WHY SEISMOLOGISTS CAN'T PREDICT EARTHQUAKES

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News

Italy puts seismology in the dock

Scientists who assessed earthquake risk at L'Aquila could be indicted on manslaughter charges.

Nicola Nosengo

ROME

The deadly earthquake that struck the central Italian city of L'Aquila on 6 April 2009, has had a bizarre aftershock: some of Italy's top seismologists could face charges of manslaughter for not alerting the population before the disaster.

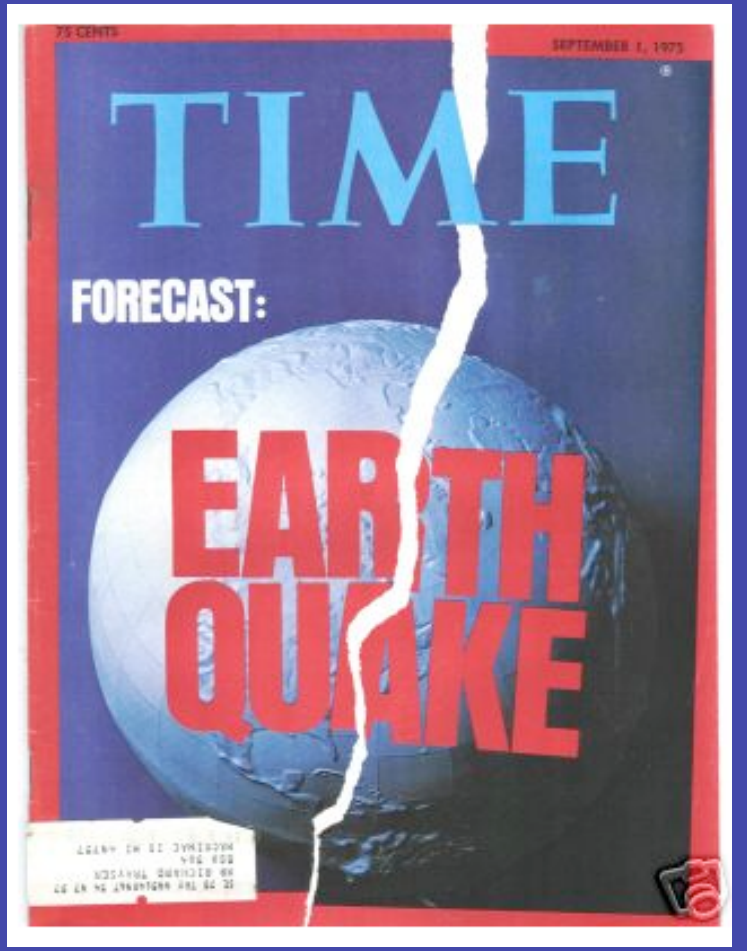
"Only fools and charlatans predict earthquakes"
Charles Richter (1900-1985)

1970's optimism

Scientists will *"be able to predict earthquakes in five years*."
Louis Pakiser
U.S. Geological Survey, 1971

"We have the technology to develop a reliable prediction system already in hand."
Alan Cranston, U.S. senator, 1973

"The age of earthquake prediction is upon us"
U.S. Geological Survey, 1975



Similar in Japan, China, USSR

Meaningful prediction involves specifying the location, time, & size of an earthquake before it occurs

Long-term forecast

- Use earthquake history to predict next one

- Use rate of motion accumulating across fault and amount of slip in past earthquakes

Short-term prediction

-Find *precursors* - changes in earth before earthquakes *consistently resolvable from normal variability*

Despite some claims, no reliable method yet…

Need to do consistently better *than expected by chance from known statistics of earthquakes in an area*

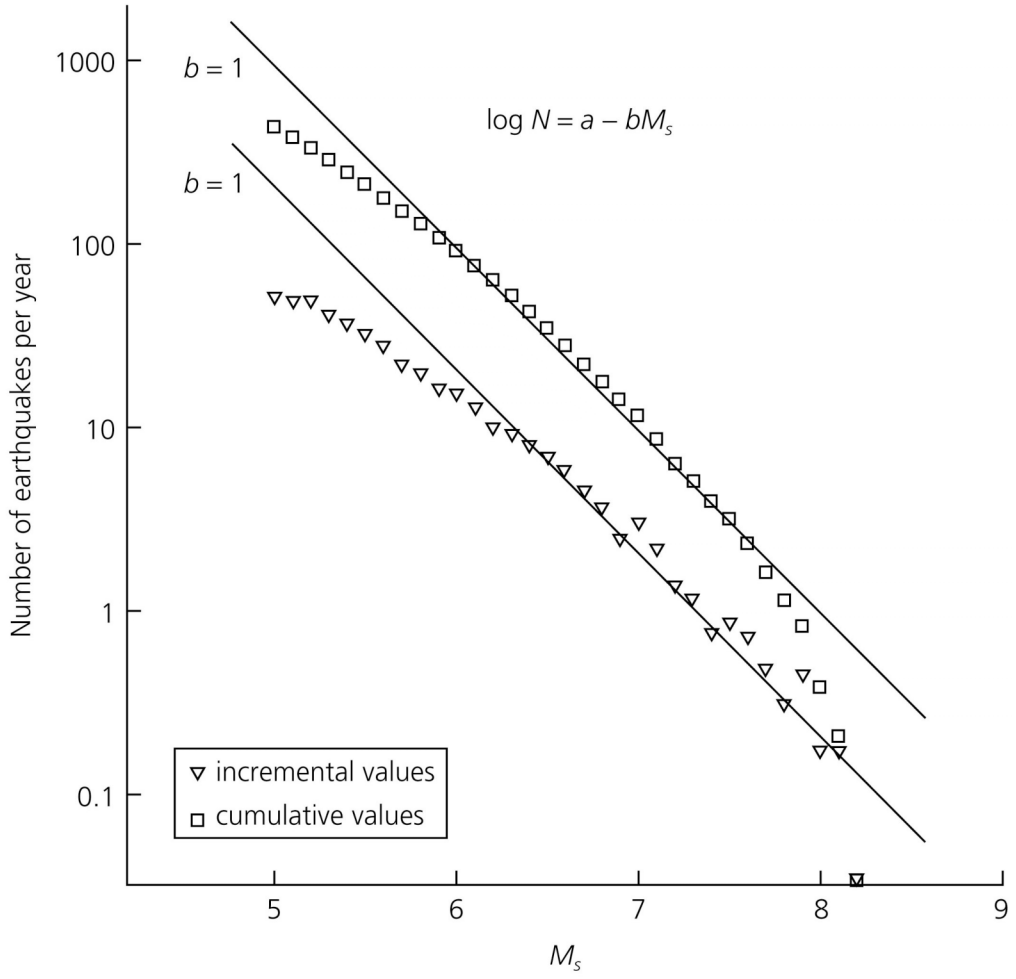
Frequency - magnitude relation (fractal scaling; b-value)

$$\log N = a_1 - bM$$

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

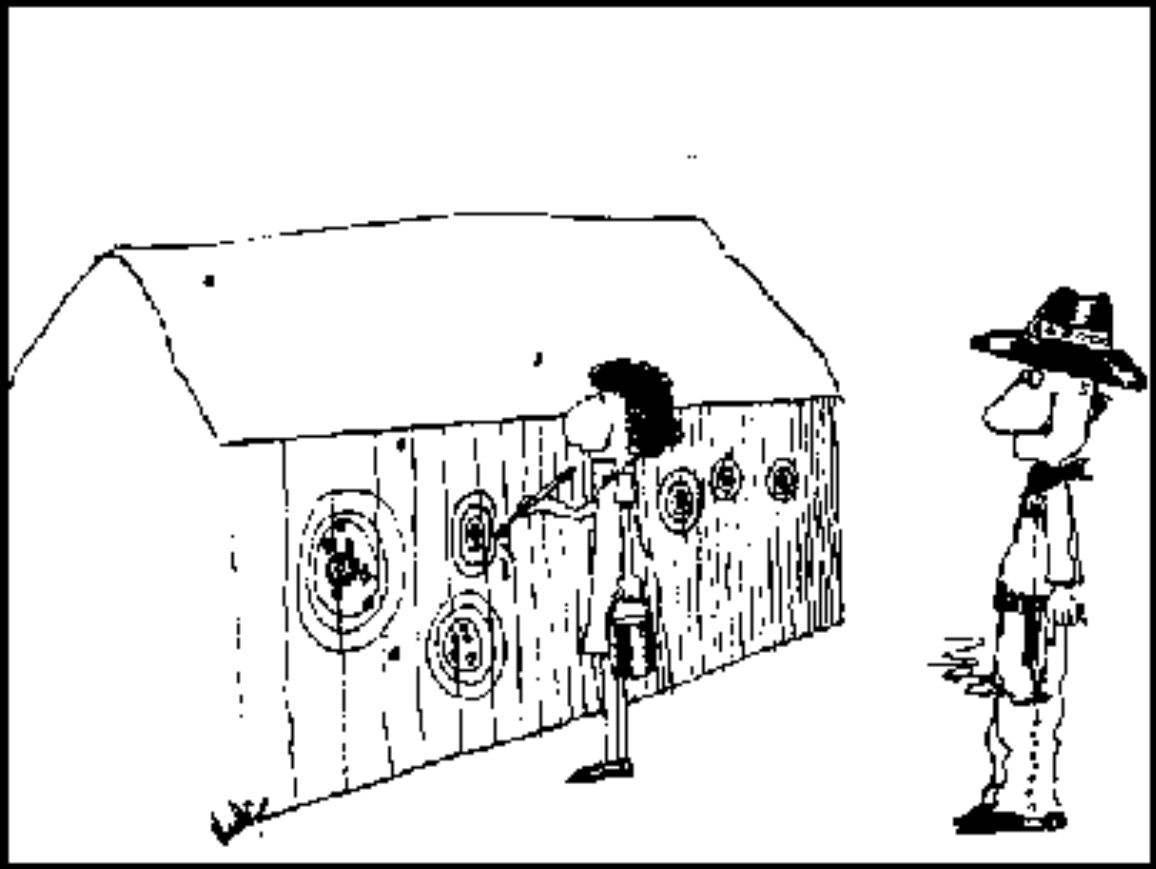
Because b is about 1, each year there is about
1 $M_s = 8$ earthquake,
10 $M_s = 7$ events,
100 $M_s = 6$ events,
and so on.

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



Postdictions - Texas sharp shooter

Shoot at barn and then draw target around bullet holes



Email: kencampbell@altavista.net

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."

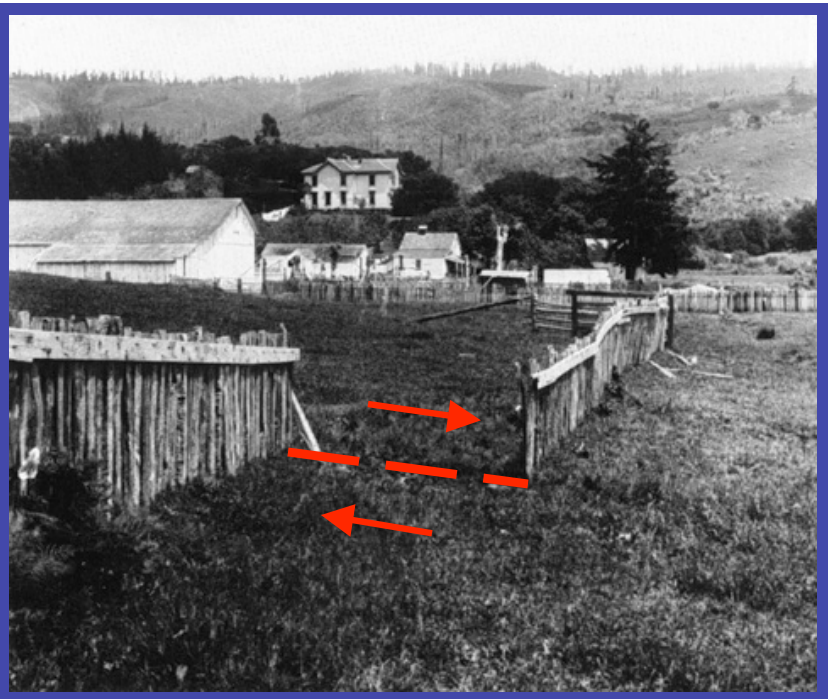
"I saw the whole city enveloped in a pile of dust caused by falling buildings."

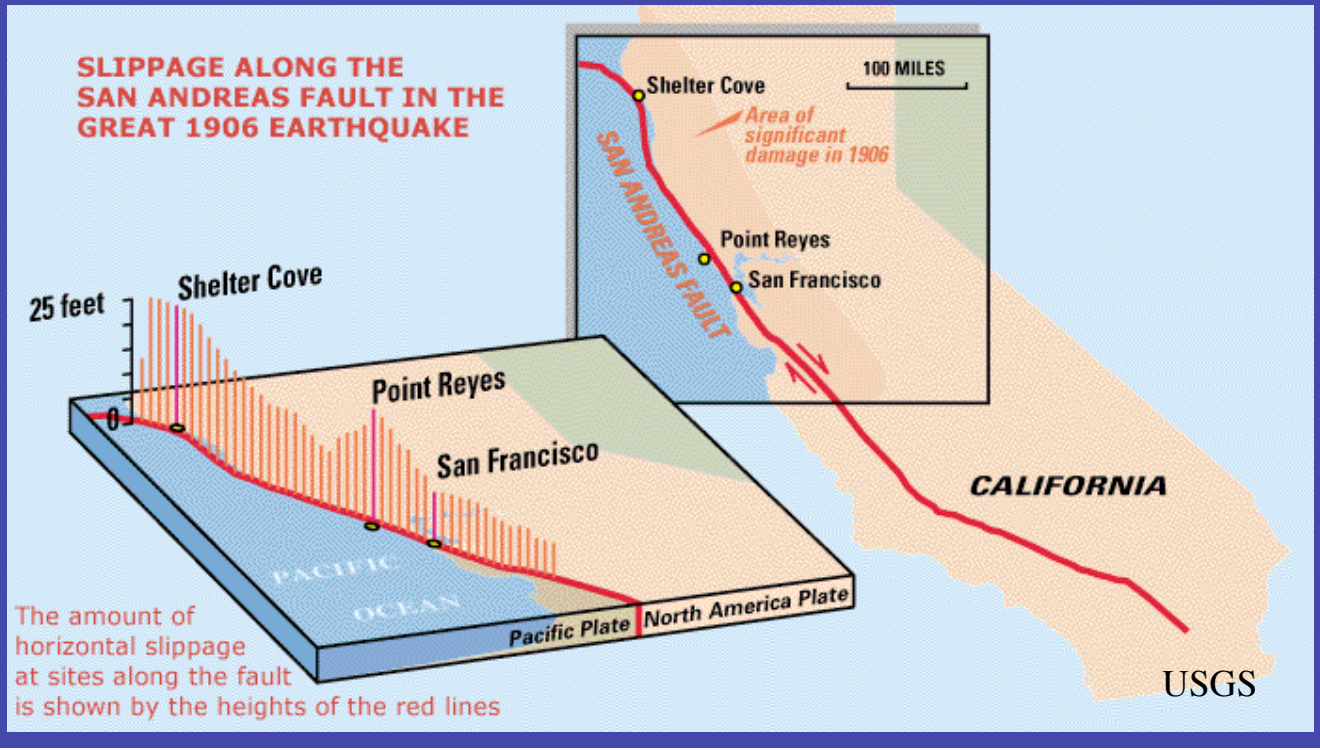
"Inside of twelve hours half the heart of the city was gone"

