

Earthquakes and Earth's Structure

Chapter 10 and 11 (review)

EXAM I Wednesday

88 pts. total

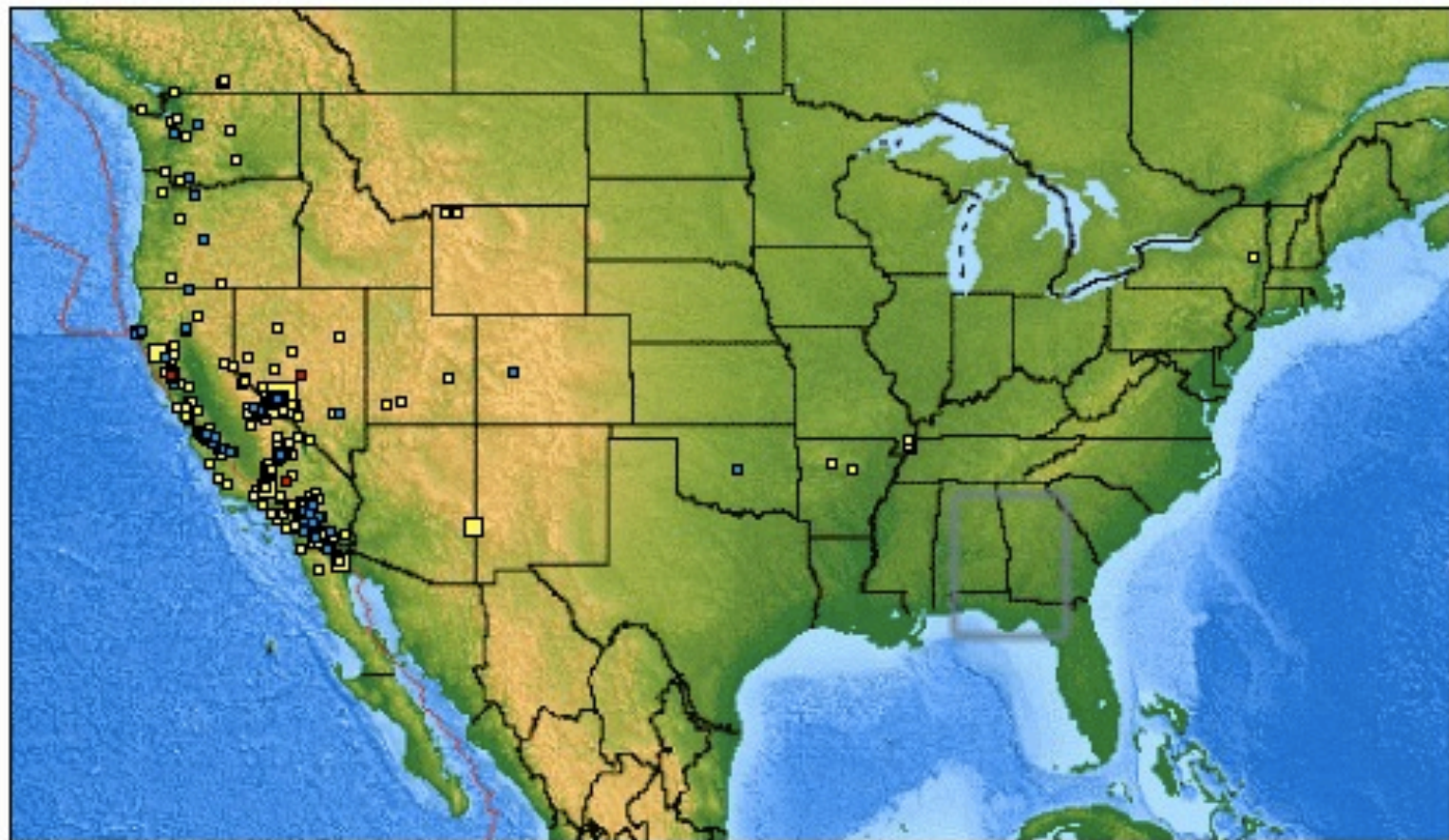
- 62 pts. PassSheet
- 26 pts. Better-Than
- + 8 pts. Extra Credit

<http://earthquake.usgs.gov/earthquakes/recenteqsus/>

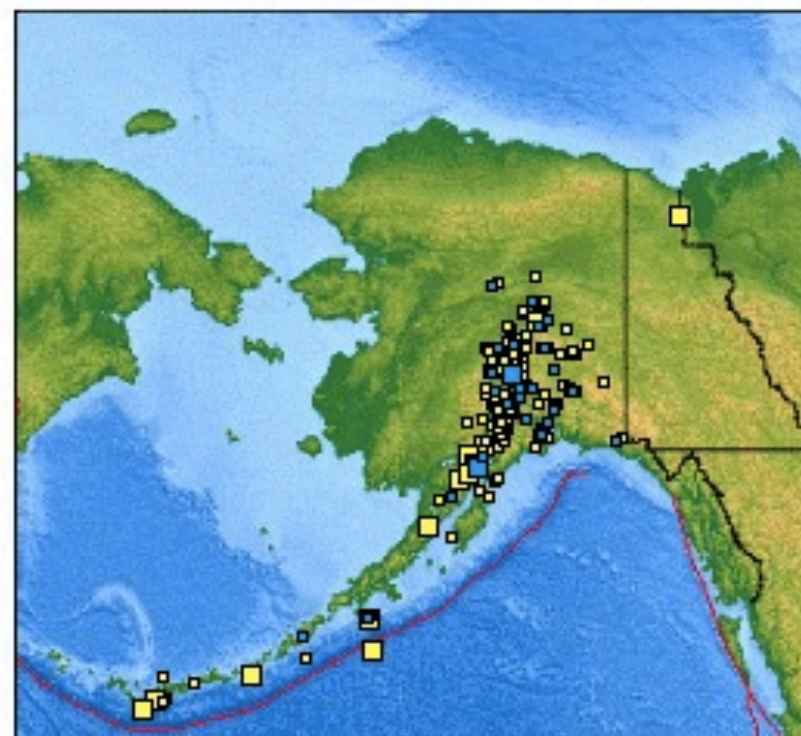
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Mon Feb 18 20:27:03 UTC 2013

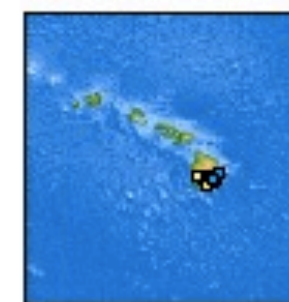
794 earthquakes on these maps



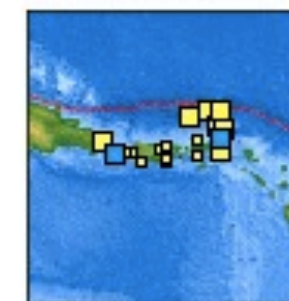
CONTIGUOUS 48 STATES



ALASKA



HAWAII



PUERTO RICO

magnitudes

□ >5

□ >3

□ >1

⊗ not yet known

■ last hour

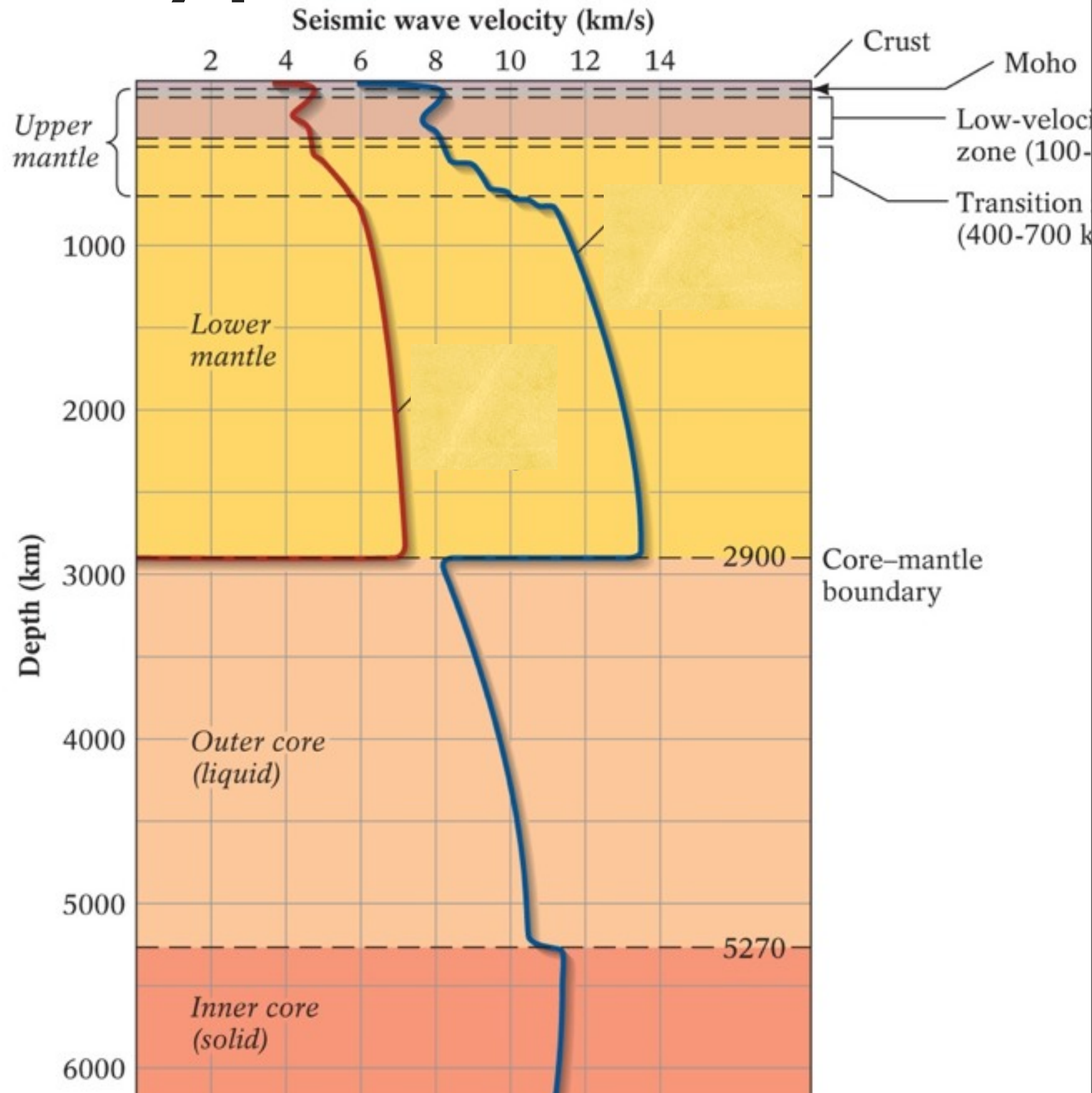
■ last day

■ last week

The red and blue lines on the graph show two different velocity profiles for seismic waves in Earth.

The blue line likely represents_____.

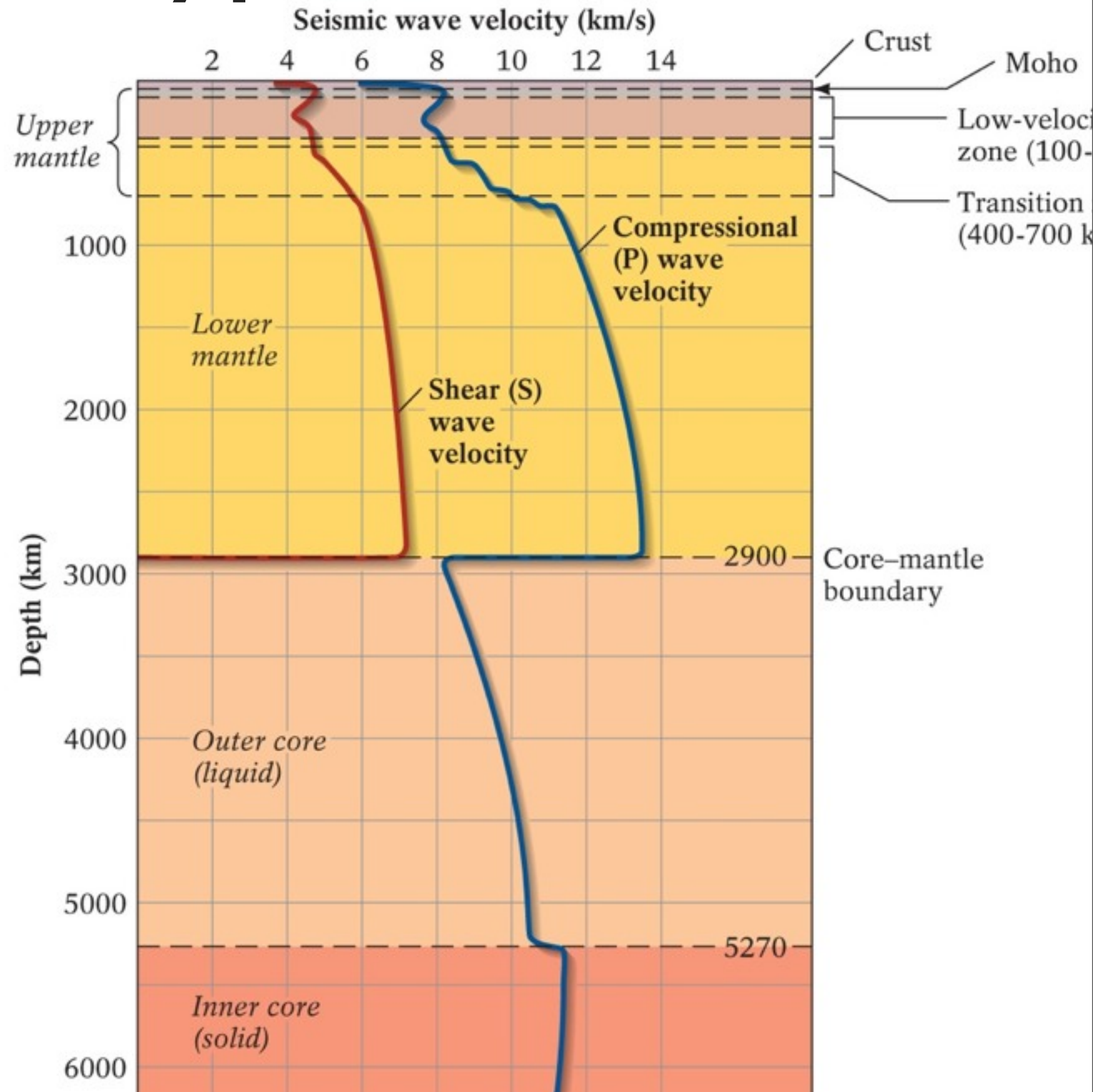
- a) Love waves
- b) P-waves
- c) Rayleigh wave
- d) S-wave
- e) not enough information



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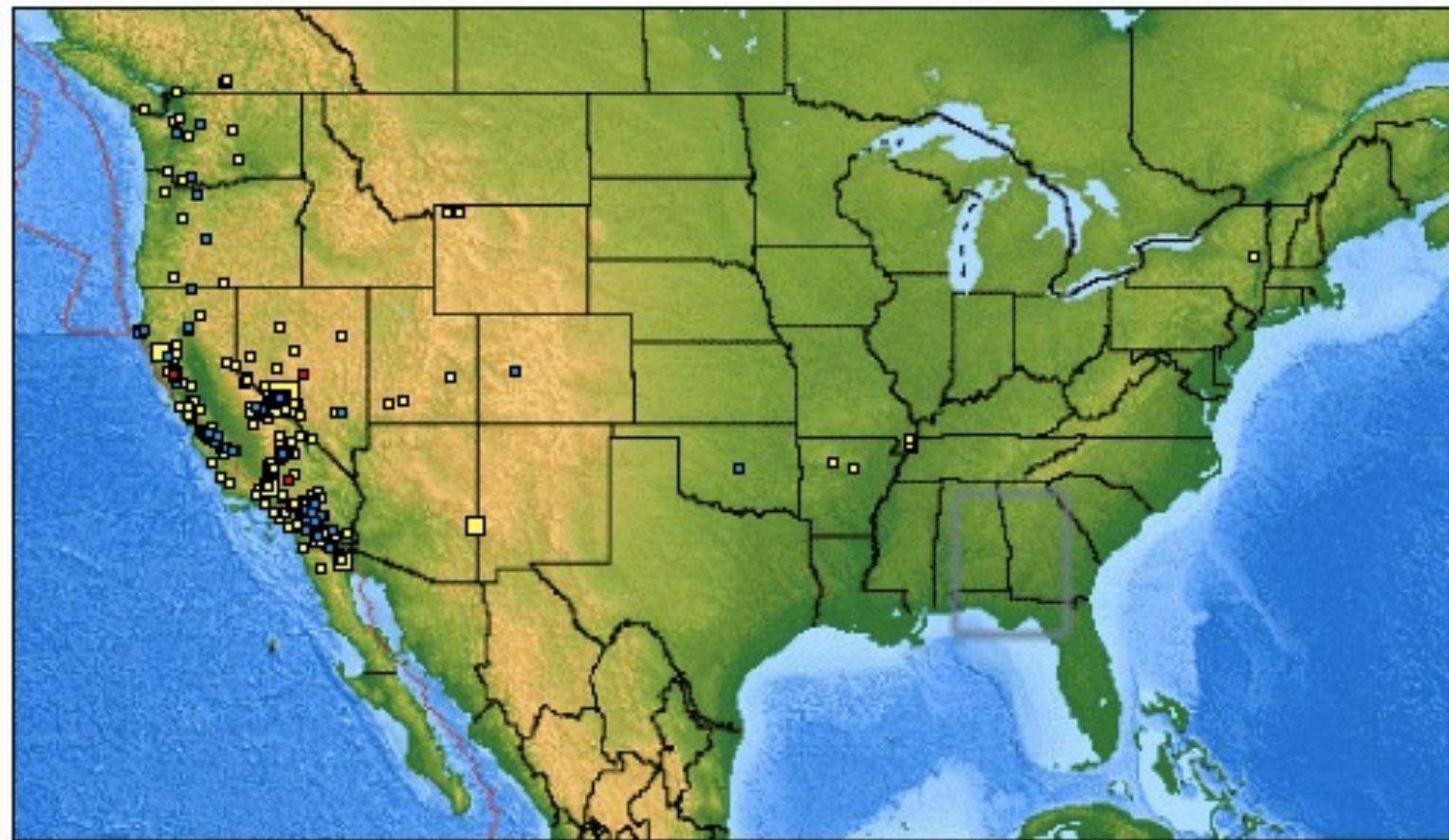
Earthquakes and Earth's Structure

