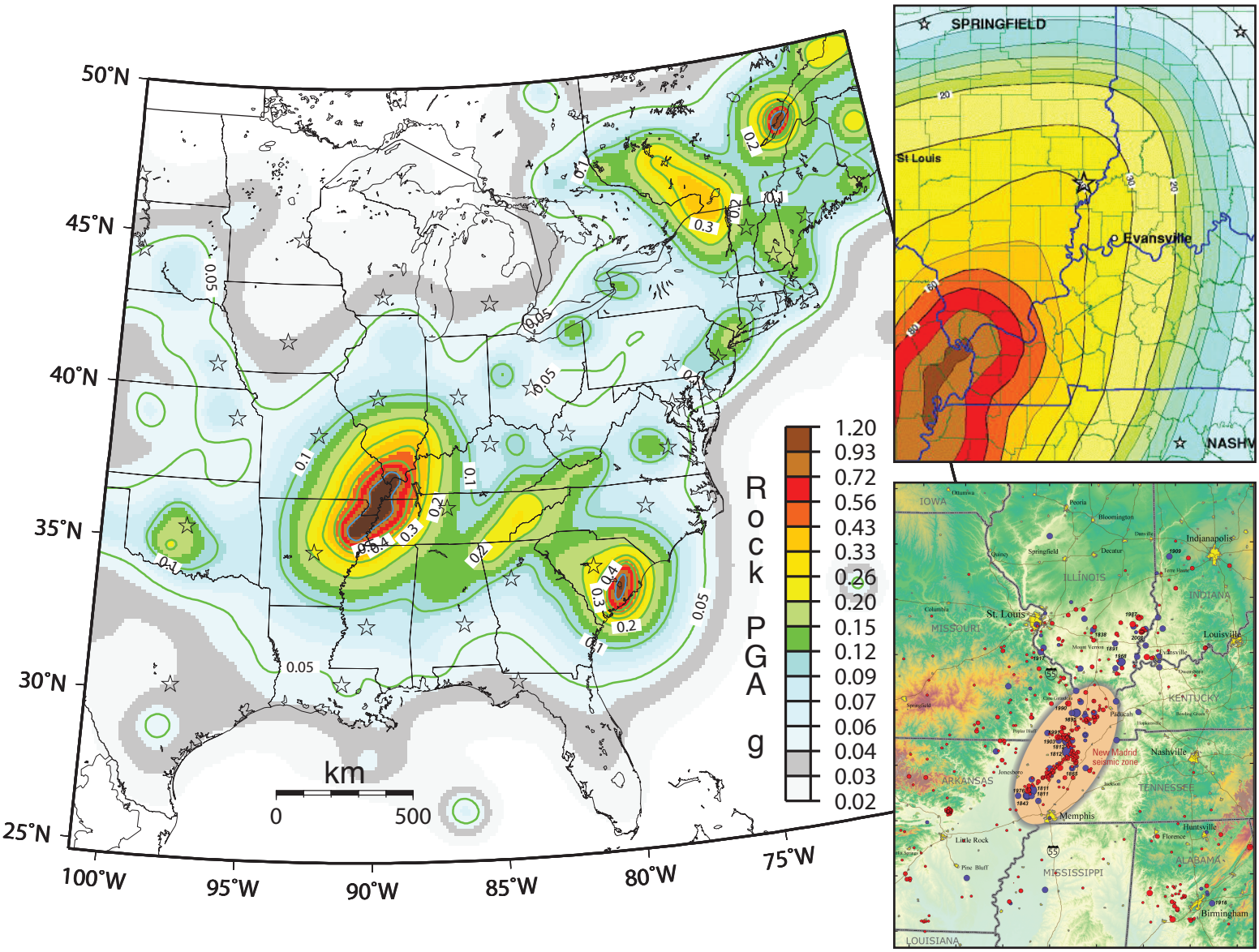
Meeting of Central and Eastern U.S. (CEUS) Earthquake Hazards Program

October 28-29, 2009
Memphis, TN



USGS
science for a changing world

Larry Salomone

CEUS SSC Project Manager

Development of CEUS Seismic Source Characterization Model

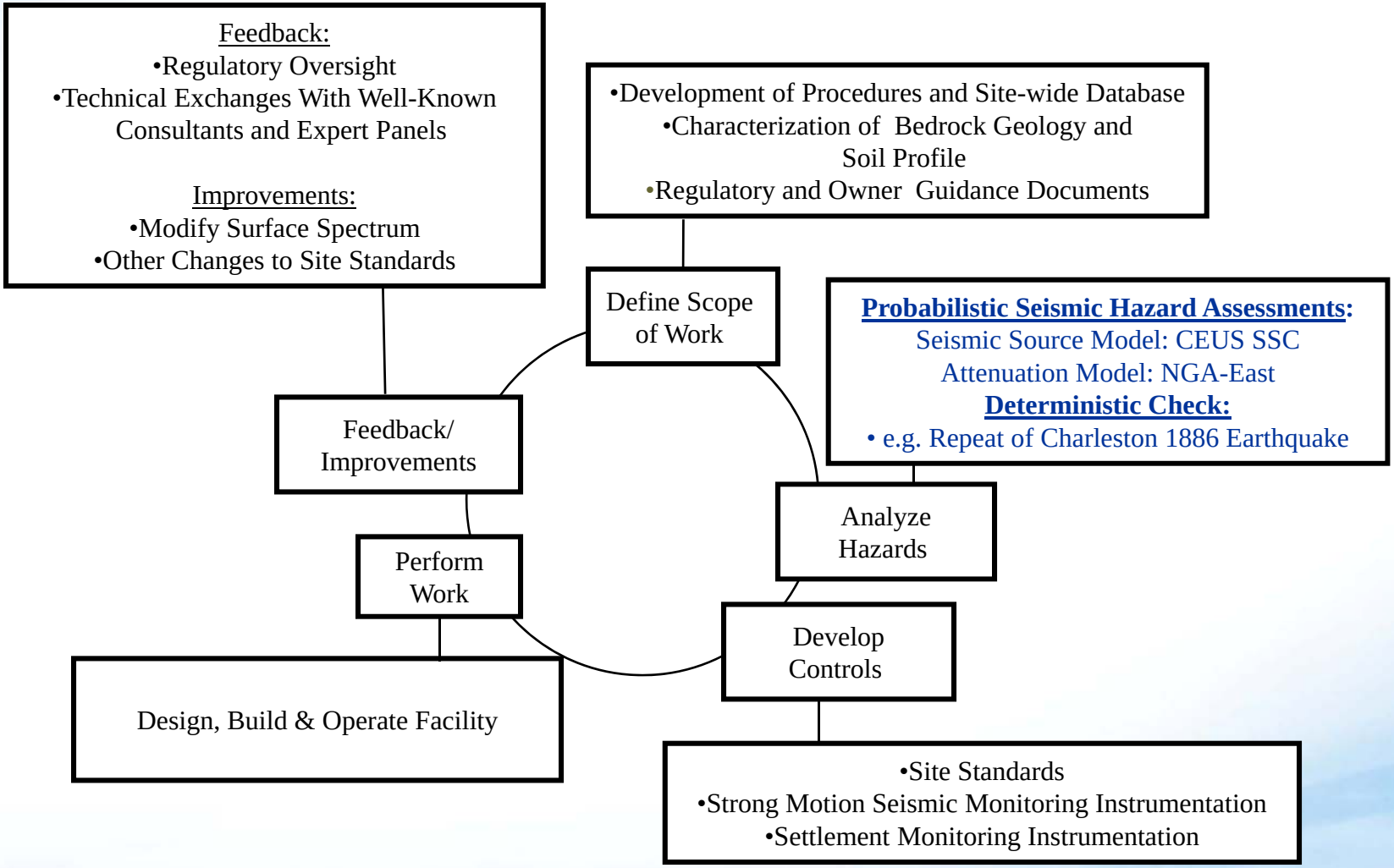
Earthquake Hazards Program Meeting
October 28-29, 2009
Memphis, TN

Lawrence Salomone
Project Manager

GENERAL GUIDING PRINCIPLES

- 1) Managing the seismic issue is critical to control cost and delays for critical mission nuclear facilities.
- 2) Having a stable, consistent and defensible seismic design spectrum throughout the design phase of critical mission nuclear facilities is essential.
- 3) Accomplishing more for less with reduced risk through standardization and partnering is important to advance science and the state of practice.

Disciplined, Systematic Approach to Seismic Safety



SSHAC Goal of Capturing Informed Technical Community

(excerpted from K.Coppersmith WS#3 Presentation, 8/25-26/09)

- Represent the views of the informed technical community
  - "Regardless of the scale of the PSHA study, the goal remains the same: to represent the center, the body, and the range of technical interpretations that the larger informed technical community would have if they were to conduct the study." (SSHAC, p.21)
- Informed
  - Familiar with site-specific databases
  - Have been through the same interactive process
- Not just aggregation process for parameter values across a panel of experts
  - Very few parameters can be directly assessed in PSHA
  - Need to evaluate data, develop models, quantify uncertainties in conceptual models
  - Consensus required only that composite (community distribution) is appropriate
- The assessment that have captured ITC is very similar to the "reasonable assurance" standard used by regulatory community
  - It is the preponderance of the evidence that allows a decision to be made in the face of uncertainty
- In the end, a properly conducted SSHAC process will provide reasonable assurance that the ITC has been captured

Seismic Source Characterization (SSC) Model - Project Milestones

- Project Plan as EPRI Technical Update – June, 2008 (Completed)
- Workshop #1: Significant Issues and Databases – July 21-23, 2008 (Completed)
- Workshop #2: Alternative Interpretations – February 18-20, 2009 (Completed)
- Complete Database and Seismicity Catalog Development – June 30, 2009 (Completed)
- Workshop #3: Feedback on CEUS SSC Sensitivity Model – August 25-26, 2009 (Completed)
- Complete Hazard Input Document (HID) for Preliminary CEUS SSC model – February 26, 2010
- Construct Final CEUS SSC Model – April 30, 2010
- Paleoliquefaction Task Report – June 15, 2010
- Prepare Draft Technical Report and Perform Other Report Preparation Tasks– July 31, 2010 to December 31, 2010
  - Review of Draft Report by PPRP
  - Incorporate Review Comments
  - Review project documentation for transparency
  - Prepare internal documentation package to document computer codes and archive hazard calculations
  - Obtain copyright releases for GIS database as required
- Publish Final Technical Report – December 31, 2010

A Sound-Science Plan for U.S. Energy Independence

(Prepared By Larry Salomone, 7/19/08)

Develop Communication Plan For Energy Independence

Box 10

Box 1

Increase Oil & Natural Gas Supplies

(Transition to Alternate Energy Sources)

•Drill U.S. Land/Offshore Reserves (2010 – 2015)
•Convert Coal to Oil
•Develop Oil Shale Reserves

Box 2

Build New Oil Refineries (2015)
•Improve Geographic Coverage

Box 4

Reduce Material & Construction Costs
•Incentive for U.S. mfg. industry

Box 6

Use Nuclear Power to Produce Hydrogen for High Volume Users (2020)

Reduce Use of Natural Gas to Produce Hydrogen:
•Petrochemical Industry
•Fertilizer Manufacturing Companies

Box 3

Increase Base-load Supply
•Build Nuclear Power Plants
•50 Units (25% of U.S. Demand) (2016 - 2020)
•300 Units (70%+ of U.S. Demand) (2050)

Box 7

Reduce Gasoline Consumption

•Use Plug-In Hybrid Electric Cars (2010)
•Use Hydrogen-Powered Buses and Cars (ICE:2015; FC:2020)
•Reassess new ethanol production requirements

Box 8

Supplement Energy Supply
License new clean coal facilities if research confirms soundness of clean coal technology (ongoing)
•Build Biomass Facilities (2014)

Box 5

Expand/Modernize Infrastructure
•Upgrade Bulk Power Grid (Ongoing)
•License Spent Fuel Underground Repository (2020)
•Build Reprocessing Facilities(2020)

Box 9

Supplement Energy Supply
•Use wind & solar if applicable (ongoing)
•Requires lines to get power to grid & T&S

Laura Glaser

AmeC Geomatrix

CEUS Earthquake Catalog

Meeting of CEUS Earthquake Hazards Program

October 28-29, 2009

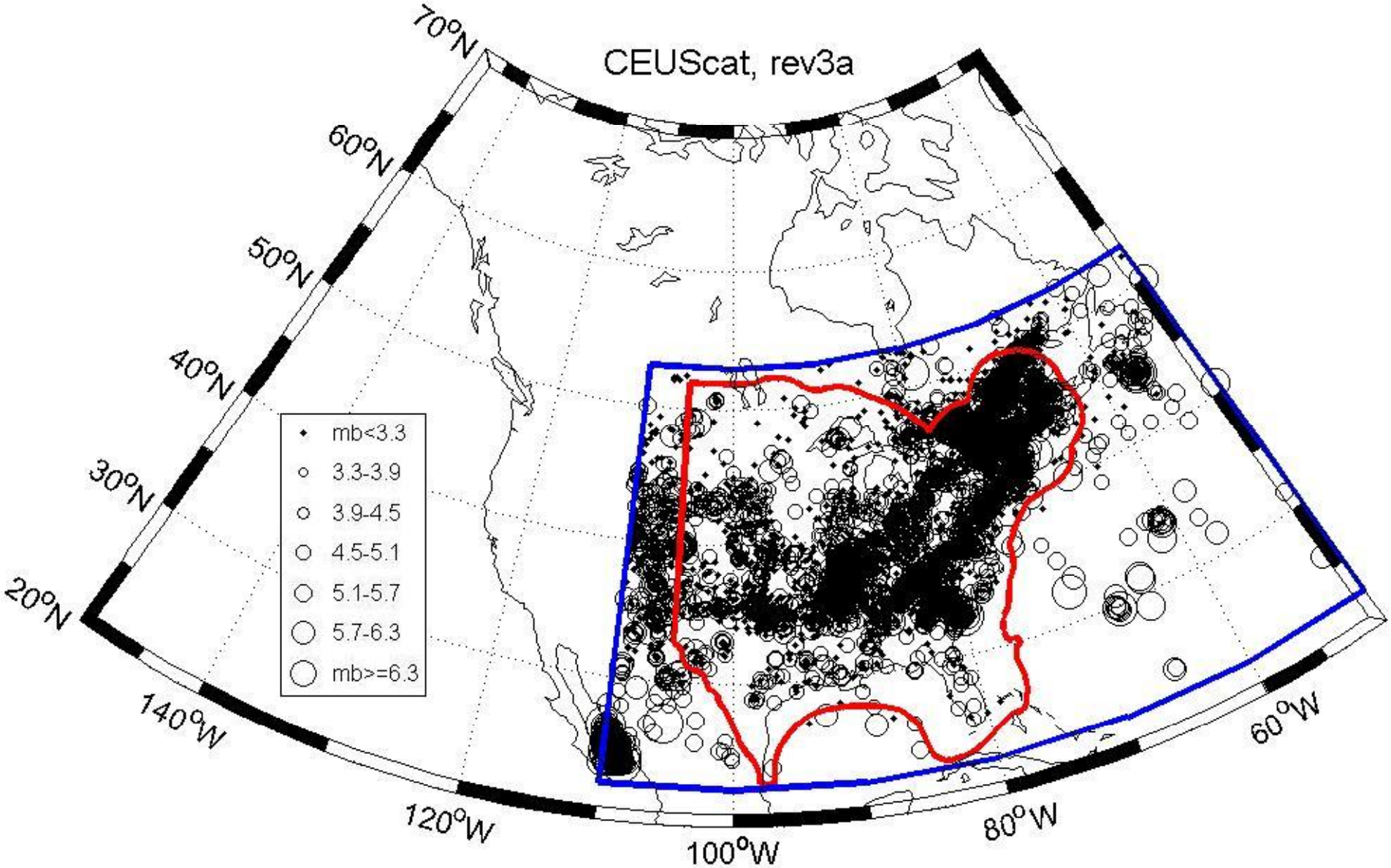
Valentina Montaldo-Falero
Laura Glaser
Bob Youngs
AMEC Geomatrix

AMEC Geomatrix

Catalog Development

- Compile events from CEUS catalogs
- Assign each event a unique ID
- Create database that preserves duplicates
- Choose a preferred entry
- Update fields from literature (location, depth, etc.)
- Flag non-tectonic events
- Remove duplicates
- Develop conversions to moment magnitude
- Decluster
- Assess completeness

CEUS Project Catalog



Catalog Sources

National Sources – USGS, GSC SHEEF, NCEER, EPRI-SOG, ANSS, NEDB (Canada), ISC

Regional Sources – CERI, SUSN, SLU, Lamont Doherty, Weston Observatory (NEUSSN), Ohio Seis, Pennsylvania Catalog, Sykes (NY-Philadelphia), Bechtel - VC

Historical Catalogs – Hopper, Metzger, Munsey

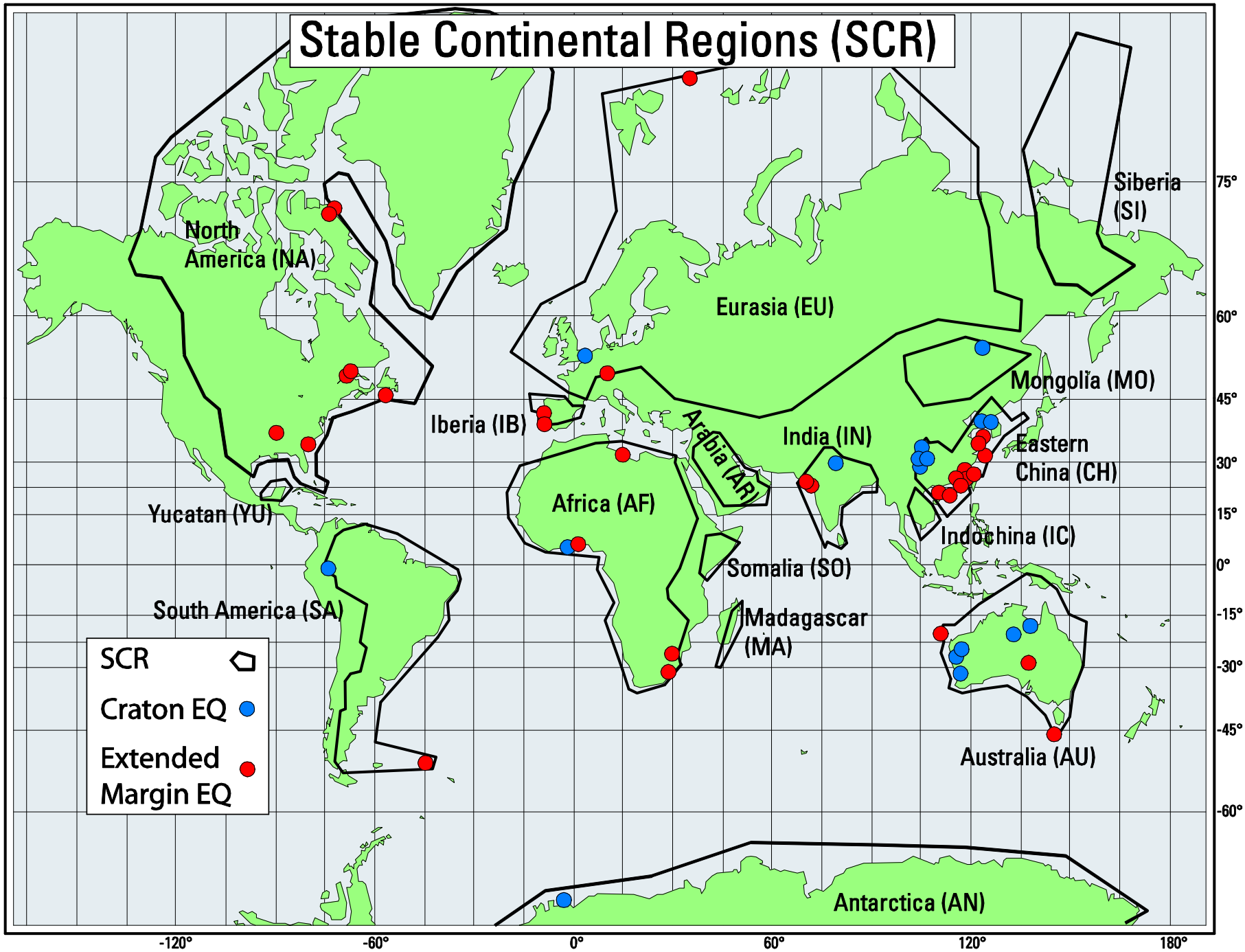
Relocated Events – Seeber and Armbruster (1993); Ruff et al. (1994); Faust et al. (1994); Lamontagne and Ranalli (1997); Dineva et al. (2004); Ma and Atkinson (2006); Ma and Eaton (2007); Ma et al. (2008)

Non-tectonic Events – Nation Earthquake Data Base (Canada), ANSS, ISC blast list, COLAs, Literature

Catalog Now In Review - Selection of preferential catalog entries, Identify additional data sources that should be included

Russ Wheeler

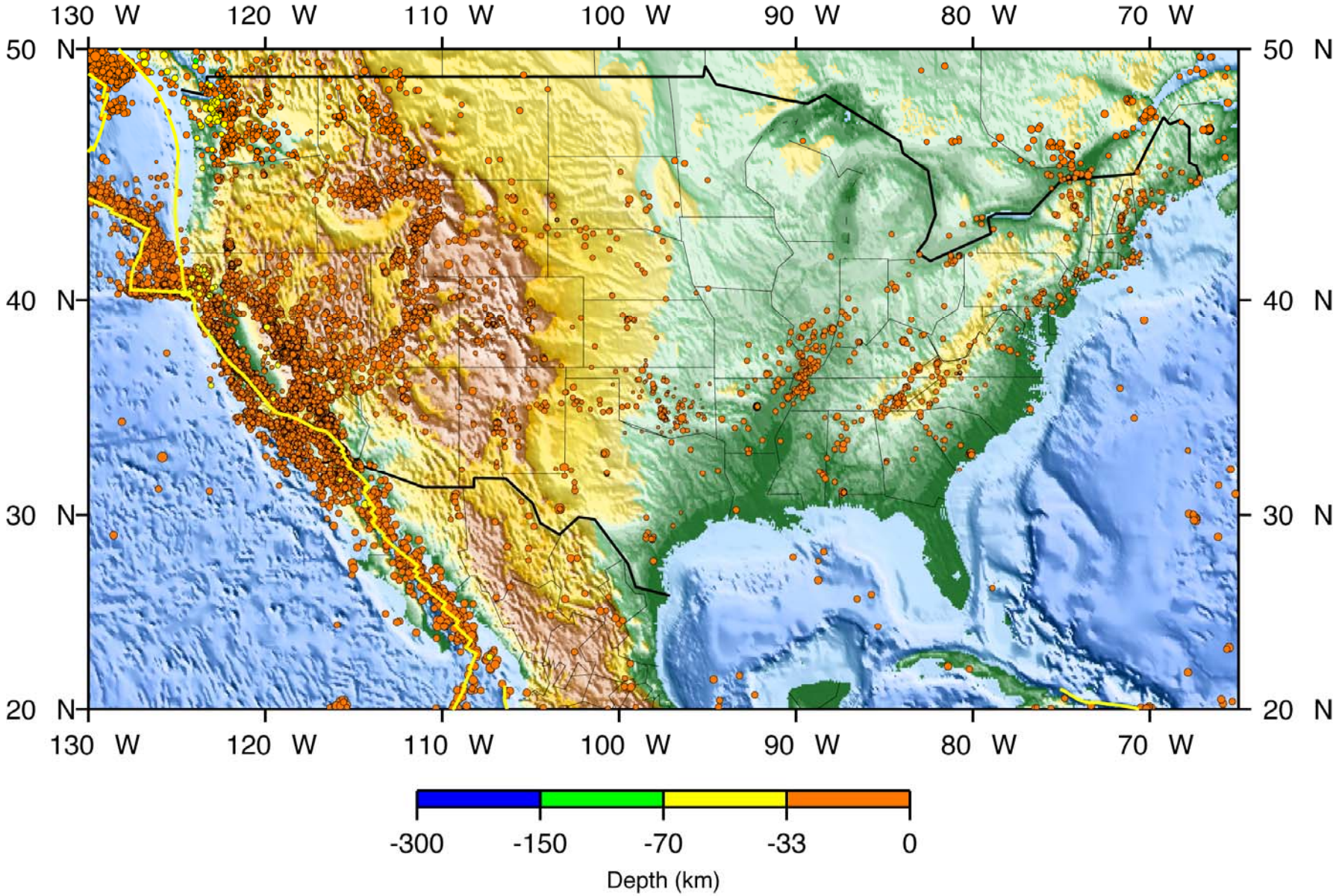
US Geological Survey


Stable Continental Regions (SCR)
North America (NA)
Eurasia (EU)
Siberia (SI)
Mongolia (MO)
Iberia (IB)
Arabia (AR)
India (IN)
Eastern China (CH)
Africa (AF)
Yucatan (YU)
Indochina (IC)
Somalia (SO)
South America (SA)
Madagascar (MA)
Australia (AU)
Antarctica (AN)
SCR
Craton EQ
Extended Margin EQ
75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
-120°
-60°
0°
60°
120°
180°

