Mid-continent earthquakes: the need for a system approach

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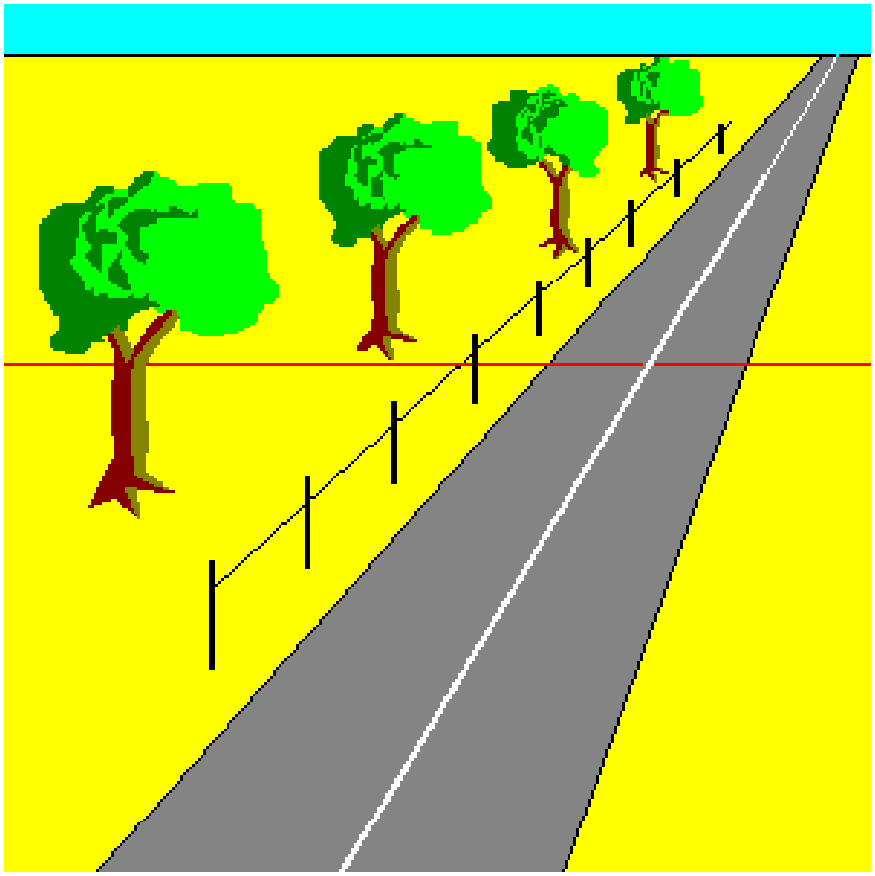
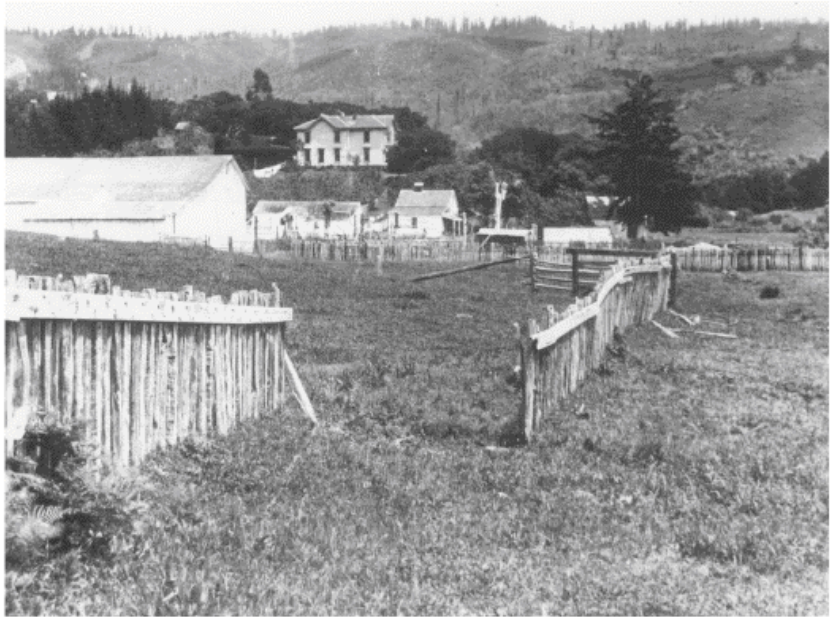
Earthquakes result from sudden slip on fault planes

1906 San Francisco Earthquake

San Andreas Fault

Elastic Rebound Model

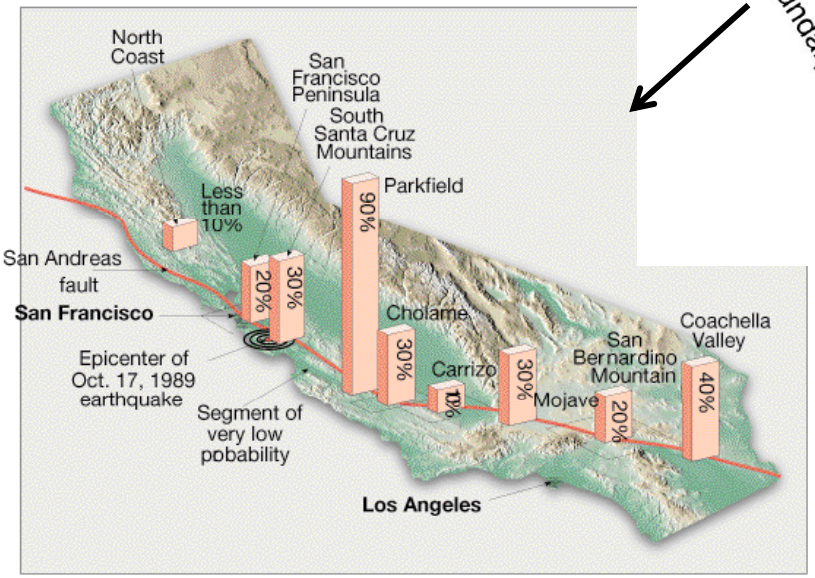




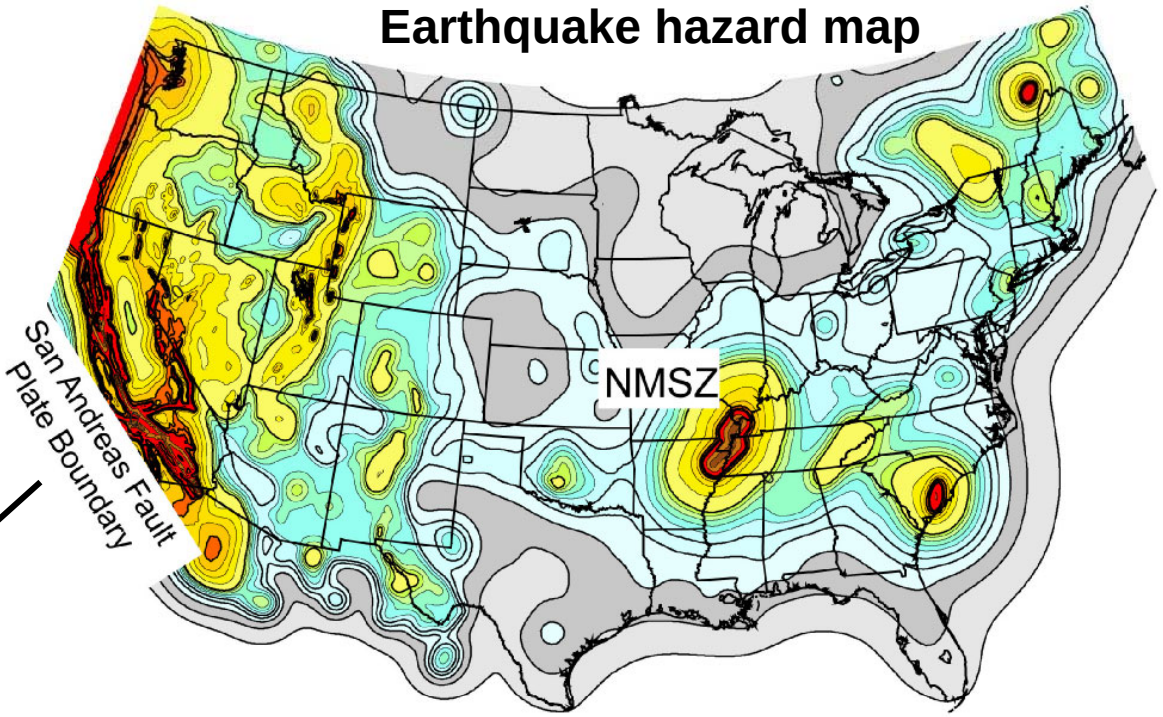
Fence offset by the 1906 San Francisco earthquake

So we assume:

1) **Large earthquakes repeat on the same fault;**
2) **Recent seismicity indicate how active the fault is.**



