51-100-21 Environmental Geology
Summer 2006 • Tuesday & Thursday 6 - 9:20 p.m. • Dr. Beyer

Announcements

Today:

- lecture on Chapter 5 - Earthquakes!
- video - Northridge, California earthquake, 1994

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Earthquakes - Ch. 5

I. Locations of Earthquakes
II. Earthquake Processes
III. Effects of Earthquakes
IV. Earthquake Risk and Prediction

Website:

U.S. Geological Survey Earthquake Hazards Program

http://earthquake.usgs.gov/

Earthquakes in the Movies

http://www.earthquakecountry.info/10.5/MajorMovieMisconceptions/

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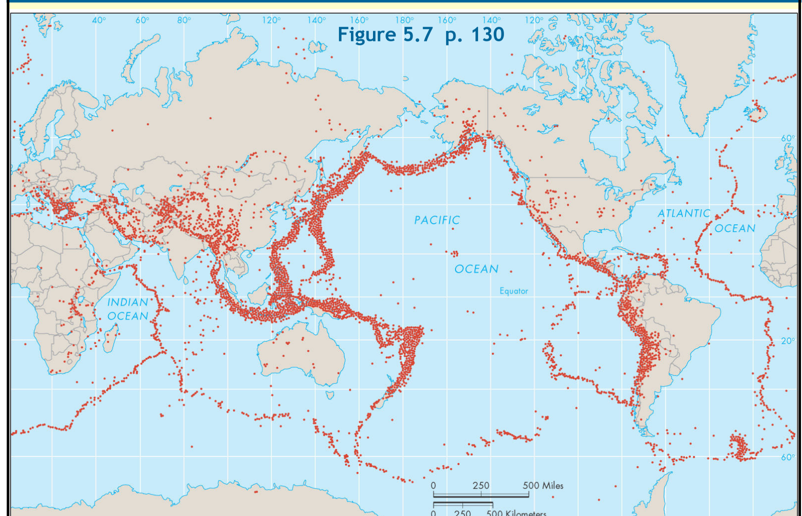
I. Locations of Earthquakes

Figure 5.7 p. 130



I. Locations of Earthquakes

Earthquakes occur:

1. at plate boundaries (*interplate earthquakes*)
2. within single plates (*intraplate earthquakes*)
   - hot spots
   - ancient failed continental rift zones
   - fracture zones

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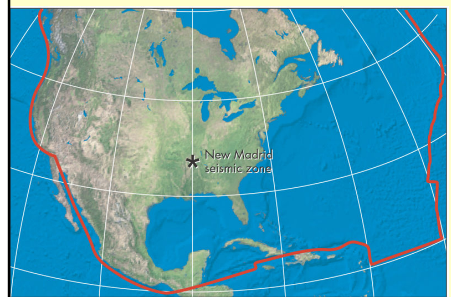
I. Locations of Earthquakes

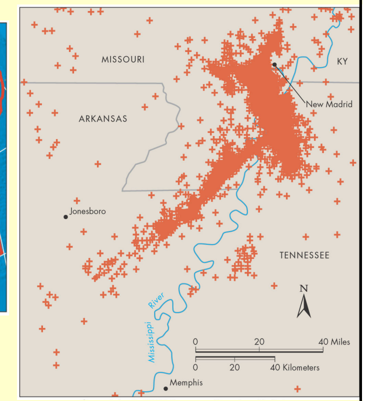
Ancient failed continental rift zone:

Figure 5.8 p. 131

New Madrid Fault Zone, 1811-1812



earthquakes since 1974

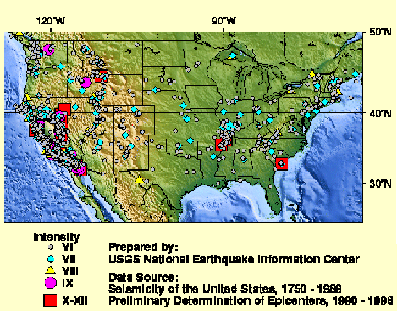


I. Locations of Earthquakes

Fracture Zone:

Charleston, South Carolina, 1886

Locations of US Earthquakes Causing Damage
1750 - 1996
Modified Mercalli Intensity VI - XII



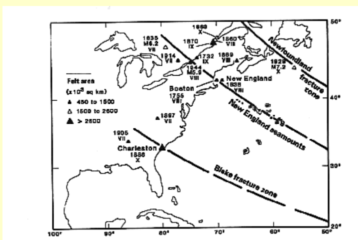


Figure 6.22 Location of earthquake epicenters in the eastern United States and fracture-zone extensions of transform faults on the mid-Atlantic spreading center.

