Department of Geological Sciences, Faculty of Sciences
Masaryk University/Brno & Czech Geological Society

September 12-14, 2011

Short Course on Geological Hazards

Lecture 2 (Mon PM):

Four Earthquake Topics Relevant to SHA

- **Tectonic Environment** (Age, Stress Regime)
- **Key Equ. Parameters** (Mo, Mw, stress drop, slip)
- **Seismicity Parameters** (n[Mw], Mmax, Mchar)
- **Ground Motions** (in Time and Spectral Domains)

Klaus H. Jacob

Lamont-Doherty Earth Observatory
of Columbia University, NY
jacob@ldeo.columbia.edu

<u>Before</u> Addressing Seismic Hazards Assessment (SHA) itself, we first look at some basic Seismology Facts:

i.e. Basic Issues of:

- **The Tectonic Environment** (Age of Crust and Activity, Stress, ...)
- **Individual Earthquakes** (Moment, Magnitude, Stress Drop, ...)
- **Seismicity Rates** (Gutenberg-Richter Power Law)
- **Ground Motions** (as f(d,Mw), in Time and Spectral Domains, etc.)

that are Relevant to Seismic Hazard Assessment (SHA)

Basic Observations on:

- The Seismo-Tectonic Environment
- Individual Earthquakes,

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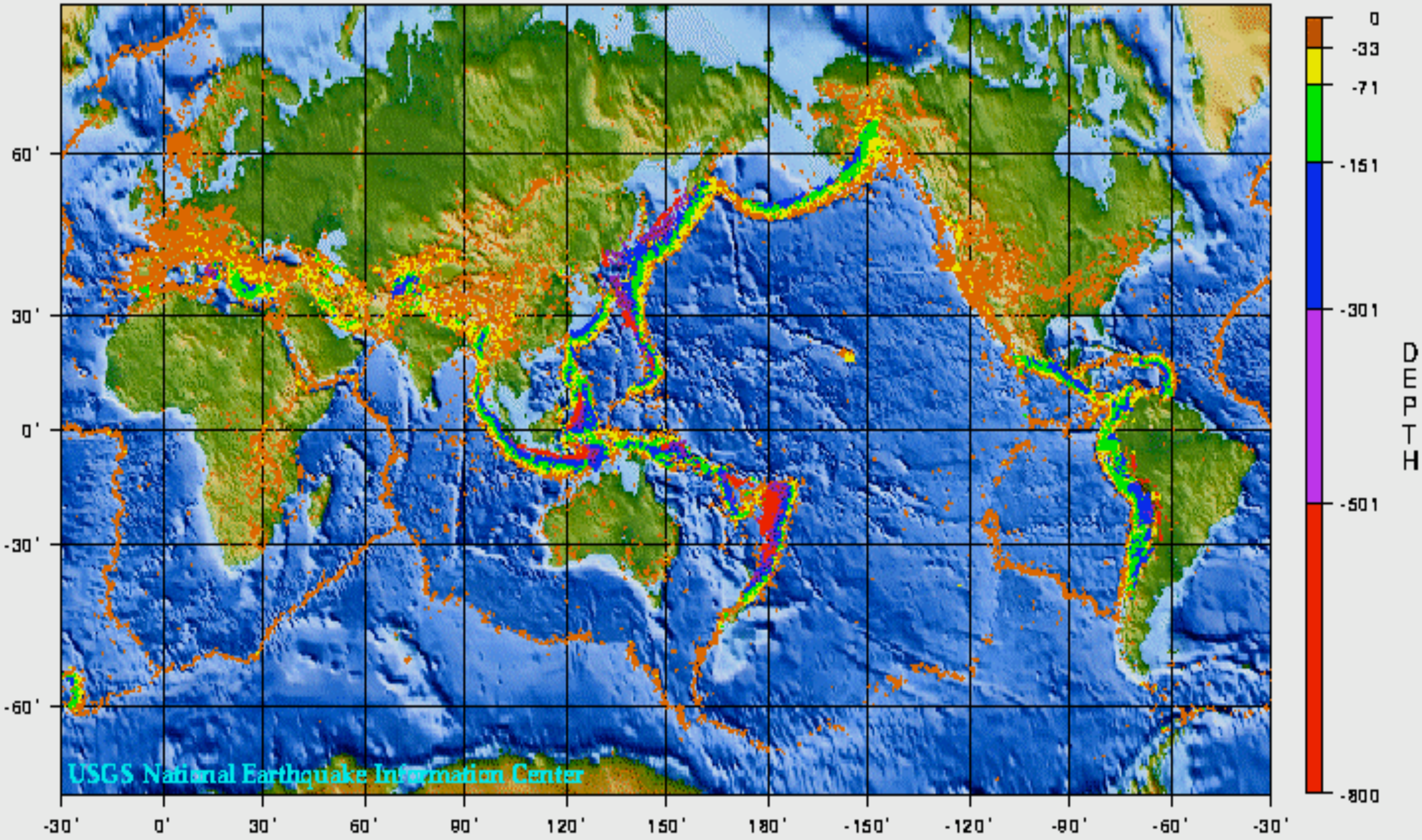
- Seismicity Rates, and
- Ground Motions

Relevant to Seismic Hazard Assessment (SHA):

World Seismicity: 1975 - 1995



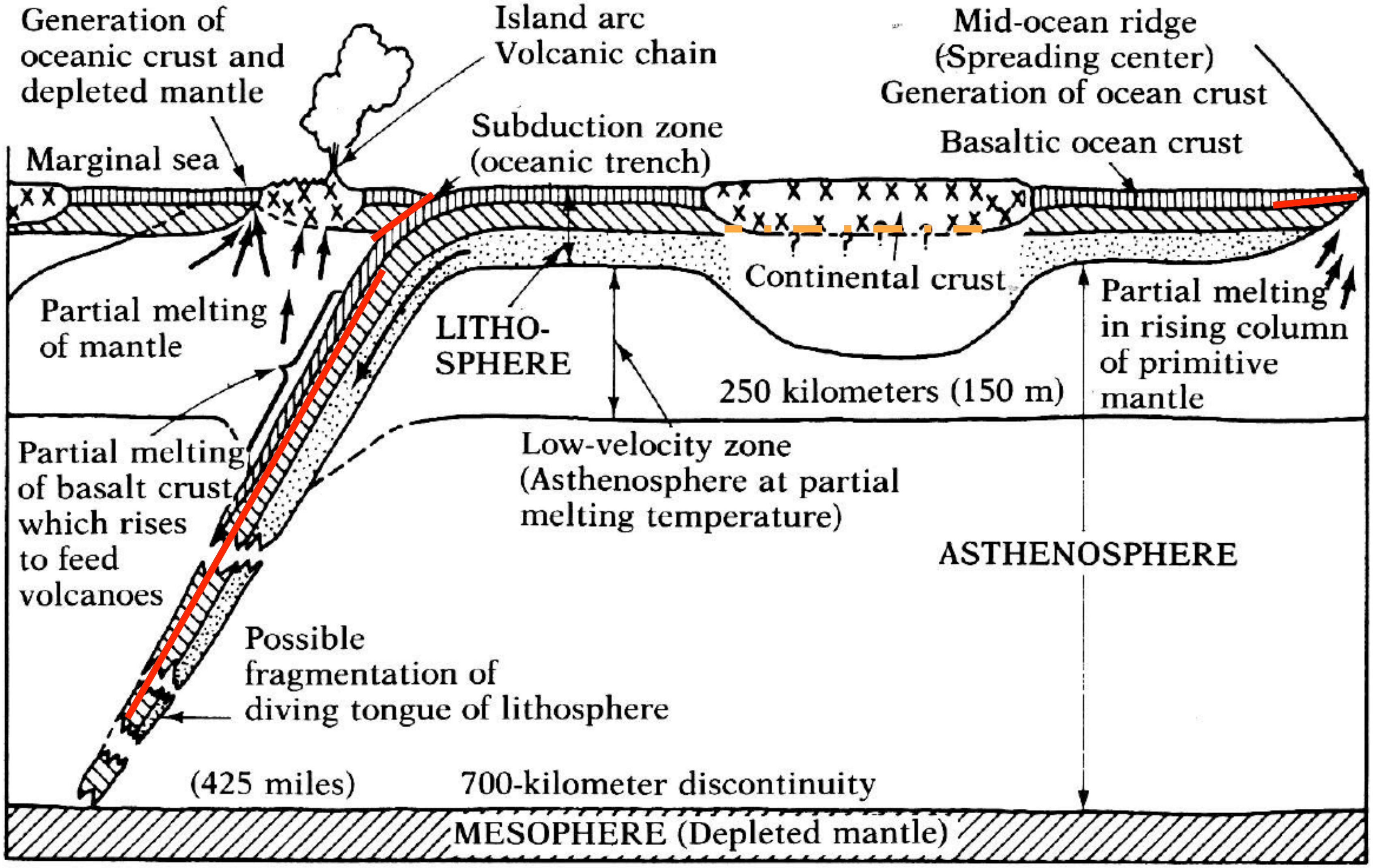
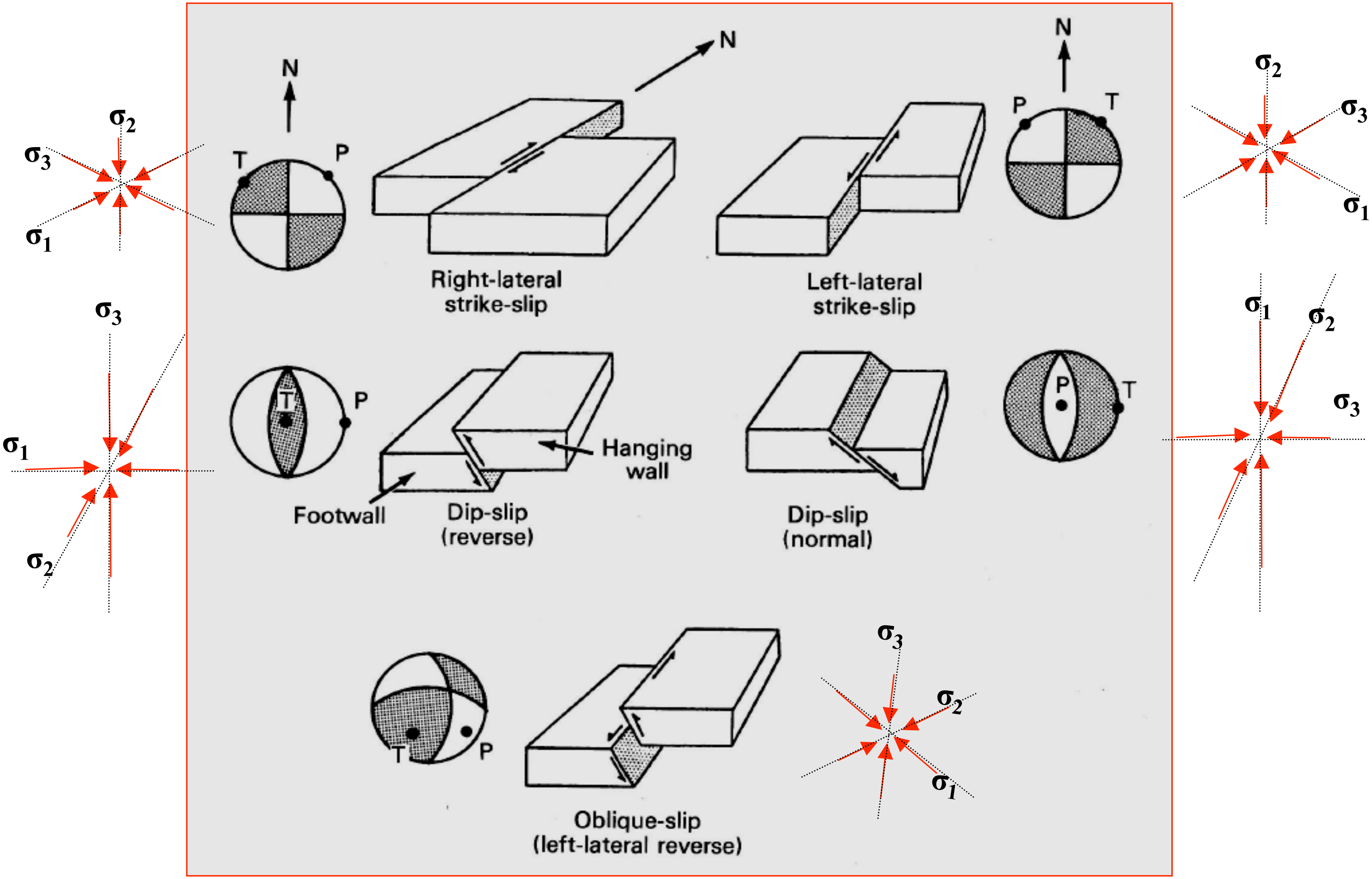
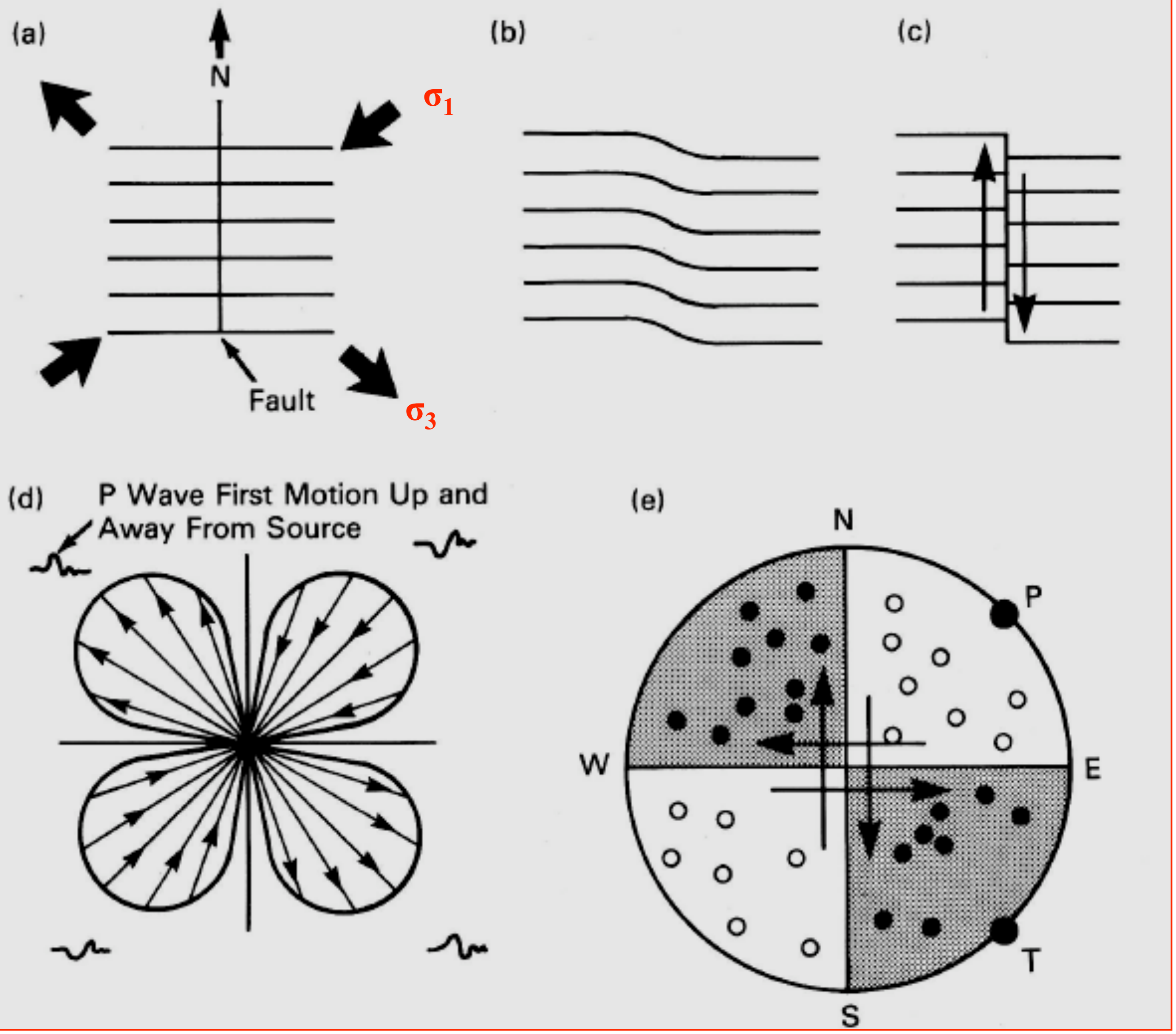


FIGURE 4.3 Schematic cross-section of a lithospheric plate (after Dewey 1972). Note that the mantle includes the mesosphere, the asthenosphere and the lower part of the lithosphere. Changes in rock composition or properties define the boundaries between these elements.

The principal stresses are ordered by magnitude: $\sigma_1 > \sigma_2 > \sigma_3$




(a)
N
σ1
Fault
σ3
(b)
(c)
(d)
P Wave First Motion Up and Away From Source
(e)
N
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W
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S

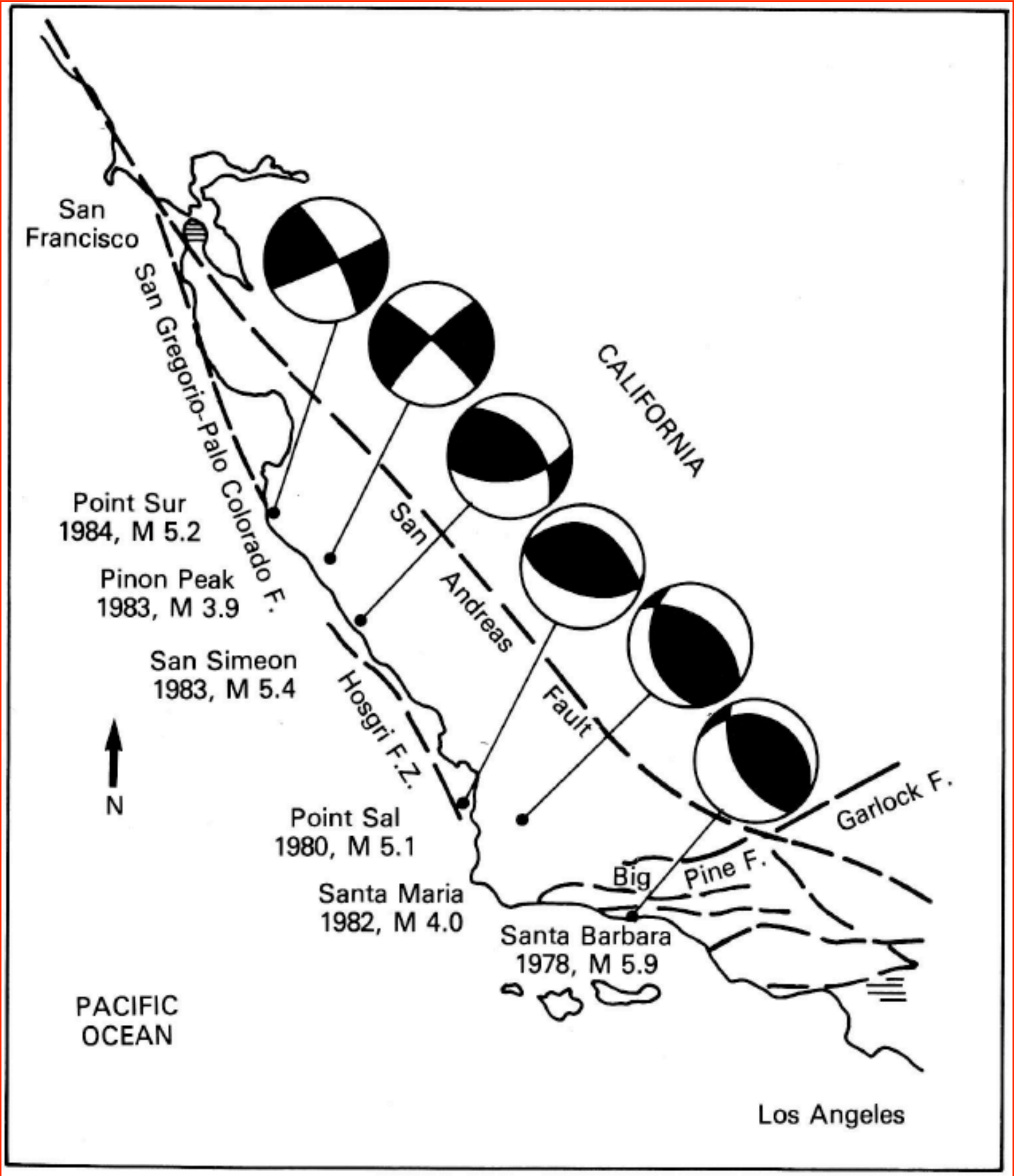
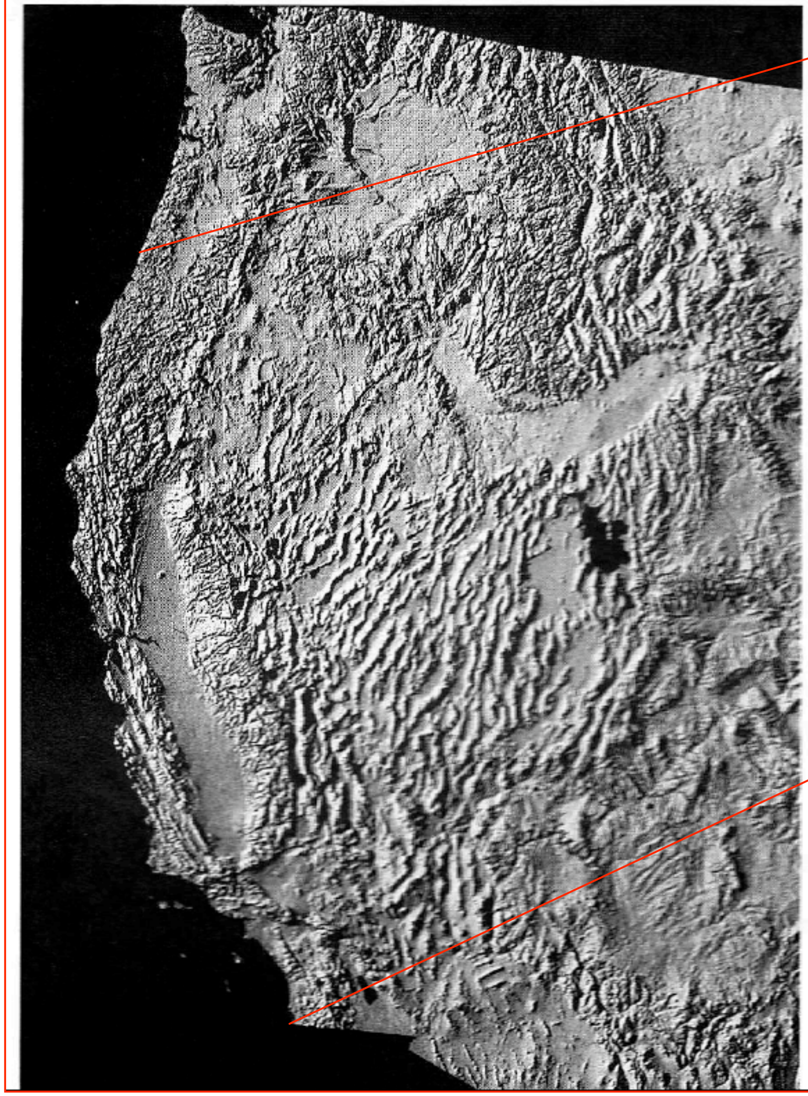


FIGURE 2.8 Earthquake focal mechanisms along the coast of central California. Strike-slip faulting in the northwest changes to oblique and reverse faulting toward the southeast (after Eaton 1984).