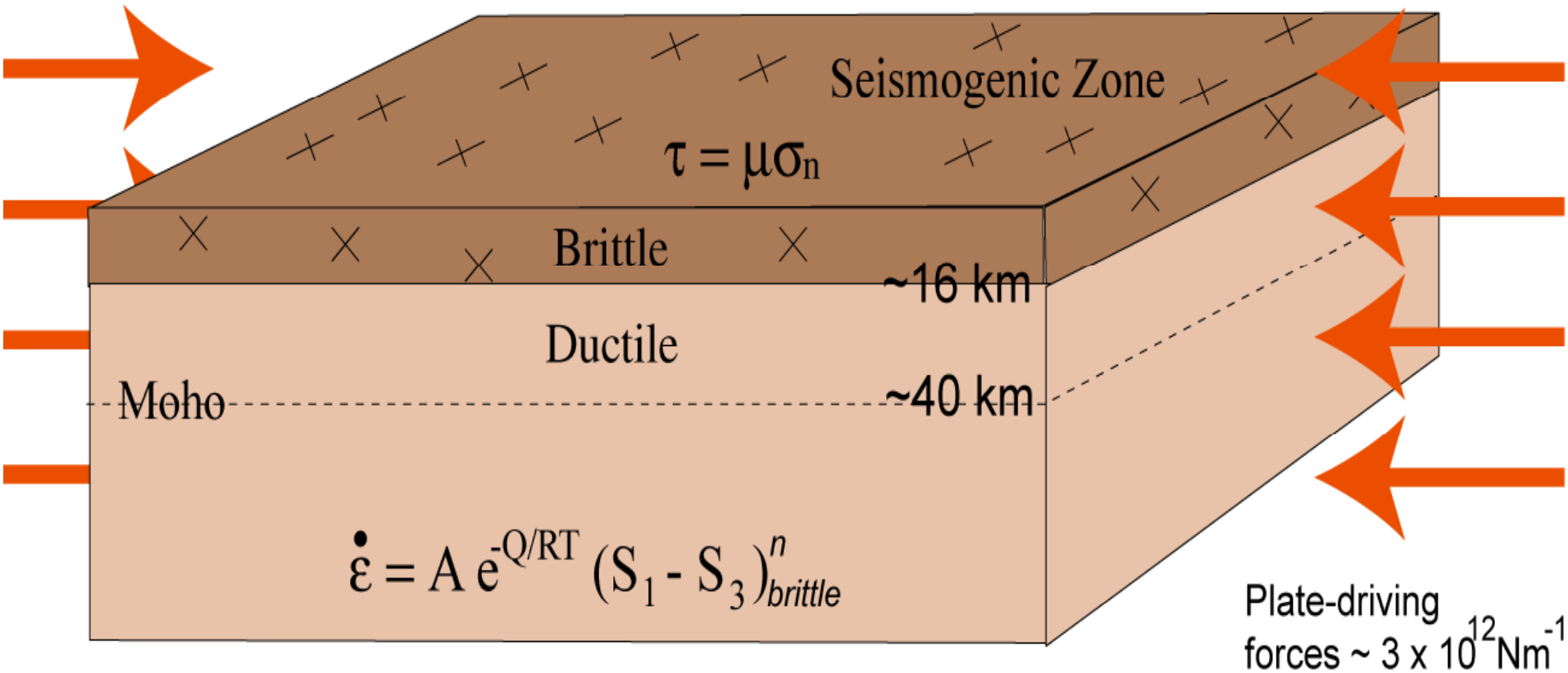
Walter Mooney

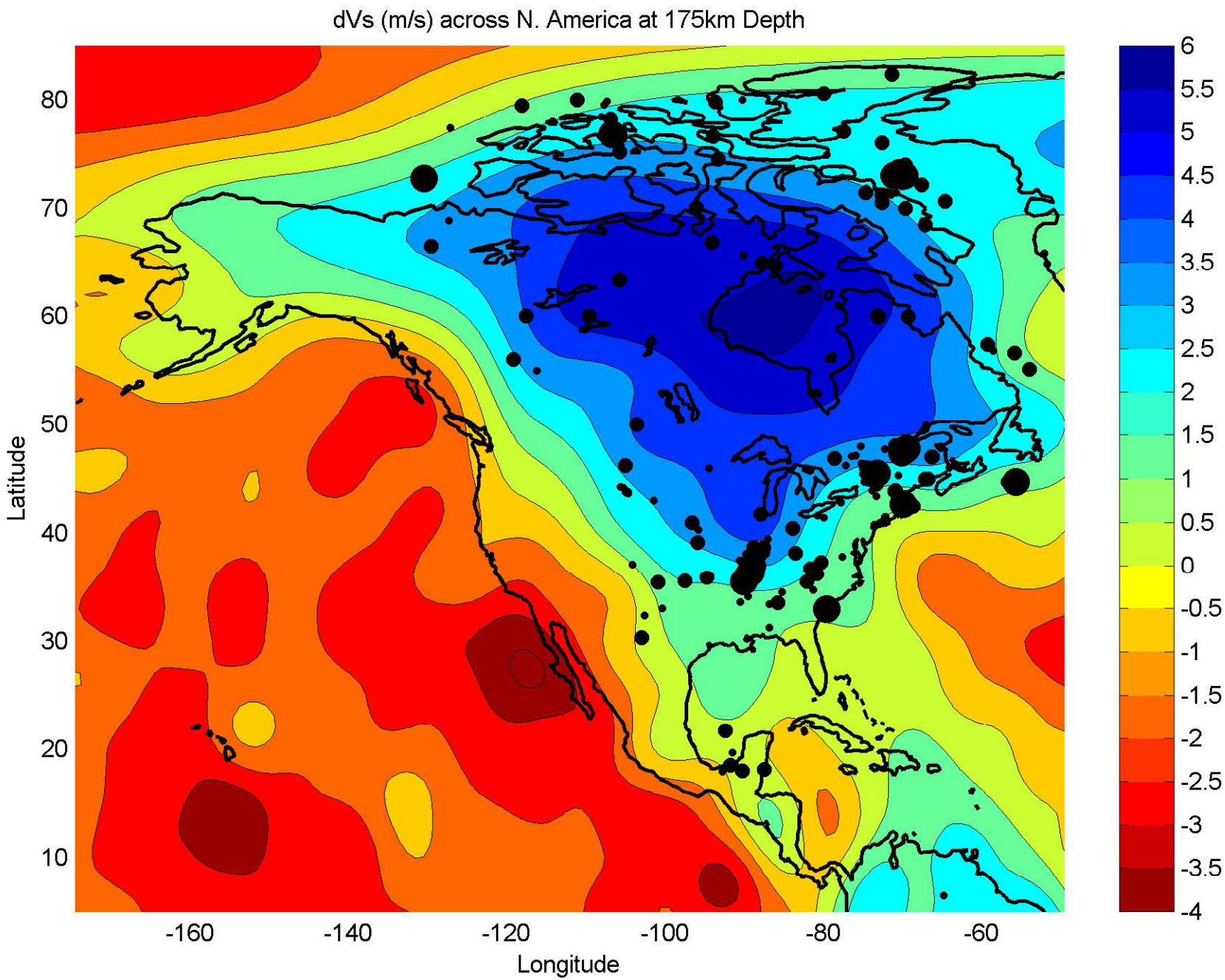
US Geological Survey

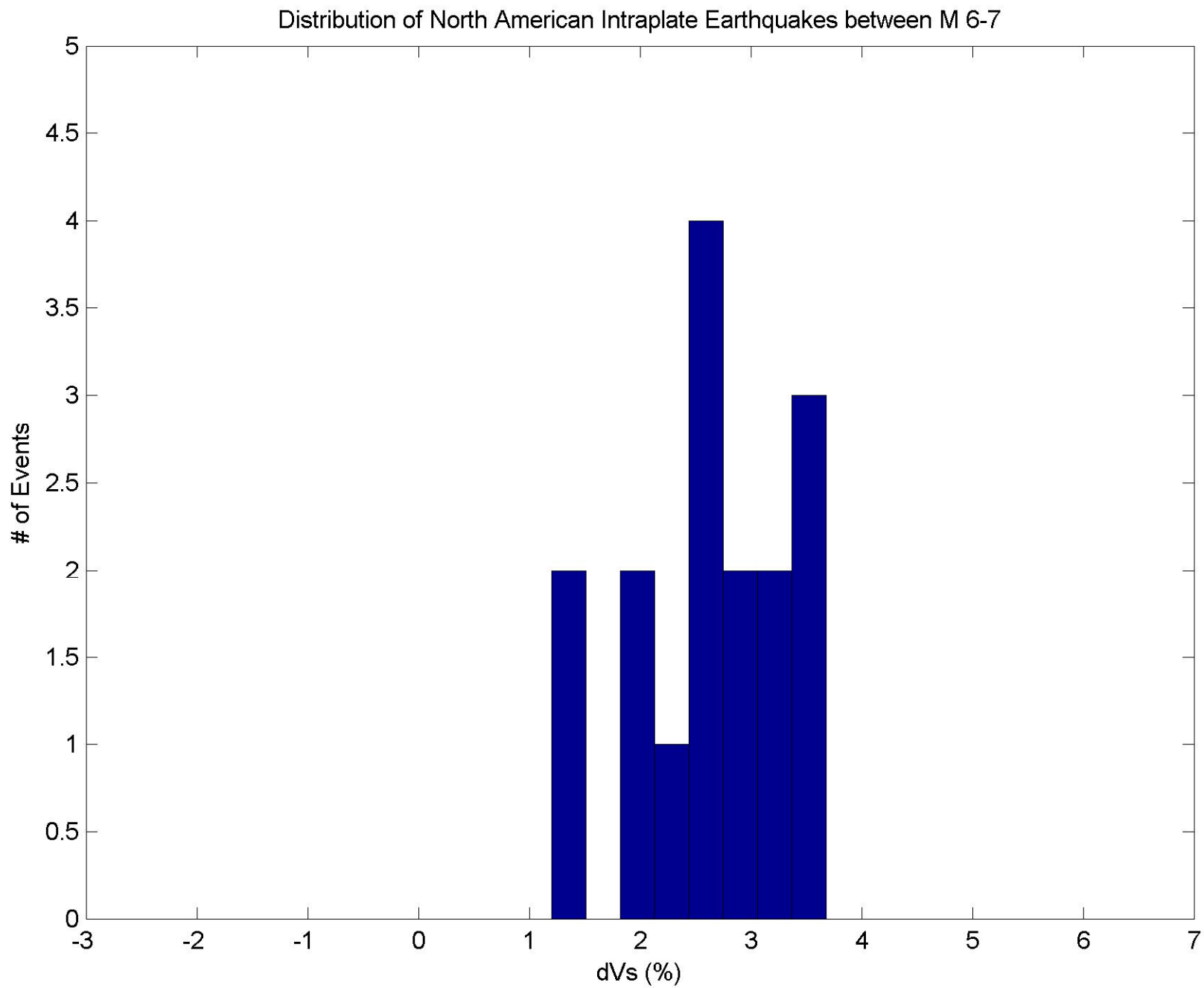
Seismicity of the US, 1977-1997



Lithosphere is Generally in a State of Failure Equilibrium




dVs (m/s) across N. America at 175km Depth
Latitude
80
70
60
50
40
30
20
10
-160
-140
-120
-100
-80
-60
Longitude
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4


Distribution of North American Intraplate Earthquakes between M 6-7
# of Events
dVs (%)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
-3
-2
-1
0
1
2
3
4
5
6
7

John Ebel

Boston College

Weston Observatory

Dept. of Geol. & Geophys.
Boston College

Aftershock and Foreshock Statistics in the NEUS: The Approach

- Collect a dataset of foreshocks and aftershocks from large (M≥6) stable continental region (SCR) earthquakes worldwide. Determine the time and magnitude of the largest foreshock and aftershock (if any) for each mainshock.

- Determine the Omori-Law parameters (a, b, and p) for SCR aftershock sequences. Augment the M≥6 dataset with aftershock sequences for M<6 earthquakes where local monitoring has accumulated aftershock data. Compare these Omori-Law parameters to those for earthquakes in California.

- Assume that the foreshock and aftershock data for SCR events follow the same distributions as that in the central and eastern U.S. (CEUS). Develop recommended procedures for foreshock and aftershock forecasts for the CEUS based on the SCR and California data.

Weston Observatory

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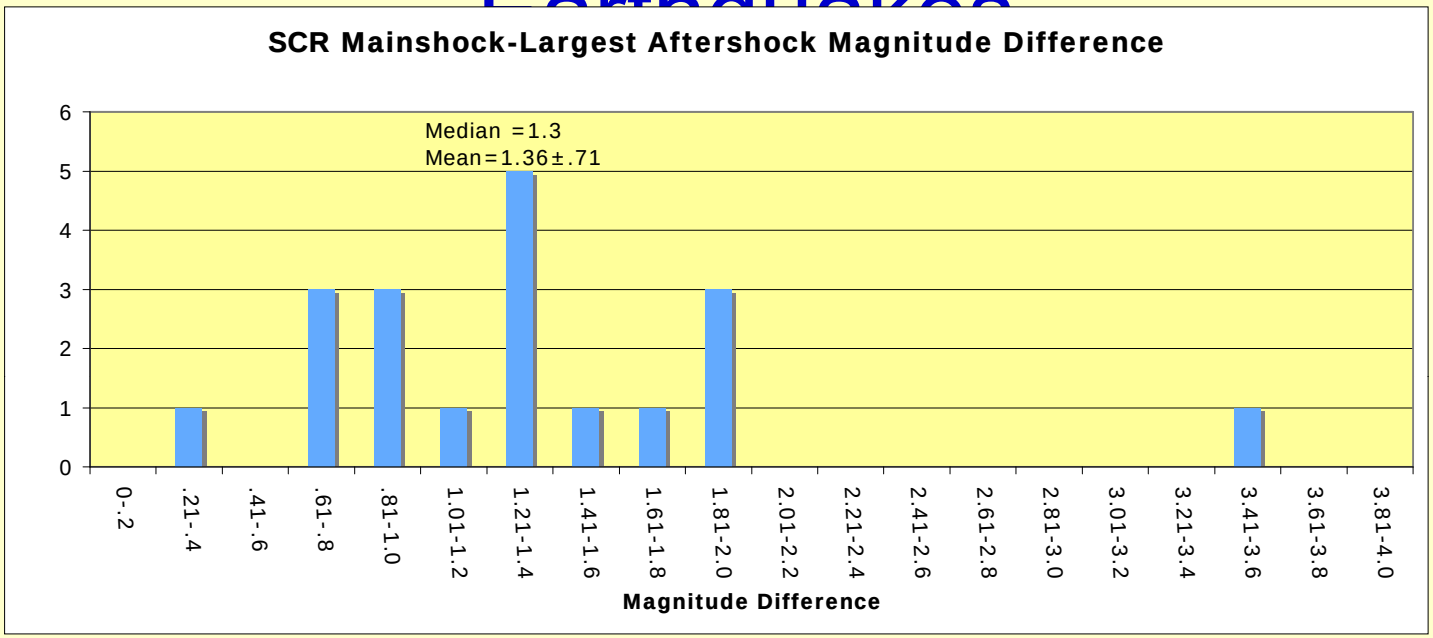
Boston College

Aftershock and Foreshock Characteristics of M≥6 SCR Earthquakes



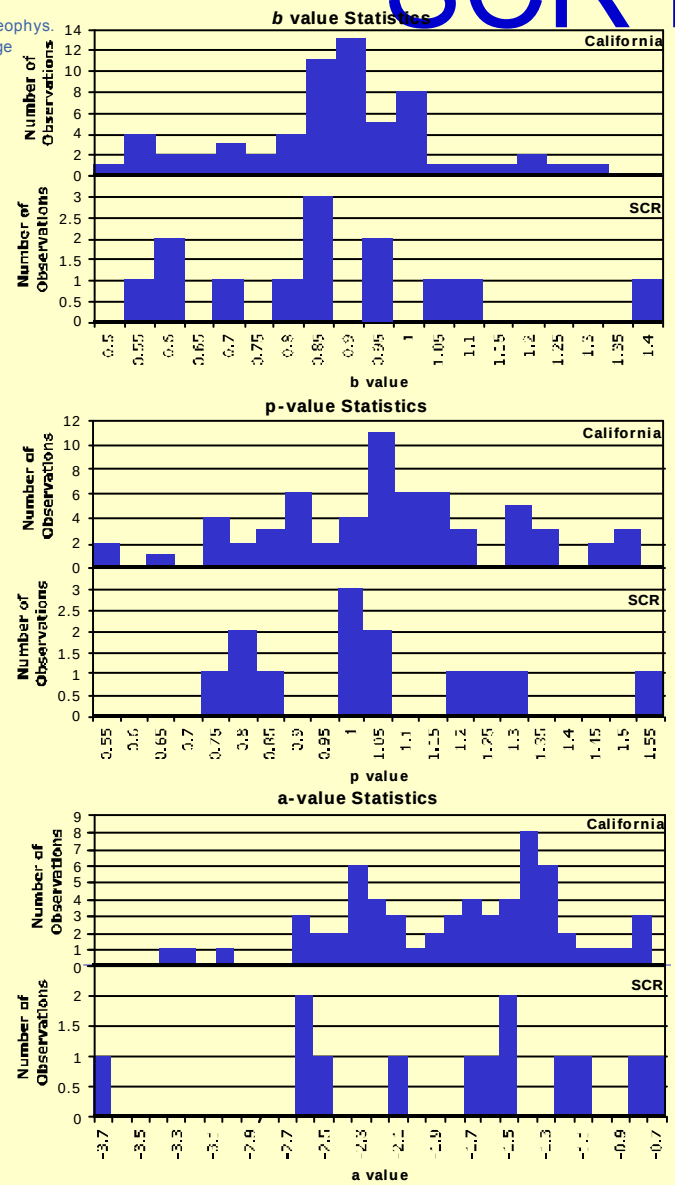
Days after Mainshock	Number of Largest Mainshocks	% of Total SCR Mainshocks
<=1	3	16%
<=5	8	42%
<=10	8	42%
<=30	11	58%
<=60	14	74%

In 3 out of 18 cases (17%), the largest aftershock took place more than a year after

- 8 of 19 SCR mainshocks had at least 1 foreshock of M≥4.5 within 30 days of the mainshock. Assuming an average rate of 4 SCR M≥4.5 mainshocks per year, then for the time period **from 1968-2003 about 5% of the M≥4.5 SCR were foreshocks of subsequent mainshocks**.

Weston Observatory
Dept. of Geol. & Geophys.
Boston College

Omori-Law Parameters of SCR Earthquakes



The mean values for the SCR and California *b*, *p* and *a* values are statistically the same:

b value means:

SCR -- .865±.226; California -- .872±.171

p value means:

SCR -- 1.046±.221; California -- 1.060±.221

a value means:

SCR -- -1.815±.832; California -- -1.800±.578

Weston Observatory

Dept. of Geol. & Geophys.
Boston College

Proposed Aftershock Forecasting Scheme for the CEUS

- Immediately following a significant CEUS earthquake, issue aftershock forecast based on the "generic California" aftershock parameters: *a*=-1.67, *b*=.91, *p*=1.08. Estimate the largest aftershock as about 1.3 magnitude units less than the mainshock and with a 70% chance of occurring within 60 days of the mainshock.
- If the CEUS event is M≥4.5, issue a forecast of a 5% probability that a larger earthquake could take place within the following 30 days.
- Use the first day of aftershocks to revise the value of *a*. If enough aftershocks have taken place to constrain *b*, first recompute *b* before revising *a*. Issue a revised aftershock forecast.

After 1 day, 8 aftershocks with M≥2.0 are detected. Use this information to revise the *a* parameter from -1.67 to -2.22. Issue a revised forecast exactly 1 day after the mainshock

Mt. Carmel, IL Forecast Results

Forecast Issued Immediately Following the Earthquake

Forecast	***Actual***
29 M 2 EQs in next 24 hours	8 M 2 aftershocks
43 M 2 EQs in next 7 days	16 M 2 aftershocks

Forecast Issued 1-Day Following the Earthquake

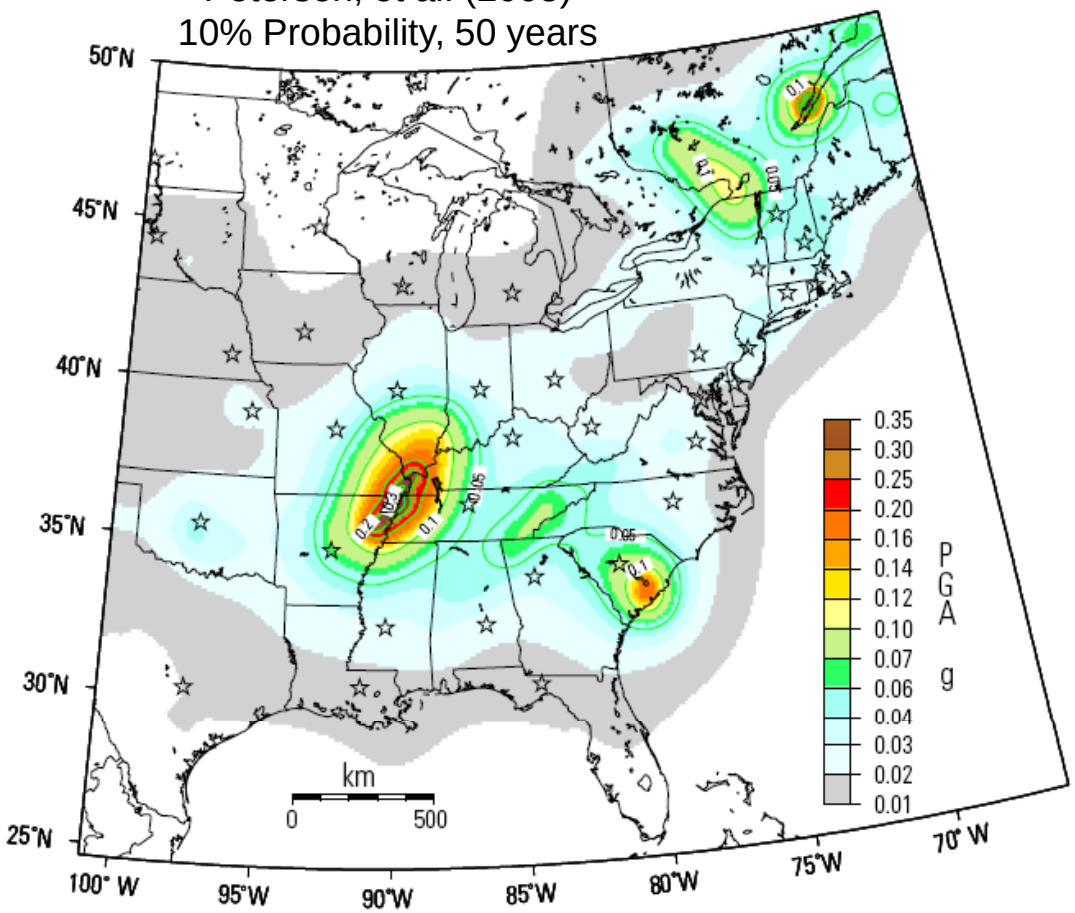
Forecast	***Actual***
2 M 2 EQs in next 24 hours	2 M 2 aftershocks
4 M 2 EQs in next 7 days	8 M 2 aftershocks

Largest Forecast Aftershock Magnitude = 3.8
Largest Observed Aftershock Magnitude = 4.6

Alan Kafka

Boston College

Petersen, et al. (2008)
10% Probability, 50 years



USGS National Seismic Hazard Maps
Past Seismicity → Future Earthquakes

Questions:

(1) Is the "tendency for future earthquakes to occur near past earthquakes" a real, measurable, physical phenomenon?