Earthquake hazard map



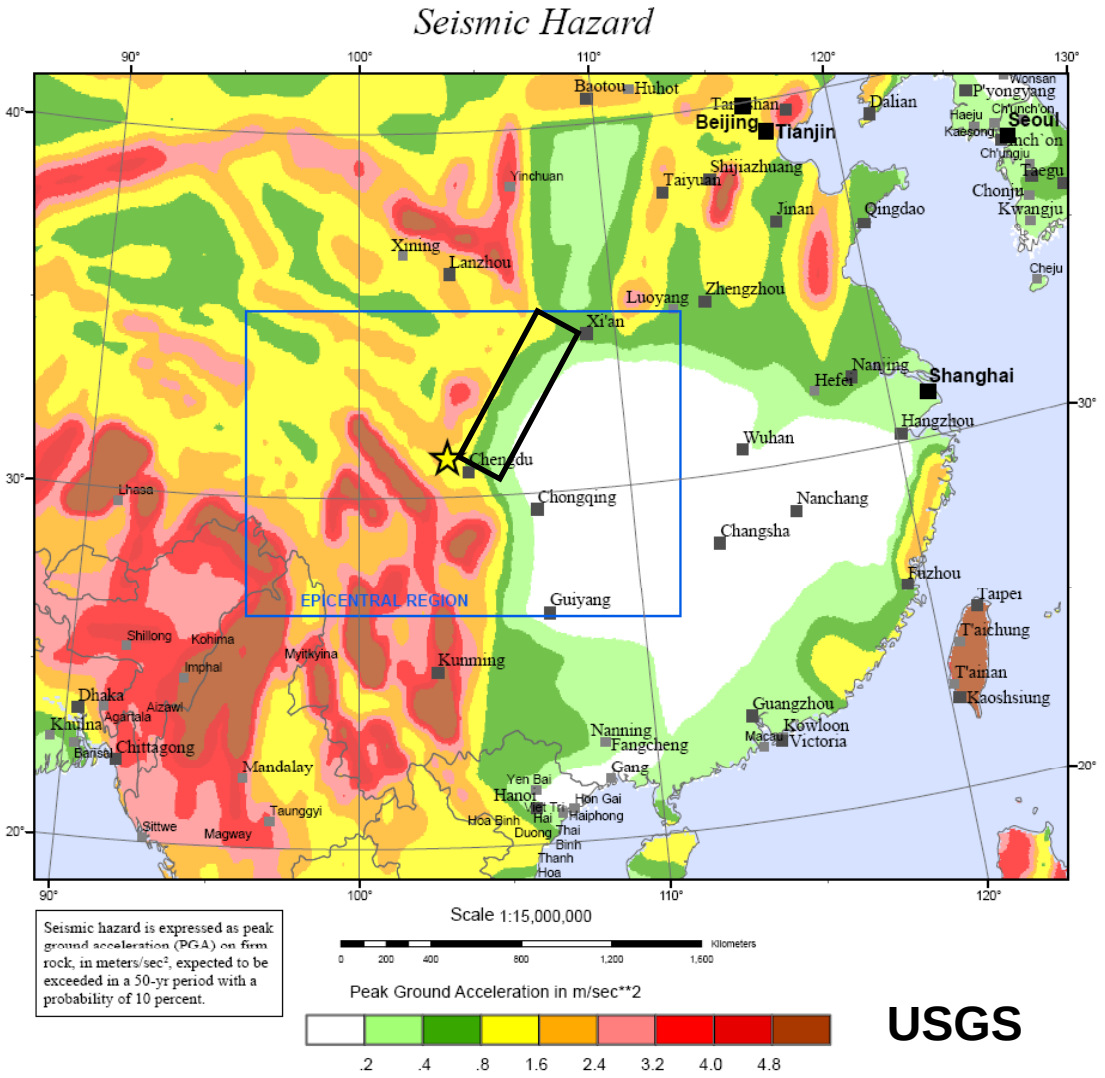
Probabilistic assessment of seismic hazard in the United States. Parsons (2009), based on Frankel, A. *et al. US Geol. Surv. Open-File Rep.* 02-420 (2002). Warm colors show regions with the highest probability of strong shaking.

Did not work well for many recent large earthquakes in mid- continents

12 May 2008 Wenchuan earthquake (Mw 7.9), China

~90,000 people killed

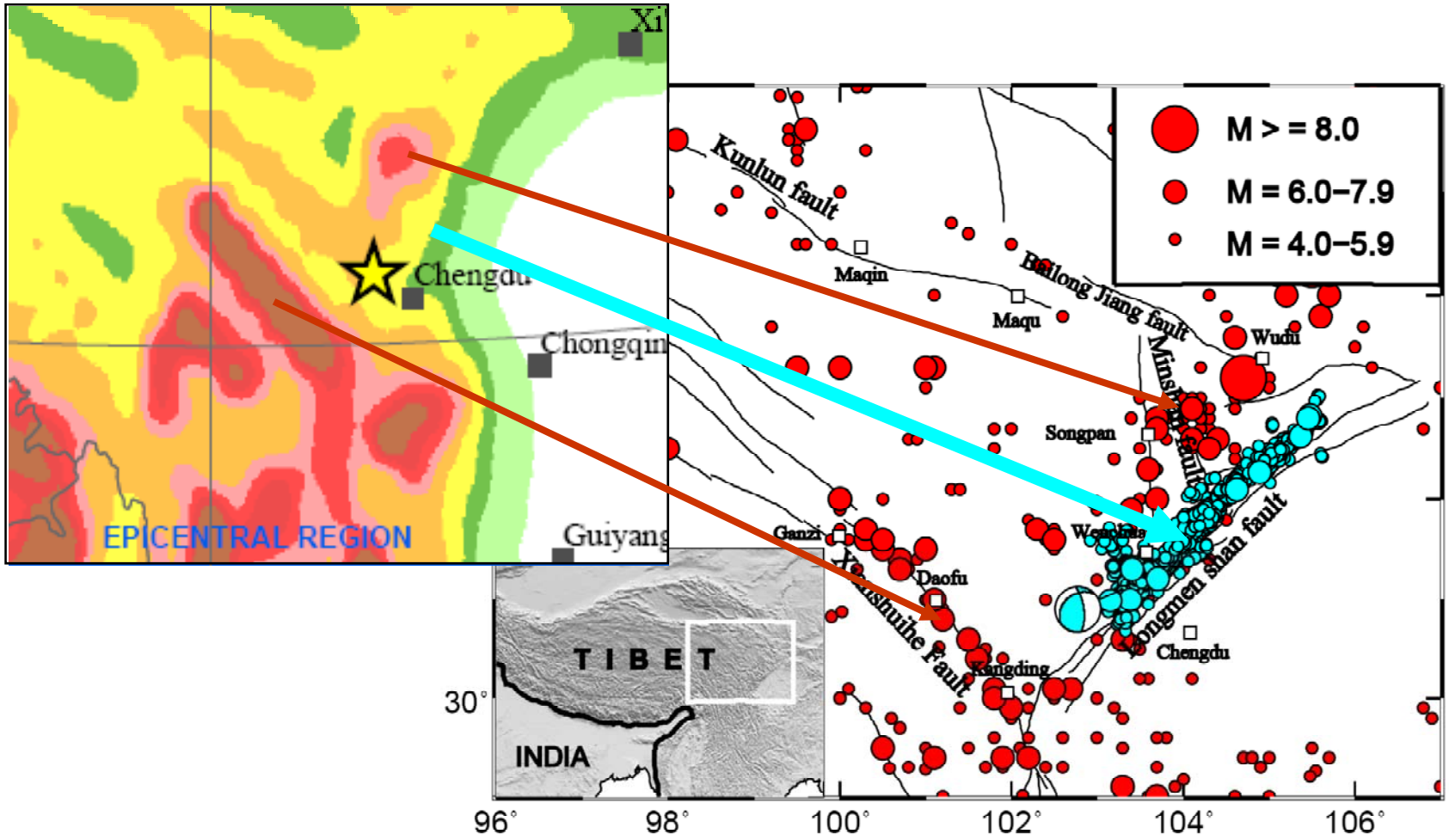
The 2008 Wenchuan earthquake was not expected!



USGS

Why not?

