What do we know about earthquake hazard in the New Madrid Seismic Zone?

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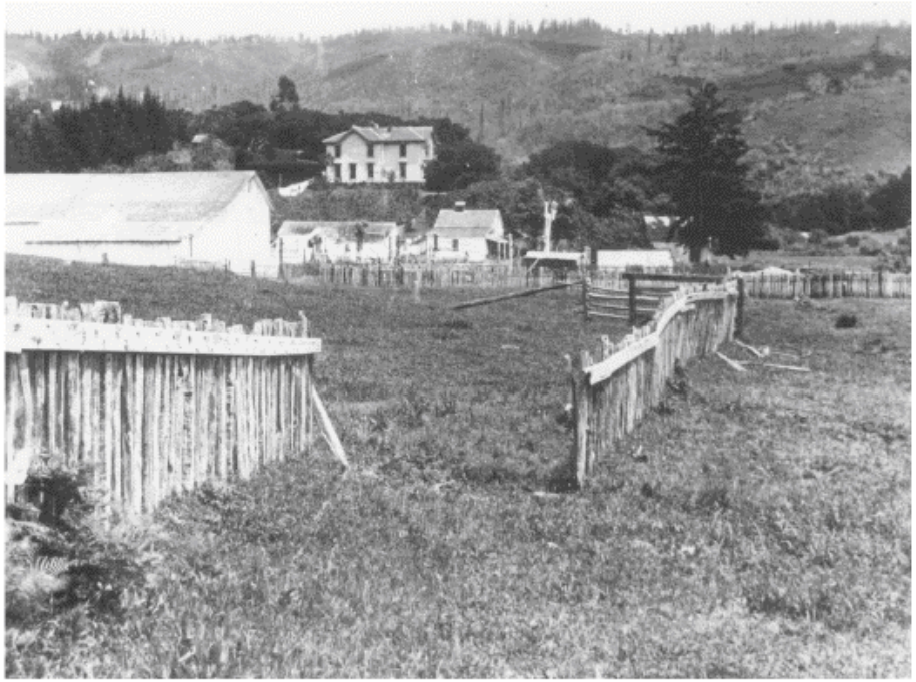
Outline

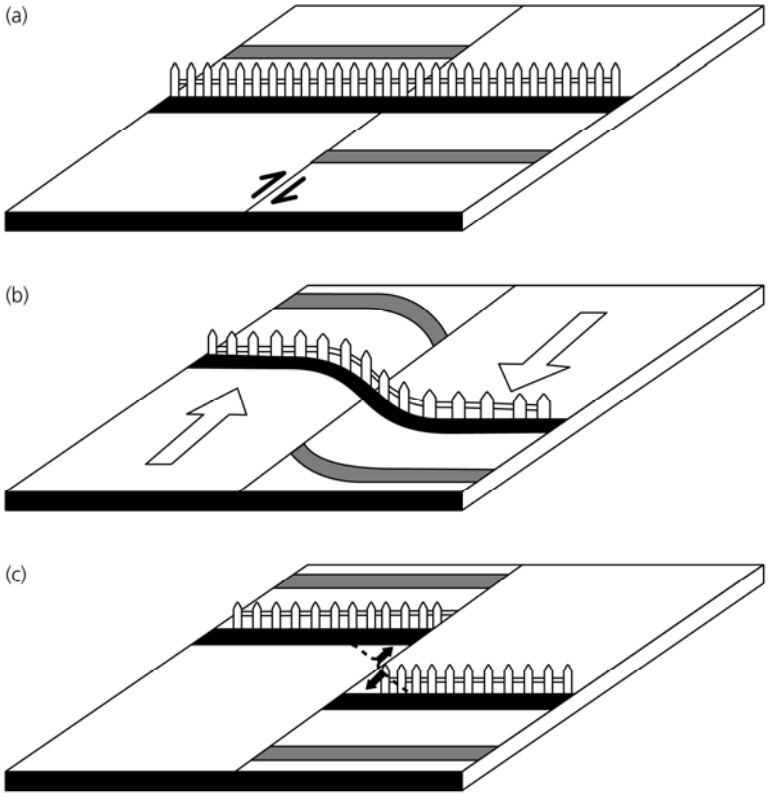
- The puzzles of New Madrid earthquakes
- Insights from North China
- Intraplate earthquakes are different
- Implications for hazard assessment

The Elastic Rebound Model for Earthquakes

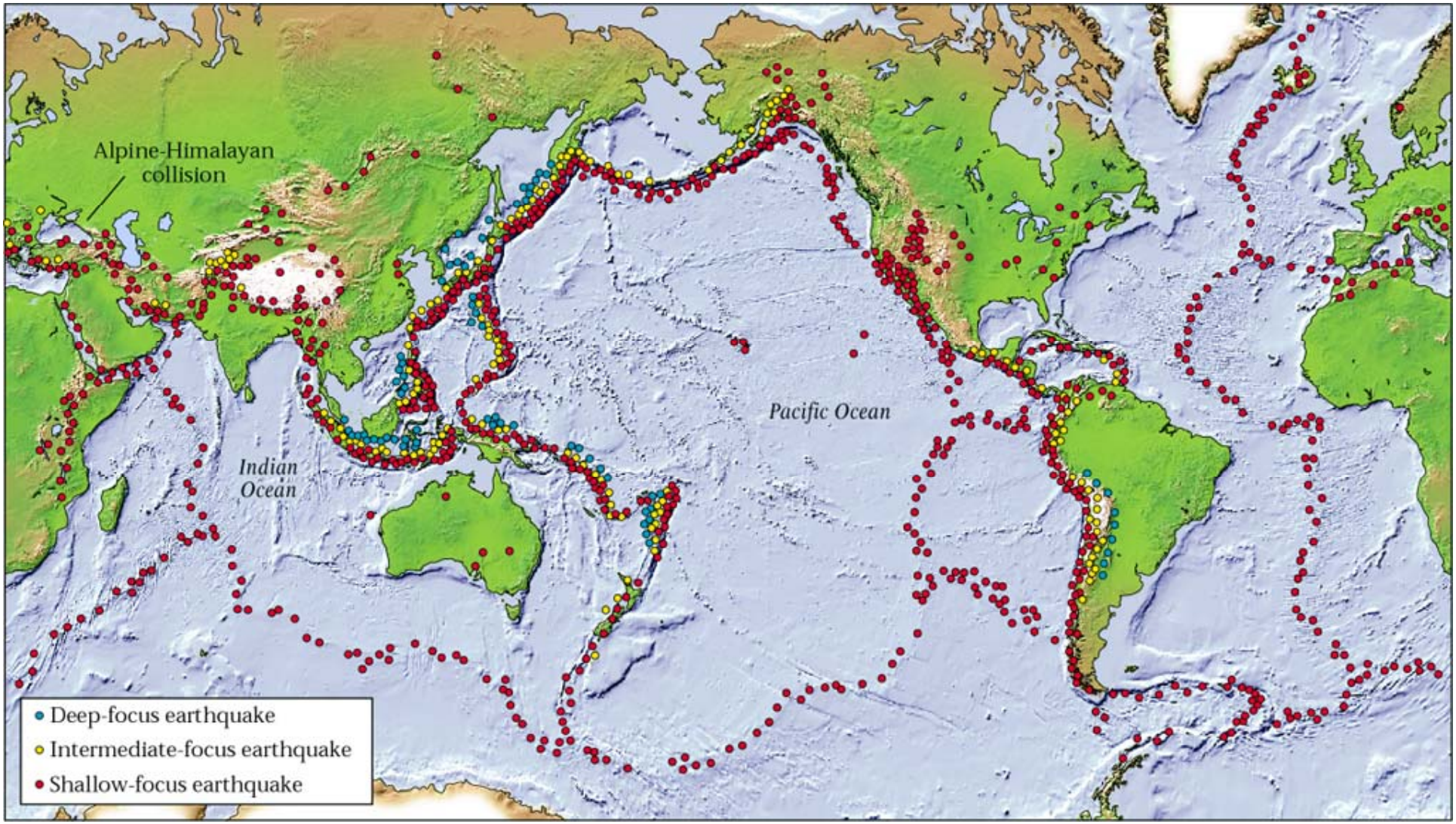
Over many years, rocks on opposite sides of the fault move, but friction on the fault "locks" it and prevents slip

