EARTHQUAKE HAZARDS & PREDICTION

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"Only fools and charlatans predict earthquakes"

Charles Richter

"It is hard to predict earthquakes, especially before they happen."

Hiroo Kanamori

Distinguish between hazards and risks for earthquakes or other natural disasters.

Hazard is natural occurrence of earthquakes and the resulting ground motion and other effects.

Risk is the danger the hazard poses to life and property.

High hazard areas can have low risk because few people live there, and modest hazard areas can have high risk due to large populations and poor construction.

MITIGATING EARTHQUAKE RISK

Figure 1.2-7: Building collapse during the Dec. 7, 1988, earthquake in Armenia.

Hazards can't be reduced by human actions - *but risks can.*

SAN FRANCISCO EARTHQUAKE
April 18, 1906

3000 deaths
28,000 buildings
destroyed
(most by fire)
$10B damage

"The whole street was undulating as if the waves of the ocean were coming toward me."

"I saw the whole city enveloped in a pile of dust caused by falling buildings."

"Inside of twelve hours half the heart of the city was gone"

EMERGENCY RESPONSE

Mayor formed citizen committee & took charge

Army immediately supported police & fire (how well?)

Prompt state, federal, & private aid

Displaced housed in tent cities with services

Free postal service provided

Tendency to blame fire rather than earthquake for damage

Eventually, earthquake damage accepted & safer buildings required

"If, as they say, God spanked the town for being over frisky

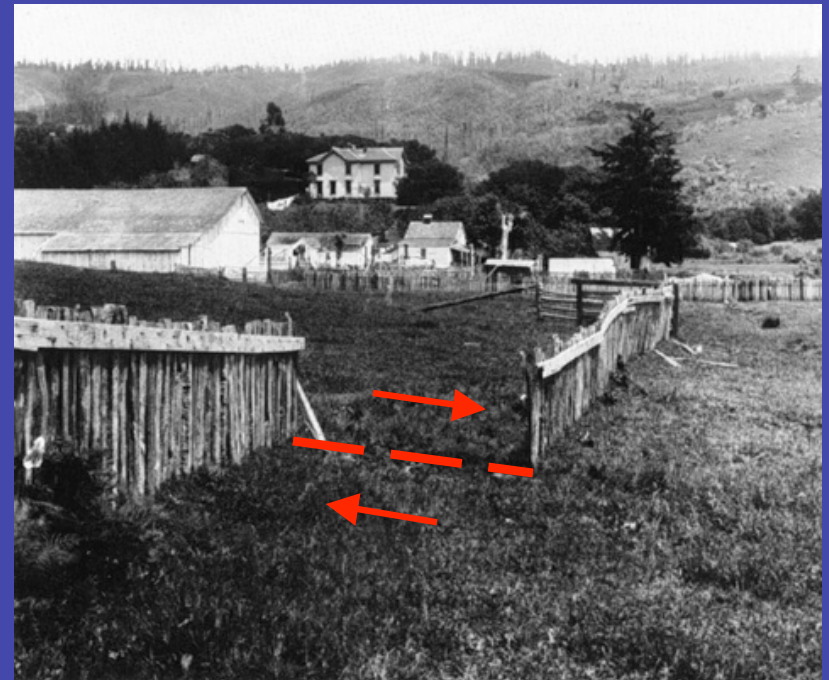Why did he burn the churches down and spare Hotaling's whiskey?"

What caused it?

What shook the buildings?
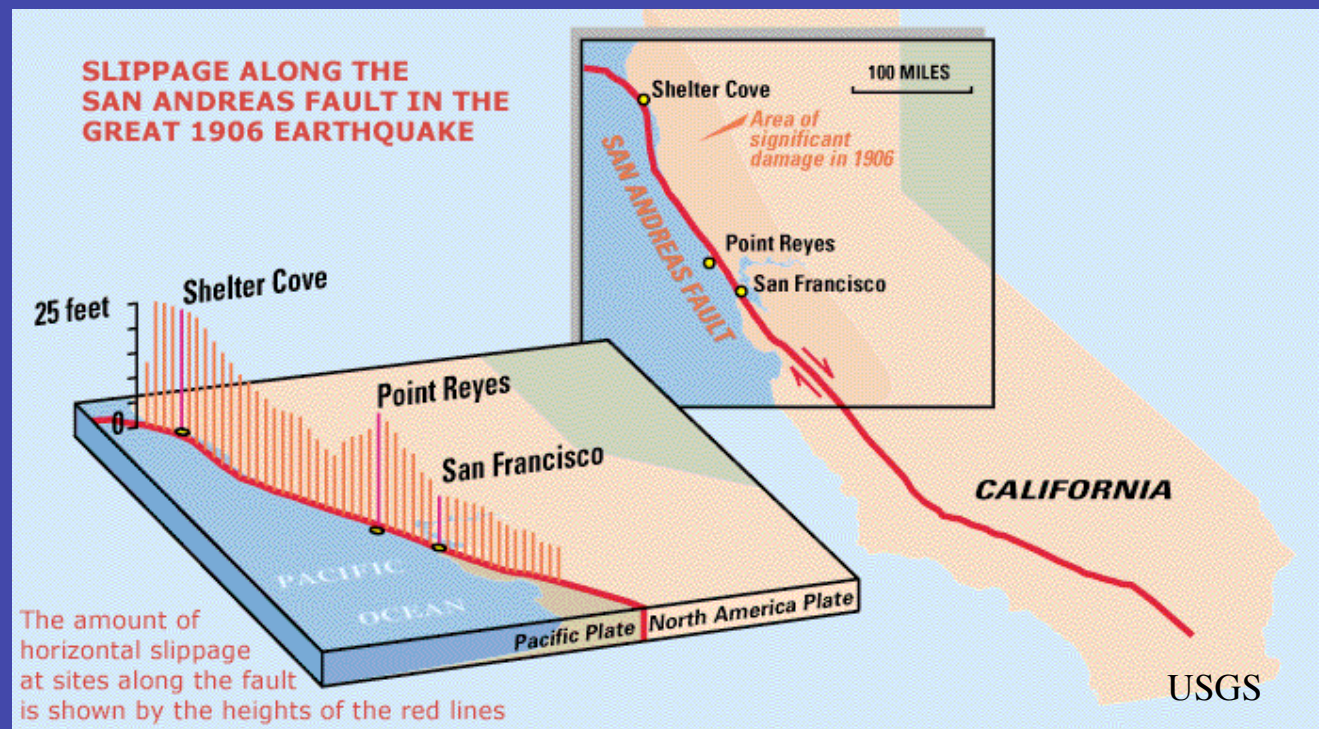
THE GROUND MOVED!

Average 12 feet (4 m) of motion
West side moved north

Motion along hundreds of miles of San Andreas Fault

What is the fault?

Why does the ground move?

SLIPPAGE ALONG THE SAN ANDREAS FAULT IN THE GREAT 1906 EARTHQUAKE

25 feet

Shelter Cove

Point Reyes

San Francisco

PACIFIC OCEAN

Pacific Plate | North America Plate

The amount of horizontal slippage at sites along the fault is shown by the heights of the red lines

100 MILES

Shelter Cove

Area of significant damage in 1906

SAN ANDREAS FAULT

Point Reyes

San Francisco

CALIFORNIA

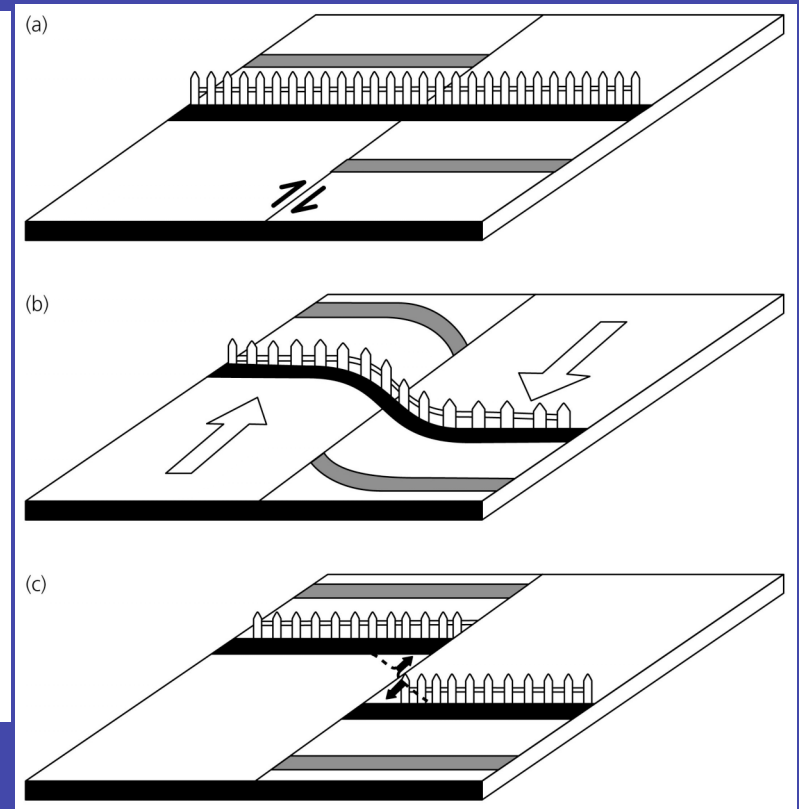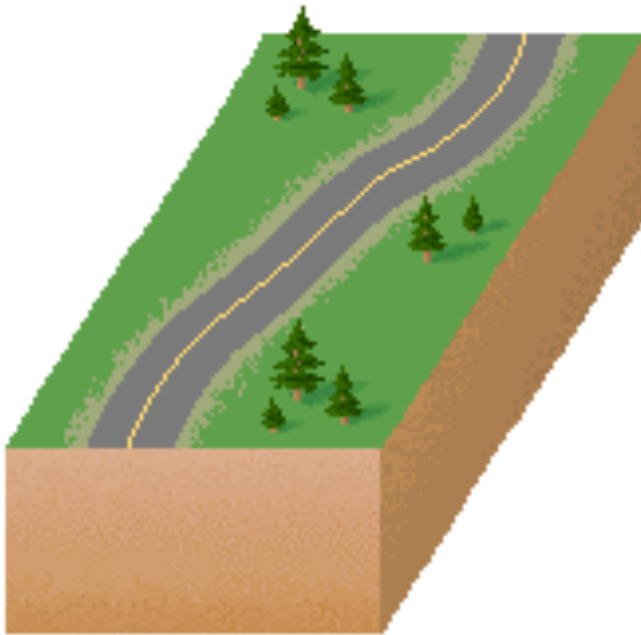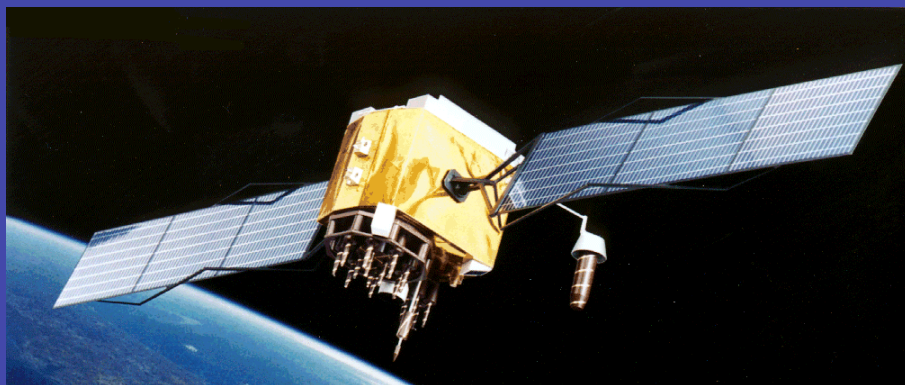USGS

