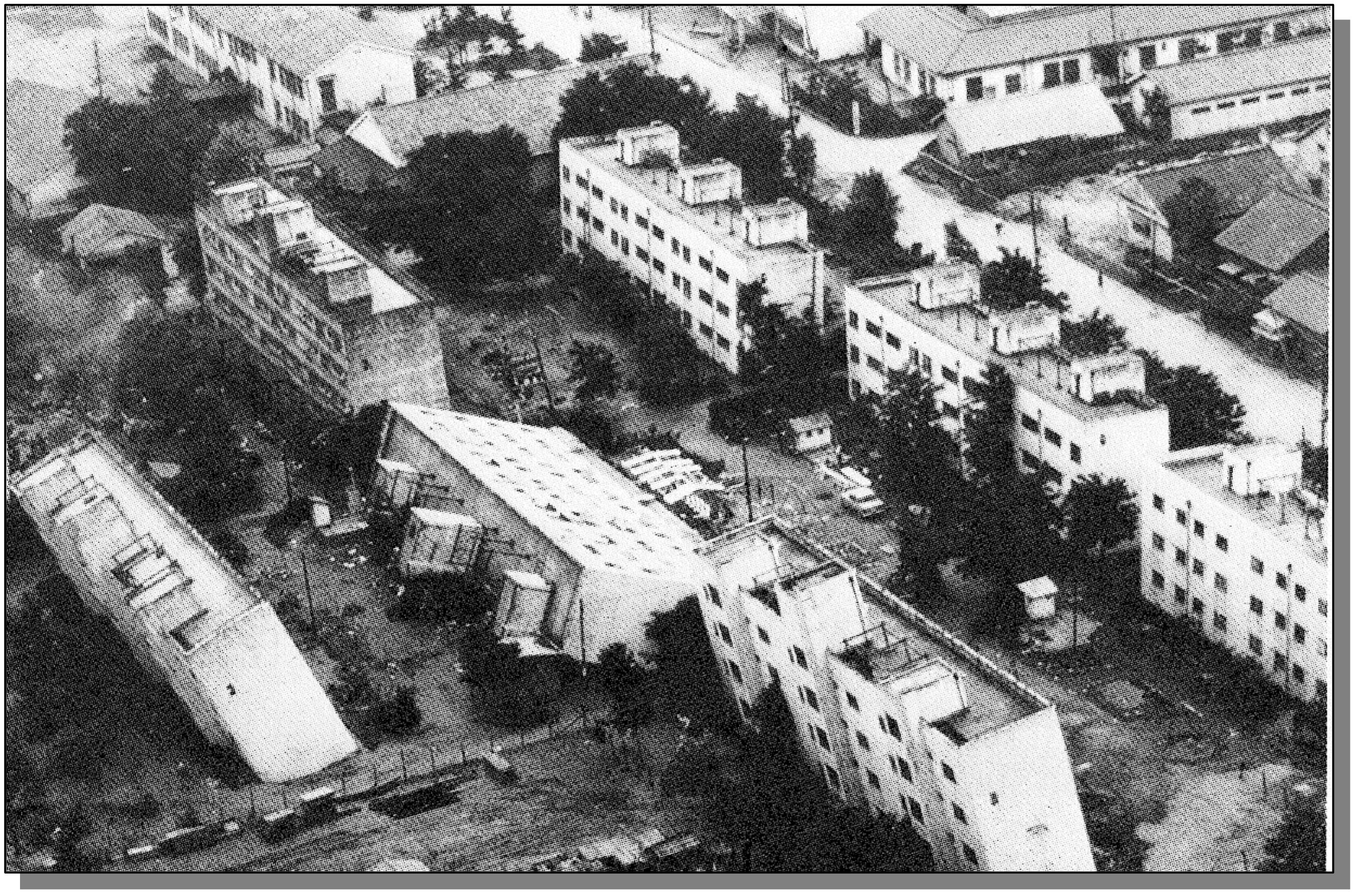
Earthquakes Mechanics and Effects



Earthquakes: Cause and Effect

- Why earthquakes occur
- How earthquakes are measured
- Earthquake effects
- Mitigation strategy
- Earthquake time histories

Seismic Activity: 1961-1967

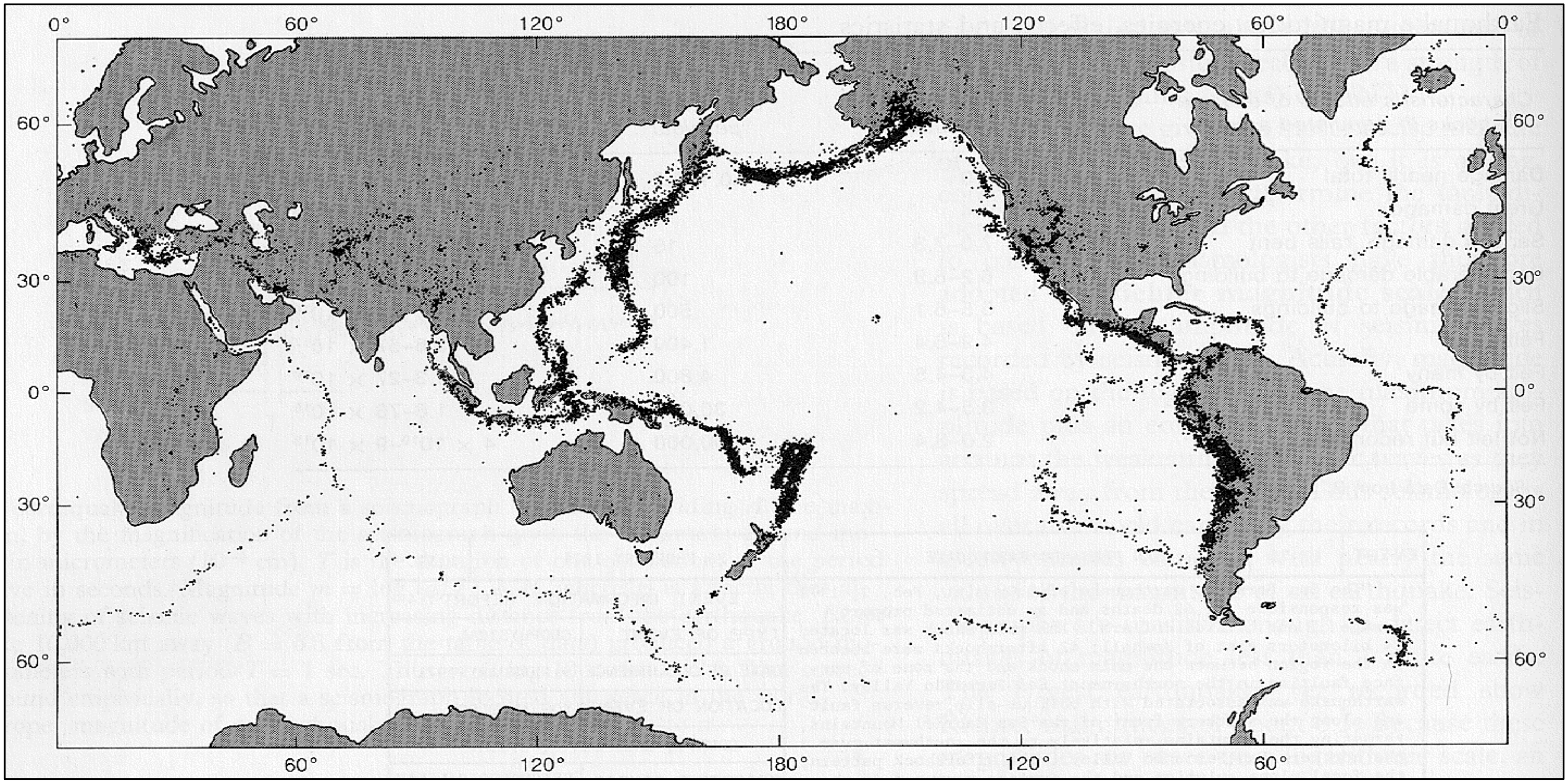


Plate Boundaries

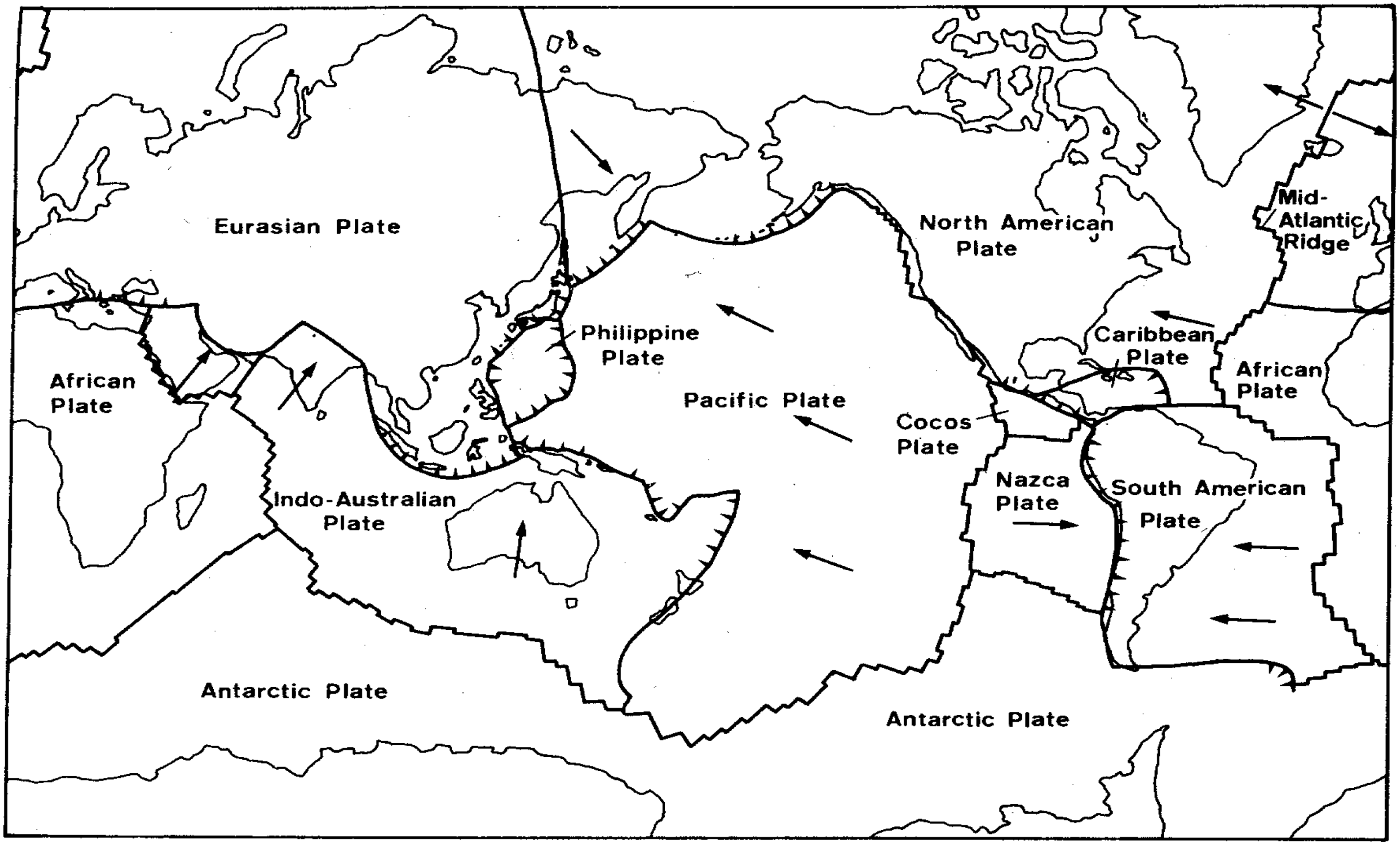


Plate Tectonics: Driving Mechanism

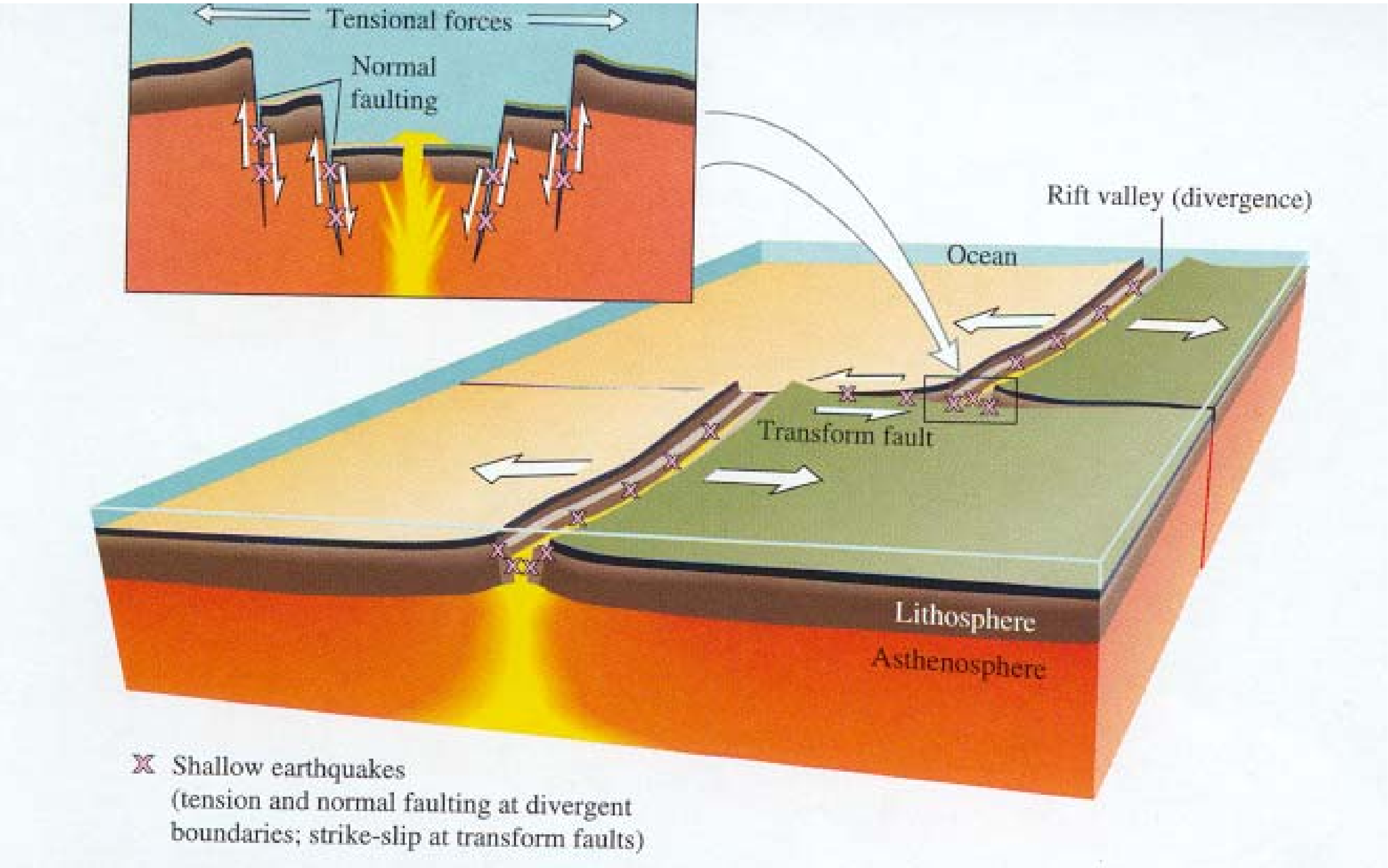
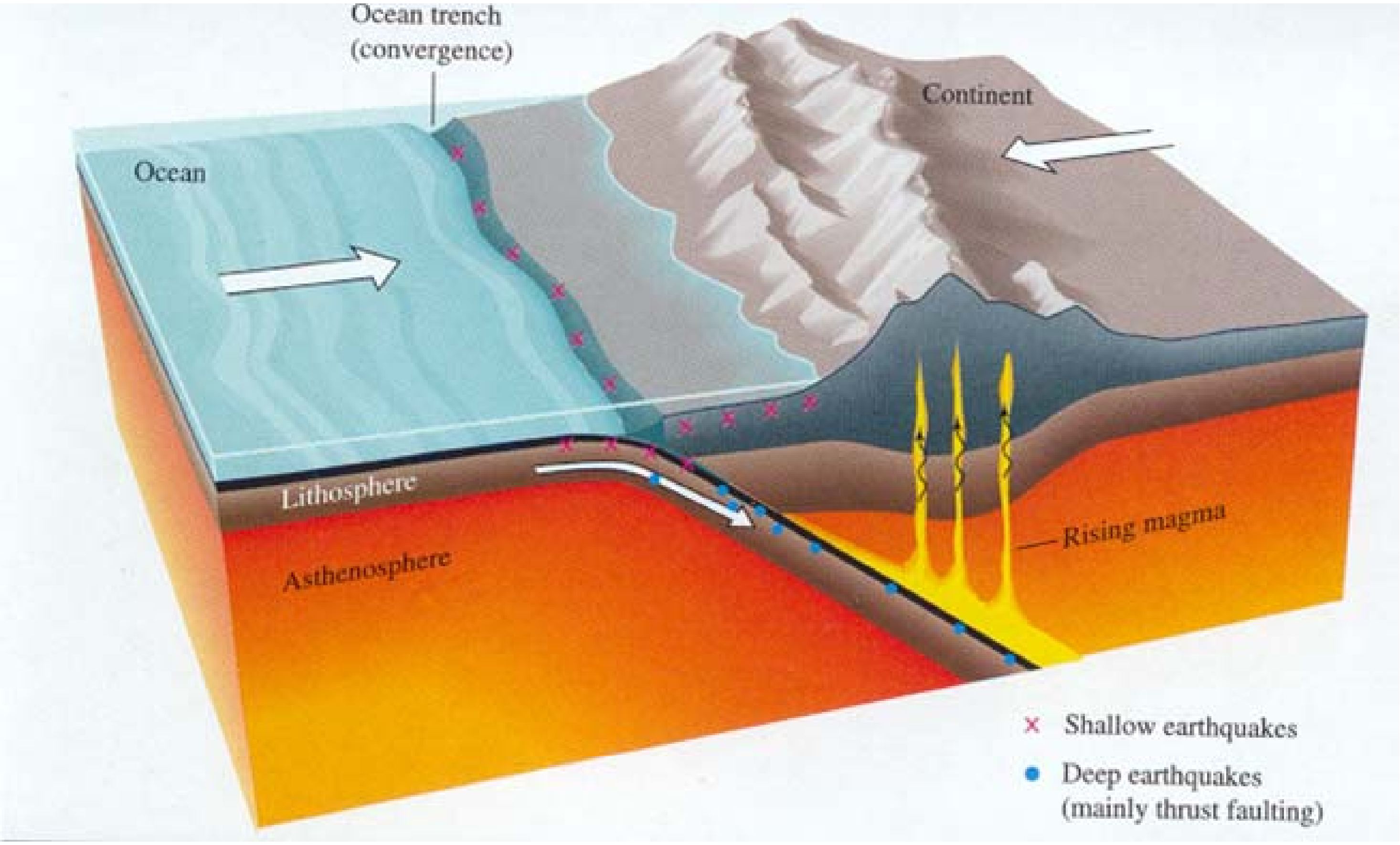
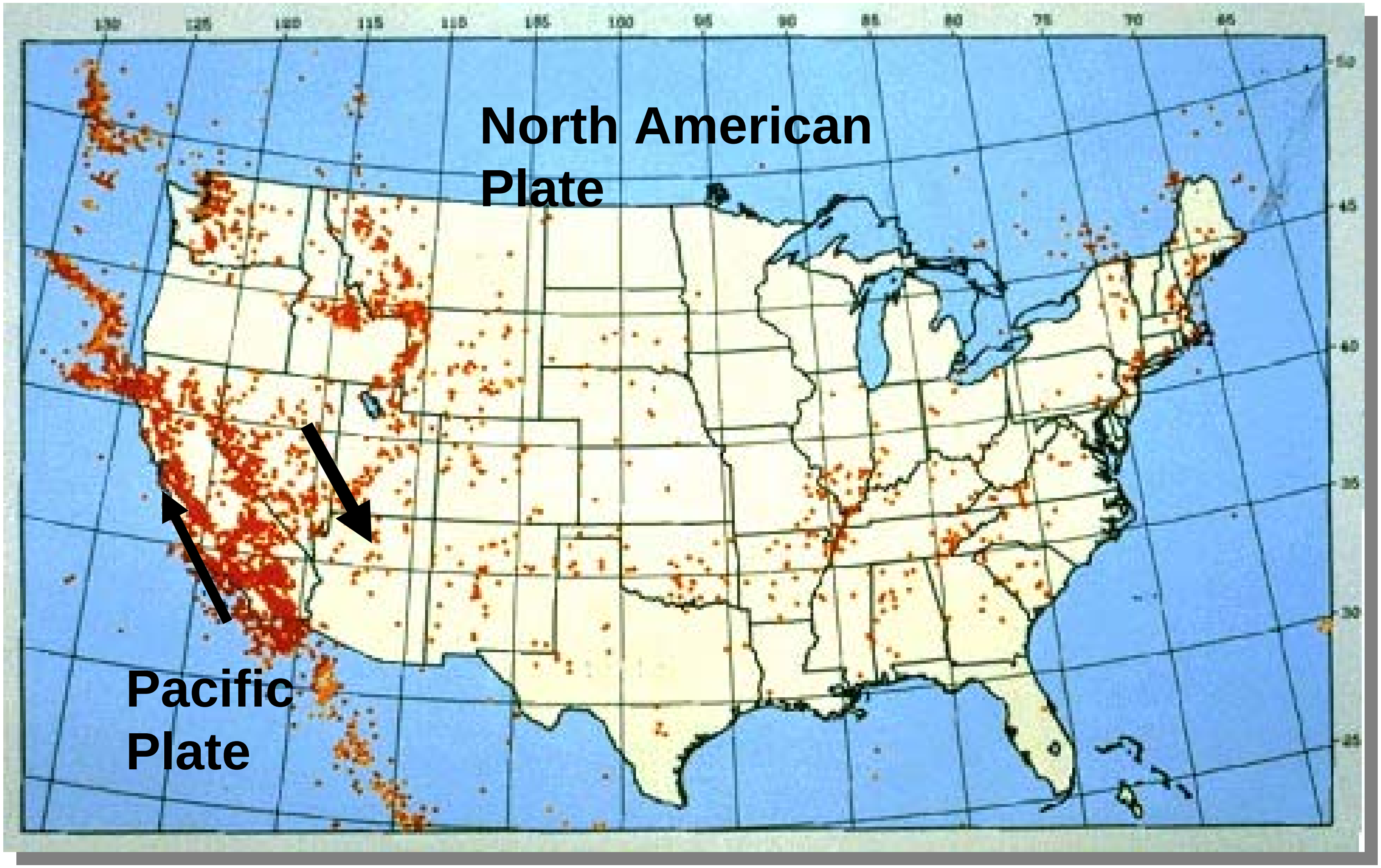


