Characterizing Earthquake Hazard of the New Madrid Region for the National Seismic Hazard Maps

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The National Seismic Hazard Maps: An Open Consensus-Building Process

From Petersen et al. (2008)

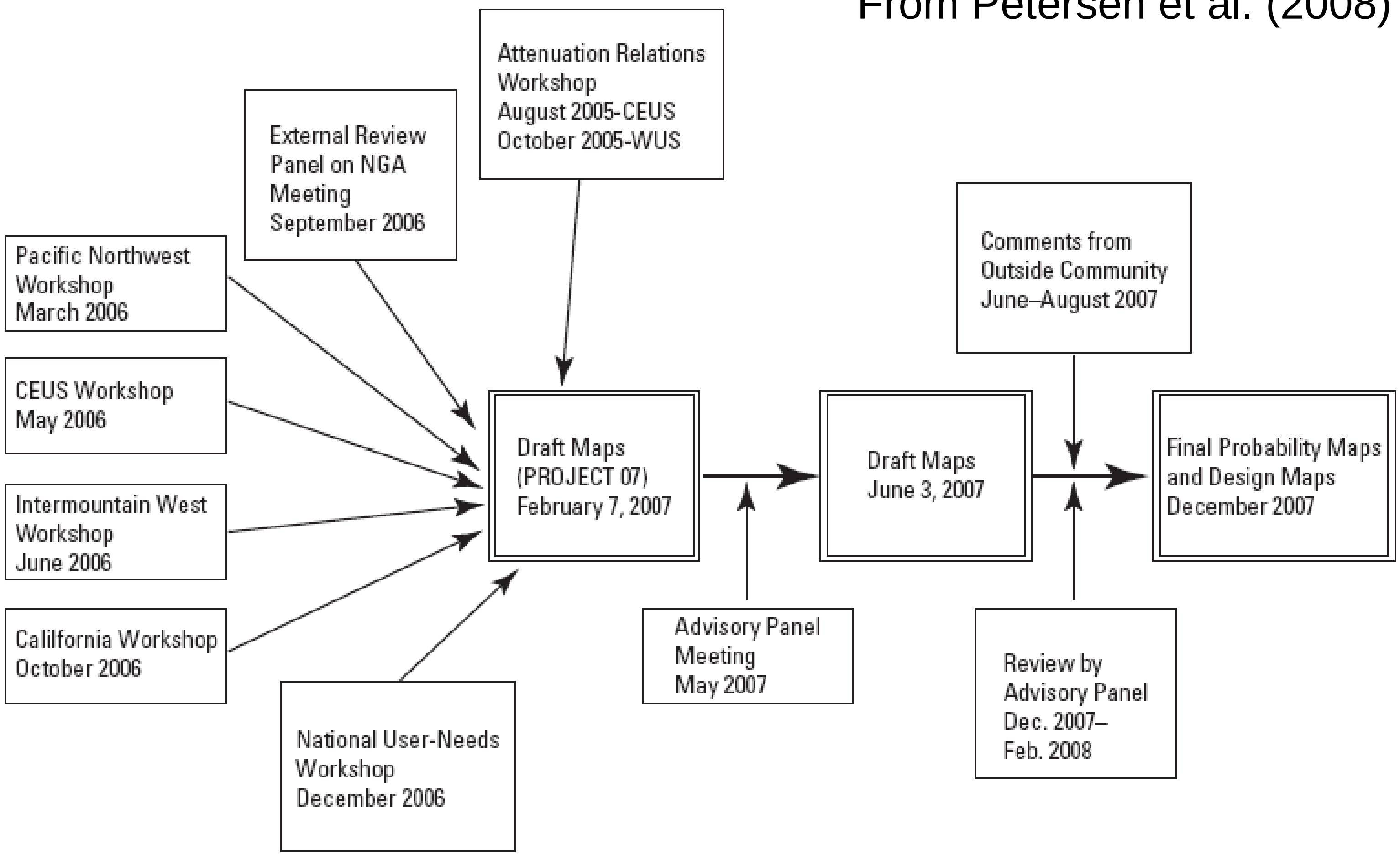
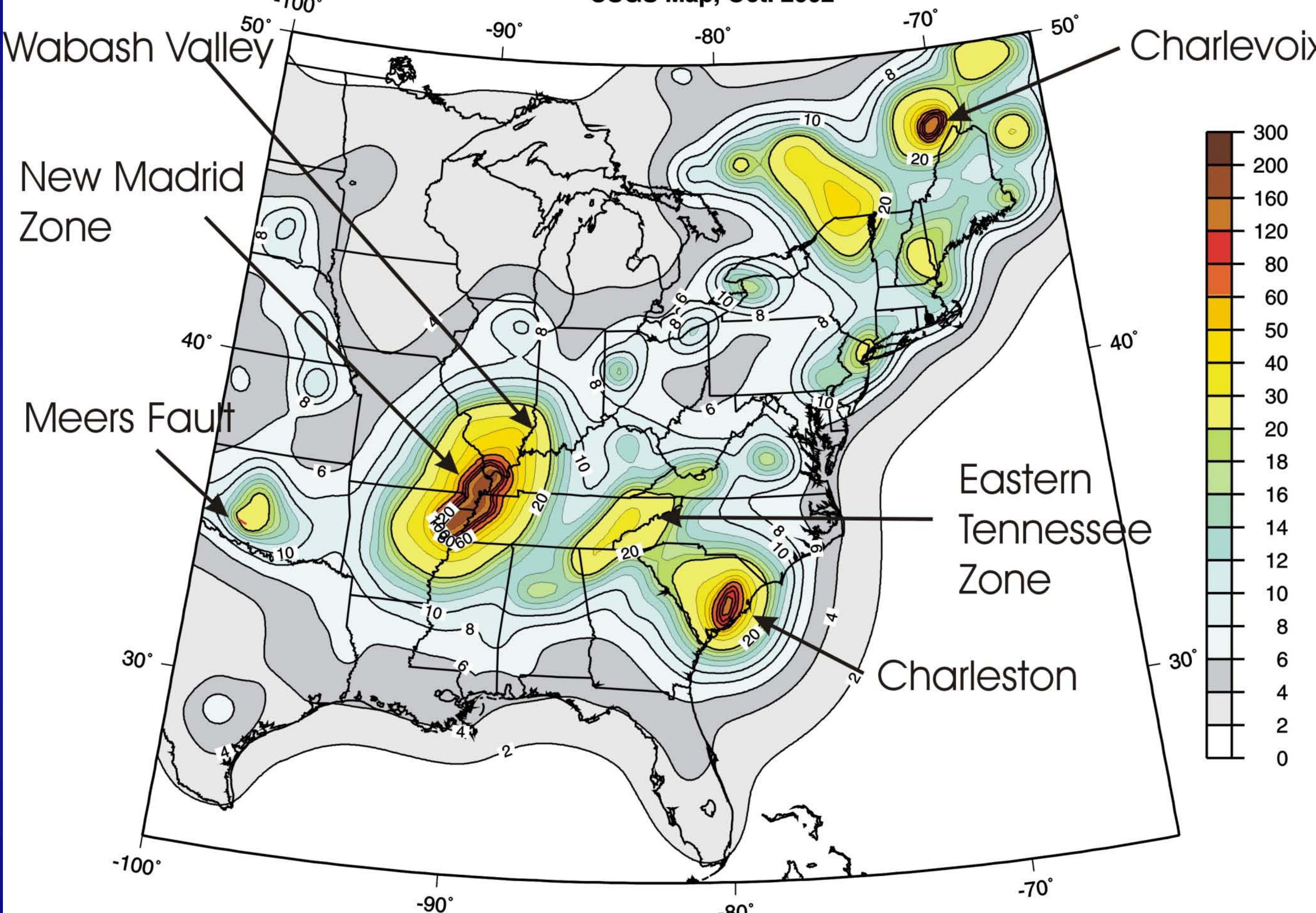


Figure 1. Process for developing the 2008 USGS National Seismic Hazard Maps. CEUS, Central United States; WUS, Western United States.

Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years
USGS Map, Oct. 2002



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The Smoking Guns for New Madrid Earthquakes

- 1811-12: three largest earthquakes felt as far away as New England, producing intensity 8+ in W. TN, very large liquefaction area; estimates of largest magnitude from intensities: 7.2 (Hough and Page, in review), 7.8 (Bakun and Hopper), 8. (Johnston)
- About 1450 A.D.: sequence of three large earthquakes with similar liquefaction area as 1811-12 (Tuttle et al., 2002)
- About 900 A.D.: sequence of three large earthquakes with similar liquefaction area as 1811-12 (Tuttle et al., 2002)
- also: M6.6 earthquake in 1895 in Charleston, MO; M6 in 1843 in Marked Tree, AR; history of M5.1 and smaller events since 1900

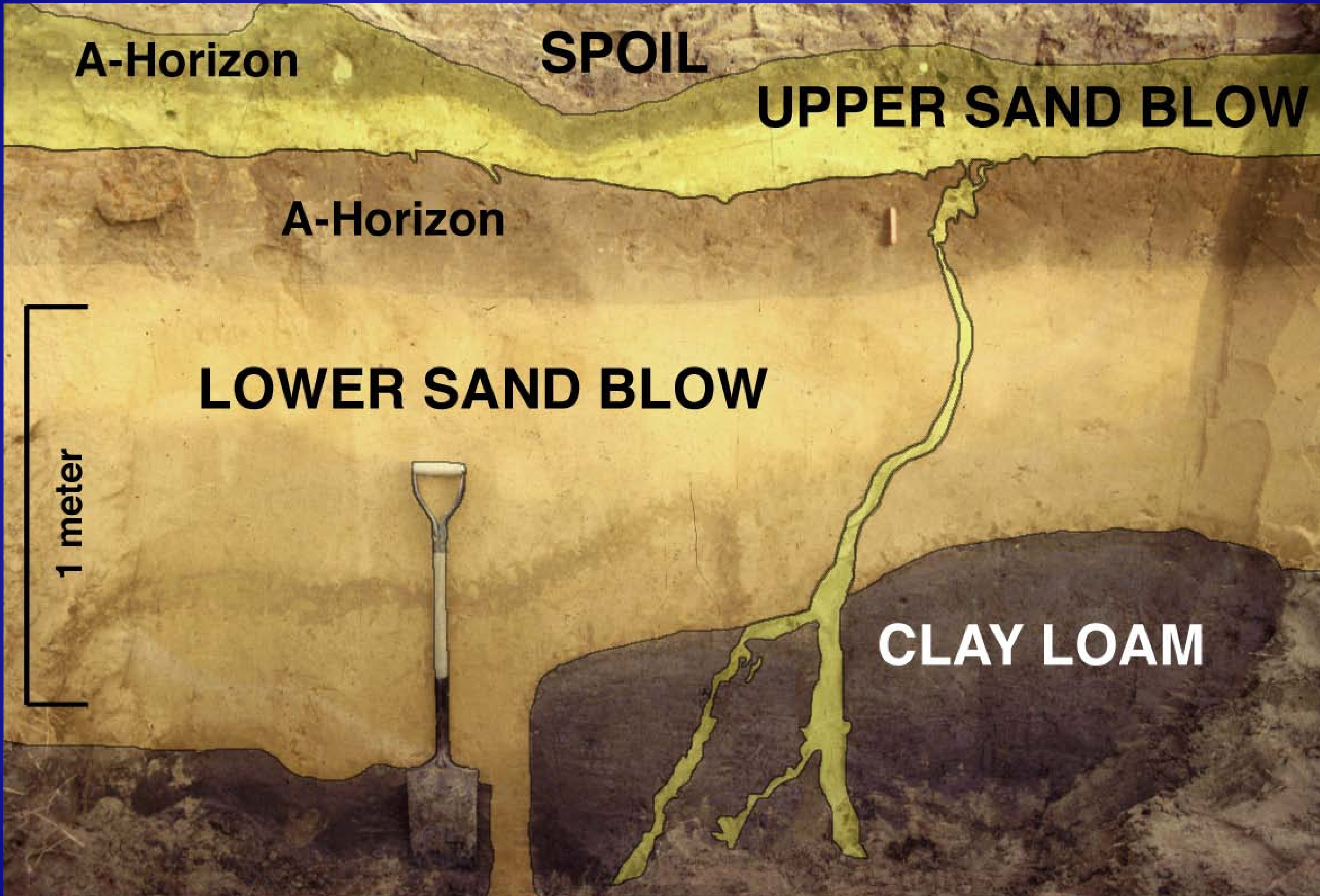
1811-1812 Liquefaction

136-acre sand boil

Lateral spreading

Slide from Tom Holzer

Slide provided by E.S. Schweig



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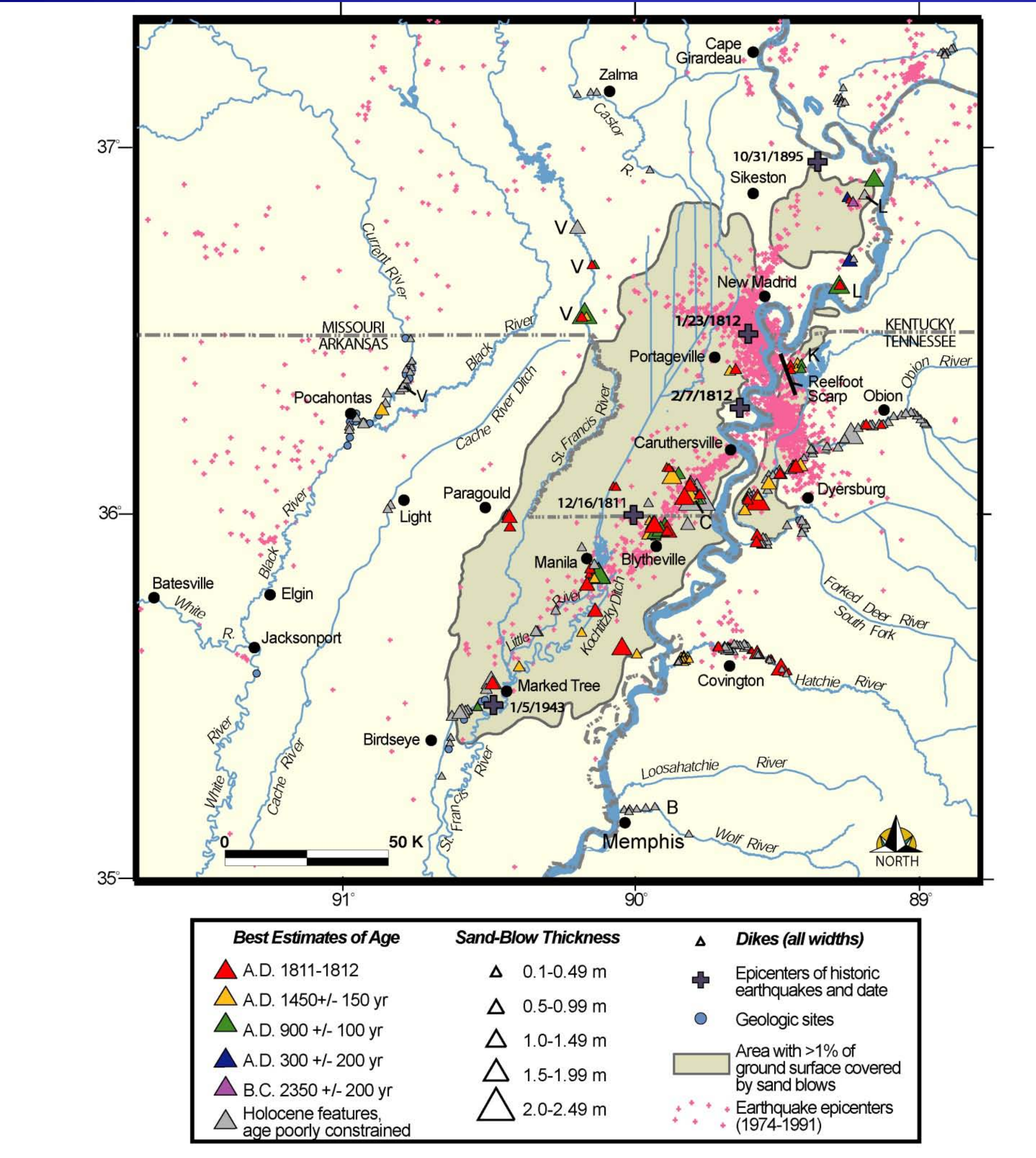

