RIFTS AND SWELLS: GEOPHYSICAL CONSTRAINTS ON CAUSALITY

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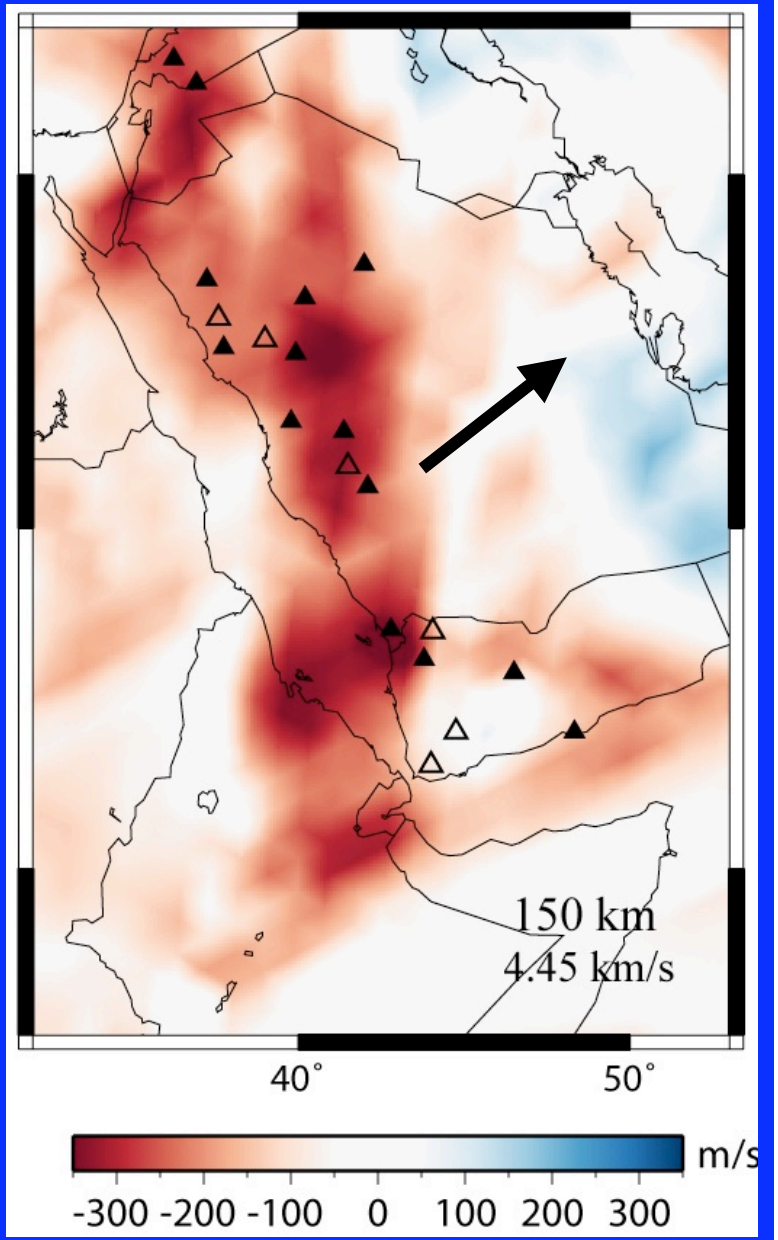
(Revised version received June 11, 1982)

"Forming the great linear rift systems needed to rend apart a continent may require an alignment of neighboring hotspot swells, such as the present-day juxtaposition of the Ethiopian and East African plateaus, or rapid plate motion causing an elongation of the thermal swells."

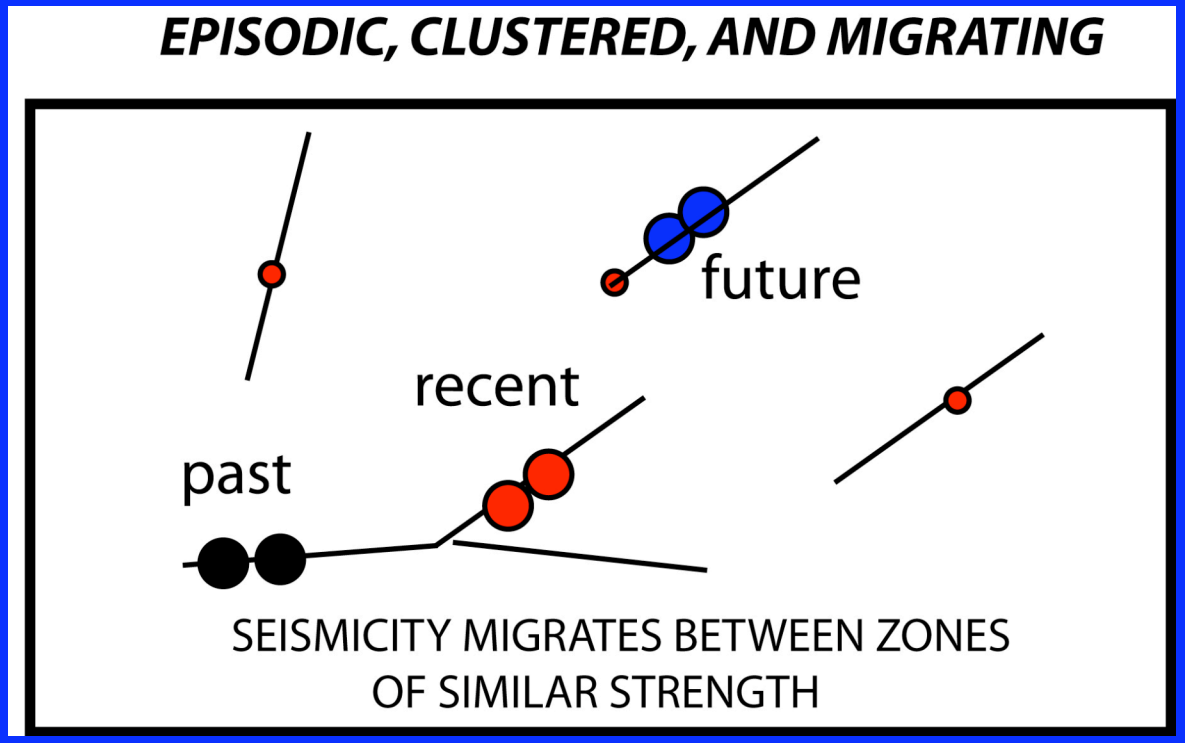


Chang, Merino, Van der Lee, Stein & Stein, 2010

Disaster Deferred: How new science is changing views of earthquake hazards in the Midwest

Seth Stein

Northwestern University



"How wonderful that we have met with a paradox. Now we have some hope of making progress." Niels Bohr

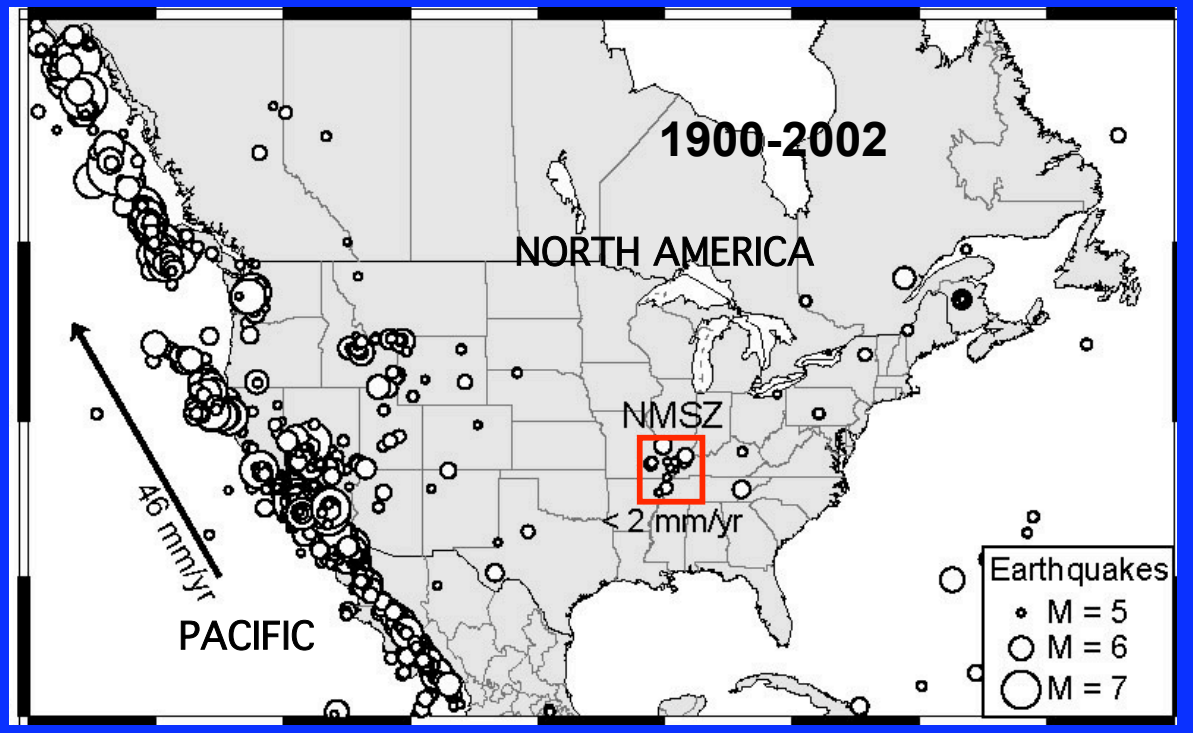
New Madrid seismic zone

M 7 earthquakes in 1811-12

Small quakes continue (M>6 about every 175 years)

