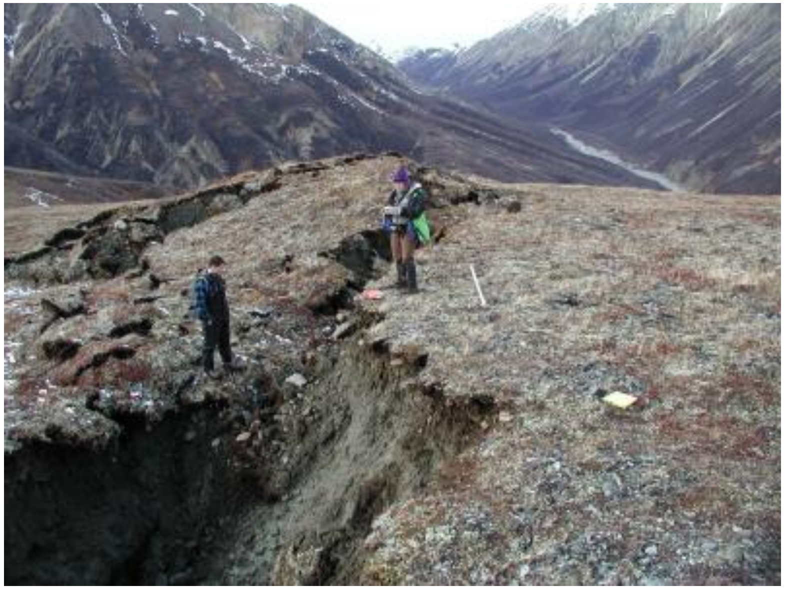
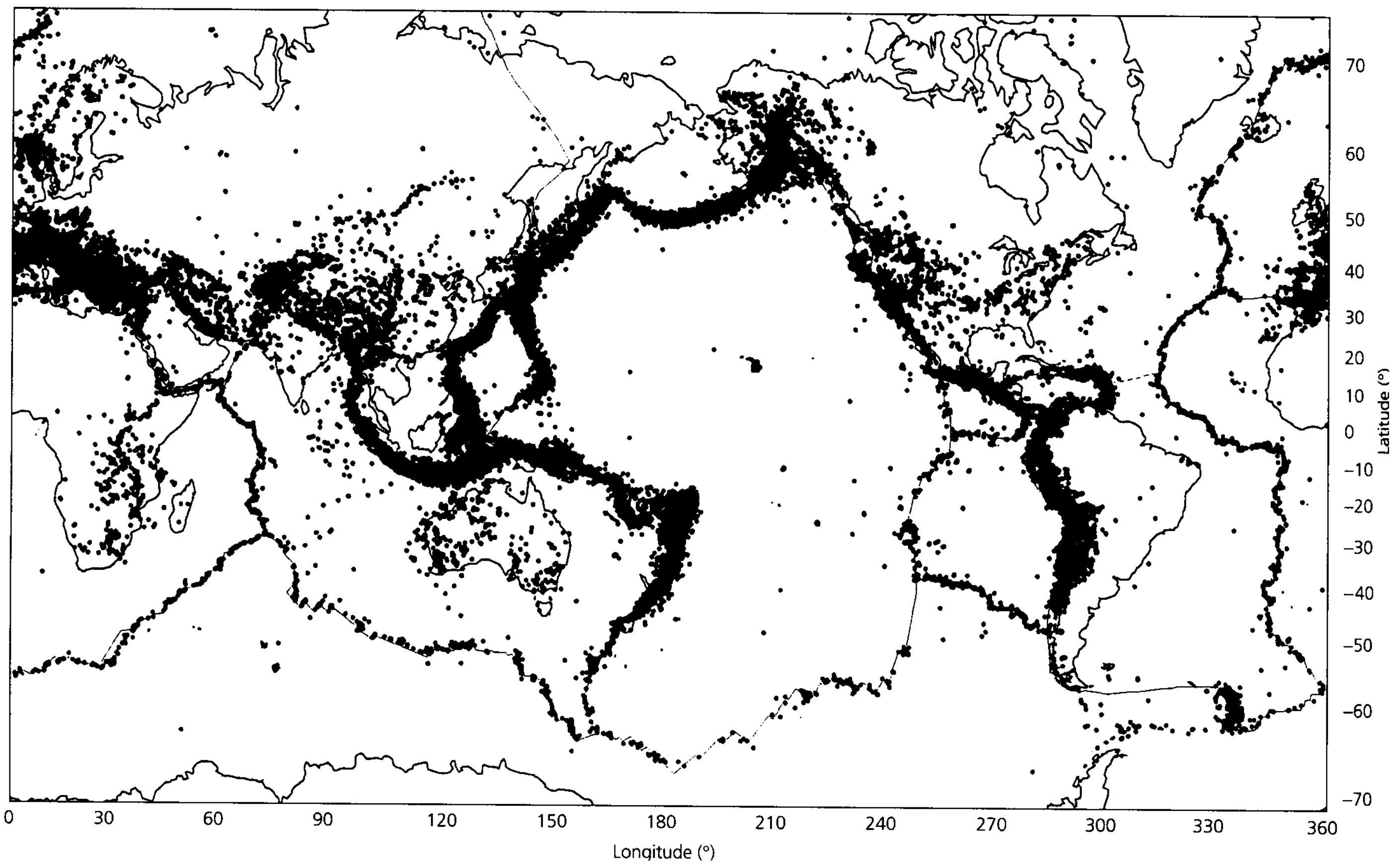
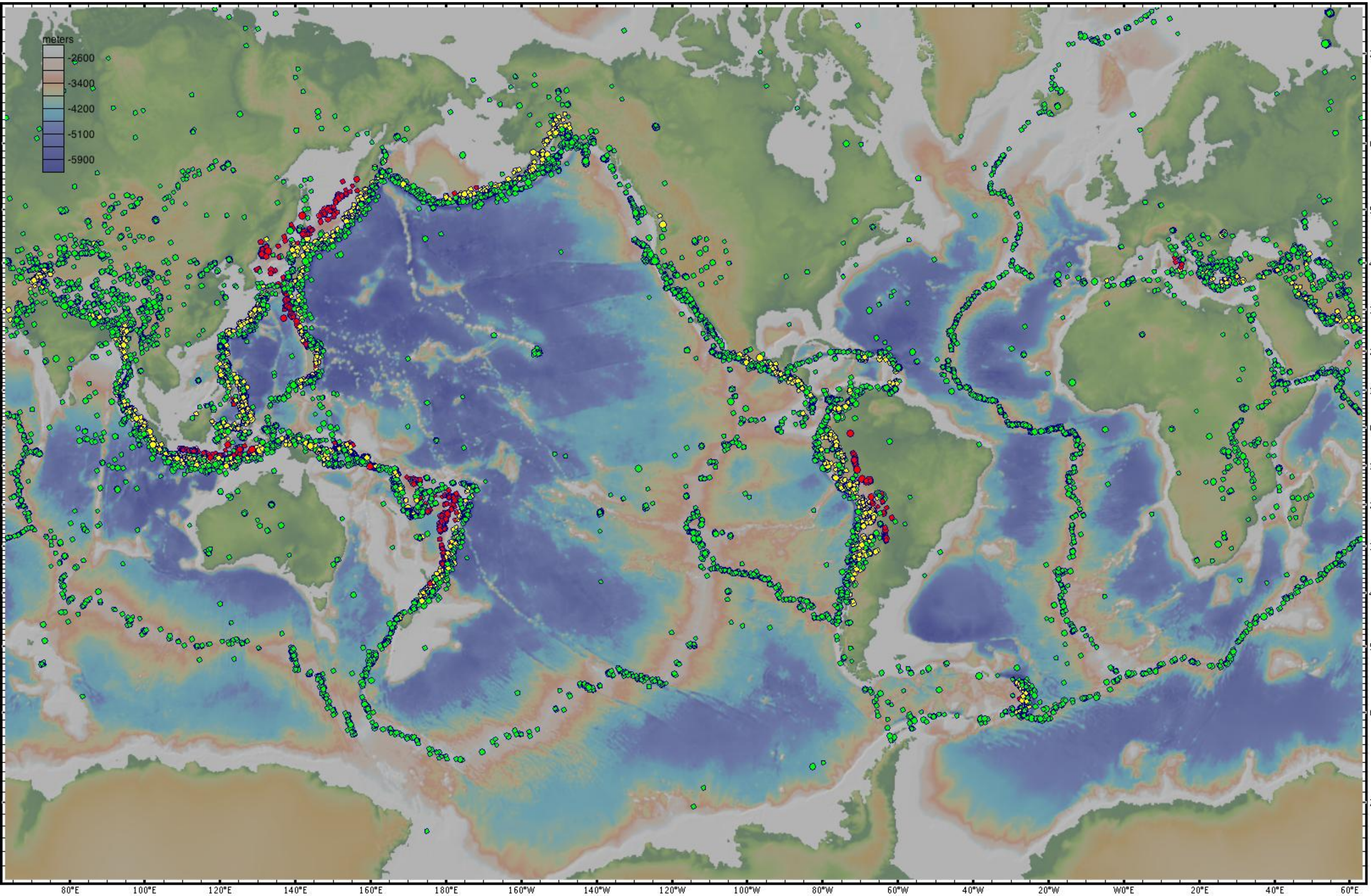
Lecture 8 – Seismo-tectonics
read KKV ch. 5.2