(mis-)guided by the lack of recent seismicity

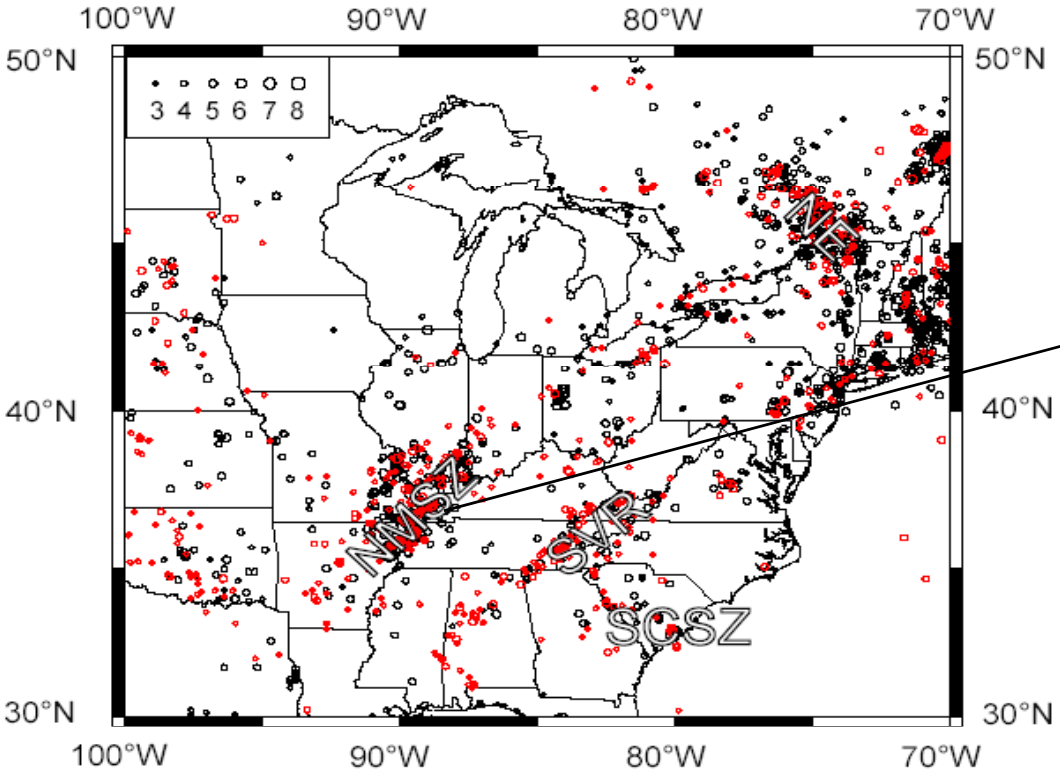


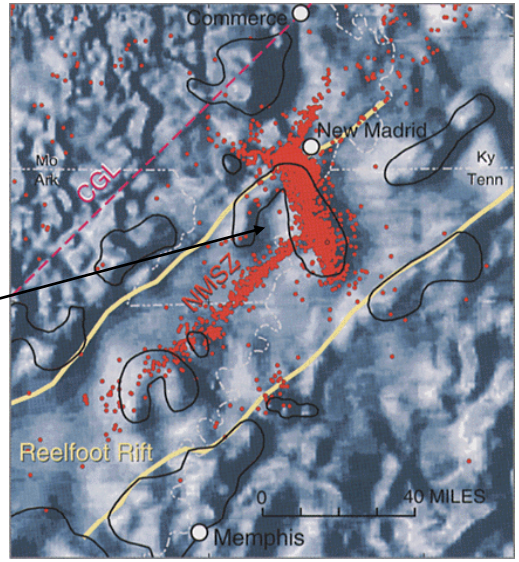
- Earthquakes prior to the 2008 Wenchuan event
- Aftershocks of the Wenchuan event delineating the rupture zone

In general we assume:

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

Hence large historic earthquakes and recent seismicity…

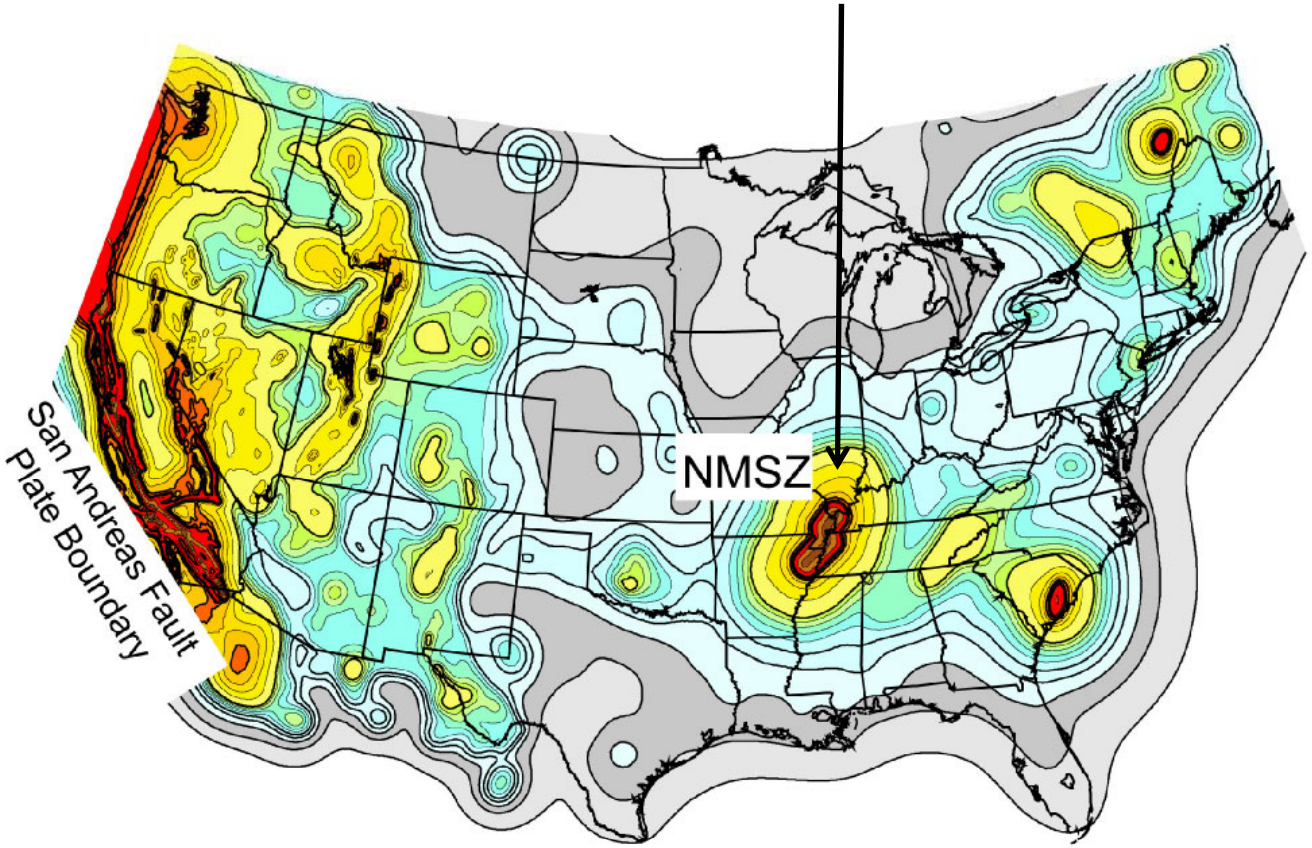




The New Madrid Seismic Zone (NMSZ):