Motion along ~ 500 km of previously unrecognized San Andreas Fault

~ 4 m of ground motion

West side moved north

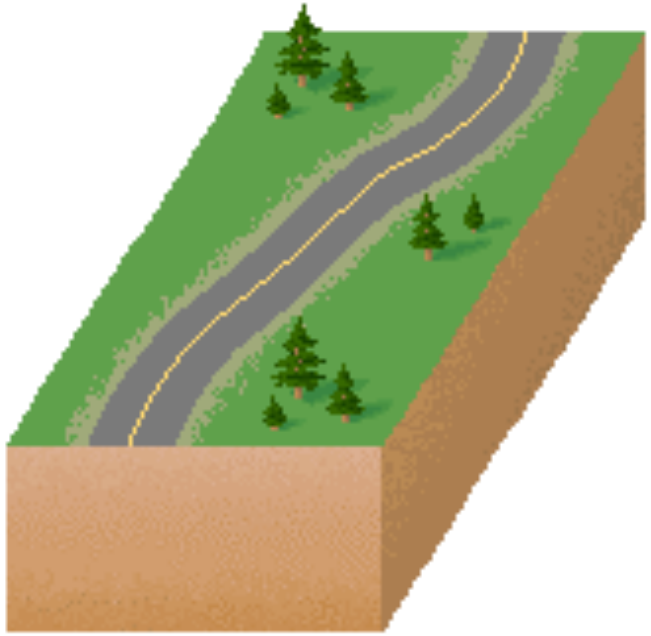


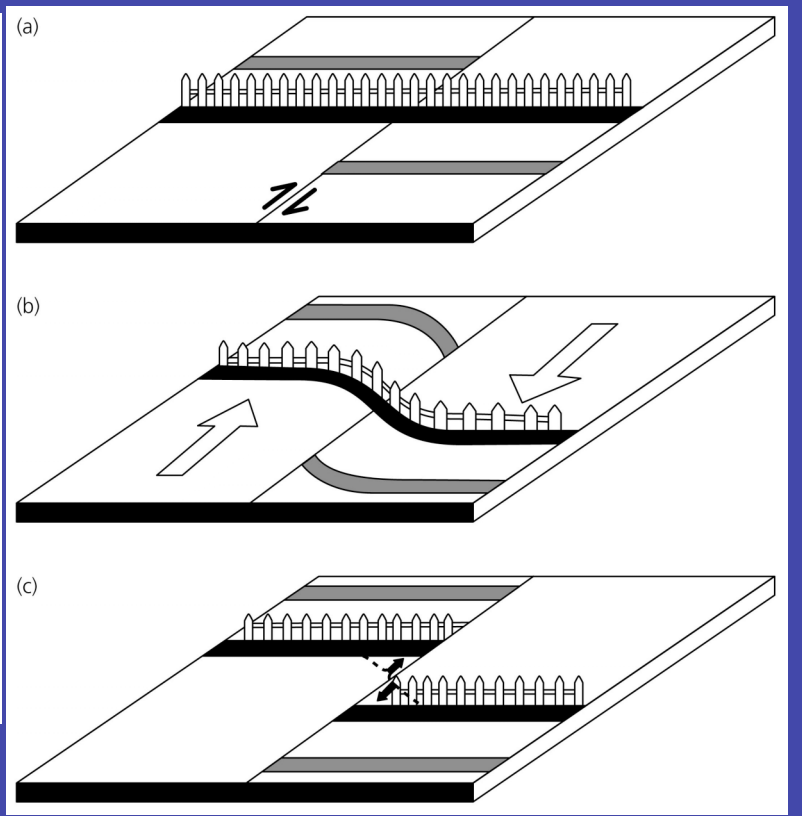


ELASTIC REBOUND

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

Eventually strain accumulated overcomes friction, and fault slips in earthquake



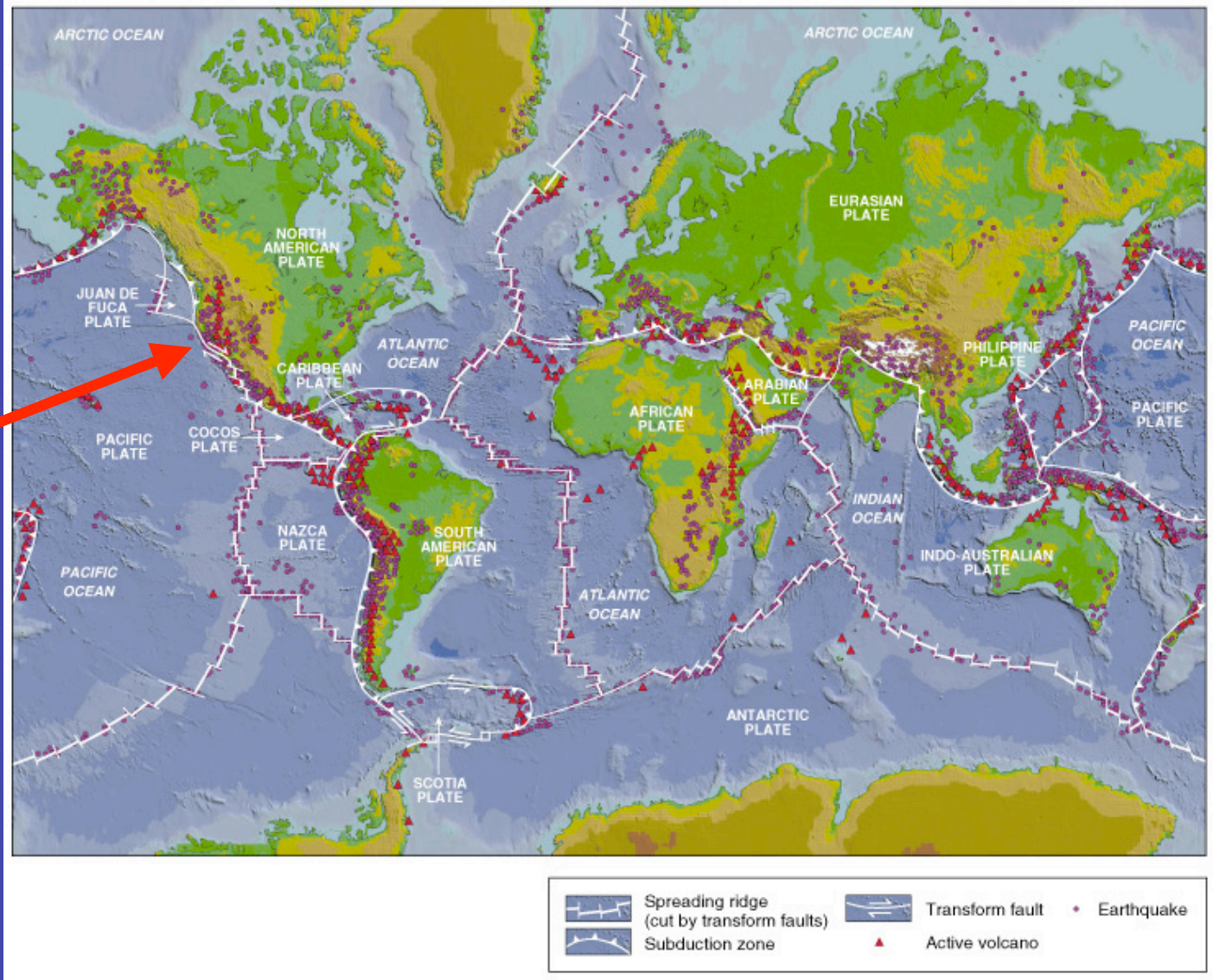


Took 60 years to figure out why this happens!

EARTH'S OUTER SHELL - PLATES

Plates move at few cm/yr

San Andreas fault: boundary between Pacific & North American plates



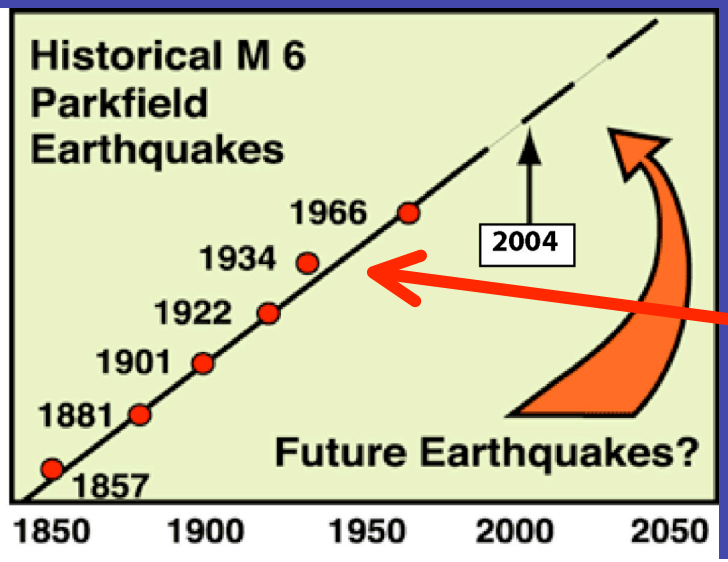
Hard to predict when block will slip

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; U.S. Geological Survey predicted 95% confidence by 1993

Occurred in 2004 (16 years late)



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

Discounting misfit of 1934 quake predicted higher confidence

Science, 10/8//04

SEISMOLOGY

Parkfield Keeps Secrets After A Long-Awaited Quake

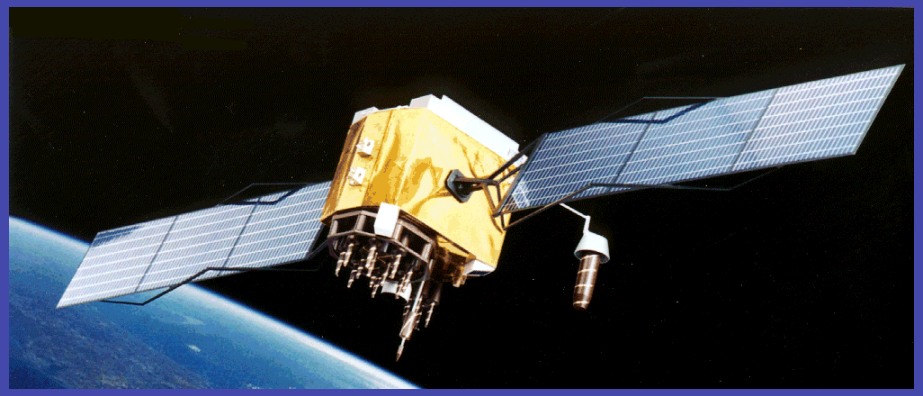
Last week's moderate-to-strong earthquake in central California has justified seismologists' belief that Parkfield (population 37) was the place to wait for a sizable quake they could study. "It's right in the very middle of our network," says geophysicist Malcolm Johnston of the U.S. Geological Survey (USGS) in Menlo Park, California, about the densest fault-monitoring system in the world. It cost more than $10 million over 20 years. "We got great stuff," says Johnston.

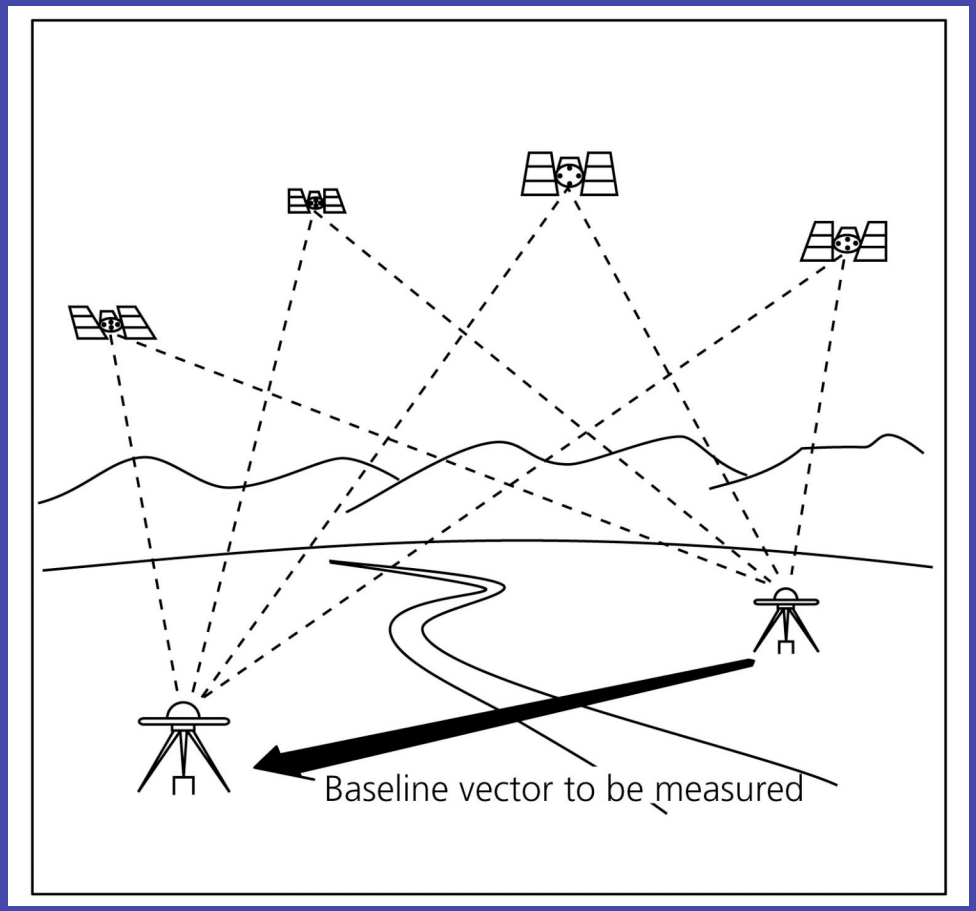
But they didn't get it entirely right. When seismologists began the Parkfield Earthquake Prediction Experiment in the 1980s, they expected to capture the next magnitude 6 in unprecedented detail within a few years. Instead, they had to wait 2 decades, a delay that casts additional doubt on models of predictable seismic behavior. And far from providing practical experience in the nascent science of short-term earthquake prediction, Parkfield 2004 seems to have given no warning that would lend hope to the field of short-term quake forecasting. All in all, Parkfield has driven home the point that even one of the world's best behaved fault segments can be pretty cantankerous.

"Parkfield is geophysics' Waterloo. If the earthquake comes without warnings of any kind, earthquakes are unpredictable and science is defeated." (*The Economist*)

No precursors in seismicity (foreshocks), strainmeters, magnetometers, GPS, creepmeter

$30 million spent on "Porkfield" project





Stein & Wysession, 2003

GPS: GLOBAL POSITIONING SYSTEM

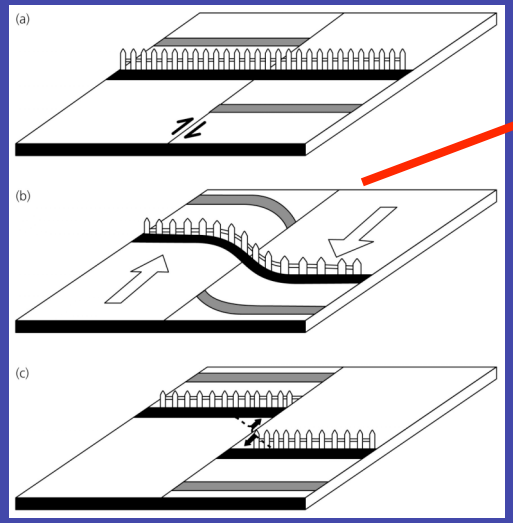
Satellites transmit radio signals

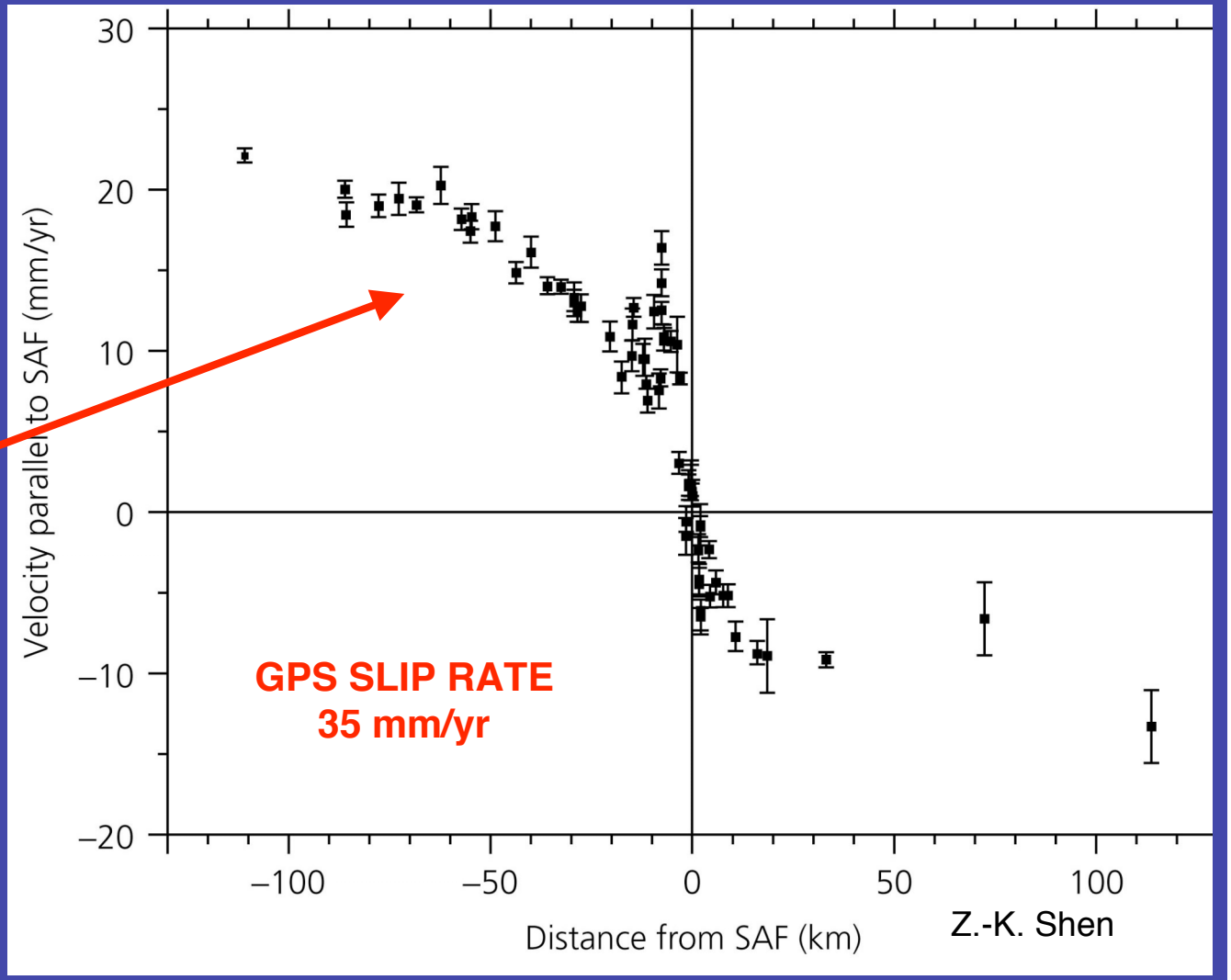
Receivers on ground record signals and find their position from the time the signals arrive