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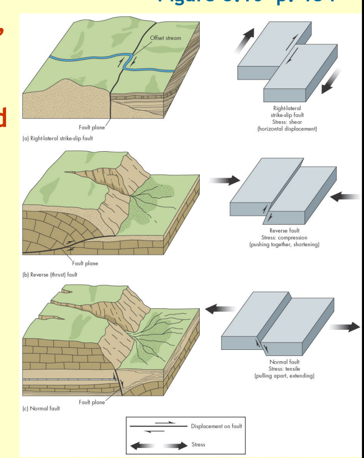
II. Earthquake Processes

Earthquakes occur due to movement along **faults.**

Figure 5.10 p. 134

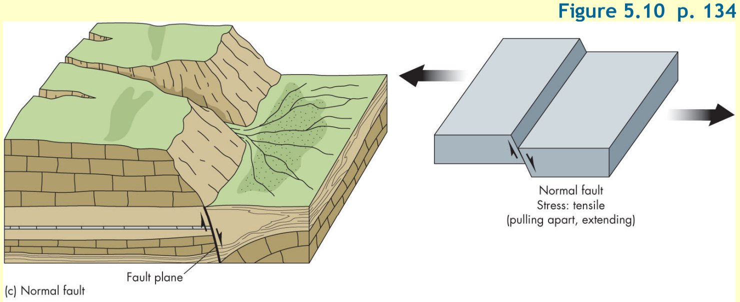
- type of fault depends on sense, or direction, of motion
- direction of motion determined by direction of stress on the rocks
- direction of stress relates to tectonic setting



Types of Faults

Normal fault → stress: tension → extension, stretching

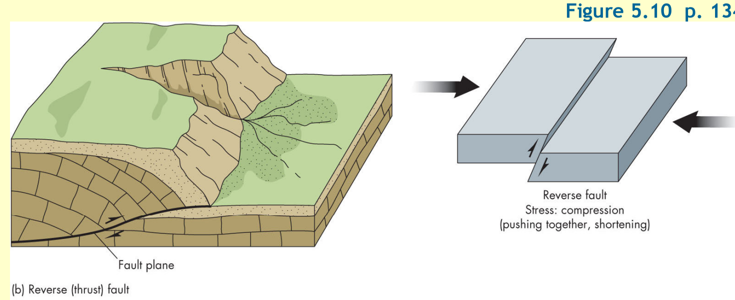
Figure 5.10 p. 134



Types of Faults

Reverse (thrust) fault → stress: compression → convergence, shortening

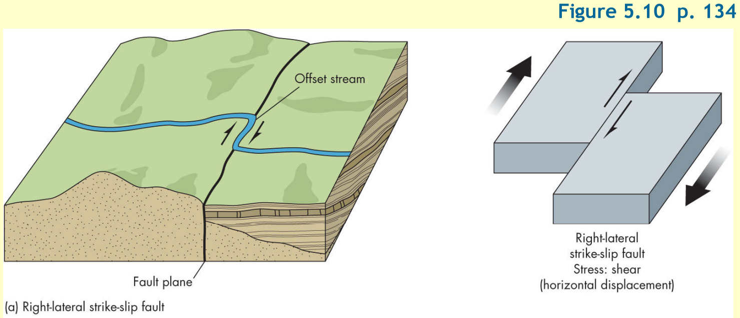
Figure 5.10 p. 134



Types of Faults

Strike-slip fault → stress: shear → lateral movement

Figure 5.10 p. 134



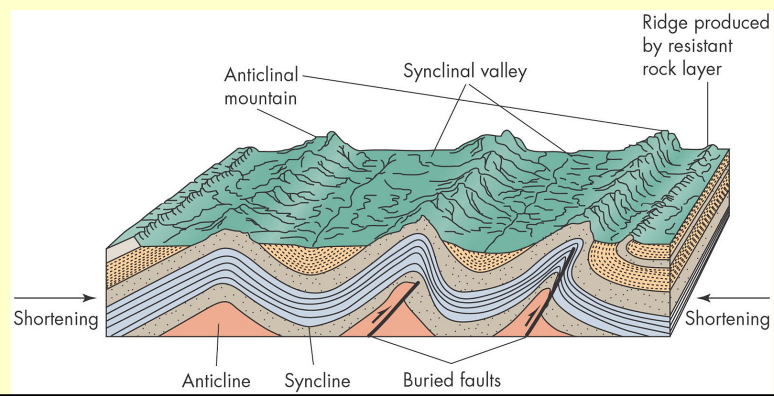
Types of Faults

Buried reverse (thrust) fault → folds

anticline: upfold over buried fault

syncline: downfold

Figure 5.11 p. 135



II. Earthquake Processes

Table 5.5 p. 135

TABLE 5.5 Terminology Related to Recovery of Fault Activity

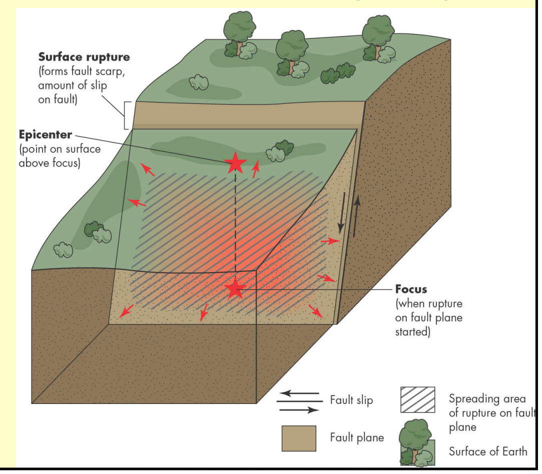
Geologic Age			Years before Present	Fault Activity
Era	Period	Epoch		
Cenozoic	Quaternary	Historic Holocene	200	Active
			10,000	
		Pleistocene		Potentially active
	Tertiary	Pre-Pleistocene	1,650,000	
			65,000,000	Inactive
	Pre-Cenozoic time			
			4,500,000,000	
	Age of Earth			

After California State Mining and Geology Board Classification, 1973.