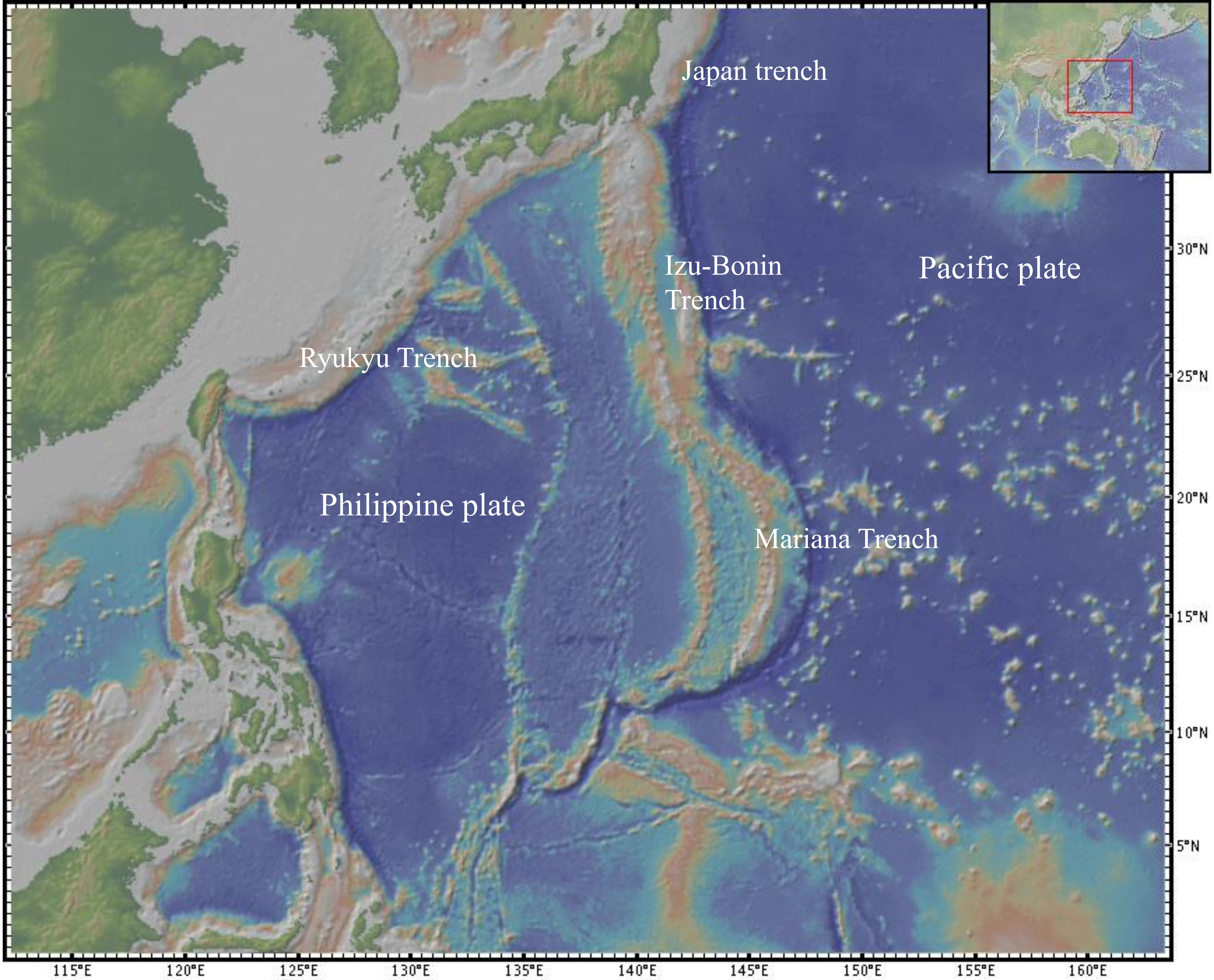


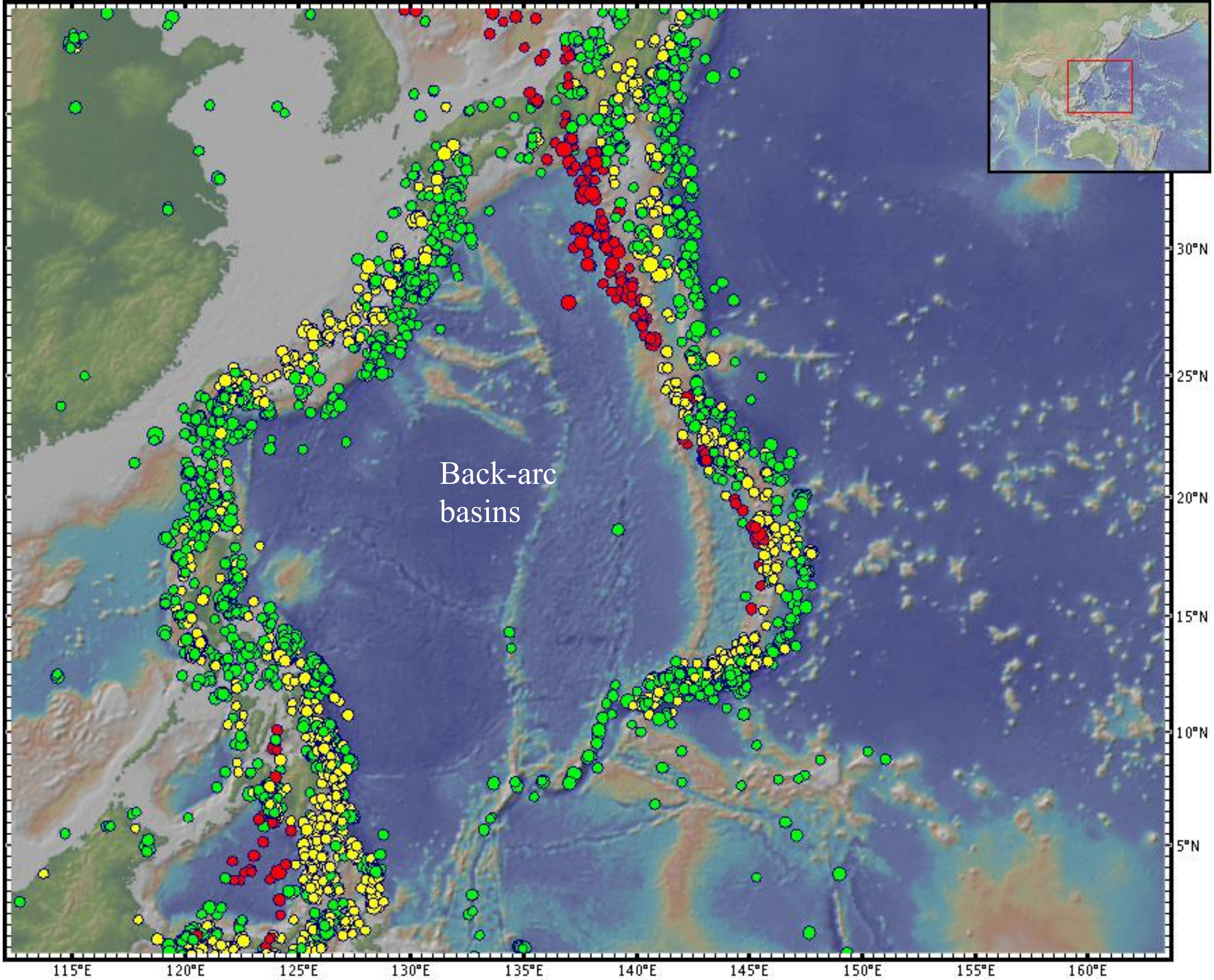
Global distribution of earthquakes



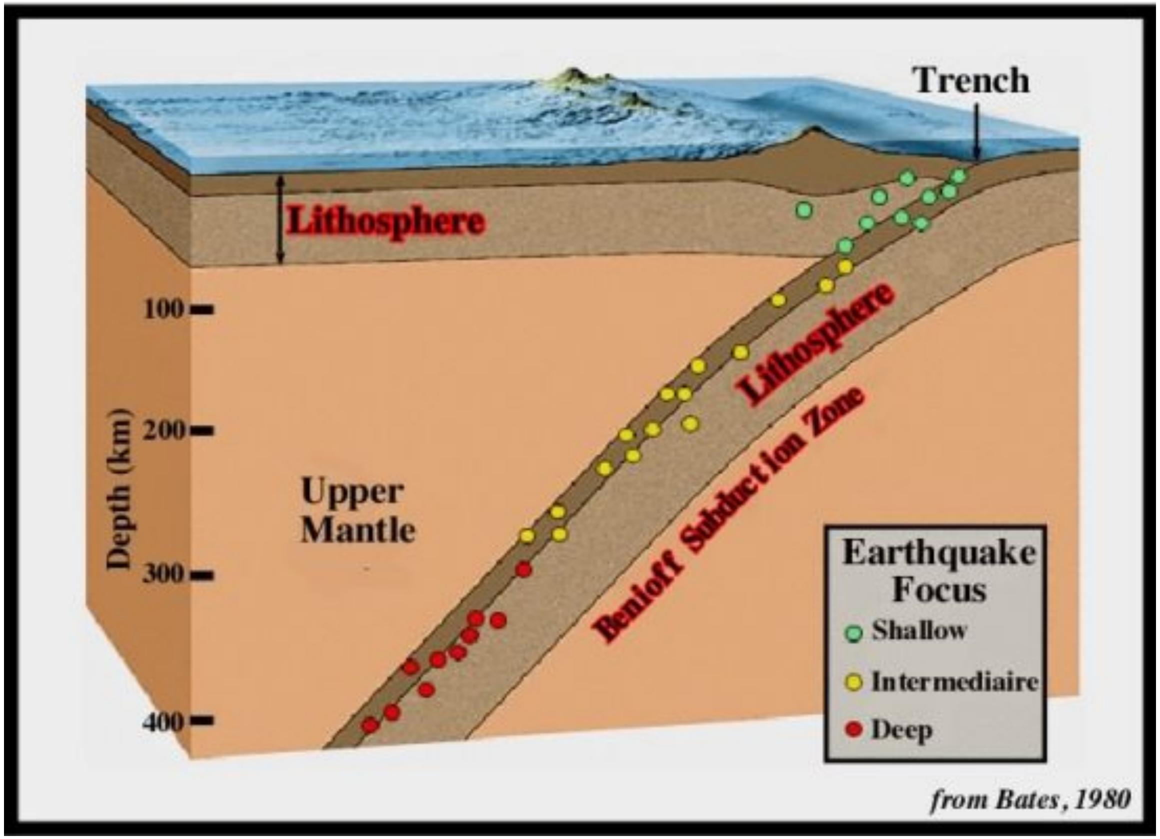
Focal Depths: green < 50 km, yellow = 50 to 250 km, red > 250 km



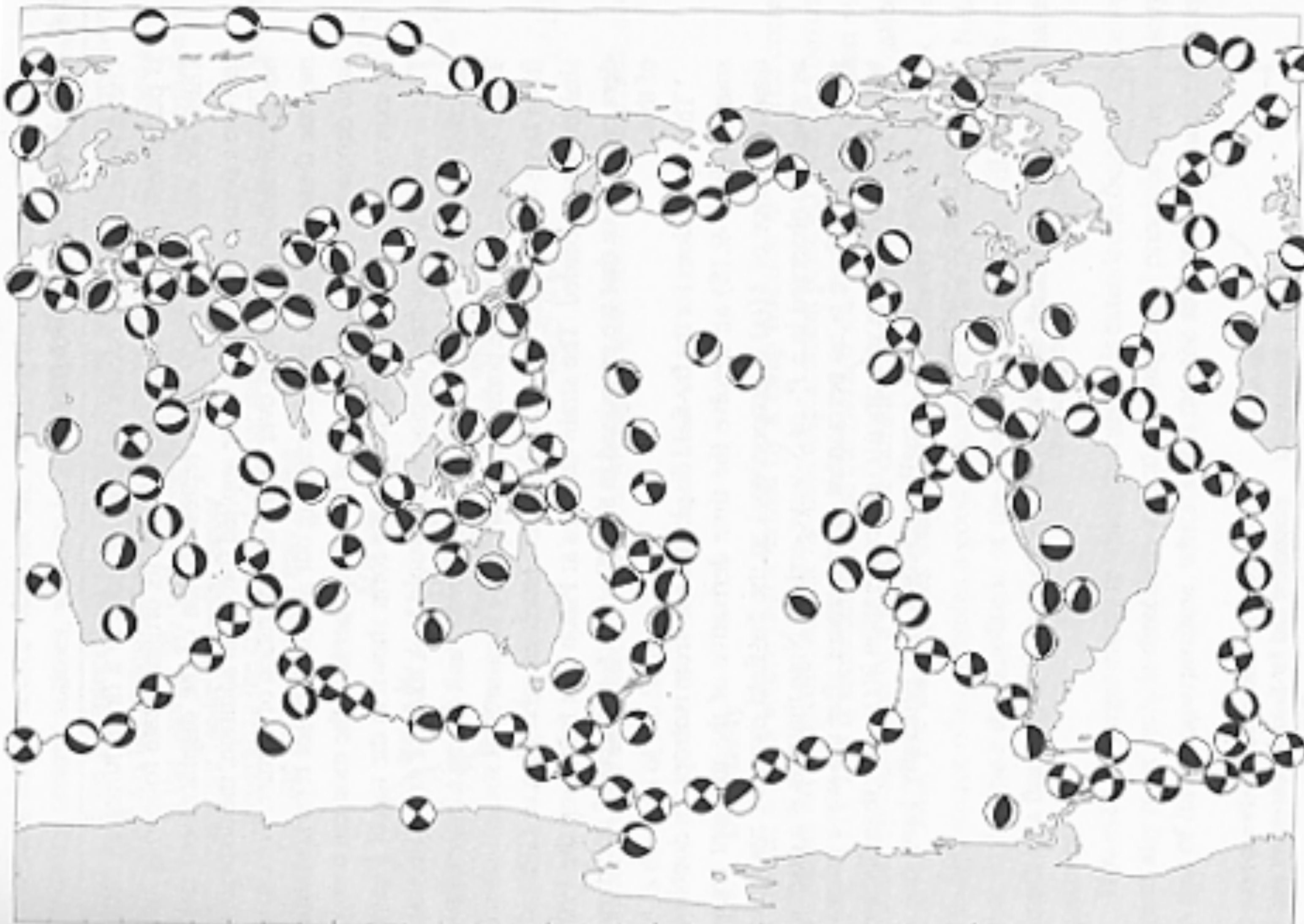

Japan trench
Izu-Bonin
Trench
Pacific plate
Ryukyu Trench
Philippine plate
Mariana Trench
30°N
25°N
20°N
15°N
10°N
5°N
115°E
120°E
125°E
130°E
135°E
140°E
145°E
150°E
155°E
160°E

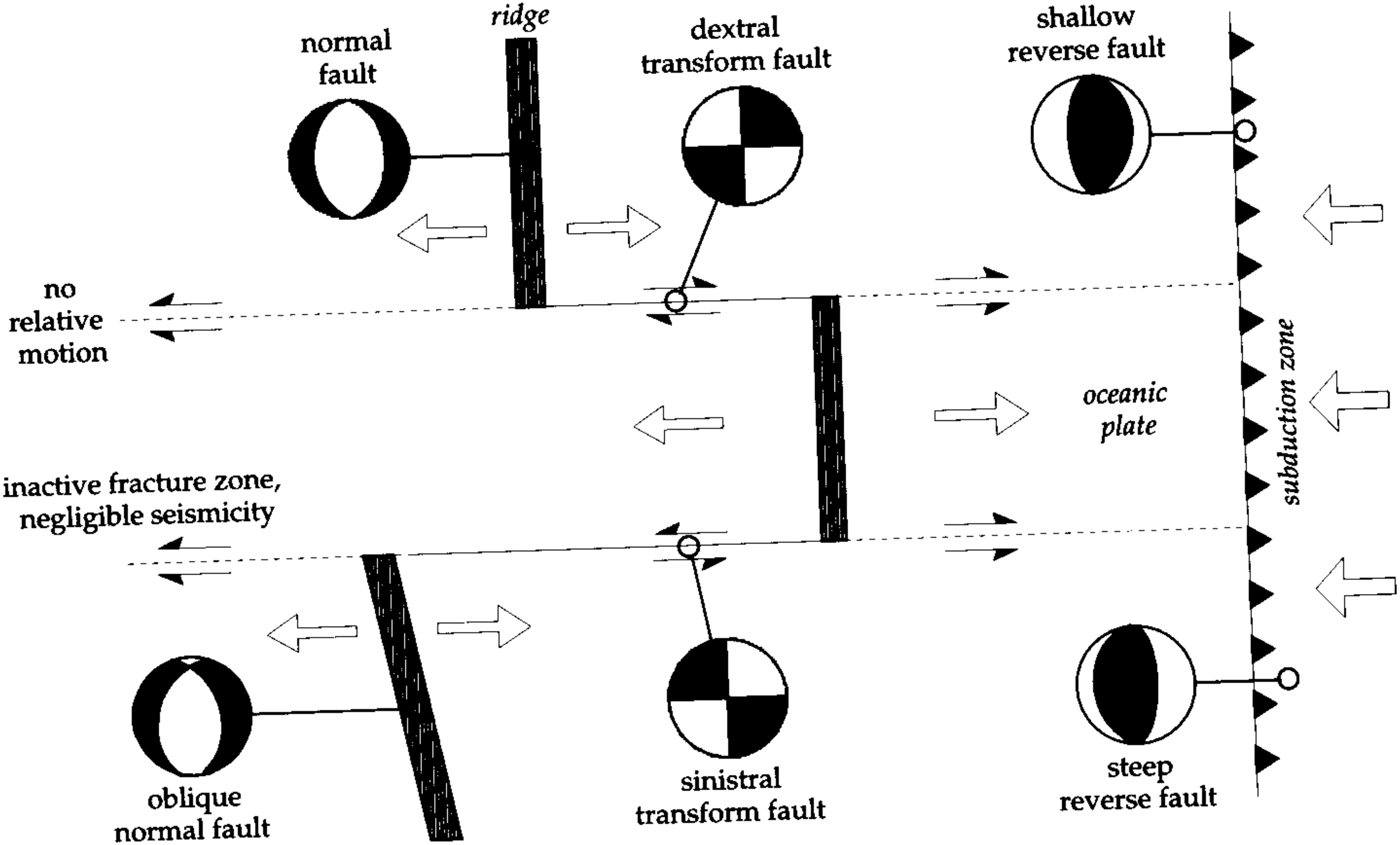

Back-arc basins
30°N
25°N
20°N
15°N
10°N
5°N
115°E
120°E
125°E
130°E
135°E
140°E
145°E
150°E
155°E
160°E

Benioff zone

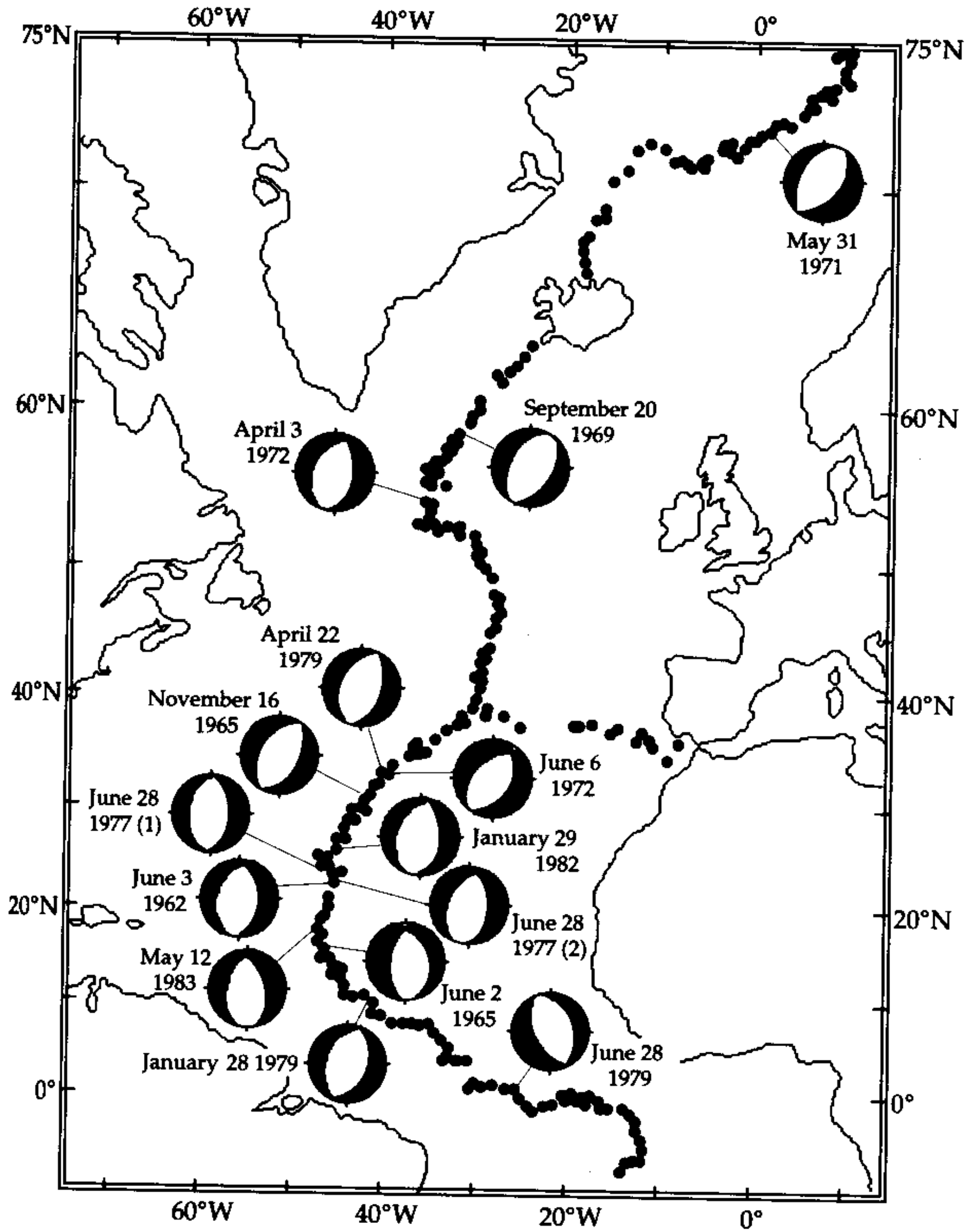


Global distribution of the earthquake focal mechanisms





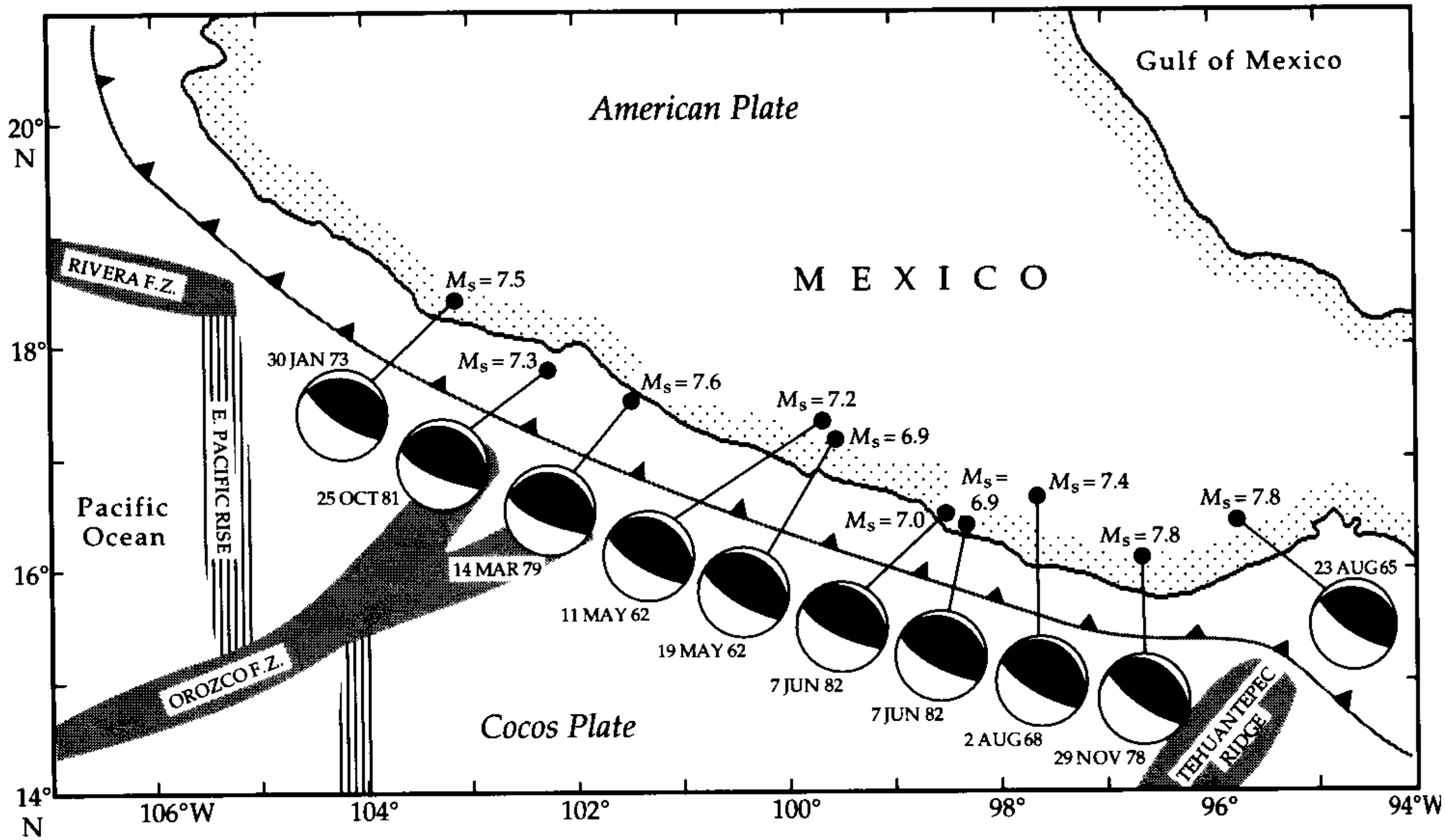
ridge
normal fault
dextral transform fault
shallow reverse fault
no relative motion
oceanic plate
subduction zone
inactive fracture zone, negligible seismicity
oblique normal fault
sinistral transform fault
steep reverse fault