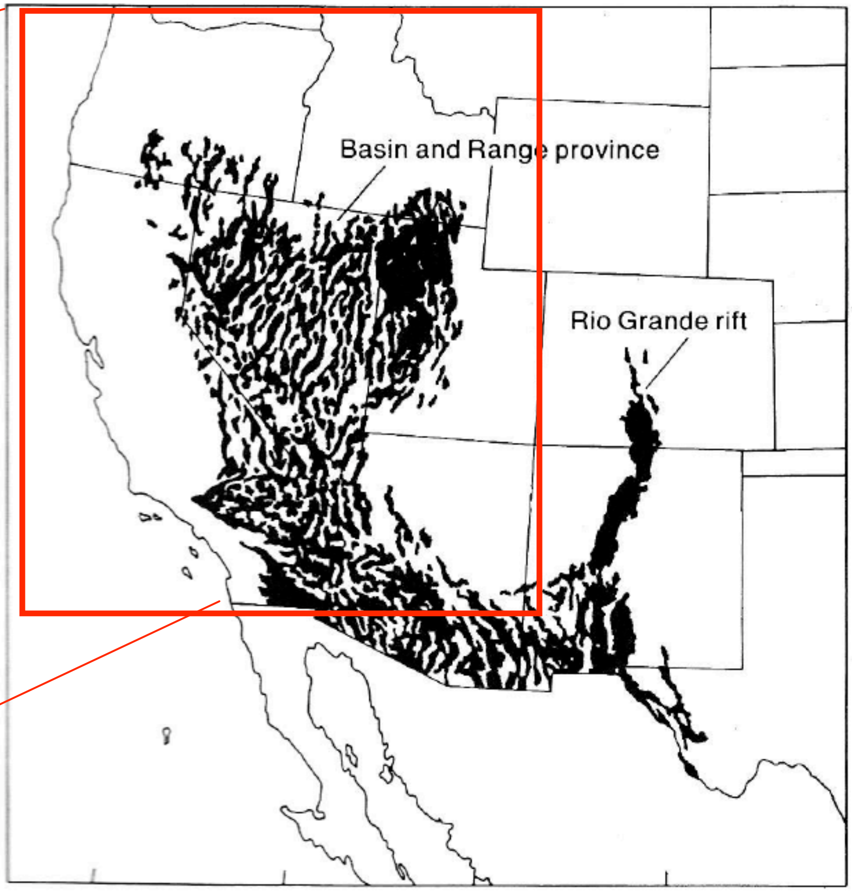
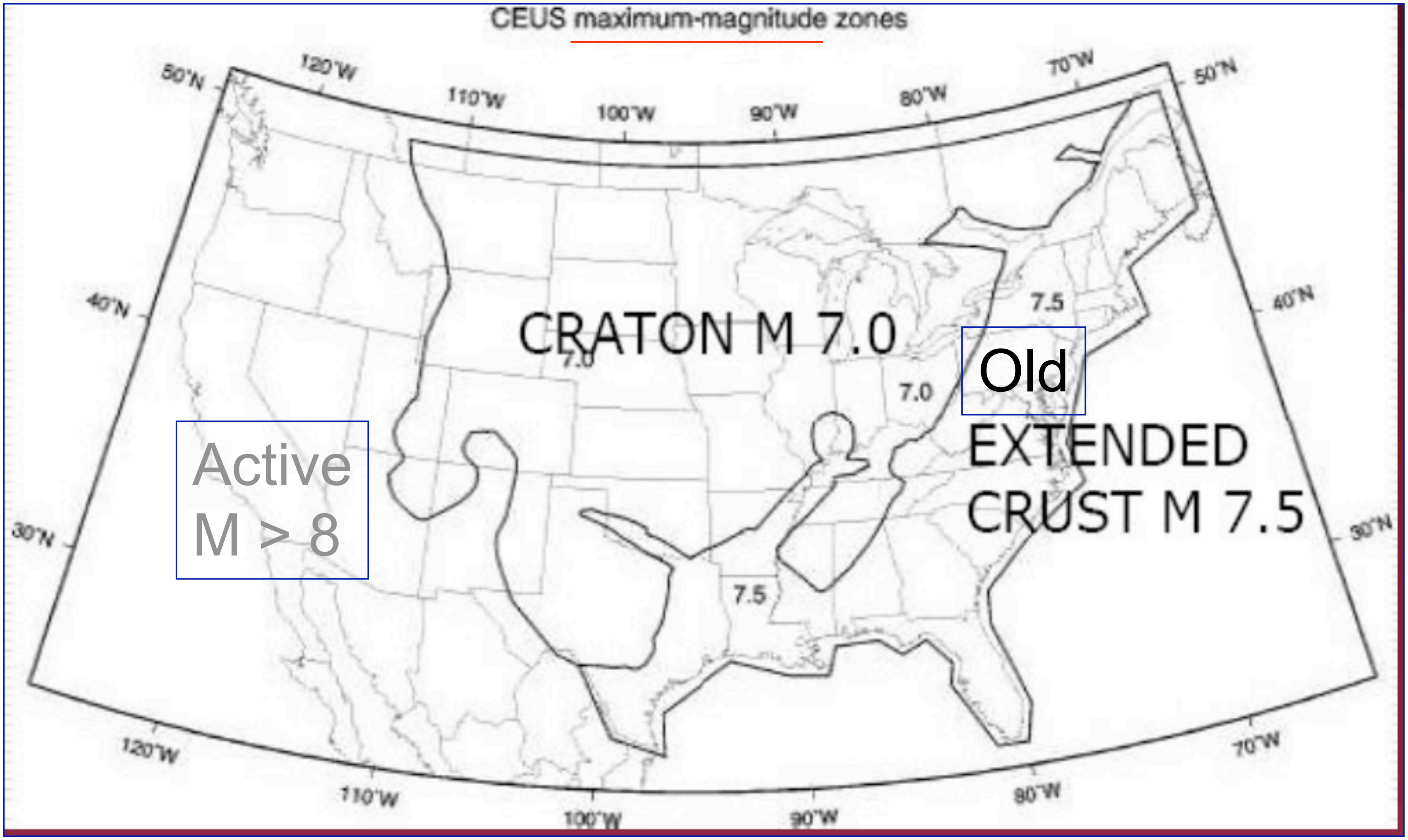


Figure 5.13 Extended topography of Basin and Range province and Rio Grande rift. The sediment-filled basins are colored dark.

Distributed Rifting vs. Single Localized Rift Valley: both strongly attenuate propagation of seismic waves: “Low Q”



Low Q /
High Attenuation

Very High Q /
Very Low attenuation

Medium Q /
Medium Attenuation

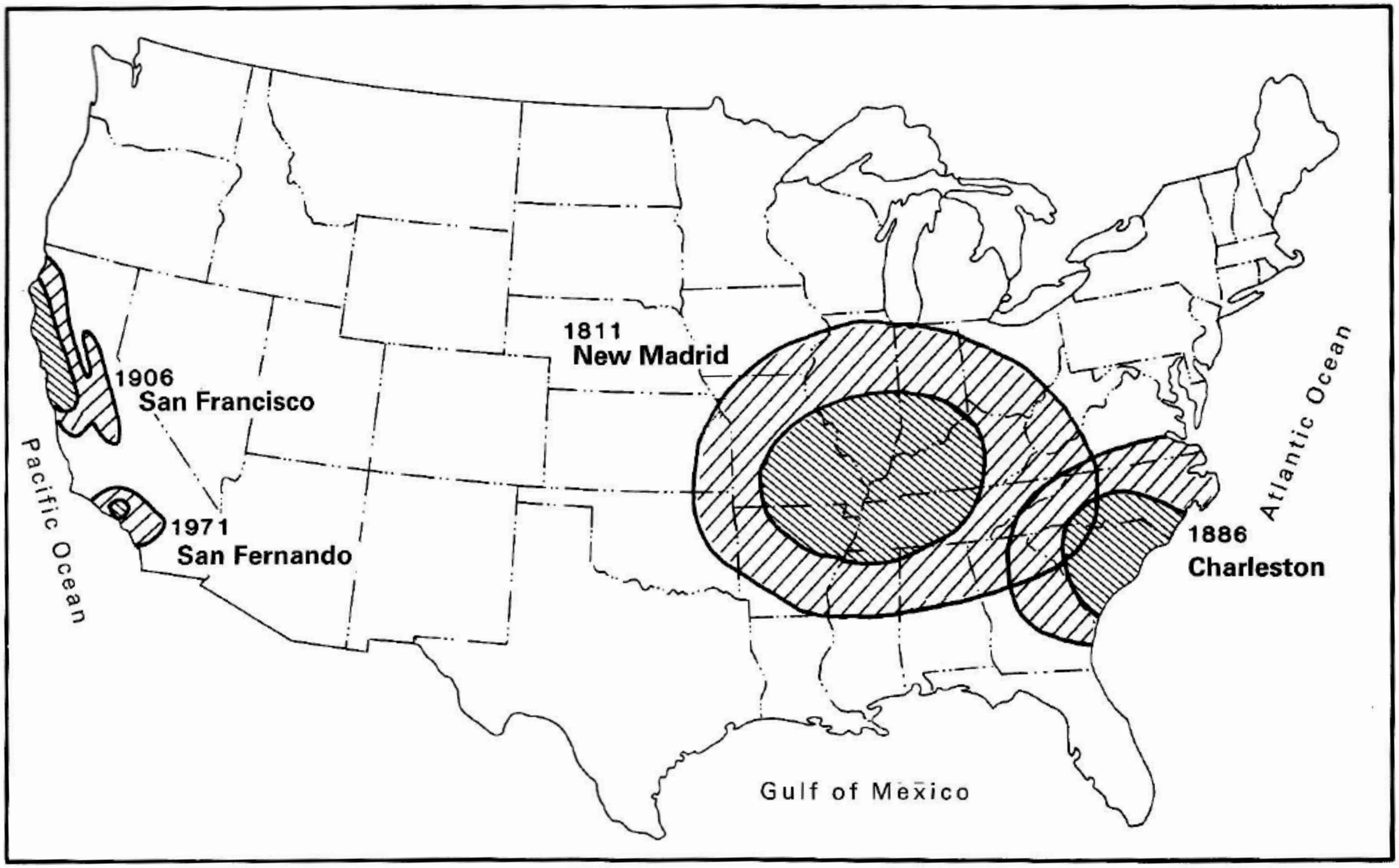


Figure 5.16 Felt areas of some large earthquakes in the United States. Inner-ruled areas are Mercalli intensities greater than VII; ruled areas are intensities VI to VII.

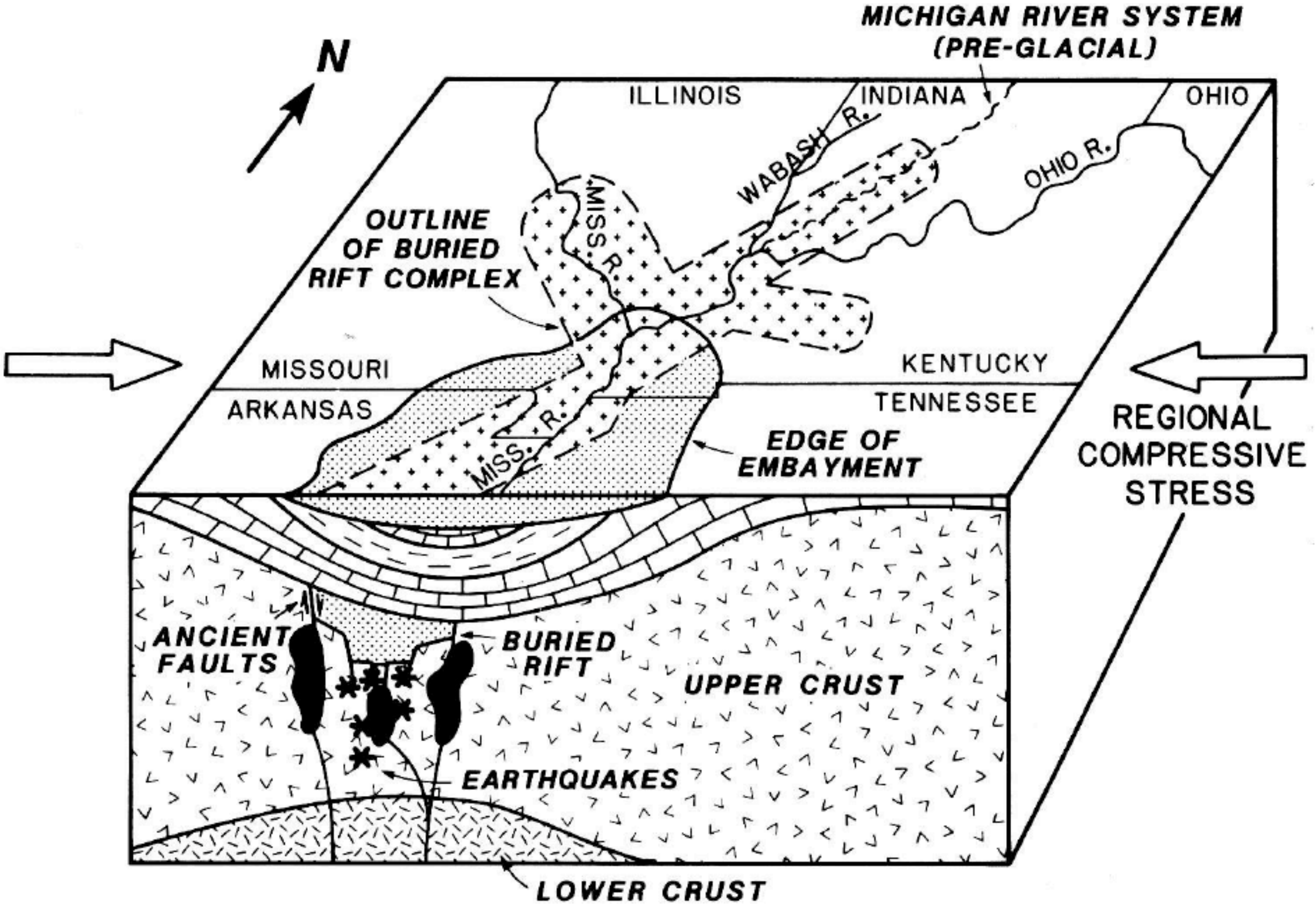
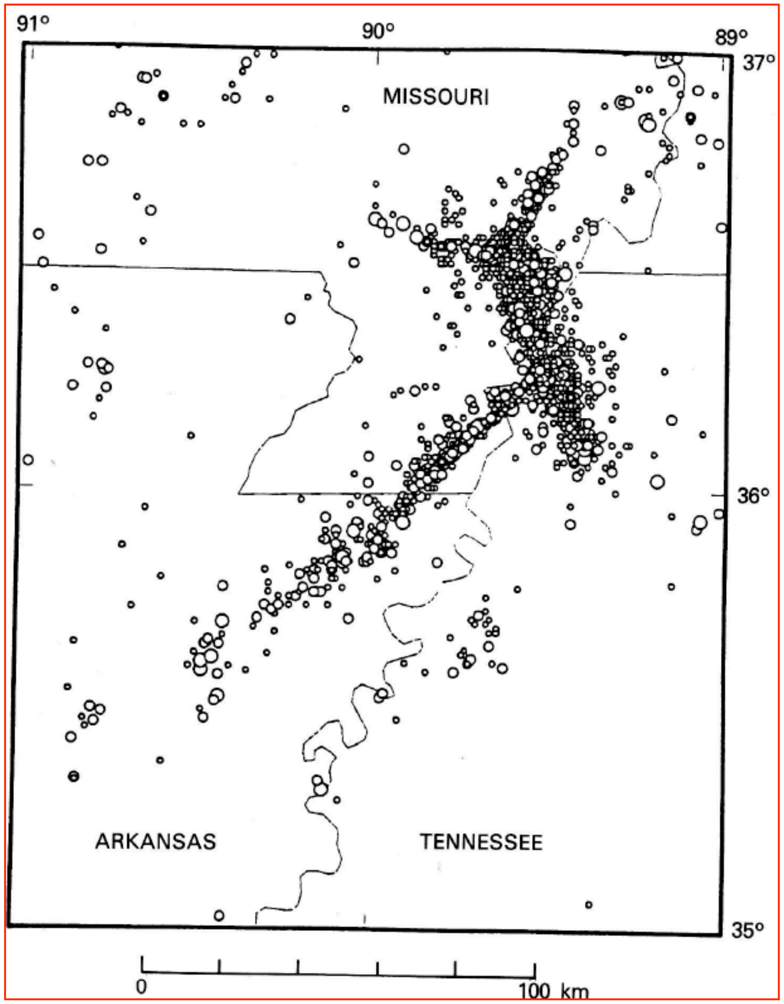


FIGURE 4.8 Block diagram illustrating the present configuration of the New Madrid Rift Complex. Dark areas indicate intrusions near the edge of the buried rift. An uplifted and possibly anomalously dense lower crust is suggested as the cause of the positive gravity anomaly associated with the upper Mississippi Valley (after Braile and others 1986).



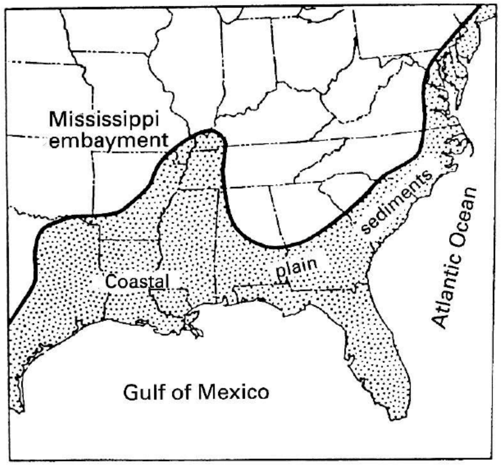


Figure 5.18 Map of coastal-plain sediments deposited by rivers eroding North America. Note that the Mississippi River embayment juts northward well into North America. Why? There is a failed rift at depth. A smaller, failed rift heads off into southern Oklahoma.

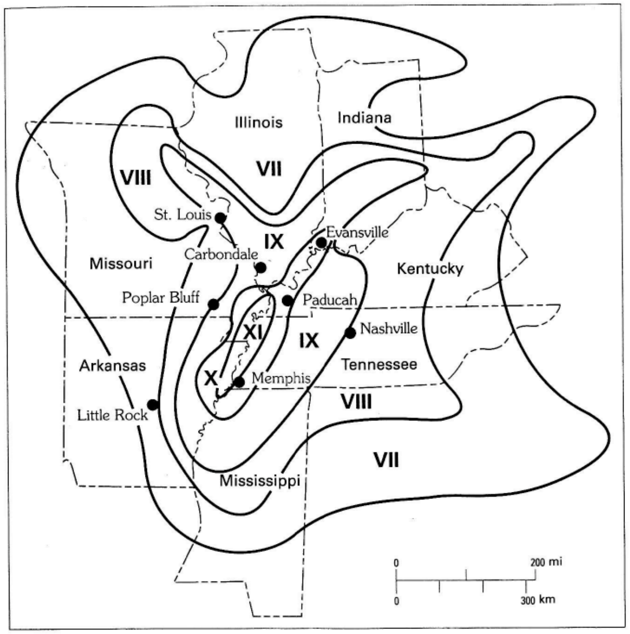


Figure 5.17 Map showing estimated Mercalli intensities expected from a recurrence of an 1811–1812 New Madrid earthquake. Intensity VIII and above indicates heavy structural damage.

Source: R. M. Hamilton and A .C. Johnston, "Tecumseh's prophecy: Preparing for the next New Madrid earthquake" in *U.S. Geological Survey Circular 1066.*

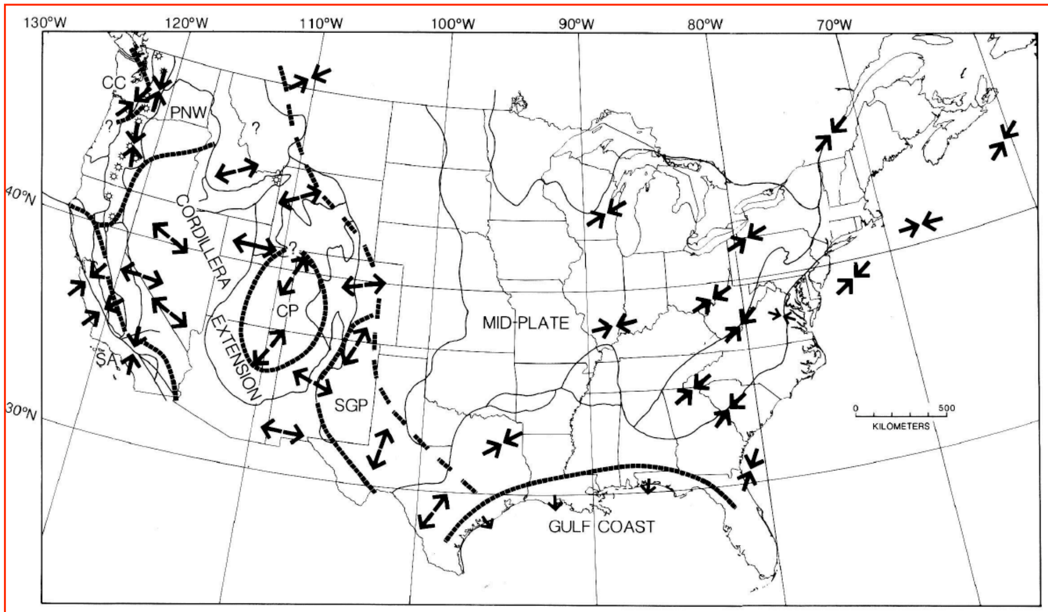
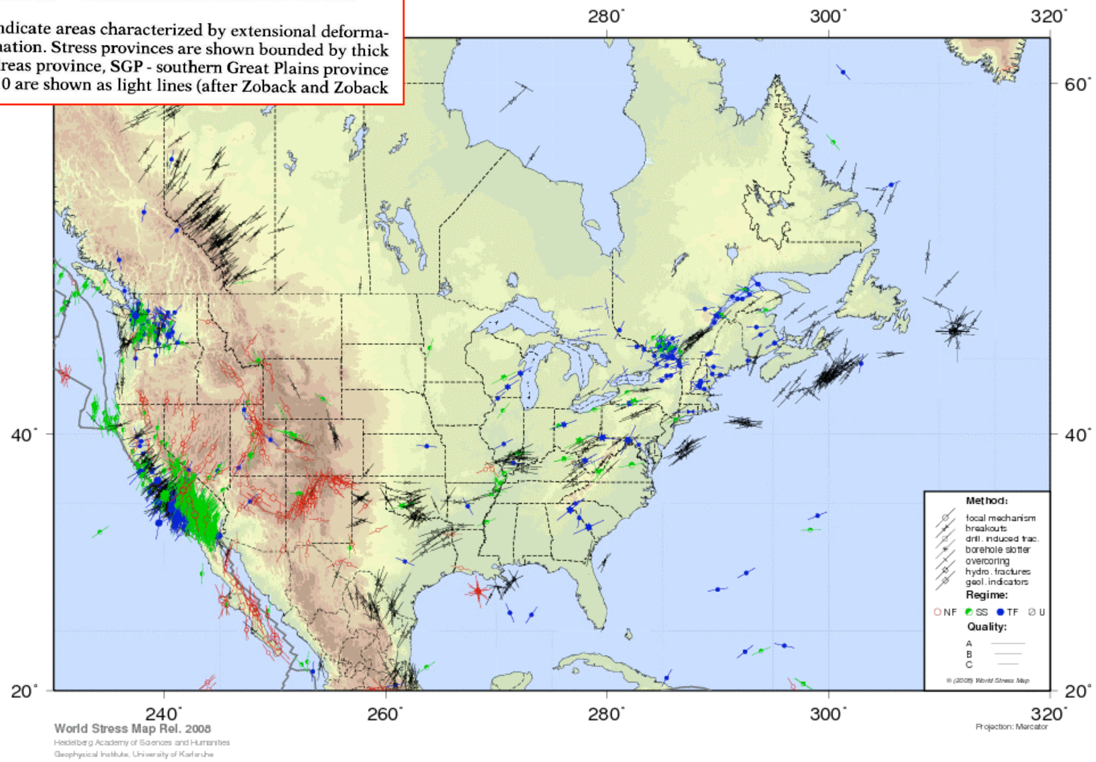


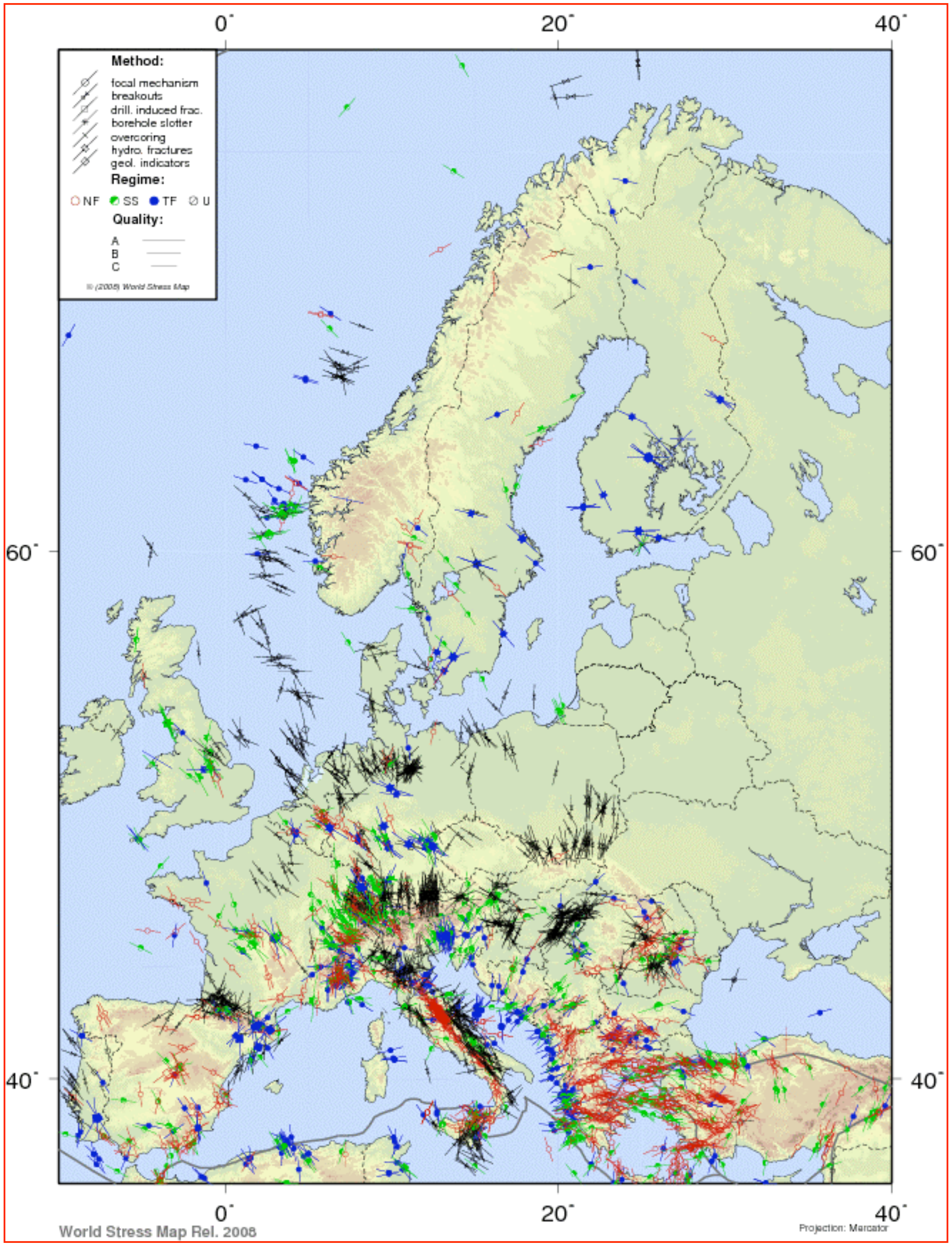
FIGURE 4.10 Generalized stress map of the United States. Outward pointing arrows indicate areas characterized by extensional deformation and inward pointing arrows indicate areas characterized by compressional deformation. Stress provinces are shown bounded by thick dashed lines: CC - Cascade convergent province, PNW - Pacific northwest, SA - San Andreas province, SGP - southern Great Plains province and CP - Colorado Plateau interior. Physiographic province boundaries from Figure 4.10 are shown as light lines (after Zoback and Zoback 1989).