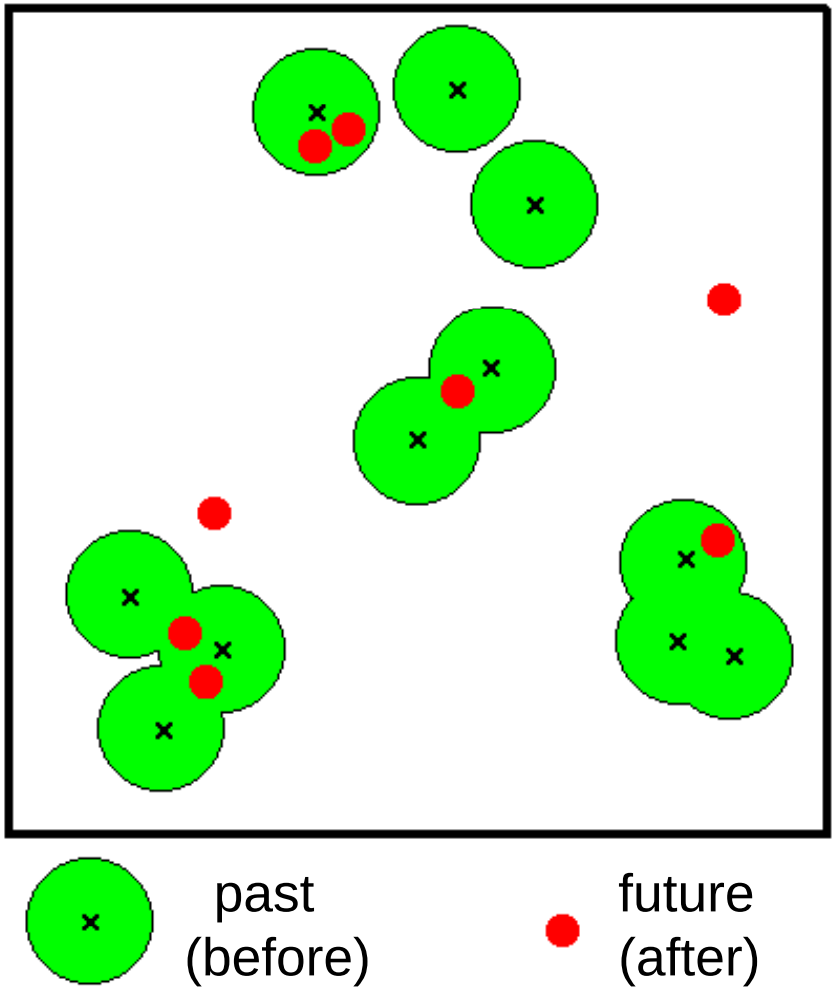
(2) Do we have samples that are representative of this phenomenon?

(3) Can we measure it?

"If you can't measure it, it isn't science."
- Lord Kelvin

“Cellular Seismology”

(analogous to a cellular phone system)



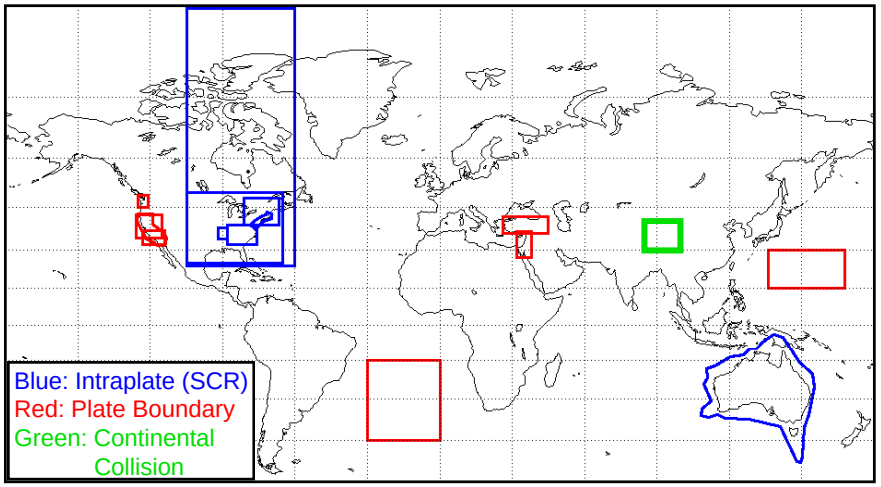
Choose a radius such that circles fill P percentage of map area.

$\hat{\rho}$ = 6/8 = 75% = sample of binomial random variable, ρ.

ρ = Probability(“success”)

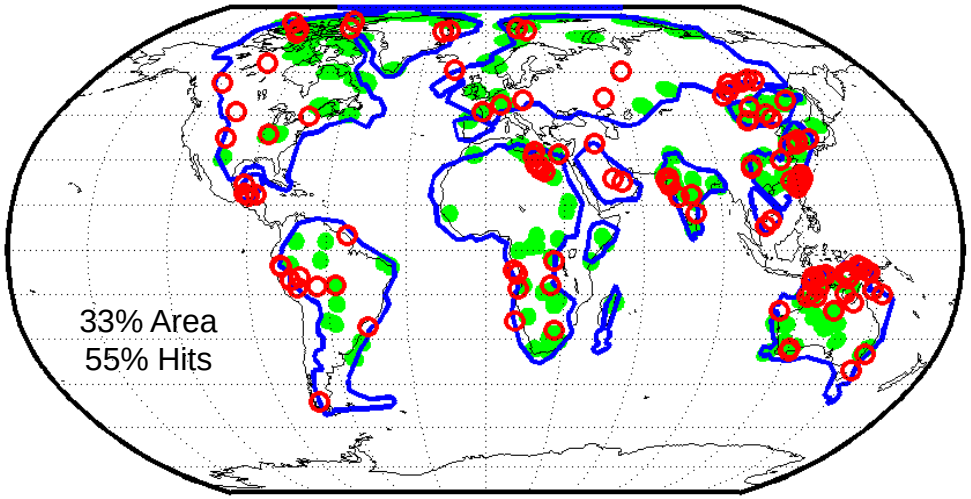
success = red circle occurs within one of the green circles.

From Kafka (2002, 2007)



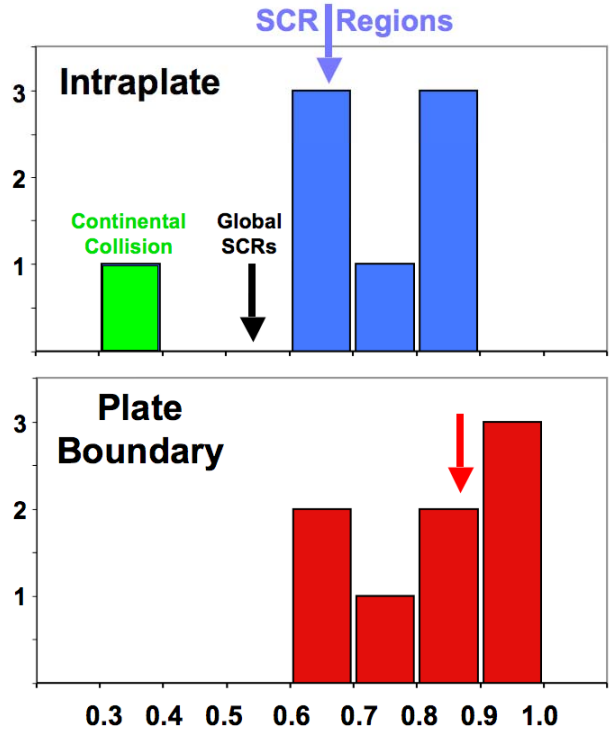
Tectonic regions analyzed by: Kafka (2002, 2007), Kafka and Ebel (2009), and This Study.

CS for Stable Continental Regions (SCRs) on a global scale

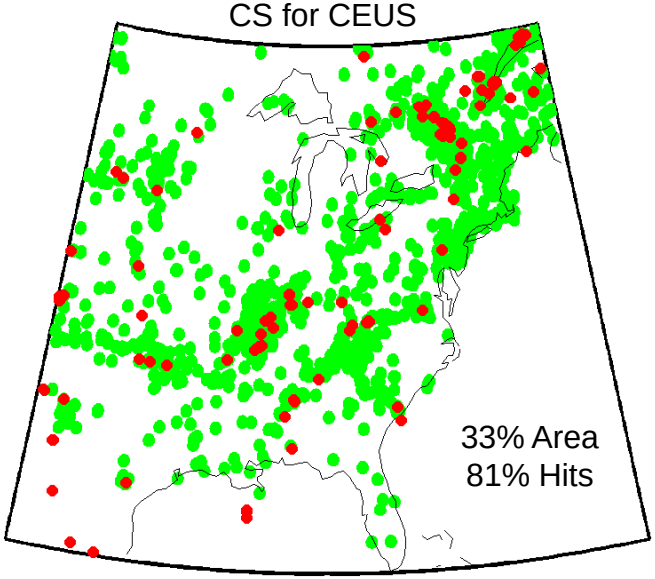


Before: 1964-1999, M≥5.0
After: 2000-2008, M≥5.0

Observed %Hits (33% Map Area) for the Different Tectonic Regions Analyzed



CS for CEUS

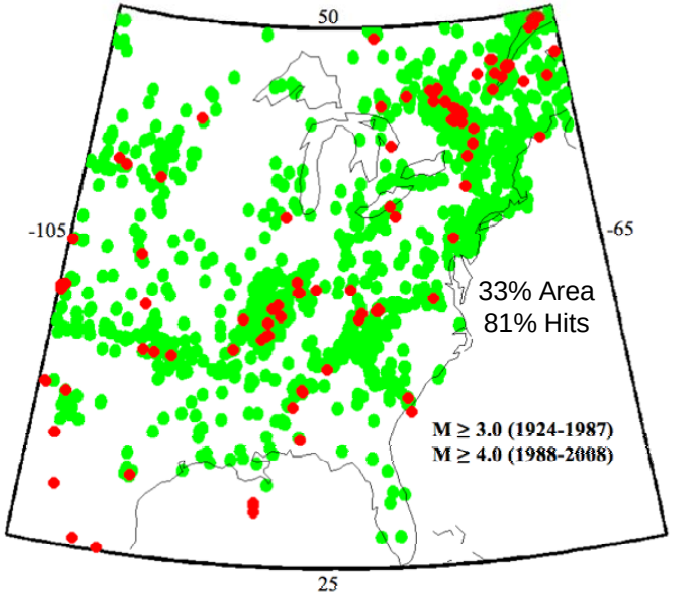


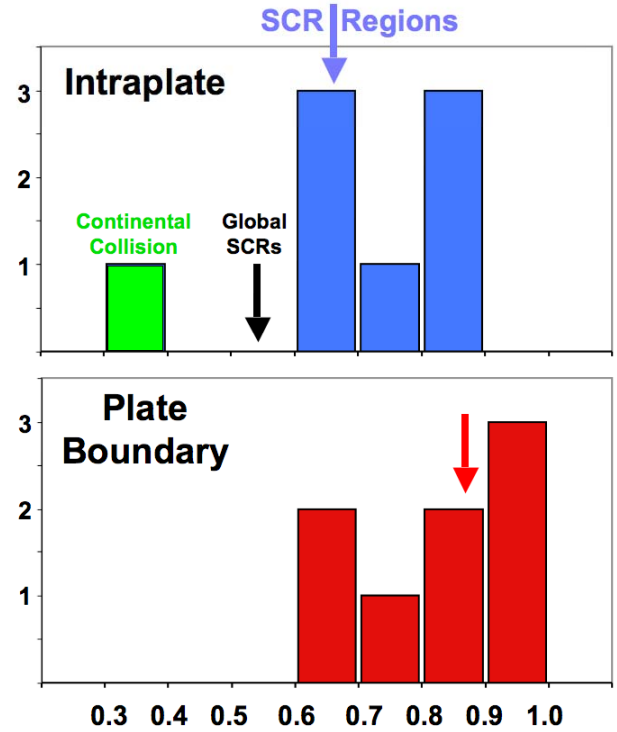
Before: 1924-1987, M≥3.0
After: 1988-2008, M≥4.0

SUMMARY

1. CS forecast for CEUS: 81±7% probability that future earthquakes will occur within these green CS zones, which cover 33% of the map area.

2. CS forecast probabilities generally lower for intraplate regions than for plate boundary regions?





Gail Atkinson

University of Western Ontario

Ground Motion Trends and Issues for Eastern North America

Gail M. Atkinson

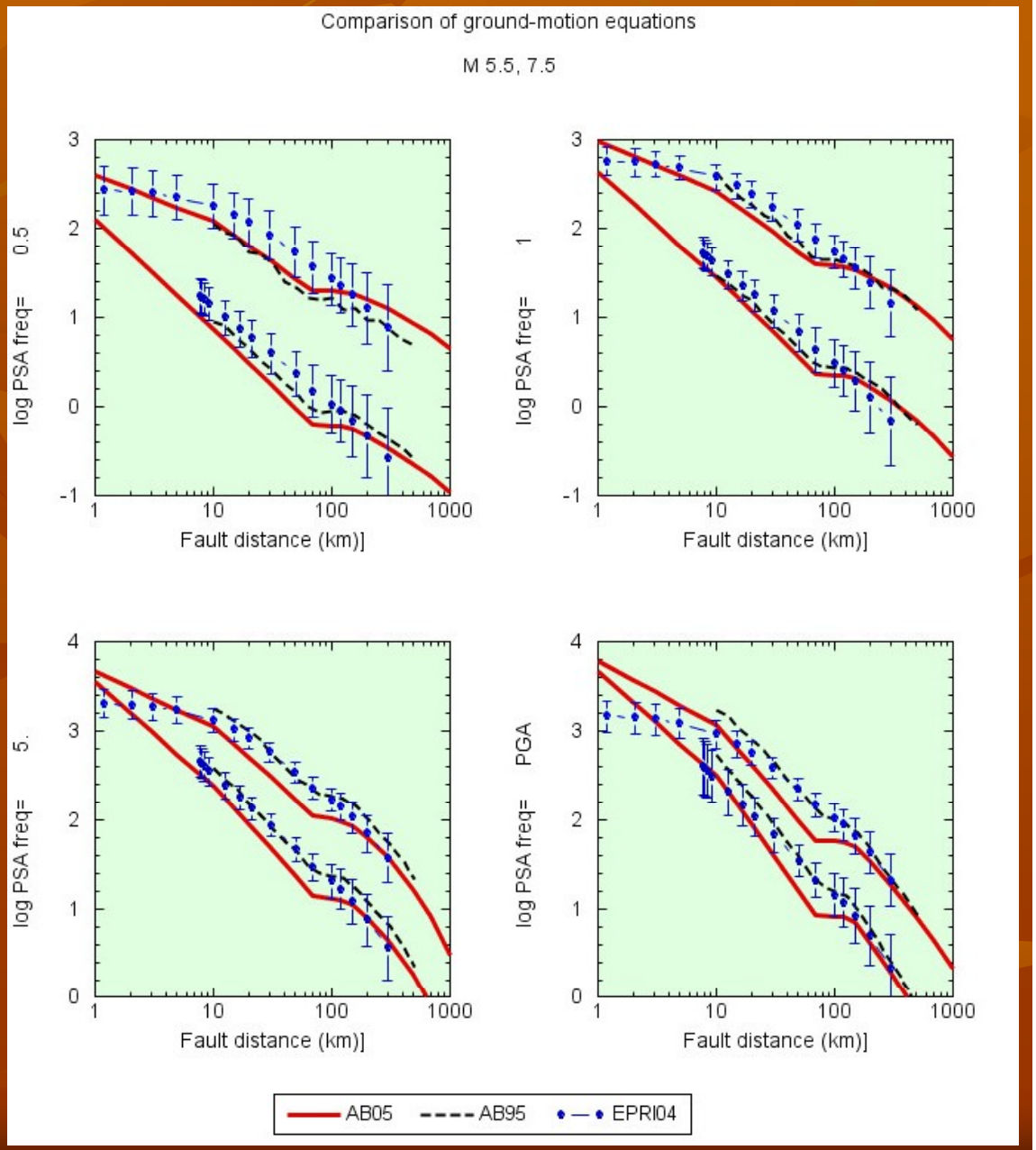
University of Western Ontario

Key Points

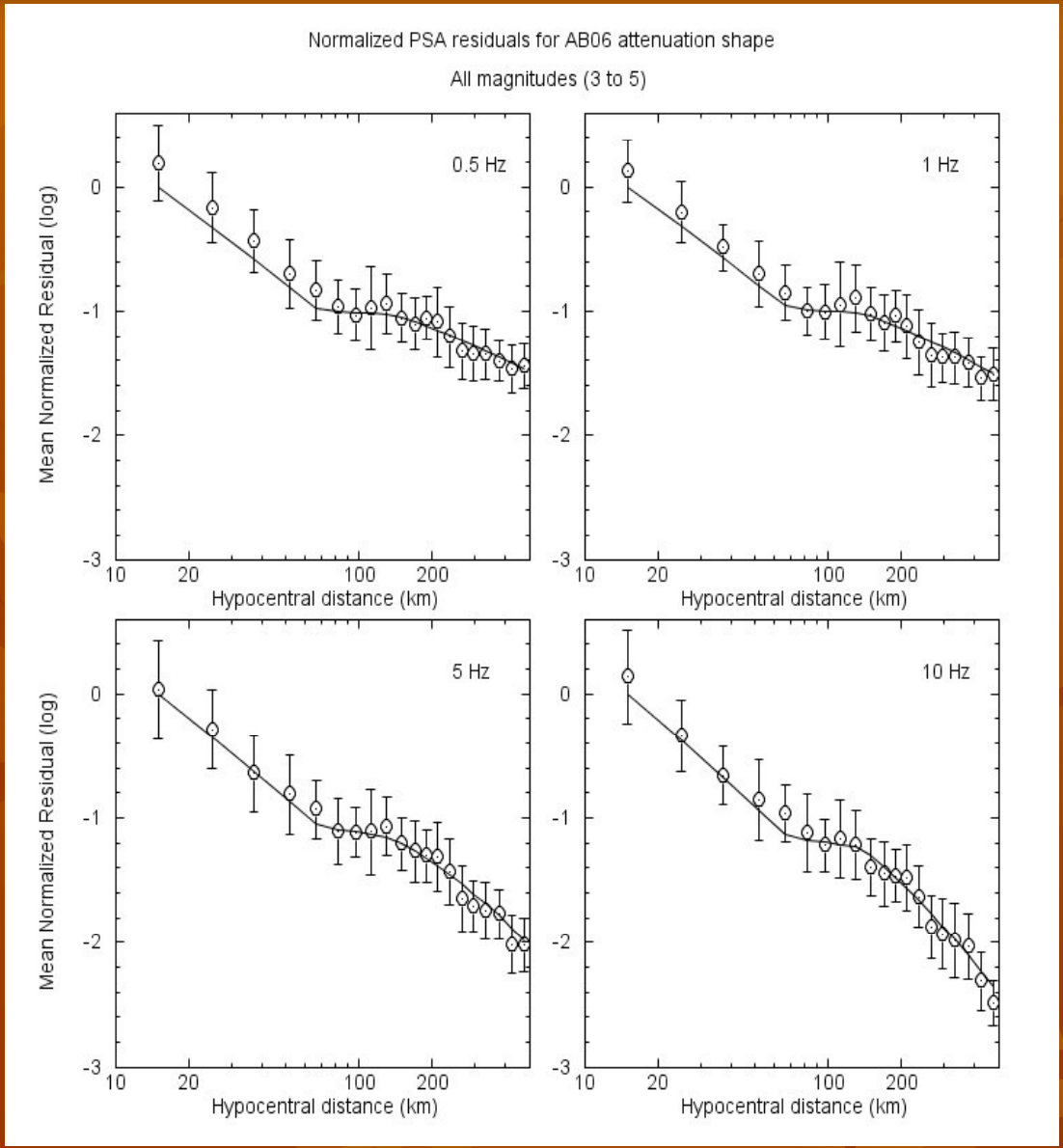
- Ground-motion predictions in ENA require knowledge of source, path and site effects (encapsulated in GMPEs)
- Definition of these elements in ENA is based on non-unique and uncertain deductions from relatively sparse ground motion (and intensity) data (especially sparse for larger magnitudes)
  - There are significant source-attenuation trade-offs!
- Constraints on source and attenuation from regional observations is generally combined with overall source-scaling theory to provide ENA GMPEs for engineering applications

Recent GMPEs for ENA

- Atkinson and Boore (2006) GMPE makes most comprehensive use of ENA ground-motion data, combined with stochastic finite-fault modeling – but uncertainties are significant

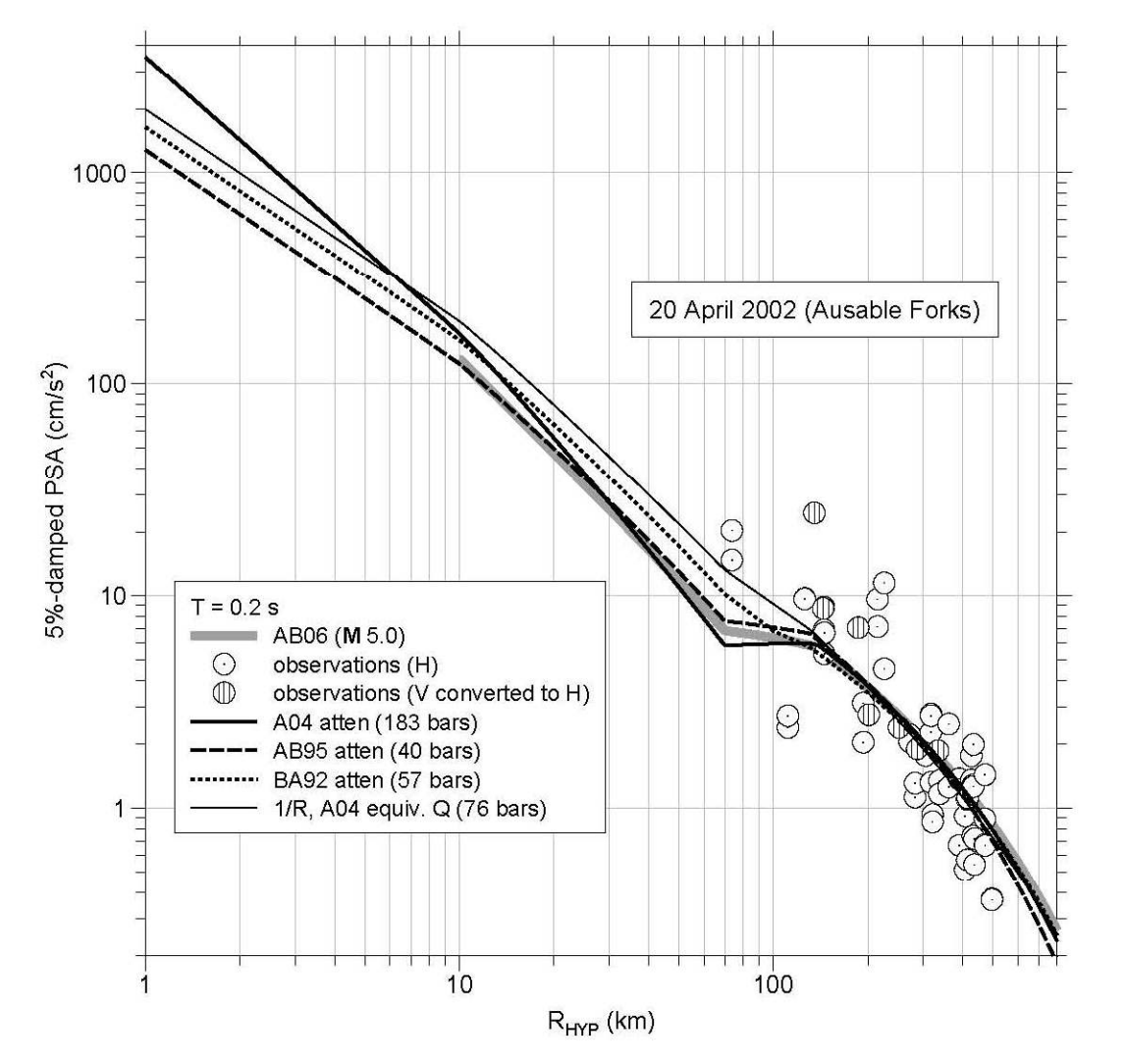


Attenuation shape: A key issue is the attenuation function – geometric spreading near-source and nature of Moho bounce transition. AB06 attenuation shape well-constrained for events of M3.5-5.0, but insufficient data to verify predicted behavior for larger events



Example of trade-offs of source and attenuation for ENA (Boore, Campbell and Atkinson, 2009)

- *Observed and simulated PSA vs. distance for the Ausable Forks earthquake, starting at 1 km to emphasize the difference in predicted ground motions at close distances. Figure from Boore et al. (2009).*



Email me for recent references: gmatkinson@aol.com

- Atkinson, G. and D. Boore (2006). Ground motion prediction equations for earthquakes in eastern North America. Bull. Seism. Soc. Am., **96**, 2181-2205.
- Atkinson, G. and D. Boore (2007). Errata: Ground motion prediction equations for earthquakes in eastern North America. Bull. Seism. Soc. Am., **97**, 1032.
- Atkinson, G. (2008). Alternative ground-motion prediction equations for eastern North America from a Referenced Empirical Approach: Implications for epistemic uncertainty. Bull. Seism. Soc. Am., **98**, 1304-1318.
- Atkinson, G., D. Boore, K. Assatourians, K. Campbell and D. Motazedian (2009). The meaning of stress drop and other parameters in point-source versus finite-fault simulations. Bull. Seism. Soc. Am., **99**, in press.
- Atkinson, G. and M. Morrison (2009). Regional variability in ground motion amplitudes along the west coast of North America. Bull. Seism. Soc. Am., **99**, 2393-2409.
- Atkinson, G. and D. Wald (2007). Modified Mercalli Intensity: A surprisingly good measure of ground motion. Seism. Res. L., **78,** 362-368.
- Boore, D., K. Campbell and G. Atkinson (2009). Determination of stress parameters for eight well-recorded earthquakes in eastern North America. Bull. Seism. Soc. Am., submitted.

