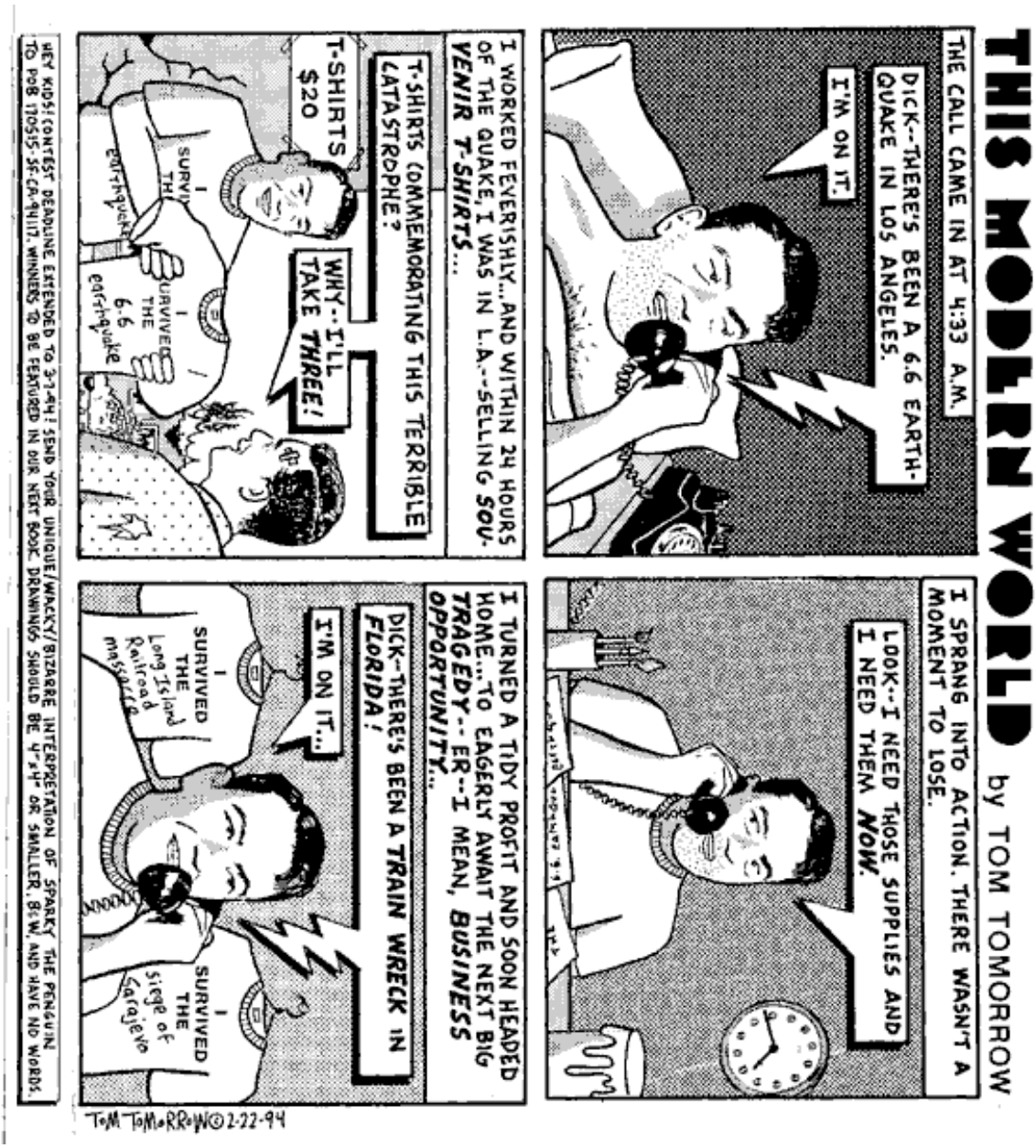
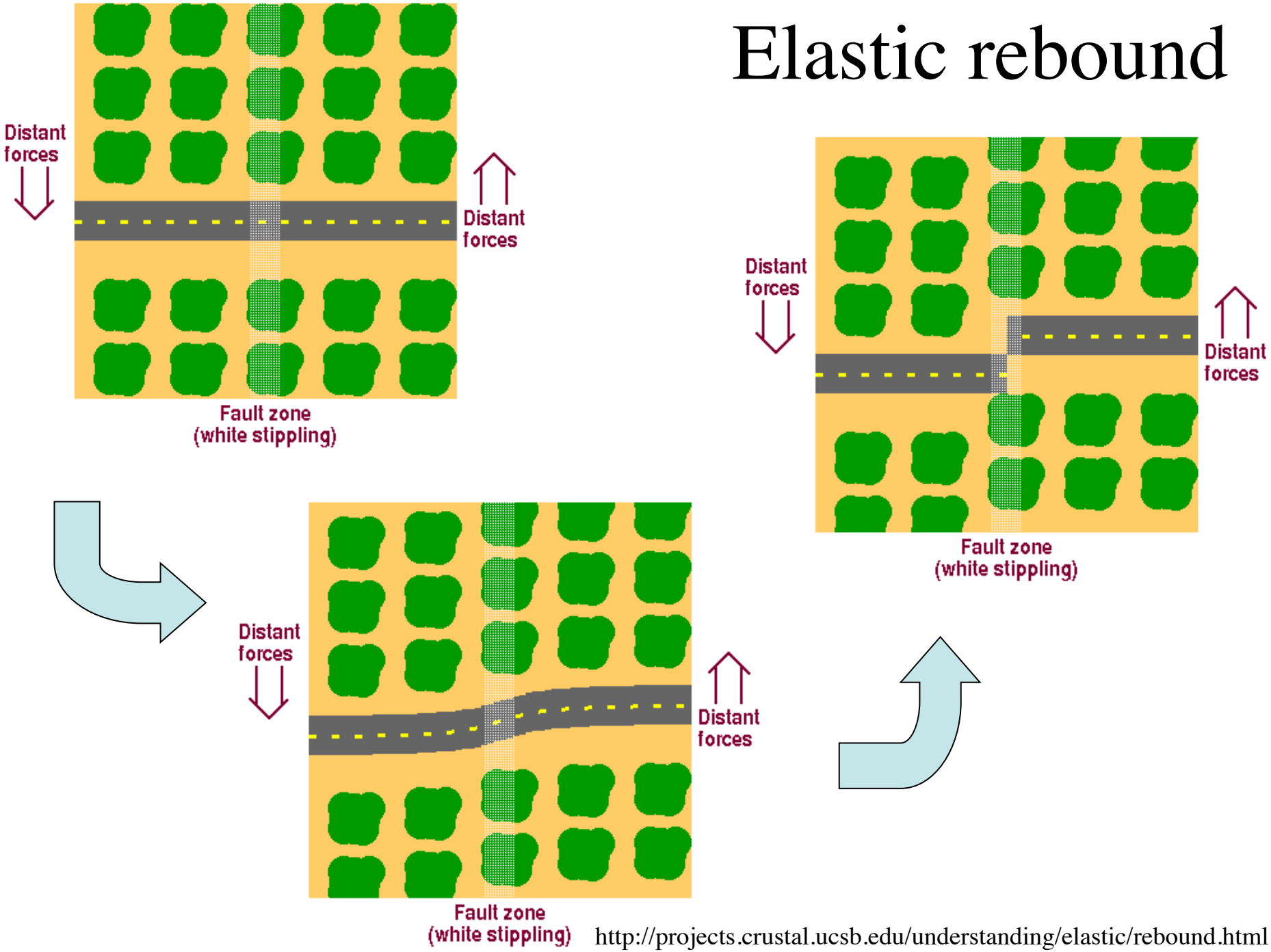
Earthquakes



http://thismodernworld.com/comic-archive

Elastic rebound



http://projects.crustal.ucsb.edu/understanding/elastic/rebound.html

Elastic rebound

- Rocks store energy elastically
- When stored stress exceeds the strength of the friction on the fault OR the strength of the rock… snap.
- The longer between quakes, the more energy is stored. The deformation can be measured as a way to predict the size of the next quake.

Basic Earthquake Terms

- Focus (Hypocenter):
- Epicenter:

Basic Earthquake Terms

- Focus (Hypocenter): where the fault ruptures, where the earthquake actually begins.
  - Usually underground
  - Rupture can propagate along the surface – size of quake depends on the amount of rupture
- Epicenter: point on Earth's surface above the focus, where surface waves begin

Earthquake waves

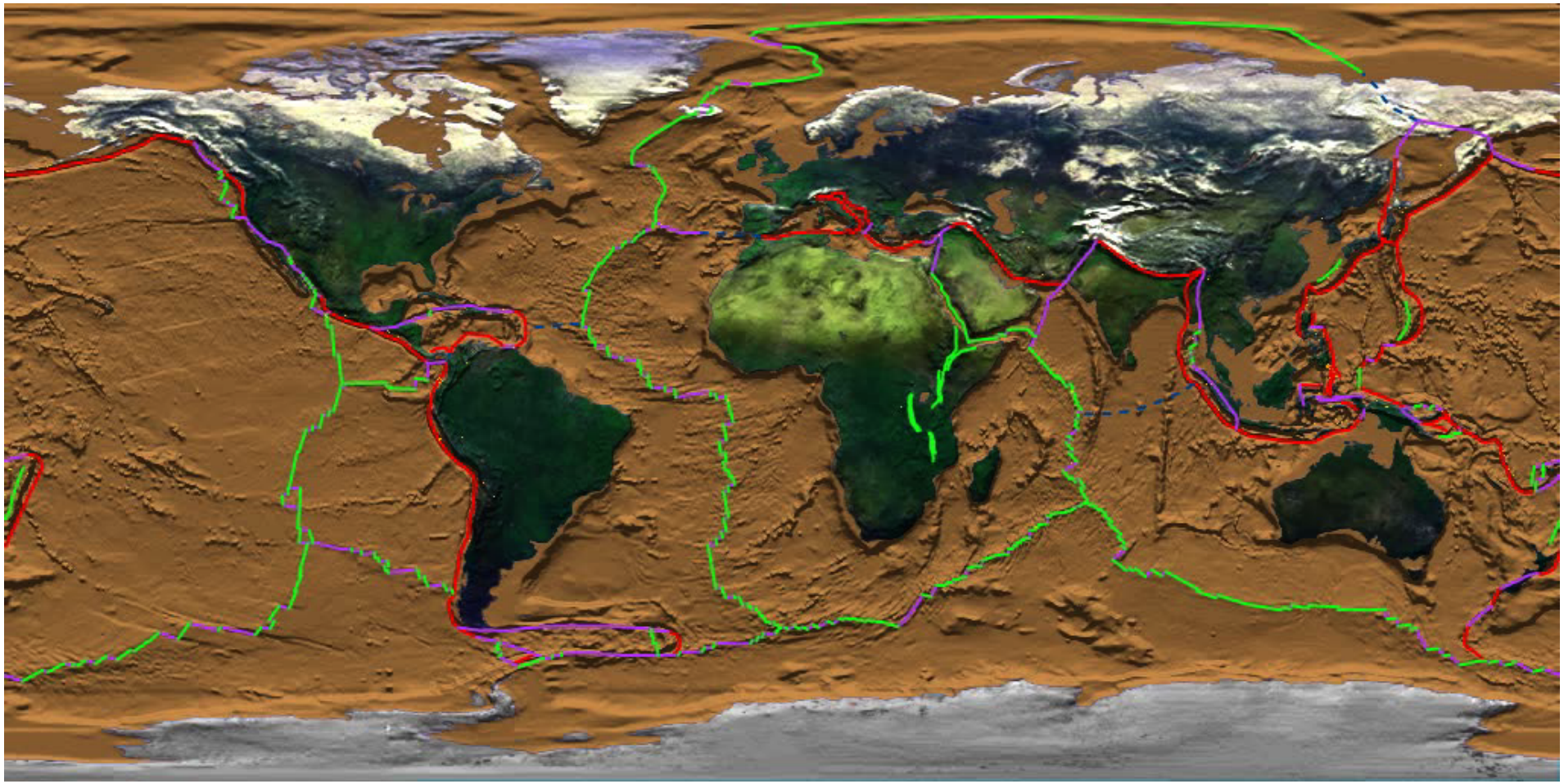
- Body waves: run through interior of Earth
  - P (primary) wave – compressional, fast
  - S (secondary) wave – transverse, slower
- Surface waves: ripples at surface of Earth, much slower