Big ones might happen again

Don't know why, when, how dangerous



Somehow

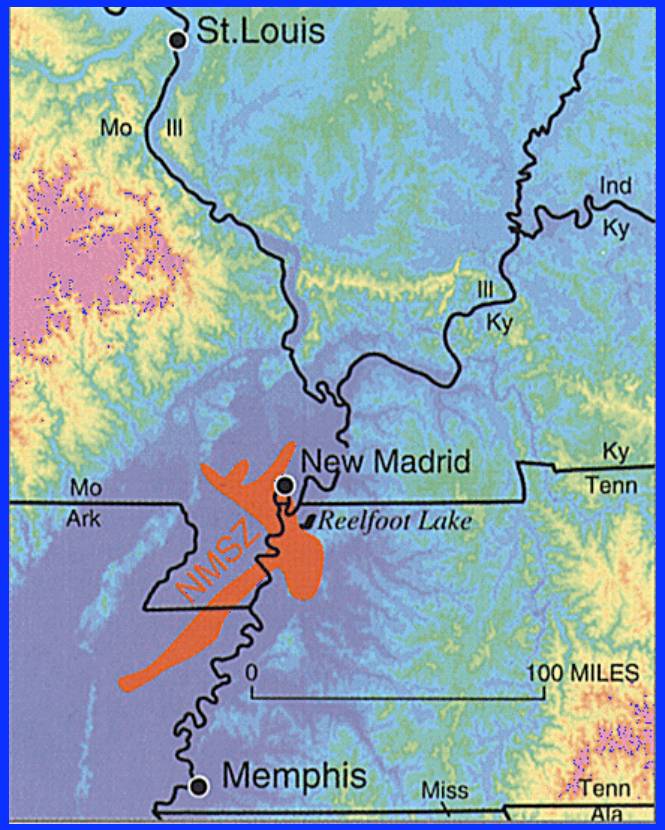
1811-12 events acquired image as almost mythical cataclysms

Hazard said comparable to or greater than California

New Madrid earthquakes can be considered

- Minor curiosity showing that plates differ slightly from ideal model of no internal deformation

- Opportunity to explore how continental interiors deform, since little's known



What happened in 1811-12

What GPS data show about ongoing deformation

Model for intracontinental earthquakes

Implications for seismic hazards & policy

Collaborators 1990-present

Northwestern

PhD students

Andrew Newman (now Georgia Tech)
John Weber (now Grand Valley State)
Joe Engeln (now Missouri DNR)

Postdocs

Giovanni Sella (now National Geodetic Survey)
Resty Pelayo

Undergrad/Ms

James Hebden

Grad student field assistants

Gary Acton, Lisa Leffler, Lynn Marquez, Richard Sedlock, Mark Woods

Others

Eric Calais & Andy Freed (Purdue)
Mian Liu (Missouri)
Tim Dixon & Ailin Mao (Miami)
John Schneider (Geosci. Australia)
Joseph Tomasello (Reeves Firm)
Qingsong Li (LPI)
Andres Mendes (AON)
Mike Bevis (Ohio State)
Ken Hudnut (USGS)
Glen Mattioli (Arkansas)
Roy van Arsdale (Memphis)

Undergrad field Assistants

Grand Valley State

Field engineers

UNAVCO, JPL

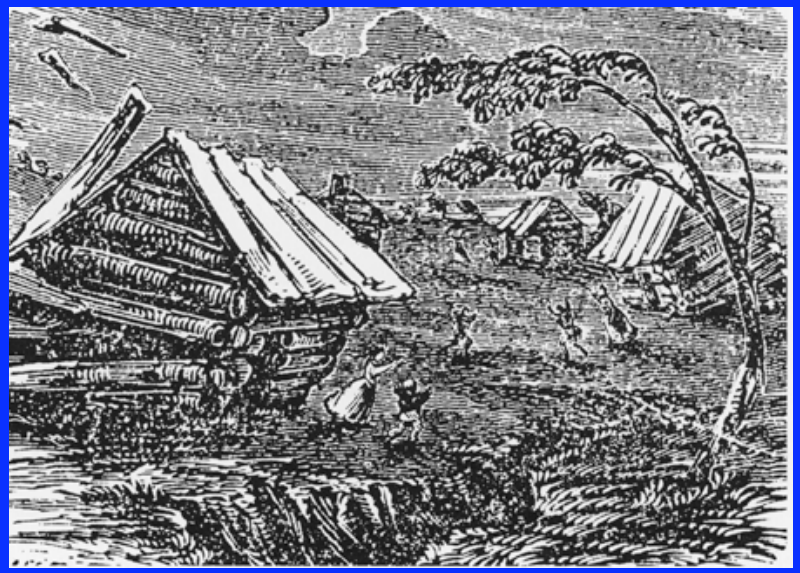
New Madrid:

December 16, 1811: "The house danced about, and seemed as if it would fall on our heads. I soon conjectured the cause of our trouble, and cried out that it was an Earthquake, and for the family to leave the house, which we found very difficult to do, owing to its rolling and jostling about. The shock was soon over, and *no injury was sustained, except the loss of the chimney*."

The earthquakes went on and on. Most were small, but one on January 23, 1812 was large enough to disrupt riverbanks and create more sand blows.

February 7, 1812 : " A concussion took place much more violent than those preceding." The town's houses, which sustained some damage like broken chimneys in the previous earthquakes but had not collapsed, *were "all thrown down*."

Sequence of earthquakes over months, with three major shocks

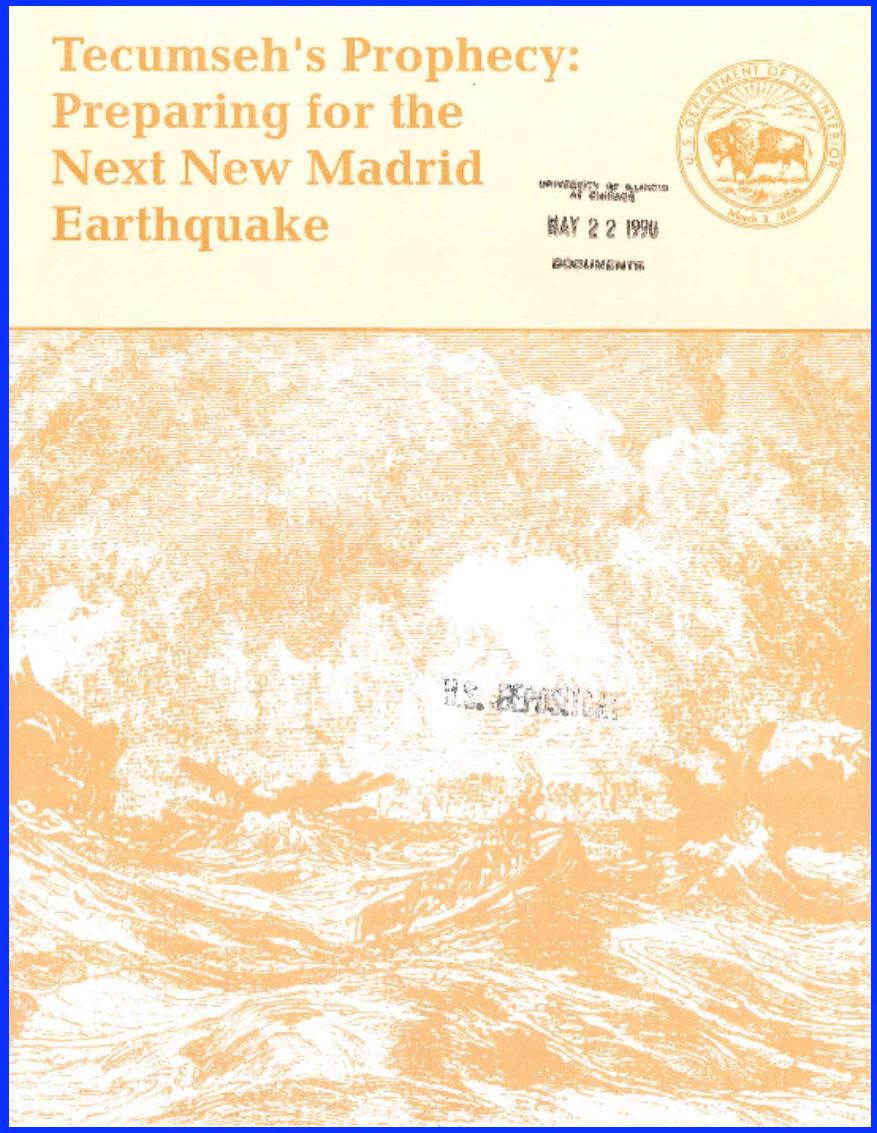


Historical Society of Missouri

Postdiction, not prediction

Shawnee chief Tecumseh didn't prophecy the earthquakes

Addressing tribes *after the earthquakes, he pointed to what had happened* as divine support for his cause: "The Great Spirit is angry with our enemies. He speaks in thunder, and the earth swallows up villages."