Shahram Pezeshk

University of Memphis

Updated Ground-Motion Prediction Equations for Eastern North America Using Hybrid Empirical Method

Shahram Pezeshk and Arash Zandieh

Department of Civil Engineering

The University of Memphis

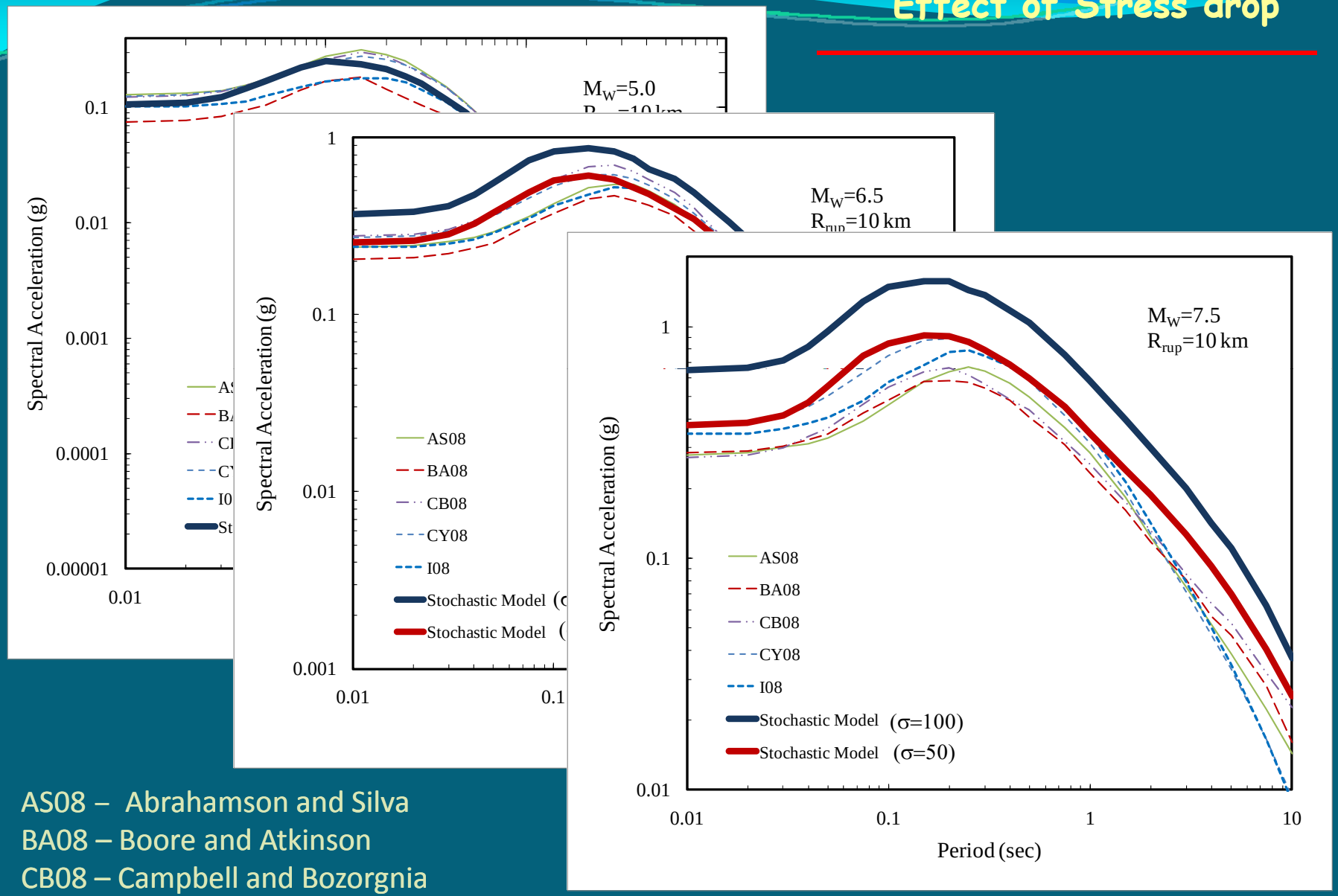
Behrooz Tavakoli

Bechtel Corp, Washington, D.C.

Models Used in Developing the Central U.S. Ground Motion Relations (2008 Update of the U.S. National Seismic Hazard Maps)

- Stochastic Point Source (single corner source)
  - Toro et al. (1997)
  - Silva et al. (2002) – Constant Stress Drop with Saturation
- Stochastic Point Source (single corner source with Moho Bounce)
  - Frankel et al. (1996)
- Finite Fault - Dynamic Corner Frequency
  - Atkinson and Boore (2006) with 140 bar stress drop
  - Atkinson and Boore (2006) with 200 bar stress drop
- Hybrid-Empirical Model
  - Campbell (2003)
  - Tavakoli and Pezeshk (2005)
- Full Waveform Simulation
  - Somerville et al. (2001)

Effect of Stress drop

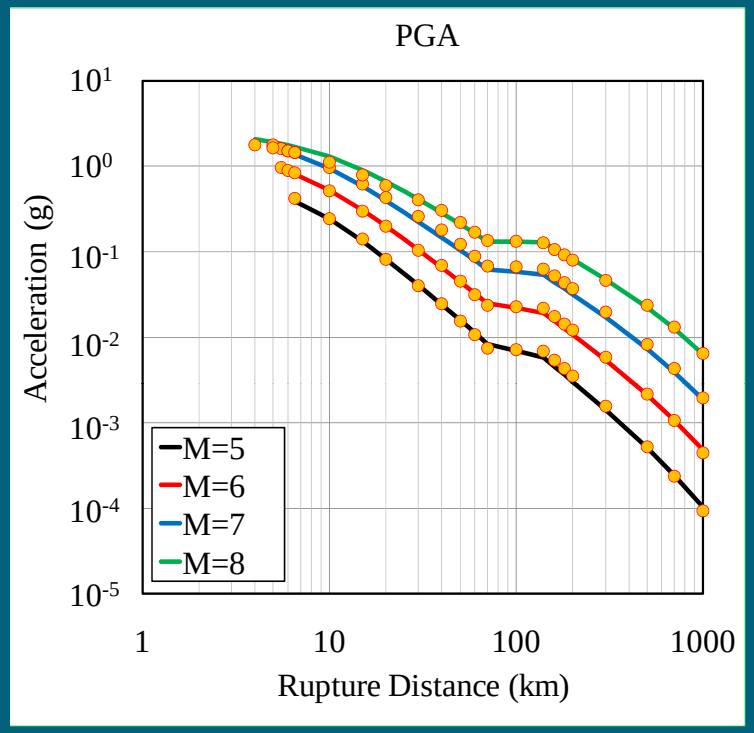


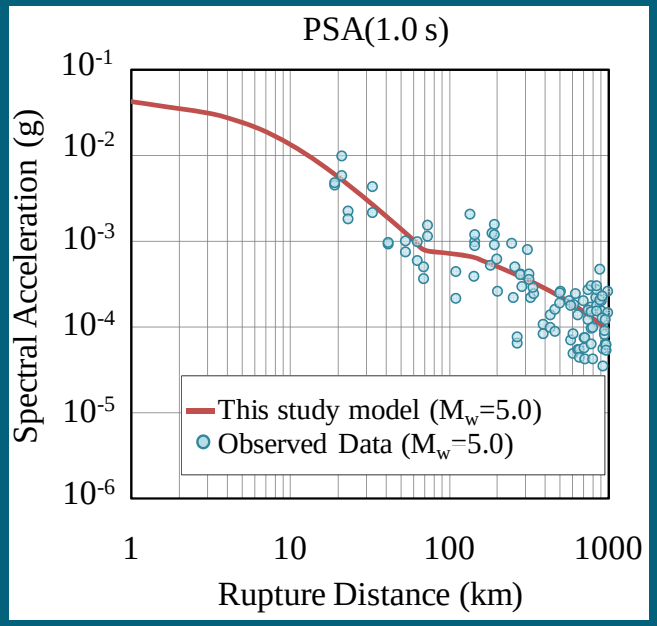
AS08 – Abrahamson and Silva
BA08 – Boore and Atkinson
CB08 – Campbell and Bozorgnia
CY08 – Chiou and Youngs
I08 – Idriss

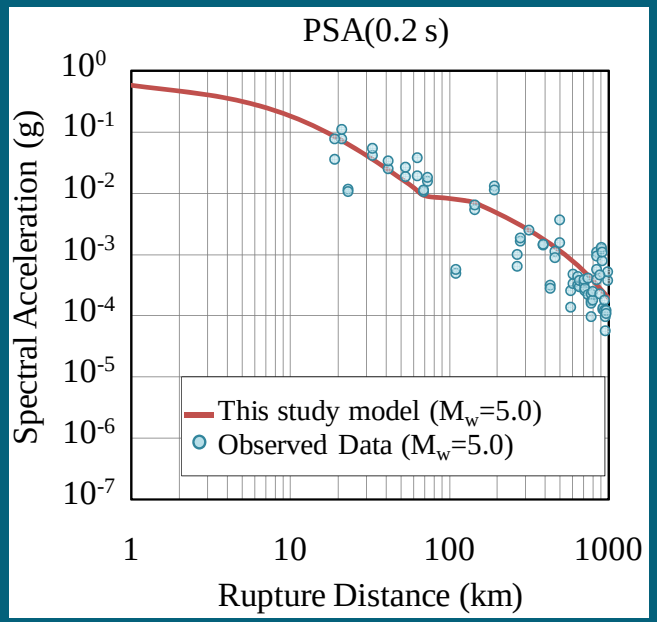
Median Parameter Values Used with the Stochastic Method in WNA and ENA

Parameter	WNA	ENA
Stress drop, $\Delta\sigma$ (bars)	$\begin{cases} 100; & 5 \le M_W < 6 \\ 80; & 6 \le M_W < 7 \\ 60; & M_W \ge 7 \end{cases}$	250
Geometric spreading, $Z(R)$	$\begin{cases} R^{-1.0}; R < 40\,km \\ R^{-0.5}; R \ge 40\,km \end{cases}$	$\begin{cases} R^{-1.3}; R < 70\,km \\ R^{+0.2}; 70 \le R < 140\,km \\ R^{-0.5}; R \ge 140\,km \end{cases}$
Path duration, T_p (sec)	$0.05R$	$\begin{cases} 0; & R \le 10\,km \\ +0.16R; & 10 < R < 70\,km \\ -0.03R; & 70 < R \le 130\,km \\ +0.04R; & R > 130\,km \end{cases}$
Quality factor, Q	$180 f^{0.45}$	$893 f^{0.32}$
Site profile	Generic rock, Boore and Joyner (1997), V_{s30}=620 m/s	Generic rock, Boore and Joyner (1997), V_{s30}=2800 m/s
Site amplification, $A(f)$	Quarter-wavelength, Boore and Joyner (1997)	Quarter-wavelength, Boore and Joyner (1997)
Kappa, κ_0 (sec)	0.04	0.006

Updated Ground-Motion Prediction Equation for ENA







Observed data from:
Atkinson and Boore (2006)

Conclusions

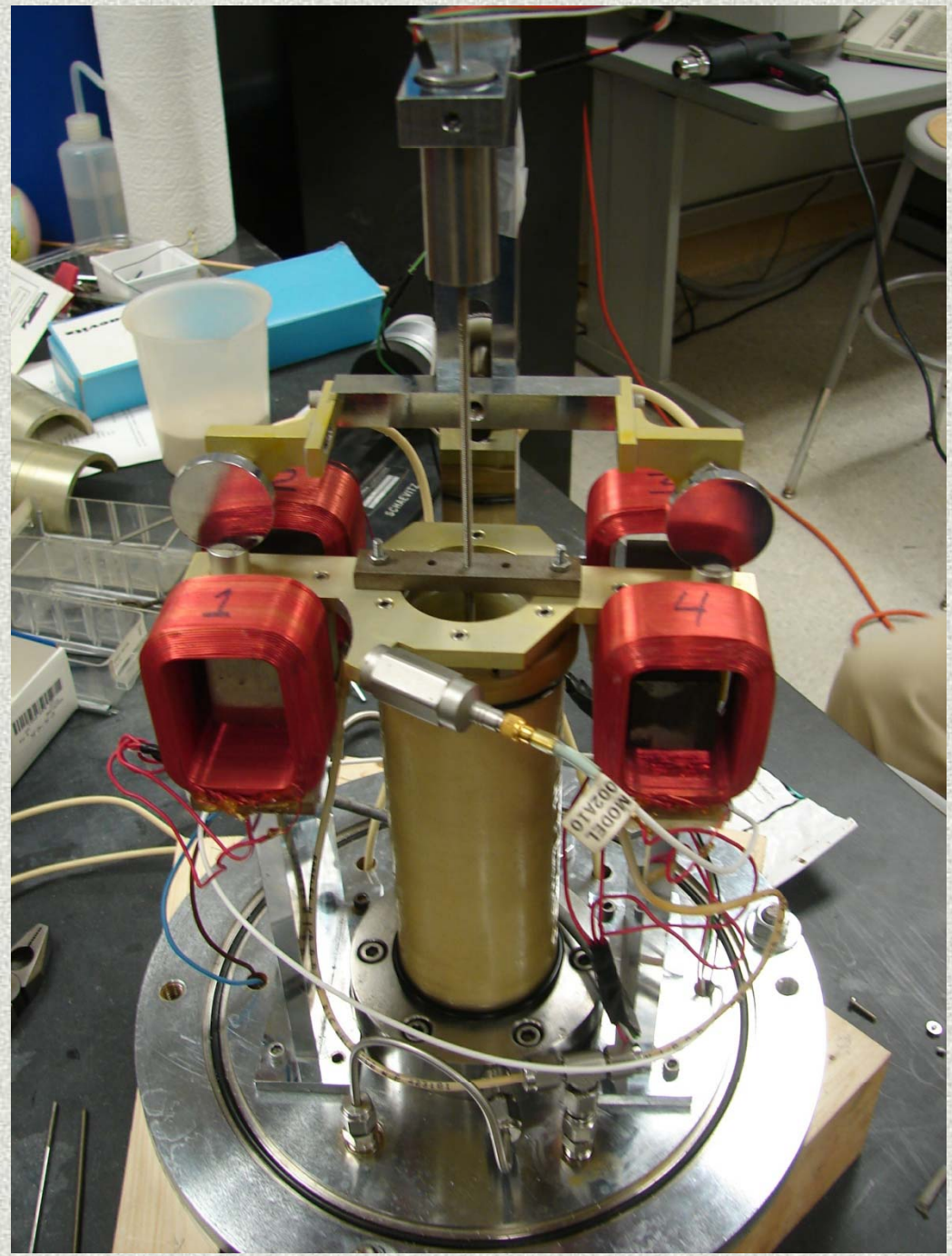
- A hybrid empirical method is used to develop a new ground-motion prediction model in ENA.
- It uses WNA empirical ground-motion models from the Next Generation Attenuation (NGA) project and also, the most recent updated seismological parameters by Atkinson, et al. (2010), Atkinson and Boore (2006), and Atkinson (2004) for ENA stochastic simulations.
- To improve the accuracy of stochastic simulations we used:
  - A variable stress drop model for WNA in which stress drops reduces as magnitude increases.
  - A combined source model which is a combination of double-corner and single-corner point source for both regions for a better representation of ground motion at near-source distances and large magnitudes.
  - A magnitude dependent focal depth as defined in Atkinson and Silva (2000) to consider the finite-fault geometry in point-source stochastic model.

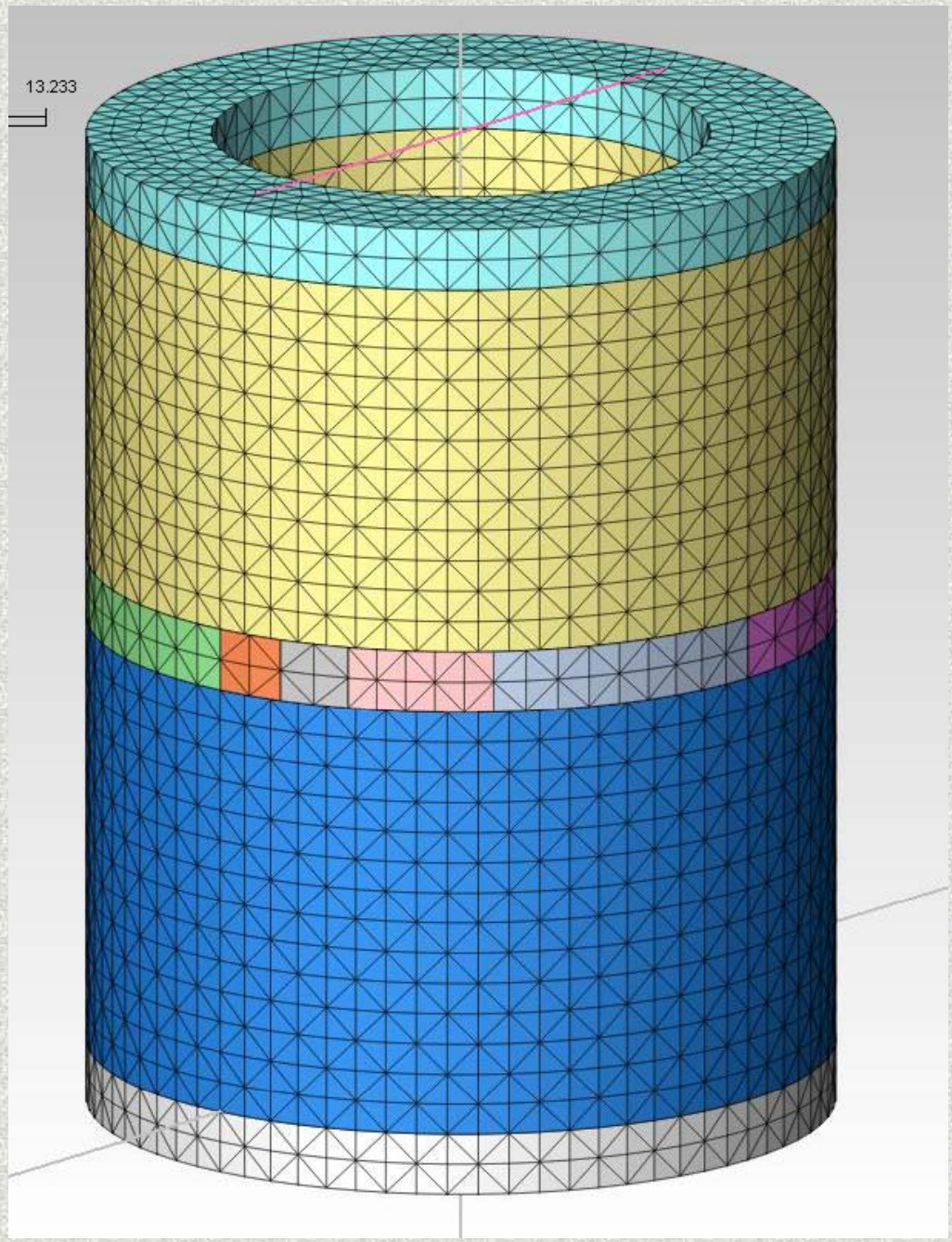
Richard Ray

University of South Carolina

RESONANT COLUMN-TORSIONAL SHEAR

- Hollow Cylinder Specimen
- Magnet and Coil Drive System
- Accelerometer R-C
- Proximitor T-S

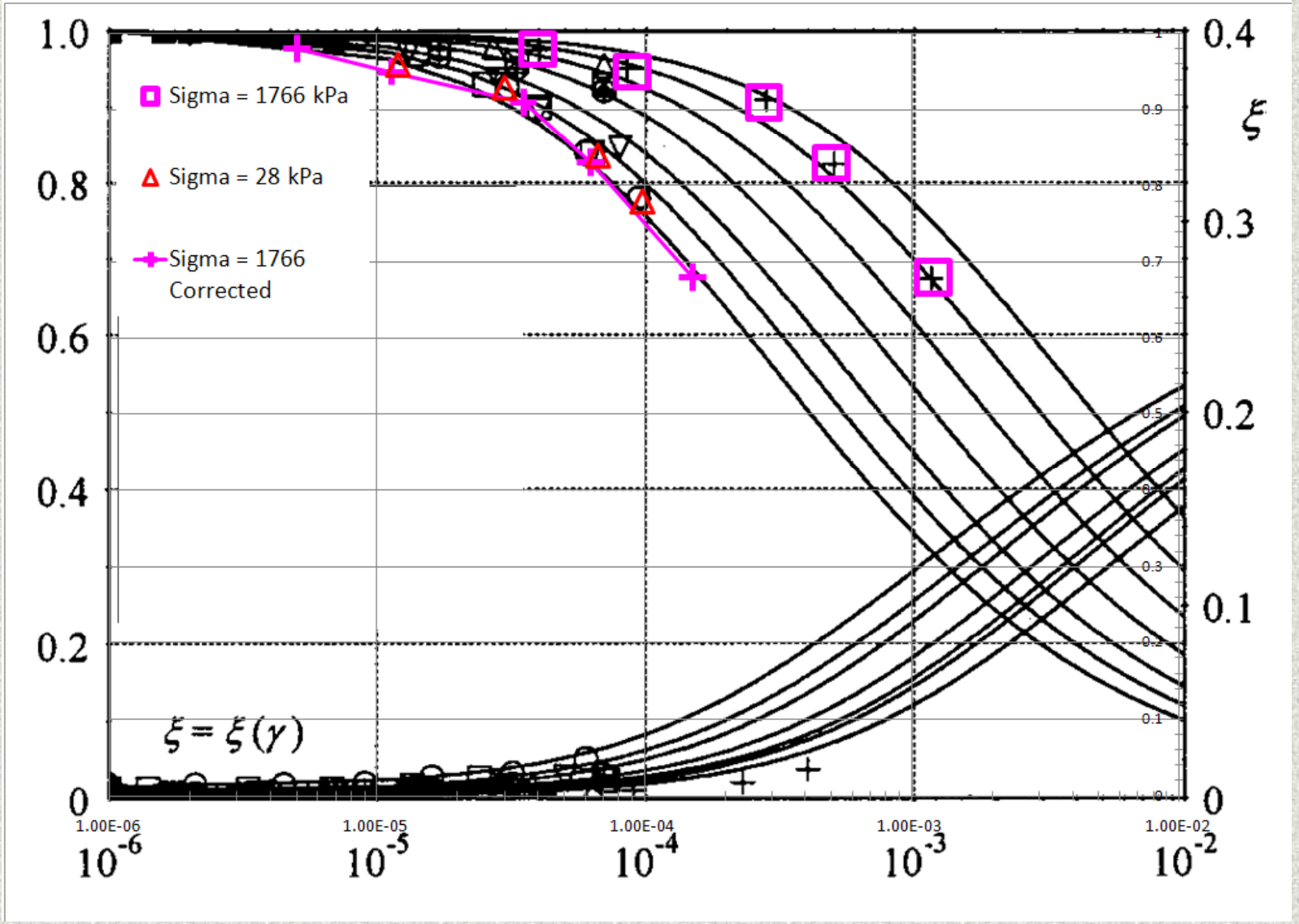




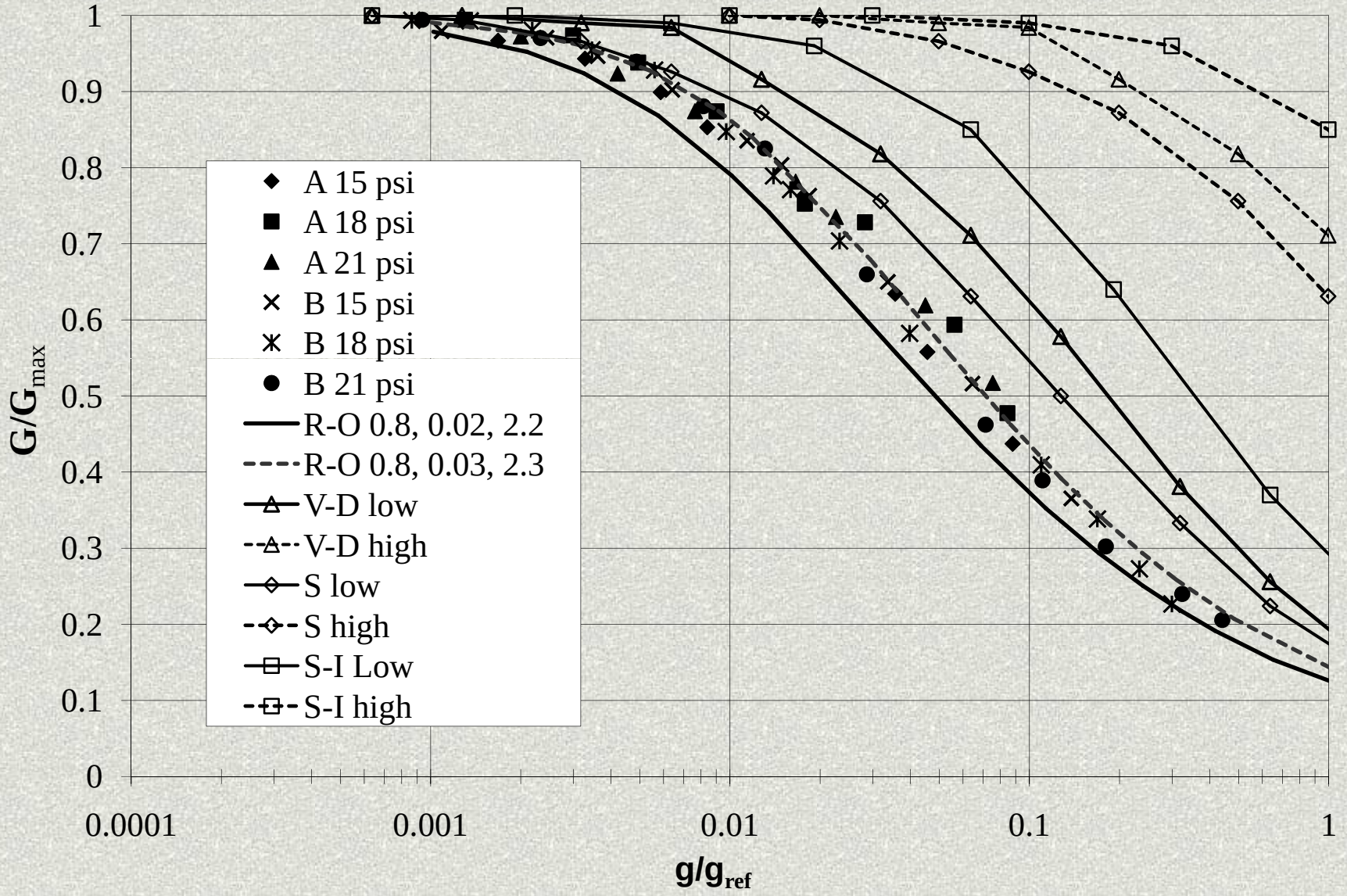
Finite Element Modeling

- 3-D Torsional Model
- Linear/Non-Linear Materials
- Progressively Larger Voids or Inclusions

