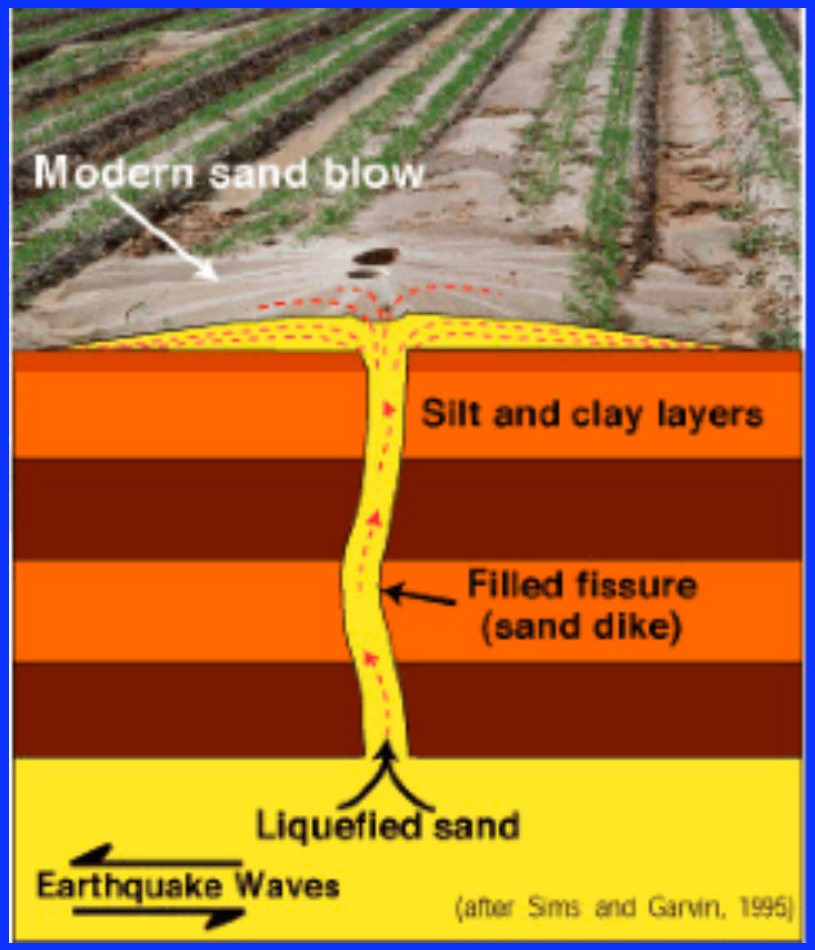
8. Faults switching on and off

You must unlearn what you have learned.

Alan Kafka

Because paleoseismology shows large events in 900 & 1450 AD, we started GPS in 1991 expecting to find deformation accumulating, consistent with M7-8 events ~500 years apart



After 8 years, 3 campaigns, 70 people from 9 institutions … 0 +/- 2 mm/yr!

1999 surprise: no motion: 0 +/- 2 mm/yr

2 Centuries Later, Good News for Quake Area, Maybe

The New York Times Science, Tuesday, April 27, 1999. By Sandra Blakeslee

Midwesterners who worry about earthquakes got some good news last week: their risk of catastrophe may have been vastly overstated.

New measurements taken around New Madrid, MO - the epicenter of devastating earthquakes in 1811 and 1812 - show that the ground there is scarcely moving. According to many scientists, this means that it will take 2,500 to 10,000 years before another very large earthquake could occur in the region, although smaller, less damaging earthquakes are possible.

"The motions are small to zero," said Dr. Seth Stein, a professor of geological sciences at Northwestern University in Evanston, Ill., who made the new measurements. Earlier evidence showing rapid regional ground motion, a geologic sign that large quakes are probable, "was based on honest scientific errors," Dr. Stein said.

Slow Deformation and Lower Seismic Hazard at the New Madrid Seismic Zone

Andrew Newman,[1] Seth Stein,[1*] John Weber,[2] Joseph Engeln,[3] Ailin Mao,[4] Timothy Dixon[4]

Global Positioning System (GPS) measurements across the New Madrid seismic zone (NMSZ) in the central United States show little, if any, motion. These data are consistent with platewide continuous GPS data away from the NMSZ, which show no motion within uncertainties. Both these data and the frequency-magnitude relation for seismicity imply that had the largest shocks in the series of earthquakes that occurred in 1811 and 1812 been magnitude 8, their recurrence interval should well exceed 2500 years, longer than has been assumed. Alternatively, the largest 1811 and 1812 earthquakes and those in the paleoseismic record may have been much smaller than typically assumed. Hence, the hazard posed by great earthquakes in the NMSZ appears to be overestimated.

No motion

Recent cluster likely ended

Seismicity migrates

Hazard overestimated

April 1999

It is also possible that 1811–1812–style earthquakes may never recur. If more accurate future surveys continue to find essentially no interseismic slip, we may be near the end of a seismic sequence. It has been suggested that because topography in the New Madrid region is quite subdued, the NMSZ is a feature no older than a few million years and perhaps as young as several thousand years (*21*). Therefore, New Madrid seismicity might be a transient feature, the present locus of intraplate strain release that migrates with time between fossil weak zones.

Although much remains to be learned about this intriguing example of intraplate tectonics, the present GPS data imply that 1811–1812–size earthquakes are either much smaller or far less frequent than previously assumed. In either case, it seems that the hazard from great earthquakes in the New Madrid zone has been significantly overestimated. Hence, predicted ground motions used in building design there, such as the National Seismic Hazard Maps (*22*) that presently show the seismic hazard there exceeding that in California, should be reduced.

MAXIMUM MOTION STEADILY CONVERGES TO ZERO

Rate v of motion of site that started at x_1 and reaches x_2 in time T

$$v = (x_1 - x_2)/T$$

If position uncertainty is given by standard deviation σ

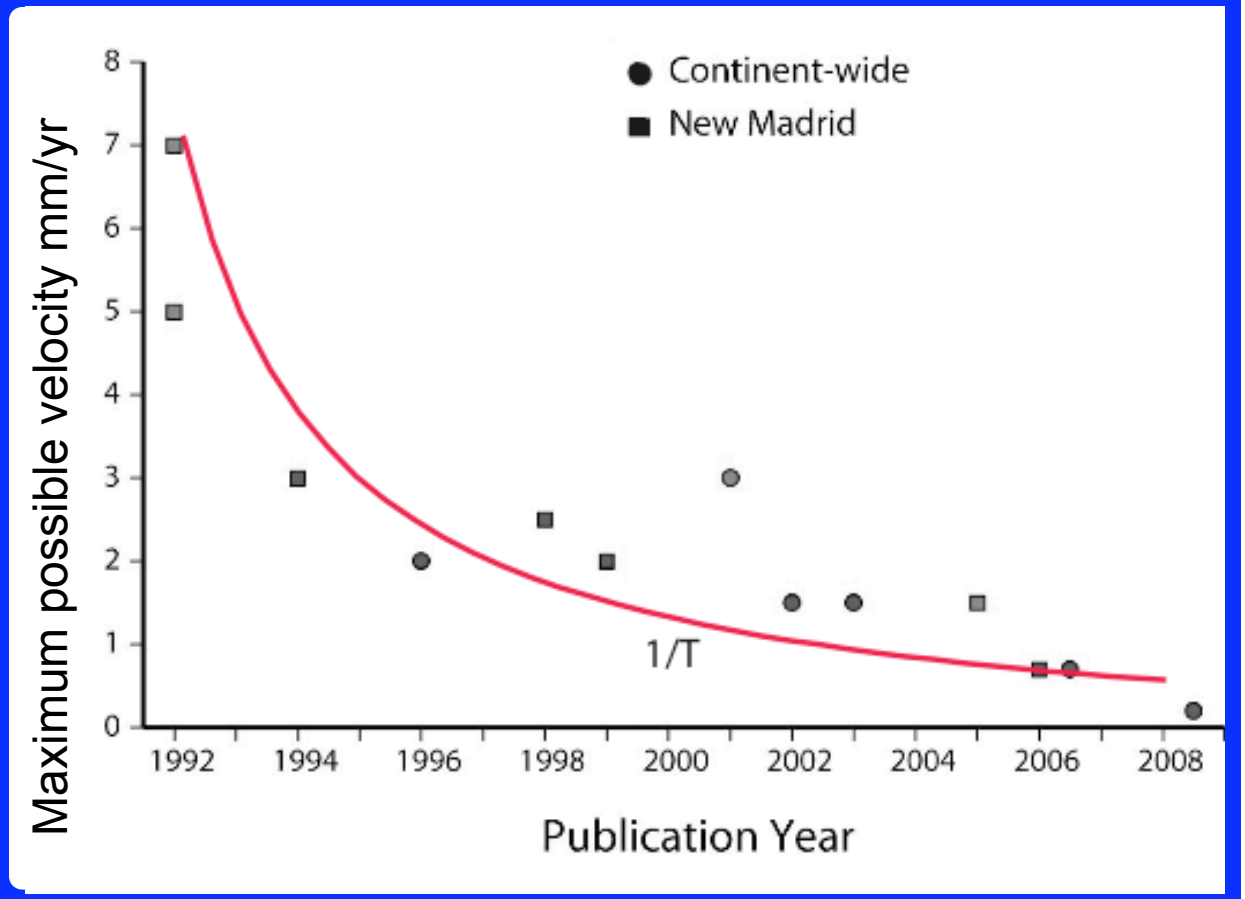
Rate uncertainty is

$\sigma_v = 2^{1/2} \sigma / T$

Rate precision improves with longer observations

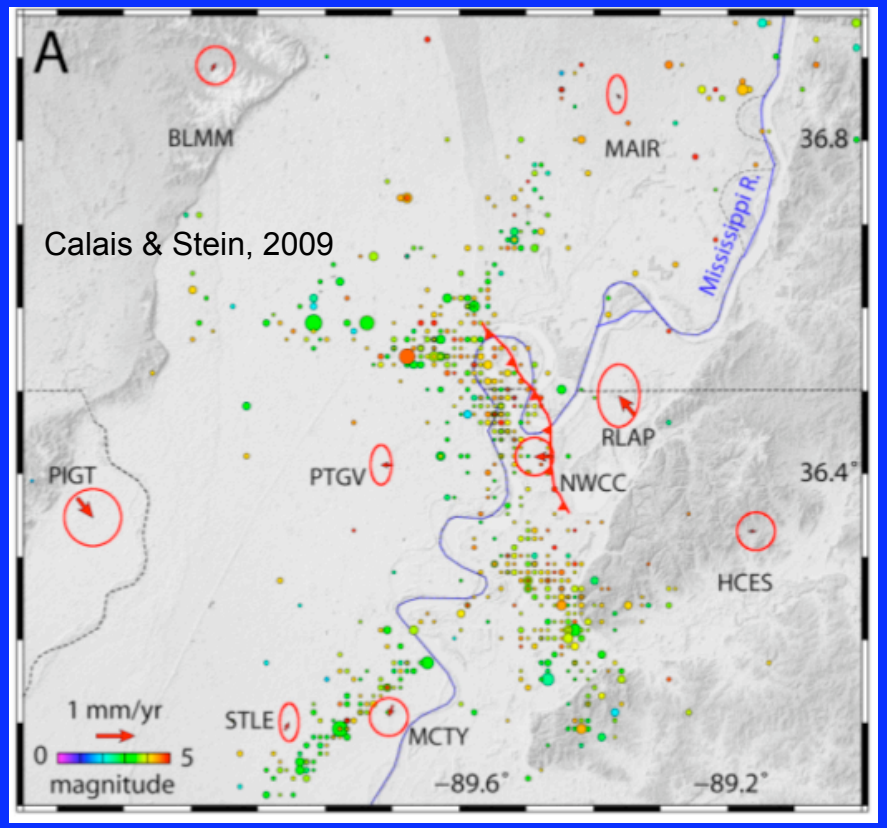
Rates < 0.2 mm/yr, will continue to converge on zero unless ground motion starts