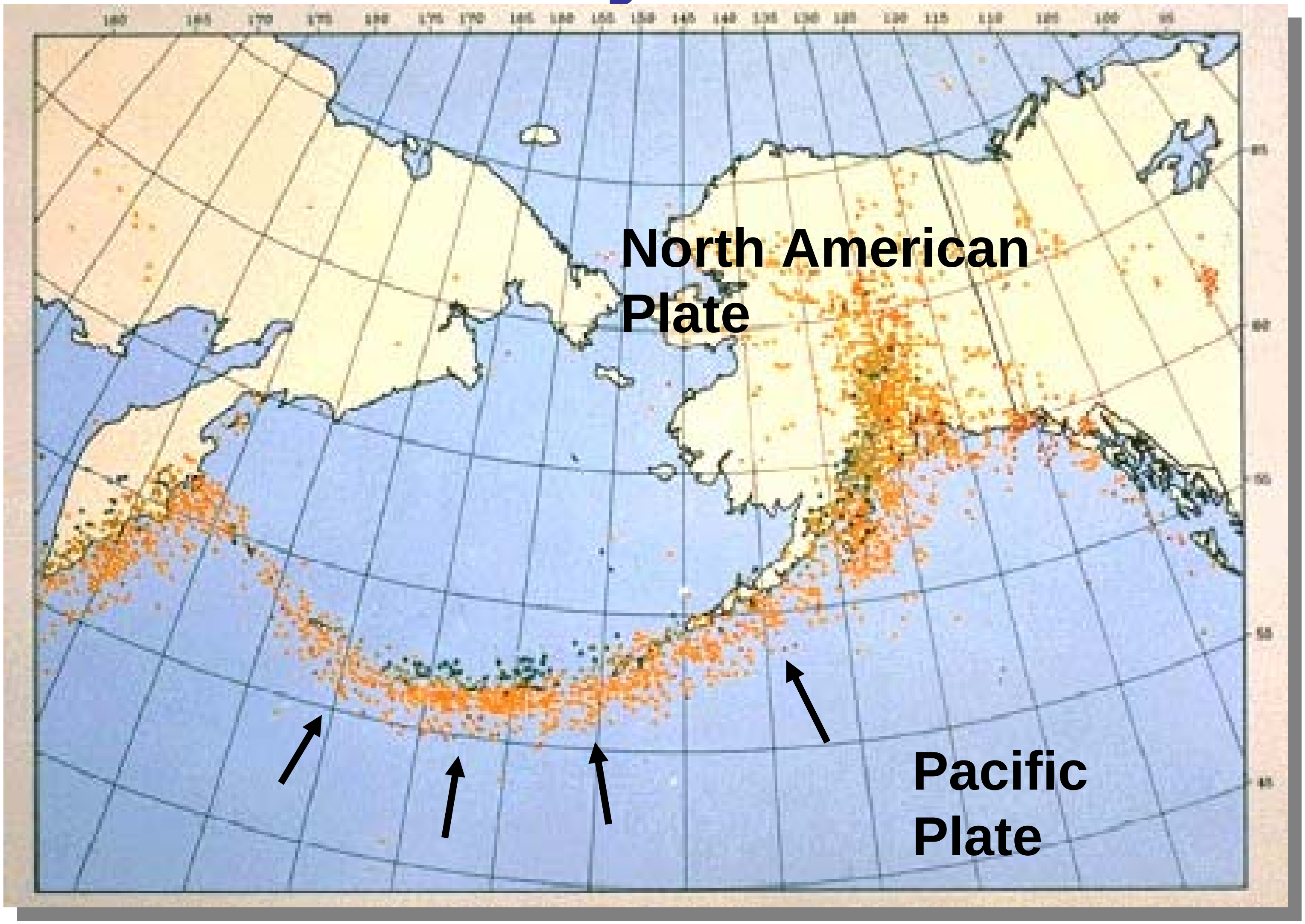
Plate Tectonics: Details in Subduction Zone



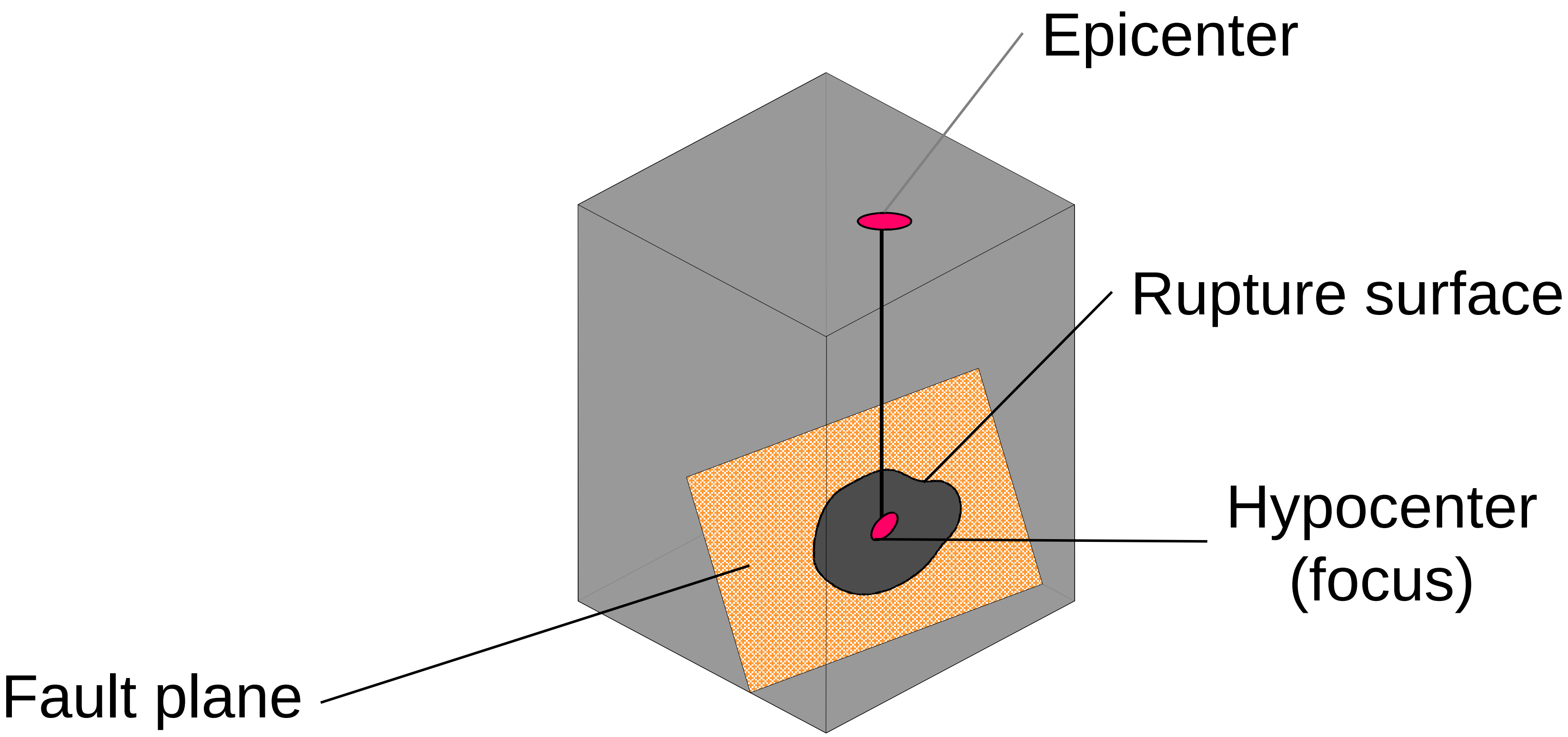
Seismicity of North America



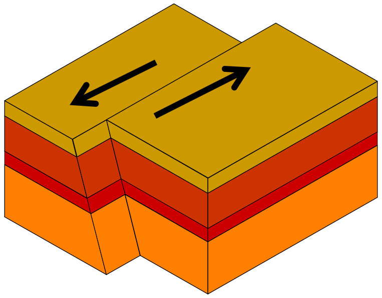
Seismicity of Alaska



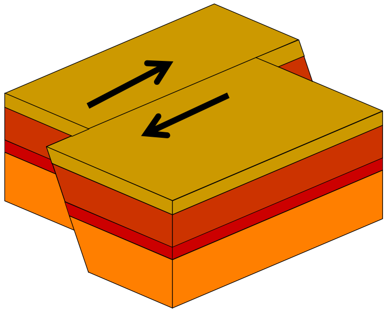
Faults and Fault Rupture



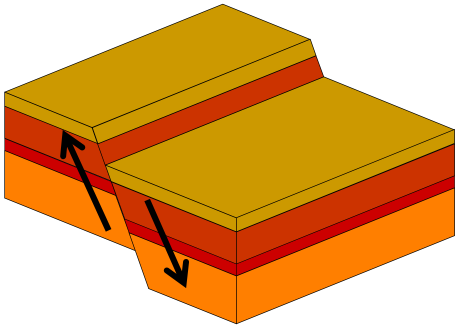
Types of Faults



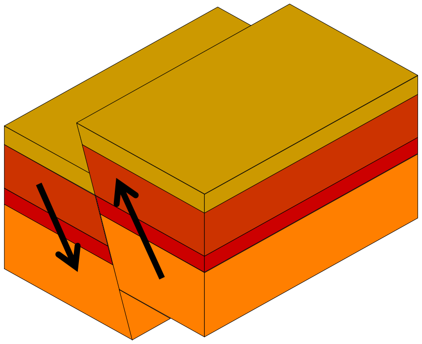
Strike slip
(left lateral)



Strike slip
(right lateral)