World Stress Map Rel. 2008

Heidelberg Academy of Sciences and Humanities

Geophysical Institute, University of Karlsruhe


Method:
focal mechanism
breakouts
drill. induced frac.
borehole slotter
overcoring
hydro. fractures
geol. indicators
Regime:
NF SS TF U
Quality:
A
B
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© (2008) World Stress Map
0°
20°
40°
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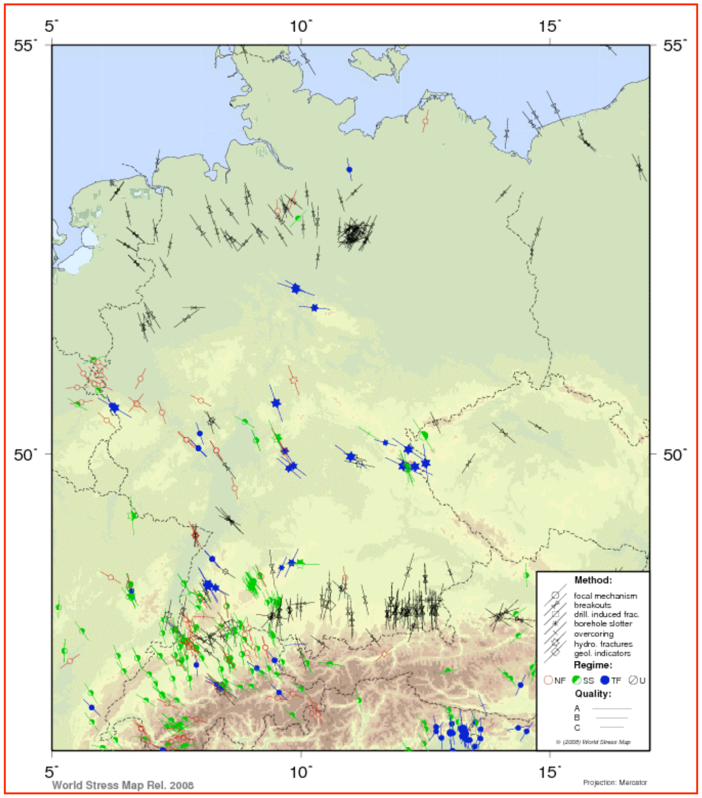
World Stress Map Rel. 2008
Projection: Mercator


5°
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Method:
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© (2008) World Stress Map
World Stress Map Rel. 2008
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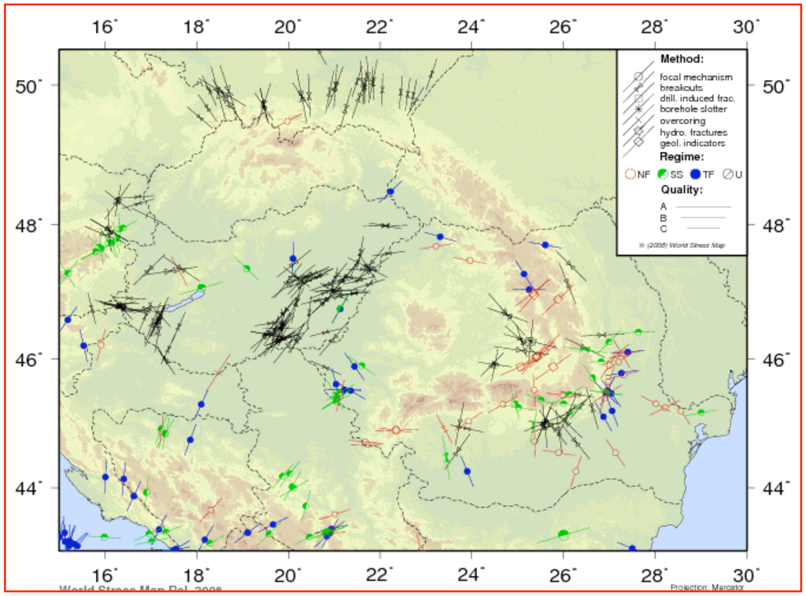
16°
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overcoring
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Regime:
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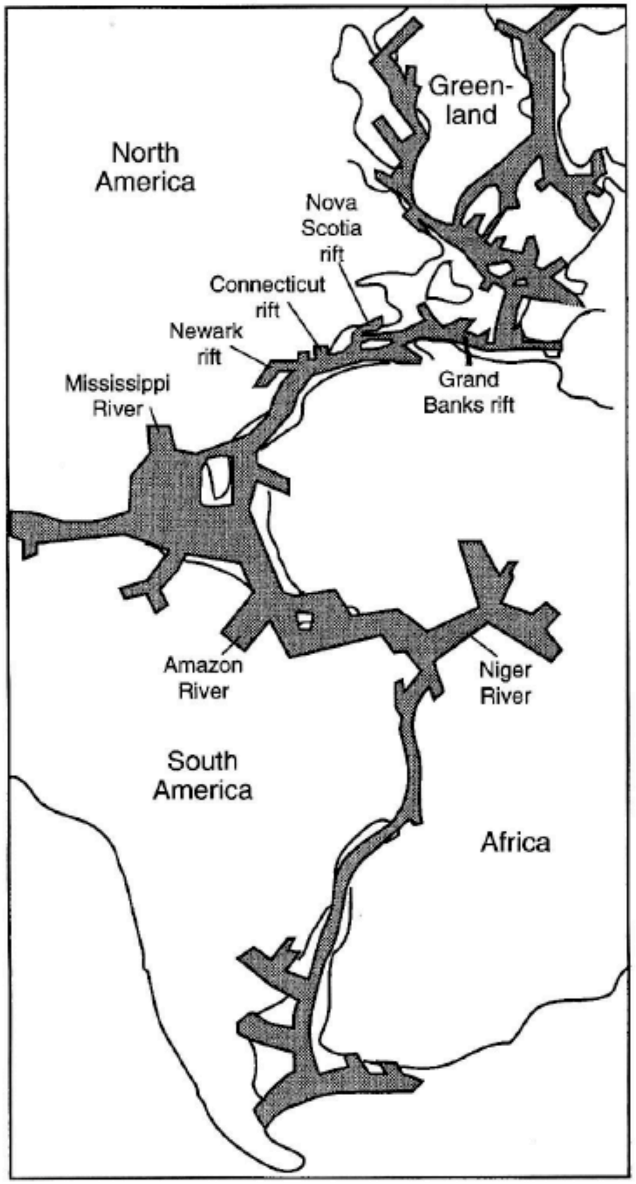

Figure 5.20 Schematic map of rifts that tore at Pangaea about 220 million years ago. Successful rifts combined to open the Atlantic Ocean basin.

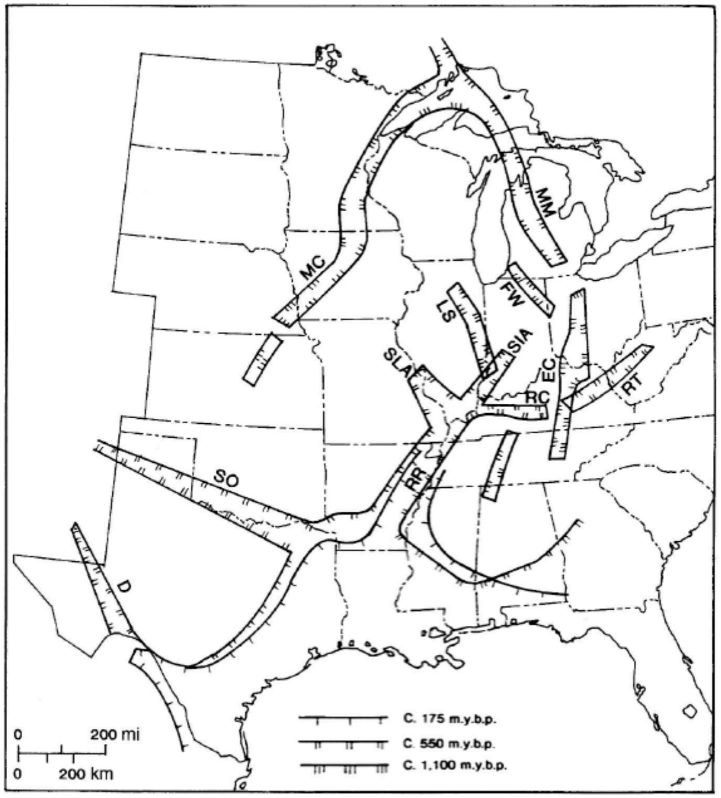

Figure 5.21 Map showing approximate locations of buried, ancient rifts in the central United States. Rifting occurred during three principal times—around 220 to 175 million years ago, 600 to 500 million years ago, and 1,100 to 1,000 million years ago. Some older rifts were apparently rifted again under later plate-tectonic regimes. Rifts are: D, Delaware; EC, East Continent; FW, Fort Wayne; LS, La Salle; MC, Mid-Continent; MM, Mid-Michigan; RC, Rough Creek; RR, Reelfoot rift; RT, Rome Trough; SIA, Southern Indiana Arm; SLA, St. Louis Arm; and SO, Southern Oklahoma.

Source: D. W. Gordon, *U.S. Geological Survey Professional Paper 1364.*

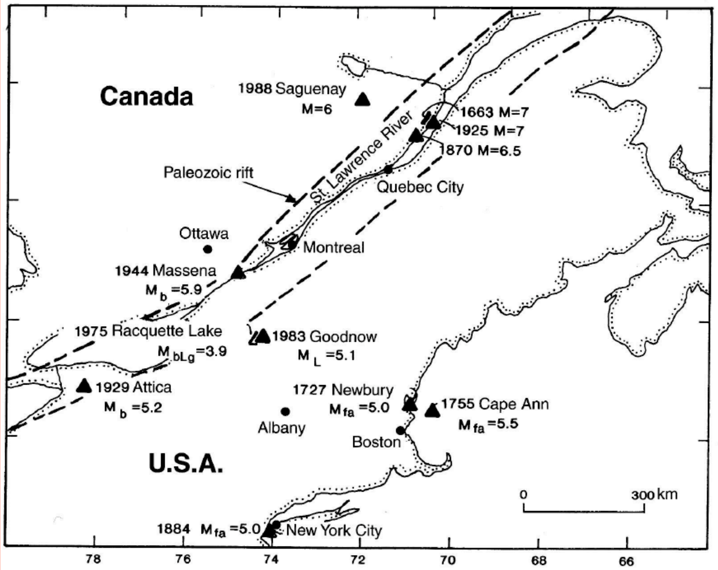

Figure 5.22 Some earthquake locations in the St. Lawrence River valley area and the approximate location of the 600 to 500 million-year-old rift valley. M_{fa} equals magnitude estimated from felt area. Large earthquakes northeast of Quebec City lie in circular Charlevoix seismic zone.

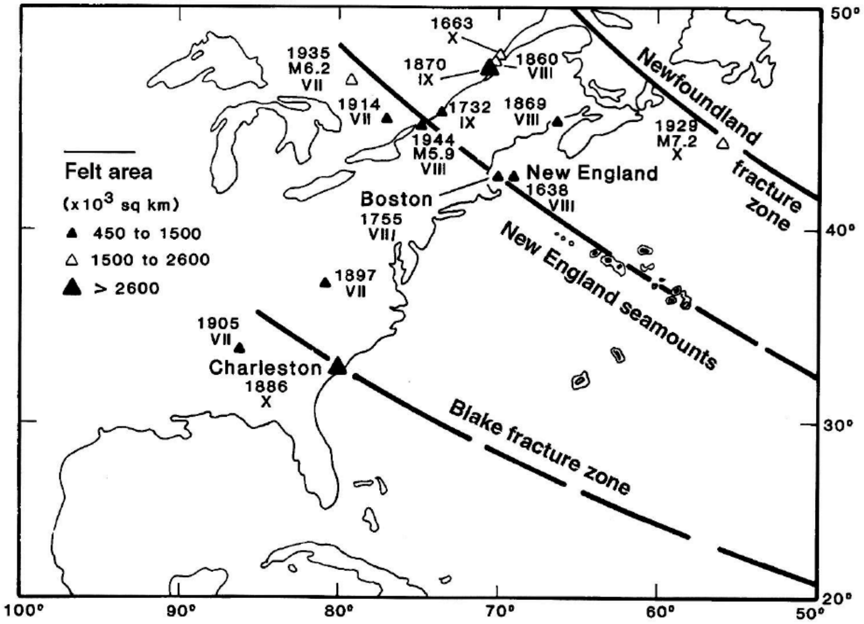

Figure 5.23 Location of earthquake epicenters in the eastern United States and Canada and fracture-zone extensions of transform faults on the mid-Atlantic spreading center.

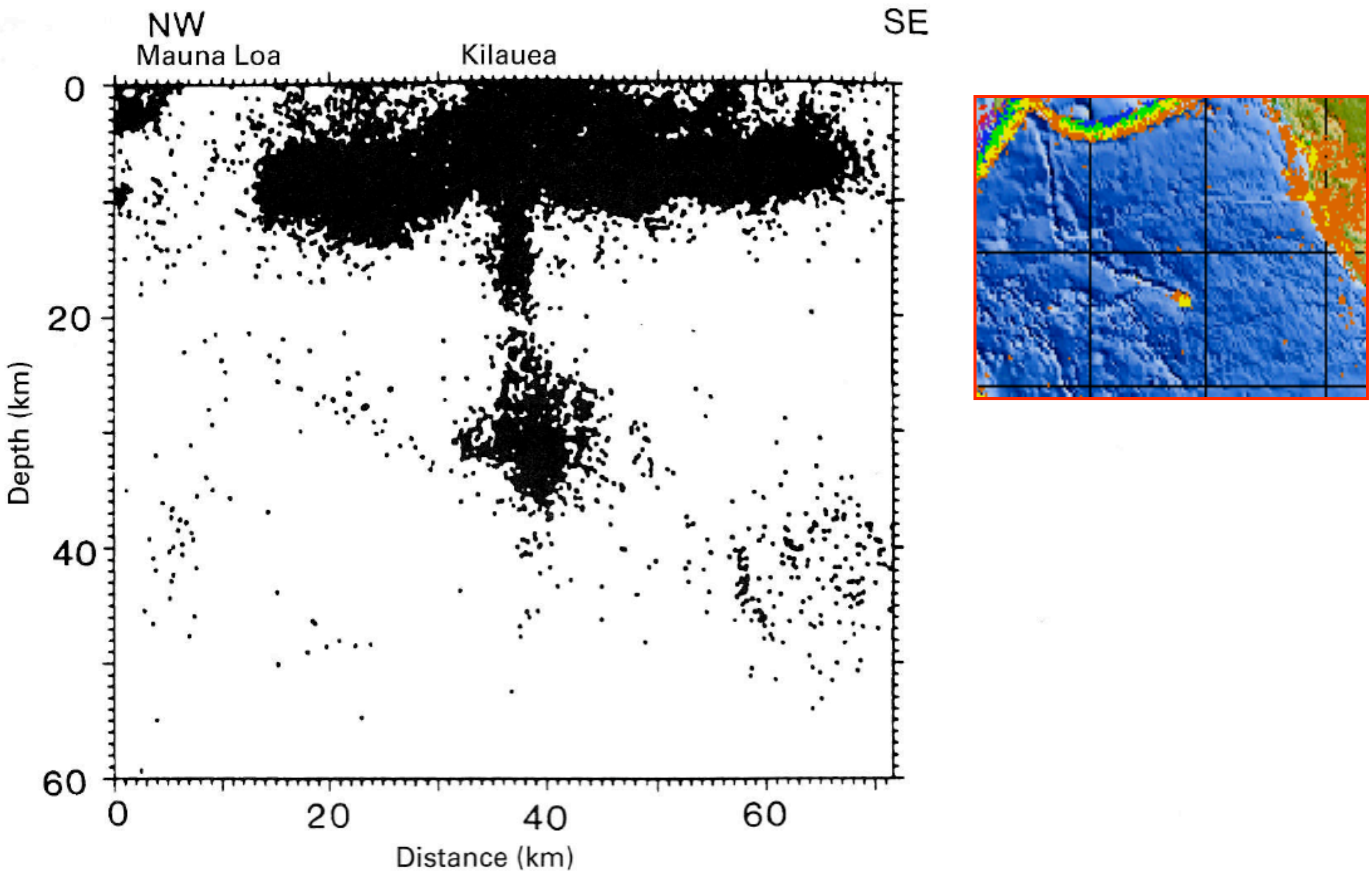

Figure 5.26 Cross section showing hypocenters beneath Kilauea volcano on flank of larger Mauna Loa volcano,

Questions?

Basic Observations on:

- The Tectonic Environment
- How to Quantify an Individual Earthquake

  (SHA-relevant parameters only)

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- Seismicity Rates and
- Ground Motions

Relevant to Seismic Hazard Assessment (SHA):

Basic Earthquake Quantities and Relations for Quantifying Seismicity Rates:

Earthquake Moment: $M_o = \mu A u$

μ is the elastic shear modulus of rock near the fault
A is the area of the earthquake rupture
u is average displacement across ruptured fault

$M_o = (16/7)\, r^3\, \Delta\sigma$ with **r** fault radius and **Δσ** static stress drop **~const**.

Moment Magnitude: $M_w = 2/3 \log_{10} M_o - 10.7$

Static Stress Drop: $\Delta\sigma = M_o\,(7/16) / r^3$

$= (7/16)\, \mu\, (u/r)$

$8.5\, M_o\, (f_o/\beta)^3 \approx \text{const}$

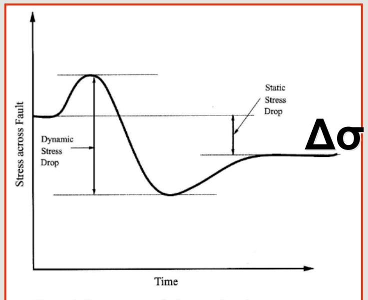


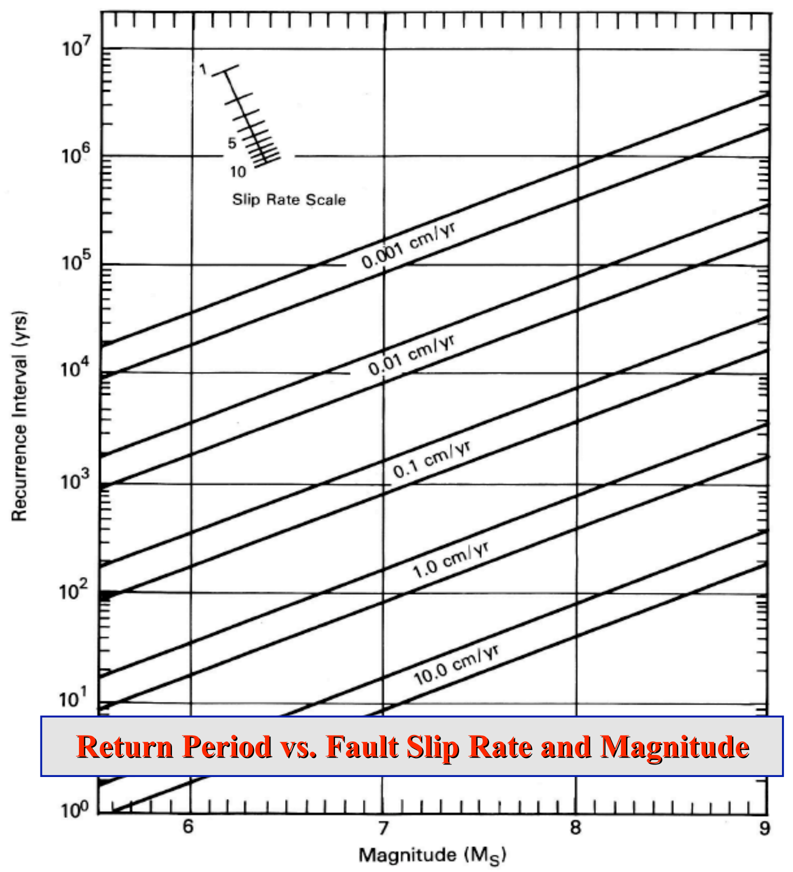
Figure 8. Stress across a fault at one location as an earthquake occurs.

Corner Frequency: $f_o = 0.37\, \beta / r =$

$\sim \beta / (M_o/\Delta\sigma)^{1/3} \sim M_o^{-1/3}$

Moment Rate: $\dot{M}_o = \mu A \dot{s}$

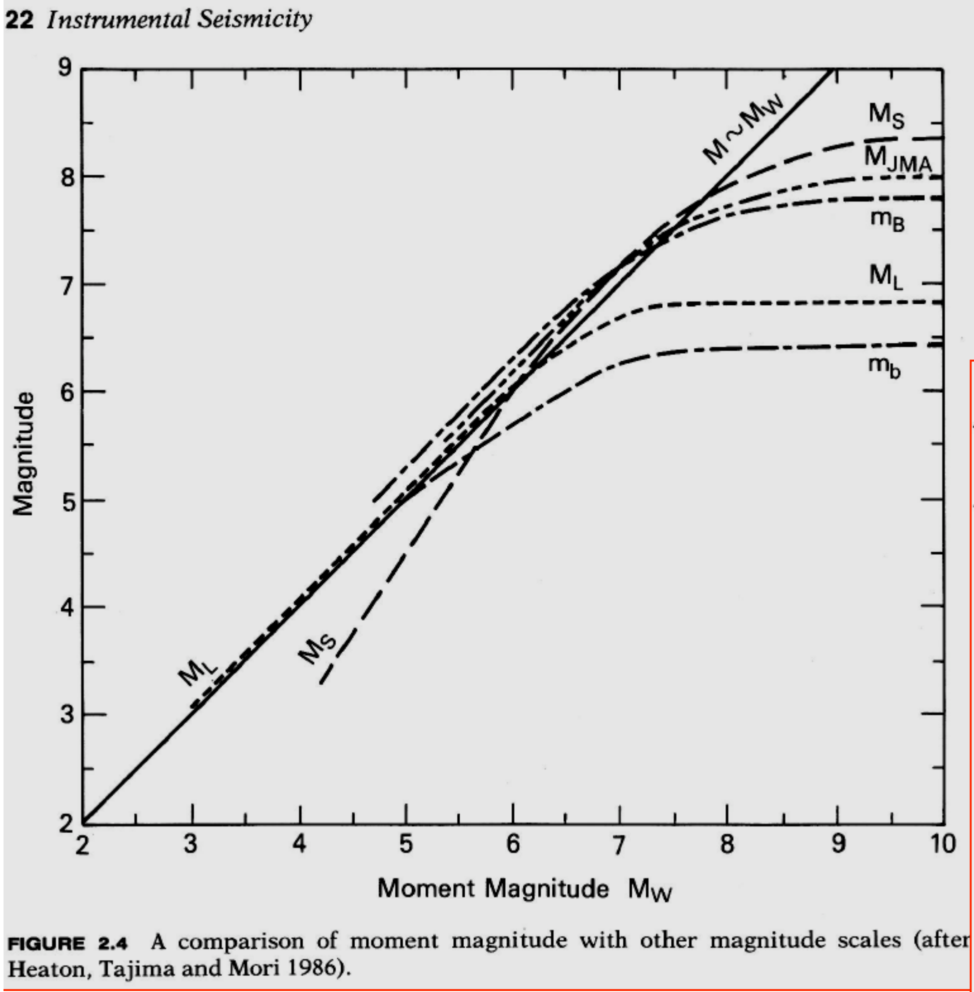
with $\dot{s}$ long-term slip rate



Return Period vs. Fault Slip Rate and Magnitude

FIGURE 5.4 Relation between recurrence interval (years), fault slip rate (cm/yr) and earthquake magnitude (M_S). Assumptions include: no slip is caused by smaller earthquakes or fault creep, and the average fault displacement is one half of the maximum displacement shown in Figure 5.1 (after Slemmons 1982).

Most Current PSHAs use Saturation-Free Moment Magnitude M_w



22 *Instrumental Seismicity*

FIGURE 2.4 A comparison of moment magnitude with other magnitude scales (after Heaton, Tajima and Mori 1986).

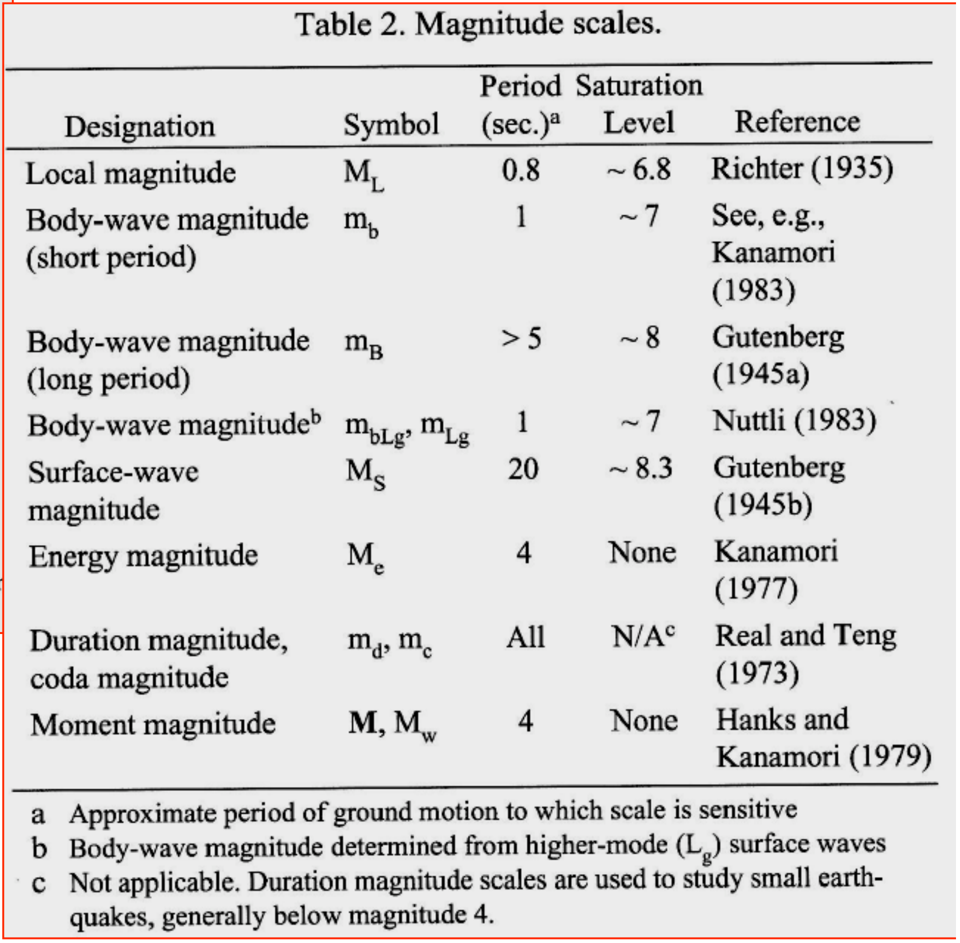


Table 2. Magnitude scales.

Designation	Symbol	Period (sec.)[a]	Saturation Level	Reference
Local magnitude	M_L	0.8	~ 6.8	Richter (1935)
Body-wave magnitude (short period)	m_b	1	~ 7	See, e.g., Kanamori (1983)
Body-wave magnitude (long period)	m_B	> 5	~ 8	Gutenberg (1945a)
Body-wave magnitude[b]	m_{bLg}, m_{Lg}	1	~ 7	Nuttli (1983)
Surface-wave magnitude	M_S	20	~ 8.3	Gutenberg (1945b)
Energy magnitude	M_e	4	None	Kanamori (1977)
Duration magnitude, coda magnitude	m_d, m_c	All	N/A[c]	Real and Teng (1973)
Moment magnitude	**M**, M_w	4	None	Hanks and Kanamori (1979)

[a] Approximate period of ground motion to which scale is sensitive

[b] Body-wave magnitude determined from higher-mode (L_g) surface waves

[c] Not applicable. Duration magnitude scales are used to study small earthquakes, generally below magnitude 4.