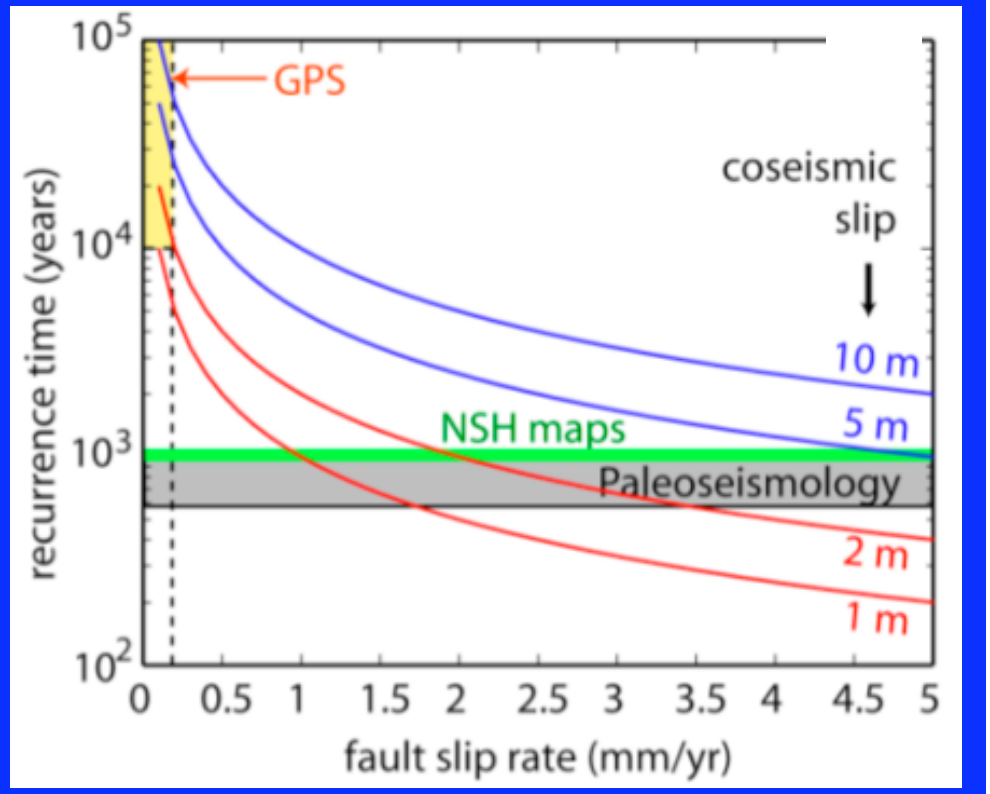
Strain rate does the same: $< 2 \times 10^{-9}$ /yr and shrinking



Calais & Stein, 2009

GPS INCONSISTENT WITH STEADY-STATE SEISMICITY





Motions with respect to rigid North America < 0.2 mm/yr & within error ellipses. Data do not require motion, and restrict any motion to being very slow.

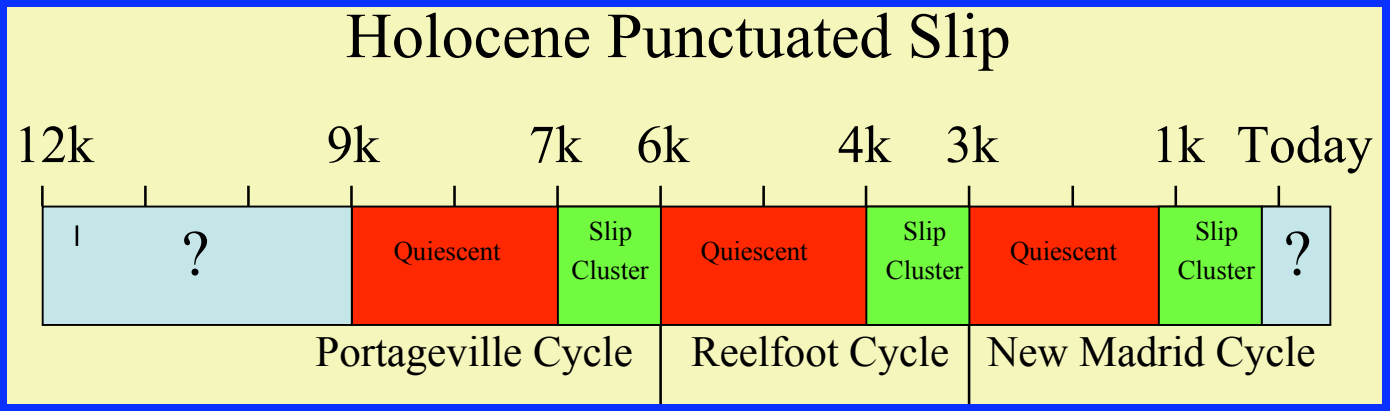
Very long time needed to store up slip needed for a future large earthquake

For steady motion, M 7 at least 10,000 years away: M 8 100,000

Large earthquake cluster in past 2000 years isn't representative of long term NMSZ behavior

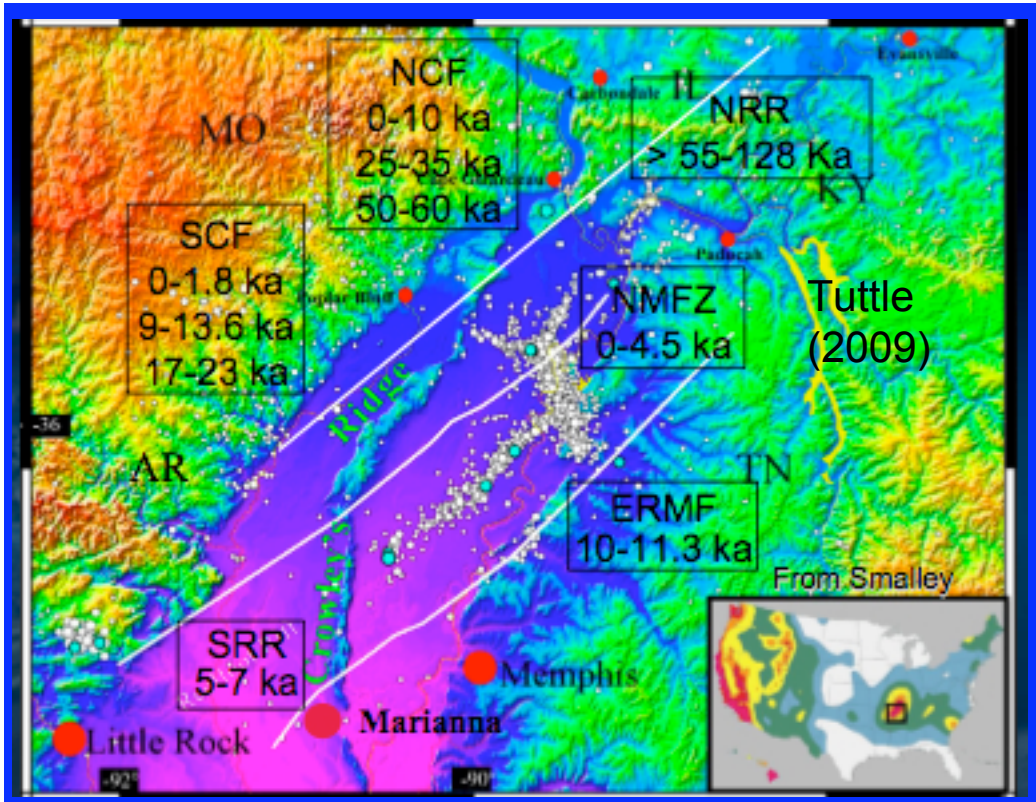
Lack of significant fault topography, jagged fault, seismic reflection, and other geological data also imply that recent pulse of activity is only a few thousand years old

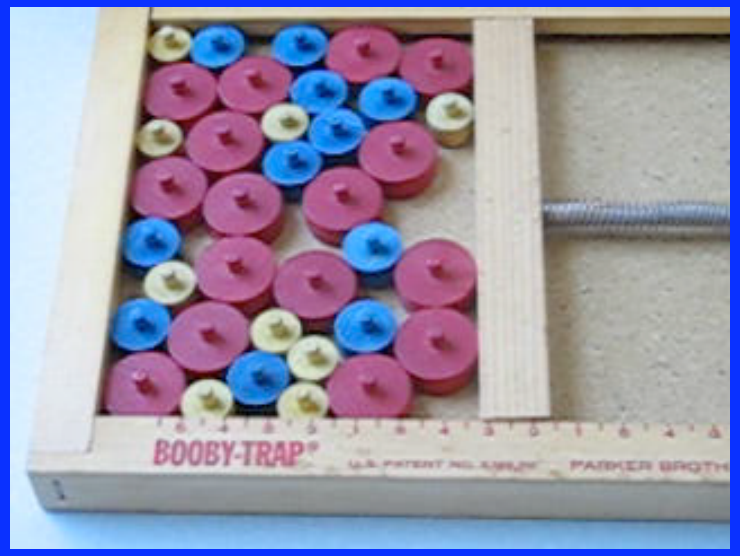
Recent cluster likely ended



New Madrid earthquake history inferred from Mississippi river channels

Holbrook et al., 2006





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

Activity 8.1: Booby-Trap

1) Set up the game

- Remove pieces that you think won't cause an "earthquake" (feeling pieces is allowed)