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



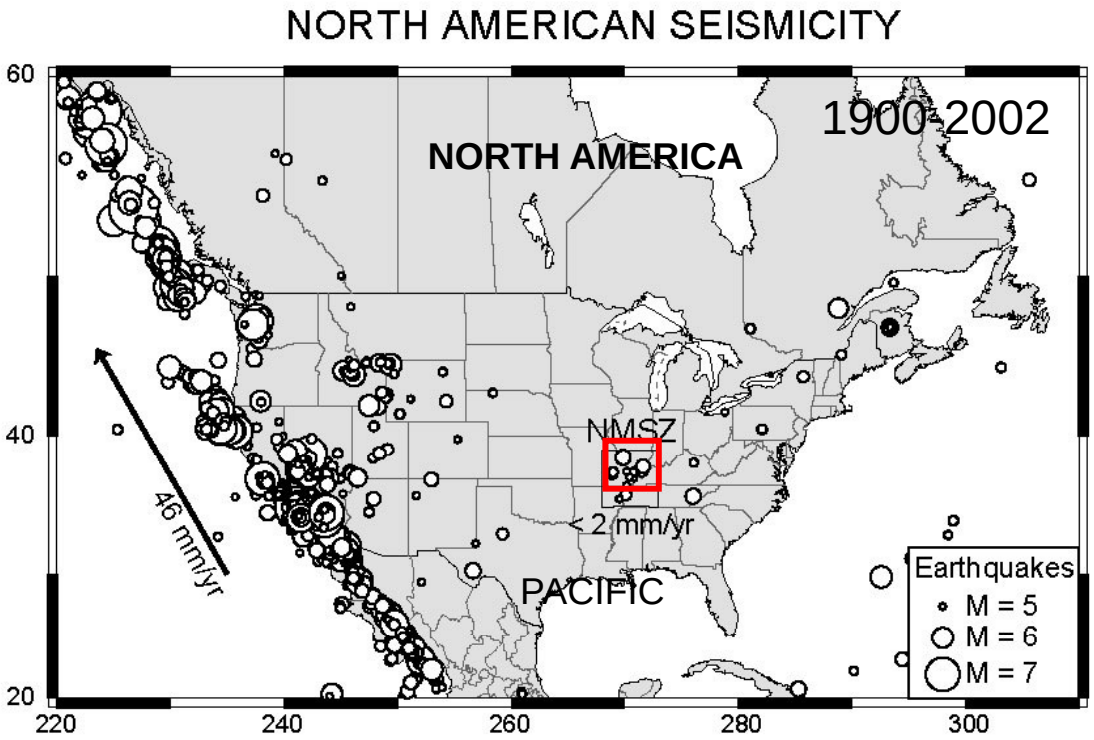


Earthquake Locations



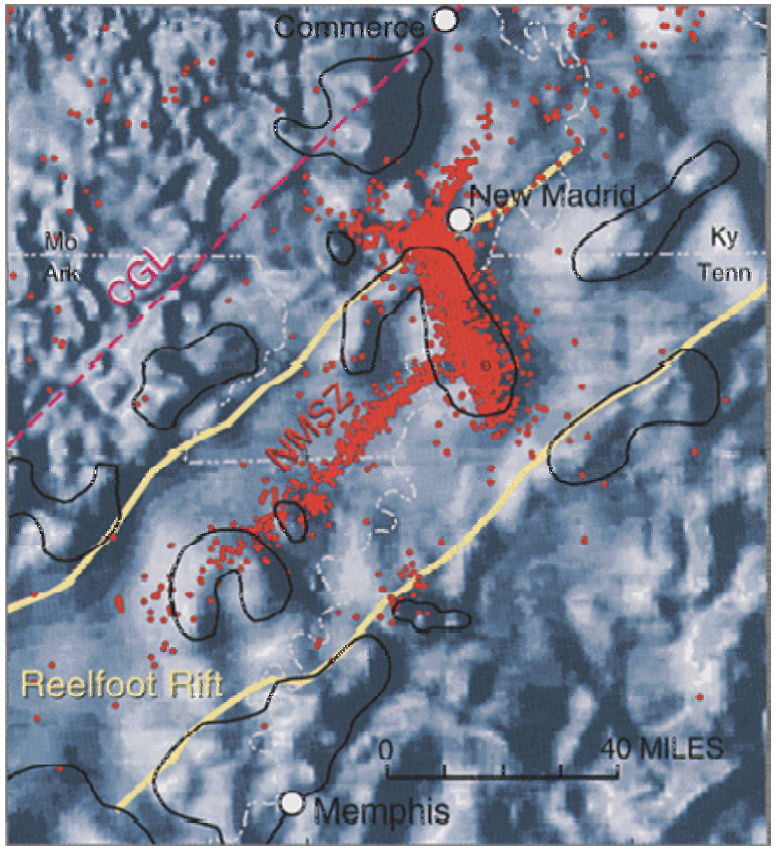
THE PUZZLES OF NEW MADRID EARTHQUAKES

New Madrid seismic zone

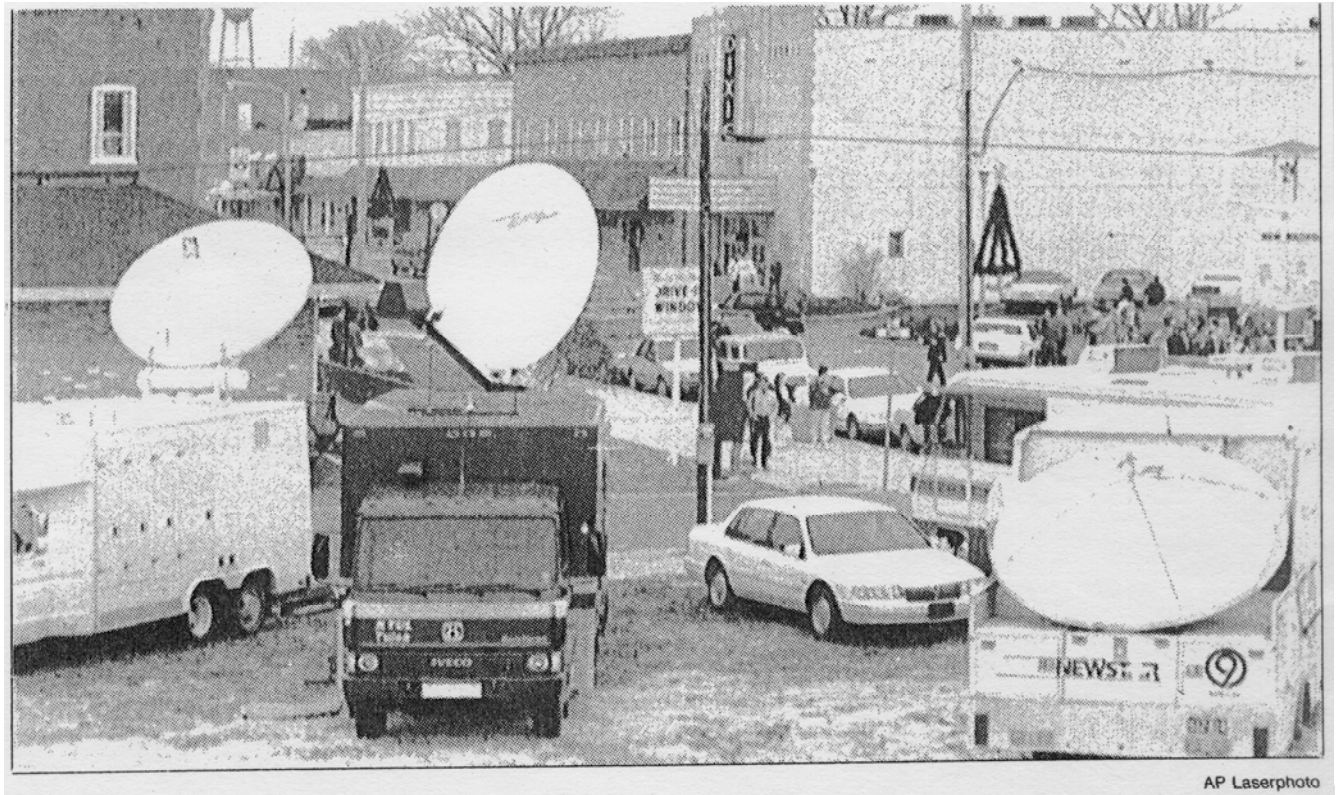


The 1811-1812 New Madrid Earthquake Sequence

- 3-4 earthquakes within one month
- All were probably greater than magnitude 7.0
- The course of the Mississippi River was changed (Reelfoot Lake was created)
- >4000 seismic events recorded since 1977



Public fear 1811-12 recurrence

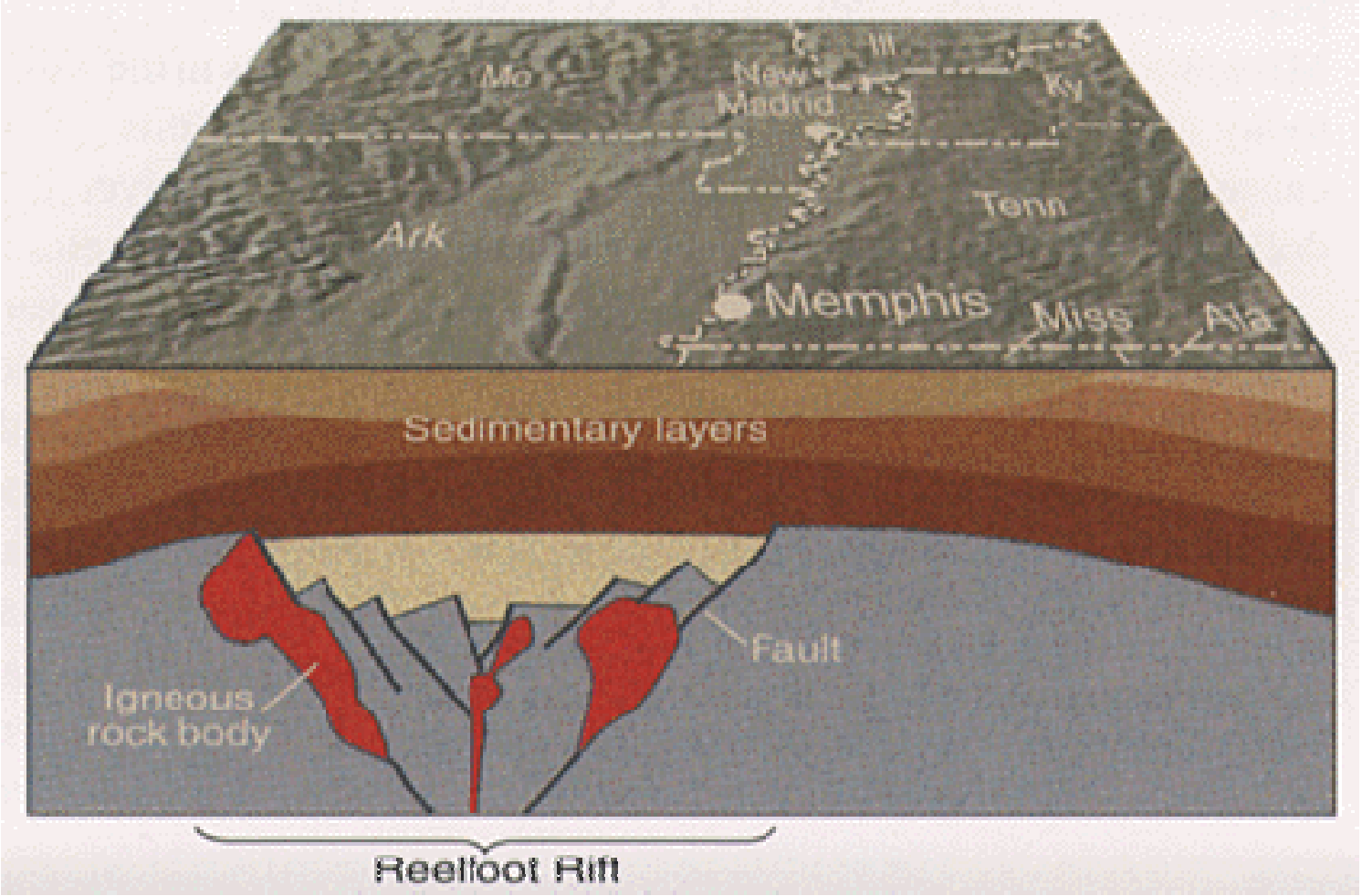


AP Laserphoto

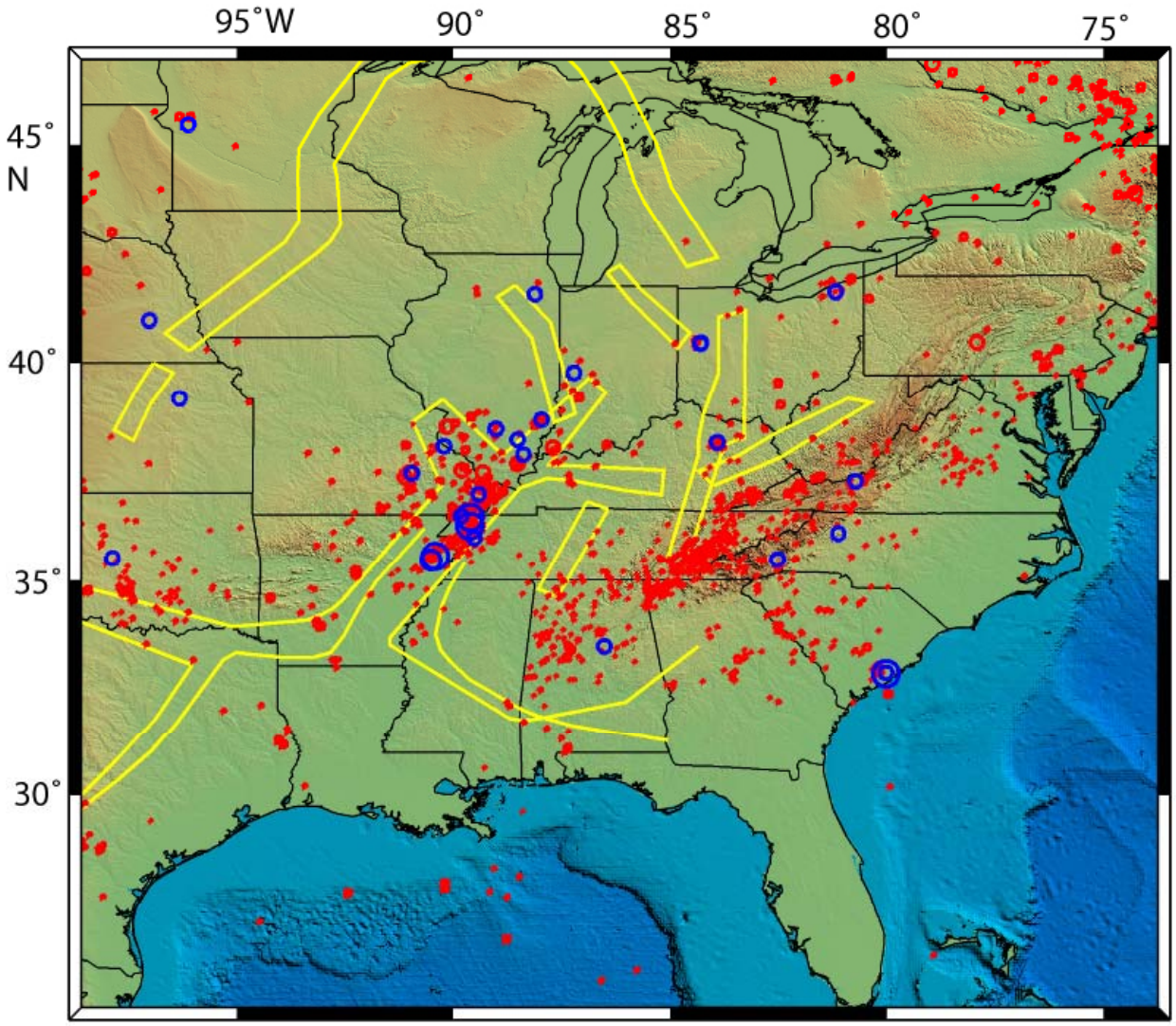
Television trucks near Main Street in New Madrid, Mo., Sunday afternoon are just part of the flood of media that has poured into the town on the now-famous fault for the predicted quake.

Earthquake predicted for December 1990
by Iben Browning didn't happen

Why Earthquakes in Missouri?

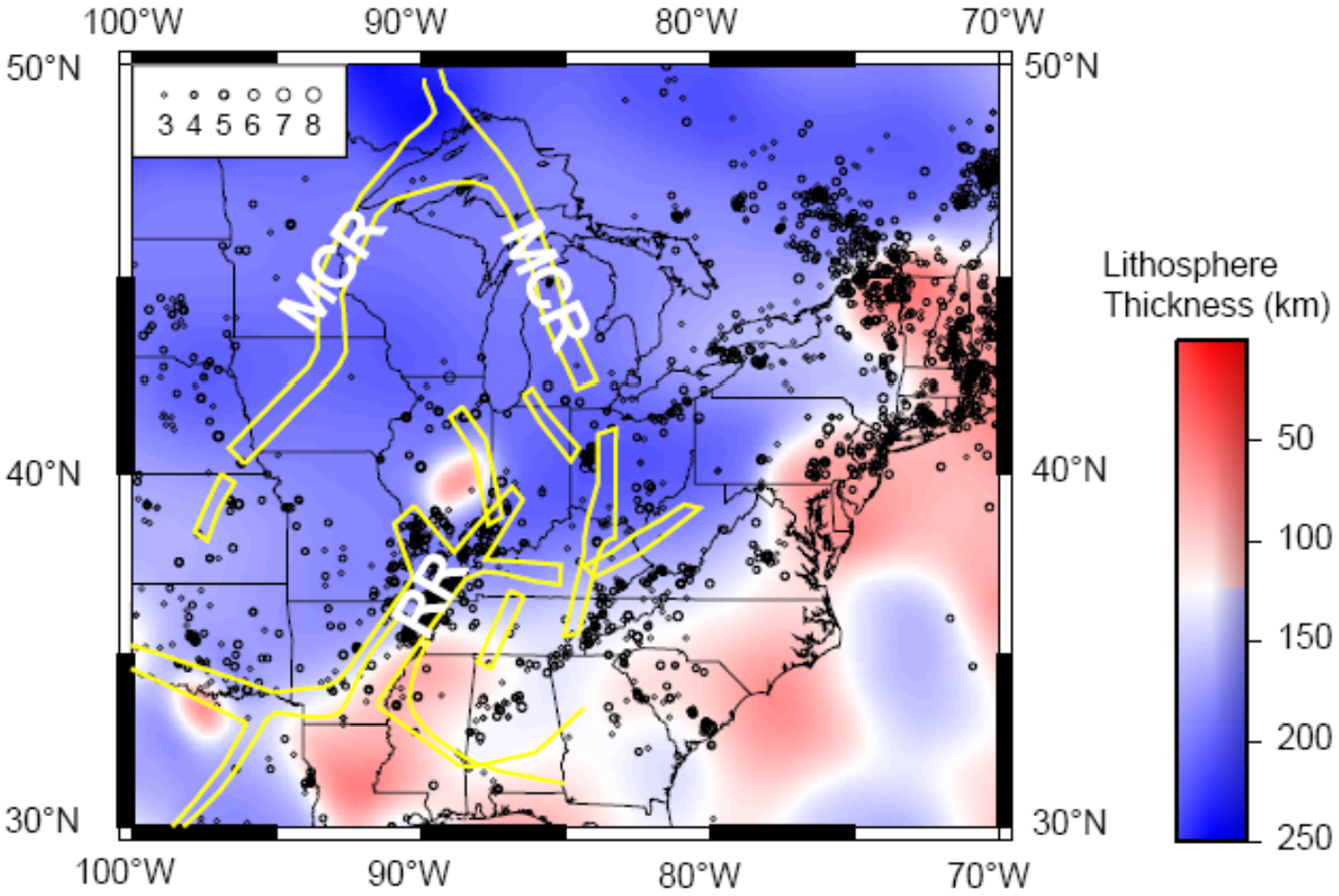


Ancient rift zones



Not all rift zones are seismic!