Rupture Process / Duration of Rupture / Slip Distribution / Rise Times / Stress Asperities - Barriers / Directivity:

All affect the Spectral Content of Radiated Seismic Waves

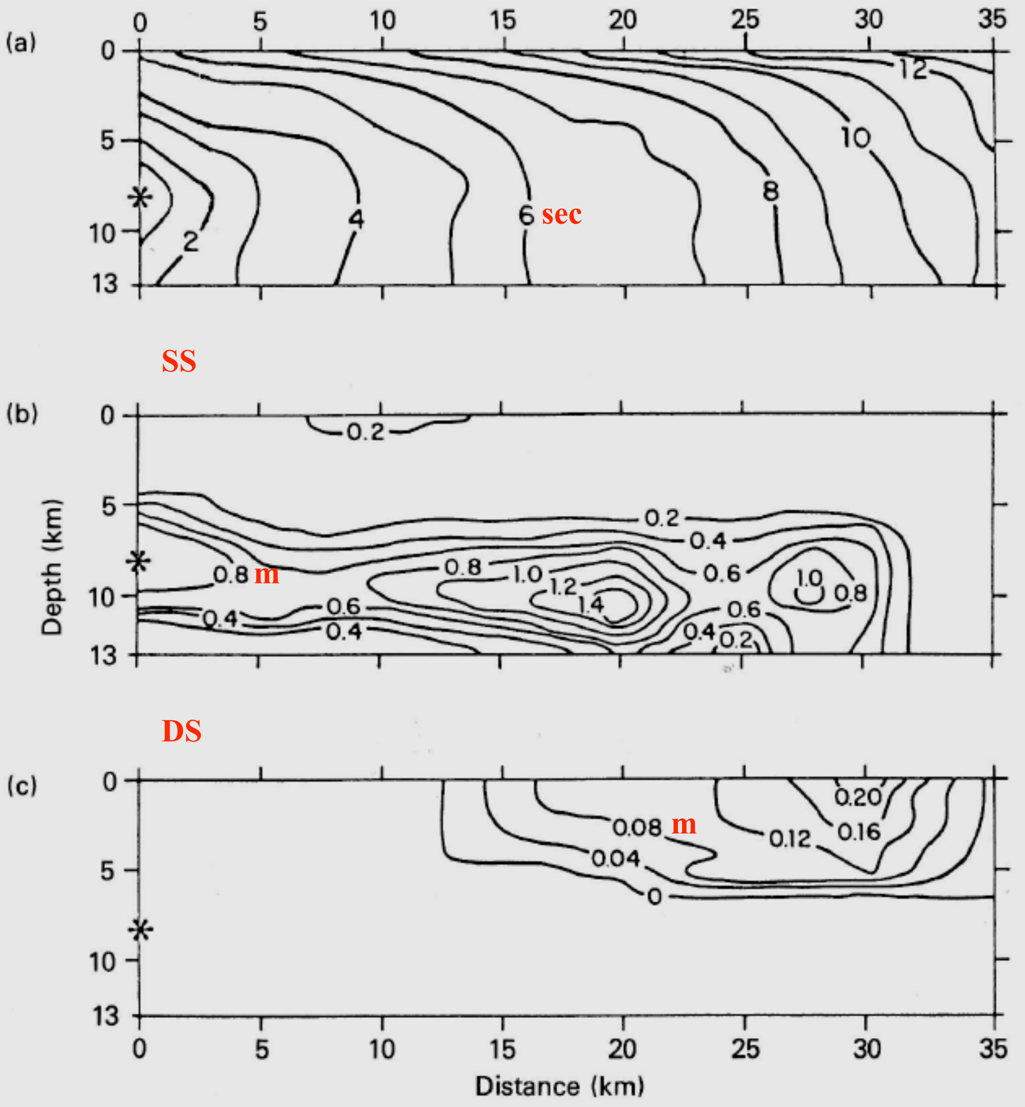


FIGURE 6.9 Rupture front times and final offsets along the Imperial Fault during the October 15, 1979 Imperial Valley, California earthquake as inferred from strong-motion data. (a) position of rupture front with time (seconds), (b) final strike-slip offset (meters) and (c) final dip-slip offset (meters). Hypocenter is shown as a star (after Archuleta 1984).

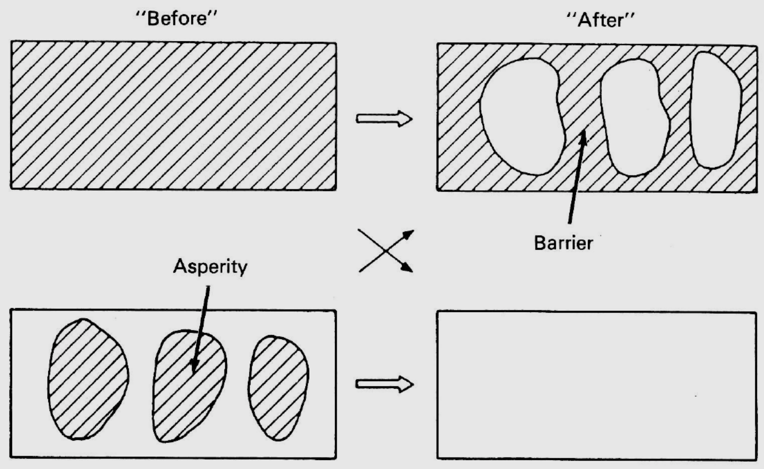


FIGURE 6.10 Barrier (upper) and asperity (lower) models of fault rupture (after Aki 1984).

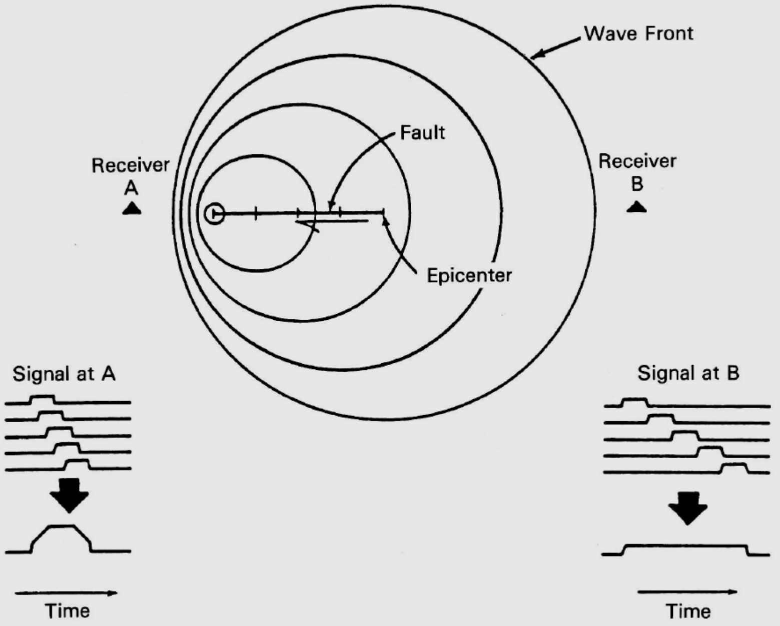
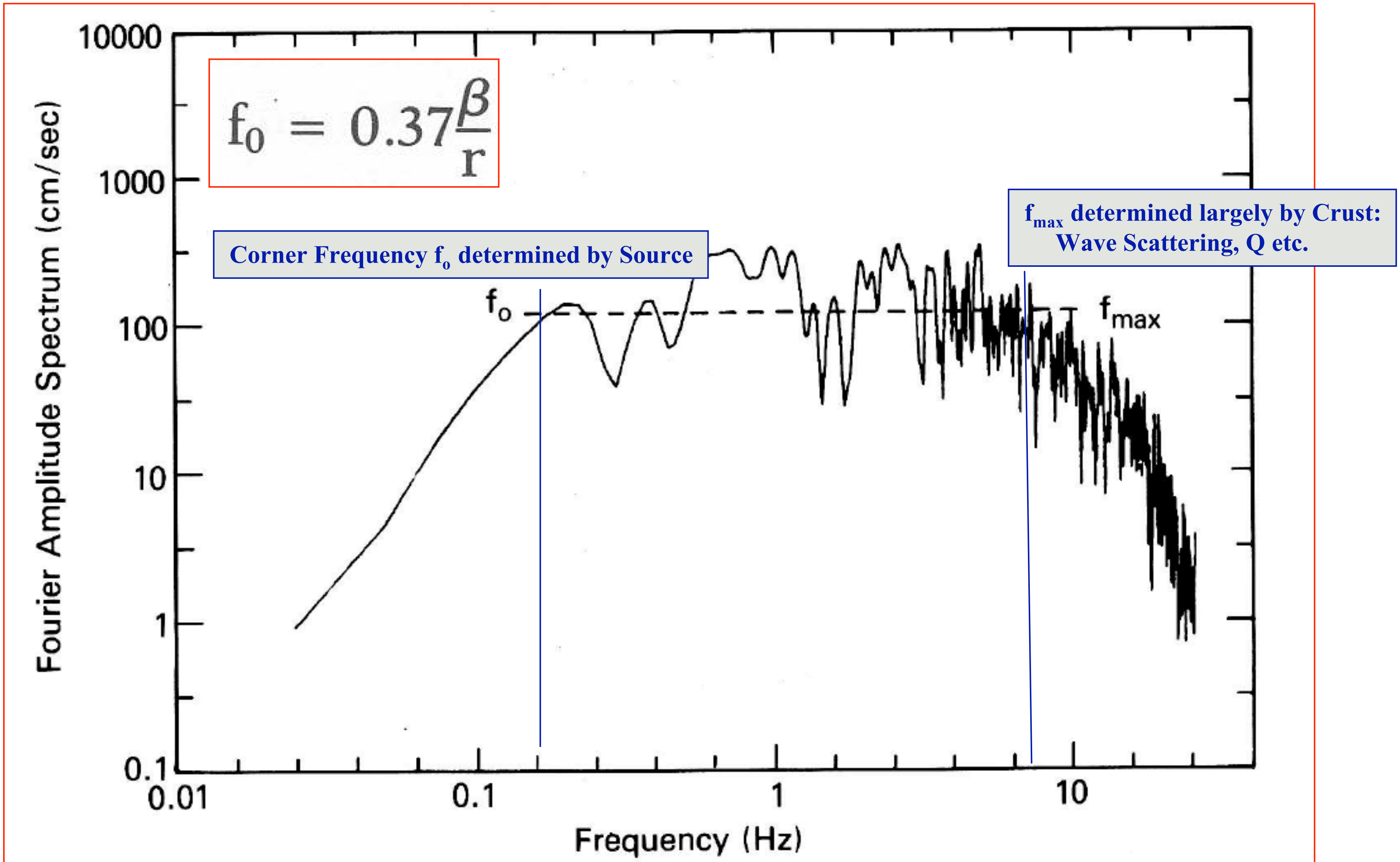


FIGURE 6.11 Directivity or focusing of seismic energy. Snapshot of wave fronts (after Del Mar Technical Associates 1979).



$$f_0 = 0.37\frac{\beta}{r}$$

Corner Frequency f_o determined by Source

f_{max} determined largely by Crust: Wave Scattering, Q etc.

FIGURE 6.7 Fourier amplitude acceleration spectrum of the February 9, 1971 San Fernando, California earthquake recorded at Pacoima Dam (horizontal, S15°W component). f_0 and f_{max} are estimated as indicated (after Hanks 1982).

$f_o = 0.37\ \beta / r$ (Corner Frequency)

slowly <u>decreases</u> with Moment :

$f_o \sim \beta / (M_o/\Delta\sigma)^{1/3}$

and since stress drop $\Delta\sigma \approx$ const,
=> $1/T_o = f_o \sim M_o^{-1/3}$

or: $T_o \sim M_o^{1/3}$

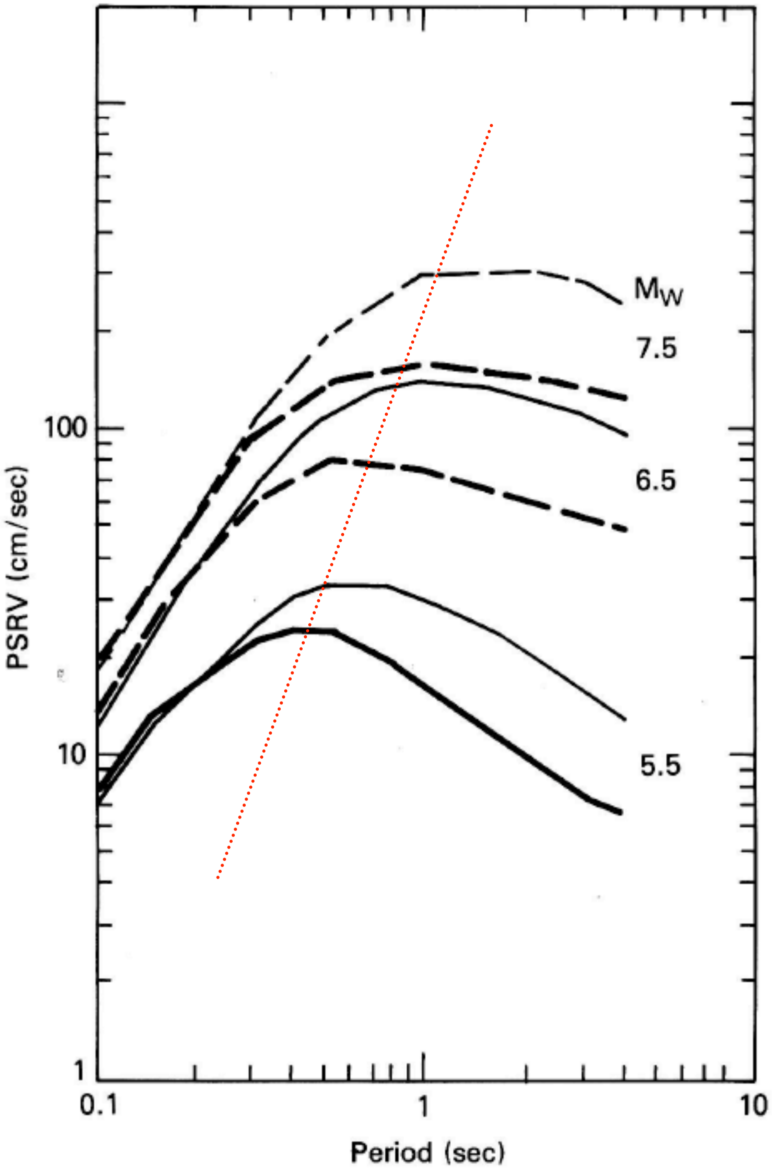


FIGURE 7.8 Estimated 5% damped response spectra for rock (heavy line) and soil (thin line) sites at a distance of 0 km from the surface projection of the causative fault for M_W = 5.5, 6.5 and 7.5 earthquakes. Curves are dashed when not constrained by the data (after Joyner and Fumal 1985).

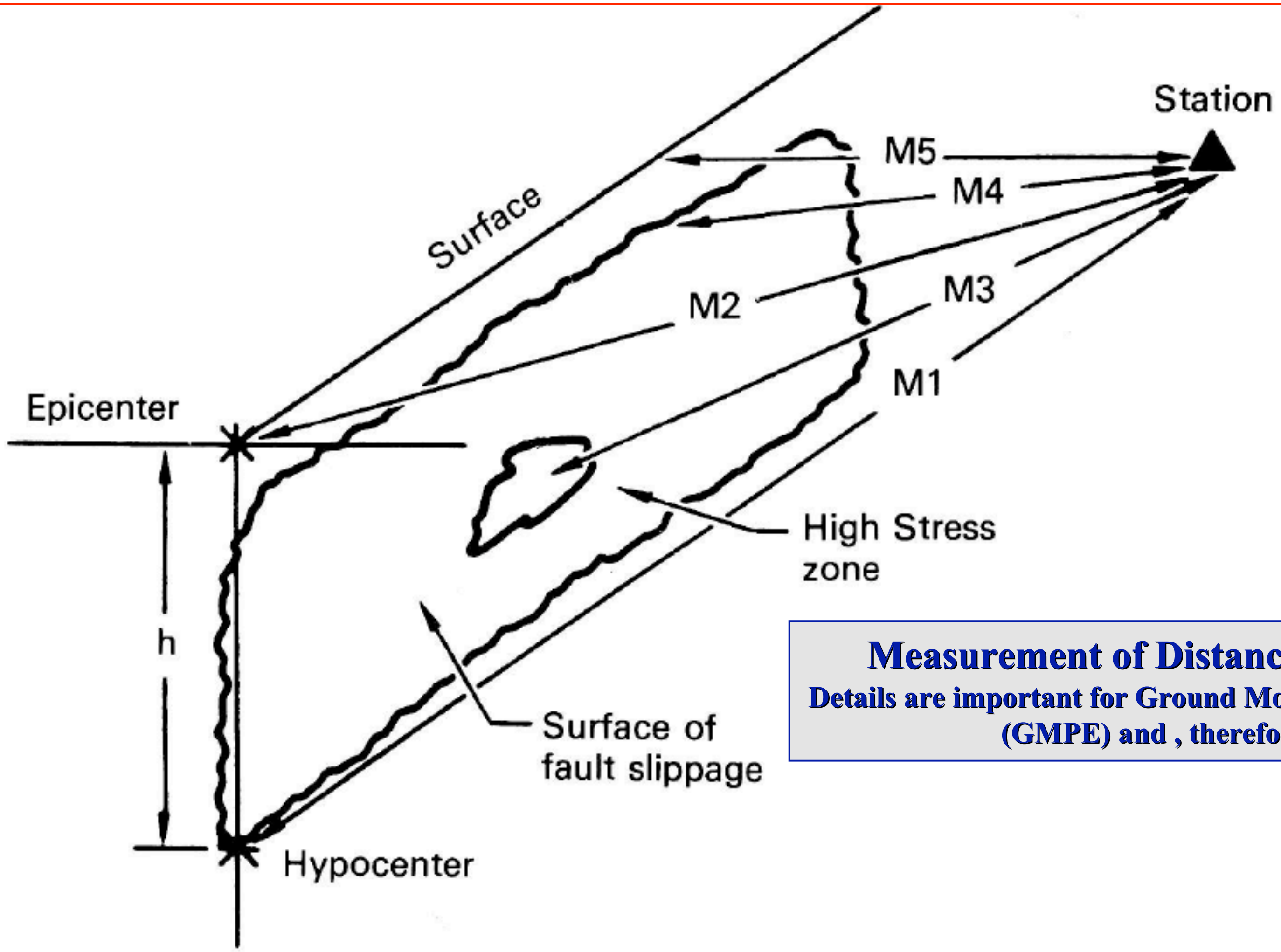
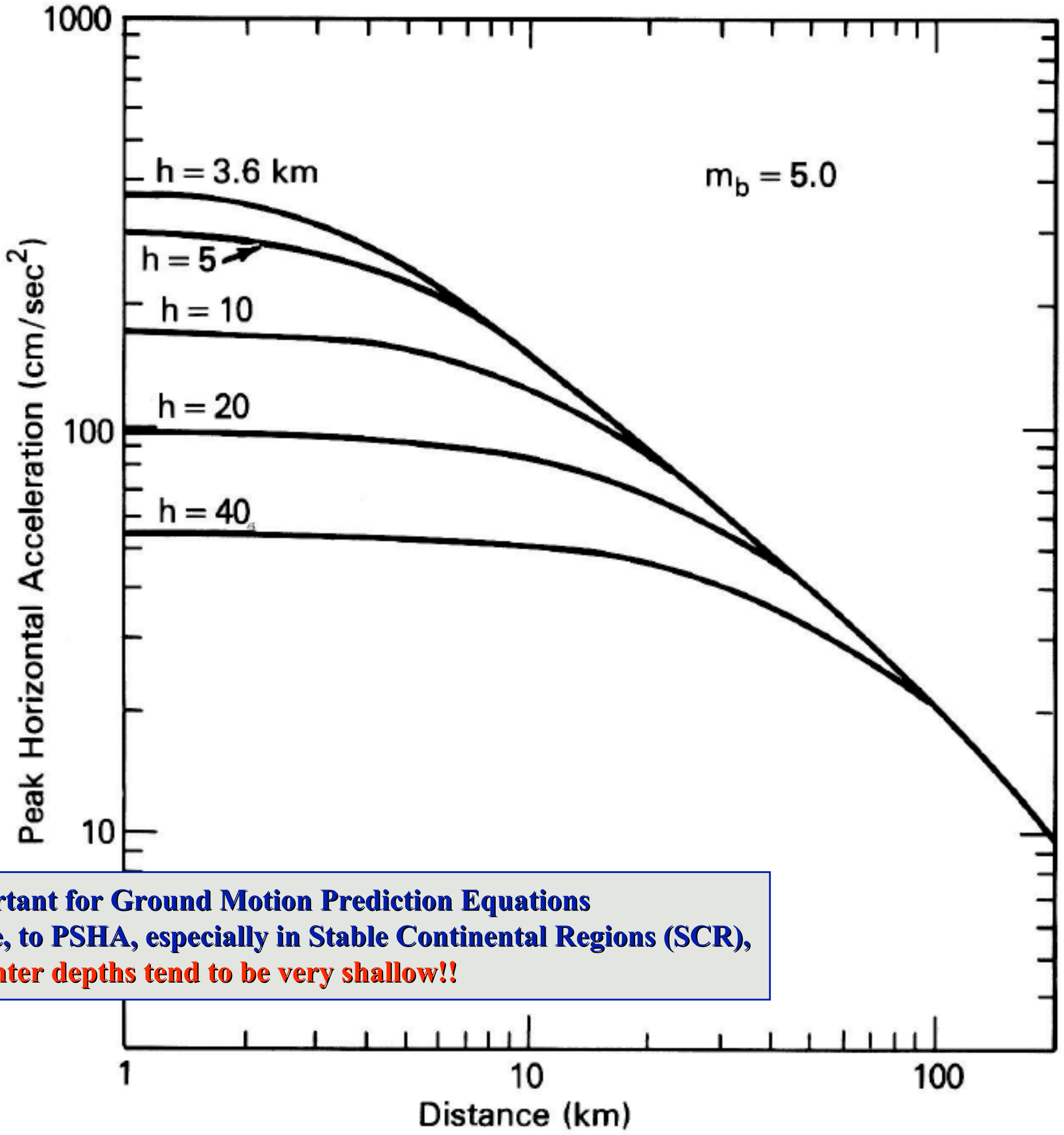


FIGURE 7.3 Schematic illustration of methods of distance measurement used in the determination of the distance value to be associated with a ground motion observation. M1 is the hypocentral distance (focal depth is h), M2 is the epicentral distance. M3 is the distance to the center of high-energy release (or high localized stress drop), M4 is the closest distance to the slipped fault, in this case, the fault rupture does not extend to the surface, and M5 is the closest distance to the surface projection of the fault rupture (after Shakal and Bernreuter 1981).

Measurement of Distances to the Source:

Details are important for Ground Motion Prediction Equations (GMPE) and , therefore, PSHA !!



Depth is important for Ground Motion Prediction Equations and , therefore, to PSHA, especially in Stable Continental Regions (SCR), where hypocenter depths tend to be very shallow!!

FIGURE 7.9 The effect of hypocentral depth (h) on peak horizontal acceleration for the central and eastern United States (after Nuttli and Herrmann 1984).

Ground Motion Prediction Equations (GMPEs, here for PGA) as a function of Distance for discrete Magnitudes and for different authors/datasets for the Central and Eastern US, i.e. Stable Continental Regions (SCR).
Note the degree of “epistemic” uncertainty between the different authors’ GMPEs.