Chapter 10 and 11 (review)

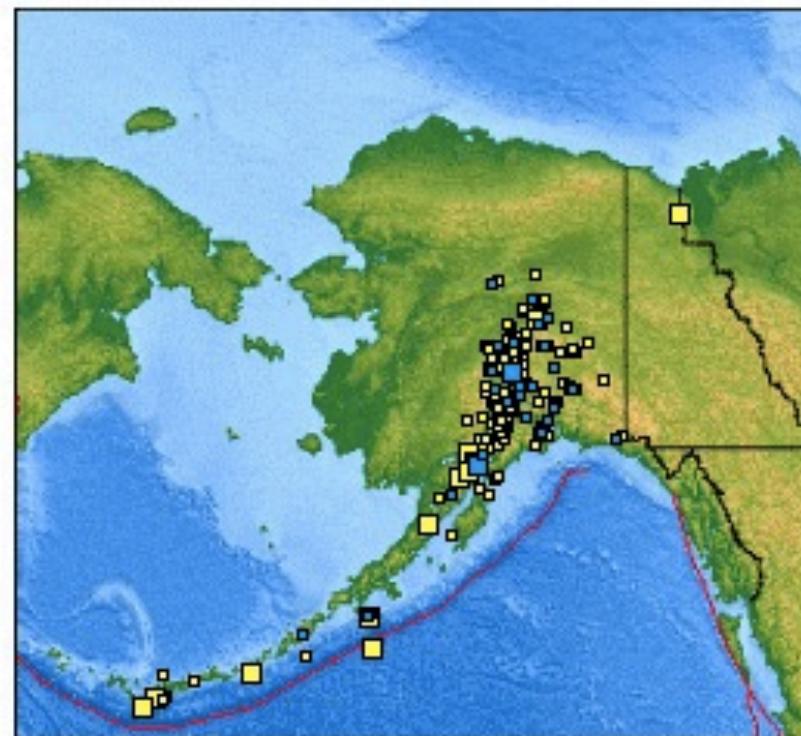
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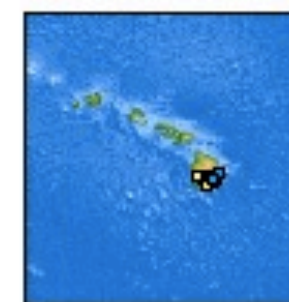
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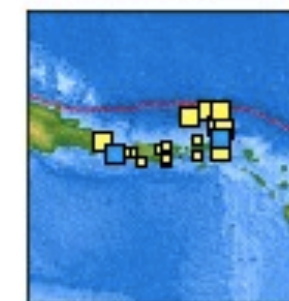
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magnitudes

□ >5

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■ last day

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Earthquake Magnitude Scales

Mercalli Intensity Scale - defines the intensity of an earthquake by the amount of Damage. Measured from I-XII. Effected by distance, building code, human interpretation and underlying geology.

Richter Scale-

Moment Magnitude Scale-

1886 Charleston South Carolina Earthquake

Based on response of
humans and structures

I not felt except for a few

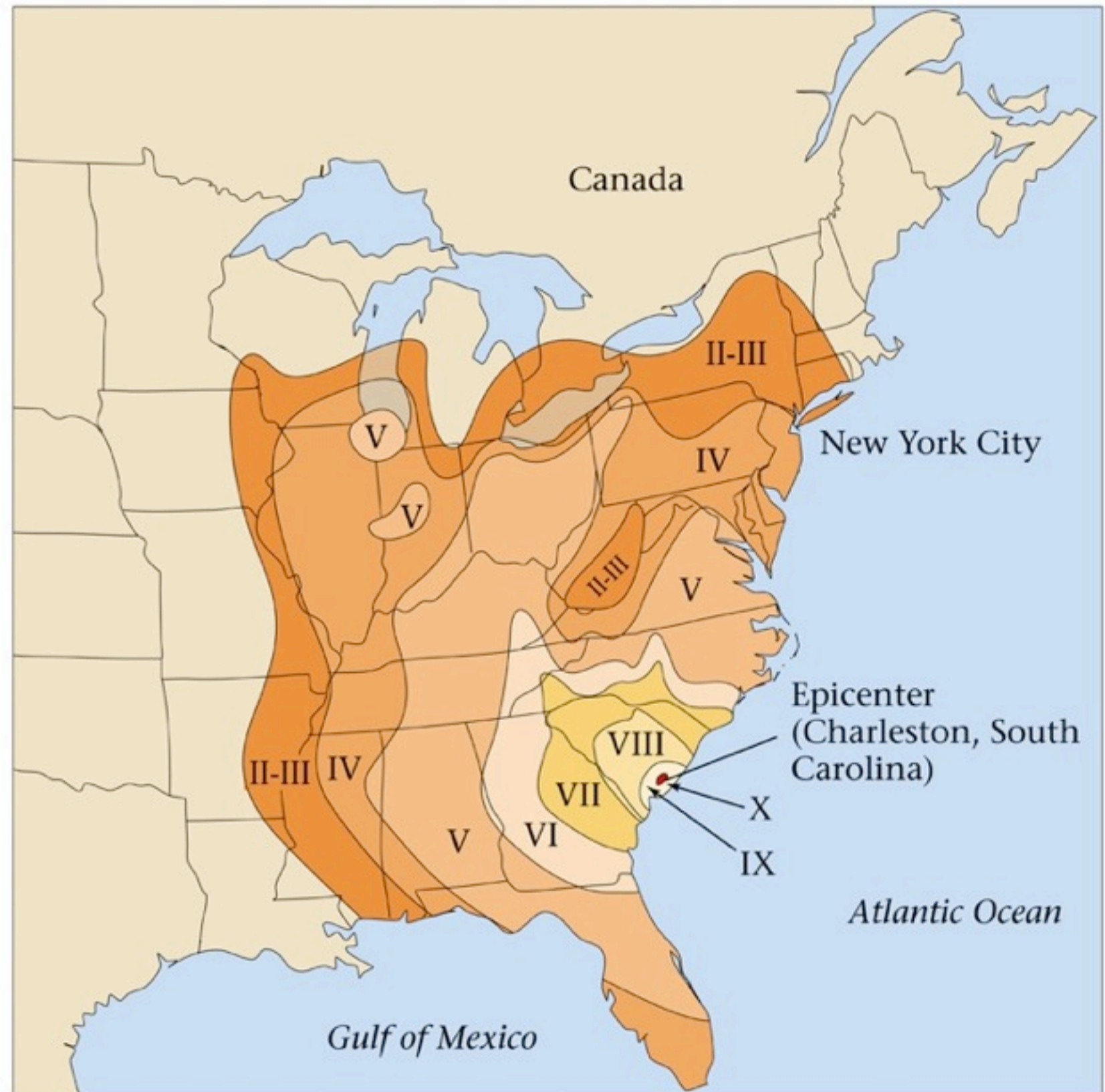
V Most people awakened

X Masonry structures
collapse

XII Complete destruction
and surface waves seen

Full description
of the scale on
page 320

Mercalli Intensity Scale



Earthquake Magnitude Scales

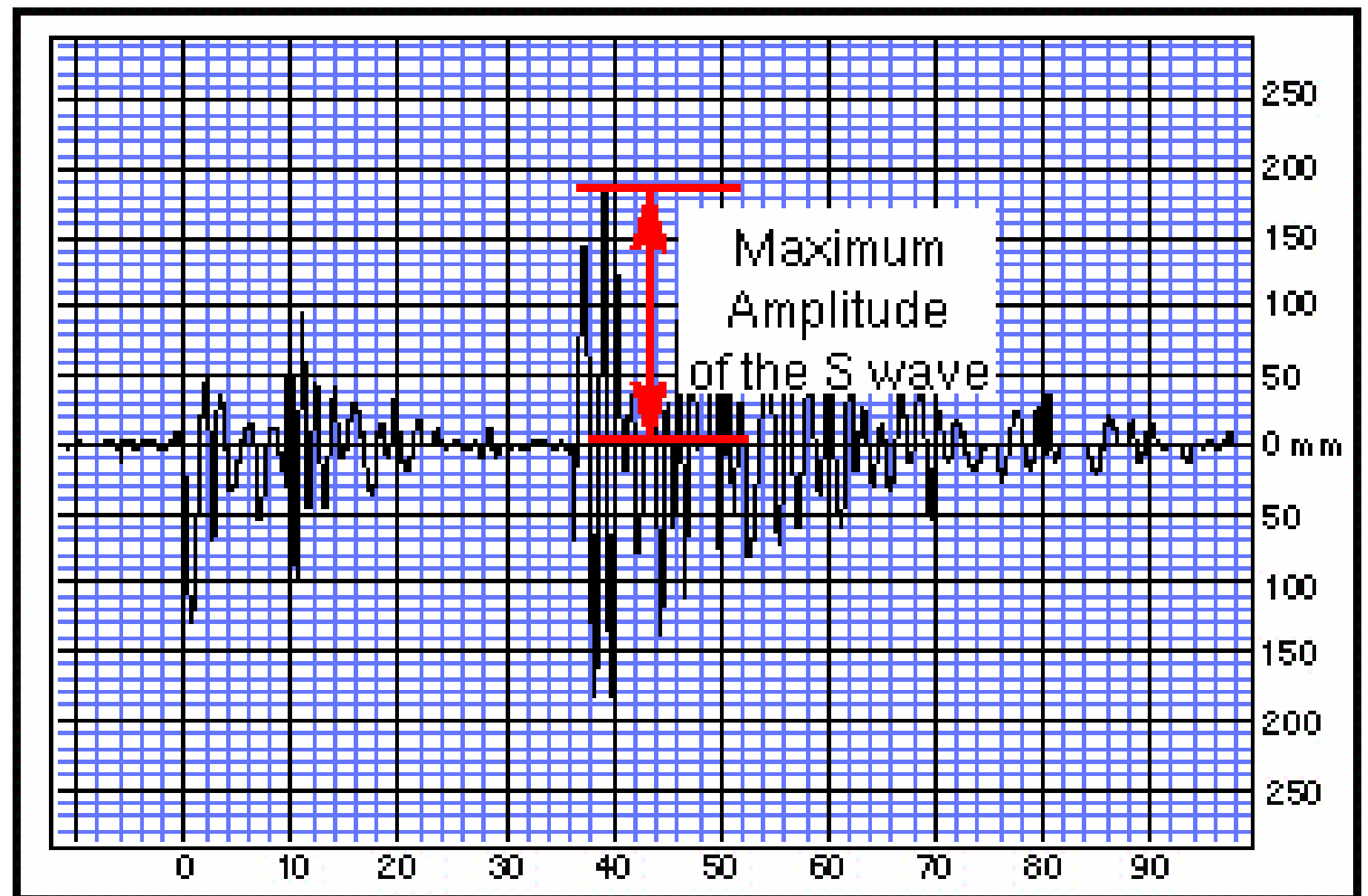
Mercalli Intensity Scale - defines the intensity of an earthquake by the amount of Damage. Measured from I-XII. Effected by distance, building code, human interpretation and underlying geology.

Richter Scale - measure of the largest deflection of the S-wave on a seismic gram as compared to a characteristic Earthquake. Can have negative magnitude values (10x change between units). Effected by distance from the epicenter.

Moment Magnitude Scale-

Richter Magnitude Magnitude

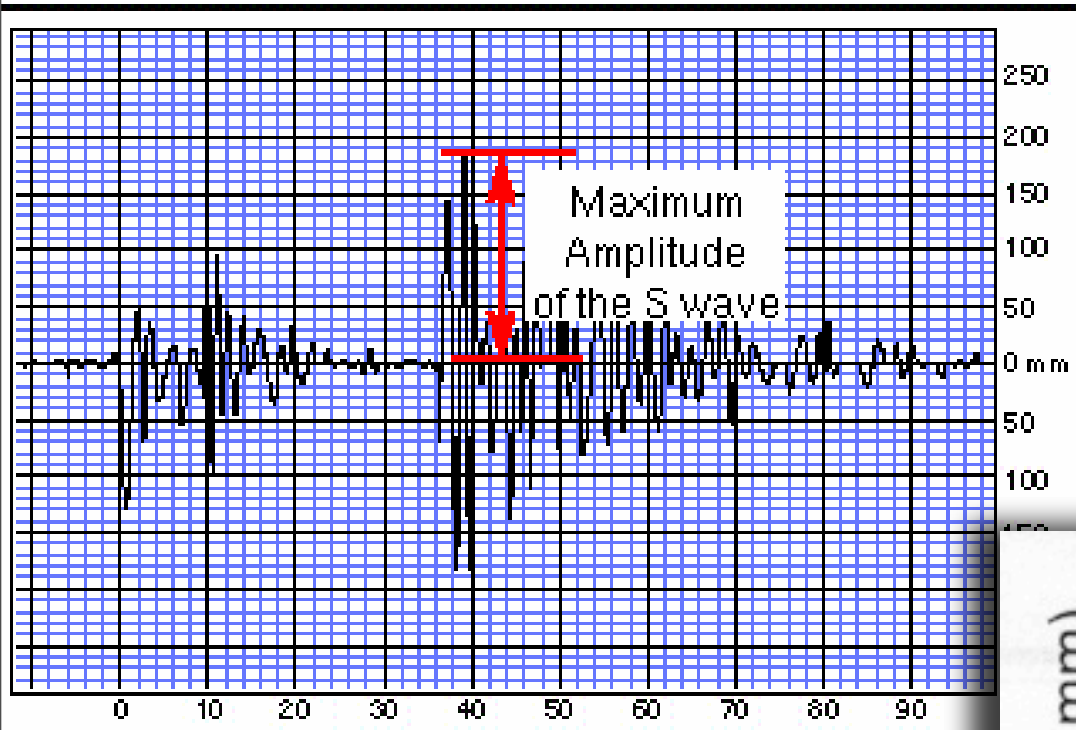
$$D = \Delta t \times \left(\frac{v_p \times v_s}{v_p - v_s} \right)$$



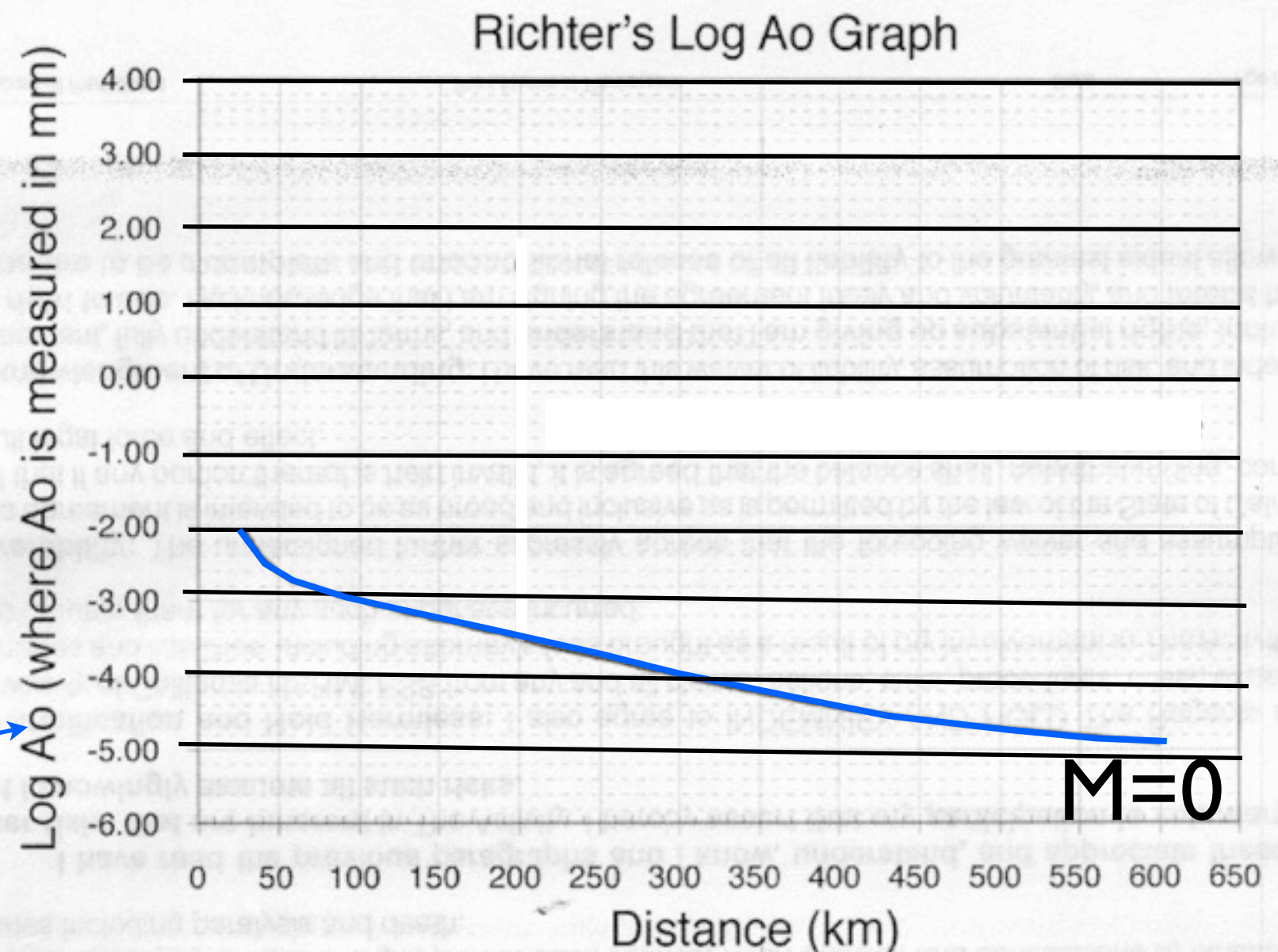
$V_p = 6 \text{ km/s}$
 $V_s = 3 \text{ km/s}$

Richter Magnitude Magnitude

What does the Richter curve tell us about the relationship between ground shaking and distance from the epicenter?