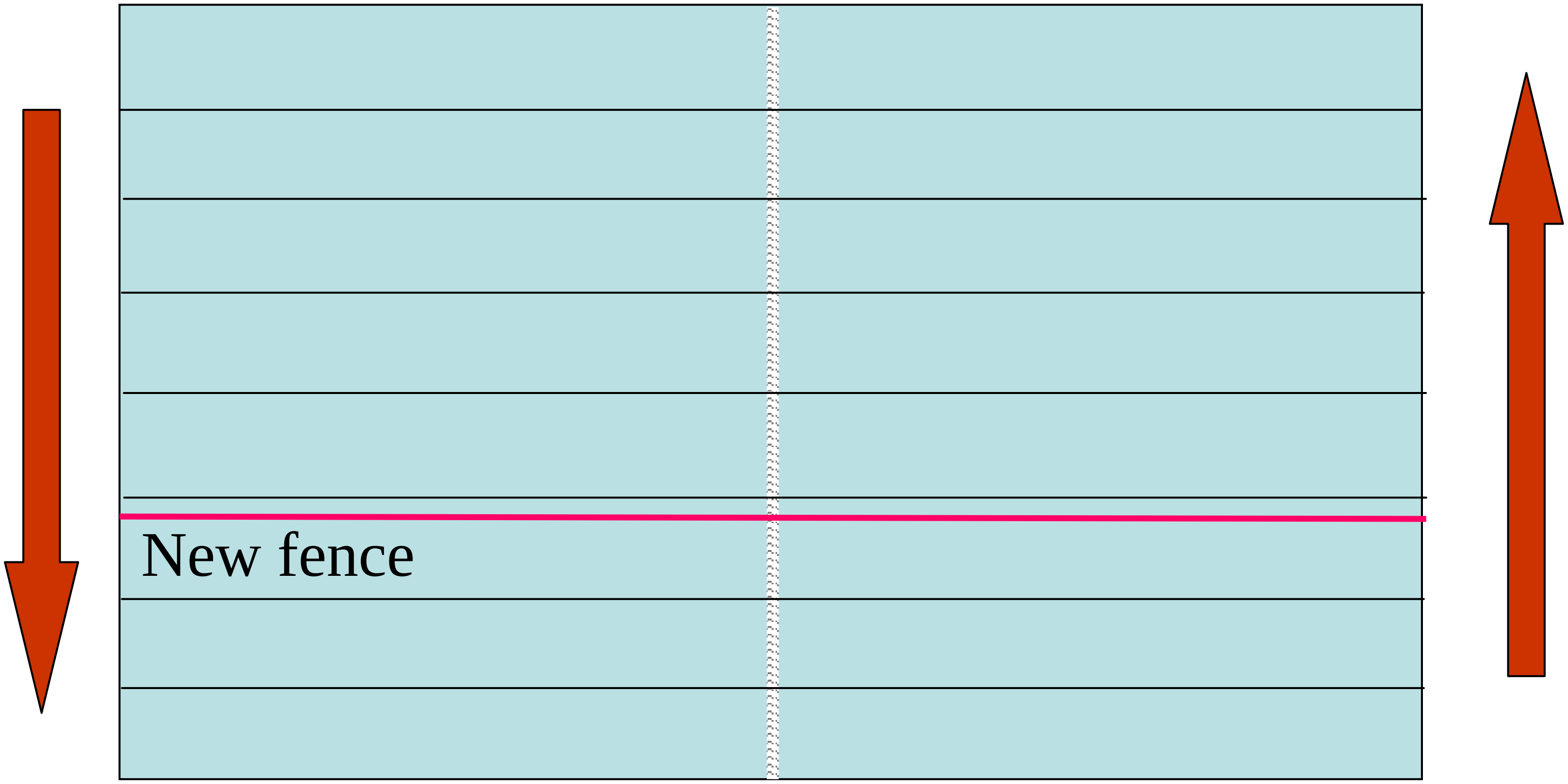
Normal



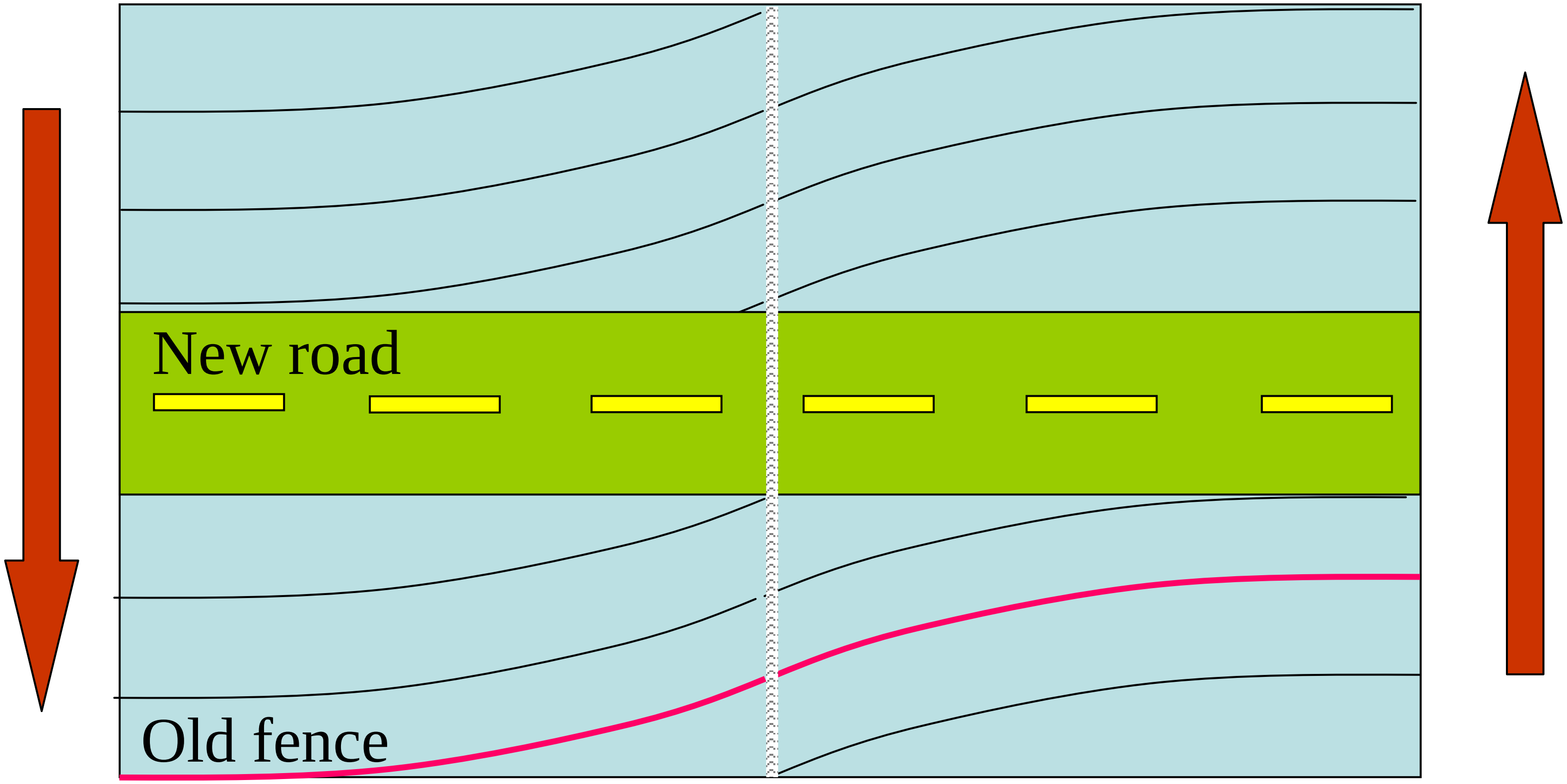
Reverse (thrust)

Elastic Rebound Theory

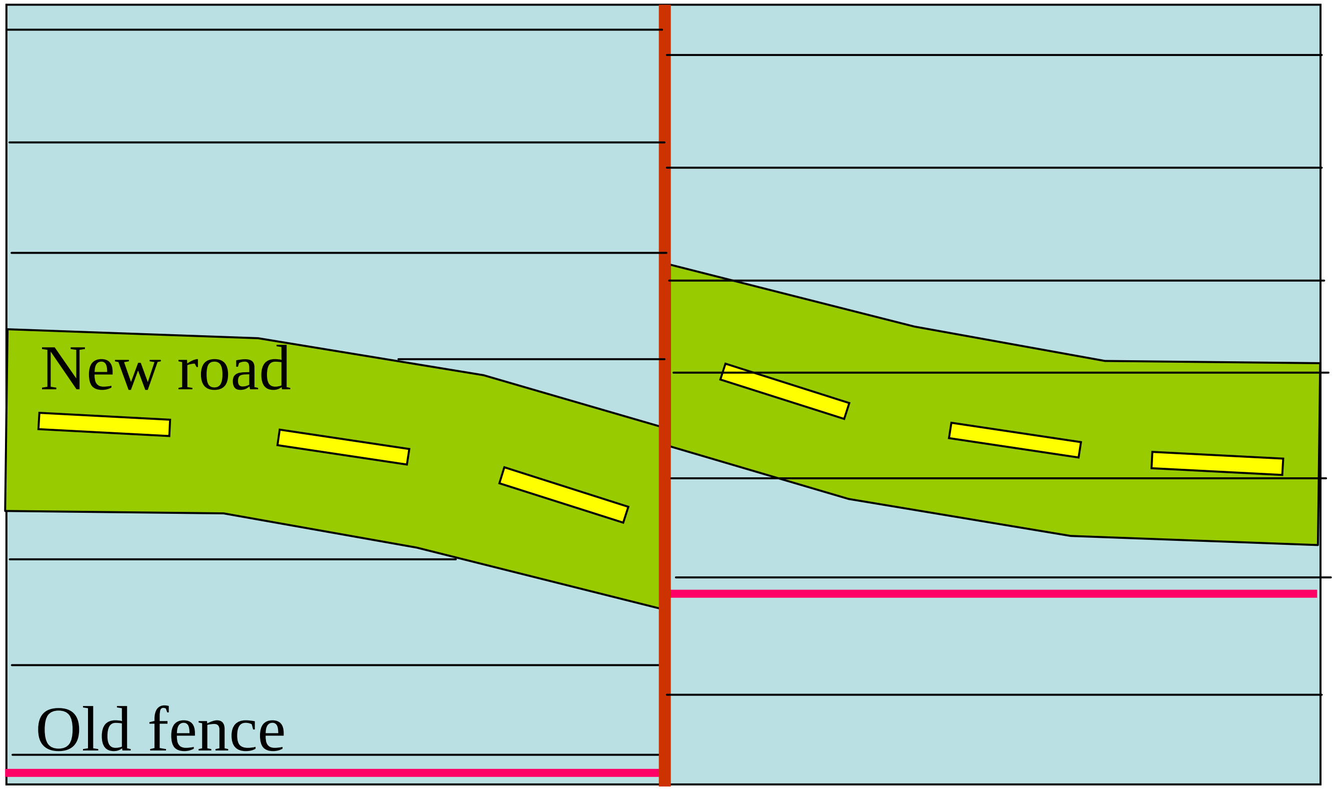
Time = 0 Years

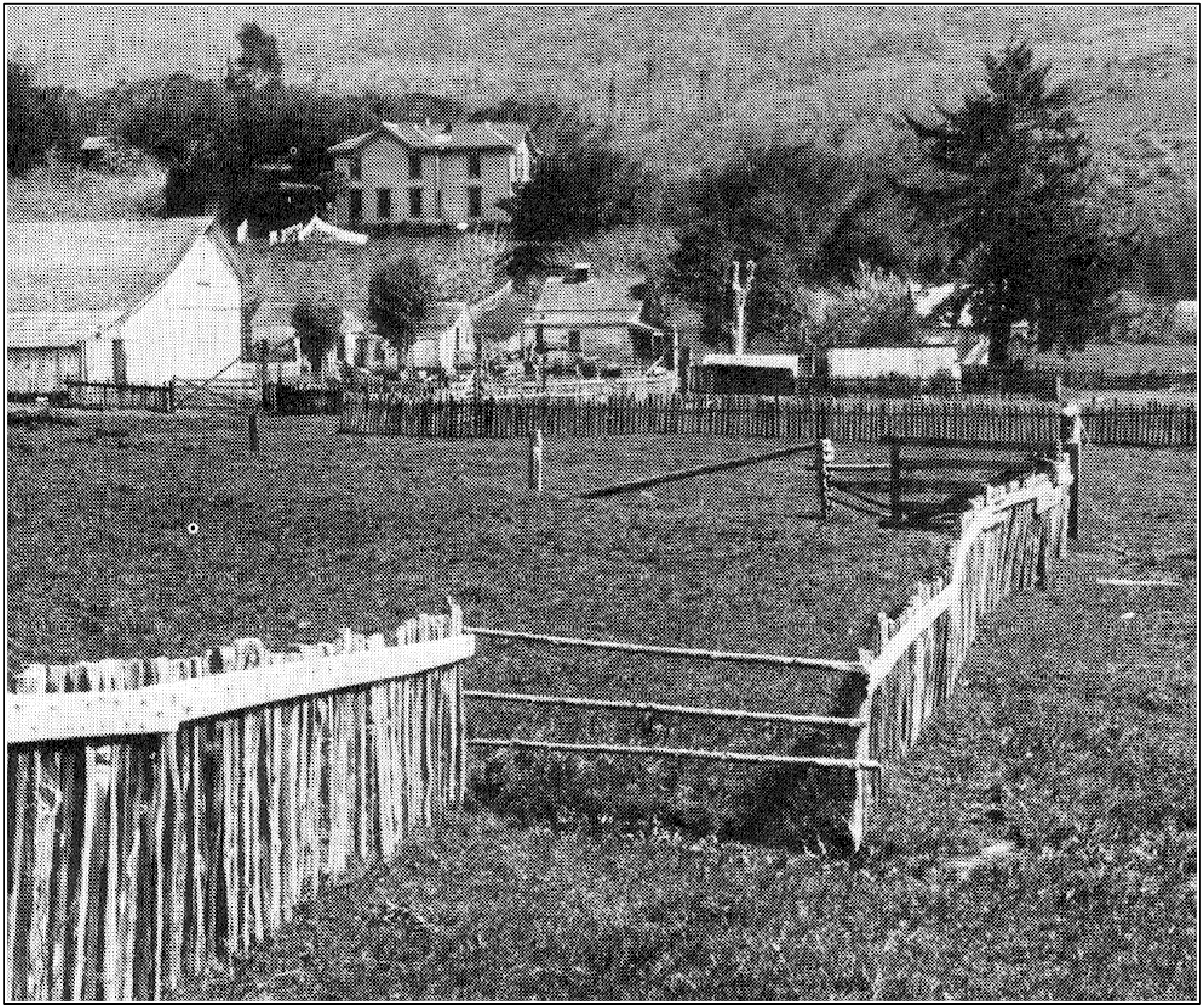


Time = 40 Years

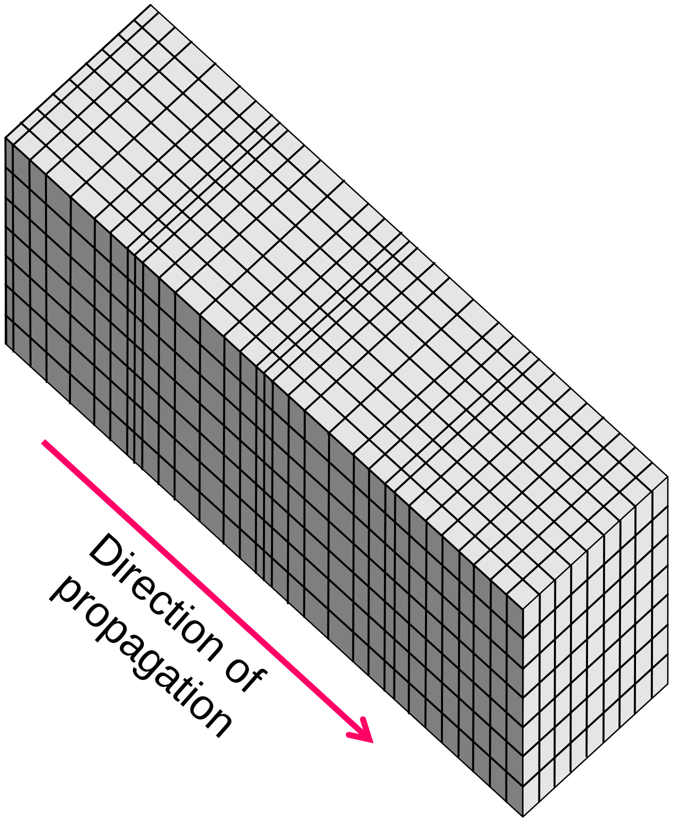


Time = 41 Years

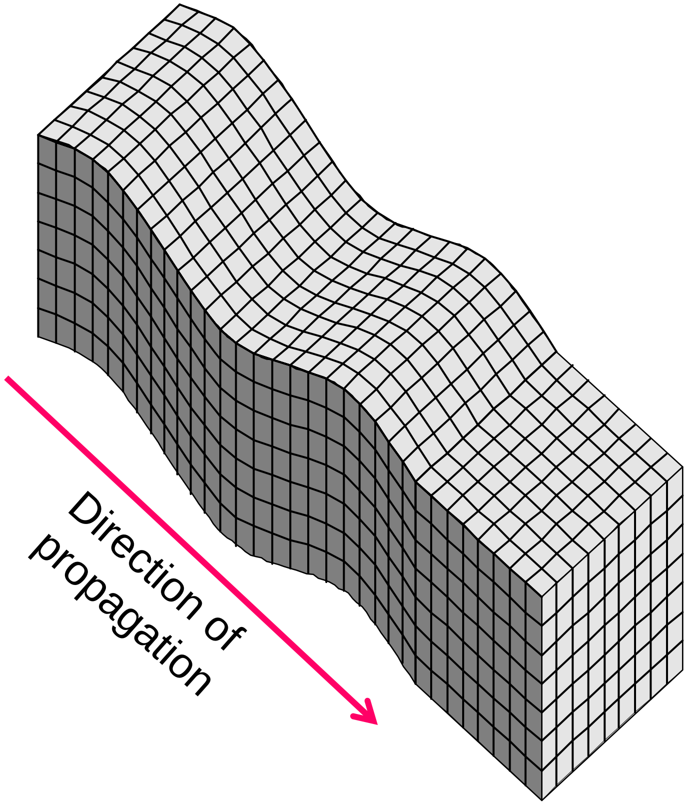




Seismic Wave Forms (Body Waves)

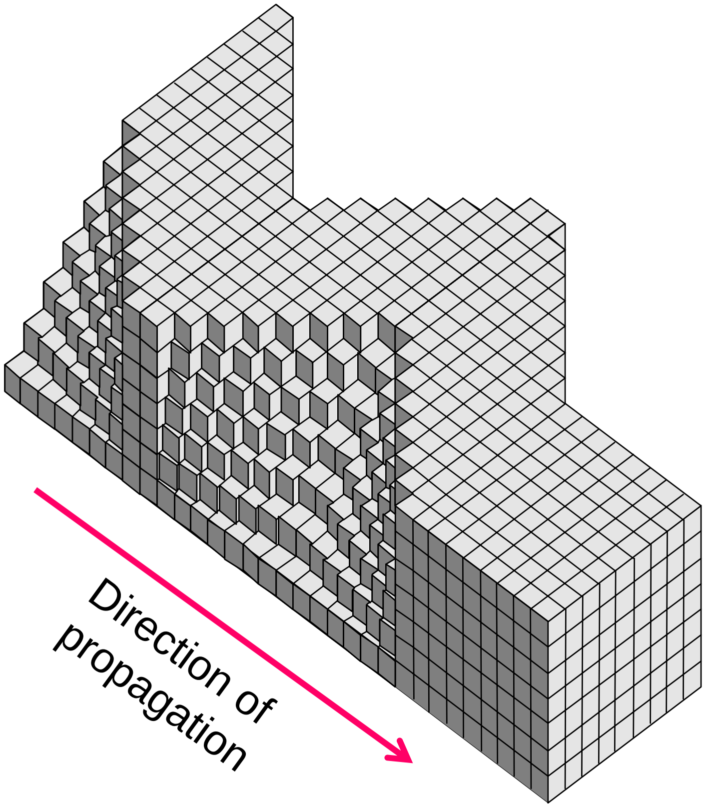


Compression wave
(P wave)

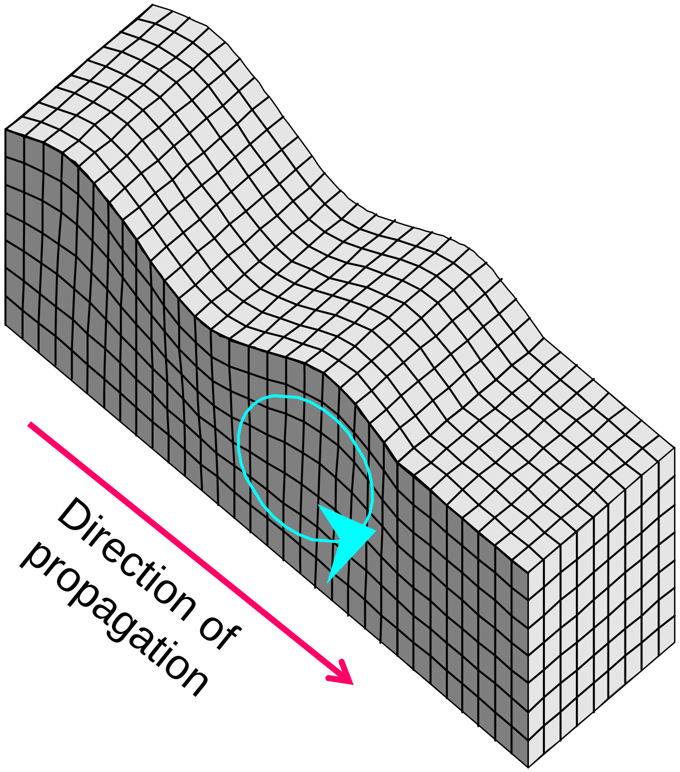


Shear wave
(S wave)

Seismic Wave Forms (Surface Waves)