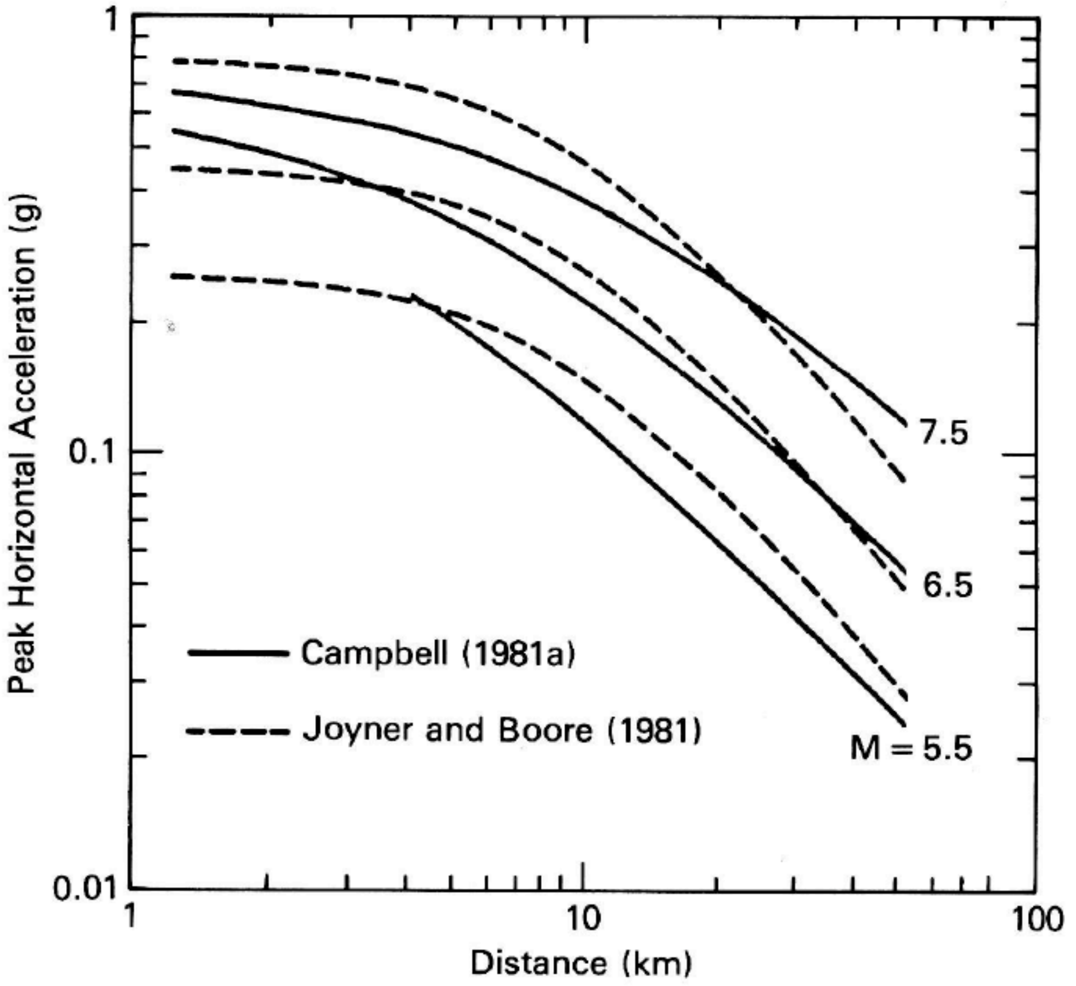
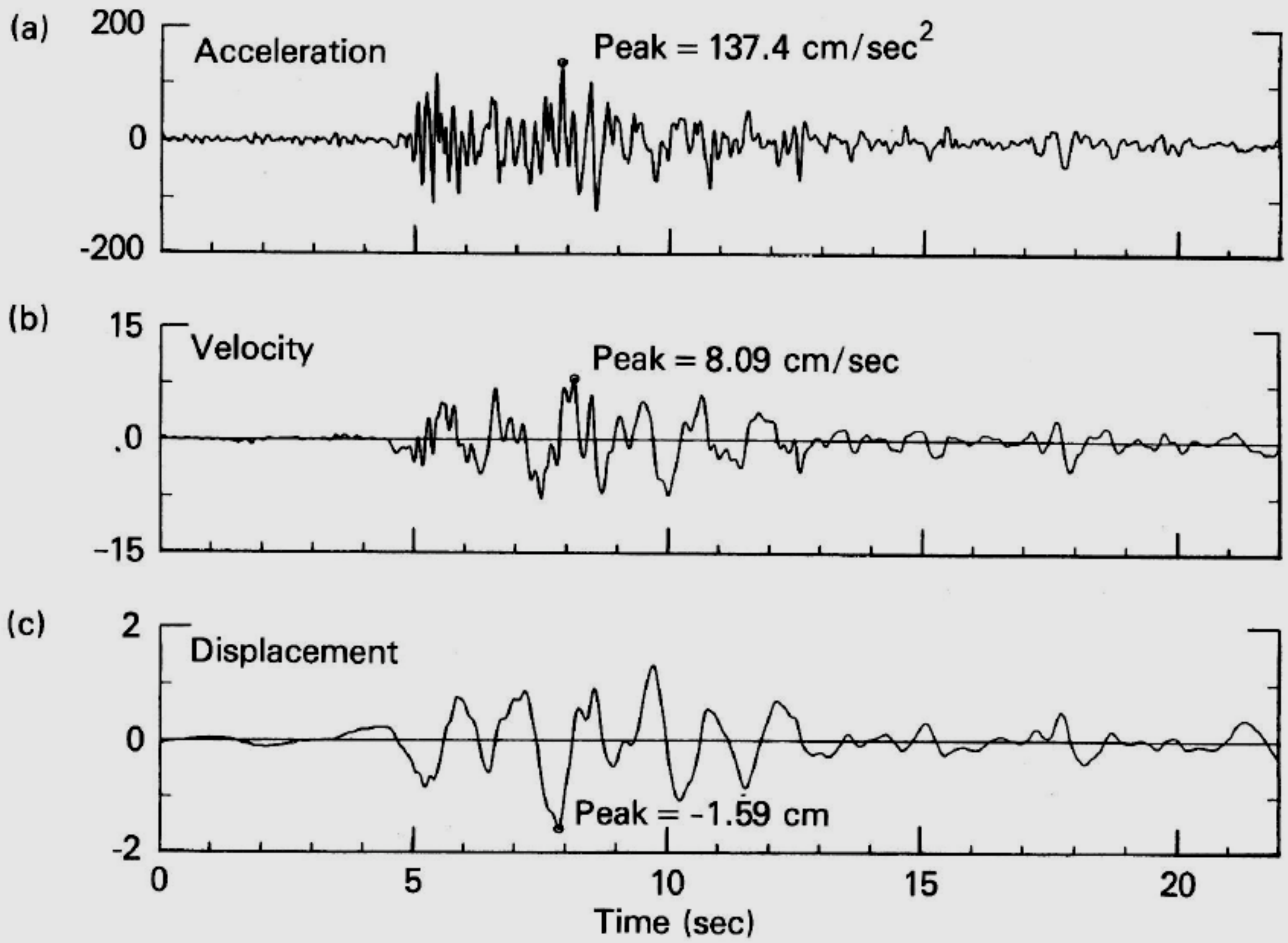


FIGURE 7.4 Median (50th percentile) estimates for peak horizontal acceleration from Campbell (1981a) and Joyner and Boore (1981). Joyner and Boore (1981) estimates of the maximum horizontal component have been reduced by 12% so that they may be compared with the (Campbell 1981a) estimates of the mean horizontal component (after Campbell 1981a).

Ground Motions can be represented either in Acceleration, Velocity or Displacement Space.
Although they contain the same information, they have different Engineering Applications: Forces, vs. Strains vs. Displacements



Attenuation / Scattering:

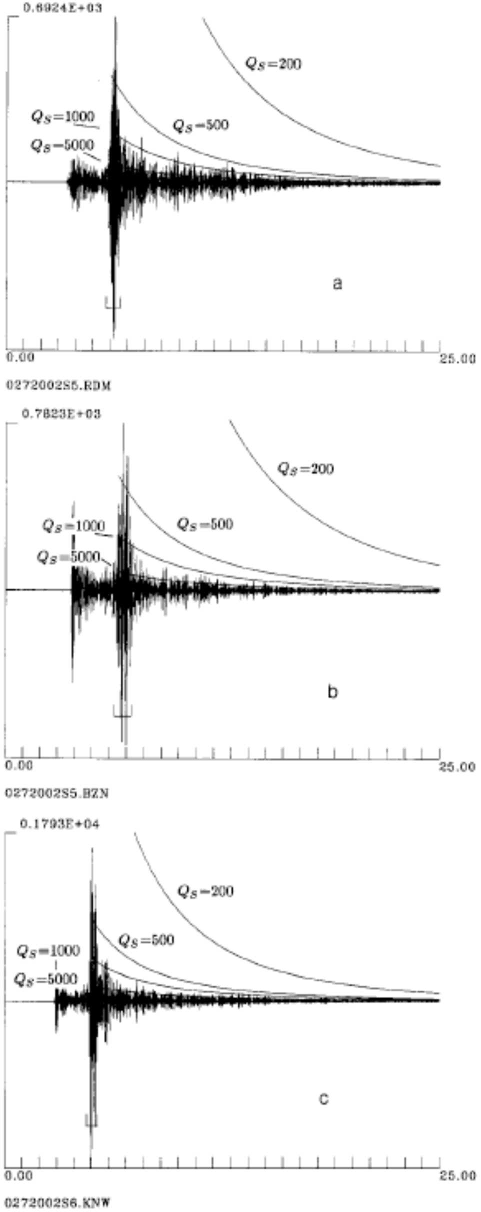


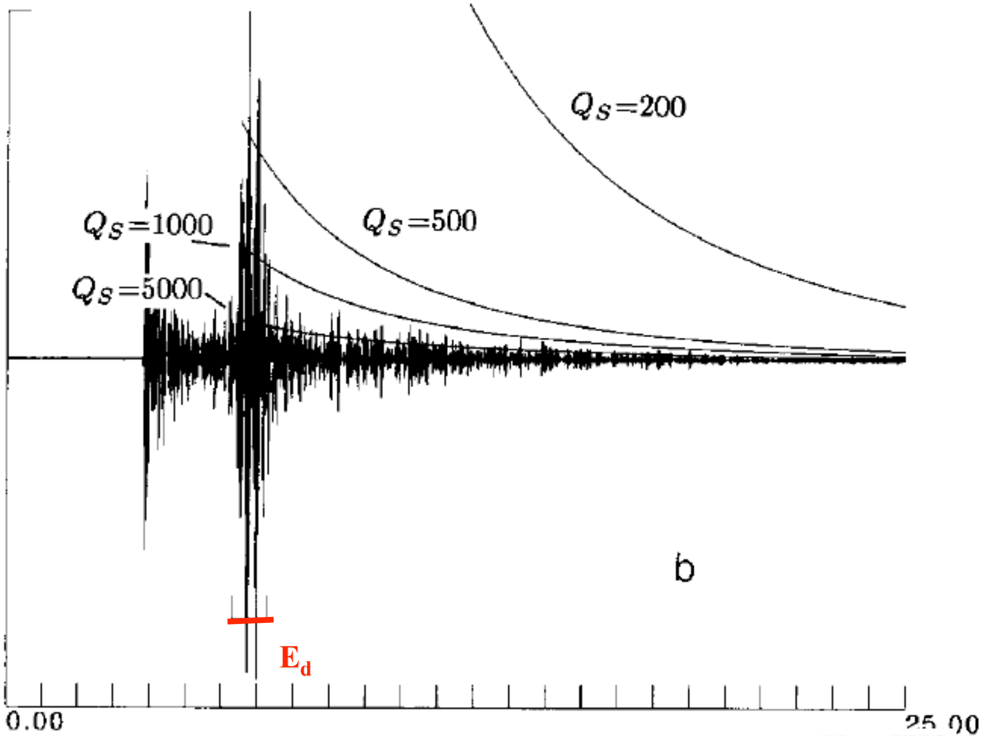
FIG. 15. (a to c) Bandpass-filtered (25 to 35 Hz) seismograms for event 2 at three stations, along with coda envelopes predicted by the energy-flux model for scattering Q's of 200, 500, 1,000, and 5,000. Intrinsic Q was fixed at 1,300. Predicted coda amplitudes are based on the energy in the direct S wave which is found by integrating the square of the amplitude over the time interval indicated by the bar beneath each seismogram.

$$E_D = E_T e^{-\omega t/Q_S},$$

$$E_C = E_T - E_D.$$

$$E_C = E_T(1 - e^{-\omega t/Q_S}).$$

E_T= Total Energy Radiated;
E_d = Energy in “direct” Wave Package;
E_c = Scattered Energy transferred into the “coda” of the waves;
Q_s = “Scattering-Q”
NOTE: (**1/Q_s**) is the energy scattered per wave length of propagation path;
High Q_s => Low Scattering; Low Q_s => High Scattering;



ARTHUR FRANKEL AND LEIF WENNERBERG

Questions?

Basic Observations on:

- The Tectonic Environment
- Individual Earthquakes,
- Seismicity Rates (and Maps)
- Ground Motions

Relevant to Seismic Hazard Assessment (SHA):

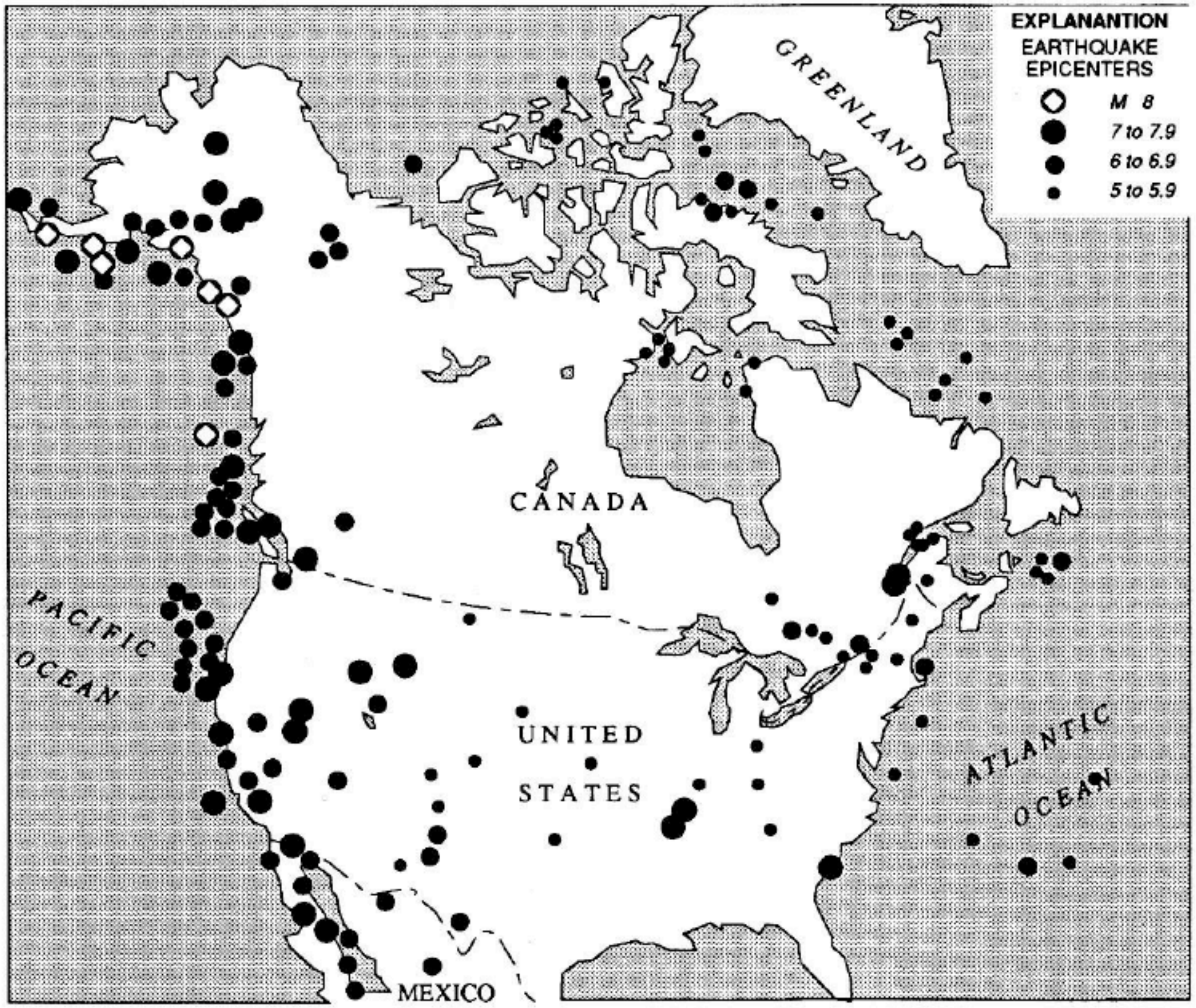


FIGURE 3. Epicenters of large (M > 6) historical earthquakes in North America. M > 5 events since 1930 also plotted for region east of 110° W. (After Page and Basham.[15])

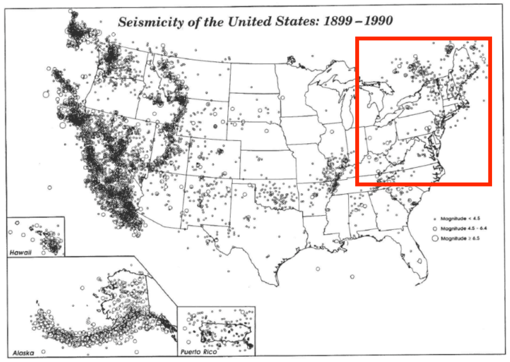
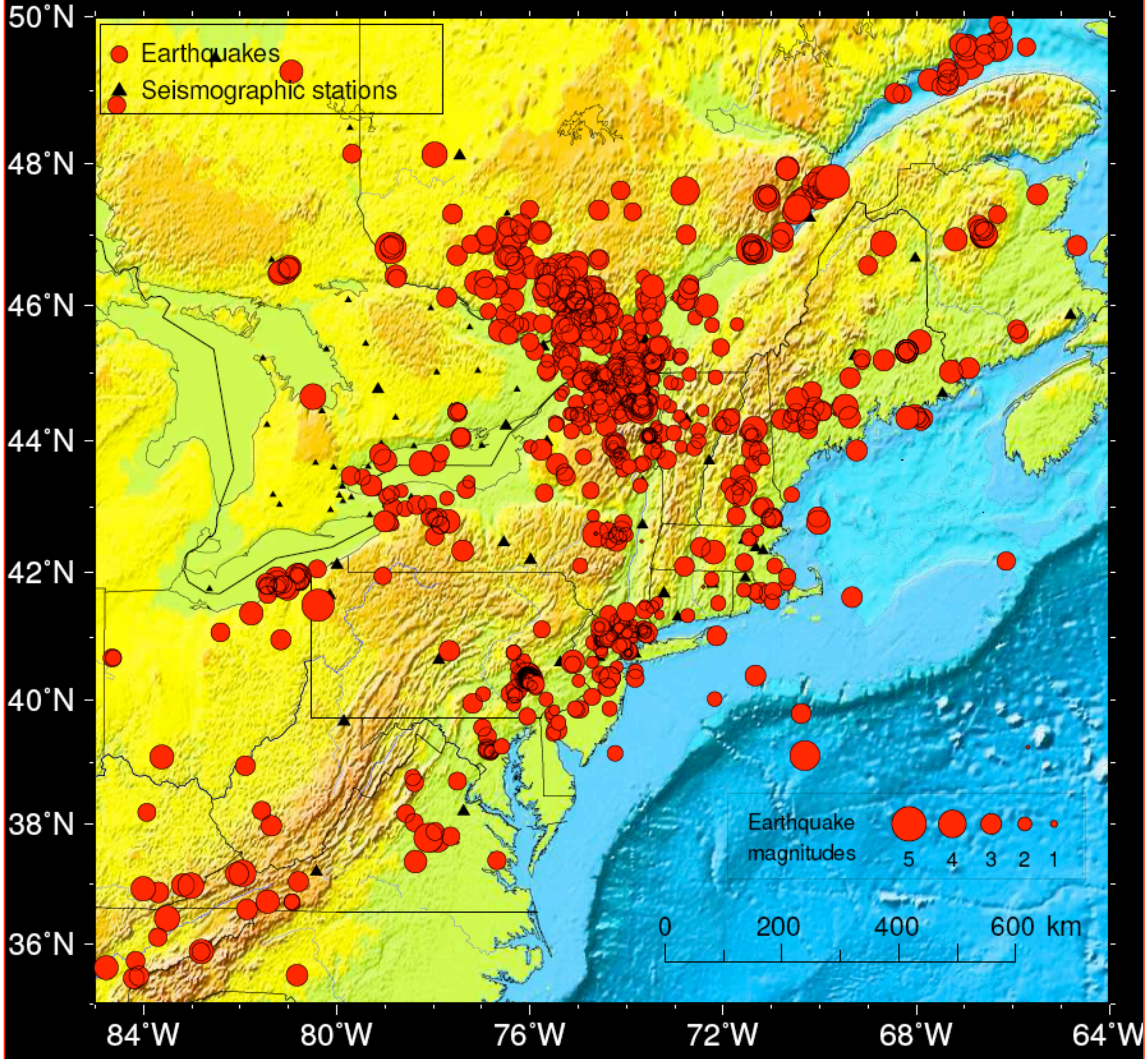


Figure 5.1 Epicenters of earthquakes in the United States, southern Canada and northern Mexico, 1899–1990.
Source: U.S. Geological Survey National Earthquake Information Center.

Earthquakes in NE United States and Canada 1990 - 2006



Earthquake locations by the Lamont Cooperative Seismographic Network, US Geological Survey and the Geological Survey of Canada.
September 2006, Won-Young Kim, Lamont-Doherty Earth Observatory of Columbia University, <www.ldeo.columbia.edu/LCSN>.

Probability P, Exposure Time t, Avg. Recurrence Period T, and Annual Avg. Frequency of Occurrence λ=1/T, for a Poisson Process of Randomly Occurring (causally independent) Events (Eqs., ...):

$$P \;=\; 1- e^{-t/T} \;=\; 1 - e^{-\lambda t}$$
$$1-P = e^{-t/T}\;; \quad \Longrightarrow$$

with $T = 1/\lambda$ or $\lambda = 1/T$

$$\ln(1-P) = \ln e^{-t/T} = -t/T$$

$$\lambda = -[\ln(1-P)]/t$$ = average rate

$$T = -t/\ln(1-P)$$ = average Rec. Period

P%	t(y)	T (y)
10%	50y	475y
2%	50y	2475y
~62%	t =	T

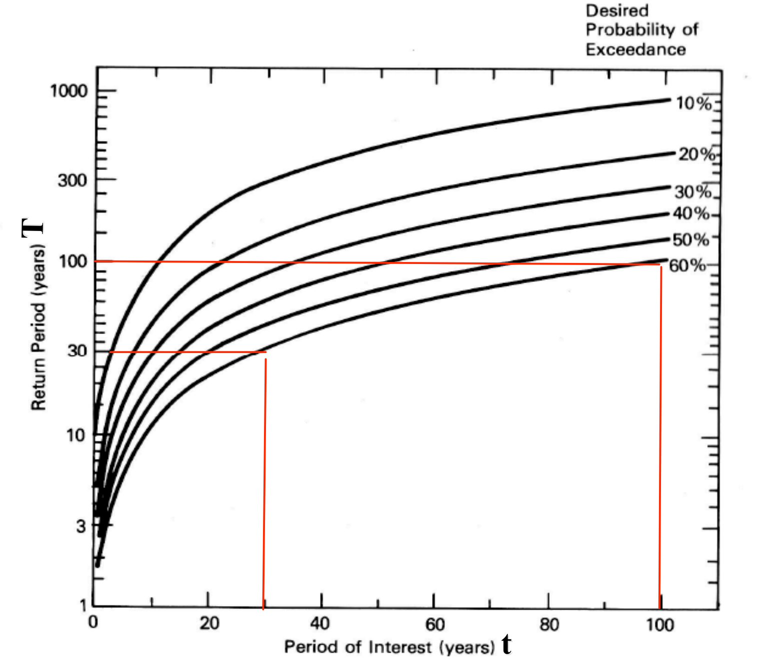


FIGURE 10.3 Relationship between return period, period of interest and desired probability of exceedance during the period of interest for the Poisson model (after TERA Corporation 1980).

Note: For $t \ll T \Longrightarrow P \approx 1/T = \lambda$

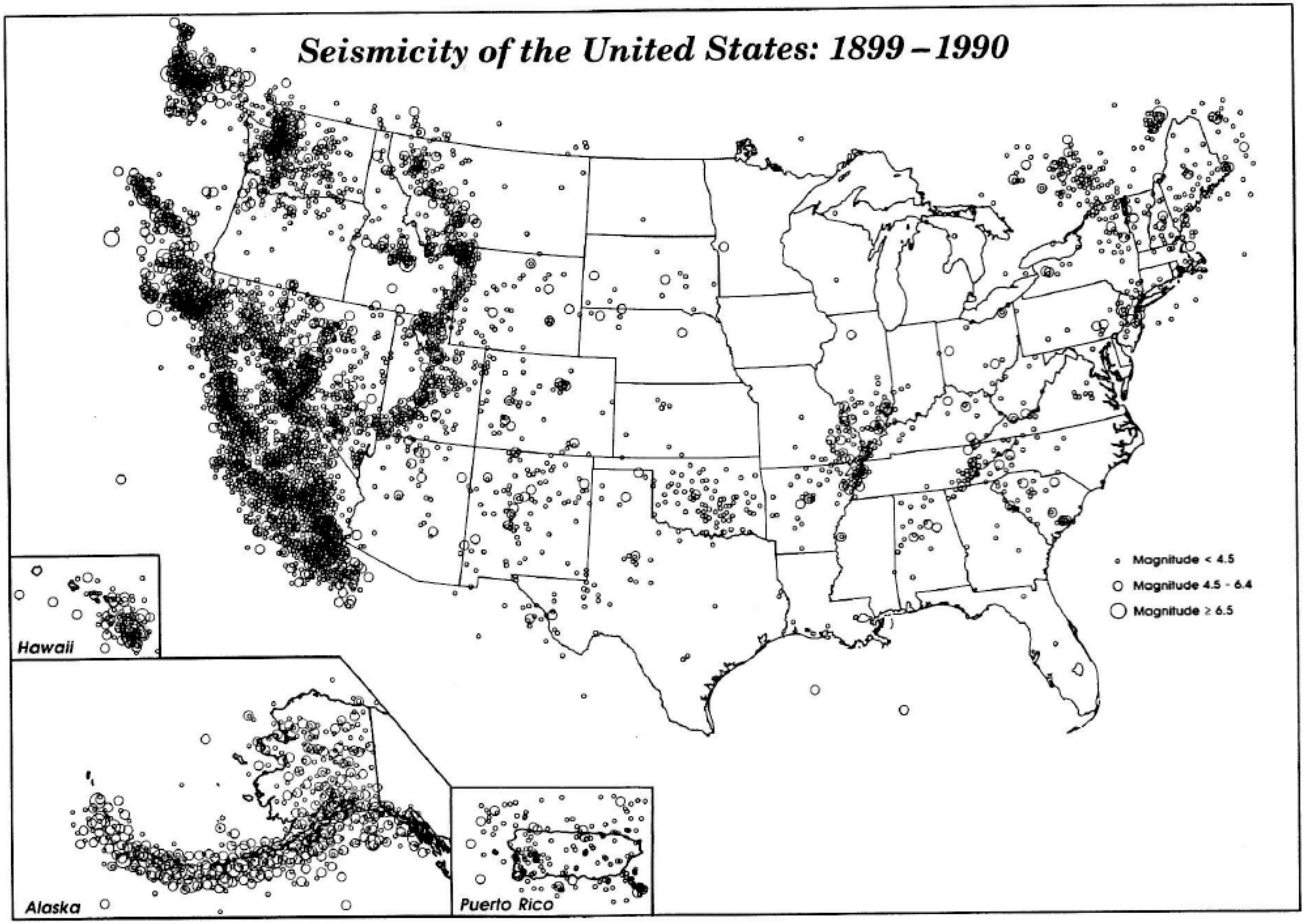
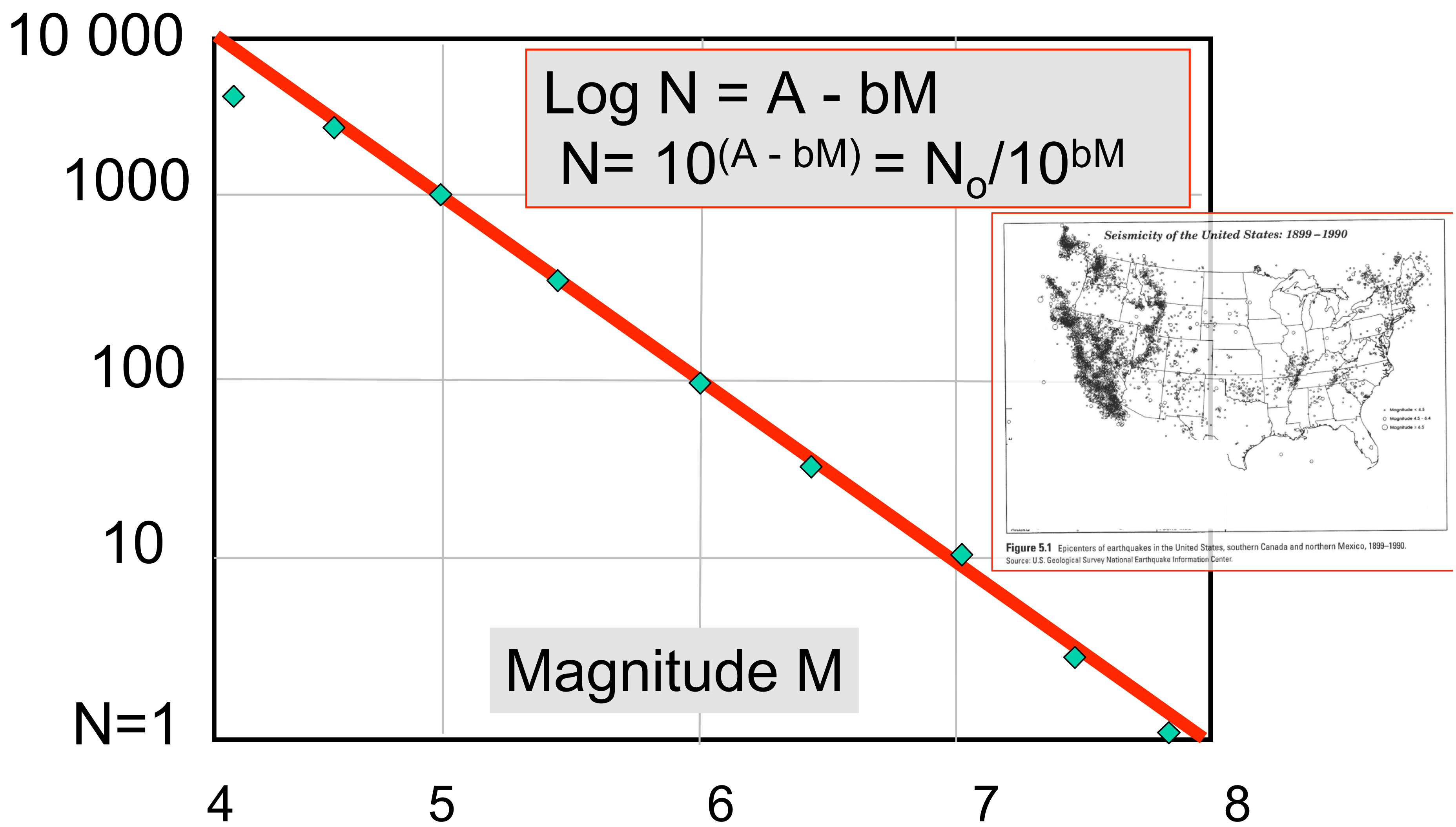


Figure 5.1 Epicenters of earthquakes in the United States, southern Canada and northern Mexico, 1899–1990.

