Earthquake Hazards in the San Francisco Bay Region:

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Earthquake Science Center

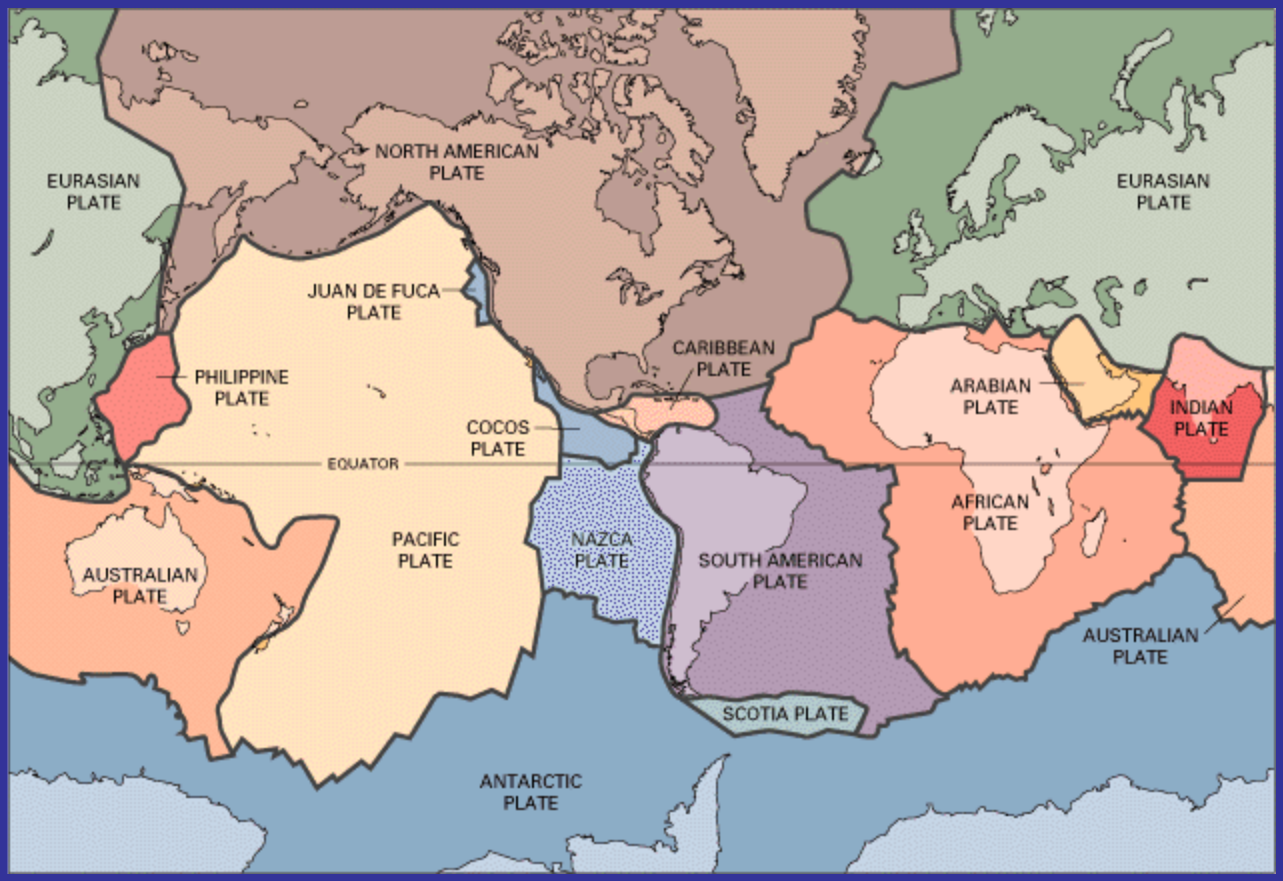
U. S. Geological Survey

Menlo Park, CA

10.5

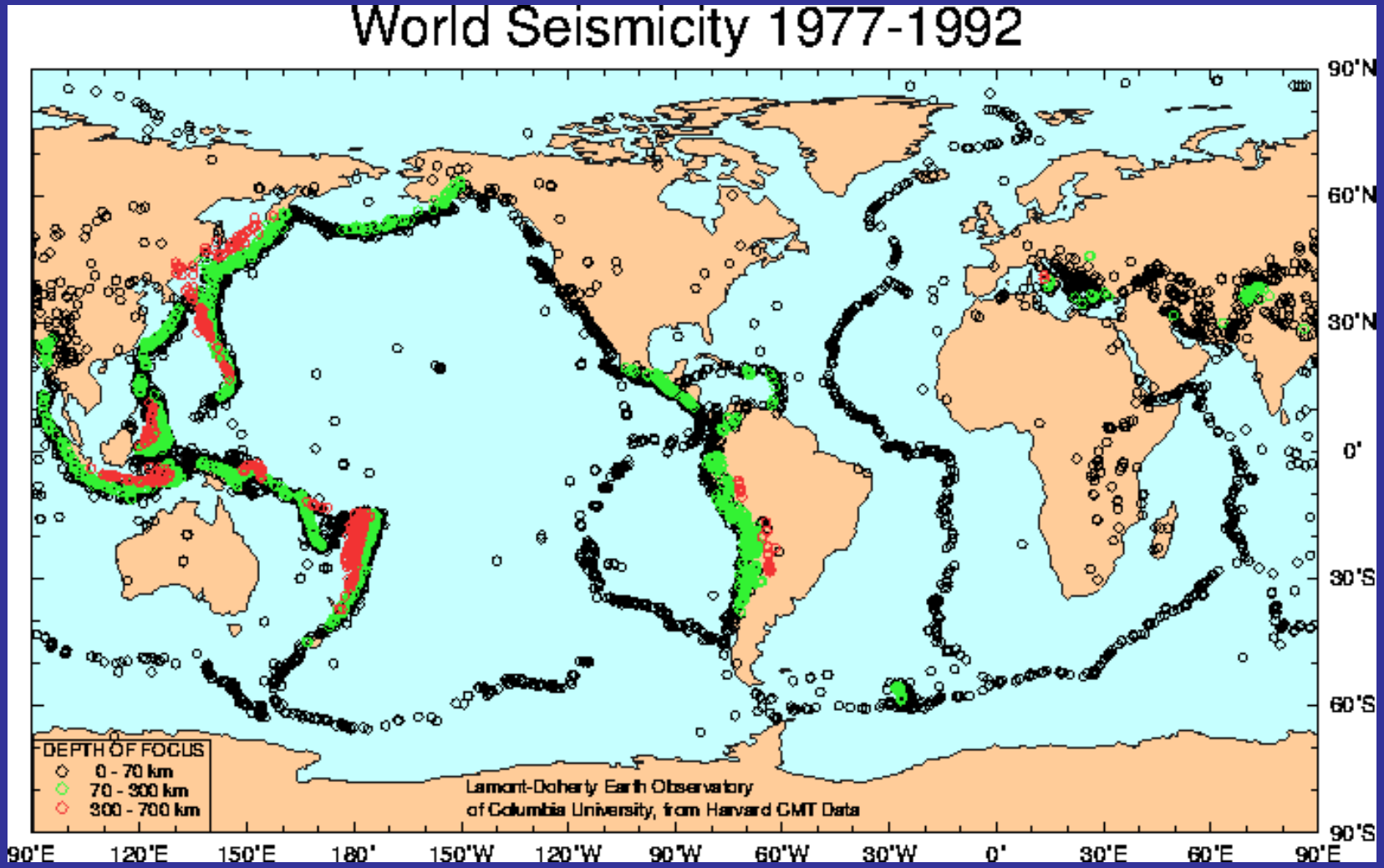
THE DAY THE EARTH WOULD NOT STAND STILL

Our dynamic planet

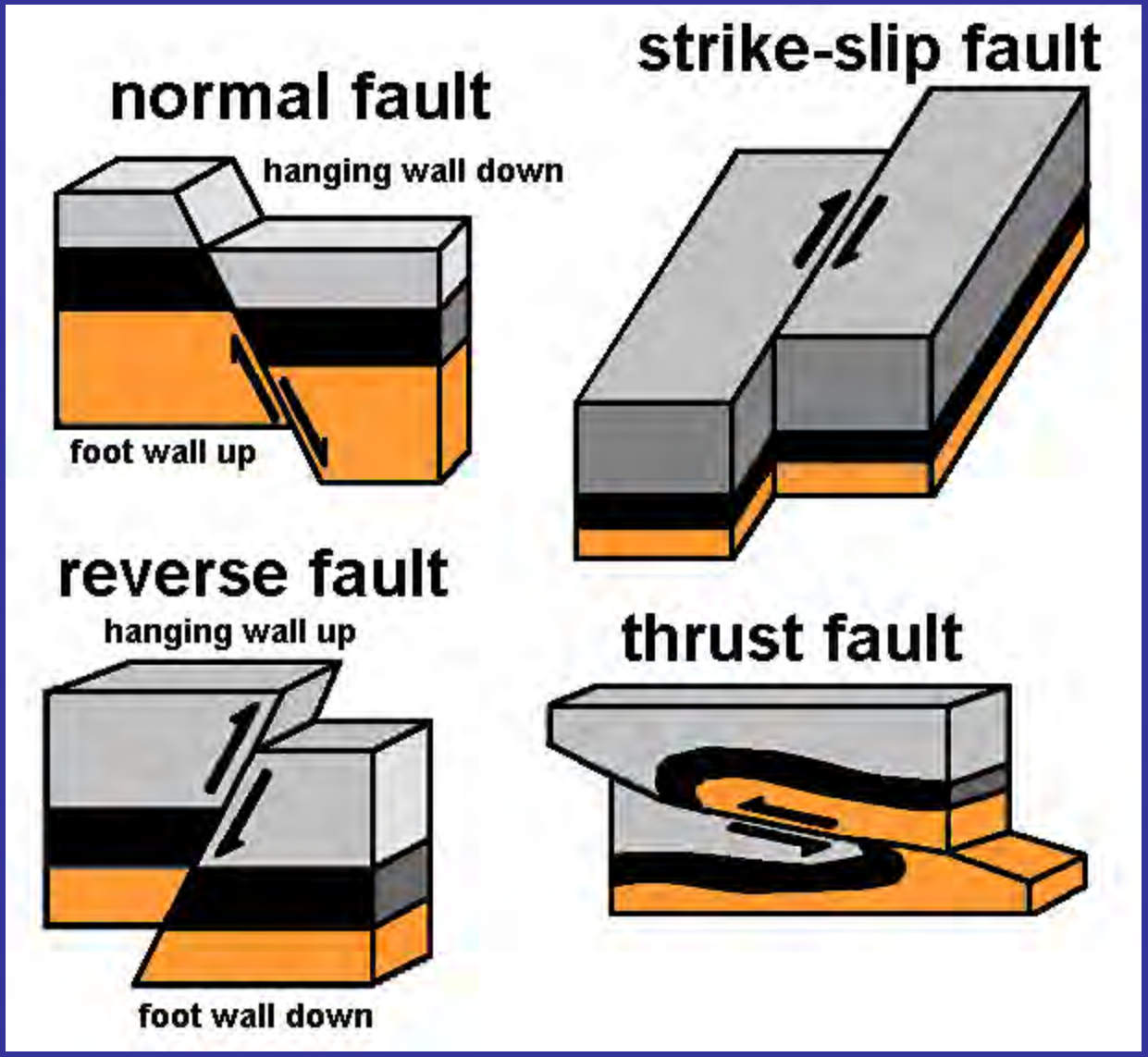


Has a rigid, outer shell ~ 100 km (60 mi) thick called the lithosphere (from Greek meaning stone sphere). The lithosphere composed of the crust and upper mantle is broken up into segments, or tectonic plates, that move relative to one another causing earthquakes.