Log of
millimeters
displacement by
peak S-wave



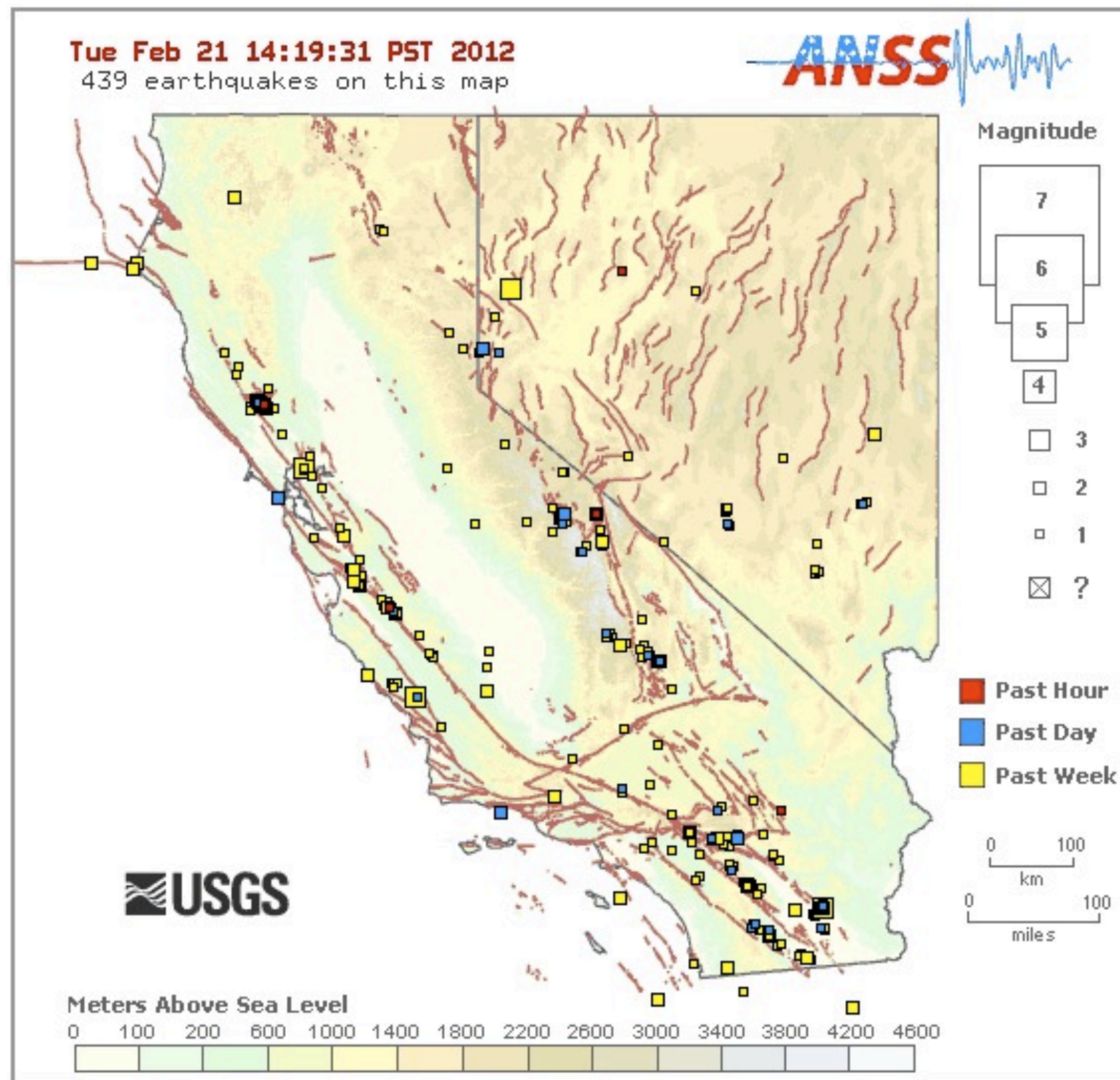
Earthquake Magnitude Scales

Mercalli Intensity Scale - defines the intensity of an earthquake by the amount of Damage. Measured from I-XII. Effected by distance, building code, human interpretation and underlying geology.

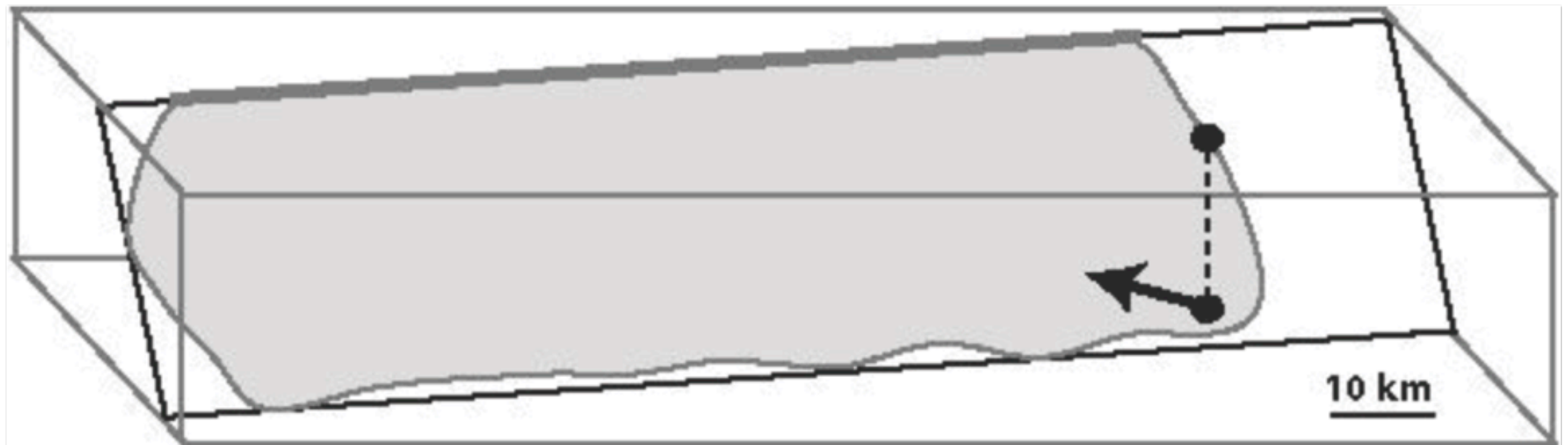
Richter Scale - measure of the largest deflection of the S-wave on a seismic gram as compared to a characteristic Earthquake. Can have negative magnitude values (10x change between units). Effected by distance from the epicenter.

Moment Magnitude Scale - A measure of the energy released. $\text{Magnitude} = \text{Area} * \text{Displacement} * (\text{rock property})$
33x energy change between units.

Do small earthquakes relieve stress on the fault and help to prevent large EQ's?

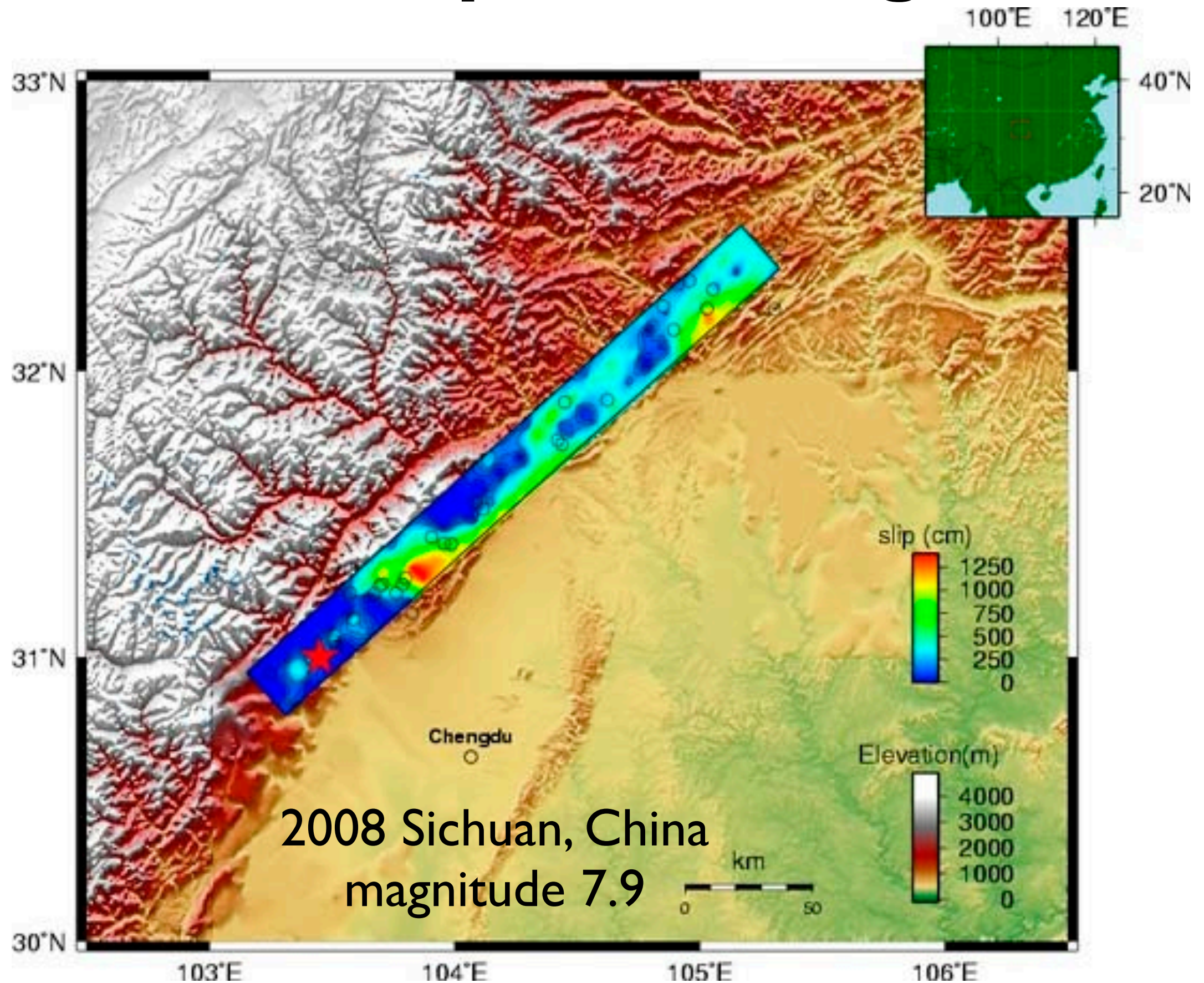


Area of Fault Rupture During EQ



Moment Magnitude Scale - A measure of the energy released. $\text{Magnitude} = \text{Area} * \text{Displacement} * (\text{rock property})$

Area of Fault Rupture During EQ



Late Pleistocene structural evolution of the Camarillo fold belt: Implications for lateral fault growth and seismic hazard in Southern California

Duane E. DeVecchio¹, Edward A. Keller², Markus Fuchs³, and Lewis A. Owen⁴

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³DEPARTMENT OF GEOGRAPHY, JUSTUS-LIEBIG-UNIVERSITY GIESSEN, D-35390 GIESSEN, GERMANY

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Late Pleistocene structural evolution of the Camarillo fold belt: Implications for lateral fault growth and seismic hazard in Southern California