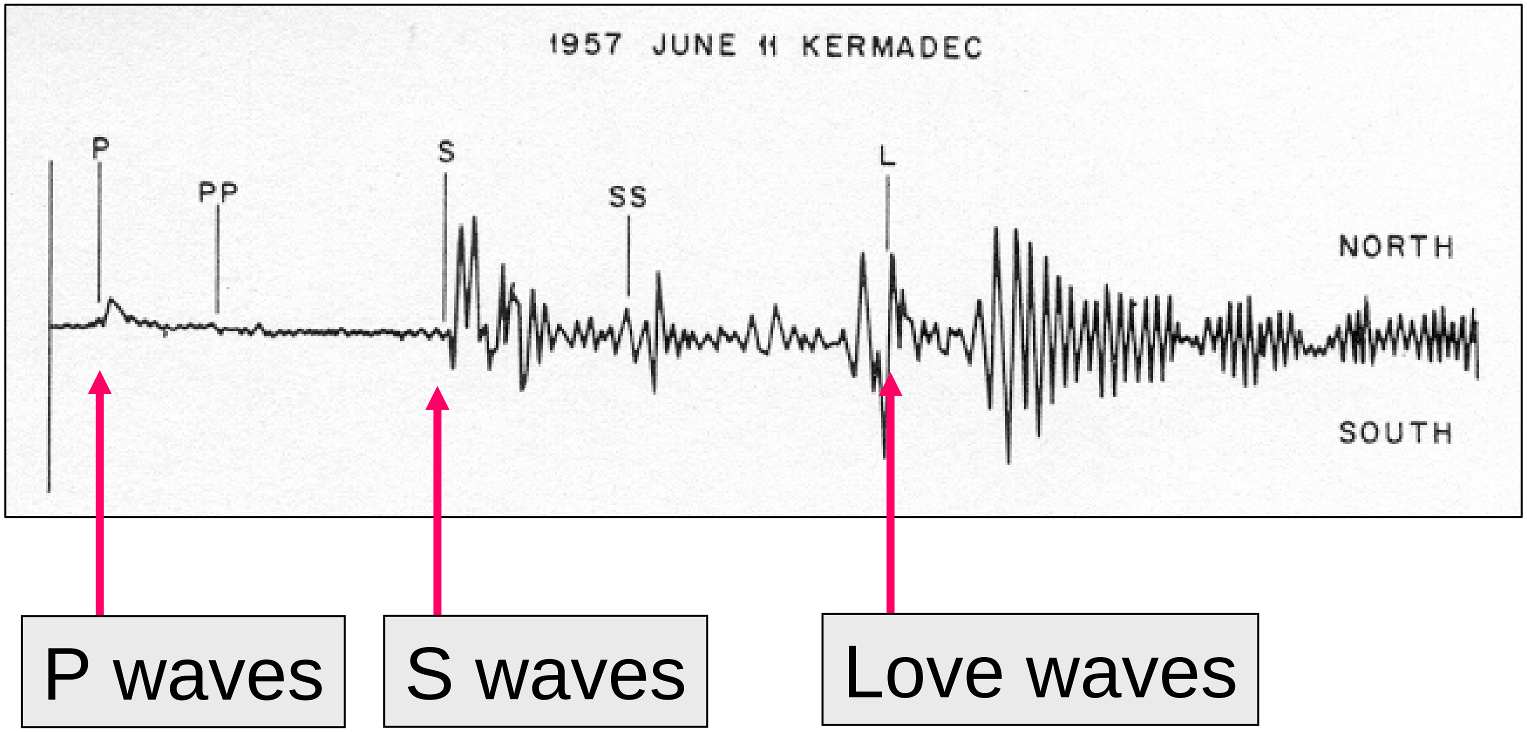


Love wave



Rayleigh wave

Arrival of Seismic Waves

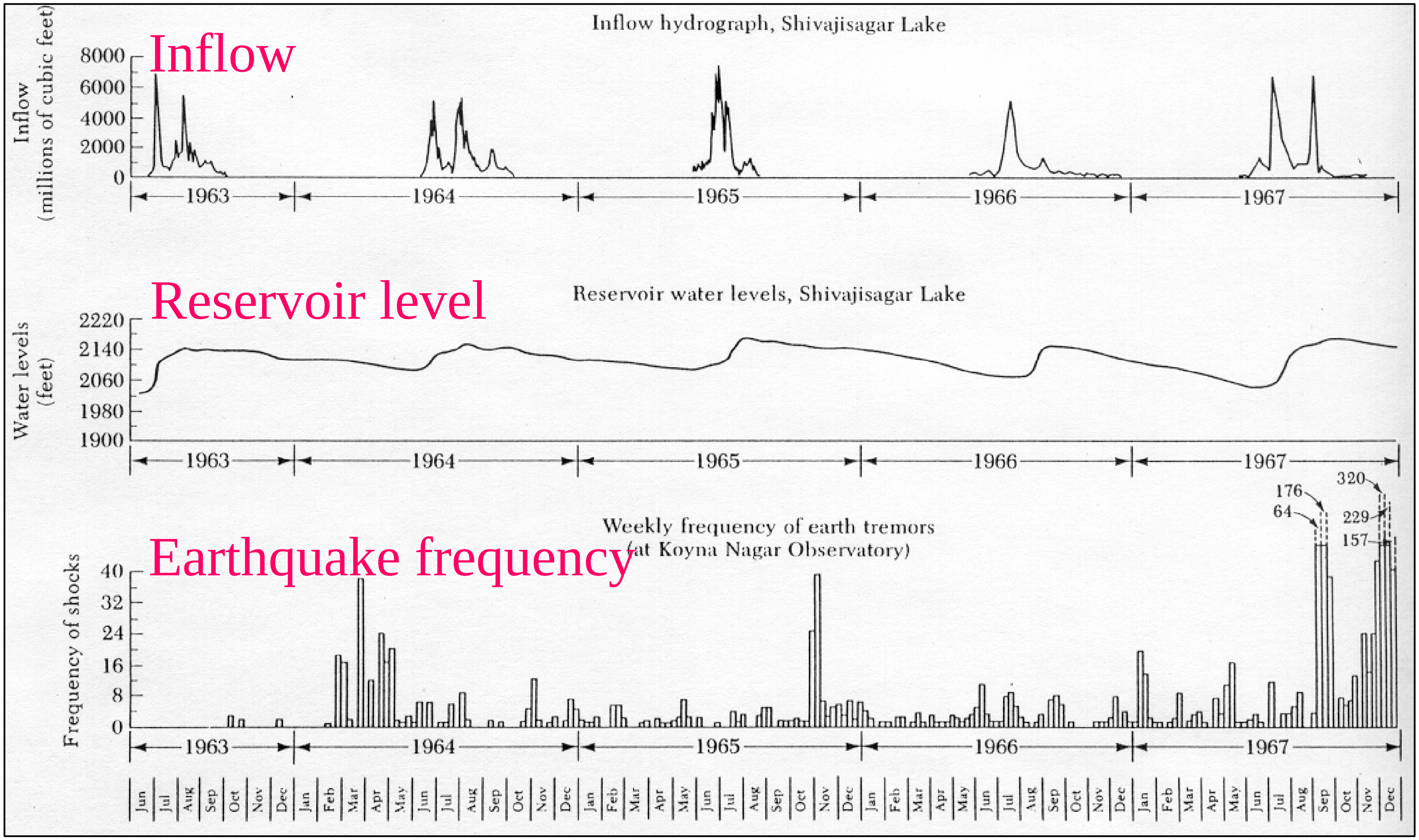


P waves

S waves

Love waves

Relationship Between Reservoir Level and Seismic Activity at Koyna Dam, India



Effects of Seismic Waves

- Fault rupture
- Ground shaking
- Landslides
- Liquefaction
- Tsunamis
- Seiches

Surface Fault Rupture,
1971 Earthquake in San Fernando, California

Cause of Liquefaction

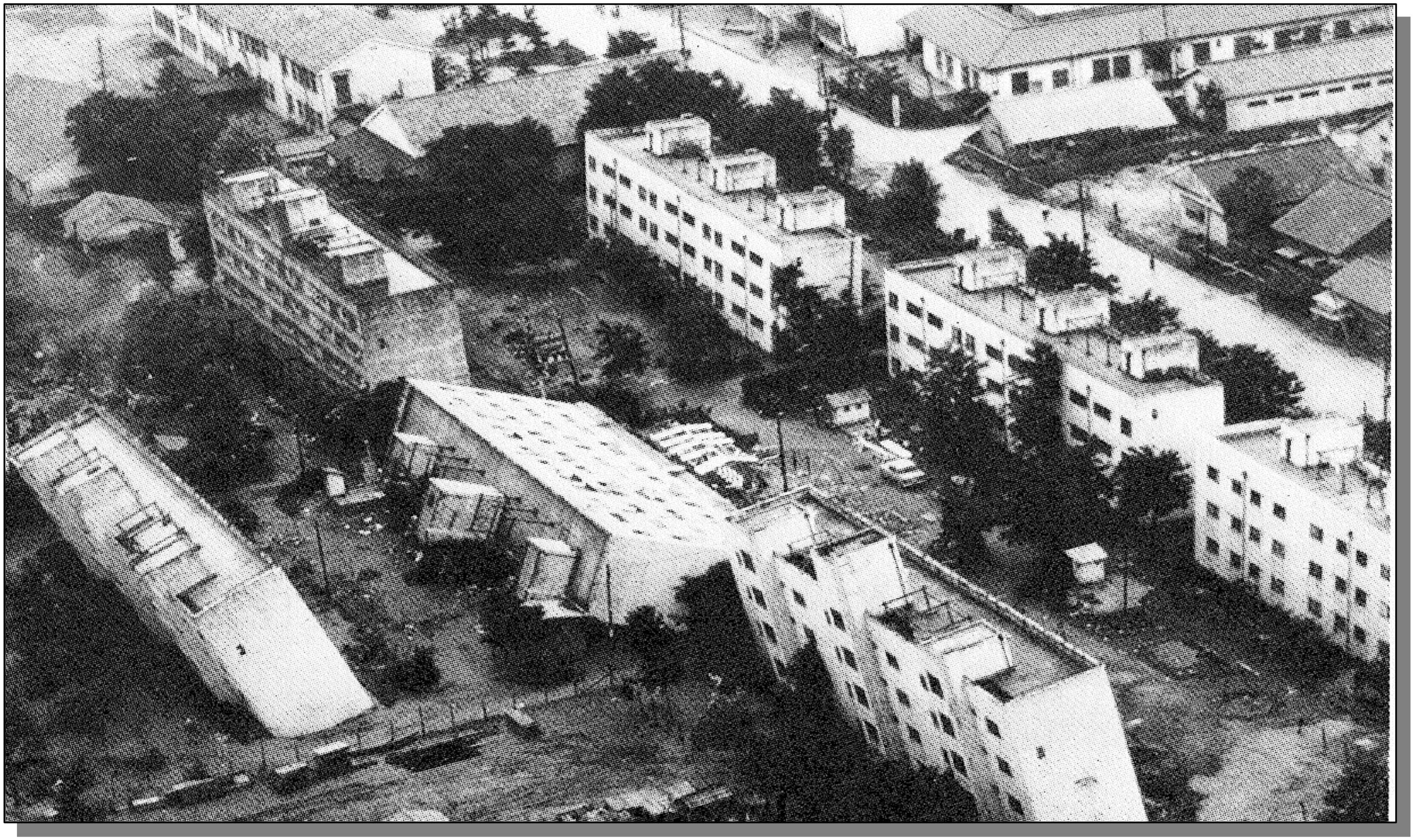
"If a saturated sand is subjected to ground vibrations, it tends to compact and decrease in volume.

If drainage is unable to occur, the tendency to decrease in volume results in an increase in pore pressure.

If the pore water pressure builds up to the point at which it is equal to the overburden pressure, the effective stress becomes zero, the sand loses its strength completely, and liquefaction occurs."

Seed and Idriss (1971)

Liquefaction Damage, Niigata, Japan, 1964



Liquefaction and Lateral Spreading, 1993 Earthquake in Kobe, Japan

Landslide on Coastal Bluff, 1989 Earthquake in Loma Prieta, California

Cause of Tsunamis

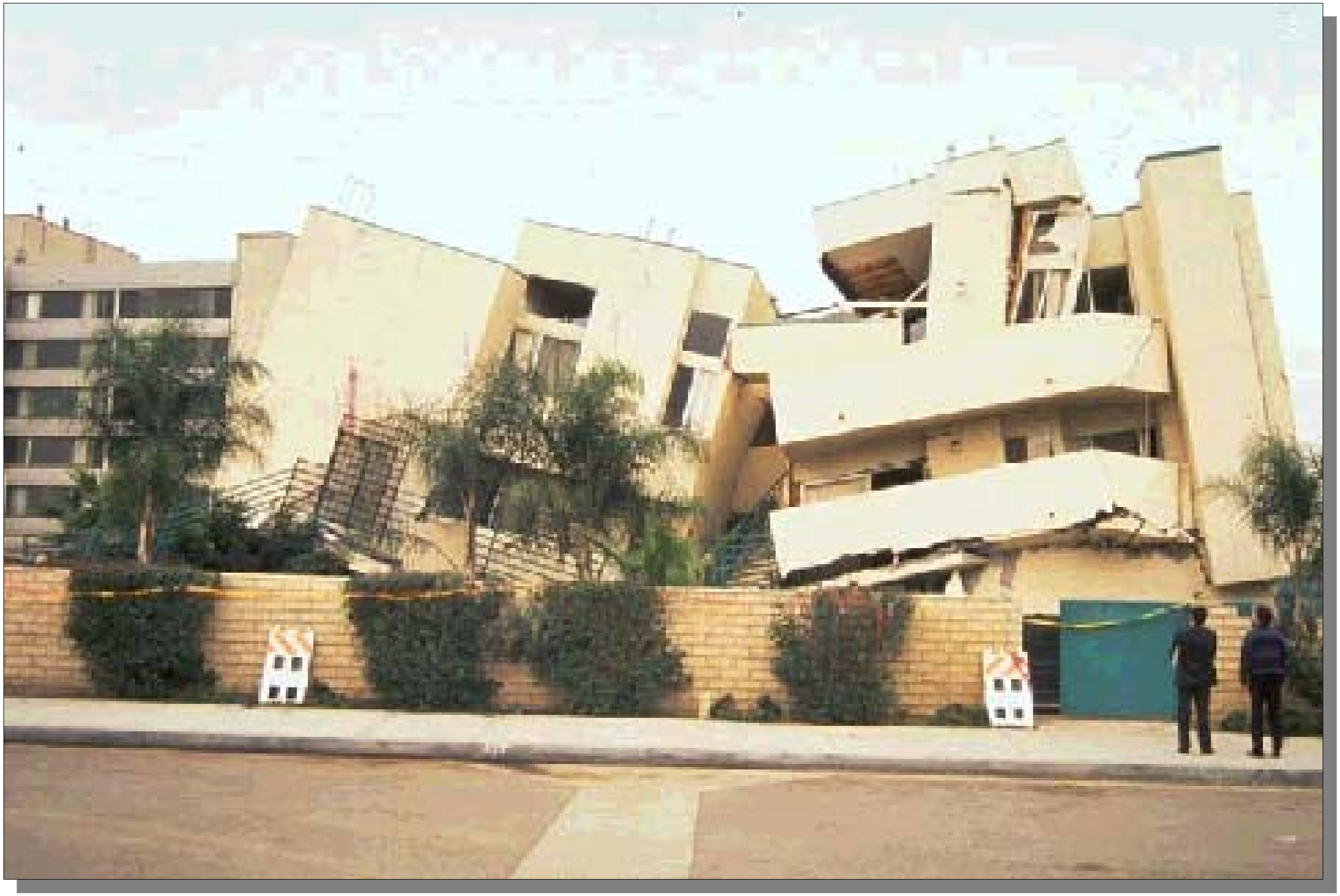
Tsunamis are created by a sudden vertical movement of the sea floor.

These movements usually occur in subduction zones.

Tsunamis move at great speeds, often 600 to 800 km/hr.

Tsunami Damage, Seward, Alaska, 1964

Result of Ground Shaking, 1994 Earthquake in Northridge, California



Mitigation Strategies

Earthquake effect	**Strategy**
Fault rupture	Avoid
Tsunami/seiche	Avoid
Landslide	Avoid
Liquefaction	Avoid/resist
Ground shaking	**Resist**

Measuring Earthquakes

INTENSITY

- Subjective
- Used where instruments are not available
- Very useful in historical seismicity

MAGNITUDE

- Measured with seismometers
- Direct measure of energy released
- Possible confusion due to different measures

Modified Mercalli Intensity

- Developed by G. Mercalli in 1902 (after a previous version of M. S. De Rossi in the 1880s)
- Subjective measure of human reaction and damage
- Modified by Wood and Neuman to fit California construction conditions
- Intensity range I (lowest) to XII (most severe)

Modified Mercalli Intensity

I. Not felt except by a few under especially favorable circumstances.

II. Felt only by a few persons at rest, especially on upper floors if buildings. Suspended objects may swing.

III. Felt quite noticeably indoors, especially on upper floors of buildings. Standing automobiles may rock slightly. Vibration like passing truck.