From Tuttle et al. (2002)

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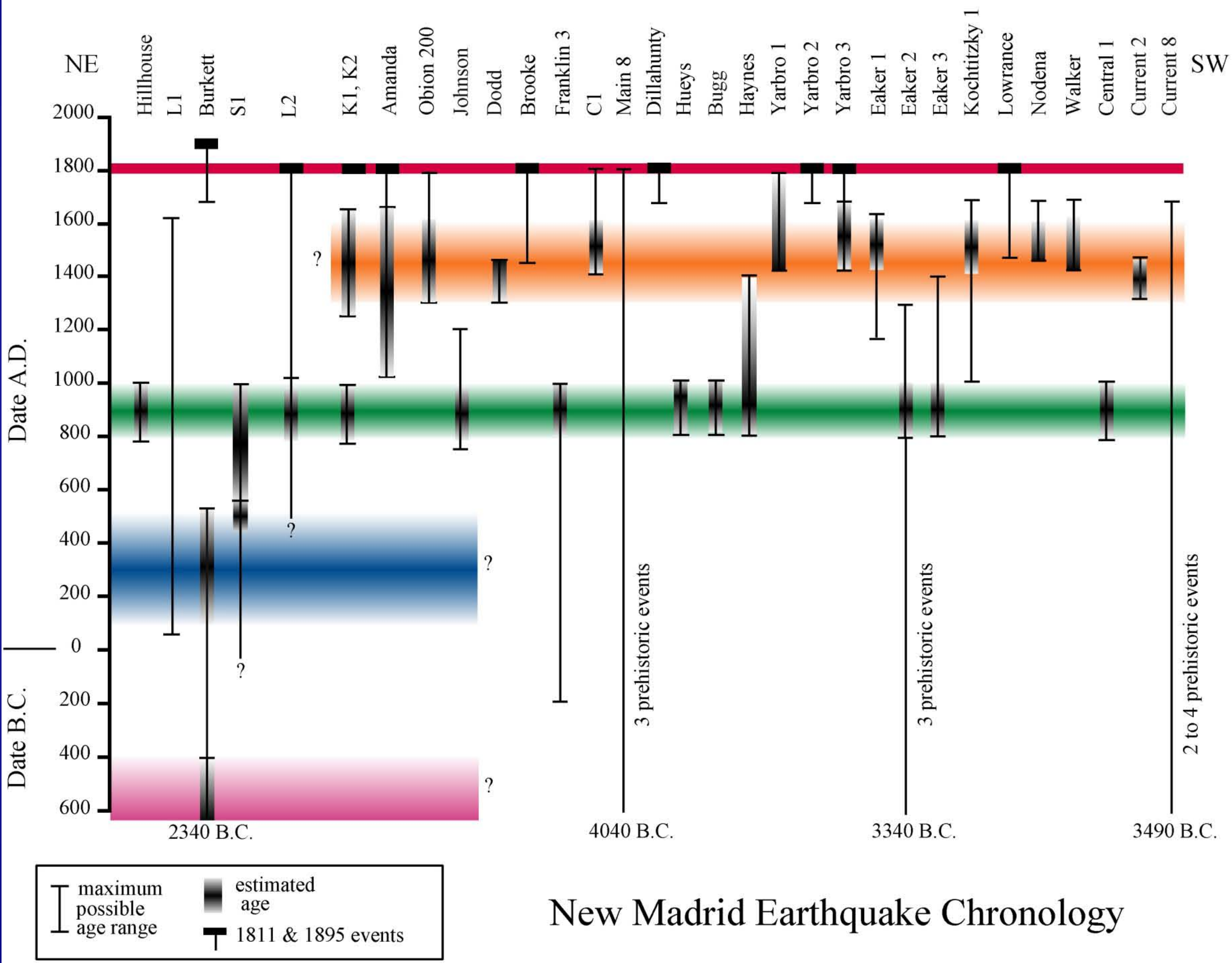

KELSON ET AL.: HOLOCENE EARTHQUAKES, REELFOOT FAULT 6153

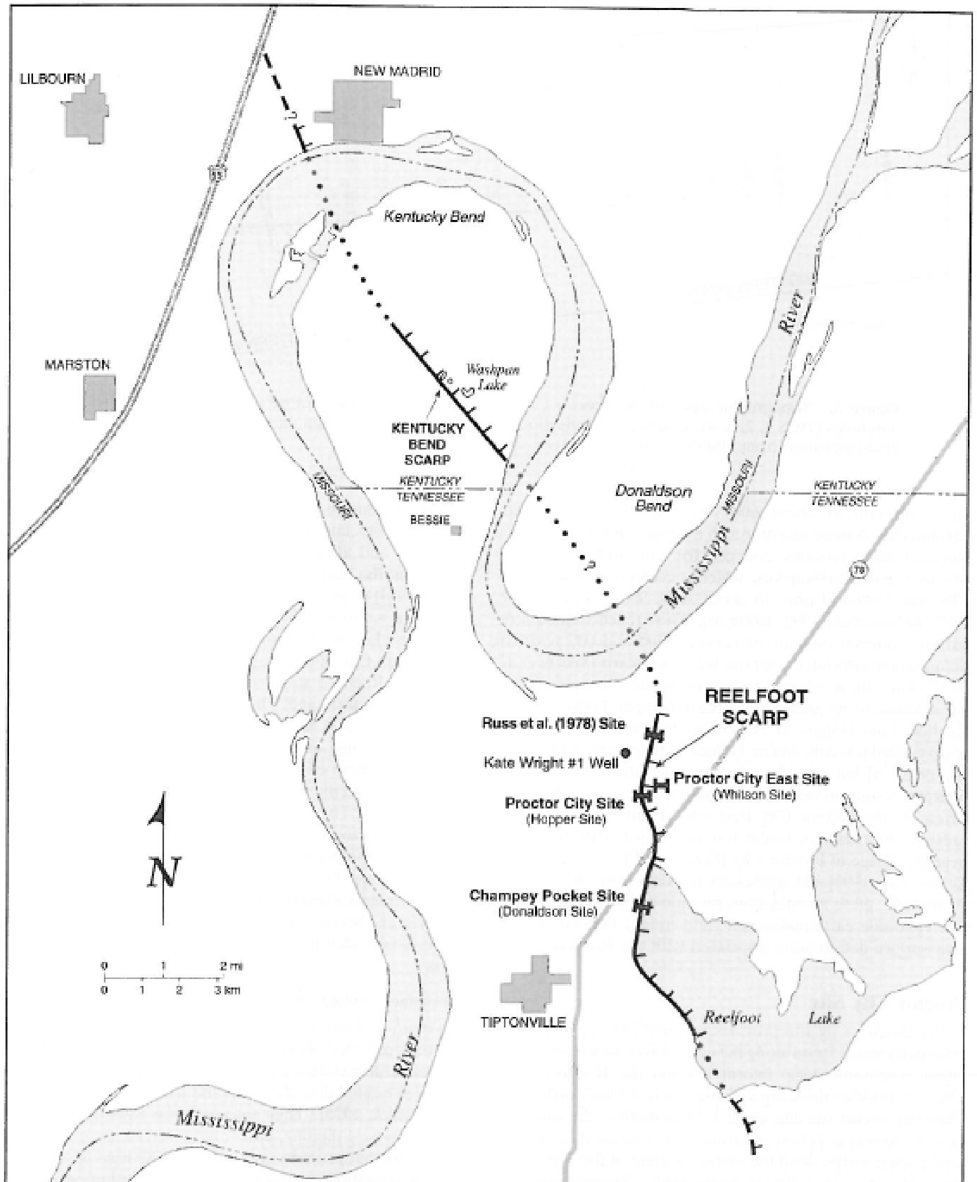

Figure 2. Location map showing the Reelfoot scarp (dotted where beneath Reelfoot Lake or eroded, dashed where inferred), the Kentucky Bend scarp, and trench sites of this and previous studies.

Reelfoot Fault scarp; trenching shows evidence of earthquakes in 1812, 1200-1650, and 780-1000 AD

Figure from Kelson et al. 1996

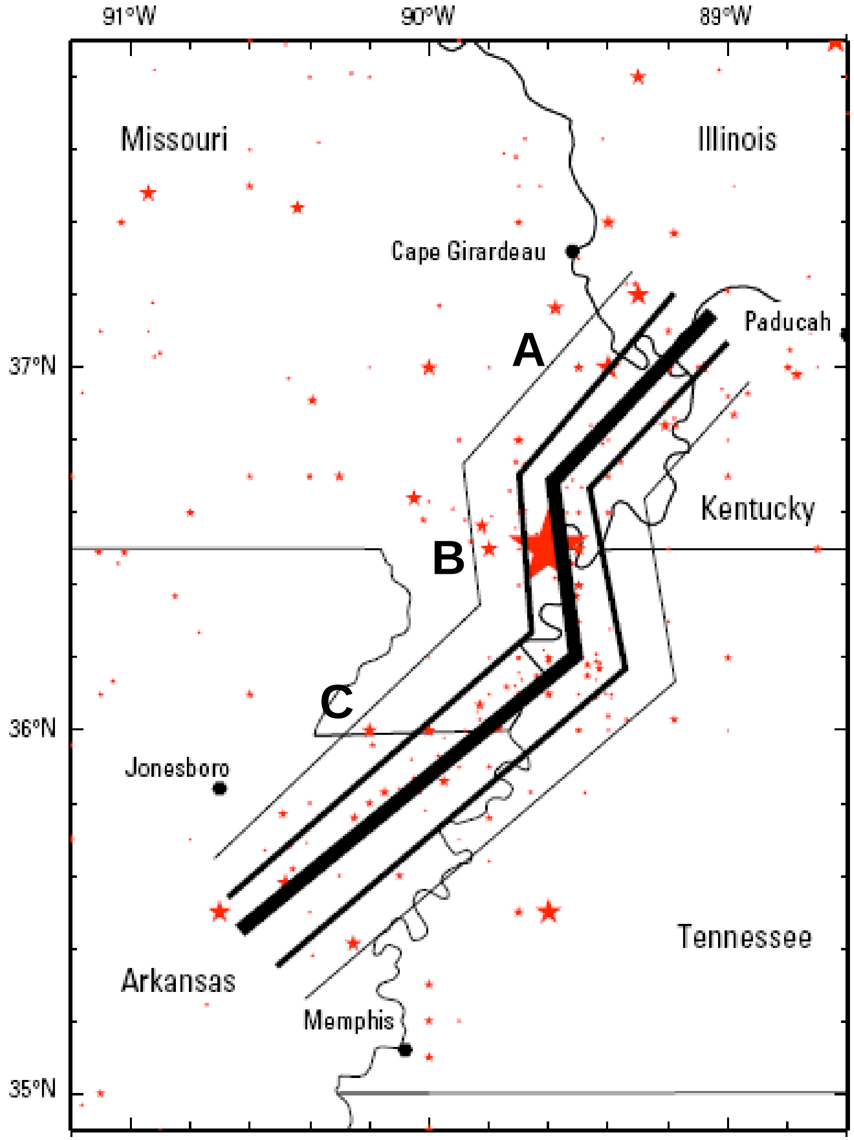

Figure 5. Historical seismicity (M≥3) and locations of the modeled New Madrid hypothetical faults. Relative weights assigned to the hypothetical faults shown by line width. Size of red stars indicates relative size of earthquake.

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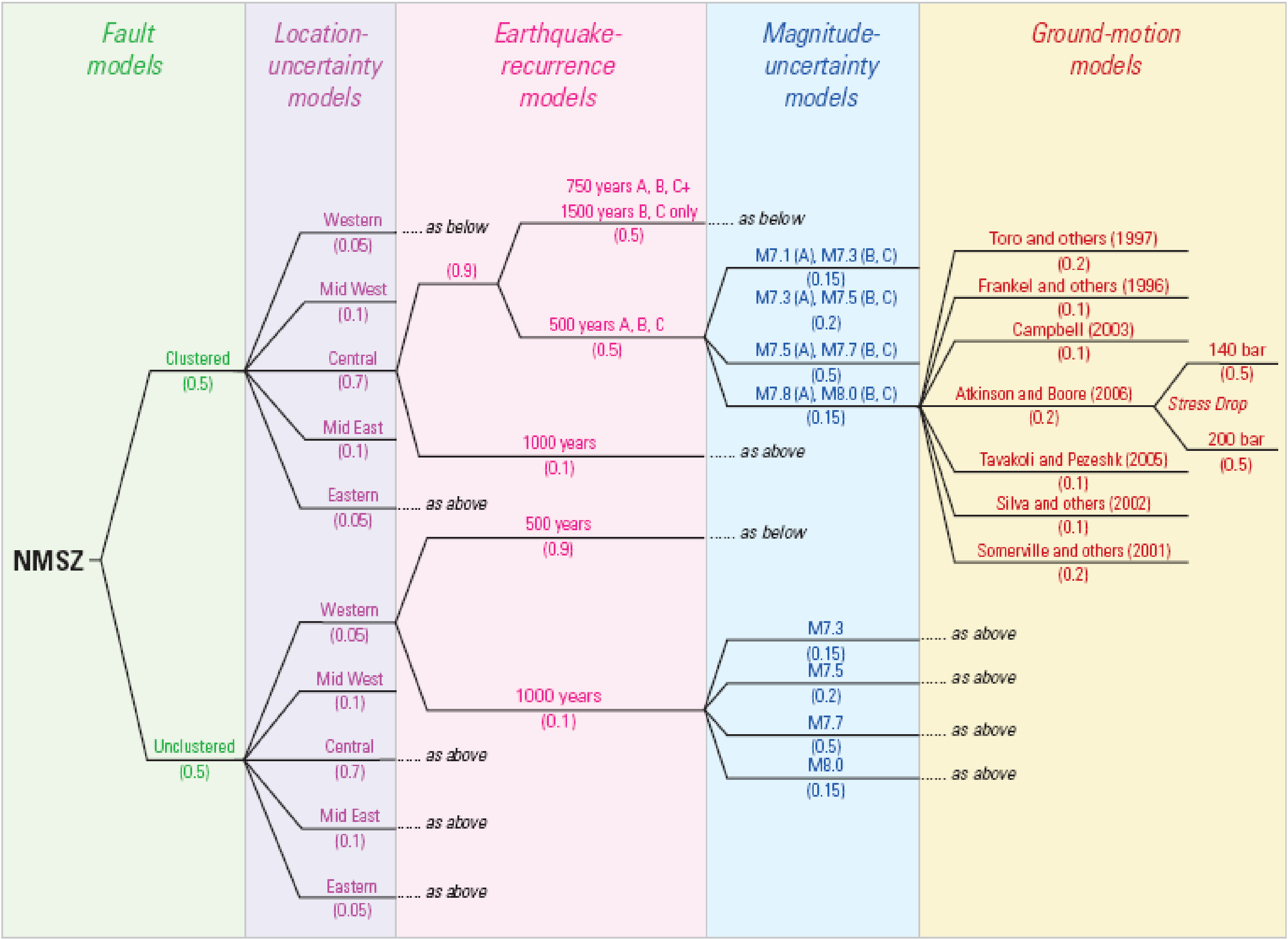
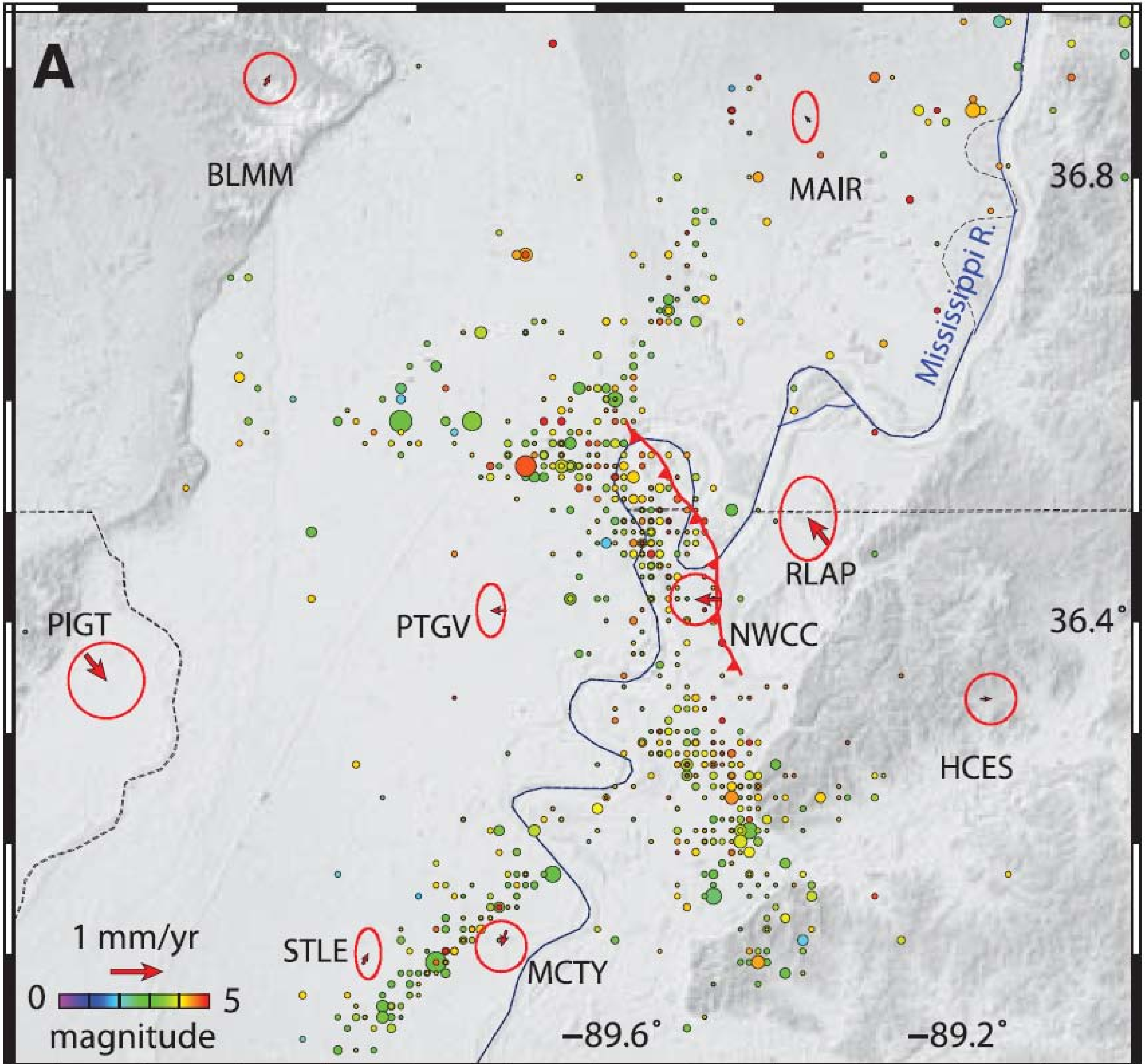