ELASTIC REBOUND

Over many years, rocks on opposite sides of the fault move, but friction on the fault "locks" it and prevents slip

Eventually strain stored is more than fault rocks can withstand, and the fault slips in earthquake

Took 60 years to figure out why this happens!
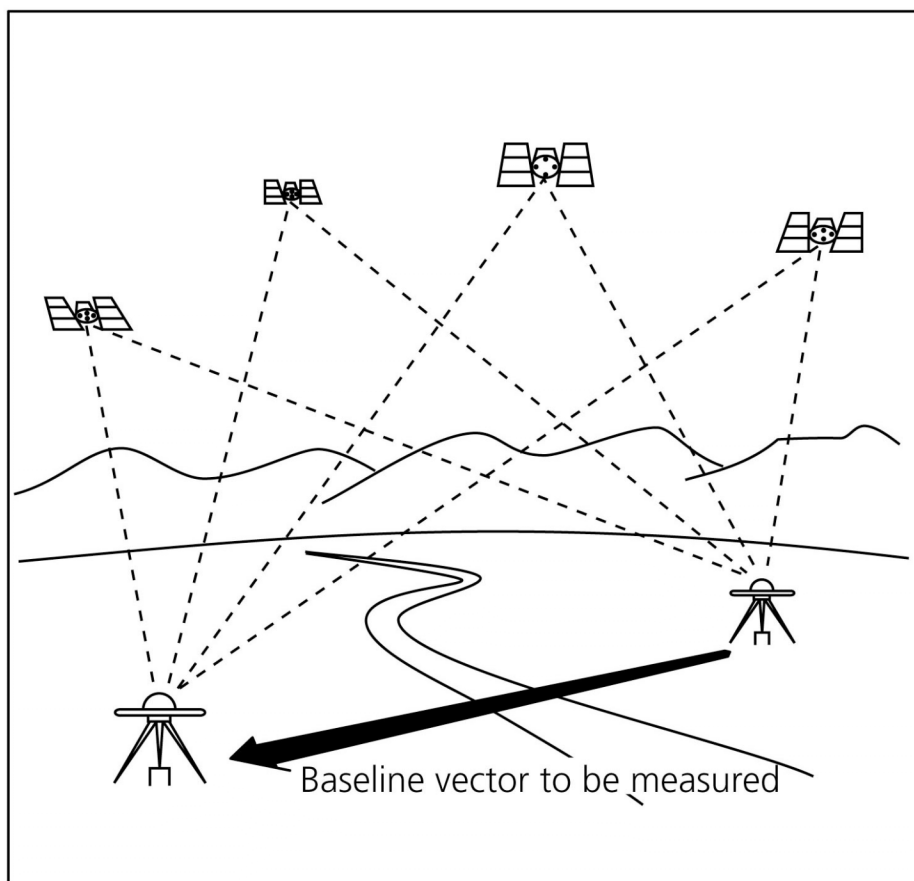
GPS: GLOBAL POSITIONING SYSTEM

24 Satellites
5-8 overhead most of the world

Transmit radio signals

Receivers on ground record signals and find their position from the time the signals arrive
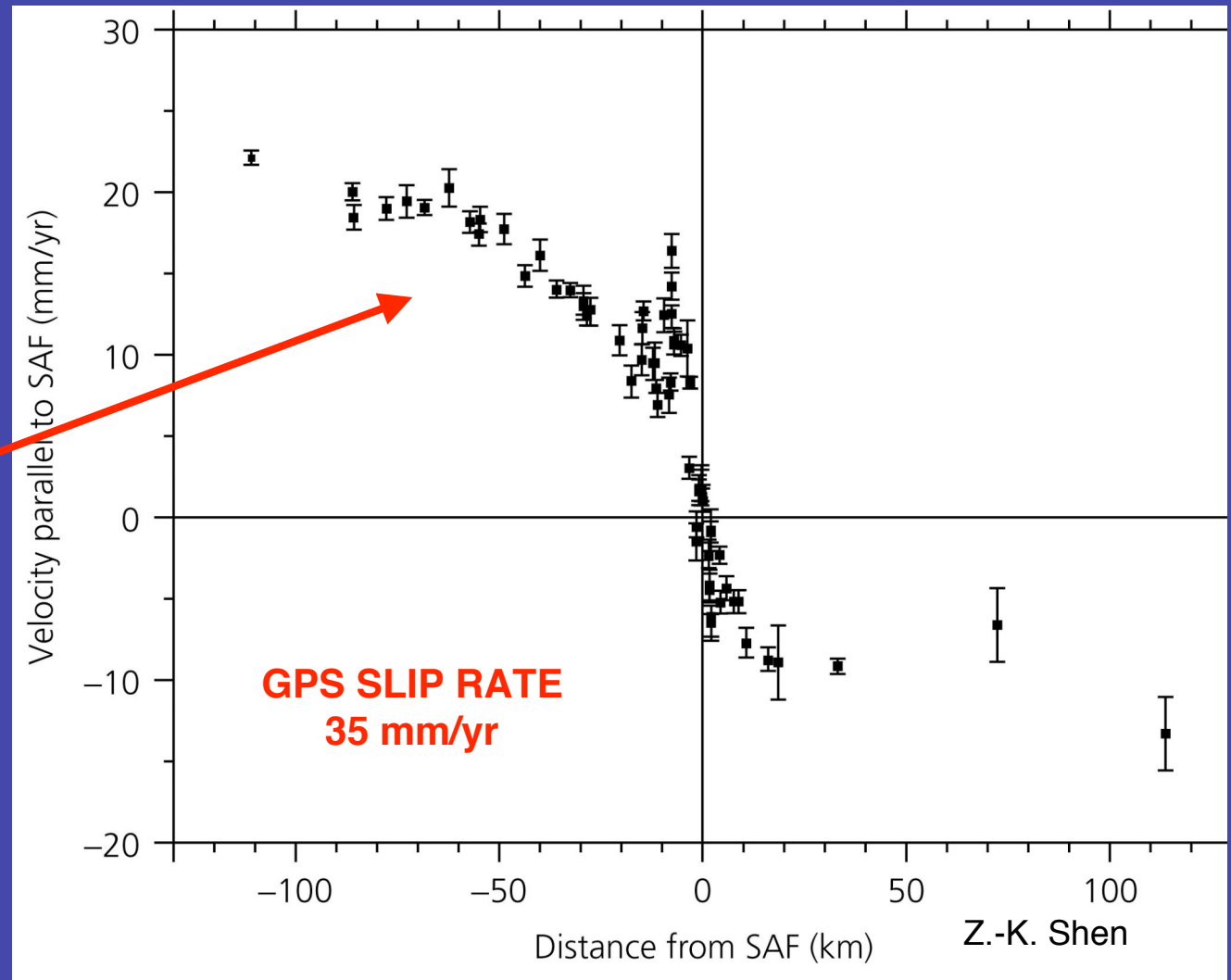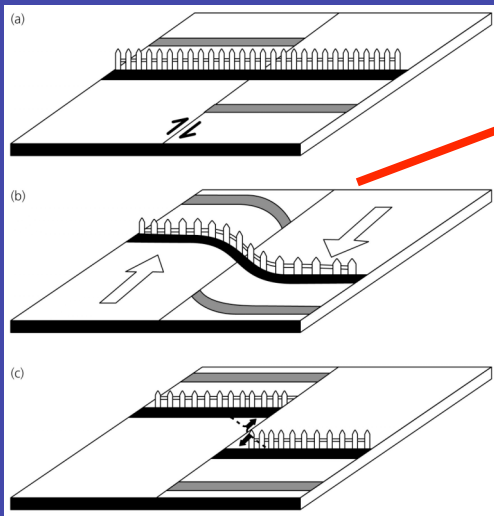
Positions used in many applications

For tectonics, find motions from changes in position over time

Baseline vector to be measured

Stein & Wysession, 2003

San Andreas: GPS site motions show deformation accumulating that will be released in future earthquakes