Modified Mercalli Intensity

IV. During the day, felt indoors by many, outdoors by few. At night, some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing automobiles rocked noticeably. [0.015 to 0.02g]

V. Felt by nearly everyone, many awakened. Some dishes and windows broken. Cracked plaster. Unstable objects overturned. Disturbance of trees, poles and other tall objects. [0.03 to 0.04g]

VI. Felt by all. Many frightened and run outdoors. Some heavy furniture moved. Fallen plaster and damaged chimneys. Damage slight. [0.06 to 0.07g]

Modified Mercalli Intensity

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. Noticed by persons driving cars. [0.10 to 0. 15g]

VIII. Damage slight in specially designed structures, considerable in ordinary construction, great in poorly built structures. Fall of chimneys, stacks, monuments. Sand and mud ejected is small amounts. Changes in well water. Persons driving cars disturbed. [0.25 to 0.30g]

Modified Mercalli Intensity

IX. Damage considerable in specially designed structures, well designed frame structures thrown out of plumb, damage great in substantial buildings with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. [0.50 to 0.55g]

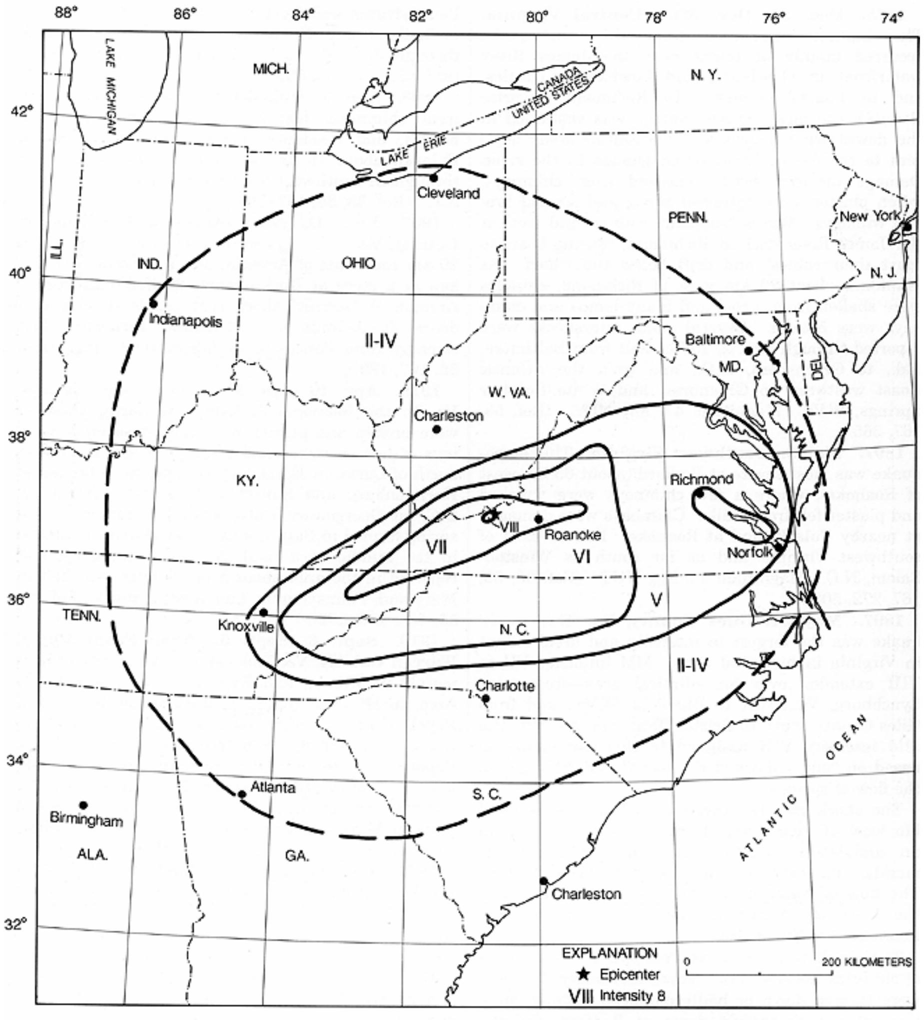
X. Some well built wooden structures destroyed. Most masonry and frame structures destroyed with foundations badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed over banks. [More than 0.60g]

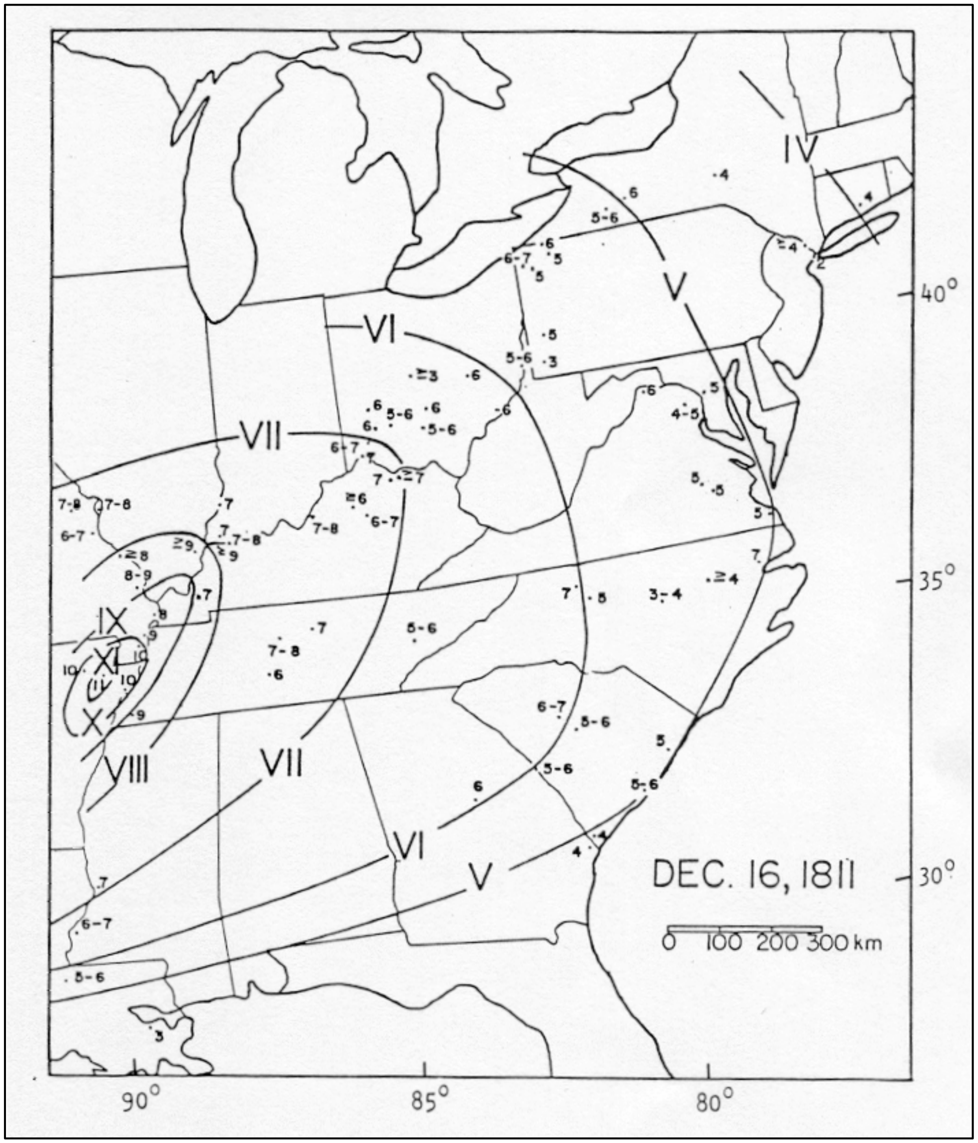
Modified Mercalli Intensity

XI. Few, if any, (masonry) structures left standing.
Bridges destroyed. Broad fissures in ground.
Underground pipelines completely out of service.
Earth slumps and land slips in soft ground.
Rails bent greatly.

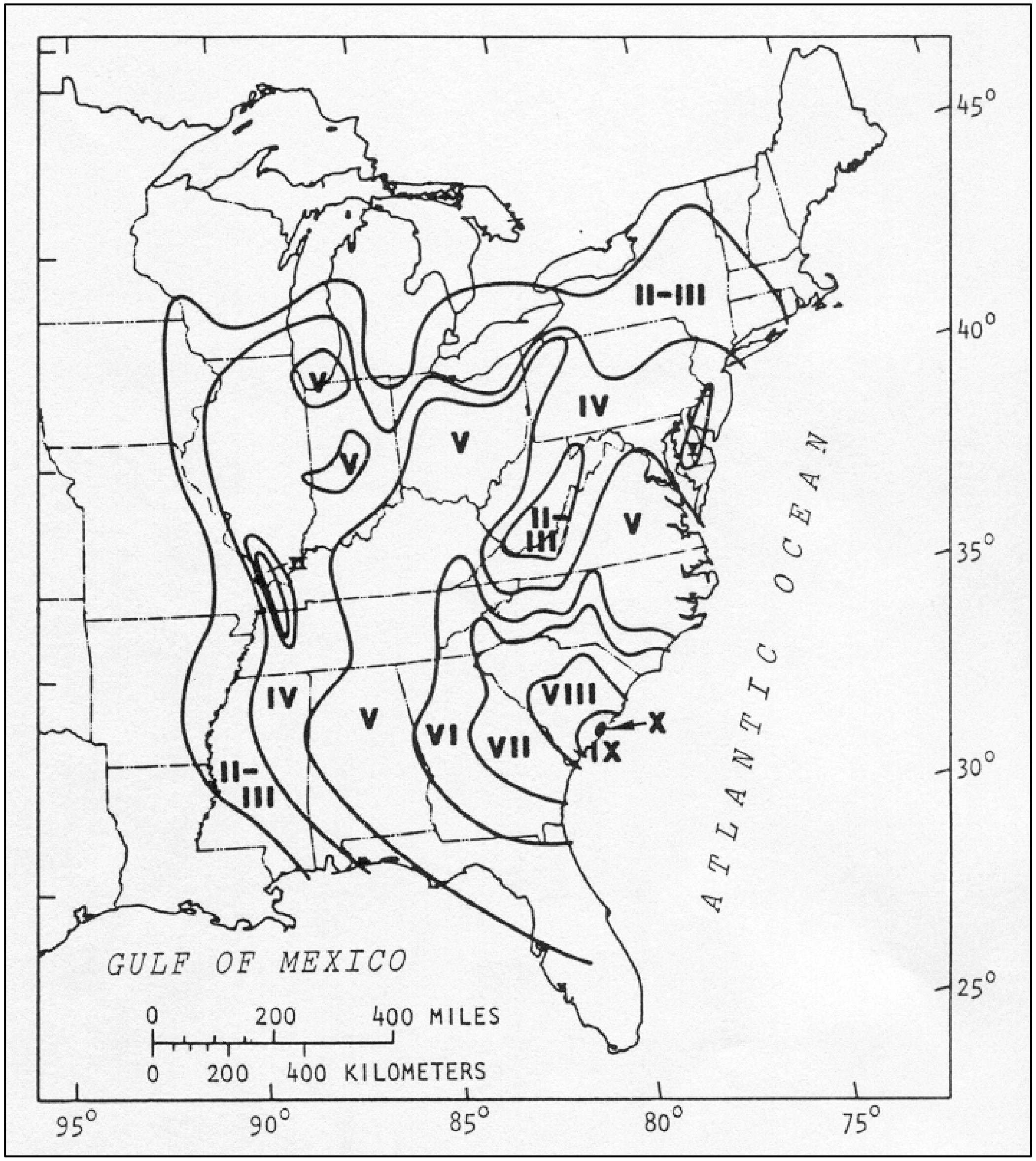
XII. Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into air.

Isoseismal Map for the Giles County, Virginia, Earthquake of May 31, 1897.



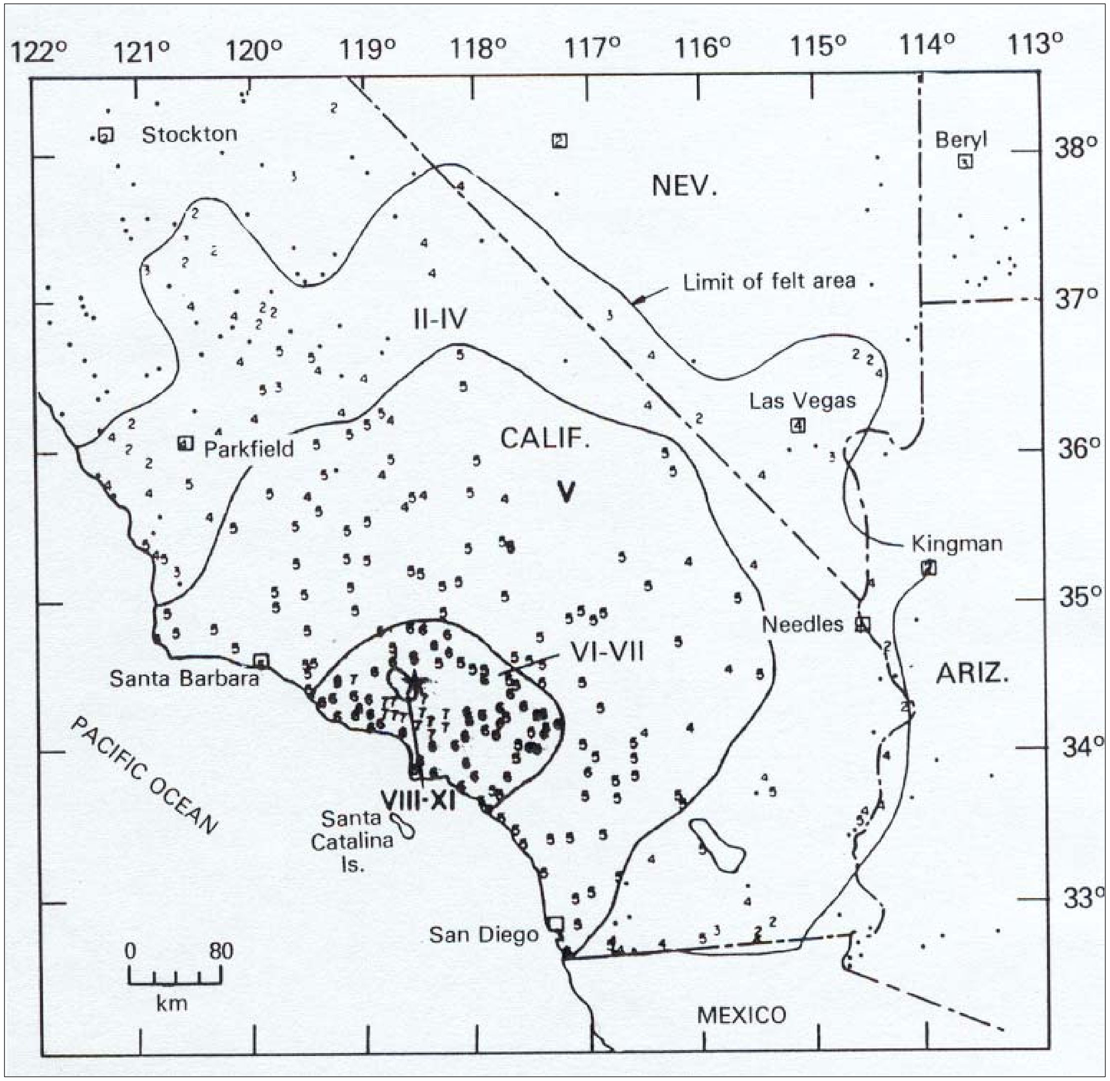


Isoseismal Map For New Madrid Earthquake of December 16, 1811

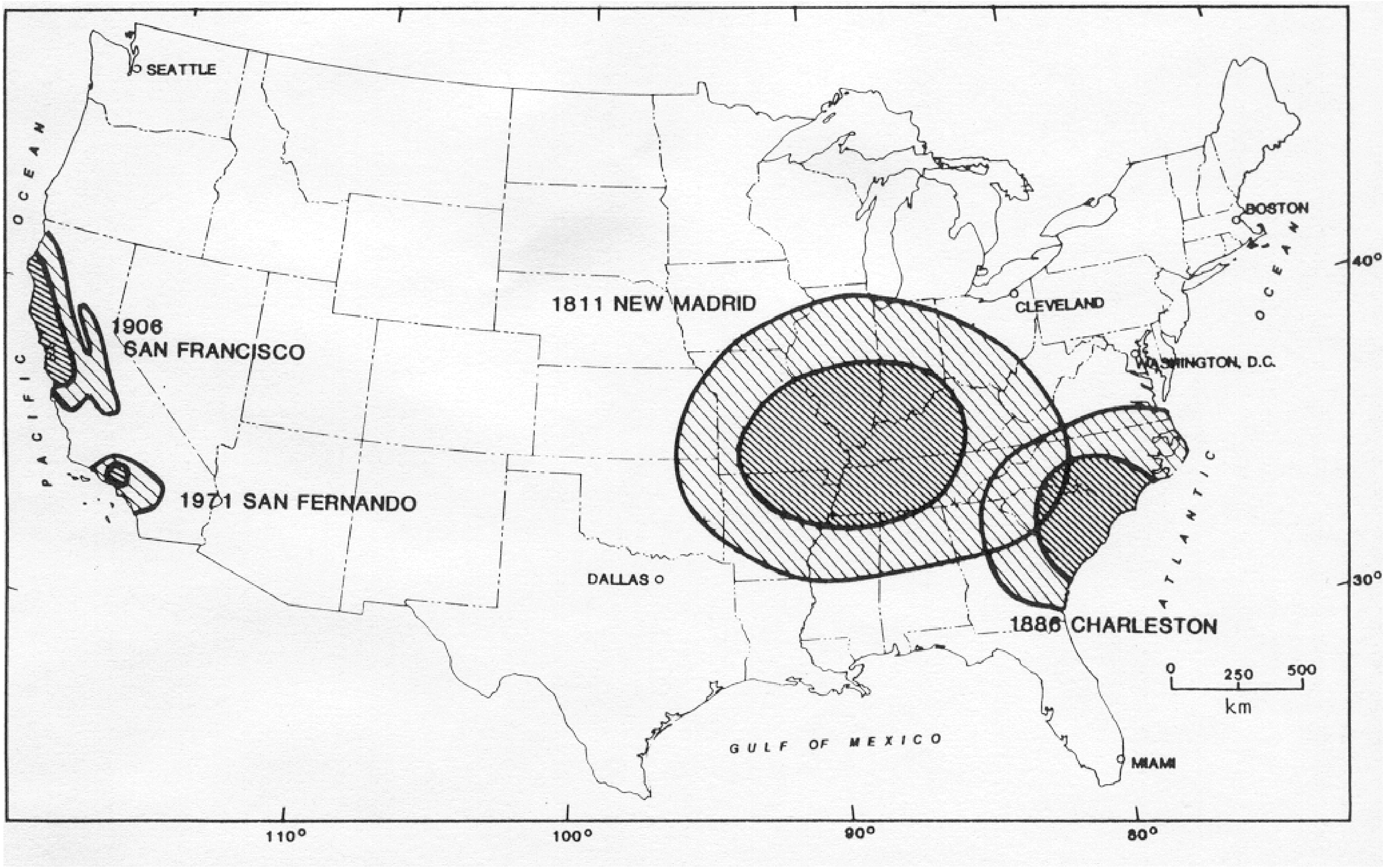


Isoseismal Map for 1886 Charleston Earthquake

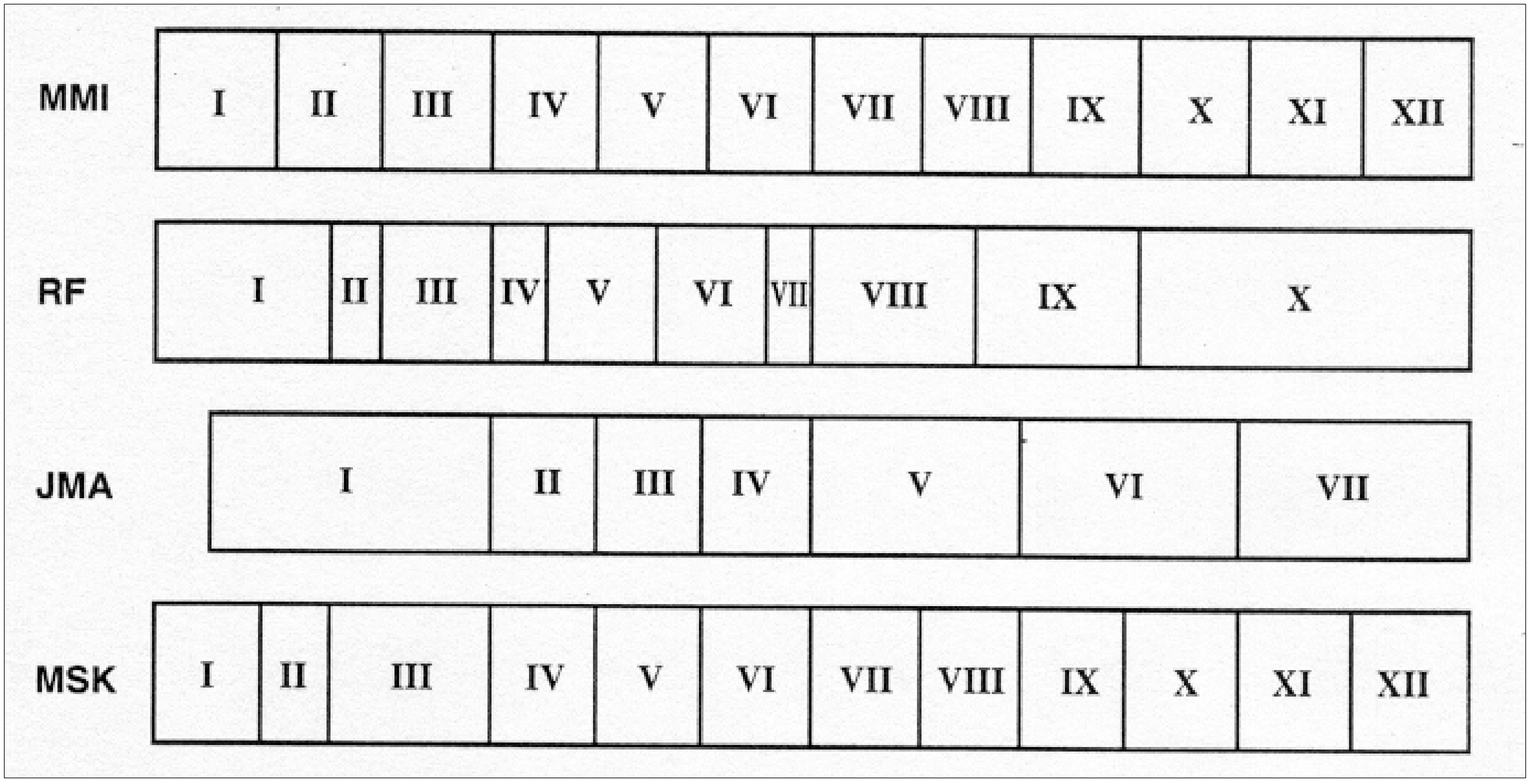
Isoseismal Map for February 9, 1971, San Fernando Earthquake