Figure 6. Logic tree for the New Madrid seismic zone (NMSZ). Parameters in this figure include some aleatory variability as well as depicted epistemic uncertainty. A, B, and C refer to the northern, central, and southern segments shown in figure 5. Location and magnitude branches may include aleatory variability and epistemic uncertainty; we have not treated these separately. We treat aleatory variability in ground motion in the hazard code.

USGS Estimates of Probabilities of Earthquakes in the New Madrid Seismic Zone

- M7.3-8.0 in next 50 years: 7- 10%
- M7.3-8.0 in next 100 years: 15-20%
- M ≥ 6.0 in next 50 years: 25-40%
- M ≥ 6.0 in next 100 years: 45-65%

Estimates for M ≥ 6.0 include M7.5-8 earthquakes
M 7.5-8 time-dependent estimates use a coefficient of variation of 0.5 for recurrence time



Motions Derived from GPS data 2000-2009

Figure from Calais and Stein (2009) Science paper

"observations do not require motions different from zero"

"strains less than 1.3×10^{-9}/yr Motions less than 0.2 mm/yr"

Medical Archive Site

Northeast Ohio Medical Industry, Hospital and Health Care News

Inside

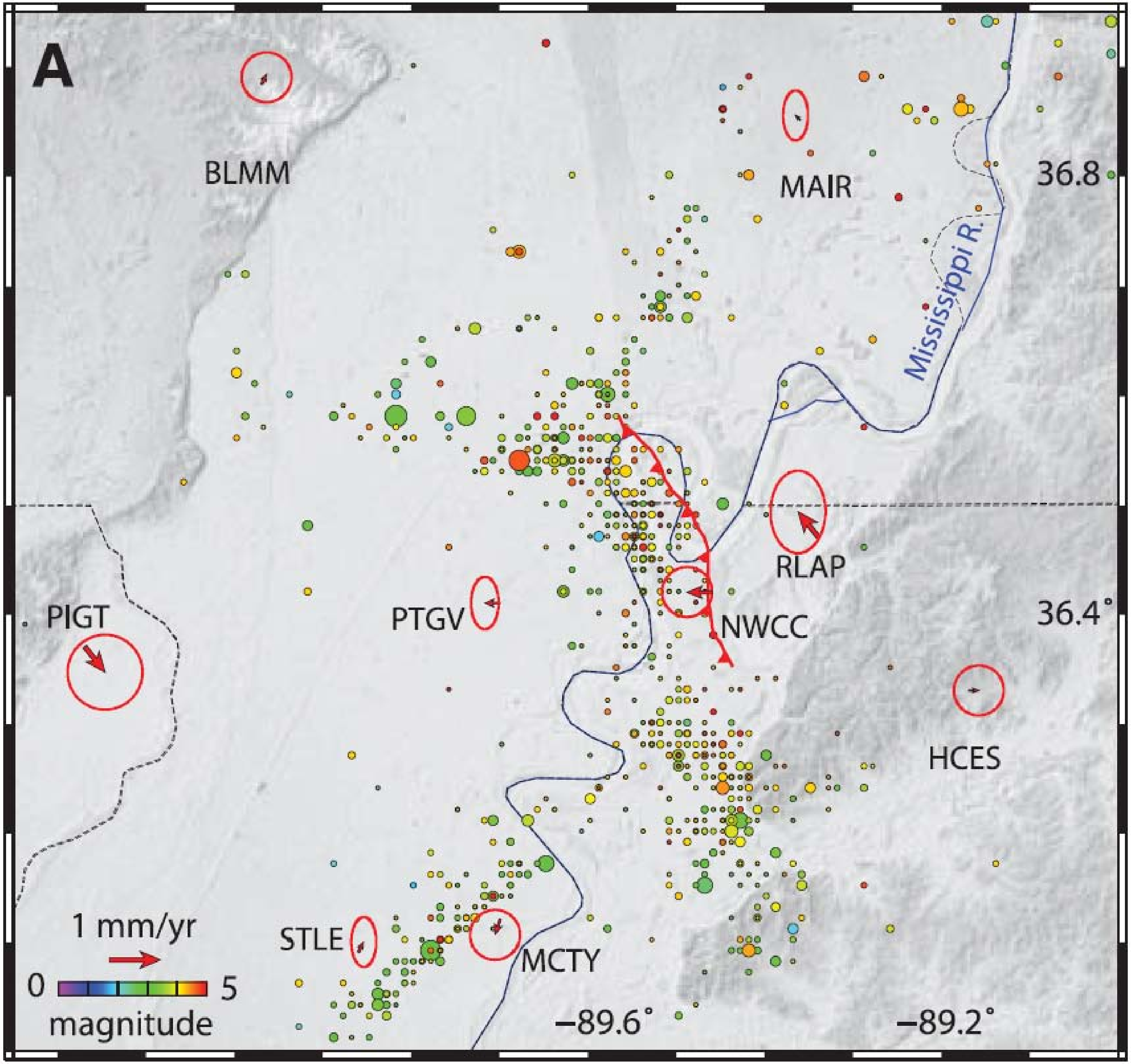
New Madrid fault no problem, geophysicists Seth Stein and Eric Calais say

By metro

April 08, 2009, 7:22AM

Jason Geil / The Kentucky Post via AP

Cincinnati (seen here from the Roebling Bridge) would be the largest Ohio city at risk of damage from a New Madrid fault earthquake. Scientists differ about how likely such a quake is.



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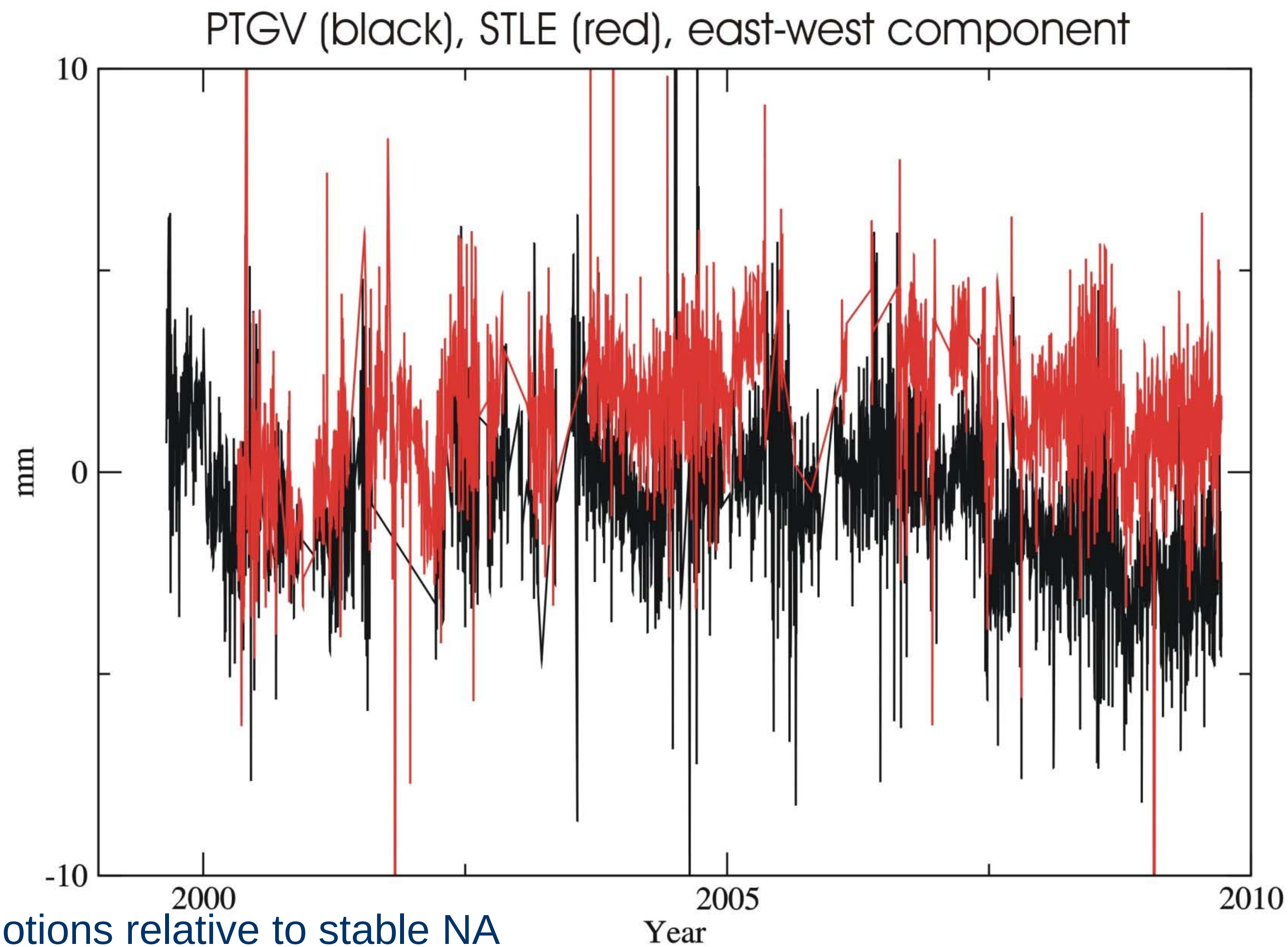
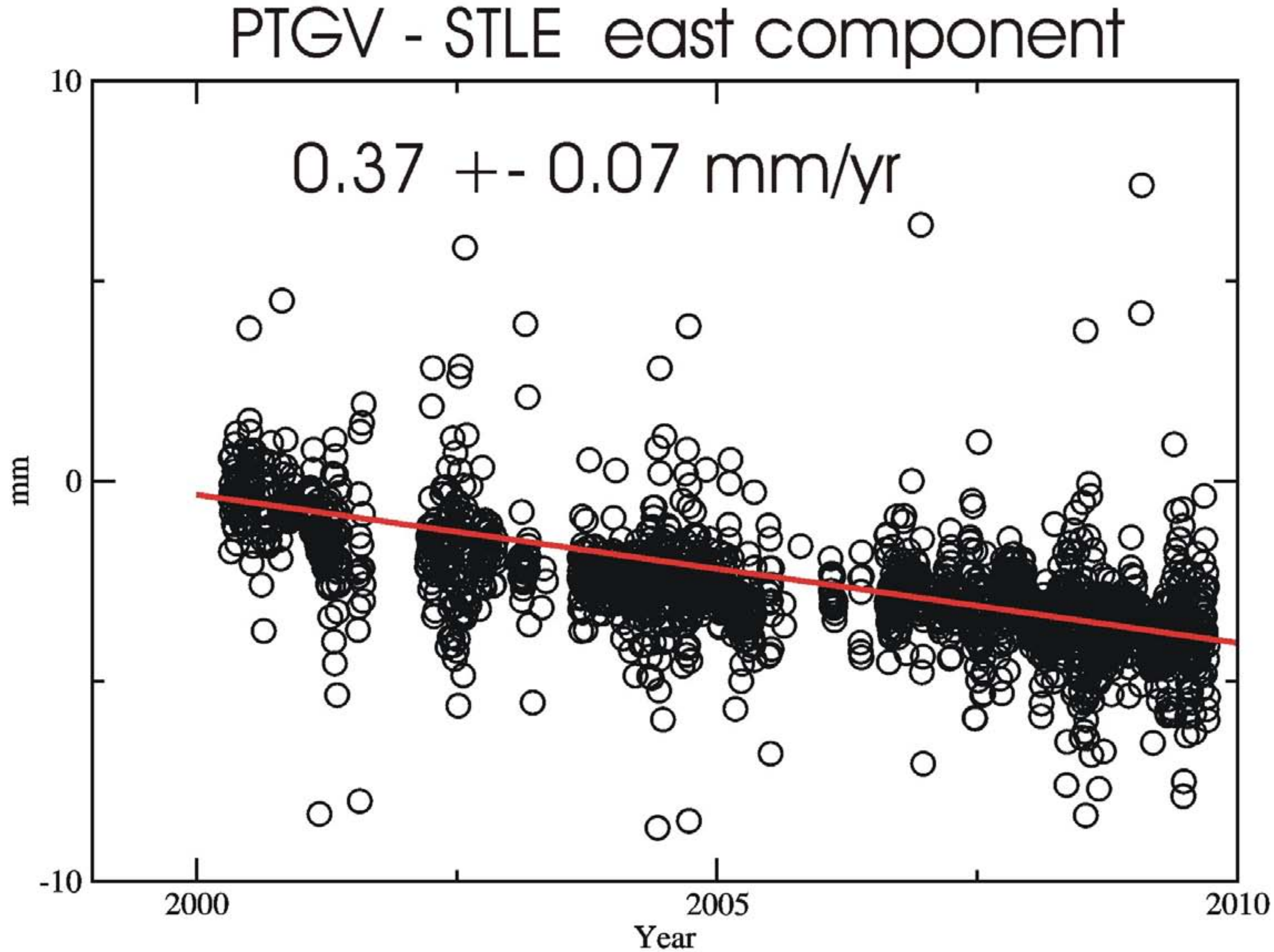
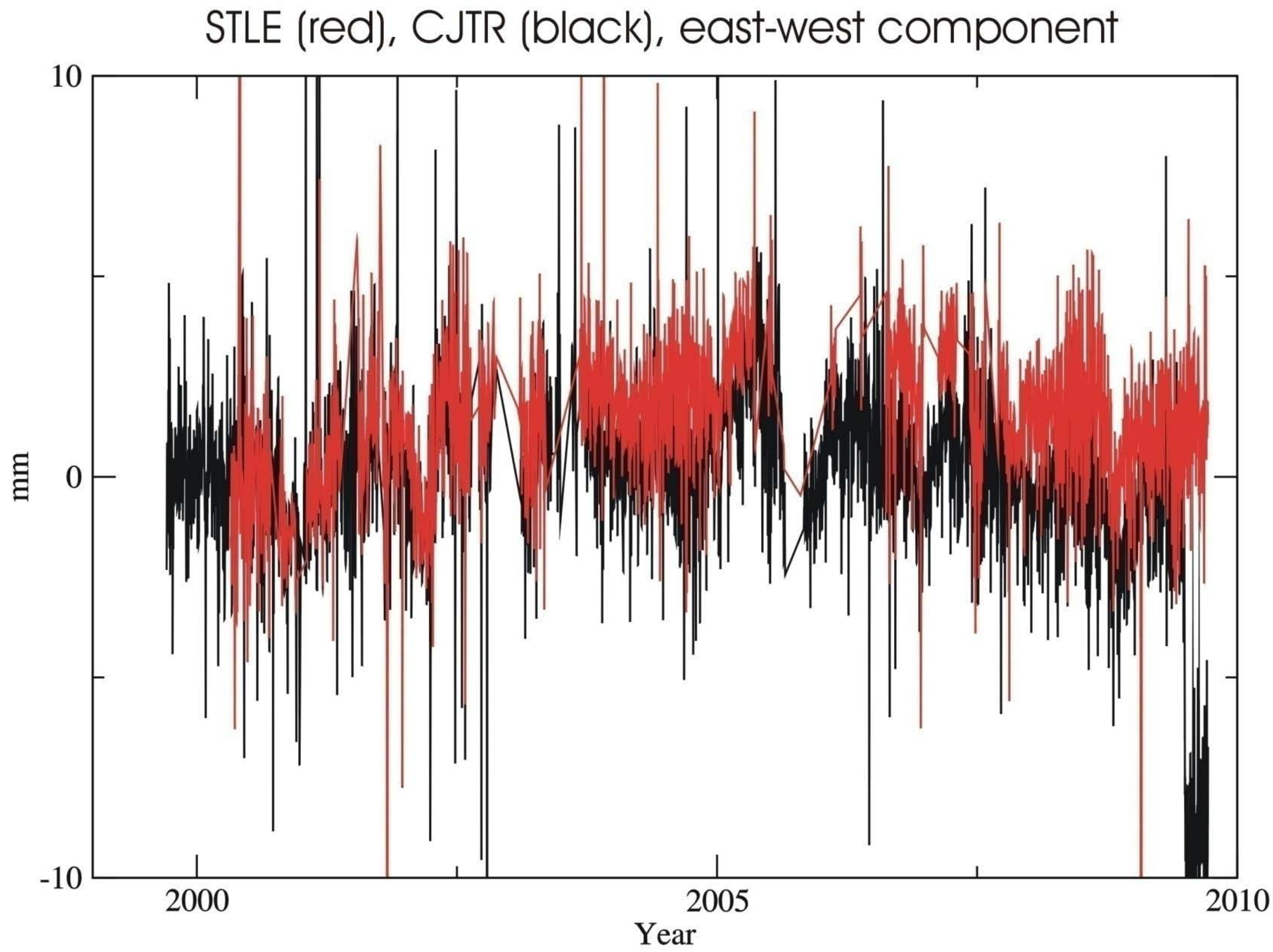


