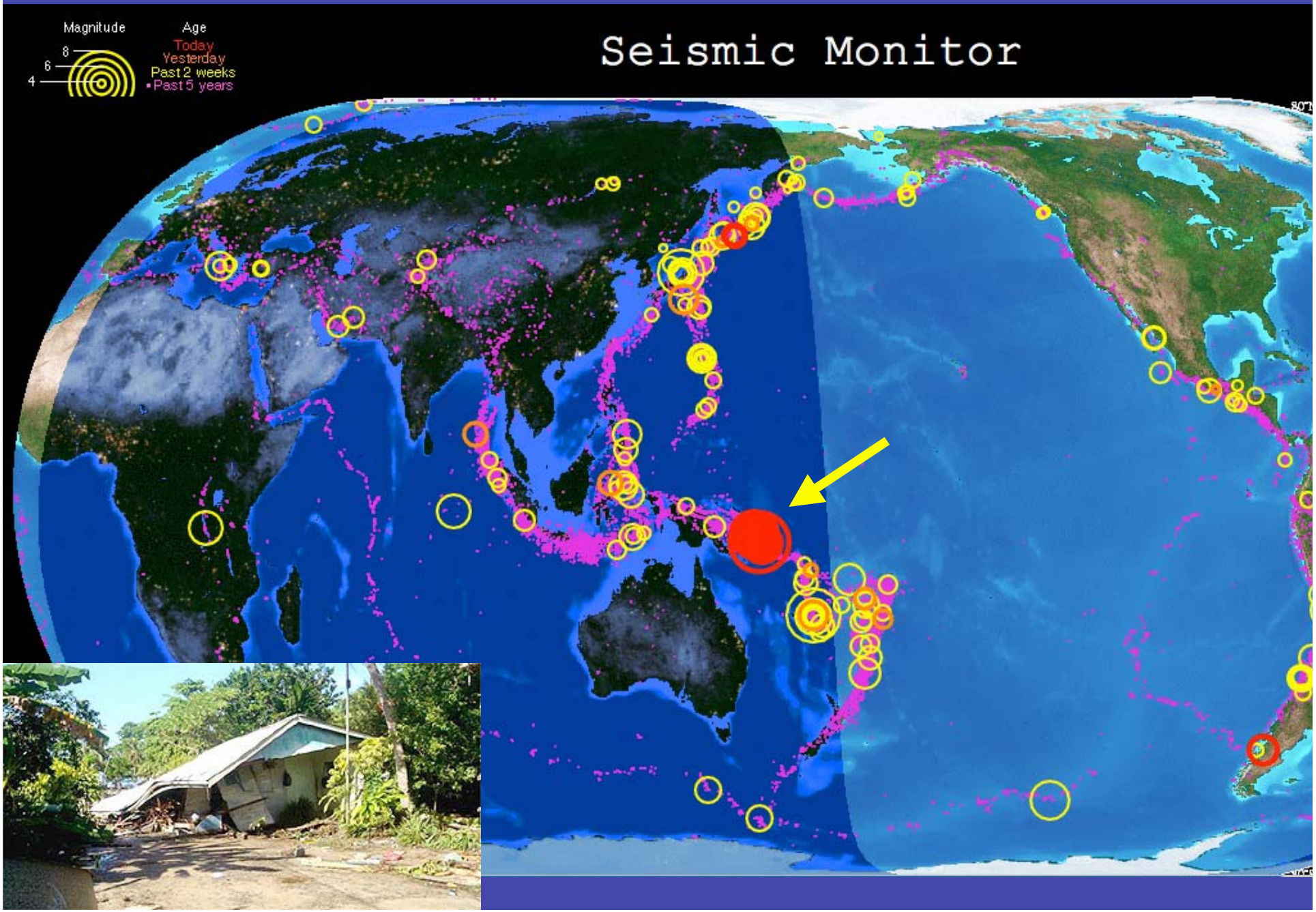








Magnitude 8.0 quake in Solomon Islands triggers tsunami



What's left?