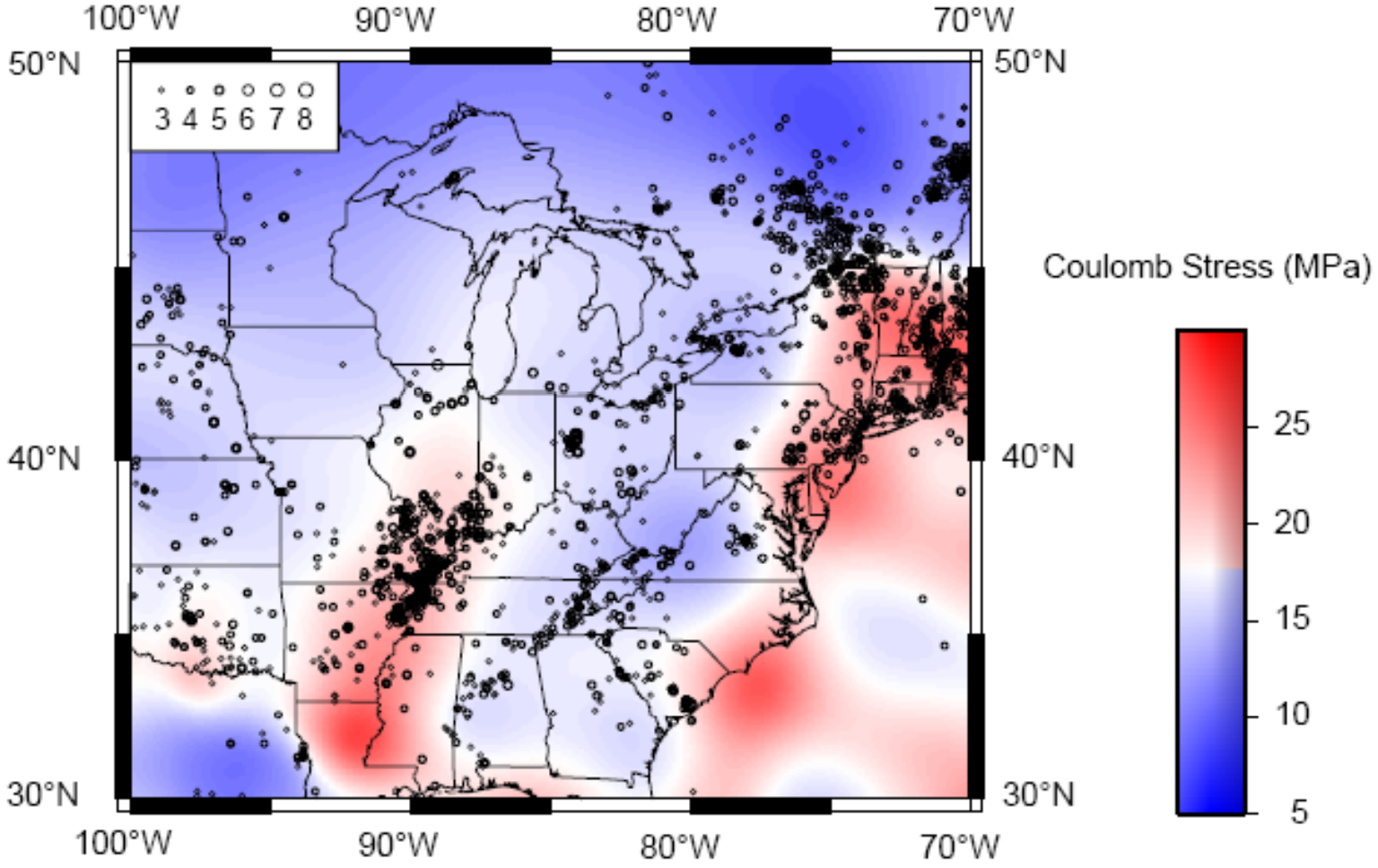
Why Earthquakes in Missouri?



Seismicity are concentrated around the edges of the North American craton

Li et al., 2007

High stress is predicted where lithospheric thickness changes most



Some spatial correlation between seismicity and stress, but …

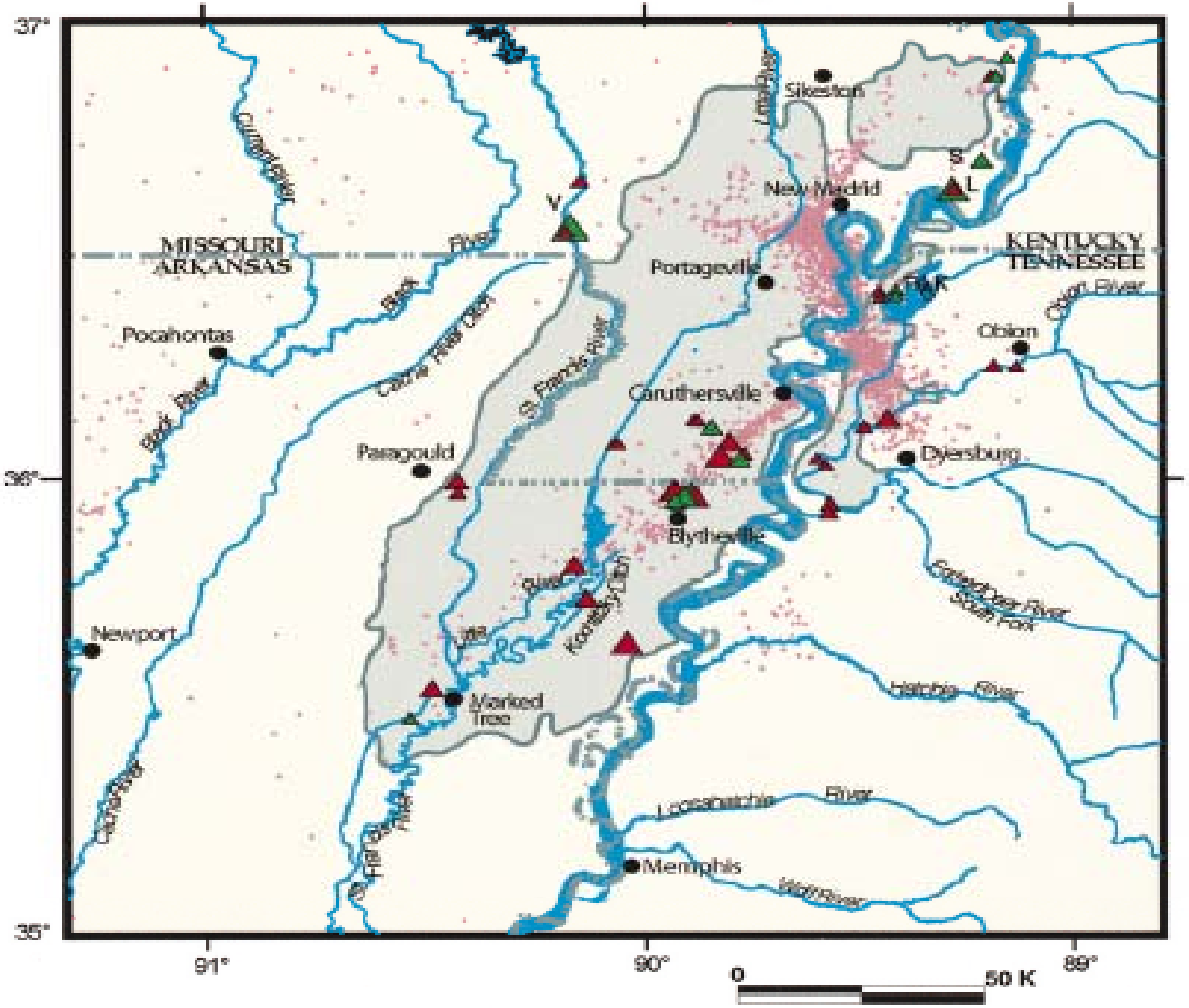
Li et al., 2007

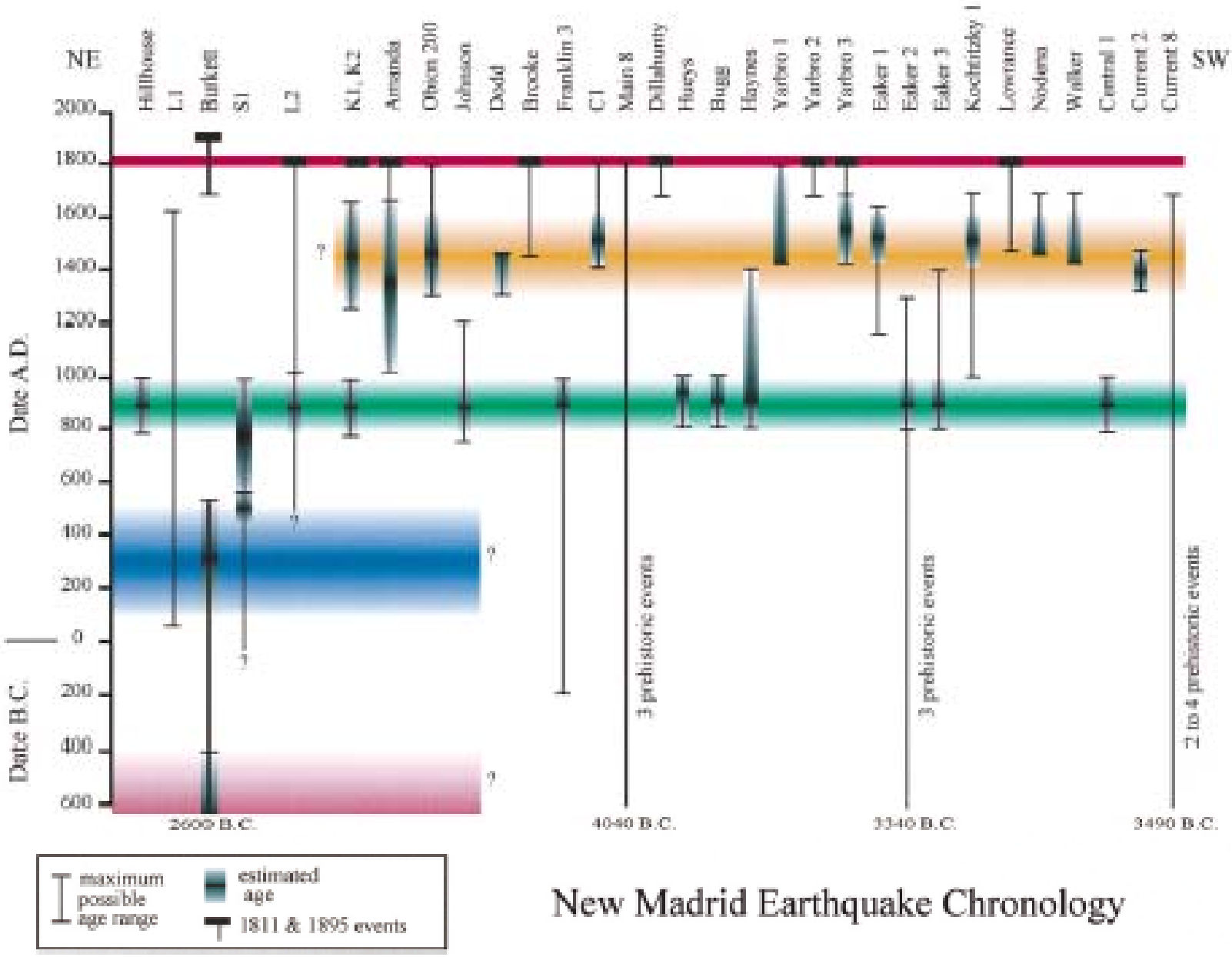
Current debate

- “it’s coming!” - paleoseismic data indicate ~500 years recurrence interval for the large events;

- “don’t worry, be happy” – geodetic evidence of low (near zero) strain accumulation rate.