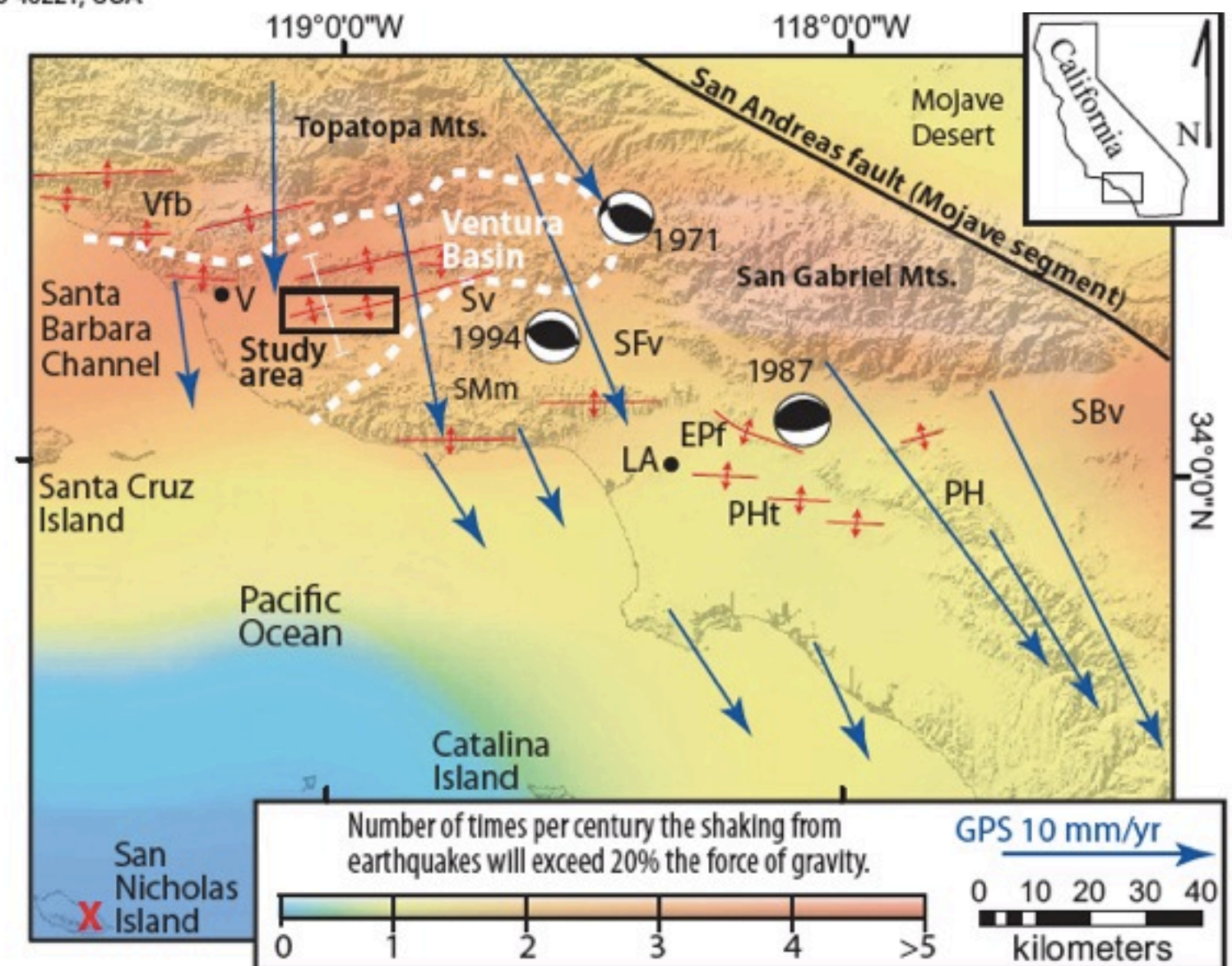
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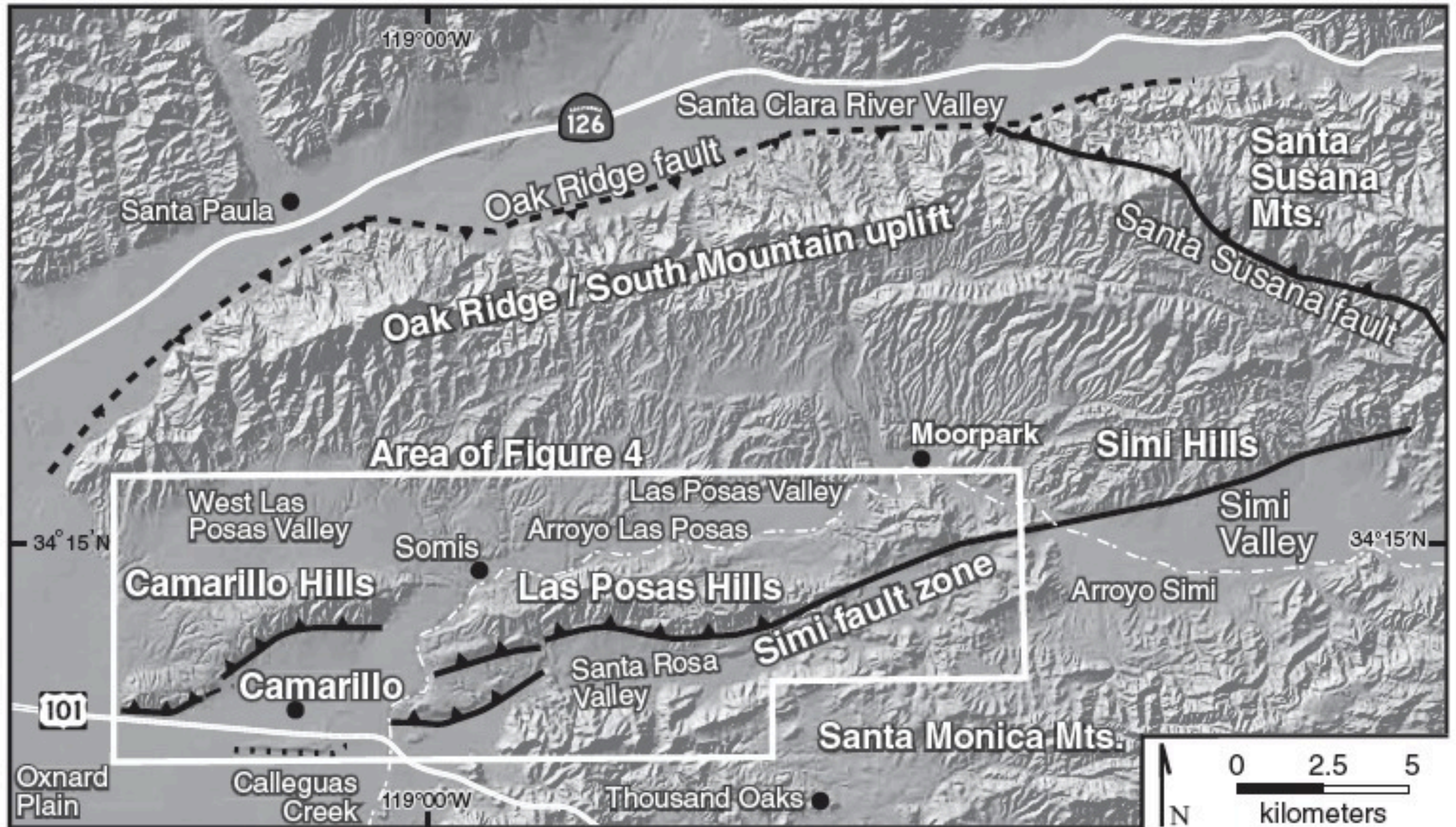
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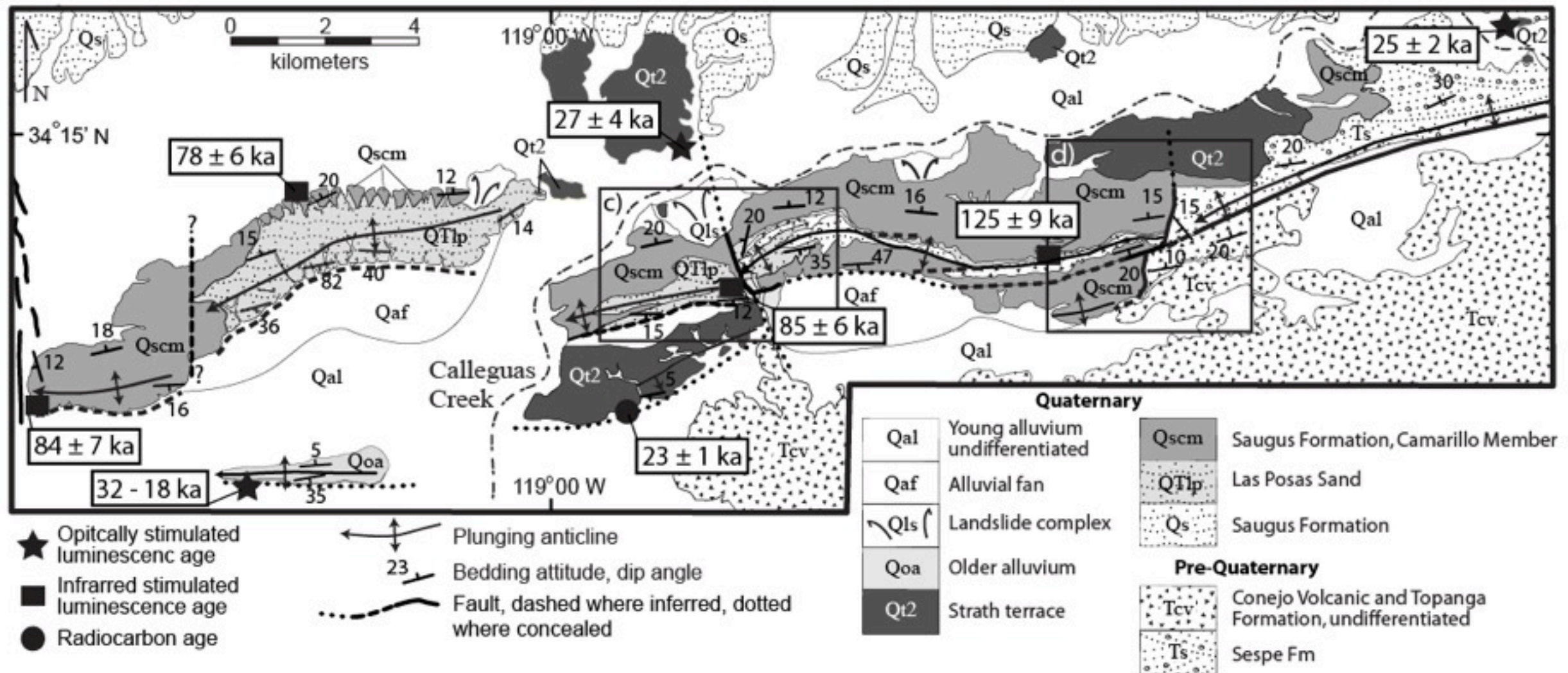
Camarillo Fold Belt



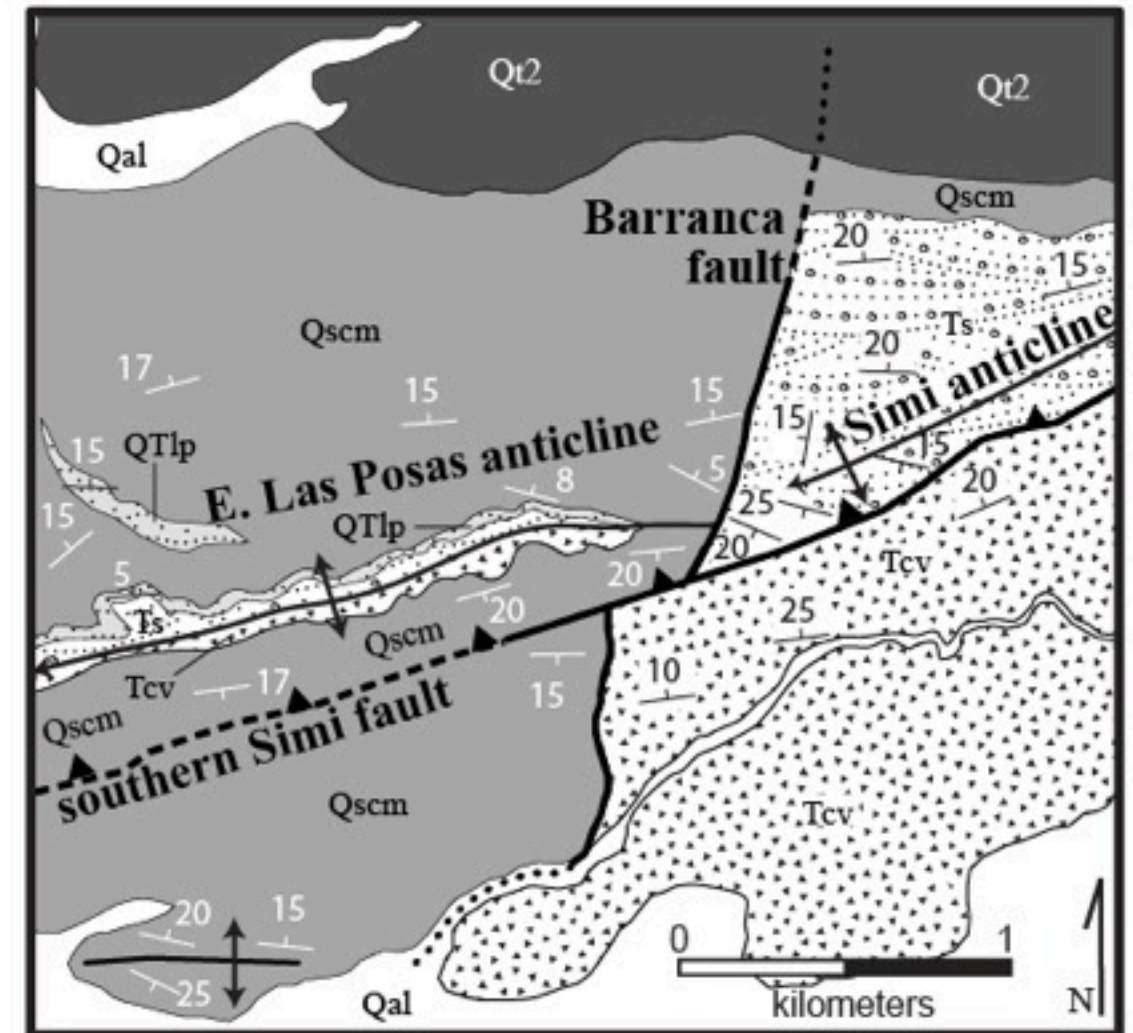
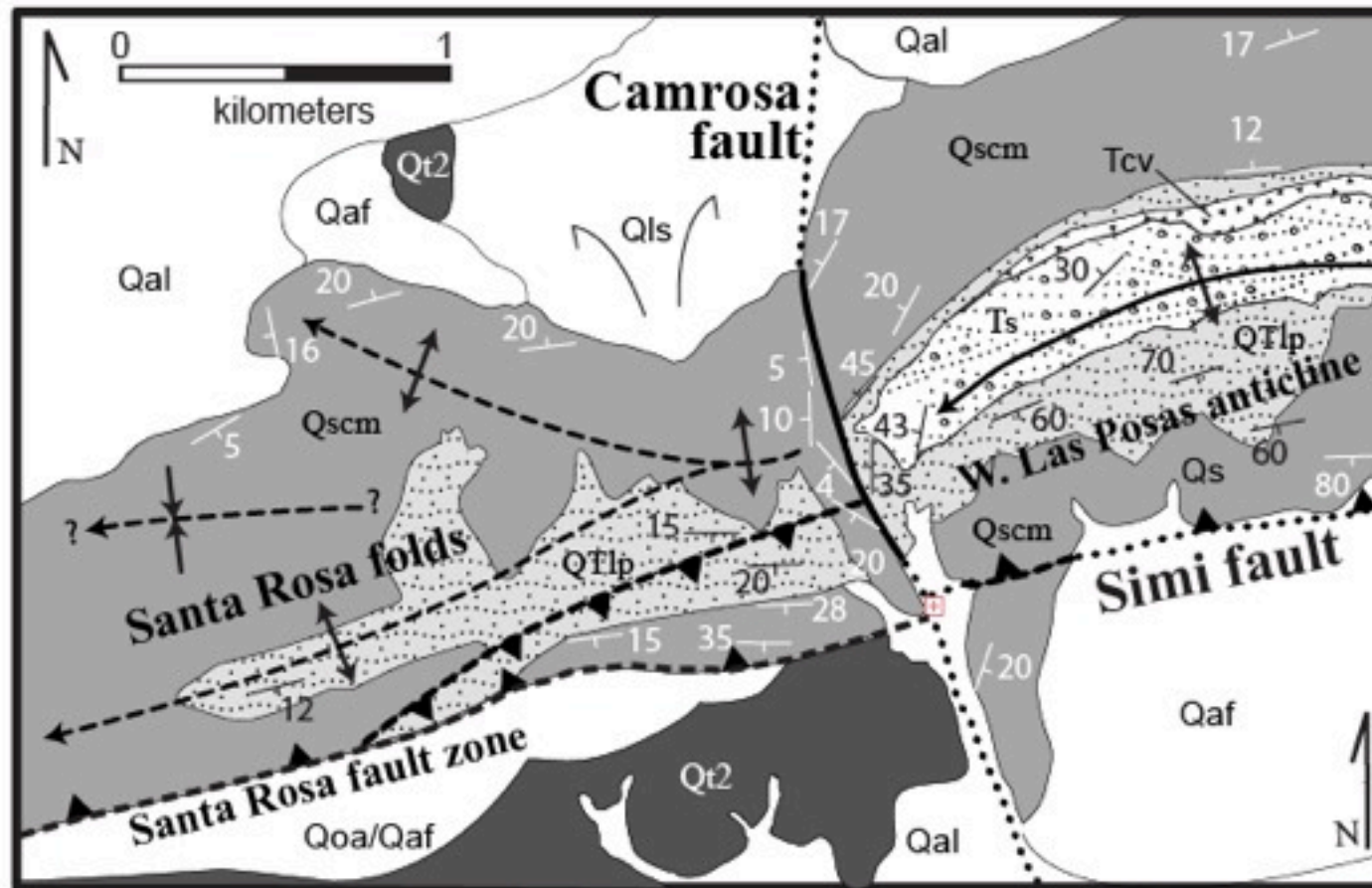
Camarillo Fold Belt