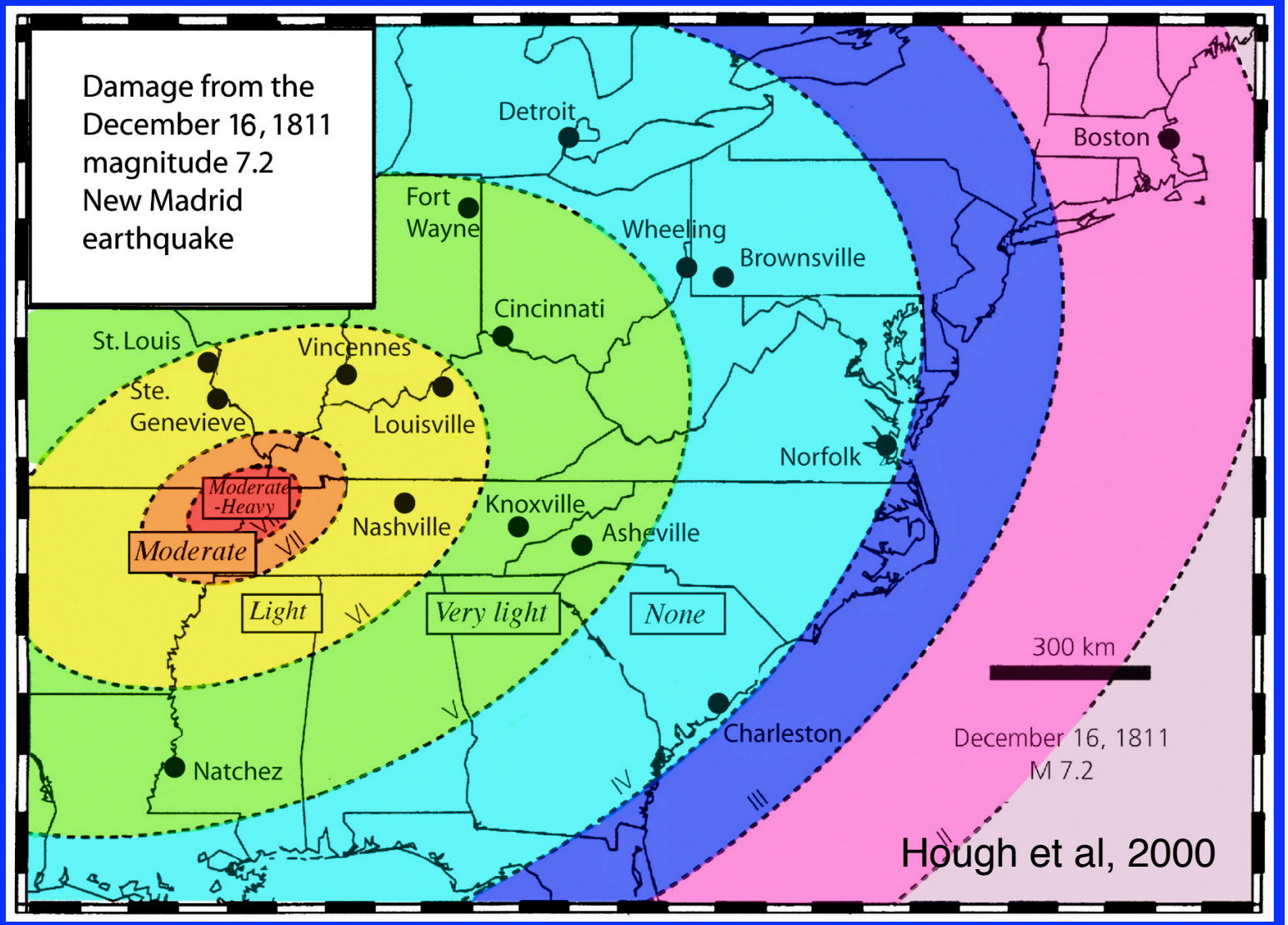


Shaking intensity (Hough et al., 2000) yields low/mid-magnitude 7 first inferred (Nuttli, 1973), not subsequently quoted 8 (Johnston, 1996)

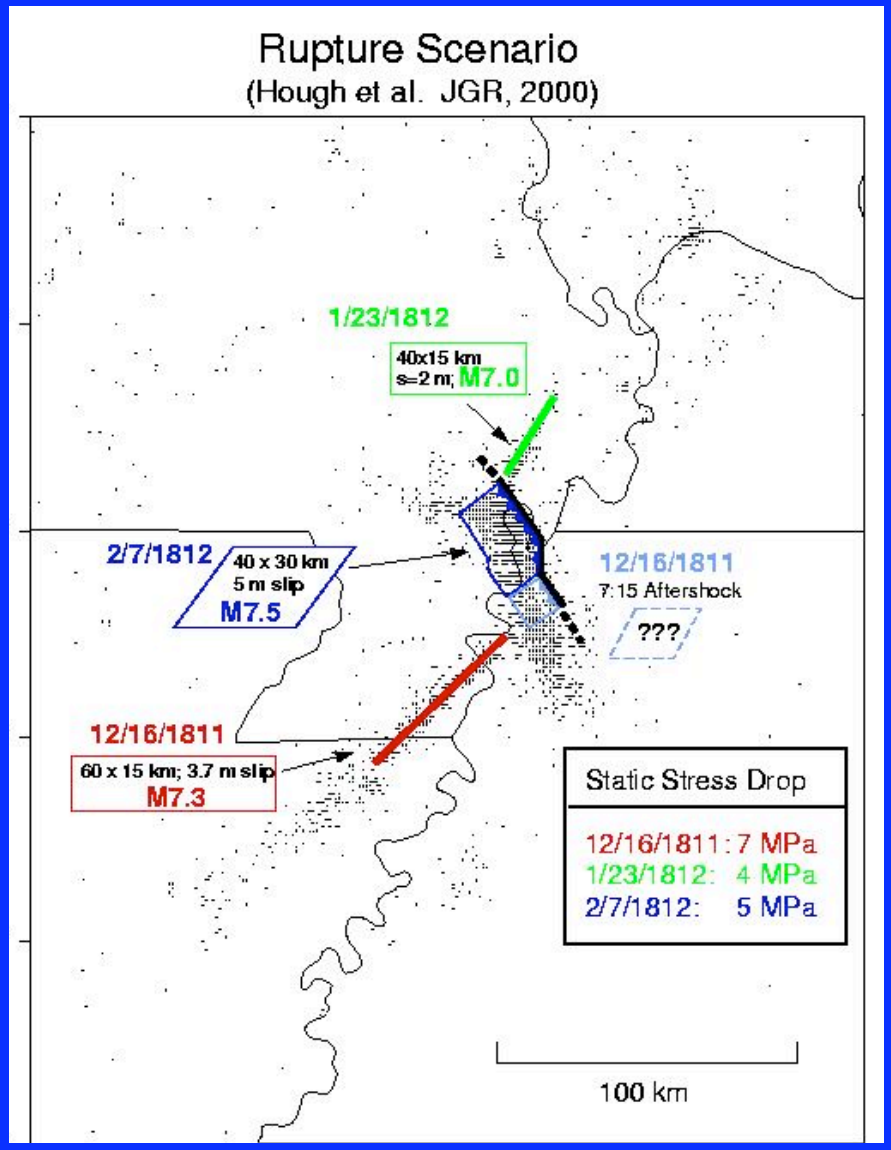
Log cabin damage at New Madrid

Minor damage in St Louis, Nashville, Louisville, etc.

Not felt in Boston, no church bells ring



These were big earthquakes



Hidden Fury

The New Madrid Earthquake Zone

The danger posed by the New Madrid earthquake zone along the Mississippi River.

27 minutes
DVD-R version available
Color
Closed Captioned
Grade Level: 7-12, College, Adult
US Release Date: 1993
Copyright Date: 1993
ISBN (VHS): 1-56029-468-X
ISBN (DVD): 1-59458-441-9

Produced by Doug Prose/Earth Images Foundation

"Interesting, easy to follow, full of good information."
***** *Journal of Geological Education*

The New Madrid earthquake zone, located along the Mississippi River near Memphis, Tennessee, has received little attention in recent years. But in 1811 it was the site of the most powerful series of earthquakes ever known on earth. Some two million square miles were affected, and shocks were felt as far away as Montreal, Canada - 1,200 miles from the epicenter.

But a lot smaller & more common than often stated

SEISMIC MOMENT Mo =
fault area * slip * rigidity
(dyn-cm)

MOMENT MAGNITUDE Mw =
log Mo /1.5 - 10.73

NORTHRIDGE 1994
Mo 1 x10 ^{26}
Mw 6.7
slip 1 m

LOMA PRIETA 1989
Mo 5.4 x10 ^{26}
Mw 6.9
slip 2 m

NEW MADRID 1811-12
Mo 1.1 x10^{27}
Mw 7.3
slip 4 m

Mo 3.9 x10^{26}
Mw 7.0
slip 2 m

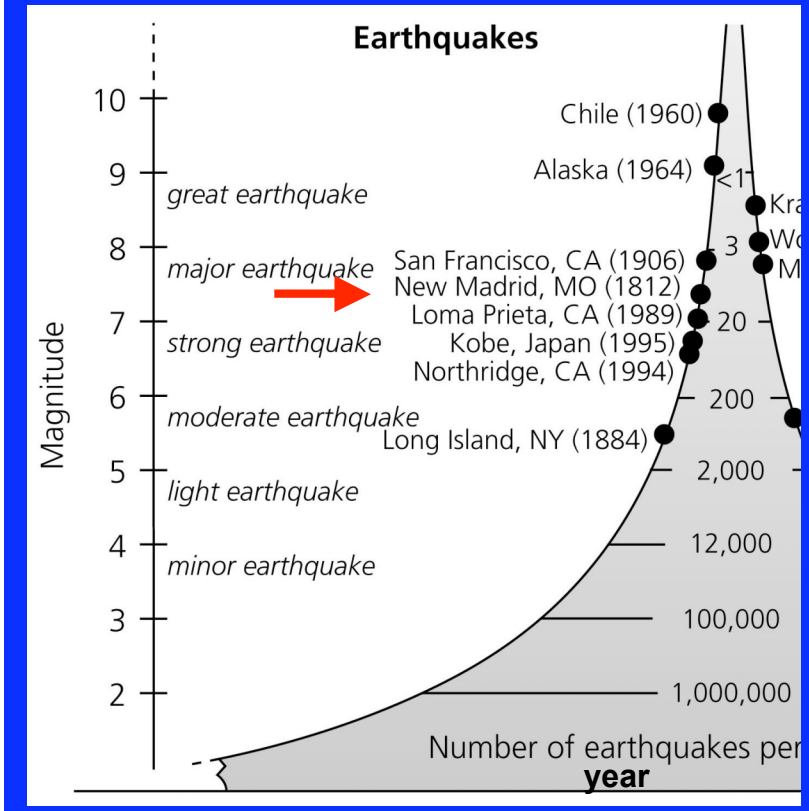
Mo 2.2 x10^{27}
Mw 7.5
slip 5 m

SAN FRANCISCO 1906
Mo 5 x10 ^{27}
Mw 7.8
slip 4 m

SUMATRA 2004
Mo 1 x10 ^{30}
Mw 9.3
slip 11 m

150 km

5-10 earthquakes of this size occur each year



Stein & Wysession (2003)
after IRIS

Did the Mississippi run backwards after February shock?