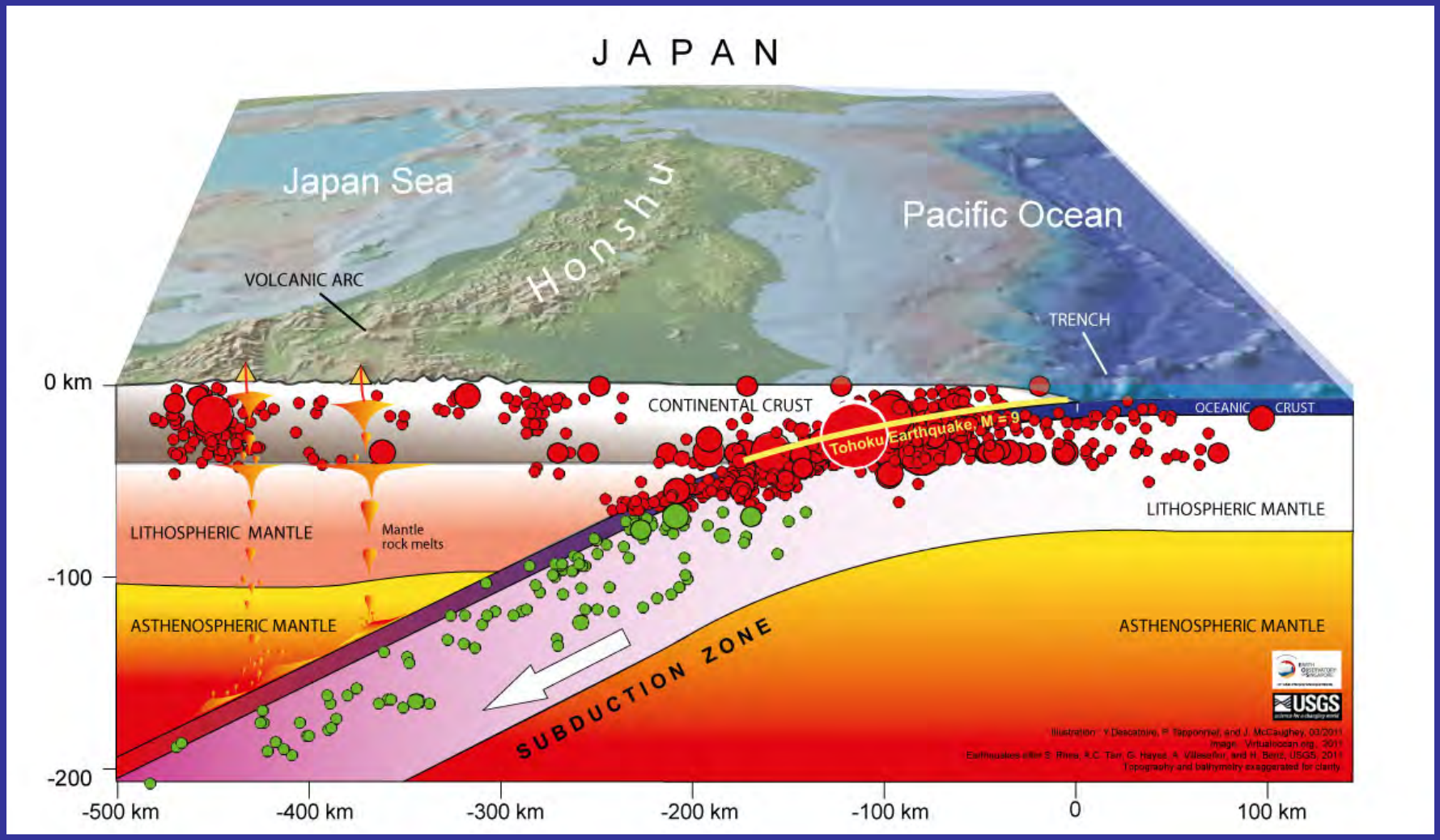
Map of earthquake locations and depths. Depths: black: 0 – 70 km; Green: 70 - 300 km; Red: 300 - 700 km. Magnitude > 5.5



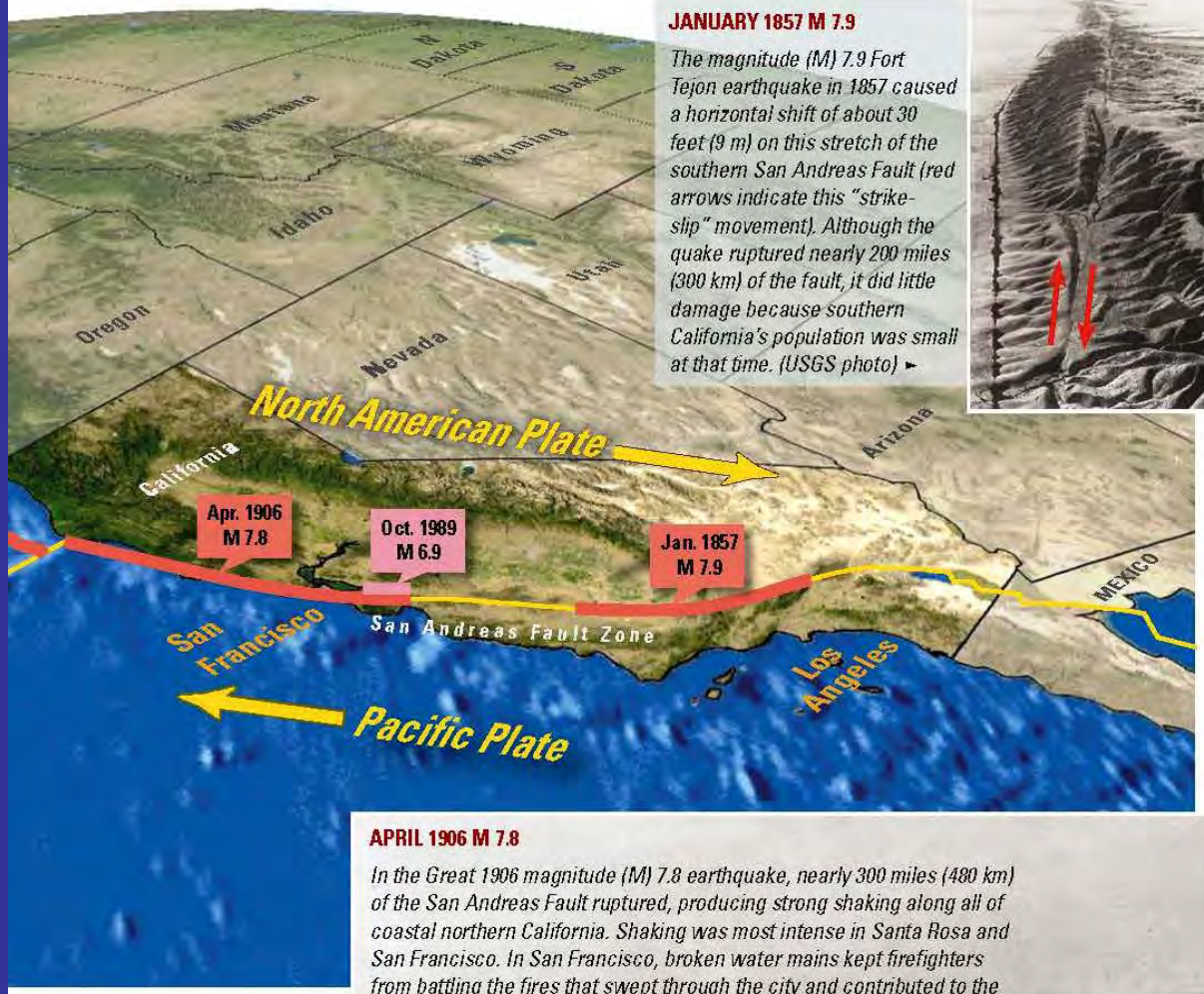
Fault – a planar fracture or discontinuity in a volume or rock across which there has been displacement as a result of earth movement



Earthquakes (red & green circles) > magnitude 5.0 in the period 1964-2007, and the 2011 M 9.0 Tohoku (Japan) earthquake and aftershocks.



Shocks in green >70 km below the surface. Seismic slip shown in yellow (500 km along strike and 200 km along width). In comparison, the1906 M 7.8 San Francisco quake ruptured 500 km along strike but only 20 km along width (100,000 sq km vs 10,000 sq km)



JANUARY 1857 M 7.9

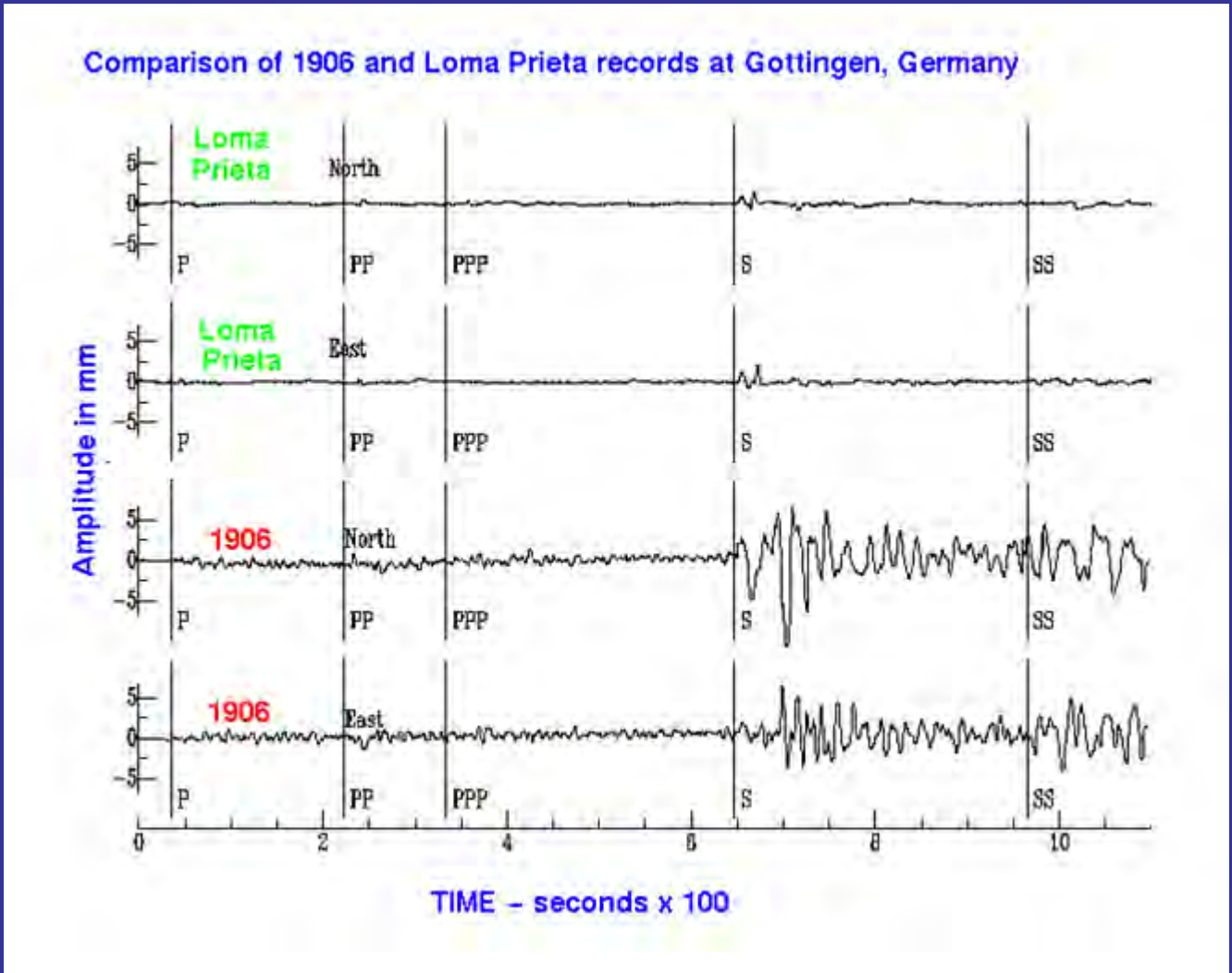
The magnitude (M) 7.9 Fort Tejon earthquake in 1857 caused a horizontal shift of about 30 feet (9 m) on this stretch of the southern San Andreas Fault (red arrows indicate this "strike-slip" movement). Although the quake ruptured nearly 200 miles (300 km) of the fault, it did little damage because southern California's population was small at that time. (USGS photo) ►

APRIL 1906 M 7.8

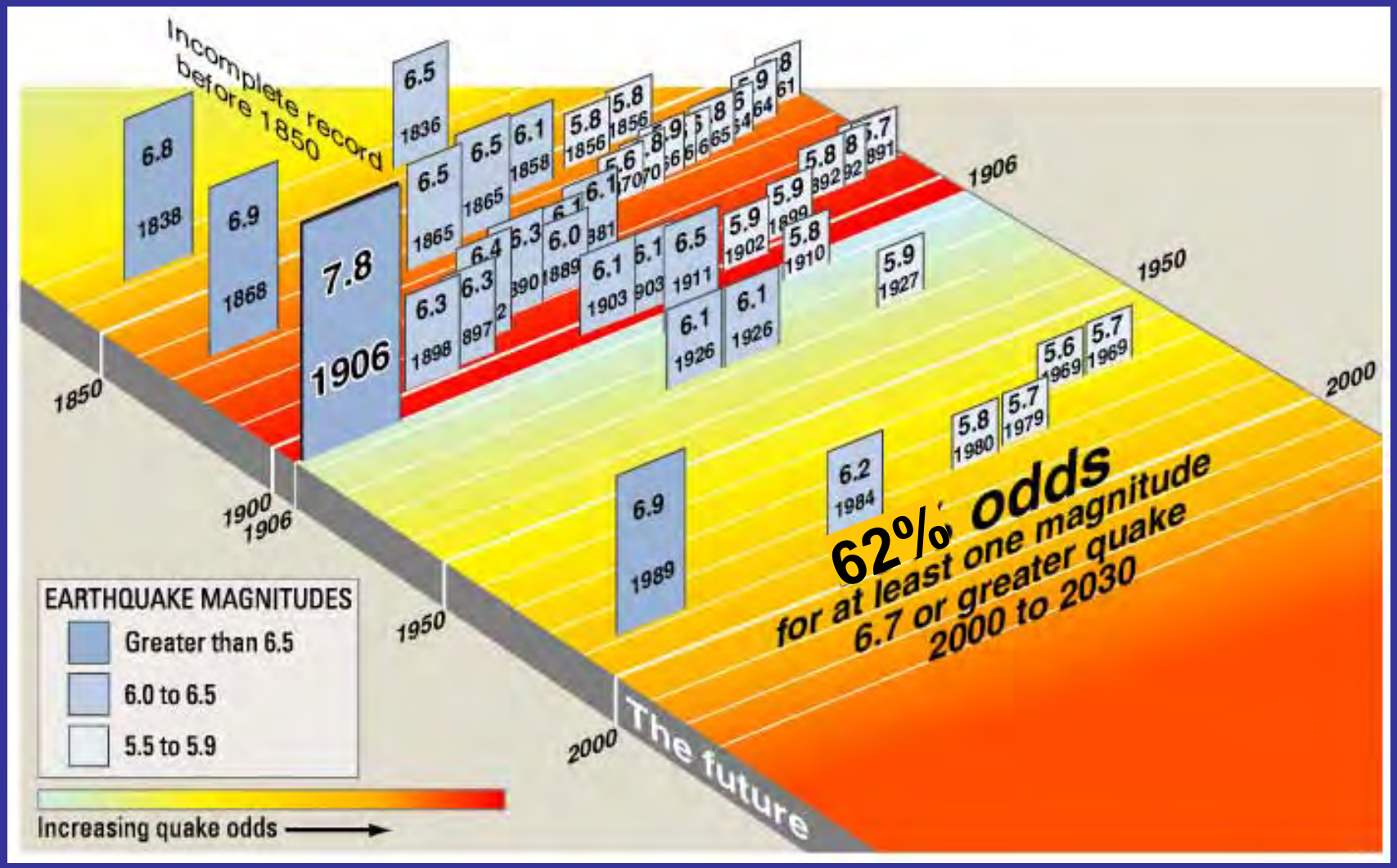
In the Great 1906 magnitude (M) 7.8 earthquake, nearly 300 miles (480 km) of the San Andreas Fault ruptured, producing strong shaking along all of coastal northern California. Shaking was most intense in Santa Rosa and San Francisco. In San Francisco, broken water mains kept firefighters from battling the fires that swept through the city and contributed to the devastation shown in this photograph (looking south) taken from a tethered balloon 5 weeks after the earthquake.