II. Earthquake Processes

Earthquake terms:
- epicenter
- focus
- rupture
- surface rupture

Figure 5.3 p. 125



II. Earthquake Processes

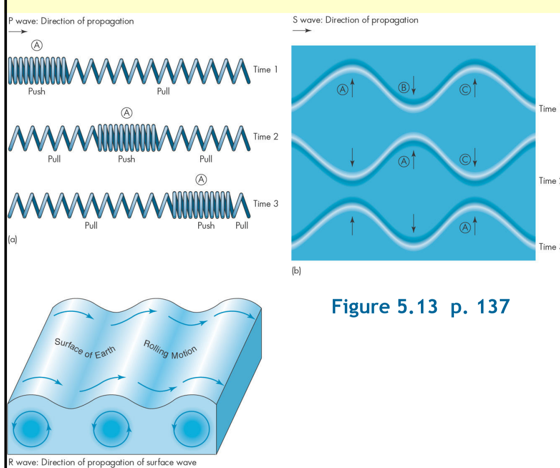


Figure 5.13 p. 137

Seismic waves:

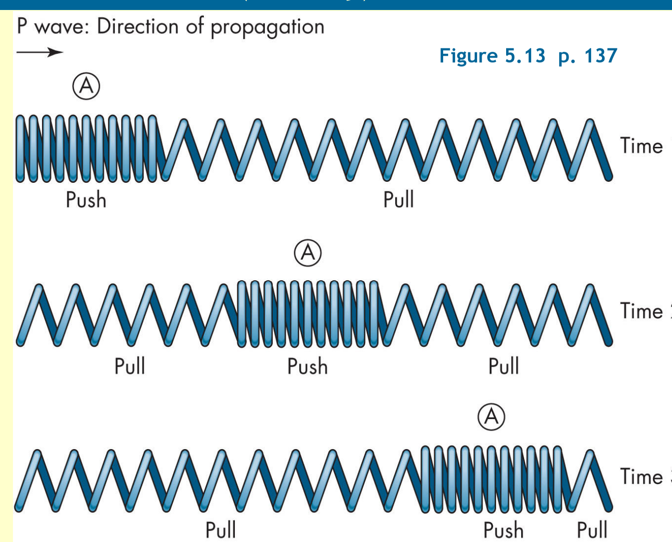
P-waves

S-waves

R-waves

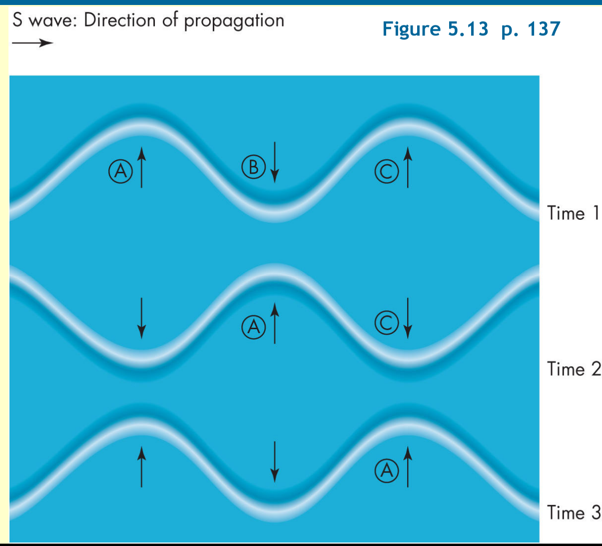
P (Primary) Waves

Figure 5.13 p. 137



S (Secondary) Waves

Figure 5.13 p. 137



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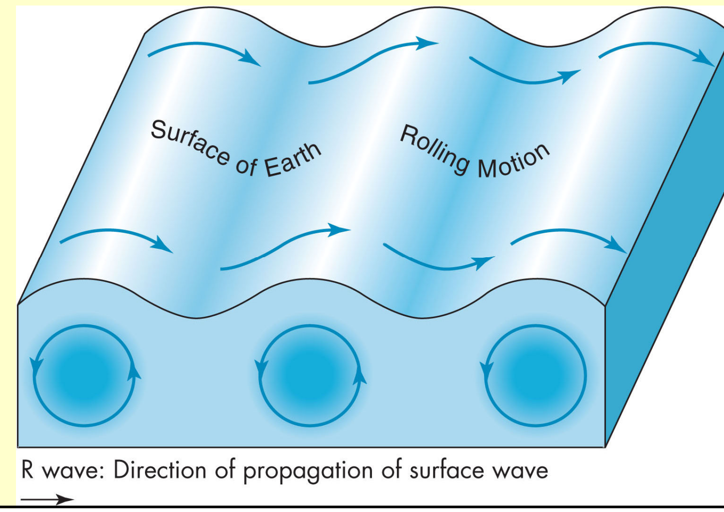
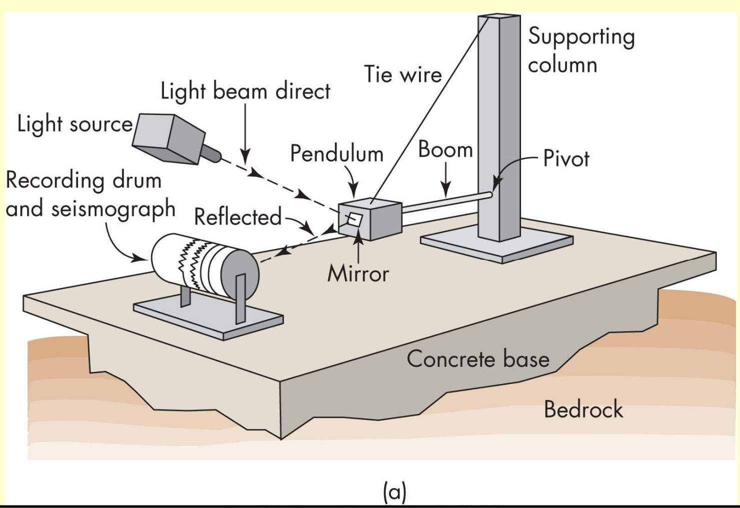
R (Rayleigh) Waves