Source: U.S. Geological Survey National Earthquake Information Center.



$$\text{Log } N = A - bM$$

$$N = 10^{(A - bM)} = N_o/10^{bM}$$

Figure 5.1 Epicenters of earthquakes in the United States, southern Canada and northern Mexico, 1899–1990.
Source: U.S. Geological Survey National Earthquake Information Center.

Log Cumulative Number **N** of Earthquakes with Magnitude ≥M per 100 yr in the Contiguous US, vs. Magnitude **M**.

Example: $A=8$ ($N_o=10^8$), and $b=+1$ (Slope is -1);

“Power Law”

Basic Relations for Quantifying Seismicity Rates:

Gutenberg-Richter (Power) **Law**

of *Cumulative* Earthquake Frequency N vs. (Moment) Magnitude M_w:

$\log_{10} N = A - b\, M_w$ valid for a given area F(km^2) and time period T (years)

$N = 10^{A - b\, Mw}$

Normalized Form: $\log_{10} n = a - b\, M_w$ n = number of earthquakes per year per km^2

$n = 10^{a - b\, Mw} = n_o\, 10^{-b\, Mw} = n_o / 10^{b\, Mw}$

$n_o = 10^a$ is the number of earthquakes per year per km^2 with magnitude M≥0

Using the **Natural Logarithm $\ln_e$ instead of $\log_{10}$**, the exponential G-R frequency of occurrence vs. Magnitude equation takes on the form:

$\ln n = n_o - \beta M$ n = number of earthquakes per year

$n(M) = n_o\, e^{-\beta M}$ with $n_o = 10^a$ number of earthquakes per unit time for M≥0;

and $\beta = b \ln 10 \approx 2.3b$; when minimum magnitude Mmin is used, then

$n(M) = n_{o\,min}\, e^{-\beta(M - Mmin)}$ for $Mmin \leq M \leq \infty$ and $n_{o\,min}$ number of earthquakes per unit time for M≥Mmin;

For Details on equations for **truncated exponential functions with M≥Mmax**, as often used in PSHA, see McGuire (2004) pp. 38-43 and graph shown on subsequent slide.

Use of **truncated** G-R relation by specifying an upper bound magnitude $\mathbf{m_u}$

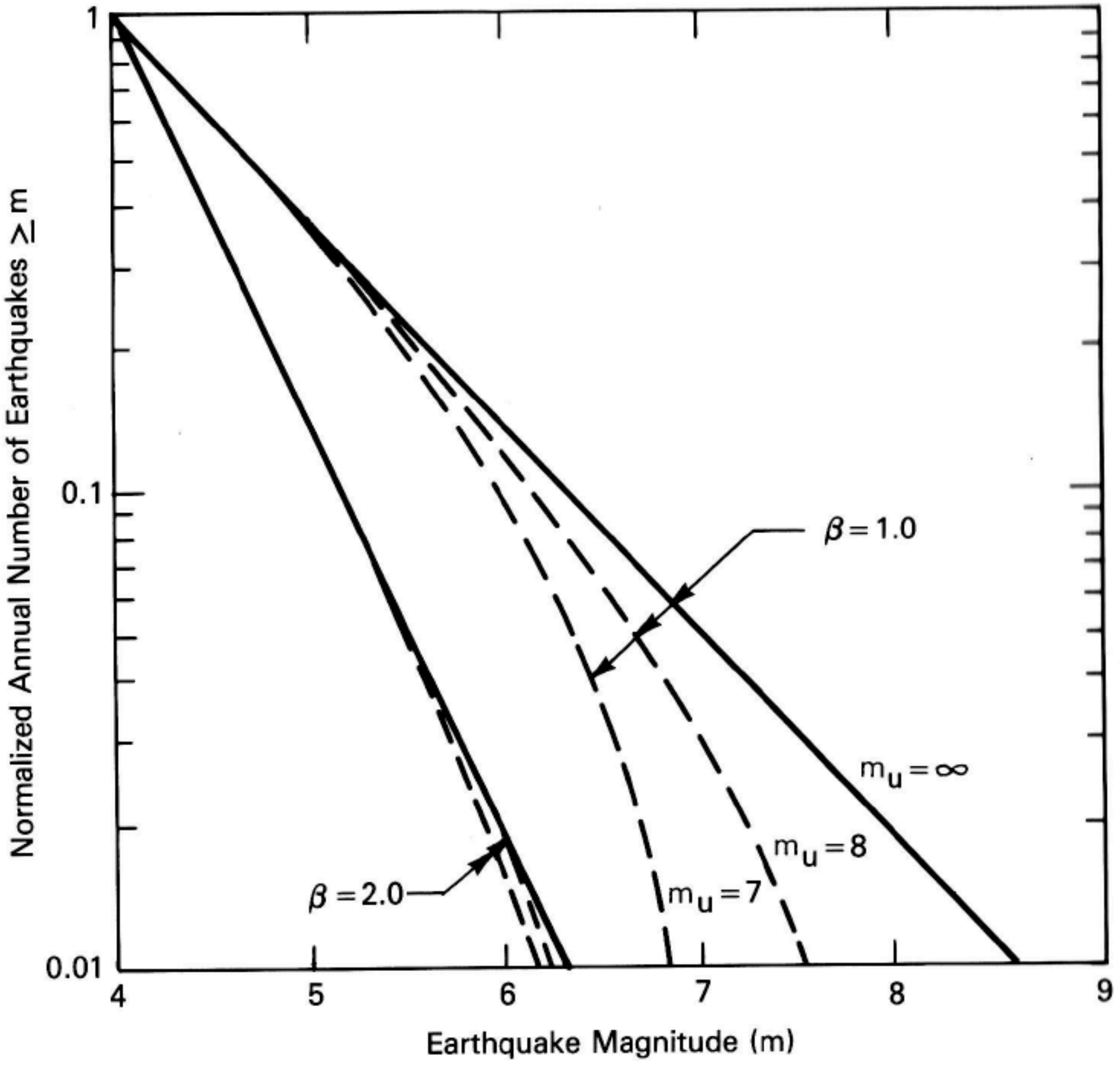


FIGURE 11.7 Effect of changes in slope (β) and upper-bound earthquake magnitude (m_u) on the truncated exponential recurrence relationship. The recurrence relationships have been normalized so that the annual number of earthquakes equal to or exceeding the lower bound (m_0 = 4) is 1.0 (after Yegian 1979).

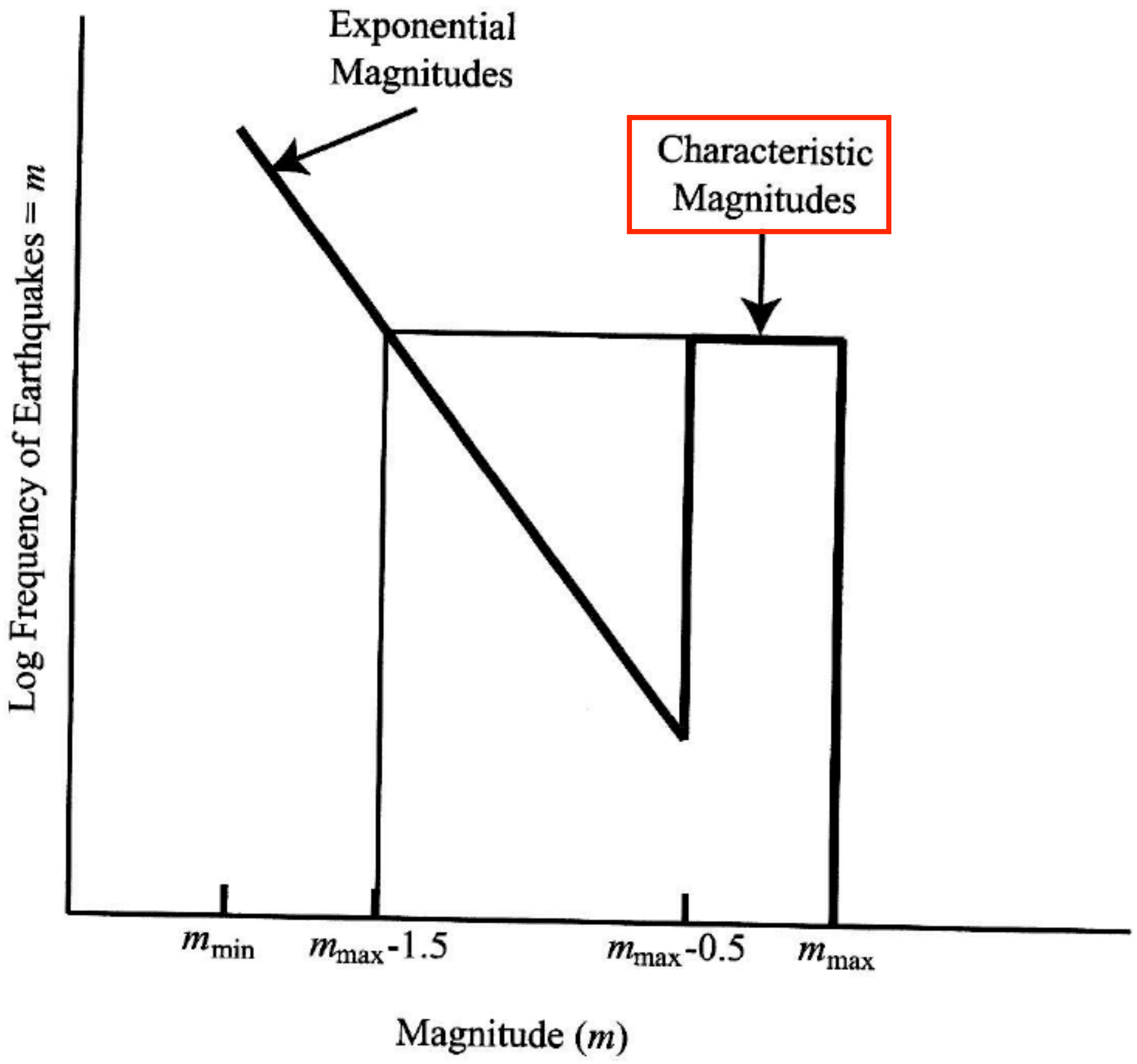


Figure 7. Characteristic magnitude model proposed by Schwartz and Coppersmith (1984).

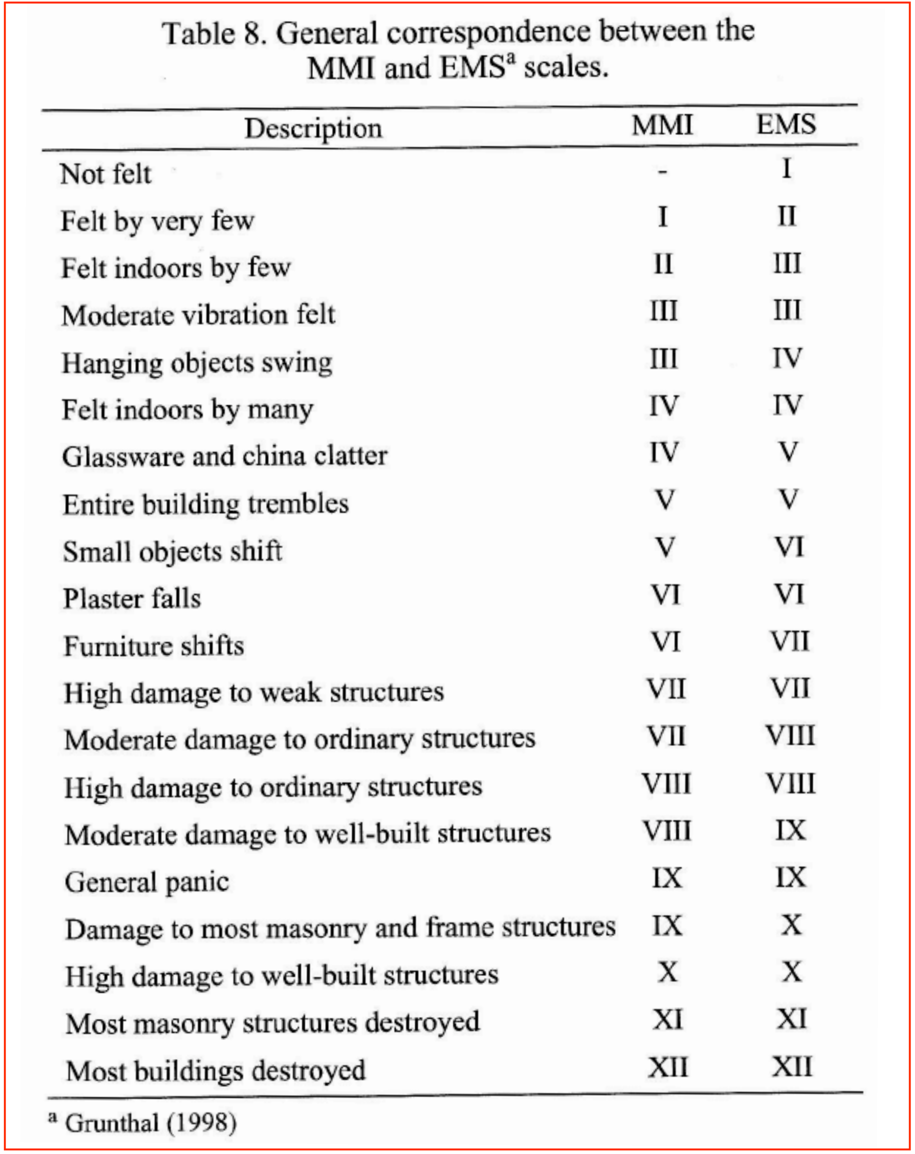


Table 8. General correspondence between the MMI and EMS[a] scales.

Description	MMI	EMS
Not felt	-	I
Felt by very few	I	II
Felt indoors by few	II	III
Moderate vibration felt	III	III
Hanging objects swing	III	IV
Felt indoors by many	IV	IV
Glassware and china clatter	IV	V
Entire building trembles	V	V
Small objects shift	V	VI
Plaster falls	VI	VI
Furniture shifts	VI	VII
High damage to weak structures	VII	VII
Moderate damage to ordinary structures	VII	VIII
High damage to ordinary structures	VIII	VIII
Moderate damage to well-built structures	VIII	IX
General panic	IX	IX
Damage to most masonry and frame structures	IX	X
High damage to well-built structures	X	X
Most masonry structures destroyed	XI	XI
Most buildings destroyed	XII	XII

[a] Grunthal (1998)

Using Different Felt Intensity Scales:

MMI Modified Mercalli Intensity,
EMS (European Macroseismic Scale)

and

Translating them into Magnitudes:

e.g.:

$m_l = 1.3 + 0.6\ Ie$

With Ie = epicentral Intensity in MMI

after Gutenberg & Richter, 1942

Other Authors Use Felt Area F

for a given MMI

and relate it to magnitude (M, m_b, m_l, M_s, etc.)

Different Relations must be used for active regions vs. SCR when translating Felt Areas of historic earthquakes into Magnitudes,

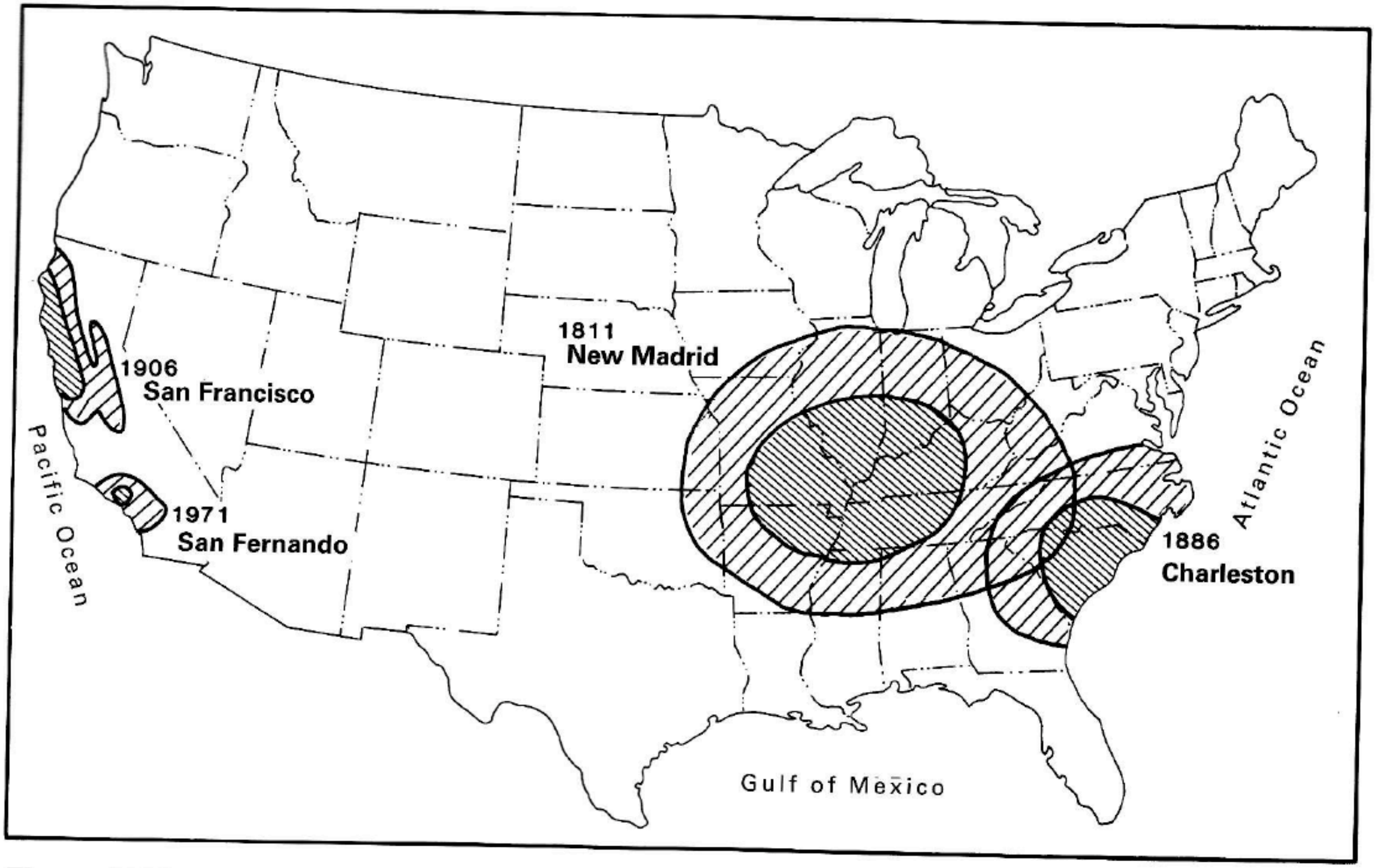


Figure 5.16 Felt areas of some large earthquakes in the United States. Inner-ruled areas are Mercalli intensities greater than VII; ruled areas are intensities VI to VII.

Questions?

Basic Observations on:

- The Tectonic Environment
- Individual Earthquakes,
- Seismicity Rates
- Ground Motion Relations

Relevant to Seismic Hazard Assessment (SHA):

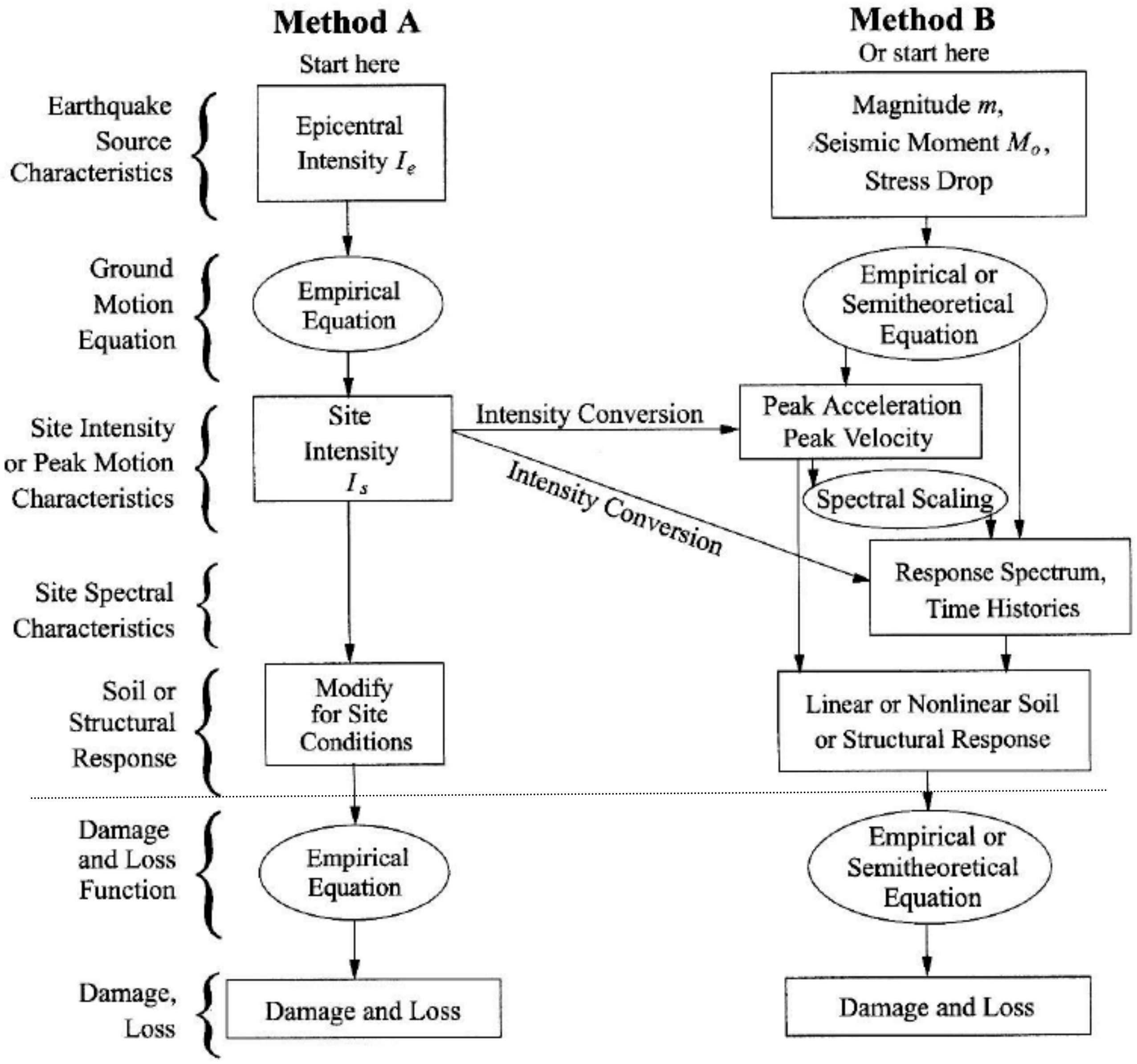


Figure 10. Steps in estimating site ground motion characteristics, soil or structural response, damage, and loss.