Motions relative to stable NA

Original time series provided by Robert Smalley, Univ. of Memphis



+- is one standard deviation, derived from model with white noise, flicker noise, and random walk, using Max Likelihood Estimation method of Langbein (2004)



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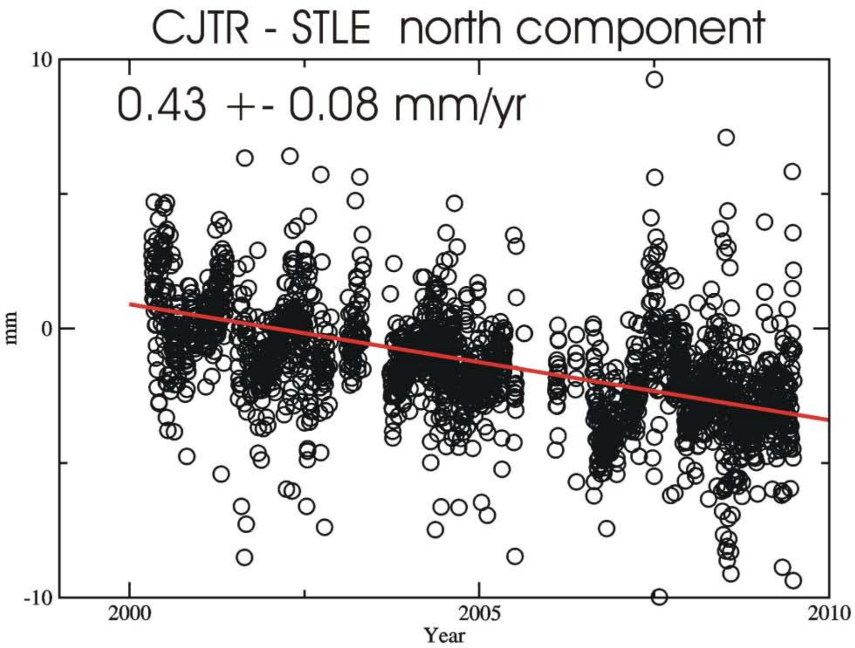
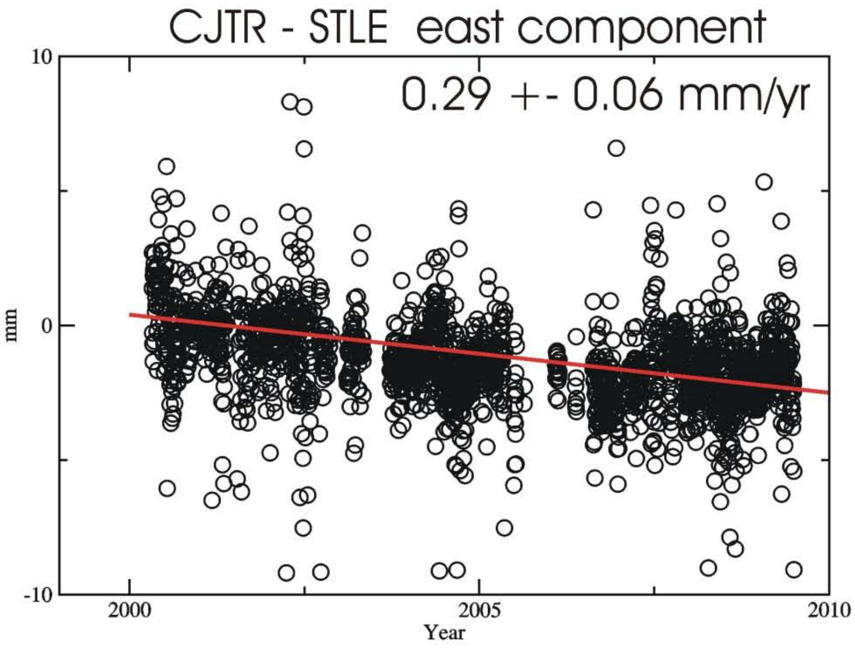
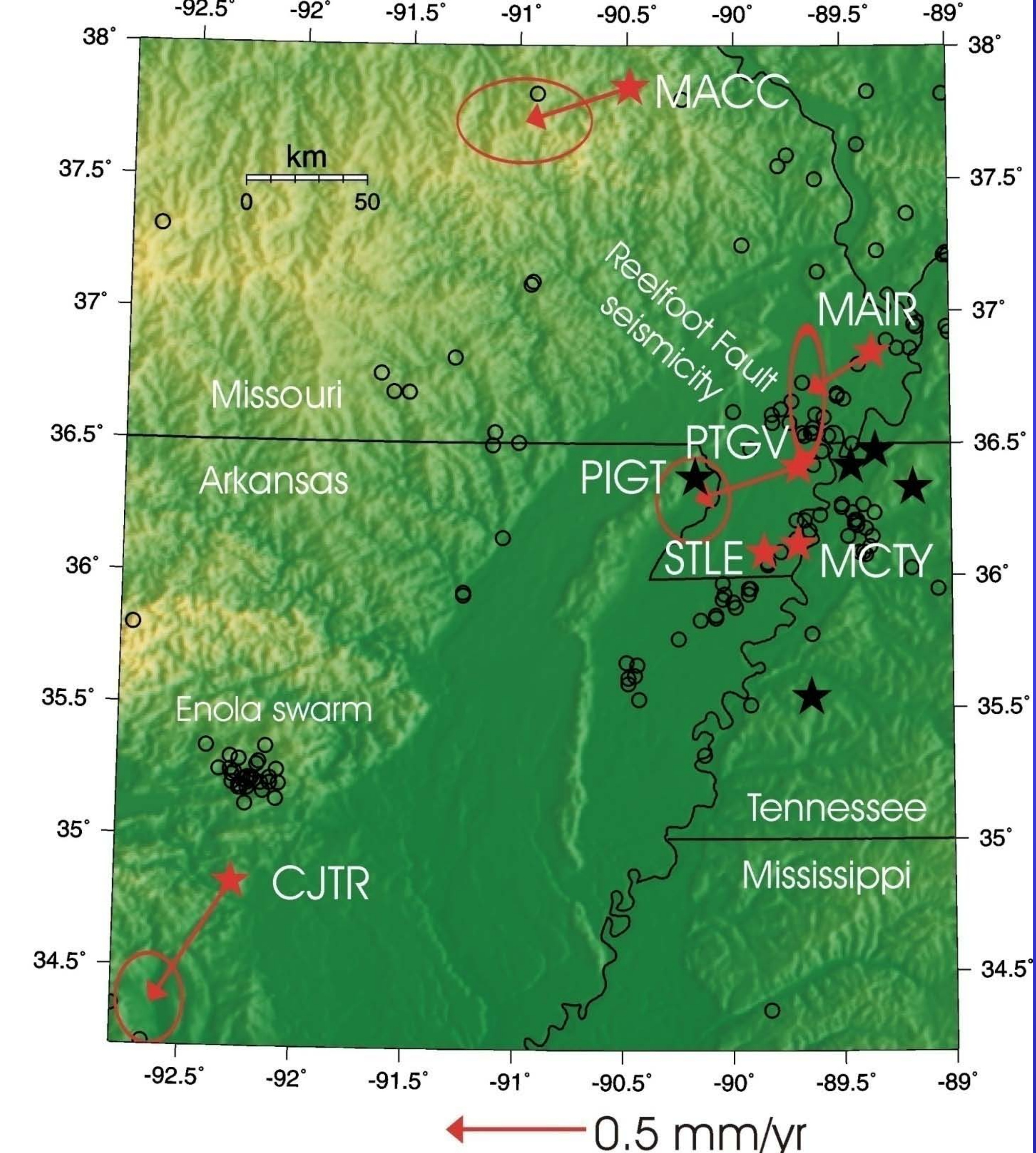
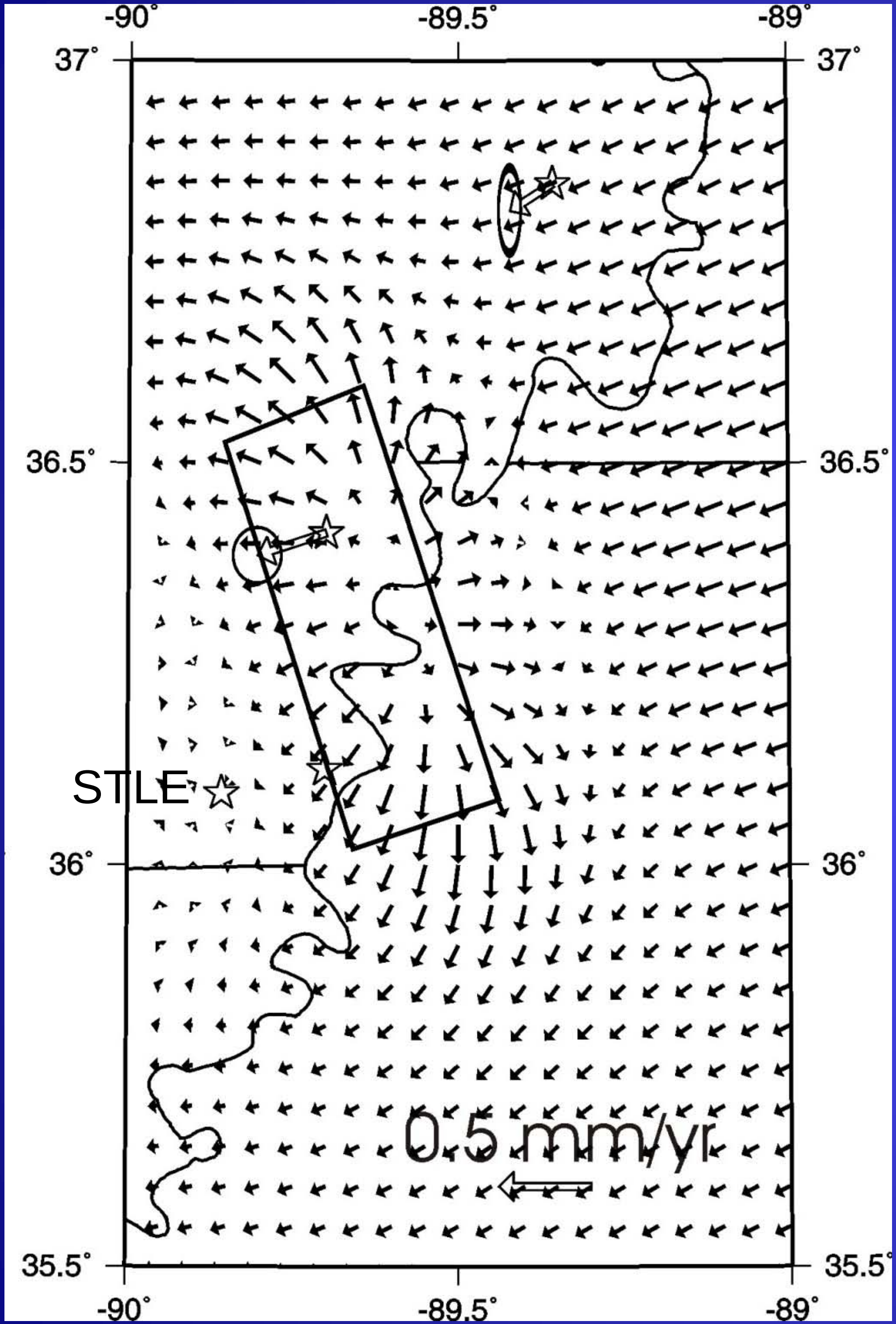

CJTR - STLE north component
0.43 +- 0.08 mm/yr
10
0
-10
mm
2000
2005
2010
Year


CJTR - STLE east component
0.29 +- 0.06 mm/yr
10
0
-10
mm
2000
2005
2010
Year



Motions with respect to station STLE
Ellipses are 95% confidence bounds

Strain of 5 x 10^{-9} /yr, four times higher than Calais and Stein (2009)



Predicted motions (solid arrows) for 2 mm/yr creep on deep portion of Reelfoot Fault at 12-30 km depth

Open arrows are observed motions

All motions with respect to STLE

Enough slip for at least
An M7.0 earthquake every 500 years

How should we consider GPS results in hazard maps?

- Asked experts at regional workshop in 2006 what we should do (also had Memphis workshop of experts in 2000). General consensus is that the geologic and historic evidence for large earthquakes over past 4000 years outweighs 10-15 years of GPS results with multiple interpretations.

- USGS position is that, given the geological, geophysical, and seismological evidence, it is prudent to prepare for the ground shaking from future 1811-12 type earthquakes, as well as more frequent M5-6 earthquakes. This hazard should be addressed in mitigation measures, including building codes (IBC and IRC).