Like a deformed fence

GPS SLIP RATE 35 mm/yr

Z.-K. Shen

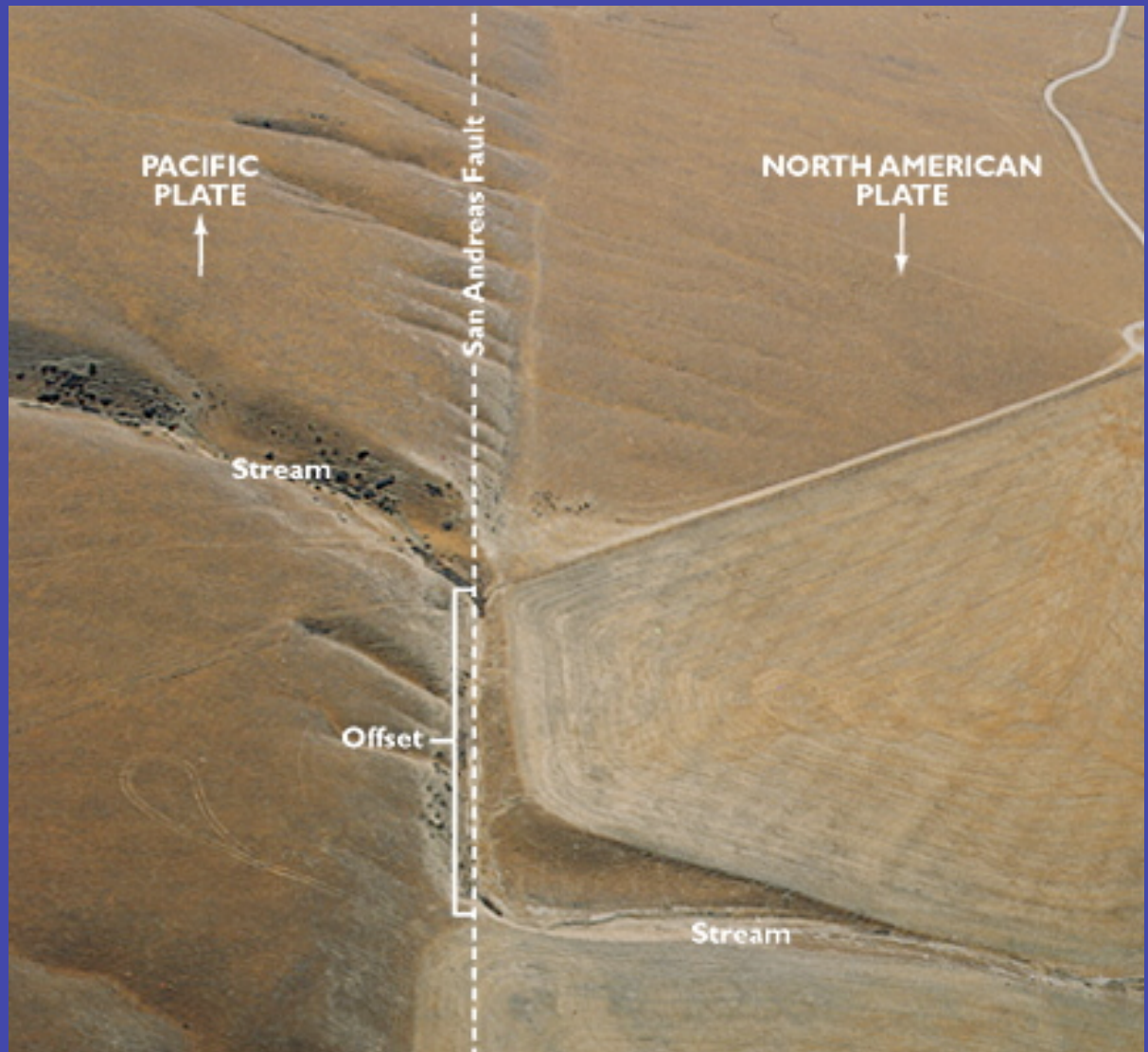**Over time, slip in earthquakes adds up to plate motion**

About 35 mm/yr motion between Pacific and North America shown by offset stream

Big earthquakes ~ 4 m slip

How often do they happen?

Last ones in 1857 & 1906: when should we expect them to recur?

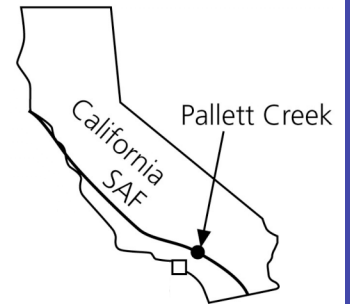**San Andreas Fault - Carrizo Plain, California**

HARD TO PREDICT EARTHQUAKES
time between them is very variable

Extend earthquake history with geologic record
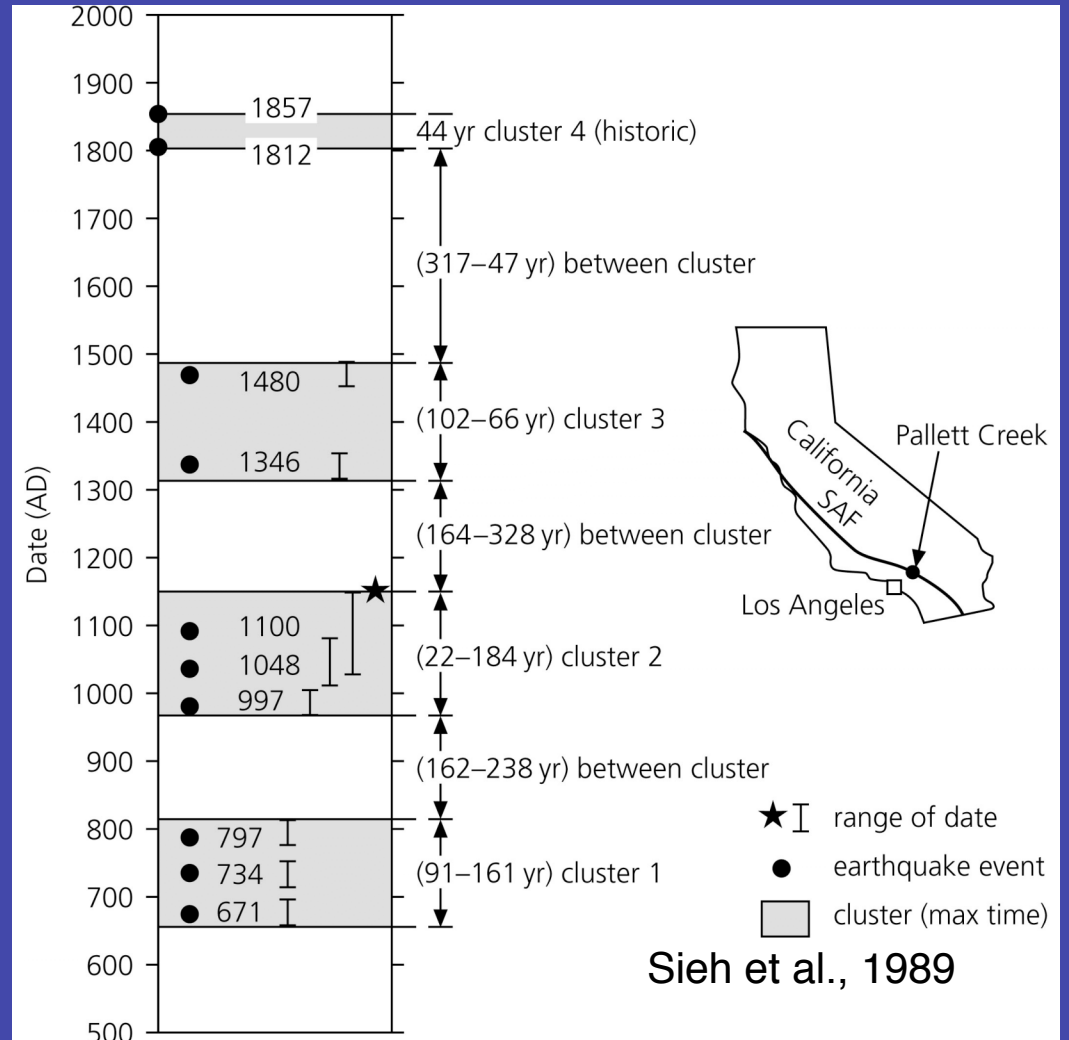
Sieh et al., 1989

HARD TO PREDICT EARTHQUAKES
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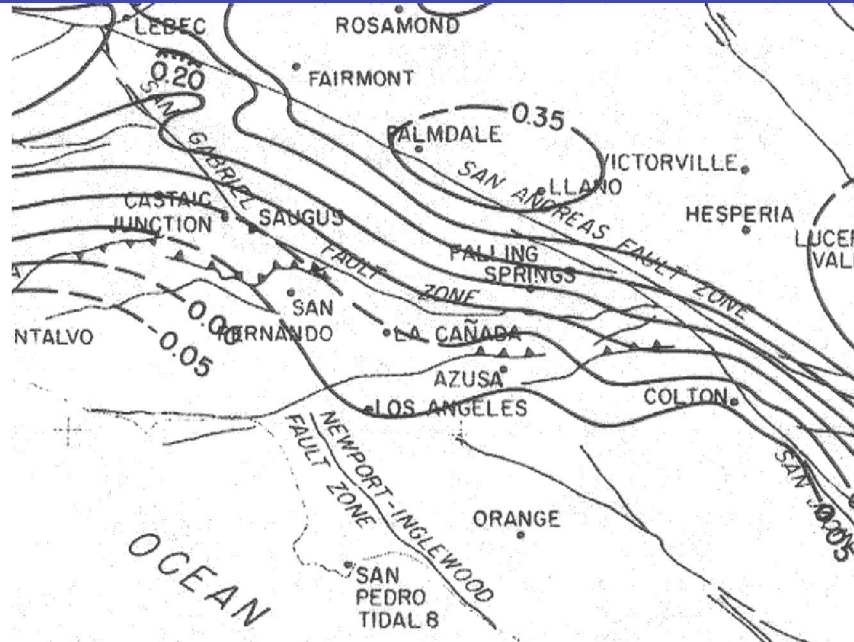