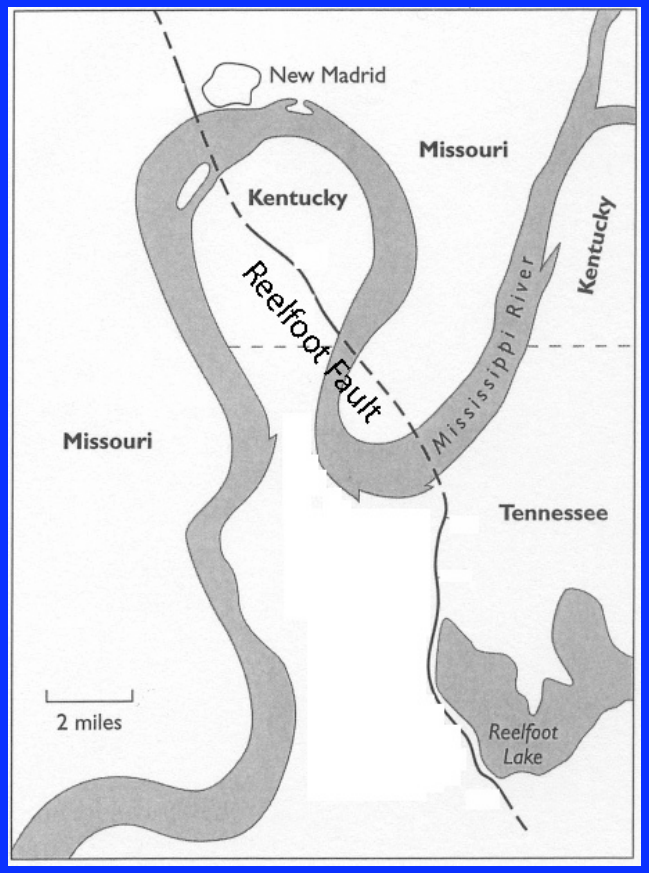
Historical Society of Missouri

"The current of the Mississippi was driven back upon its source with the greatest velocity for several hours in consequence of the elevation of its bed. But this noble river was not to be stayed in its course. Its accumulated waters came booming on, and over topping the barrier thus suddenly raised, carried everything before them with resistless power."

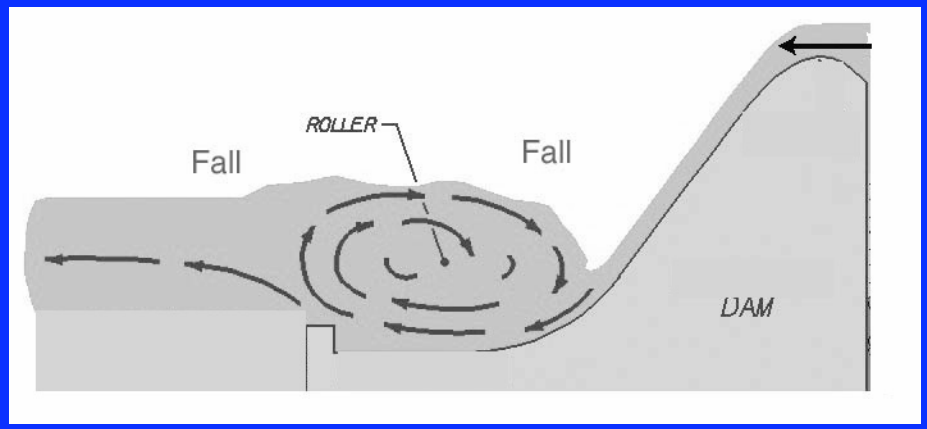
Reverse current lasted a few hours.

Real or legend?

Vertical motion on Reelfoot fault created temporary dams on riverbed that disrupted flow until current cleared them away



Sieh and LeVay, 1998



Flow over low head dam creates zone where surface water flows backwards, with waterfalls on upstream and downstream sides

Boatmen perhaps encountered bigger & more complicated version, with back flow downriver from natural dams and slower current upriver

AFTERMATH

"Loss and suffering were brought to the attention of Congress, but in the light of subsequent events *it is not certain to what extent assistance was the real object of the agitation or to what extent it was a pretext for land grabbing on the part of certain unscrupulous persons*." (M. Fuller)

People whose lands had been destroyed could get certificates to replace them. Most stayed and sold their certificates for a few cents per acre. Of 516 certificates issued, original claimants used only 20. Speculators in St. Louis acquired most of the others, and *"perjury and forgery became so common that for a time a New Madrid claim was regarded as a synonym for fraud."*

The earthquake legend grew…

Public fear 1811-12 recurrence

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

But earthquake fears are continually fed

Central United States Earthquake Consortium

...a partnership to mitigate disasters and save lives

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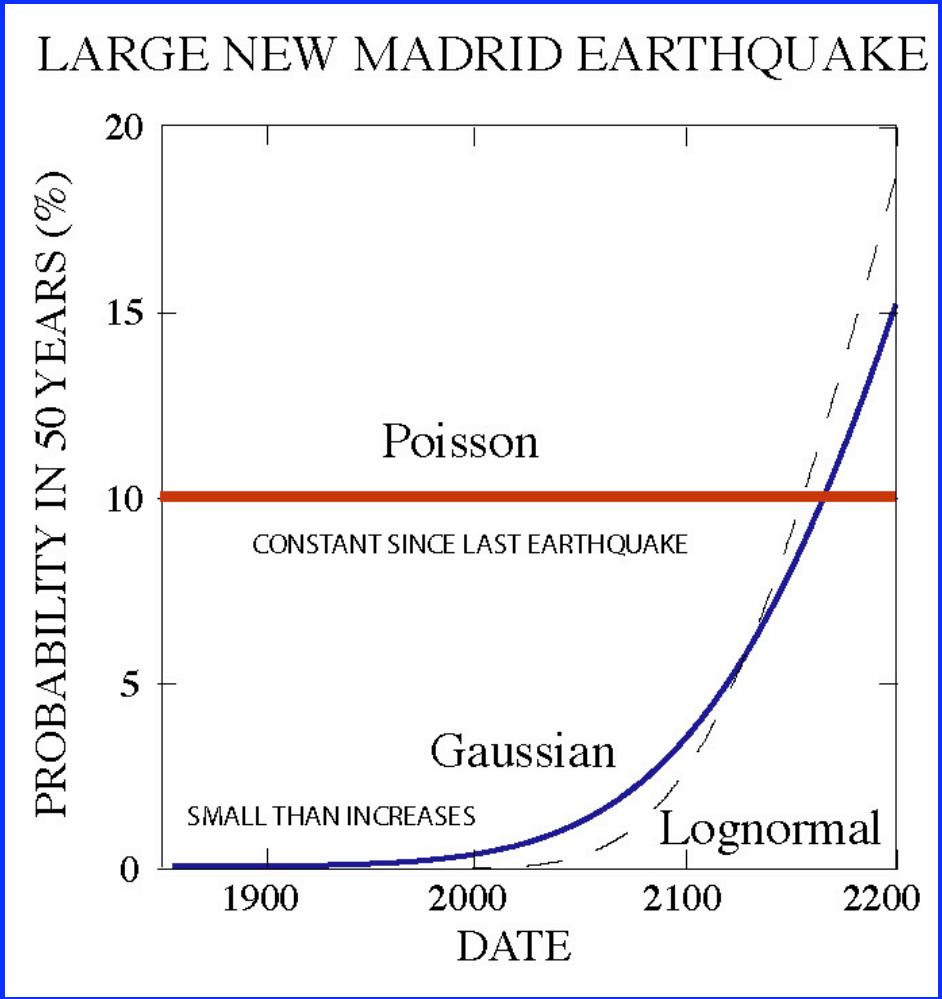
Can get any value, depending on assumptions of magnitude and recurrence

"Seismologists have predicted a 40-60% chance of a *devastating* earthquake in the New Madrid seismic zone in the next ten years. Those odds jump to 90% over the next 50 years. The potential magnitude of a *catastrophic* New Madrid quake dictates that we approach the preparedness on a regional basis"

Press release, 2000



Stein et al., 2003

“Catastrophic” & “devastating” defined as M>6 which occurs ~ once in 175 years somewhere in the New Madrid zone - most of which isn’t densely populated