- Repeat until no "free" pieces are left

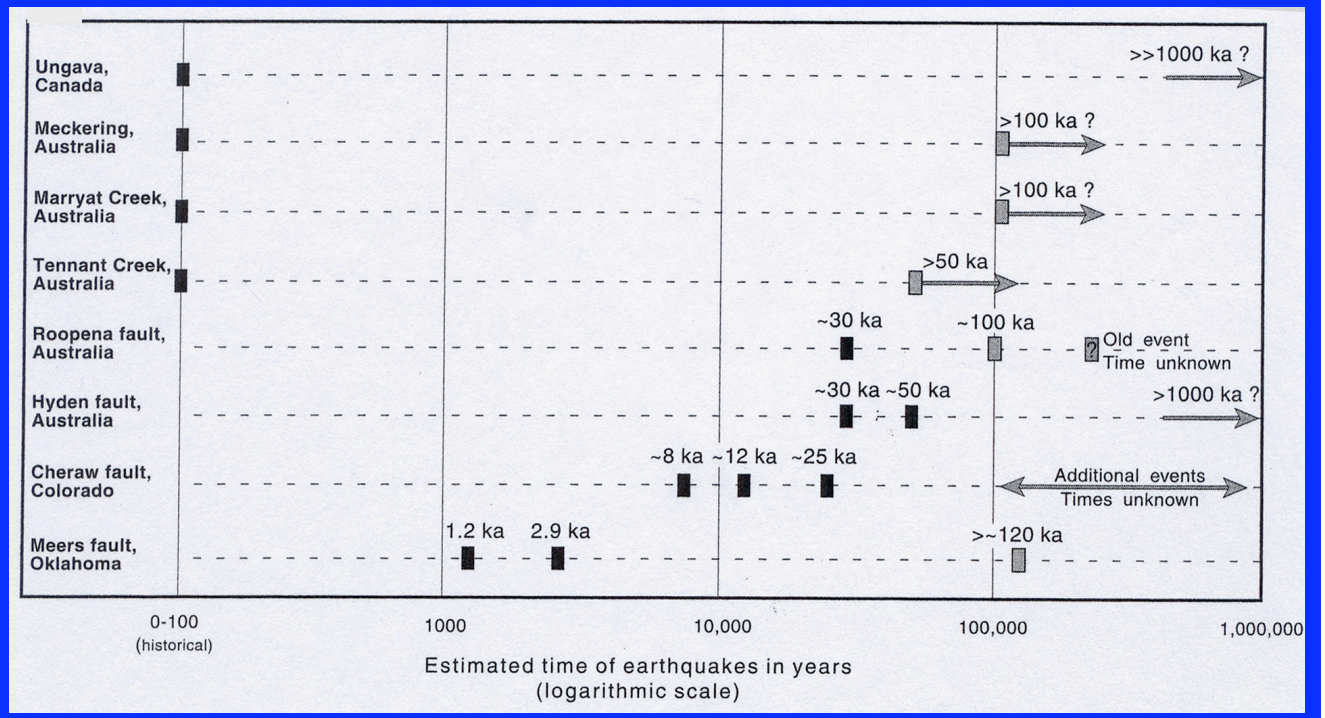
2) Reset the game

-Remove pieces that you think will cause an "earthquake" (feeling pieces is allowed)

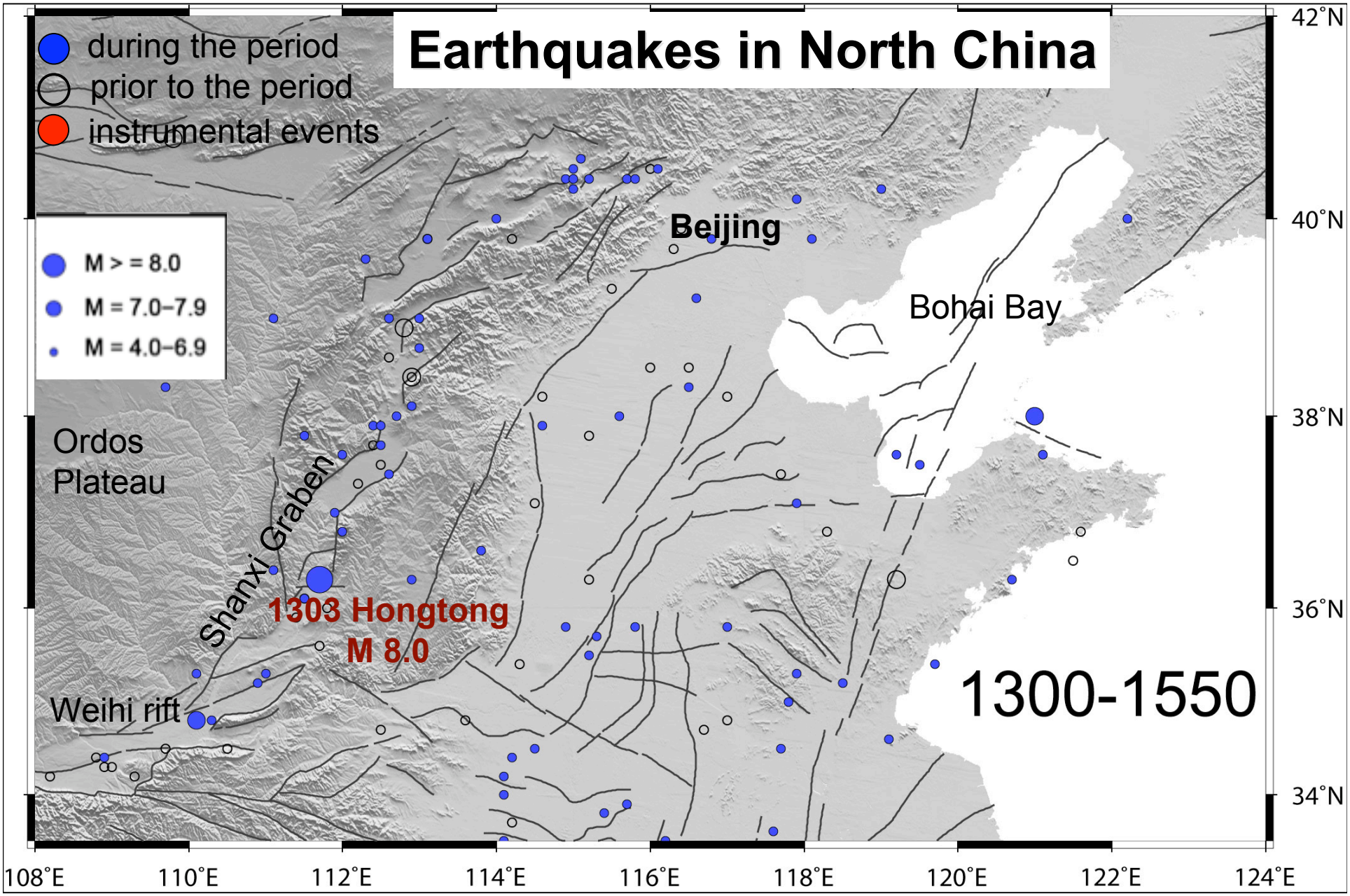
- How good are your intutions?

CONTINENTAL INTRAPLATE EARTHQUAKES ARE OFTEN EPISODIC, CLUSTERED & MIGRATING

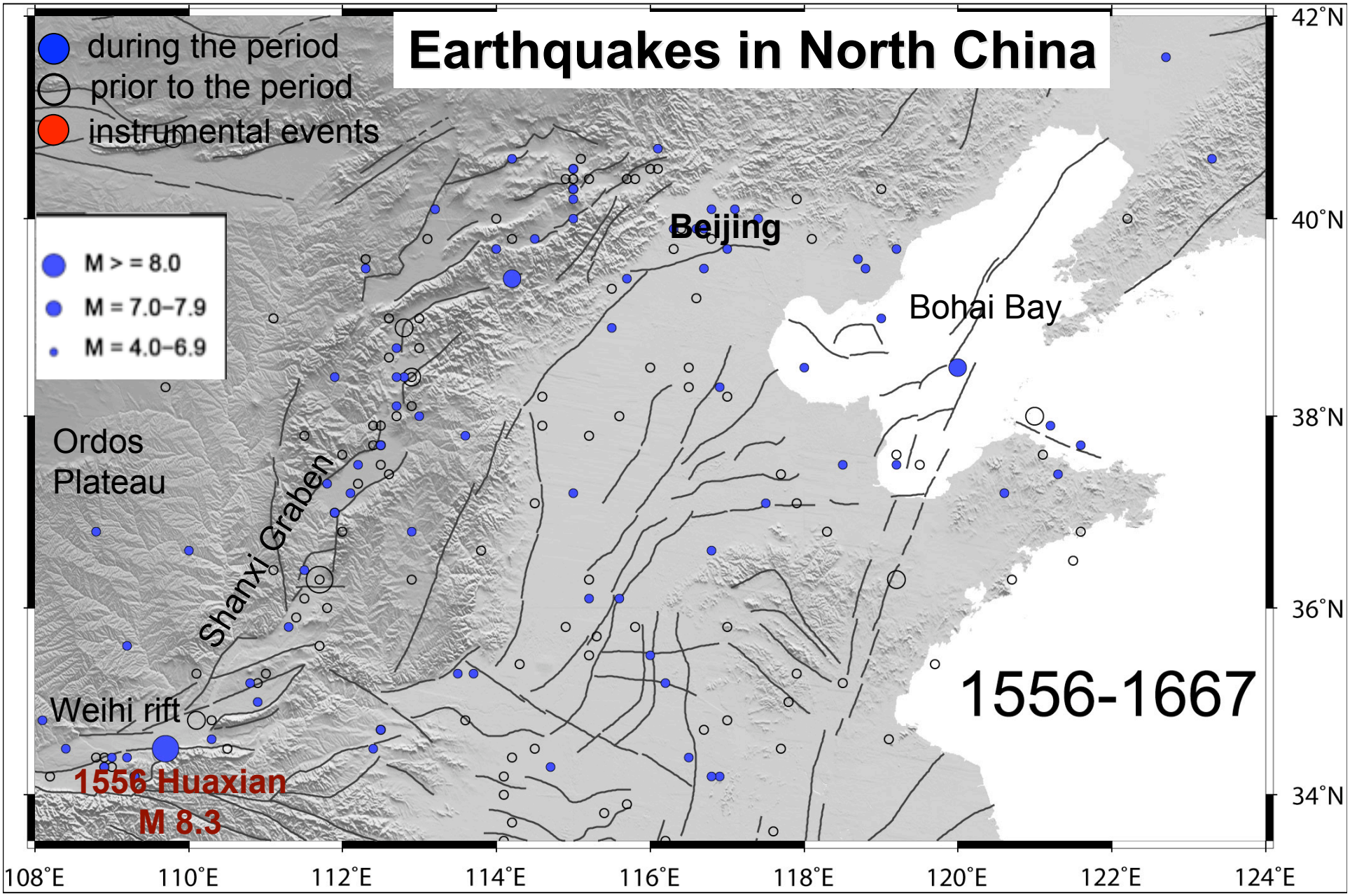
"Large continental interior earthquakes reactivate ancient faults … geological studies indicate that earthquakes on these faults tend to be temporally clustered and that recurrence intervals are on the order of tens of thousands of years or more."
(Crone et al., 2003)