High Confining Stress Made Non-Dimensional



Some Test Results With Cooper Marl



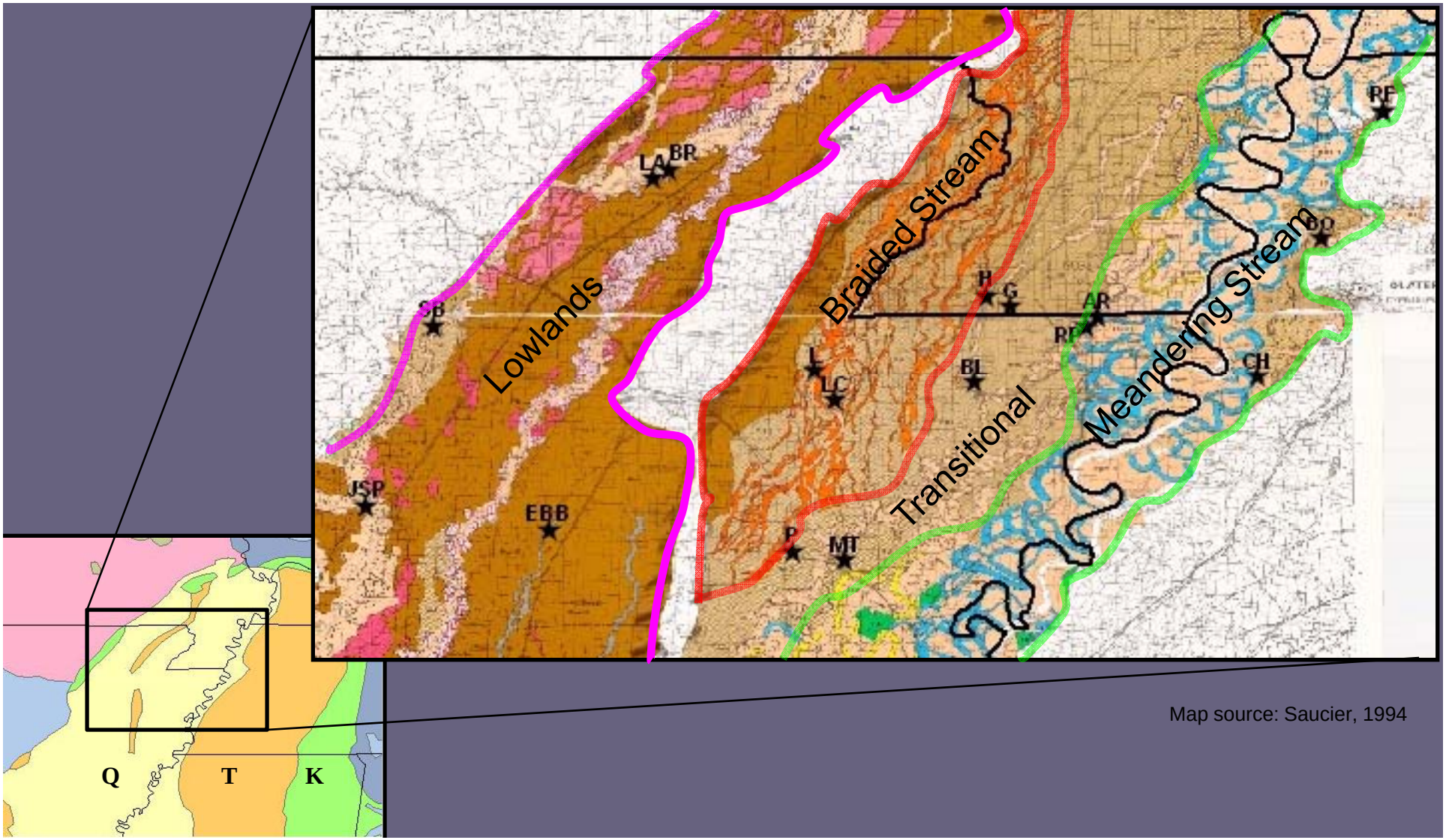
Lorraine Wolf

Auburn University

A MICROTREMOR STUDY IN THE NEW MADRID SEISMIC ZONE

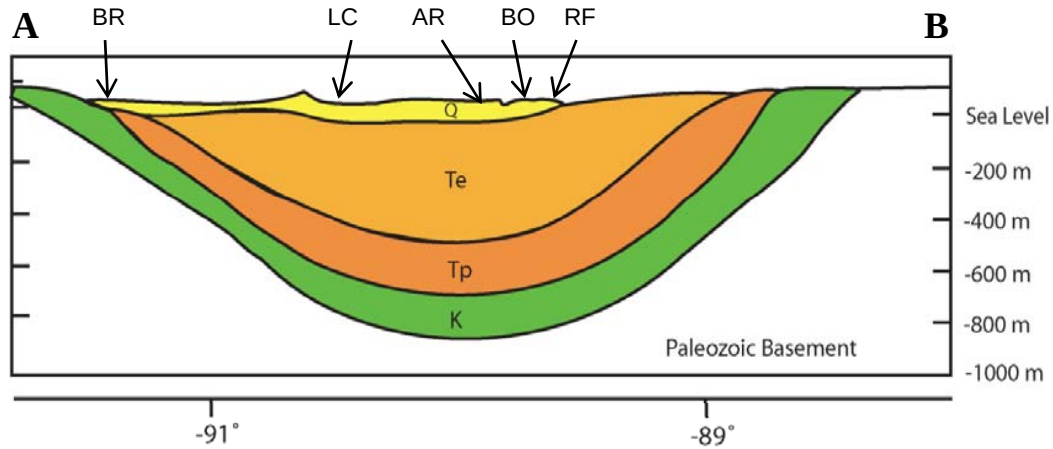
Wolf, L., and Hardesty, K., Auburn University
Bodin, P., University of Washington, Seattle

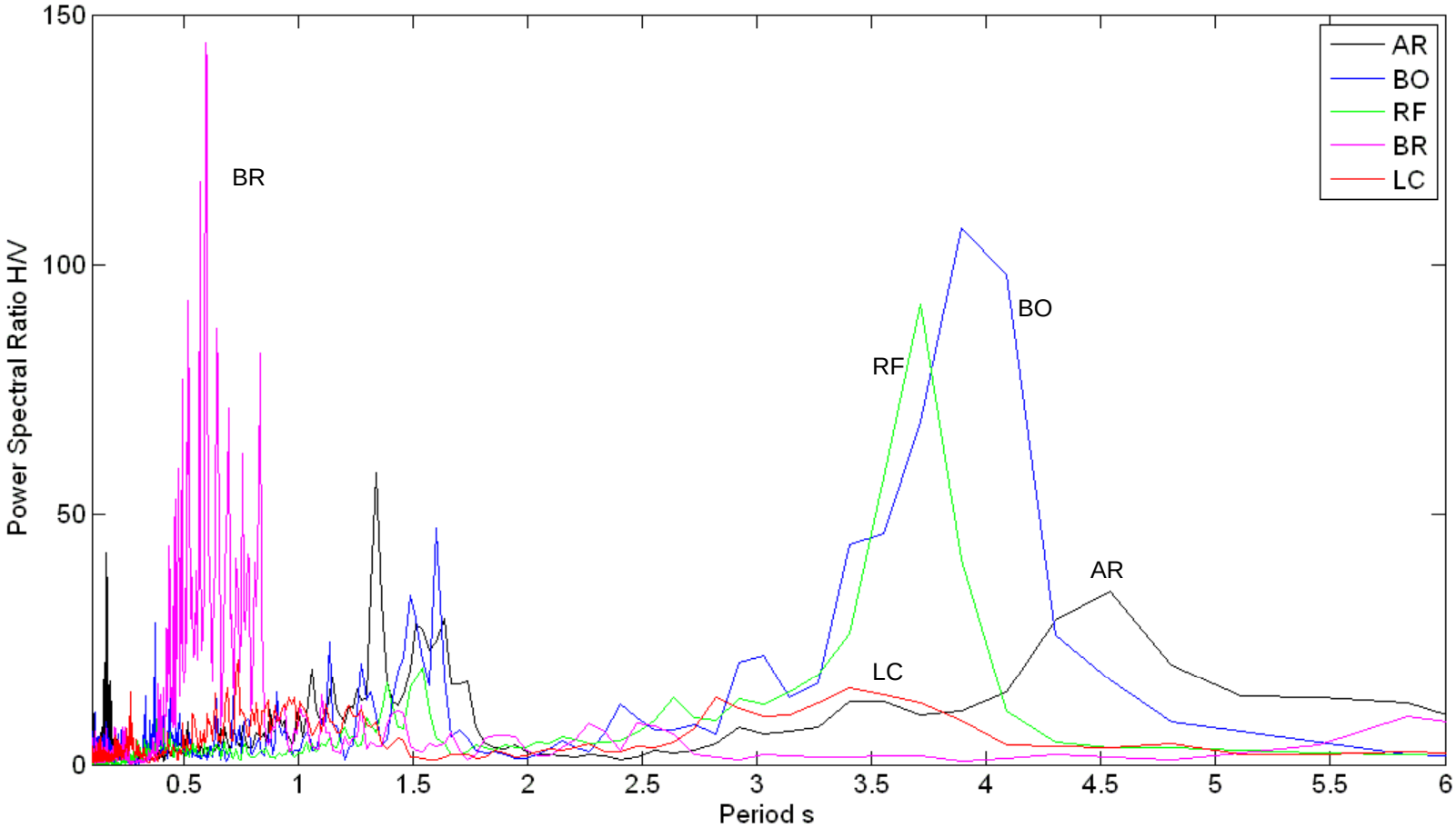
Microtremor Data Collection

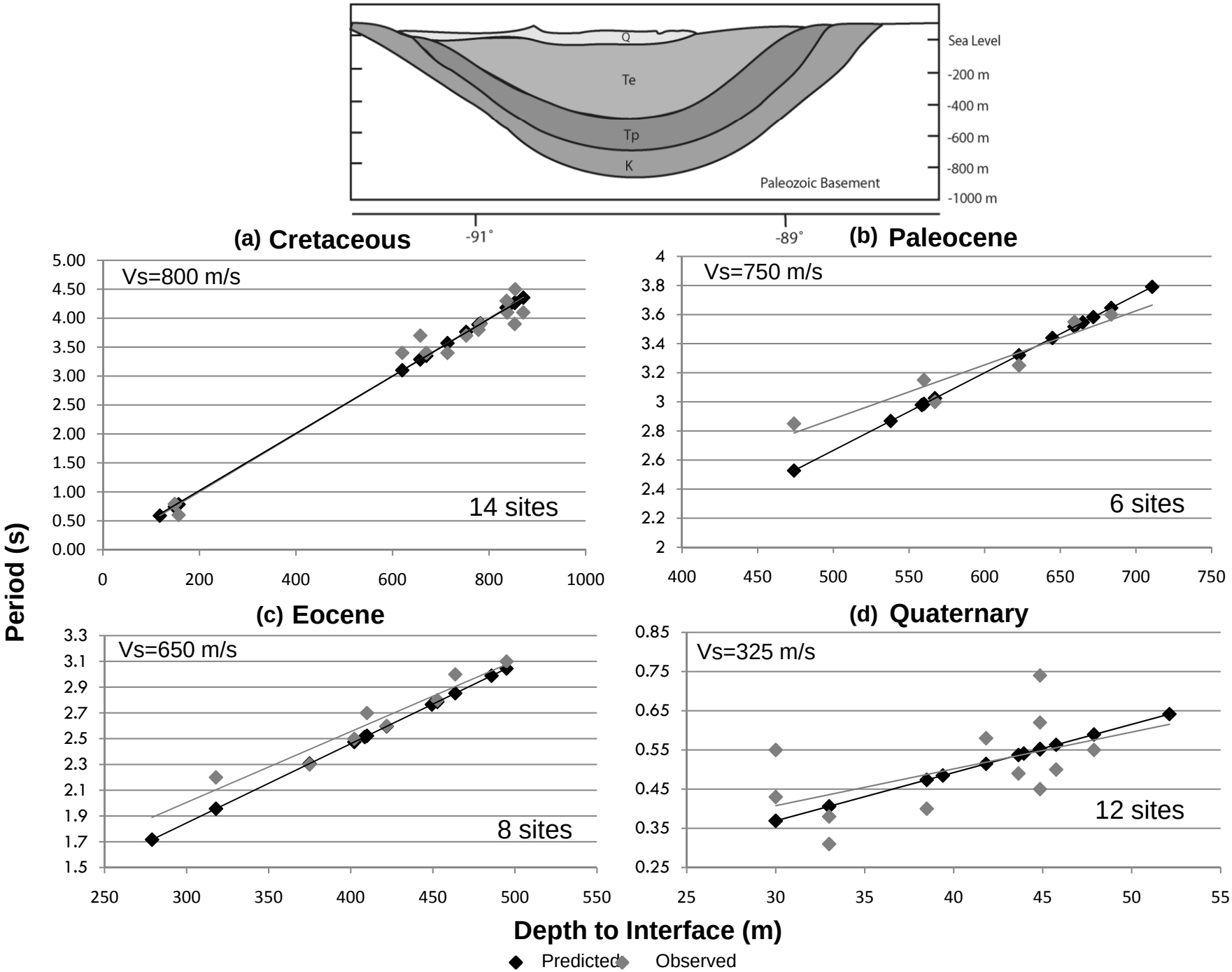


Map source: Saucier, 1994

Site	Embayment Thickness (m)	Vs (m/s)	Predicted T (s)	Observed T (s)	Error (s)	Difference (s)
BR	157	800	0.79	0.6	± .05	0.19
LC	670	800	3.35	3.4	± .2	0.05
AR	854	800	4.27	4.5	± .25	0.13
BO	782	800	3.91	3.9	± .20	0.06
RF	657	800	3.29	3.7	± .09	0.11

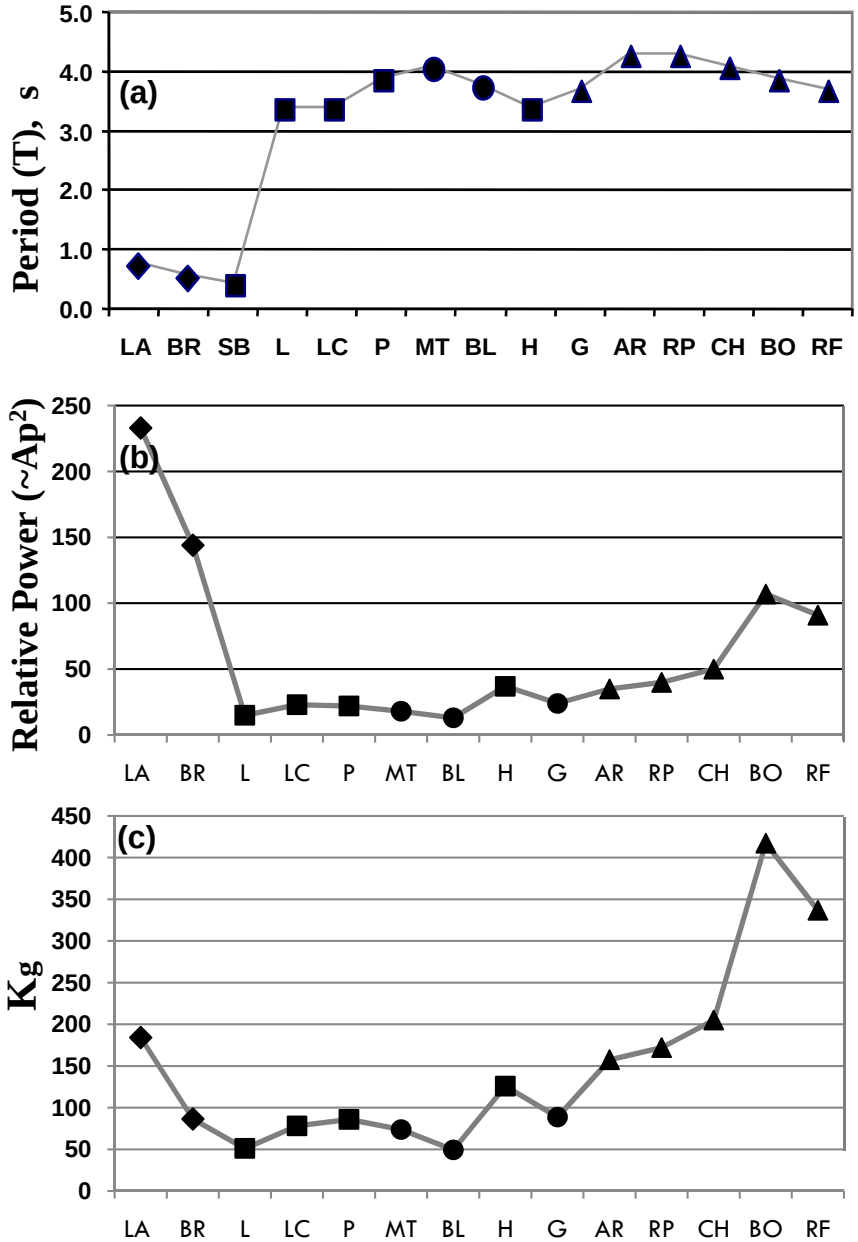





Q
Te
Tp
K
Paleozoic Basement
Sea Level
-200 m
-400 m
-600 m
-800 m
-1000 m
-91°
-89°
(a) Cretaceous
Vs=800 m/s
14 sites
(b) Paleocene
Vs=750 m/s
6 sites
(c) Eocene
Vs=650 m/s
8 sites
(d) Quaternary
Vs=325 m/s
12 sites
Period (s)
Depth to Interface (m)
Predicted
Observed

$$Kg = Ap^2 * T$$

- Lowlands
- Braided stream
- Transitional
- Meandering stream



Nathan Kent Moran

University of Memphis (CERI)

“A Phenomenon of a Most Alarming Nature!”

A Poster Presentation

FOR

USGS CENTRAL UNITED STATES EARTHQUAKE HAZARDS PROGRAM
OCTOBER 28-29 2009

Nathan K. Moran CERI

Martitia Tuttle USGS

Arch Johnston CERI

Tanya Broadbent CERI

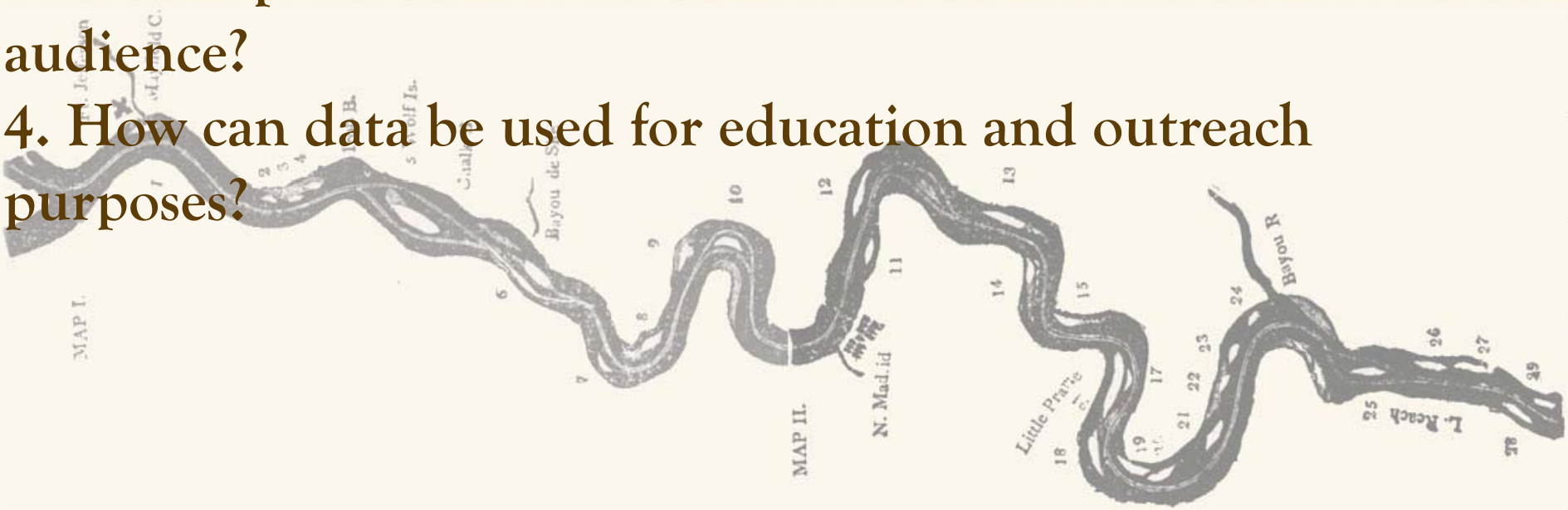
How can Historic Data be used in a Relevant Way?

1.Numerous historic accounts of earthquake mention geographic location of damage.