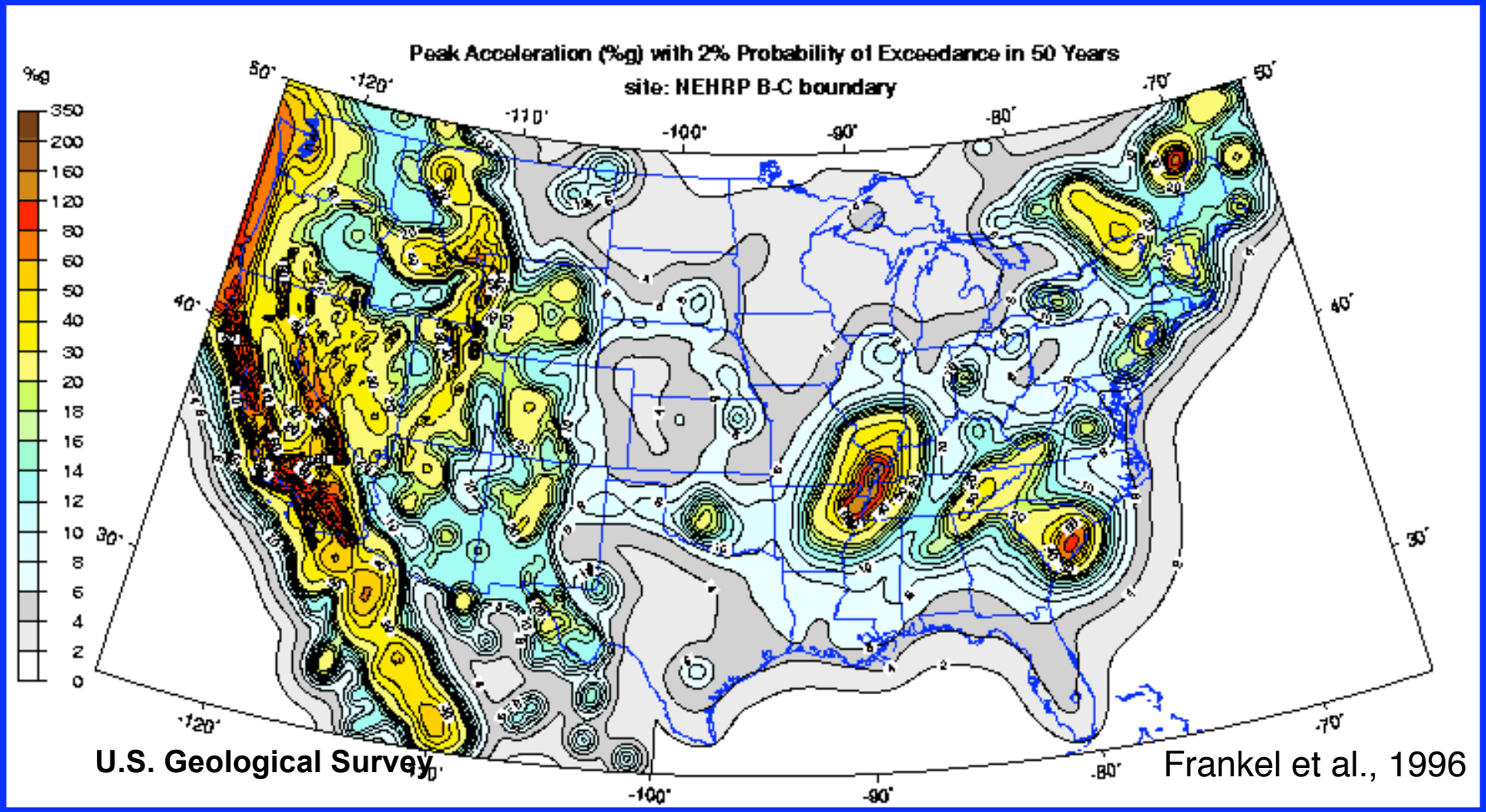
St. Louis University

Largest in the past century, 1968 (M 5.5) Illinois earthquake, caused no fatalities.

Damage consisted of fallen bricks from chimneys, broken windows, toppled television aerials, and cracked or fallen brick & plaster.

NEW MADRID SAID TO BE AS HAZARDOUS AS CALIFORNIA

Buildings should be built to same standards (FEMA)



U.S. Geological Survey

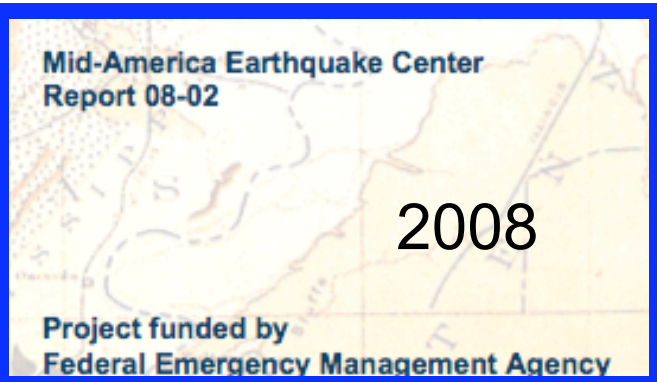
Frankel et al., 1996

$100M retrofit of Memphis VA hospital, removing nine floors, bringing it to California standard

Such measures would cost $billions over 100s of years & likely yield little or no benefit during buildings' life

Is this a wise use of resources compared to alternatives that could do more good?

Impact of Earthquakes on the Central USA



Scenario assumes 1811-12 style events recur

936 pages list types of buildings damaged, injuries, tons of rubble, and deaths.

For example, in Arkansas 37,244 people are predicted to be looking for shelter, 50,159 buildings are predicted to be destroyed, 574 deaths occur, etc…

High *precision* (# of digits)
Need to consider *accuracy* (how real)

1976 SWINE FLU
"APORKALPSE"

CDC reported "strong possibility" of epidemic. HEW thought "chances seem to be 1 in 2" and "virus will kill one million Americans in 1976."

President Ford launched program to vaccinate entire population despite critics' reservations

40 million vaccinated at cost of millions of dollars before program suspended due to reactions to vaccine

About 500 people had serious reactions and 25 died, compared to one person who died from swine flu

Y2K

Much ado made that on January 1, 2000 computer systems would fail, because dates used only two digits

U.S. government established major programs headed by FEMA

Estimated $300 billion spent on preparations

Few major problems occurred, even among businesses and foreign countries who made little or no preparation

"Apocalyptic claims do not have a good track record… arguments that simple, easily understood numbers are proof that the future holds complex, civilization-threatening changes deserve the most careful inspection."

More Damned Lies and Statistics by J. Best

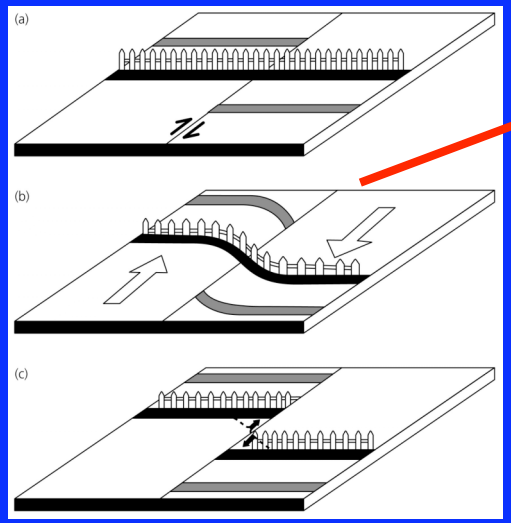
Impending doom scenarios assume 1811-12 size earthquakes will occur soon

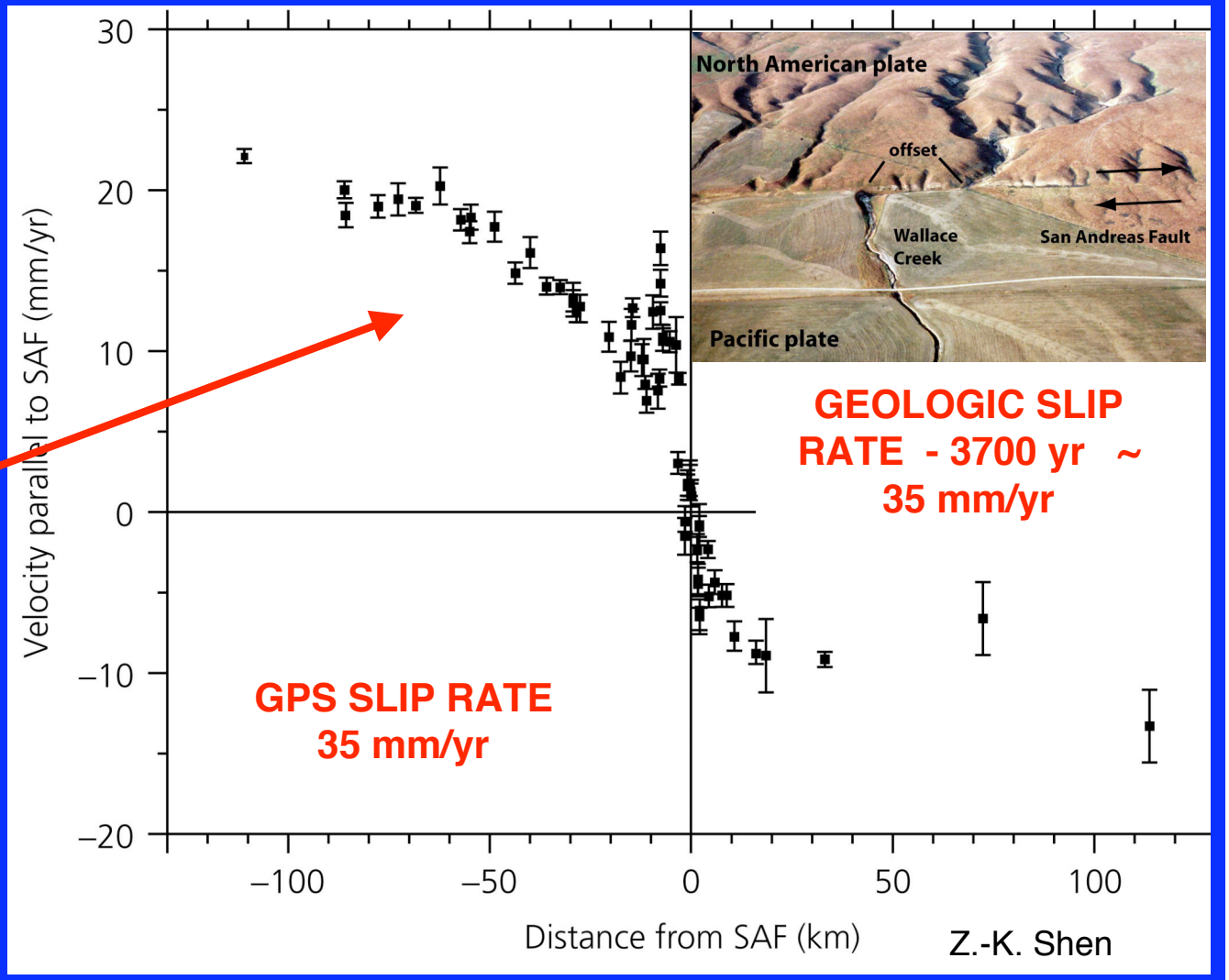
Before GPS, all we could say was that the future might be like the past…