Geologic Map and Chronology

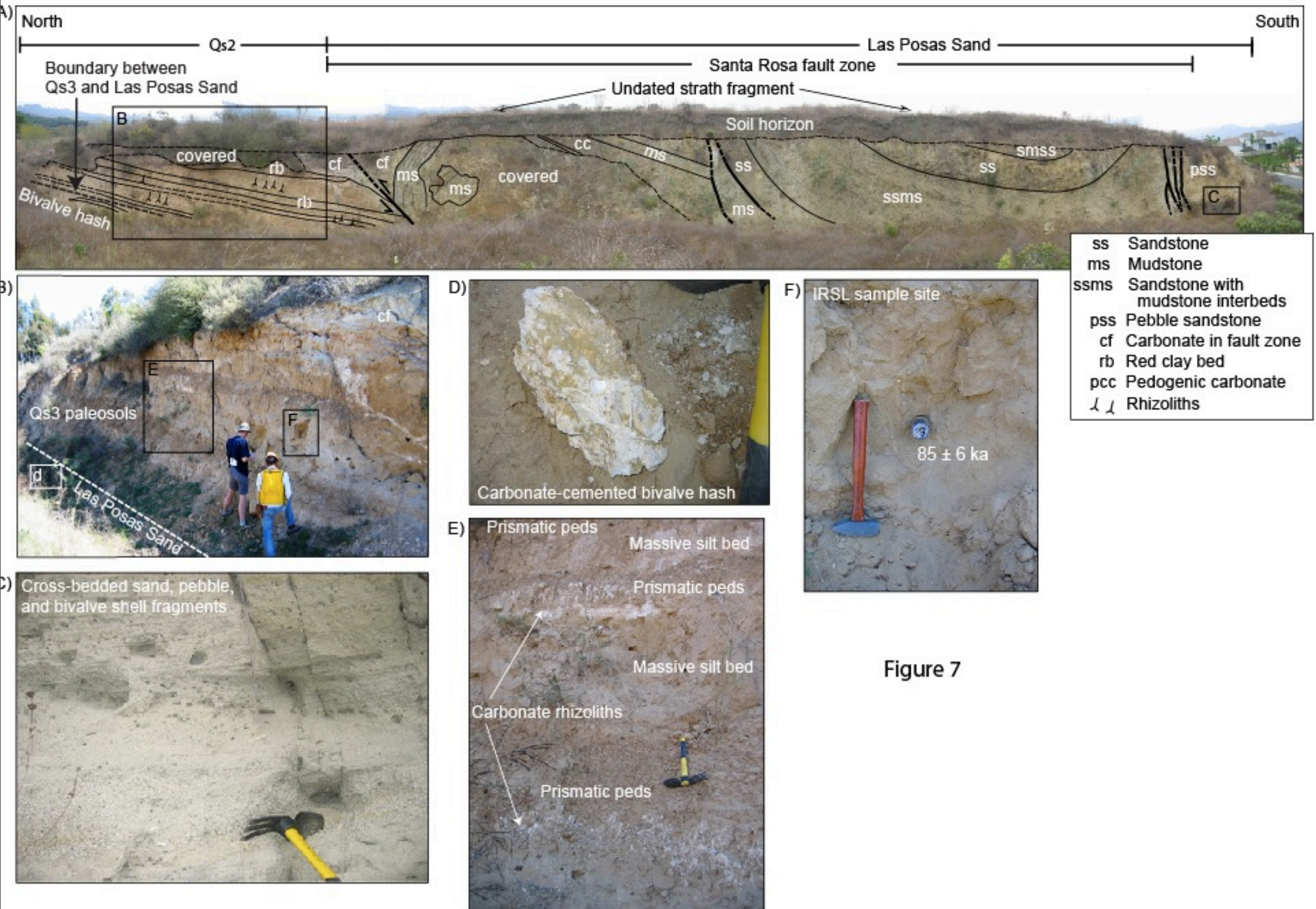
A)



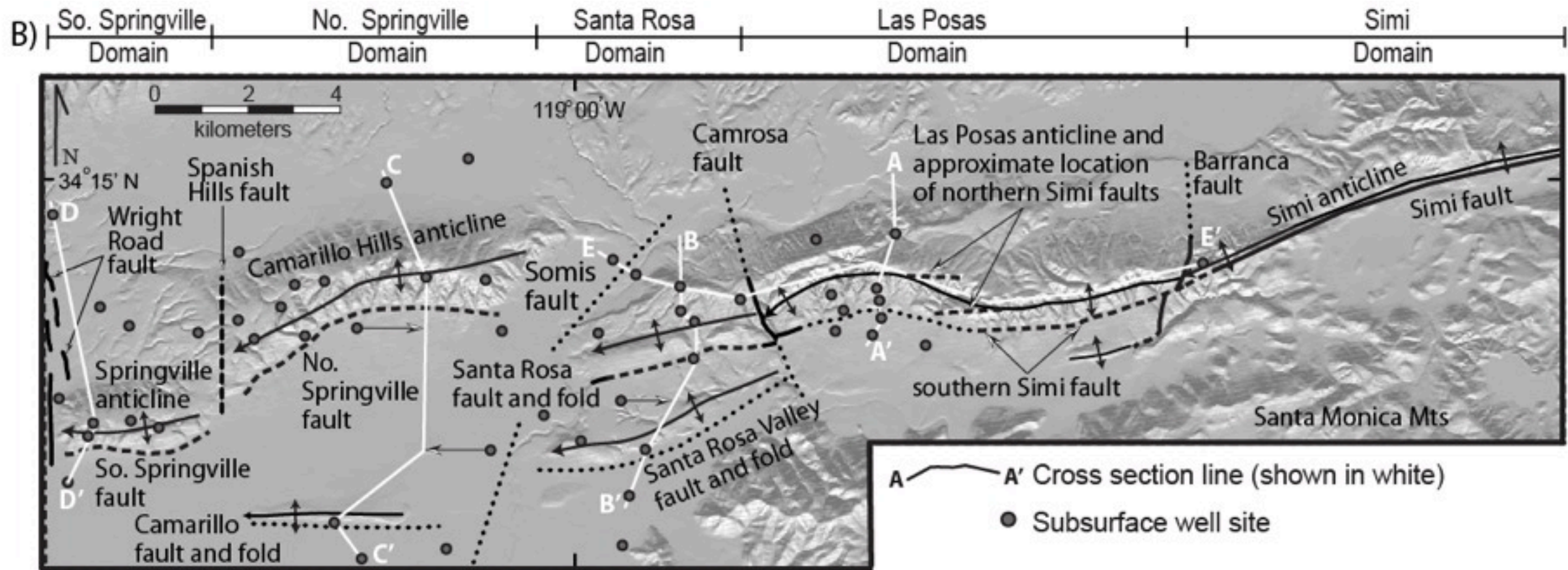
Camarillo Fold Belt



Santa Rosa fault zone



Cross Section lines and Subsurface well locations



Cross Sections

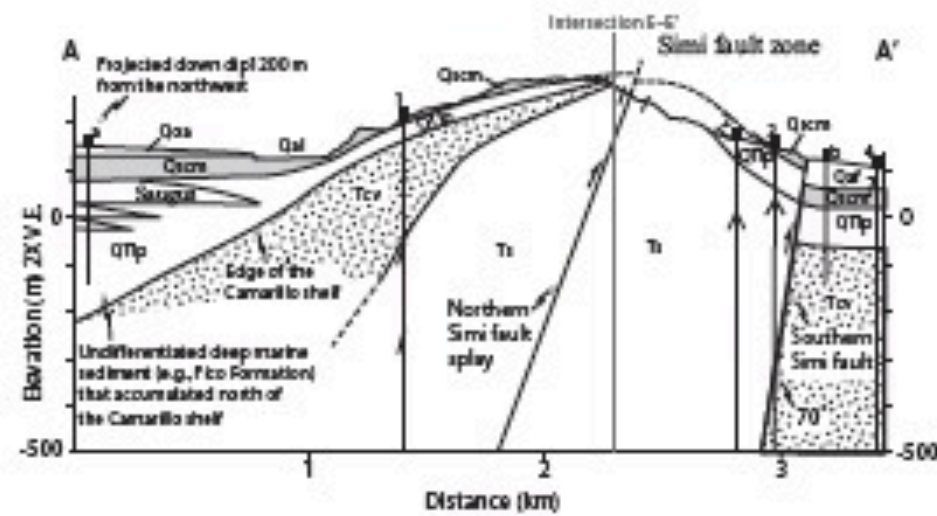
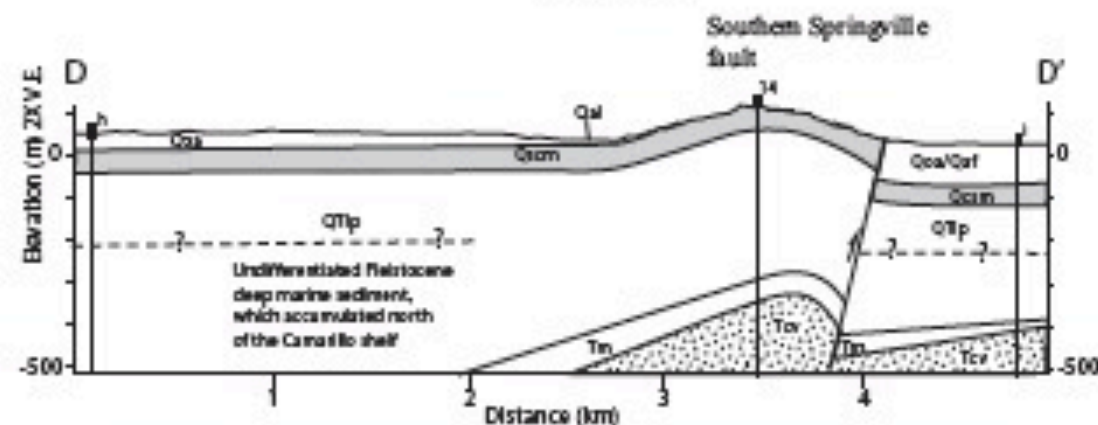
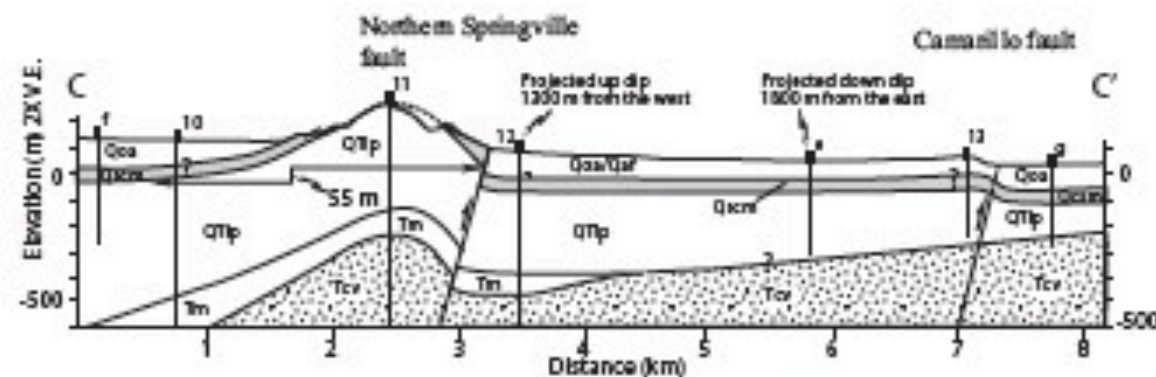
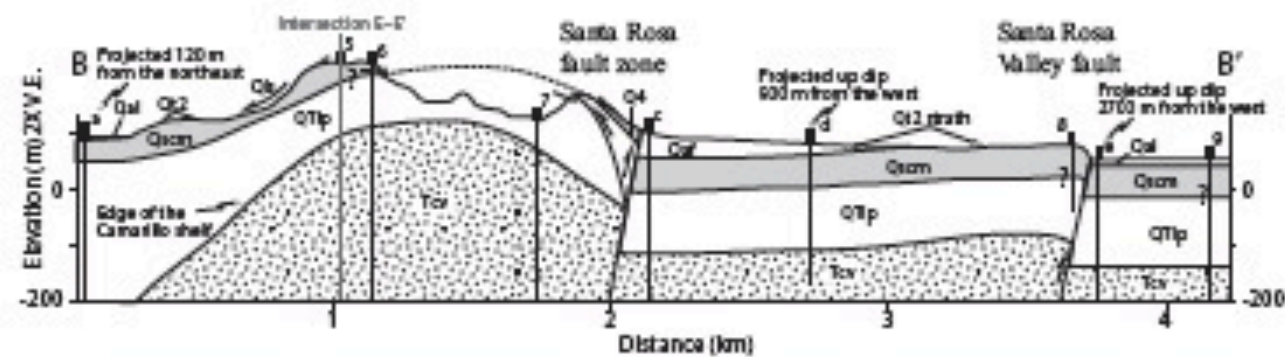
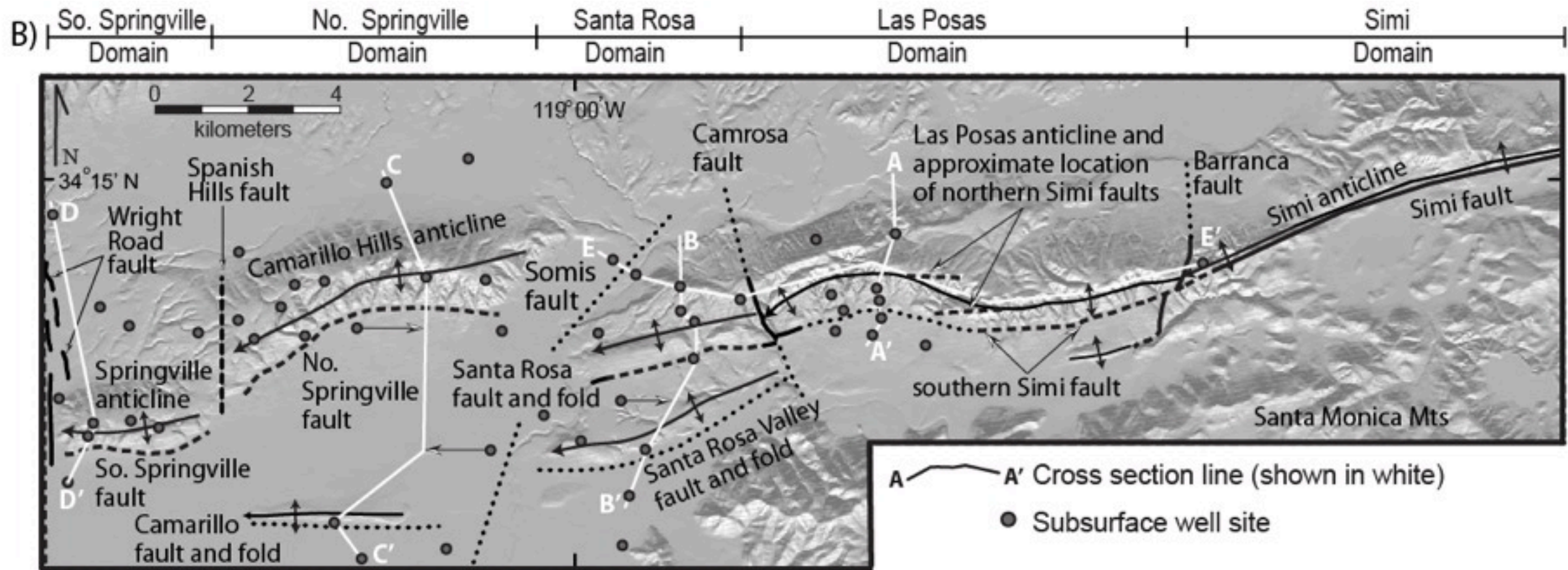


Figure 6. Four north-south-oriented cross sections across the Camarillo fold belt. See location of cross section lines (A-D) and explanation of geologic units on Figure 4. All sections have 2x vertical exaggeration and different horizontal scales. Lithologic interpretations of wells numbered 1-14 were taken from Jakes (1979), whereas interpretations of wells a-g are from Hanson et al. (2003). Queried Qcm contacts appear adjacent to wells of Jakes (1979), where differentiation of Upper Pleistocene units was not made; therefore, contacts are inferred based on projection from known depths. See Figure 4A legend for lithologic abbreviations. V.E.—vertical exaggeration. Well names: 1—Texaco Berylwood B-1; 2—Shell Everett 1; 3—Shell Everett C-2; 4—Exxon-Burket; 5—Aminoff-Burnah-Texaco Berylwood 1; 6—Burnah-Texaco Berylwood 3; 7—Texaco-Miketta 1; 8—A.J. Singer; 9—J. Schuck; 11—Arco McFarland 1; 12—Texaco-Converse 1; 13—Chevron Camarillo 1; 14—Reverse Schumate-Surpt; a—2N/21W-38B1; b—2N/20W-23H2; c—2N/20W-21L1; d—2N/20W-20B1; e—2N/20W-30M1; f—2N/21W-12H1; g—1N/21W-1B4; h—2N/21W-17F5; i—2N/21W-32E1.