Figure 5.13 p. 137



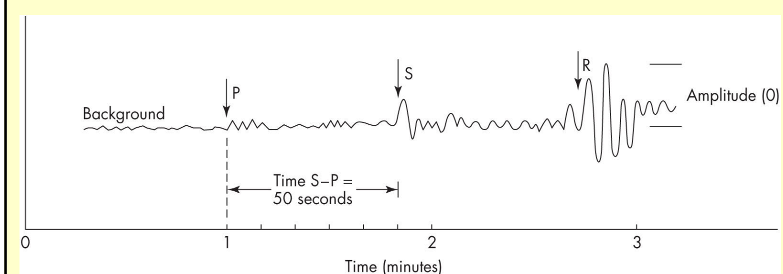
Seismograph

Figure 5.14 p. 138



Seismogram

Figure 5.14 p. 138



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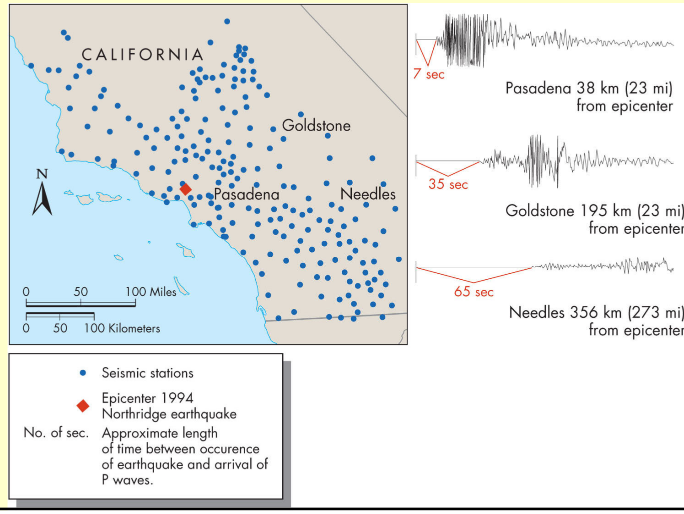
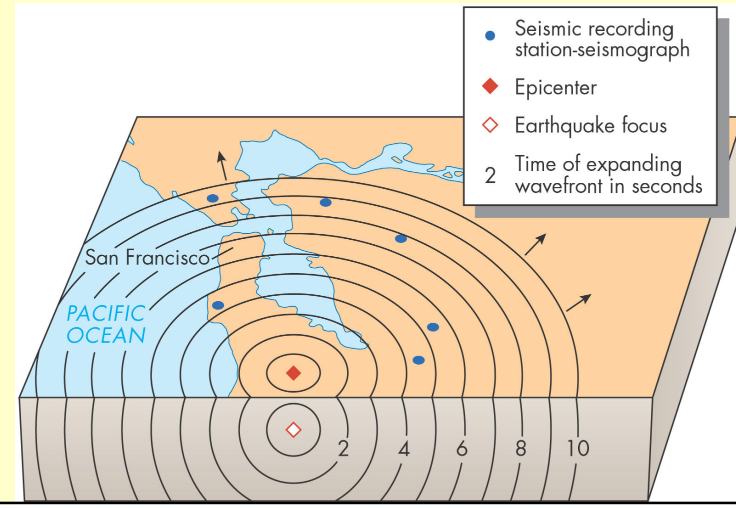
Seismogram

Figure 5.14 p. 138



Locating an Epicenter

Figure 5.15 p. 139

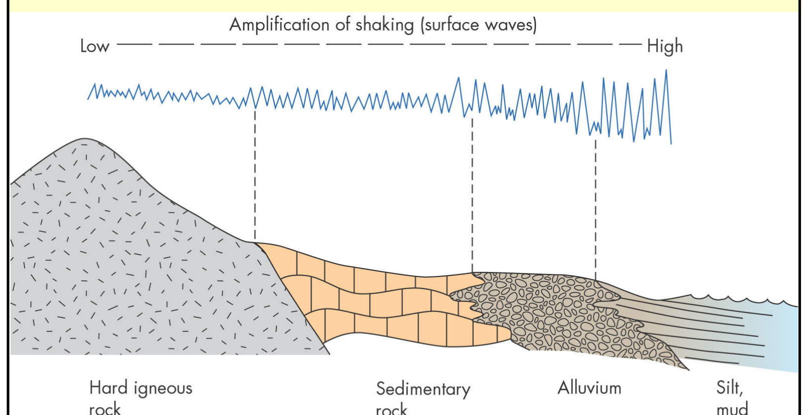


Material Amplification

- Seismic waves travel differently through different rock materials
- Propagate faster through dense and solid rocks
- Material amplification: Intensity (amplitude of vertical movement) of ground shaking more severe in unconsolidated materials
- Seismic energy attenuated more and propagated less distance in unconsolidated materials