Extend earthquake history with geologic record

Sieh et al., 1989
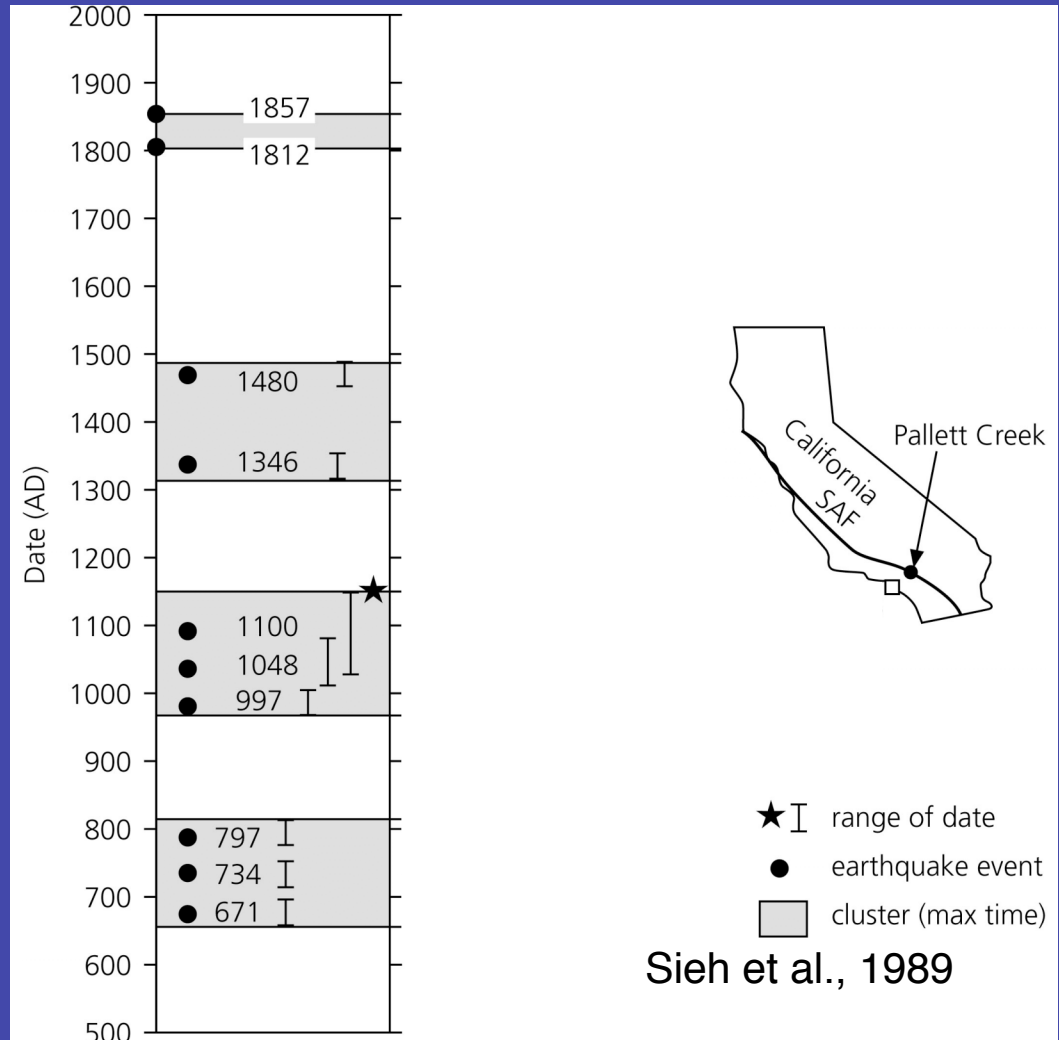
M >7   mean 132 yr   σ 105 yr
Estimated probability in 30 yrs 7-51%

HARD TO PREDICT EARTHQUAKES

Optical leveling

h_1

h_2

Height difference = $h_1 - h_2$
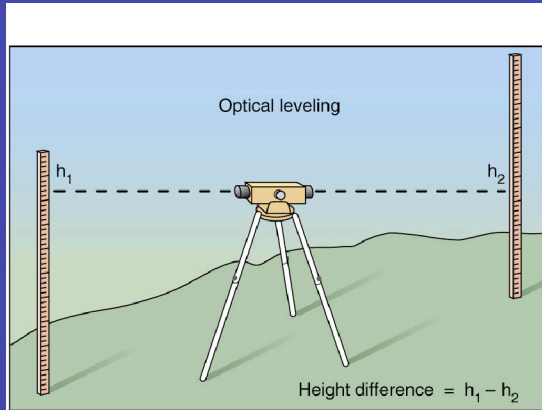
1975: Palmdale Bulge

Since this part of SAF ruptured in a major earthquake in 1857, USGS director McKelvey stated that "a great earthquake" would occur "in the area presently affected by the … 'Palmdale Bulge'... possibly within the next decade" that might cause up to 12,000 deaths, 48,000 serious injuries, 40,000 damaged buildings, and up to $25 billion in damage. The California Seismic Safety Commission stated that "the uplift should be considered a possible threat to public safety" and urged immediate action to prepare for a possible disaster. News media joined the cry.

PARKFIELD, CALIFORNIA SEGMENT OF SAN ANDREAS

M 5-6 earthquakes about every 22 years: 1857, 1881, 1901, 1922, 1934, and 1966

In 1985, expected next in 1988; predicted at 95% confidence by 1993
Didn't occur till 2004 (16 years late)

Historical M 6 Parkfield Earthquakes

1966
1934
1922
1901
1881
1857

2004

Future Earthquakes?

1850   1900   1950   2000   2050
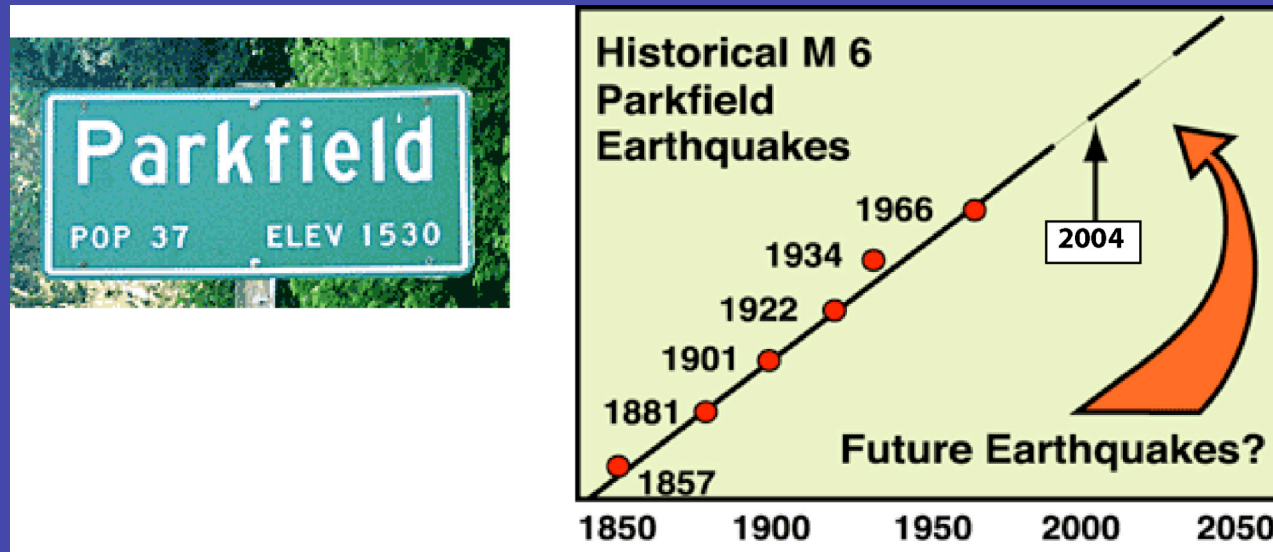
RESEARCH NEWS

Parkfield Quakes Skip a Beat

Seismologists' first official earthquake forecast has failed, ushering in an era of heightened uncertainty and more modest ambitions

Television trucks near Main Street in New Madrid, Mo., Sunday afternoon are just part of the flood of media that has poured into the town on the now-famous fault for the predicted quake.

December 1990

EARTHQUAKE FREQUENCY - MAGNITUDE

LOG-LINEAR Gutenberg-Richter RELATION

Frequency - magnitude relation (fractal scaling; b-value)

$$\log N = a_1 - bM$$

N is the number of earthquakes with magnitude greater than M that occurred in a given time.

Because b is about 1, each year there is about
1 M_s = 8 earthquake,
10 M_s = 7 events,
100 M_s = 6 events,
and so on.

Figure 4.7-1: Frequency-magnitude plot for earthquakes during 1968-1997.

$b = 1$

$b = 1$

$\log N = a - bM_s$

Number of earthquakes per year

∇ incremental values

□ cumulative values

M_s
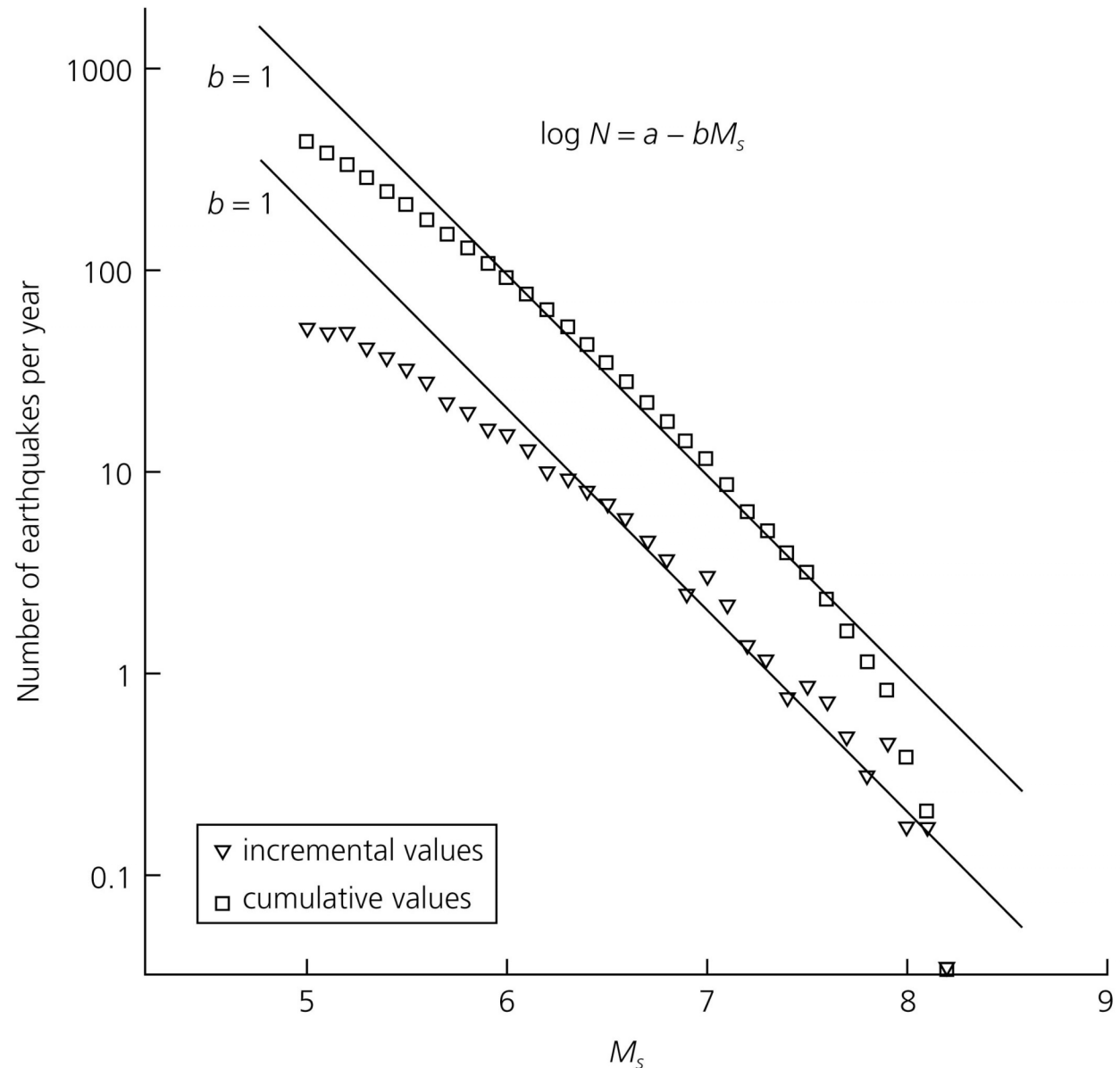
WHY CAN'T WE PREDICT EARTHQUAKES?