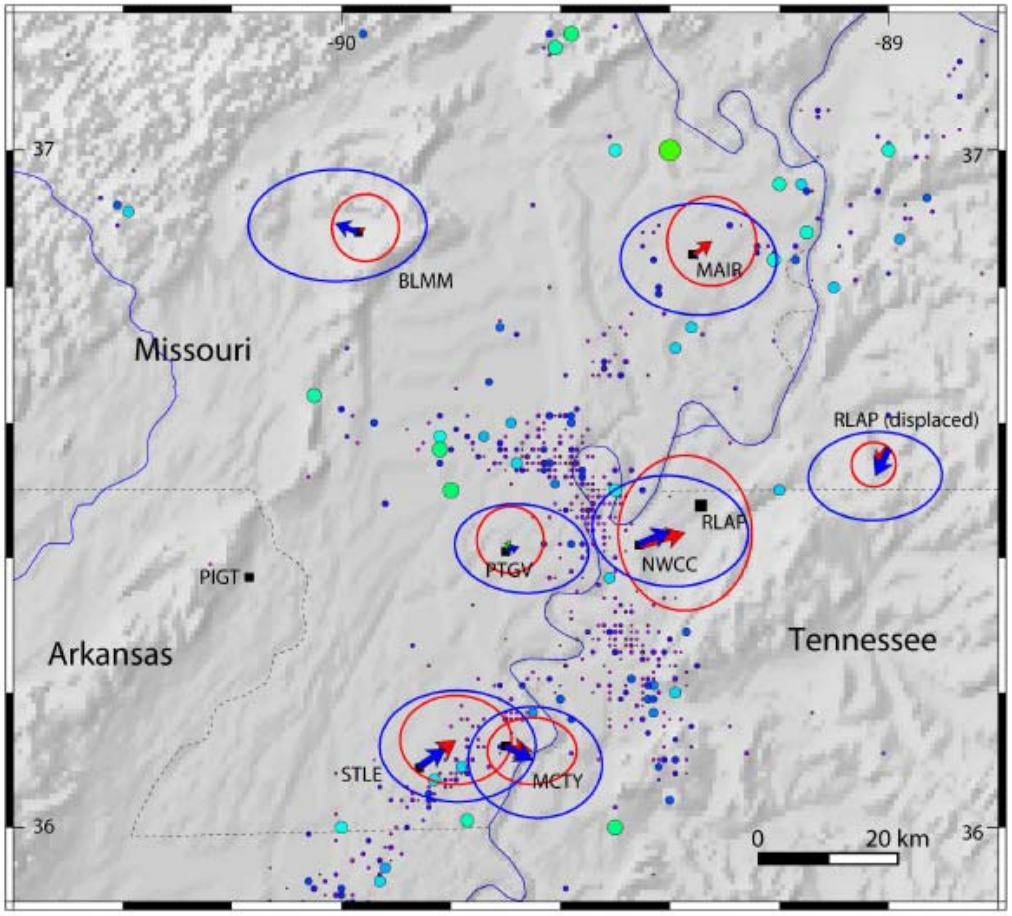
A.D. 900 and 1811-1812 Earthquake Features





Tuttle et al., 2002 SSB

NMSZ Earthquake Hazard: Strain Accumulation?

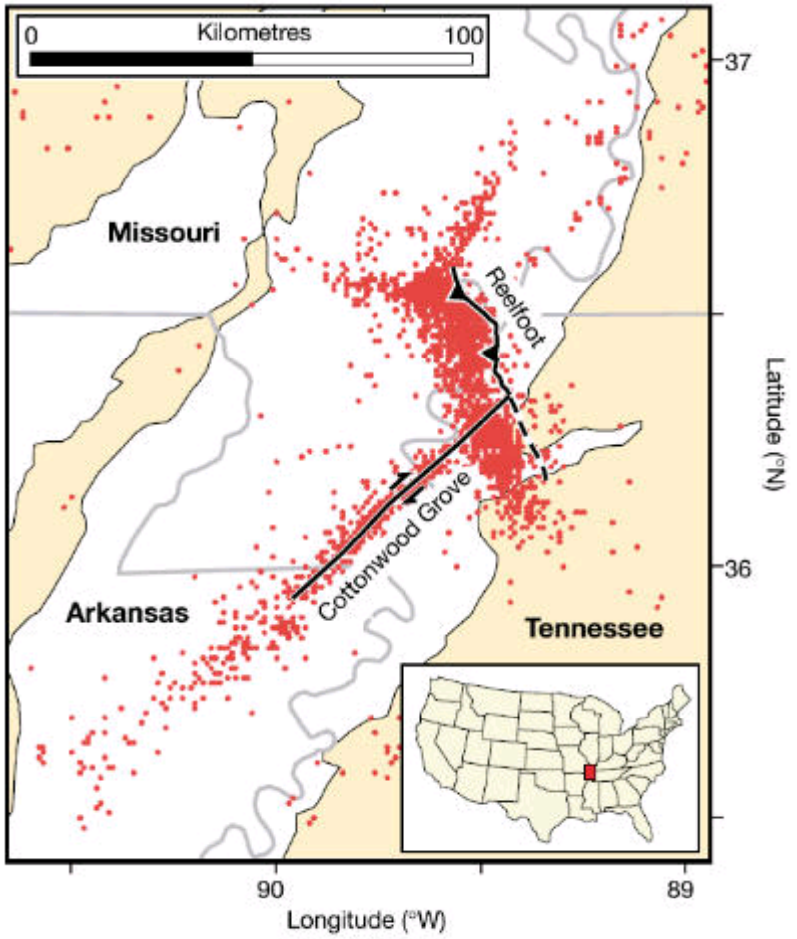


Calais et al., 2005

Present-day seismic activity in NMSZ:

Indicators of stress building up?

or aftershocks?

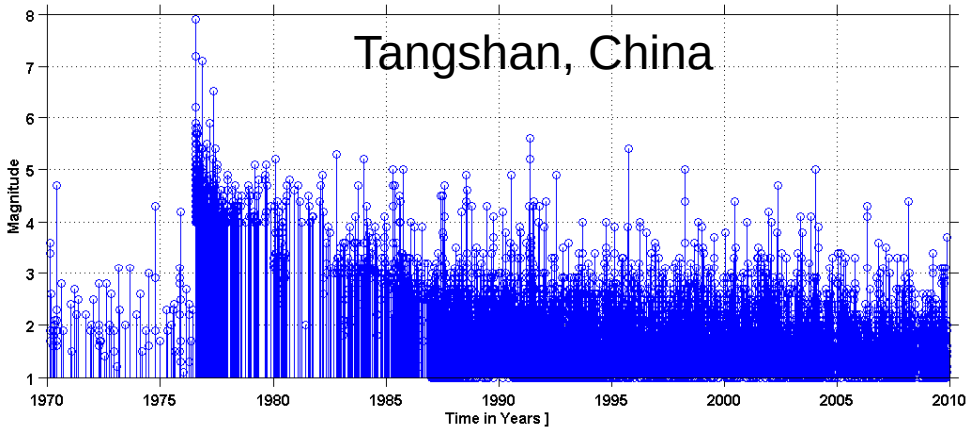


Vol 462|5 November 2009|doi:10.1038/nature08502 nature

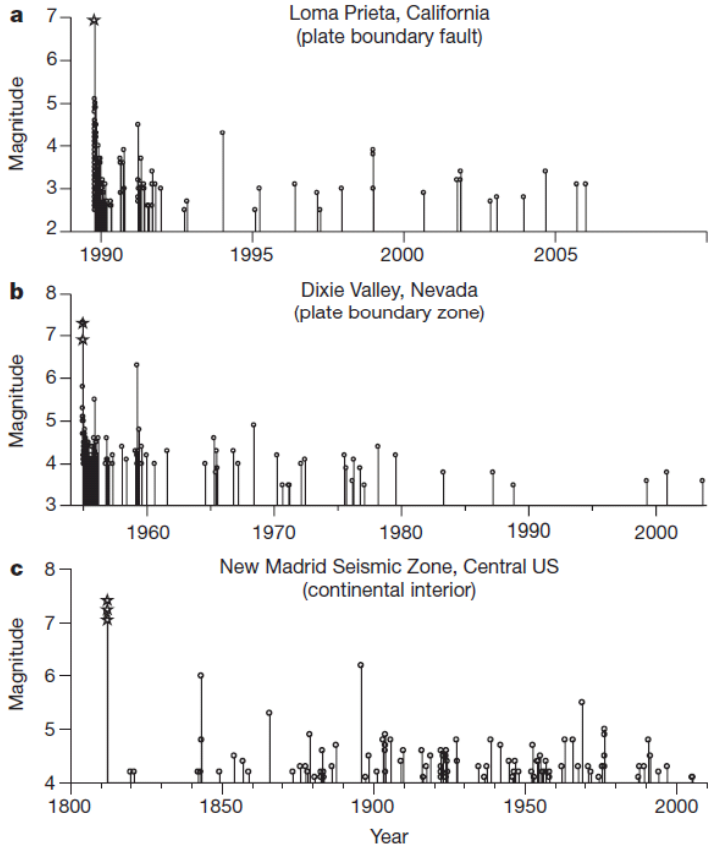
LETTERS

Long aftershock sequences within continents and implications for earthquake hazard assessment

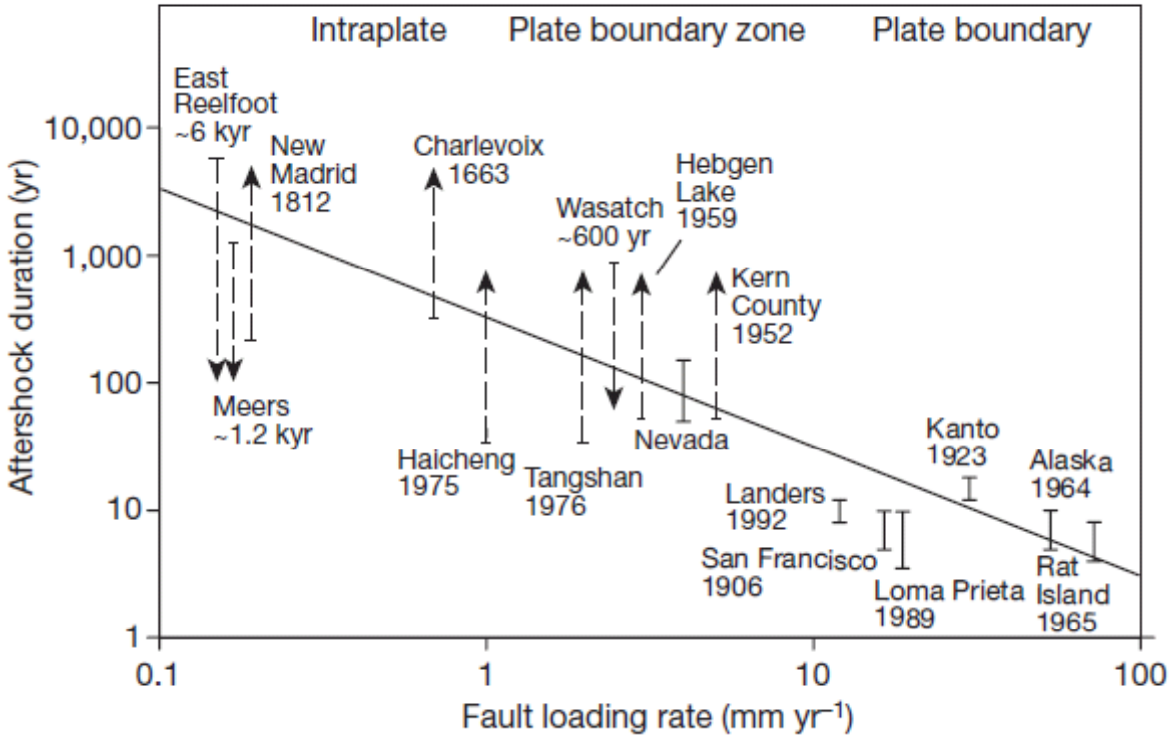
Seth Stein[1] & Mian Liu[2]