2. Normal representation would be in text format which makes it hard for many audiences to comprehend scale of damage.

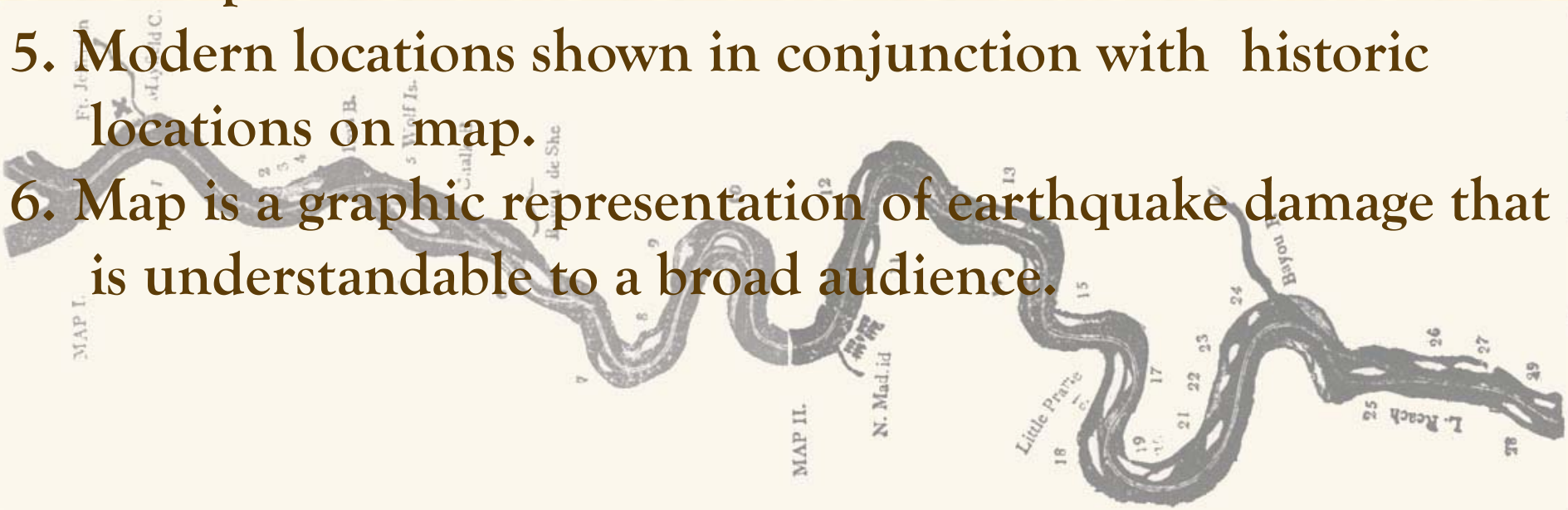
3.How to present data to technical and non technical audience?

4. How can data be used for education and outreach purposes?



Solution: Represent Damage on Map

1. Source map Zadock Cramer's The Navigator map plates.
2. Cramer pioneered island numbering system for river.
3. Eyewitness accounts use Cramer's guide and map as locator for damage.
4. Map shows damage on river from New Madrid to Memphis.
5. Modern locations shown in conjunction with historic locations on map.
6. Map is a graphic representation of earthquake damage that is understandable to a broad audience.



More Research Needed

1. Identifying and Analyzing more near and far field reports for New Madrid and other historic earthquakes in the central United States.
2. Locating background information on eyewitnesses and their reports.
3. Using known accounts to further define site response.
4. Finding boundaries of felt area for New Madrid earthquakes.
5. Use historic information to help define possible epicenters for New Madrid and other historic earthquakes.
6. Use historic information to help inform and educate public on earthquake risk in central United States.

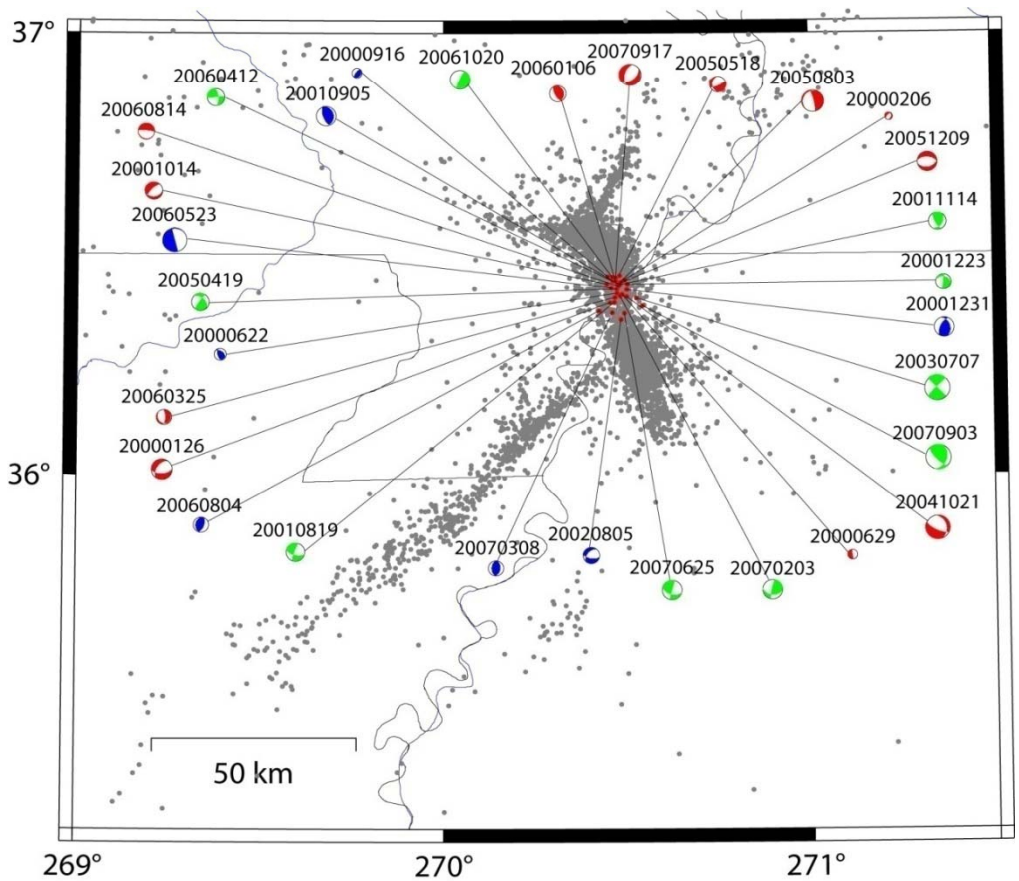
Stephen Horton

University of Memphis (CERI)

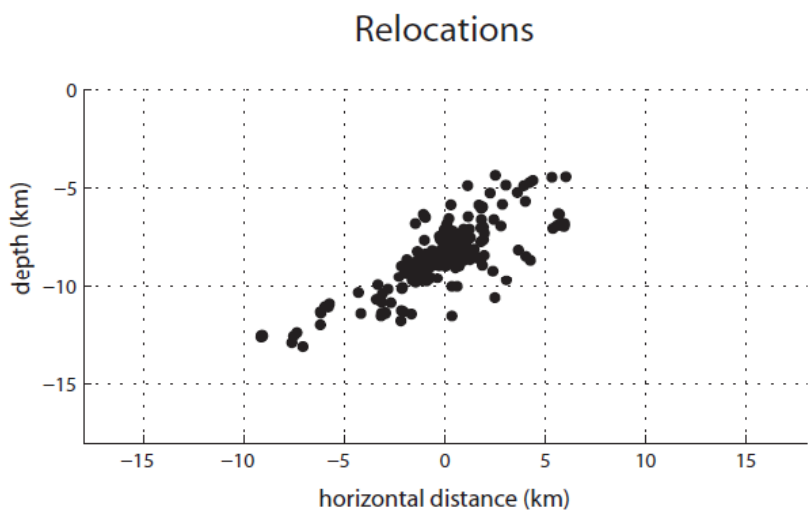
SEISMOTECTONICS OF THE NEW MADRID SEISMIC ZONE

Stephen Horton, Meredith Dunn, Paul Ogwari, CERI at University of Memphis and Gregory Johnson, Quantum Technology Sciences

Northern Central Segment (RF)



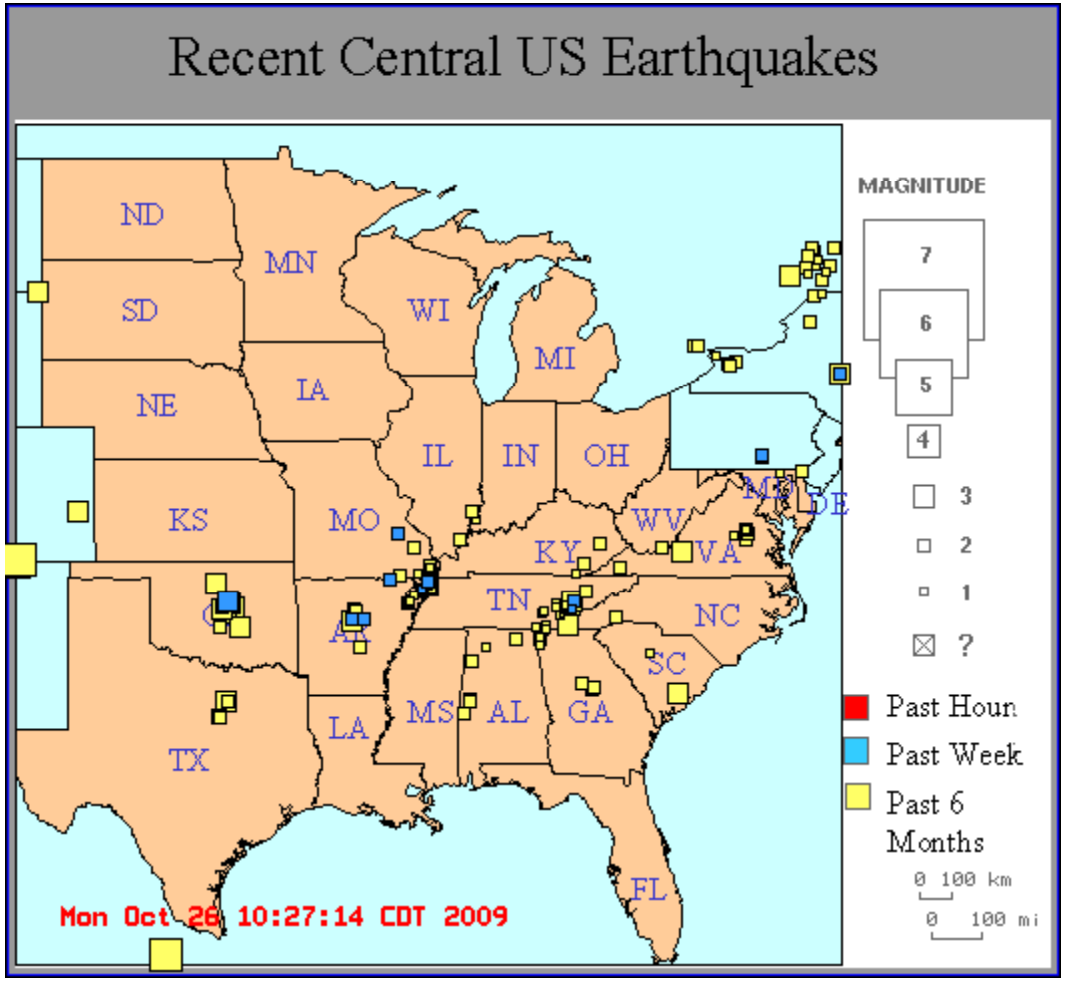
Greg Johnson, Using Earthquake Focal Mechanisms to Investigate Seismotectonics in the New Madrid Seismic Zone, MS Thesis, 2008. Map showing 8 reverse focal mechanisms, 12 normal focal mechanisms, and 10 strike-slip focal mechanisms.



Meredith M. Dunn, High Resolution Earthquake Locations and Velocity Models in the New Madrid Seismic Zone, Ph.D. Dissertation, 2009.

Relocations of the northern portion of the central thrust fault. Dip estimated to be 30-32 degrees for relocations, more shallow than southern portion of fault cross section is oriented N25W.

Induced Seismicity in Arkansas and Oklahoma?



Charles Langston

University of Memphis (CERI)

www.ceri.memphis.edu

THE UNIVERSITY OF MEMPHIS®
Center for Earthquake Research and Information

The Search for Non-volcanic Tremor in the NMSZ Using a Phased Seismic Array

Charles Langston

Duayne Rieger (Yale)

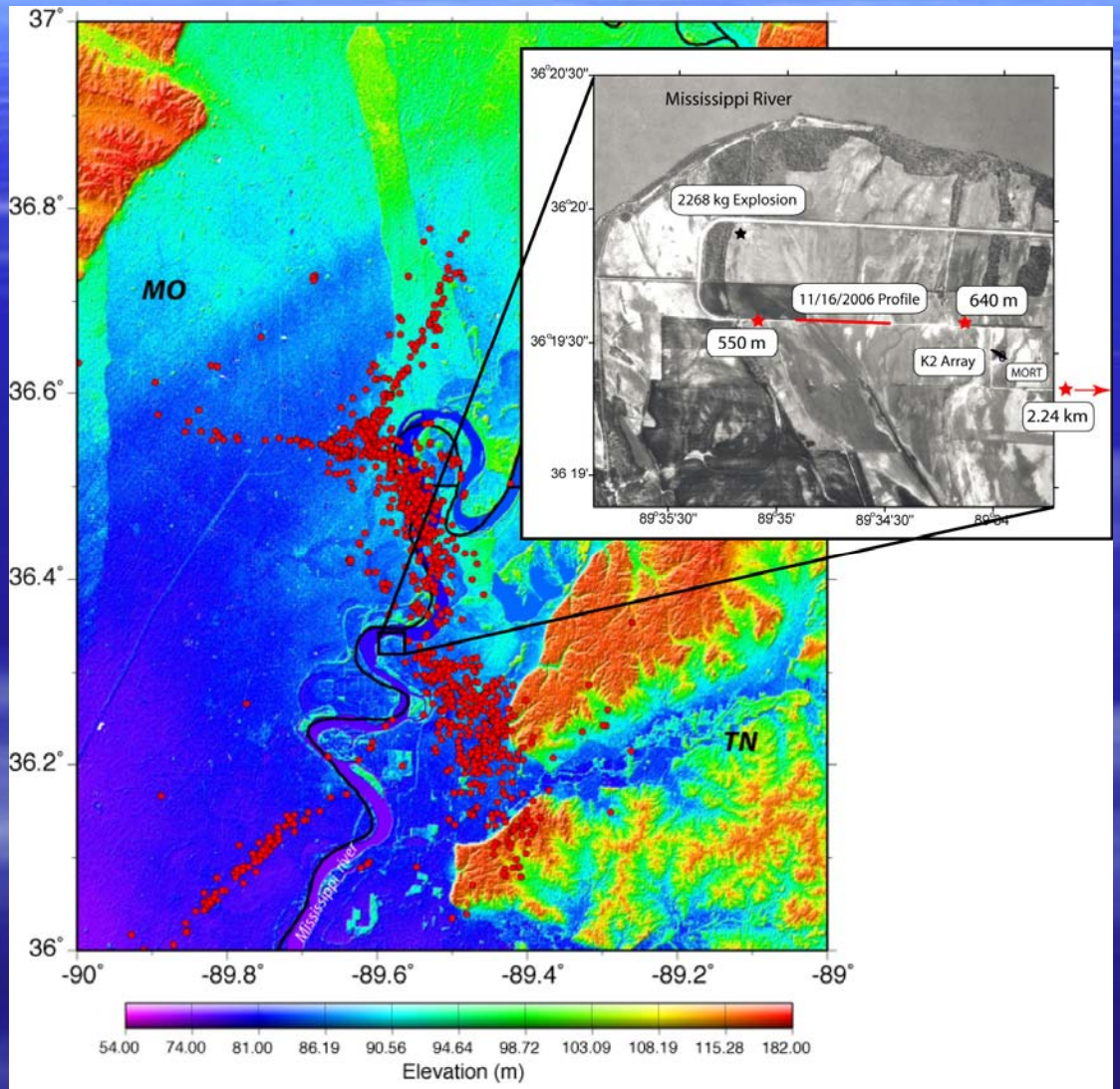
M. Beatrice Magnani

Heather DeShon

Stephen Horton

2006 Reflection Profile

(Acknowledge Rob Williams and David Worley)



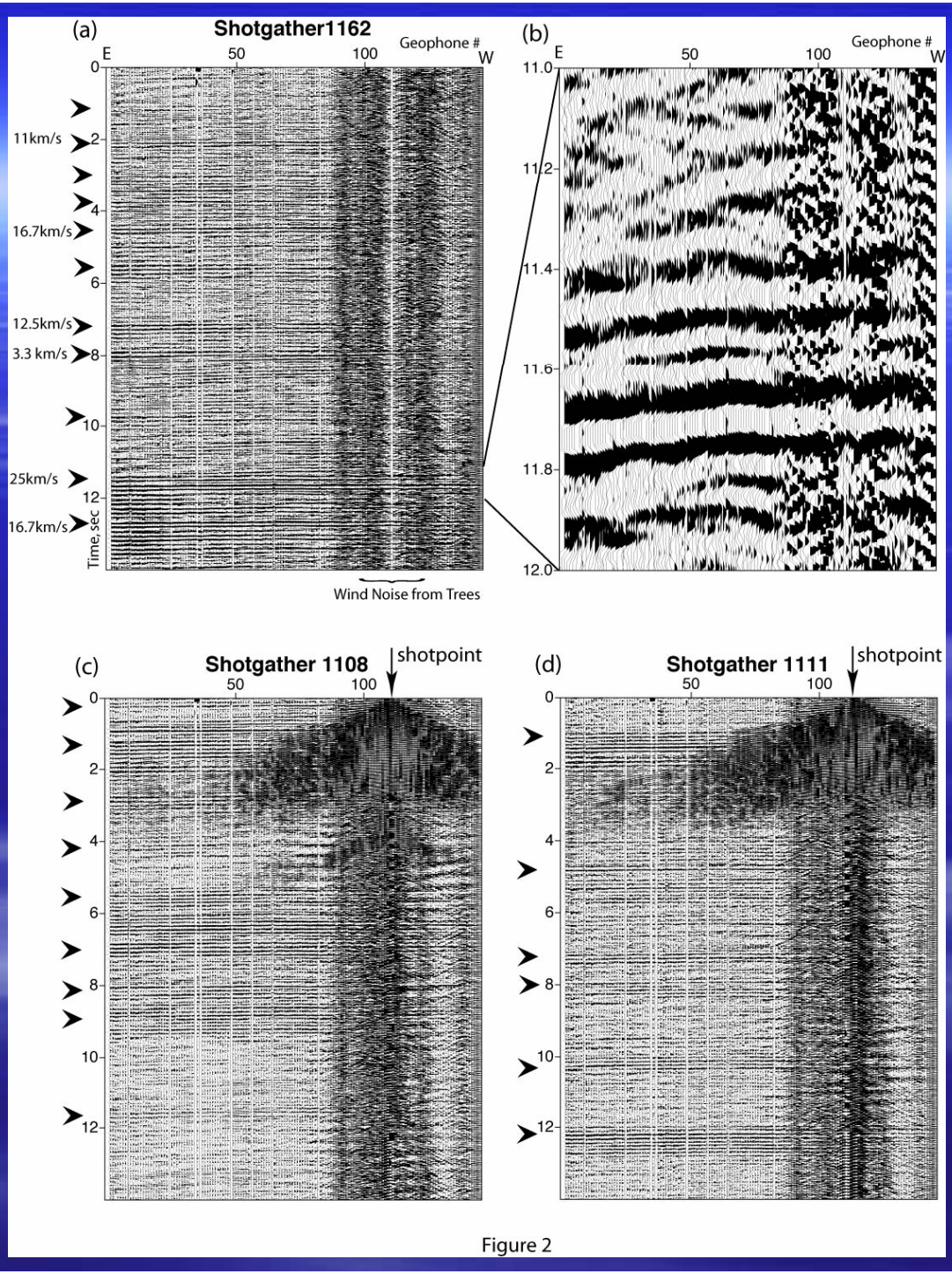
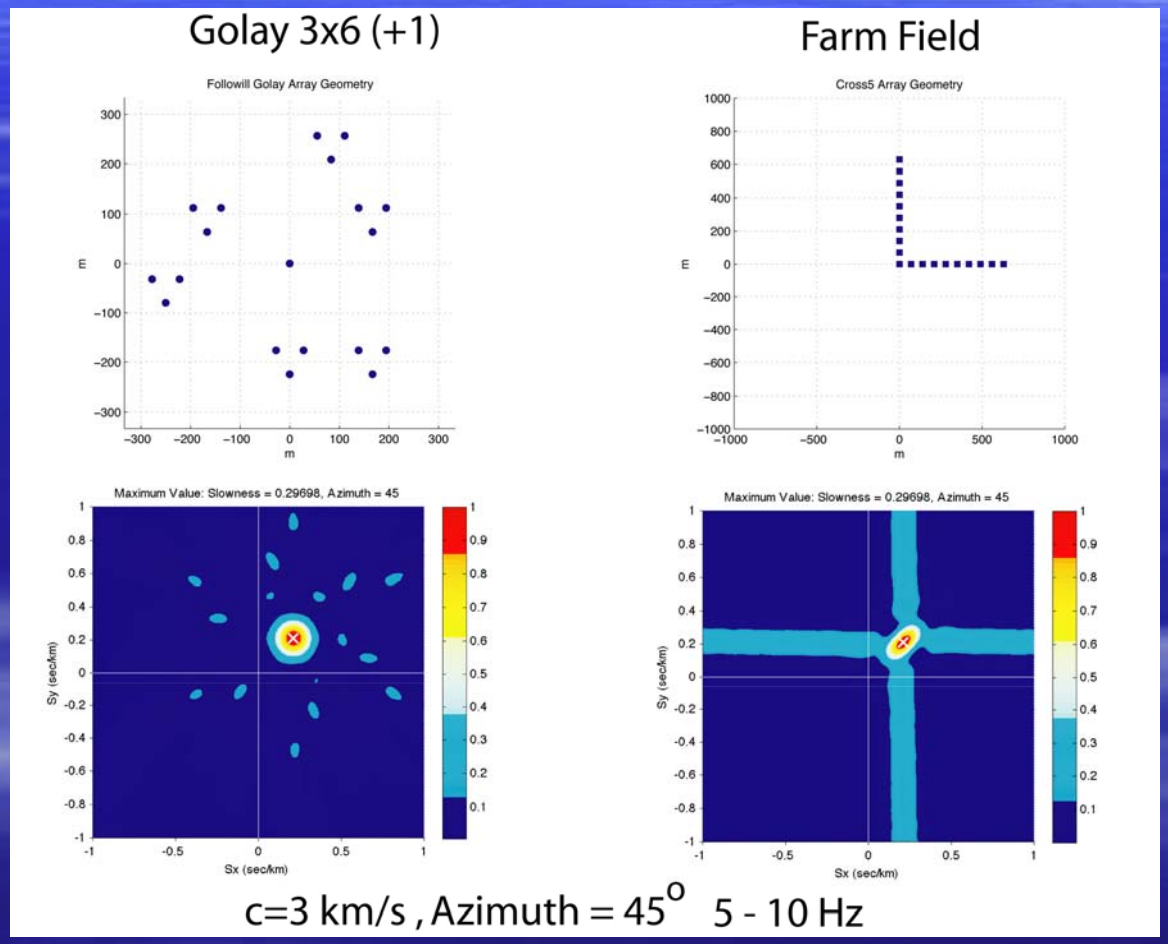

(a)
Shotgather1162
Geophone #
E
W
50
100
0
2
4
6
8
10
12
Time, sec
11km/s
16.7km/s
12.5km/s
3.3 km/s
25km/s
16.7km/s
Wind Noise from Trees
(b)
11.0
11.2
11.4
11.6
11.8
12.0
(c)
Shotgather 1108
shotpoint
(d)
Shotgather 1111
shotpoint

Figure 2

Array Experiment



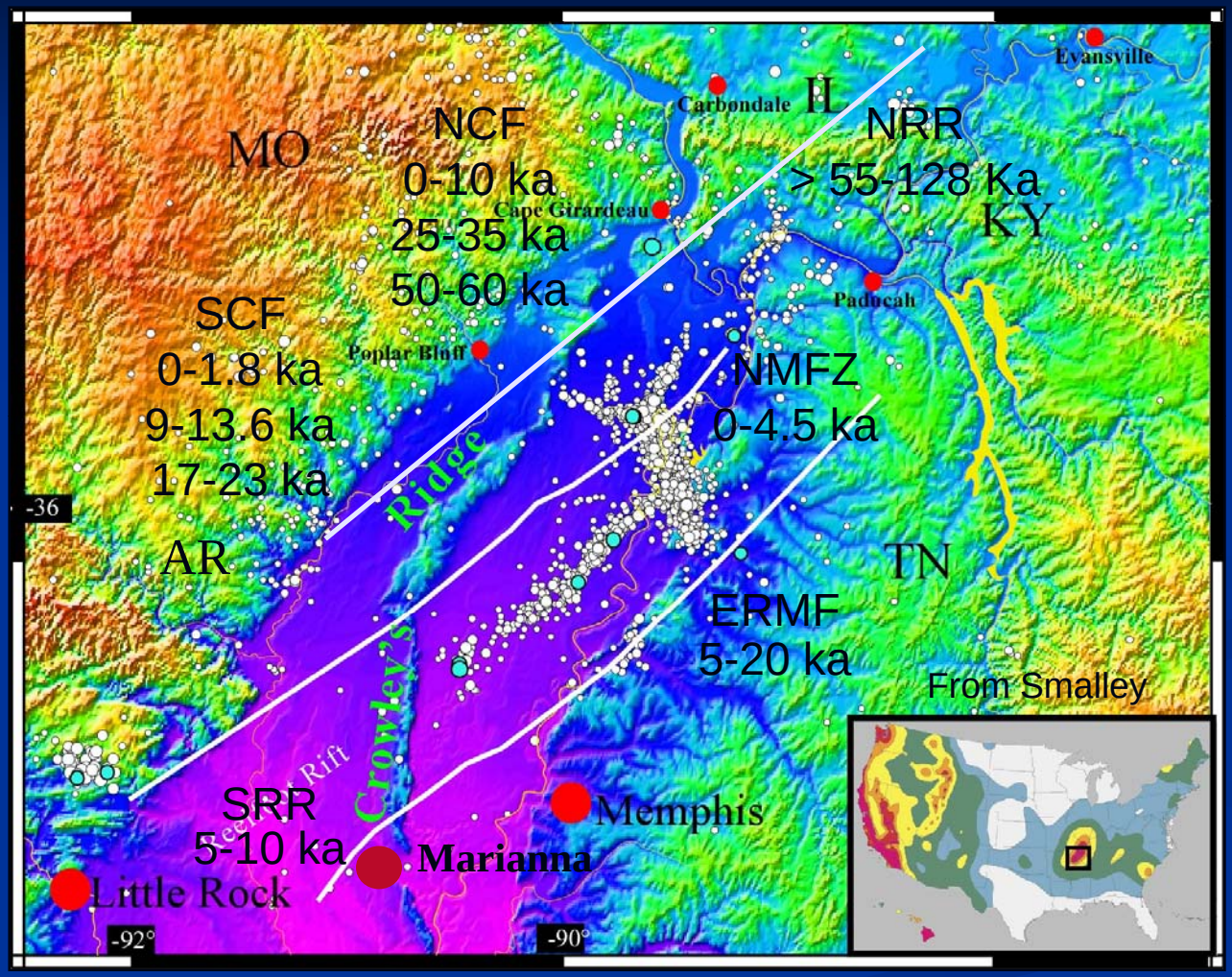
Martitia Tuttle

US Geological Survey

Migration of Large Paleoearthquakes Suggests Distributed Strain in the Central United States

Tish Tuttle & Natasha McCallister, USGS, Memphis; Buddy Schweig, USGS, Denver; Haydar Al-Shukri, University of Arkansas, Little Rock; Randy Cox, University of Memphis, Memphis

Migration Hypothesis



Seismicity migrated across greater New Madrid region during past tens of thousands of years and recently shifted to New Madrid fault zone (McBride et al., 2002).