Material Amplification

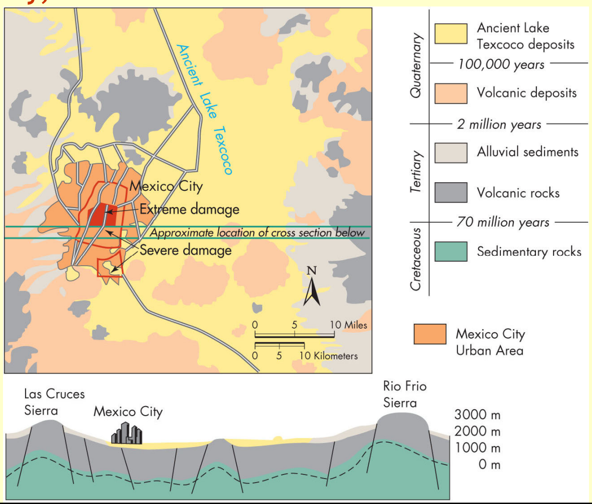
Figure 5.16 p. 140



Material Amplification

Mexico City, 1985

Figure 5.17 p. 141



Material Amplification

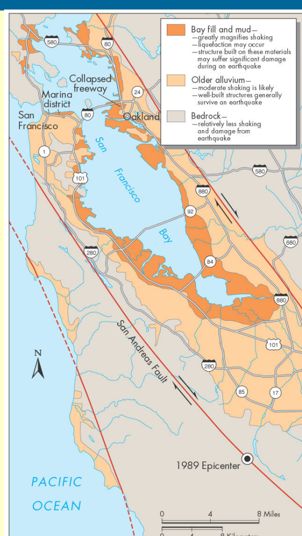
Figure 5.17 p. 141

Material Amplification

Loma Prieta, 1989

(San Francisco)

Figure 5.18 p. 142



Material Amplification

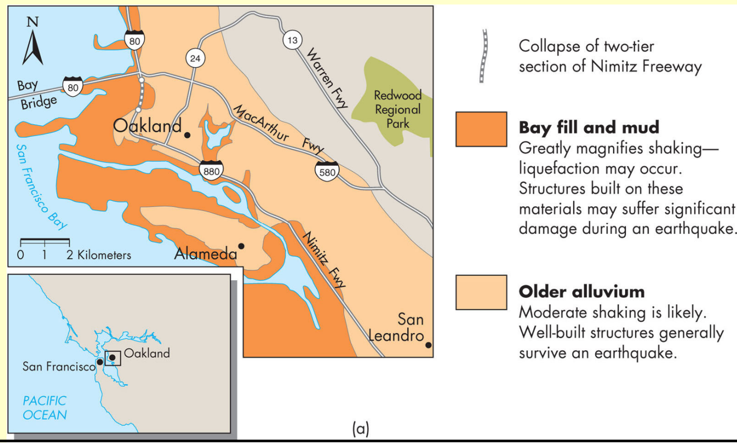
Loma Prieta, 1989 (San Francisco)

Figure 5.20 p. 143

Material Amplification

Loma Prieta, 1989 (San Francisco)

Figure 5.19 p. 143



(a)

Material Amplification

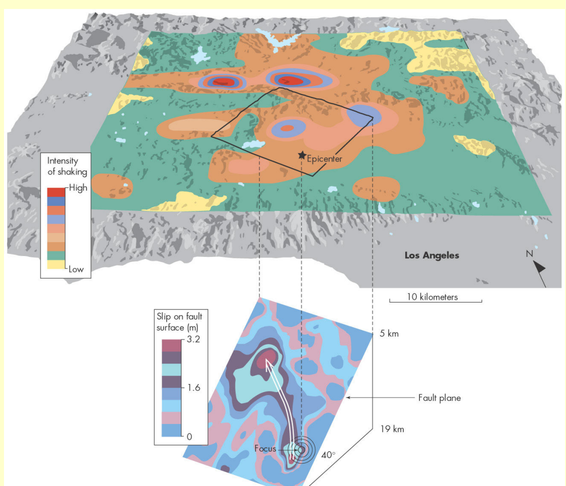
Loma Prieta, 1989 (San Francisco)

Figure 5.19 p. 143

Directivity and Depth of Focus

Northridge, 1994

Figure 5.21 p. 144



Earthquake Magnitude

- Richter scale: The amplitude of ground motion
  - Increasing one order in magnitude, a tenfold increase in amplitude
- Moment magnitude scale
  - Measuring the amount of strain energy released
  - Based on the amount of fault displacement
  - Applicable over a wider range of ground motions than Richter scale
- Earthquake energy: Increase one order in magnitude, about a 32-times increase in energy

Earthquake Magnitude

Table 5.3 p. 126

TABLE 5.3 Relationships between Magnitude, Displacement, and Energy of Earthquakes

Magnitude Change	Ground Displacement Change[1]	Energy Change
1	10 times	About 32 times
0.5	3.2 times	About 5.5 times
0.3	2 times	About 3 times
0.1	1.3 times	About 1.4 times

[1] Displacement, vertical or horizontal, that is recorded on a standard seismograph.