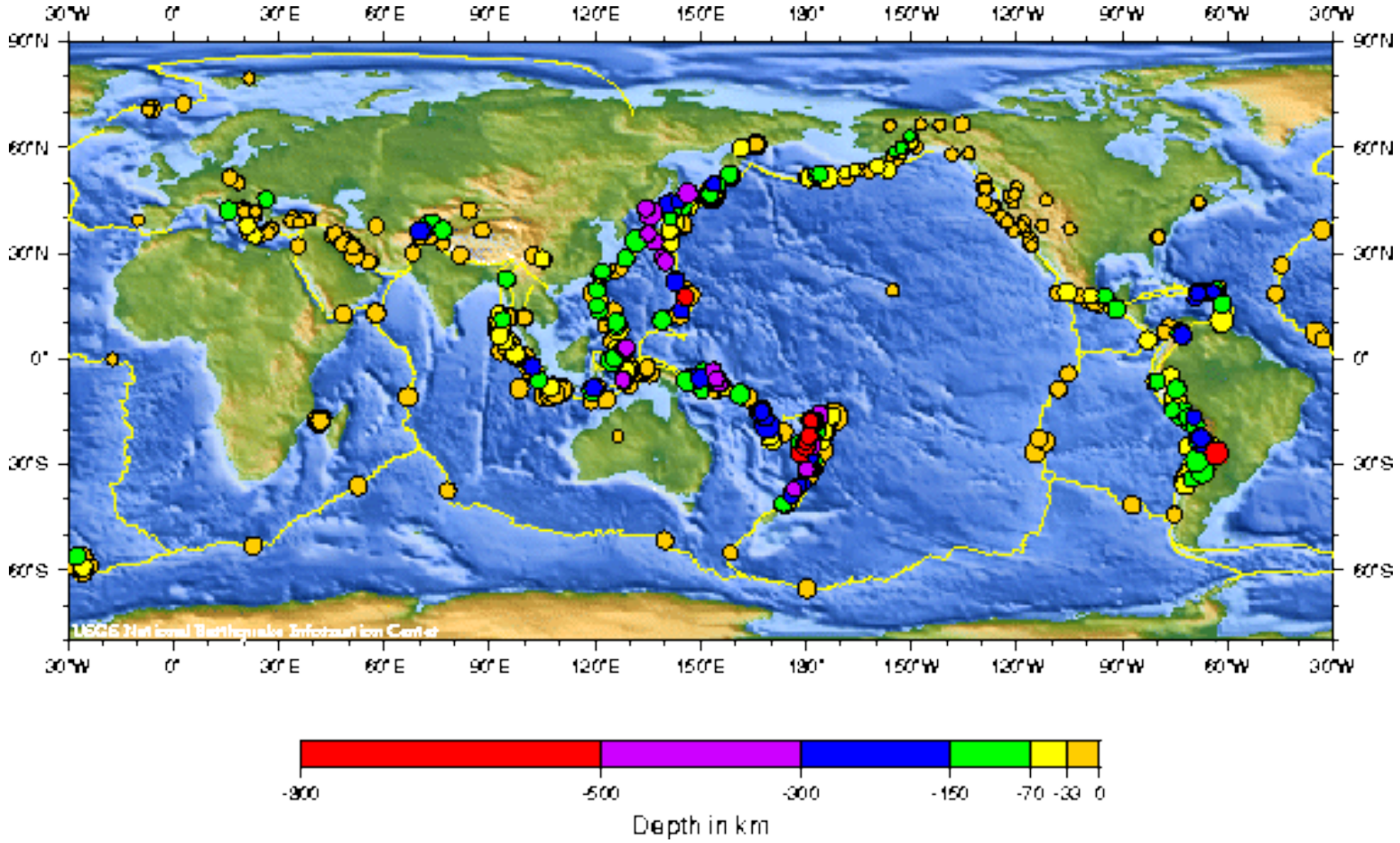
Finding the epicenter

- Use difference in travel time between P and S wave to find distance to epicenter
- Use several stations to triangulate the one place that is the right distance from each station

USGS

Earthquakes and plates




30°W
0°
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
90°N
60°N
30°N
0°
30°S
60°S
-300
-150
-70
-33
0
Depth in km

USGS

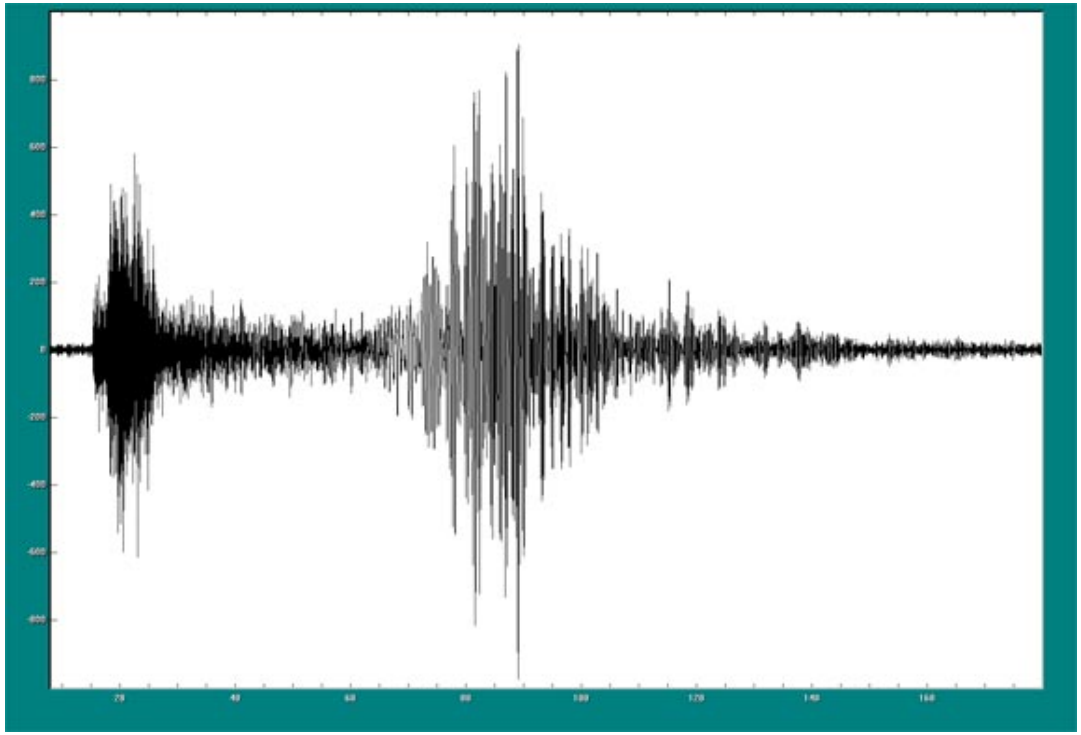
Earthquakes and plates

- Diverging: small, shallow
- Subduction zone: small to very large, shallow to deep
- Suture zone: small to large, shallow to medium depth
- Transform: small to large, shallow

Magnitude v. intensity

- Magnitude: amount of energy released in the earthquake
  - Moment magnitude - depends on the area of the surface that ruptures and the average displacement
  - Estimated by amplitude of seismogram

Dec. 26, 2004, Sumatra



http://cbsphilly.files.wordpress.com/2011/04/seismograph1.jpg?w=300

What happened to Richter?

- Richter magnitude estimated energy from amplitude of the seismogram
- Could not distinguish between very large magnitudes
- Required use of a specific seismometer

Intensity

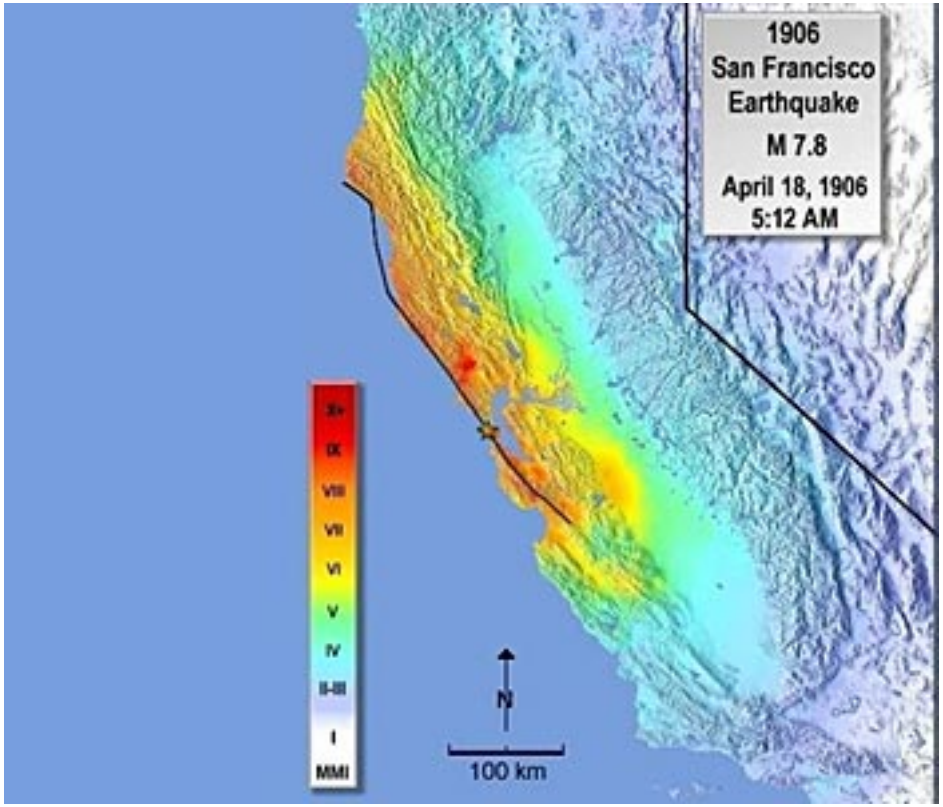
- Degree of shaking

I. Instrumental	Not felt by many people unless in favourable conditions.
II. Weak	Felt only by a few people at best, especially on the upper floors of buildings. Delicately suspended objects may swing.
III. Slight	Felt quite noticeably by people indoors, especially on the upper floors of buildings. Many do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration similar to the passing of a truck. Duration estimated.
IV. Moderate	Felt indoors by many people, outdoors by few people during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rock noticeably. Dishes and windows rattle alarmingly.
V. Rather Strong	Felt outside by most, may not be felt by some outside in non-favourable conditions. Dishes and windows may break and large bells will ring. Vibrations like large train passing close to house.
VI. Strong	Felt by all; many frightened and run outdoors, walk unsteadily. Windows, dishes, glassware broken; books fall off shelves; some heavy furniture moved or overturned; a few instances of fallen plaster. Damage slight.
VII. Very Strong	Difficult to stand; furniture broken; damage negligible in building of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken. Noticed by people driving motor cars.
VIII. Destructive	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture moved.
IX. Violent	General panic; 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.
X. Intense	Some well built wooden structures destroyed; most masonry and frame structures destroyed with foundation. Rails bent.
XI. Extreme	Few, if any masonry structures remain standing. Bridges destroyed. Rails bent greatly.
XII. Cataclysmic	Total destruction - Everything is destroyed. Lines of sight and level distorted. Objects thrown into the air. The ground moves in waves or ripples. Large amounts of rock move position. Landscape altered, or leveled by several meters. In some cases, even the routes of rivers are changed.

http://www.ualberta.ca/~dumberry/geoph110/seiserqk.htm

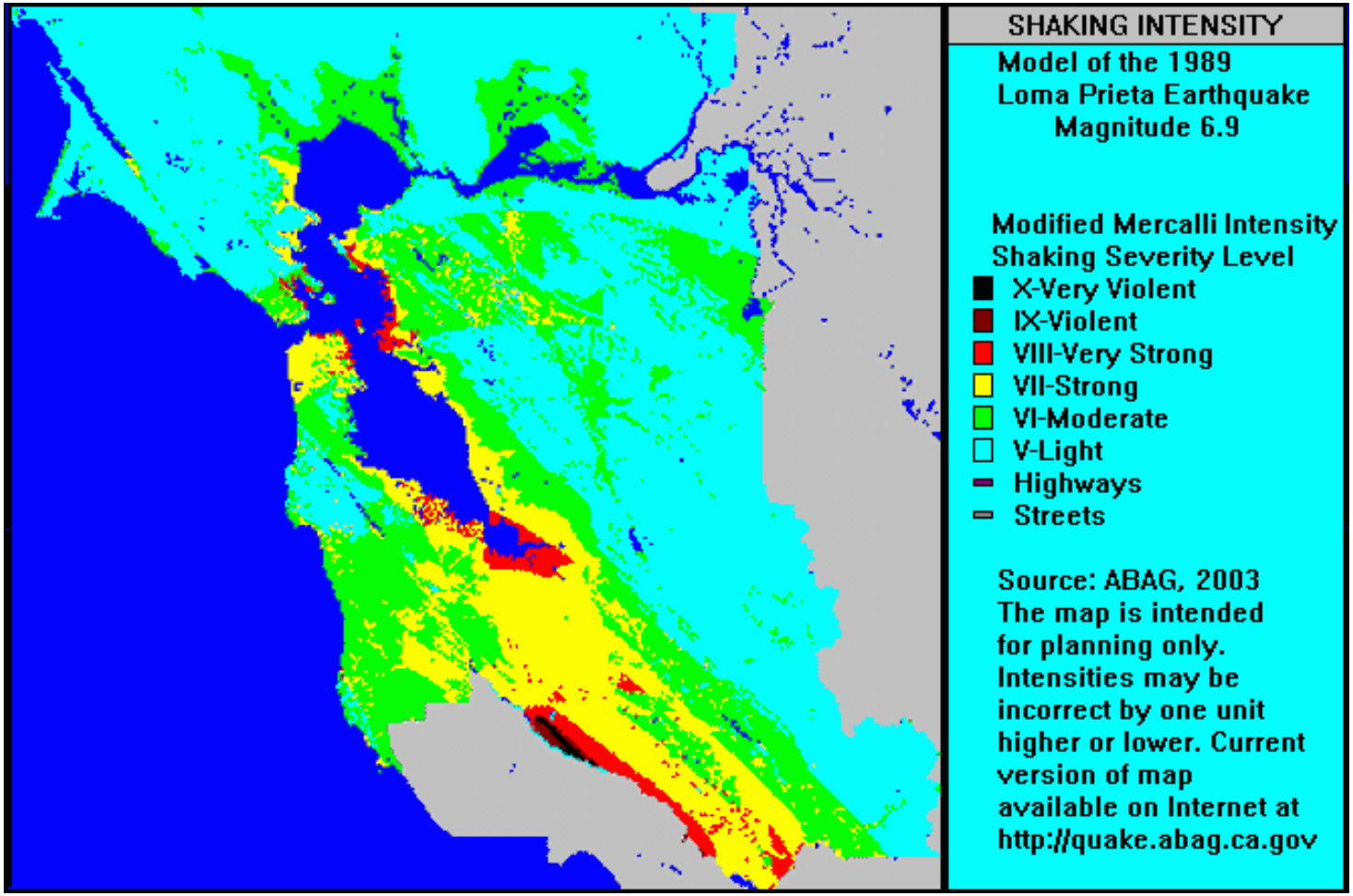
Intensity depends on..