- We need to do more research to understand the GPS data
- Need to expand GPS network and understand why some stations are so noisy
- Need to have all the GPS position time series for the CEUS (and the Nation) available from one web site
- Need to develop a variety of earthquake models for intraplate regions and test against the data
- Don’t neglect potential hazard from other sources in the central U.S. (Wabash Valley, eastern Reelfoot rift, etc.). Need systematic paleoseismic search for prehistoric large earthquakes throughout CEUS

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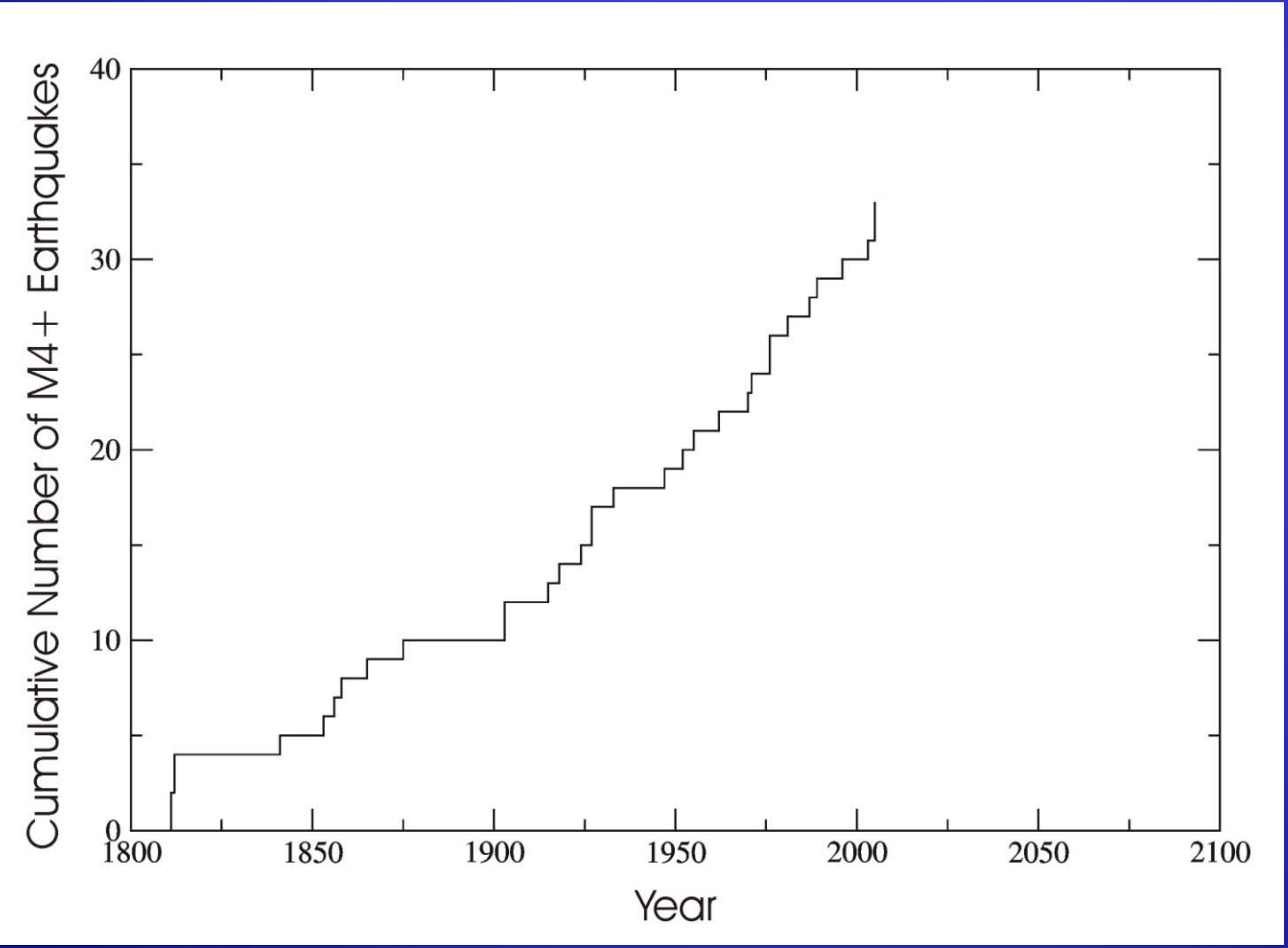
Electric Power Research Institute CEUS Seismic Source Characterization for nuclear facilities (draft 2010)

- Convened workshops of experts for inputs, used SSHAC level 3, technical integrators
- Treats New Madrid area as a repeating large magnitude source; gives very low weight to Calais and Stein interpretation
- Similar magnitude range as used in NSHM
- Similar recurrence time as used in NSHM

Are current earthquakes in New Madrid aftershocks of 1811-12? Observed rate of M4+ earthquakes does not indicate this.
In any case, hazard estimate is mainly driven by liquefaction evidence of large quakes



Catalog of independent earthquakes provided by C.S. Mueller

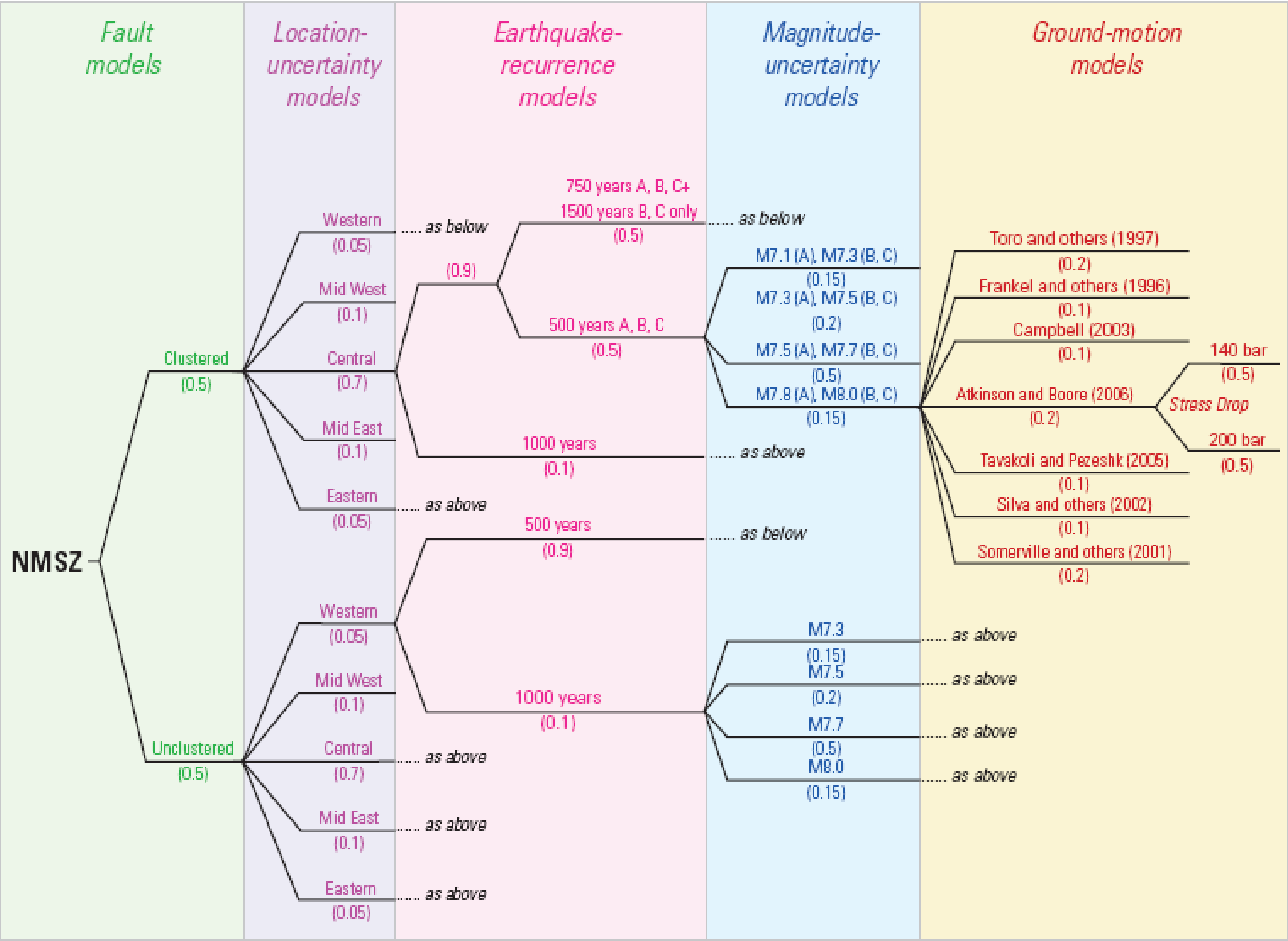
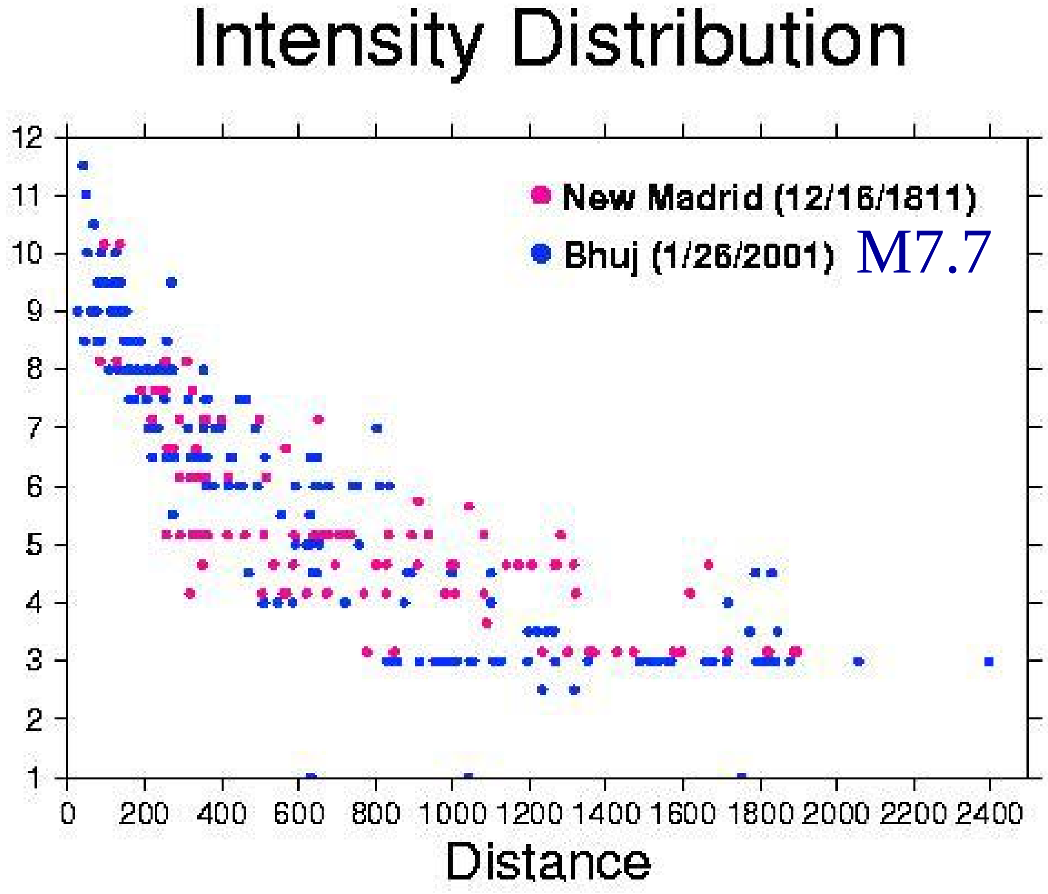


Figure 6. Logic tree for the New Madrid seismic zone (NMSZ). Parameters in this figure include some aleatory variability as well as depicted epistemic uncertainty. A, B, and C refer to the northern, central, and southern segments shown in figure 5. Location and magnitude branches may include aleatory variability and epistemic uncertainty; we have not treated these separately. We treat aleatory variability in ground motion in the hazard code.

How do we estimate magnitudes for the 1811-12, 1450, and 900 A.D. earthquakes?

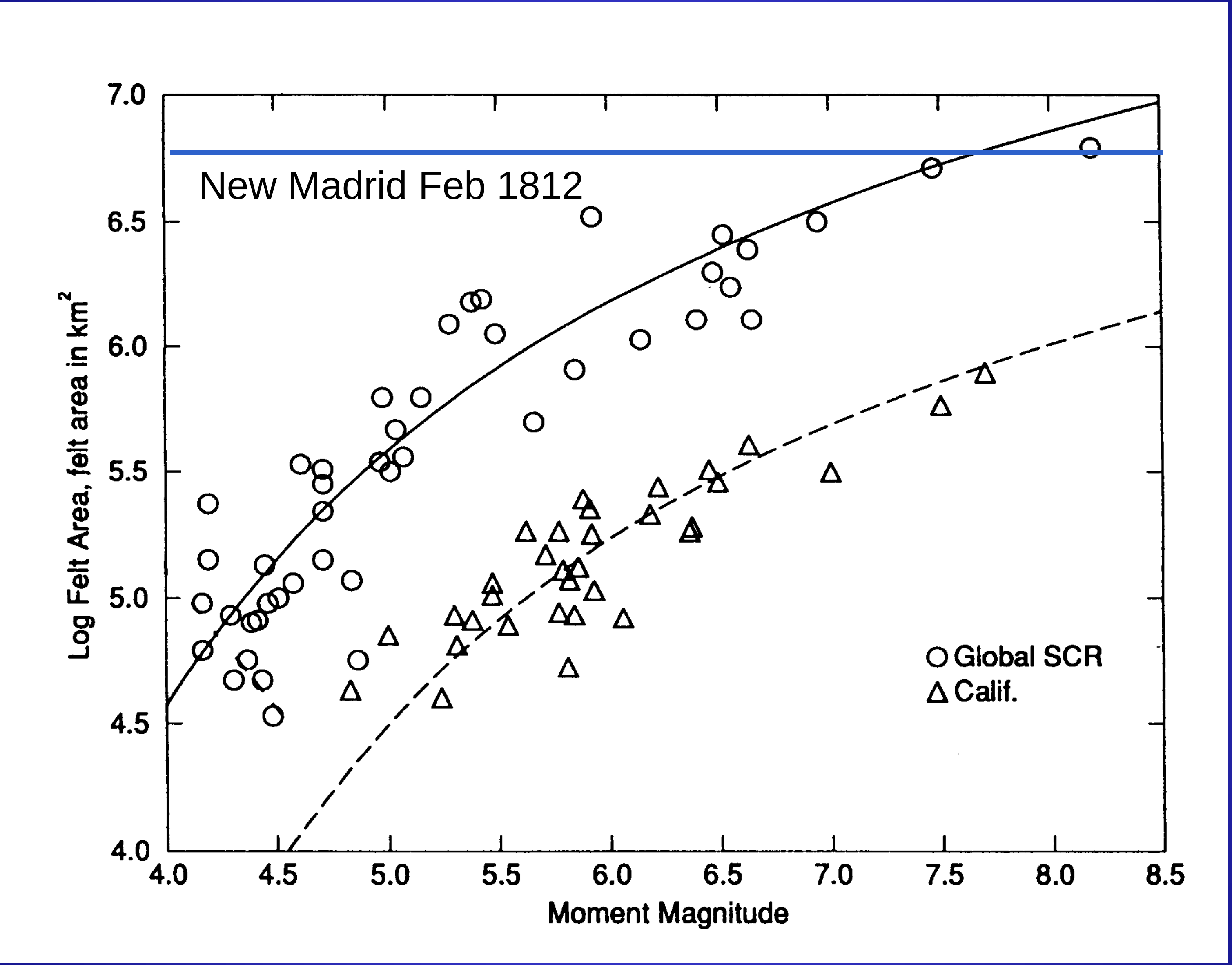
- Compare isoseismal areas of 1811-12 events with more recent stable continental region earthquakes with measured magnitudes: In 1996, Johnston determined preferred magnitude of 1811-12 events was moment magnitude 8.0.
- Re-analysis of isoseismal data with site corrections yielded M7.4-7.5 (Hough et al. 2000). New method of using intensities yielded M7.8 (Bakun and Hopper, 2003). Hough and Page (in review) had 4 experts re-evaluate 1811-12 intensities, get M7.2 for Feb 1812.
- 1450 and 900 A.D. earthquakes have similar magnitudes as 1811-12 sequence, based on similar liquefaction areas