After 35 years, it's still going…

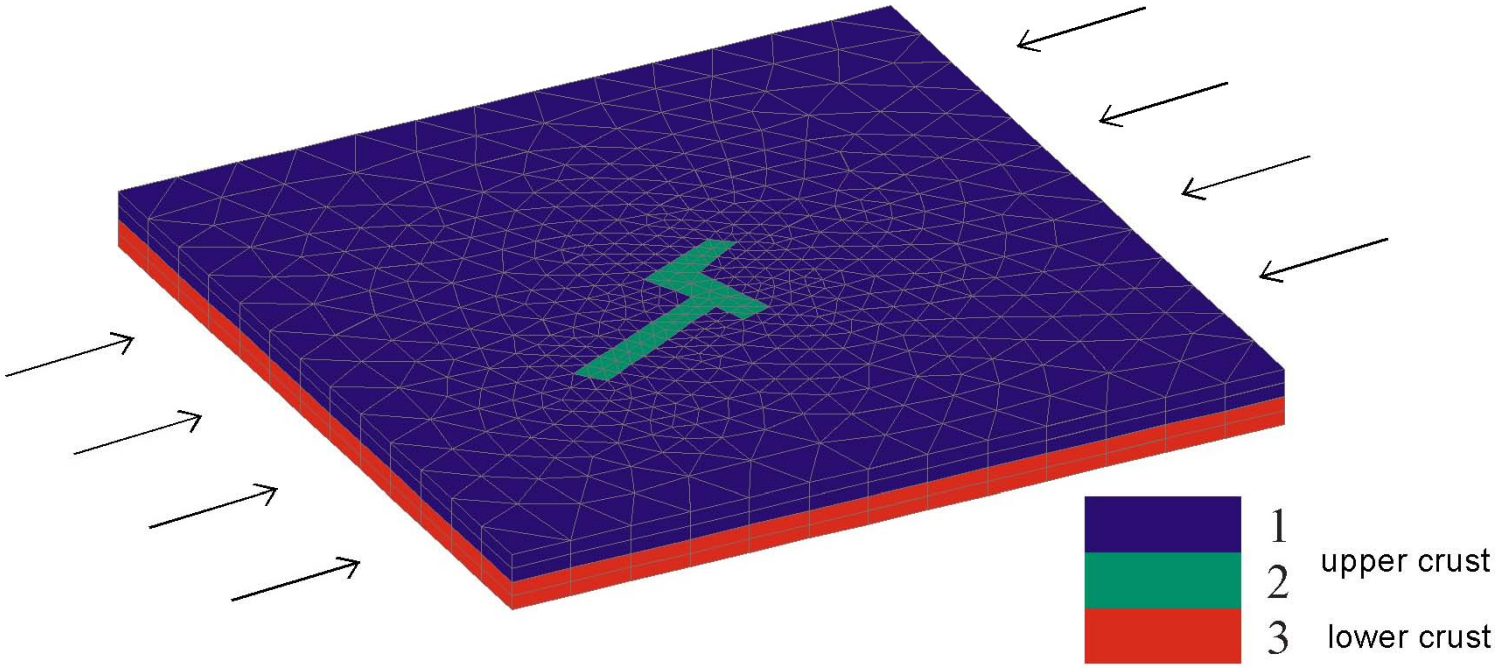


Long aftershock sequences in mid-continent

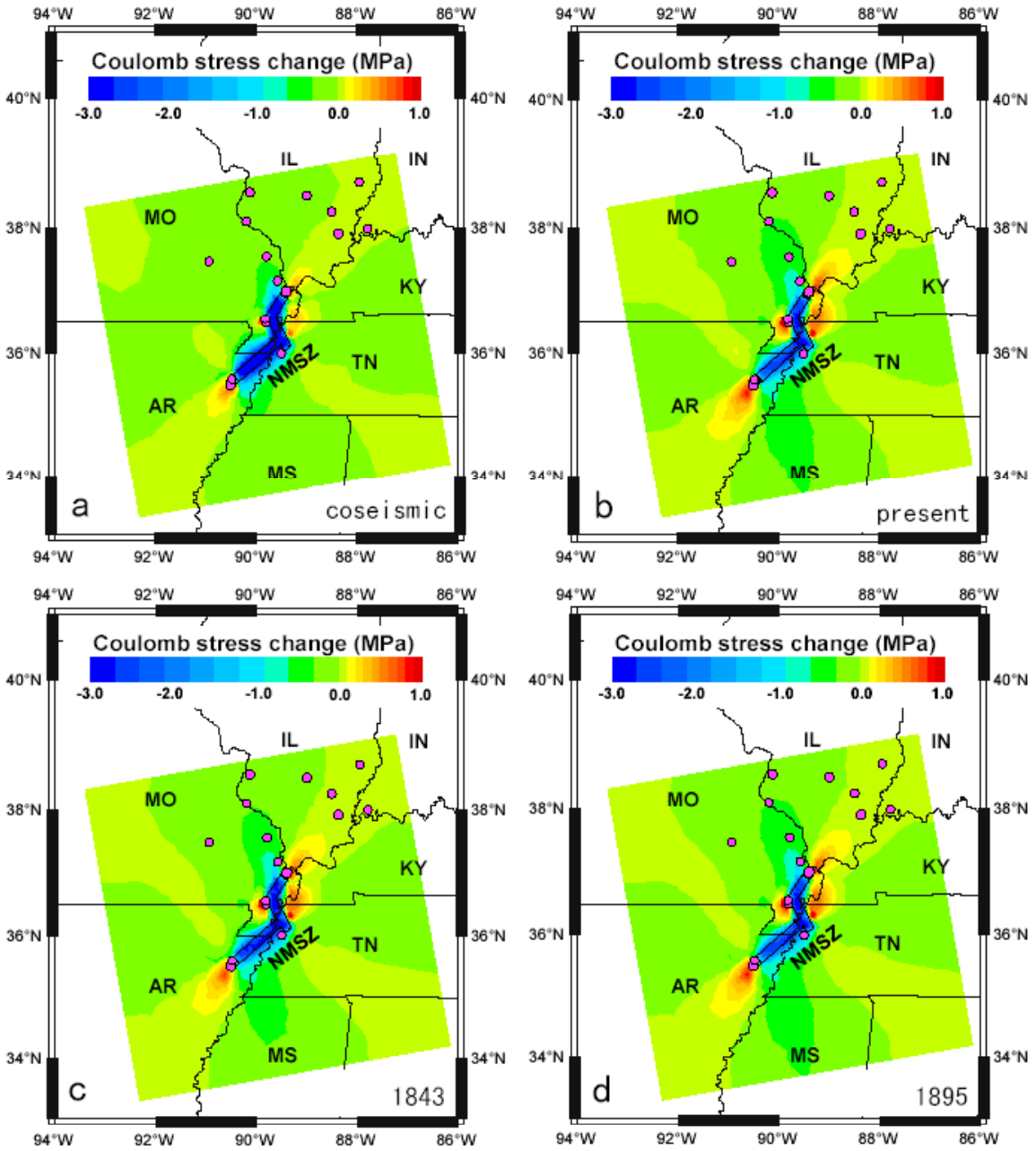


Long aftershock sequences in mid-continent are predicted from the rate- and-state frictional law (Dieterich, 1994) or viscous relaxation, for the low stressing rates or high viscosity in mid-continent.

Finite element model of stress evolution in the NMSZ

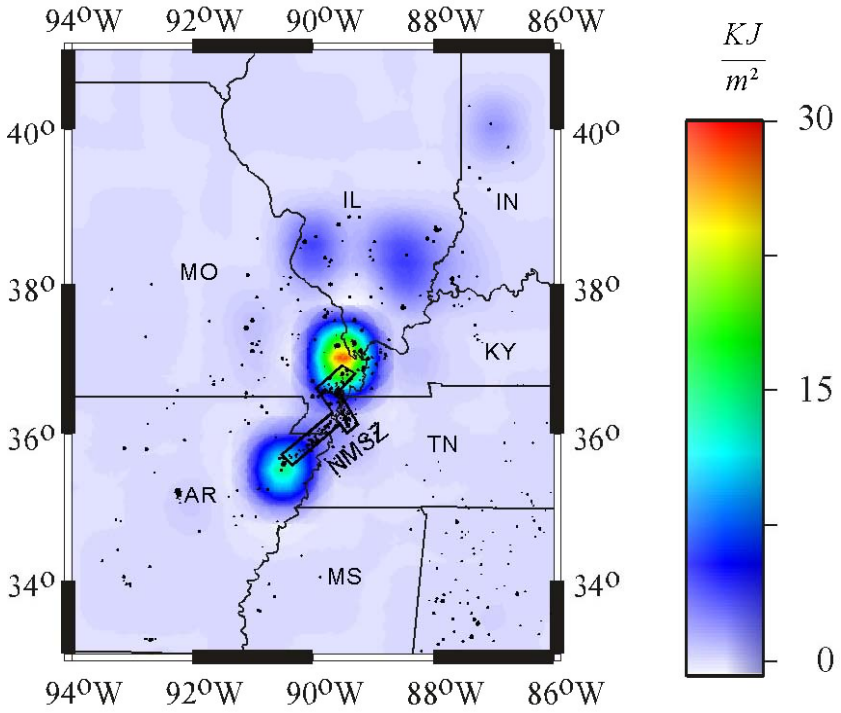


Li and Liu, GRL, 2006

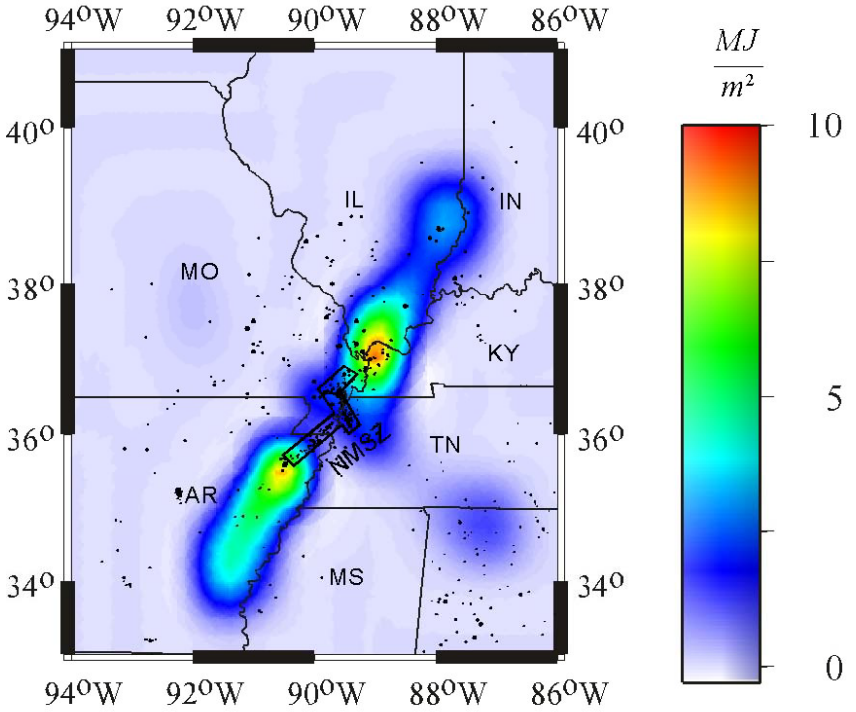


Coulomb Stress Change

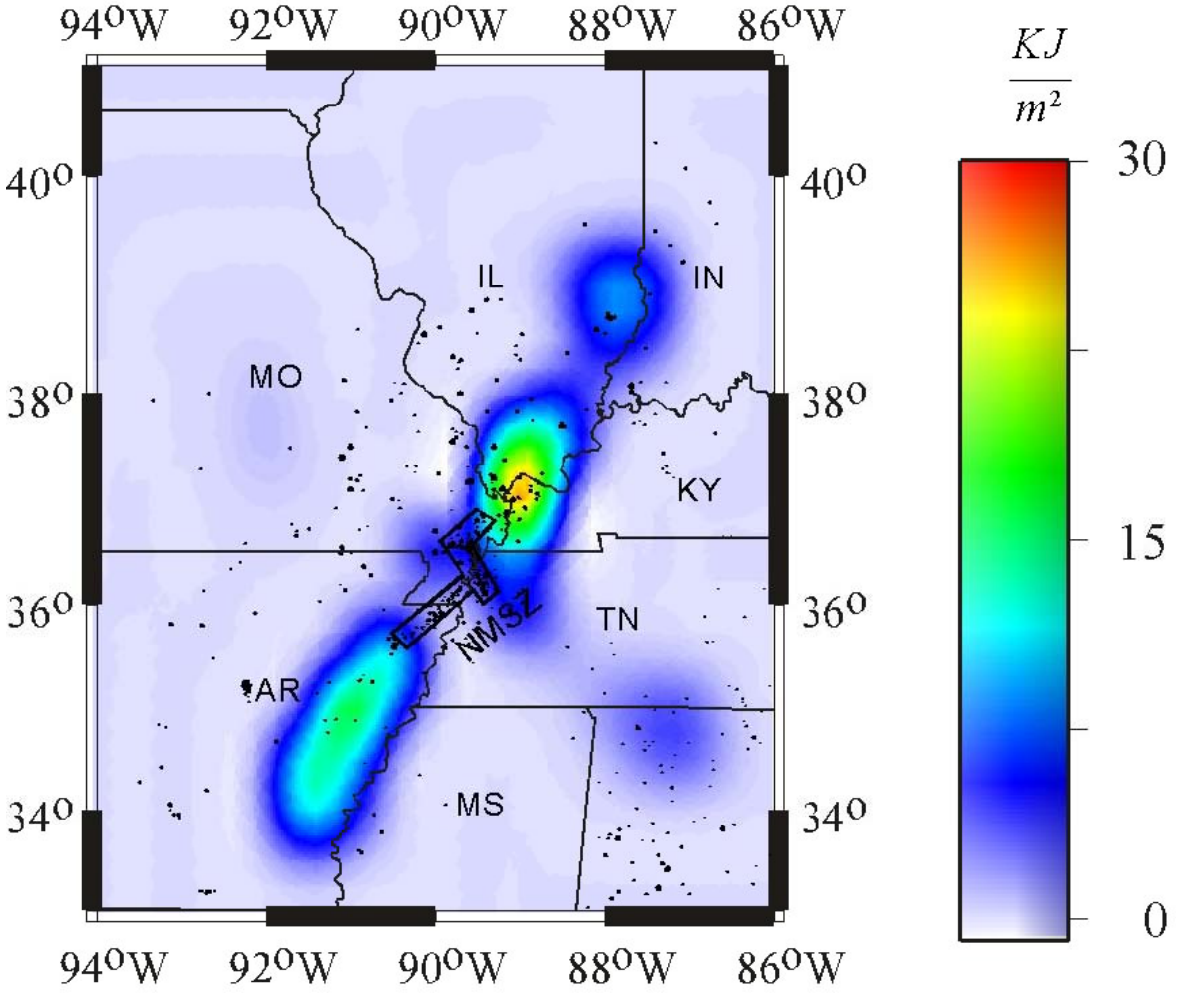
Seismic energy release since 1812



Predicted maximum strain energy since 1812



Estimated residual strain energy in the present crust



In this sense, the moderate sized earthquakes in the NMSZ area over the past 200 years are aftershocks.

NMSZ earthquake sequence is transient

- Started ~10,000 years ago;
- Probably triggered by glacial isostatic adjustment;

- How long would the sequence last?