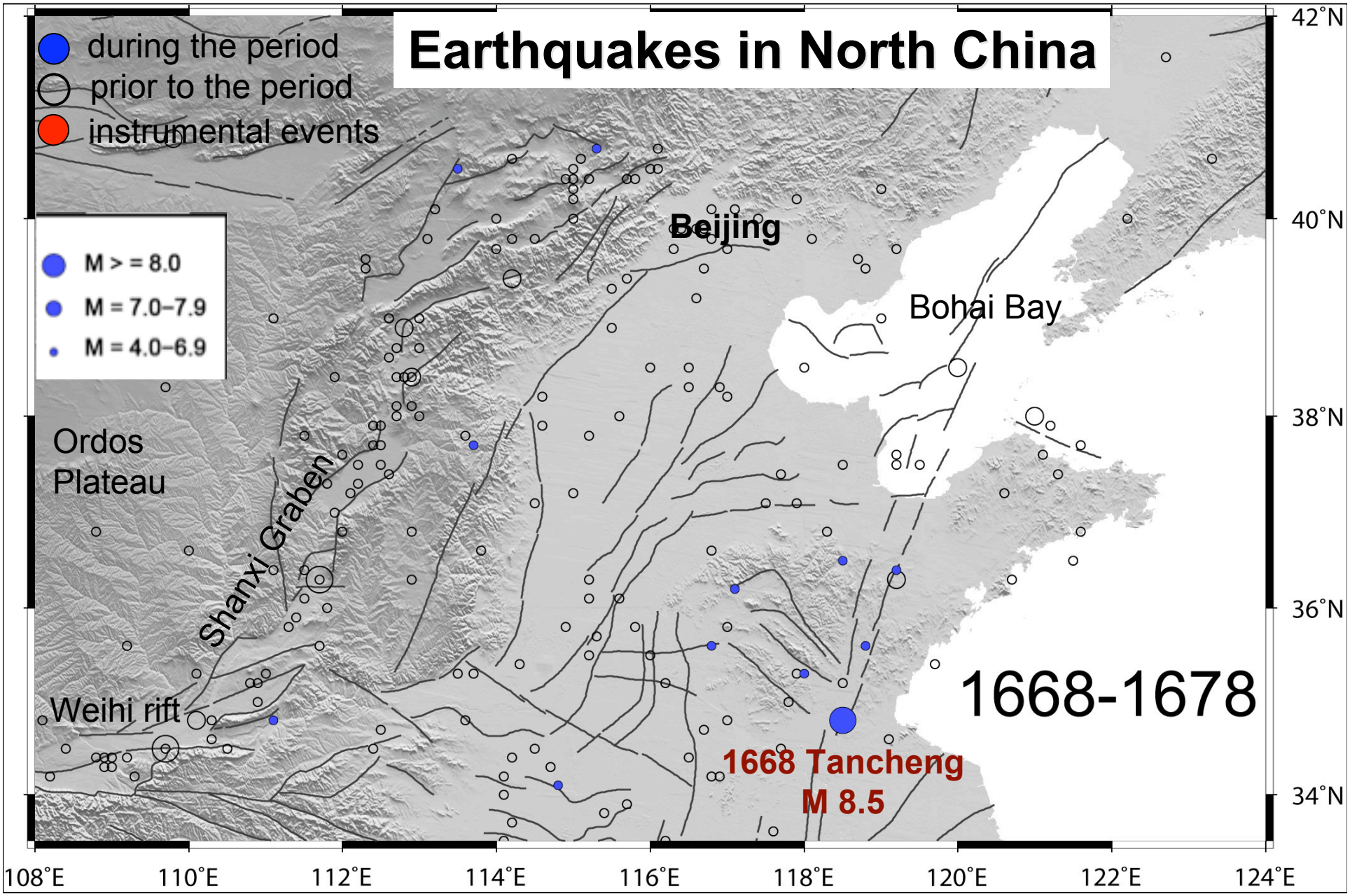
Liu, Stein & Wang 2011



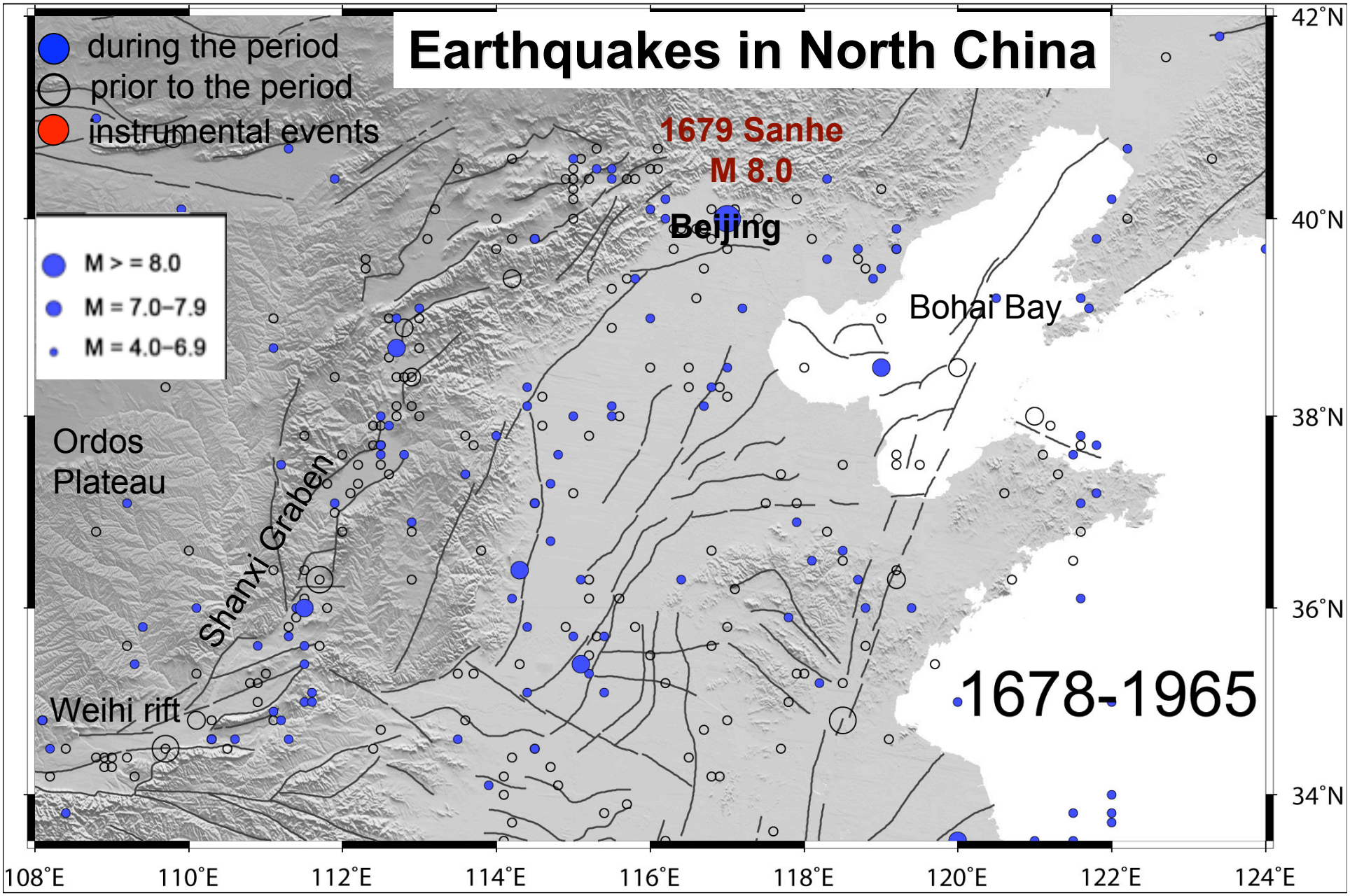
Large events often pop up where there was little seismicity!



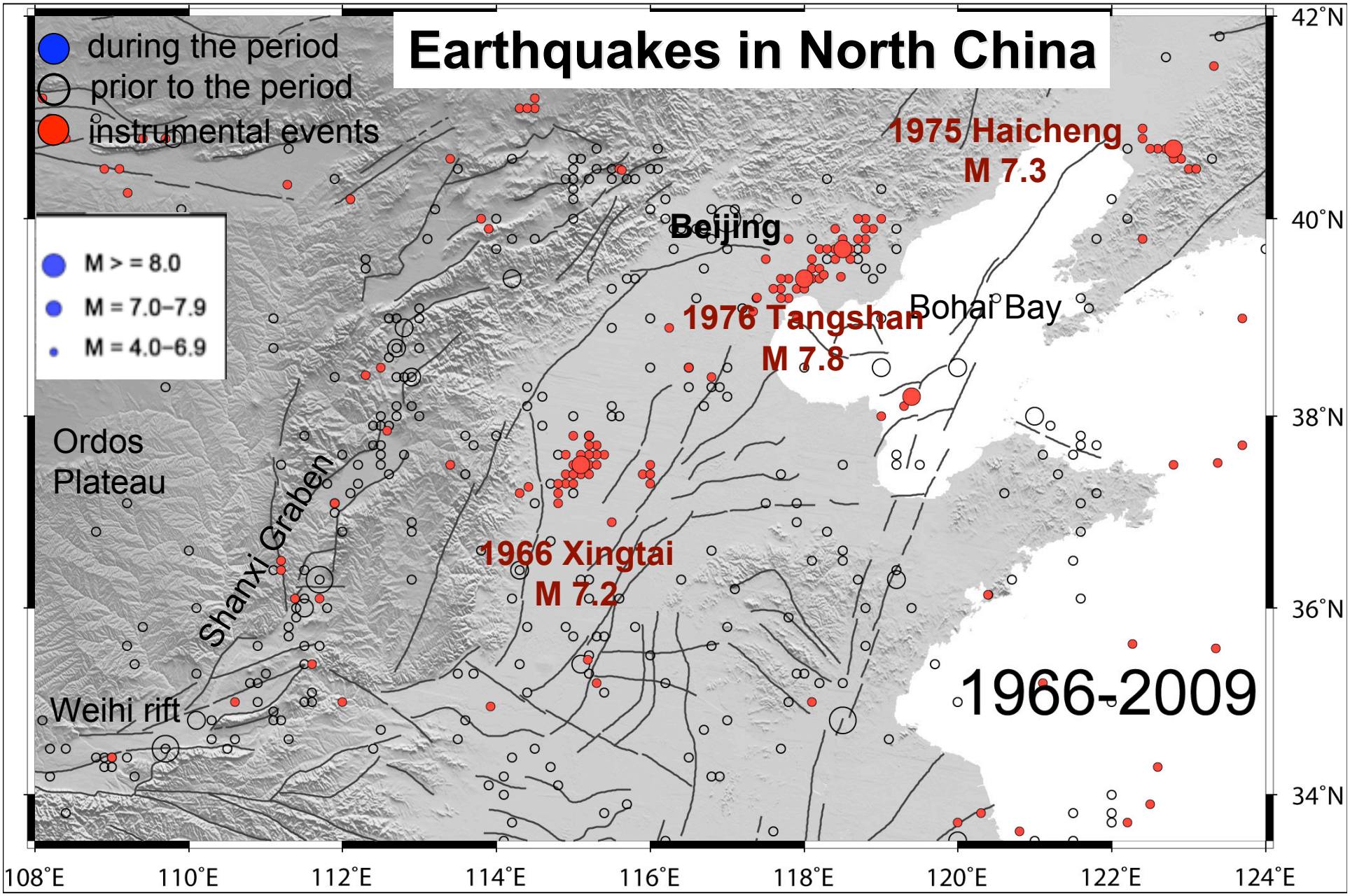
Large events often pop up where there was little seismicity!