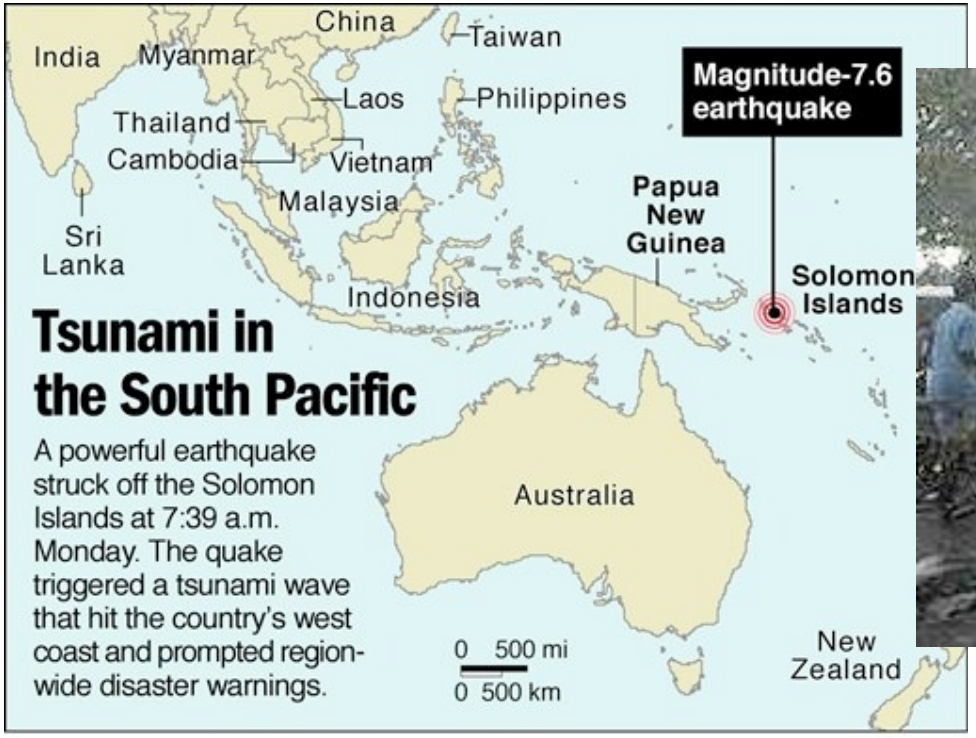
Exam III Review: Thursday April 5, 6-8pm, POST 723
Friday April 6 - HOLIDAY
Tuesday April 10 - Exam III

1) Extra credit opportunity - up to 5% of final course grade

2) 5 in-class activities / homeworks

3) Final exam (not cumulative)

Optional field trip to Kilo Moana research vessel
Tuesday May 1, 12-3pm, transportation provided