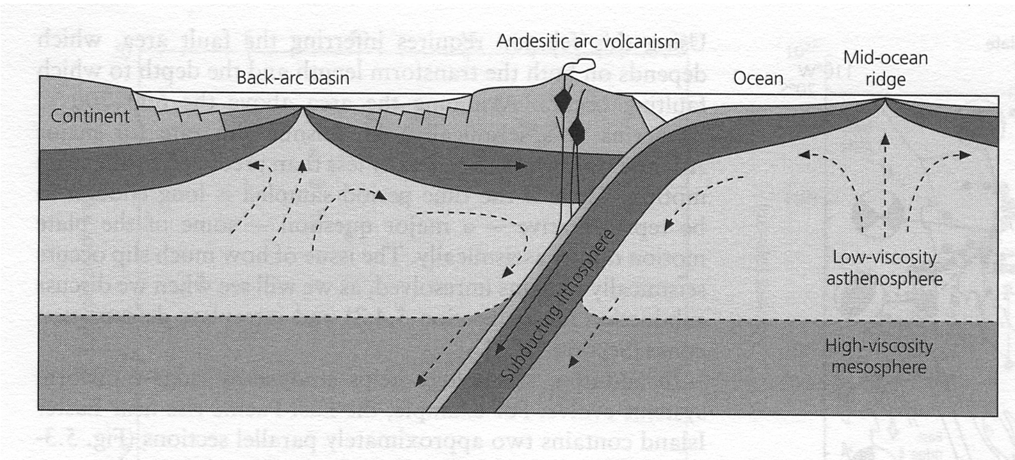
60°W
40°W
20°W
0°
75°N
75°N
May 31
1971
60°N
60°N
April 3
1972
September 20
1969
April 22
1979
40°N
40°N
November 16
1965
June 6
1972
June 28
1977 (1)
January 29
1982
June 3
1962
20°N
20°N
June 28
1977 (2)
May 12
1983
June 2
1965
June 28
1979
January 28 1979
0°
0°
60°W
40°W
20°W
0°

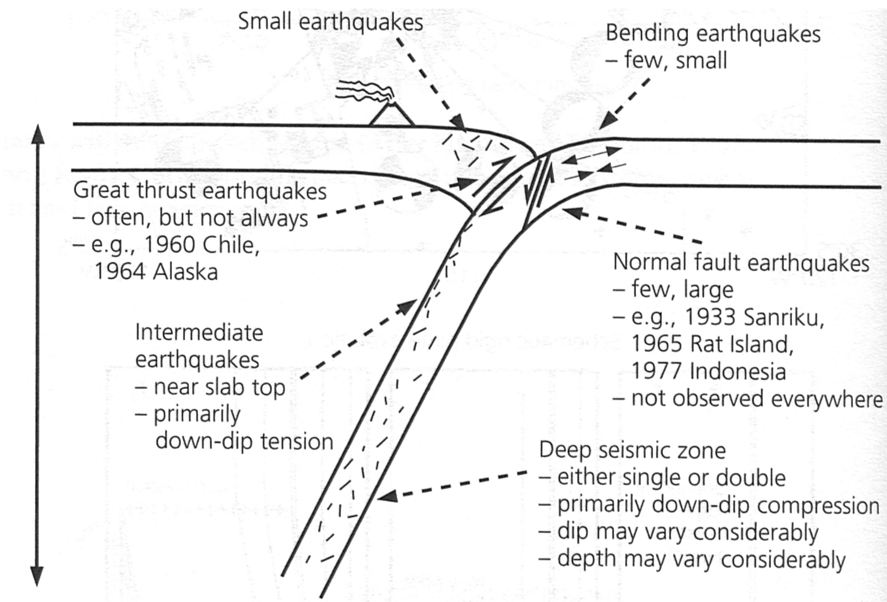
ı

).

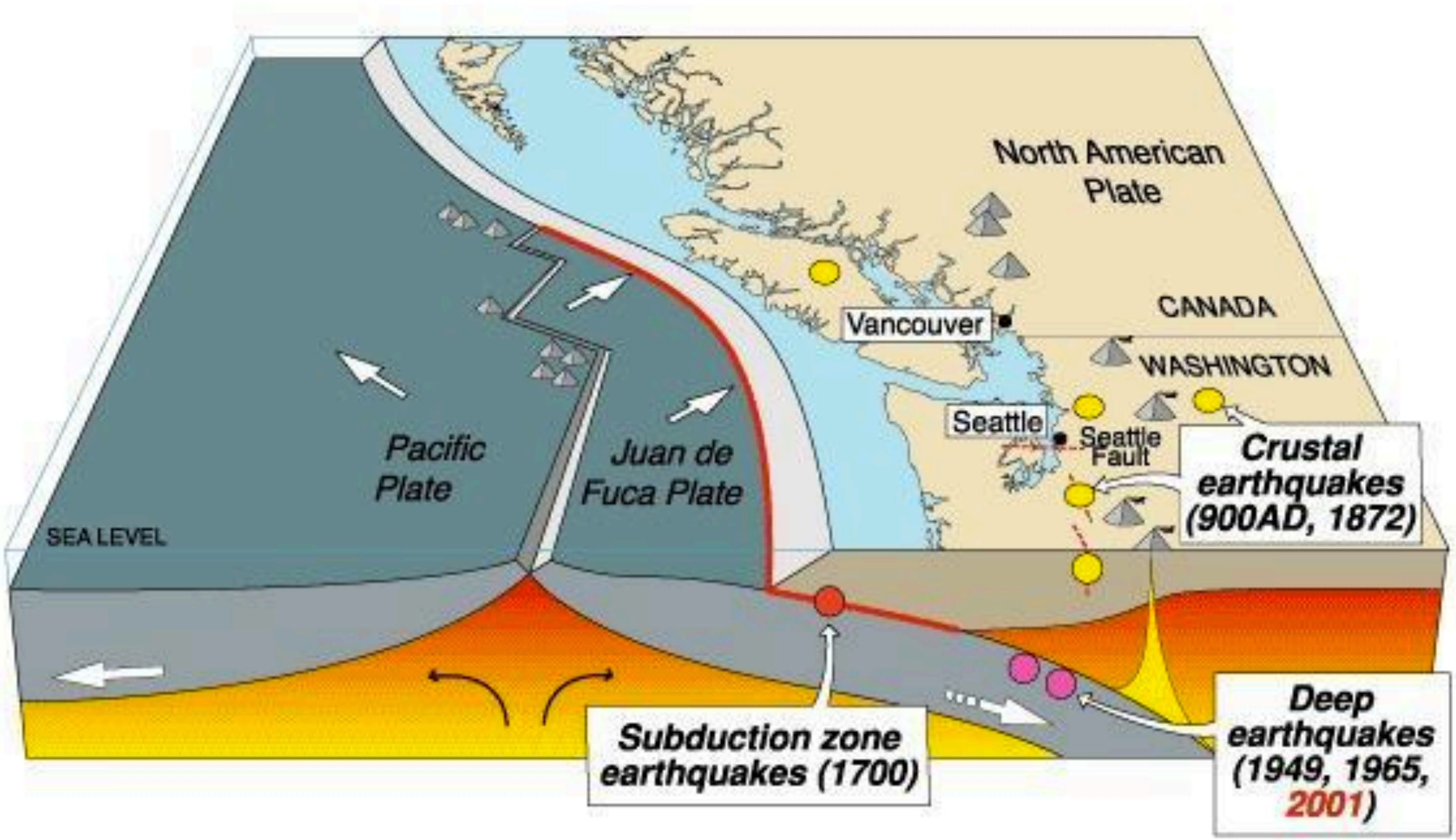


Gulf of Mexico
American Plate
M E X I C O
Pacific Ocean
Cocos Plate
RIVERA F.Z.
E. PACIFIC RISE
OROZCO F.Z.
TEHUANTEPEC RIDGE
30 JAN 73
$M_S = 7.5$
25 OCT 81
$M_S = 7.3$
14 MAR 79
$M_S = 7.6$
11 MAY 62
$M_S = 7.2$
19 MAY 62
$M_S = 6.9$
7 JUN 82
$M_S = 7.0$
7 JUN 82
$M_S =$ 6.9
2 AUG 68
$M_S = 7.4$
29 NOV 78
$M_S = 7.8$
23 AUG 65
$M_S = 7.8$
20° N
18°
16°
14° N
106°W
104°
102°
100°
98°
96°
94°W


Andesitic arc volcanism
Back-arc basin
Mid-ocean ridge
Ocean
Continent
Subducting lithosphere
Low-viscosity asthenosphere
High-viscosity mesosphere


Small earthquakes
Bending earthquakes
– few, small
Great thrust earthquakes
– often, but not always
– e.g., 1960 Chile,
1964 Alaska
Normal fault earthquakes
– few, large
– e.g., 1933 Sanriku,
1965 Rat Island,
1977 Indonesia
– not observed everywhere
Intermediate
earthquakes
– near slab top
– primarily
down-dip tension
Deep seismic zone
– either single or double
– primarily down-dip compression
– dip may vary considerably
– depth may vary considerably

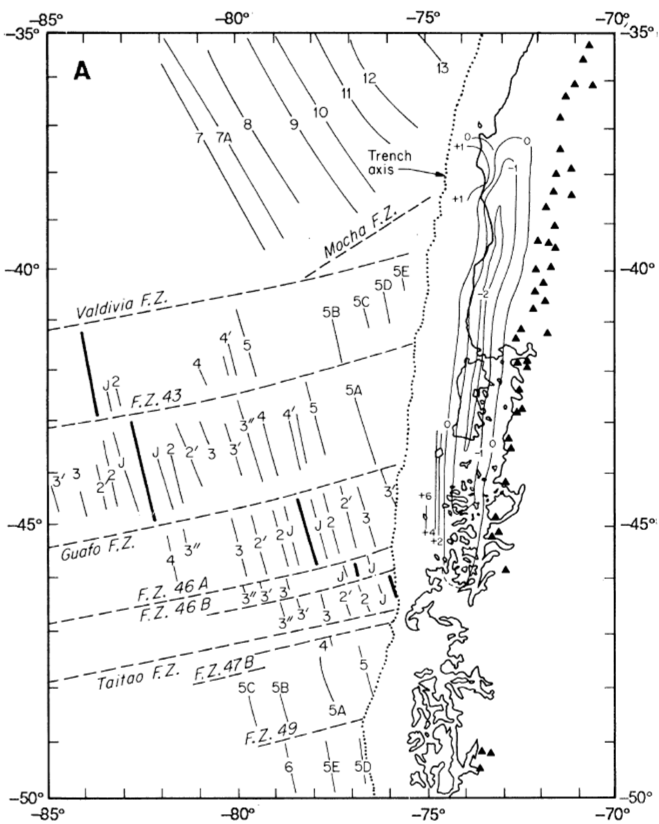
Cascadia earthquake sources

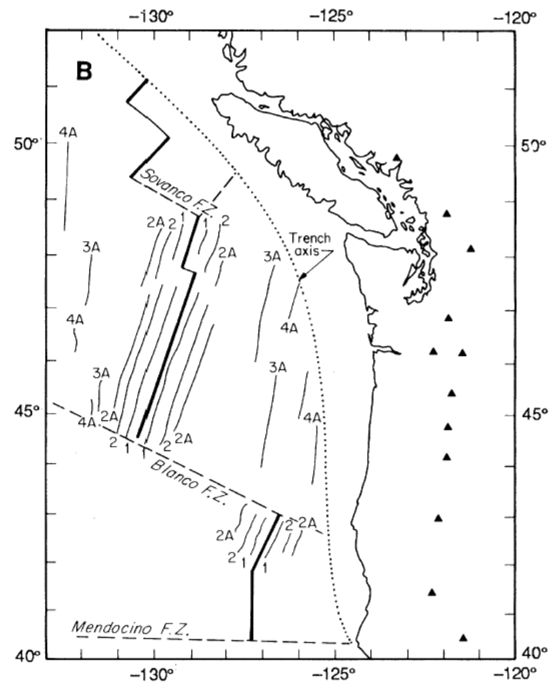


Earthquake Hazards on the Cascadia Subduction Zone

Thomas H. Heaton and Stephen H. Hartzell (1987)

Large subduction earthquakes on the Cascadia subduction zone pose a potential seismic hazard. Very young oceanic lithosphere (10 million years old) is being subducted beneath North America at a rate of approximately 4 centimeters per year. The Cascadia subduction zone shares many characteristics with subduction zones in southern Chile, southwestern Japan, and Colombia,





Similarities between Southern Chile trench and Cascadia:

Is subduction of young crust a predictor of large earthquakes?

(But, 120 Ma crust involved in Japan 2011)

THE NEW YORKER

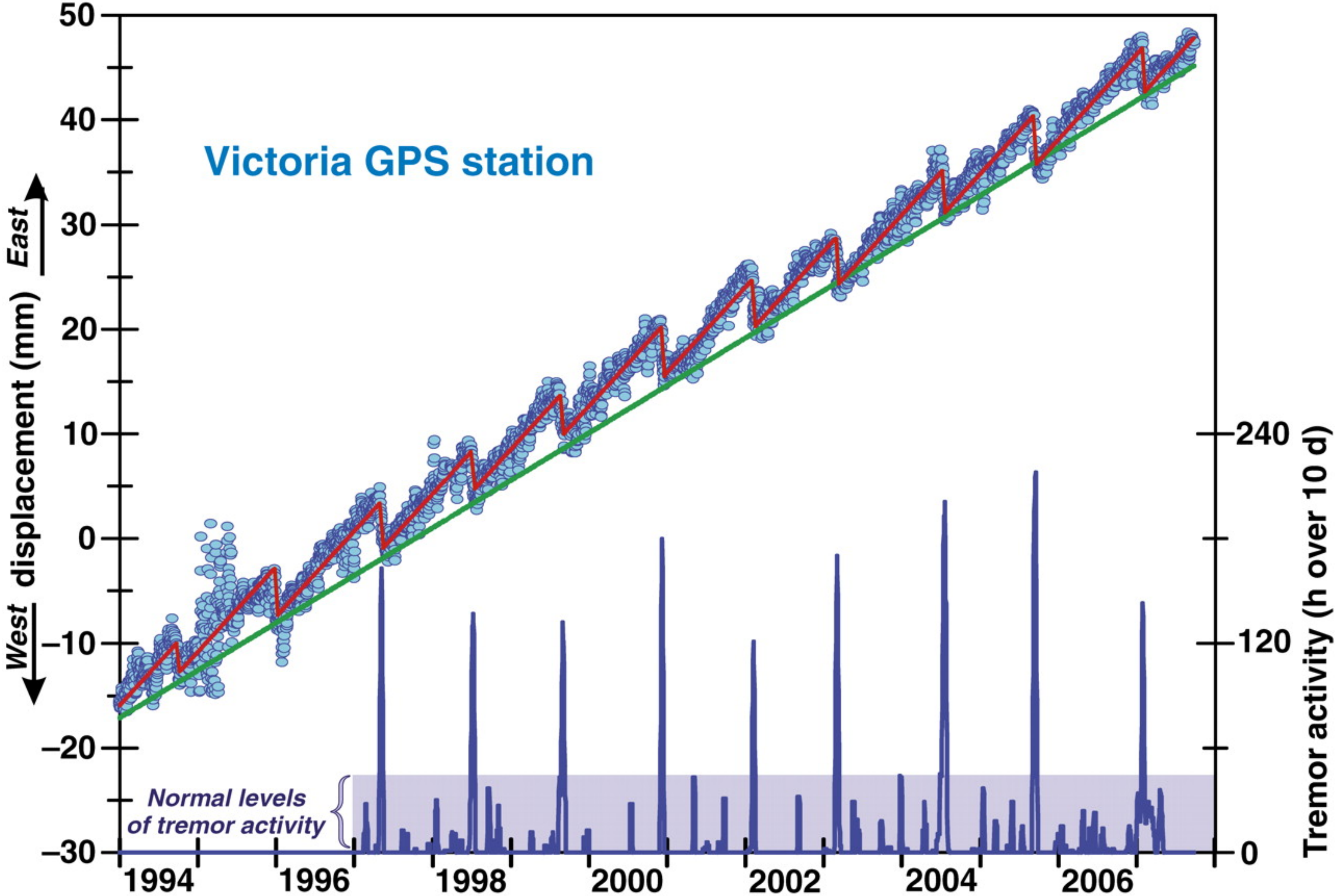
THE REALLY BIG ONE

An earthquake will destroy a sizable portion of the coastal Northwest. The question is when.