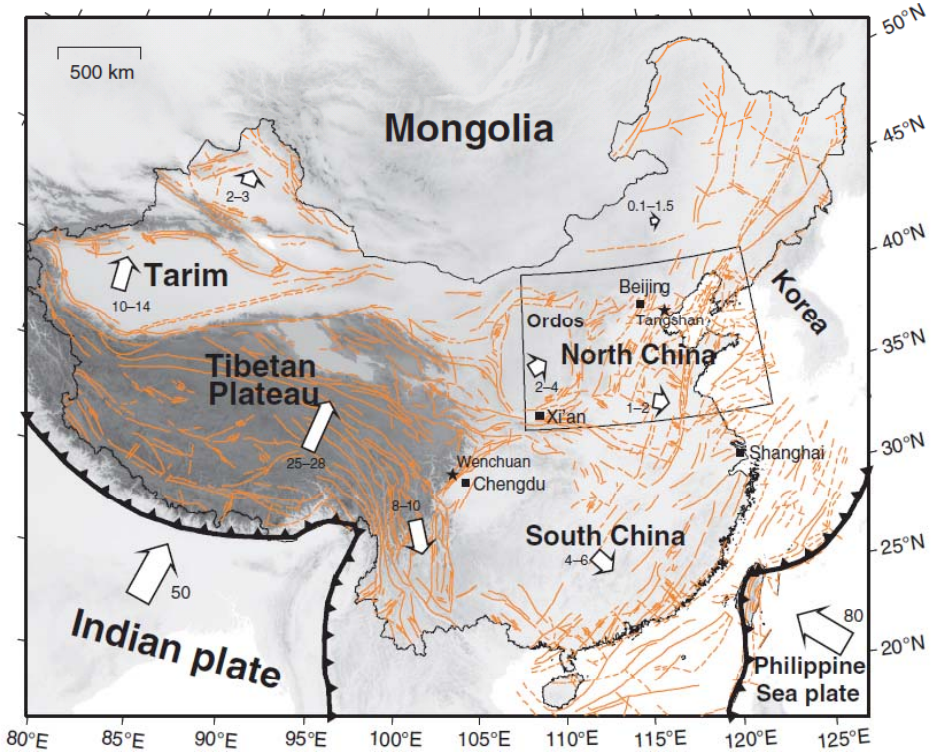
SPATIOTEMPORAL MIGRATION: INSIGHTS FROM NORTH CHINA

LITHOSPHERE Data Repository item 2011080. doi: 10.1130/L129.1

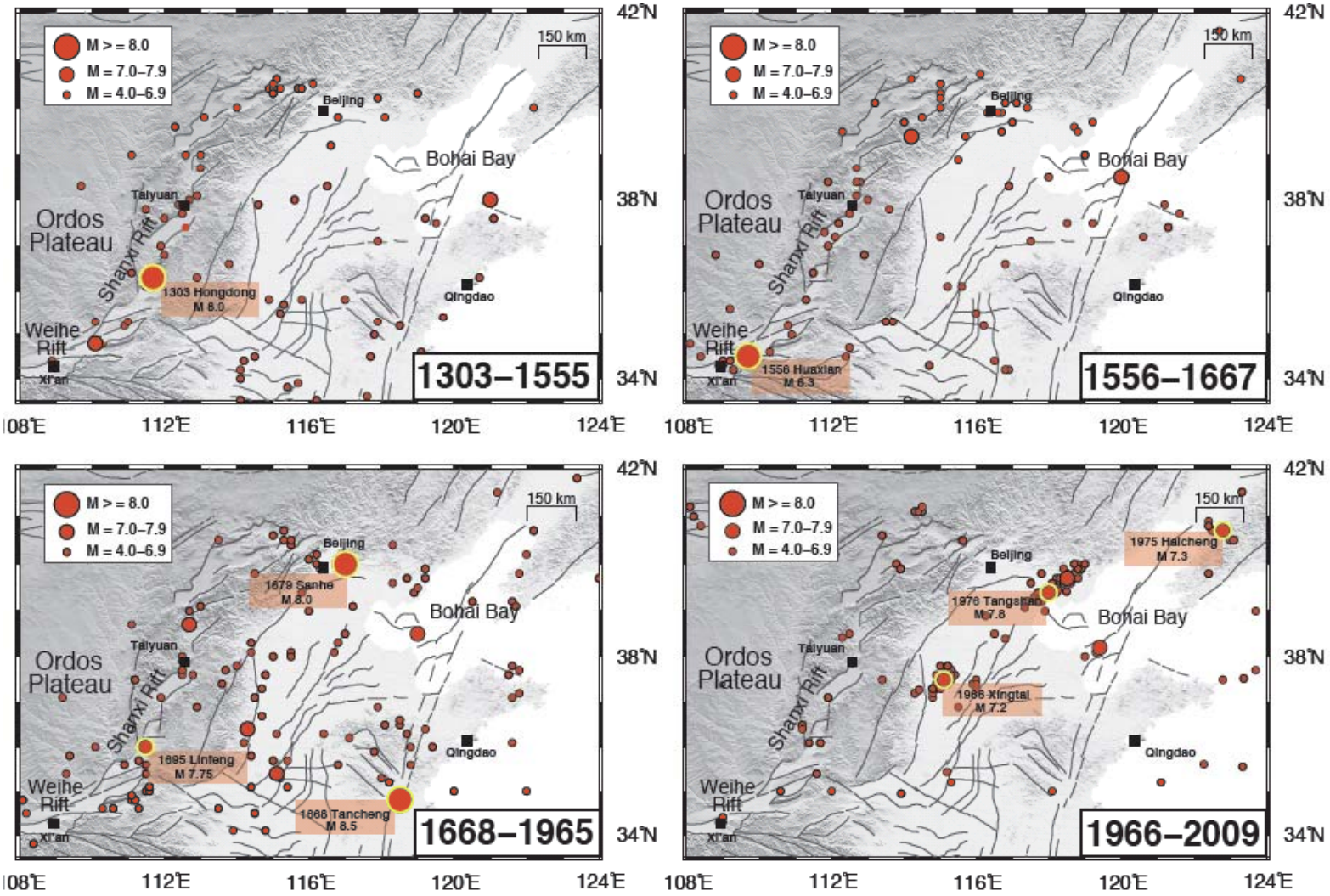
SHORT RESEARCH

2000 years of migrating earthquakes in North China: How earthquakes in midcontinents differ from those at plate boundaries

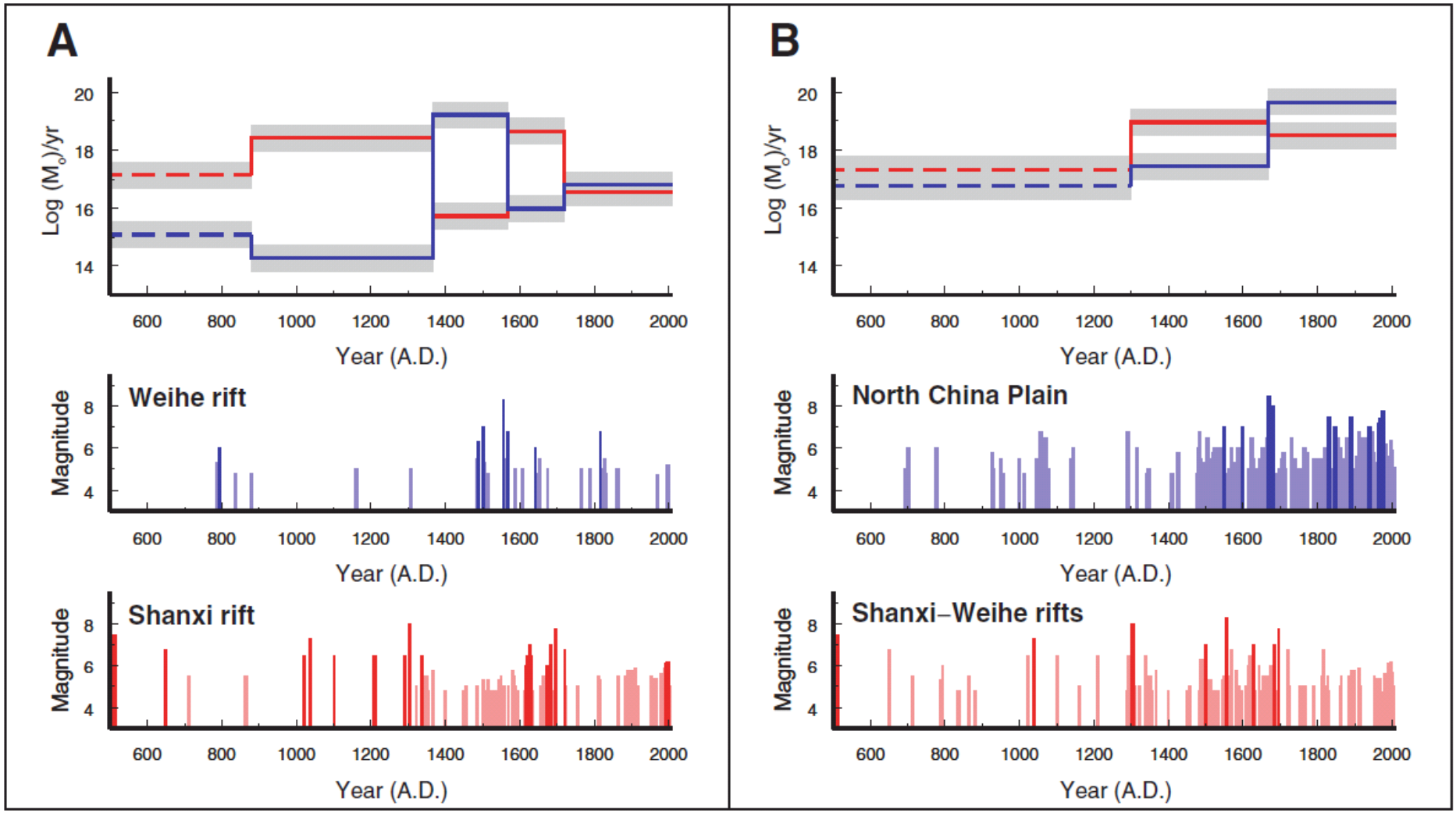
Mian Liu[1,*], Seth Stein[2], and Hui Wang[3]



Migrating Large Earthquakes In North China



No large ruptures have repeated on the same fault segment in the past 2000 years!



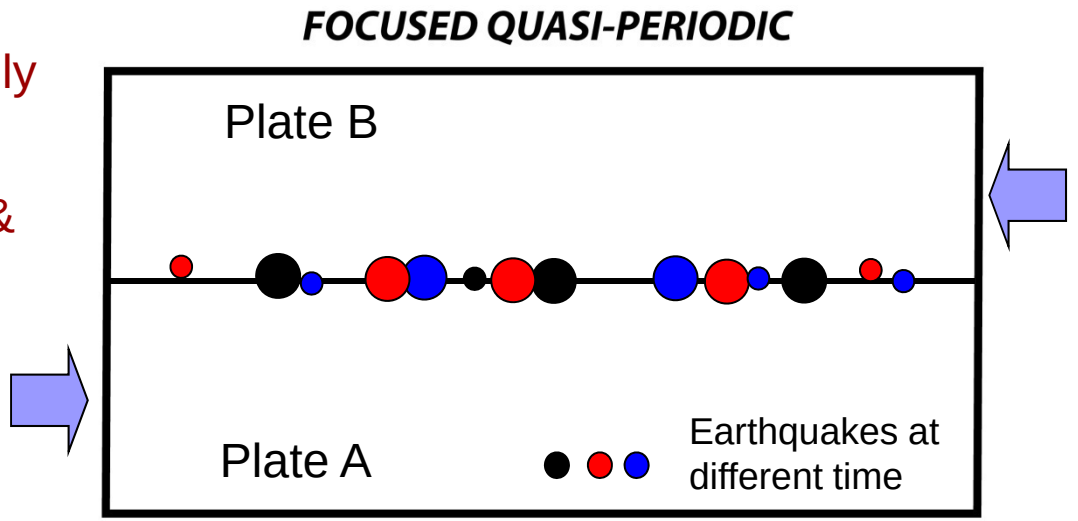
Complementary moment release between major fault systems indicates mechanical coupling between these faults

WHY ARE INTRAPLATE EARTHQUAKES DIFFERNET?