Historical Earthquakes And faults in the San Francisco Bay Area

Below are seismograms for the N- and E-oriented horizontal sensors for the 1989 magnitude 6.9 Loma Prieta and the 1906 magnitude 7.8 San Francisco earthquakes recorded in Gottingen, Germany.

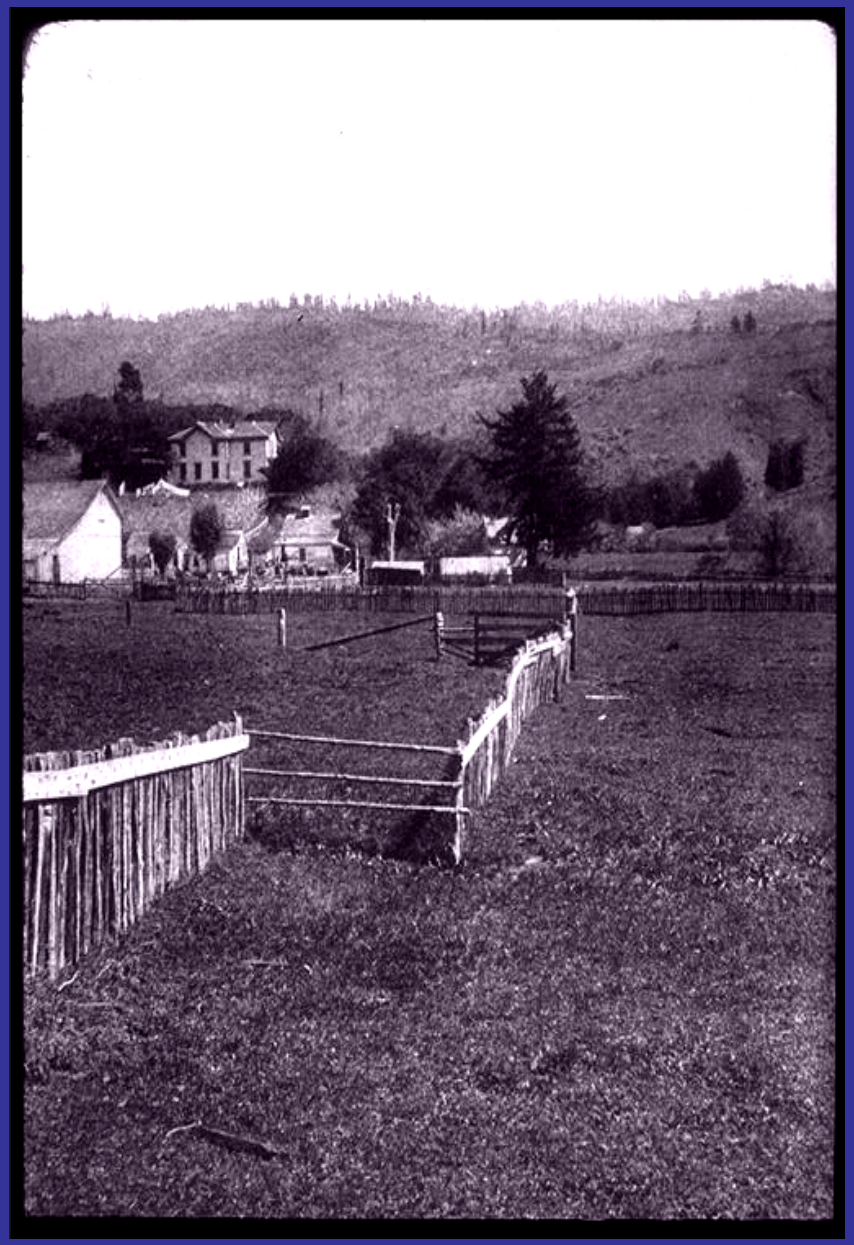


Histograph of magnitude 5.5 and larger earthquakes in the greater SF Bay Area from 1836 to 2000



Alameda County Courthouse in San Leandro before (insert) and after 1868 M 6.9 Hayward Earthquake

8.5-foot fence offset near Pt Reyes (left) and 1906 ground rupture NW of Olema in Marin County (right) from 1906 M 7.8 San Francisco earthquake.



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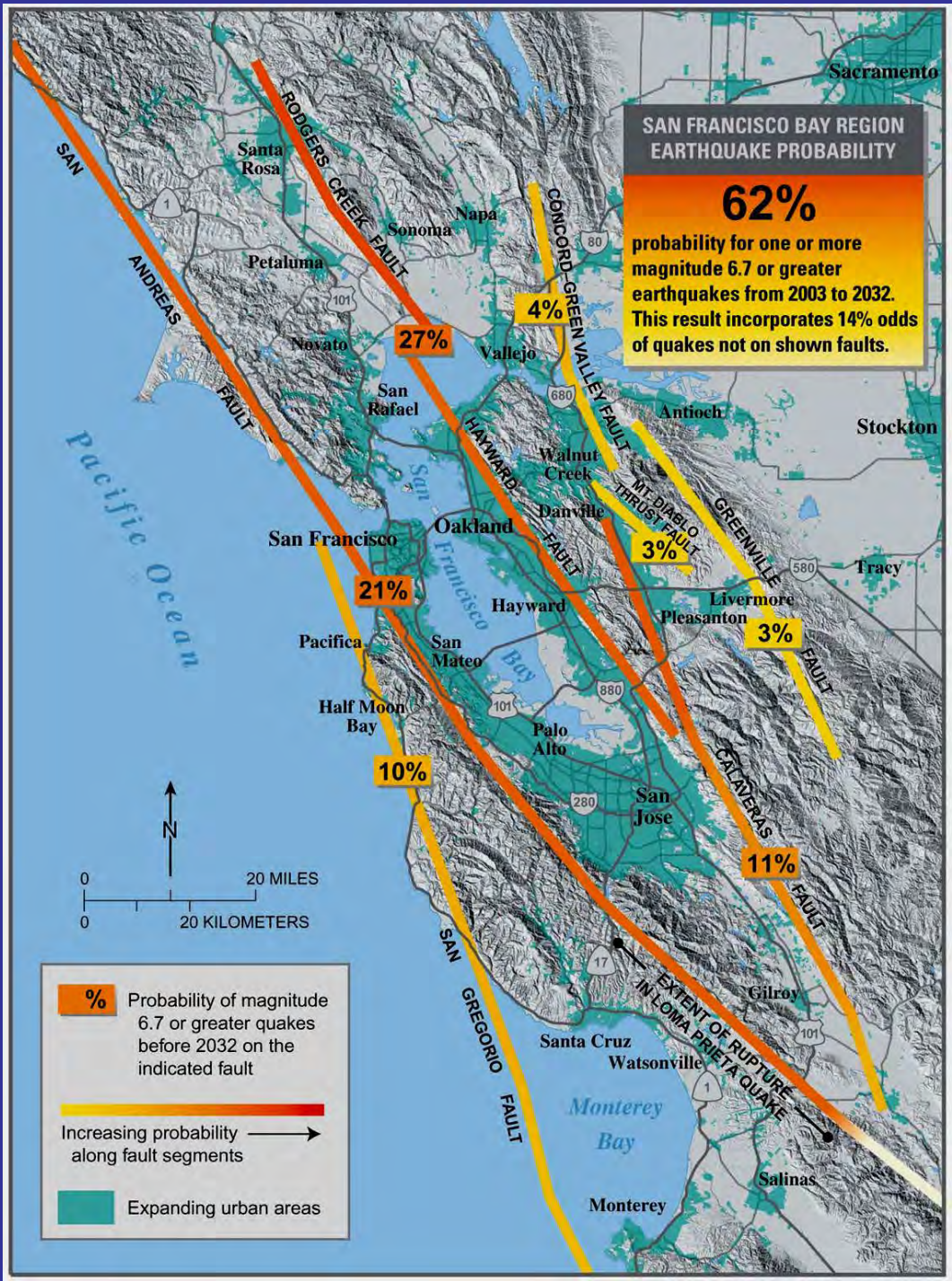
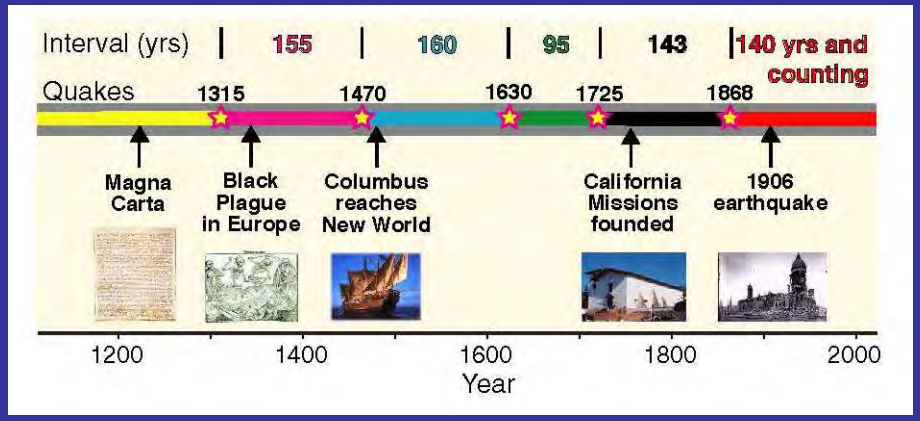
Loma Prieta, California, M 6.9 Earthquake October 17, 1989. Boulder Creek in the Santa Cruz Mountains. The lack of adequate shear walls and construction on fill contributed to the failure of this structure.

Major earthquake likely in San Francisco Bay Region by 2032



Is the Hayward Fault our Nation's Most Dangerous?

1) The Hayward Fault is the single most urbanized earthquake fault in the US – in 1868 there were only 24,000 people living near the fault in Alameda County, now there are more than 2.4 million. Many homes and other structures are built directly on the fault's trace, and major freeways, roads, gas and water pipelines, and electrical transmission lines cross the fault.
2) Trenching of the fault revealed 12 large quakes in the past 1,900 years. The last five events occurred at intervals of 95 to 160 years, with an average interval of 138 years.



Most Earthquake Damage Is Caused by Shaking...

Damage in earthquakes is mainly from shaking. The intensity of shaking that a structure will experience during an earthquake is a function of three main factors:

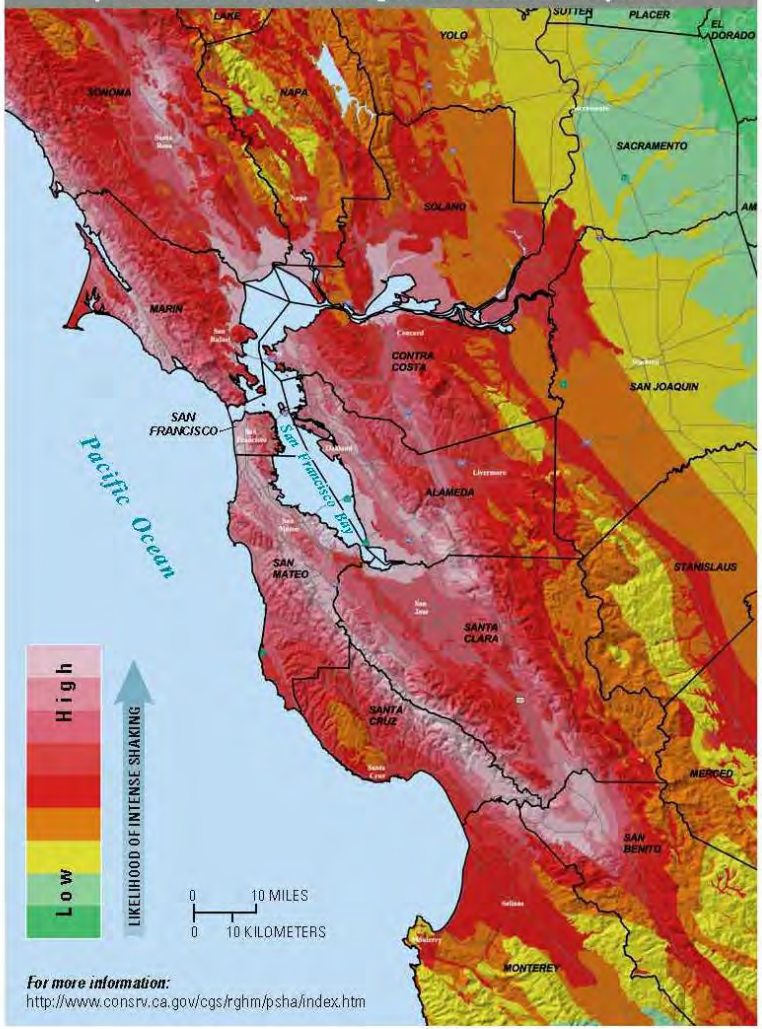
(1) The magnitude of the earthquake—the larger the quake, the stronger the shaking.