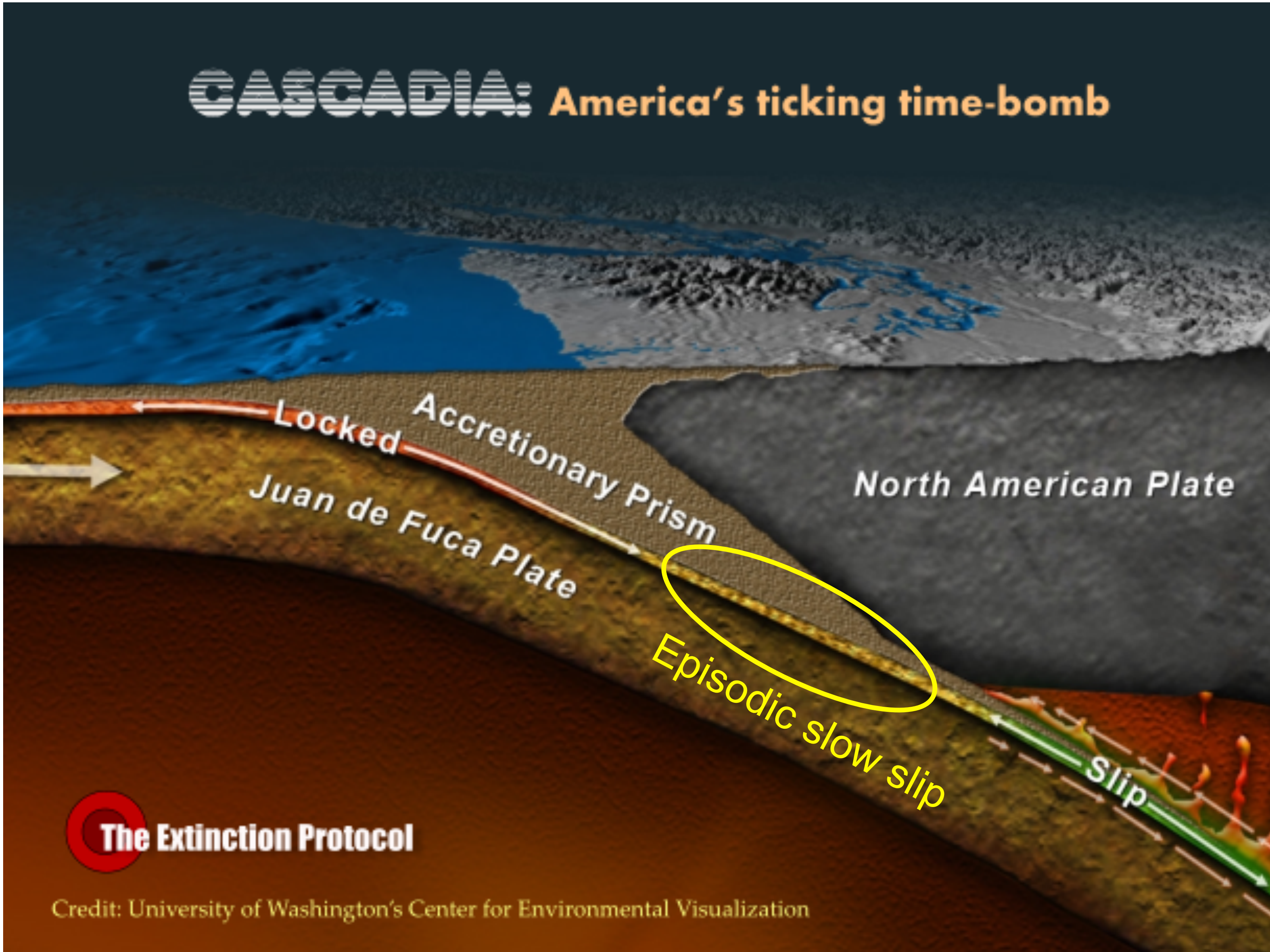
By Kathryn Schulz

When the 2011 earthquake and tsunami struck Tohoku, Japan, Chris Goldfinger was two hundred miles away, in the city of Kashiwa, at an international meeting on seismology. As the shaking started, everyone in the room began to laugh. Earthquakes are common in Japan—that one was the third of the week—and the participants were, after all, at a seismology conference. Then everyone in the room checked the time.

Slow slip and tremor



Rogers and Dragert


CASCADIA: America's ticking time-bomb
Locked
Accretionary Prism
North American Plate
Juan de Fuca Plate
Episodic slow slip
Slip
The Extinction Protocol
Credit: University of Washington's Center for Environmental Visualization

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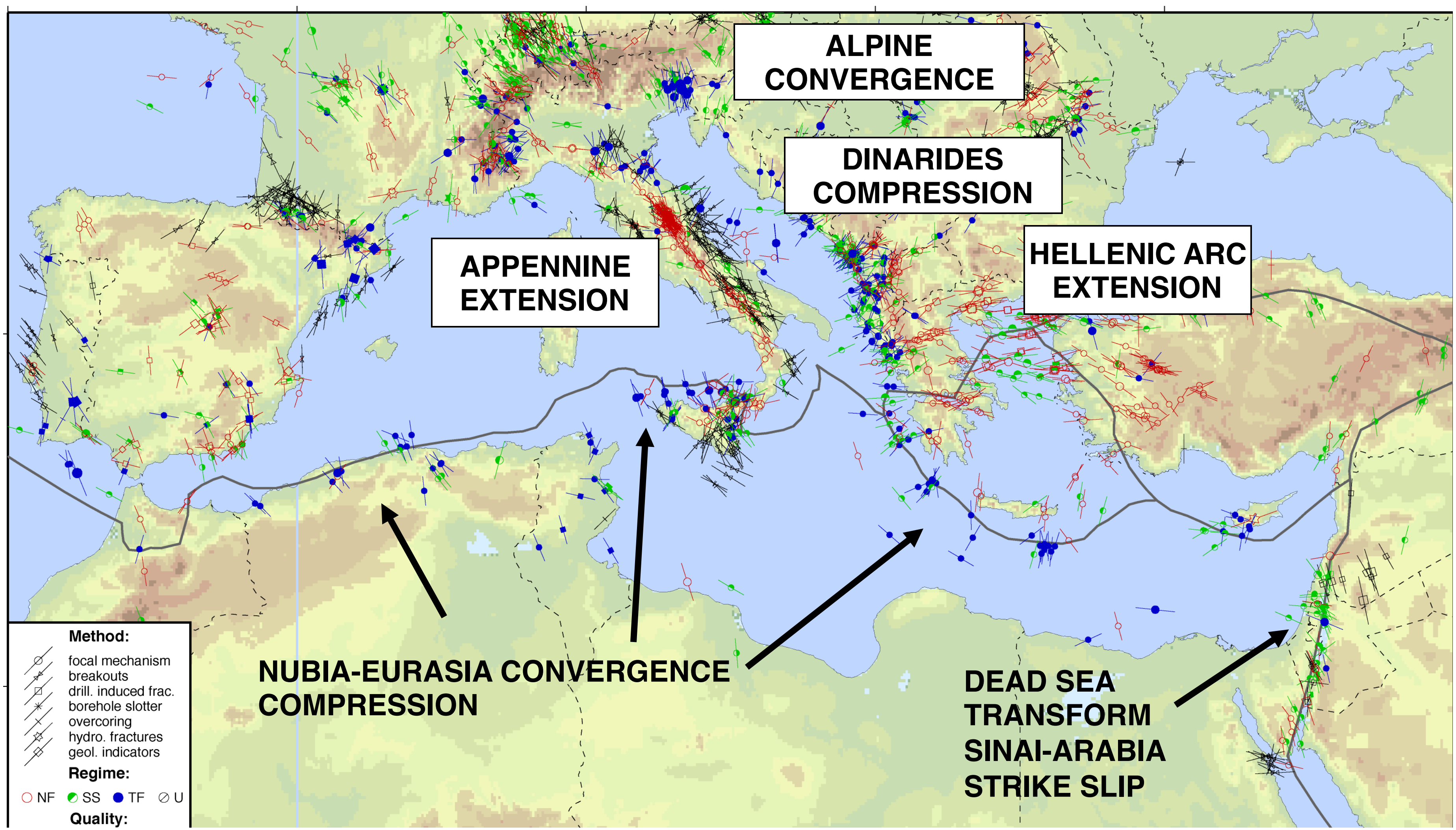
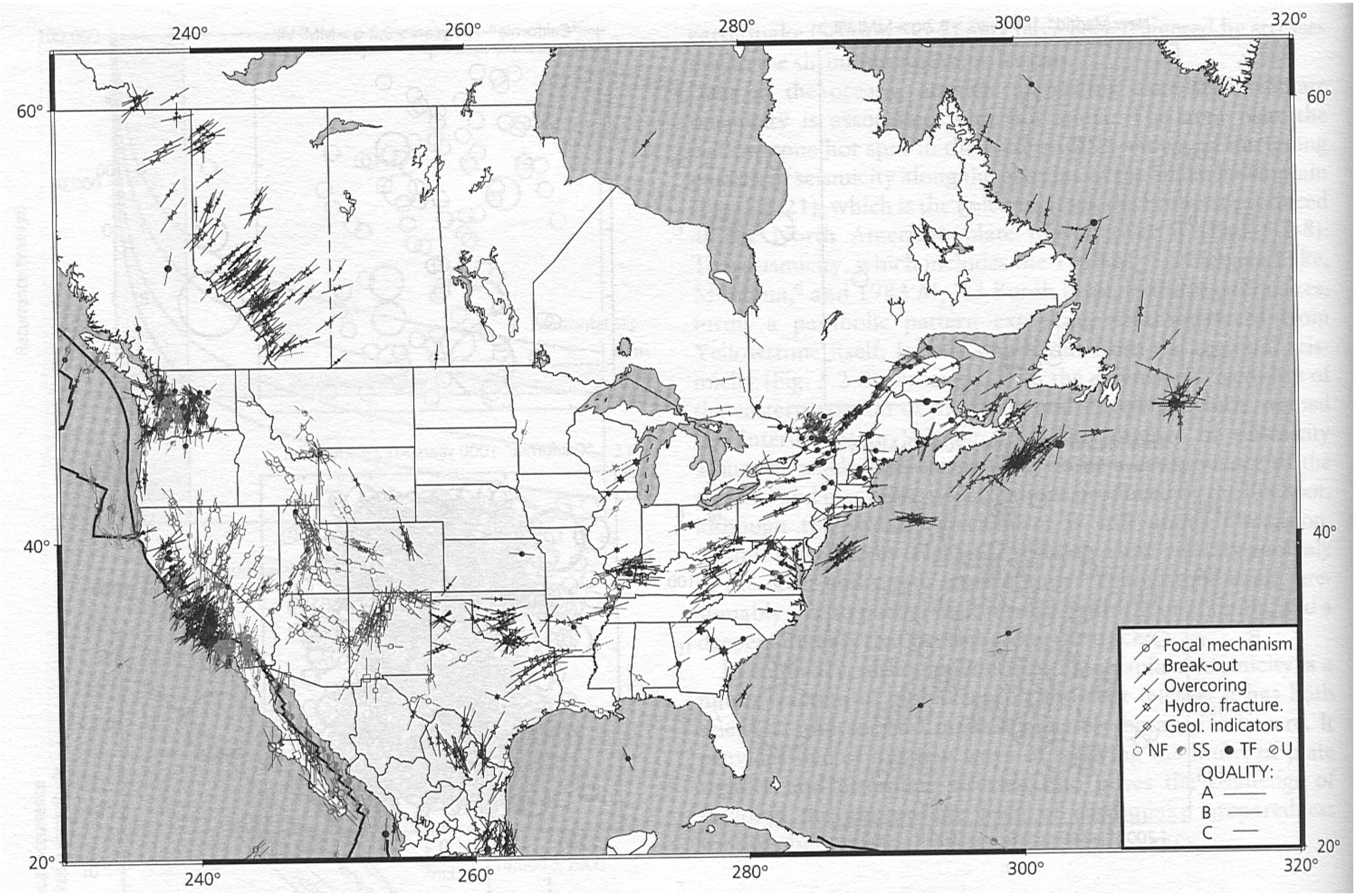
WORLD STRESS MAP Combines earthquake mechanisms & other stress indicators



US stress map



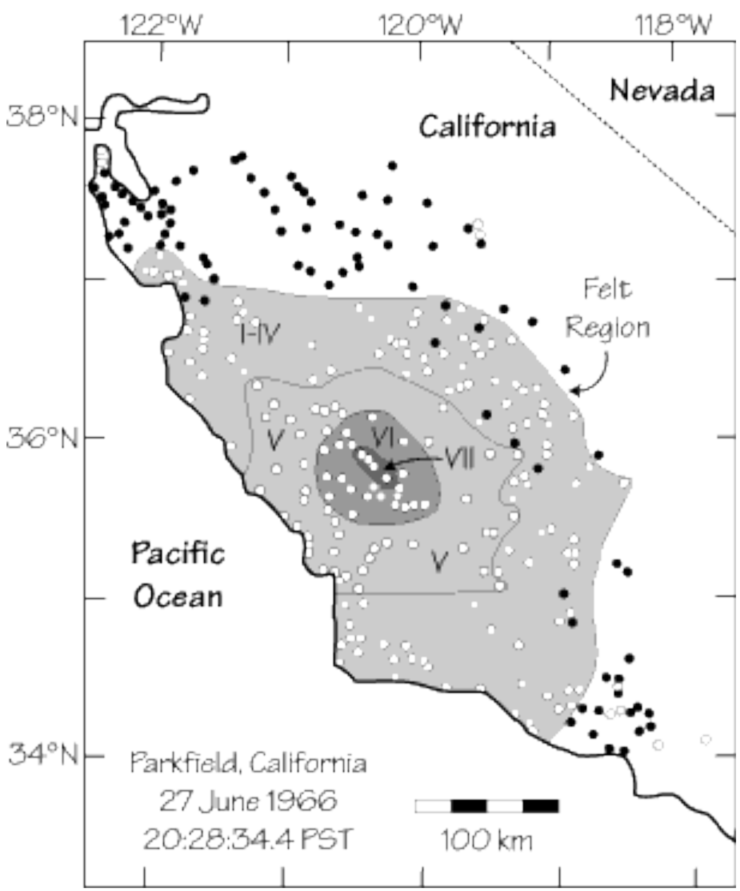
How do we measure the earthquake size?