Camarillo Anticline



Paloeseismic Trench across the Camarillo Anticline



Paloeseismic Trench across the Camarillo Anticline

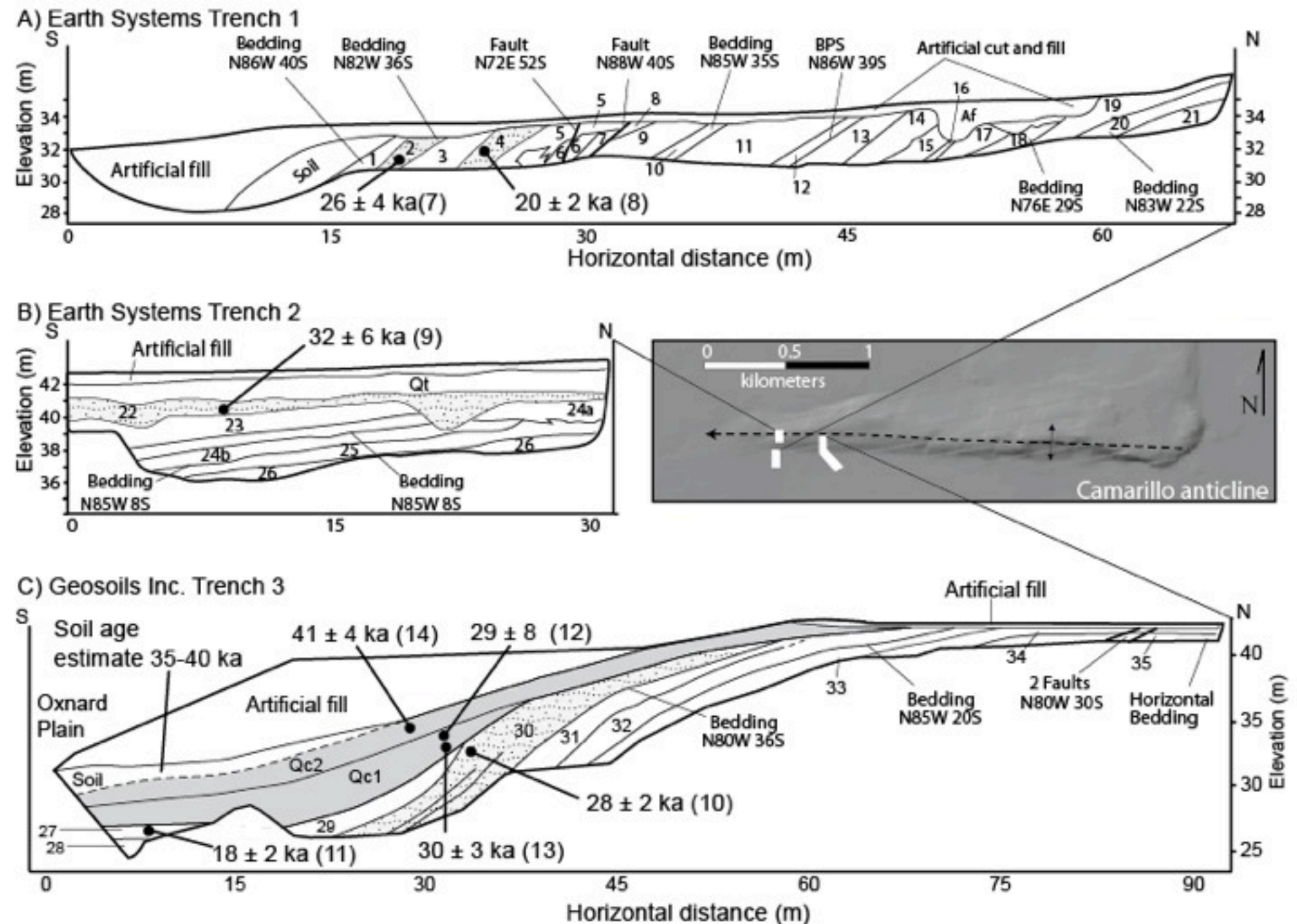
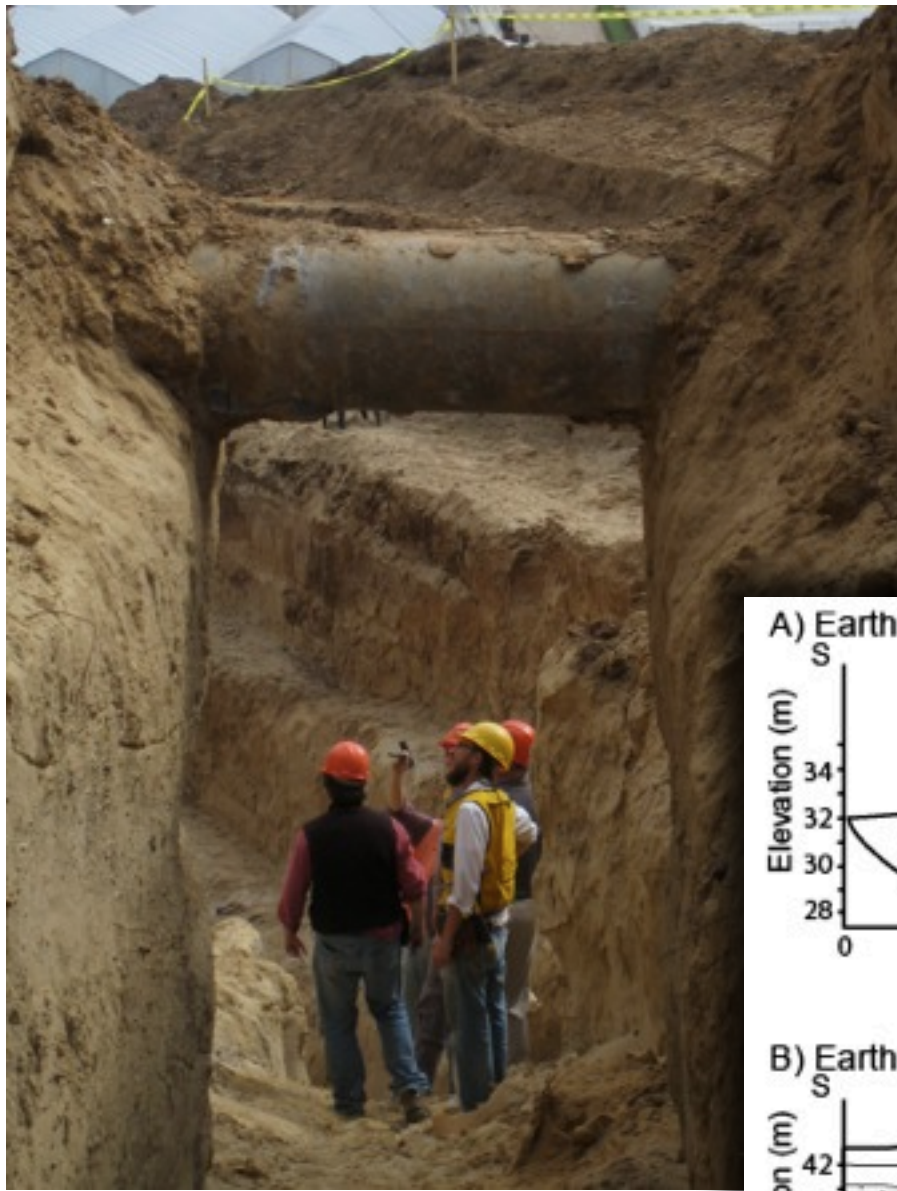


TABLE 2. MAGNITUDES AND RATES OF DEFORMATION

Fault name	Structural domain	Total uplift (m)	Fault uplift (m)	Fold uplift (m)	Fault slip (m)	Shortening (%)	Age range of offset datum (ka)	Fault slip rate range (mm/yr)*	Total uplift rate range (mm/yr)*	Shortening rate range (mm/yr)*
Simi	Simi		24		26		23–25 [†]	1.0–1.1		
Southern Simi (long-term)	Las Posas	297	97	200	104	5	116–134 [§]	0.8–0.9	2.2–2.5	0.8–1.0
Southern Simi (short-term)			24		26		23–25 [†]	1.0–1.1		
Southern Santa Rosa (long-term)	Santa Rosa	225	78	147	83	3	78–86*	1.0–1.1	2.6–2.8	0.7–0.8
Southern Santa Rosa (short-term)			25–30		27–32		23–25 [†]	1.1–1.4		
Santa Rosa Valley	Santa Rosa	30	30	0	32		23–25 [†]	1.3–1.4 ^{††}	1.2–1.3 ^{††}	
Northern Springville	No. Springville	356	92	264	98	6	78–86*	1.1–1.3	4.1–4.6	1.7–1.8
Southern Springville	So. Springville	174	74	100	78	4	78–86*	0.9–1.0	1.9–2.2	0.6–0.7
Camarillo		45					26–40**	N/A	1.1–1.7	

Note: Gray boxes represent compound systems discussed in text.

*Rate estimate represents minimums where based on the age of Q_{cs}m and Q_{oa}, which is always older than the timing of tectonic deformation.

[†]Age of the Qt₂ surface based the weighted mean of two optically stimulated luminescence (OSL) dates (Table 1) and a single radiocarbon age DeVecchio et al. (2012).

[§]Age range estimate based on infrared stimulated luminescence (IRSL) age and associated error on deformed Q_{cs}m strata within the Las Posas domain (see Fig. 4A; Table 1).

*Age range estimate based on the weighted mean of three IRSL ages from the base of Q_{cs}m west of the Camrosa fault (see Fig. 4A; Table 1).

**The upper age limit is based on the minimum possible age of the soil and the minimum age of OSL samples from the forelimb of the anticline assuming a water content of 50%, whereas the lower age is based on the maximum age of the soil (see text for discussion).

^{††}Rate estimate is a maximum because deformation began before the Qt₂ strath was cut (see text for discussion).

TABLE 3. CAMARILLO FOLD BELT EARTHQUAKE MAGNITUDE MODEL AND FAULT RECURRENCE INTERVALS

Fault name	Structural domain	Length (km)*	Area (km ²) [†]		Max (M _w) [§]		Max (M _w) [*]		Recurrence interval (yr)**
			Depth (5 km)	Depth (17 km)	Min	Max	Min	Max	
Simi fault system	Simi–Las Posas–Santa Rosa	31.4	267.3	401.0	6.5	6.7	6.6	6.8	715–1000
Southern Santa Rosa	Santa Rosa	4.4	37.5	79.6	5.7	6.0	5.9	6.2	900–1000
Santa Rosa Valley	Santa Rosa	4.8	40.9	86.8	5.8	6.1	5.9	6.2	770
No. Springville Fault	Northern Springville	6	51.1	108.5	5.9	6.2	6.0	6.3	715–910
So. Springville	Southern Springville	3.5	29.8	63.3	5.7	6.0	5.8	6.1	910–1100
Camarillo	–	5.5	46.8	99.5	5.8	6.1	6.0	6.3	590–910

Note: Gray box represents the compound Simi–Las Posas–Santa Rosa system discussed in text.

*Fault length is assumed to be the surface rupture length and may be slightly different than map length.

[†]Calculated fault area extends from 5 km and 17 km to the surface.

[§]Moment magnitude calculated from fault plane area with rupture at a depth of 12 km, using a regression of global reverse-motion earthquakes, $M_w = 4.33 + 0.90 \cdot \log(\text{area})$ from Wells and Coppersmith (1994).

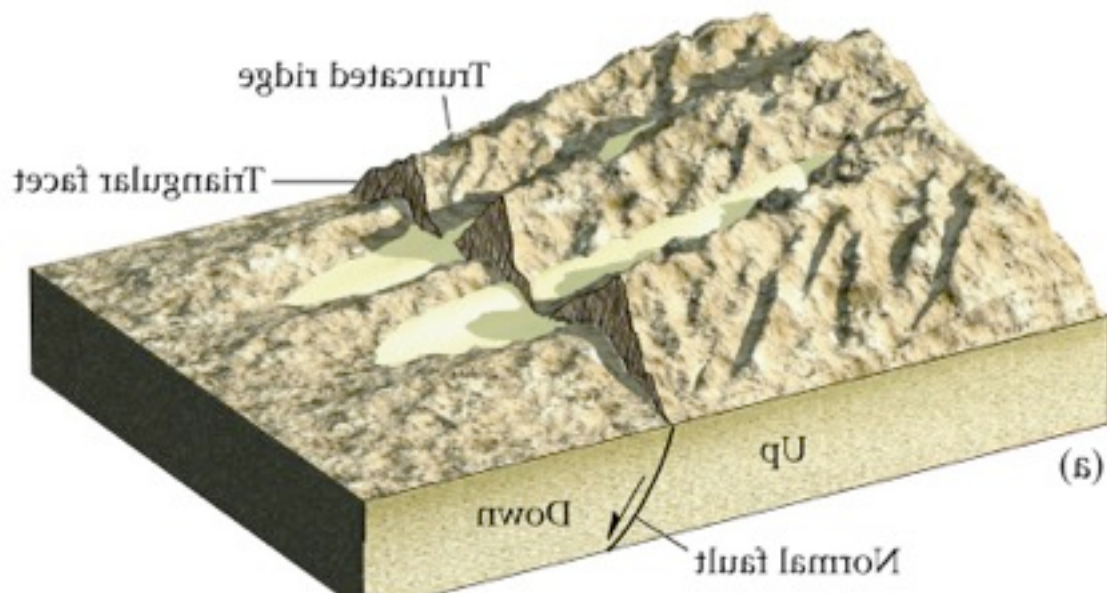
*Moment magnitude calculated from fault plane area with rupture at a depth of 12 km, using a regression of global reverse-motion earthquakes, $M_w = 4.56 + 0.86 \cdot \log(\text{area})$ from Dolan et al. (1995).

**Average coseismic slip was assumed to be 1 m based on previous paleoseismic observations from the Springville and Simi faults (Gonzalez and Rockwell, 1991; Hitchcock et al., 1998). Recurrence interval was calculated by dividing average slip by the rate of fault slip (Table 3).

Grand Tetons



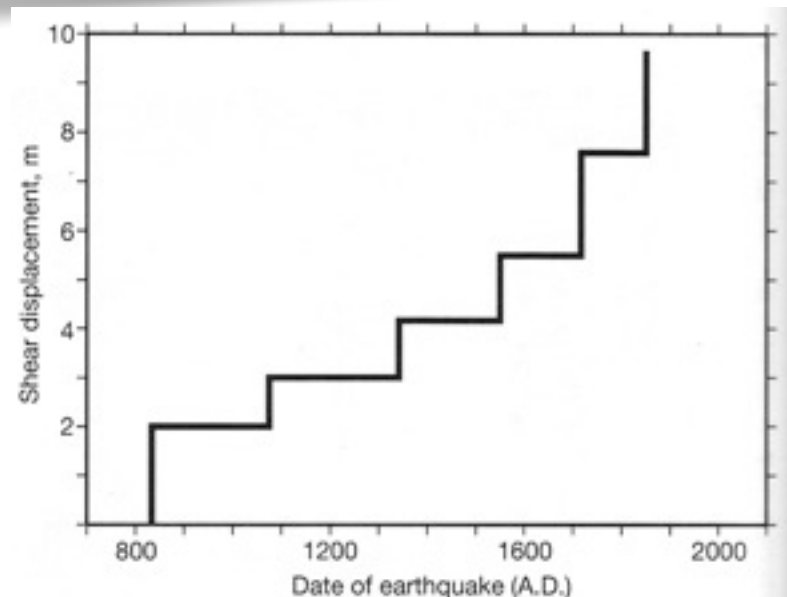
Grand Tetons



1954 Fairview Peak fault Scarp (M=7.2)



Normal
Displacement
32 km long
Avg. 1.2 m



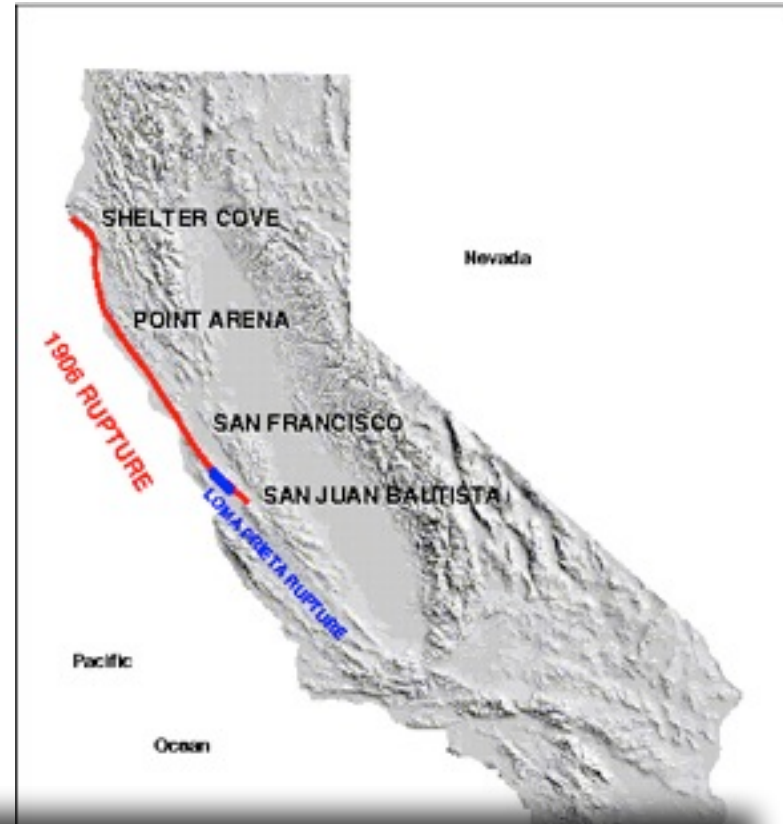
1999 Chi Chi Earthquake, Taiwan (M= 7.6)