Find mm/yr motions from changes in position over time

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

Like a deformed fence



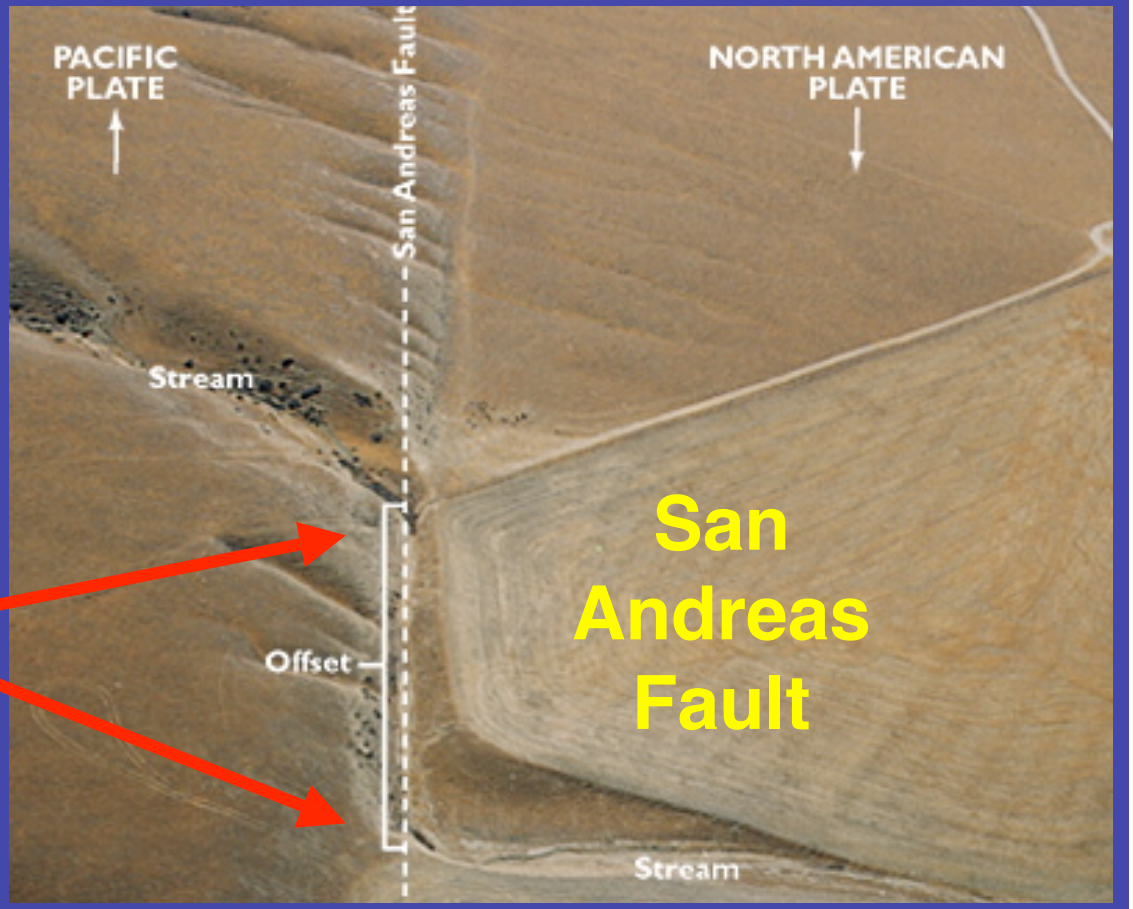


Over time, slip in large earthquakes adds up to plate motion

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

Expect large earthquakes about every
4 m / (35 mm/yr) or 115 years

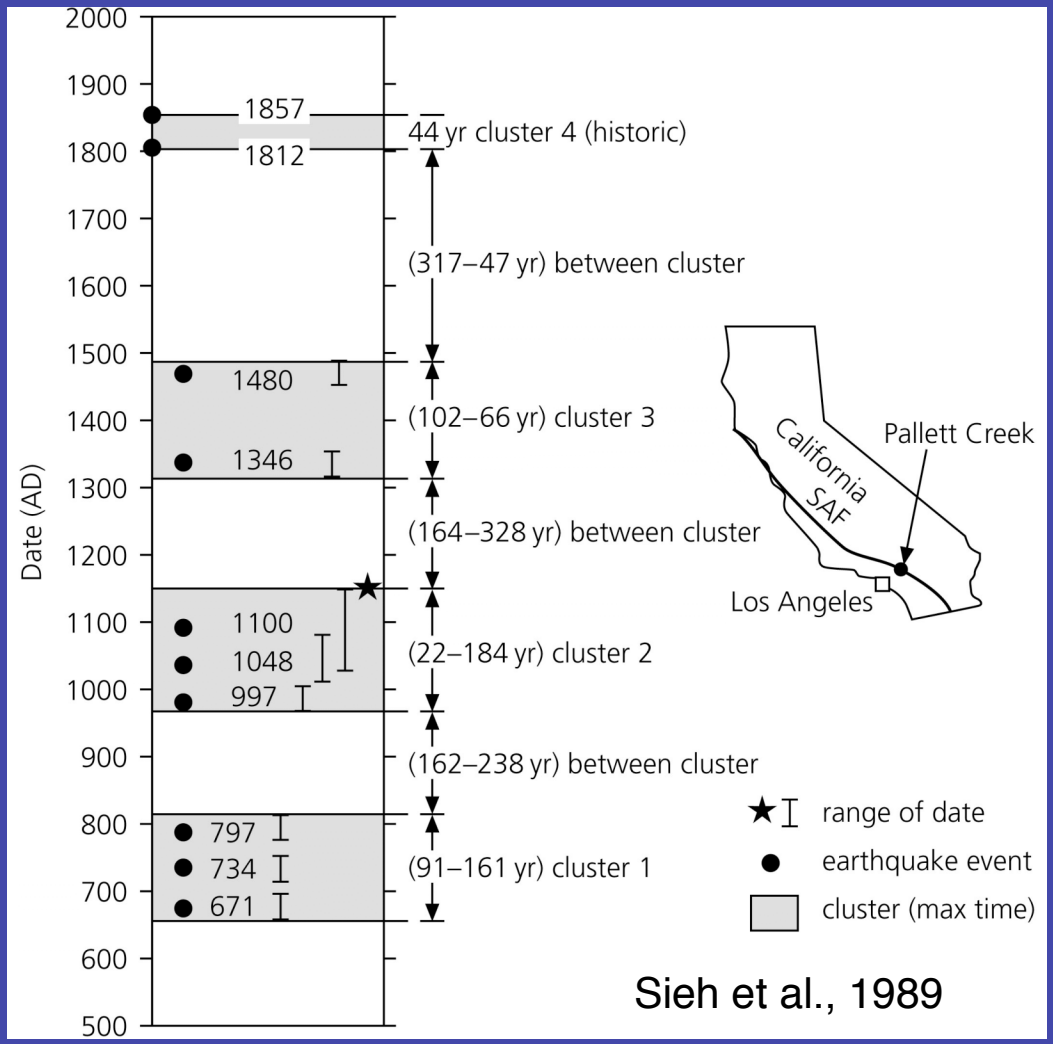
Last one here in 1857…



"We are predicting another massive earthquake certainly within the next 30 years and most likely in the next decade or so." W. Pecora, U.S. Geological Survey Director, 1969

Time between earthquakes is very variable

Extend earthquake history with geologic record



M >7 mean 132 yr σ 105 yr

1857+132 = 1988

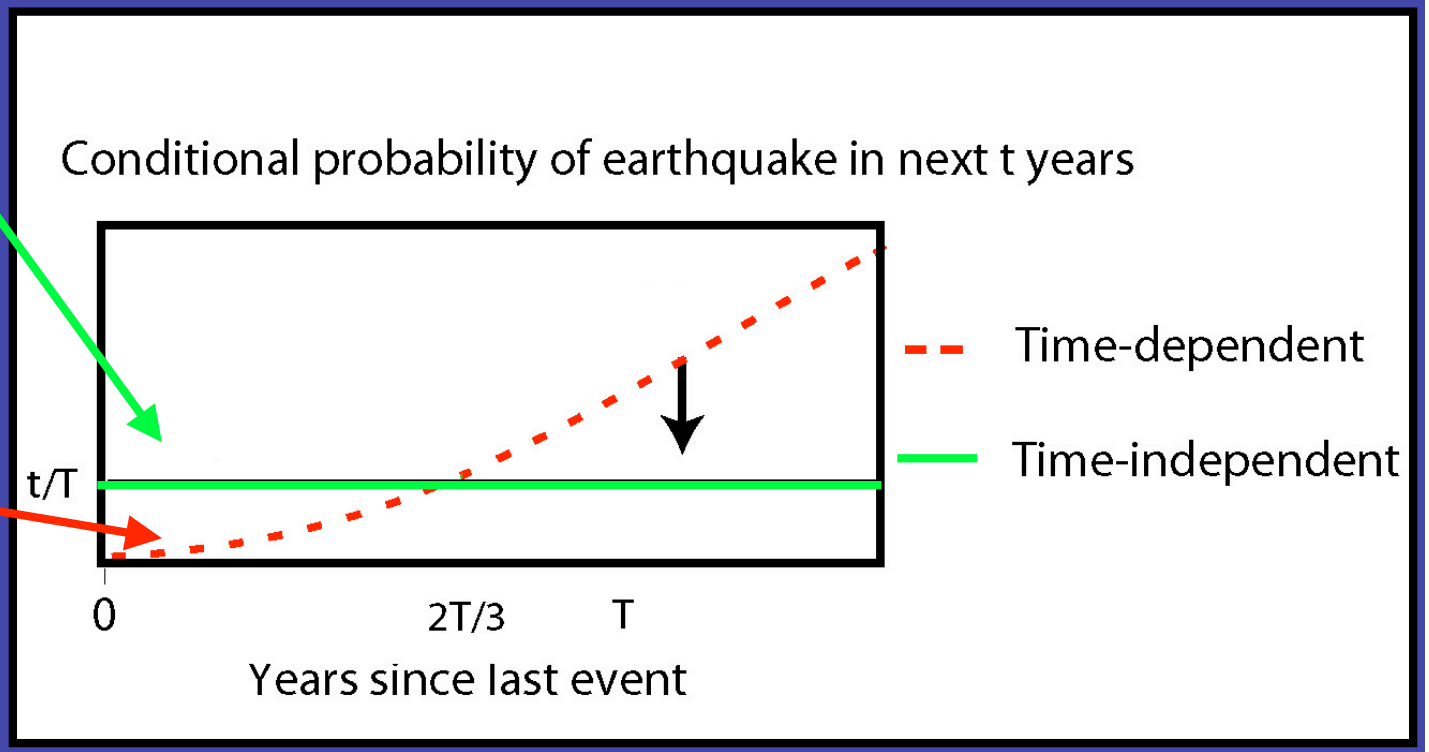
Estimated probability in 30 yrs 7-51%

ALTERNATIVE MODELS FOR RECCURRENCE YIELD DIFFERENT PROBABILITIES

Constant since last event: time independent

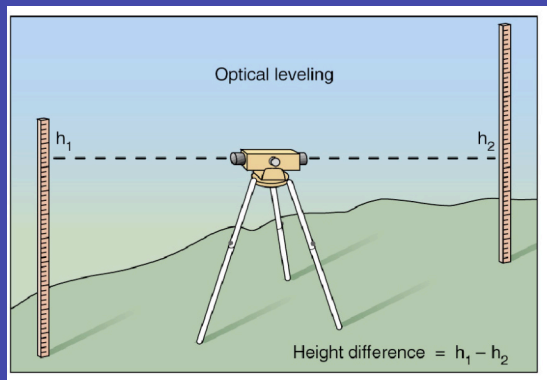
Small after last event, then grows: time dependent

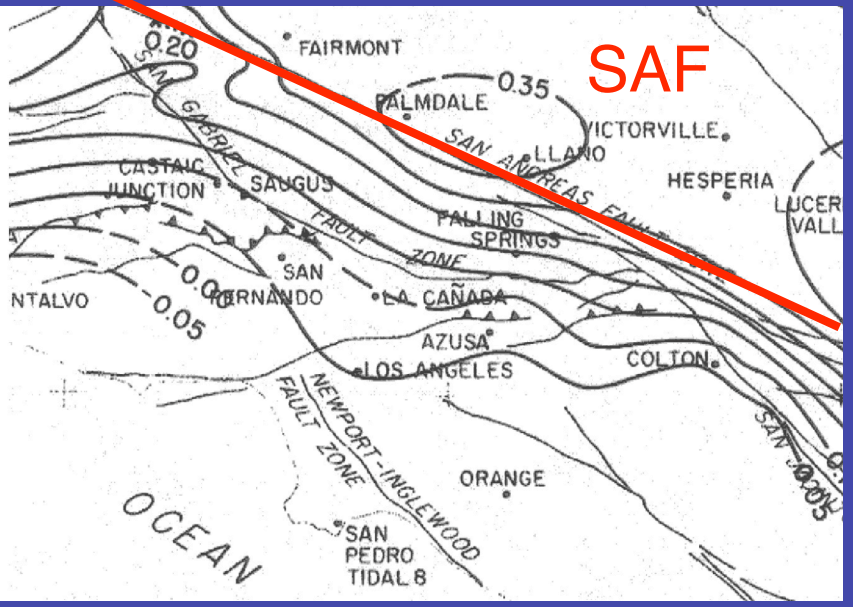
Time dependent lower until ~2/3 mean recurrence



Hebden & Stein, 2008

1975 PALMDALE BULGE – uplift reported





USGS director stated that *"a great earthquake" would occur "in the area ... 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. California Seismic Safety Commission stated that *"the uplift should be considered a possible threat to public safety"* and urged immediate preparations…

35 years later, nothing yet..

WHY CAN'T WE PREDICT EARTHQUAKES?

So far, no clear evidence for consistent precursors before earthquakes.