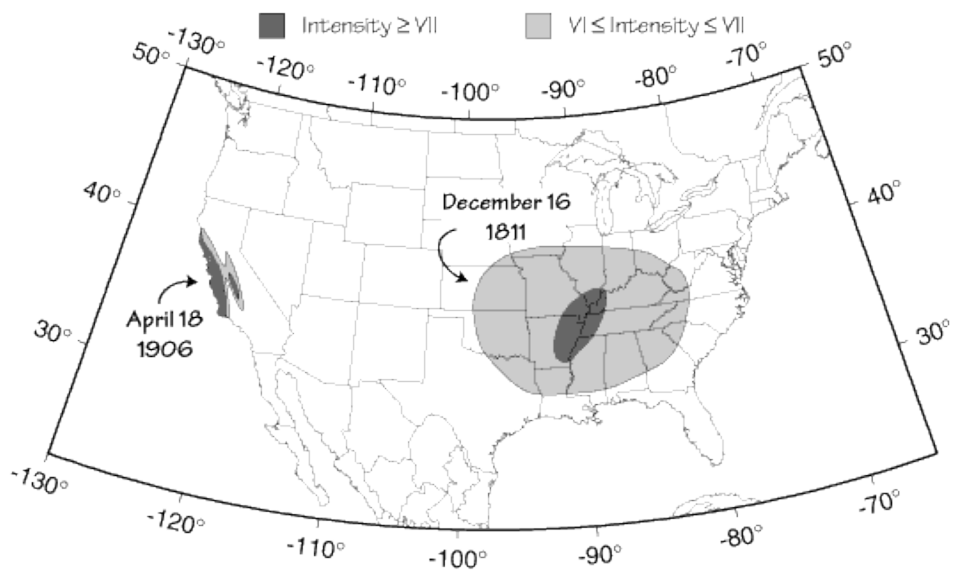
Imperceptible … Total Destruction

I II III IV V VI VII VIII IX X XI XII

Modified Mercalli Scale

- Intensity: based on damage

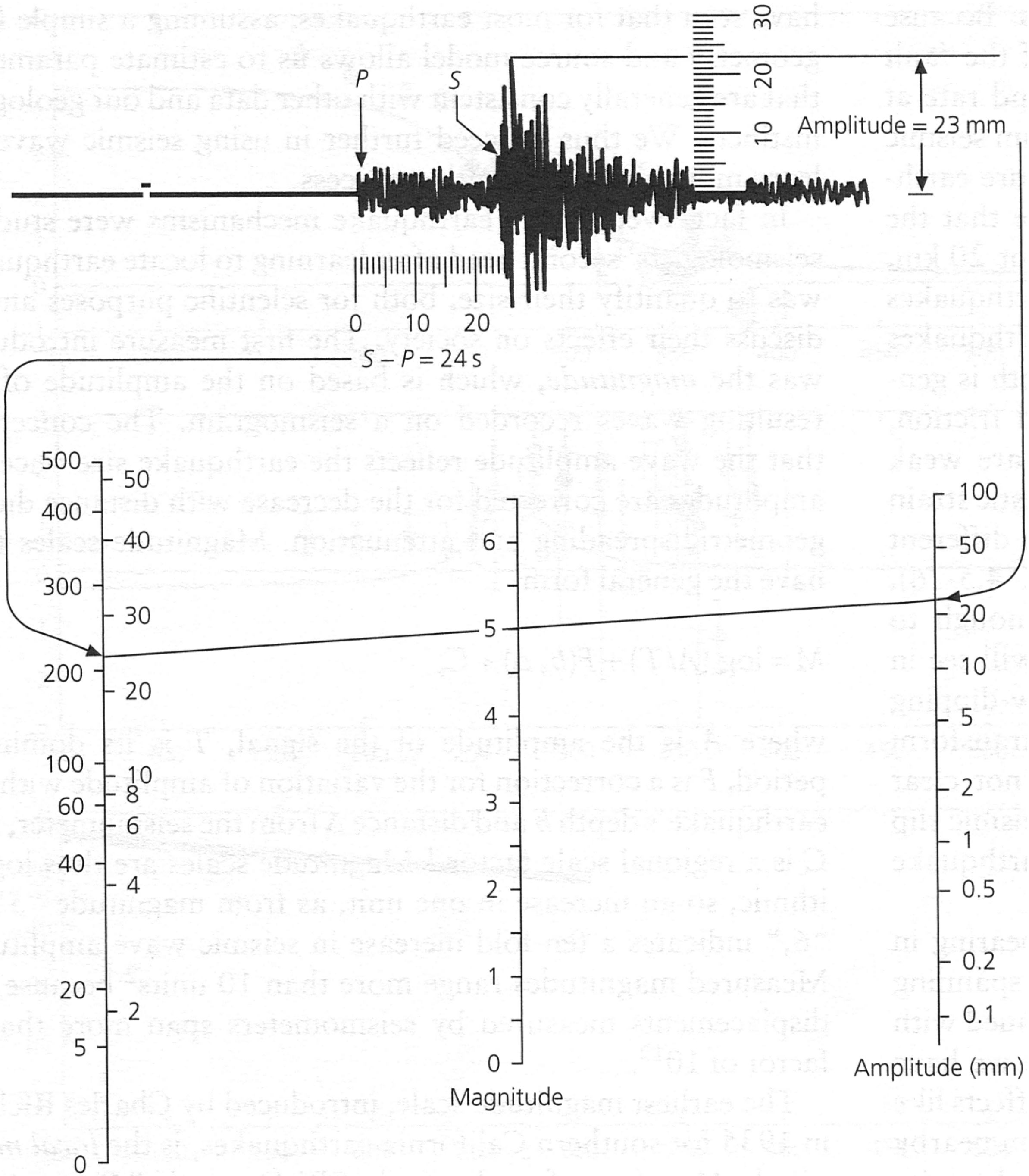




How do we measure the earthquake size?

- Intensity: based on damage
- Magnitude (Richter scale)

L.A. story


P
S
30
20
10
Amplitude = 23 mm
0
10
20
S – P = 24 s
500
400
300
200
100
60
40
20
5
0
50
40
30
20
10
8
6
4
2
6
5
4
3
2
1
0
Magnitude
100
50
20
10
5
2
1
0.5
0.2
0.1
Amplitude (mm)

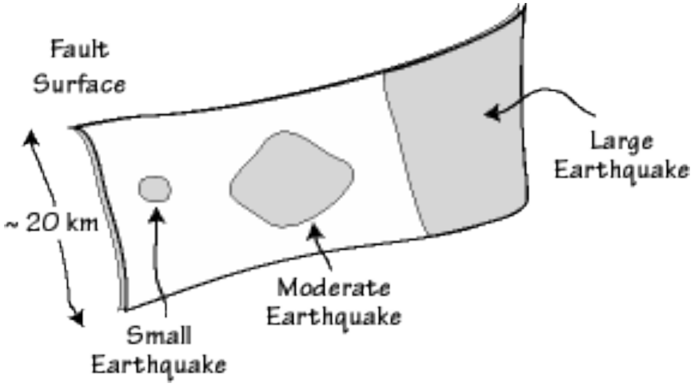
How do we measure the earthquake size?

- Intensity: based on damage
- Magnitude: $M = \log(\text{amplitude}) + a\Delta + b$

Maximum Intensity	I–II	III	IV–V	VI	VII	IX–X	XI	XII
Magnitude	2.0	3.0	4.0	5.0	6.0	7.0	8.0	8.5

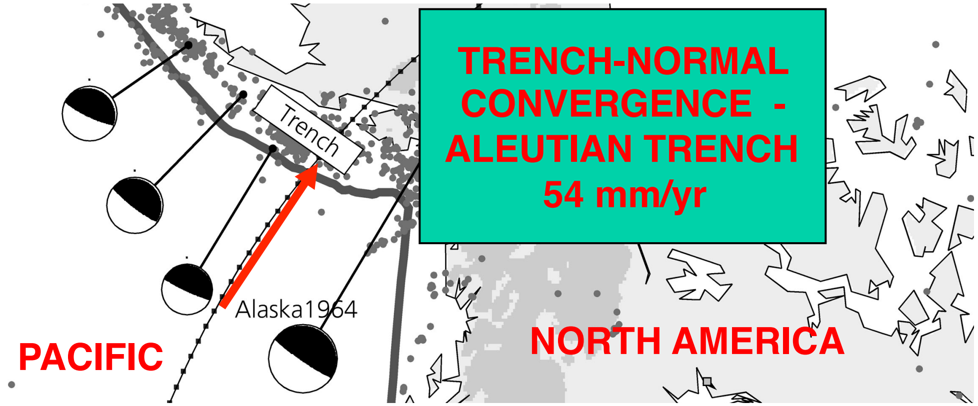
How do we measure the earthquake size?

- Intensity: based on damage
- Magnitude: M = log(amplitude) + aΔ + b
- Moment: Mo = shear modulus X rupture area X offset



1964 ALASKA EARTHQUAKE
M_s 8.4 M_w 9.1

Pacific subduction beneath North America



~ 7 m of slip on 500x300 km^2 of Aleutian Trench

Second largest earthquake recorded until Indonesia (2004) and Japan (2011) quakes

~ 130 deaths

Catalyzed idea that great thrust fault earthquakes result from slip on subduction zone plate interface

1971 M_s 6.6 SAN FERNANDO EARTHQUAKE

1.4 m slip on 20x14 km^2 fault

Thrust faulting from compression across Los Angeles Basin

Fault had not been previously recognized

65 deaths, in part due to structural failure

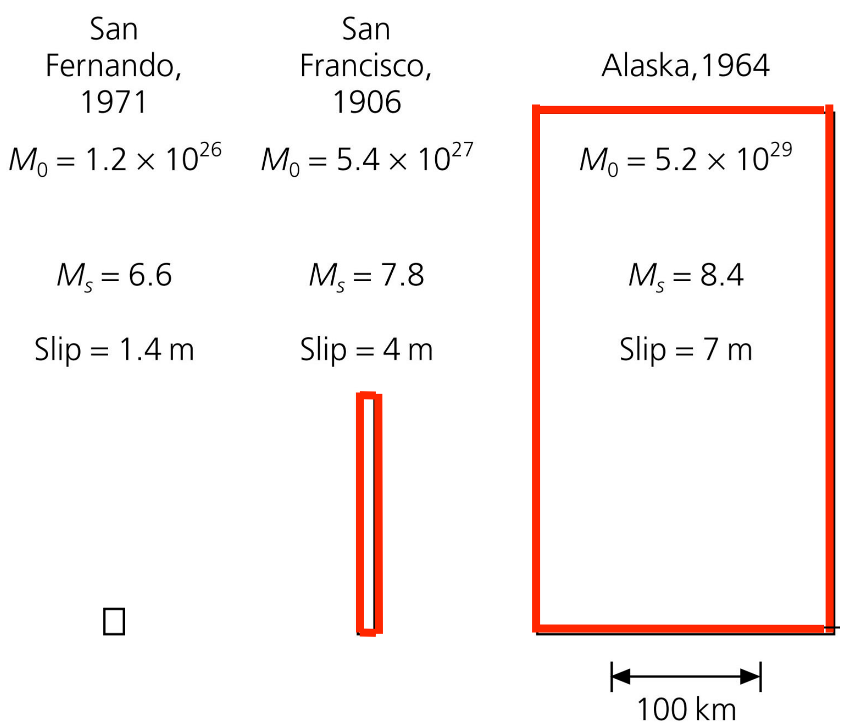
Prompted improvements in building code & hazard mapping

COMPARE EARTHQUAKES USING SEISMIC MOMENT M_0

$$M_0 = \mu \bar{D} S$$

$$\bar{D} = \text{average slip (dislocation)}$$

$$S = \text{"average" fault area}$$



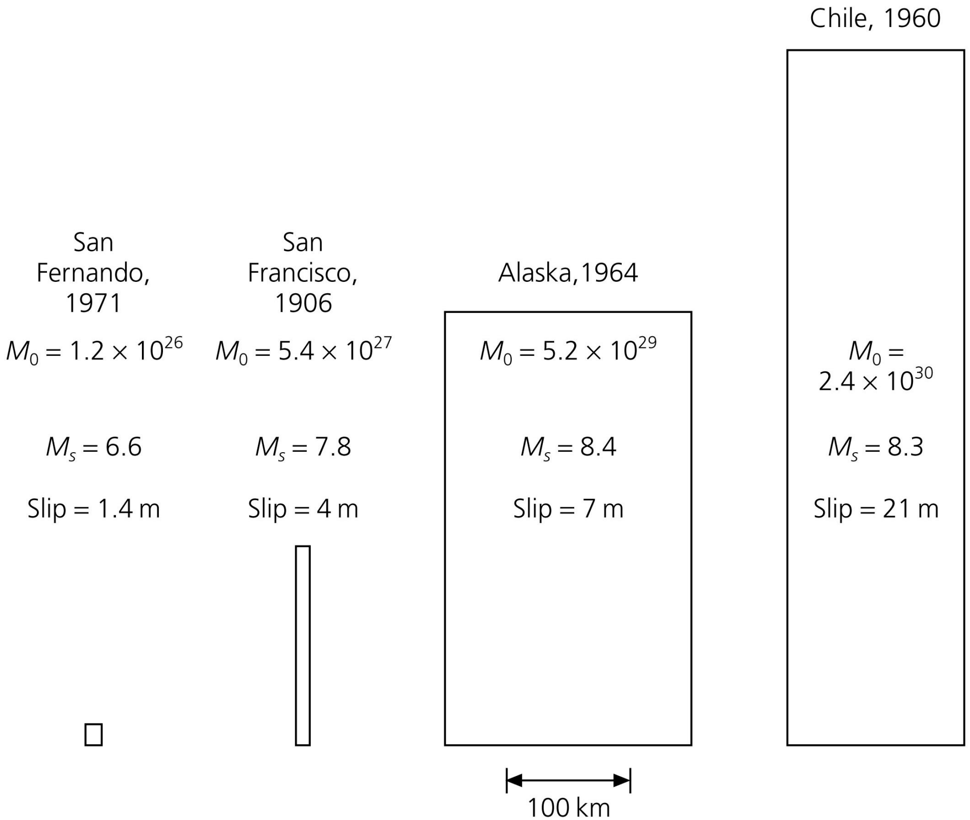
Magnitudes, moments (dyn-cm), fault areas, and fault slips for several earthquakes

Alaska & San Francisco differ much more than M_s implies

M_0 more useful measure

Units: dyne-cm or N-m

Directly tied to fault physics



Moment magnitude M_w

Magnitudes saturate:

No matter how big the earthquake

m_b never exceeds ~6.4

M_s never exceeds ~8.4

M_w defined from moment so never saturates

Moment magnitude:

$$M_w = \frac{\log M_0}{1.5} - 10.73$$

(with M_0 in dyn-cm)

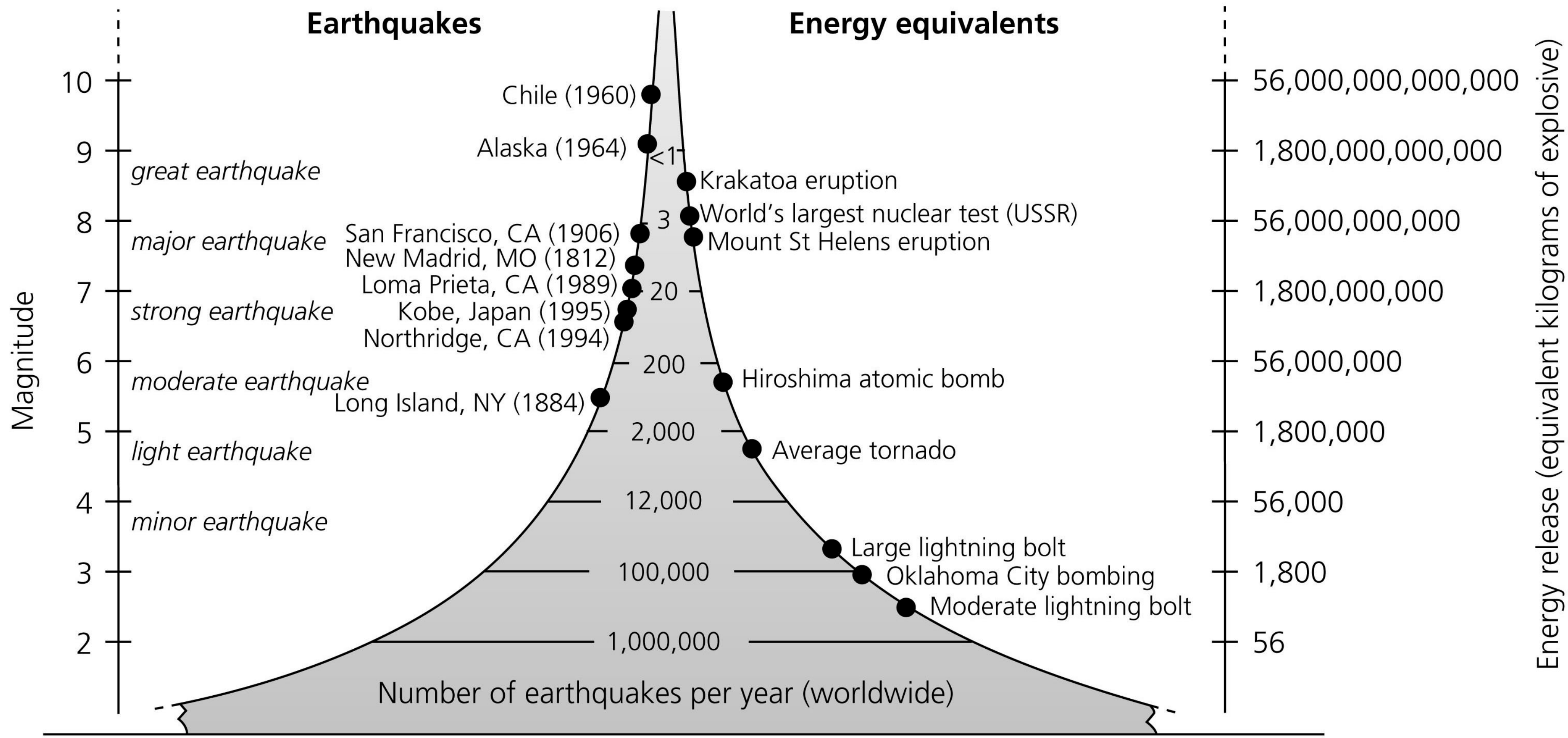
note units!