So far, no clear evidence for observable behavior before earthquakes.

Maybe lots of tiny earthquakes happen frequently, but only a few grow by random process to large earthquakes

In chaos theory, small perturbations can have unpredictable large effects - flap of a butterfly's wings in Brazil might set off a tornado in Texas

If there's nothing special about the tiny earthquakes that happen to grow into large ones, the time between large earthquakes is highly variable and nothing observable should occur before them.

If so, earthquake prediction is either impossible or nearly so.

2x**2 -1		difference
0.750	0.749	0.00
0.125	0.122	0.00
-0.969	-0.970	0.00
0.877	0.883	-0.01
0.538	0.558	-0.02
-0.421	-0.377	-0.04
-0.646	-0.716	0.07
-0.166	0.026	-0.19
-0.945	-0.999	0.05
0.785	0.994	-0.21
0.233	0.978	-0.75
-0.892	0.912	-1.80
0.590	0.665	-0.07
-0.303	-0.116	-0.19
-0.817	-0.973	0.16
0.334	0.895	-0.56
-0.777	0.601	-1.38
0.208	-0.278	0.49
-0.914	-0.845	-0.07
0.670	0.430	0.24
-0.103	-0.631	0.53
-0.979	-0.204	-0.77
0.916	-0.916	1.83
0.678	0.680	0.00
-0.080	-0.075	0.00
-0.987	-0.989	0.00
0.949	0.955	-0.01
0.800	0.823	-0.02
0.281	0.354	-0.07
-0.842	-0.749	-0.09
0.419	0.122	0.30
-0.649	-0.970	0.32
-0.157	0.882	-1.04
-0.951	0.555	-1.51
0.808	-0.383	1.19
0.304	-0.706	1.01
-0.815	-0.002	-0.81
0.329	-1.000	1.33
-0.784	1.000	-1.78

small perturbations grow

83
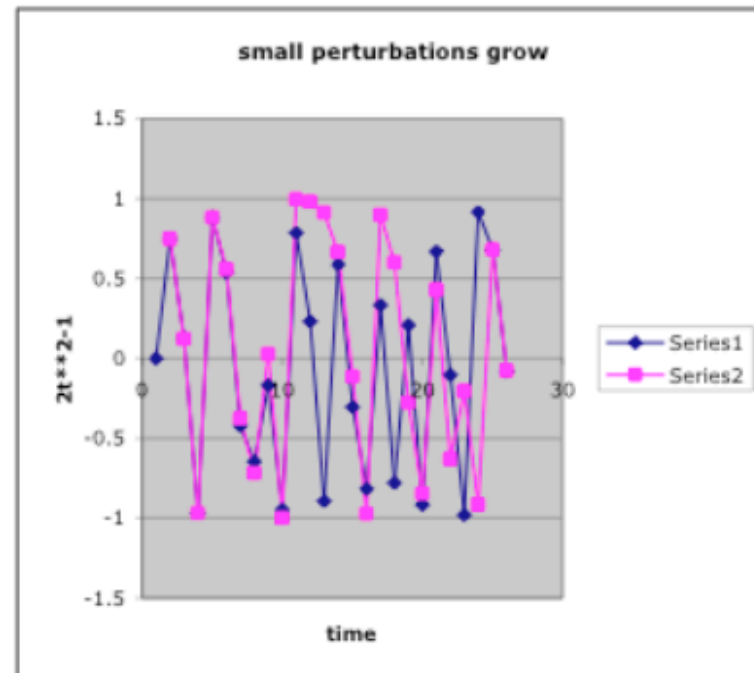
MOST EARTHQUAKES AT PLATE BOUNDARIES, WHERE MOTION IS FAST

SOME FROM SLOW MOTION INSIDE PLATES

New Madrid seismic zone in central U.S.

M 7 earthquakes in 1811-12

Small earthquakes continue

Big ones might happen again
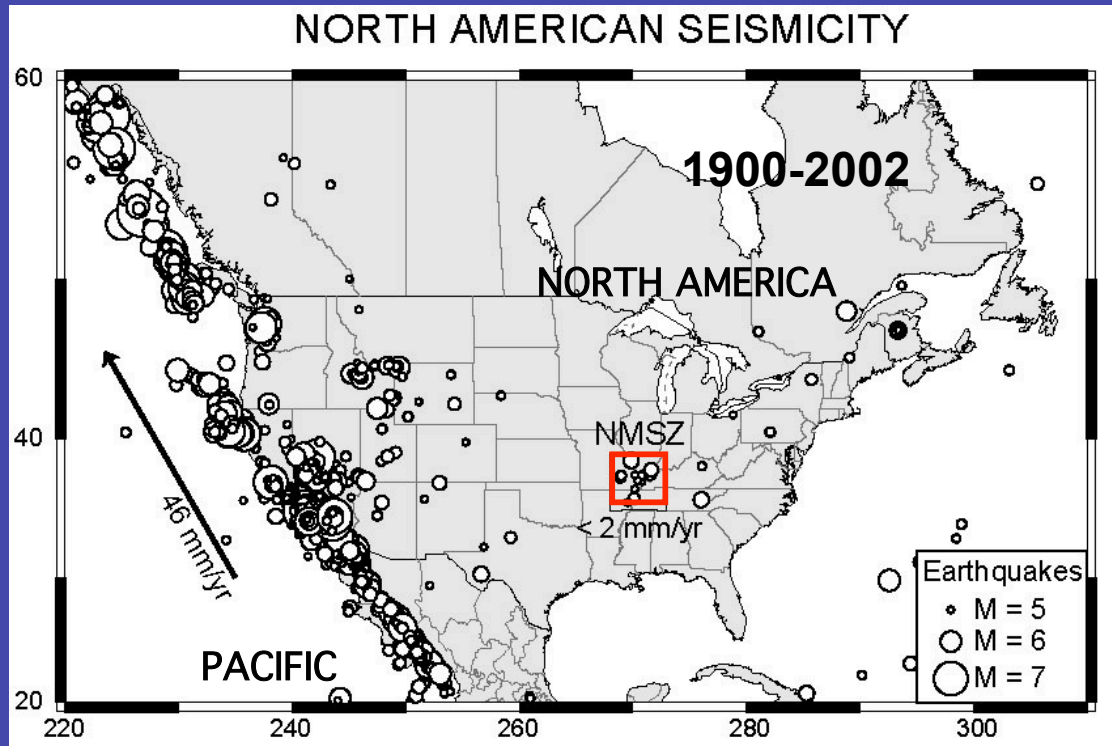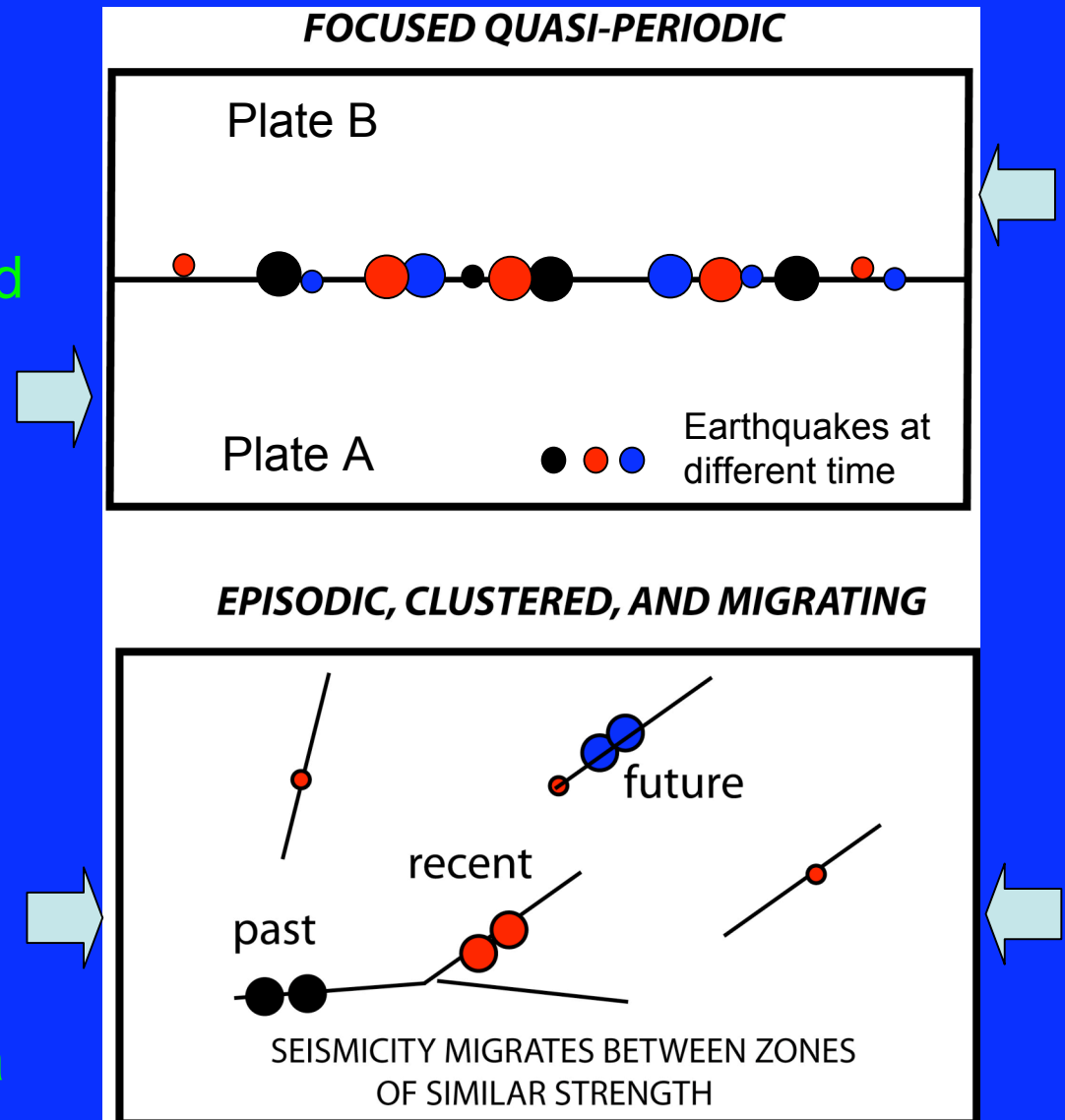
Don't know why, when, how dangerous
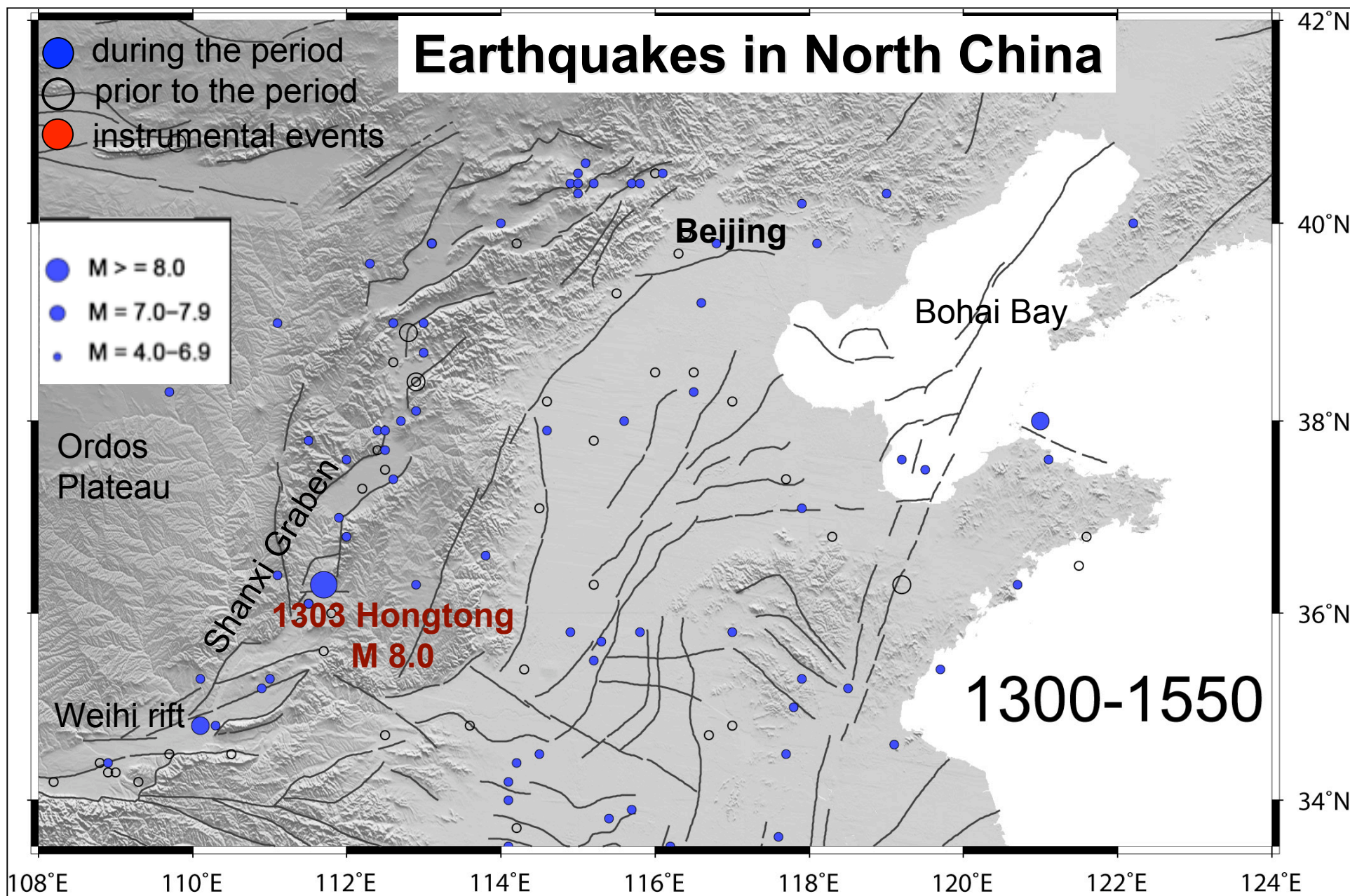
Plate Boundary Earthquakes