Large events often pop up where there was little seismicity!

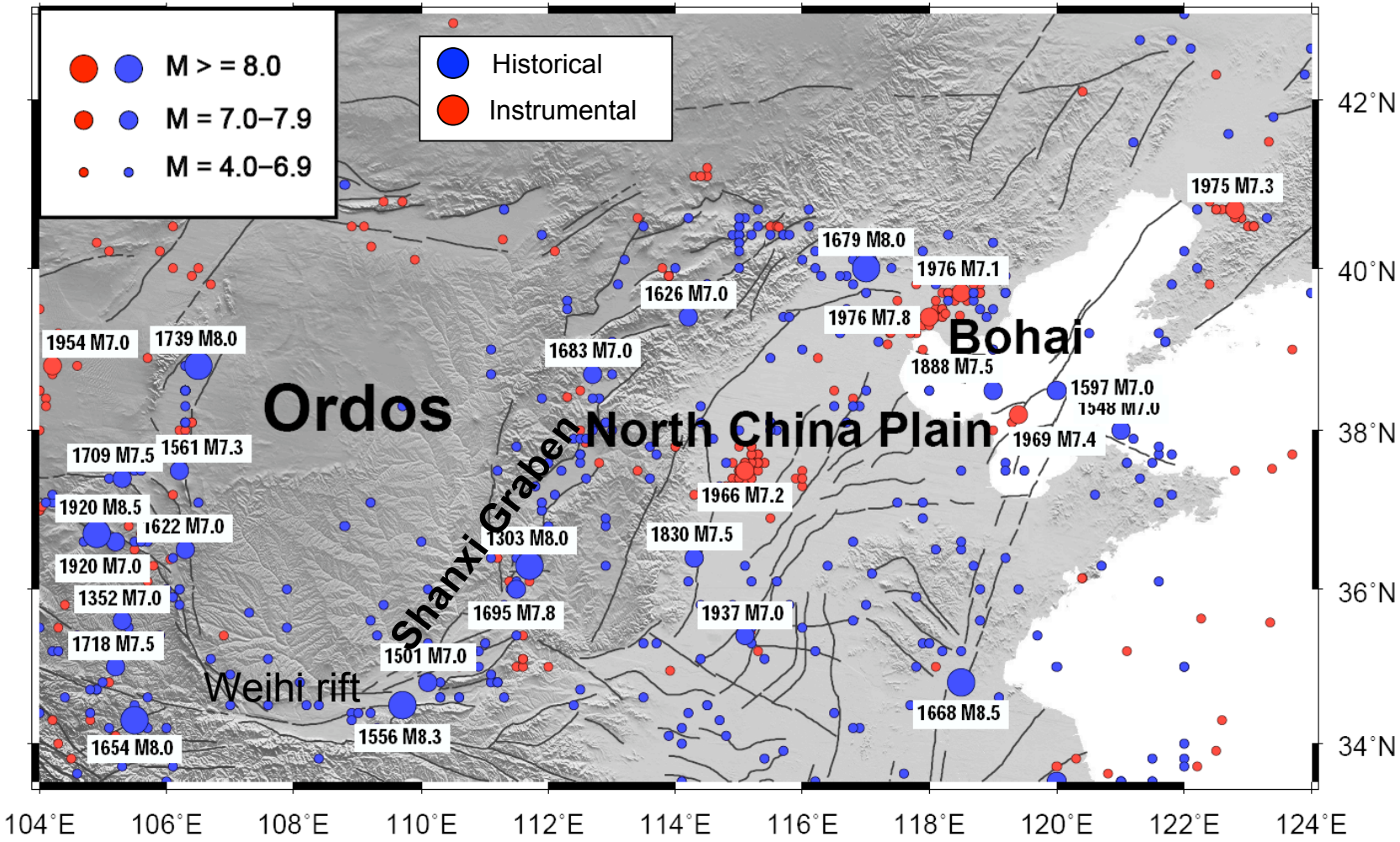


Large events often pop up where there was little seismicity!

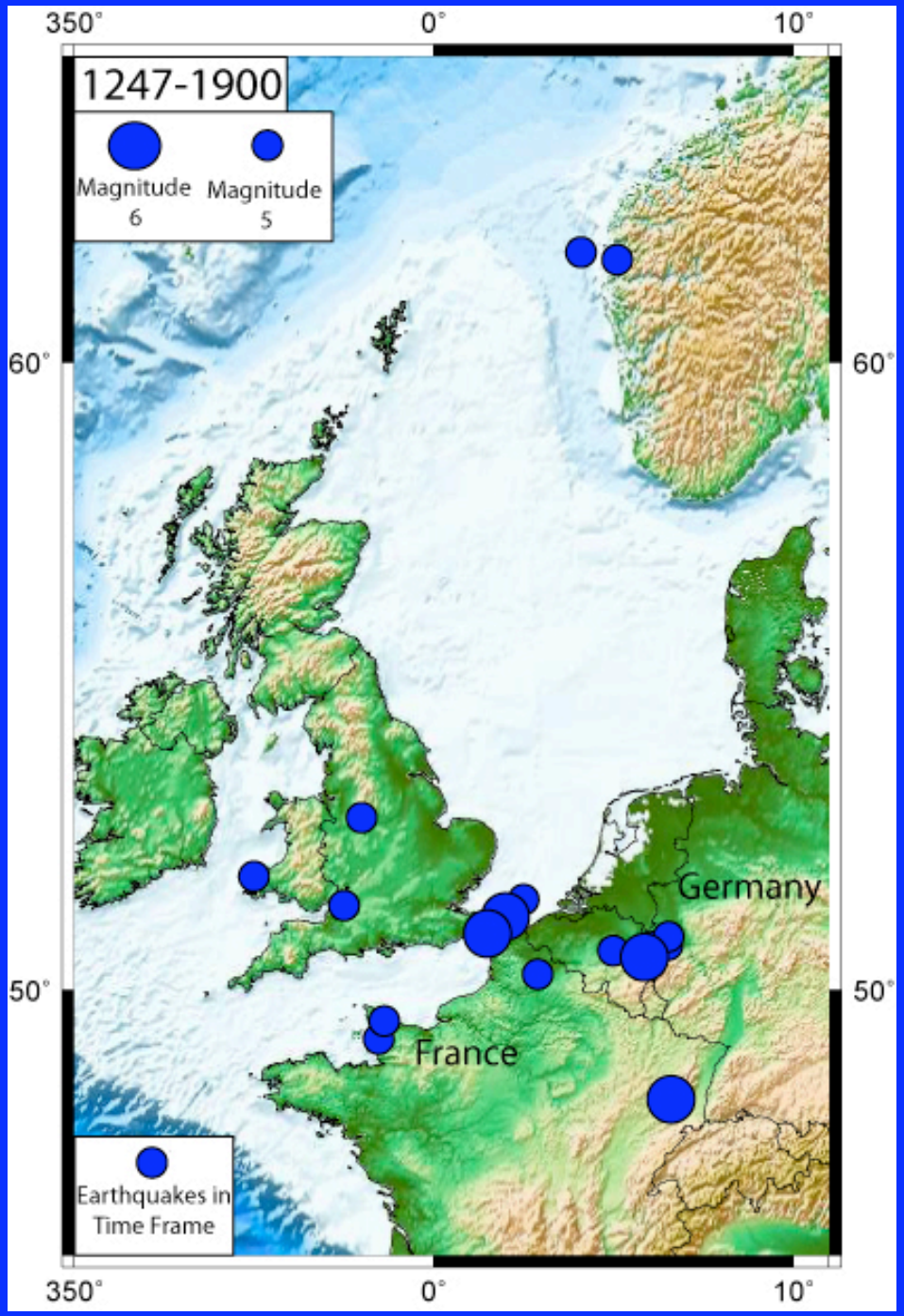


Large events often pop up where there was little seismicity!