Earthquake	Body wave magnitude m_b	Surface wave magnitude M_s	Fault area (km^2) length × width	Average dislocation (m)	Moment (dyn-cm) M_0	Moment magnitude M_w
Truckee, 1966	5.4	5.9	10 × 10	0.3	8.3×10^{24}	5.8
San Fernando, 1971	6.2	6.6	20 × 14	1.4	1.2×10^{26}	6.7
Loma Prieta, 1989	6.2	7.1	40 × 15	1.7	3.0×10^{26}	6.9
San Francisco, 1906		8.2	320 × 15	4	6.0×10^{27}	7.8
Alaska, 1964	6.2	8.4	500 × 300	7	5.2×10^{29}	9.1
Chile, 1960		8.3	800 × 200	21	2.4×10^{30}	9.5

How do we measure the earthquake size?

- Intensity: based on damage
- Magnitude: $M = \log(\text{amplitude}) + a\Delta + b$
- Moment: Mo = shear modulus X rupture area X offset
- Energy: $\log(E) = 1.5\,M + 5.2$

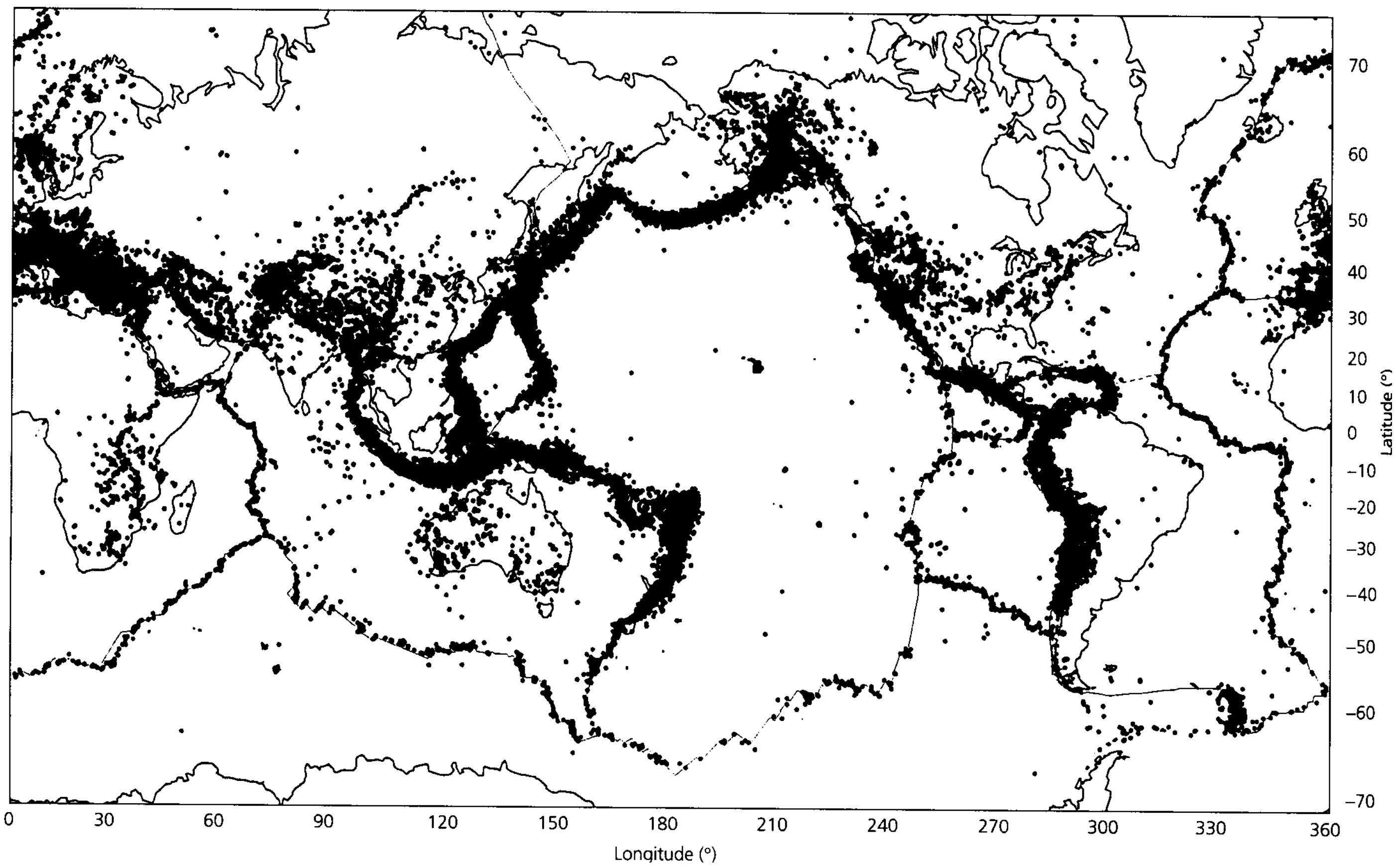
Comparison of frequency, magnitude, and energy release.



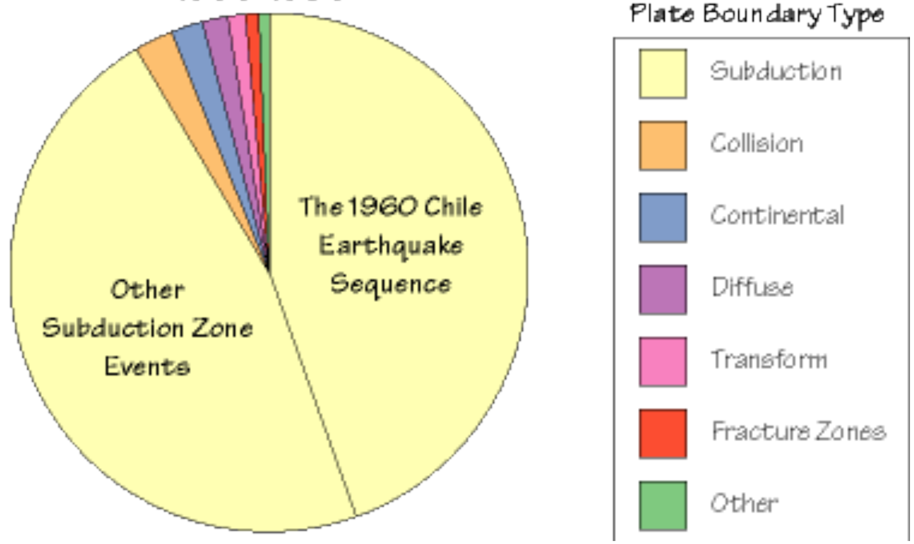
Earthquakes of a given magnitude are ~10 times less frequent than those one magnitude smaller. An M7 earthquake occurs approximately monthly, and an earthquake of M> 6 about every three days. Hence although earthquake predictor I. Browning claimed to have predicted the 1989 Loma Prieta earthquake, he said that near a date there would be an M6 earthquake somewhere, a prediction virtually guaranteed to be true.

Magnitude is proportional to the logarithm of the energy released, so most energy released seismically is in the largest earthquakes. An M 8.5 event releases more energy than all other earthquakes in a year combined. Hence the hazard from earthquakes is due primarily to large (typically magnitude > 6.5) earthquakes.

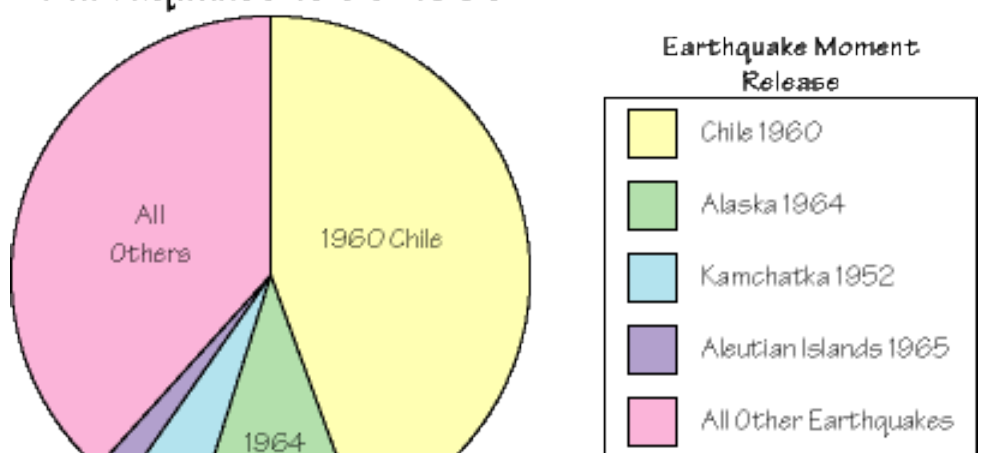
Where is most of seismic energy released?



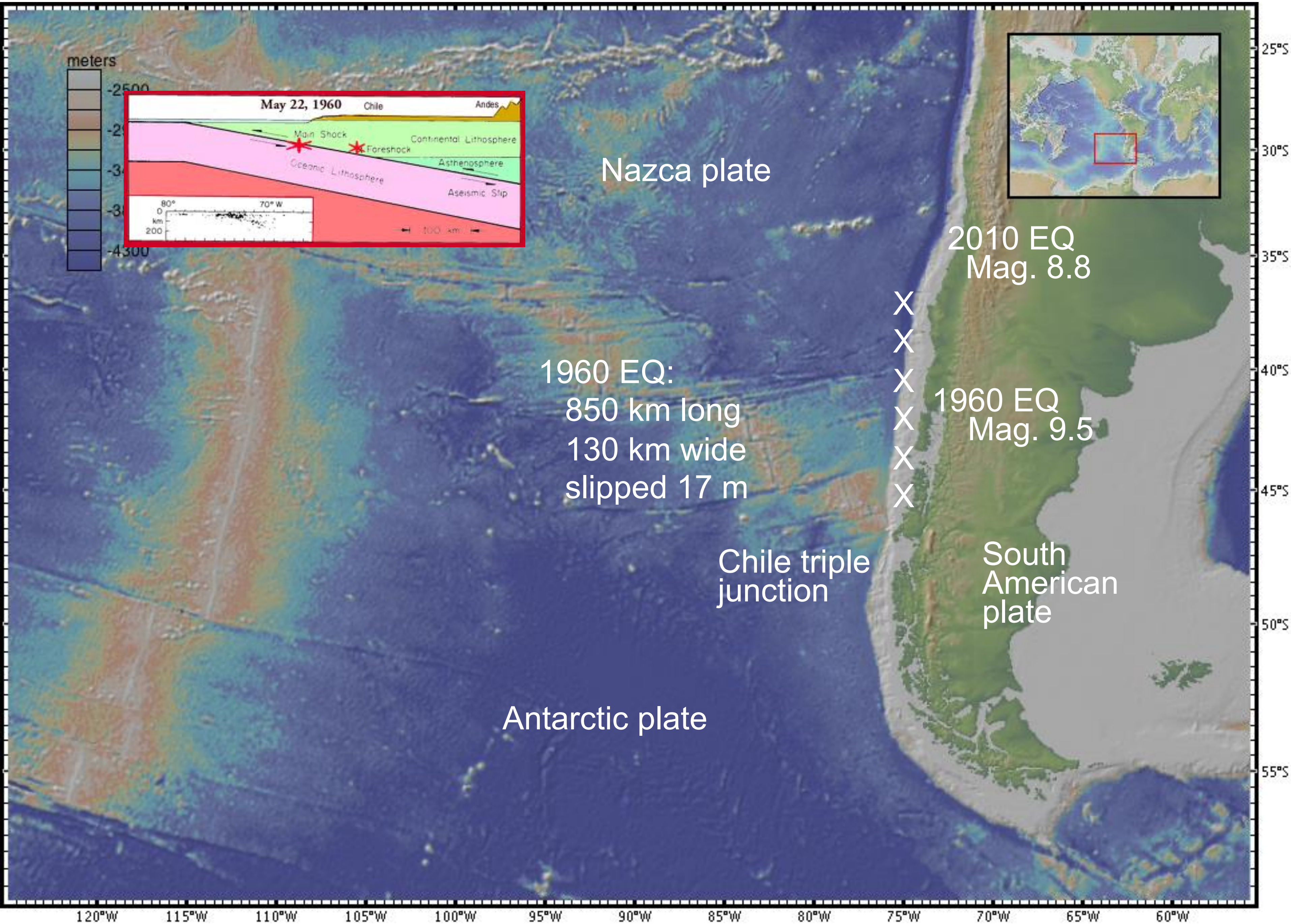
Shallow Earthquake Moment Release 1900-1989