- Distance from epicenter



USGS

Geological substrate



USGS

Loma Prieta, 1989

USGS

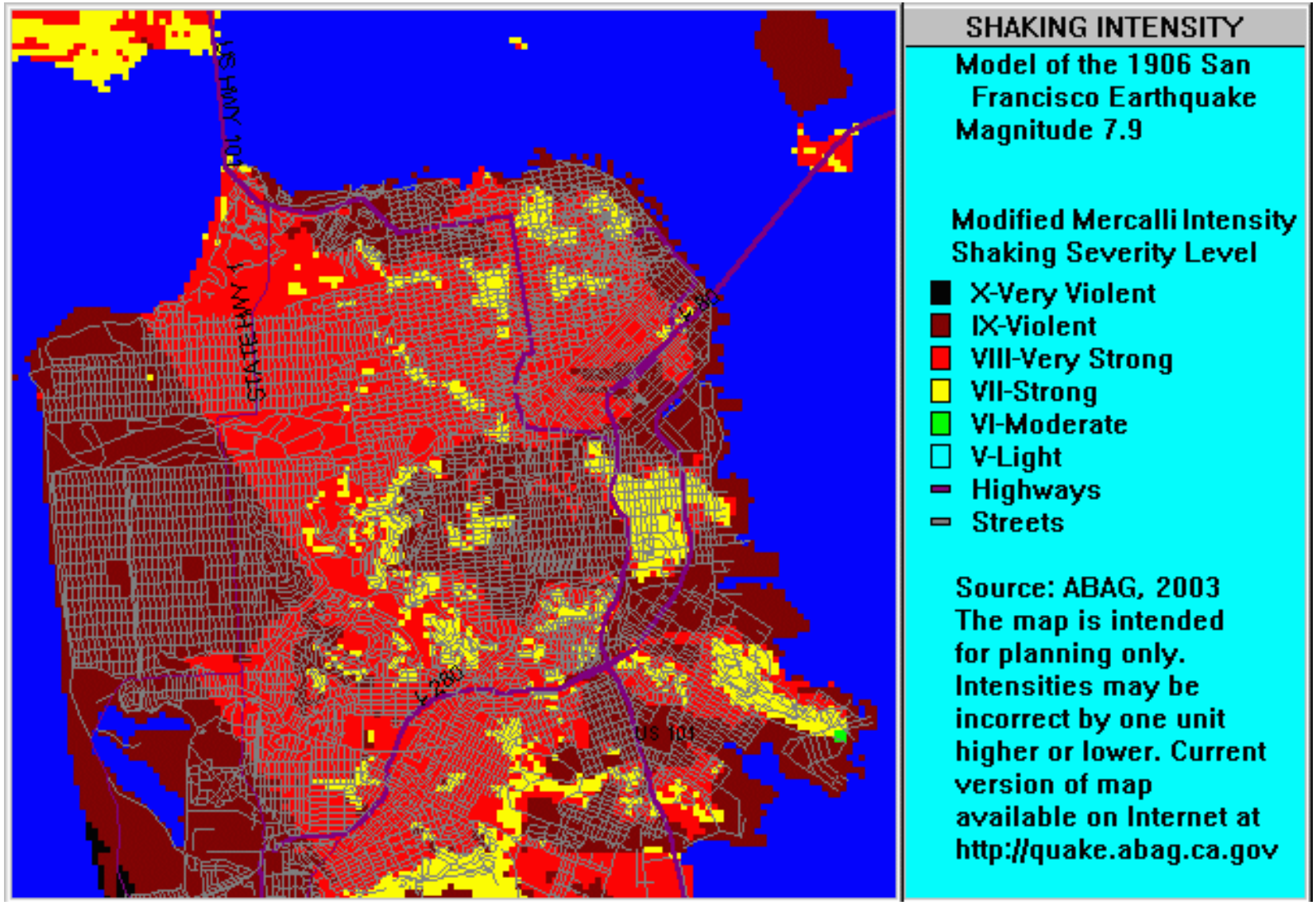
Hazards

- Ground motion
- Liquefaction
- Landslides
- Fire
- Tsunamis

Ground motion

USGS

Pakistan, 2004


US HWY 101
STATE HWY 1
US 101
SHAKING INTENSITY
Model of the 1906 San Francisco Earthquake
Magnitude 7.9
Modified Mercalli Intensity
Shaking Severity Level
X-Very Violent
IX-Violent
VIII-Very Strong
VII-Strong
VI-Moderate
V-Light
Highways
Streets
Source: ABAG, 2003
The map is intended for planning only. Intensities may be incorrect by one unit higher or lower. Current version of map available on Internet at http://quake.abag.ca.gov

USGS

Liquefaction

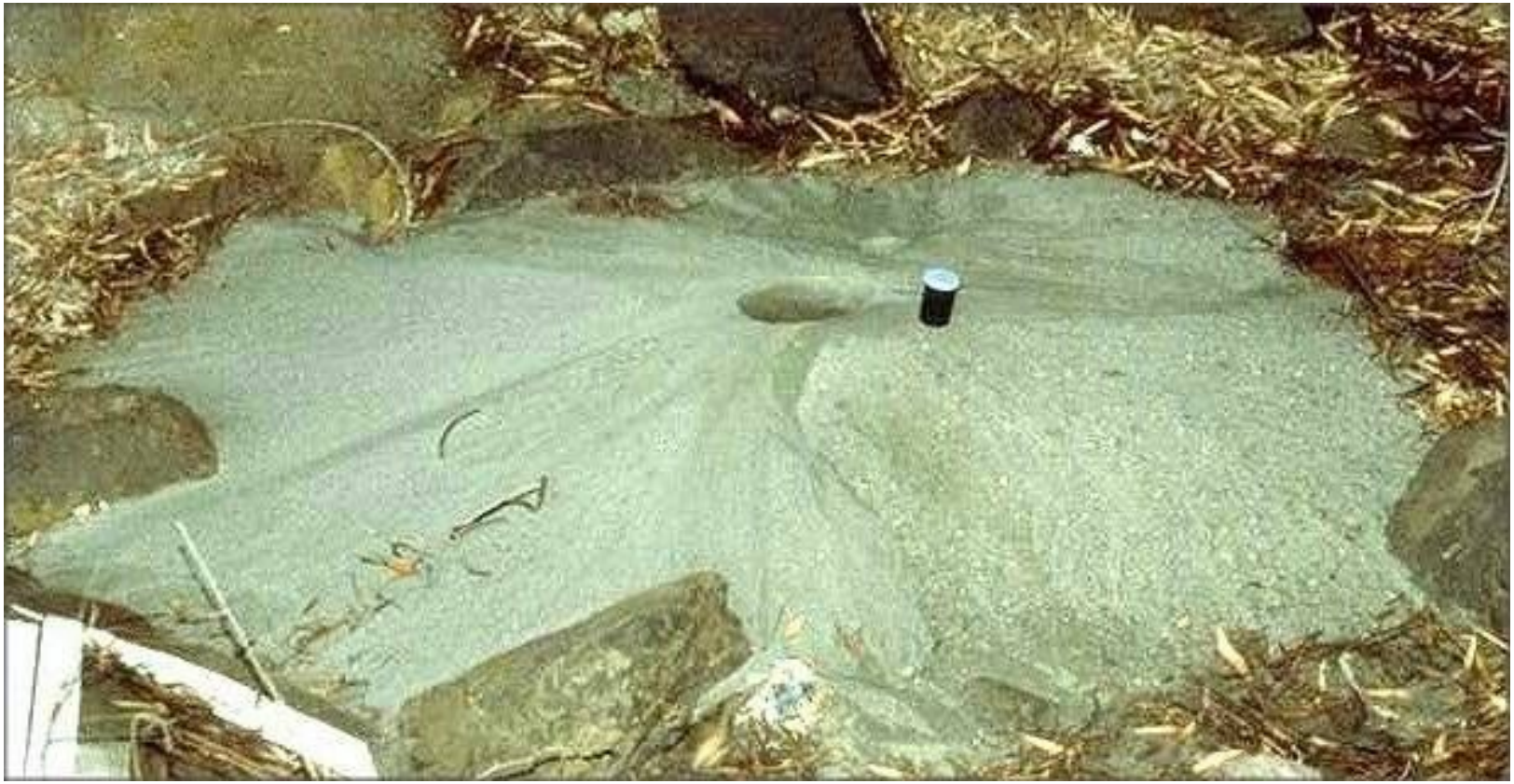
Water-soaked sediment; during earthquake, sediment sinks