Comparison of Isosiesmal Intensity for Four Earthquakes



Comparisons of Various Intensity Scales



MMI = Modified Mercalli
RF = Rossi-Forel
JMA = Japan Meteorological Agency
MSK =Medvedez-Spoonheur-Karnik

Instrumental Seismicity

Magnitude (Richter, 1935)

Also called local magnitude

M_L = Log [Maxumum Wave Amplitude (in mm/1000)]

Recorded Wood-Anderson seismograph

100 km from epicenter

Magnitude (in general)

$$M = Log\ A + f(d,h) + C_S + C_R$$

A is wave amplitude

$F(d,h)$ accounts for focal distance and depth

C_S and C_R, are station and regional corrections

Other Wave-Based Magnitudes

M_S Surface-wave magnitude (Rayleigh waves)

m_b Body-wave magnitude (P waves)

M_B Body-wave magnitude (P and other waves)

m_{bLg} (Higher order Love and Rayleigh waves)

M_{JMA} (Japanese, long period)

Moment Magnitude

Seismic moment = $M_O = \mu A D$

[Units = force times distance]

Where:

μ = modulus of rigidity

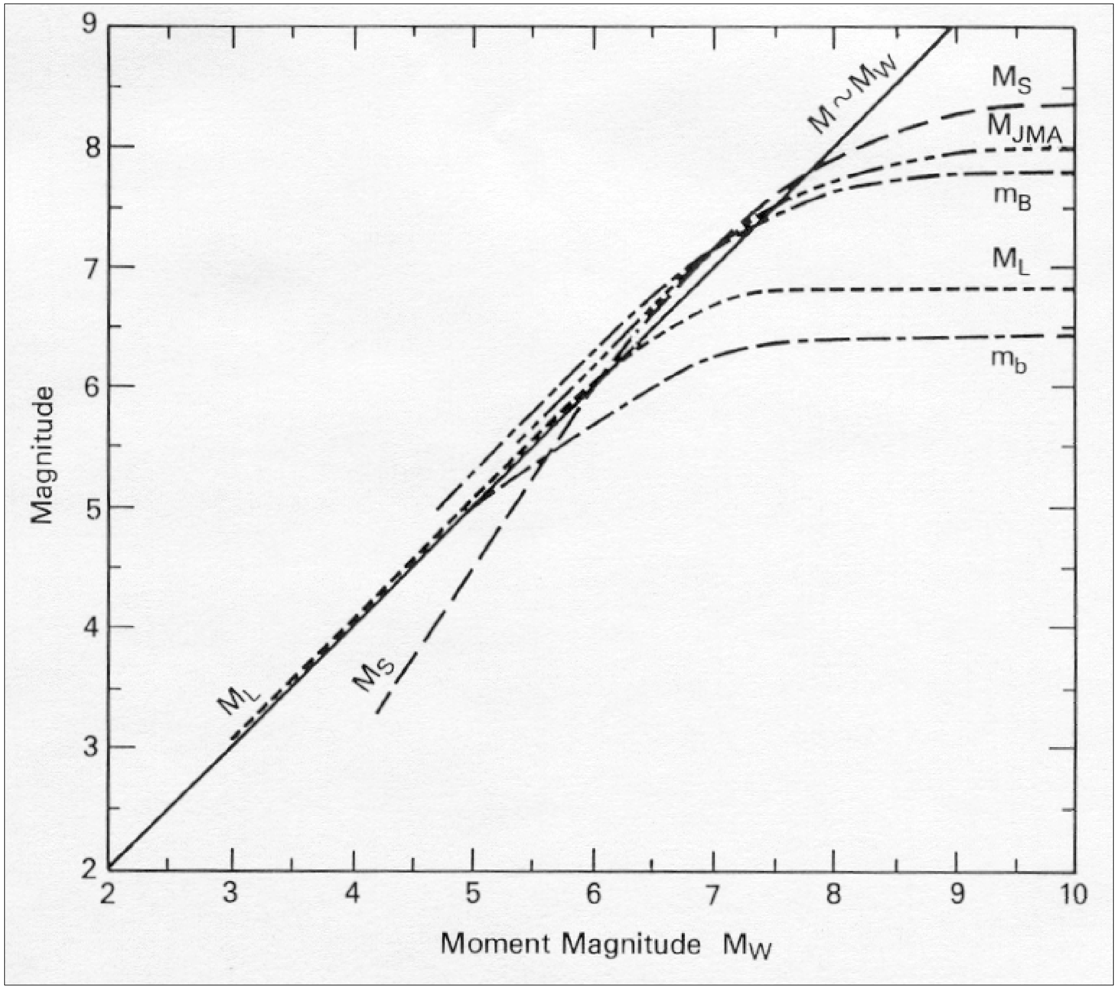
A = fault rupture area

D = fault dislocation or slip

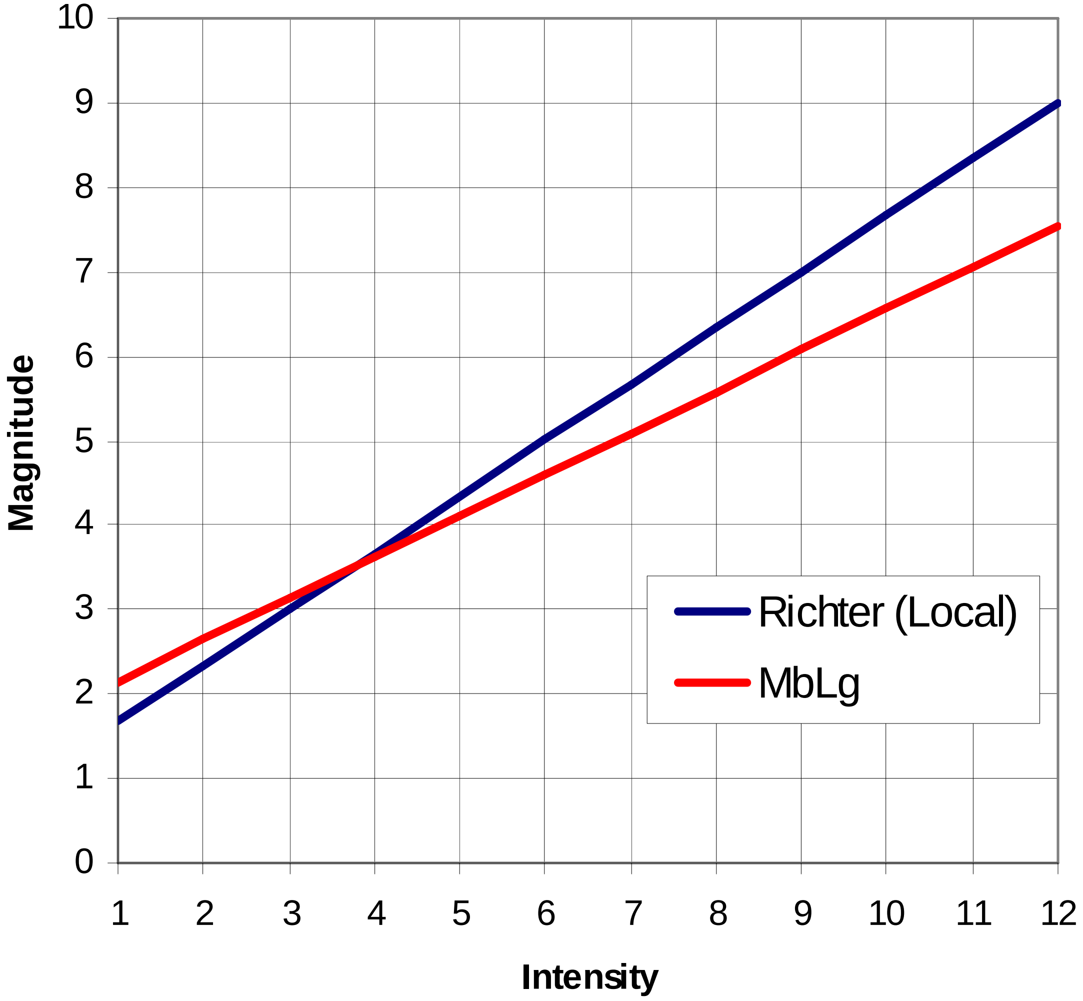
Moment magnitude = $M_W = (\mathit{Log}\ M_O - 16.05)/1.5$

(Units = dyne-cm)

Moment Magnitude vs Other Magnitude Scales (Magnitude Saturation)



Approximate Relationship Between Magnitude and Intensity

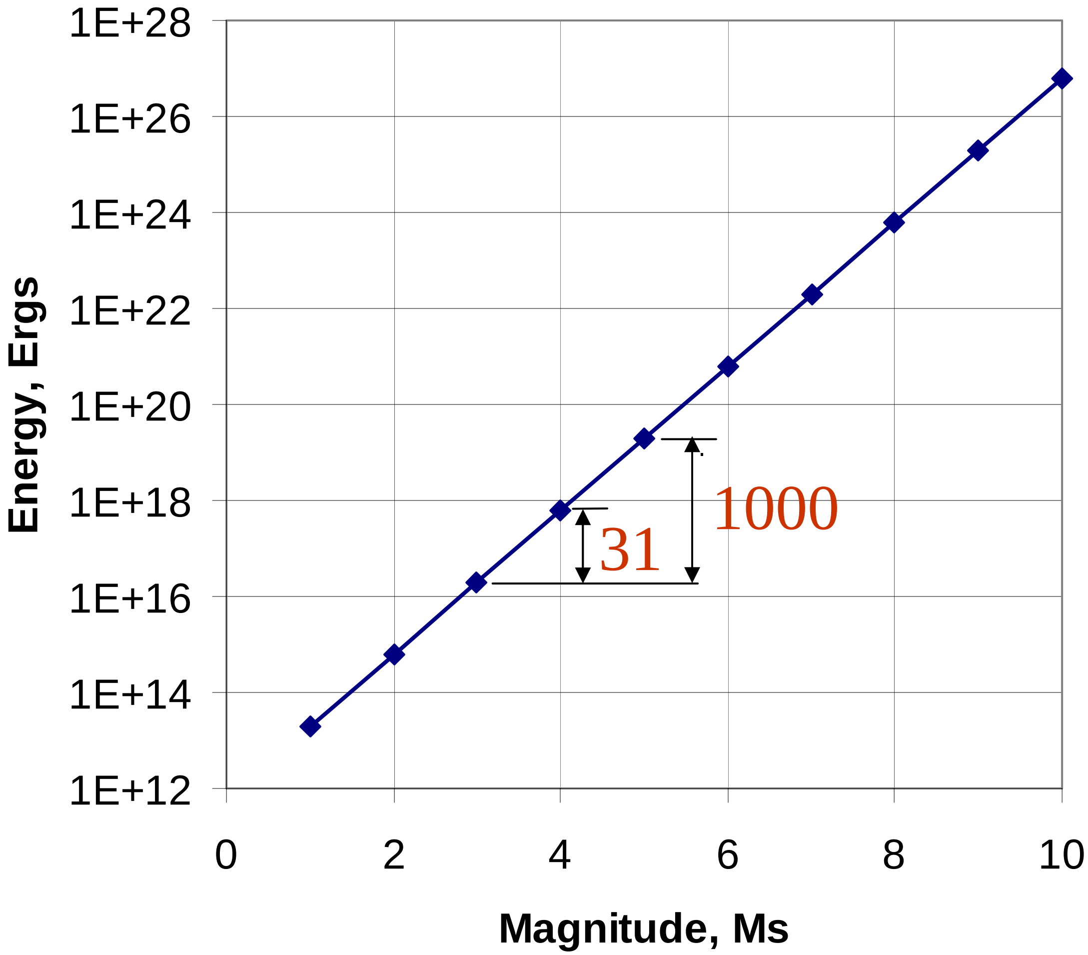


$$\boxed{\hat{M}_L = 0.67 I_0 + 1}$$

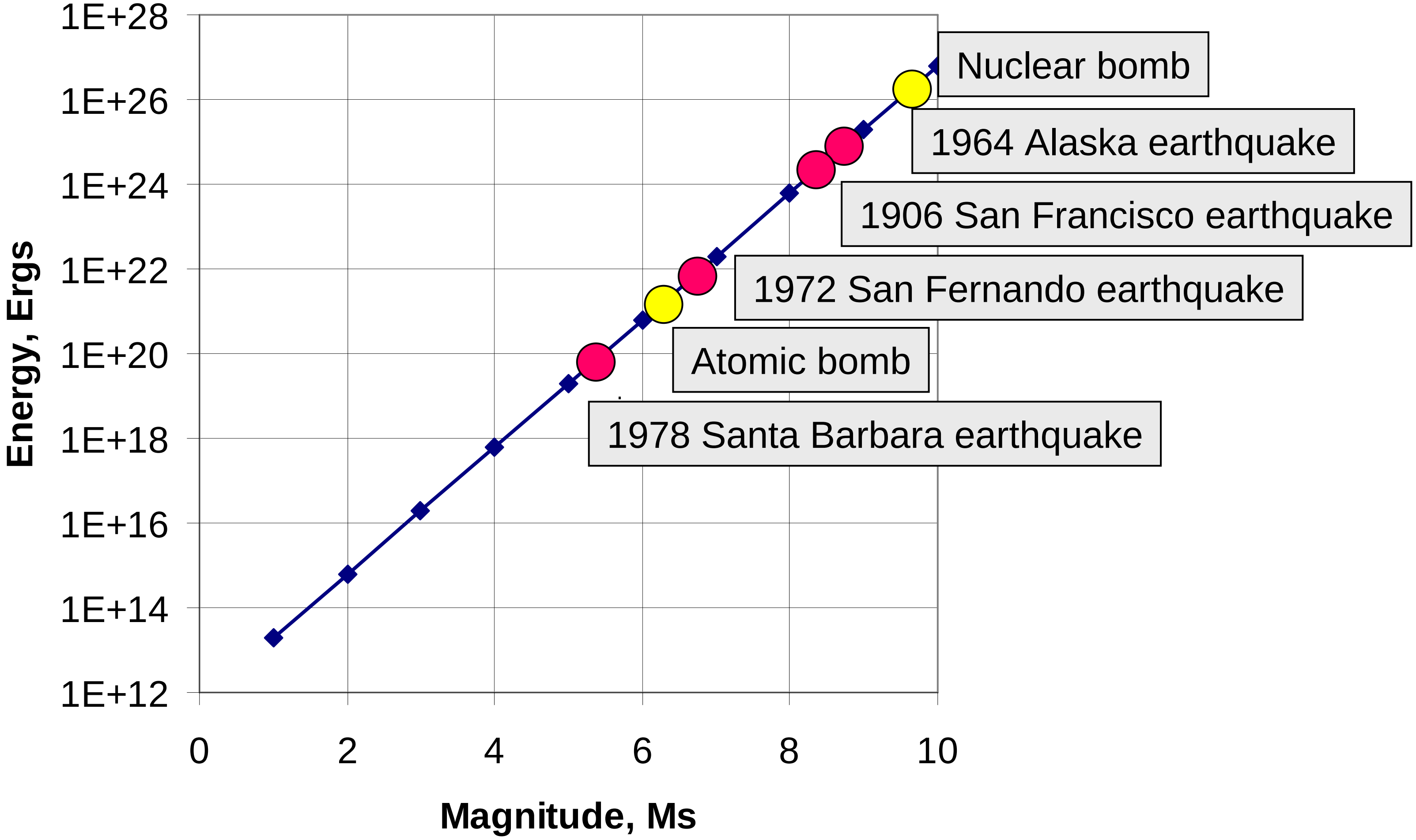
$$\boxed{\hat{m}_{bLg} = 0.49 I_0 + 1.66}$$