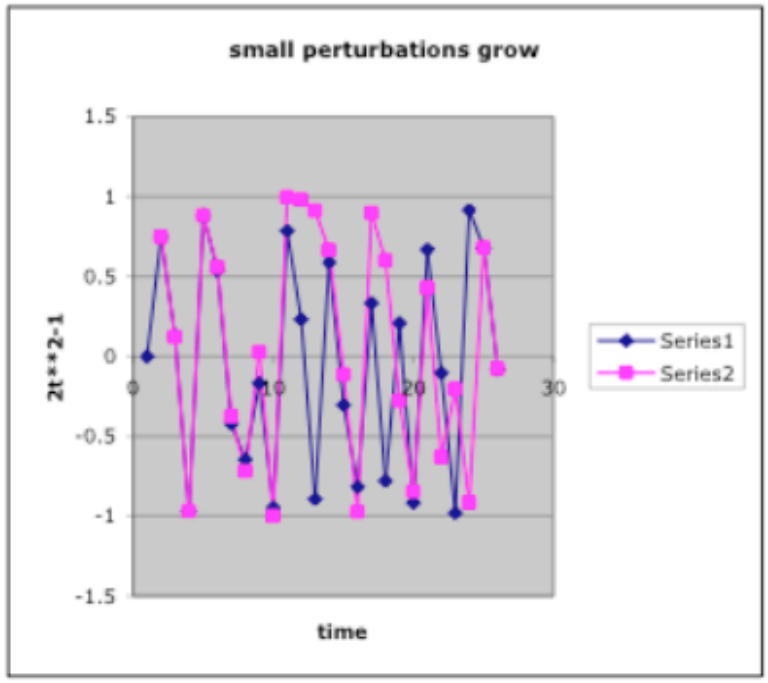
Maybe lots of tiny earthquakes happen frequently, but only a few grow by random process to large earthquakes

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.

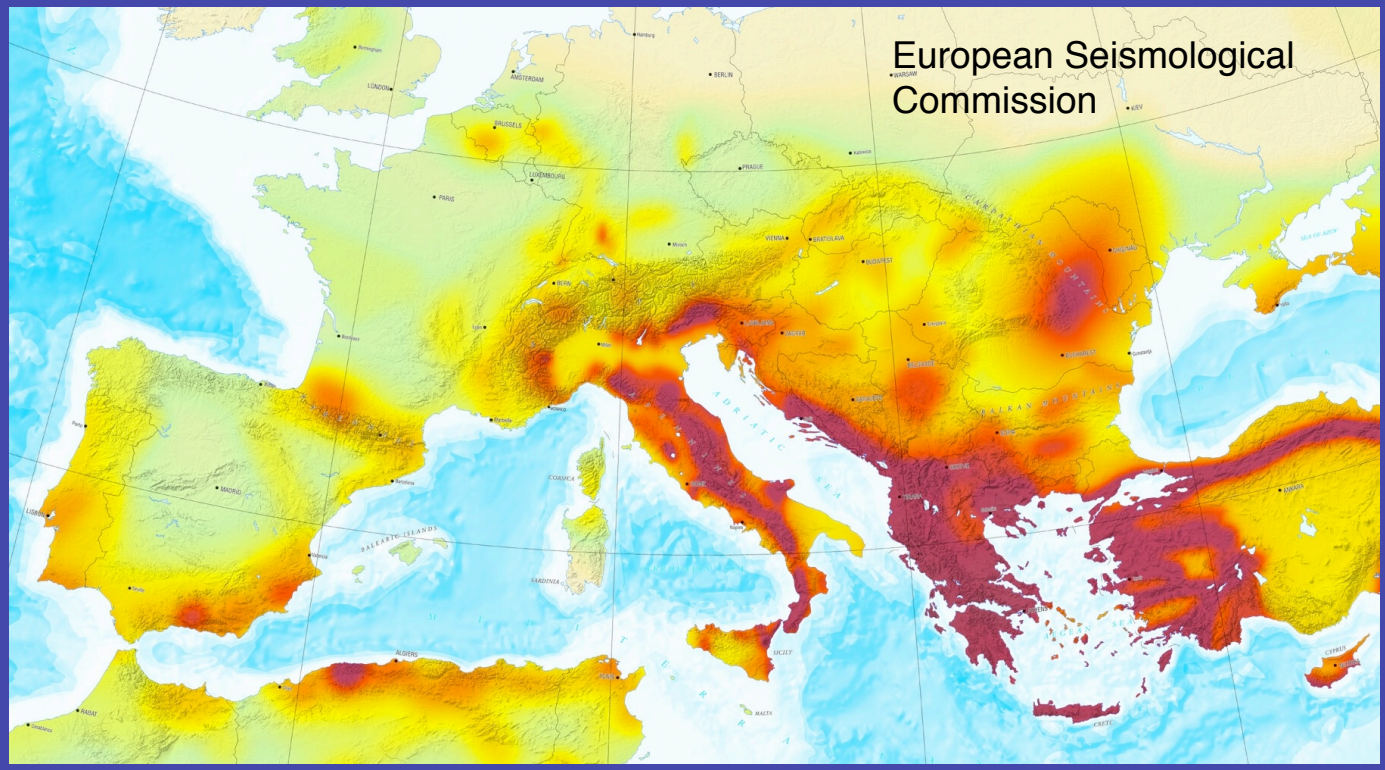
If so, earthquake prediction is either impossible or nearly so.

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



Nonlinearity from growth of small perturbations

To design buildings, try to predict the hazard defined as maximum shaking (acceleration) they'll face in some time period, which isn't easy



"A game of chance against nature, of which we still don't know all the rules" (Lomnitz, 1989)

Earthquake hazard isn't a physical thing we measure. It's something we *define* and use computer programs to predict. Different assumptions produce very different maps.

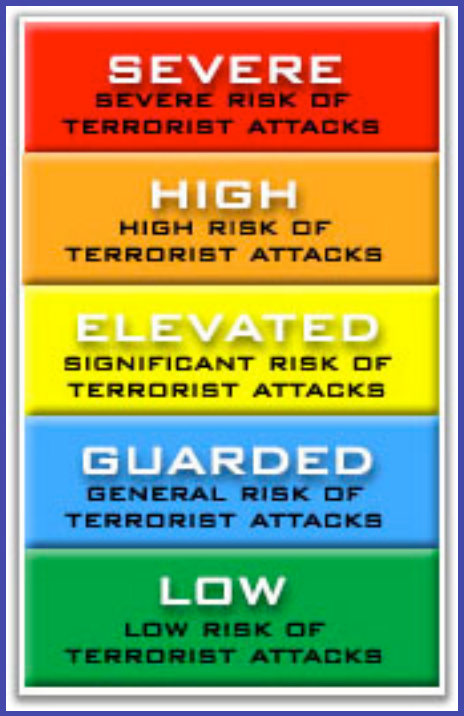
- ***What's the definition*** **of hazard (political, not scientific)**

- ***Where*** **and** ***when*** **will earthquakes occur?**

- **If they occur, then**

- ***How large*****?**

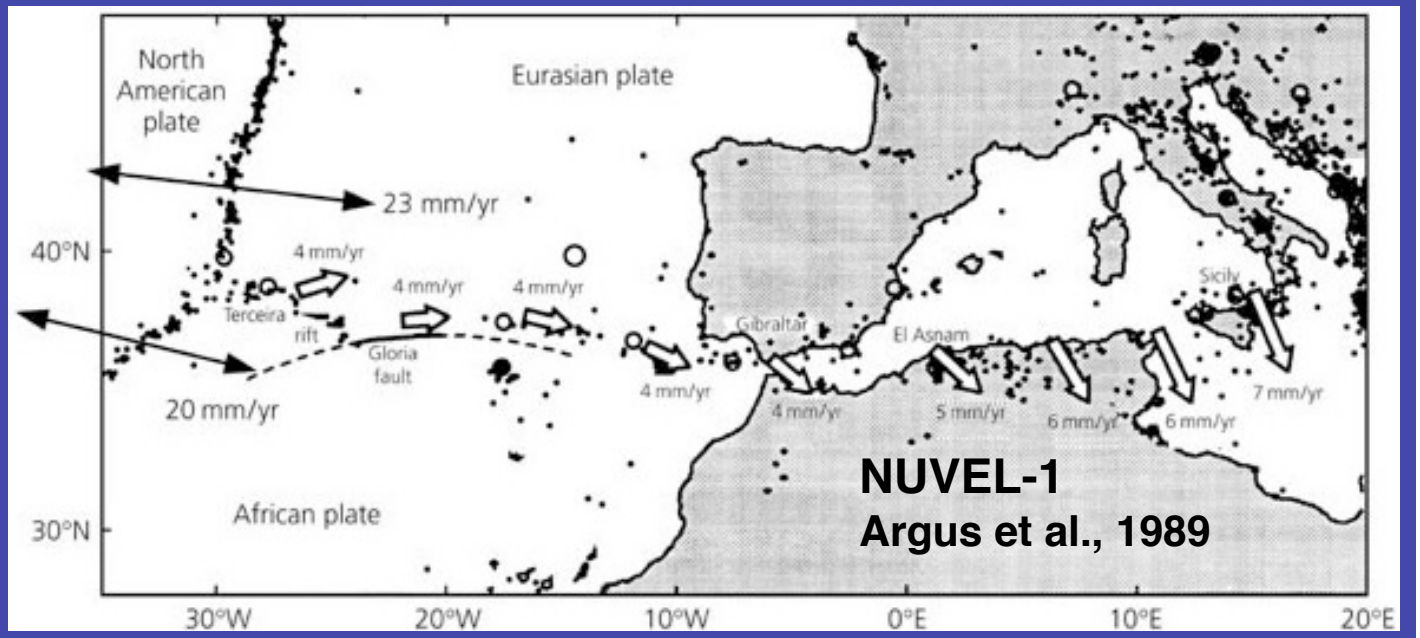
- ***How strong*** **will ground motion be?**



These aren't well understood, especially where large earthquakes are rare, so hazard estimates are highly subjective & have considerable uncertainties

SHORT RECORD OF SEISMICITY & HAZARD ESTIMATE

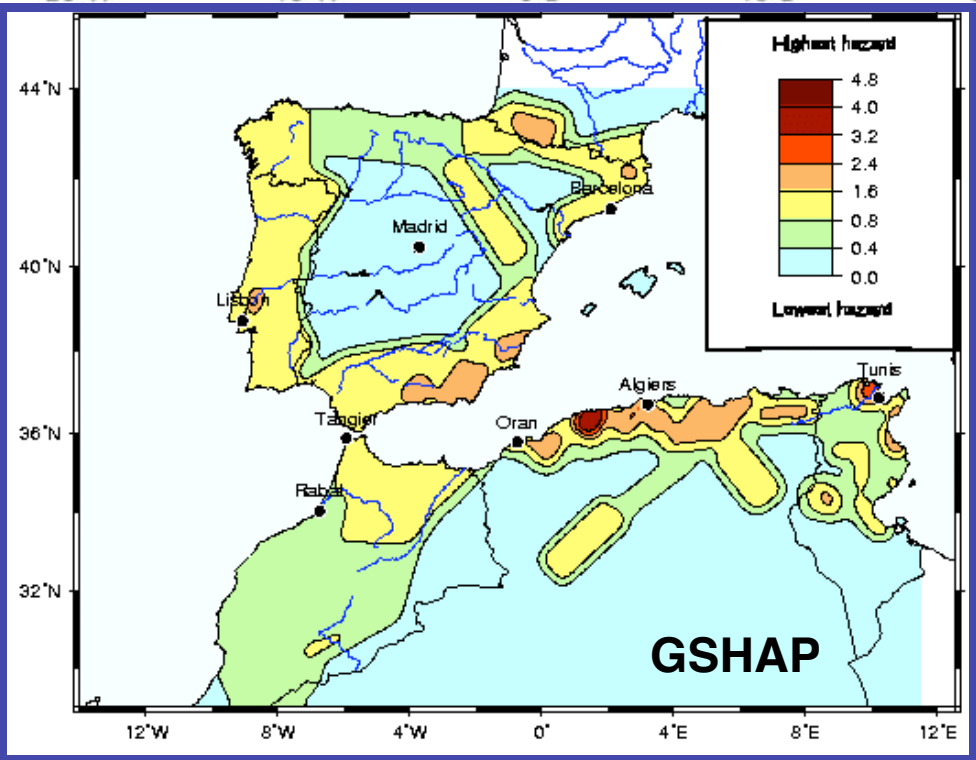
Africa-Eurasia convergence rate varies smoothly



Predicted hazard from historic seismicity is highly variable

Likely overestimated near recent earthquakes, underestimated elsewhere

More uniform hazard seems more plausible - or opposite if time dependence considered



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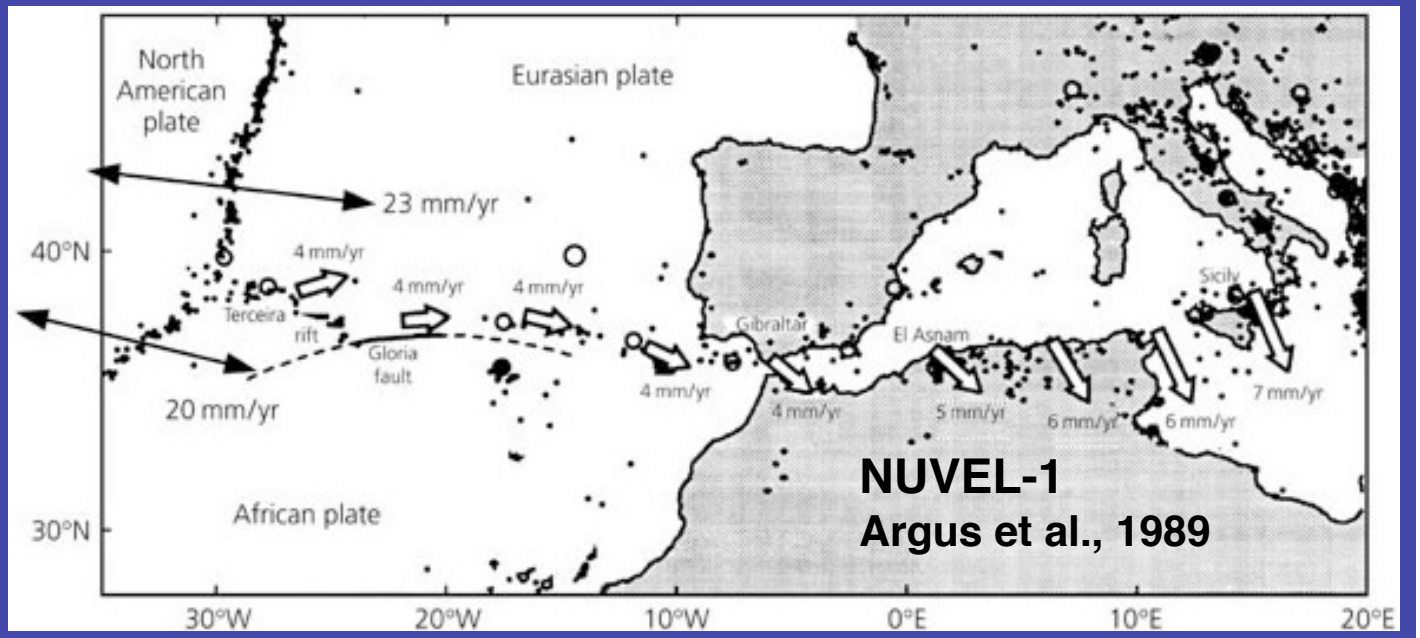