Now we can test this hypothesis

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

Like a deformed fence

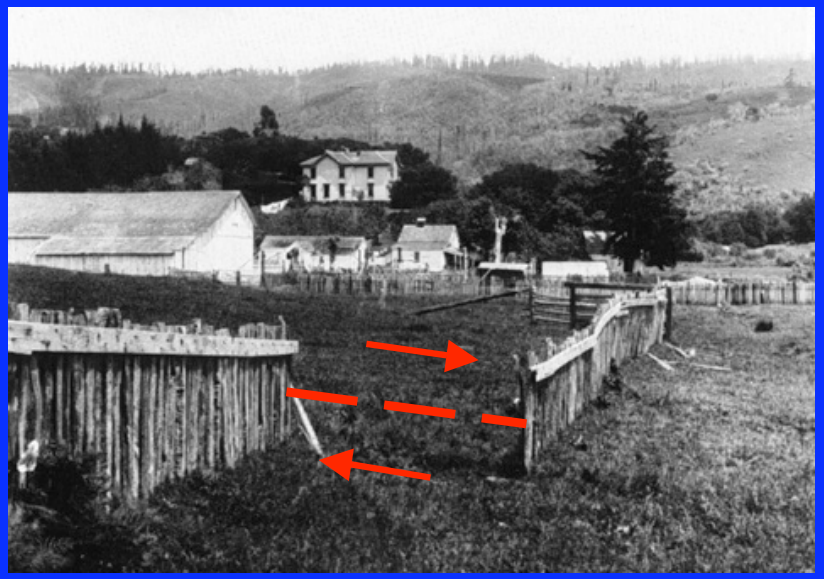




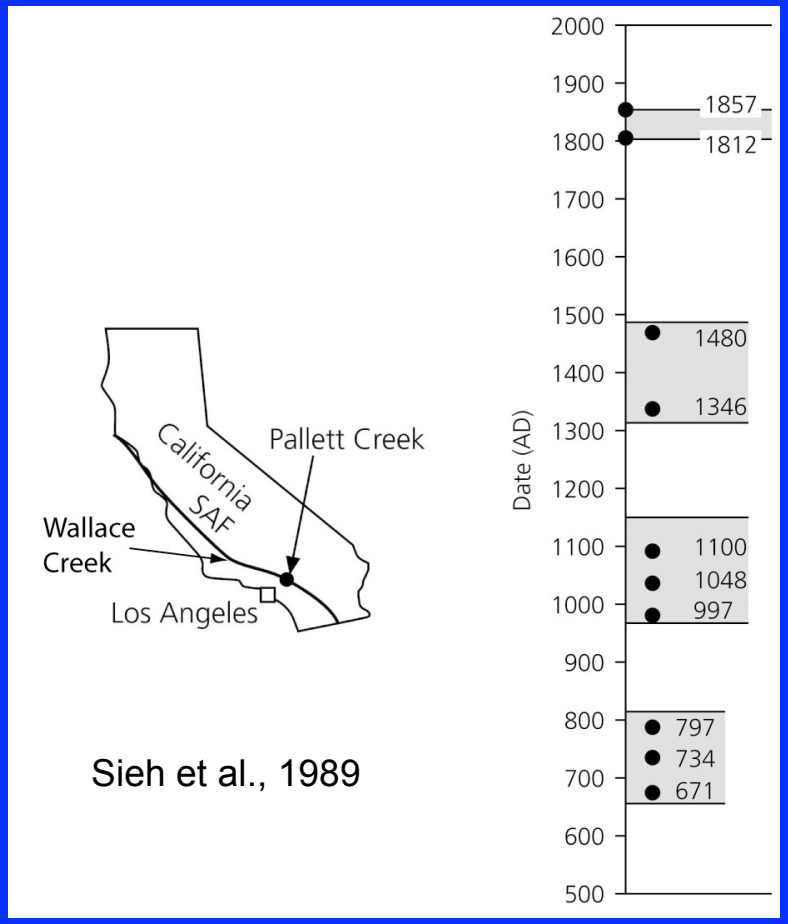
Geodetic, geologic, & plate motion rates agree

GPS site motions consistent with paleoseismic earthquake recurrence, showing steady motion

1906 San Francisco
M 7.7 Slip 4 m



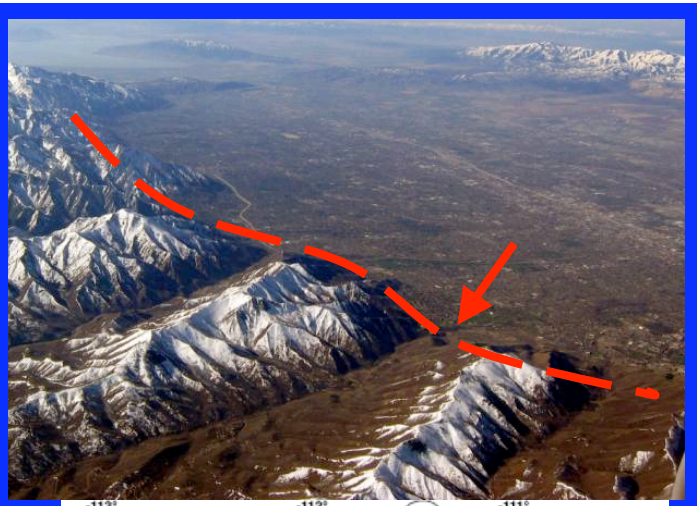
Expect earthquakes about
every 4 m / 35 mm/yr
or ~ 144 years



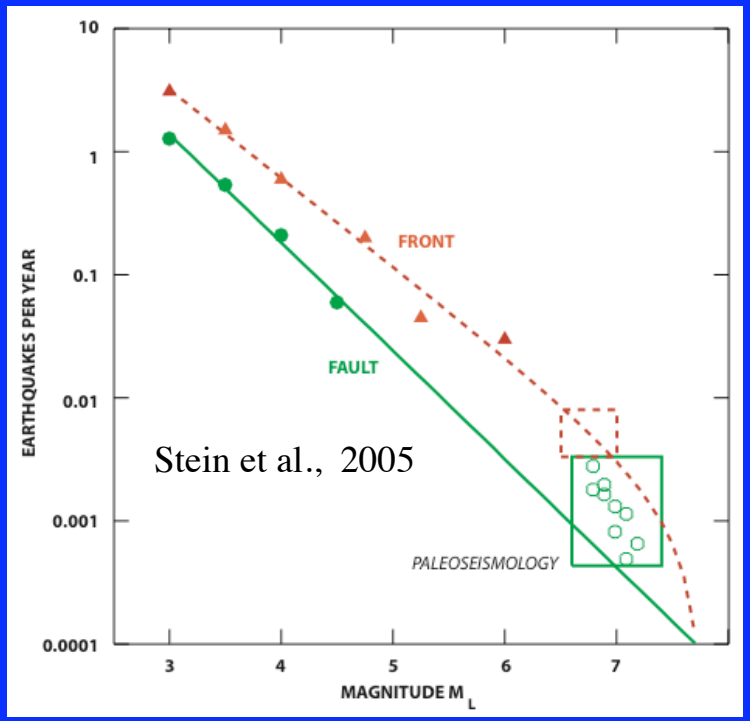
Sieh et al., 1989

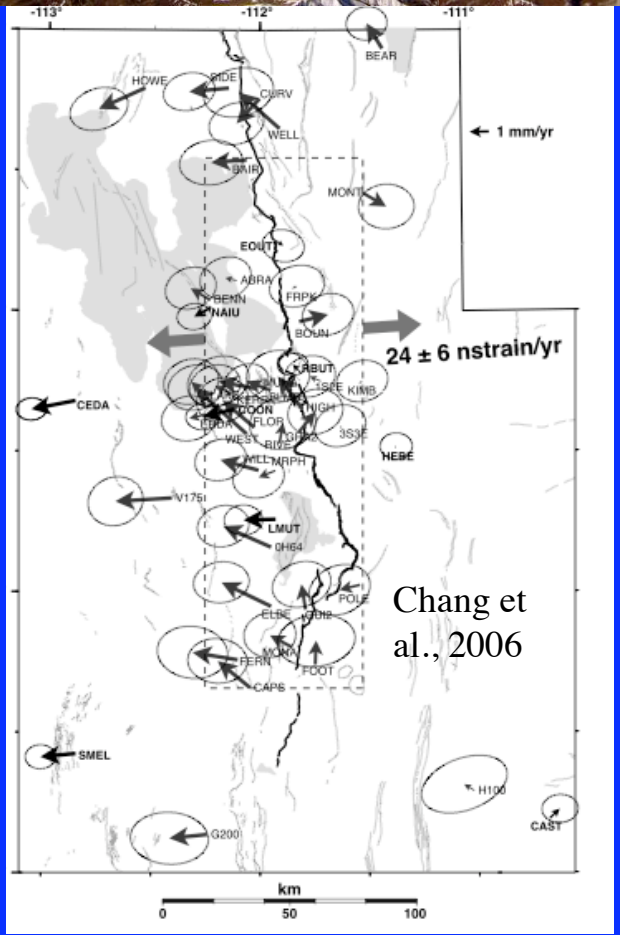
M >7 mean 132 yr

Wasatch: GPS site motions show 1-2 mm/yr deformation accumulating that will be released in future large earthquakes



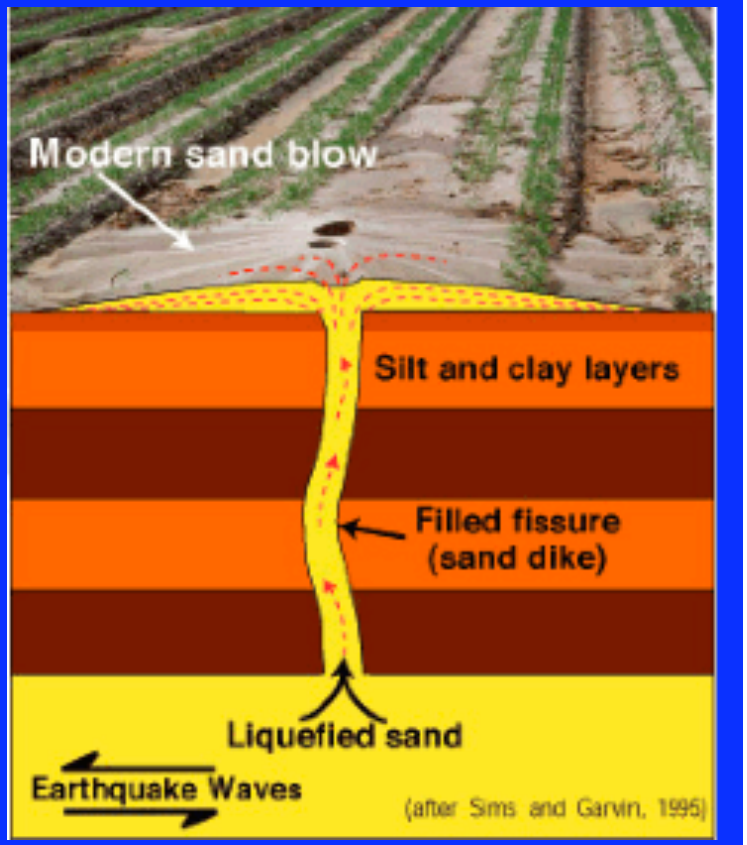
Consistent with M 7 expected ~ 1000 yr from seismicity & paleoseismology