U.S. Geological Survey. 2000. *Earthquakes, facts and statistics*. http://neic.usgs.gov. Accessed 1/3/00

Earthquake Magnitude

Table 5.2 p. 126

TABLE 5.2 Worldwide Magnitude and Frequency of Earthquakes by Descriptor Classification

Descriptor	Magnitude	Average Annual No. of Events
Great	8 and Higher	1
Major	7–7.9	18
Strong	6–6.9	120
Moderate	5–5.9	800
Light	4–4.9	6,200 (estimated
Minor	3–3.9	49,000 (estimated)
Very minor	<3.0	Magnitude 2–3 about 1000 per day
		Magnitude 1–2 about 8000 per day

U.S. Geological Survey. 2000. *Earthquakes, facts and statistics*. http://neic.usgs.gov. Accessed 1/3/00

Earthquake Intensity

- Modified Mercalli Scale
  - 12 divisions
  - Qualitative severity measurement of damages and ground movement
  - Based on ground observations, instead of instrument measurement
  - Scale depending on earthquake's magnitude, duration, distance from the epicenter, site geological conditions, and conditions of infrastructures (age, building code, etc.)

Earthquake Intensity

Table 5.4 p. 127

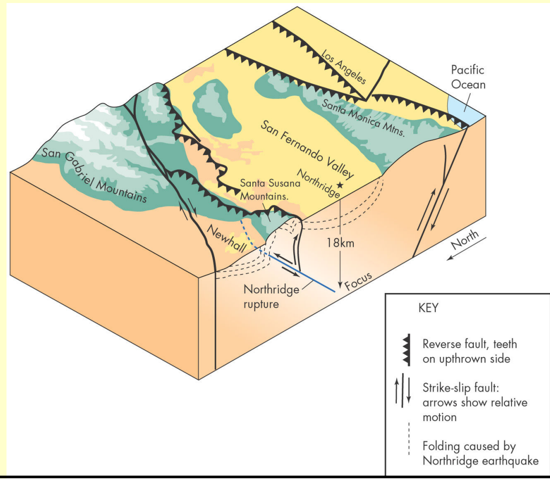
TABLE 5.4 Modified Mercalli Intensity Scale (abridged)

Intensity	Effects
I	Felt by very few people.
II	Felt by only a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration feels like the passing of a truck.
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make cracking sound; sensation like heavy truck striking building; standing motor cars rock noticeably.
V	Felt by nearly everyone; many awakened. Some dishes, windows, and so on, broken; a few instances of cracked plaster; unstable objects overturned; disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.
VI	Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage is 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; some chimneys broken. Noticed by persons driving cars.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures; panel walls thrown out of frame structures; fall of chimneys, factory stacks, columns, monuments, walls; heavy furniture overturned; sand and mud ejected in small amounts; changes in well water; disturbs persons driving cars.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings are shifted off foundations. Ground cracked conspicuously. Underground pipes are broken.
X	Some well-built wooden structures are destroyed; most masonry and frame structures with foundations destroyed; ground badly cracked. Rails bent. Landslides considerable from riverbanks and steep slopes. Shifted sand and mud. Water is splashed over banks.
XI	Few, if any (masonry) structures remain standing. Bridges are destroyed. Broad fissures are formed in ground. Underground pipelines are taken out of service. Earth slumps and land slips on soft ground occurs. Train rails are bent.
XII	Damage is total. Waves are seen on ground surfaces. Lines of sight and level distorted. Objects are thrown upward into the air.

From Wood and Neuman, 1931, by U.S. Geological Survey, 1974, *Earthquake Information Bulletin* 6(5):28

Earthquake Intensity: Northridge, CA 1994

Figure 5.2 p. 124



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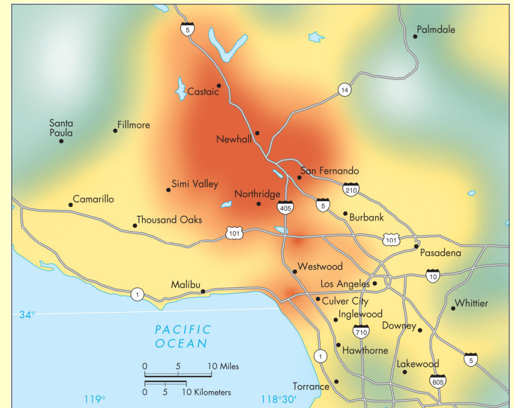
Earthquake Intensity: Northridge, CA 1994

Figure 5.6 p. 129



Instrumental intensity	I	II-III	IV	V	VI	VII	VIII	IX	X+
Shaking	not felt	weak	light	moderate	strong	very strong	severe	violent	extreme
Damage	none	none	none	very light	light	moderate	moderate/heavy	heavy	very heavy

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Earthquake Intensity: Seattle, WA 2001

Figure 5.6 p. 129

Instrumental intensity	I	II-III	IV	V	VI	VII	VIII	IX	X+
Shaking	not felt	weak	light	moderate	strong	very strong	severe	violent	extreme
Damage	none	none	none	very light	light	moderate	moderate/heavy	heavy	very heavy

Earthquake Cycles

- Faulting and elastic rebound
- Stages of earthquake cycle
  - Inactive and aftershock stage
  - Stress accumulation stage
  - Foreshocks
  - Main shock (major earthquake)
- Earthquake cycle over time: Recurrence intervals
- Earthquake cycle in space: Seismic gaps