East-Central Arkansas

- Near Marianna, AR, large sand blows formed between 5-7 ka, and possibly as early as 10 ka.
- Ages of sand blows do not match NM chronology and no large sand blows have been found in Marianna that formed during NM events in 1811-1812, 1450 AD, or 900 AD.
- Therefore, Marianna sand blows formed as result of very large local paleoearthquakes.
- ERMFZ and WRFZ are likely sources of events; numerous sand blows occur along lineaments parallel to these fault zones.
- Recent trenching of sand blows along one such lineament revealed unusual fracture that cross cuts older sand blow and may be related to faulting.

Western Tennessee

- Cox et al. (2001 and 2006) identified 150-km-long lineament interpreted as surface expression of ERMF.
- Faulting of Late Quat fluvial deposits found at several trench sites along lineament; interpreted as multiple events between 5-20 ka, and possibly as recently as 2 ka.

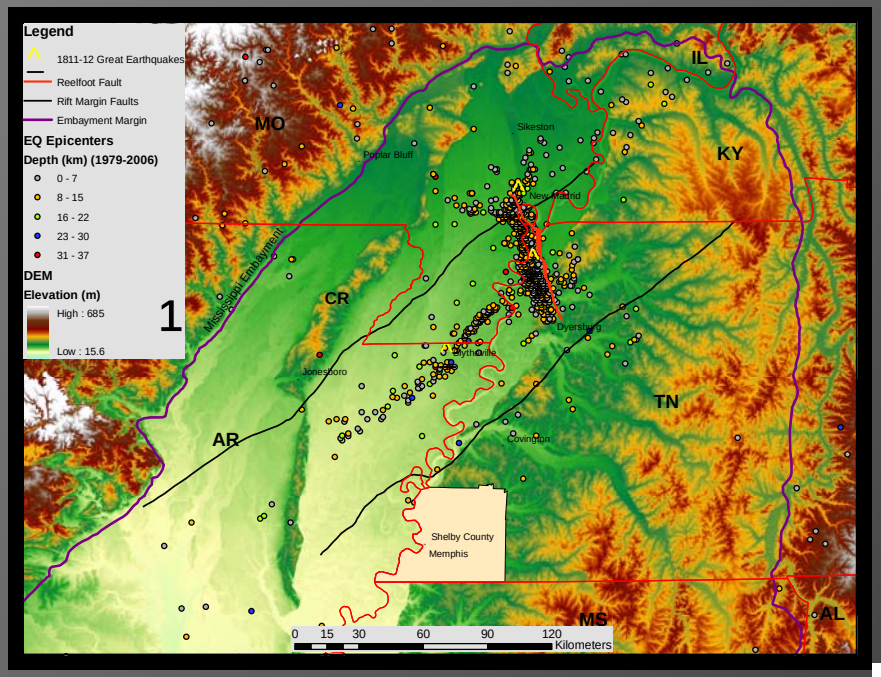
Conclusions

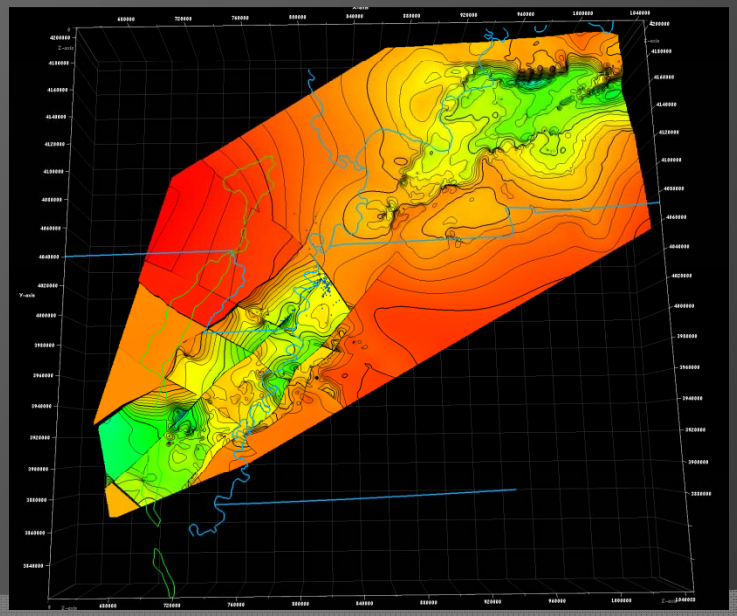
- Paleoseismic findings outside NMSZ suggest deformation localized by Reelfoot Rift but distributed across multiple faults and over much larger area.
- Might help to explain possibly low strain rates estimated from geodetic measurements.
- Additional info needed on Late Quat history of ERMF & WRFZ to better resolve threat to Memphis, Little Rock, etc.

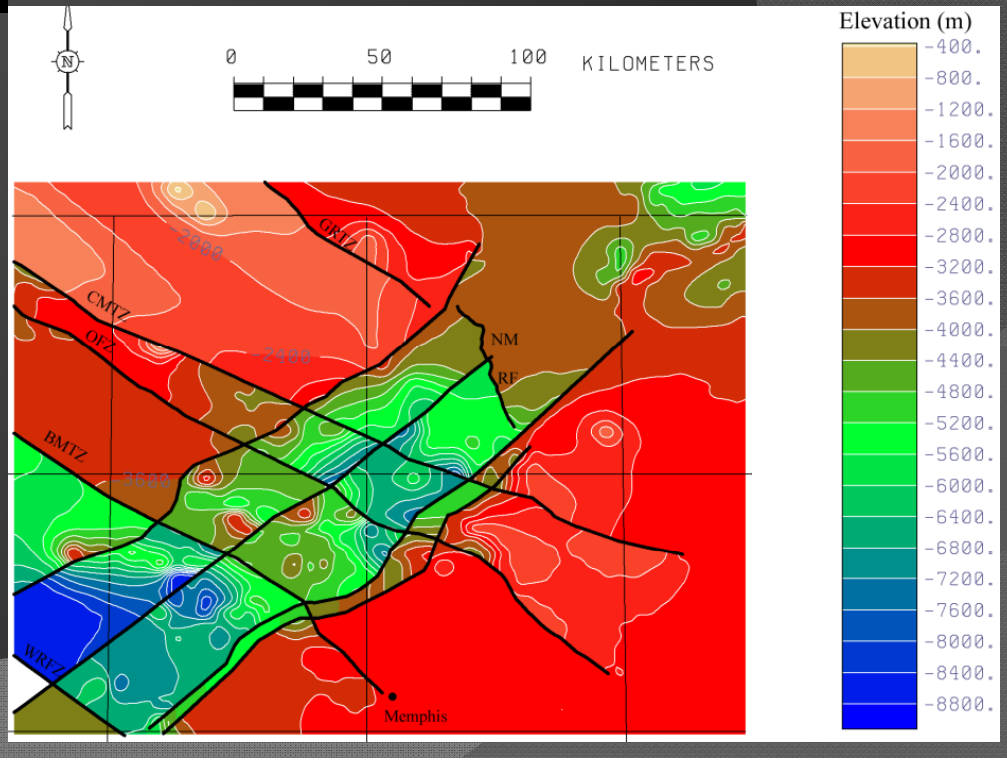
Roy Van Arsdale

University of Memphis

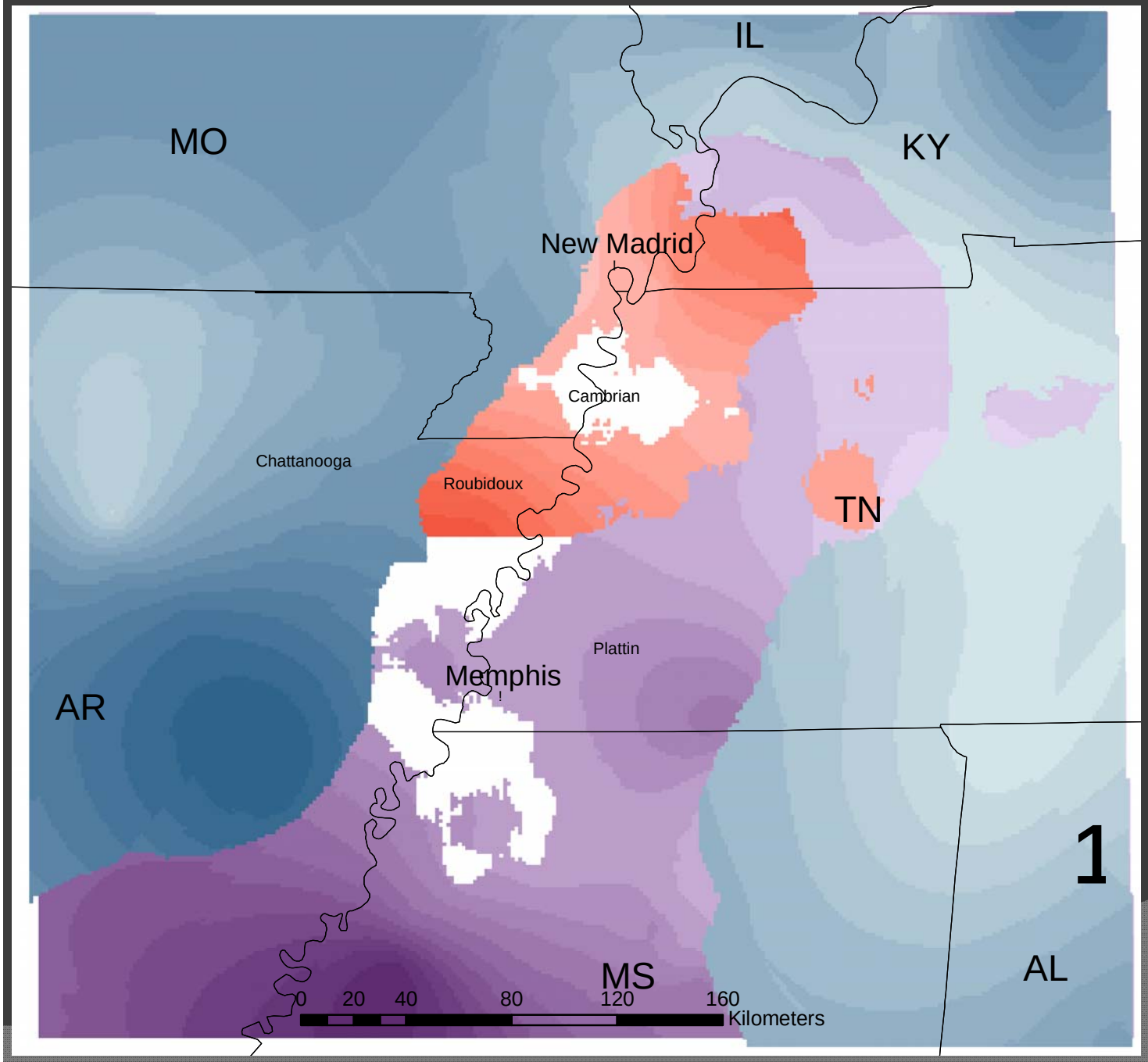
Regional Modeling of the Reelfoot rift and Surrounding Area