- Major fault loaded rapidly at constant rate

- Earthquakes spatially focused & temporally quasi-periodic
Past is good predictor

Intraplate Earthquakes

- Tectonic loading collectively accommodated by a complex system of interacting faults
- Loading rate on a given fault is slow & may not be constant
- Earthquakes can cluster on a fault for a while then shift
Past can be poor predictor

FOCUSED QUASI-PERIODIC

Plate B

Plate A

Earthquakes at different time

EPISODIC, CLUSTERED, AND MIGRATING

future

recent

past

SEISMICITY MIGRATES BETWEEN ZONES OF SIMILAR STRENGTH

Stein, Liu & Wang 2009

Earthquakes in North China

Large events often pop up where there was little seismicity!

Earthquakes in North China

during the period
prior to the period
instrumental events

M >= 8.0
M = 7.0-7.9
M = 4.0-6.9

Beijing

Bohai Bay

Ordos
Plateau

Shanxi Graben

Weihi rift

1556 Huaxian
M 8.3

1556-1667

Large events often pop up where there was little seismicity!

Earthquakes in North China

Legend:
- blue filled circle — during the period
- black open circle — prior to the period
- red filled circle — instrumental events

Magnitude scale:
- M >= 8.0
- M = 7.0–7.9
- M = 4.0–6.9

Ordos Plateau

Shanxi Graben

Weihi rift

Beijing

Bohai Bay

1668 Tancheng M 8.5

1668-1678

Large events often pop up where there was little seismicity!

Earthquakes in North China

1679 Sanhe M 8.0

Beijing

Bohai Bay

Ordos Plateau

Shanxi Graben

Weihi rift

1678-1965

during the period
prior to the period
instrumental events

M >= 8.0
M = 7.0–7.9
M = 4.0–6.9

Large events often pop up where there was little seismicity!

Earthquakes in North China

1975 Haicheng
M 7.3

Beijing

Bohai Bay

1976 Tangshan
M 7.8

Ordos
Plateau

Shanxi Graben

1966 Xingtai
M 7.2

Weihi rift

1966-2009

during the period
prior to the period
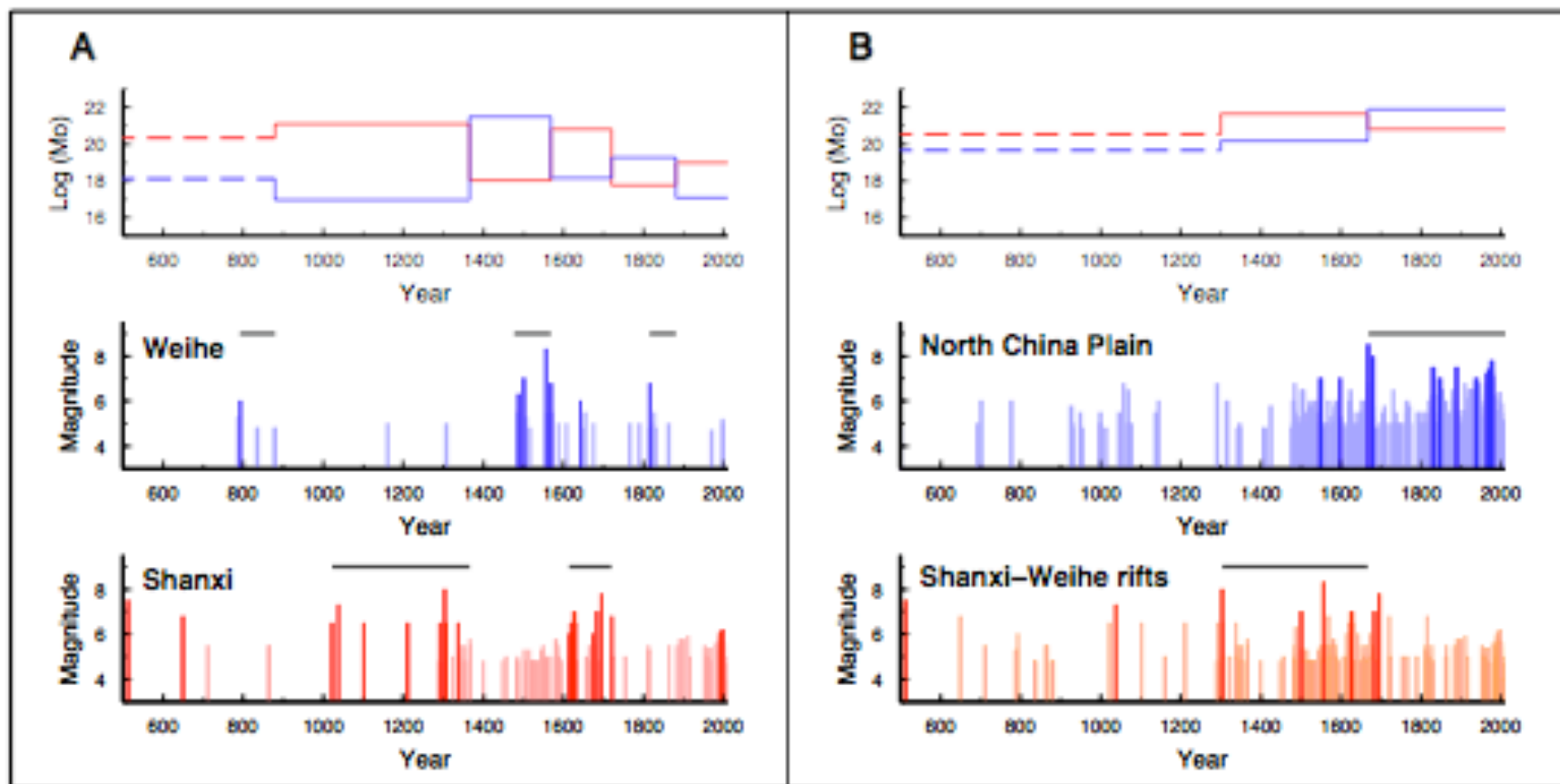instrumental events