Different GMPE must be used for active regions vs. SCR

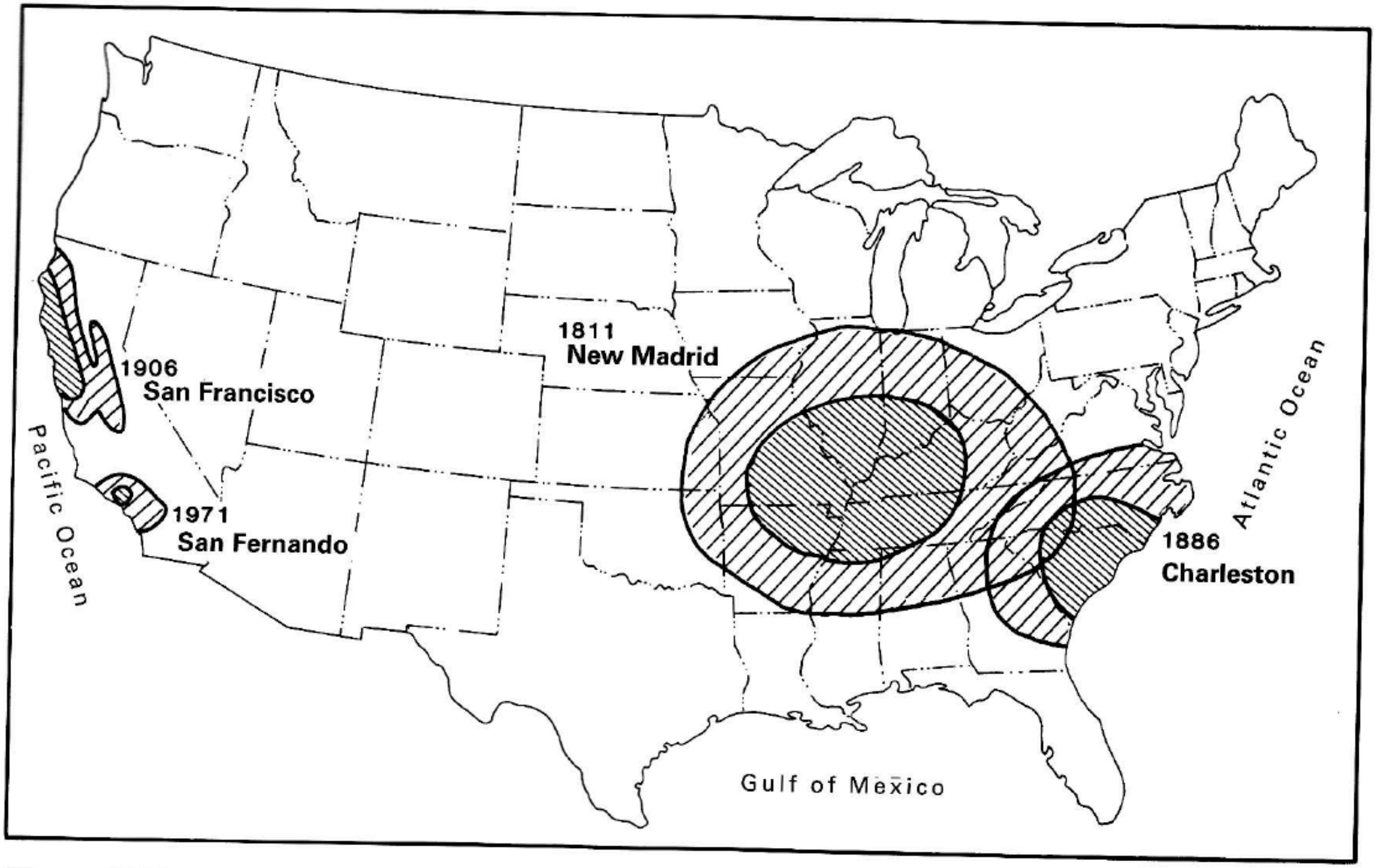


Figure 5.16 Felt areas of some large earthquakes in the United States. Inner-ruled areas are Mercalli intensities greater than VII; ruled areas are intensities VI to VII.

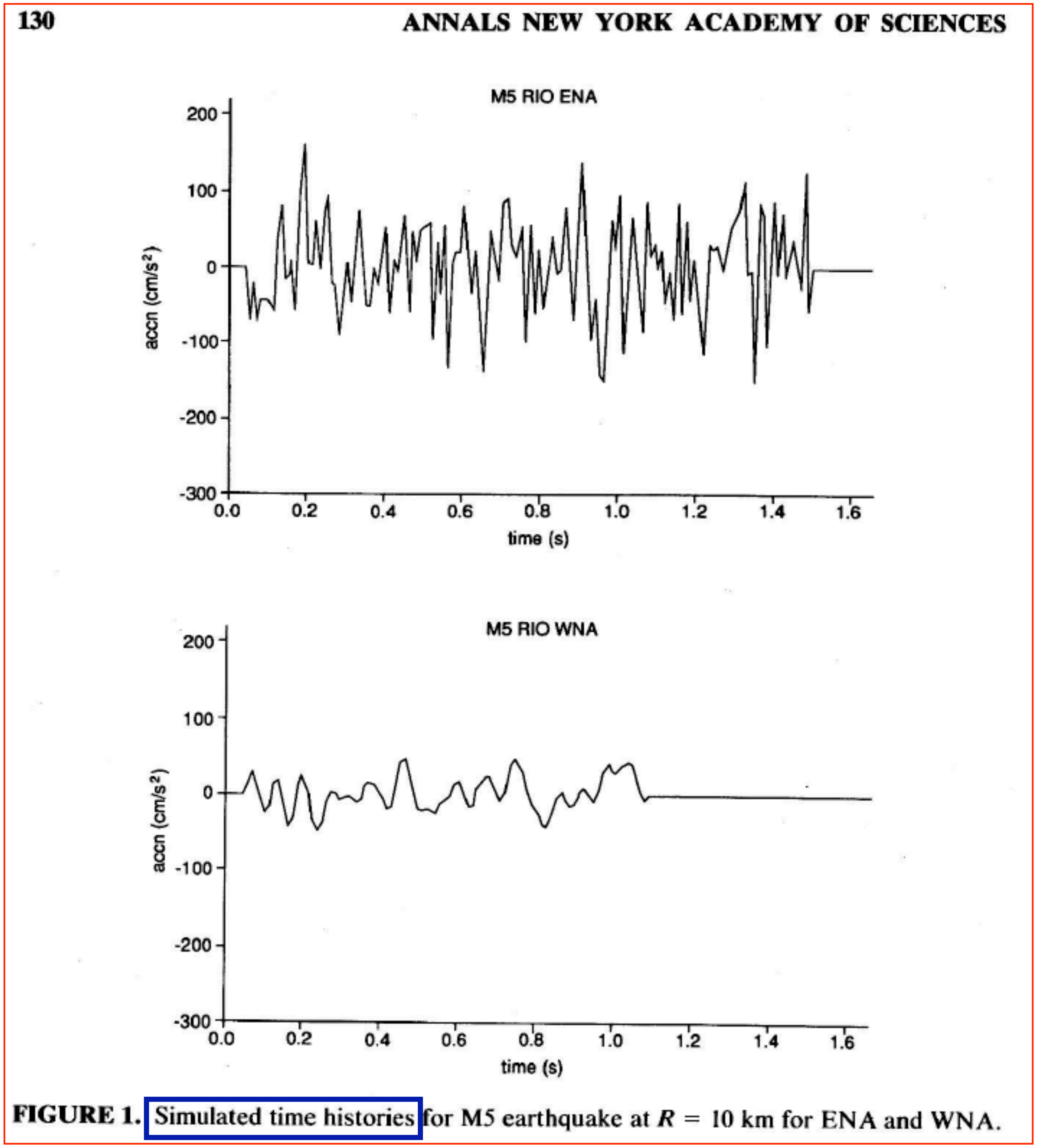


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FIGURE 1. Simulated time histories for M5 earthquake at $R = 10$ km for ENA and WNA.

ENA / CEUS = SCR ground motions contain more high frequencies

In WNA / tectonically active regions high frequencies are suppressed !

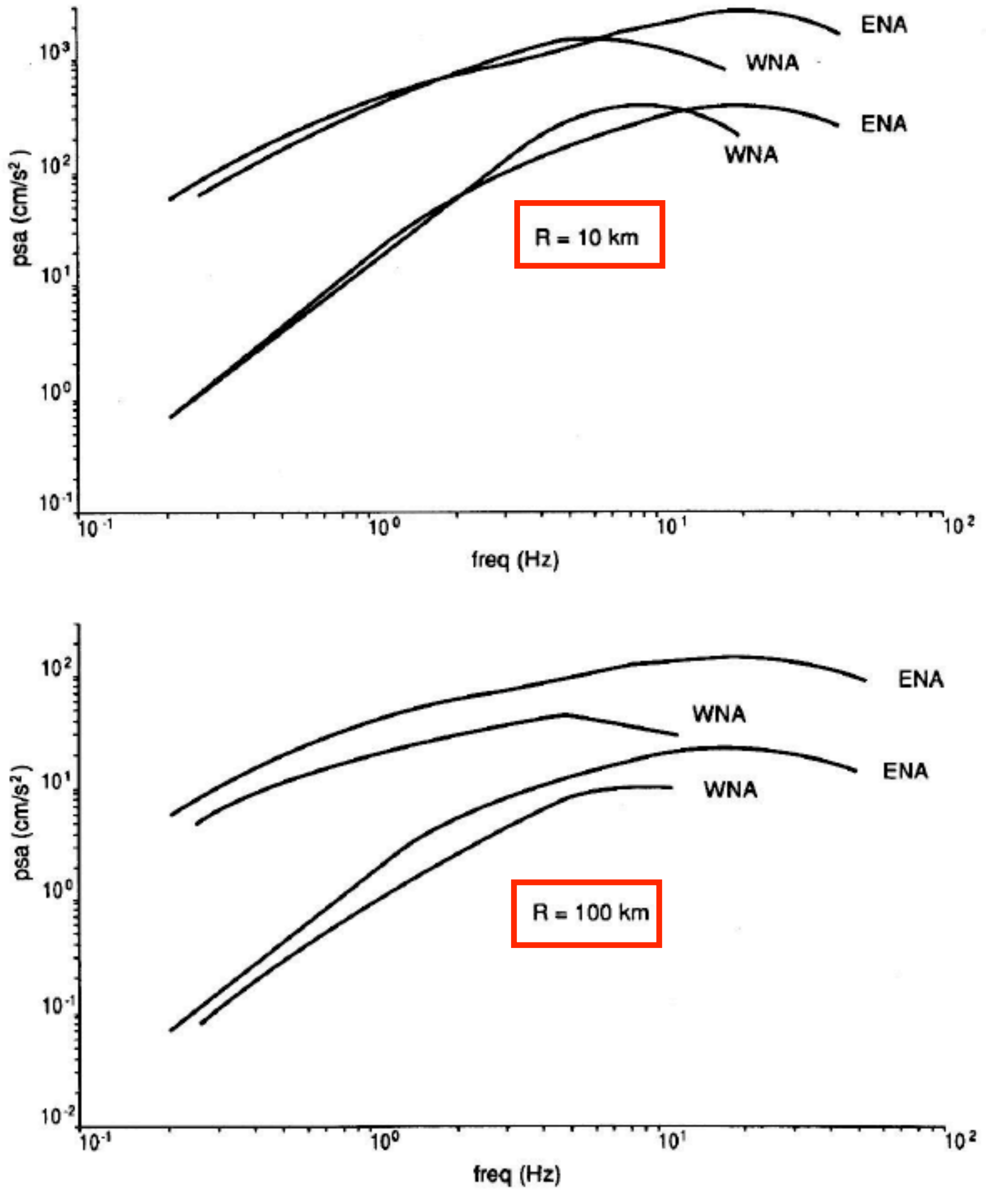
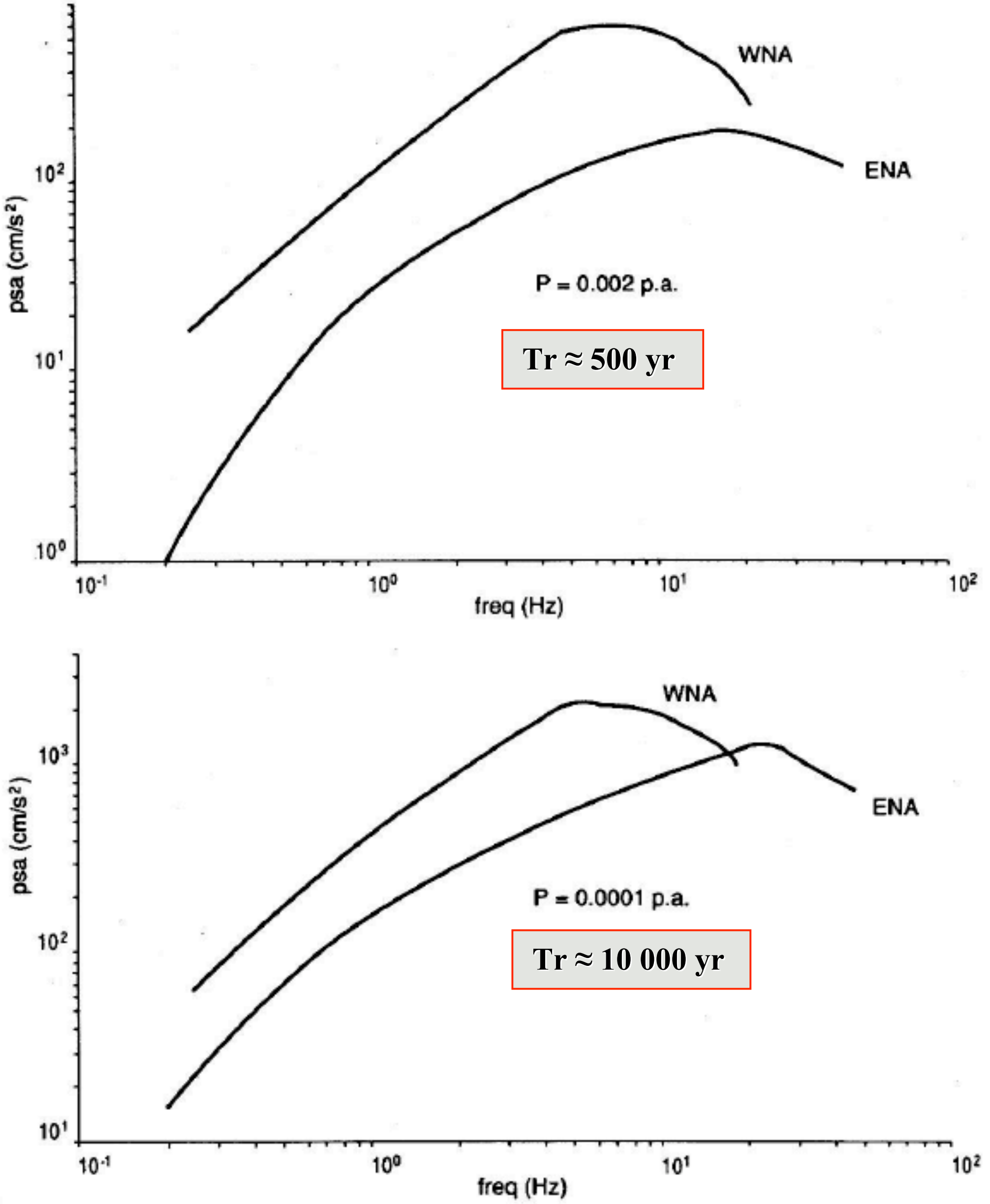


FIGURE 2. Median response spectra (5% damped) for M5 and M7 earthquakes at $R = 10$ and $R = 100$ km for ENA and WNA.

The ENA / CEUS = SCR -
ground motions
contain
more high frequencies
especially at large distances R



Tr ≈ 500 yr

Tr ≈ 10 000 yr

FIGURE 4. Response spectra (5% damped) for ENA and WNA examples for probabilities of 0.002 and 0.0001 per annum.

Uniform Hazards Spectra UHS
For two annual probabilities
10% and 0.5% in 50 years.

For a UHS, the likelihood is the same for all spectral amplitudes $S_a(f)$ irregardless of frequency f.

The lower the annual probability, the more the spectral ground motion levels from ENA, or Stable Continental Regions (SCR) in general, start to exceed the WNA (or active region -) spectral Ground Motion levels, at high frequencies f≥10Hz.

4.2 *Empirical Ground Motion Equations*

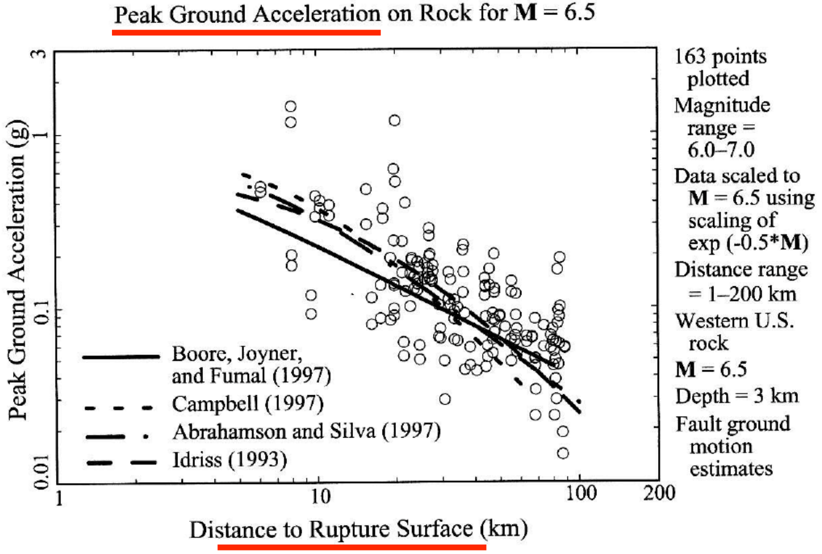
Empirically based estimates of ground motion characteristics are the oldest estimates in seismic hazard analysis, dating from the 1960s. They are popular for regions where many data are available, and they typically have the following type of form:

$$\ln A = c_o + f(m) + f(r) + f(soil) + \varepsilon \qquad (50)$$

or

$$I_s = c_o + f(I_e, m) + f(r) + f(soil) + \varepsilon \qquad (51)$$

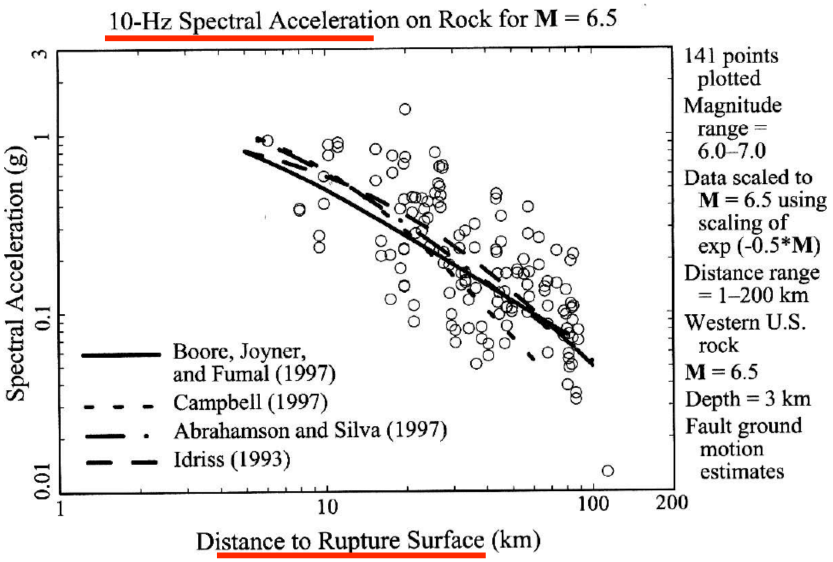
where A is ground motion amplitude, which could be a peak motion parameter or spectral amplitude; I_s is site intensity; "soil" is some quantitative, perhaps bivariate function of soil type; c_o is a constant; and ε is a random variable taking on a specific value for each observation. Some equations involve inseparable terms in magnitude m (or epicentral intensity, I_e) and distance r, as well.



163 points plotted
Magnitude range = 6.0–7.0
Data scaled to **M** = 6.5 using scaling of exp (-0.5***M**)
Distance range = 1–200 km
Western U.S. rock
M = 6.5
Depth = 3 km
Fault ground motion estimates

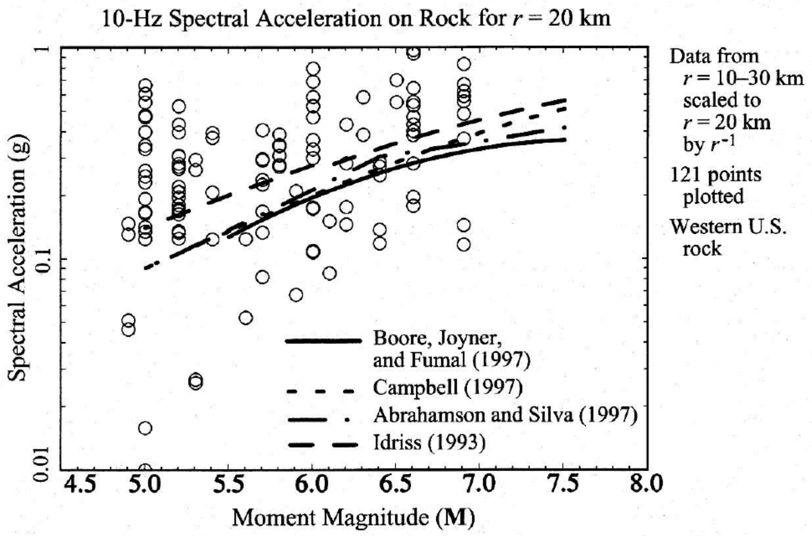
Figure 11. PGA on rock for **M** = 6.5 from four equations compared with data from **M** = 6.0–7.0. A depth of 3 km was used to plot the distance to the rupture surface for the Boore-Joyner-Fumal (1997) relation.

Note high scatter of data, represented in the GMPE by ε



141 points plotted
Magnitude range = 6.0–7.0
Data scaled to **M** = 6.5 using scaling of exp (-0.5***M**)
Distance range = 1–200 km
Western U.S. rock
M = 6.5
Depth = 3 km
Fault ground motion estimates

Figure 12. *SA* (10 Hz) on rock for **M** = 6.5 from four equations compared with data from **M** = 6.0–7.0.



Data from r = 10–30 km scaled to r = 20 km by r^{-1}
121 points plotted
Western U.S. rock

Figure 14. *SA* (10 Hz) on rock for r = 20 km from four equations compared with data from r = 10–30 km.

Ground Motions can be represented either in Acceleration, Velocity or Displacement Domain.
Although they contain the same information, they have different Engineering Applications: Forces, vs. Strains vs. Displacements

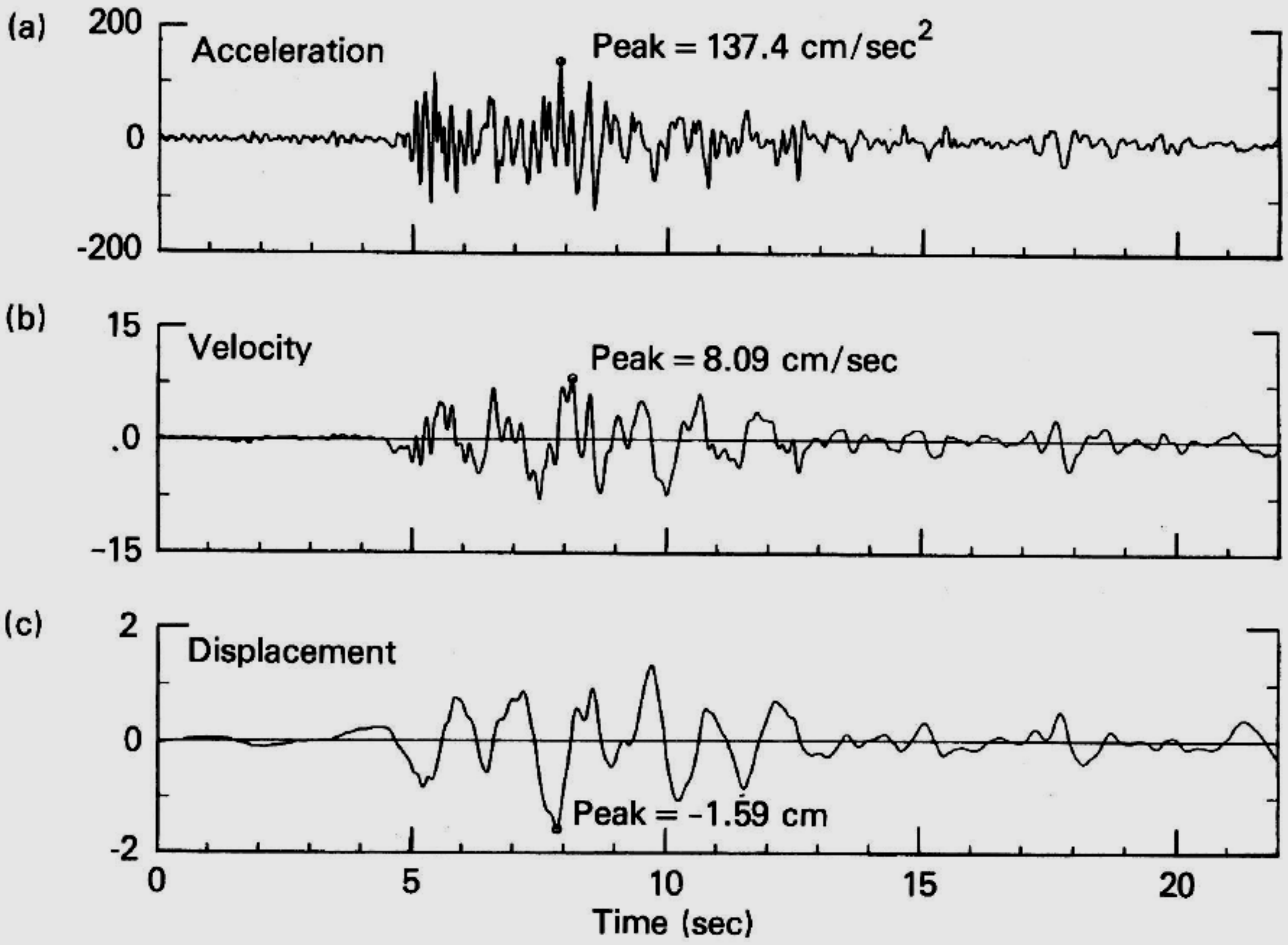
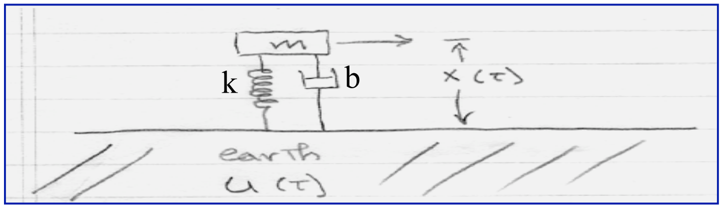
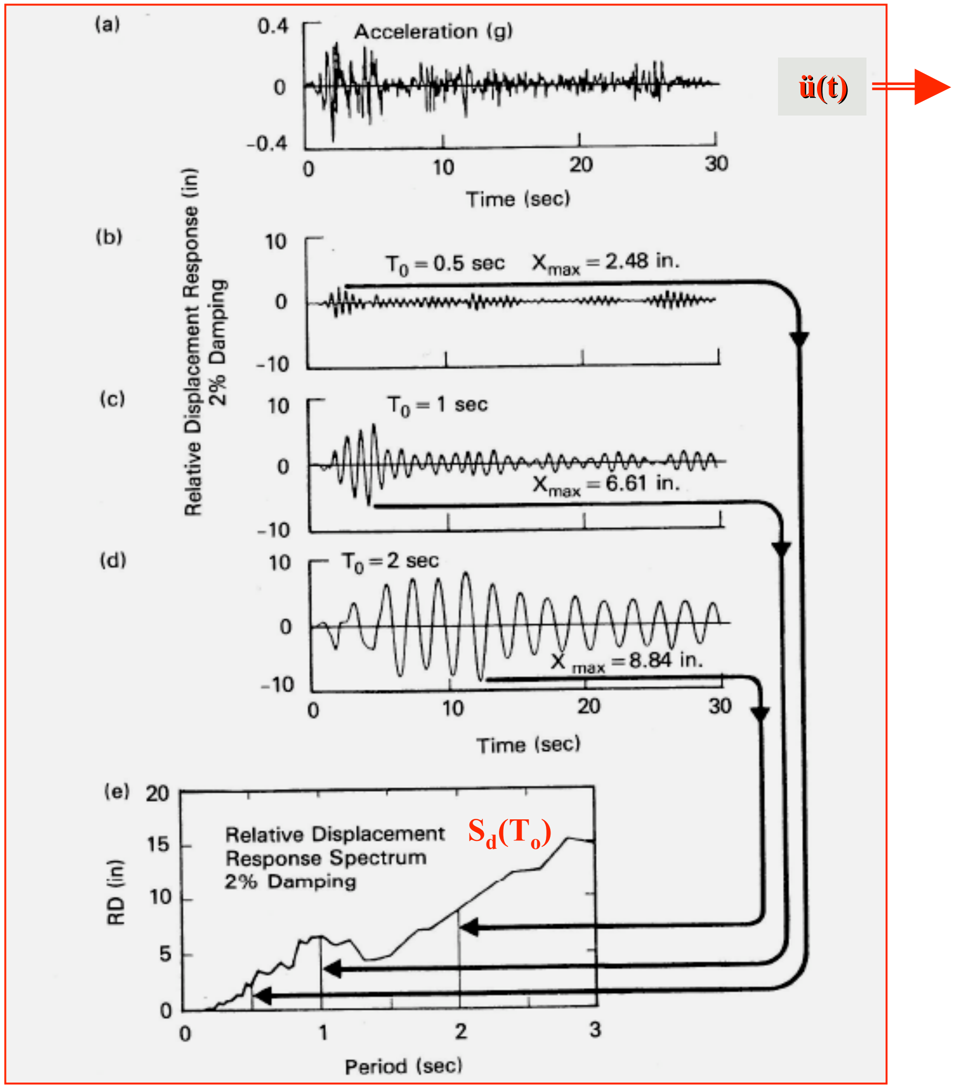


FIGURE 6.2 Instrument-corrected and noise-filtered (a) acceleration, (b) velocity and (c) displacement time histories from the accelerogram shown in figure 6.1a (after Shakal and others 1986).