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

…Lead to this



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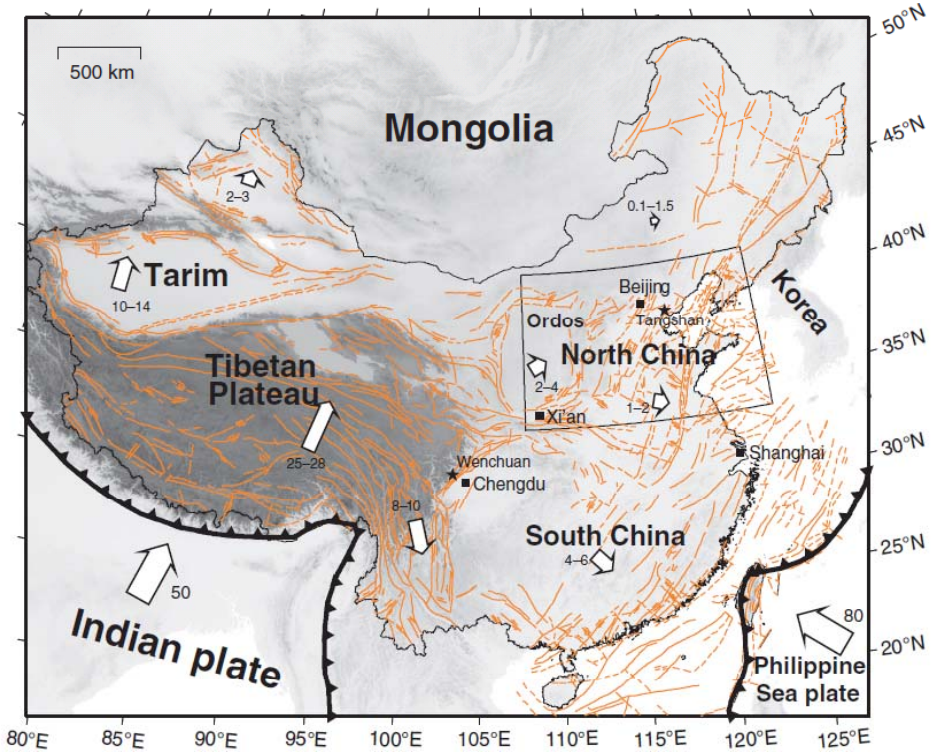
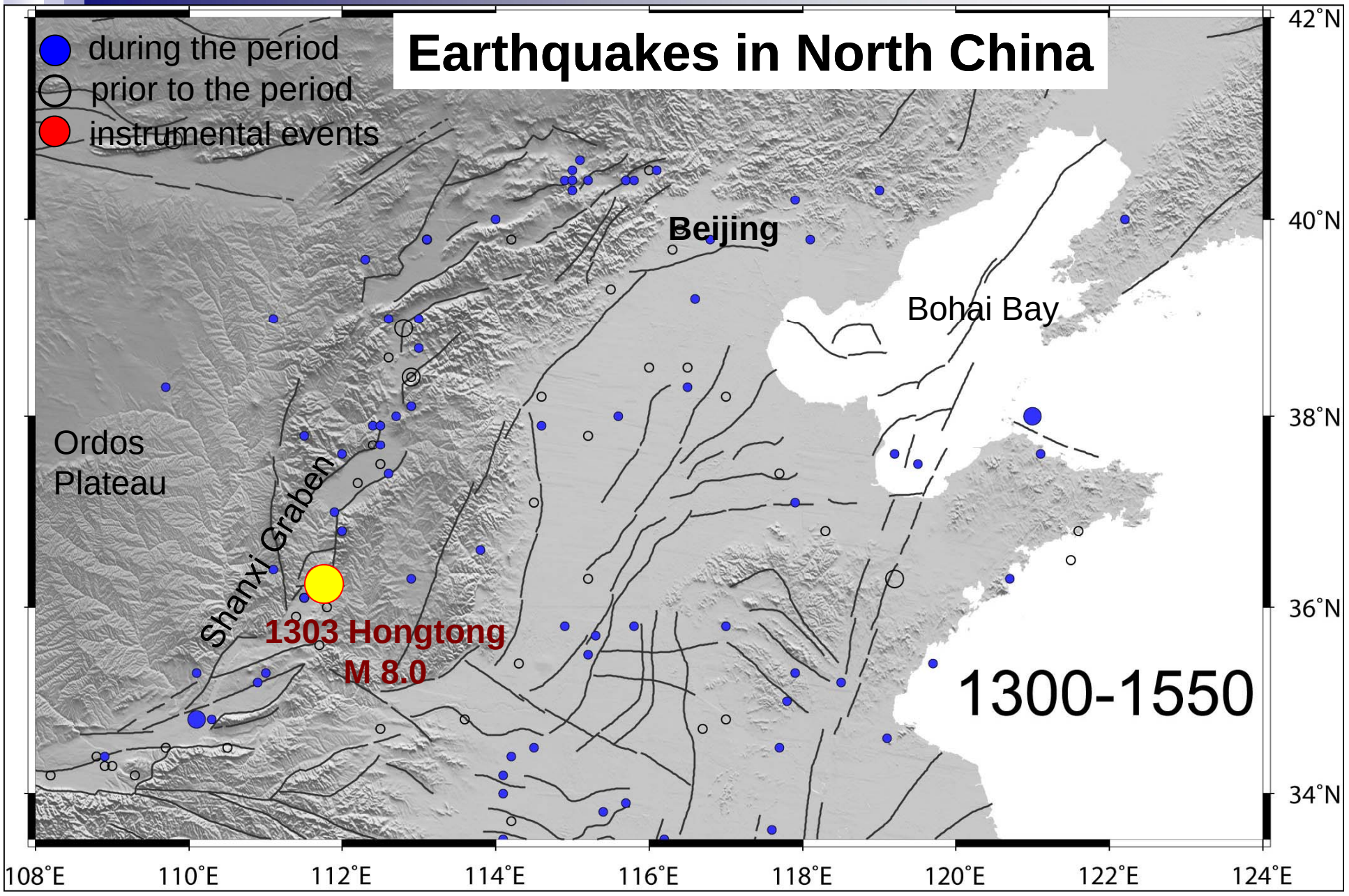
LITHOSPHERE Data Repository item 2011080. doi: 10.1130/L129.1

SHORT RESEARCH

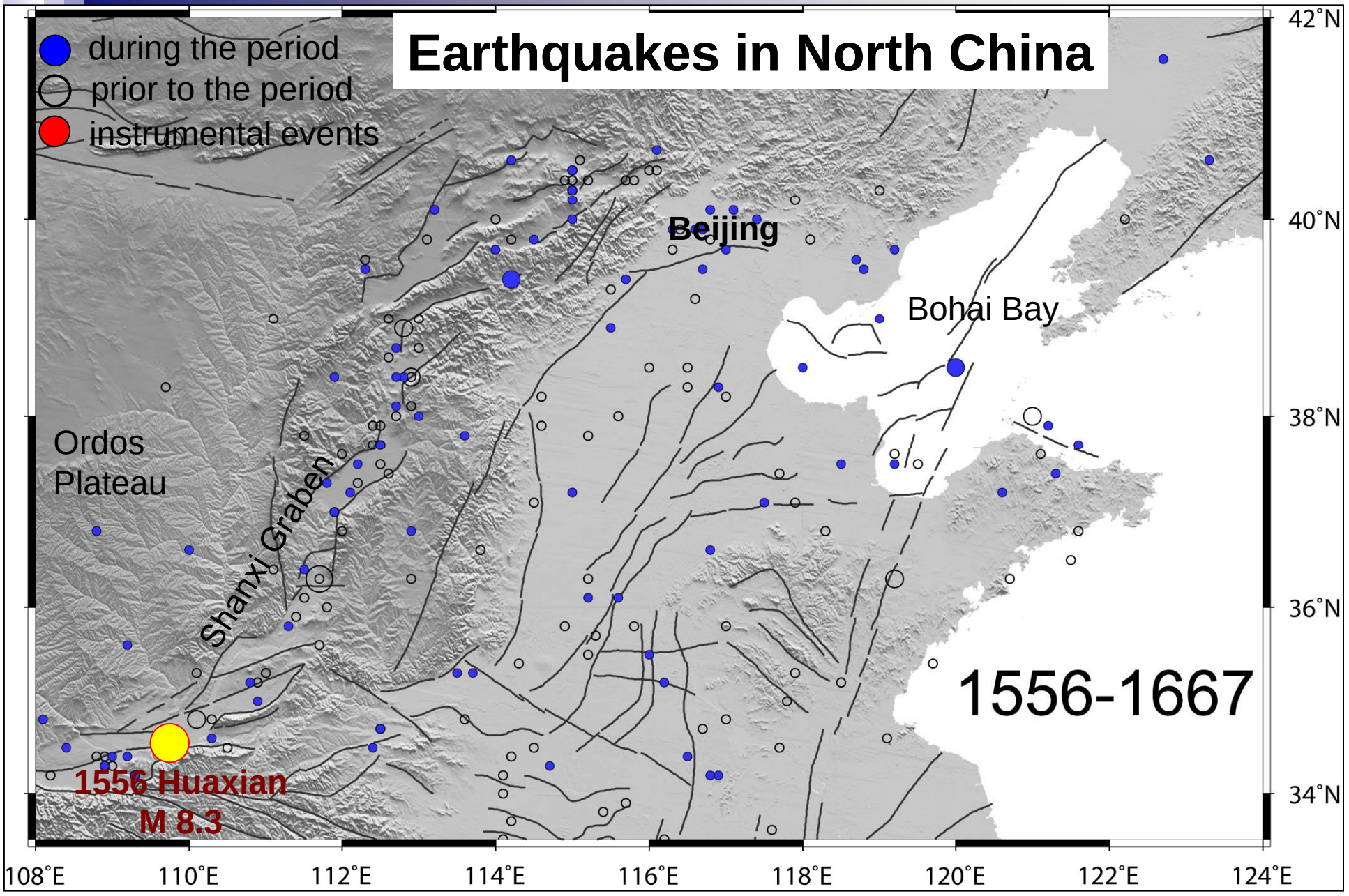
2000 years of migrating earthquakes in North China: How earthquakes in midcontinents differ from those at plate boundaries

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





Large events often pop up where there was little seismicity!