(2) The distance from the fault that ruptured—the nearer you are to the fault, the greater the shaking.

(3) The type of ground materials beneath the structure—soft soils amplify the shaking; hard bedrock does not.

Buildings in the Marina District of San Francisco were badly damaged in the 1989 Loma Prieta earthquake. "Soft story" buildings, typically with parking on ground floor, like the one pictured here, are common throughout the Bay Area and are particularly at risk when exposed to strong shaking. (USGS photo)

Expected Levels of Shaking from Future Earthquakes



For more information:
http://www.consrv.ca.gov/cgs/rghm/psha/index.htm

- *On this map, bands of highest expected shaking generally follow major faults.*
- *Shaking levels are also influenced by the type of materials underlying an area—soft soils tend to amplify and prolong shaking, even at great distances from a quake.*
- *The worst soft soils in the Bay Area are the loose clays and filled areas bordering San Francisco Bay and the Sacramento-San Joaquin Delta.*
- *Deep soils in valleys shake more than bedrock in the hills—most urban development is in the valleys.*
- *Intense shaking can damage even strong, modern buildings and their contents.*

Shaking amplification by soil type - *San Francisco Peninsula*

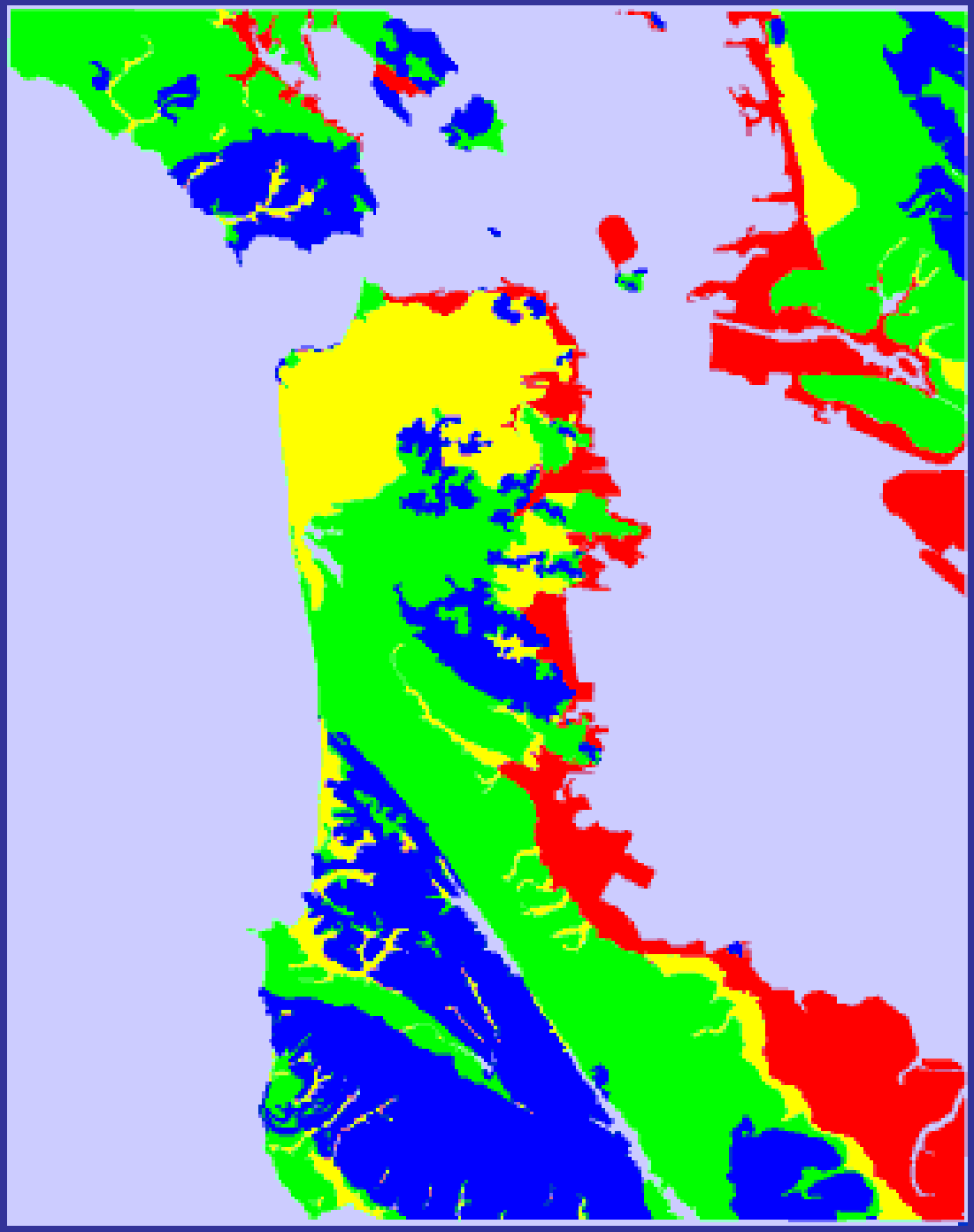
5 classes - based on stiffness of rock/soil

Blue color: Stiffest; Classes A & B, includes bedrock; little shaking amplification

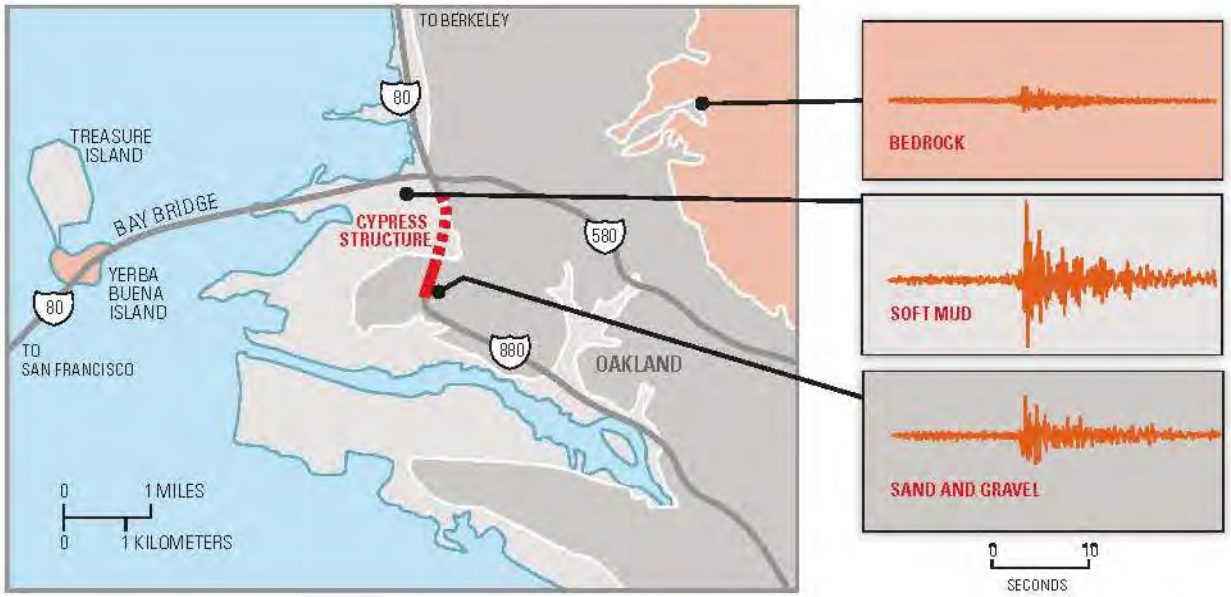
Green: Class C; sands, sandstones, mudstones, and limestone; moderate shaking amplification

Yellow: Class D; includes muds, sands, gravels, and silts; significant amplification of shaking

Red: Weakest; Class E, water-saturated mud and artificial fill); strongest amplification of shaking



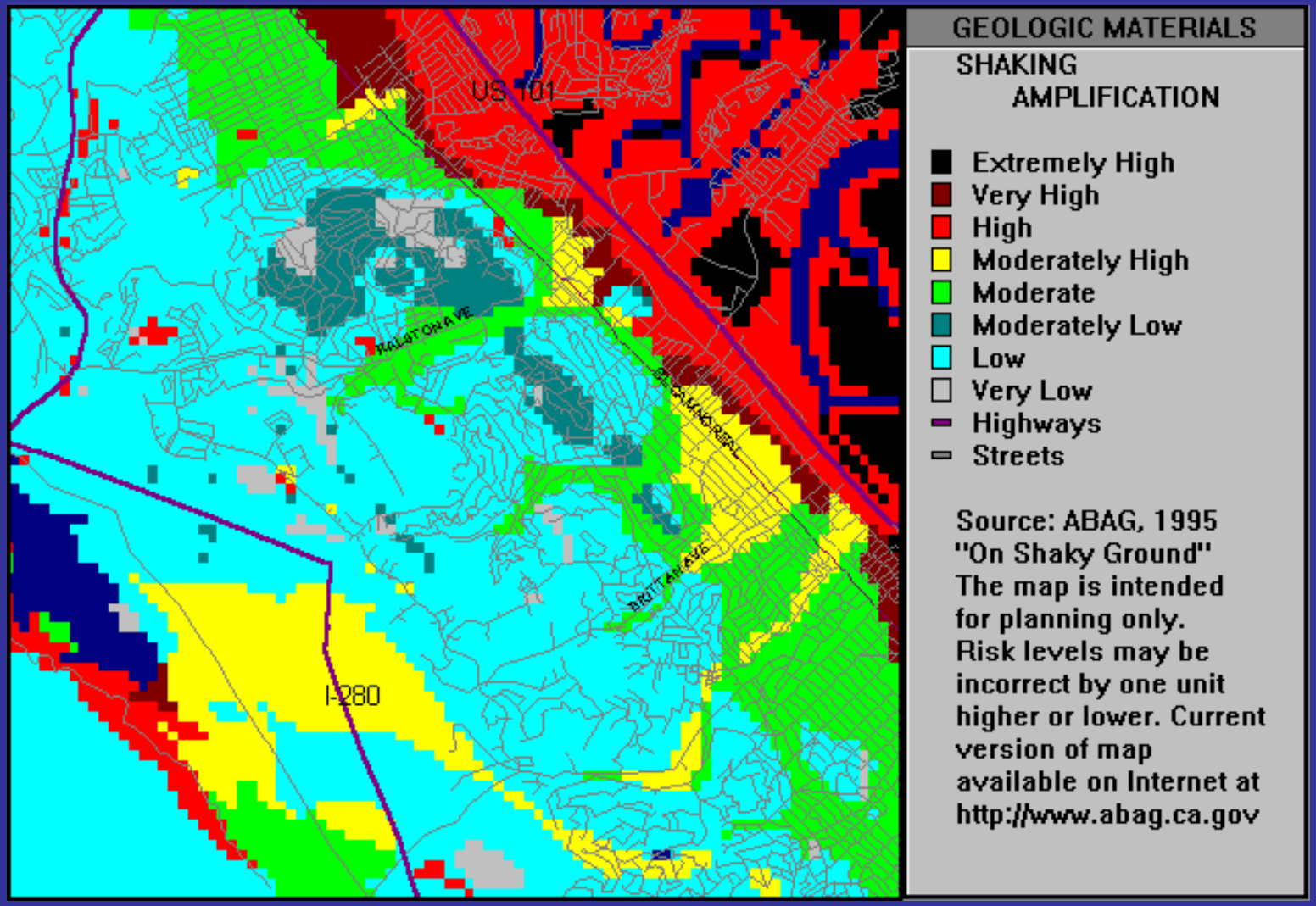
Shaking intensity at three locations in Oakland from the 1989 M 6.9 Loma Prieta earthquake