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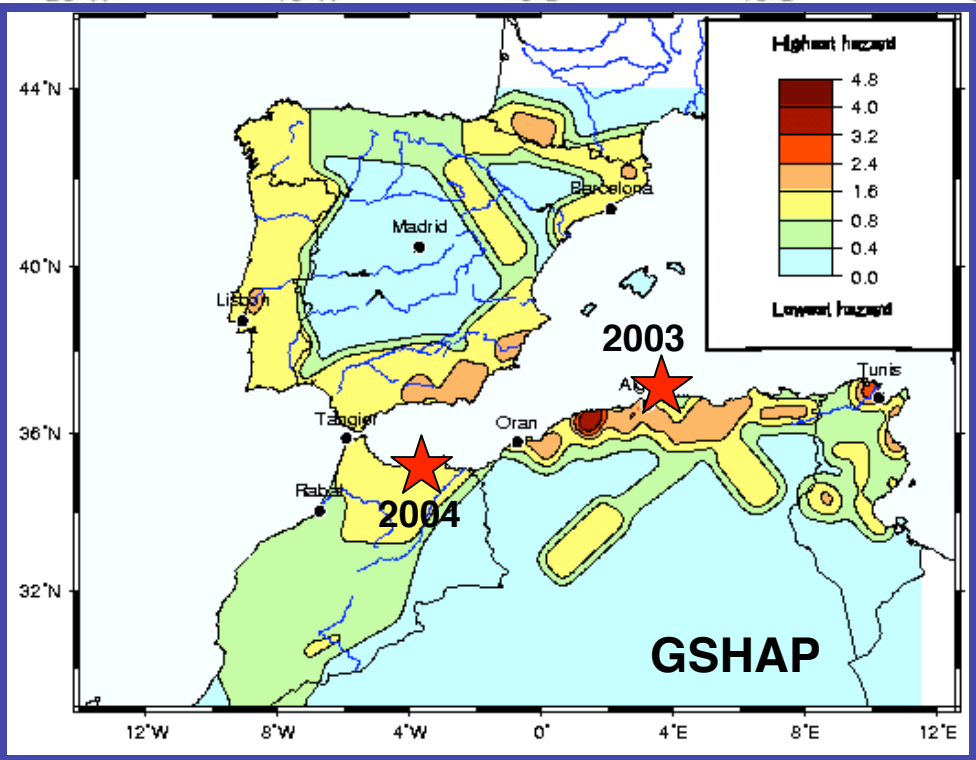
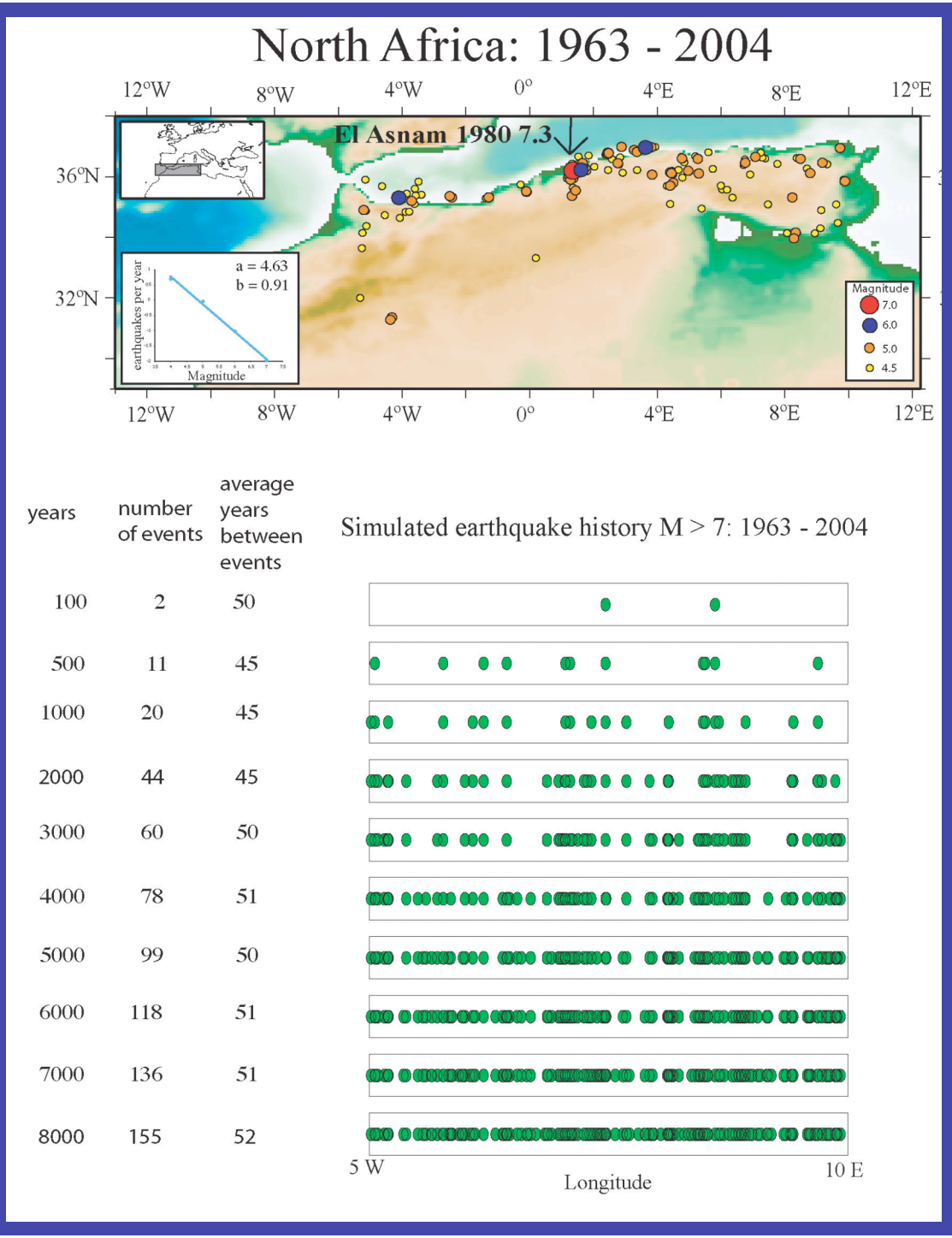
Map changes after major earthquakes



Long record needed to see real pattern without spurious gaps & concentrations



Swafford & Stein, 2007

Even harder off plate boundaries…

Plate Boundary Quakes

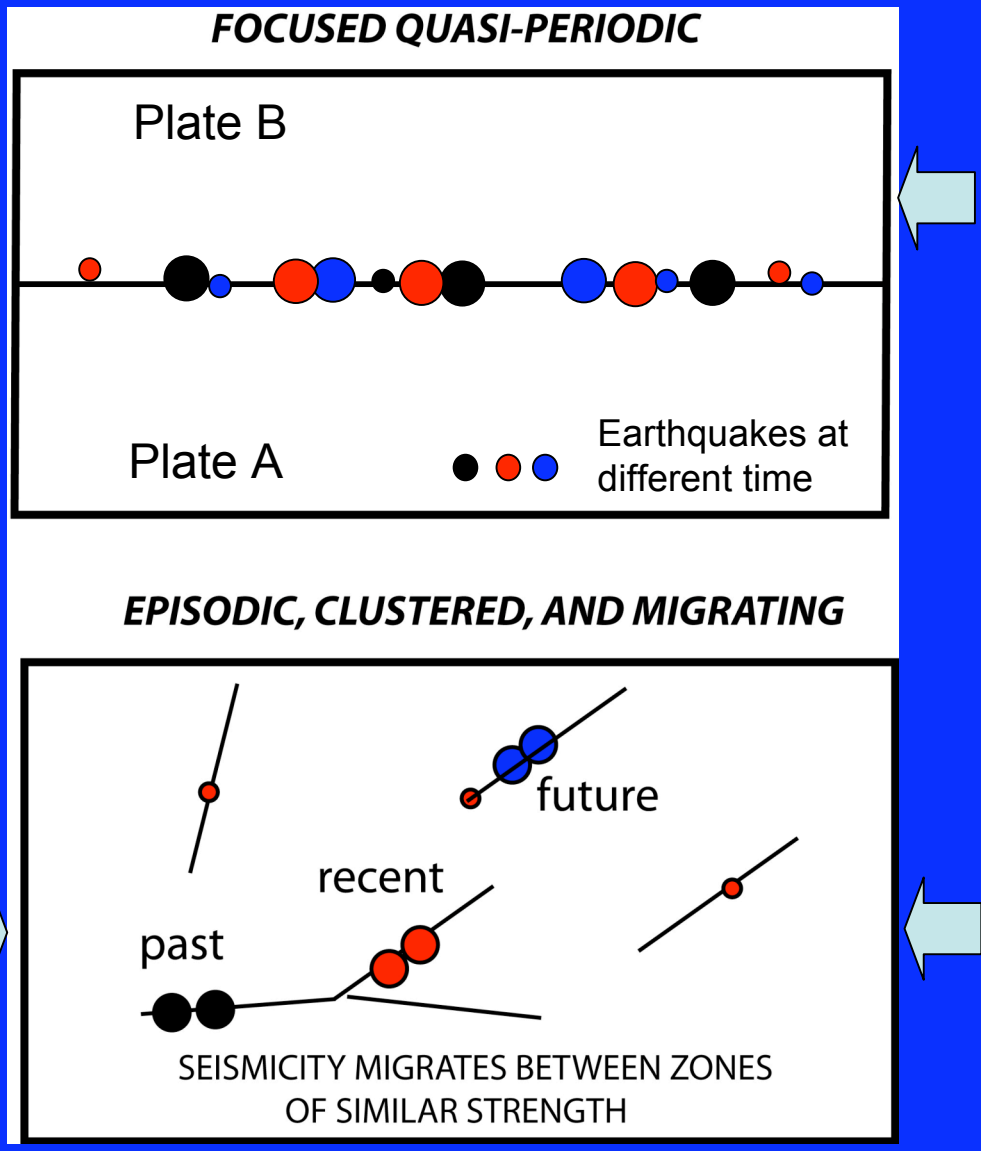
- Major fault loaded rapidly at constant rate
- Earthquakes spatially focused & temporally quasi-periodic

Past is fair predictor

Intraplate Earthquakes

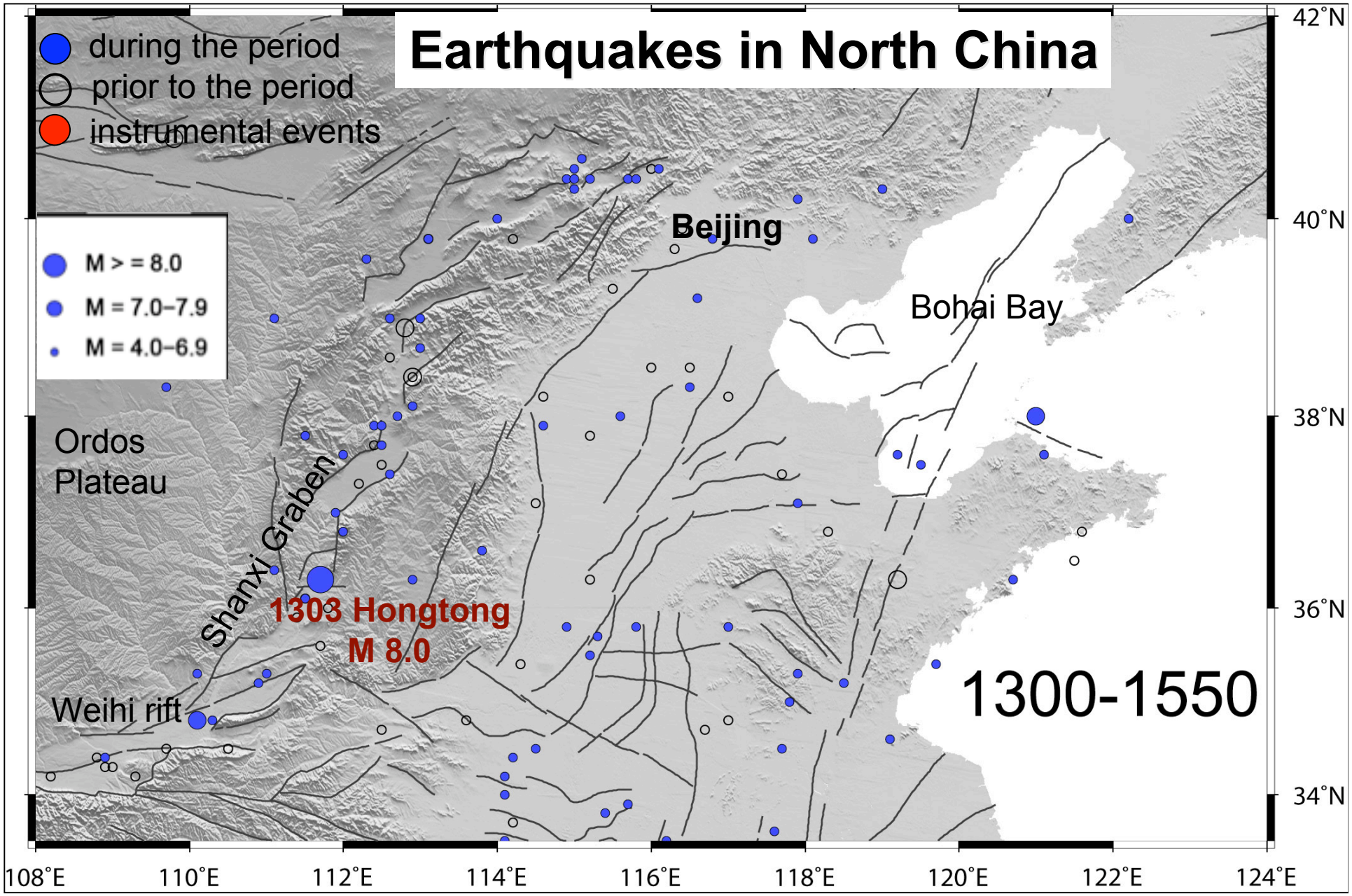
- Tectonic loading collectively accommodated by a complex system of interacting faults
- Loading rate on a given fault is slow & may not be constant
- Earthquakes can cluster on a fault for a while then shift

Past can be poor predictor

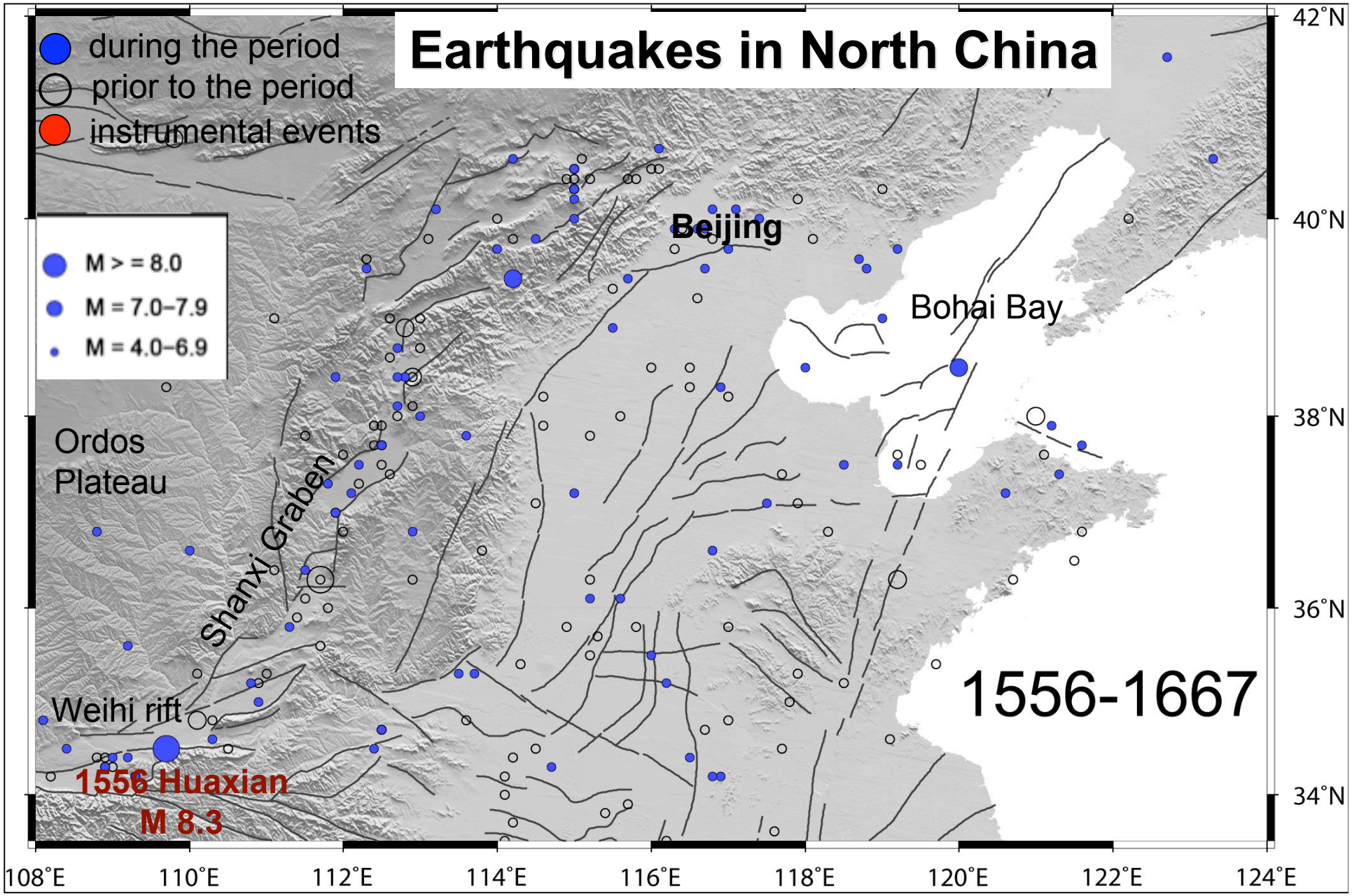


Stein, Liu & Wang 2009

Liu, Stein & Wang 2010



Large events often pop up where there was little seismicity!