USGS

Loma Prieta

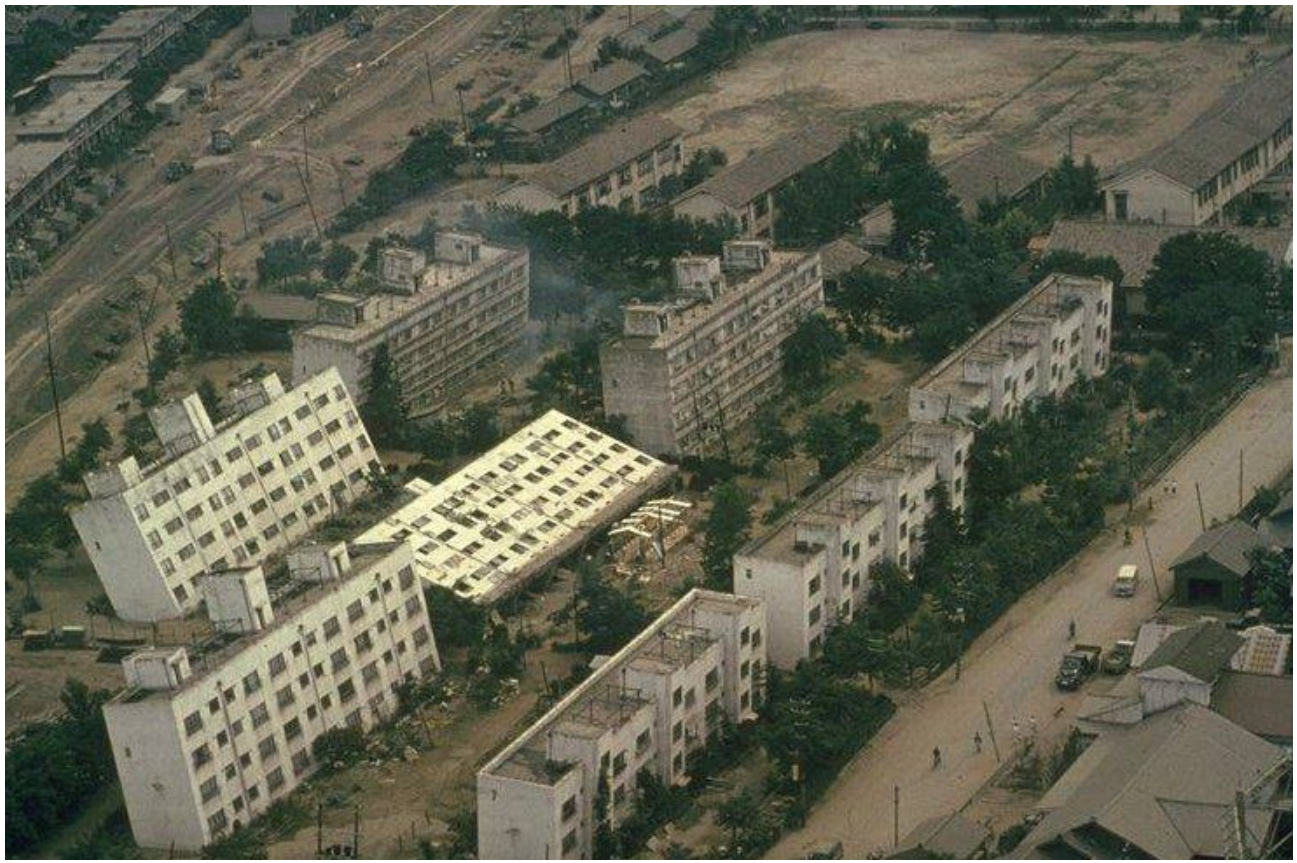
USGS

Loma Prieta



USGS

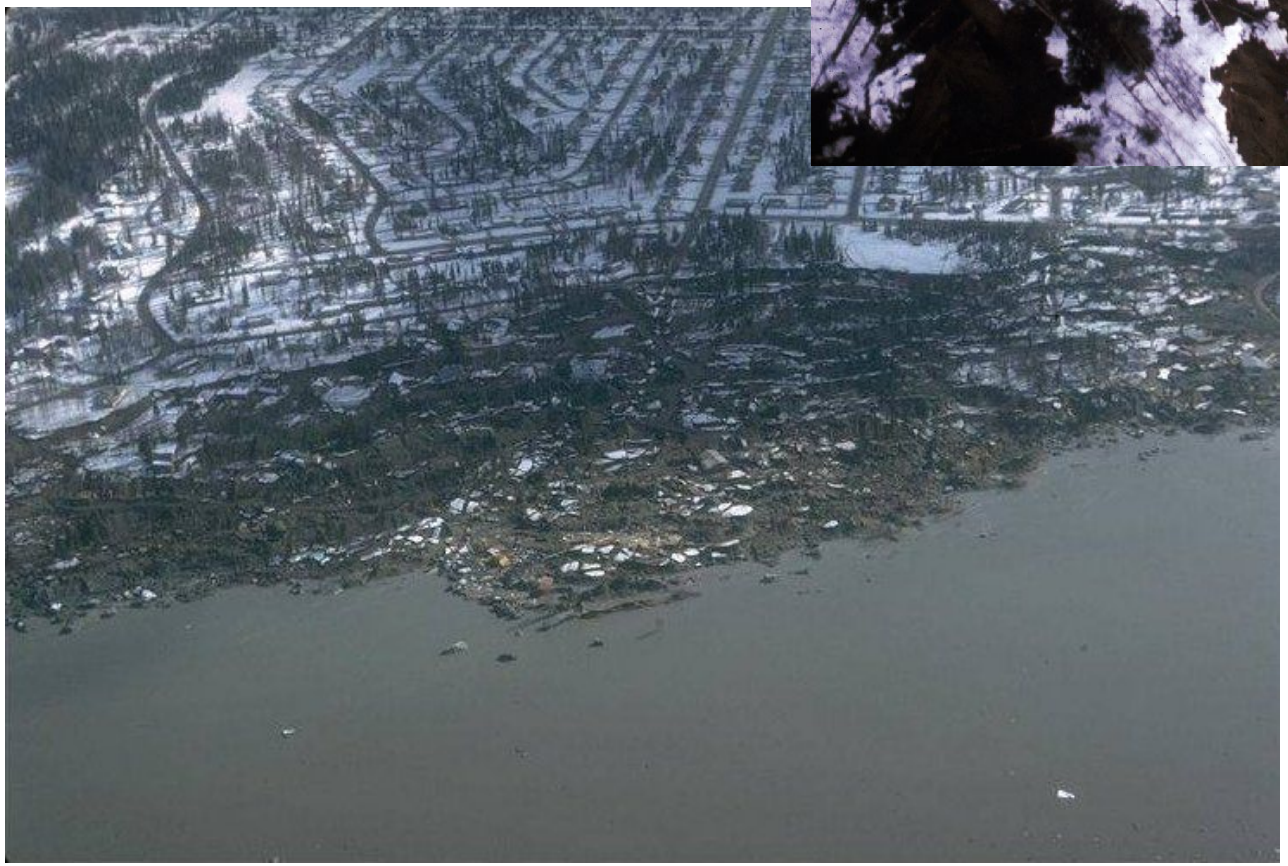
Niigata, Japan, 1964



http://www.uwiseismic.com/General.aspx?id=14

Landslides

Anchorage, 1964



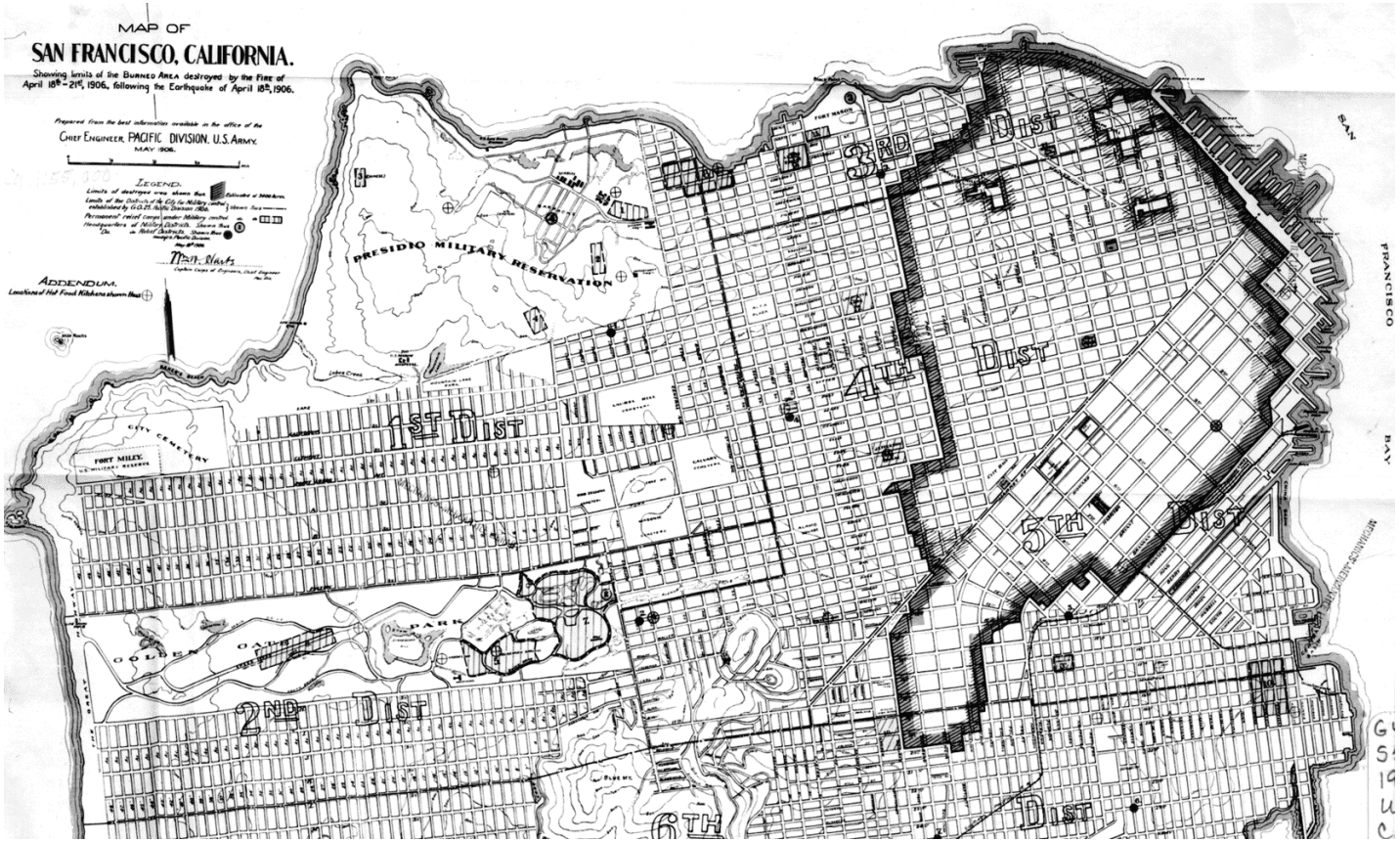
http://upload.wikimedia.org/wikipedia/commons/a/a5/AlaskaQuake-Turnagain.jpg

Northridge, 1992

Fire: San Francisco

USGS

http://www.sfmuseum.org/hist/pix49.html


MAP OF
SAN FRANCISCO, CALIFORNIA.
Showing limits of the Burned Area destroyed by the Fire of April 18th-21st, 1906, following the Earthquake of April 18th, 1906.
Prepared from the best information available in the office of the
Chief Engineer, Pacific Division, U.S. Army.
MAY 1906.
Legend.
Addendum.
Locations of Hot Food Ribbons shown thus
Presidio Military Reservation
Fort Mason
Fort Miley
Military Reserve
City Cemetery
Golden Gate Park
1st Dist
2nd Dist
3rd Dist
4th Dist
5th Dist
6th Dist
Bay
San Francisco Bay

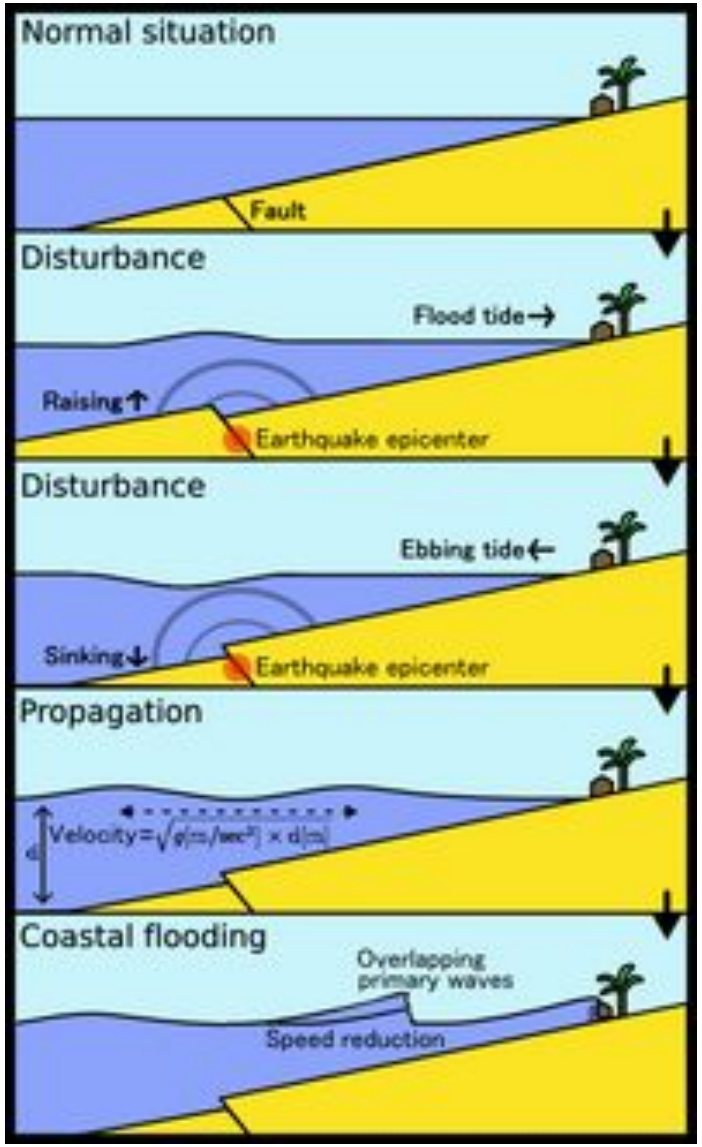
USGS

USGS

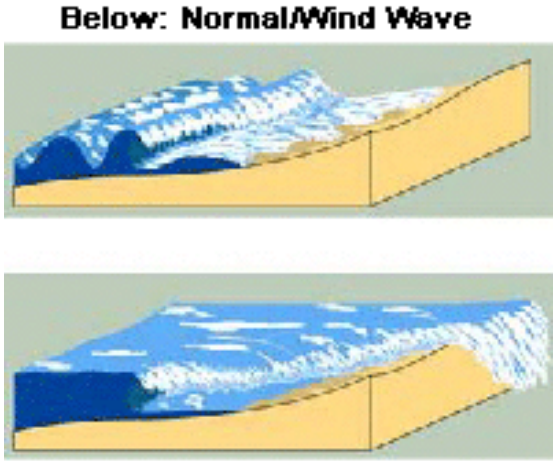
San Francisco Chronicle

Tsunami

http://commons.wikimedia.org/wiki/File:2004-tsunami.jpg?uselang=es



http://www.thesurfchannel.com/newwave/wp-content/uploads/2012/09/Tsunami_comic_book_style.png