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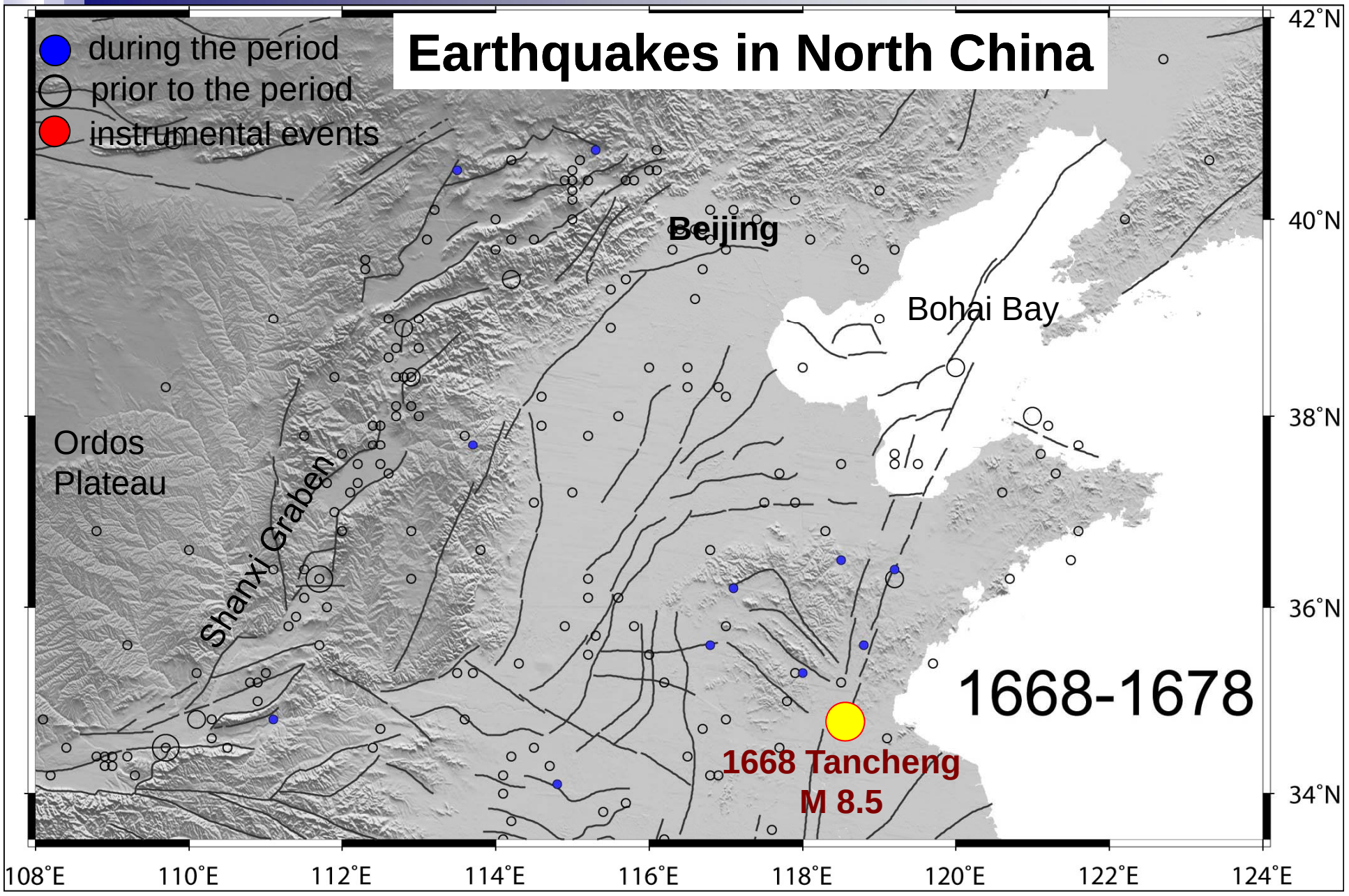

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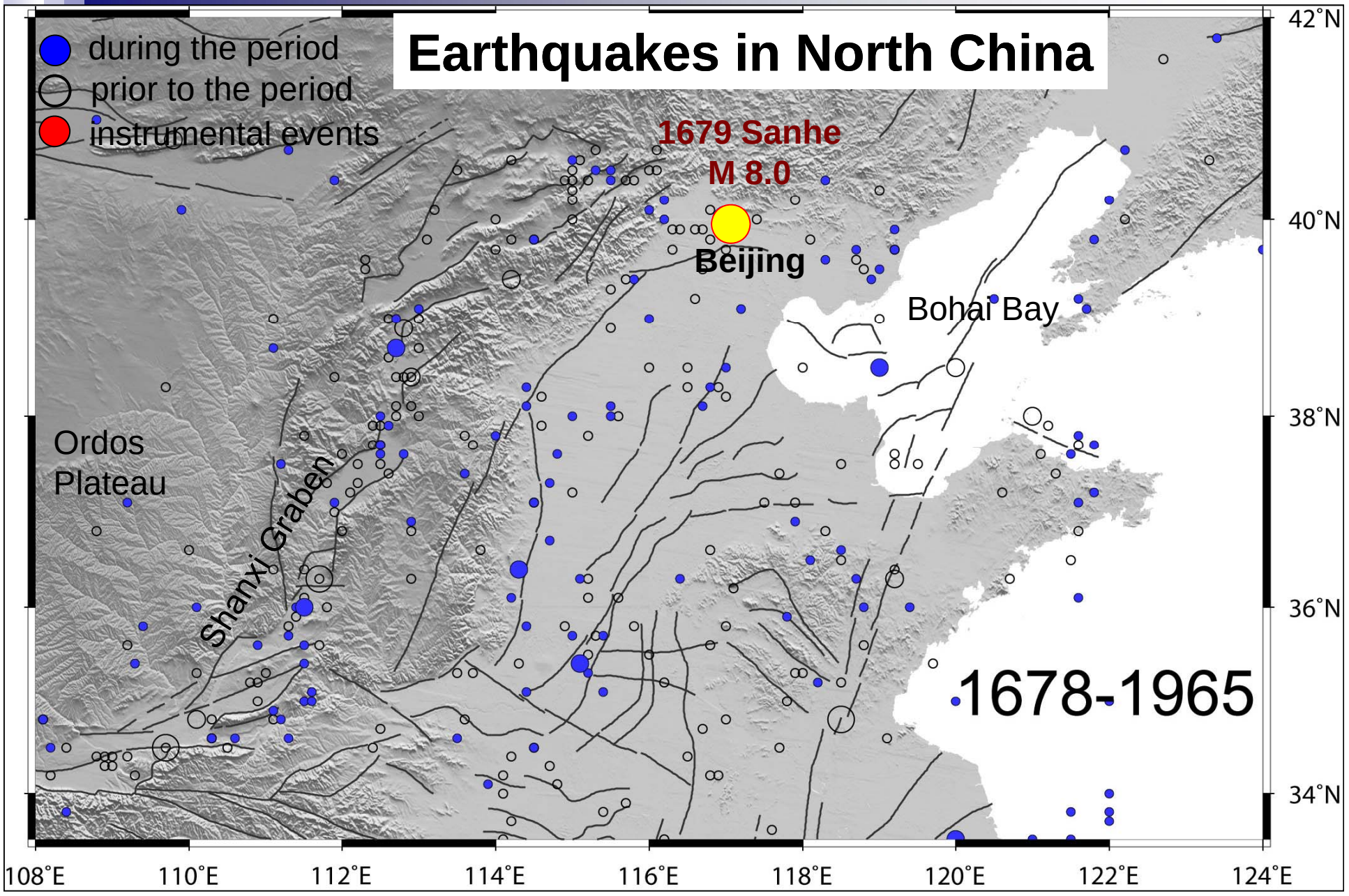