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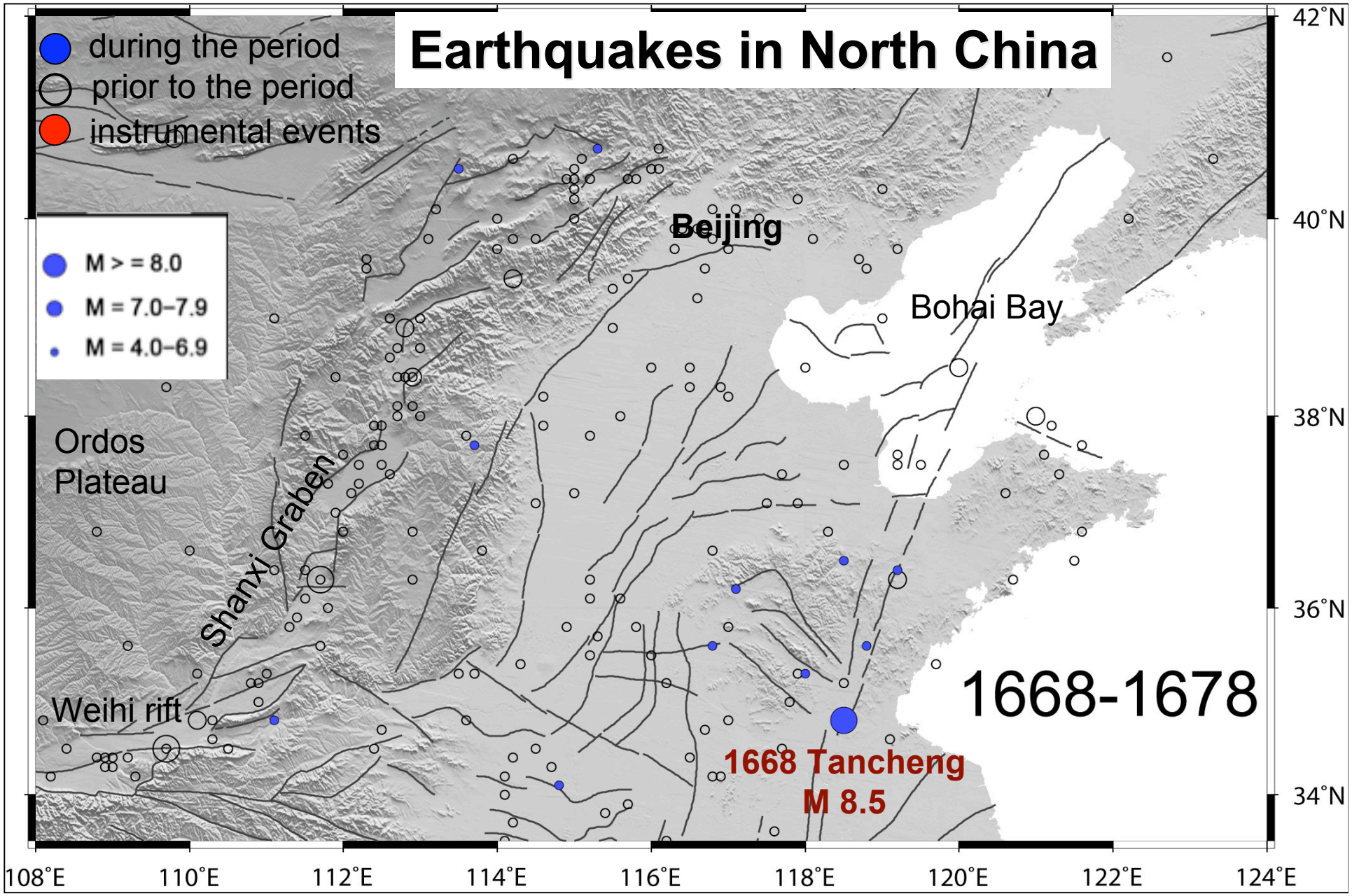

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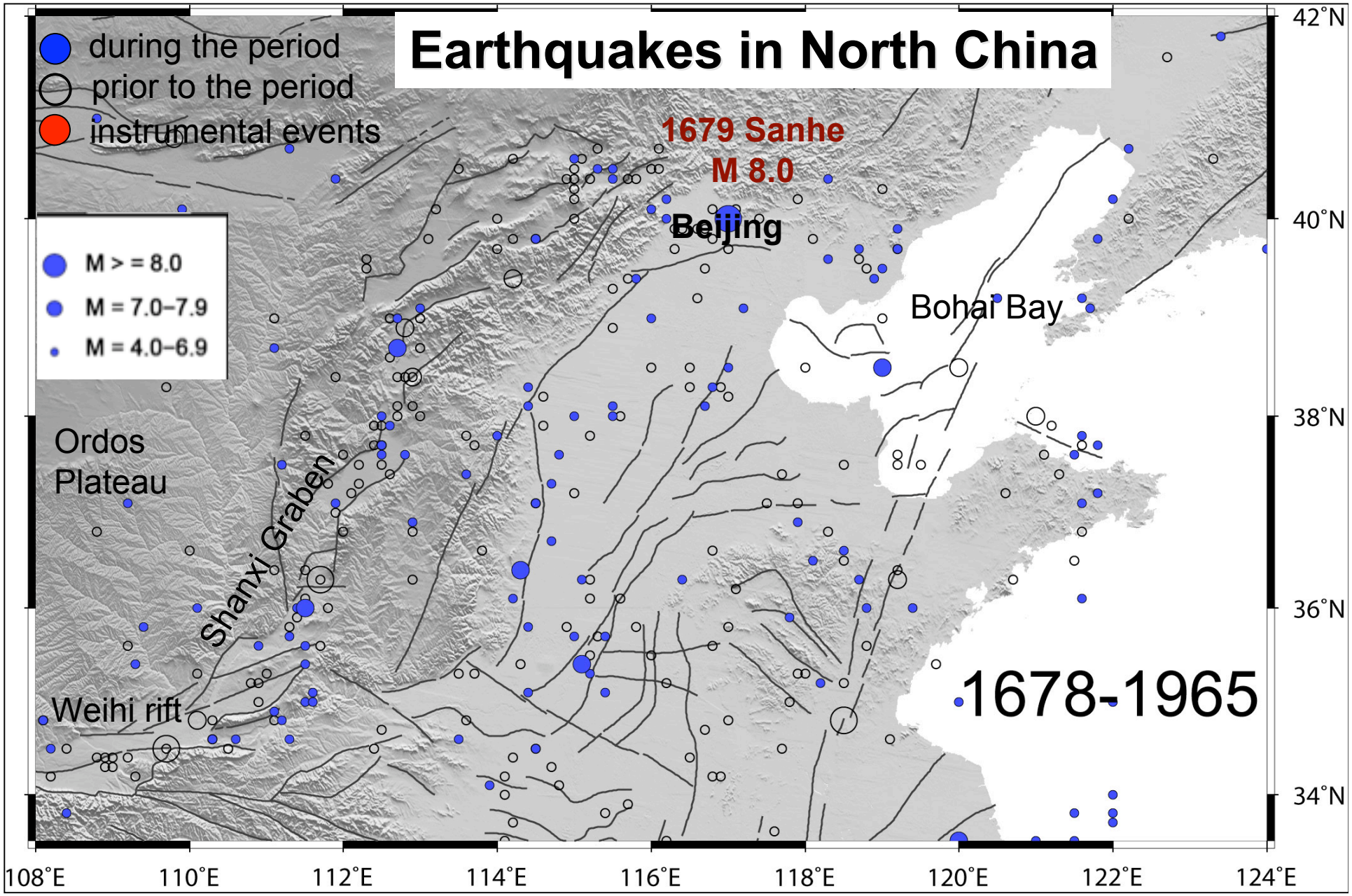

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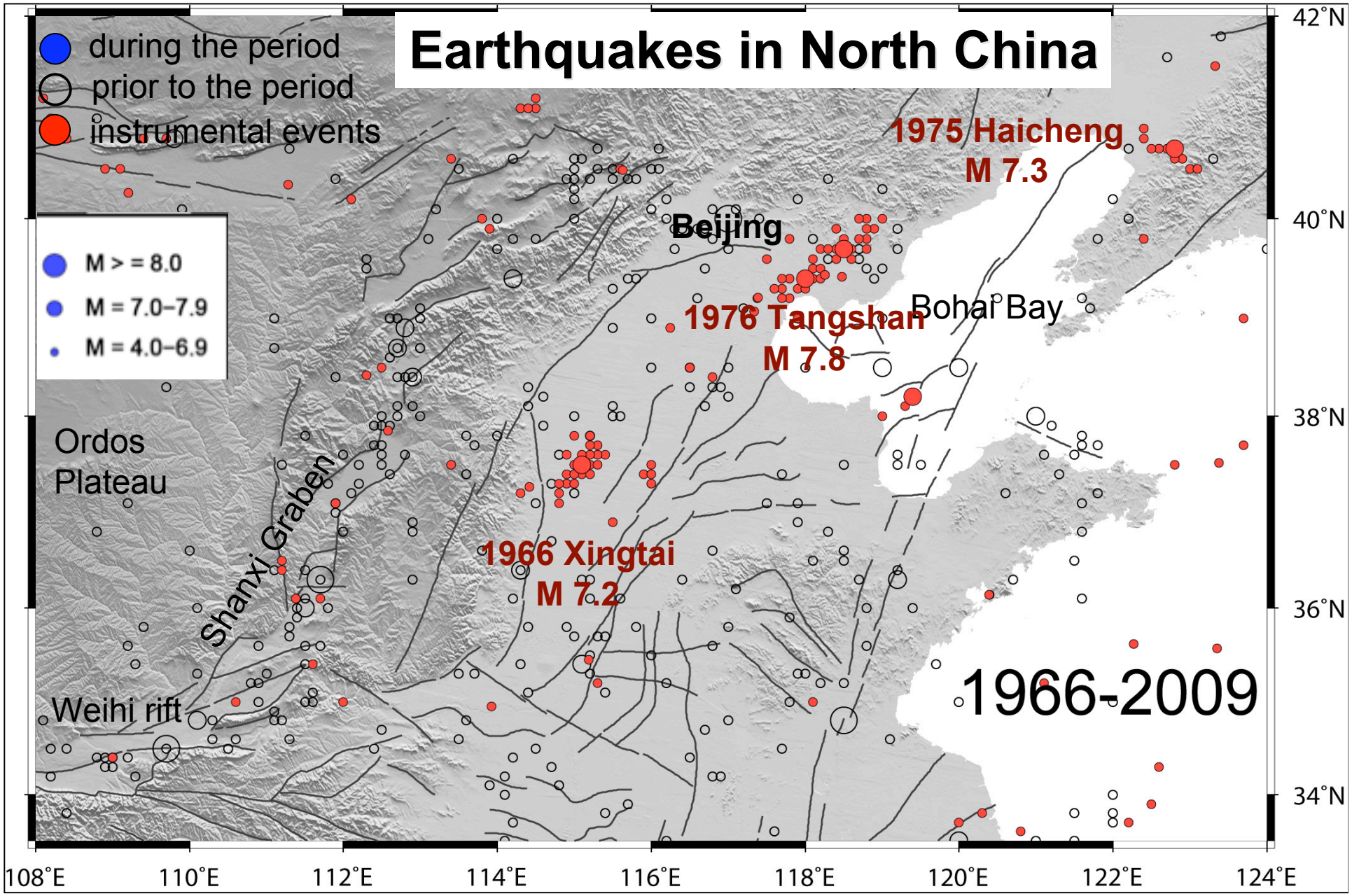

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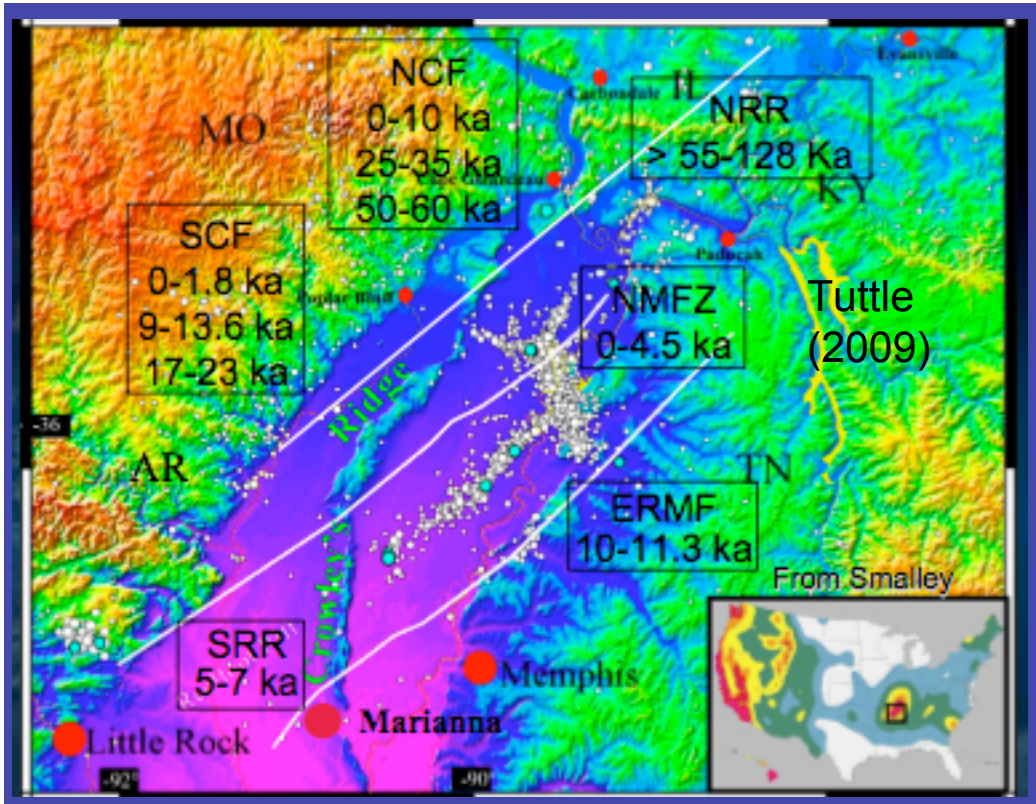
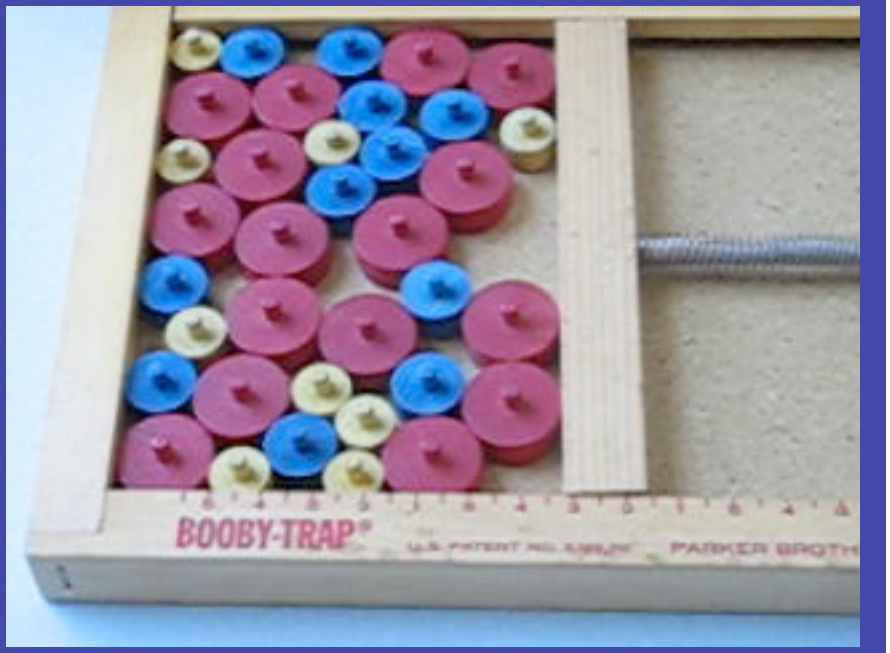