http://whatistsunami.info/wp-content/uploads/2012/07/9.jpg

Hawaii, 1946

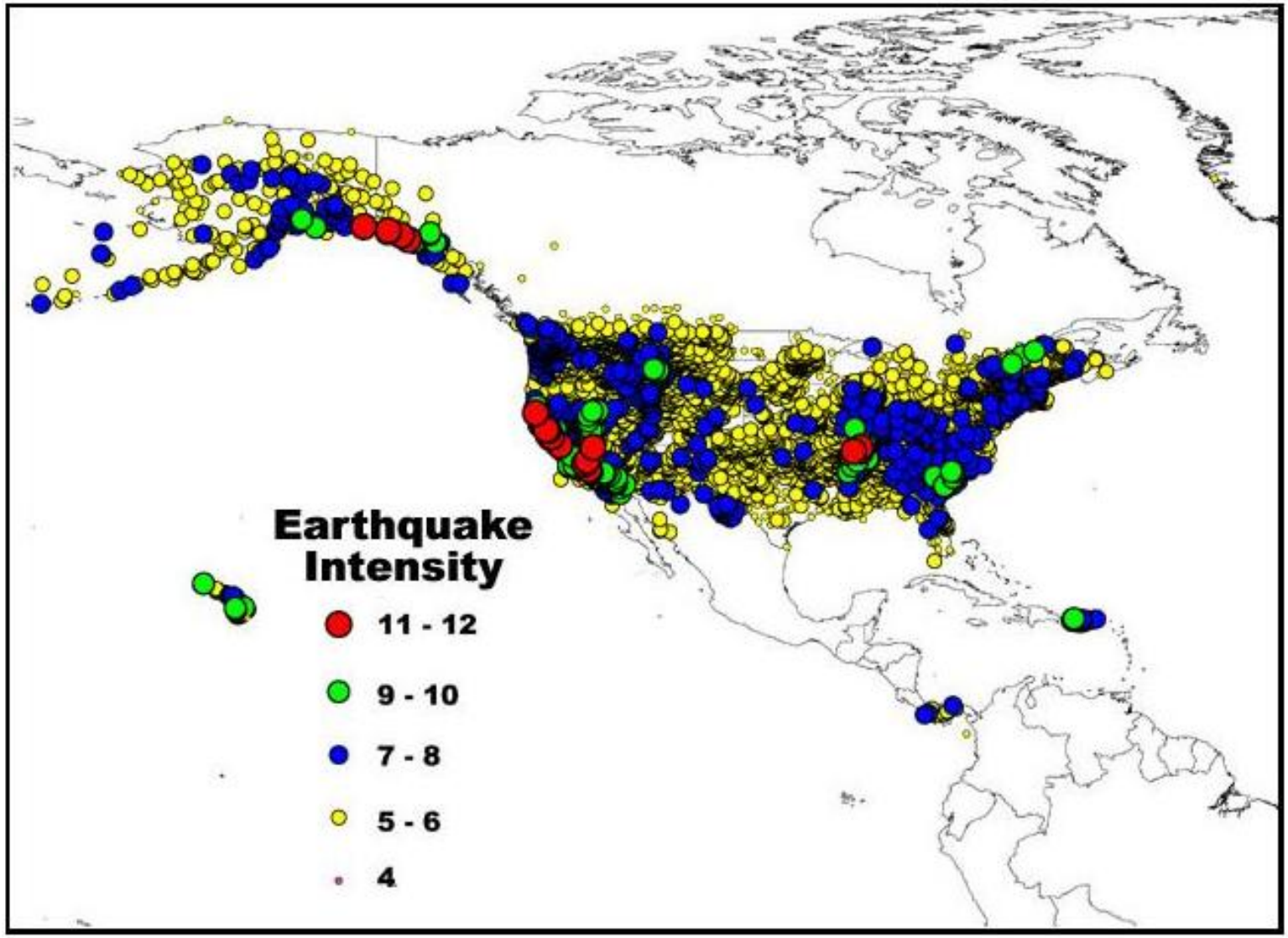
http://suite101.com/article/the-1946-aleutian-island-tsunami-a94636

USGS

Dec. 24, 2004

AP

Regions of Earthquake hazard



USGS

US Earthquake areas

- California

http://images.asme.org/MEMagazine/Articles/Web/15037.jpg

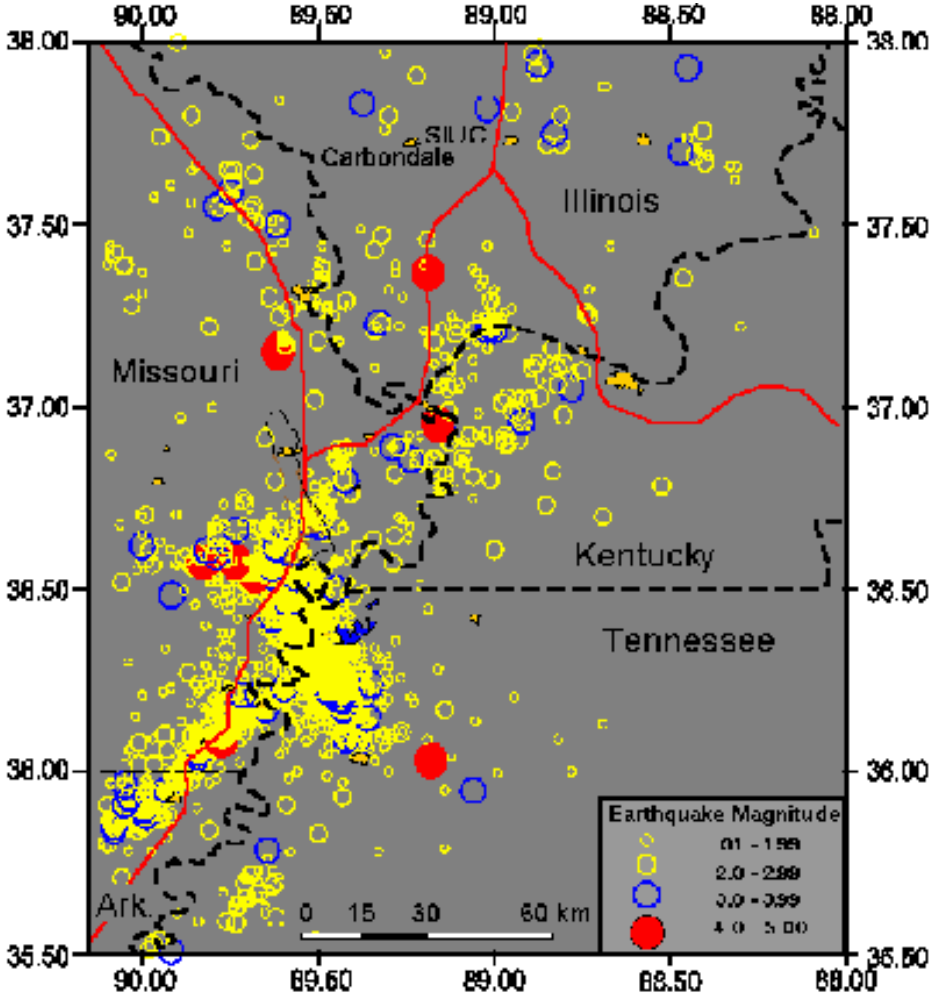
US Earthquake Areas

- California
- Alaska

http://wapi.isu.edu/envgeo/EG5_earthqks/images/ALASKATSU16.gif

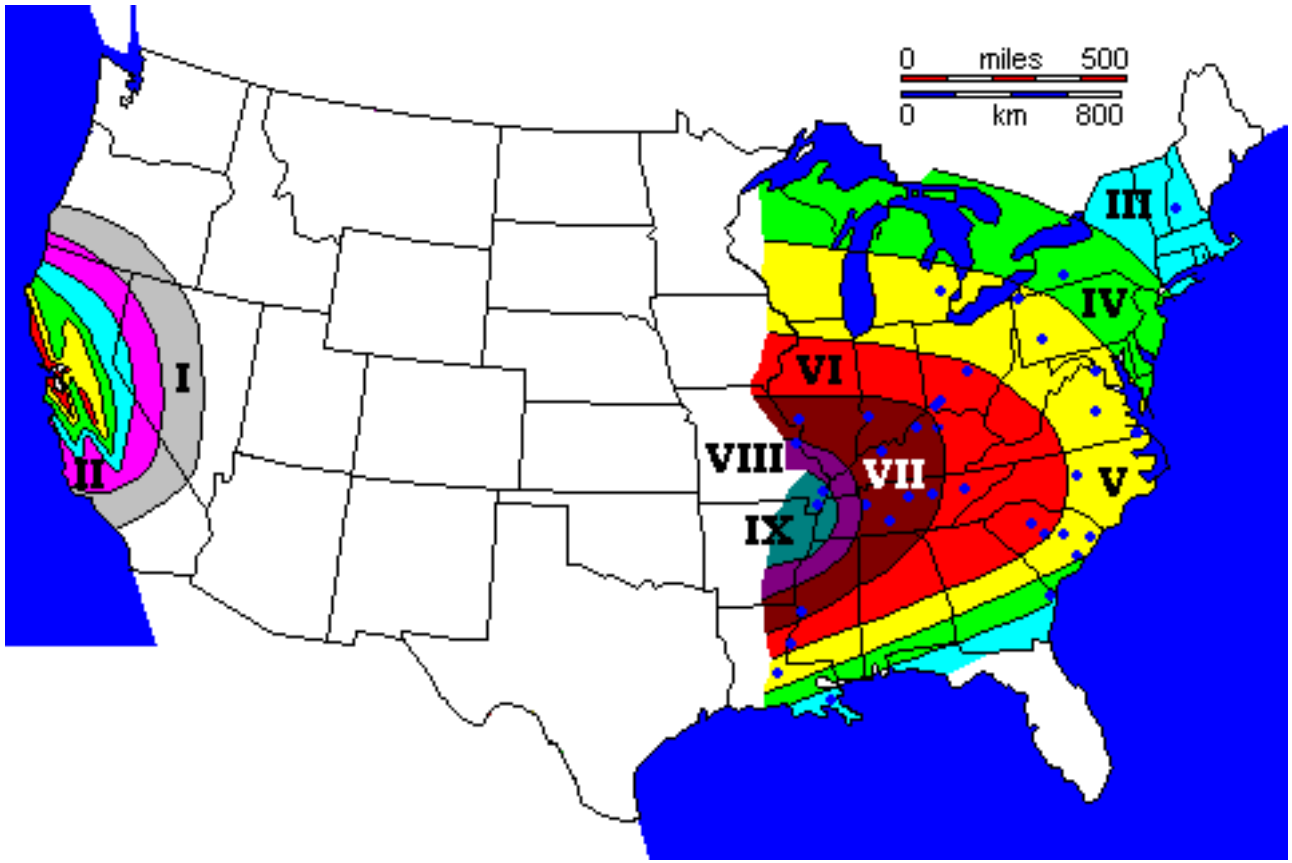
US Earthquake Areas

- California
- Alaska
- Missouri



USGS

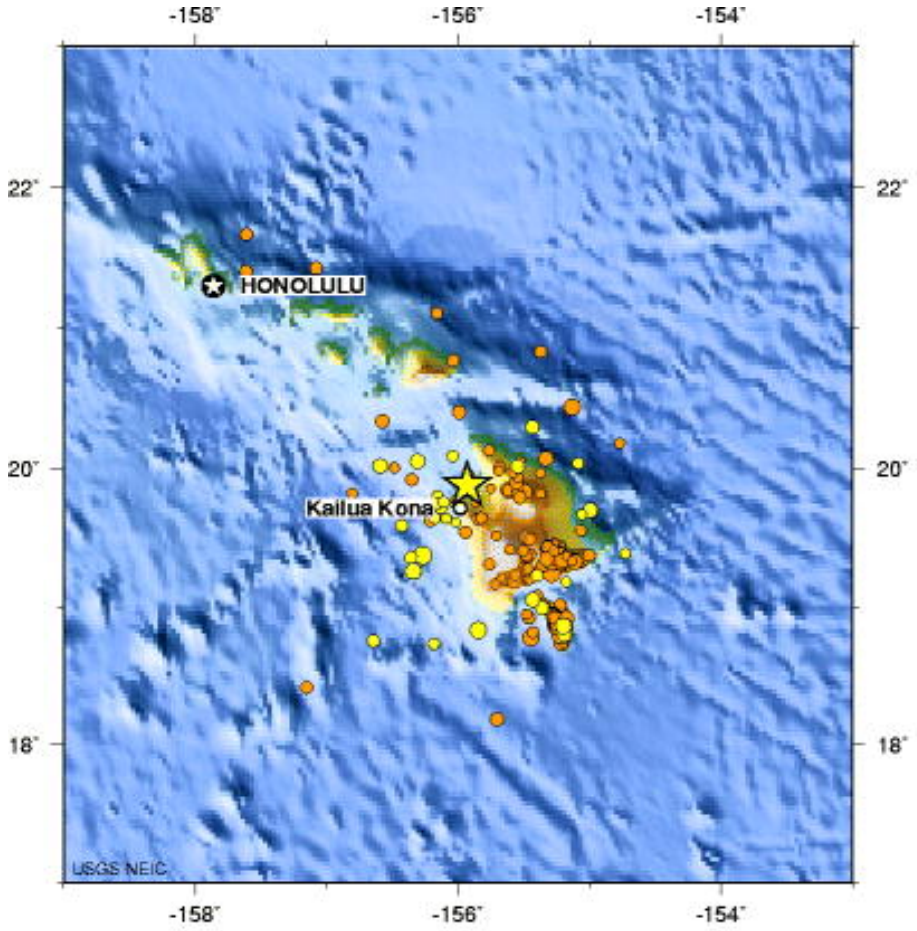
New Madrid v. 1906



USGS

US Earthquake Areas

- California
- Alaska
- Missouri
- Hawaii



ISLAND OF HAWAII, HAWAII

2006 10 15 17:07:49 UTC 19.88N 155.93W Depth: 38.9 km, Magnitude: 6.7

Seismicity 1990 to Present

Date	Epicenter Location	Maximum Intensity	Mag	No of Deaths	Damage
03 28 1868	S. Hawaii	IX	7.0	0	Extensive-S. Hawaii
04 02 1868	Southern Hawaii	XII	7.9	81	>100 houses destroyed, tsunami
10 05 1929	Hualalai	VIII	6.5	0	Extensive-Kona
08 21 1951	Kona	VIII	6.9	0	Extensive – Hilo
04 26 1973	N. of Hilo	VIII	6.2	0	Extensive – Hilo, $5.6M
11 29 1975	Kalapana	VIII	7.2	2	Extensive – Hilo, $4.1 M
11 16 1983	Kaoiki	IX	6.7	0	Extensive, Southern Hawaii, >$6M
06 25 1989	Kalapana	VII	6.2	0	Southeast Hawaii, almost $1M