At plate boundary:

•Plate boundary fault is loaded rapidly at constant rate

•Earthquakes are spatially focused & temporally quasi-periodic

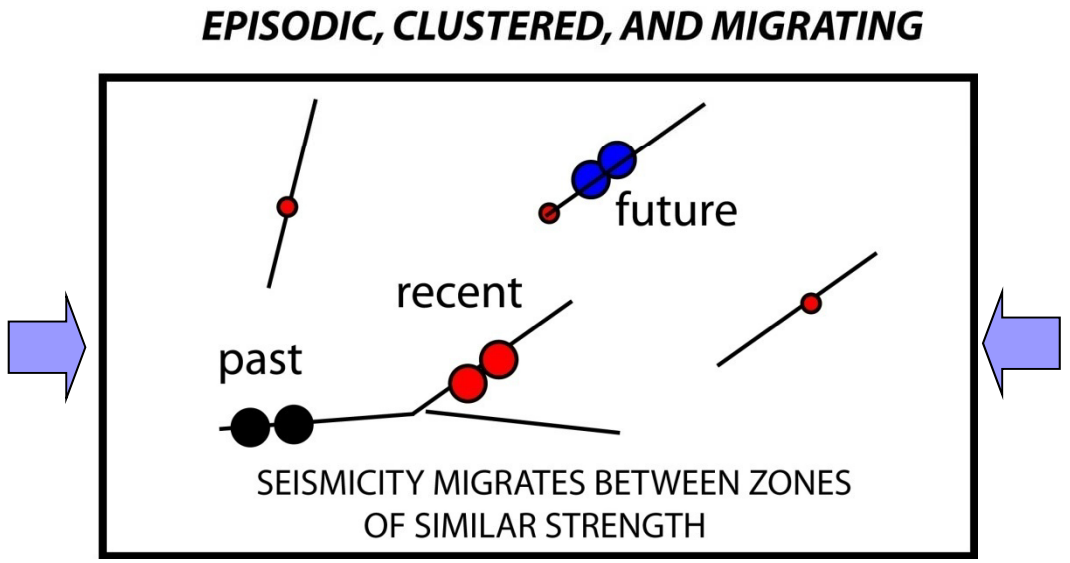


In Mid-Continent:

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

•Loading rate on a given fault is slow & may not be constant

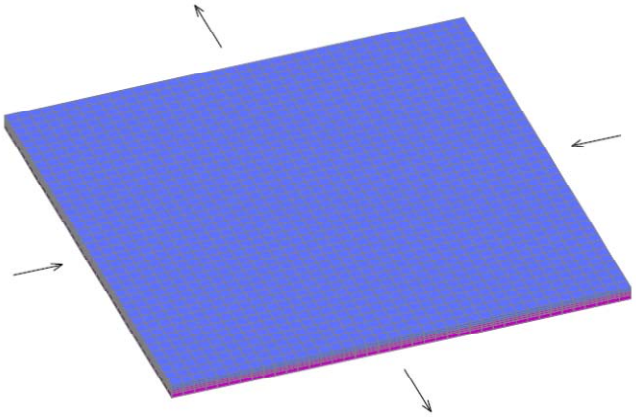
•Earthquakes can cluster on a fault for a while then shift



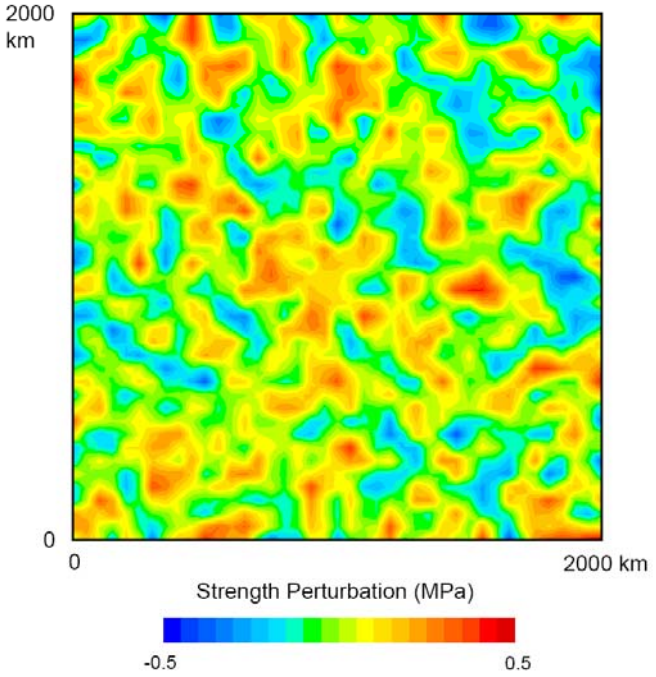
Bulletin of the Seismological Society of America, Vol. 99, No. 1, pp. 52–60, February 2009, doi: 10.1785/0120080005

Spatiotemporal Complexity of Continental Intraplate Seismicity: Insights from Geodynamic Modeling and Implications for Seismic Hazard Estimation

by Qingsong Li, Mian Liu, and Seth Stein

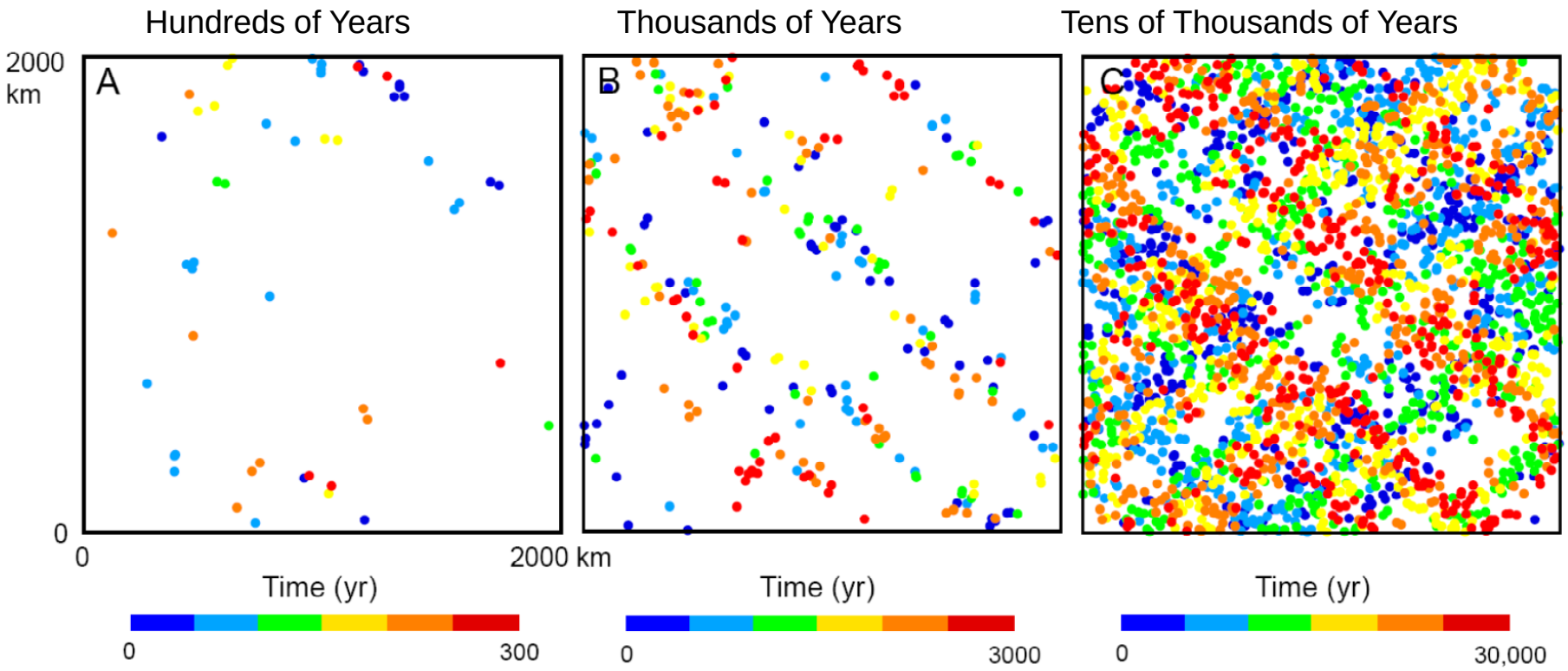


A simple viscoelastic FE model



Initial random stress perturbation

Predicted seismicity on different time scales



Over 100s of years, predicted seismicity shows both spatial clustering (in narrow belts) and scattering (across large regions).

Over a longer period (1000s of years), predicted seismicity forms networked belts, apparently aligned with the regional orientations of maximum shear stress.

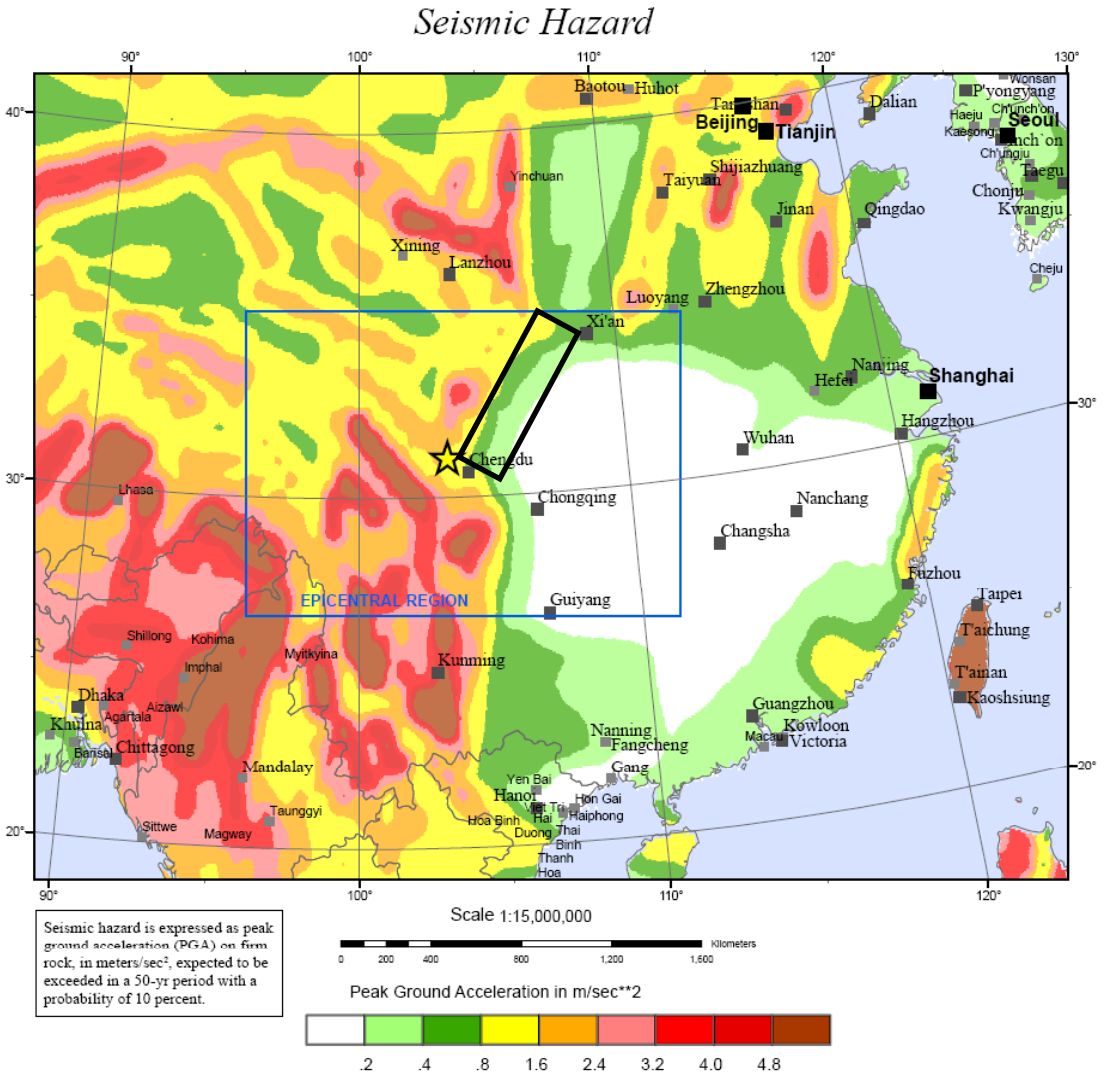
Over an even longer period (10,000s of years), the predicted seismicity appears to be randomly scattered everywhere.

IMPLICATIONS FOR HAZARD ASSESSMENT

2008 Great Wenchuan Earthquake, Sichuan, China

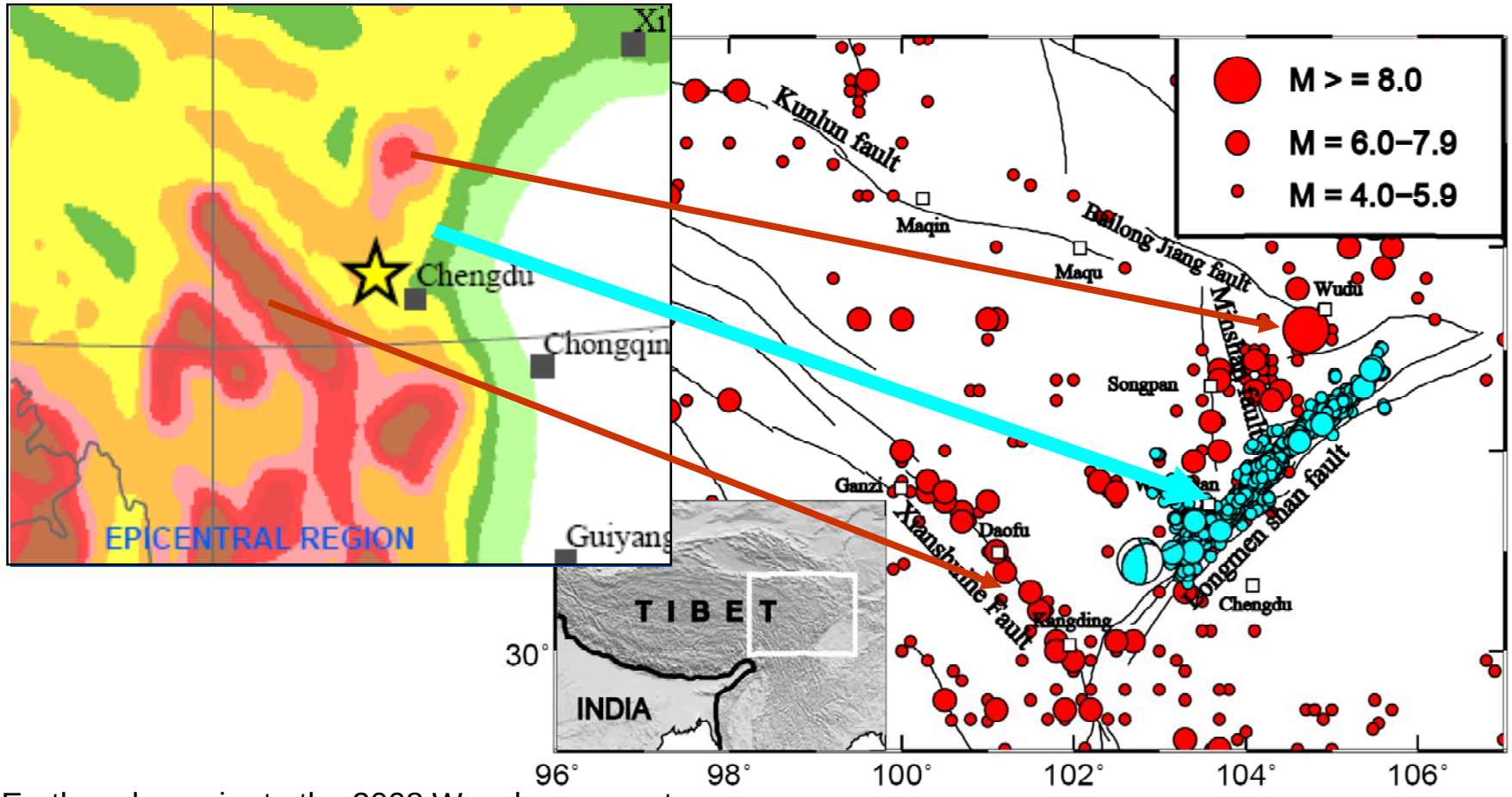
~90,000 people killed

The 2008 Wenchuan earthquake (Mw 7.9) was not expected!