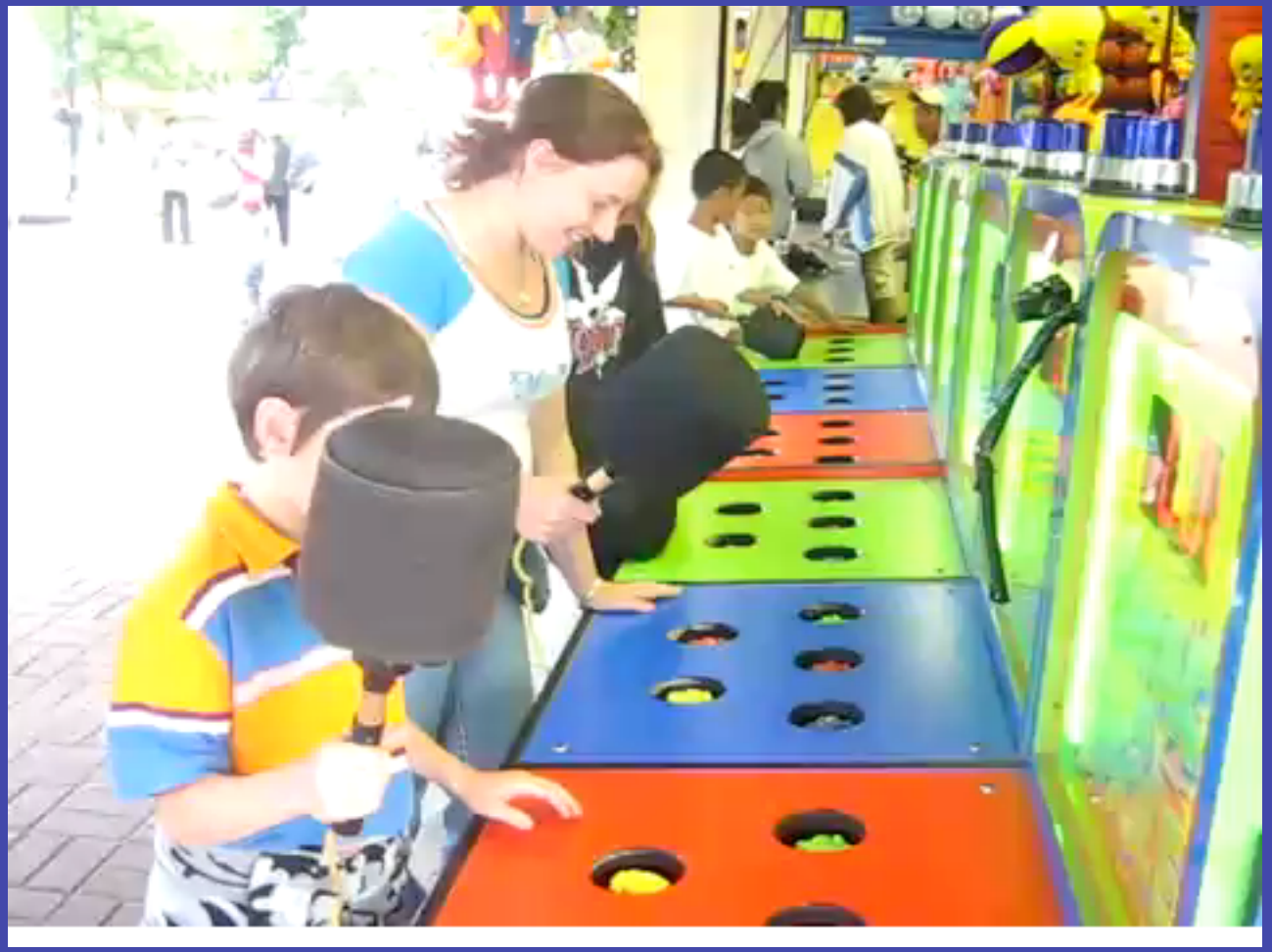


Faults active in past show little present seismicity

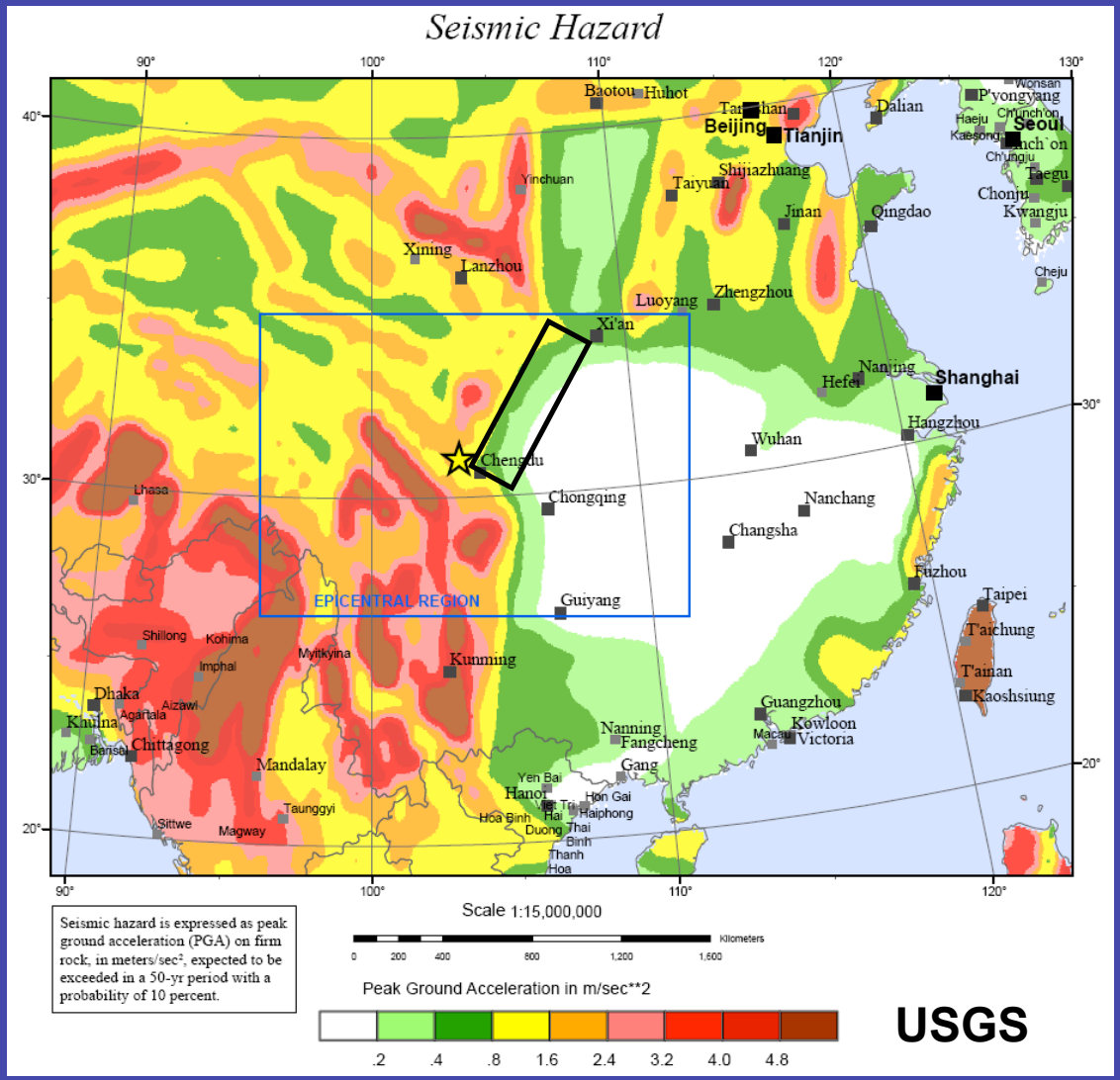
Seismicity migrates among faults due to fault interactions (stress transfer)

Meers fault, Oklahoma
Active 1000 years ago, dead now

Neglecting variability is like ‘Whack-a-mole’ - you wait for the mole to come up where it went down, but it’s likely to pop up somewhere else.

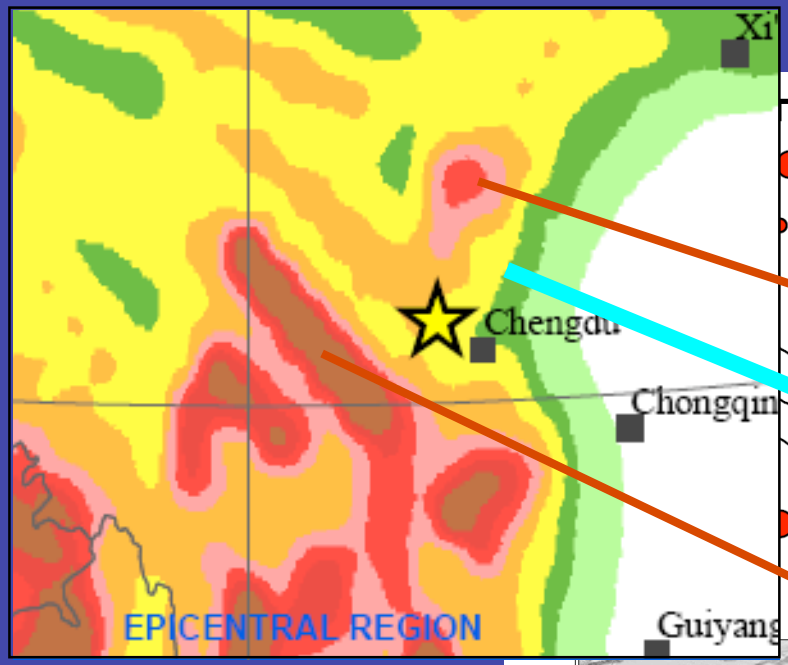


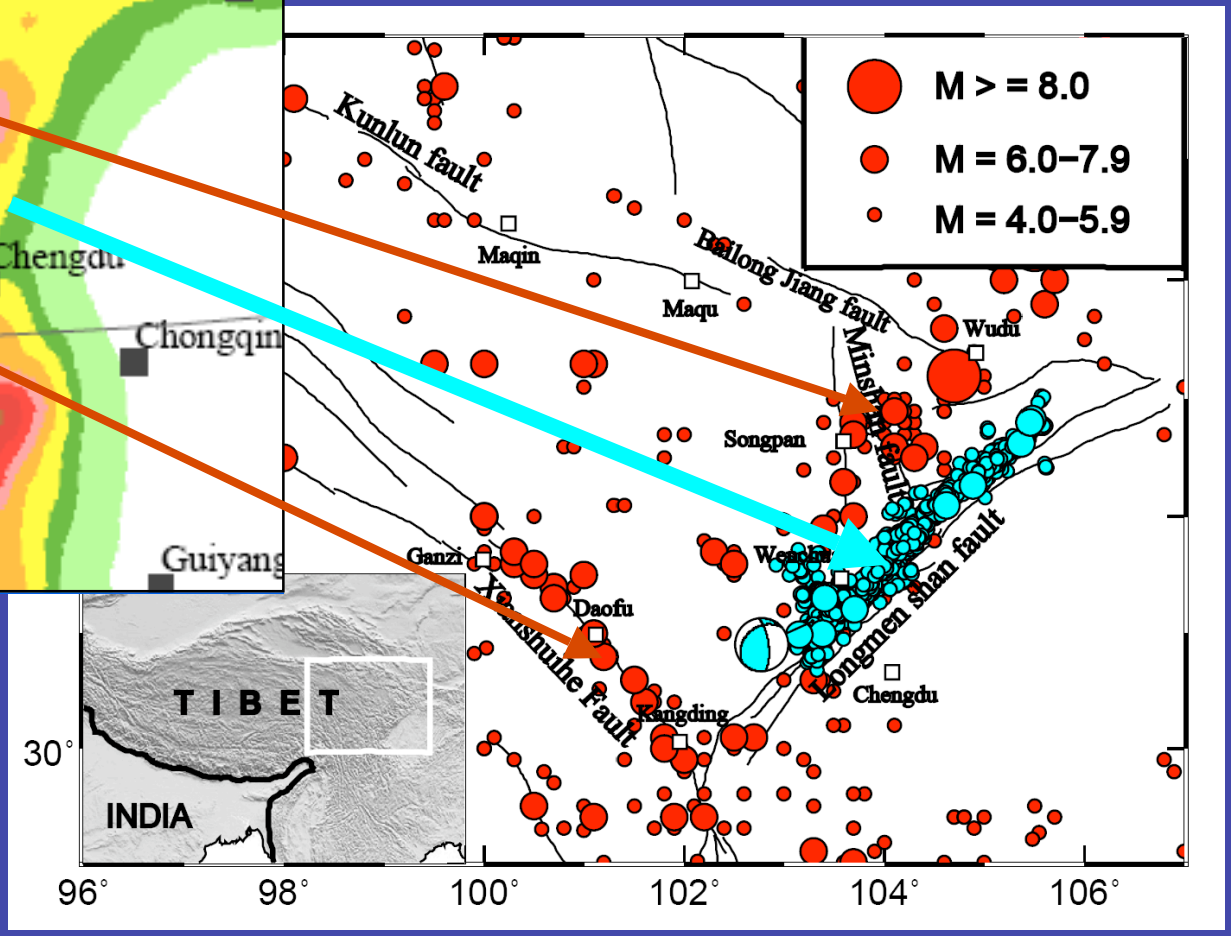
2008 Wenchuan earthquake (Mw 7.9) was not expected: map showed low hazard



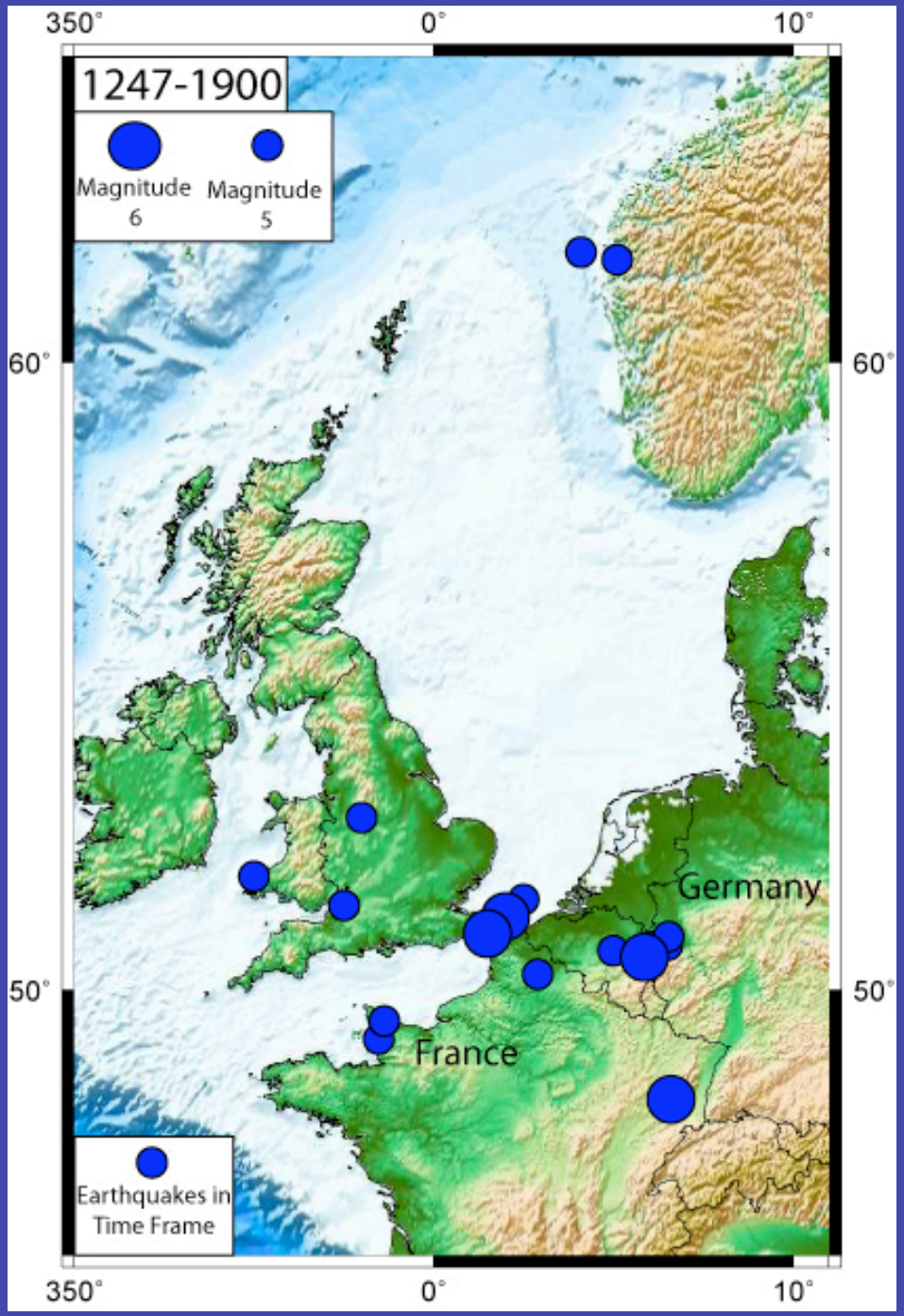
Hazard map ignored variability - assumed steady state - relied on lack of recent seismicity