Reverse Displacement
400 km long
as much as 16m offset

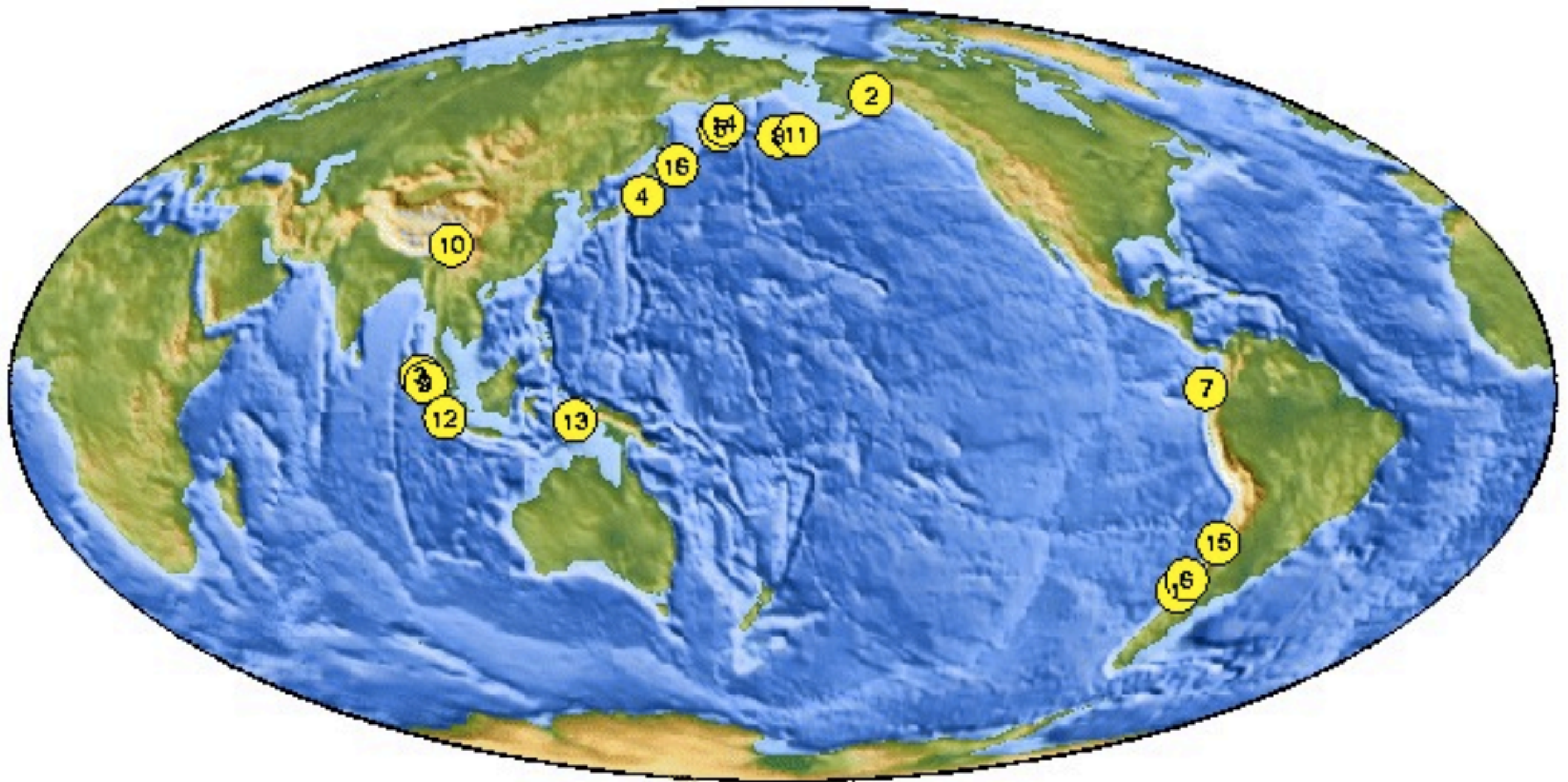


1906 San Francisco (M= 7.9)



Strike-slip Displacement
477 km Rupture length
as much as 8m offset

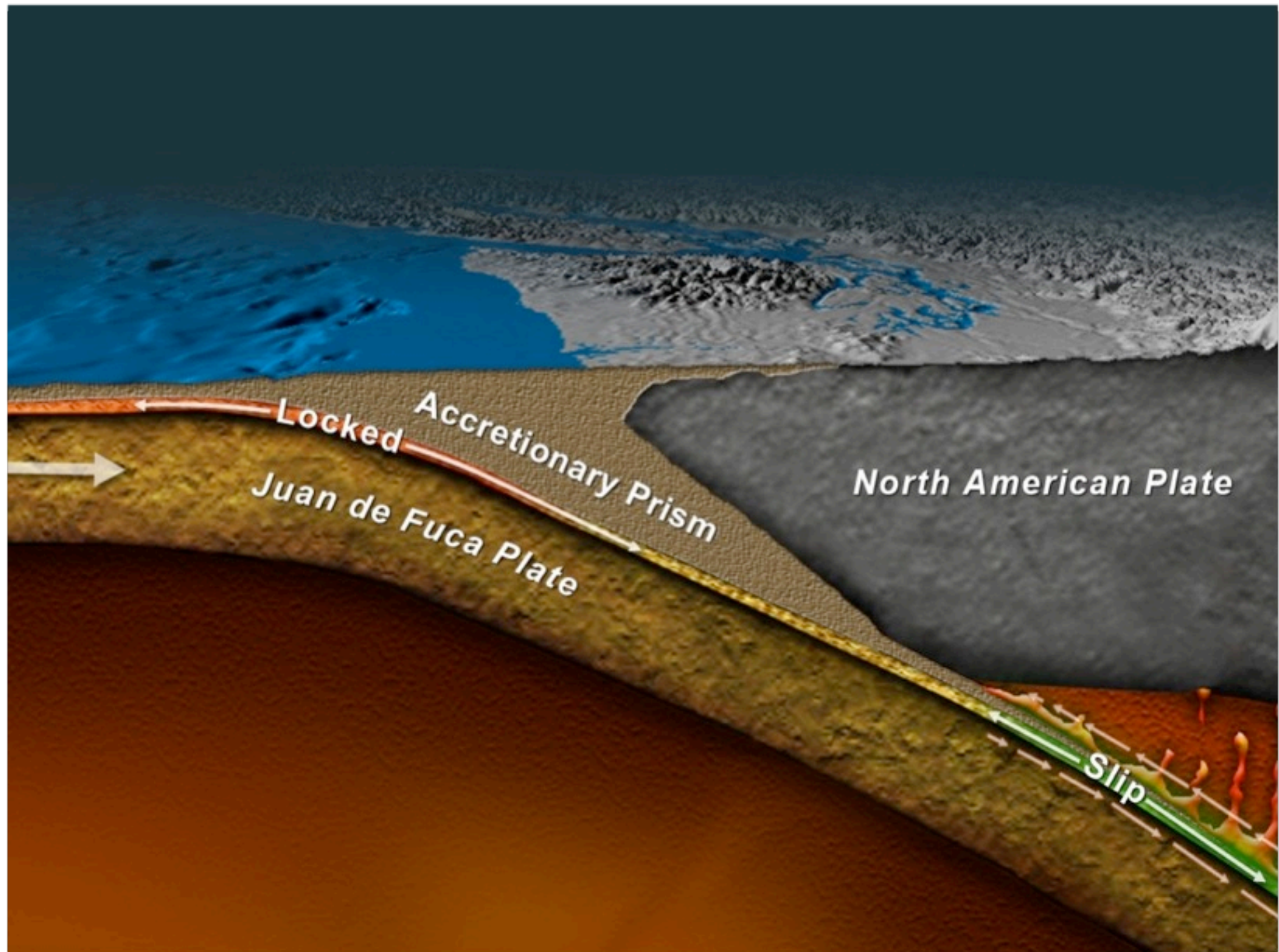
Largest Earthquakes in the World Since 1900



Four largest Recorded Earthquakes

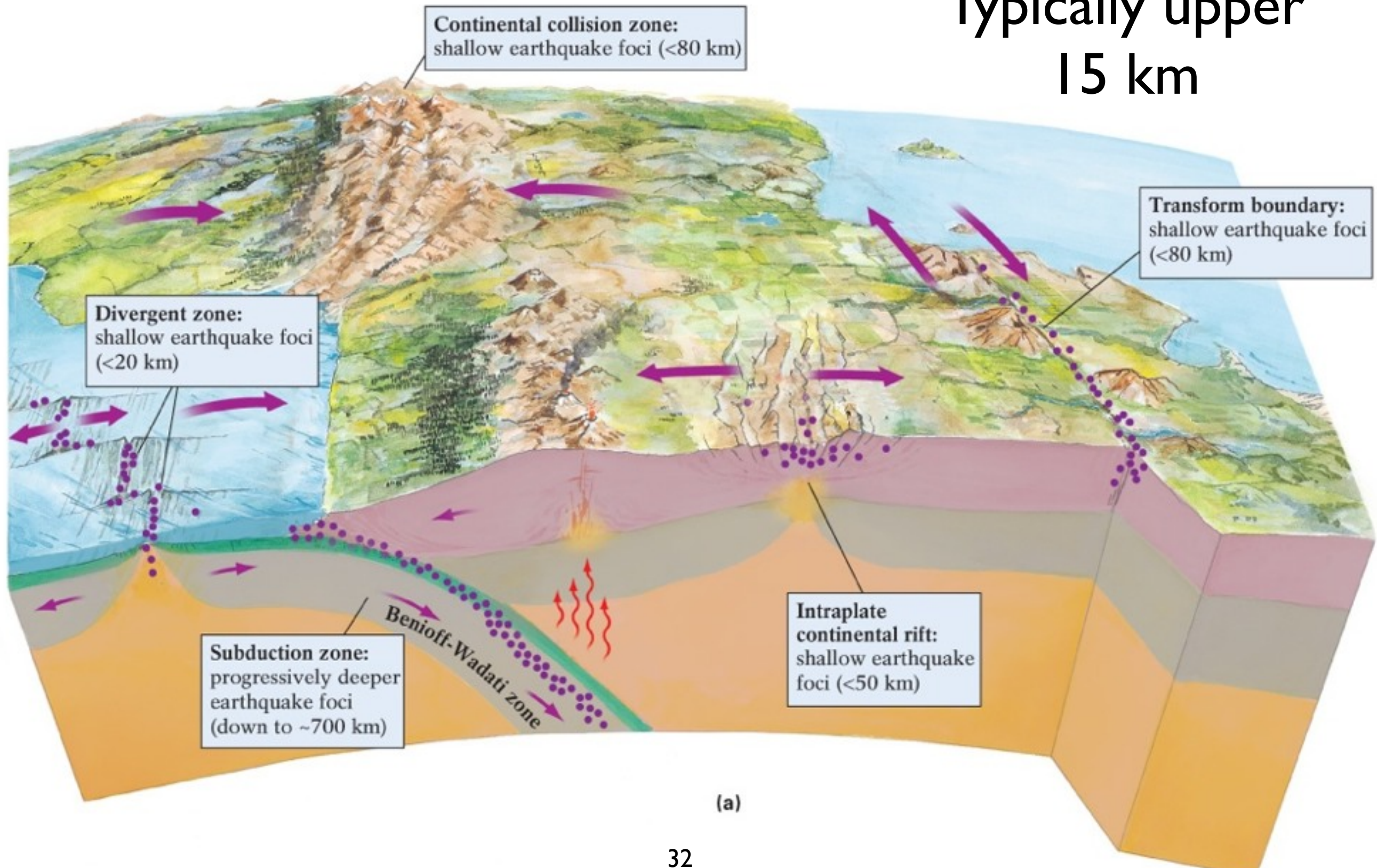
- 1) 1960 Chile Earthquake ($M = 9.5$)**
Reverse displacement, 1000 km offset 20 m
- 2) 1964 Great Alaskan Earthquake ($M = 9.2$)**
Reverse displacement, 1000 km offset 15 m
- 3) 2004 Sumatra Earthquake ($M = 9.1$)**
Reverse displacement, 1600 km offset 10 m
- 5) 2011 Tohoku Earthquake ($M = 9.0$)**
Reverse displacement, 1600 km offset 5 m

What is happening at subduction zones?



Where Earthquakes Happen

Typically upper
15 km



Hazards Associated with Earthquakes

Permanent fault offset

Shaking

- Ground Acceleration
- Amplification
- Liquifaction
- Resonance

Tsunami

Fire

Permanent Fault Offset



1999 Izmet, Turkey

Shaking Ground Acceleration

The rate of change of ground velocity as seismic waves propagate both vertically and horizontally

Based on the acceleration due to gravity

$$9.8\text{m/s}^2 \text{ (32 ft/s}^2\text{)} = 1.0g$$

Weak buildings experience damage at 0.1g

People begin to lose footing around 0.2g

In Tarzana during 1994 Northridge Earthquake

accelerations reached 1.2g vertical and 1.8g horizontal

Earthquake Shaking Potential for California

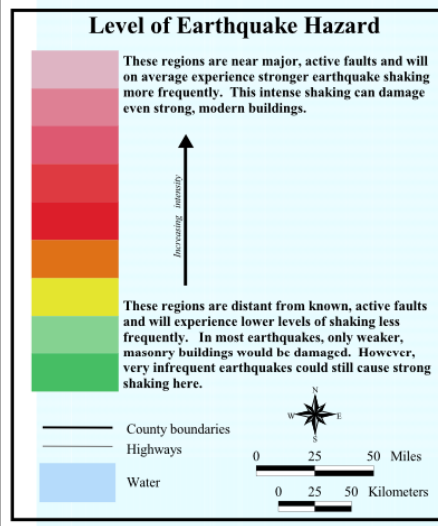
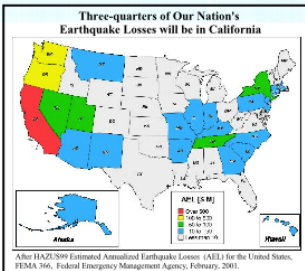
Spring, 2003

This map shows the relative intensity of ground shaking and damage in California from anticipated future earthquakes. Although the greatest hazard is in the areas of highest intensity as shown on the map, no region within the state is immune from potential for earthquake damage. Expected damages in California in the next 10 years exceed \$30 billion.

Important messages about earthquakes for Californians to remember:

- Earthquakes have produced over \$55 billion in losses in California since 1971. The next large earthquake may produce even greater losses, especially if it affects a major urban area. California's two largest urban centers lie in the State's highest seismic hazard zones.
- A large earthquake in or near a major urban center in California will disrupt the economy of the entire State and much of the nation. Effective disaster planning by State and local agencies, and by private businesses, can dramatically reduce losses and speed recovery.
- Current building codes substantially reduce the costs of damage from earthquakes, but the codes are intended only to prevent widespread loss of life by keeping the building from collapsing, not to protect the building from damage.
- If the Northridge or Loma Prieta earthquakes had occurred closer to a major population center, fatalities would have been much higher. The earthquakes in Japan (over 5,000 deaths), Taiwan (over 2,000 deaths), and Turkey (over 20,000 deaths) produced catastrophic death tolls.
- After a large earthquake, residents and businesses may be isolated from basic police, fire, and emergency support for a period ranging from several hours to a few days. Citizens must be prepared to survive safely on their own, and to aid others, until outside help arrives.
- Maps of the shaking intensity after the next major earthquake will be available within minutes on the Internet. The maps will guide emergency crews to the most damaged regions and will help the public identify the areas most seriously affected.

Efforts to reduce the losses from earthquakes have already proven effective. California's enhanced building codes; strengthened highway structures; higher standards for school and university, police and fire station construction; and well prepared emergency management and response agencies, reduced deaths, injuries and damage in recent earthquakes. Strengthening of older buildings, gaining a better understanding of California's earthquake threat, and continued education and preparedness will pay an even greater dividend to Californians in speeding response and recovery after future earthquakes.



Data Sources: Seismic Shaking Hazard calculated by the California Geological Survey from the USGS/CGS seismic hazards model (Frankel and others, 2002) considering amplification in near surface soils as shown by Wells and others (2000) using the amplification factors recommended by the Building Seismic Safety Council (1997). Major roads from Thomas Brothers Maps, Inc., 2000, 2001. Shaded relief from U.S. Geological Survey 30 meter DEMs.

Building Seismic Safety Council, 1997, 1997 Edition, Recommended Provisions for Seismic Regulations for new buildings and other structures, part 1, provisions, FEMA 302, Building Seismic Safety Council, Washington, D.C., 334 p.

Frankel, A.D., M.D. Petersen, C.S. Mueller, K.M. Haller, R.L. Wheeler, E.V. Leyendecker, R.L. Wesen, S.C. Harmsen, C.H. Chance, D.M. Perkins, and K.S. Rukhovich, 2002, Documentation for the 2002 Update of the National Seismic Hazard Maps U.S. Geological Survey Open-File Report 02-420, 37 p.