No large (M>7) events ruptured the same fault segment twice in N. China since 1303

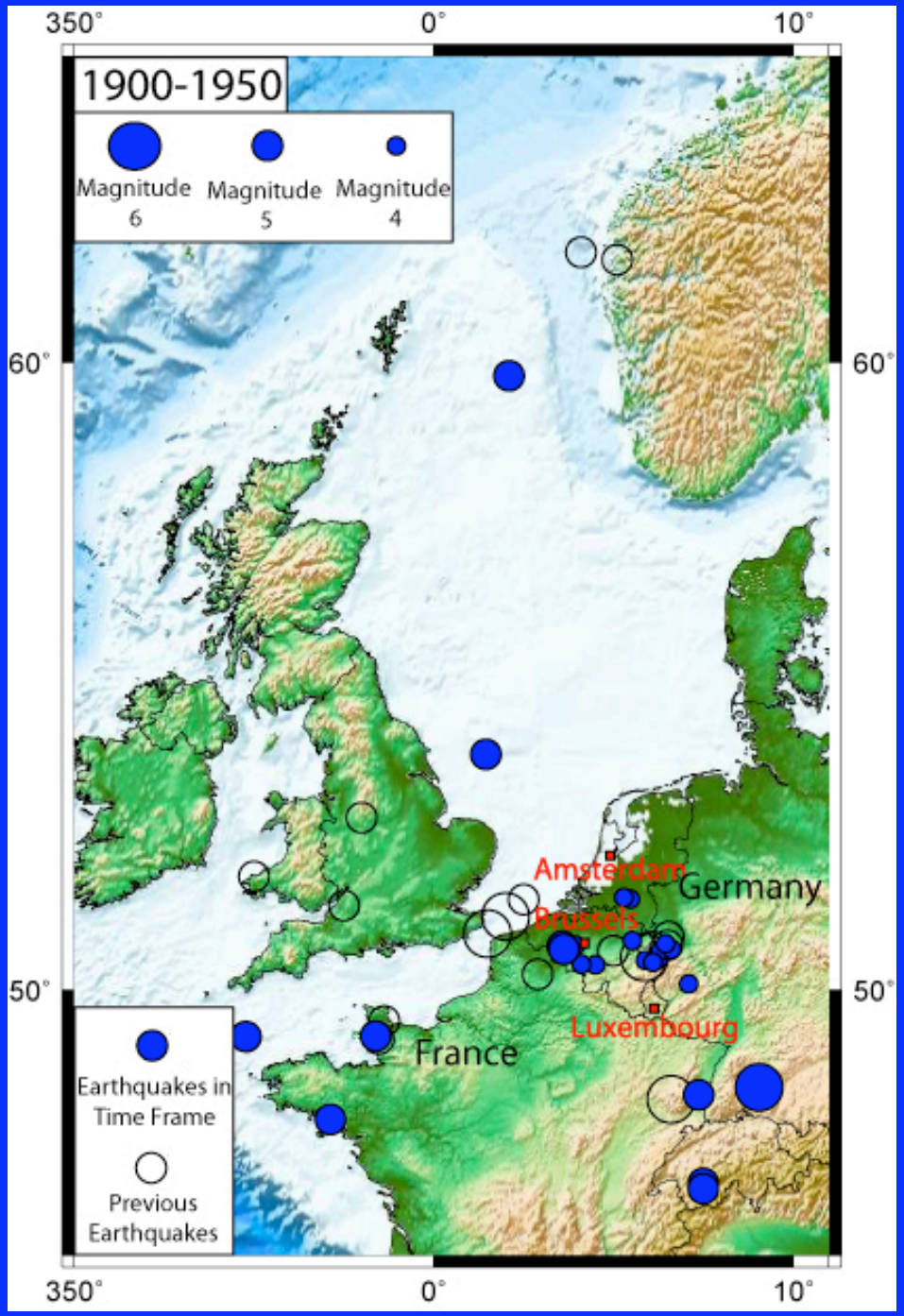


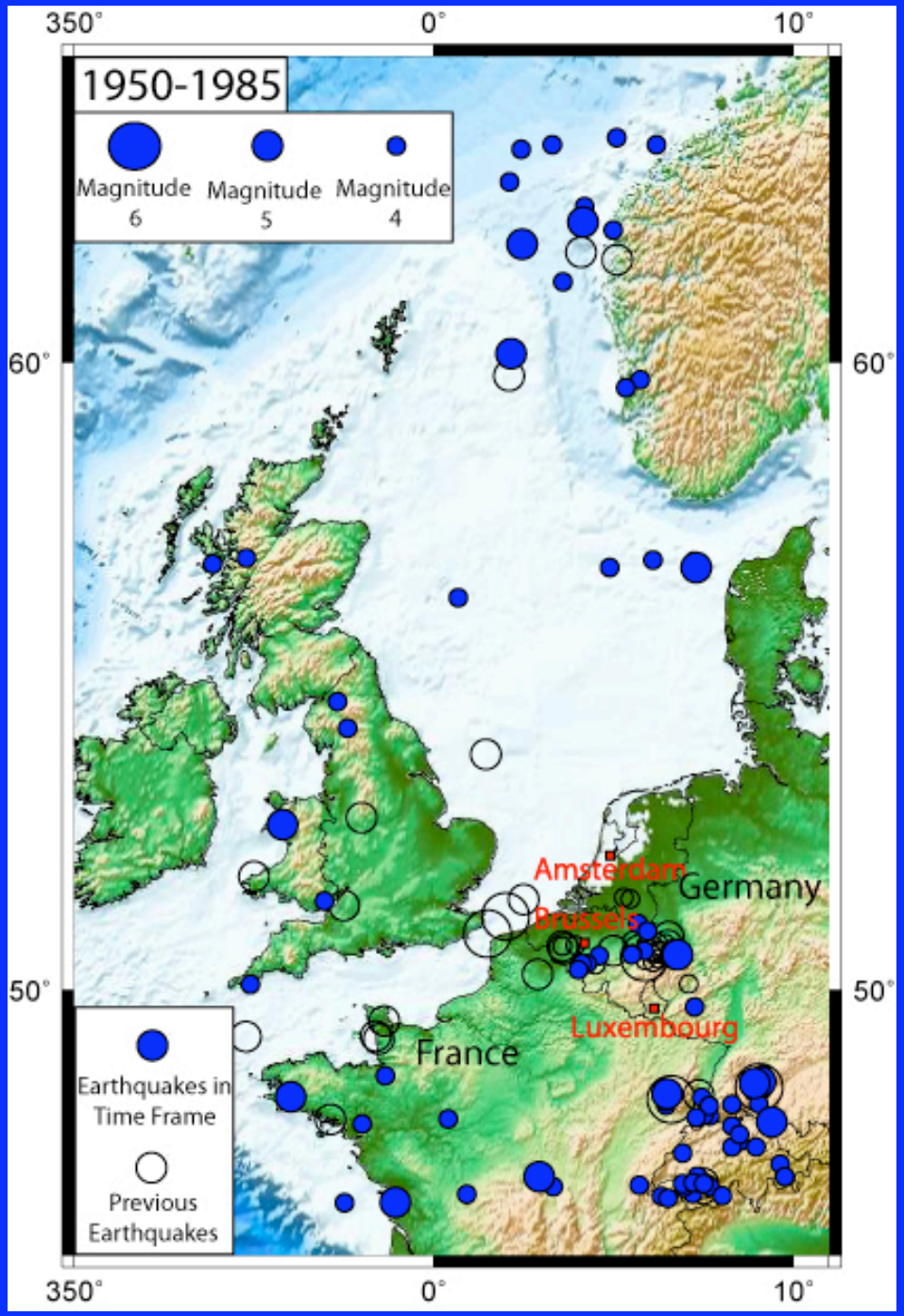
In past 200 years, quakes migrated from Shanxi Graben to N. China Plain

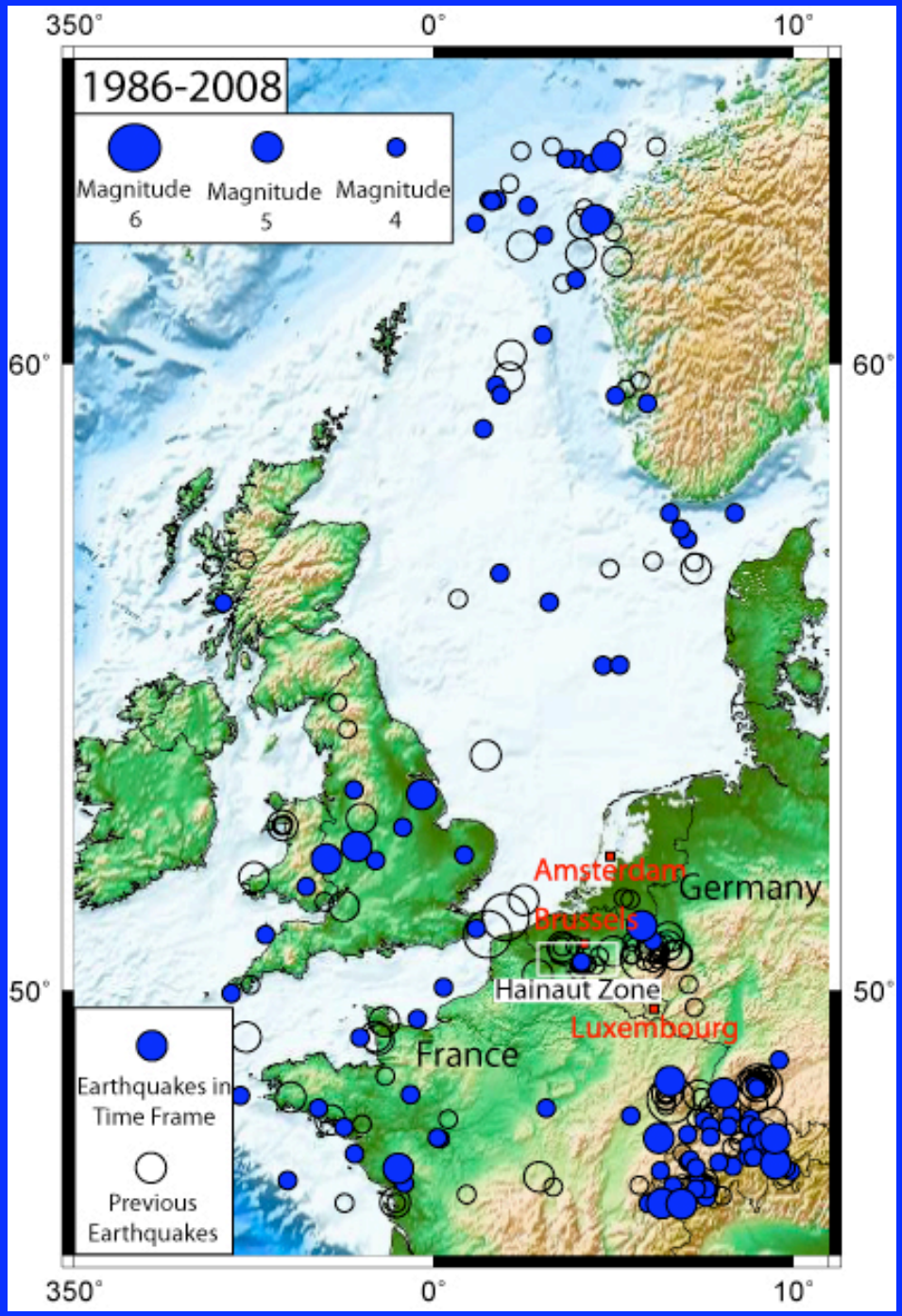


"During the past 700 years, destructive earthquakes generally occurred in different locations, indicating a migration of seismicity with time."