Soft Soils Amplify Earthquake Shaking

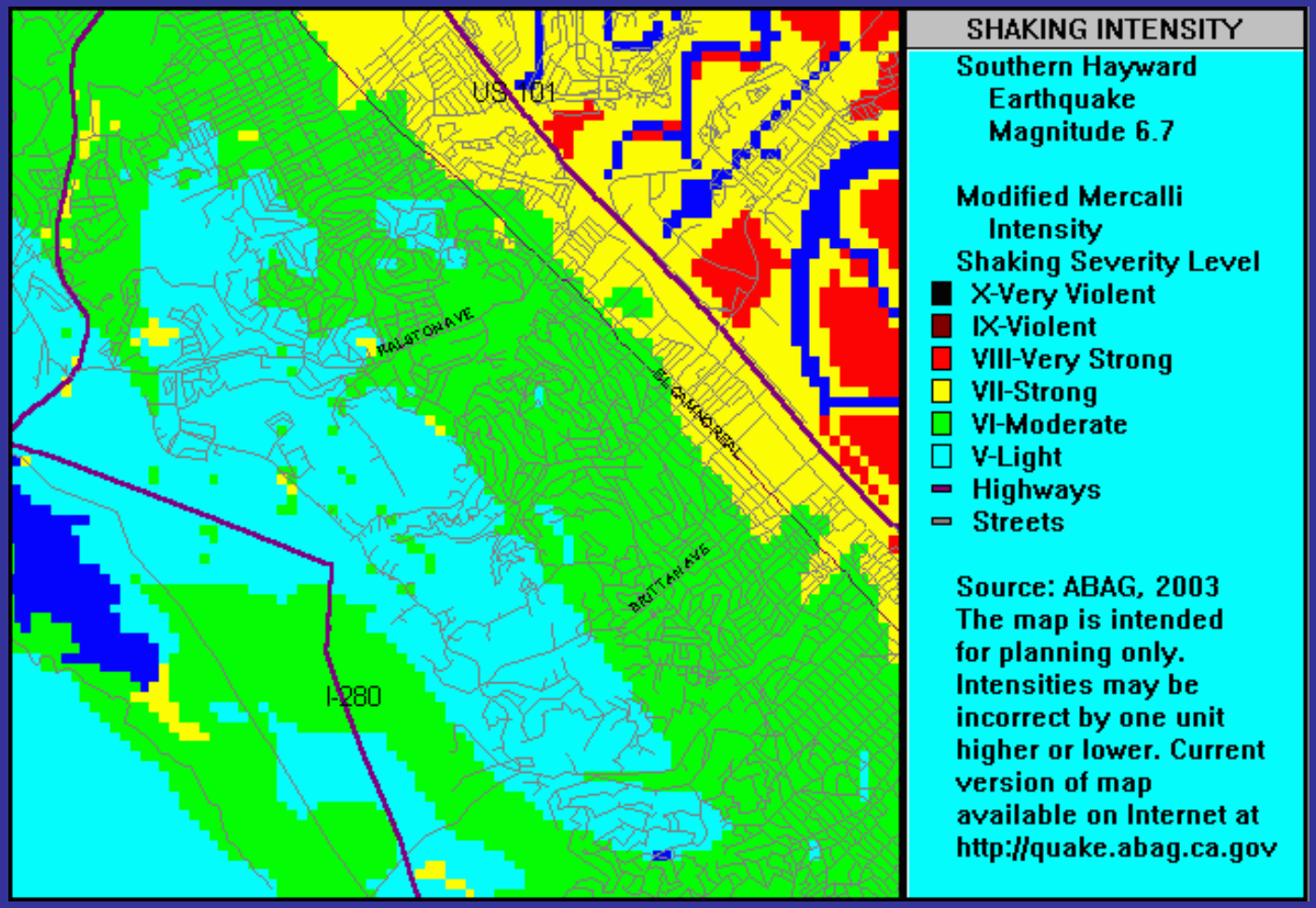
The Cypress freeway structure in Oakland was built in the 1950s, before the use of modern seismic-safety standards. Part of the structure standing on soft mud (dashed red line) collapsed in the 1989 magnitude 6.9 Loma Prieta earthquake, whose epicenter was nearly 60 miles (100 km) to the south. Adjacent parts of the structure (solid red) that were built on firmer ground remained standing. Seismograms (upper right) show that the shaking was especially severe in the soft mud. (Photo by Lloyd S. Cluff, Pacific Gas & Electric)

Earthquake Hazard Map for Belmont/San Carlos Based on Underlying Geologic Material



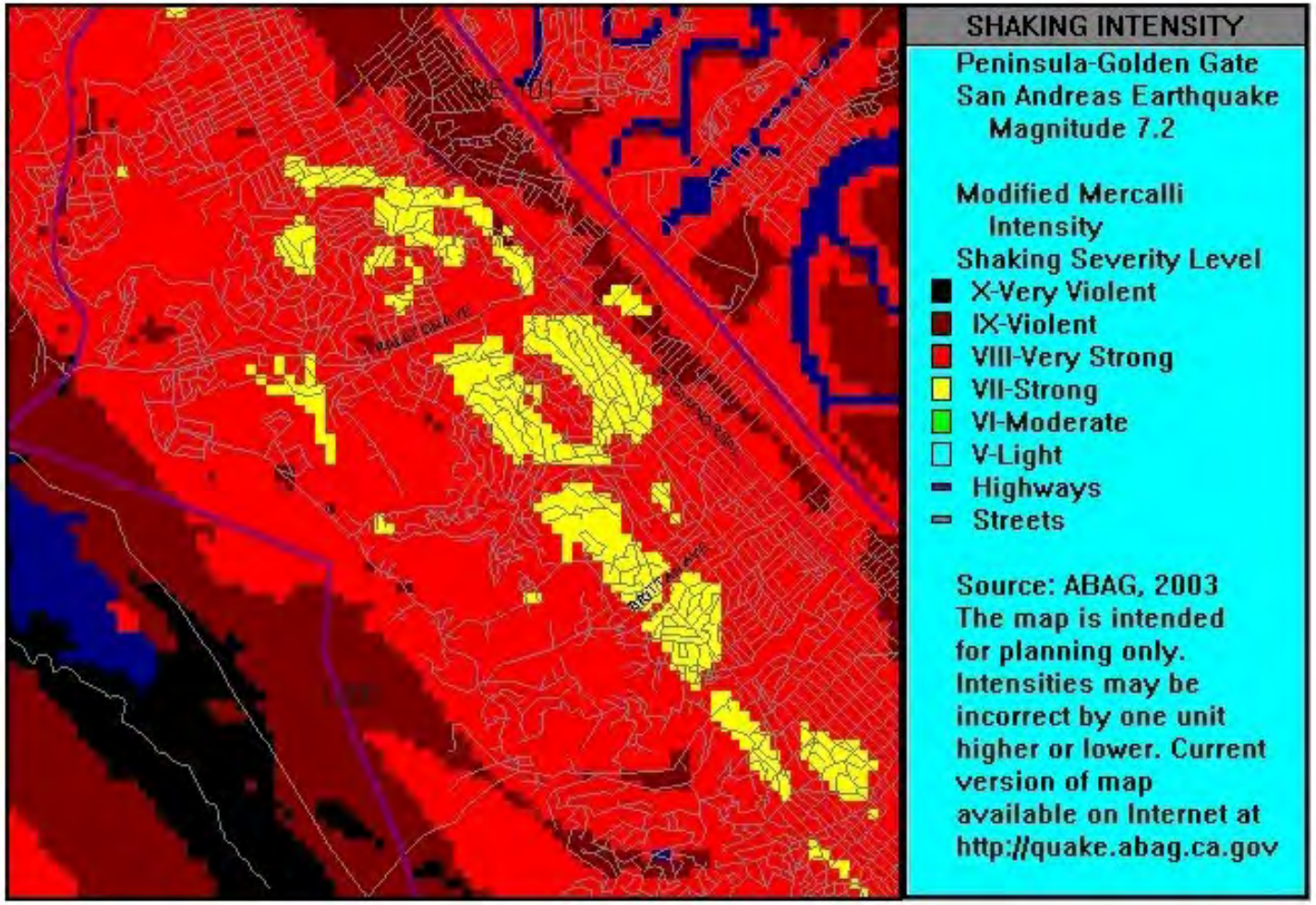
Earthquake Shaking Hazards Maps

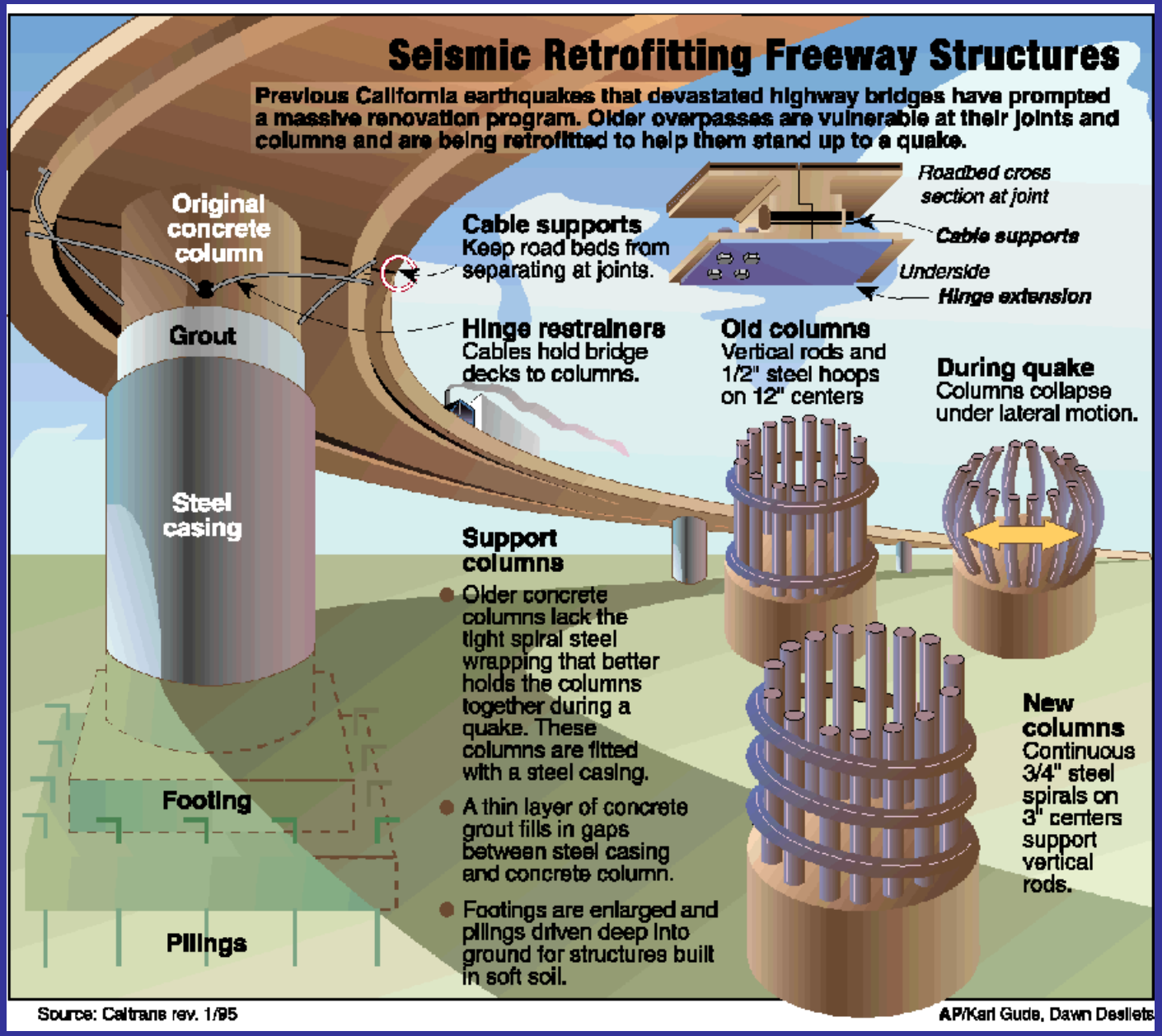
Belmont and San Carlos – M 6.7 on Southern Hayward



Earthquake Shaking Hazards Maps

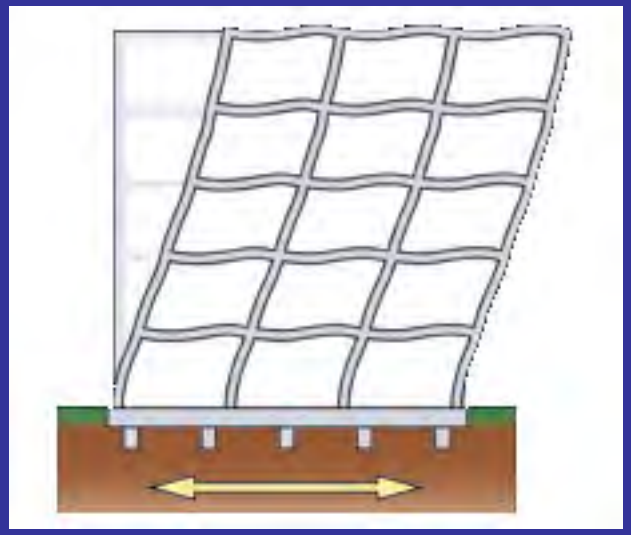
Belmont and San Carlos – M 7.2 on San Andreas Fault




Seismic Retrofitting Freeway Structures
Previous California earthquakes that devastated highway bridges have prompted a massive renovation program. Older overpasses are vulnerable at their joints and columns and are being retrofitted to help them stand up to a quake.
Original concrete column
Grout
Steel casing
Footing
Pilings
Cable supports
Keep road beds from separating at joints.
Hinge restrainers
Cables hold bridge decks to columns.
Roadbed cross section at joint
Cable supports
Underside
Hinge extension
Old columns
Vertical rods and 1/2" steel hoops on 12" centers
During quake
Columns collapse under lateral motion.
Support columns
Older concrete columns lack the tight spiral steel wrapping that better holds the columns together during a quake. These columns are fitted with a steel casing.
A thin layer of concrete grout fills in gaps between steel casing and concrete column.
Footings are enlarged and pilings driven deep into ground for structures built in soft soil.
New columns
Continuous 3/4" steel spirals on 3" centers support vertical rods.
Source: Caltrans rev. 1/95
AP/Karl Gude, Dawn Deslets