Damage from 10/15 EQ

http://www.pdc.org/PDCNewsWebArticles/2006Hawaiiearthquake3/cnn_bigisland1.jpg

http://sepwww.stanford.edu/oldsep/joe/Photos/Hawaii/Kilauea/index.html

Earthquake on faults associated with volcanic activity

http://www.hawaii.pictures-pacific.com/oahu/east-pali-lookout.html

Earthquake Safety

- With your group, brainstorm what to do BEFORE, DURING or AFTER a quake to increase your chances of surviving comfortably

EQ safety and buildings

- Unsafe structures:
  - Unreinforced masonry (brick)

Pakistan, 2005

USGS

Loma Prieta, 1989

Watsonville

http://calieathquakes2.pbworks.com/

EQ safety and buildings

- Unsafe structures:
  - Unreinforced masonry (brick)
  - Pre-1954 houses not bolted to foundation

Santa Cruz, Loma Prieta, 1989

http://caliearthquakes2.pbworks.com/

Coalinga, 1980

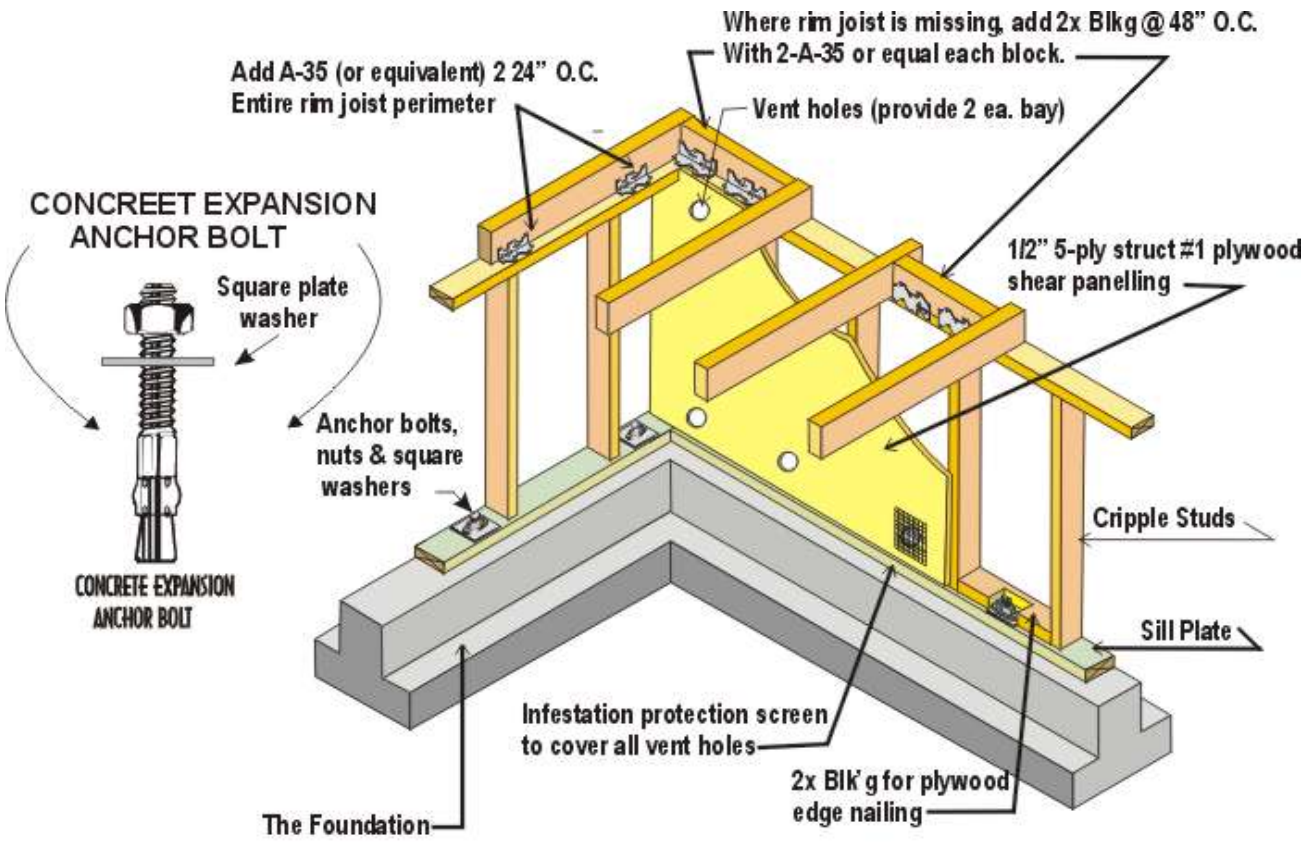
http://caliearthquakes2.pbworks.com/

EQ safety and buildings

- Unsafe structures:
  - Unreinforced masonry (brick)
  - Pre-1954 houses not bolted to foundation
  - Insufficient bracing of cripple wall

Cripple wall

Bracing the cripple wall



Failed cripple walls

http://caliearthquakes2.pbworks.com/

EQ safety and buildings

- Unsafe structures:
  - Unreinforced masonry (brick)
  - Pre-1954 houses not bolted to foundation
  - Insufficient bracing of cripple wall
  - Porch failures

Watsonville, Loma Prieta

USGS

EQ safety and buildings

- Unsafe structures:
  - Unreinforced masonry (brick)
  - Pre-1954 houses not bolted to foundation
  - Insufficient bracing of cripple wall
  - Porch failures
  - Concrete frame structures

Northridge, 1992

Pakistan, 2005

USGS

Northridge, 1992

http://caliearthquakes2.pbworks.com/

Loma Prieta, 1989

USGS

EQ safety and buildings

- Unsafe structures:
  - Unreinforced masonry (brick)
  - Pre-1954 houses not bolted to foundation
  - Insufficient bracing of cripple wall
  - Porch failures
  - Concrete frame structures
  - “Soft-story” structures - missing a wall on the first floor

Loma Prieta

USGS

Loma Prieta

USGS

Loma Prieta

USGS

Northridge, 1992

http://caliearthquakes2.pbworks.com/

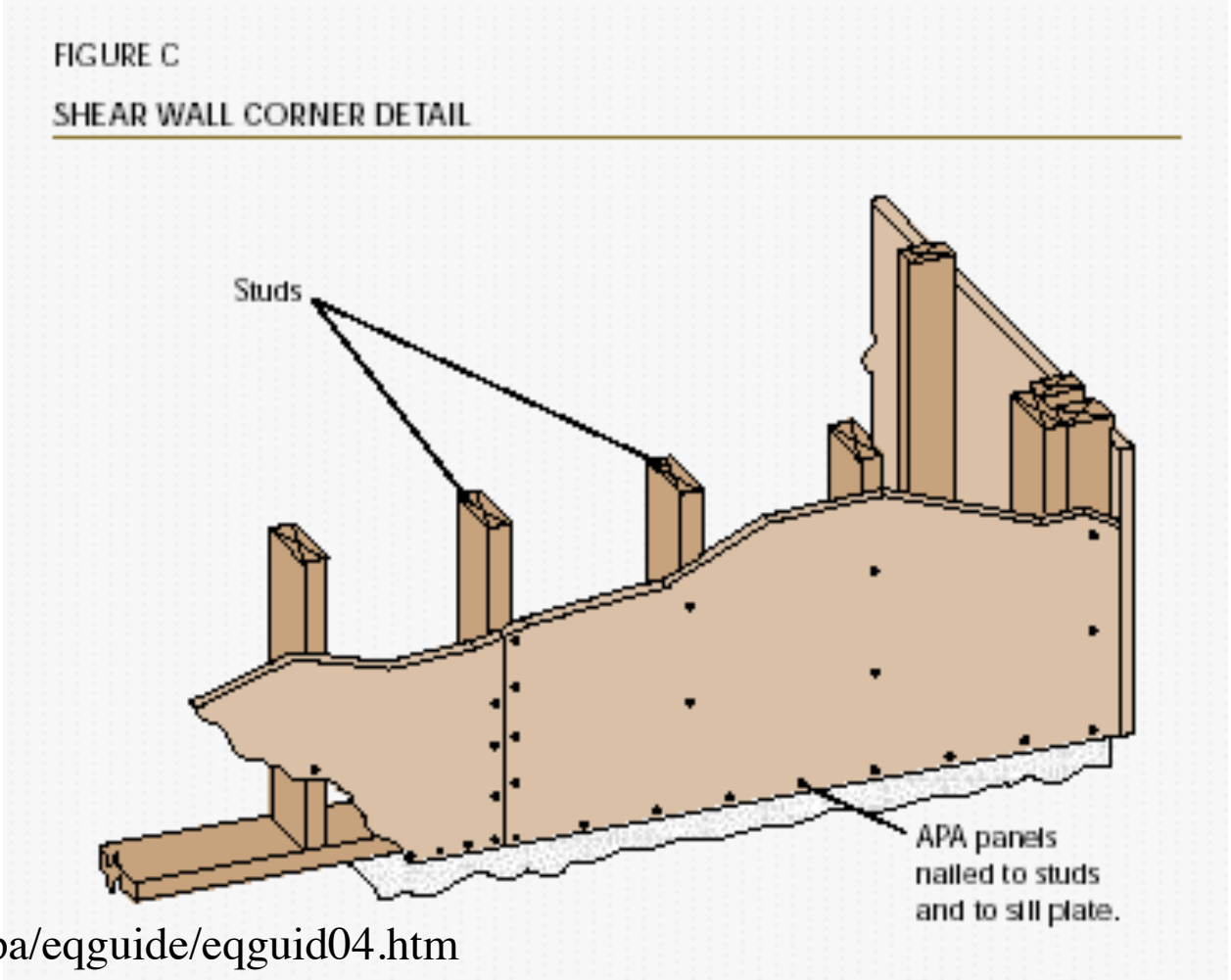
So what kinds of buildings are safe?

So what kinds of buildings are safe?

- Wood frame

So what kinds of buildings are safe?