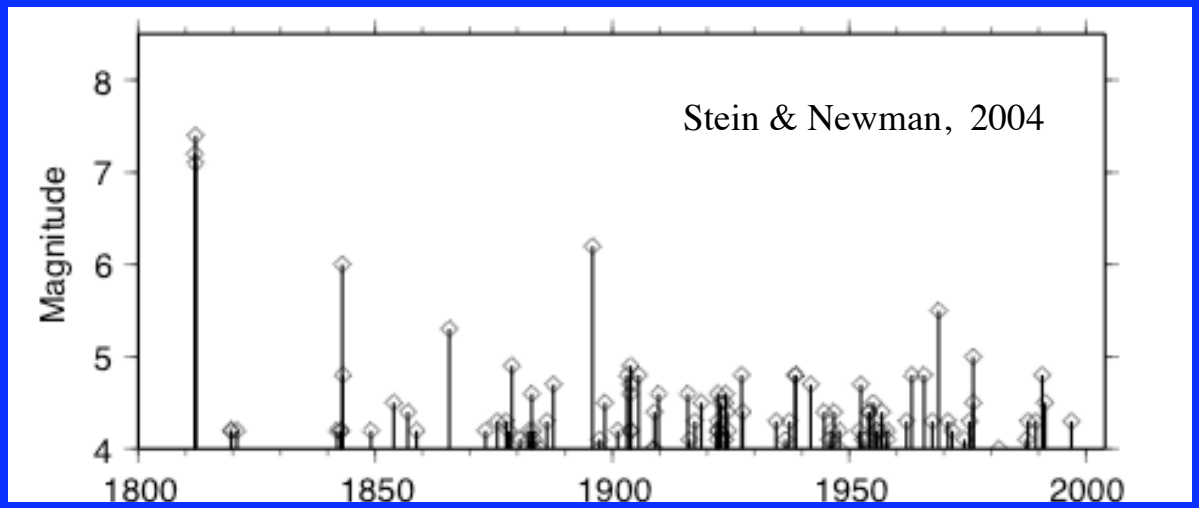
(Camelbeeck et al., 2007)

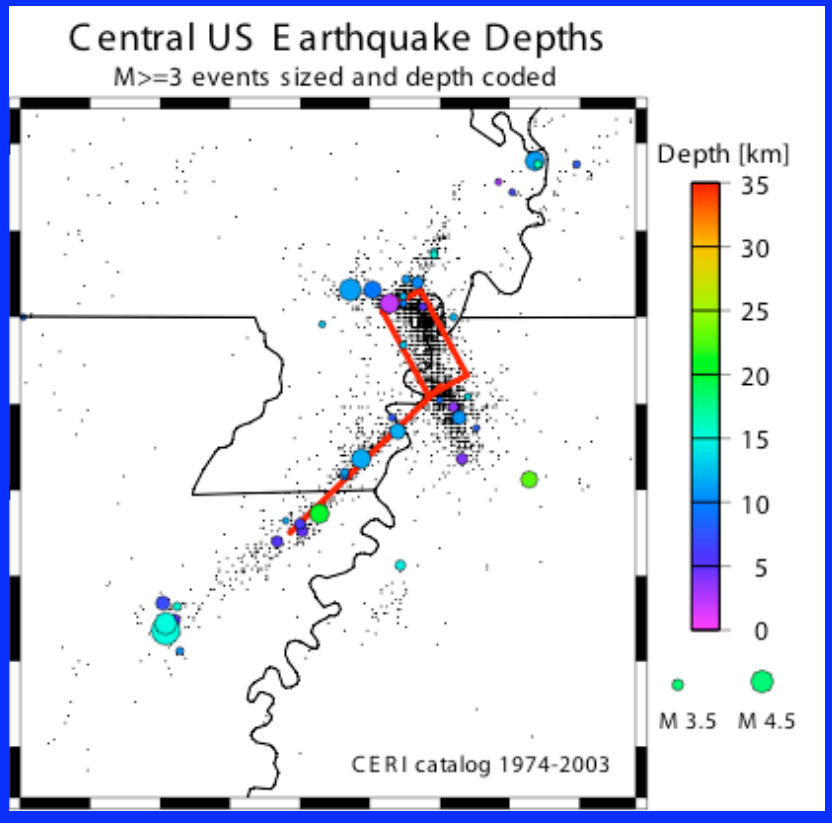

1900-1950
Magnitude 6
Magnitude 5
Magnitude 4
350°
0°
10°
60°
50°
Amsterdam
Germany
Brussels
Luxembourg
France
Earthquakes in Time Frame
Previous Earthquakes


1950-1985
Magnitude 6
Magnitude 5
Magnitude 4
350°
0°
10°
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

NEW MADRID SEISMICITY: 1811-12 AFTERSHOCKS?





Instead of indicating locus of future large earthquakes, ongoing seismicity looks like aftershocks of 1811-12

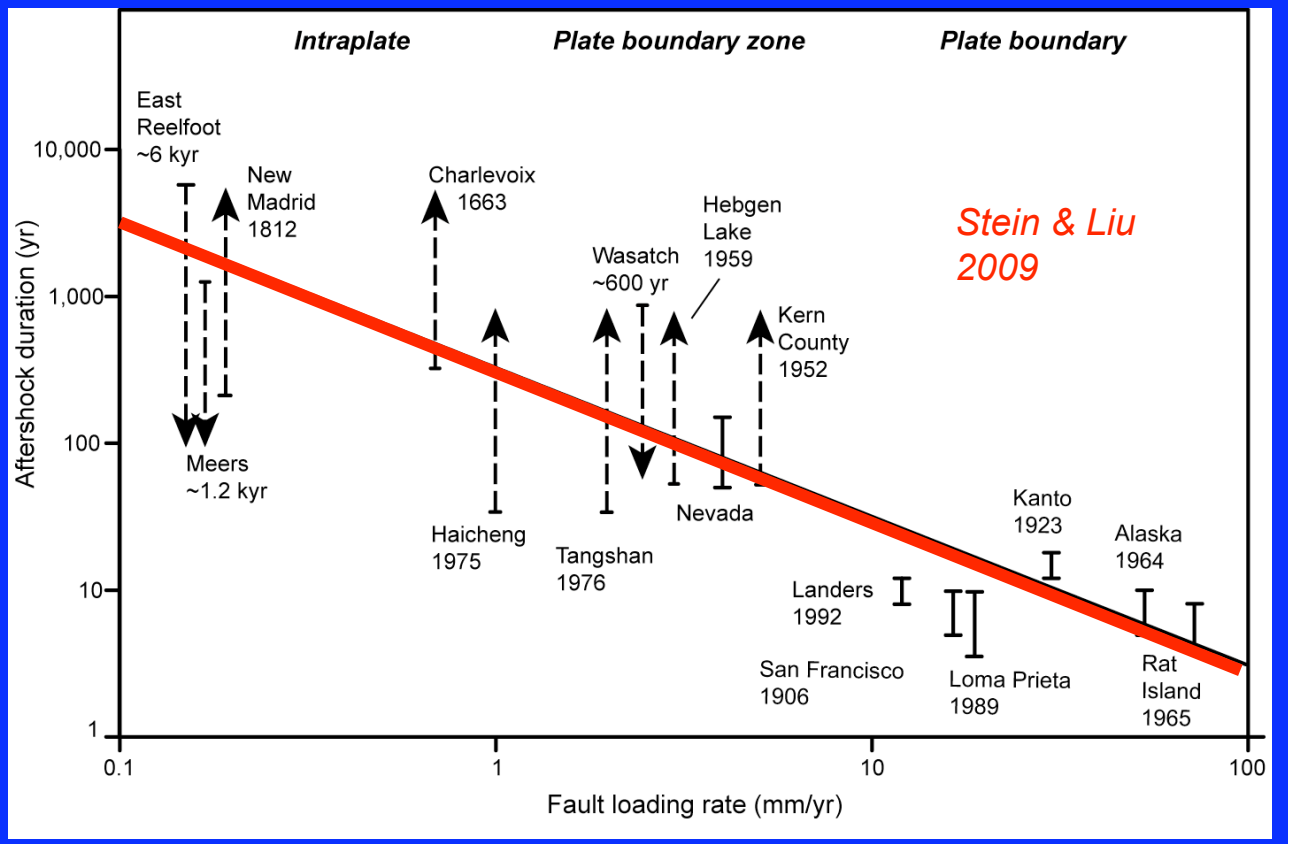
- used to delineate 1811-12 ruptures
- rate & size decreasing
- largest at the ends of presumed 1811-12 ruptures

LONG AFTERSHOCK SEQUENCES IN SLOWLY DEFORMING CONTINENTAL INTERIORS

Plate boundary faults quickly reloaded by steady plate motion after large earthquake

Faults in continents reloaded much more slowly, so aftershocks continue much longer

Current seismicity largely aftershocks rather than implying location of future large events