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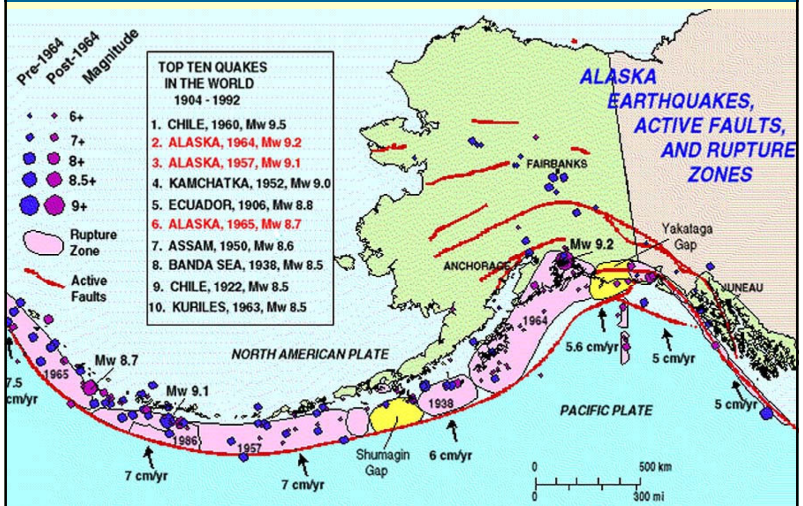
Seismic Gaps



Earthquake Cycle

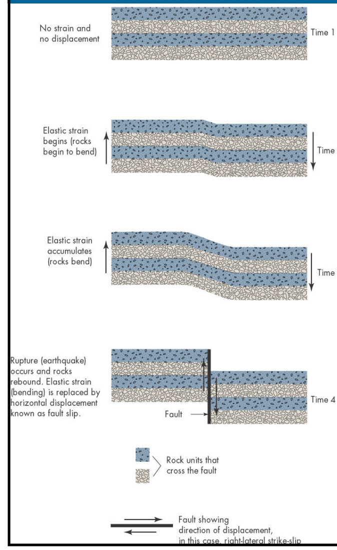


Figure 5.24 p.147

Stages of earthquake cycle
- Inactive and aftershock stage
- Stress accumulation stage
- Foreshocks
- Main shock (major earthquake)

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III. Earthquake Effects

- Primary effects
  - Ground shaking, tilting, and ground rupture
  - Loss of life and collapse of infrastructure
  - Landslides, liquefaction, and tsunamis
- Secondary effects
  - Fires, floods, and diseases

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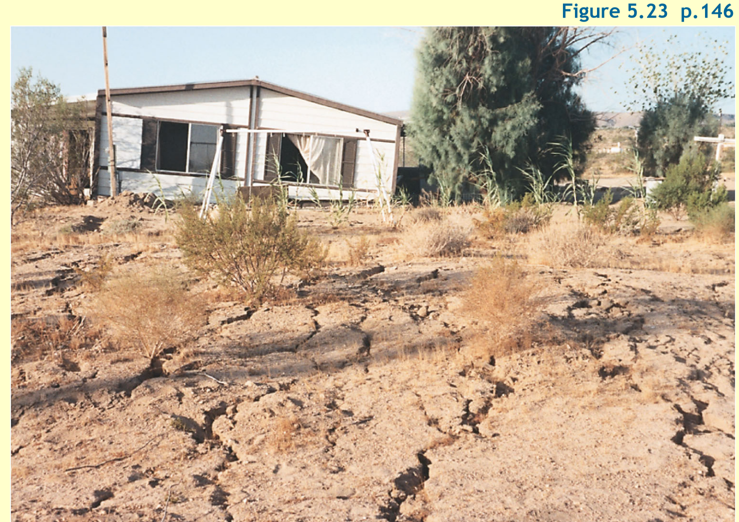
Primary Effects: Surface Ruptures

Figure 5.23 p.146



Primary Effects: Surface Ruptures

Figure 5.23 p.146

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Primary Effects: Surface Ruptures

Fault scarp

Figure 5.26 p.149

Primary Effects: Landslides

Figure 5.27 p.151

Primary Effects: Landslides

Primary Effects: Tsunami

Surviving a Tsunami—Lessons from Chile, Hawaii, and Japan

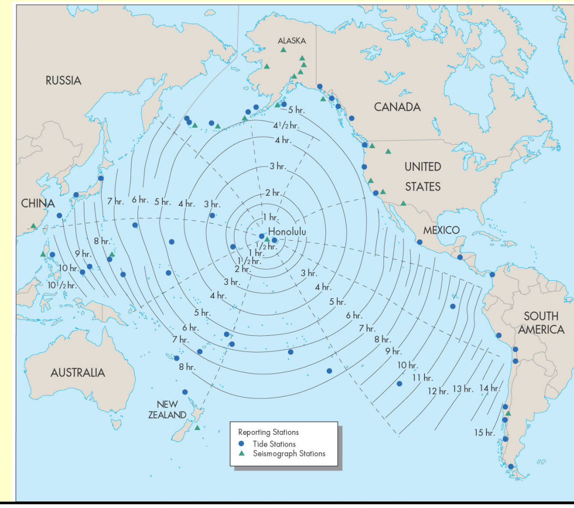
U. S. Geological Survey Circular 1187, 1999