SOURCES: ESRI; U.S. Geological Survey

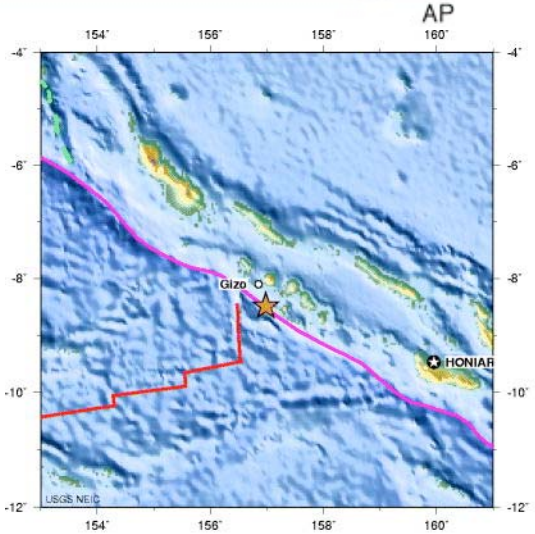
AP



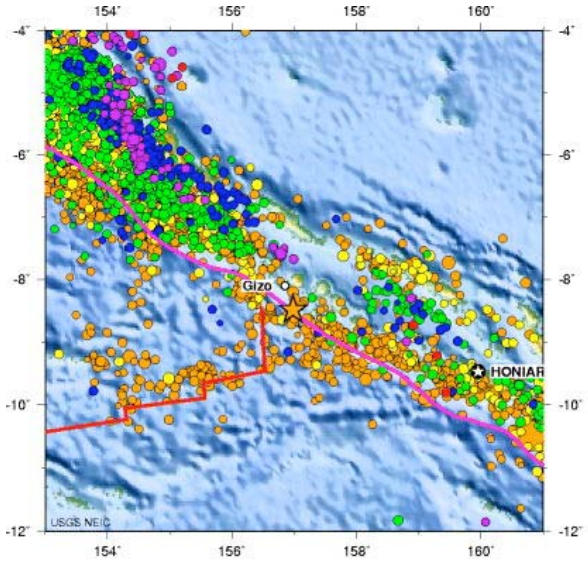
Magnitude 8.0

Subduction zone earthquake

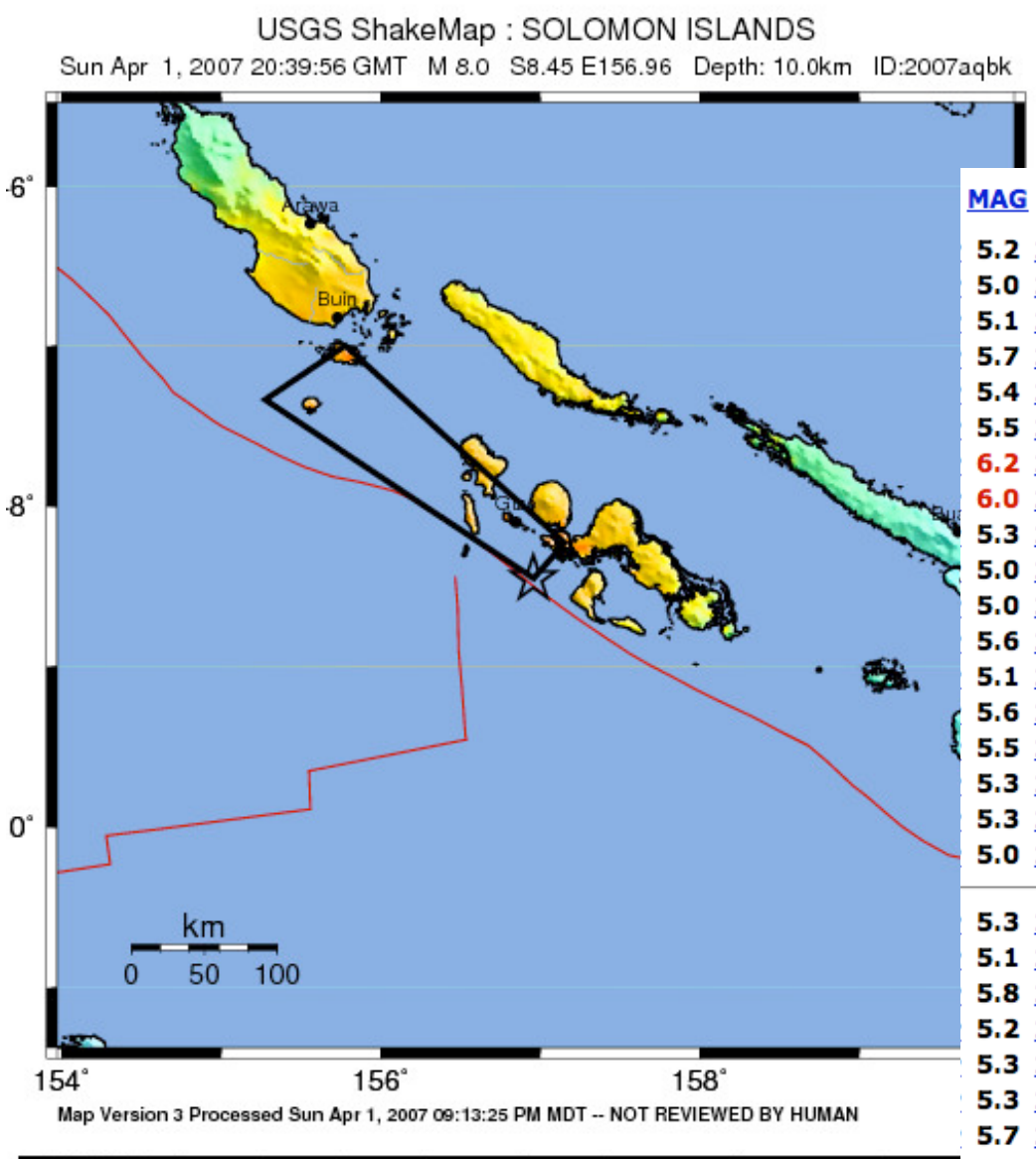
Pacific, Woodlark Australian plates



SOLOMON ISLANDS
2007 04 01 20:39:56 UTC 8.48S 156.98E Depth: 10.0 km, Magnitude: 8.0
Earthquake Location



SOLOMON ISLANDS
2007 04 01 20:39:56 UTC 8.48S 156.98E Depth: 10.0 km, Magnitude: 8.0
Seismicity 1990 to Present



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent
POTENTIAL DAMAGE Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy
POTENTIAL DAMAGE Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. 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
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*
ESTIMATED INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX

26 >5.0 magnitude shocks so far

MAG	UTC DATE-TIME y/m/d h:m:s	LAT deg	LON deg	DEPTH km	Region
5.2	2007/04/02 16:08:20	-8.622	157.778	10.0	SOLOMON ISLANDS
5.0	2007/04/02 15:40:05	-7.397	155.559	10.0	SOLOMON ISLANDS
5.1	2007/04/02 14:20:49	-8.656	157.692	10.0	SOLOMON ISLANDS
5.7	2007/04/02 13:53:07	-8.657	157.627	10.0	SOLOMON ISLANDS
5.4	2007/04/02 13:49:54	-7.811	156.518	10.0	SOLOMON ISLANDS
5.5	2007/04/02 12:35:26	-8.740	157.679	10.0	SOLOMON ISLANDS
6.2	2007/04/02 12:02:23	-8.539	157.548	10.0	SOLOMON ISLANDS
6.0	2007/04/02 10:49:15	-7.197	156.192	10.0	SOLOMON ISLANDS
5.3	2007/04/02 07:16:33	-7.465	156.145	10.0	SOLOMON ISLANDS
5.0	2007/04/02 06:58:53	44.375	149.025	52.3	KURIL ISLANDS
5.0	2007/04/02 06:52:04	44.434	149.169	10.0	KURIL ISLANDS
5.6	2007/04/02 05:33:36	-7.309	155.323	10.0	SOLOMON ISLANDS
5.1	2007/04/02 05:30:46	-7.176	155.663	10.0	SOLOMON ISLANDS
5.6	2007/04/02 04:11:40	-7.176	156.067	10.0	SOLOMON ISLANDS
5.5	2007/04/02 02:49:43	-45.219	-72.823	35.0	AISEN, CHILE
5.3	2007/04/02 01:36:16	-7.202	155.474	10.0	SOLOMON ISLANDS
5.3	2007/04/02 01:31:03	-8.196	157.108	10.0	SOLOMON ISLANDS
5.0	2007/04/02 00:10:56	-7.077	155.888	10.0	SOLOMON ISLANDS
5.3	2007/04/01 23:25:28	-7.346	156.143	10.0	SOLOMON ISLANDS
5.1	2007/04/01 23:09:39	-7.324	155.772	10.0	SOLOMON ISLANDS
5.8	2007/04/01 22:57:23	-7.321	155.995	10.0	SOLOMON ISLANDS
5.2	2007/04/01 22:45:33	-7.688	155.766	10.0	SOLOMON ISLANDS
5.3	2007/04/01 22:41:05	-6.964	155.214	10.0	BOUGAINVILLE REGI
5.3	2007/04/01 22:29:55	-7.250	155.323	10.0	SOLOMON ISLANDS
5.7	2007/04/01 21:45:38	-7.432	155.581	10.0	SOLOMON ISLANDS
5.5	2007/04/01 21:43:16	-7.705	155.608	10.0	SOLOMON ISLANDS
5.6	2007/04/01 21:26:27	-7.317	155.401	10.0	SOLOMON ISLANDS
6.4	2007/04/01 21:11:34	-7.441	155.774	10.0	SOLOMON ISLANDS
6.7	2007/04/01 20:47:32	-7.133	155.661	10.0	SOLOMON ISLANDS
8.0	2007/04/01 20:39:56	-8.453	156.957	10.0	SOLOMON ISLANDS
5.1	2007/04/01 07:09:01	9.255	91.420	30.0	NICOBAR ISLANDS, I
5.5	2007/04/01 02:51:05	32.322	137.641	368.8	IZU ISLANDS, JAPAN

Magnitude 8.0 - SOLOMON ISLANDS

2007 April 1 20:39:56 UTC

Versíon en Español

Details | Summary | Maps | Scientific & Technical | Where can I find...?

Earthquake Details

Magnitude	**8.0**
Date-Time	**Sunday, April 1, 2007 at 20:39:56 (UTC)** = Coordinated Universal Time **Monday, April 2, 2007 at 7:39:56 AM** = local time at epicenter Time of Earthquake in other Time Zones
Location	8.453°S, 156.957°E
Depth	10 km (6.2 miles) set by location program
Region	SOLOMON ISLANDS
Distances	45 km (30 miles) SSE of **Gizo, New Georgia Islands, Solomon Isl.** 205 km (125 miles) S of **Chirovanga, Choiseul, Solomon Islands** 345 km (215 miles) WNW of **HONIARA, Guadalcanal, Solomon Islands** 2145 km (1330 miles) NNE of **BRISBANE, Queensland, Australia**
Location Uncertainty	horizontal +/- 9.3 km (5.8 miles); depth fixed by location program
Parameters	Nst=152, Nph=152, Dmin=345.9 km, Rmss=1.18 sec, Gp= 43°, M-type=moment magnitude (Mw), Version=7
Source	USGS NEIC (WDCS-D)
Event ID	us2007aqbk

This event has been reviewed by a seismologist.

Did you feel it?

Report shaking and damage at your location. You can also view a map displaying accumulated data from your report and others.