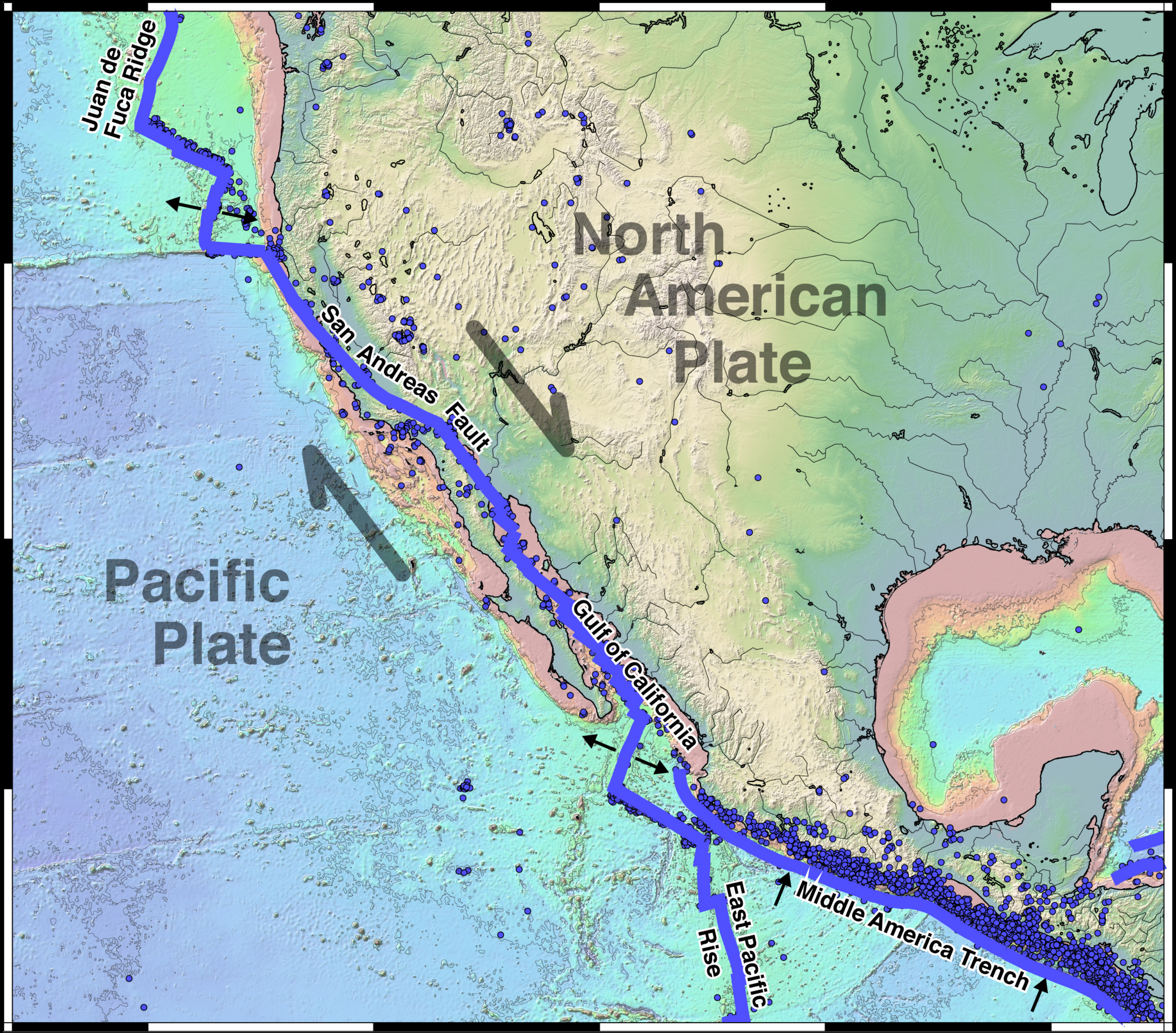


Giant Shallow Earthquakes 1900-1998

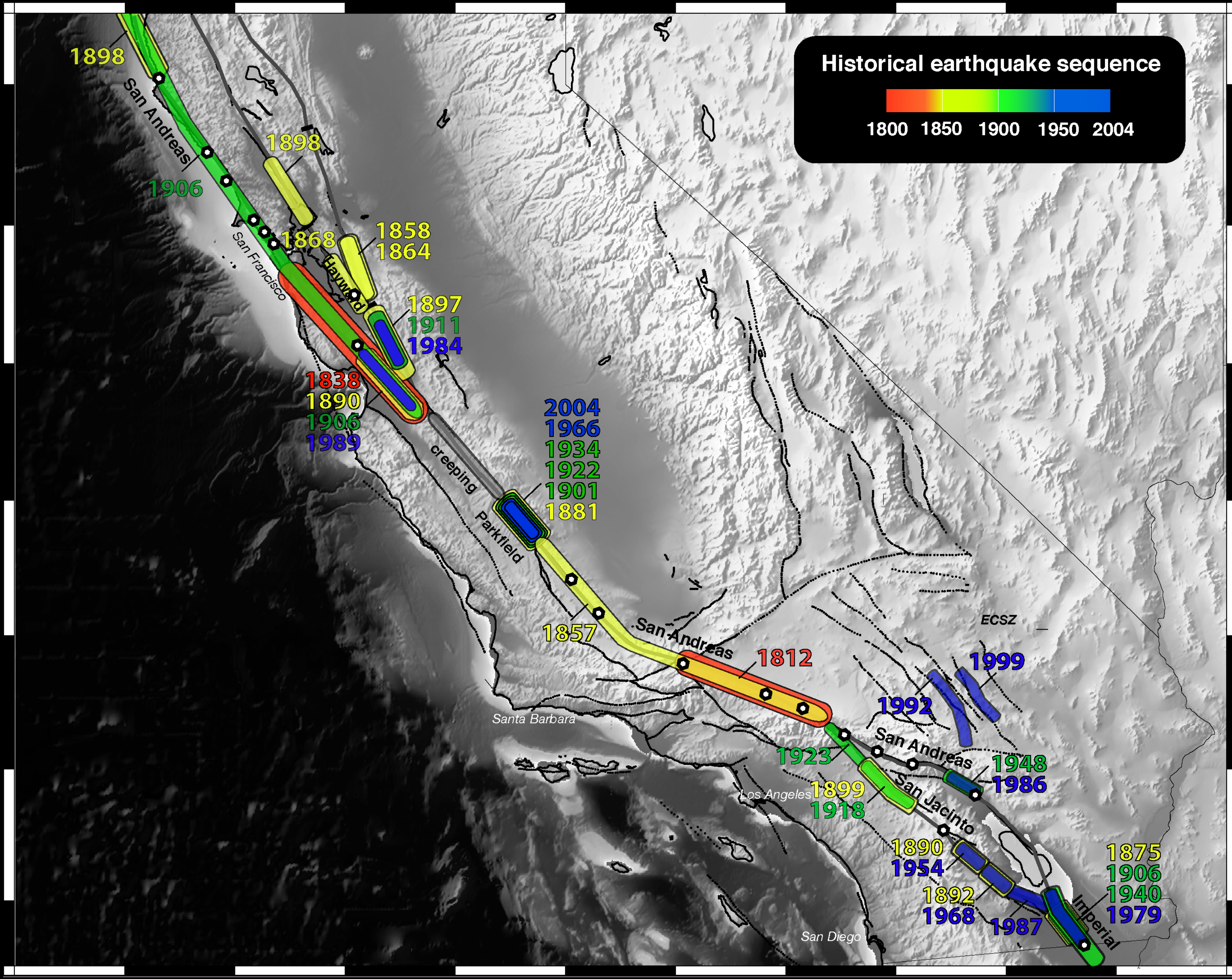


Source: Pacheco and Sykes, 1992

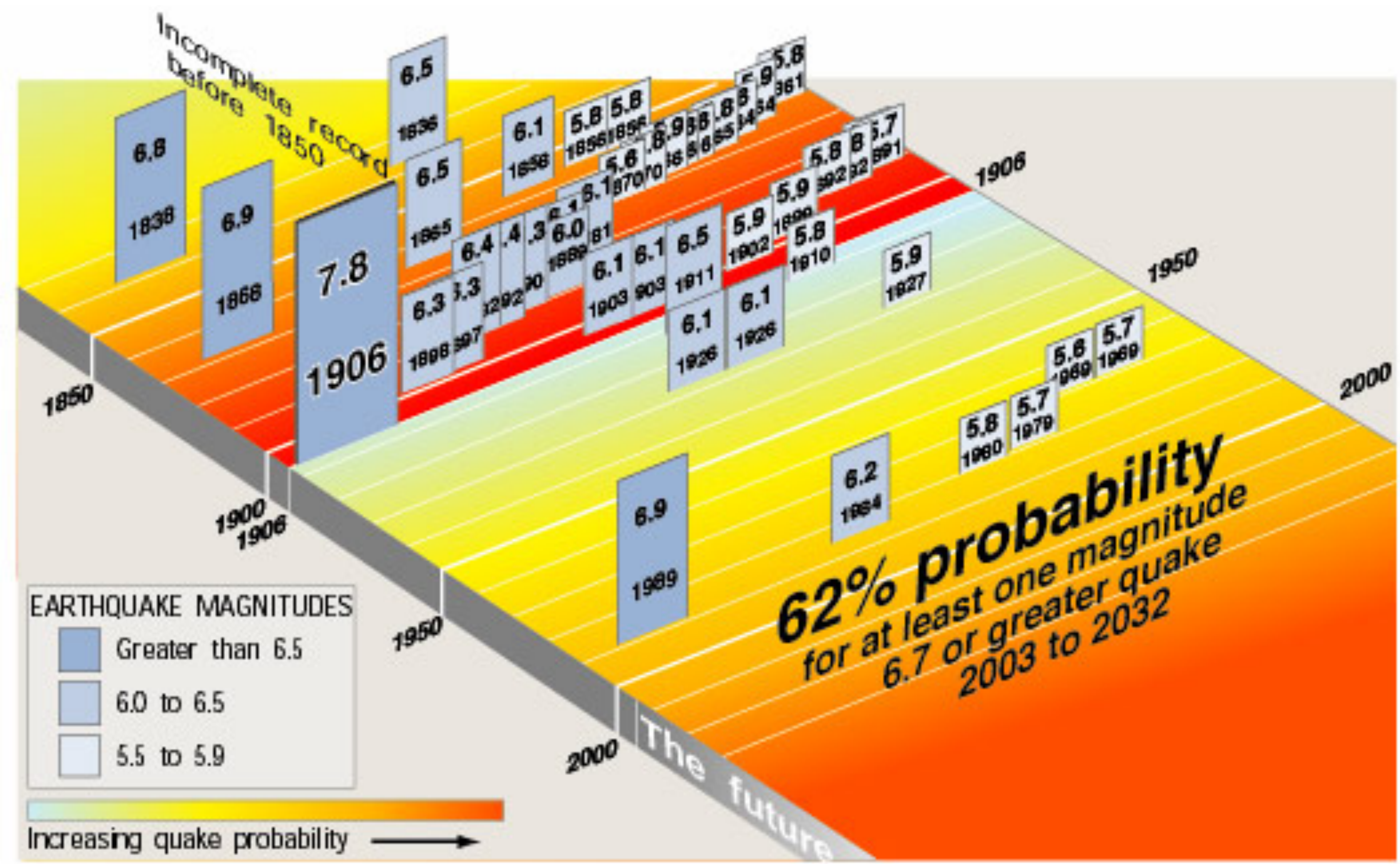

meters
-2500
-4300
May 22, 1960
Chile
Andes
Main Shock
Foreshock
Continental Lithosphere
Asthenosphere
Oceanic Lithosphere
Aseismic Slip
100 km
80°
70° W
0
km
200
Nazca plate
2010 EQ
Mag. 8.8
1960 EQ:
850 km long
130 km wide
slipped 17 m
1960 EQ
Mag. 9.5
X
X
X
X
X
X
Chile triple
junction
South
American
plate
Antarctic plate
25°S
30°S
35°S
40°S
45°S
50°S
55°S
120°W
115°W
110°W
105°W
100°W
95°W
90°W
85°W
80°W
75°W
70°W
65°W
60°W


Juan de Fuca Ridge
North American Plate
San Andreas Fault
Pacific Plate
Gulf of California
East Pacific Rise
Middle America Trench

Pre-historical Earthquakes (1000-1800)

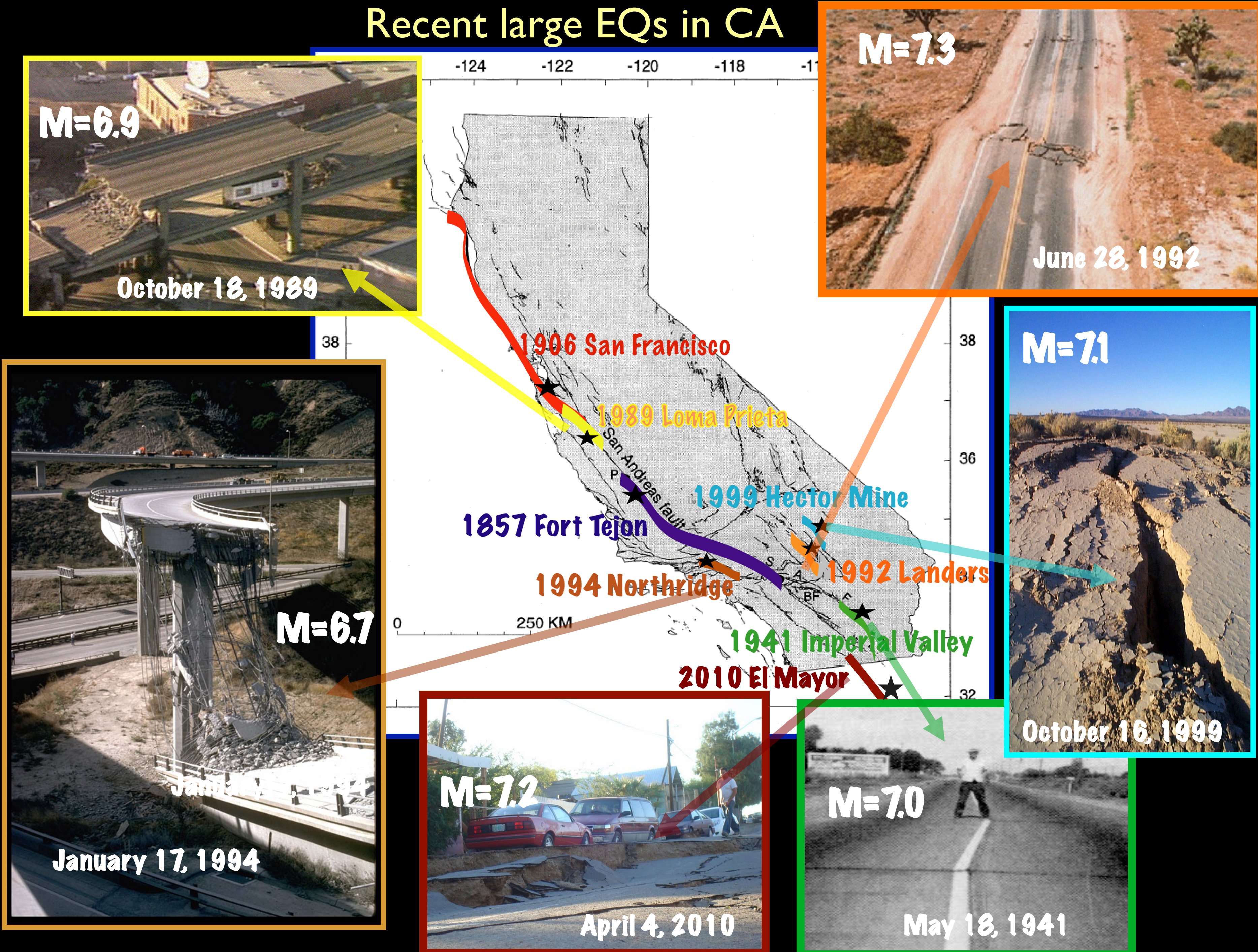


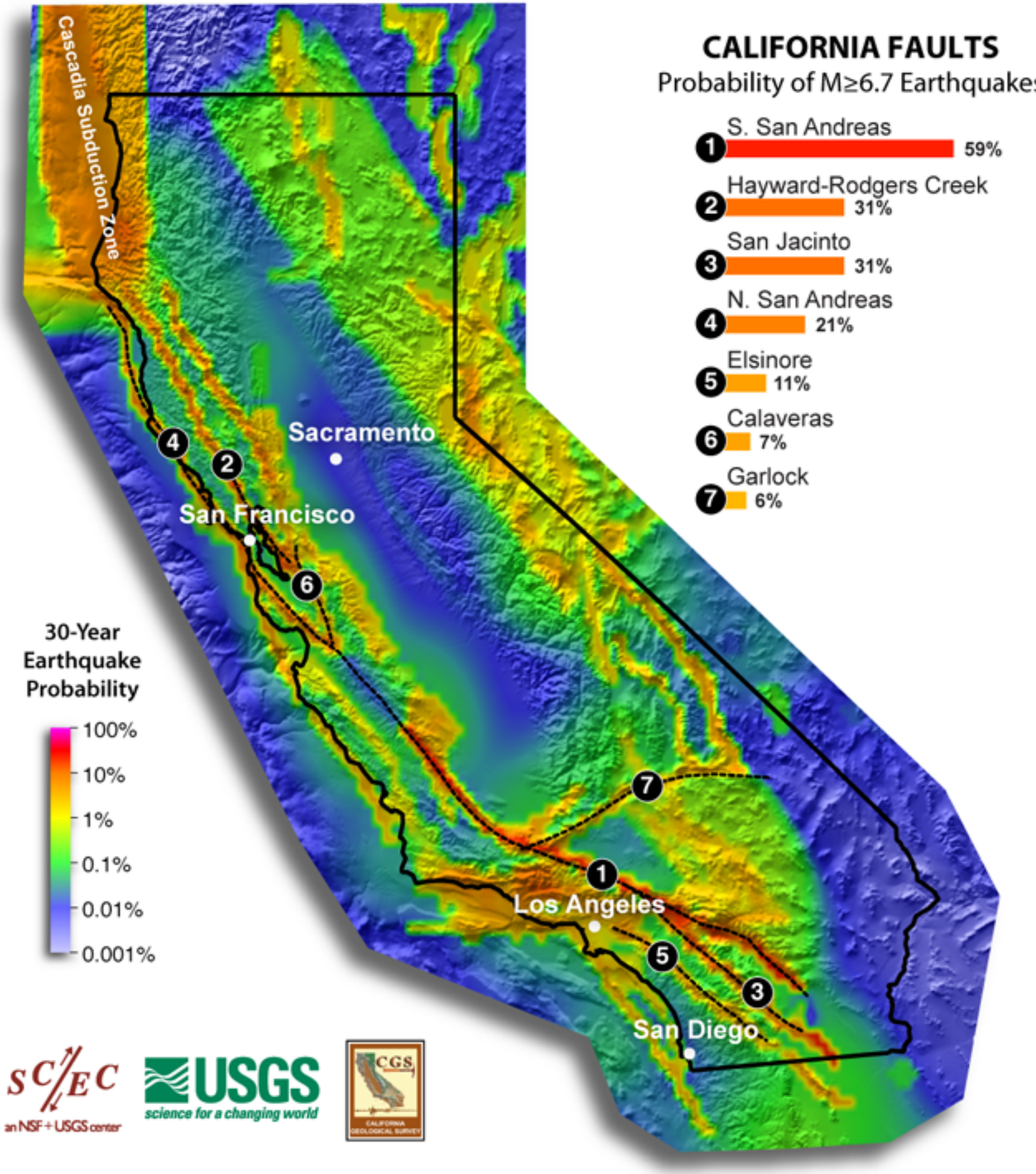
Significant earthquakes in the San Francisco Bay Area: before and after 1906