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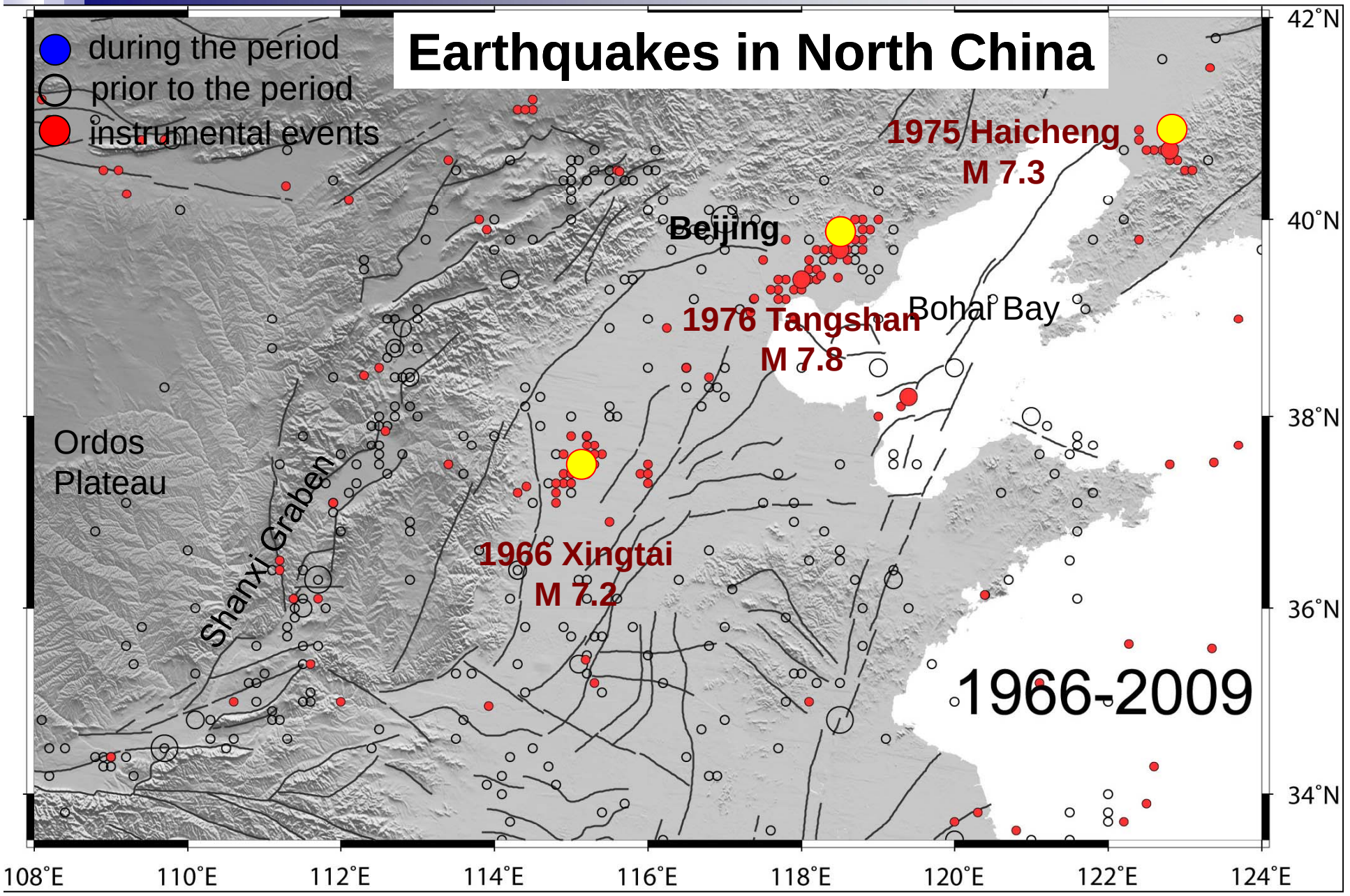
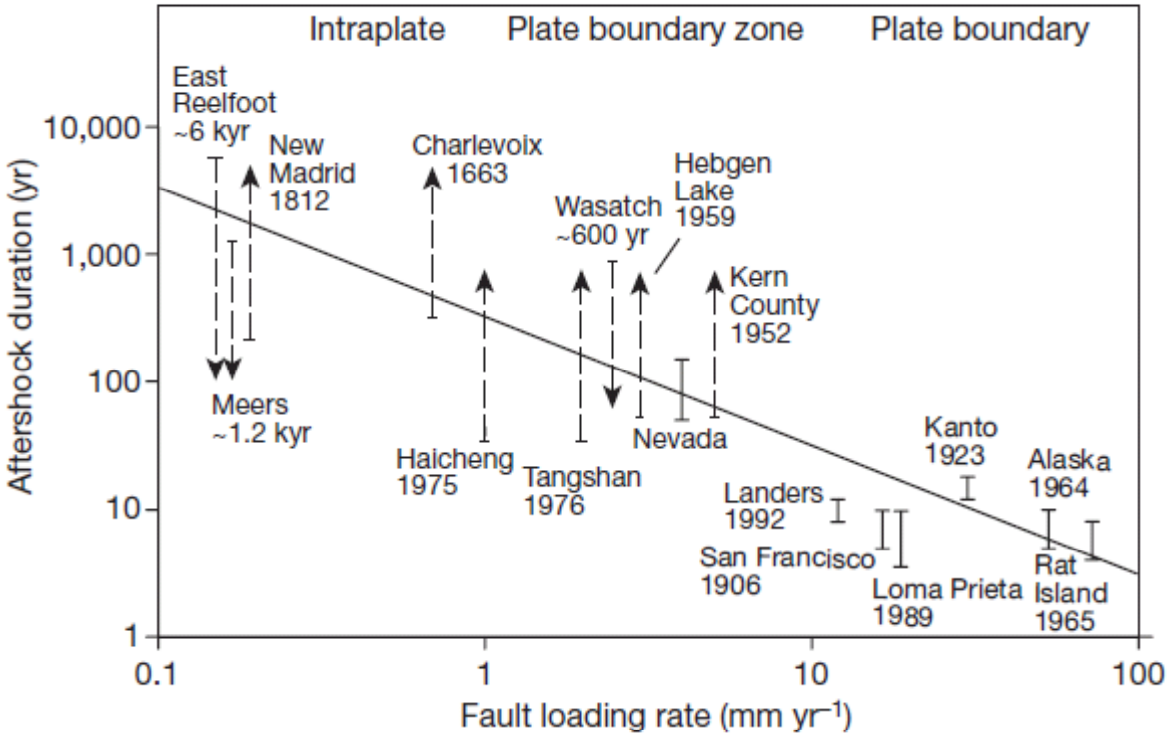


Large events often pop up where there was little seismicity!

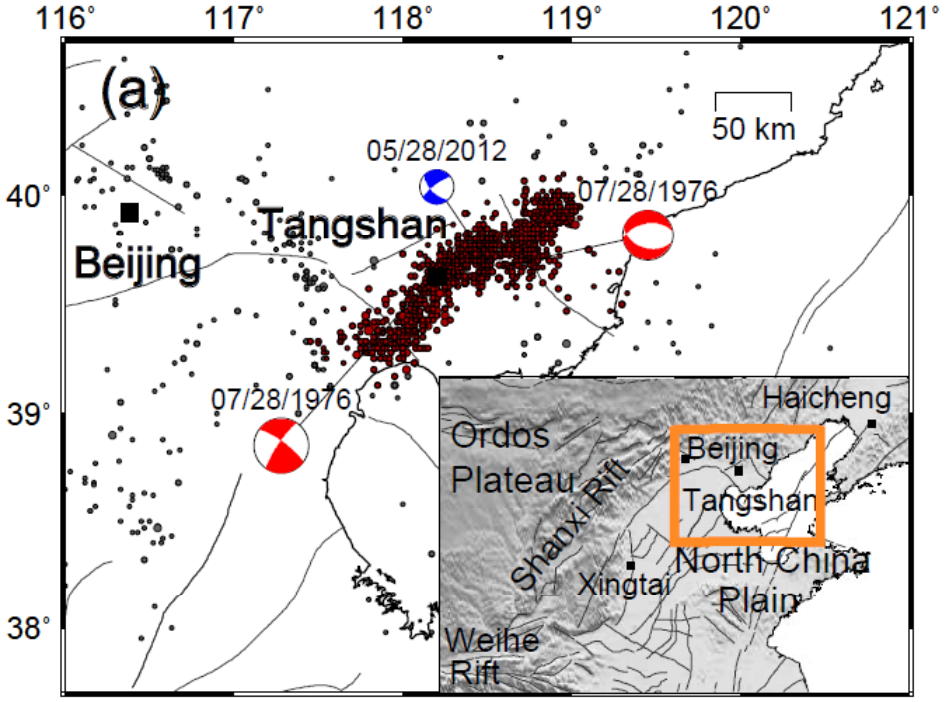
Long aftershock sequences in mid-continent

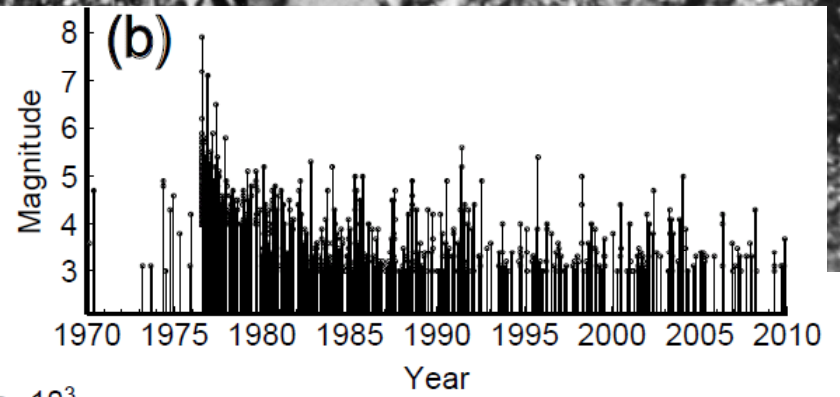


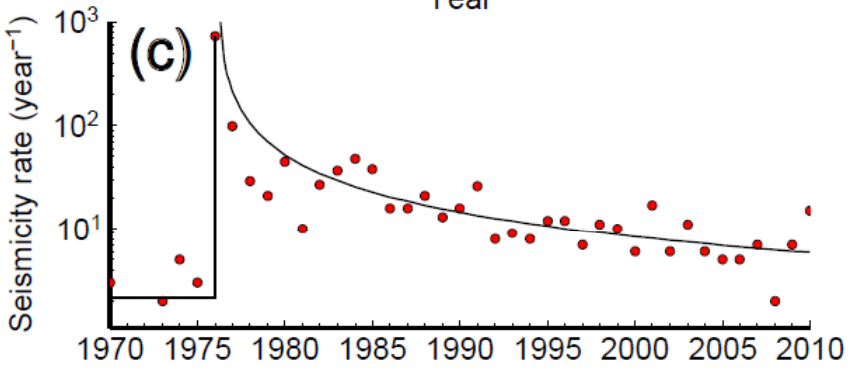
Stein & Liu, 2009 Nature

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.