Seismic Base Isolation – decouples structure from ground reducing damage

No Isolation

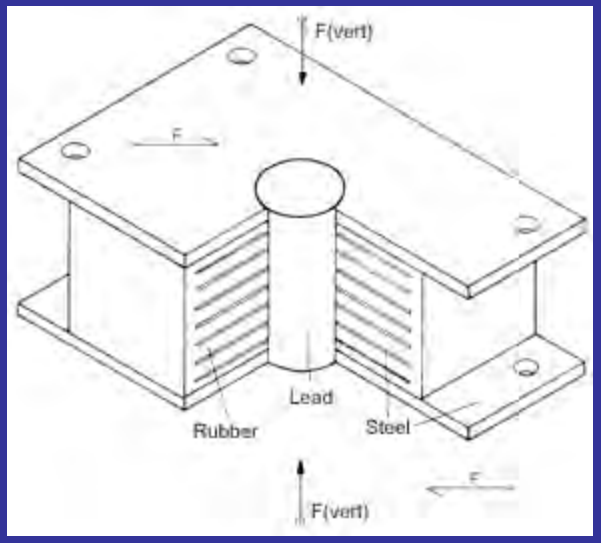


Base Isolated

Two Categories of Base Isolator Bearings: Shear units and Sliding units

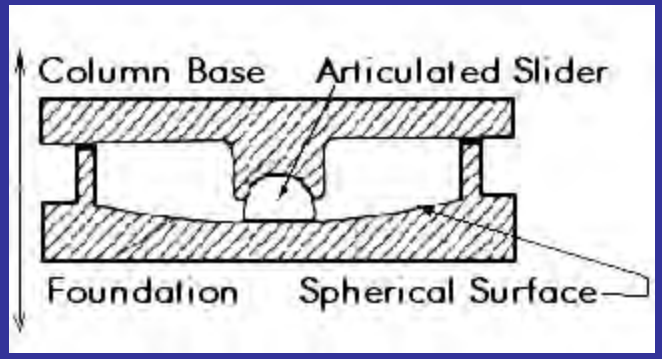
- Lead-Rubber

Shear unit



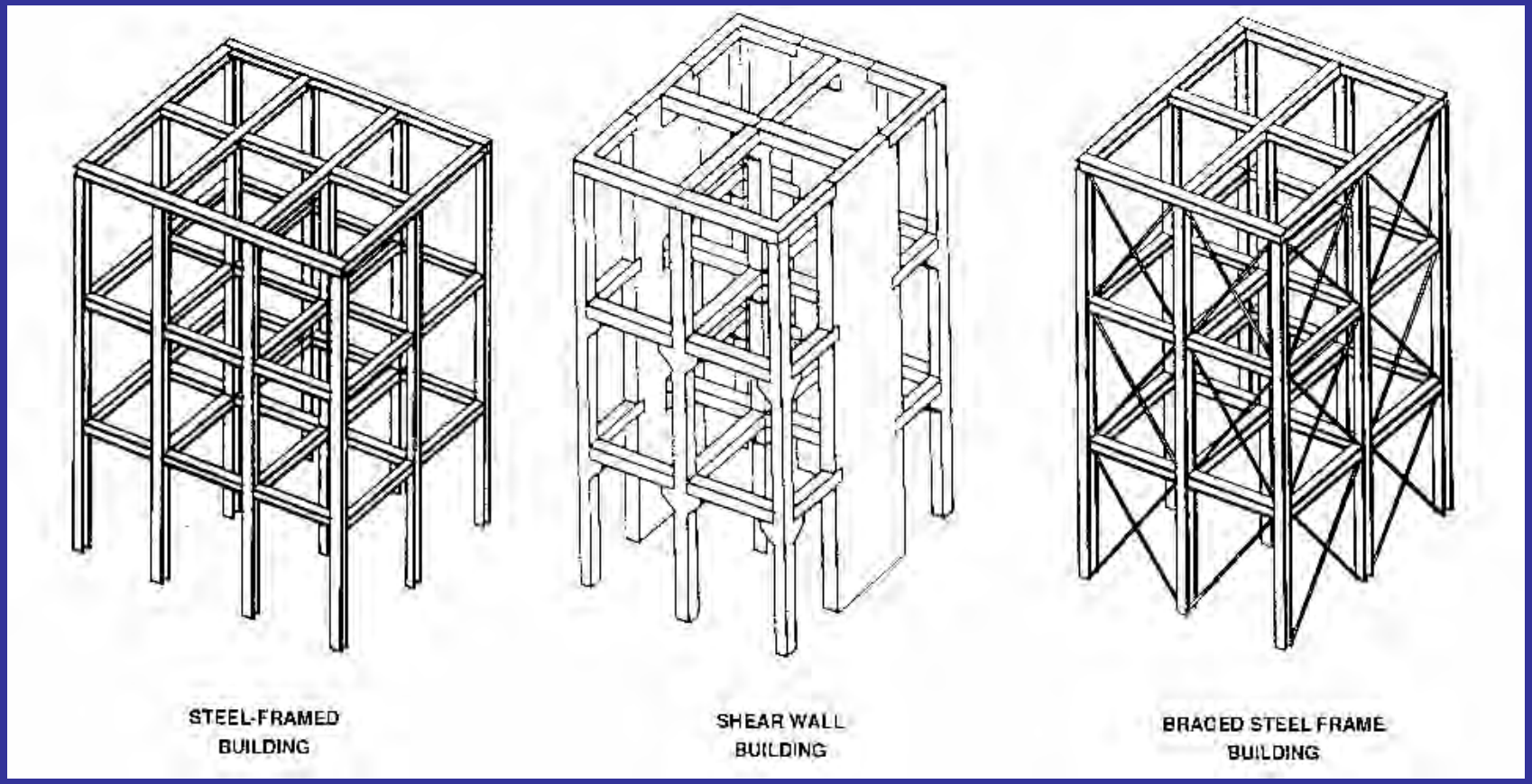
- Friction Pendulum

Sliding unit

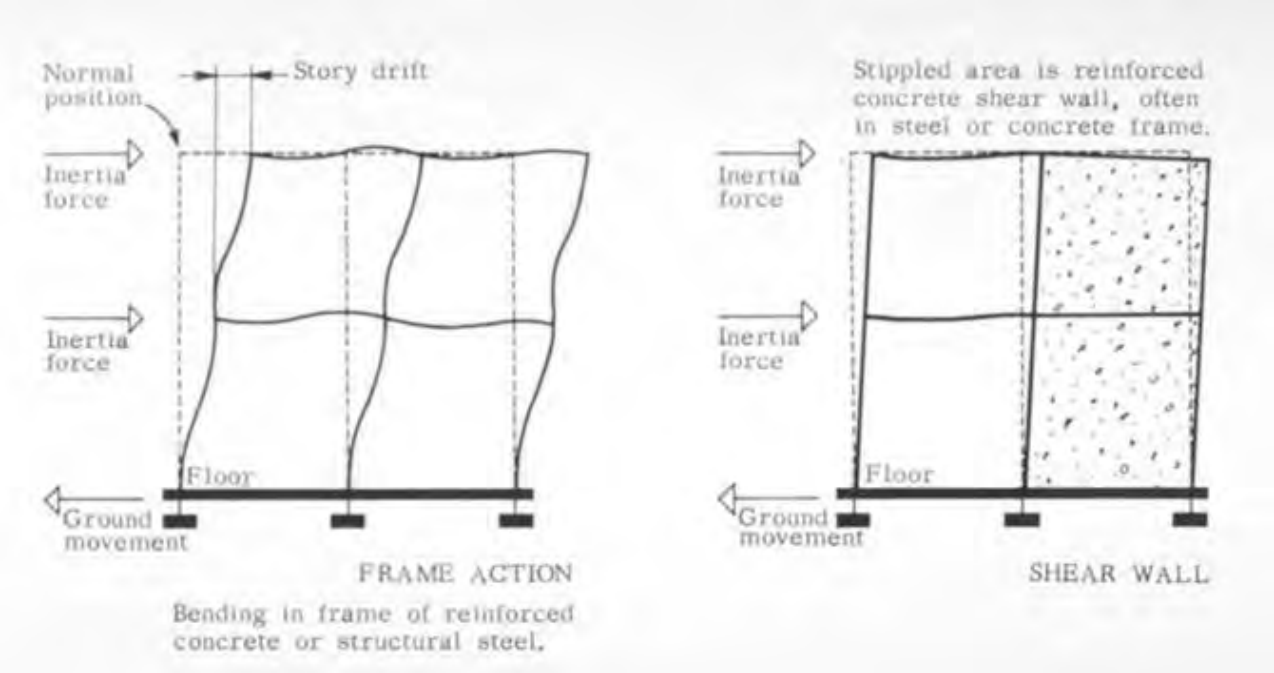


Installed Bearing

Using Shear Walls and Diagonal Bracing to Strengthen Structures



Reducing Damage via Shear Walls and Diagonal Bracing

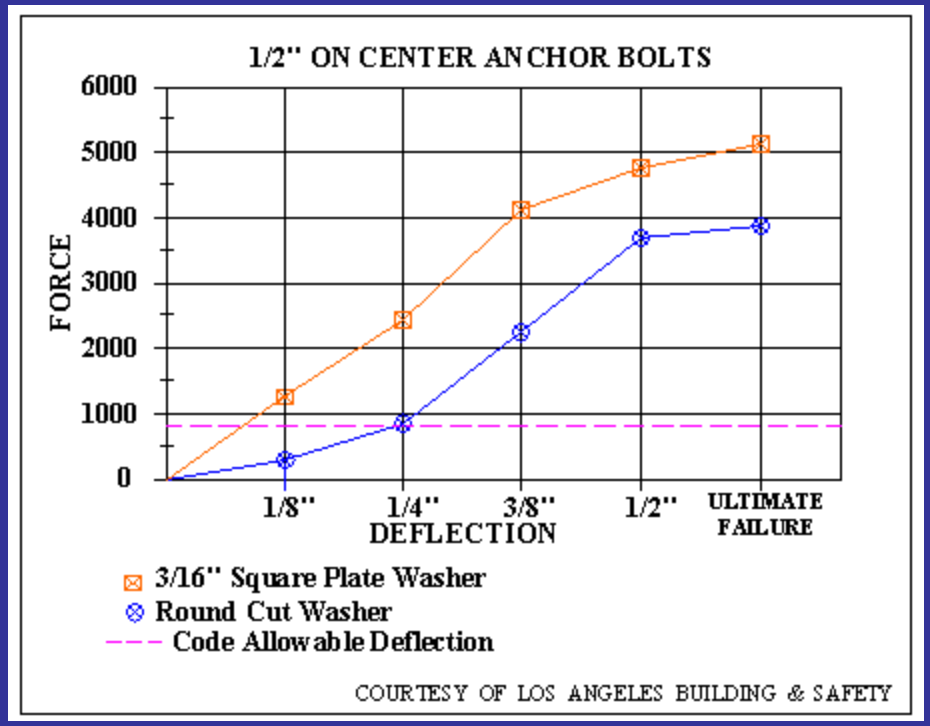


Seismic Retrofit of Homes

Using square plate washers instead of round cut washers strengthens the bolt-to-mudsill connection by 60%.

- Split sill plate with round washer

- Square plate washer



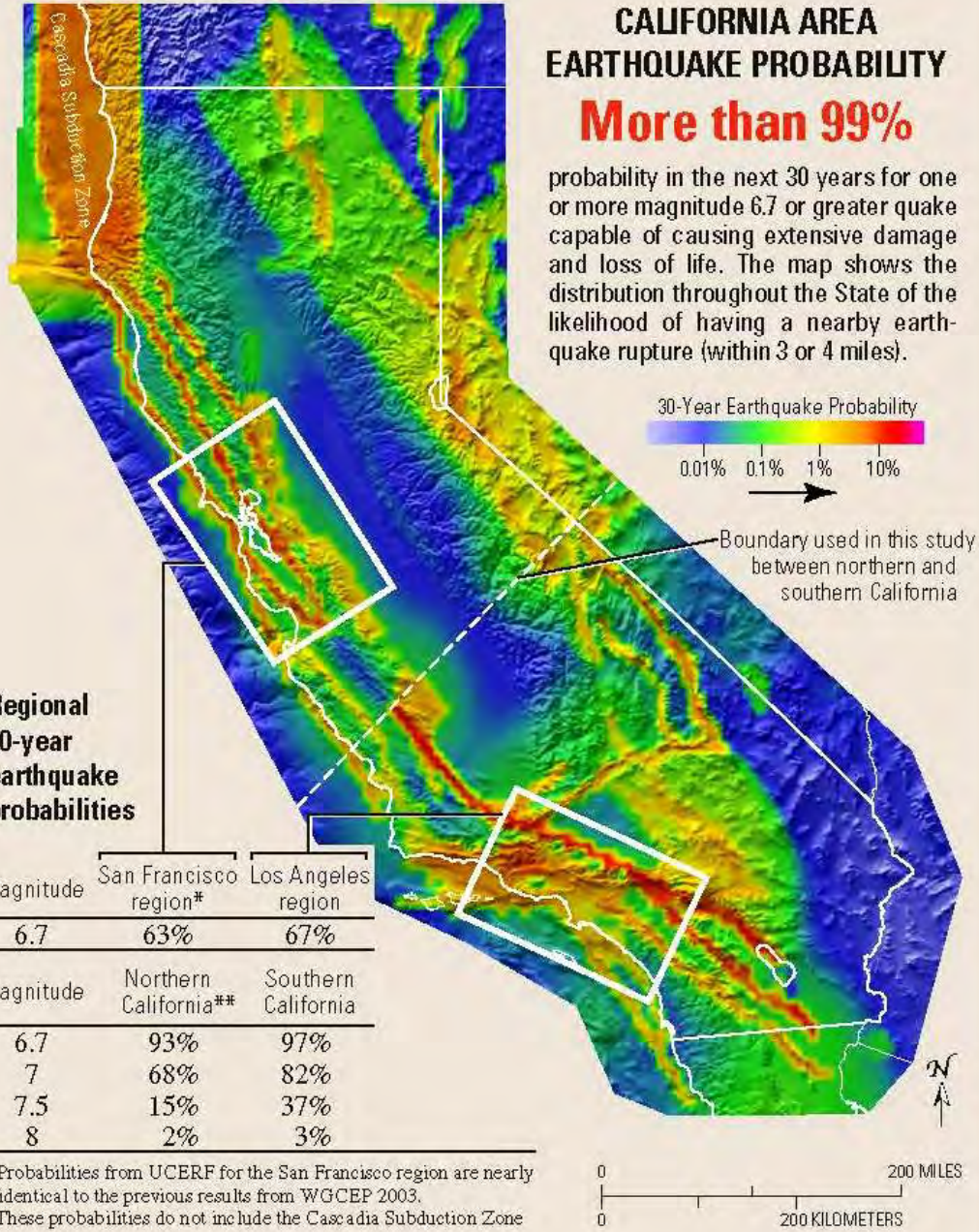
Will you be prepared for the next big quake?