What is a SDOF Damped Elastic Response Spectrum? And how to construct it:

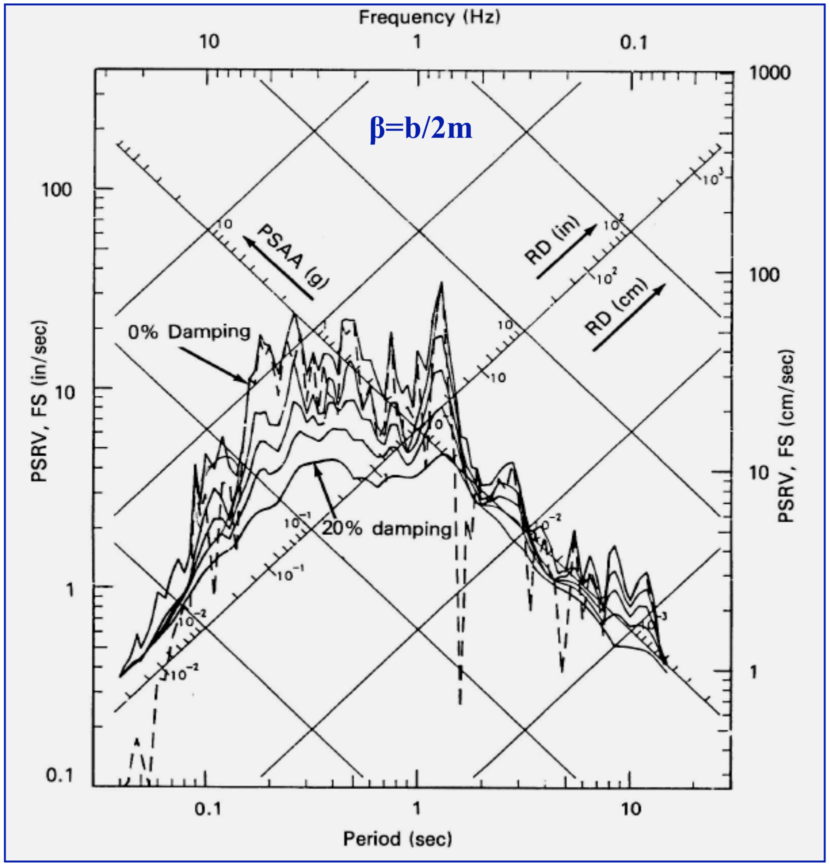
Pick the largest response excursion x_{max} of the damped single degree of freedom oscillator (SDFO) with a given natural period $T_o = 2\pi/(\sqrt{k/m})$, and damping $\beta=b/2m$, and plot x_{max} at period T_o; then repeat for many T_o ==> This yields a Displacement Response Spectrum $S_d(T_o)$. Obtain "Pseudo" Velocity- and Acceleration-Spectra S_v and S_a by multiplying $S_d(T_o)$ by ω and ω^2, respectively.

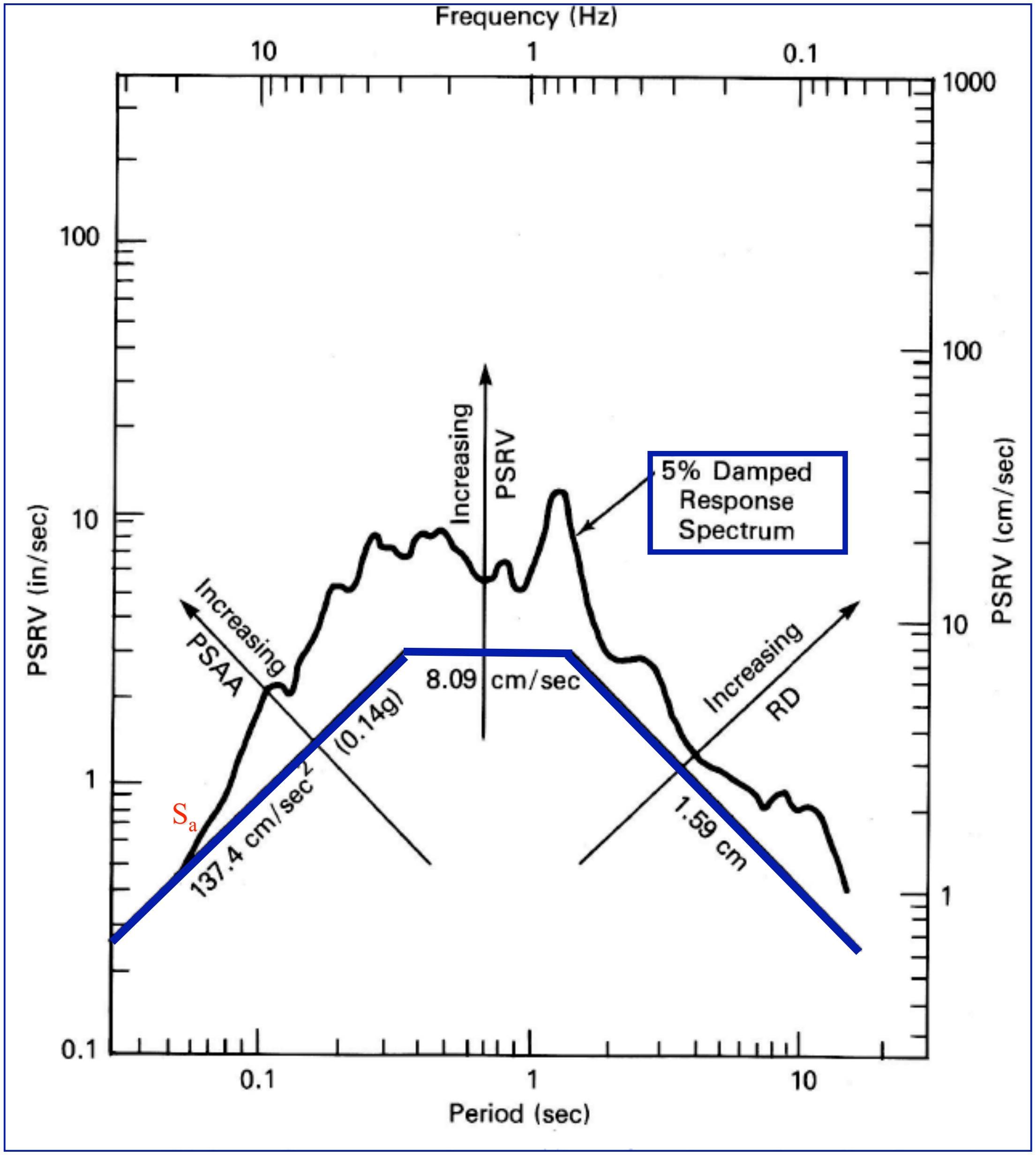


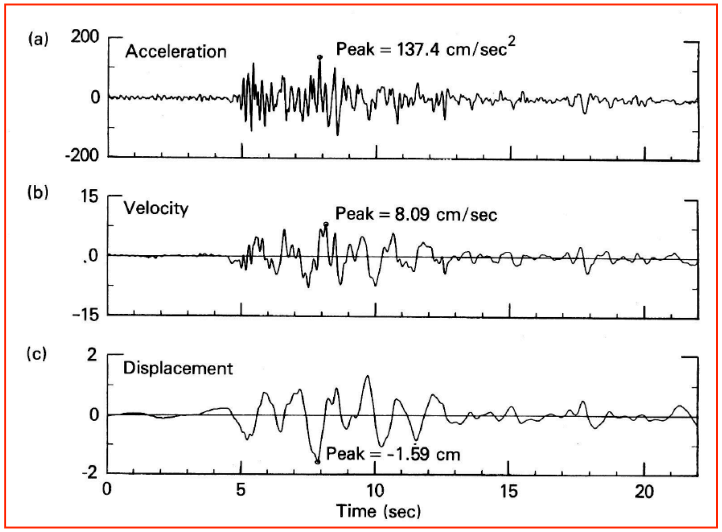


$$m(\ddot{x}+\ddot{u})+kx+b\dot{x}=0, \qquad \ddot{x}+2\beta\dot{x}+\omega_0^2 x=-\ddot{u},$$

$$\omega_0=\sqrt{\frac{k}{m}}=\text{undamped natural frequency } =2\pi/T_o$$

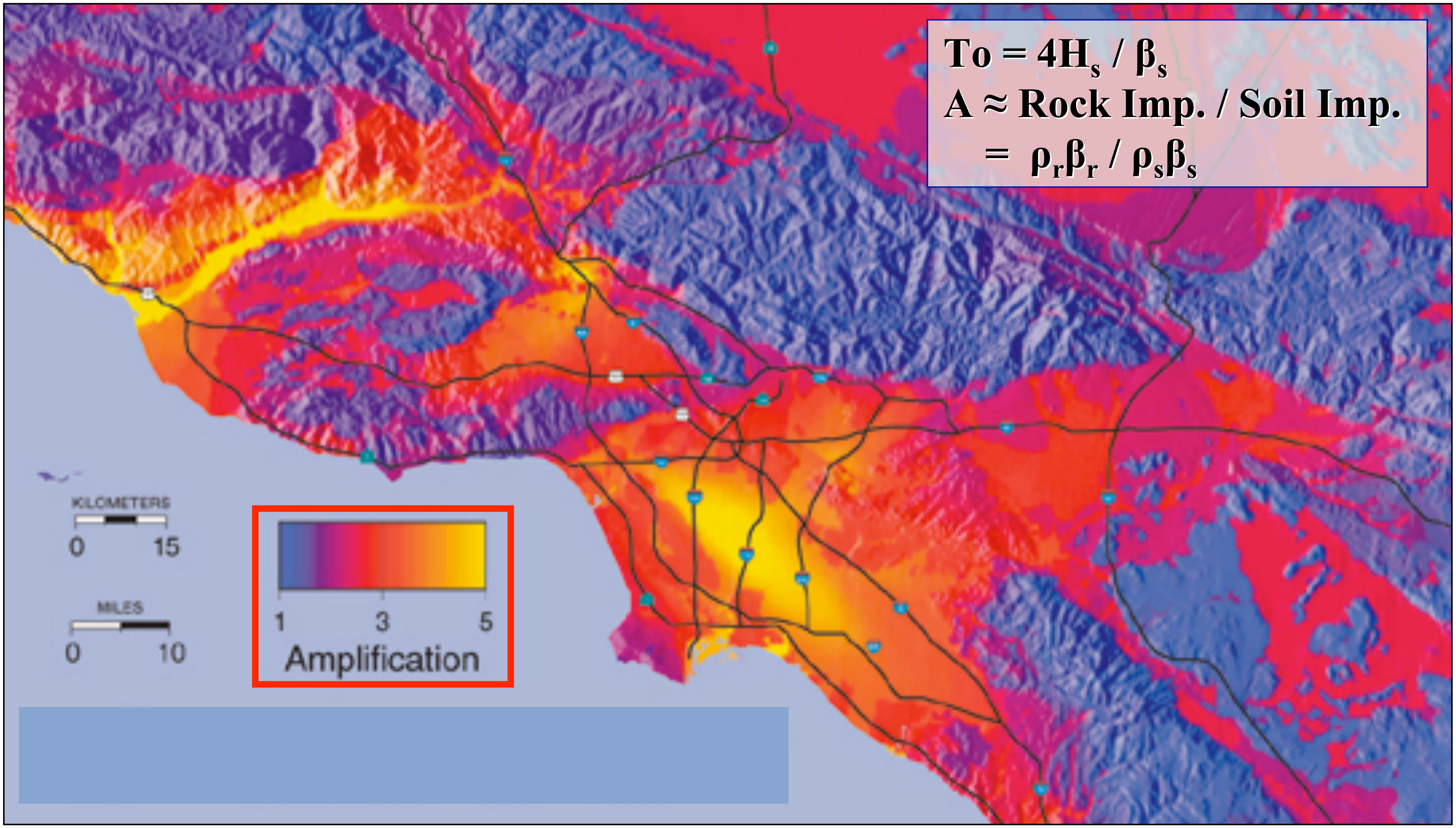






Peak Levels PGA, PGV, PGD on Seismograms for Acceleration, Velocity and Displacement are lower than the Response Spectral values S_a , S_v and S_D , but at high frequencies f (short Periods T) S_a approaches PGA asymptotically.

Site Response / Microzonation



$$T_o = 4H_s / \beta_s$$
$$A \approx \text{Rock Imp.} / \text{Soil Imp.}$$
$$= \rho_r\beta_r / \rho_s\beta_s$$

Site Response ….. is the local modification of ground motions due to near- & sub-surface soil and rock conditions. Microzonation Example: Ground Shaking Amplification Map of the L.A. Basin and vicinity (Field et. al., 2000)

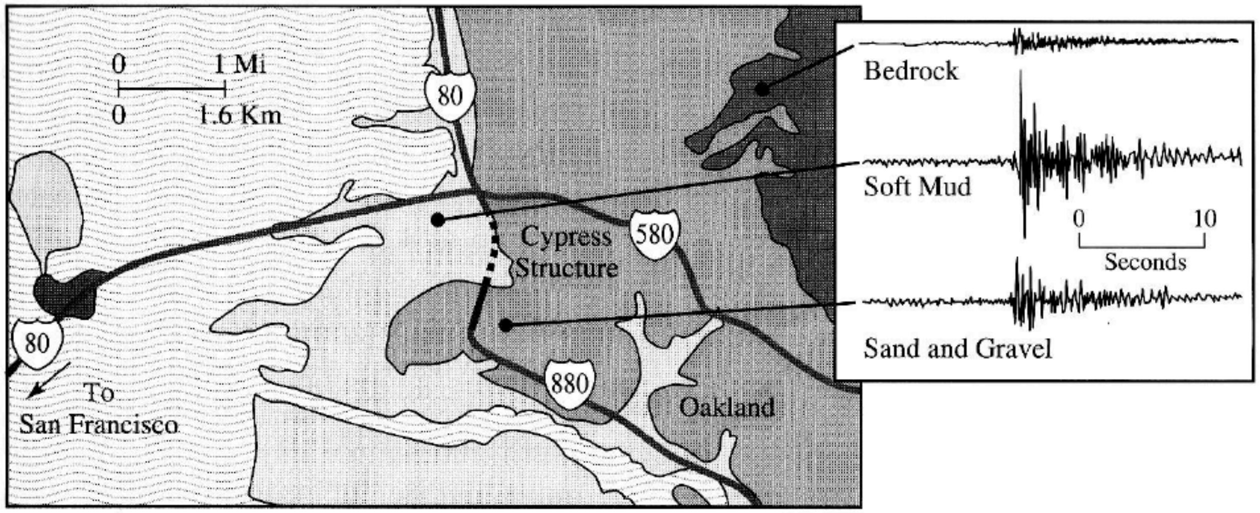
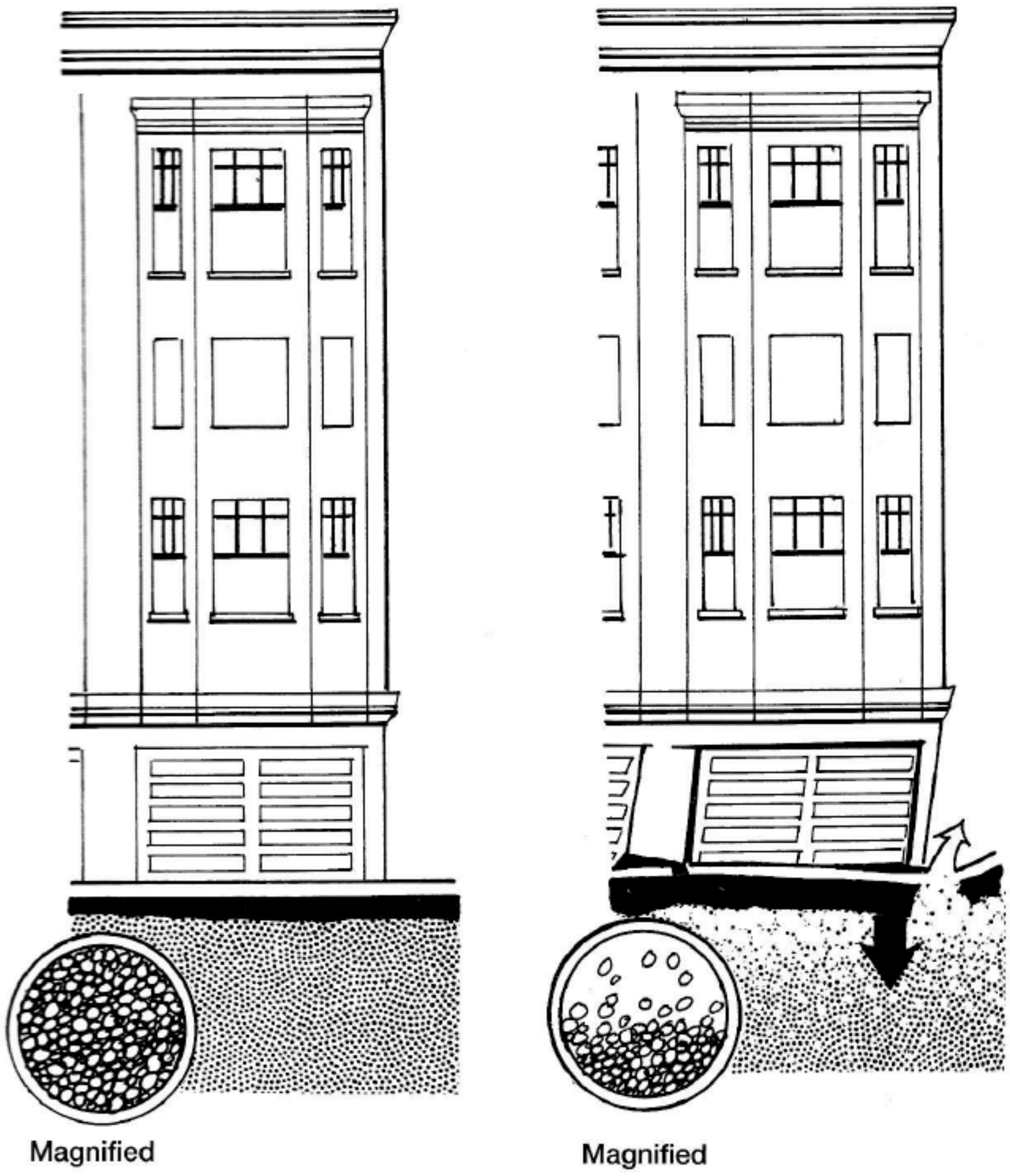


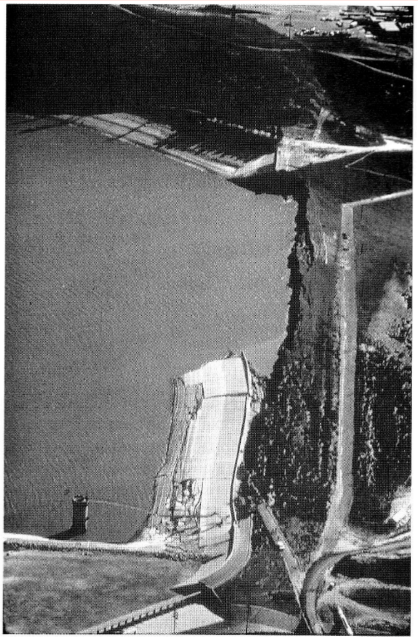
Figure 4.28 The portion of Interstate 880 elevated roadway built on top of soft bay mud collapsed (dashed black line) while the portion resting on rock still stood (solid black line). Notice how the shaking was amplified in the soft mud.



(a)

(b)

Figure 4.26 **(a)** Water-saturated sediment usually rests quietly. However, when seismic waves shake, sand grains and water can form a slurry and flow as a liquid. When earth materials liquefy, building foundations may split and buildings may fail. **(b)** A typical Marina District building collapse. Three residential stories sat above a soft first story used for car parking; now, the four-story building is three-stories tall. Photo courtesy of Dames and Moore.

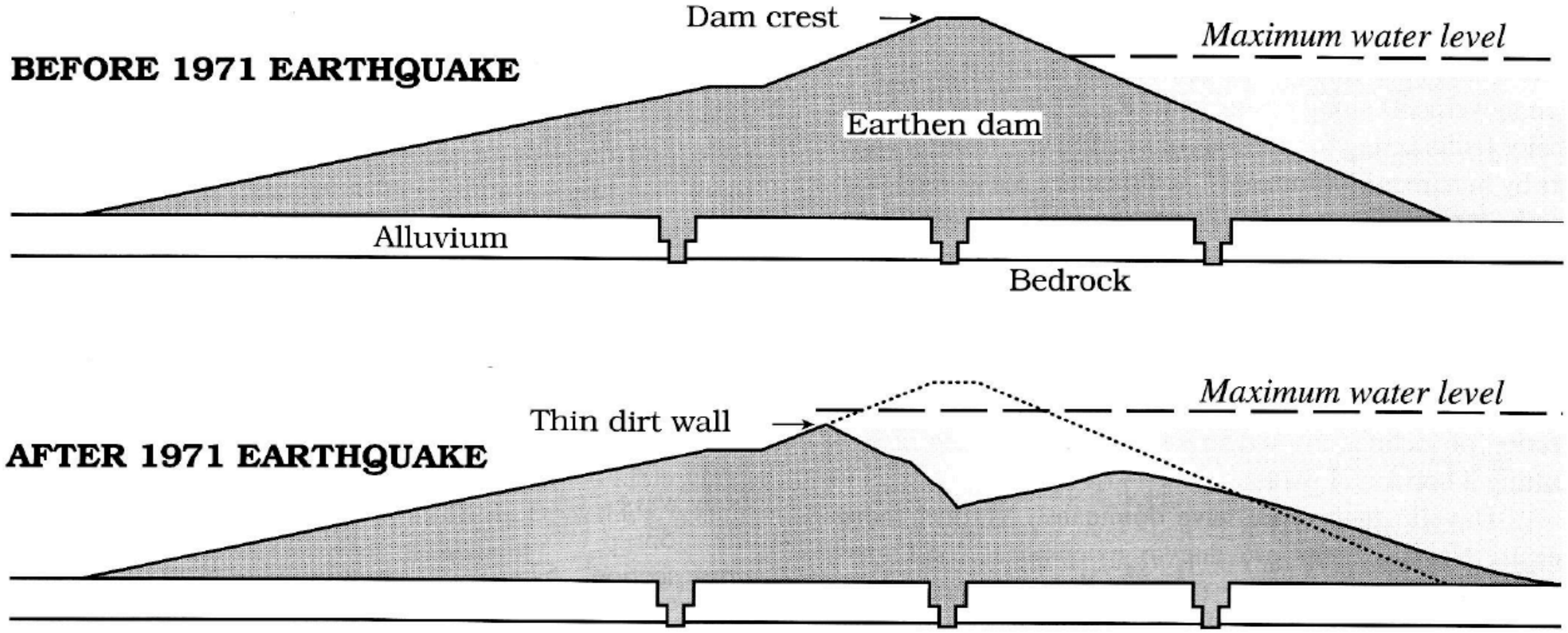


(b)

Figure 3.41 Failure of the Lower Van Norman Dam. **(a)** Landsliding lowered dam by 30 feet. **(b)** A few more seconds of strong shaking would have unleashed the deadly force of 11,000 acre-feet of water on San Fernando Valley residents below.

(a) Data Source: U.S. Geological Survey Fact Sheet 096–95, "The Los Angeles Dam Story," January 1995.

(b) Photo by Al Boost.



(a)

This concludes

Basic Observations on:

- **The Tectonic Environment**
- **Individual Earthquakes,**
- **Seismicity Rates and**
- **Ground Motions**

Relevant to Seismic Hazard Assessment (SHA):

Questions?

2d