NEW MADRID EARTHQUAKE HISTORY

Paleoseismology - primarily paleoliquefaction - shows events ~ 1450 and 900 AD



Sand blows in New Madrid area (USGS)

We started GPS at New Madrid expecting to find deformation accumulating, consistent with M7 events ~500 years apart

November 1991

After 8 years, 3 campaigns, 70 people from 9 institutions …

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

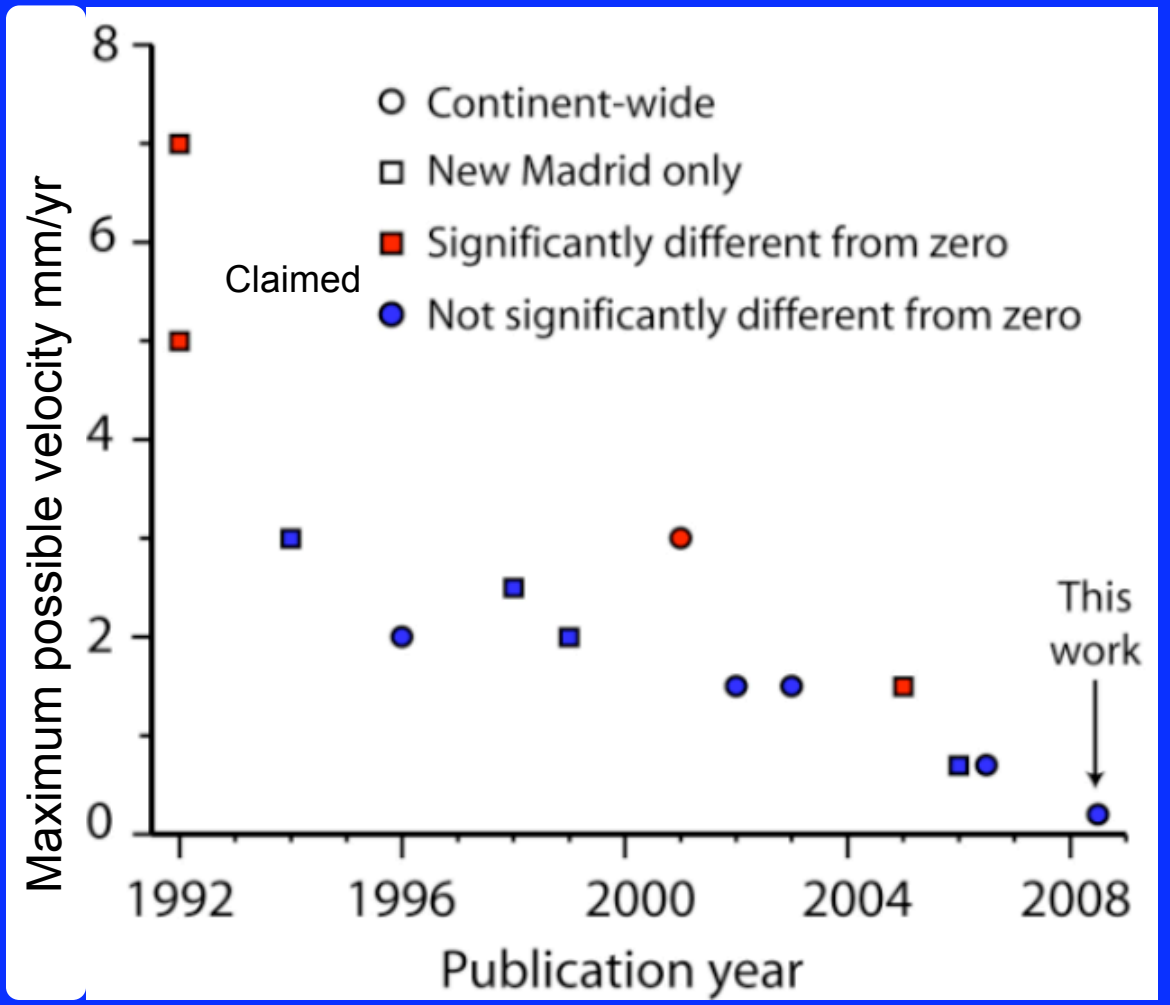
$\sigma_v = 2^{1/2} \sigma / T$

Rate precision improves with longer observations

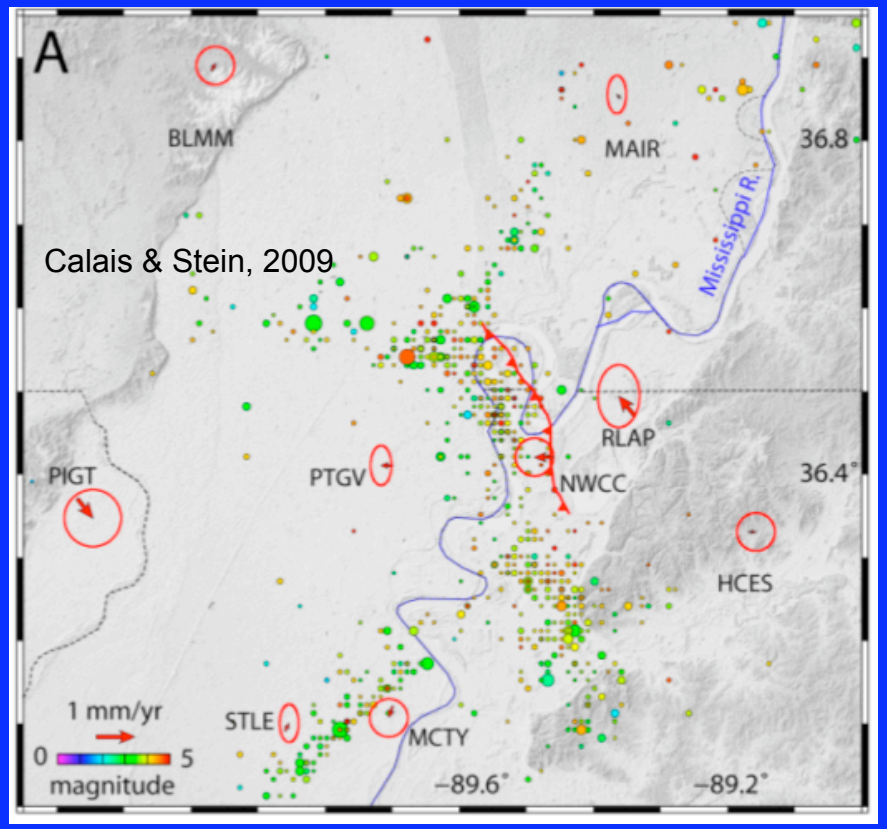
Rates < 0.2 mm/yr, will continue to converge on zero unless ground motion starts

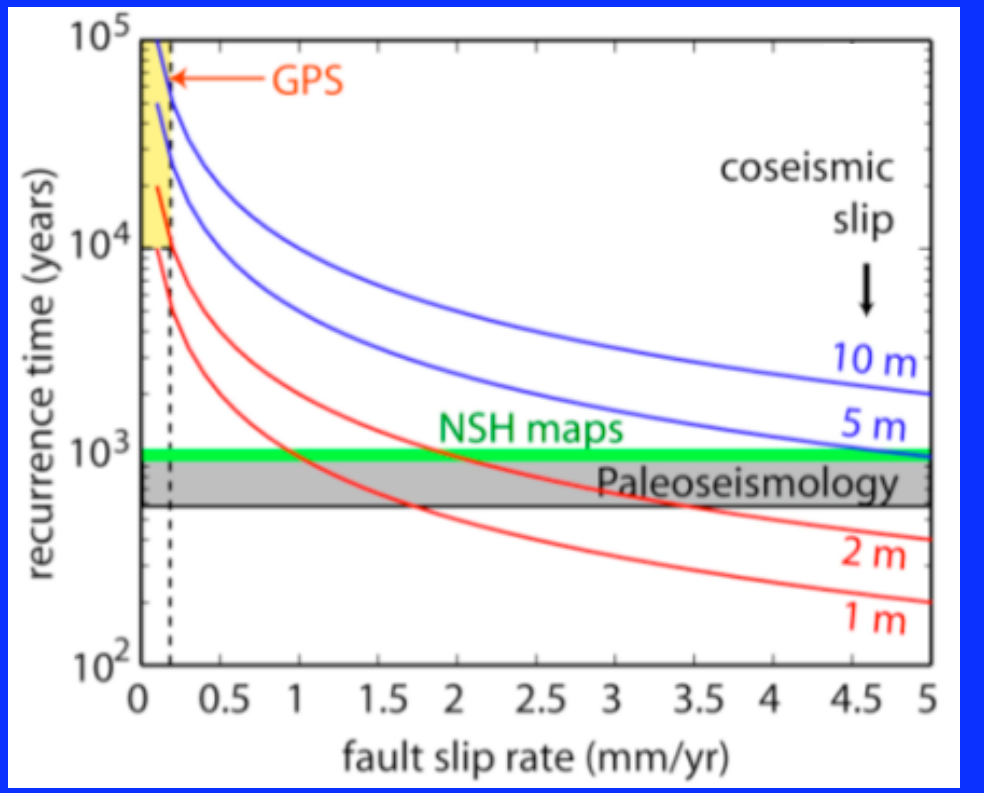
Strain rate does the same: < 2 x 10^{-9} /yr and shrinking

Calais & Stein, 2009



GPS SHOWS LITTLE OR NO MOTION





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.