Loma Prieta, California, M 6.9 Earthquake October 17, 1989. Watsonville area. Houses not bolted down securely were easily dislodged from their foundations in downtown Watsonville.

CALIFORNIA AREA EARTHQUAKE PROBABILITY

More than 99%

probability in the next 30 years for one or more magnitude 6.7 or greater quake capable of causing extensive damage and loss of life. The map shows the distribution throughout the State of the likelihood of having a nearby earthquake rupture (within 3 or 4 miles).



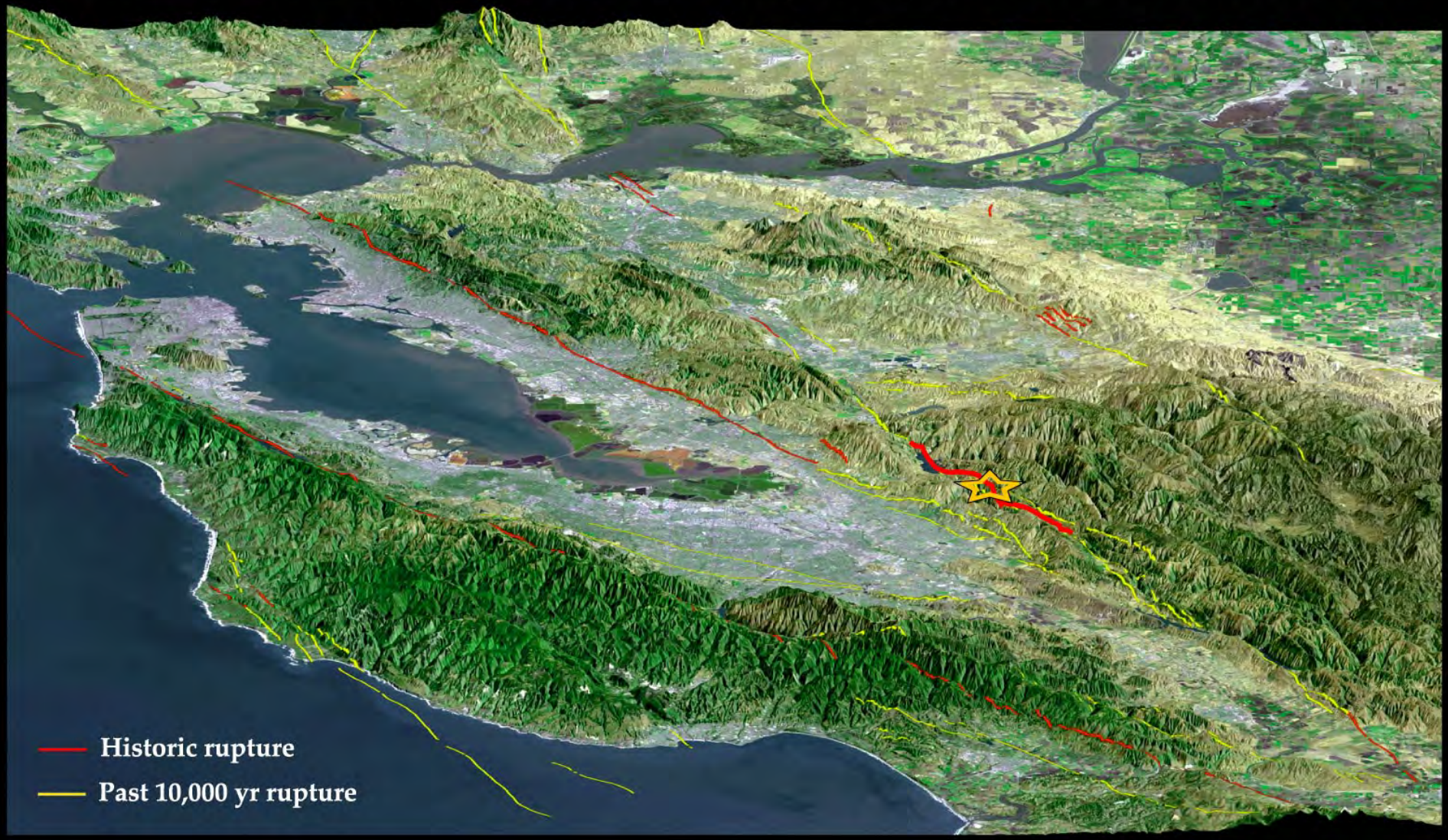
Regional 30-year earthquake probabilities

Magnitude	San Francisco region*	Los Angeles region
6.7	63%	67%

Magnitude	Northern California**	Southern California
6.7	93%	97%
7	68%	82%
7.5	15%	37%
8	2%	3%

*Probabilities from UCERF for the San Francisco region are nearly identical to the previous results from WGCEP 2003.
**These probabilities do not include the Cascadia Subduction Zone

M>6 San Francisco Bay area Earthquakes during the 75 years after the Great 1906 Shock



1911 M=6.2 shock from *Bakun* [BSSA, 1999]

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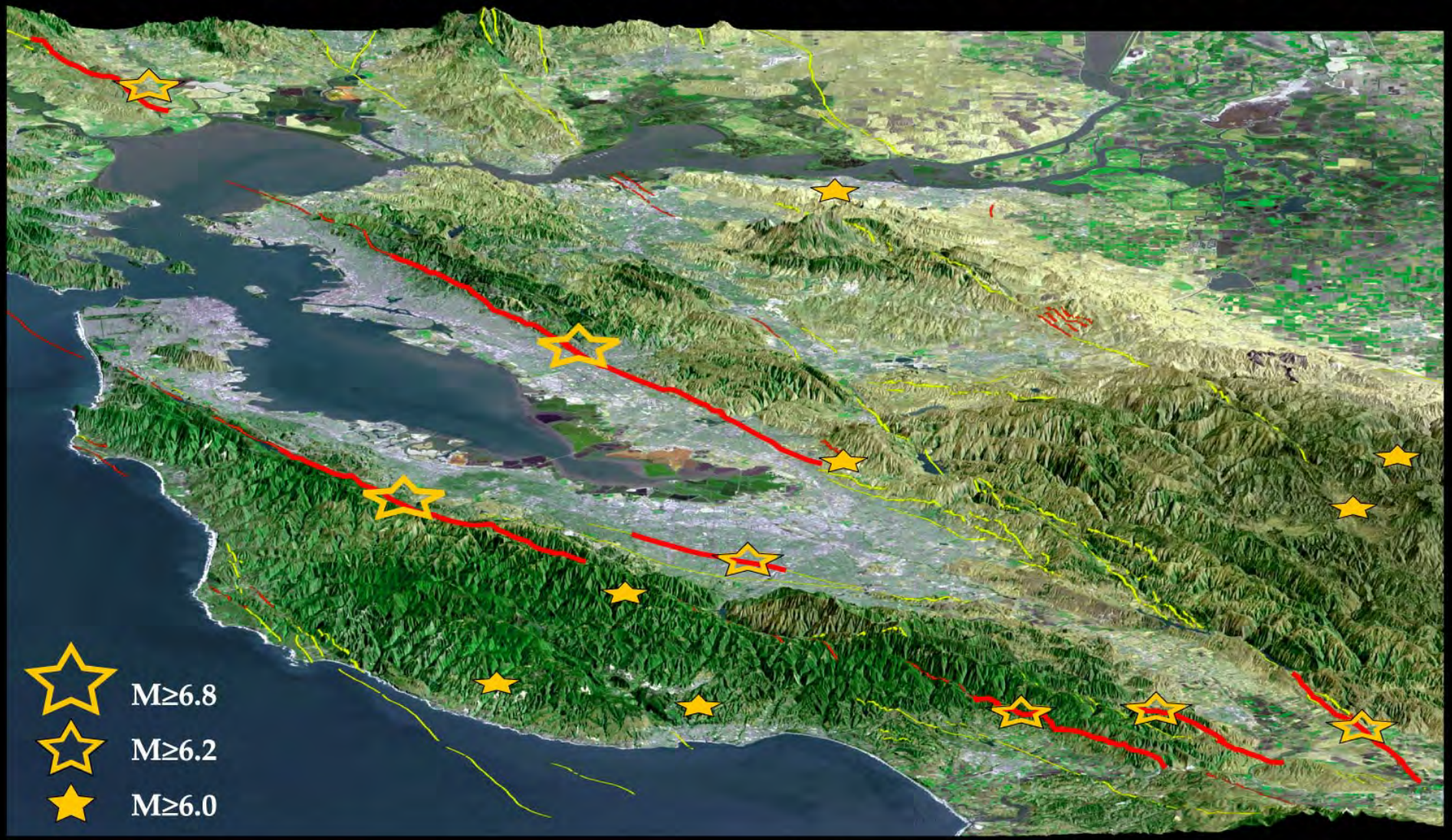
M>6 San Francisco Bay area earthquakes during the 75 years before the Great 1906 Shock



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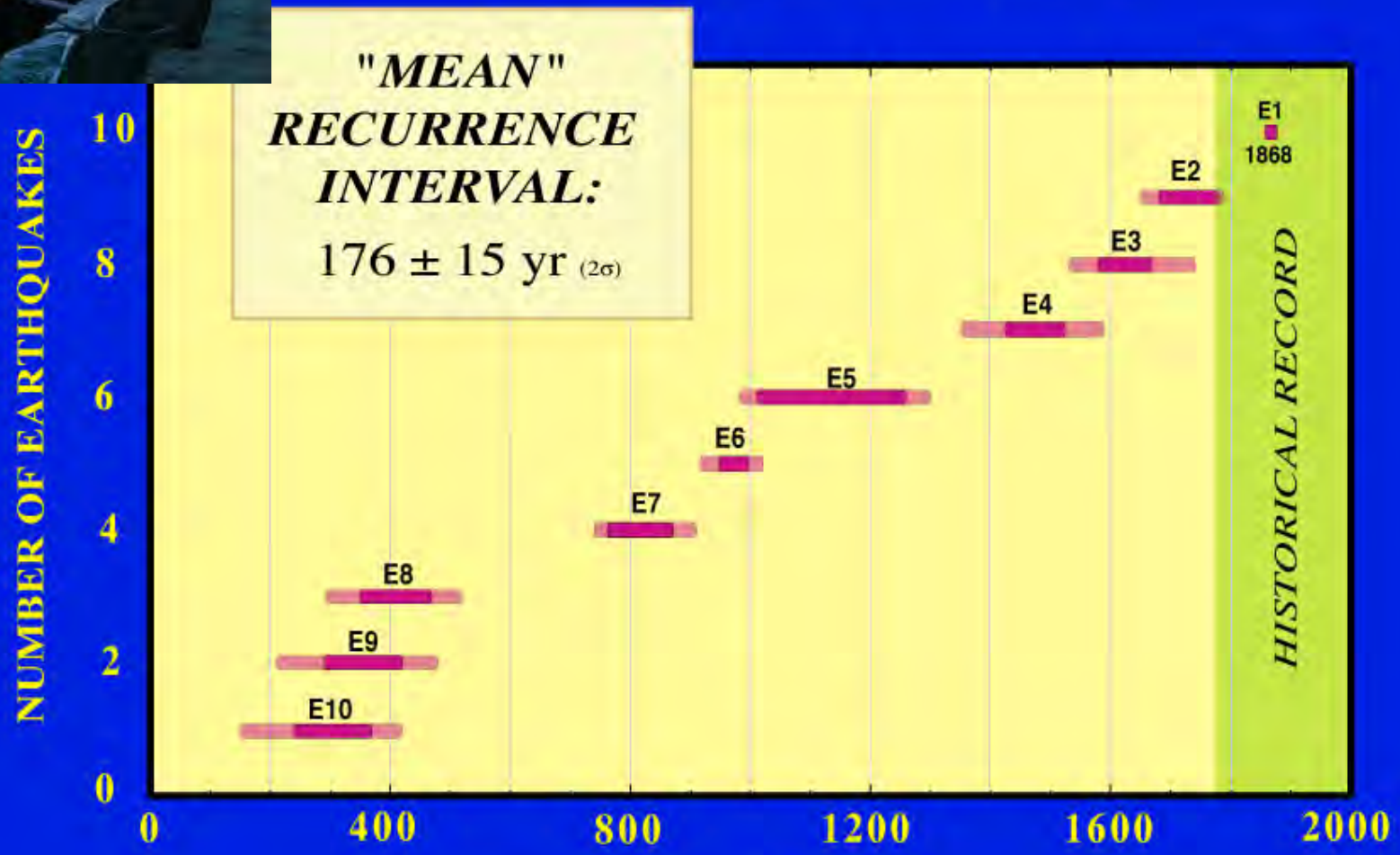
Earthquakes from *Bakun* [1999] and *Ellsworth* [1990]