Comparison of observed intensities from the 1811 New Madrid earthquake with the 2001 Bhuj India earthquake which occurred in a comparable tectonic setting; Tuttle et al. (2002) also note that max. distance to liquefaction similar for Bhuj and 1811-12 quakes



From Hough et al. (2002)

Fits using magnitude-independent stress drop, omega –2 model

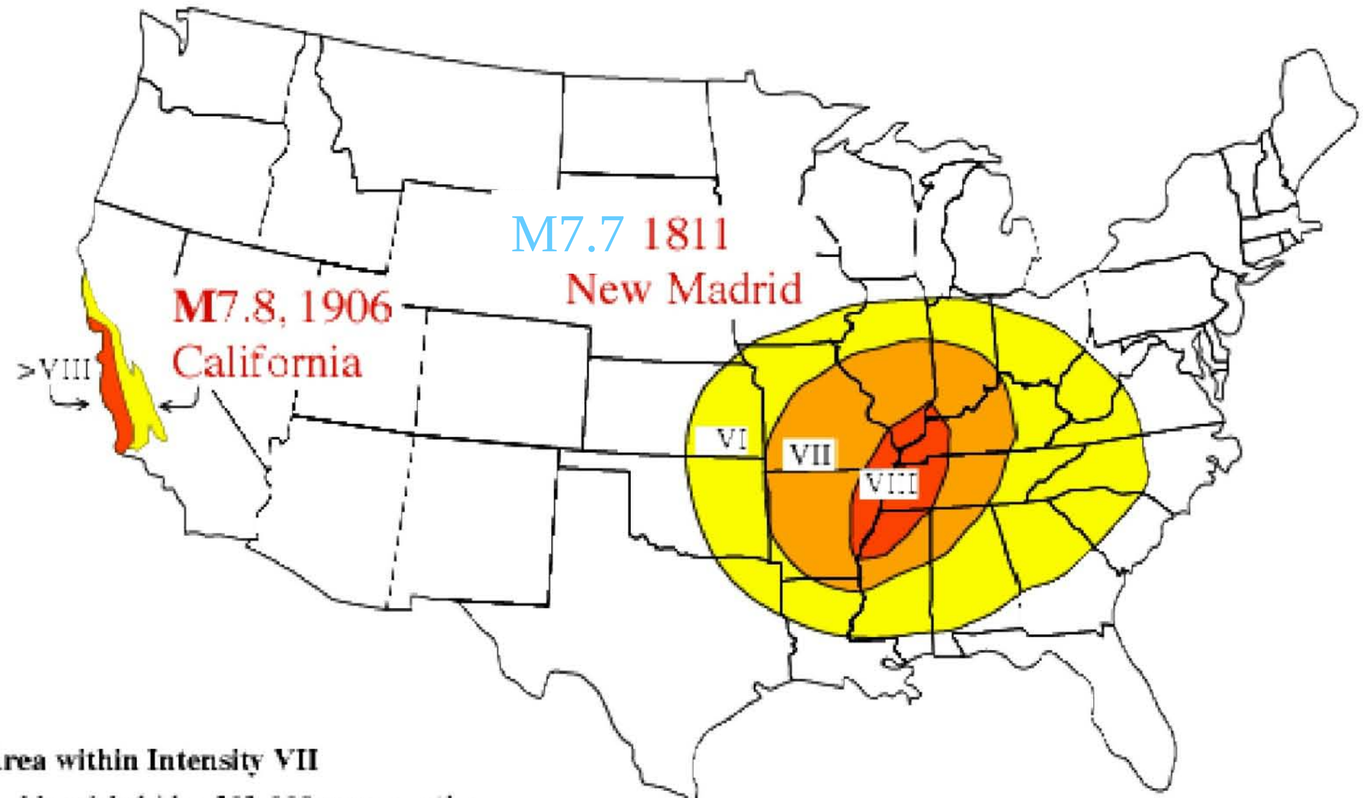


Modified From Frankel (1994), felt area-M data from Hanks and Johnston (1992)

How can seismic hazard around the New Madrid Seismic Zone be similar to that in California?

Higher ground motions (at high frequencies) for given magnitude, distance for CEUS earthquakes compared with WUS

- Higher Q in crust: less attenuation with distance
- Higher earthquake stress drop: more high-frequency ground motion for specified moment magnitude
- Determined from instrumental analysis of small and moderate events in eastern North America and isoseismals of large historic events

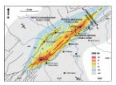


Area within Intensity VII

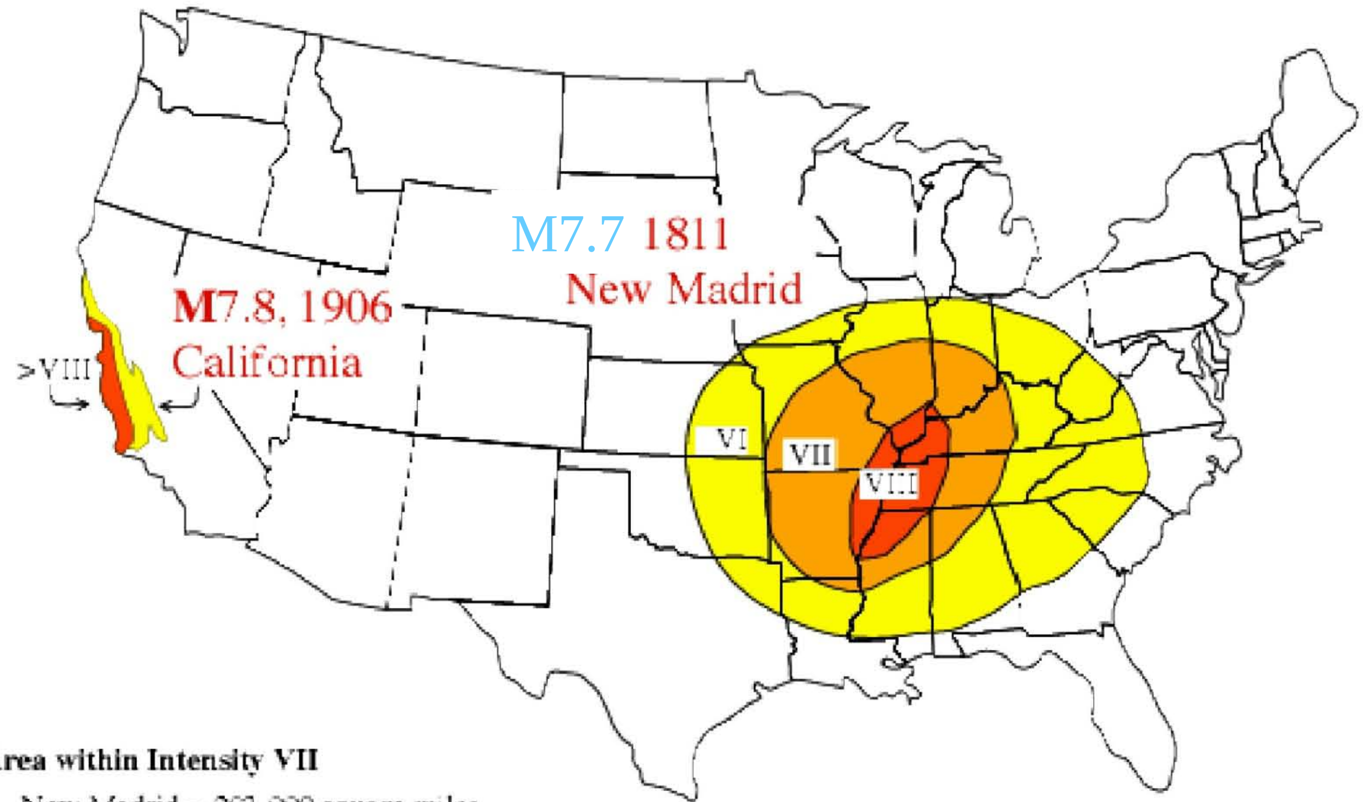
New Madrid = 203,000 square miles

San Francisco = only 12,000 square miles!

Slide from Joan Gomberg



EMS intensity for M7.9 Wenchuan earthquake (Lekkos, 2010)
Approx. same scale as U.S. map. Blue area is intensity VIII



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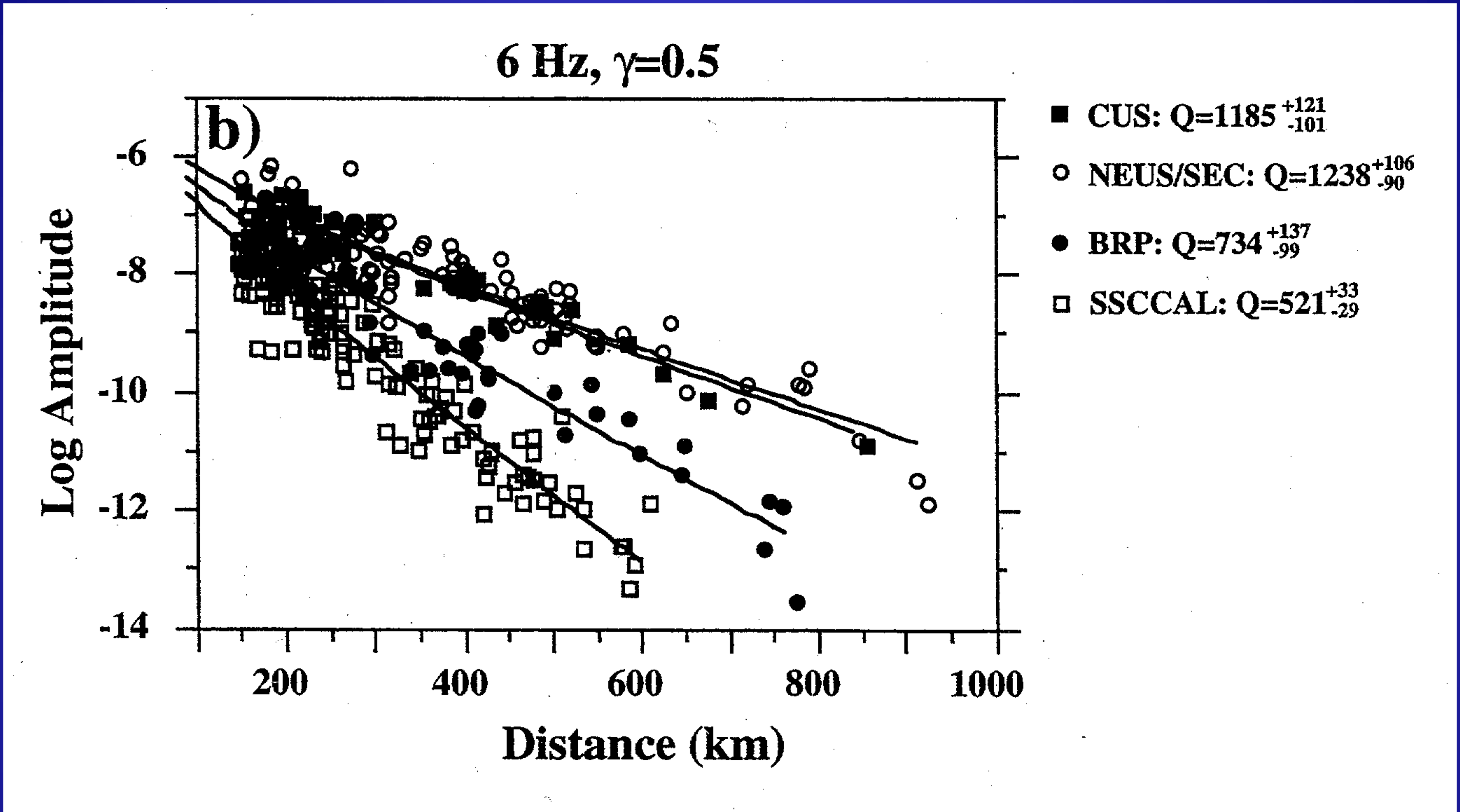
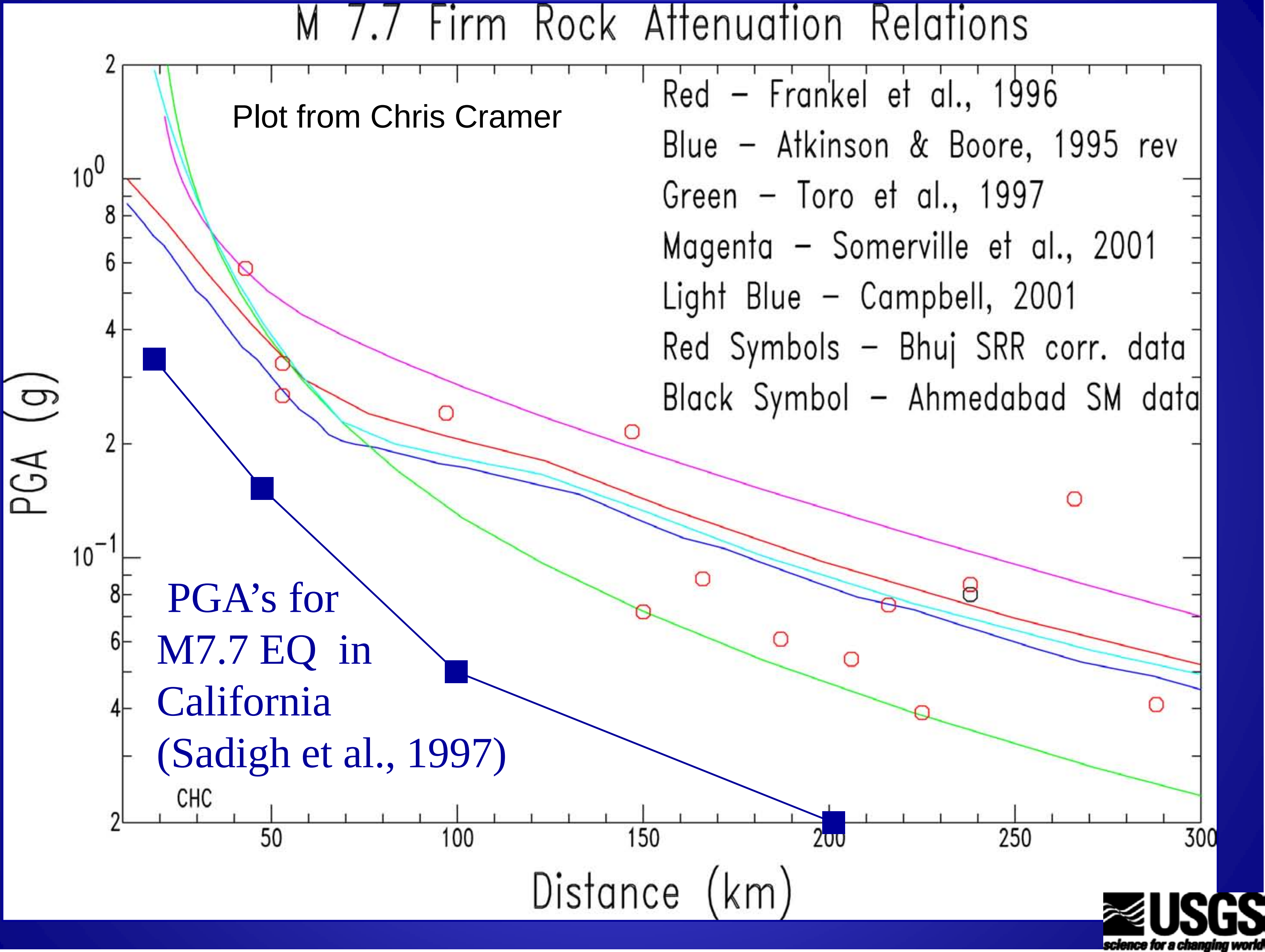


Distance-decay of regional shear waves determined by Benz et al. (1997)