M >= 8.0
M = 7.0–7.9
M = 4.0–6.9

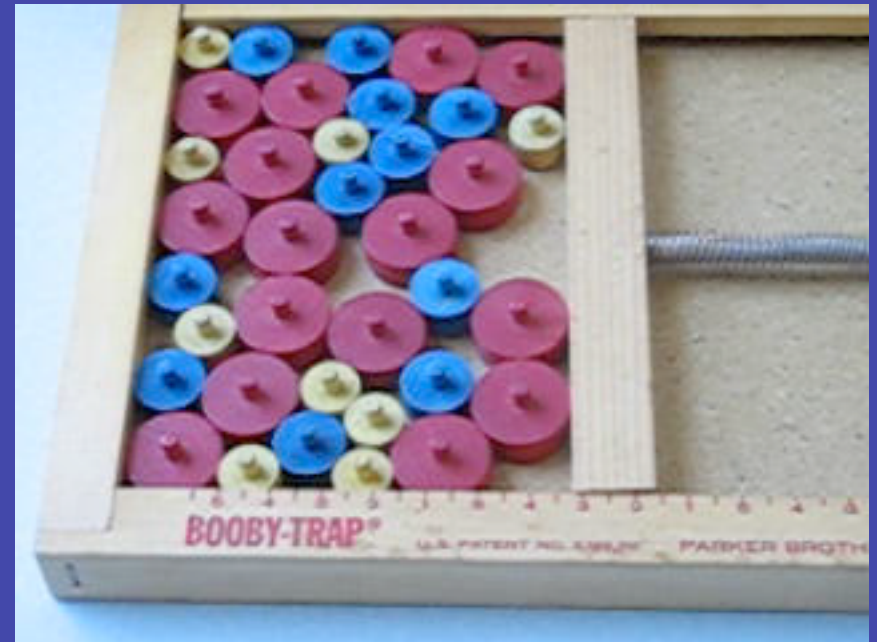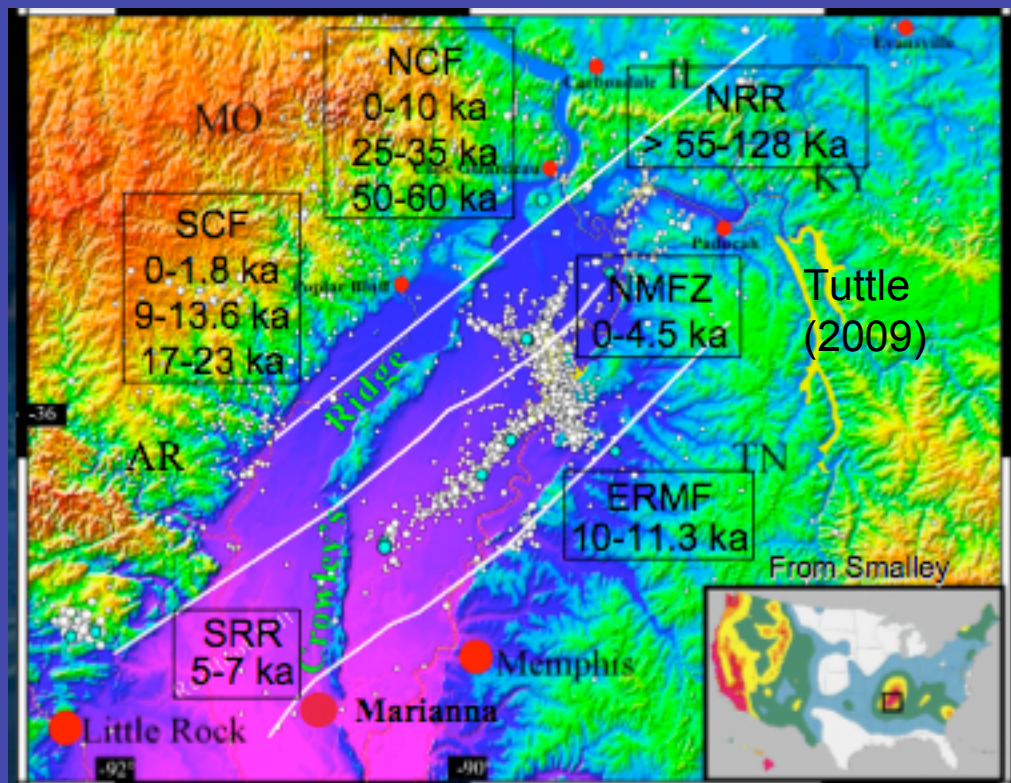Large events often pop up where there was little seismicity!

No large (M>7) events ruptured the same fault segment twice in N. China since 1303
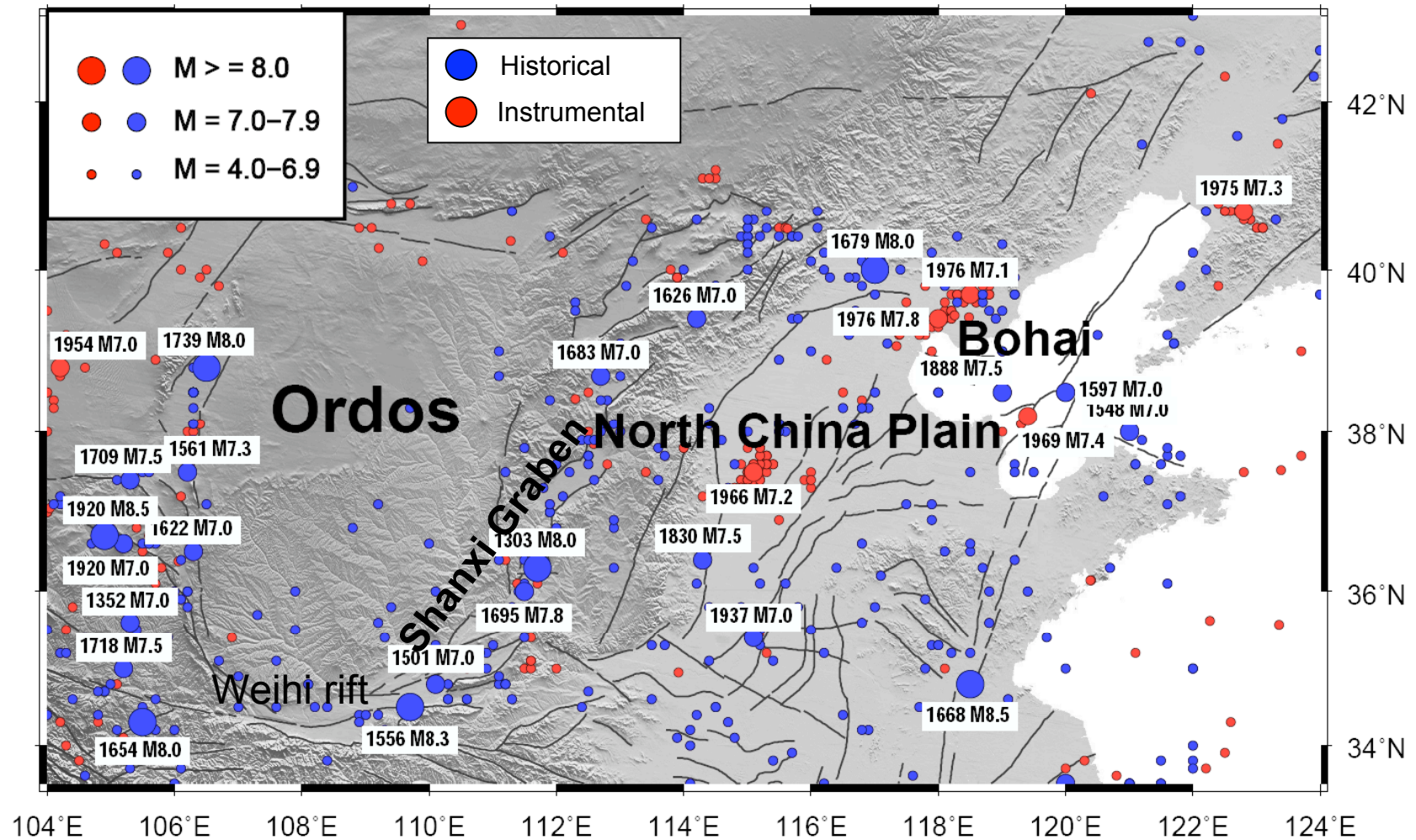
In past 200 years, quakes migrated from Shanxi Graben to N. China Plain

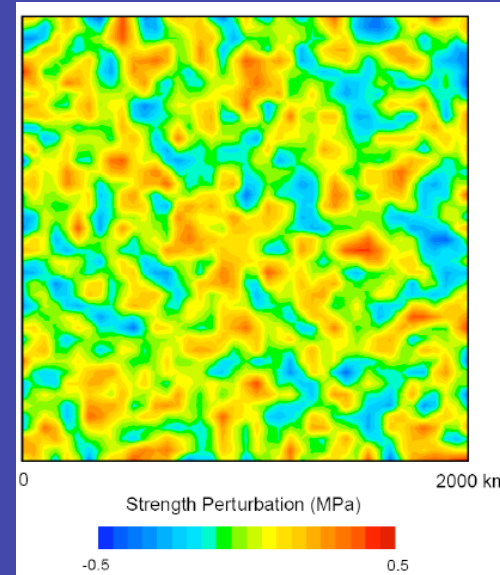# Seismic moment release shows coupled fault systems

Faults active in past show little present seismicity

Seismicity migrates among faults due to fault interactions (stress transfer)

Meers fault, Oklahoma
Active 1000 years ago, dead now
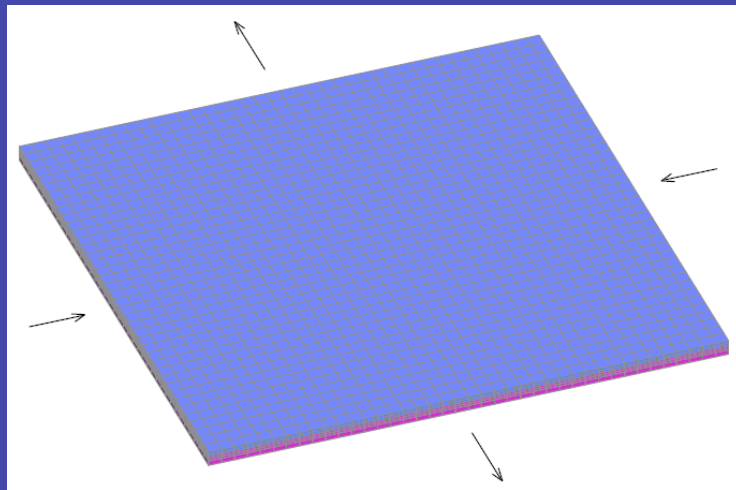
NUMERICAL MODEL