http://pubs.usgs.gov/circ/c1187/

Tsunami Animation

Primary Effects: Tsunami

Figure 5.30 p.153



III. Earthquake Effects

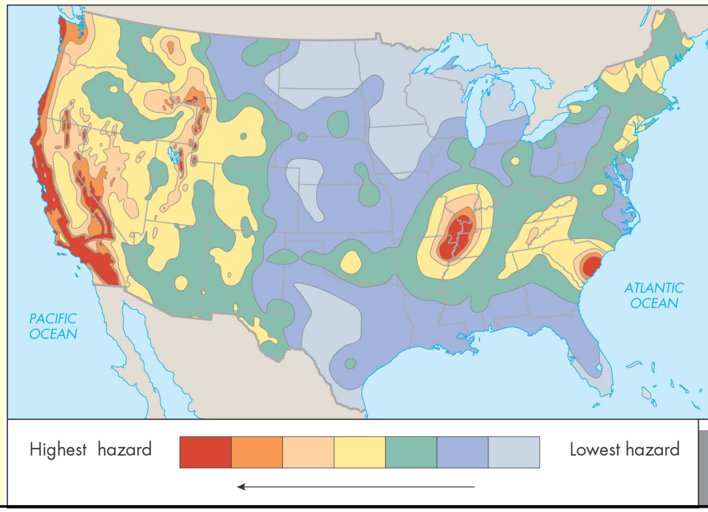
- Depending upon the frequency of seismic waves
  - ➢ Body waves (P and S) having higher frequency than surface waves
  - ➢ High frequency waves posing more threats on low structures
  - ➢ Low frequency waves posing more impact on tall structures
  - ➢ High frequency waves attenuated faster over distance, higher buildings far away from the epicenter can be damaged

IV. Earthquake Risks and Predictions

- Earthquake risks
  - ➢ Probabilistic methods for a given magnitude or intensity
  - ➢ Earthquake risk of an area
  - ➢ Earthquake risk of a fault segment
- Seismic hazard maps
- Conditional probabilities for future earthquakes

IV. Earthquake Risks and Predictions

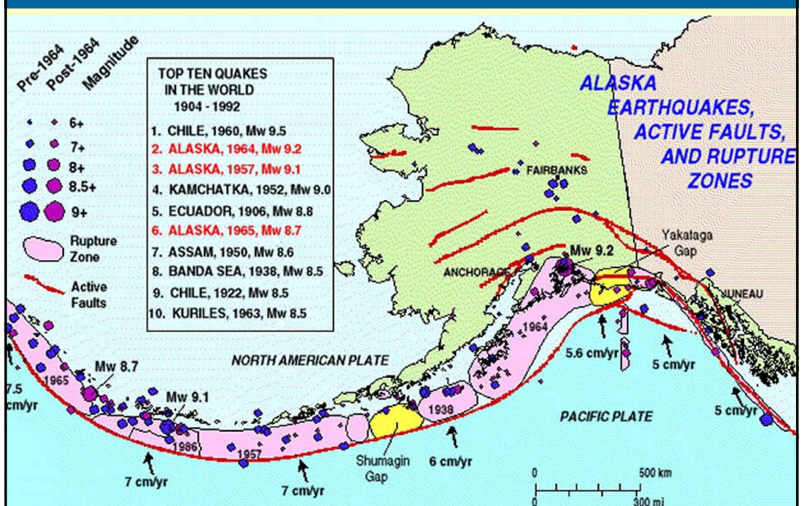
Figure 5.31 p.154



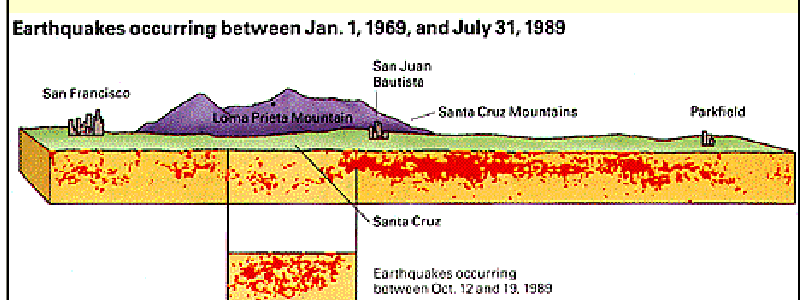
IV. Earthquake Risks and Predictions

- Long-term prediction
  - Earthquake hazard risk mapping
- Short-term prediction (forecast)
  - Frequency and distribution pattern of foreshocks
  - Deformation of the ground surface: Tilting, elevation changes
  - Emission of radon gas
  - Seismic gap along faults
  - Abnormal animal activities

Seismic Gaps



Seismic Gaps



IV. Earthquake Risks and Predictions

- Hazard Reduction Programs
  - Develop a better understanding of the source and processes of earthquake
  - Determine earthquake risk potential
  - Predict effects of earthquakes
  - Apply research results

IV. Earthquake Risks and Predictions

- Adjustments to earthquake activities
  - Site selection for critical facilities
  - Structure reinforcement and protection
  - Land-use regulation and planning
  - Emergency planning and management: Insurance and relief measures

IV. Earthquake Risks and Predictions

- Technically feasible: But only about a minute warning

- Warning system
  - Not a prediction tool
  - Can create a false alarm

- Better prediction and better warning system?