Aftershock duration α 1/loading rate

Plate Boundary Earthquakes

•Fault loaded rapidly at constant rate

• Earthquakes spatially focused & temporally quasi-periodic

Past is good predictor

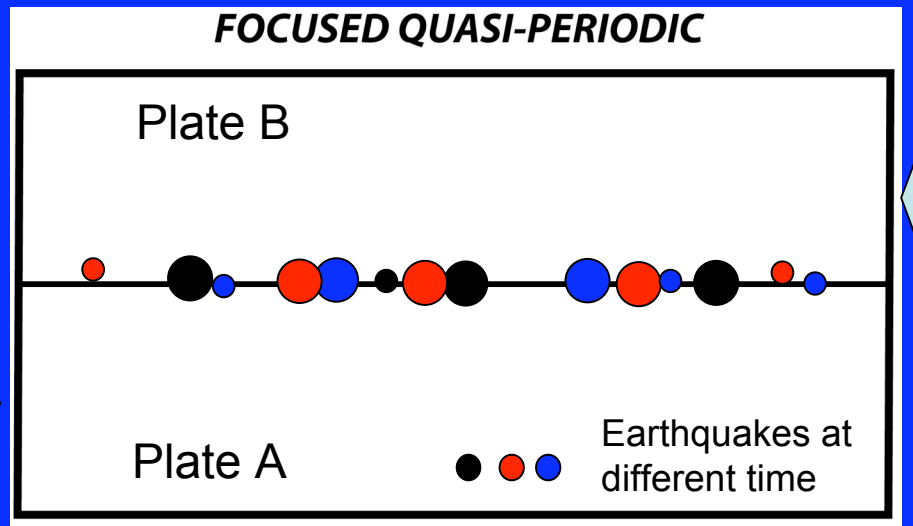
Intraplate Earthquakes

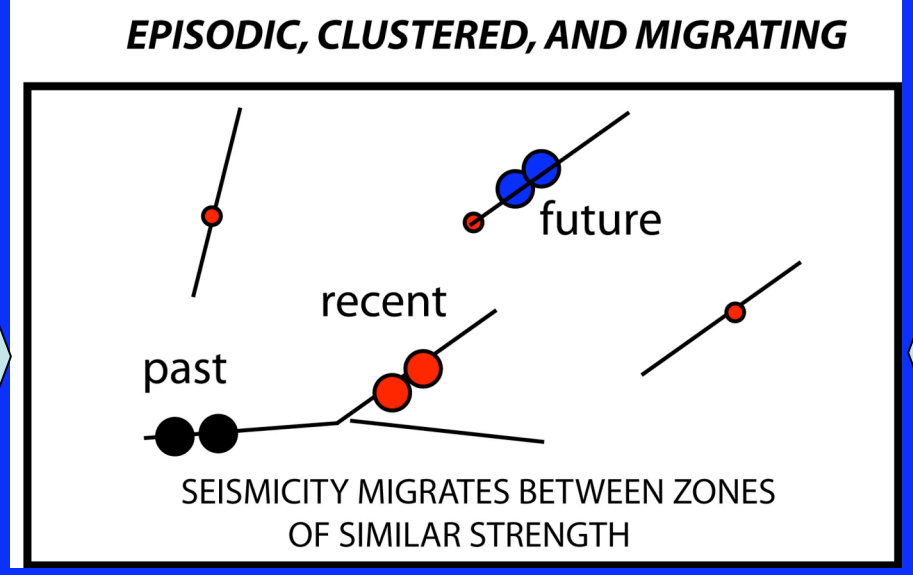
•Tectonic loading collectively accommodated by a complex system of interacting faults

•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





Faults in a region form a complex system whose evolution cannot be understood by considering an individual fault.

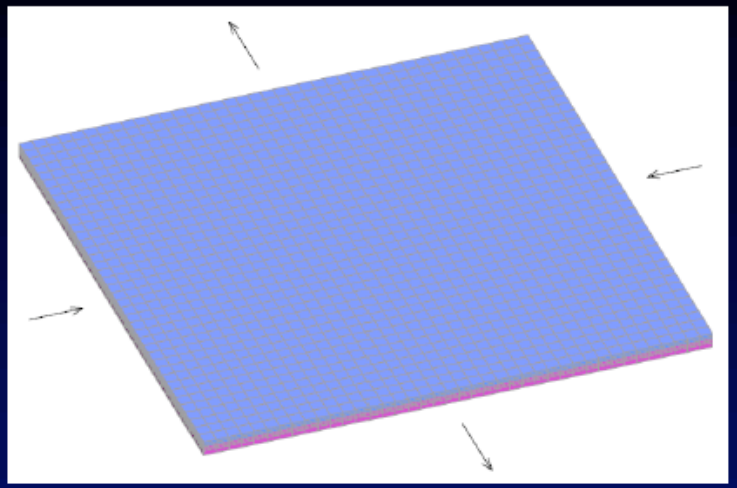
In complex systems, the whole behaves in ways more complicated than can be understood from analysis of its component parts.

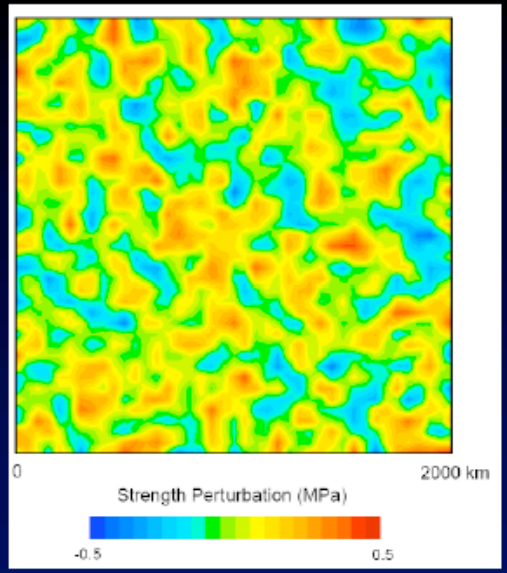
For example, the human body is more complicated than we can understand by studying individual cells.

Studying such systems requires moving beyond the traditional reductionist approach, which focuses on the system's simplest component, understands it in detail, and generalizes it for the entire system. The system is viewed as a totality, so local effects in space and time result from the system as a whole.

Activity 8.2:

Think of something else you would consider another complex system and explain why



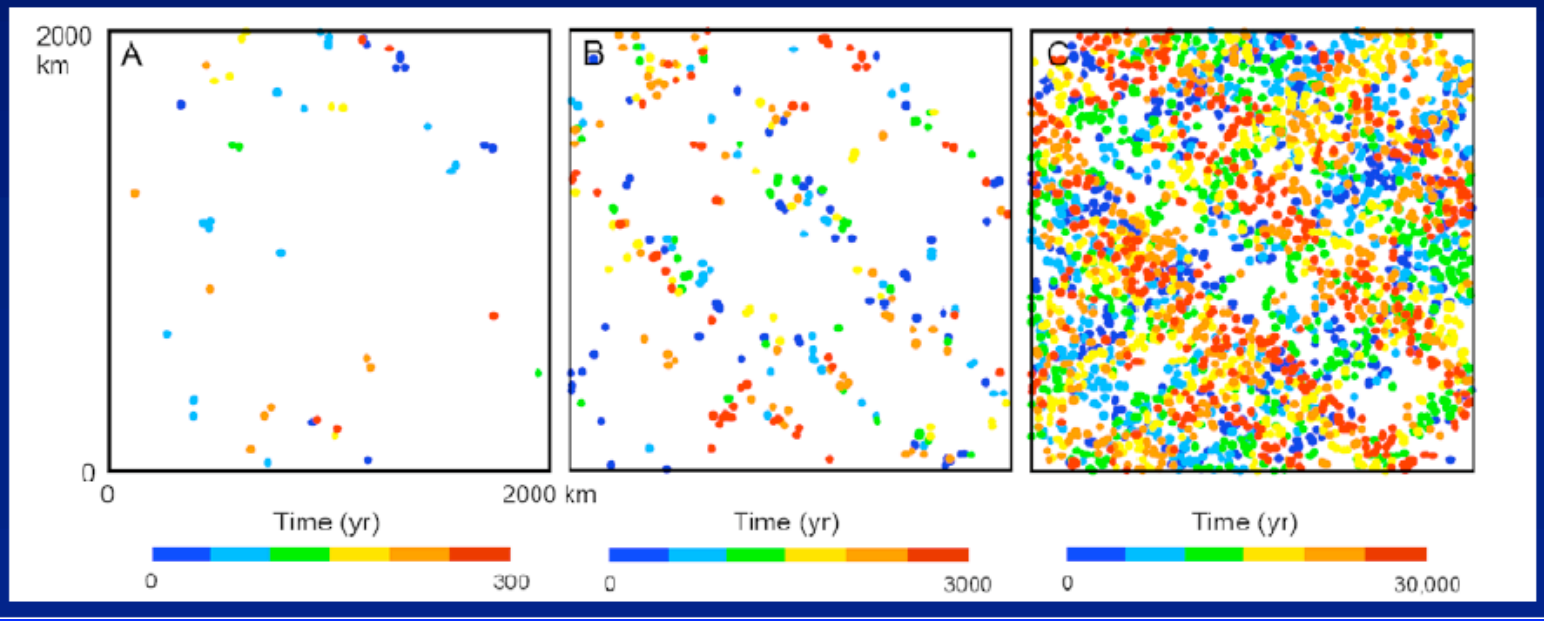


NUMERICAL MODEL

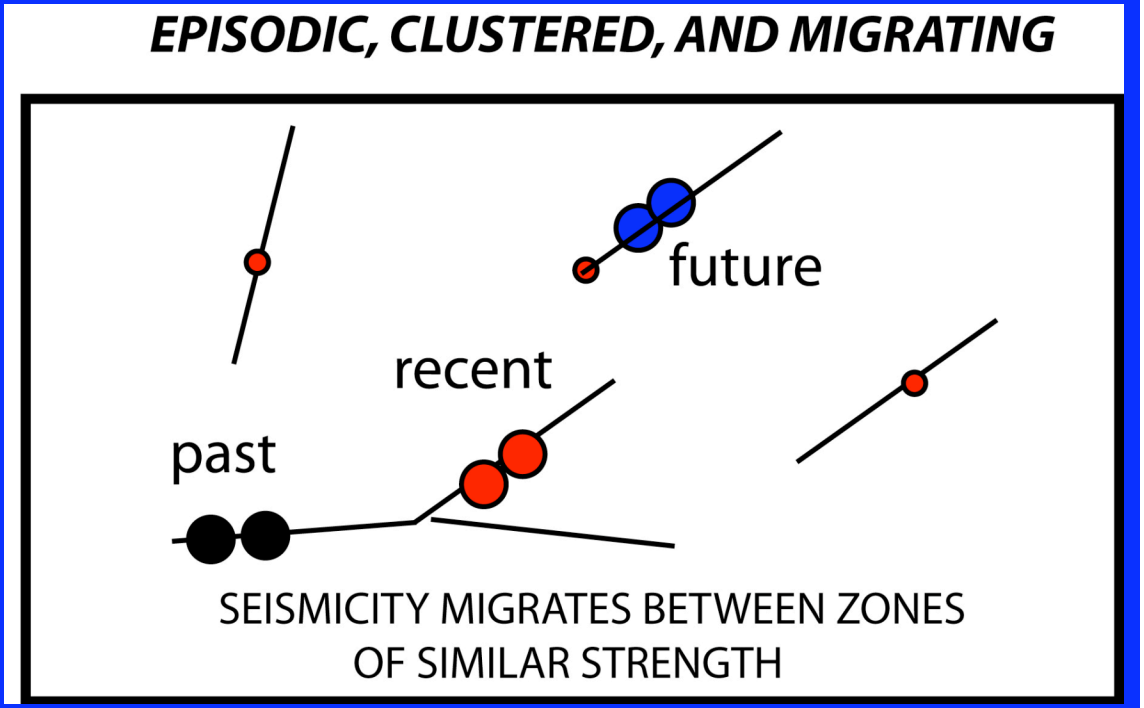
FOR INTRAPLATE EARTHQUAKES

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.



COMPLEXITY CALLS FOR HUMILITY



"Complexity demands attitudes quite different from those heretofore common in physics. Up till now, physicists looked for fundamental laws true for all times and all places. But each complex system is different; apparently there are no general laws for complexity. Instead one must reach for 'lessons' that might, with insight and understanding, be learned in one system and applied to another. Maybe physics studies will become more like human experience."

Goldenfeld & Kadanoff, 1999