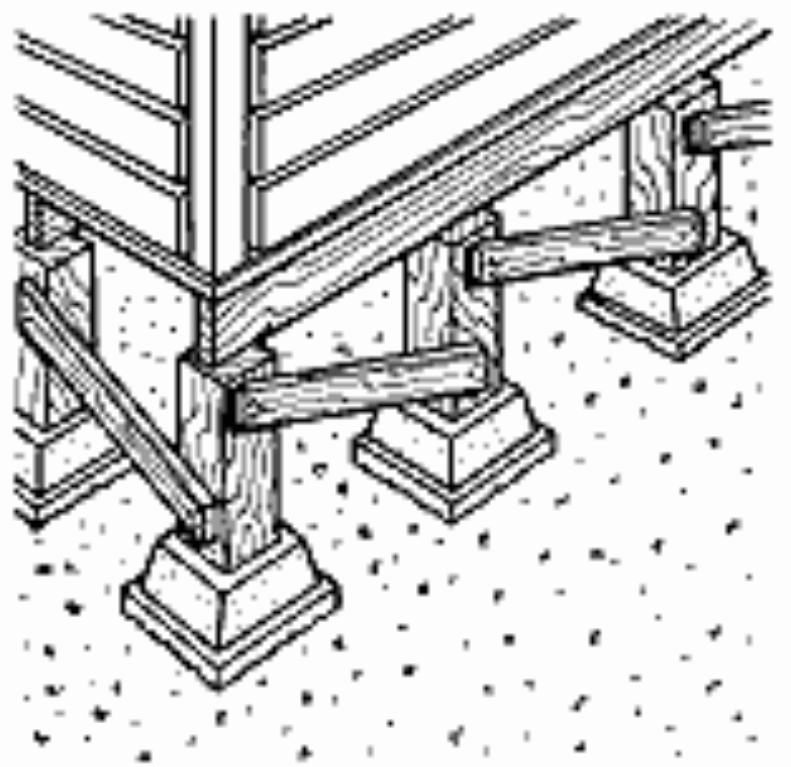
- Wood frame
- Steel frame
- Shear walls



http://www.mcvicker.com/twd/apa/eqguide/eqguid04.htm

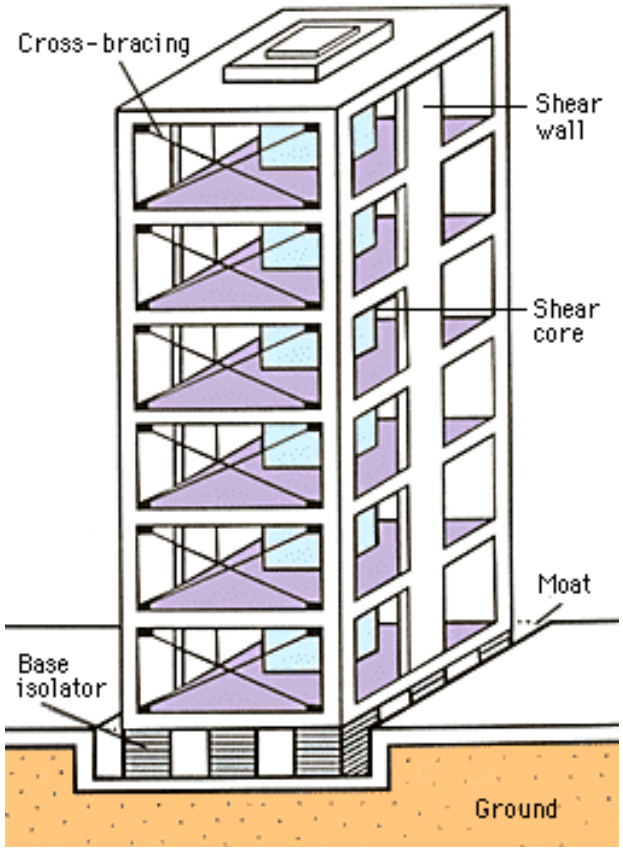
So what kinds of buildings are safe?

- Wood frame
- Steel frame
- Shear walls
- Cross-braced


Pier-and-Post Foundation

So what kinds of buildings are safe?

- Wood frame
- Steel frame
- Shear walls
- Cross-braced
- Base isolators



http://www.commonfloor.com/articles/wp-content/uploads/2009/08/110946main_earthquake1-215x300.gif

Braced steel buildings

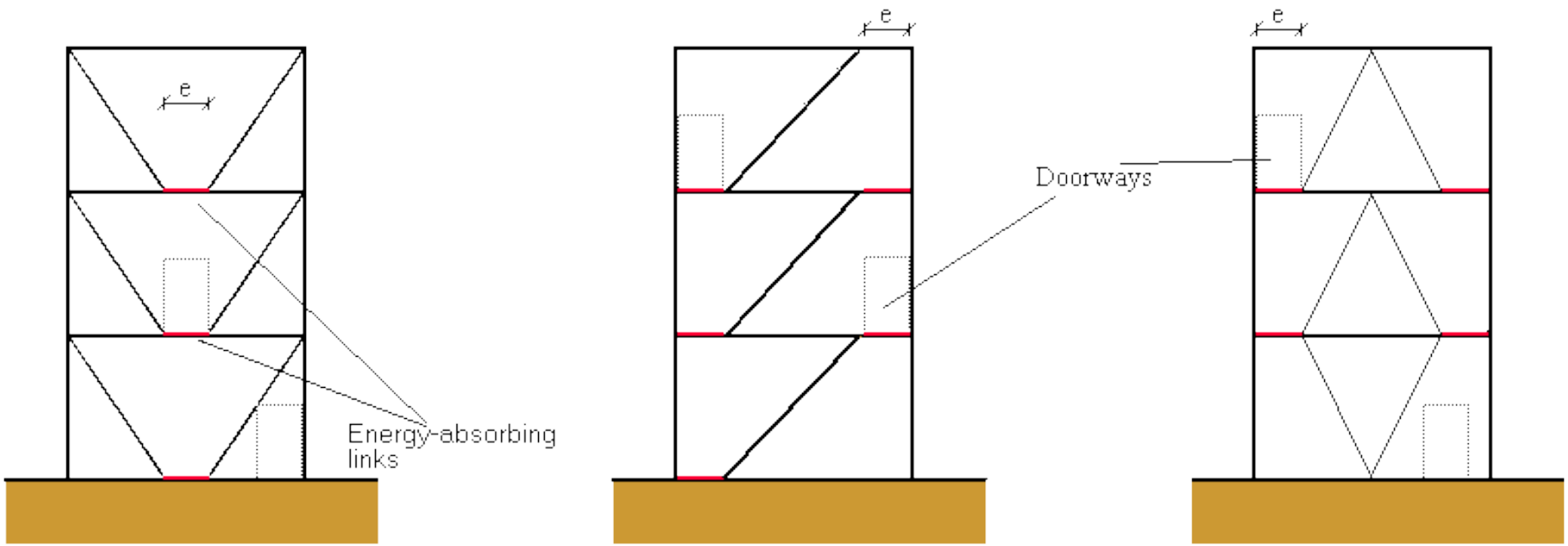


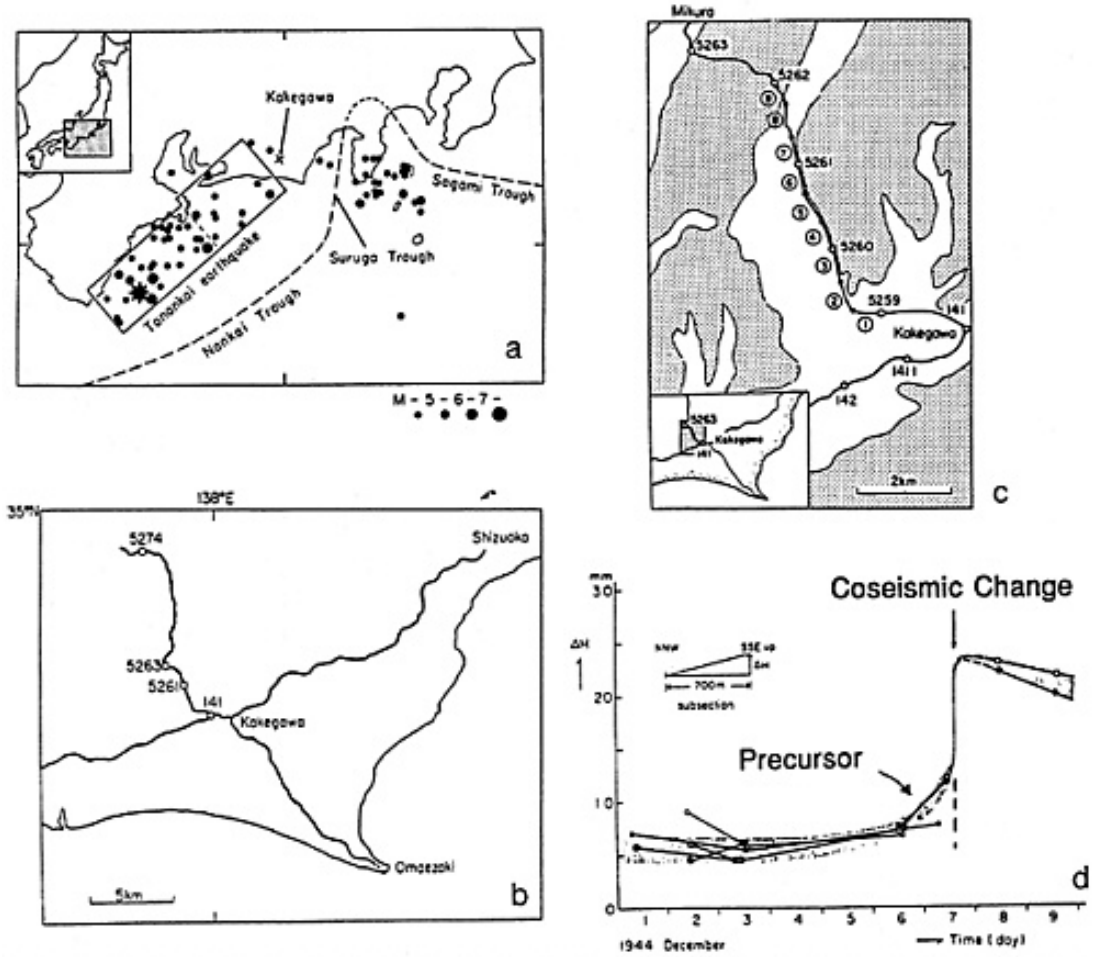
Fig. 2 Types of eccentric frames (e is the length of the link beam)