Didn't use GPS data





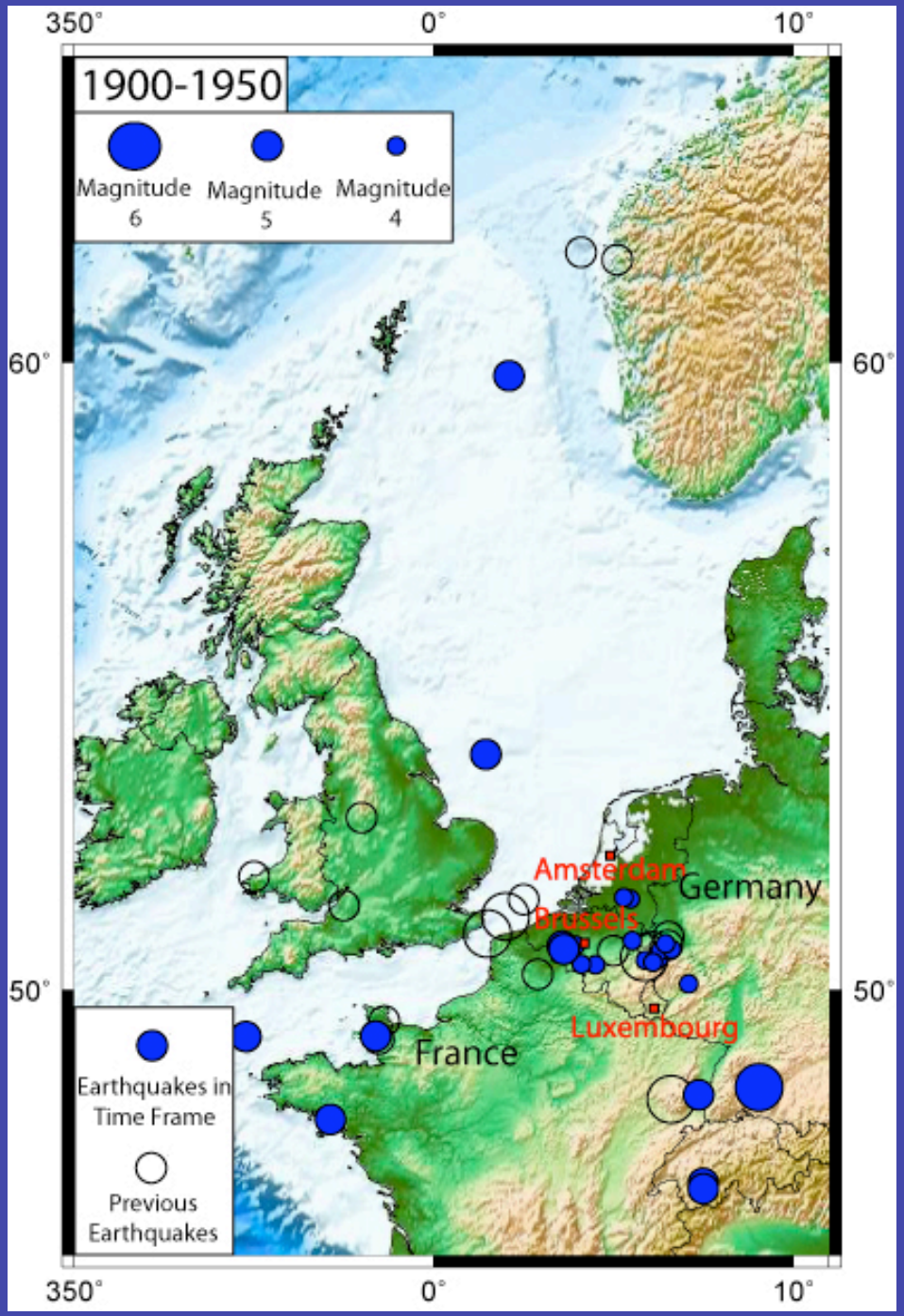
- Earthquakes prior to the 2008 Wenchuan event
- Aftershocks of the Wenchuan event delineating the rupture zone

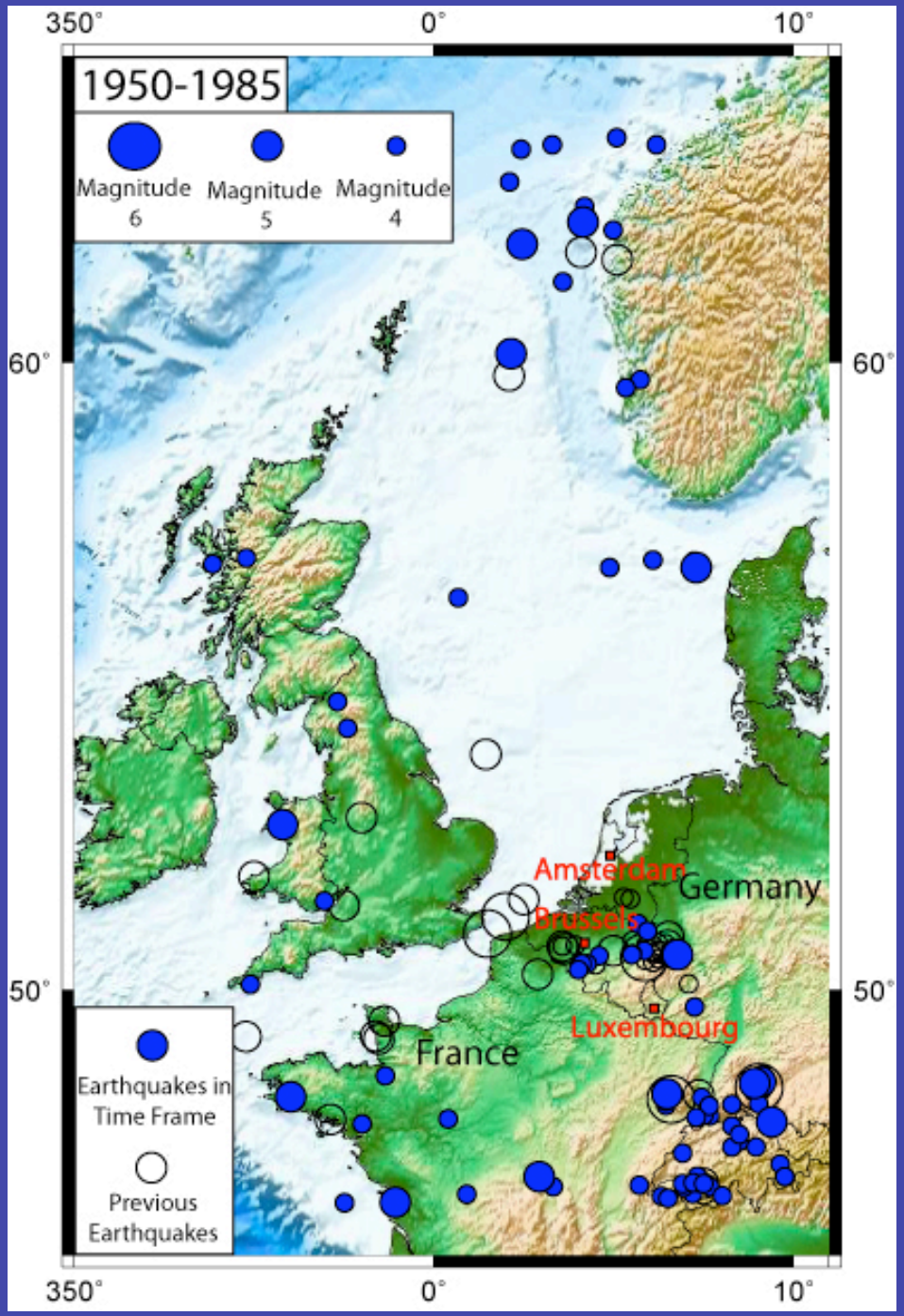


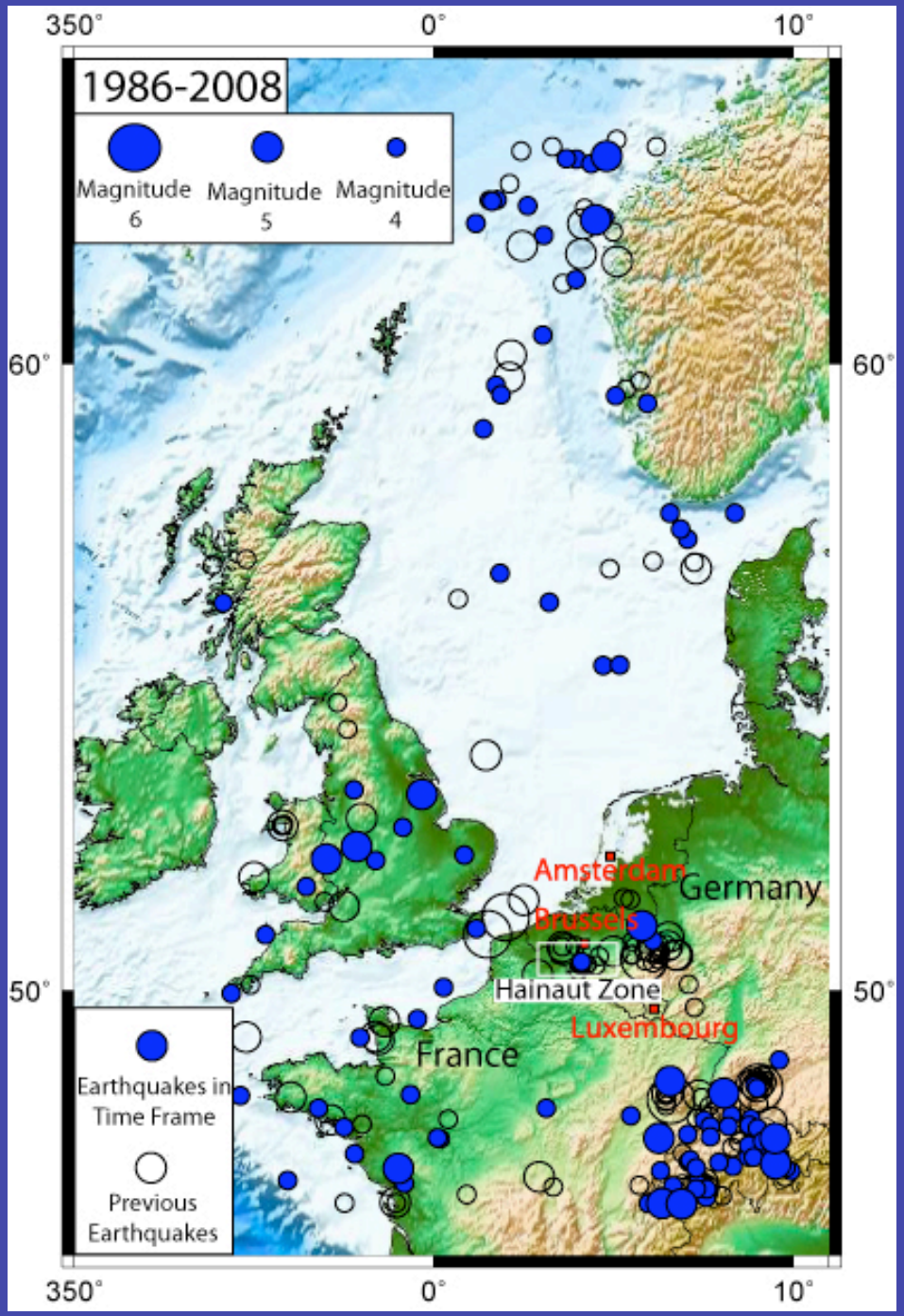
"During the past 700 years, destructive earthquakes generally occurred in different locations, indicating a migration of seismicity with time."

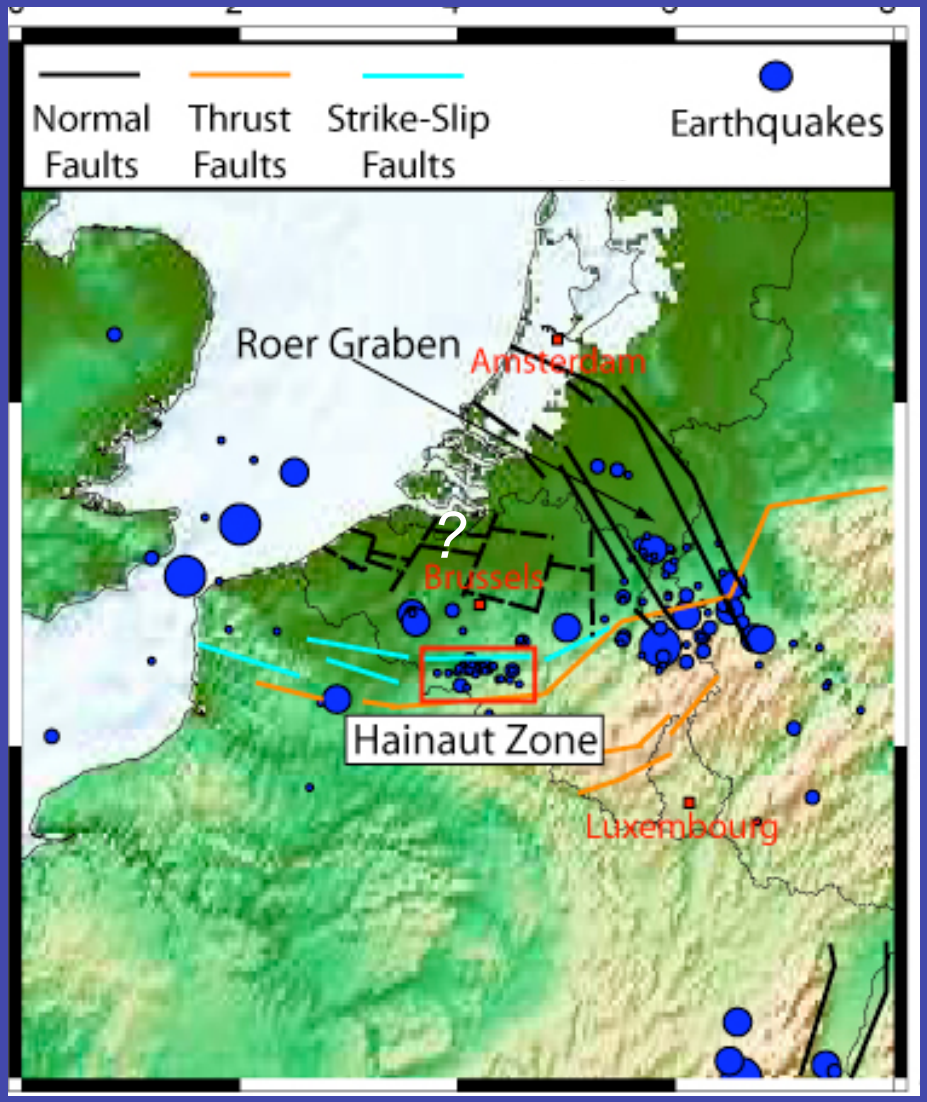
(Camelbeeck et al., 2007)

Royal Observatory of Belgium catalog


350°
0°
10°
1900-1950
Magnitude 6
Magnitude 5
Magnitude 4
60°
50°
Amsterdam
Germany
Brussels
Luxembourg
France
Earthquakes in Time Frame
Previous Earthquakes


350°
0°
10°
1950-1985
Magnitude 6
Magnitude 5
Magnitude 4
60°
50°
Amsterdam
Germany
Brussels
Luxembourg
France
Earthquakes in Time Frame
Previous Earthquakes


350°
0°
10°
1986-2008
Magnitude 6
Magnitude 5
Magnitude 4
60°
50°
Amsterdam
Germany
Brussels
Hainaut Zone
Luxembourg
France
Earthquakes in Time Frame
Previous Earthquakes


Normal Faults
Thrust Faults
Strike-Slip Faults
Earthquakes
Roer Graben
Amsterdam
?
Brussels
Hainaut Zone
Luxembourg

M 5.4

T. Camelbeeck

At present

No reliable method of predicting earthquakes

No present approaches seem promising

Barring conceptual breakthrough, earthquake prediction appears unlikely soon

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

Hiroo Kanamori

Failed prediction: New Madrid

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