Seismic Energy Release

$$\text{Log } E = 1.5\, M_S + 11.8$$



Seismic Energy Release



Ground Motion Accelerograms

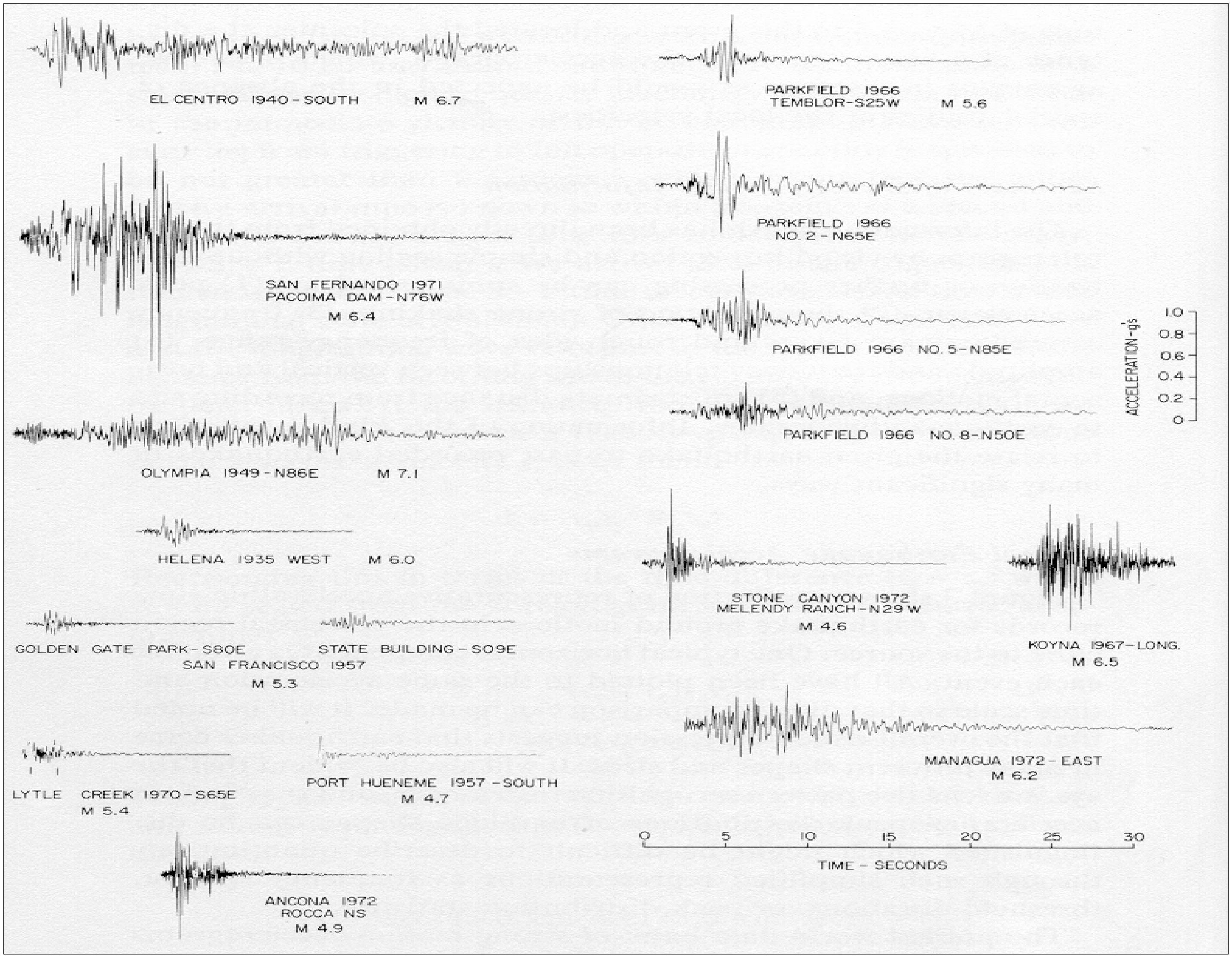
Sources:

- NONLIN (more than 100 records)
- Internet (e.g., National Strong Motion Data Center)
- USGS CD ROM

Uses:

- Evaluation of earthquake characteristics
- Development of response spectra
- Time history analysis

Sample Ground Motion Records



Ground Motion Characteristics

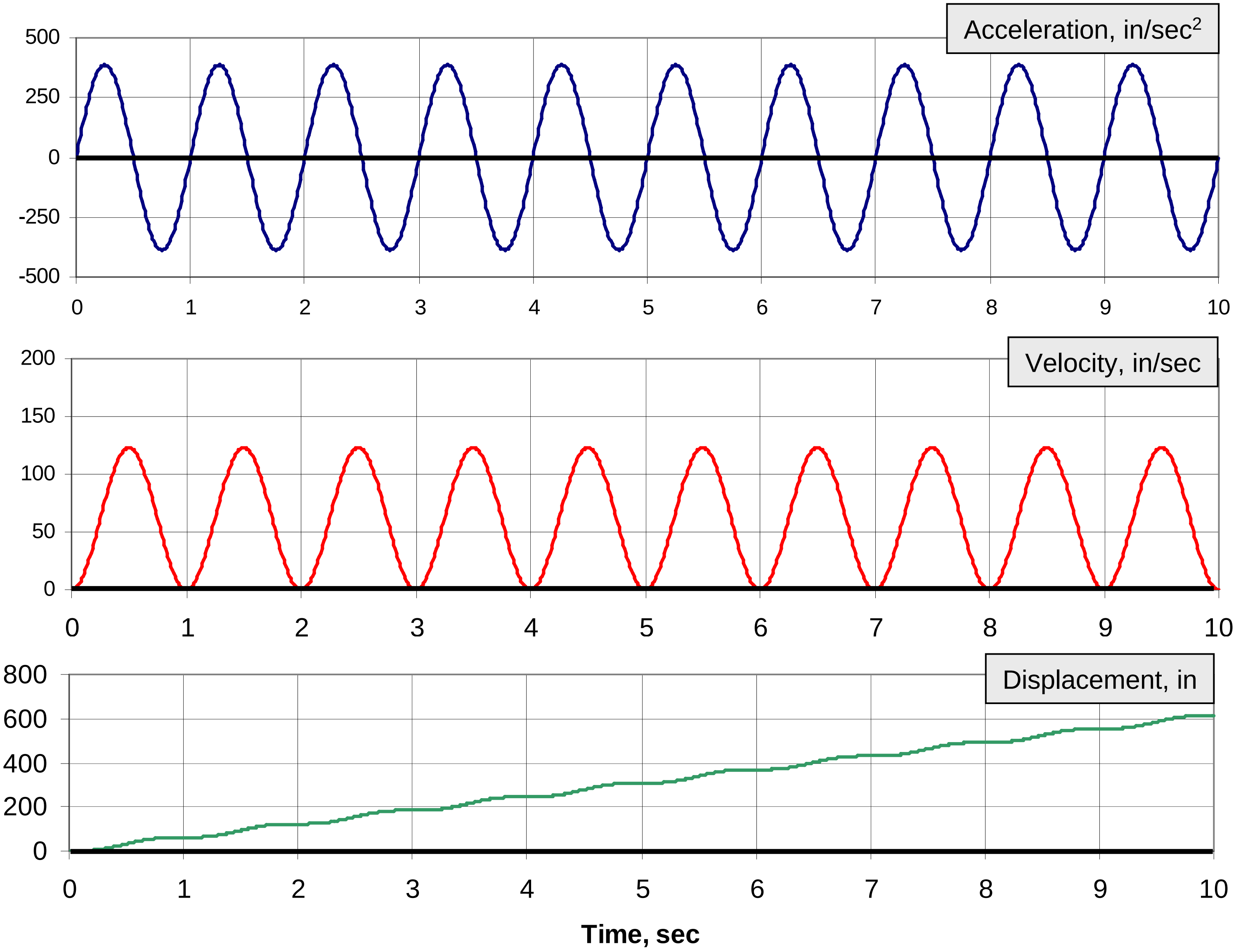
- Acceleration, velocity, displacement
- Effective peak acceleration and velocity
- Fourier amplitude spectra
- Duration (bracketed duration)
- Incremental velocity (killer pulse)
- Response spectra
- Other (see, for example, Naiem and Anderson 2002)

Corrected vs Uncorrected Motions

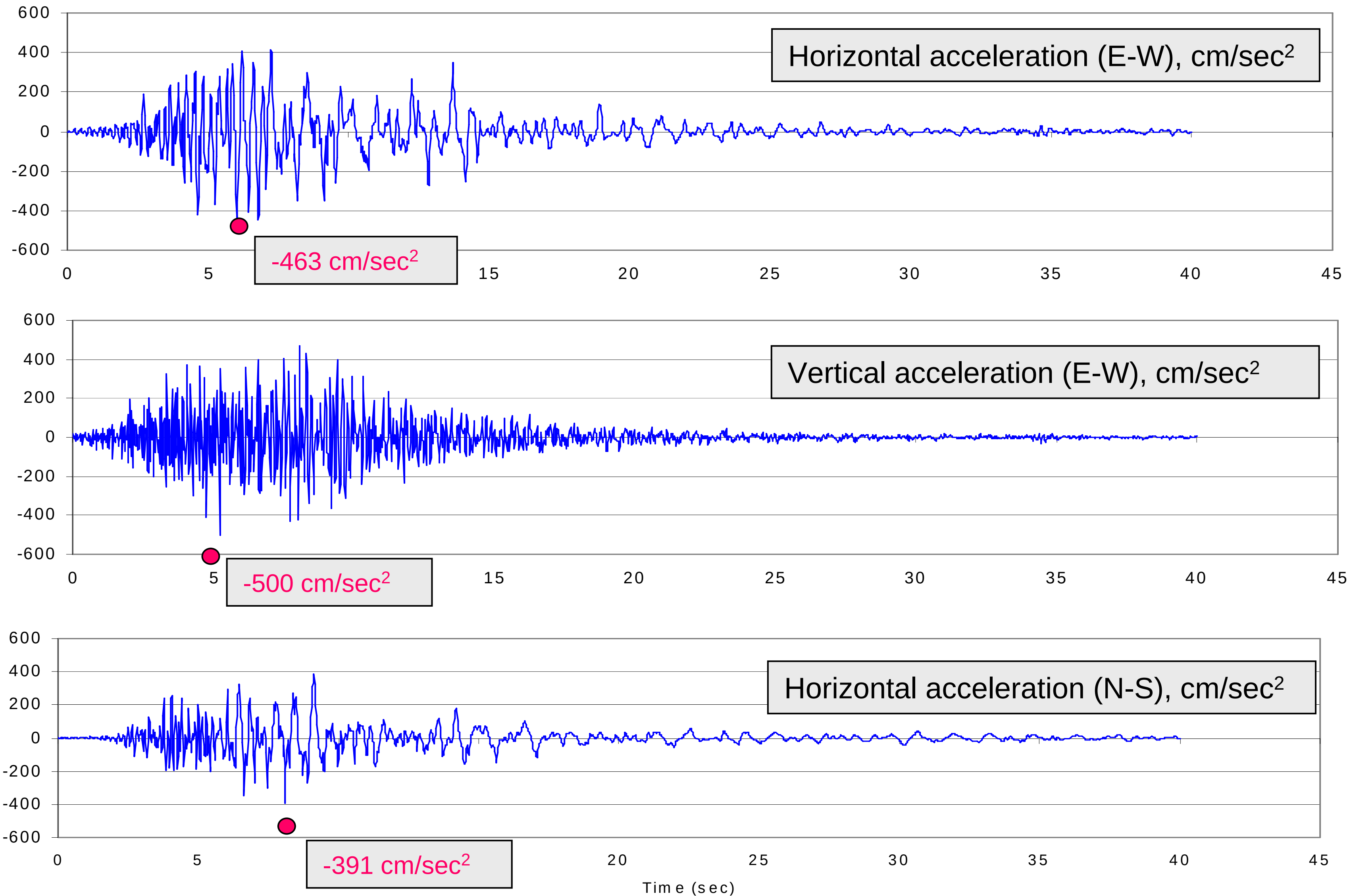
Corrections made primarily:

- To remove instrument response
- To account for base line shift

Base Line Correction for Simple Ground Motion



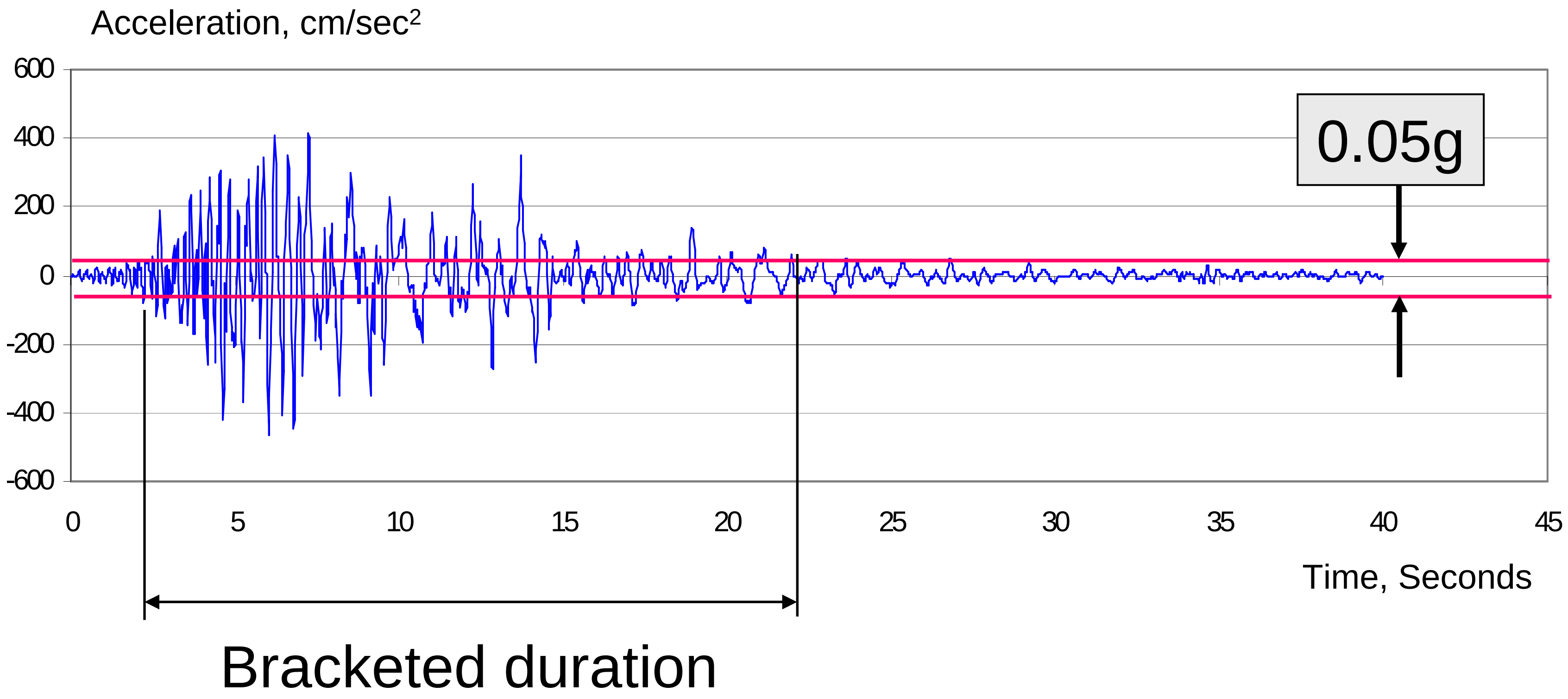
Typical Earthquake Accelerogram Set



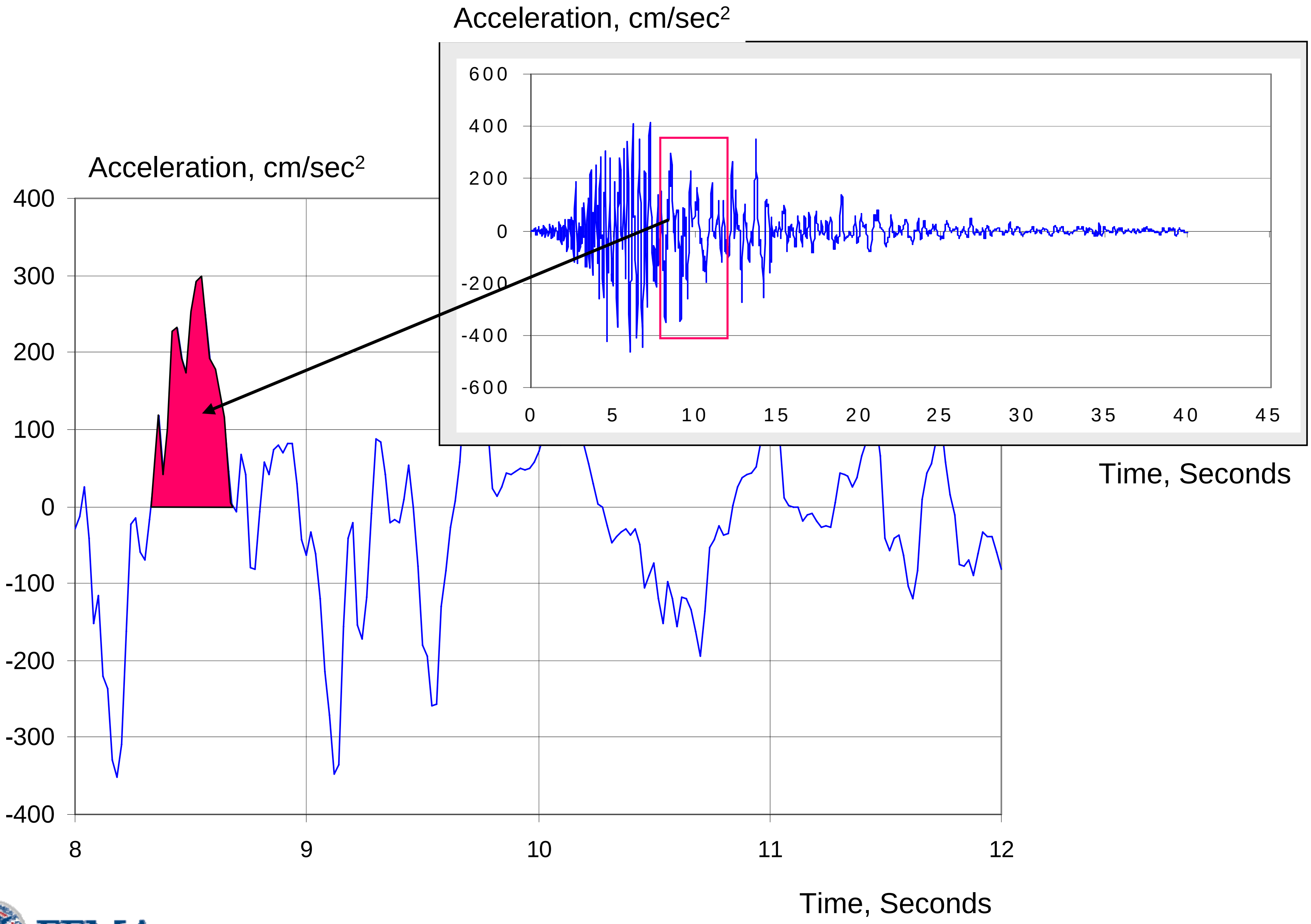
Time, Seconds

Loma Prieta Earthquake

Definition of Bracketed Duration



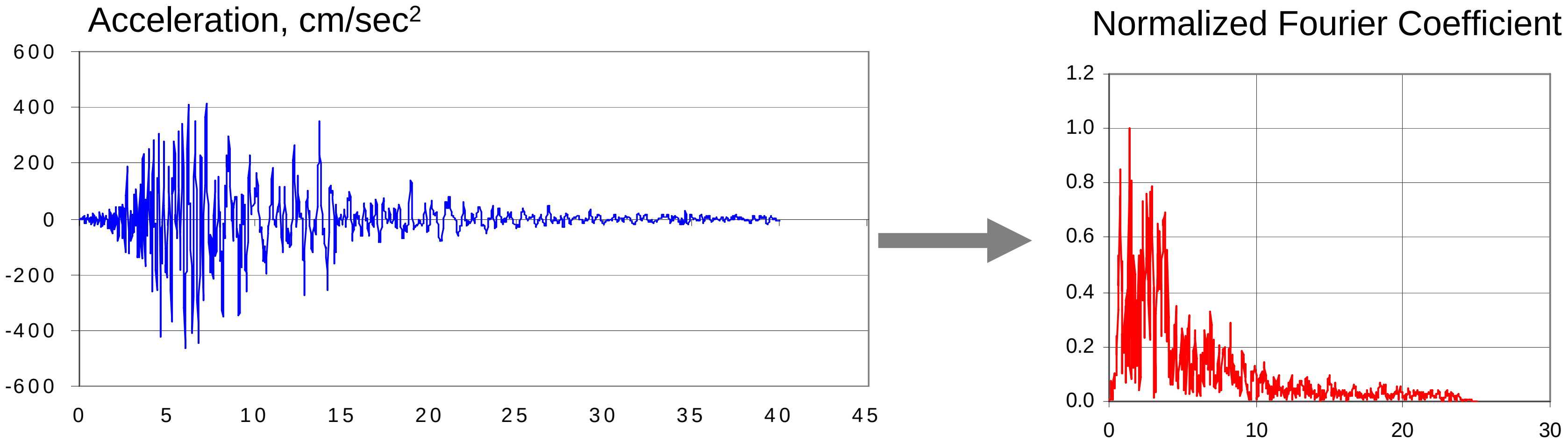
Definition of Incremental Velocity



Concept of Fourier Amplitude Spectra

$$\ddot{v}_g(t) \cong a_0 + \sum_{j=1}^{N/2} a_j \cos(2\pi j f_0) + \sum_{j=1}^{N/2} b_j \sin(2\pi j f_0) = a_0 + \sum_{j=1}^{N/2} A_j \cos(2\pi j f_0 + \phi_j)$$

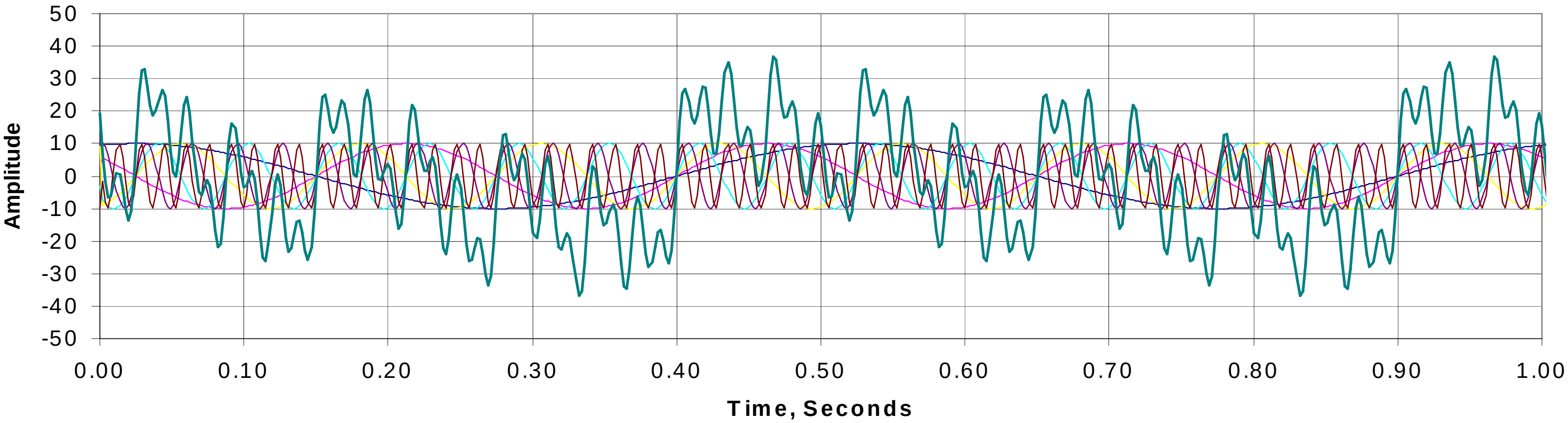
$$f_0 = df = 1/Ndt \qquad \phi_j = \arctan\left(-\frac{b_j}{a_j}\right) \qquad A_j = \sqrt{a_j^2 + b_j^2}$$

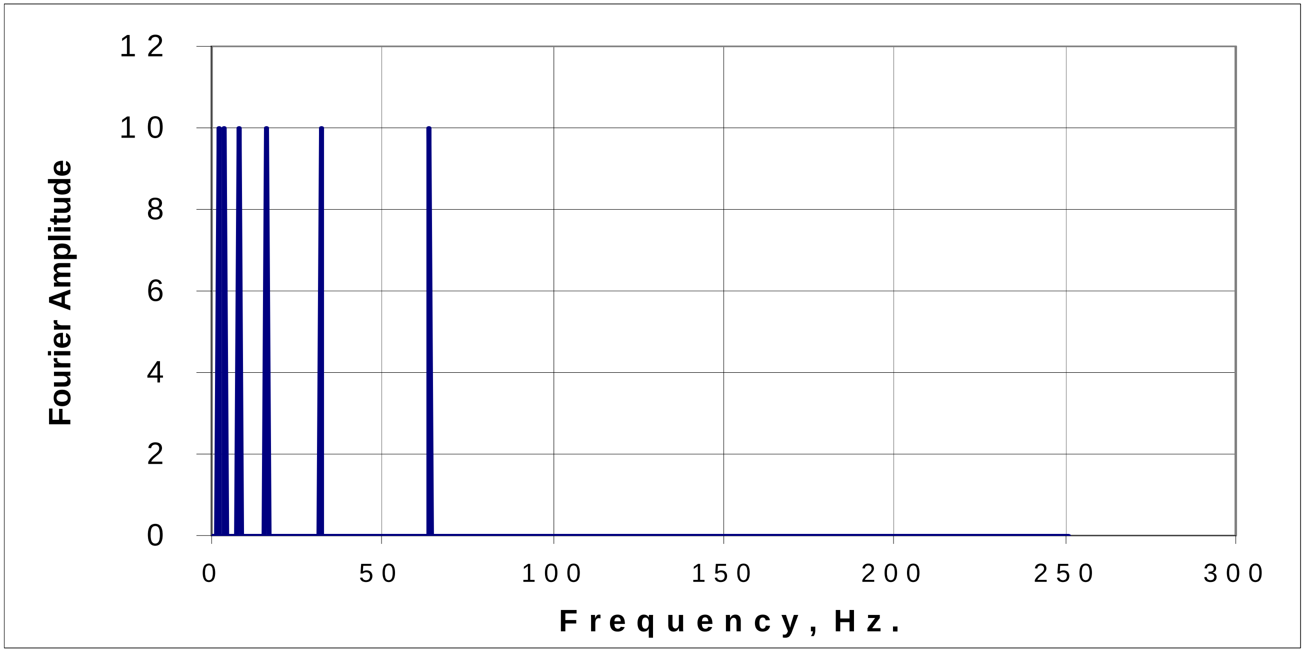


N points at timestep *dt*

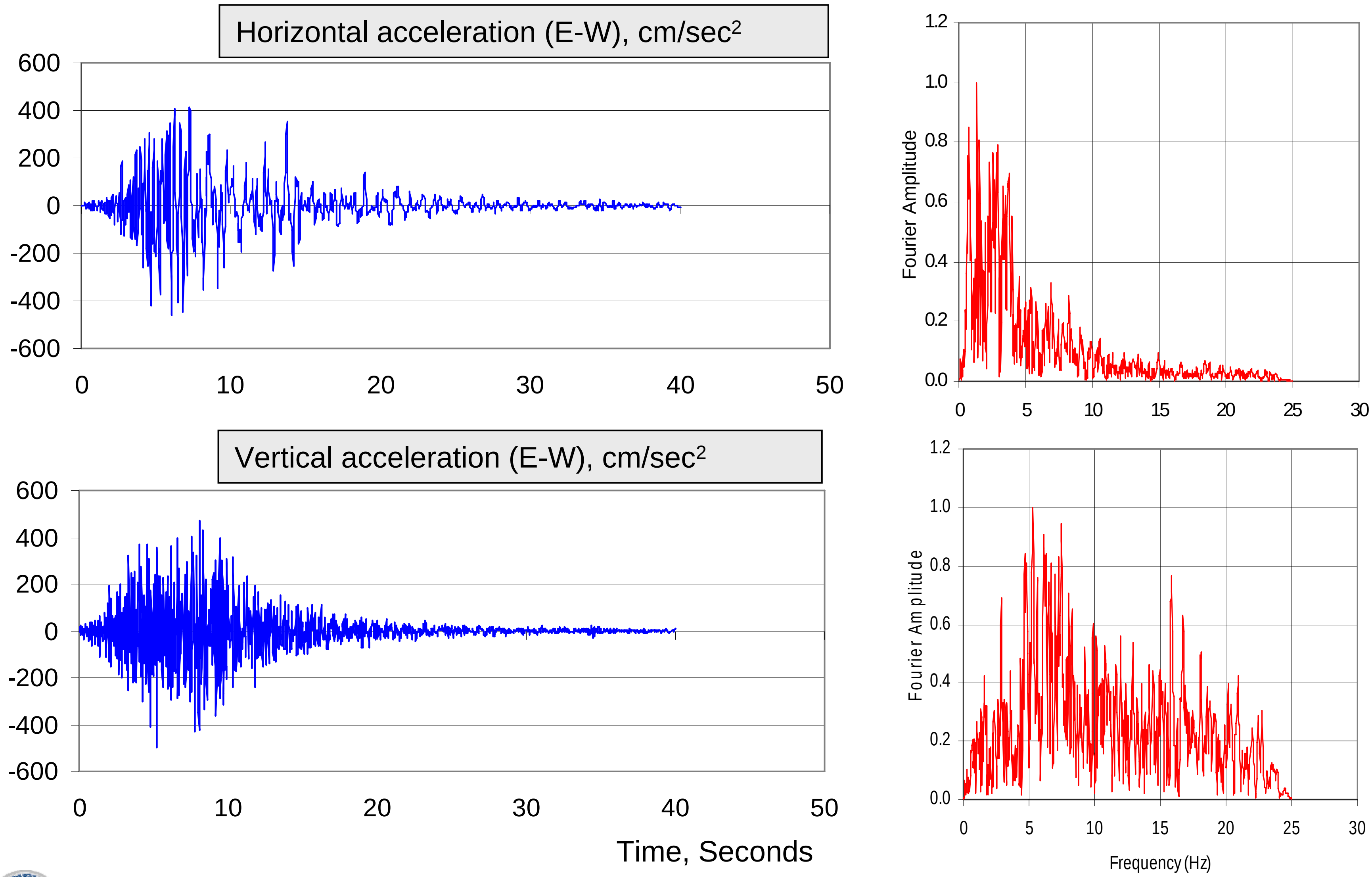
N/2 points at frequency *df*

Concept of Fourier Amplitude Spectra

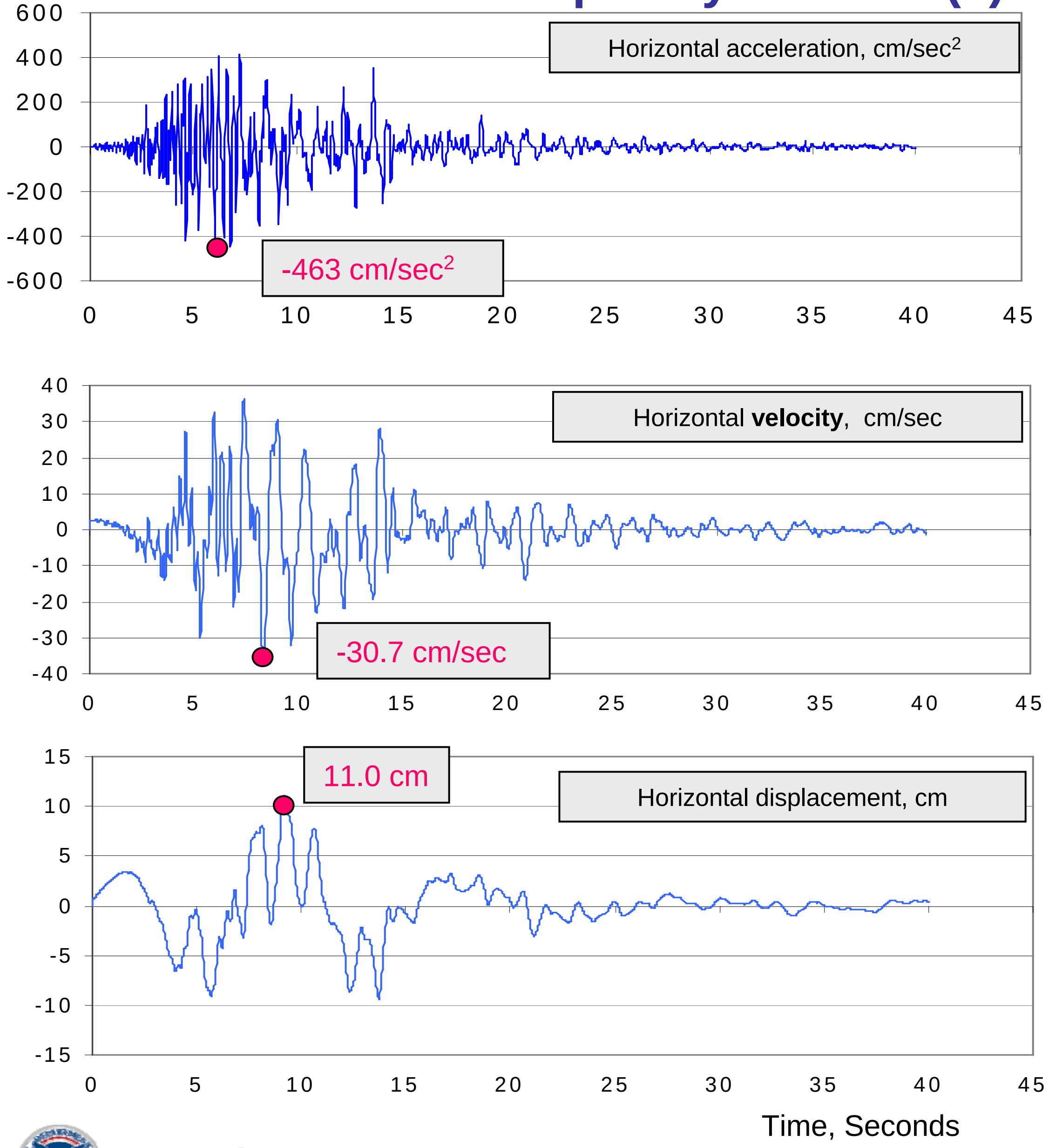


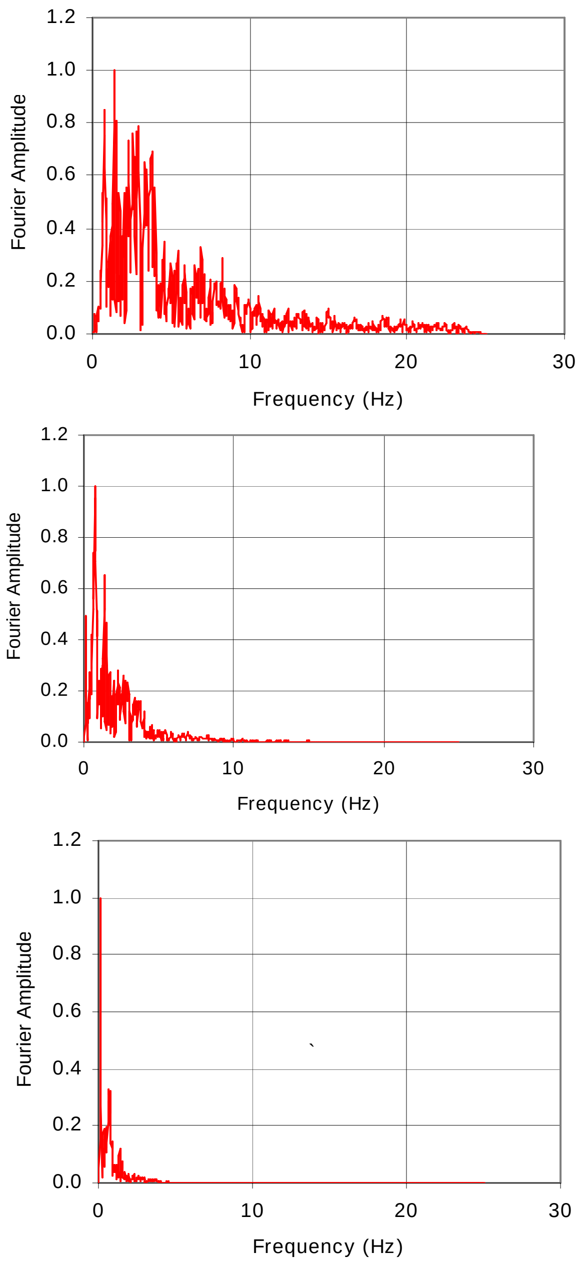


Ground Motion Frequency Content (1)



Ground Motion Frequency Content (2)





Development of an Elastic Displacement Response Spectrum