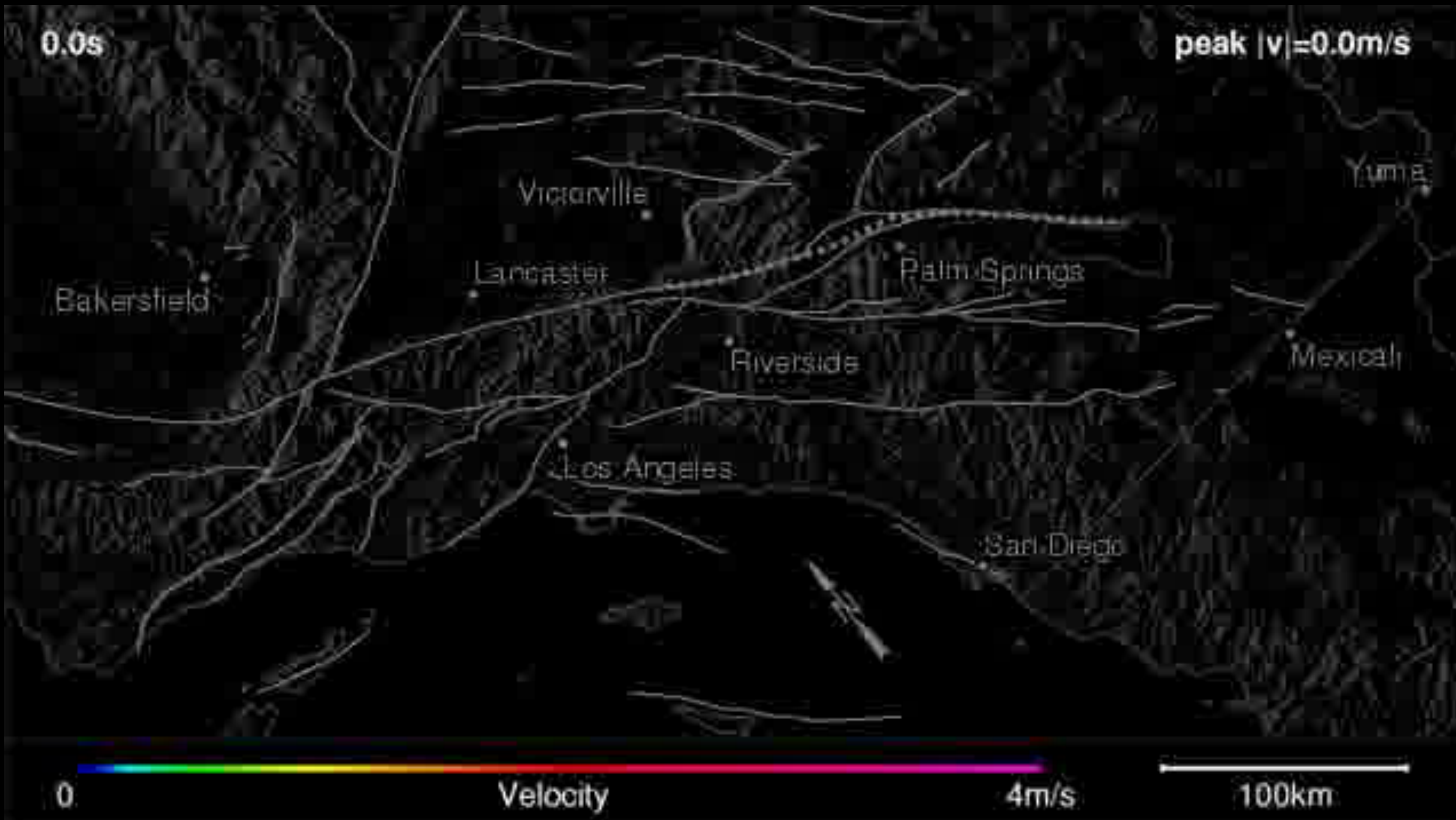


Bakun, 1999

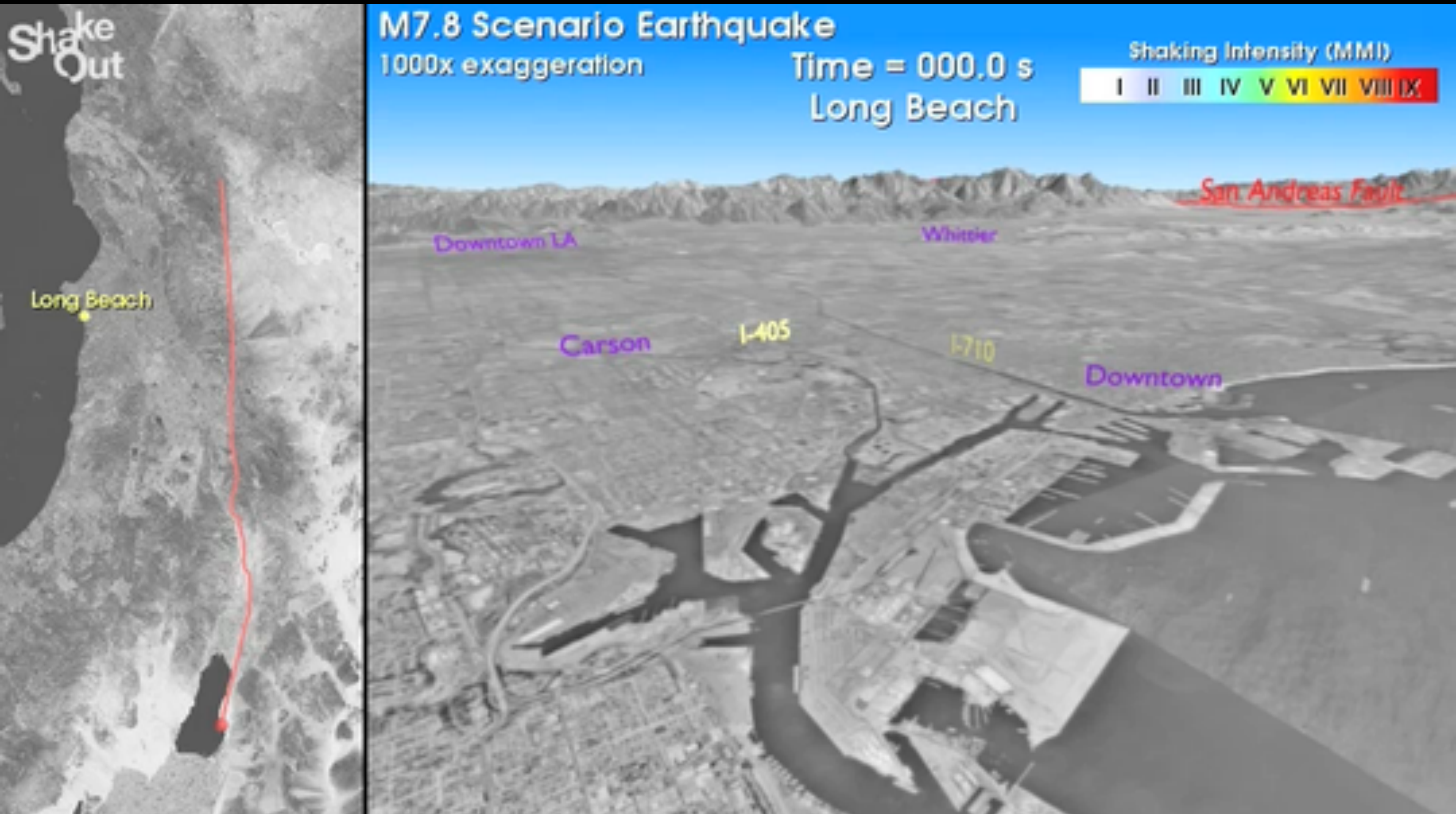
Recent large EQs in CA




CALIFORNIA FAULTS
Probability of M≥6.7 Earthquakes
1 S. San Andreas 59%
2 Hayward-Rodgers Creek 31%
3 San Jacinto 31%
4 N. San Andreas 21%
5 Elsinore 11%
6 Calaveras 7%
7 Garlock 6%
Cascadia Subduction Zone
Sacramento
San Francisco
Los Angeles
San Diego
30-Year Earthquake Probability
100%
10%
1%
0.1%
0.01%
0.001%
SCEC an NSF + USGS center
USGS science for a changing world
CGS


0.0s
peak |v|=0.0m/s
Victorville
Yuma
Bakersfield
Lancaster
Palm Springs
Riverside
Mexicali
Los Angeles
San Diego
0
Velocity
4m/s
100km

Simulation of Ground Motion



NUCLEATION

Loma Prieta strong shaking lasted < 15 seconds…

Onset and Duration of Shaking

Location	Seconds after start of earth-quake that strong shaking begins at this location	Seconds after start of earthquake that strong shaking ends at this location	Duration of very strong shaking
Palm Springs	25	60	35 sec
San Bernardino	45	75	30 sec
Los Angeles (downtown)	70	125	55 sec
Orange County	70	105	35 sec
Santa Monica	85	150	65 sec
Palmdale	75	90	15 sec
Ventura	105	160	55 sec

ShakeOut Scenario "Disaster Equation"

Widespread Strong Ground Shaking
+ Shaking of Long Duration =

300,000 buildings significantly damaged

Widespread infrastructure damage

$213 billion damages

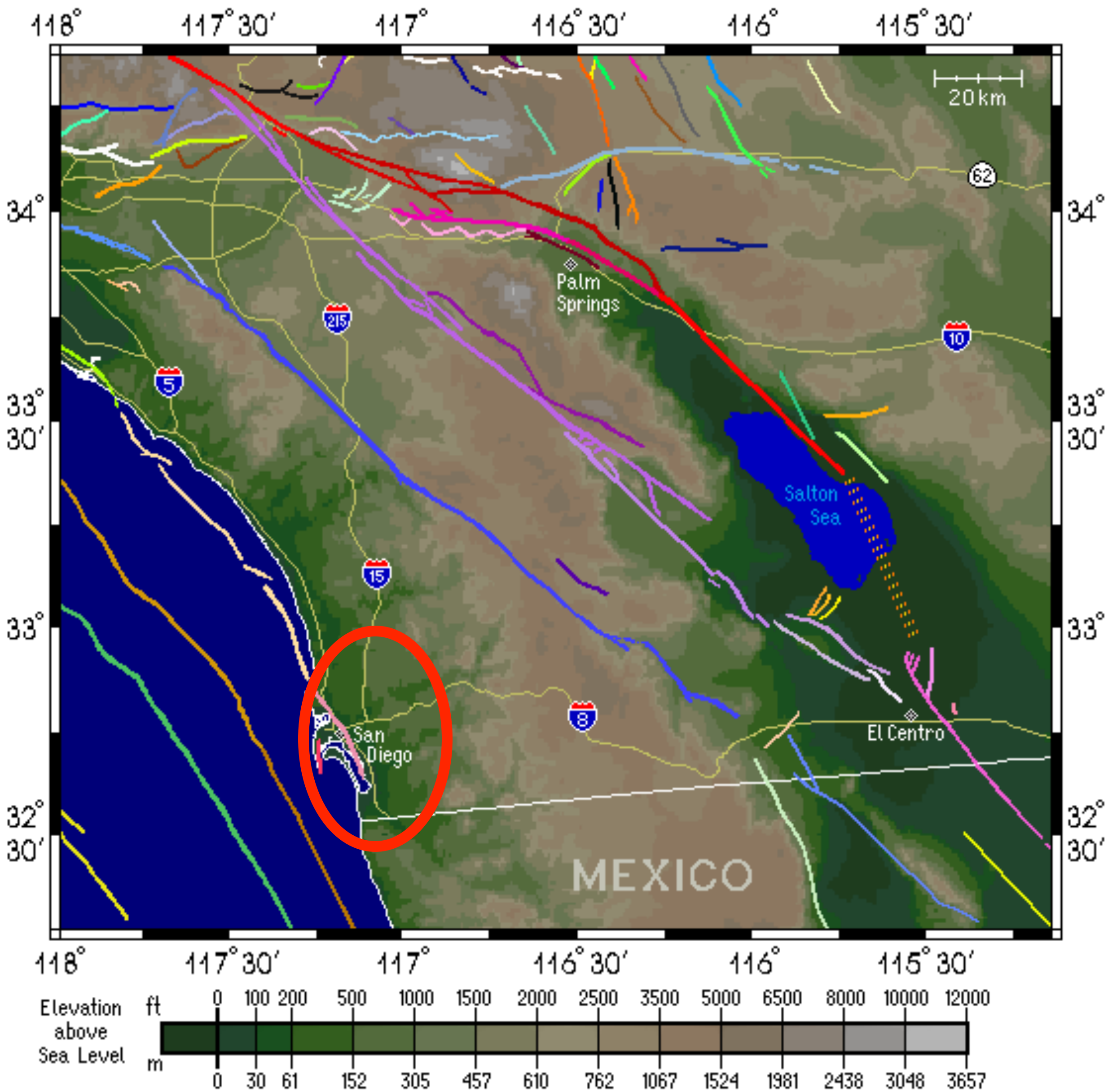
270,000 displaced persons

50,000 injuries

1,800 deaths

ShakeOut

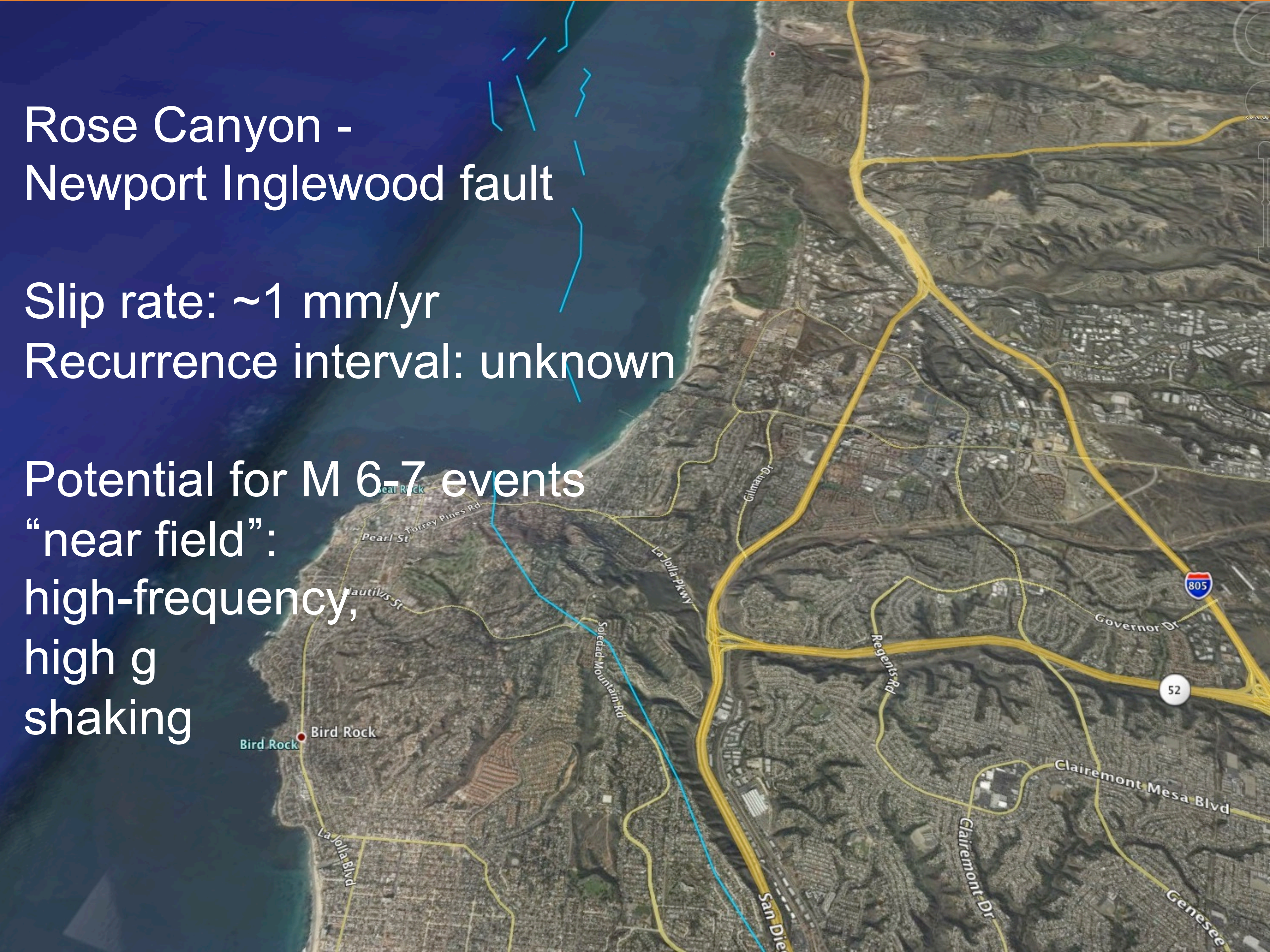
Local hazards



Rose Canyon - Newport Inglewood fault

Slip rate: ~1 mm/yr
Recurrence interval: unknown

Potential for M 6-7 events
“near field”:
high-frequency,
high g
shaking



The Great Southern California ShakeOut

- Every Fall: ShakeOut drill
- 7th year
- A day of special events to inspire southern Californians to get ready for big earthquakes
  - millions of participants: schools, families, community groups, business, etc.
- www.shakeout.org