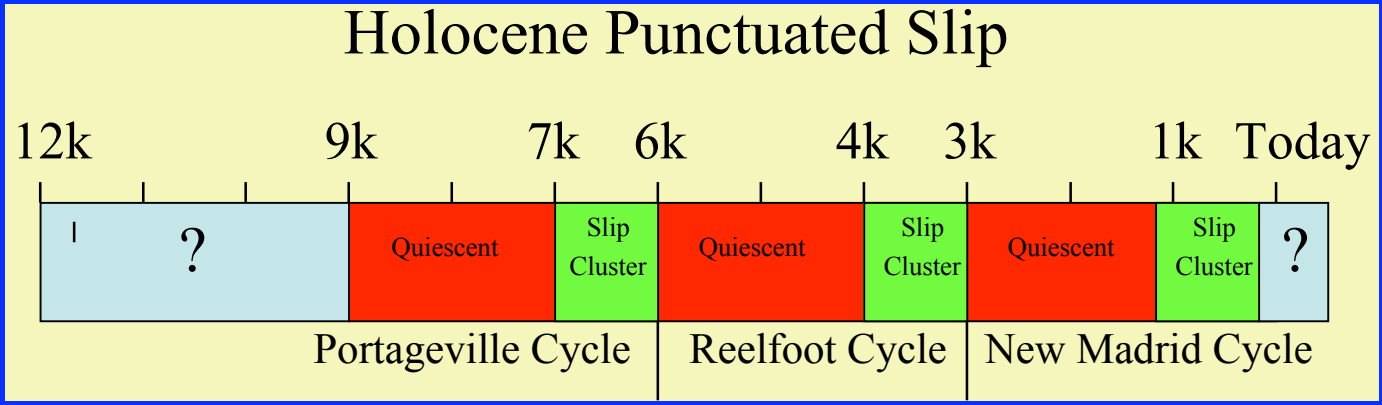
Very long time needed to store up slip needed for a future large earthquake

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

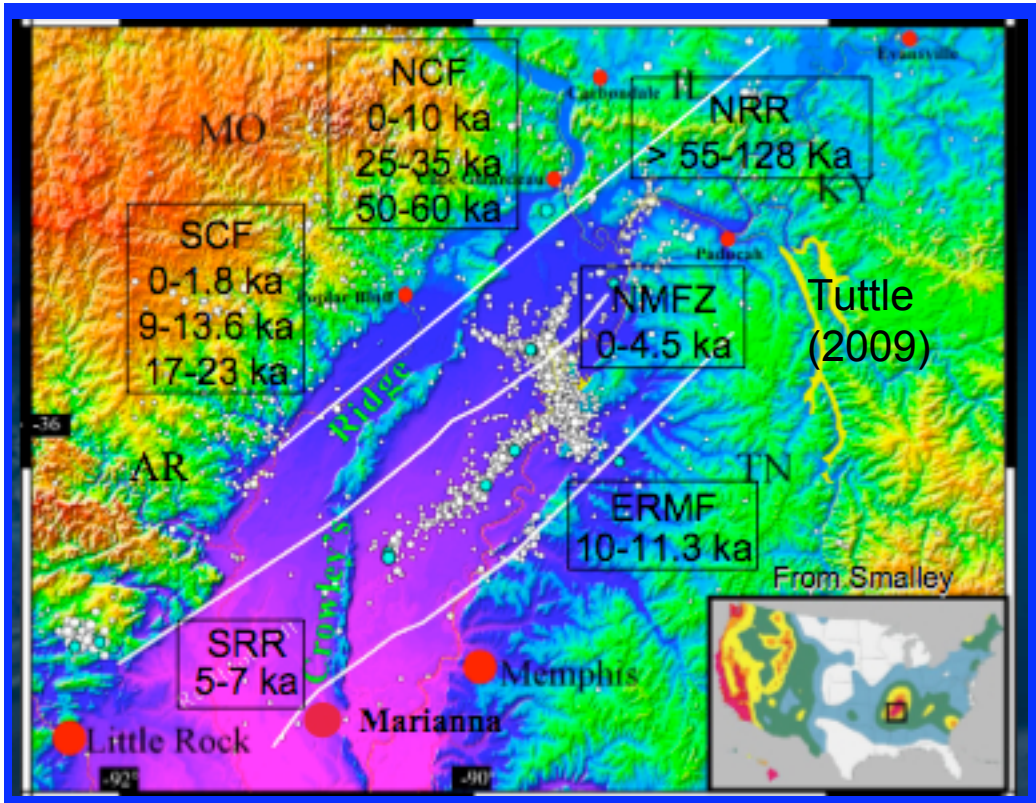
Recent cluster likely ended

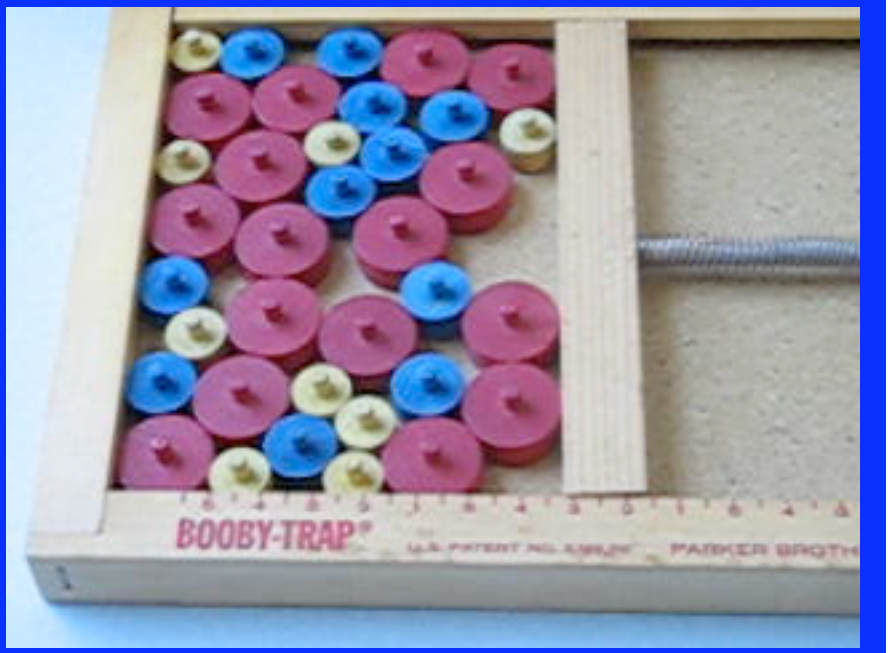
Lack of significant fault topography, jagged fault, and other geological data also imply that recent pulse of activity is only a few thousand years old



New Madrid earthquake history inferred from Mississippi river channels

Holbrook et al., 2006



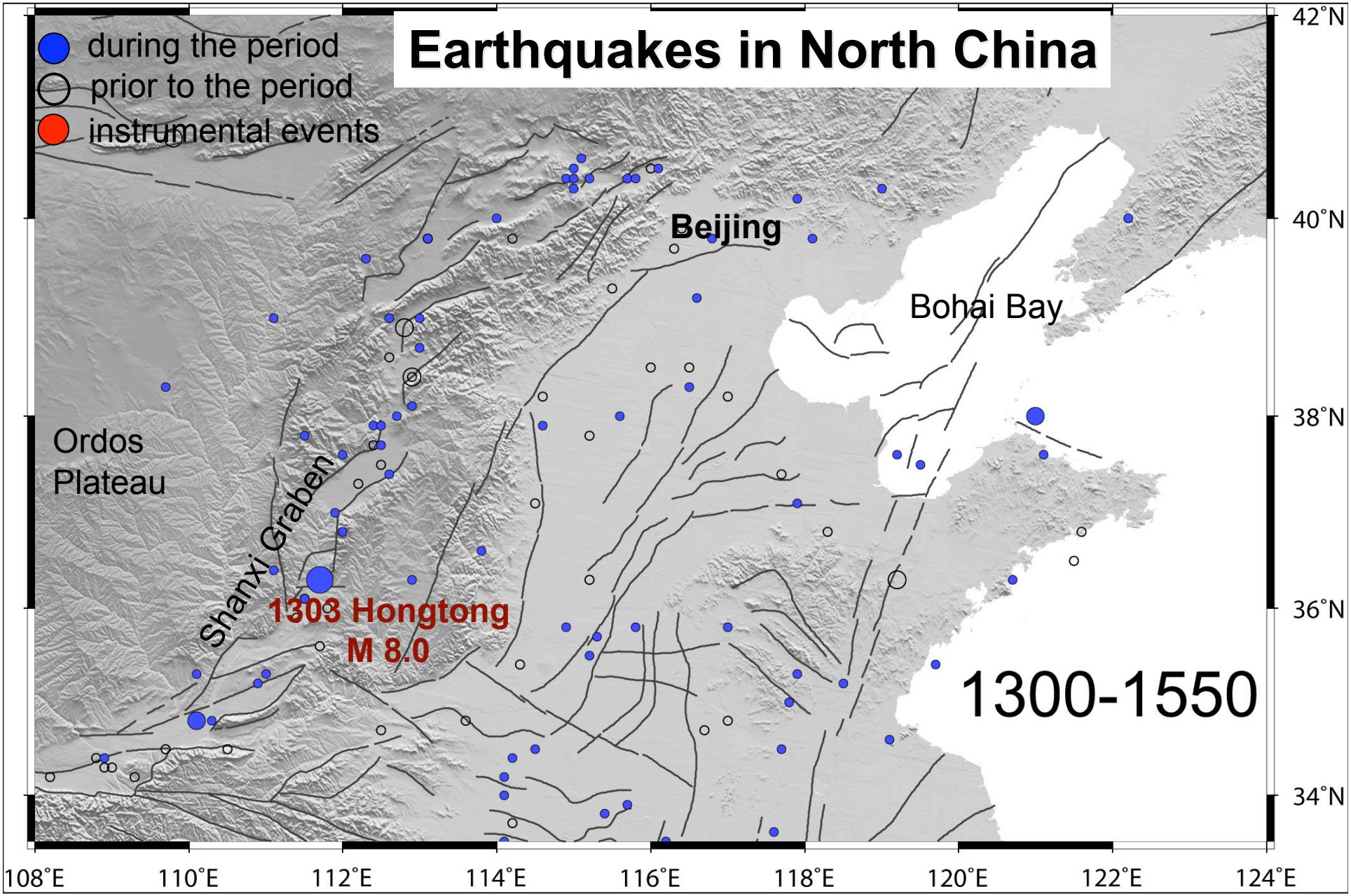


Seismicity migrates among faults due to fault interactions (stress transfer)

Faults active in past show little present seismicity

Meers fault, Oklahoma
Active 1000 years ago, dead now

Liu, Stein & Wang 2010



Large events often pop up where there was little seismicity!