Why not?

(mis-)guided by the lack of recent seismicity

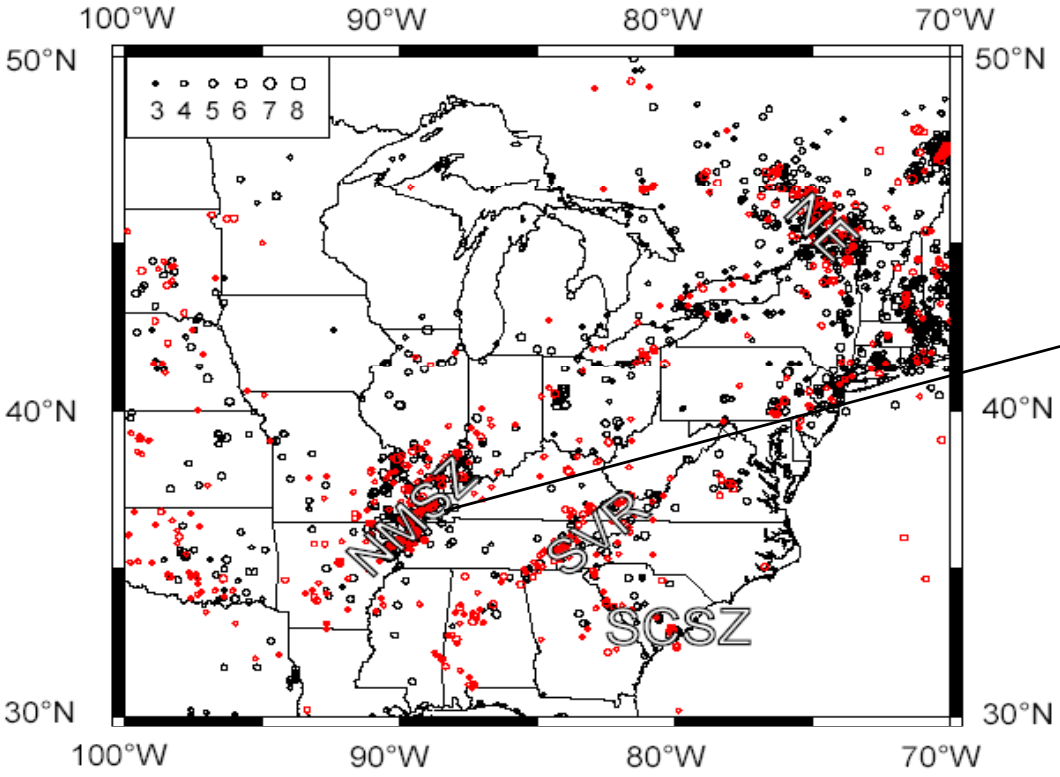


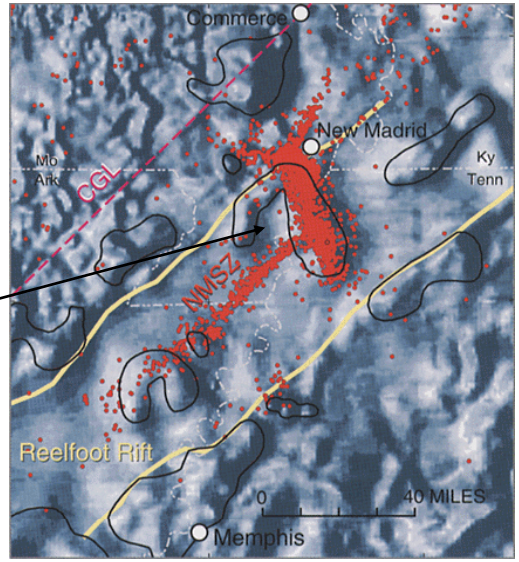
- Earthquakes prior to the 2008 Wenchuan event
- Aftershocks of the Wenchuan event delineating the rupture zone

Here we assume:

- **Past large earthquakes indicate where large earthquakes will occur;**
- **Present small earthquakes indicate stressing.**

Hence large historic earthquakes and recent seismicity…

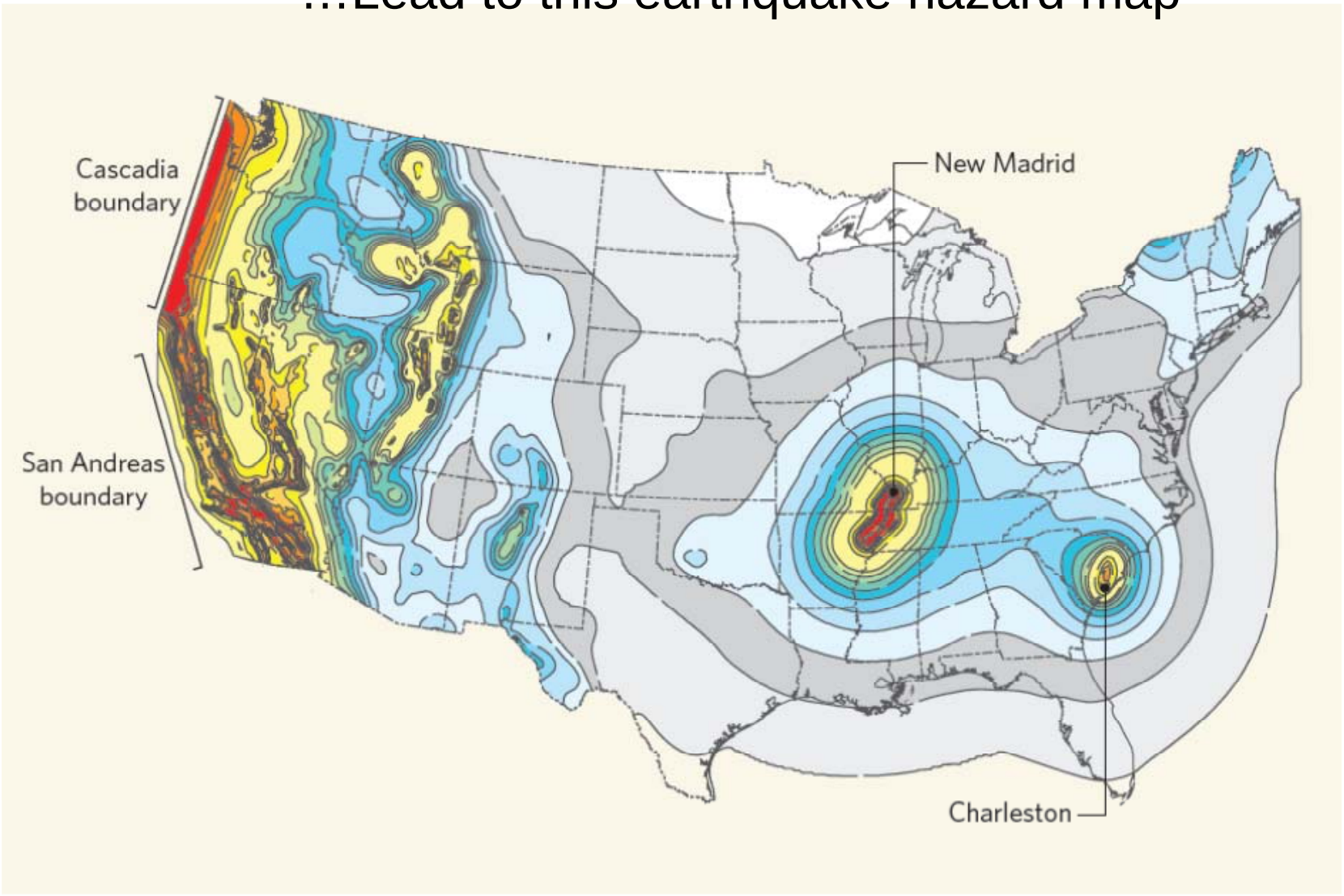




The New Madrid Seismic Zone (NMSZ):

- At least three large events (M >7.0) during 1811-1812
- More than 4000 seismic events since 1977

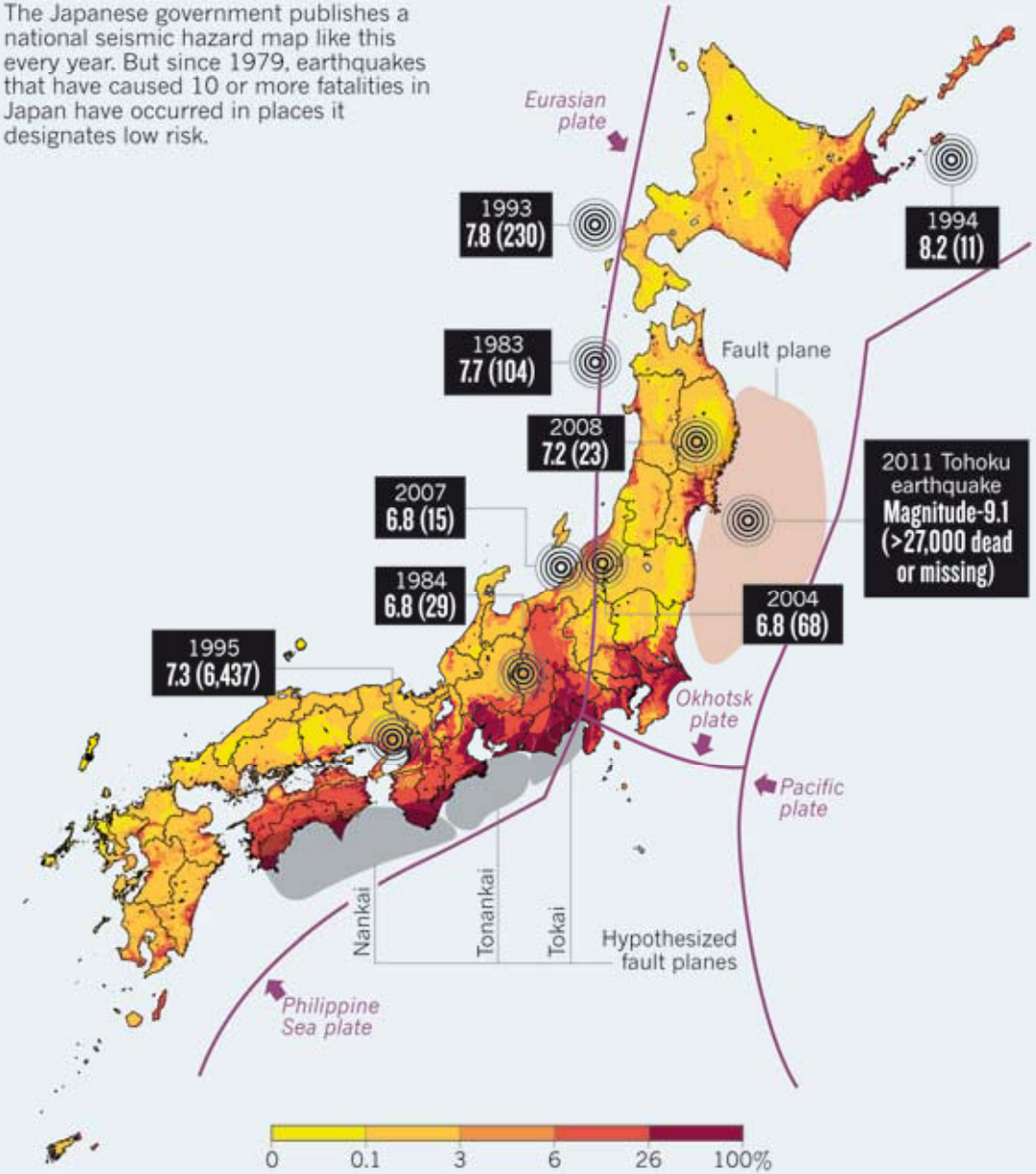
…Lead to this earthquake hazard map



Probabilistic assessment of seismic hazard in the United States. Parsons (2009), based on Frankel, A. *et al. US Geol. Surv. Open-File Rep.* 02-420 (2002). Warm colors show regions with the highest probability of strong shaking.

REALITY CHECK

The Japanese government publishes a national seismic hazard map like this every year. But since 1979, earthquakes that have caused 10 or more fatalities in Japan have occurred in places it designates low risk.



Government-designated probability of ground motion of seismic intensity of level '6-lower' or higher (on a 7-maximum intensity scale) in the 30-year period starting in January 2010

During World War II, future Nobel Prize winner Kenneth Arrow served as a military weather forecaster. “My colleagues had the responsibility of preparing long-range weather forecasts, *i.e., for the following month,” he wrote. “The statisticians* among us subjected these forecasts to verification and found they differed in no way from chance. The forecasters themselves were convinced and requested that the forecasts be discontinued. The reply read approximately like this: ‘The commanding general is well aware that the forecasts are no good. However, he needs them for planning purposes.’” (Gardner 2010).

Kenneth Arrow
1972 Nobel Prize for Economics

Thank you!