M 7.7 Firm Rock Attenuation Relations
Plot from Chris Cramer
Red – Frankel et al., 1996
Blue – Atkinson & Boore, 1995 rev
Green – Toro et al., 1997
Magenta – Somerville et al., 2001
Light Blue – Campbell, 2001
Red Symbols – Bhuj SRR corr. data
Black Symbol – Ahmedabad SM data
PGA's for
M7.7 EQ in
California
(Sadigh et al., 1997)
CHC
PGA (g)
Distance (km)
2
10^0
8
6
4
2
10^{-1}
8
6
4
2
50
100
150
200
250
300
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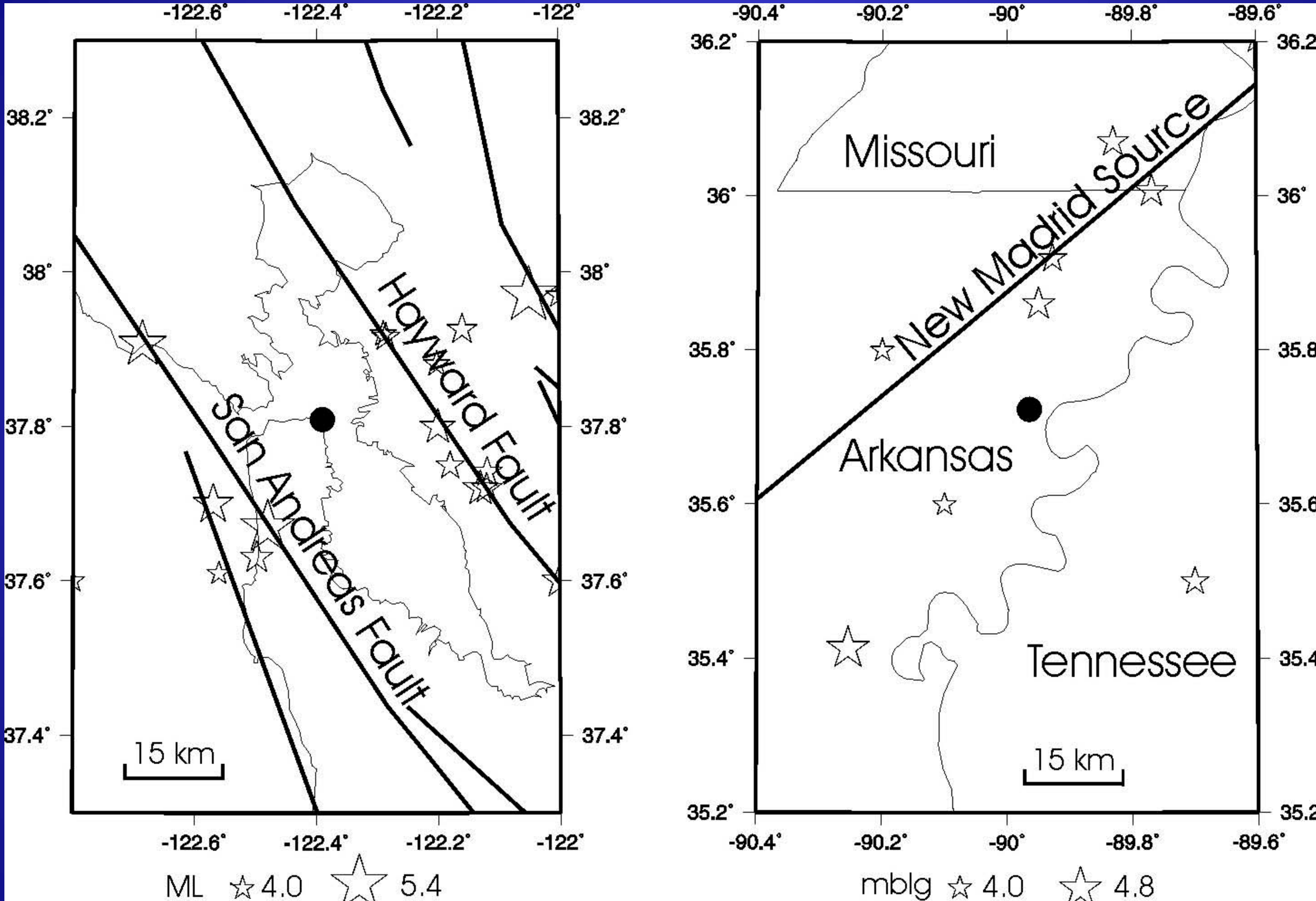
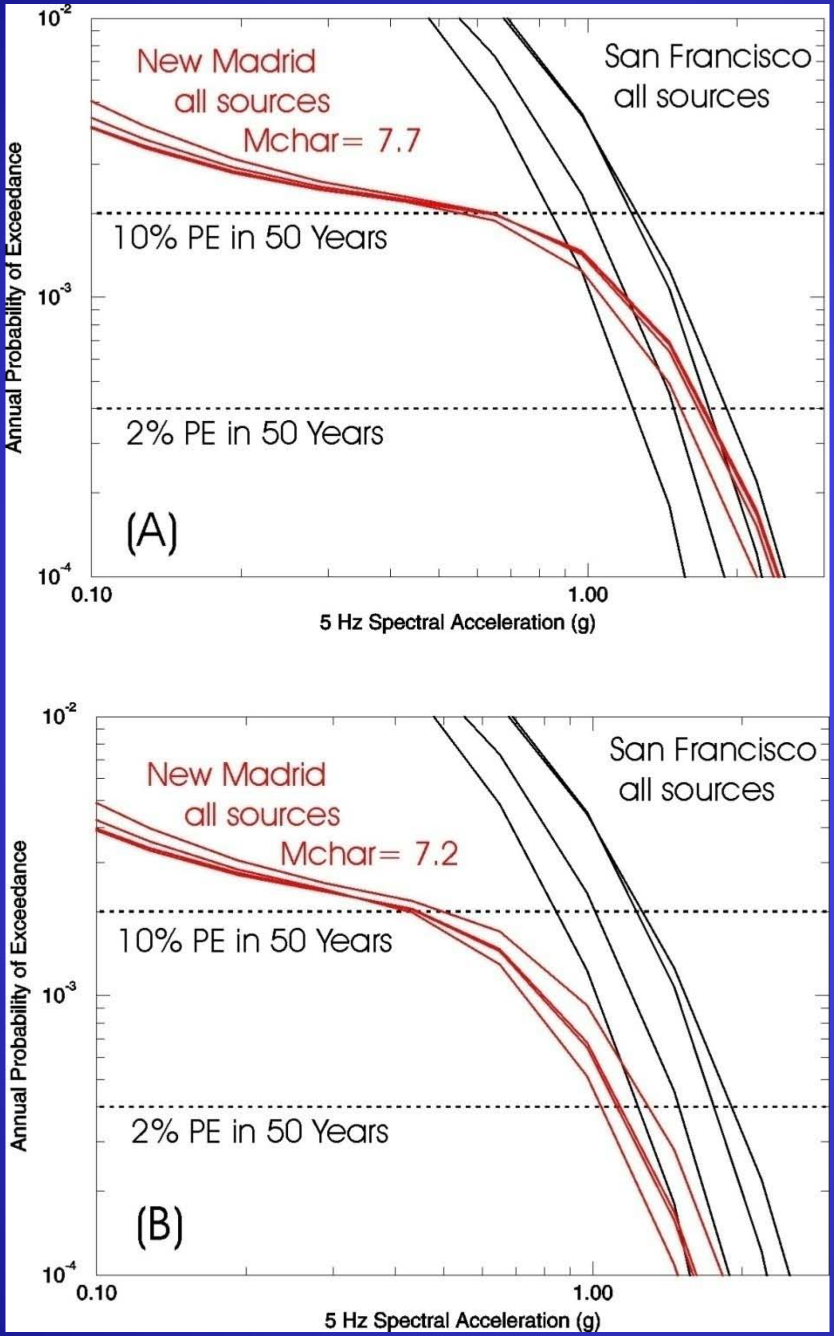

-122.6°
-122.4°
-122.2°
-122°
38.2°
38°
37.8°
37.6°
37.4°
Hayward Fault
San Andreas Fault
15 km
ML 4.0 5.4
-90.4°
-90.2°
-90°
-89.8°
-89.6°
36.2°
36°
35.8°
35.6°
35.4°
35.2°
Missouri
New Madrid Source
Arkansas
Tennessee
15 km
mblg 4.0 4.8



5 Hz Spectral Acceleration

Used in IBC

nominal natural frequency of 2 story building

Used EPRI attenuation relations for New Madrid

Figure from Frankel (2004)

Table 3. Weights for CEUS attenuation relations.

Single corner—finite fault	Weight
Toro and others (1997)	0.2
Silva and others (2002)—constant stress drop w/ saturation	0.1
Single corner—point source with Moho bounce	
Frankel and others (1996)	0.1
Dynamic corner frequency	
Atkinson and Boore (2006) 140 bar stress drop	0.1
Atkinson and Boore (2006) 200 bar stress drop	0.1
Full waveform simulation	
Somerville and others (2001) for large earthquakes	0.2
Hybrid empirical model	
Campbell (2003)	0.1
Tavakoli and Pezeshk (2005)	0.1

We adjust hard-rock values to firm-rock site condition

2009 NEHRP Provisions, 2010 ASCE 7, IBC2012

- Risk-targeted (1% chance of collapse in 50 years), uses entire hazard curve for calculation, integrates over fragility function
- As before, uses deterministic when 0.2 sec MCEr > 150%g and probabilistic is larger than deterministic

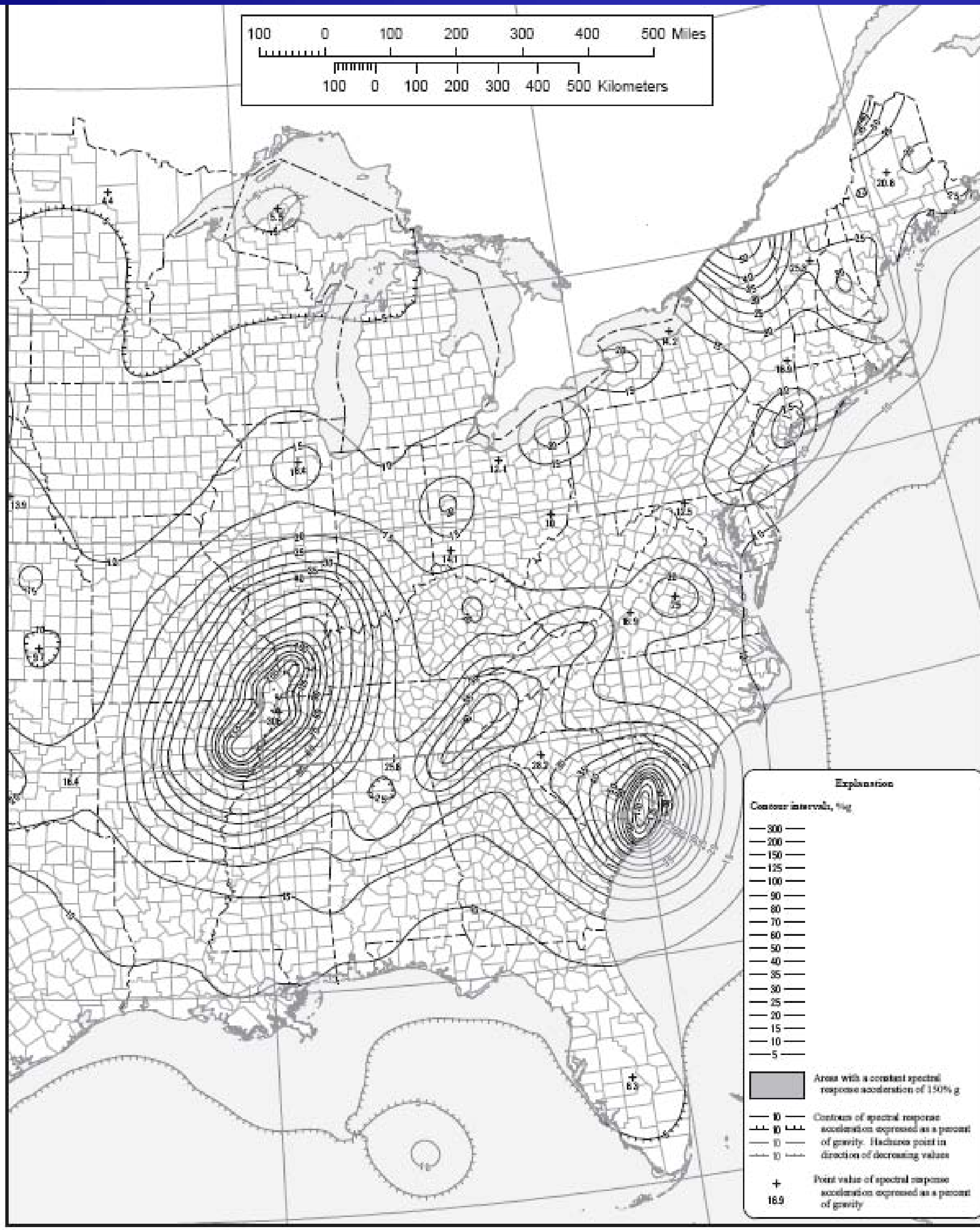
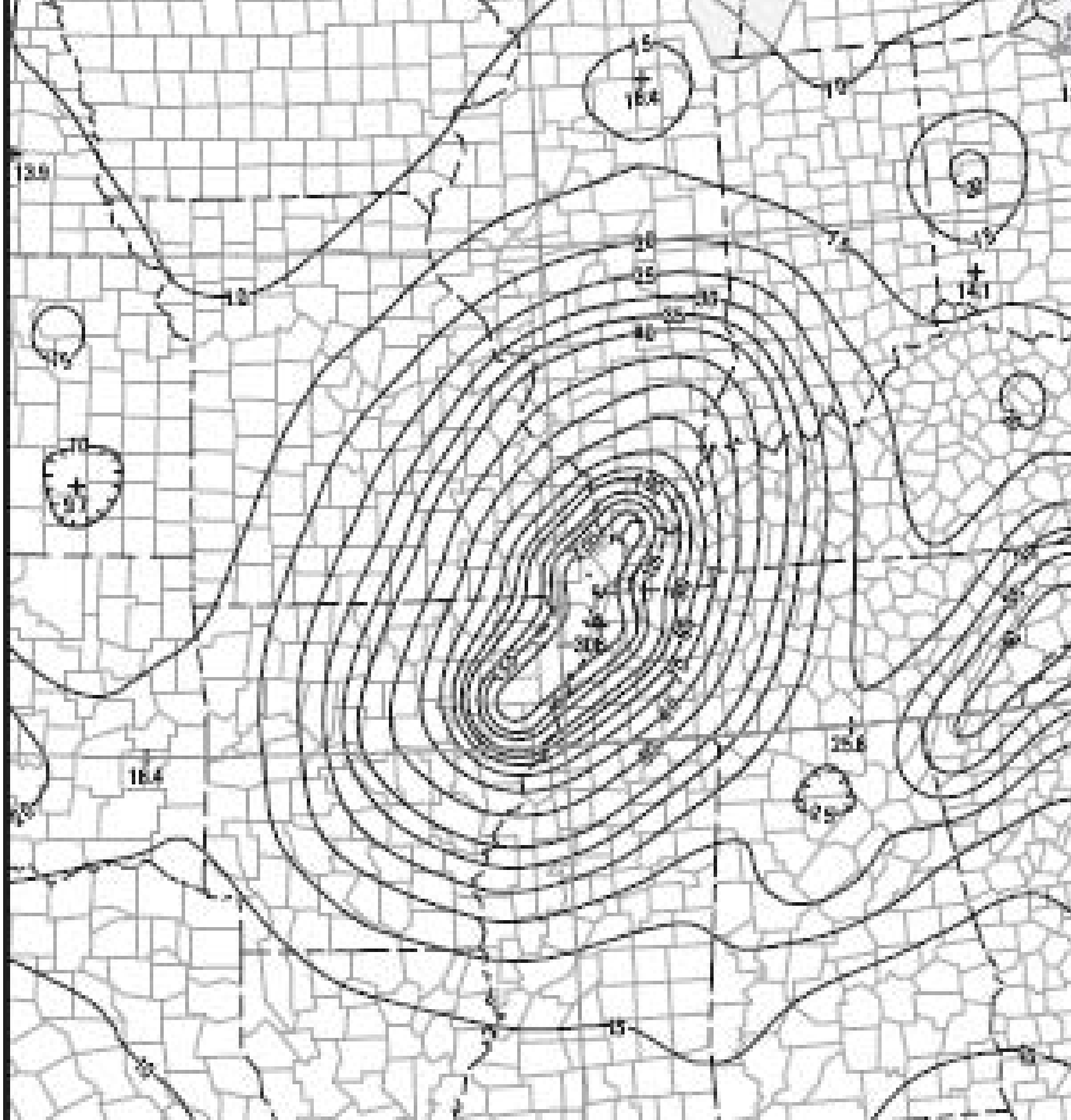


Figure 22-1 *(continued)* S_s Risk-Targeted Maximum Considered Earthquake (MCE_R) Ground Motion Parameter for the Conterminous United States for 0.2 s Spectral Response Acceleration (5% of Critical Damping), Site Class B.