Aftershock sequence of the 1976 Tangshan earthquake continues today







Implications of long-distance roaming of large mid-continent earthquakes and their long aftershock sequences:

- **Past large earthquakes indicate where large earthquakes will occur;**
  - **=> overestimate hazard in places of previous large earthquakes; underestimate hazard elsewhere;**
- **Present small earthquakes indicate stressing.**
  - **=> mistake aftershocks for precursors of large earthquakes**

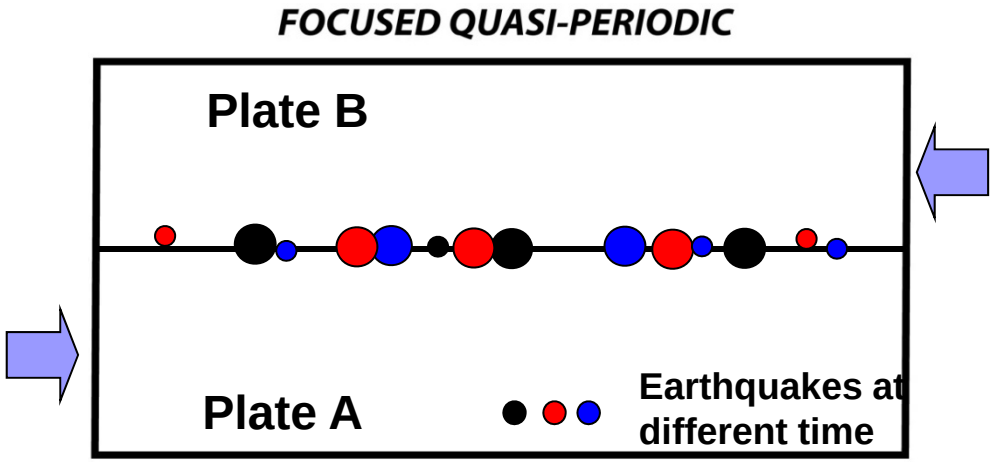
Why are mid-continent earthquakes different?

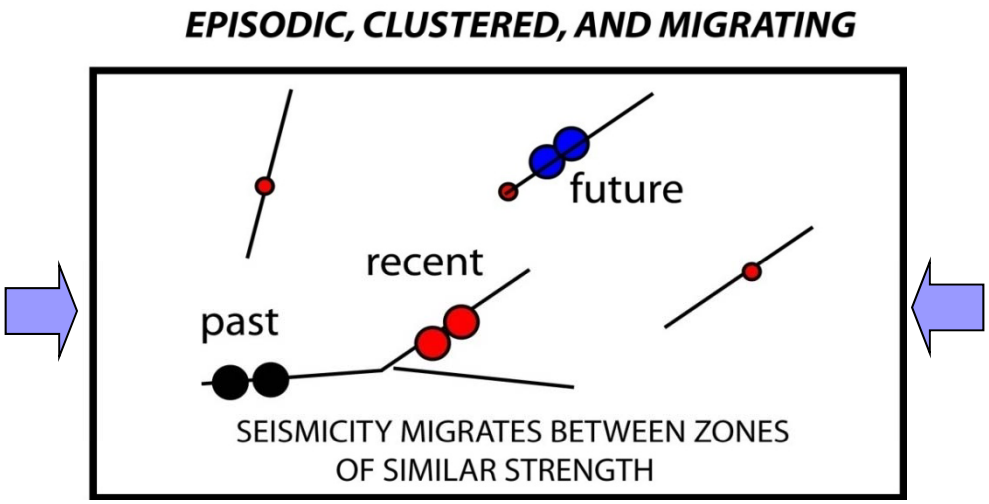
At plate boundary:

- **Plate boundary fault is loaded rapidly by steady plate motion**
- **Earthquakes focused along plate boundary faults & repeat on same fault segments**

In Mid-Continent:

- **Tectonic loading is 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**

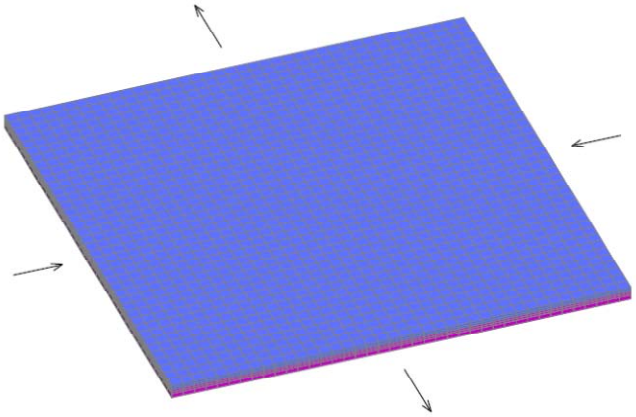




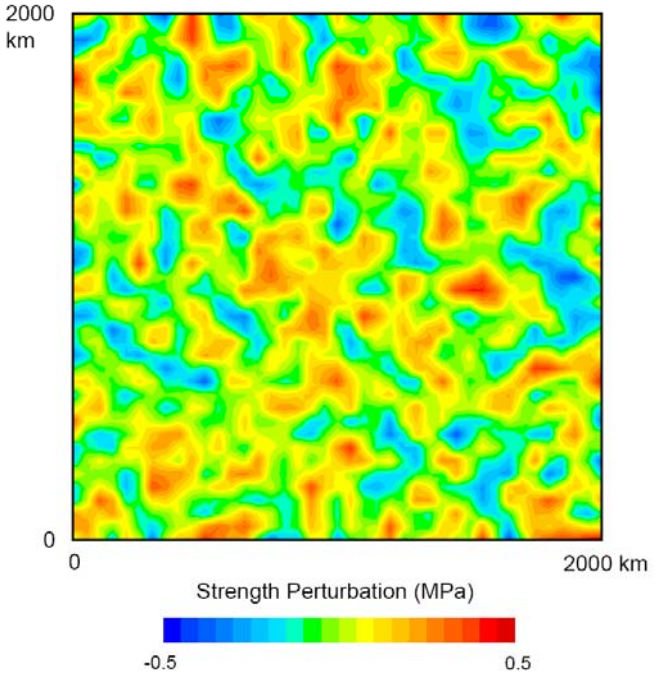
Bulletin of the Seismological Society of America, Vol. 99, No. 1, pp. 52–60, February 2009, doi: 10.1785/0120080005