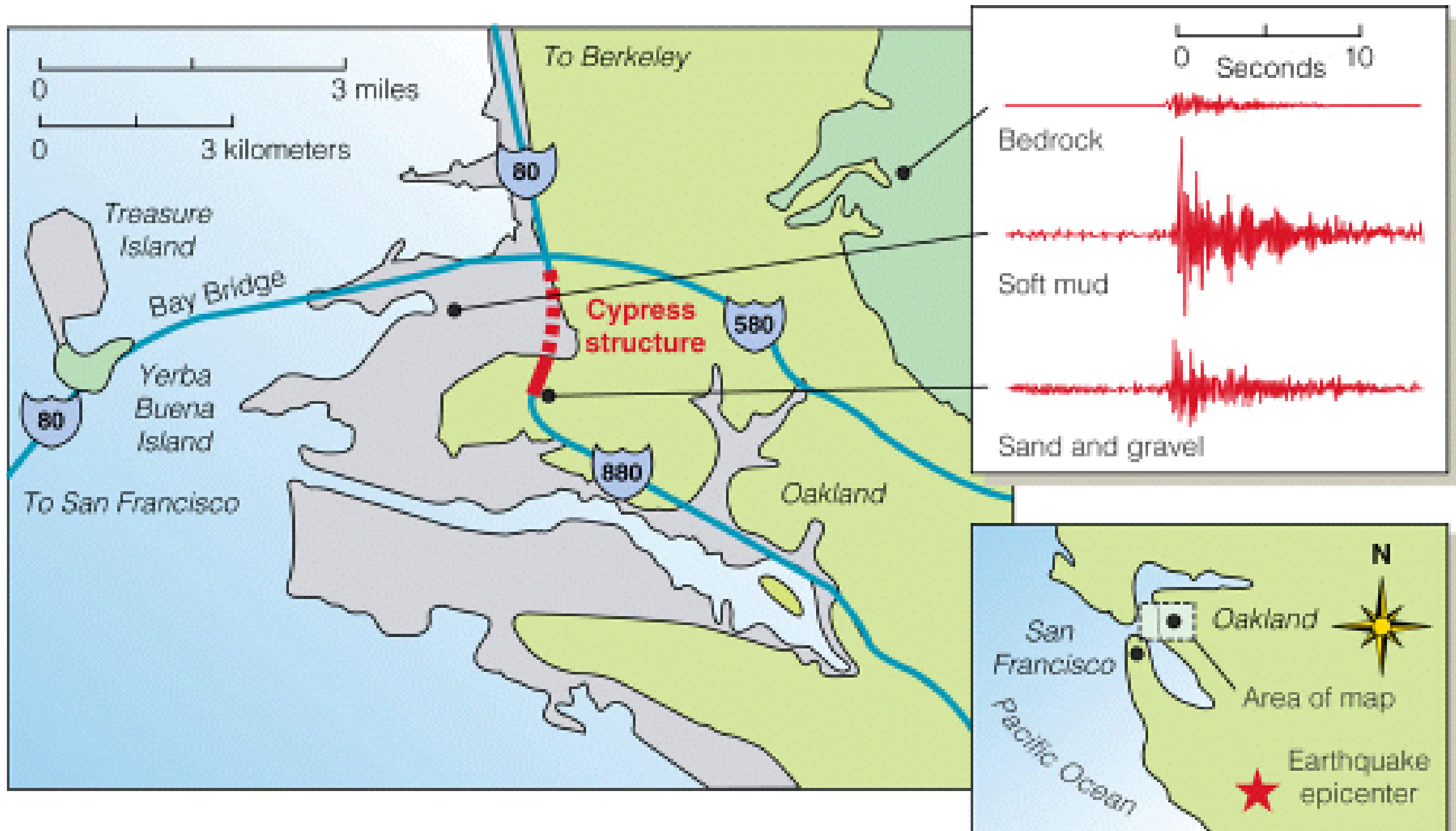
Wells, C.J., M.D. Petersen, W.A. Bryant, M.S. Reachi, S.S. Tan, G.C. Taylor, and J.A. Treiman, 2000, A site conditions map for California based on geology and shear wave velocity, Bulletin of the Seismological Society of America, v. 90, no. 4b, p. S187-S208.

Additional copies can be ordered through CSSC by calling (916) 263-5306 or the map can be downloaded from <http://www.seismic.ca.gov/cgsph.htm>.

www.seismic.ca.gov www.comets.ca.gov www.oes.ca.gov www.usgs.gov

Shaking Potential in California

Shaking Amplification



Loma Prieta, 1989

Shaking Liquefaction

The pressure of water increases with shaking pushing individual grains apart allowing substrate to flow as a liquid.

Shaking Liquefaction



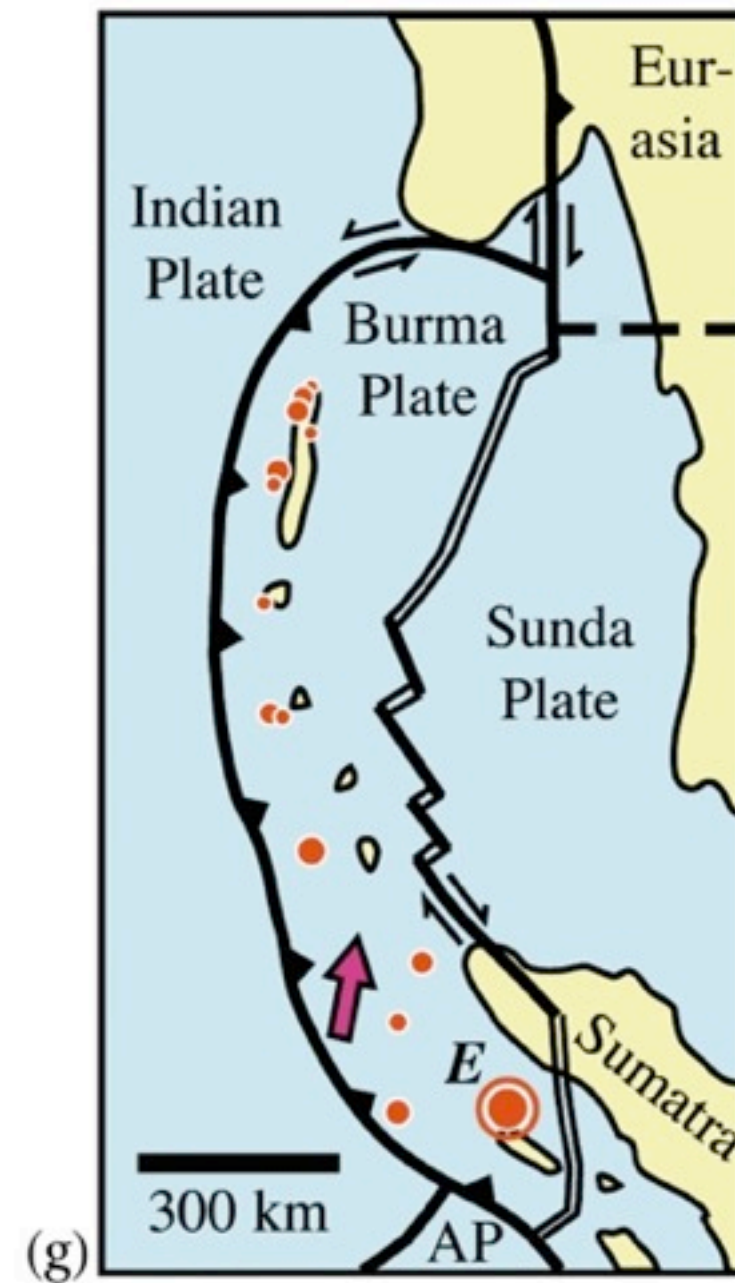
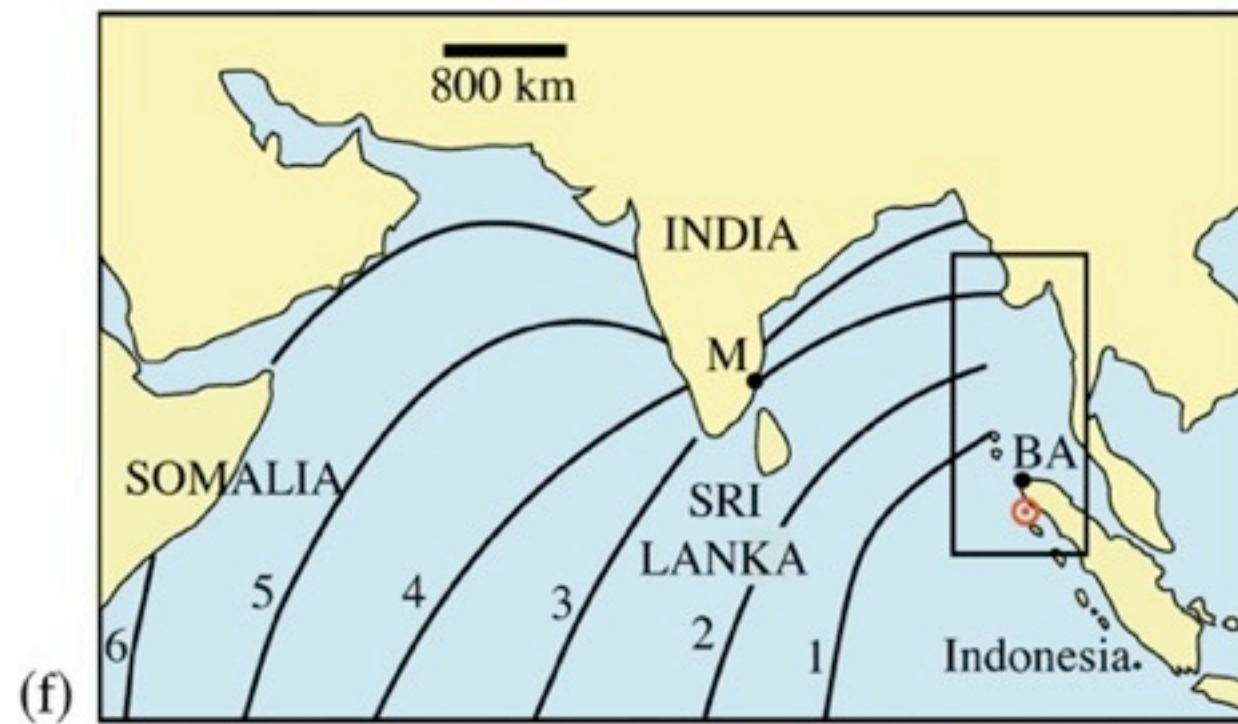
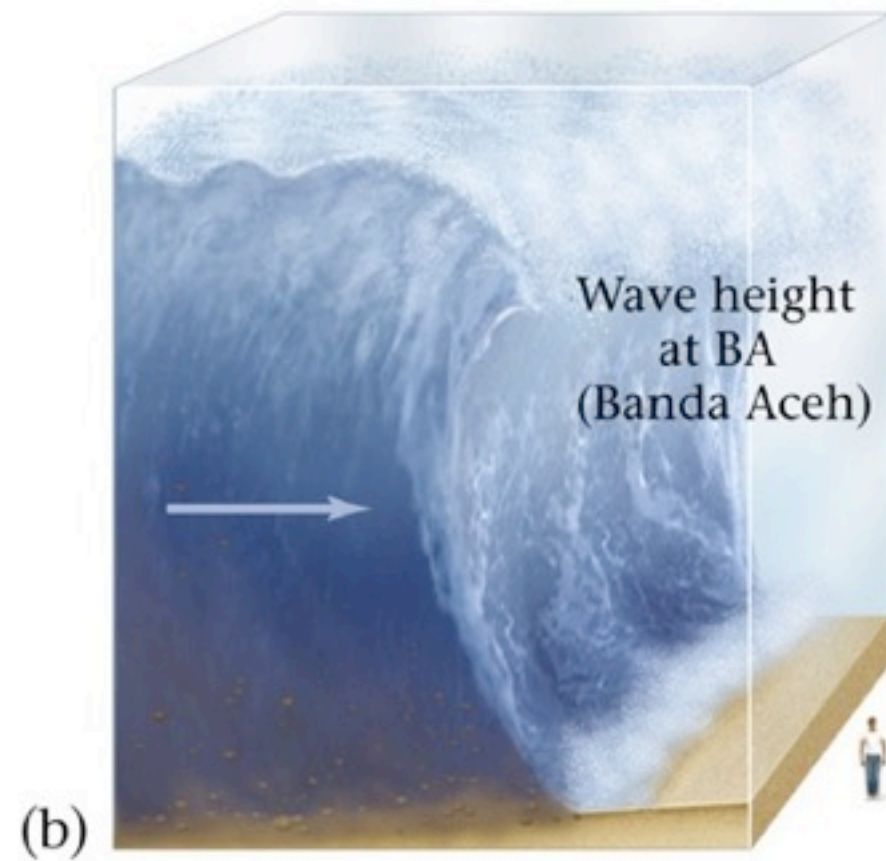
Anchorage, AK 1964

Shaking Resonance

if seismic waves and a particular building has the same vibrational frequency*, enhanced motion occurs

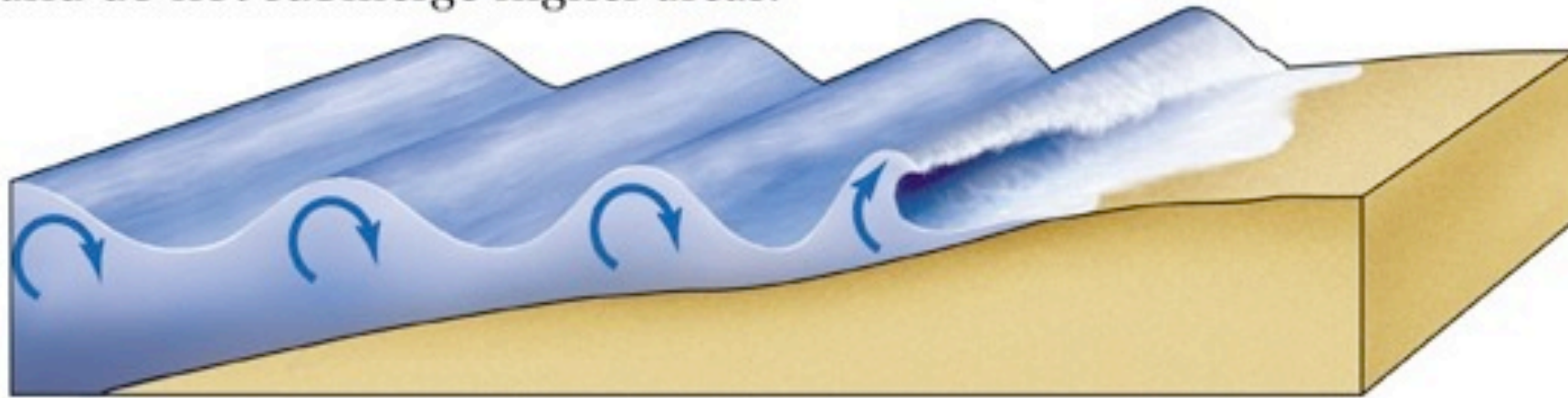
* every object has a natural vibration frequency based on SIZE and MASS

Tsunami



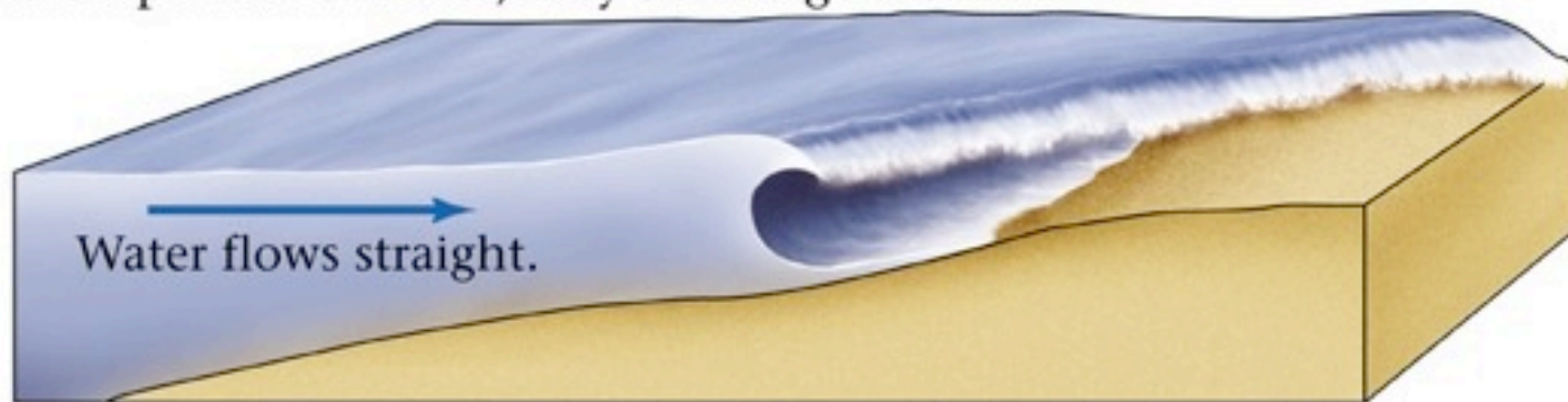
Tsunami

Wind-driven waves contain a small volume of water, and do not submerge higher areas.



(b)

Tsunamis are so wide (measured perpendicular to shore) that, like a plateau of water, they submerge the land.



(c)

Essentials of Geology

Fire

San Francisco 1906



Buildings, Fires, and Tsunami Kill!



Earthquakes are Fun!

US Geological Survey Headquarters Menlo Park, CA



2011 Tohoku Japan Tsunami Video

2011 Tohoku Japan Tsunami Video



2011 Tohoku Japan Tsunami Video

2011 Tohoku Japan Tsunami Video