2009, NEHRP Provisions
2010 ASCE 7
2012 IBC

0.2 sec MCEr map multiply by 2/3 for design value



15
18.4
20
25
30
35
40
12
14.1
16.4
15

PGA values derived from 0.2 sec S.A. design values from 2010 ASCE 7 divided by 2.25

- Memphis: 33%g PGA
- Paducah: 37%g PGA
- San Francisco: 44%g PGA
- Center of NM zone: 89%g PGA
- On San Andreas fault near SF: 78%g PGA
- PGA in northern San Fernando Valley from Northridge EQ: 80-100%g PGA
- Near source PGA in M7.9 Wenchuan EQ: 70-90%g PGA (an eq with CA characteristics)

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1994 UBC Zone Map

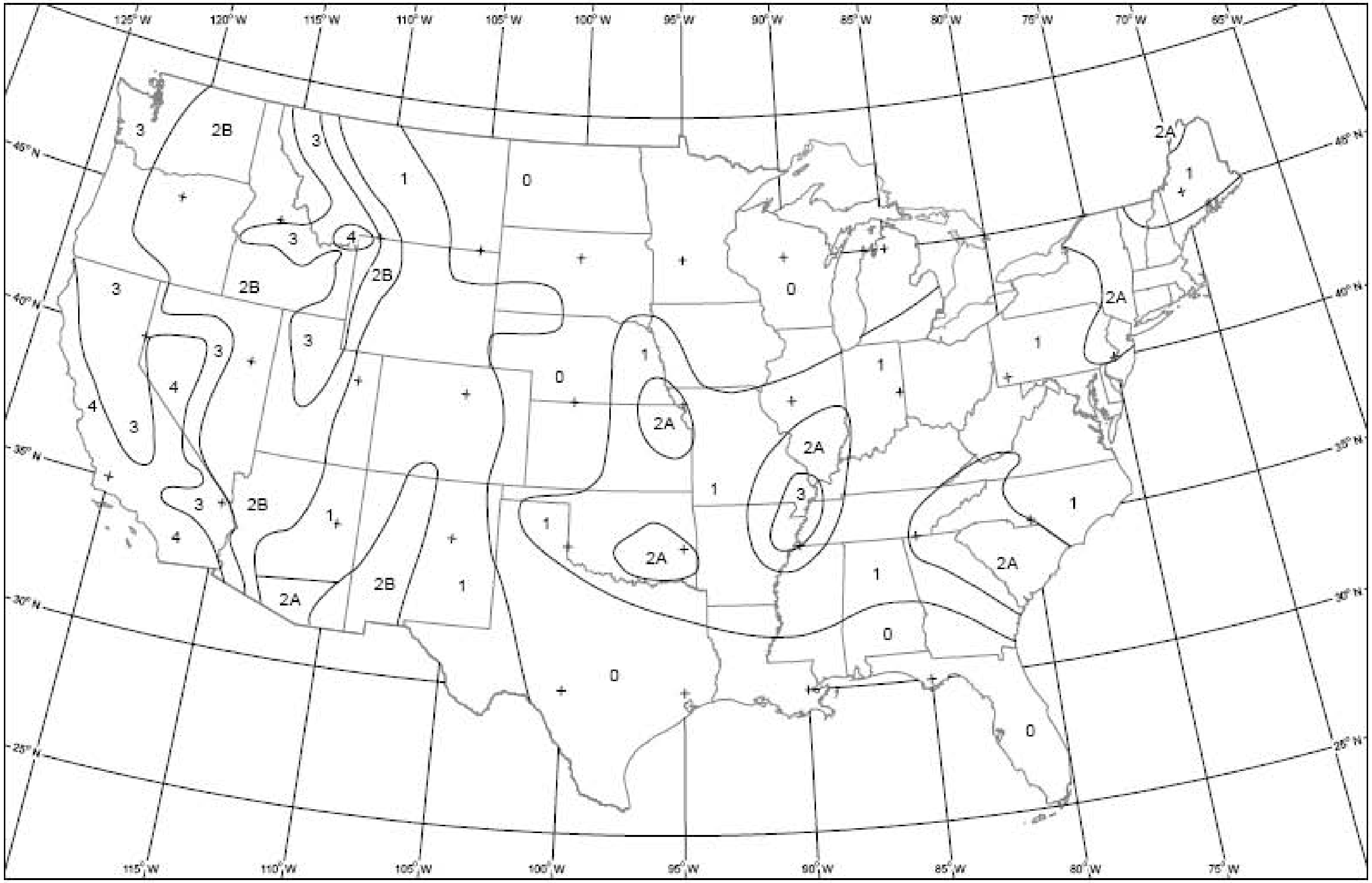
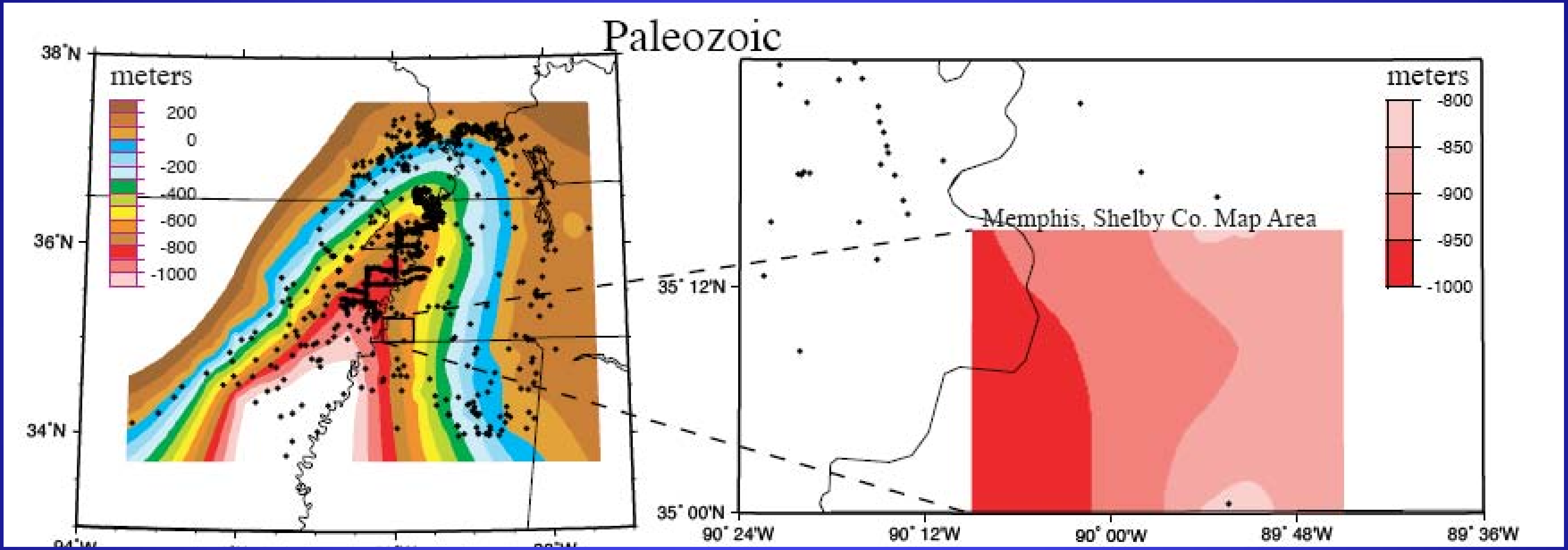


Figure A7. 1994 Uniform Building Code zone map. Zones are identified by the numbers from 0 to 4. Seismic zone factors are assigned to each zone; Zone 0 = 0, Zone1 = 0.075, Zone 2A = 0.15, Zone 2B = 0.20, Zone 3 = 0.3, and Zone 4 = 0.4. Each zone also has specific structural detailing requirements. After ICBO, 1994 (This map was redrawn from the original source, if differences occur, the original source should be used).

used Algermissen and Perkins (1976) hazard map for guidance

Thickness of Mississippi Embayment



From Cramer et al. (2004)

Embayment can deamplify 5 Hz S.A. and amplify 1 Hz S.A. compared to NEHRP amp factors

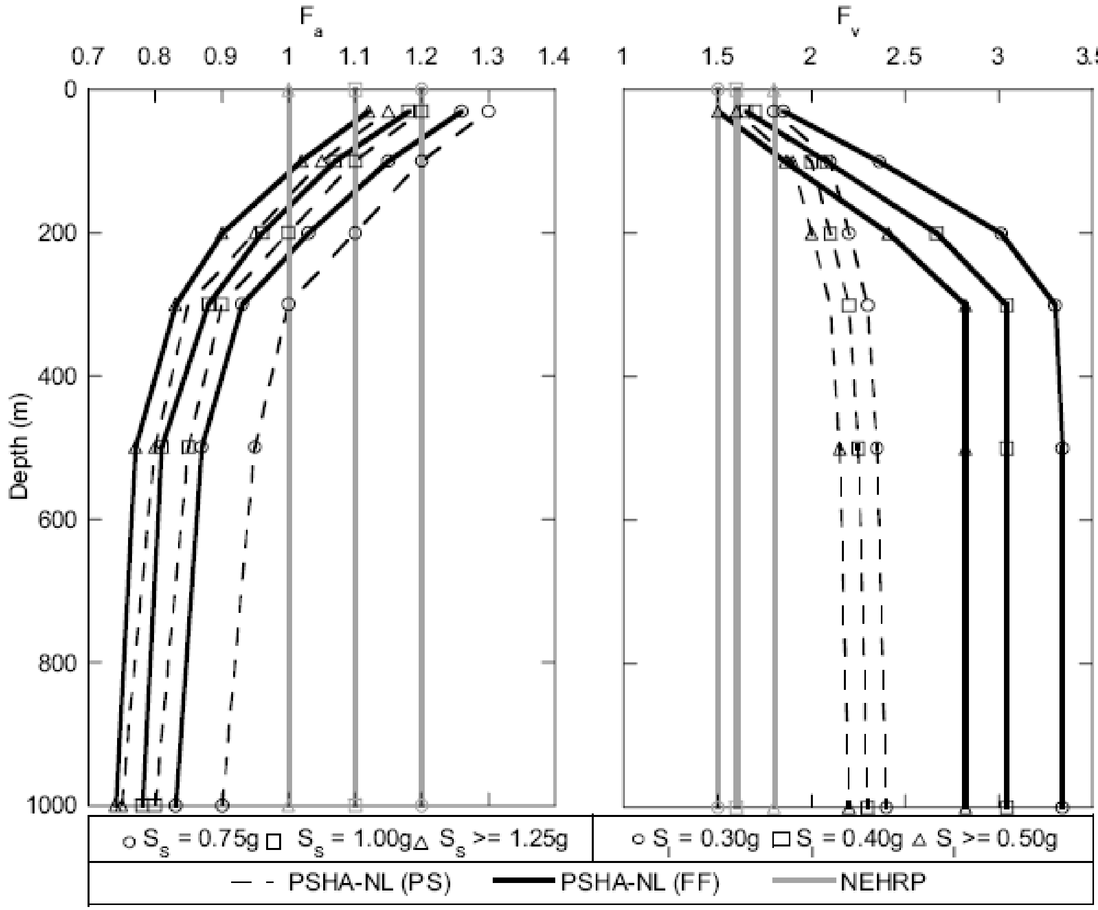
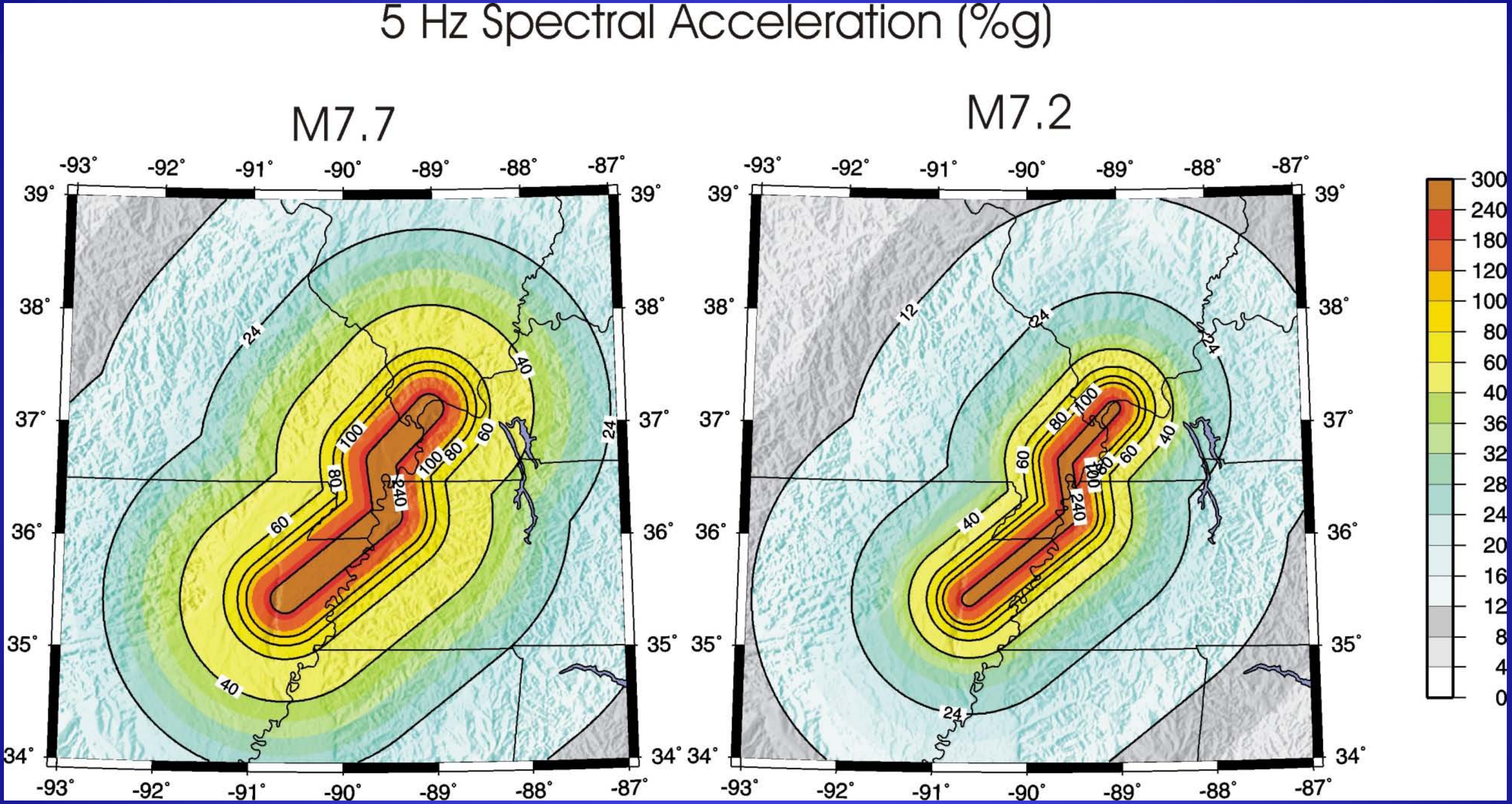


Figure 8. Simplified NEHRP-style depth-dependent site coefficients evaluated from PSHA–NL (FF) using the uplands profile and PSHA–NL (PS) using the upland profile with ME properties.

From Hashash et al. (2004)



For firm-rock site condition

Some New Madrid Research Issues

- Site amplification and nonlinearity for Mississippi Embayment
- Ground shaking levels from 1811-12 earthquakes inferred from liquefaction limits; landslides
- Crustal deformation in an intraplate area with denser GPS monitoring, InSAR
- Search for episodic tremor and slip