Prediction

- Precursors
- Seismic gaps

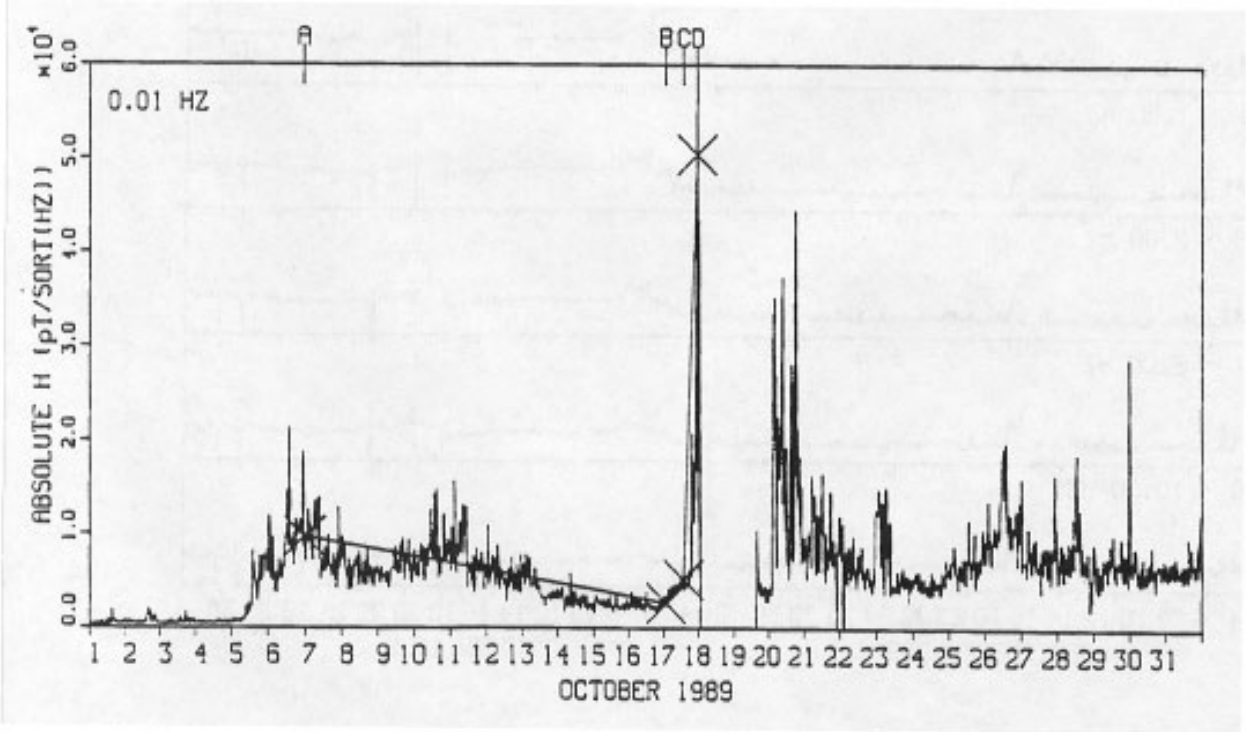
Precursors

- Ground tilt



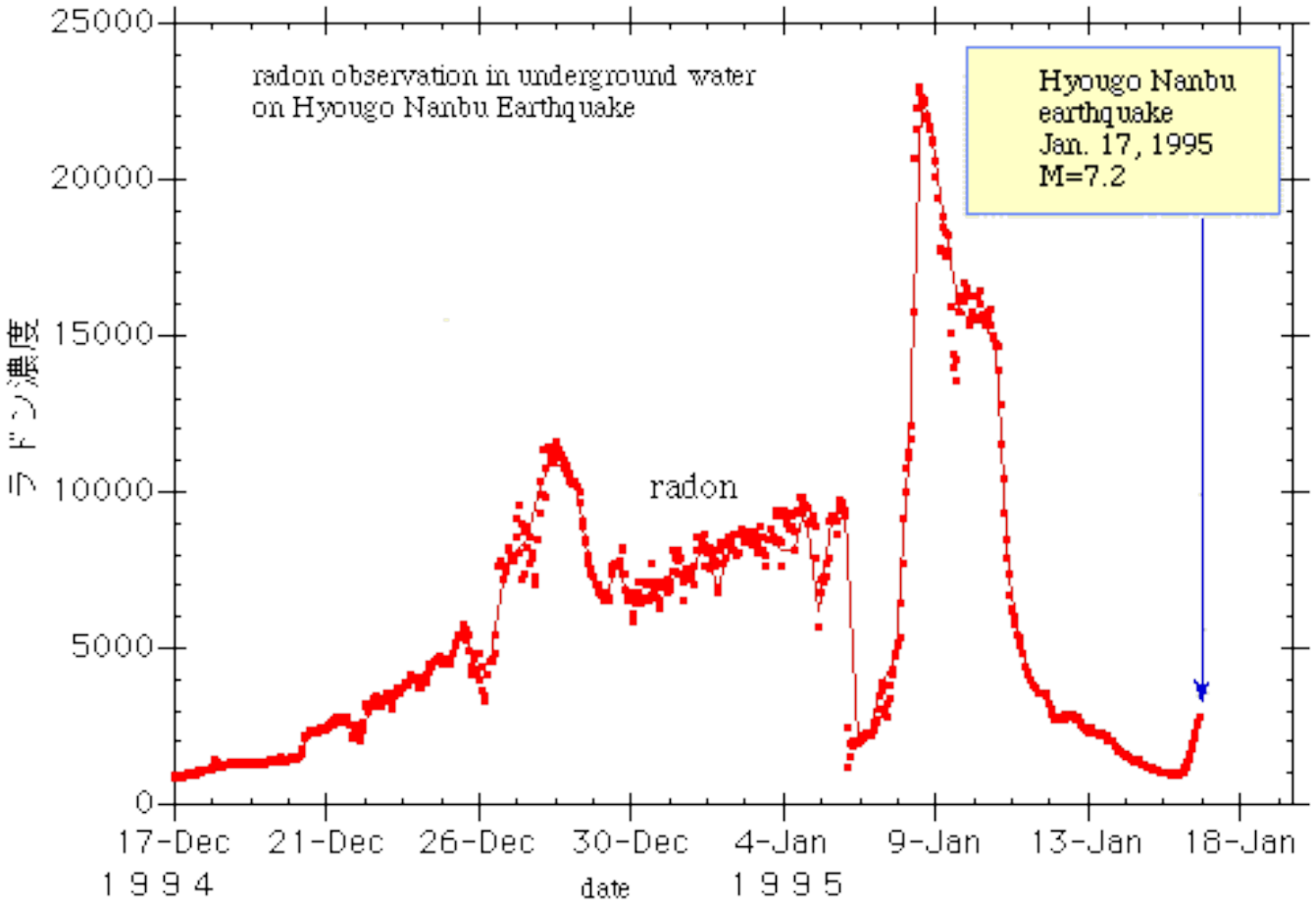
Precursors

- Ground tilt
- Seismic-wave velocities
- Electrical resistivity



Precursors

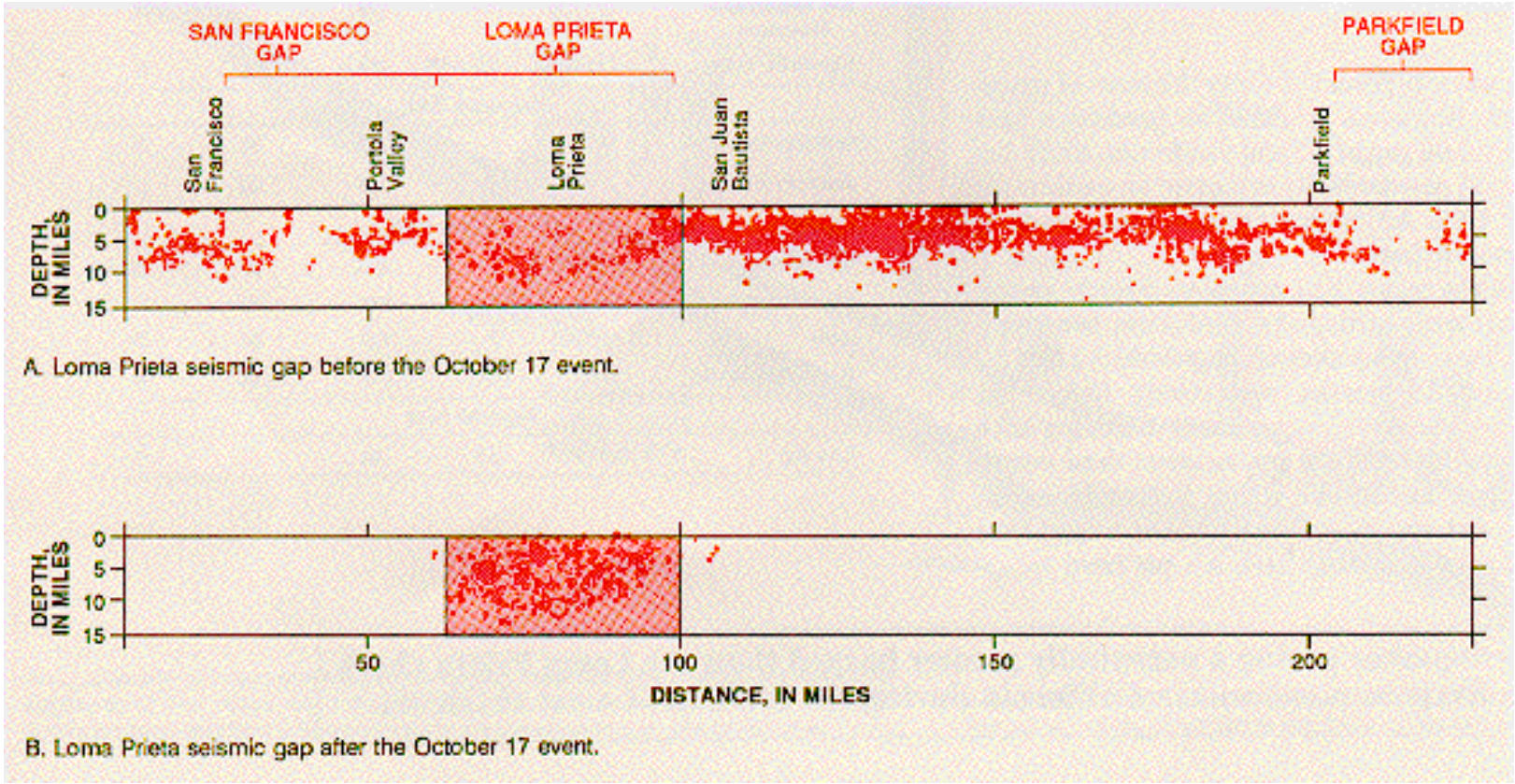
- Ground tilt
- Seismic-wave velocities
- Electrical resistivity
- Well water levels
- Radon



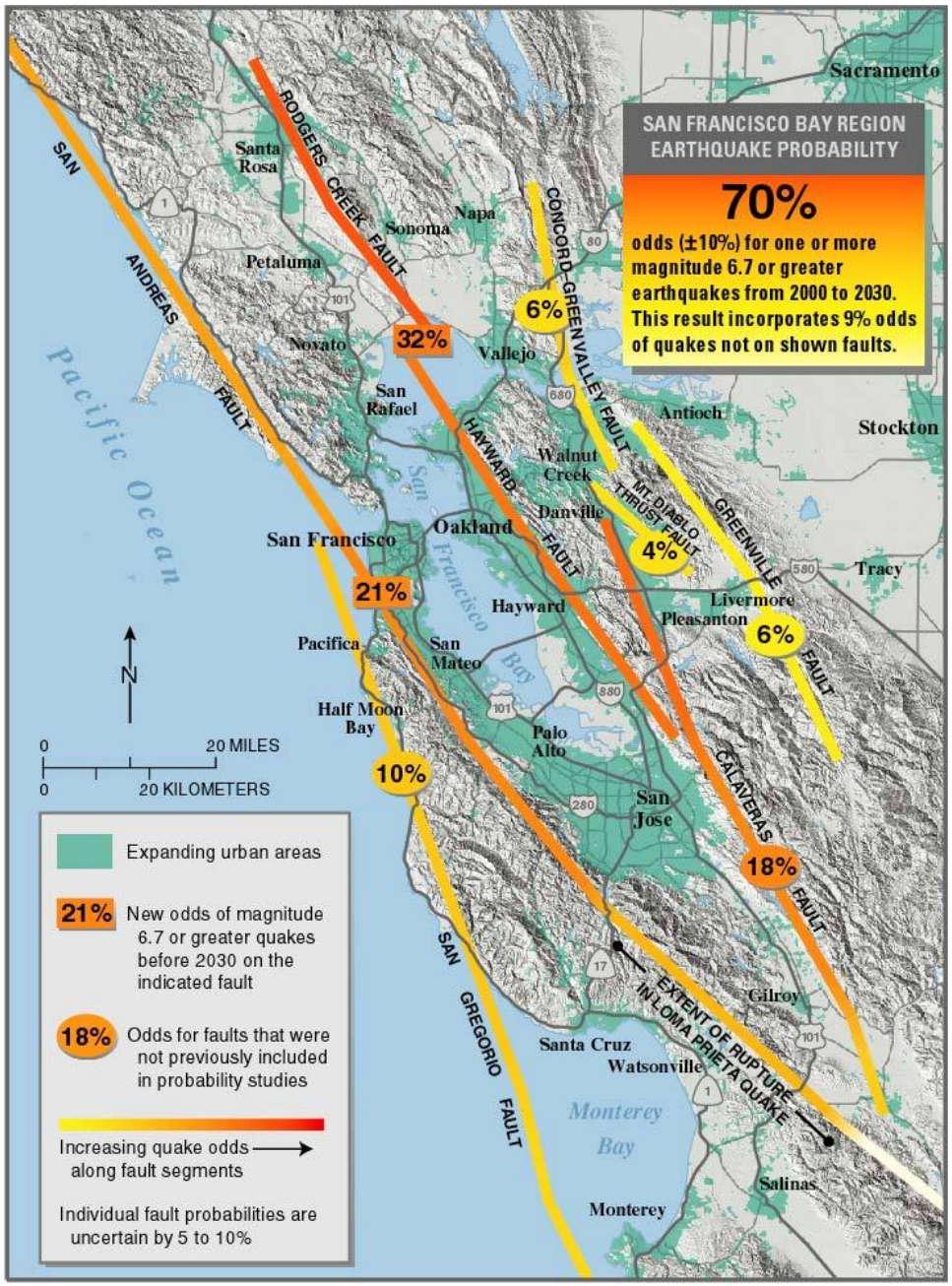
Seismic gaps

- Areas along fault with lower-than-expected frequency of earthquakes. May indicate the fault is locked up and preparing to fail.

Loma Prieta gap



USGS


SAN FRANCISCO BAY REGION
EARTHQUAKE PROBABILITY
70%
odds (±10%) for one or more magnitude 6.7 or greater earthquakes from 2000 to 2030. This result incorporates 9% odds of quakes not on shown faults.
Sacramento
Santa Rosa
Petaluma
Sonoma
Napa
Novato
Vallejo
San Rafael
Antioch
Stockton
Walnut Creek
Danville
Oakland
San Francisco
Hayward
Livermore
Pleasanton
Tracy
Pacifica
San Mateo
Half Moon Bay
Palo Alto
San Jose
Gilroy
Santa Cruz
Watsonville
Monterey
Salinas
Pacific Ocean
San Francisco Bay
Monterey Bay
SAN ANDREAS FAULT
RODGERS CREEK FAULT
CONCORD-GREEN VALLEY FAULT
HAYWARD FAULT
MT. DIABLO THRUST FAULT
GREENVILLE FAULT
CALAVERAS FAULT
SAN GREGORIO FAULT
EXTENT OF RUPTURE IN LOMA PRIETA QUAKE
6%
32%
4%
21%
6%
18%
10%
N
0 20 MILES
0 20 KILOMETERS
Expanding urban areas
21% New odds of magnitude 6.7 or greater quakes before 2030 on the indicated fault
18% Odds for faults that were not previously included in probability studies
Increasing quake odds along fault segments
Individual fault probabilities are uncertain by 5 to 10%

Parkfield experiment

- Parkfield (near Cholame Valley) had earthquakes about every 22 years for decades, all about M6.

Parkfield experiment

- Parkfield (near Cholame Valley) had earthquakes about every 22 years for decades, all about M6.
- Earthquake expected 1988

Parkfield experiment

- Parkfield (near Cholame Valley) had earthquakes about every 20 years for decades, all about M6.
- Earthquake expected 1988
- An earthquake finally happened 9/28/2004

Parkfield experiment

- Parkfield (near Cholame Valley) had earthquakes about every 20 years for decades, all about M6.
- Earthquake expected 1988
- An earthquake finally happened 9/28/2004
- Using data from quake to examine precursors

Public policy and earthquakes

- Zoning for hazard

Public policy and earthquakes

- Zoning for hazard
  - Alquist-Priolo Act, 1972
  - Set out “earthquake fault zones: 100 cities, 36 counties
  - Prohibited building on active rupture
  - Required identification and retrofit of at-risk buildings