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

by Qingsong Li, Mian Liu, and Seth Stein

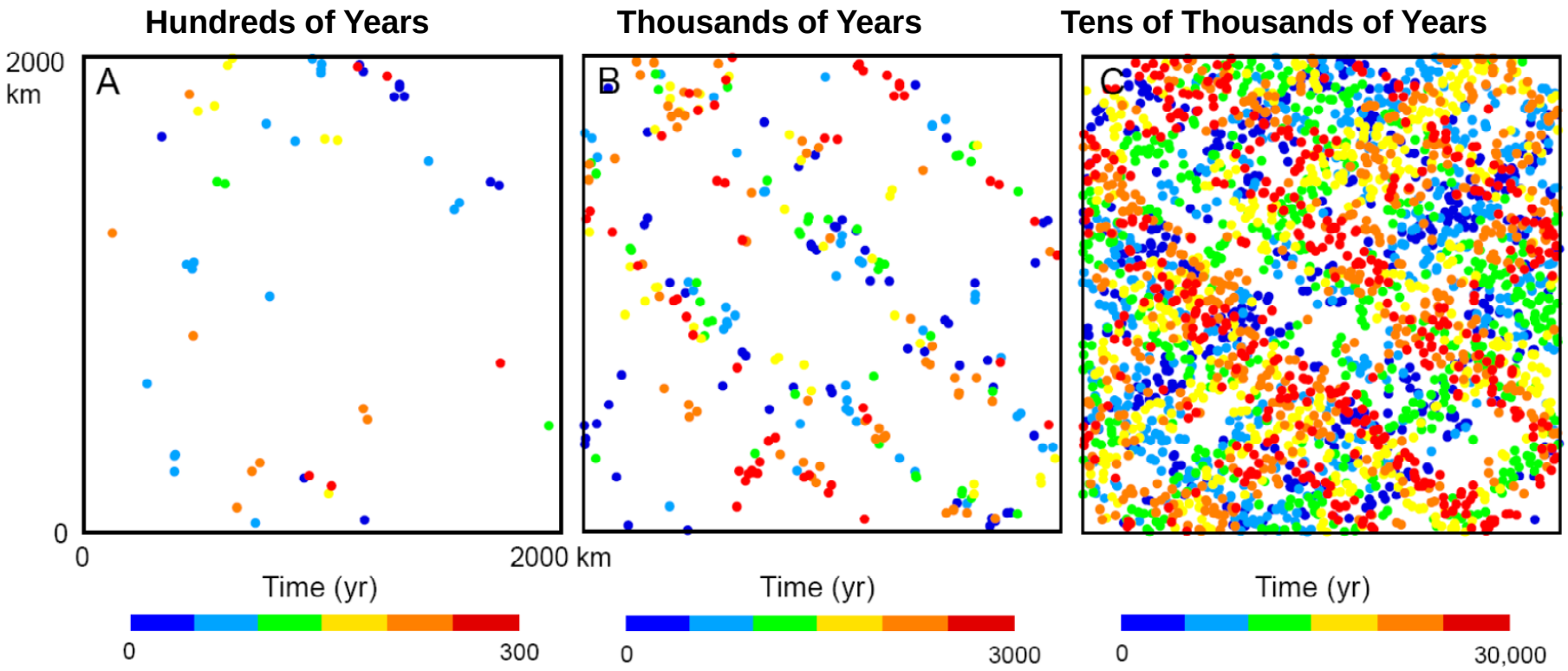


A simple viscoelastic FE model



Initial random stress perturbation

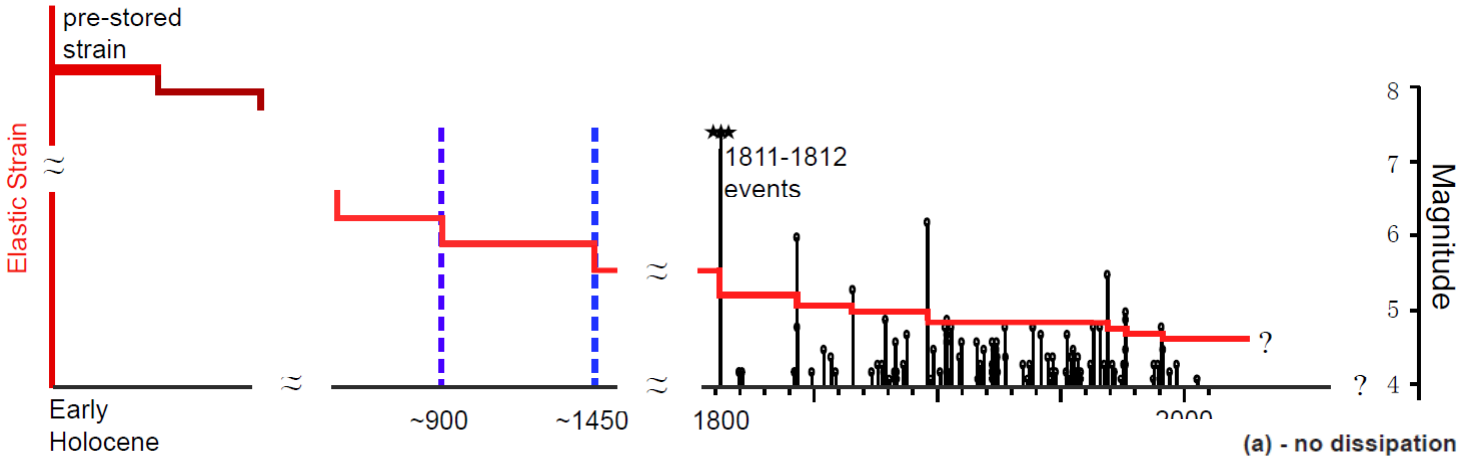
Predicted seismicity on different time scales

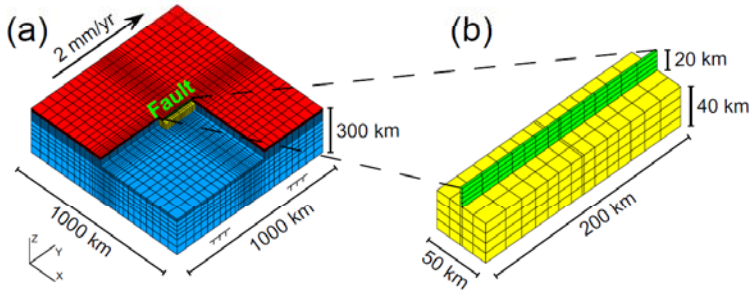


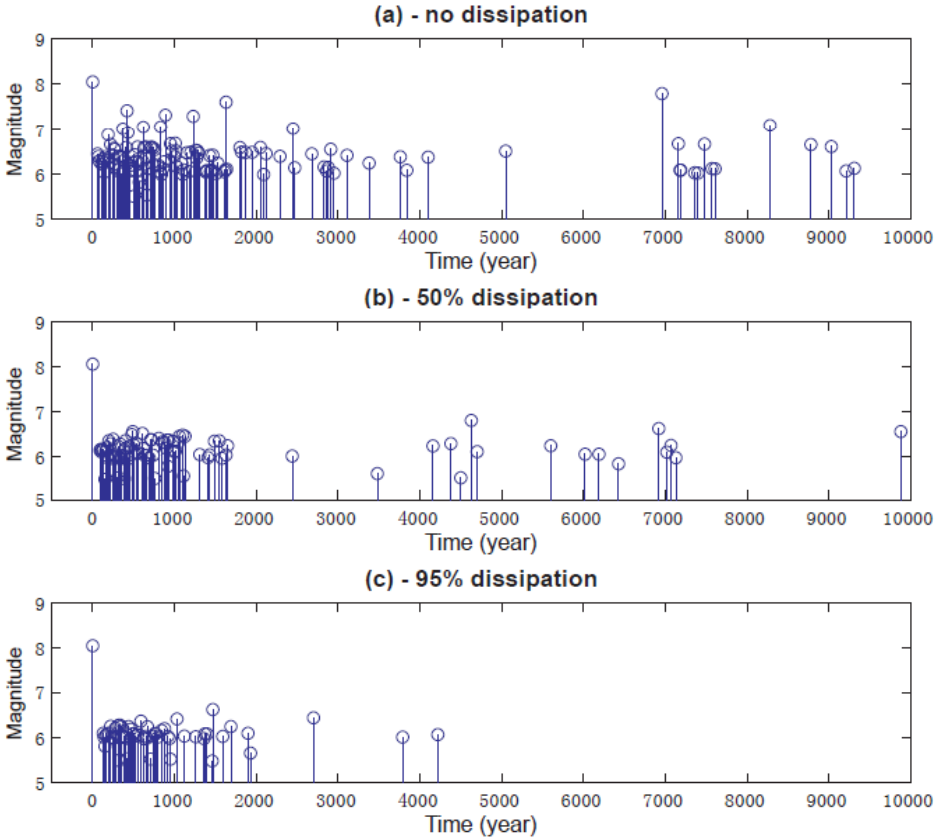
Over 100s of years, predicted seismicity shows both spatial clustering (in narrow belts) and scattering (across large regions).

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.

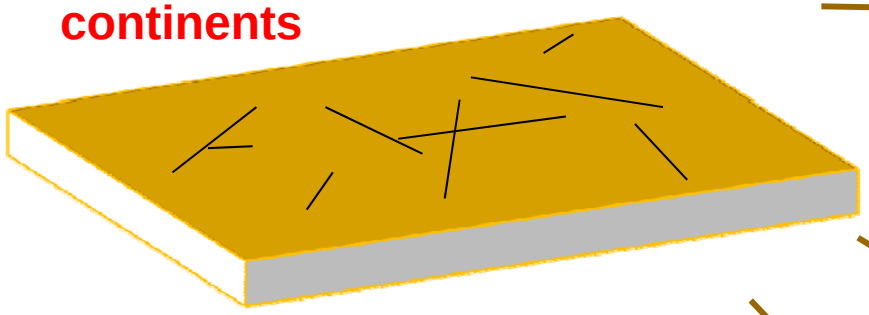

pre-stored
strain
Elastic Strain
Early
Holocene
~900
~1450
1800
1811-1812
events
?
?
Magnitude
8
7
6
5
4


(a)
2 mm/yr
Fault
300 km
1000 km
1000 km
(b)
20 km
40 km
200 km
50 km


(a) - no dissipation
(b) - 50% dissipation
(c) - 95% dissipation
Magnitude
Time (year)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
5
6
7
8
9

Mid-continent earthquakes result from fault interactions in a complex system, hence require a system approach. We need your help for:

Modeling fault interaction and earthquakes in mid-continents



Computation

Algorithms
I/O & storage
visualization

Data Integration

Heterogeneous data (syntactic wrapping)

Hazard Assessment

Multivariate analysis
Error and uncertainty

Different approaches

Deterministic vs. Stochastic models
Neural network models?

Thank you