FOR INTRAPLATE EARTHQUAKES

Li, Liu & Stein, 2008

In a few hundred years, earthquakes appear to be clusters scattered in the region. In few thousand years, clusters connect and form belts. In tens of thousands of years, earthquakes are scattered in the whole region.
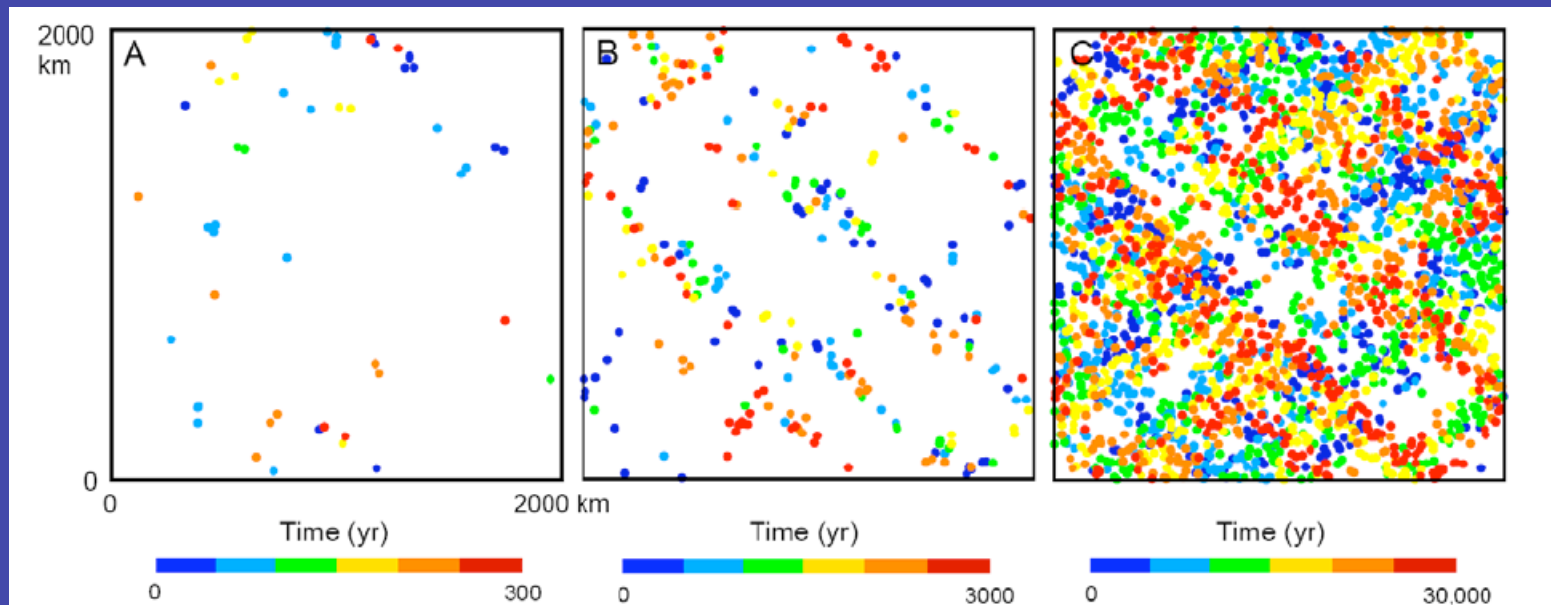
WHAT CAN WE DO?

- **Learn more about earthquakes, their causes, & effects**

- **Predict earthquakes (looks hard or impossible)**

- **Prepare for earthquakes & mitigate their damage (natural processes become disasters because of human actions)**

- **Accept earthquakes as part of our living planet**

Annual Deaths in the United States from Earthquakes
1812-2003
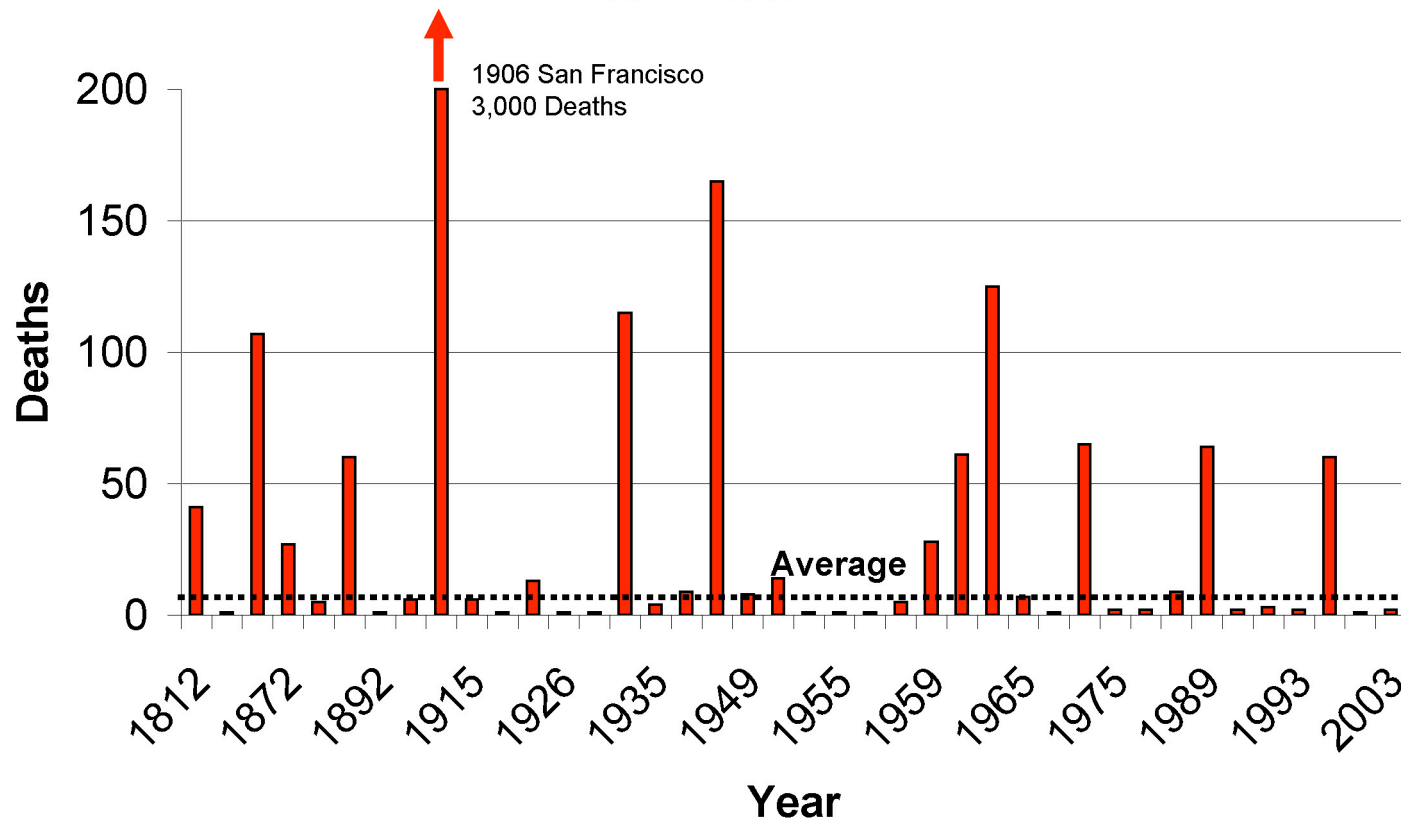
U.S. average ~10 deaths per year, but can be many more for large earthquake

Some foreign countries much more (more people living along plate boundary, weaker construction)

U.S. EARTHQUAKES

Infrequent, but occasionally major, fatalities and damage

Moderate (M 6.7) 1994 Northridge earthquake: 58 deaths, $20B damage

Challenge: find mitigation strategy that balances cost of safer construction with benefits, given other possible uses of resources

Tough problem!

Table 1.2-3. Some causes of death in the United States, 1996.

Heart Attack	733,834
Cancer	544,278
Stroke	160,431
Lung disease	106,143
Pneumonia/Influenza	82,579
Diabetes	61,559
Motor vehicle accidents	43,300
AIDS	32,655
Suicide	30,862
Liver disease/Cirrhosis	25,135
Kidney disease	24,391
Alzheimer's	21,166
Homicide	20,738
Falling	14,100
Poison	10,400
Drowning	3,900
Fires	3,200
Suffocation	3,000
Bicycle accidents	695
Severe Weather[1]	514
In-line skating[2]	25
Football[2]	18
Skateboards[2]	10
Earthquakes (1811-1983)[3]	9
Earthquakes (1984-1998)	9

[1]From the National Weather Service (property loss due to severe weather is $10-15 B/year, comparable to the Northridge earthquake, and individual hurricanes can go up to $25 B.
[2]From the Consumer Product Safety Commission
[3]From Gere and Shah [1984].
All others from the National Safety Council and National Center for Health Statistics.

DAMAGE DEPENDS ON
WHERE AND HOW WE BUILD

"Earthquakes don't kill people; buildings kill people."

1989 LOMA PRIETA, CALIFORNIA EARTHQUAKE: M 7.1

Mile of two level freeway collapsed, crushing cars & causing 42 deaths

MODIFIED MERCALLI INTENSITY SCALE

Macroscopic measure of shaking

Estimated for historic earthquakes from accounts of what happened

Plot isoseismals - intensity contours

Decays with distance

Proportional to acceleration, details unclear

I.   Shaking not felt, no damage: Not felt except by a very few under especially favorable circumstances.

II. Shaking weak, no damage: Felt only by 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 automobiles may rock slightly. Vibration like passing of truck. Duration estimated.

IV. Shaking light, no damage: During the day felt indoors by many, outdoors by very few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing automobiles rocked noticeably. (0.015g-0.02g)

V.   Shaking moderate, very light damage: Felt by nearly everyone, many awakened. Some dishes, windows, and so on broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees and poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (0.03g-0.04g)

VI. Shaking strong, light damage: Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster and damaged chimneys. Damage slight. (0.06g-0.07g)

VII. Shaking very strong, moderate damage: 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. (0.10g-0.15g)

VIII. Shaking severe, moderate to heavy damage: 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.   Persons driving cars disturbed. (0.25g-0.30g)

IX. Shaking violent, heavy damage: Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (0.50g-0.55g)

X.   Shaking extreme, very heavy damage: Some well-build wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks. (More than 0.60g)

XI. Few, if any, (masonry) structures remain 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 surfaces. Lines of sight and level destroyed. Objects thrown into the air.