1700-Year Earthquake History on the Southern Hayward Fault



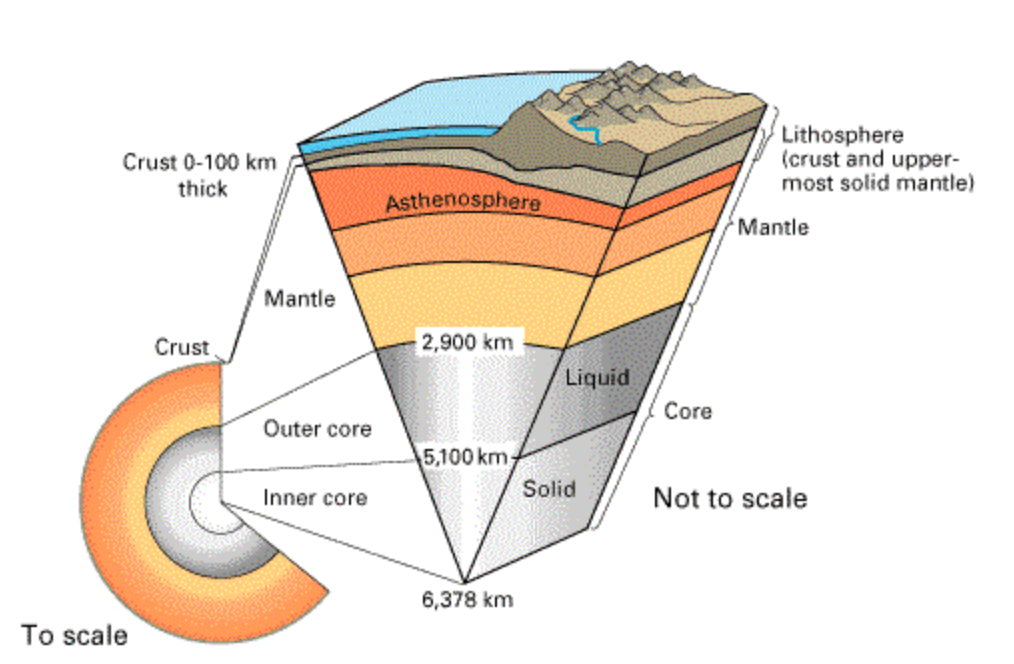
Paleoseismology

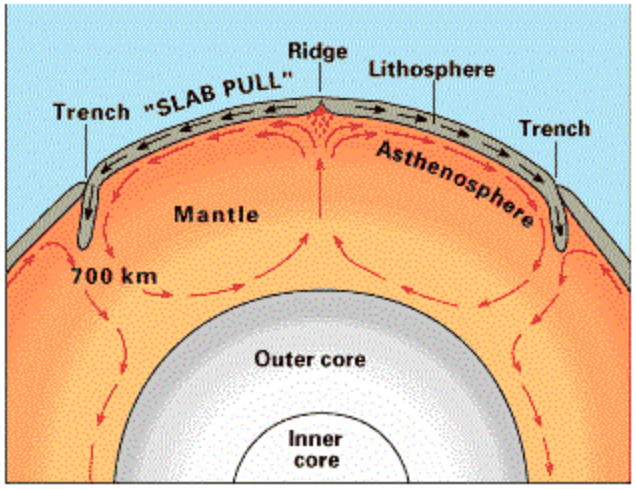
Mira Vista Golf Course, N of Berkeley

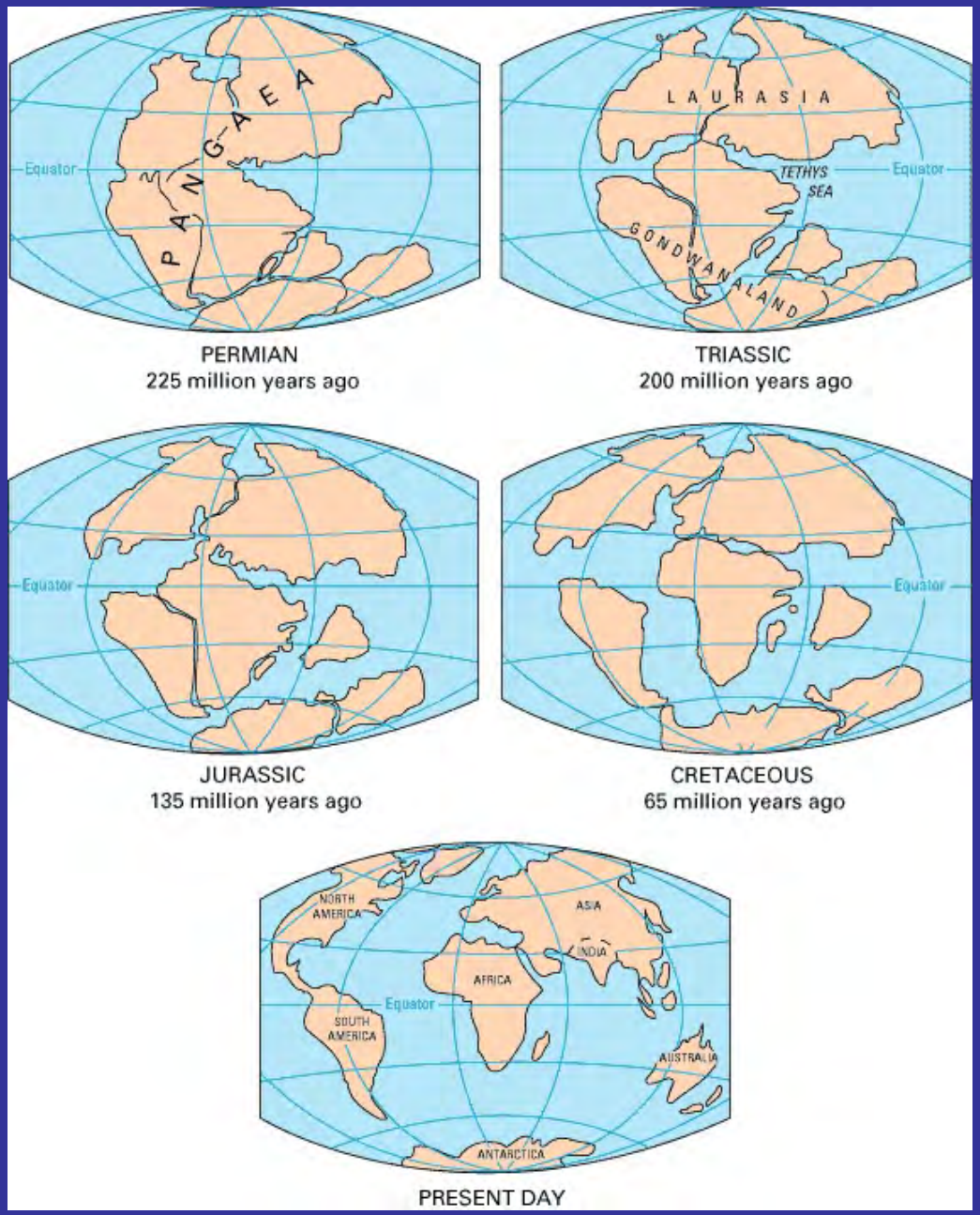
Earth's Layers

and

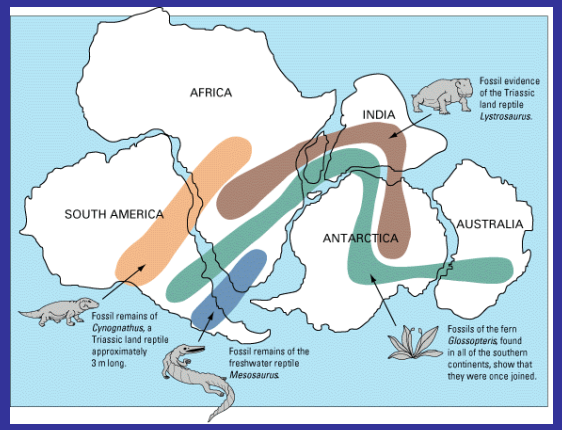
Convection currents that drive motions of the plates



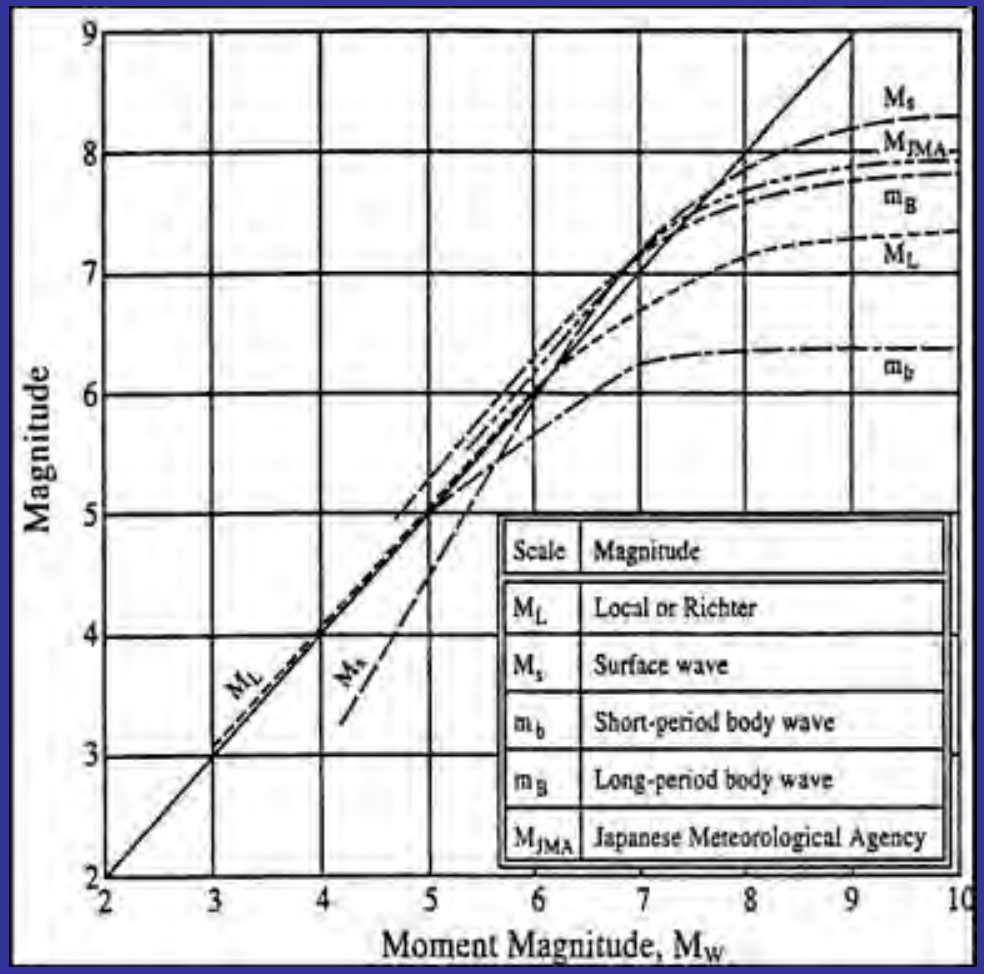


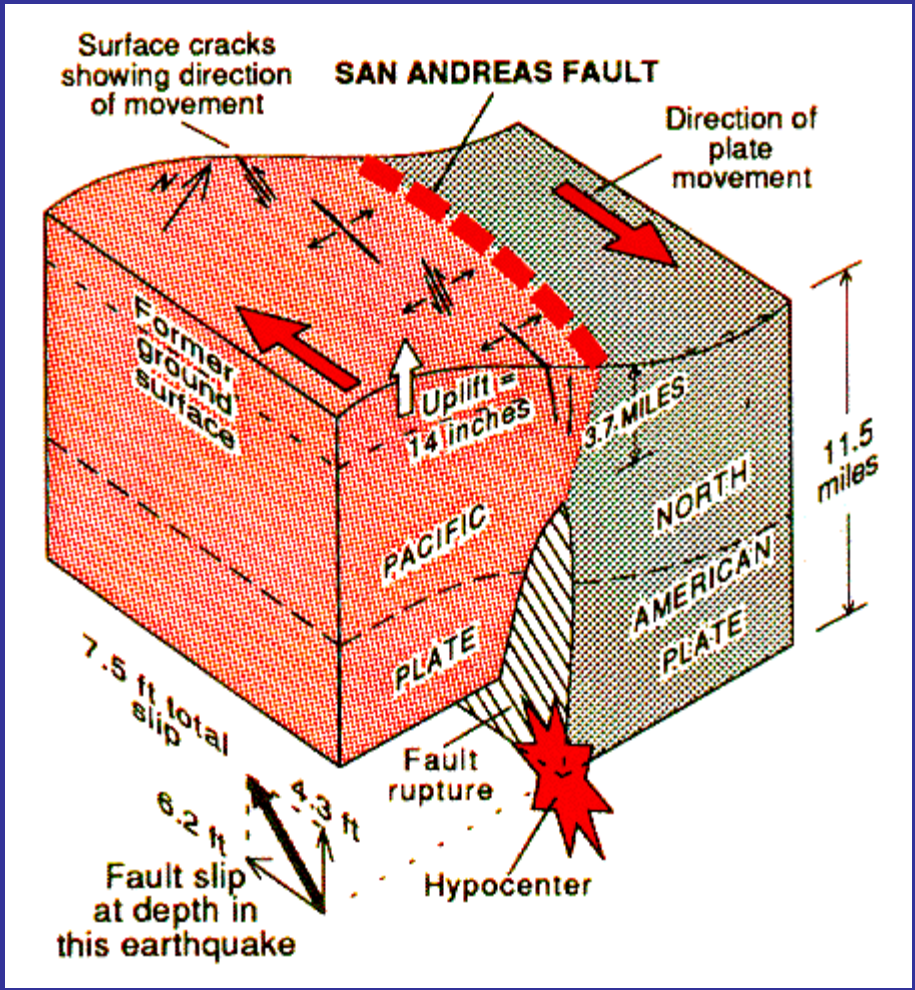


Break-up of the supercontinent *Pangaea* (meaning "all lands" in Greek), which figured prominently in the *theory of continental drift* -- the forerunner to the theory of plate tectonics.



Relationship between different magnitude scales: moment magnitude Mw, surface-wave magnitude Ms, body-wave magnitude m_B, and local magnitude ML




Surface cracks showing direction of movement
SAN ANDREAS FAULT
Direction of plate movement
Former ground surface
Uplift = 14 inches
3.7 MILES
11.5 miles
NORTH AMERICAN PLATE
PACIFIC PLATE
7.5 ft total slip
6.2 ft
4.3 ft
Fault slip at depth in this earthquake
Fault rupture
Hypocenter