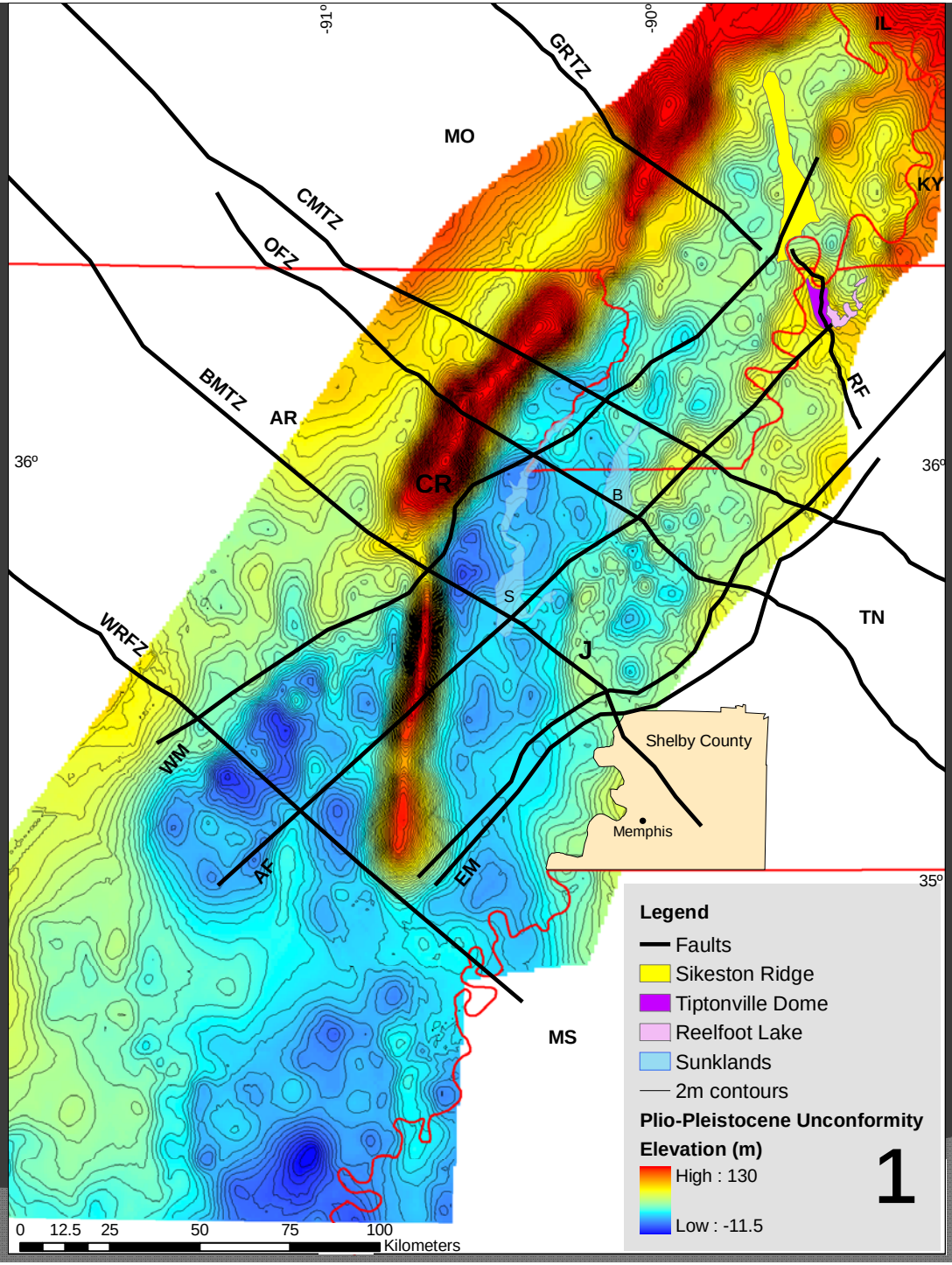




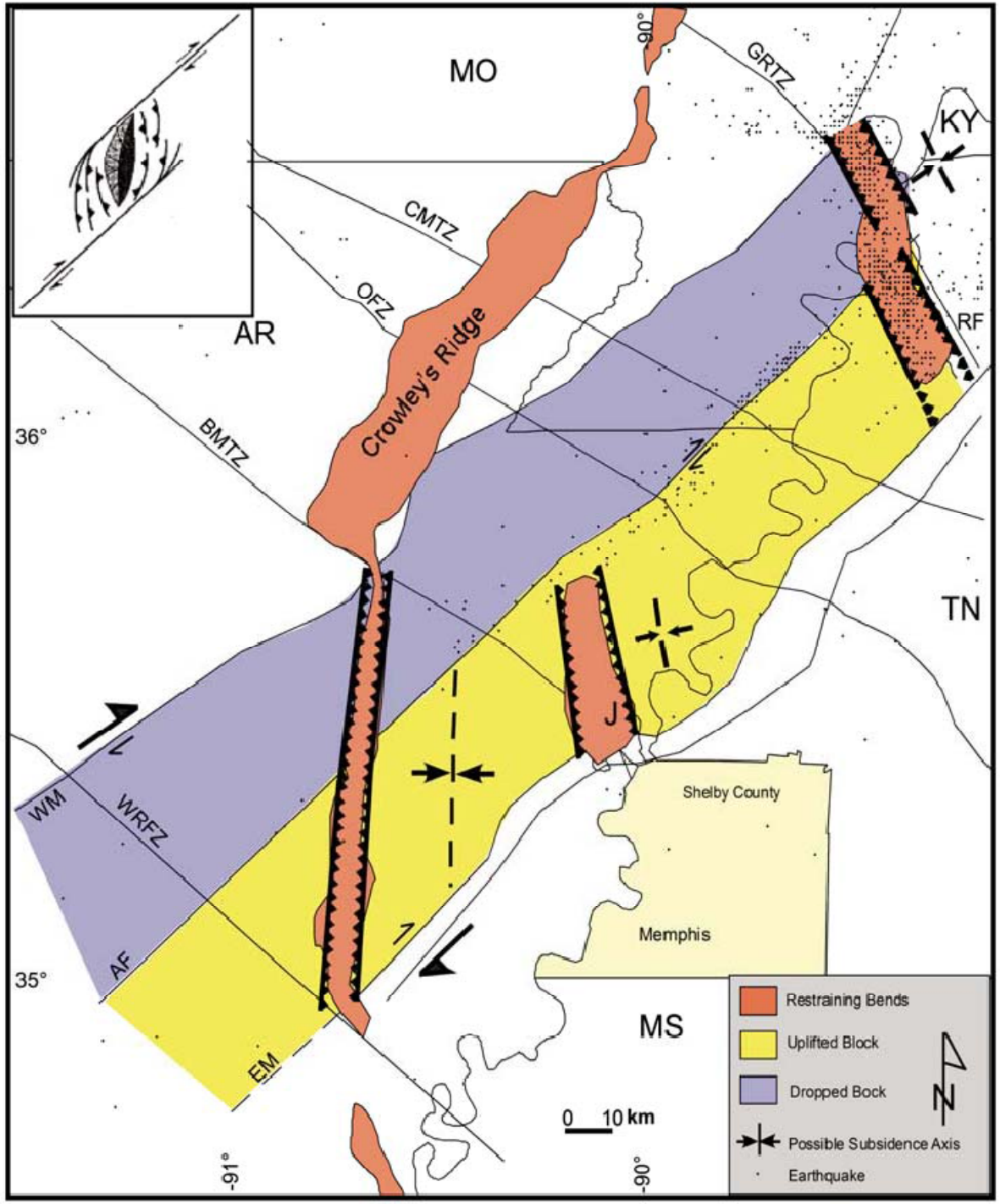


Paleozoic Subcrop





Pliocene-Pleistocene Unconformity / Base of Mississippi River Alluvium



Csontos – Van Arsdale Tectonic Model

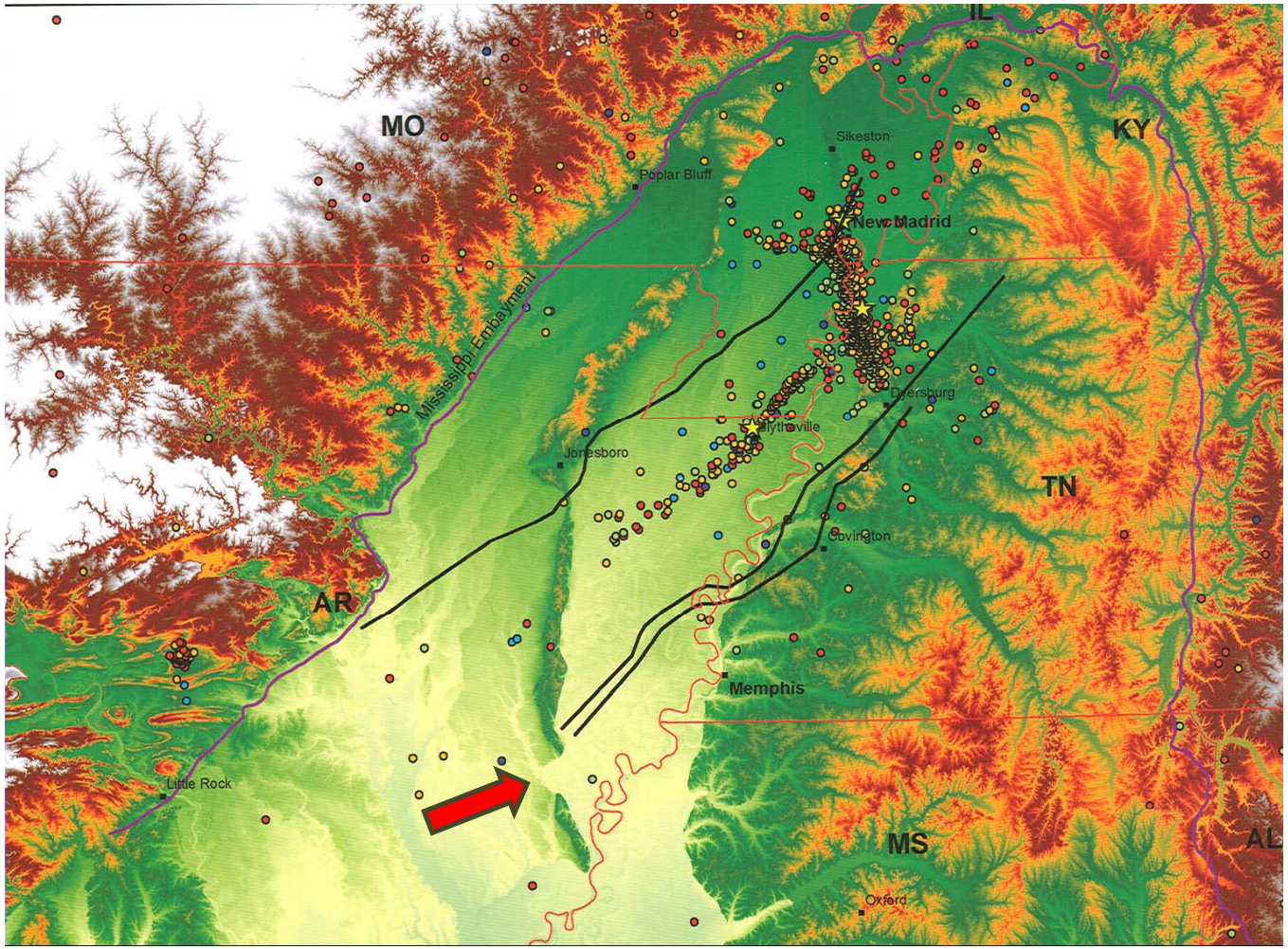
Margaret Guccione

University of Arkansas, Fayetteville

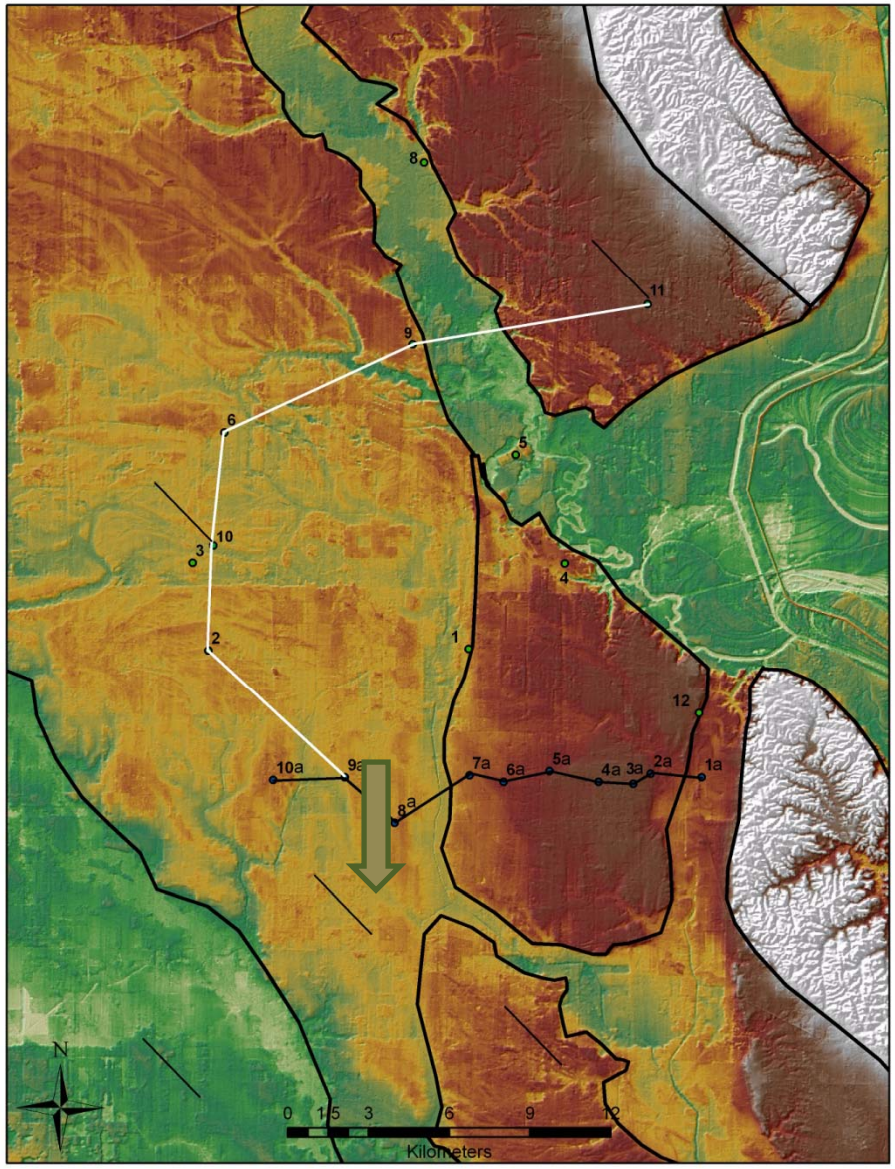
TANTALIZING SUGGESTIONS OF LATE PLEISTOCENE TO MIDDLE HOLOCENE SURFACE DEFORMATION AT THE SOUTHEASTERN MARGIN OF THE REELFOOT RIFT, MARIANNA, ARKANSAS

DANIEL S. RAINS and MARGARET J. GUCCIONE

Dept. of Geosciences, University of Arkansas, Fayetteville, AR 72701



Modified from Van Arsdale 2009



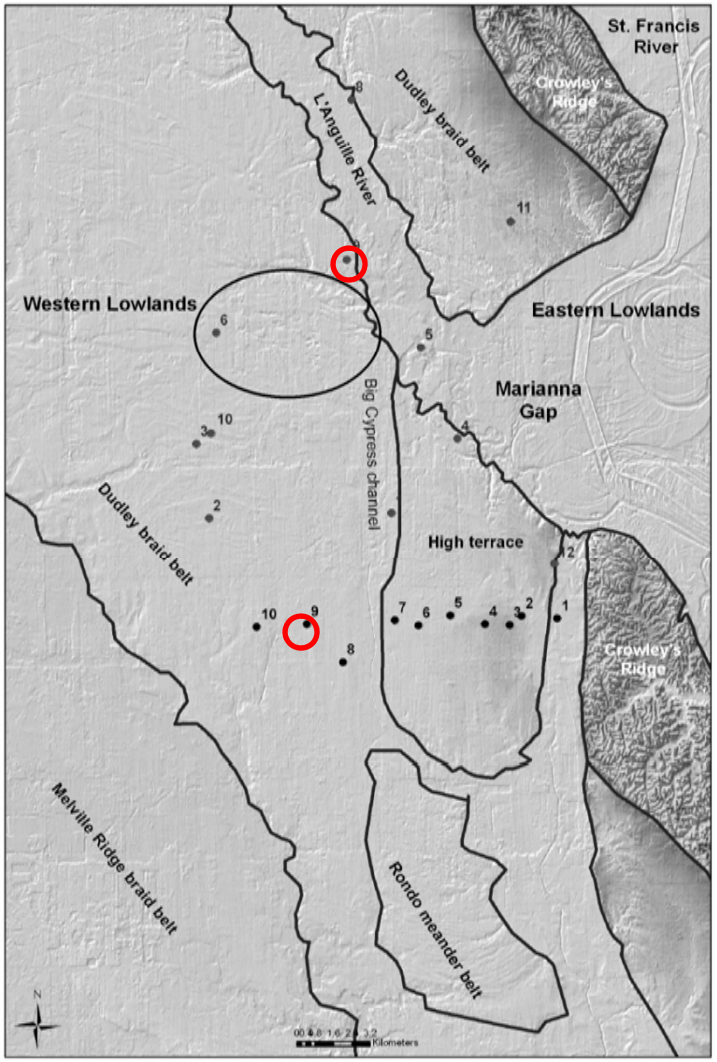
DEM of the Marianna Gap

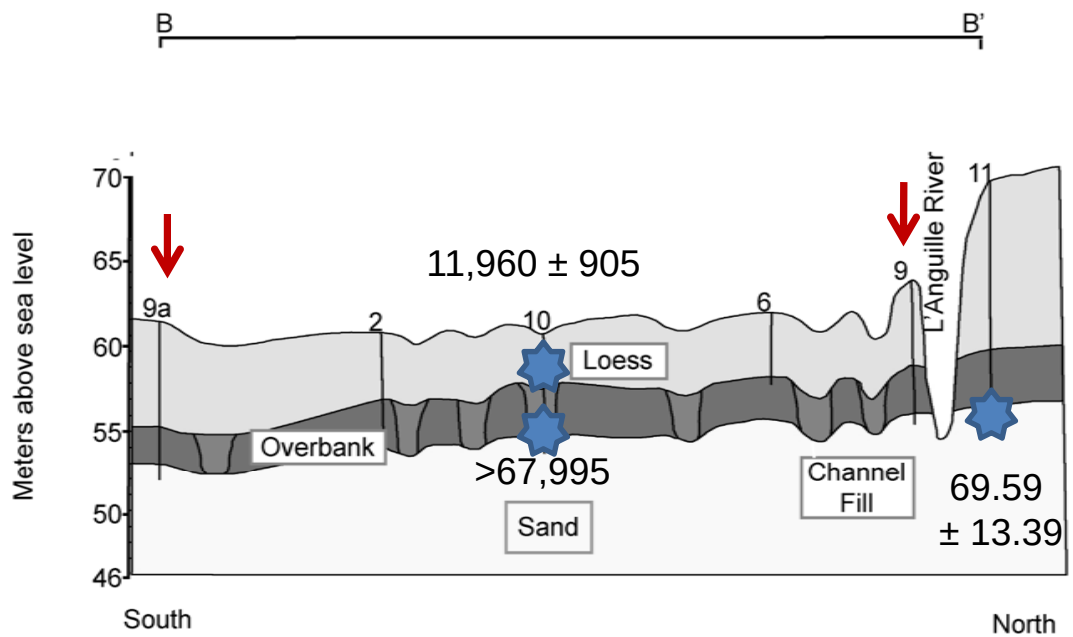
west of Marianna Gap, streams are deflected from the normal north-south path to a

west-east path. They flow toward, but not through the gap.

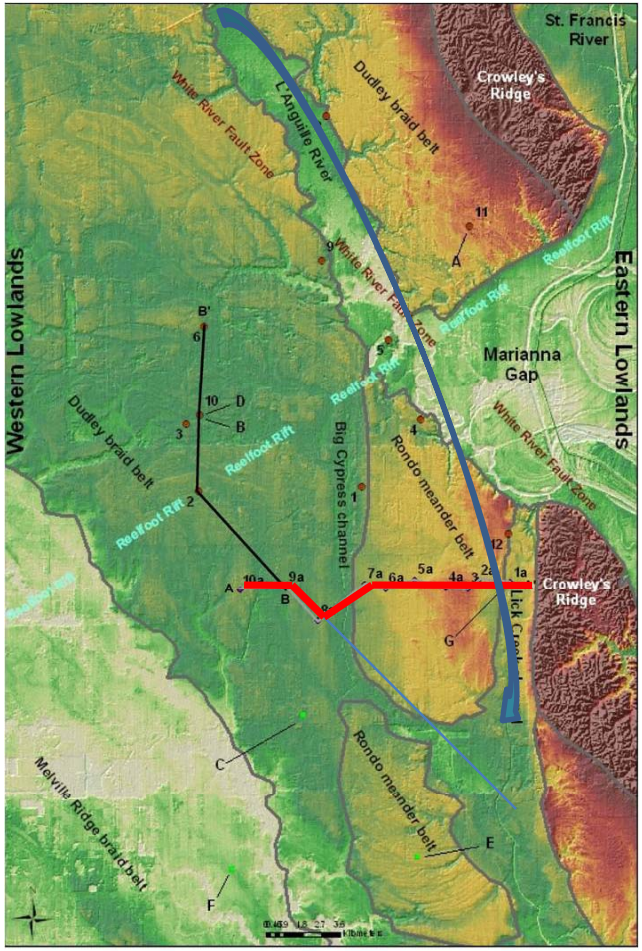
Paleochannels are ca. 60-70 ka

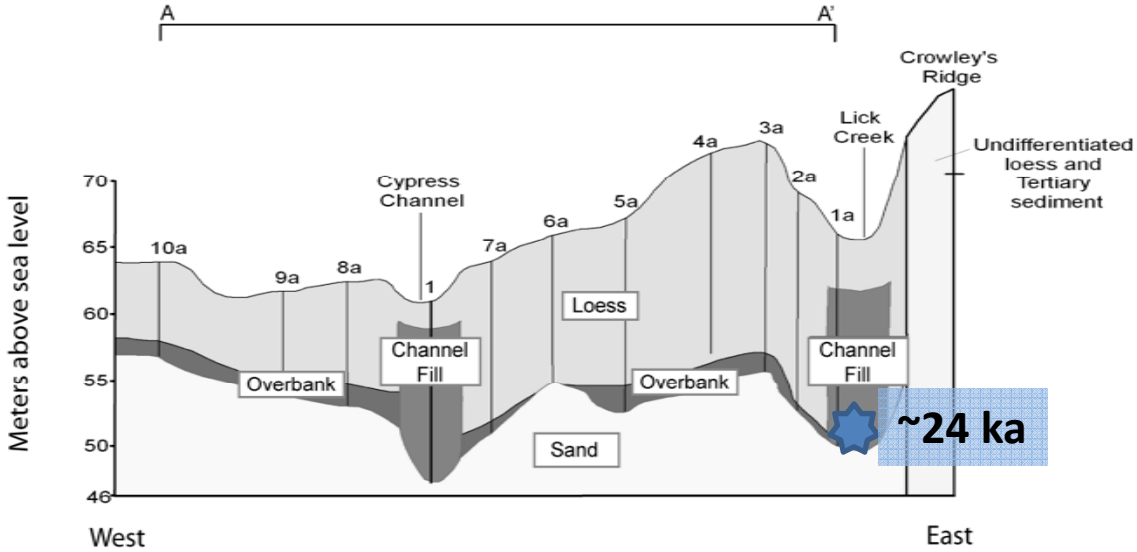
Loess deposited 25-12 ka thins west of gap, compared to north and south of gap Wind scour through a low divide in gap may have reduced thickness





L'Anguille River restricted west of Gap between 24 and ca. 12 ka





Meander bend of Mississippi meander belt 3 (4-7ka) truncates Crowleys Ridge at Marianna Gap

Conclusions

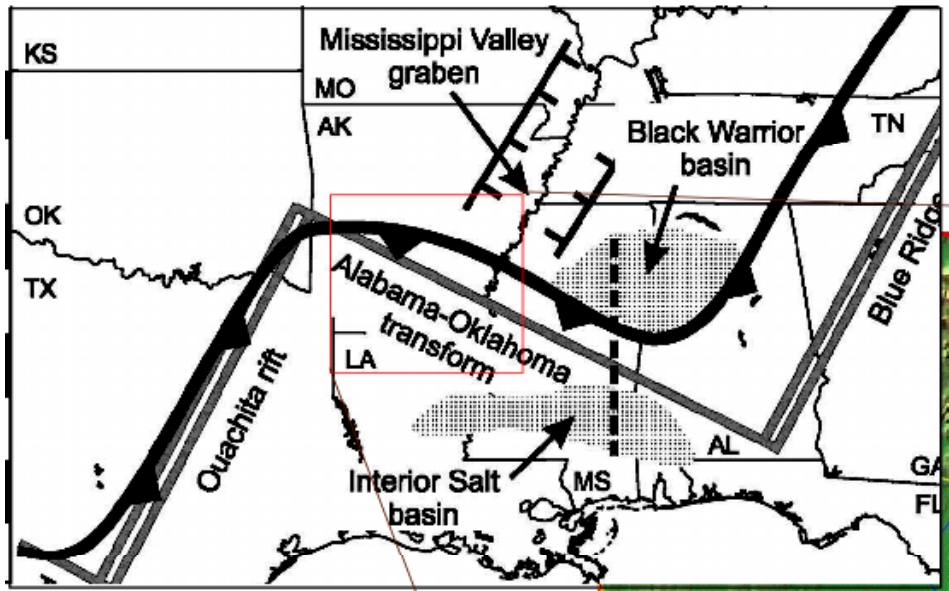
1. A low area west of Crowley's Ridge and a low divide in the Ridge existed 70-15 ka
2. The Gap was breached by meandering Mississippi River 4-7 ka (Saucier, 2004)
3. Crowley's Ridge north and south of Marianna Gap is offset by 10 km
4. Mid Holocene (5-7 ka) liquefaction features (Tuttle and Mahdi, 2006) indicate seismic activity which may be responsible for breaching of Marianna Gap

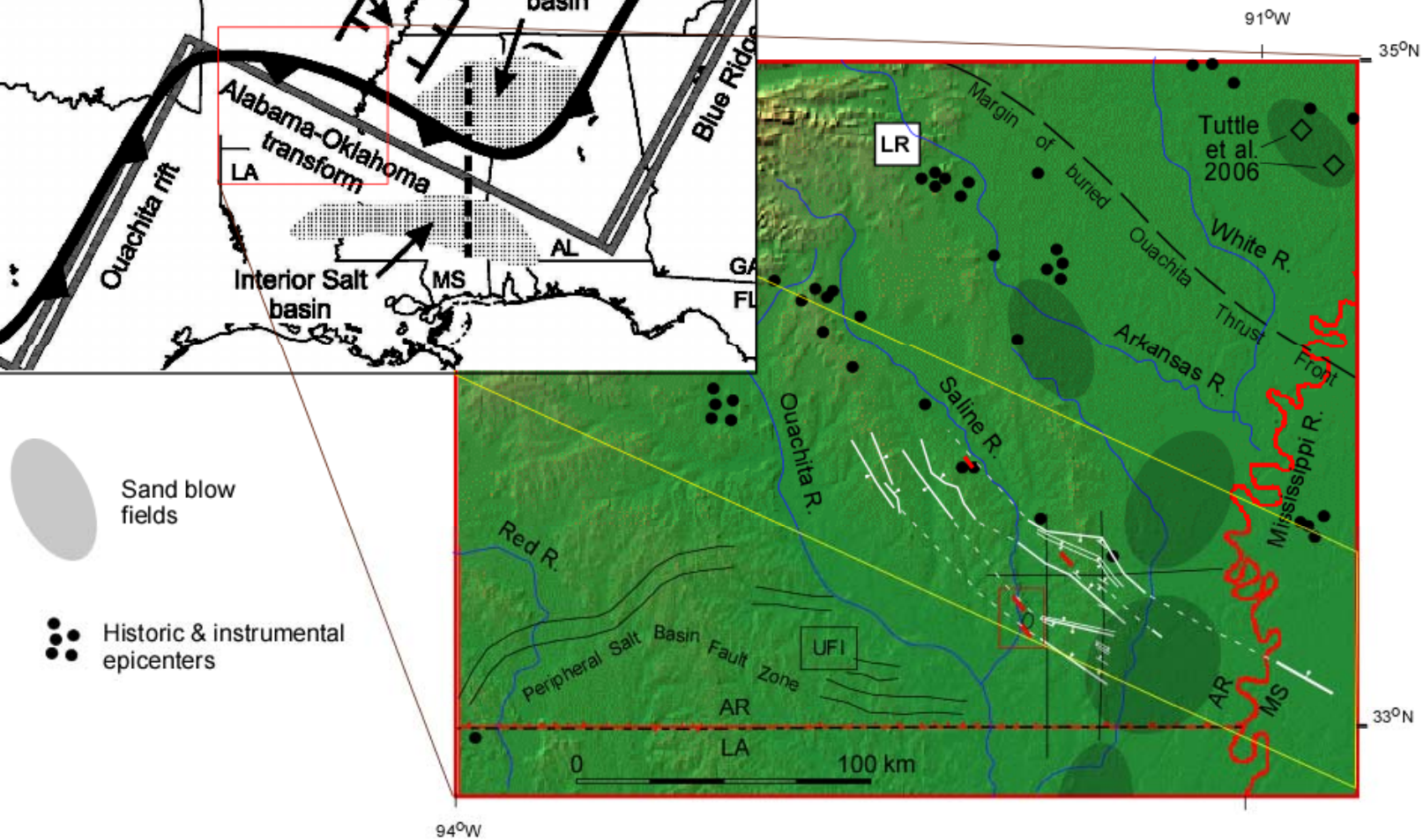
Randal Cox

University of Memphis

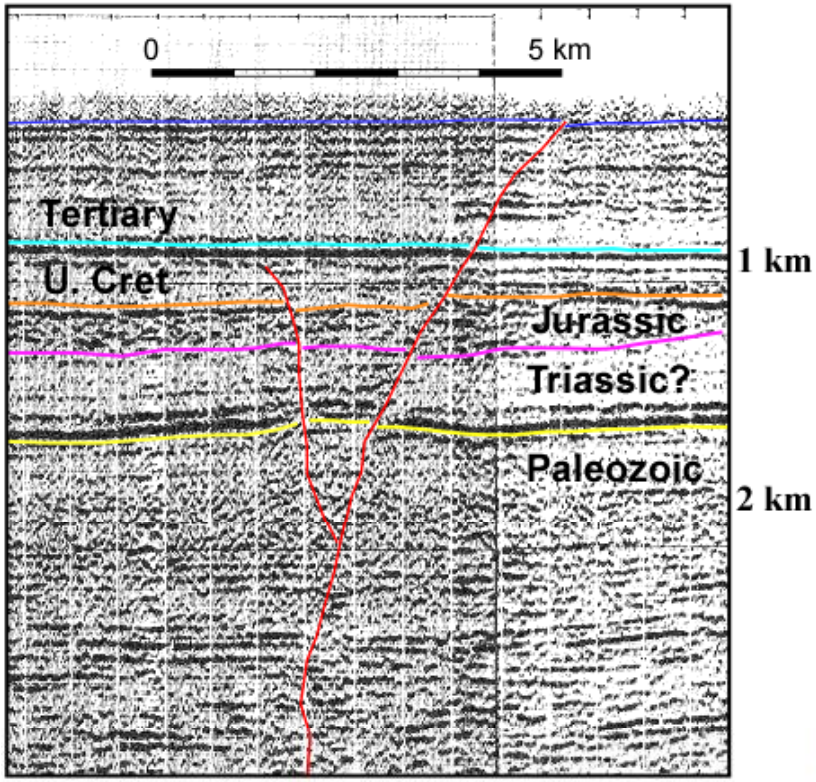
Progress report on investigation of Holocene faulting and liquefaction along the southern margin of the North American craton (Alabama-Oklahoma transform)

Randy Cox, Tom Brezina, Sarah Machin, Arleen Hill, Chris Gardner, Dept. of Earth Sciences, University of Memphis
Josh Gordon, Southwestern Energy, Conway ,AR
Jamie Harris, Millsaps College, Jackson, MS
Steve Forman, University of Illinois, Chicago

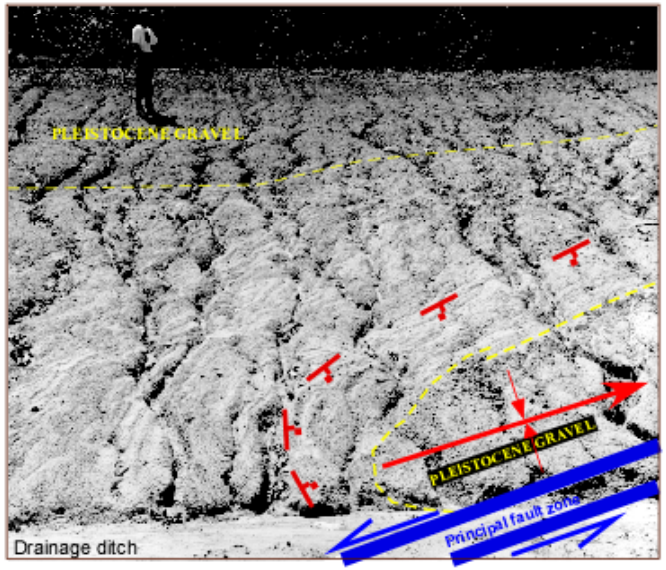


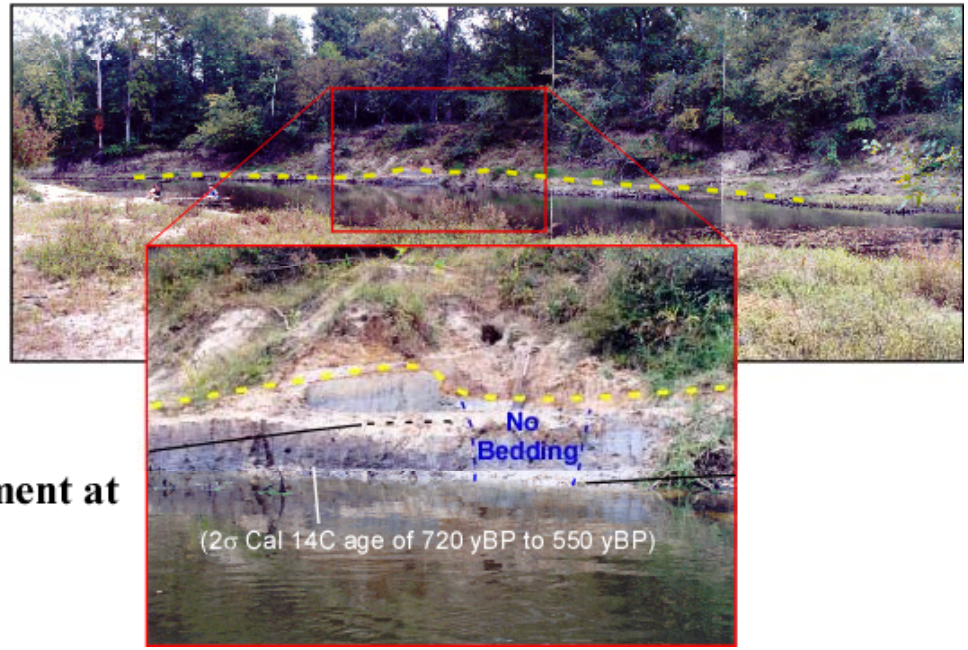


Flower structure beneath Monticello, Arkansas

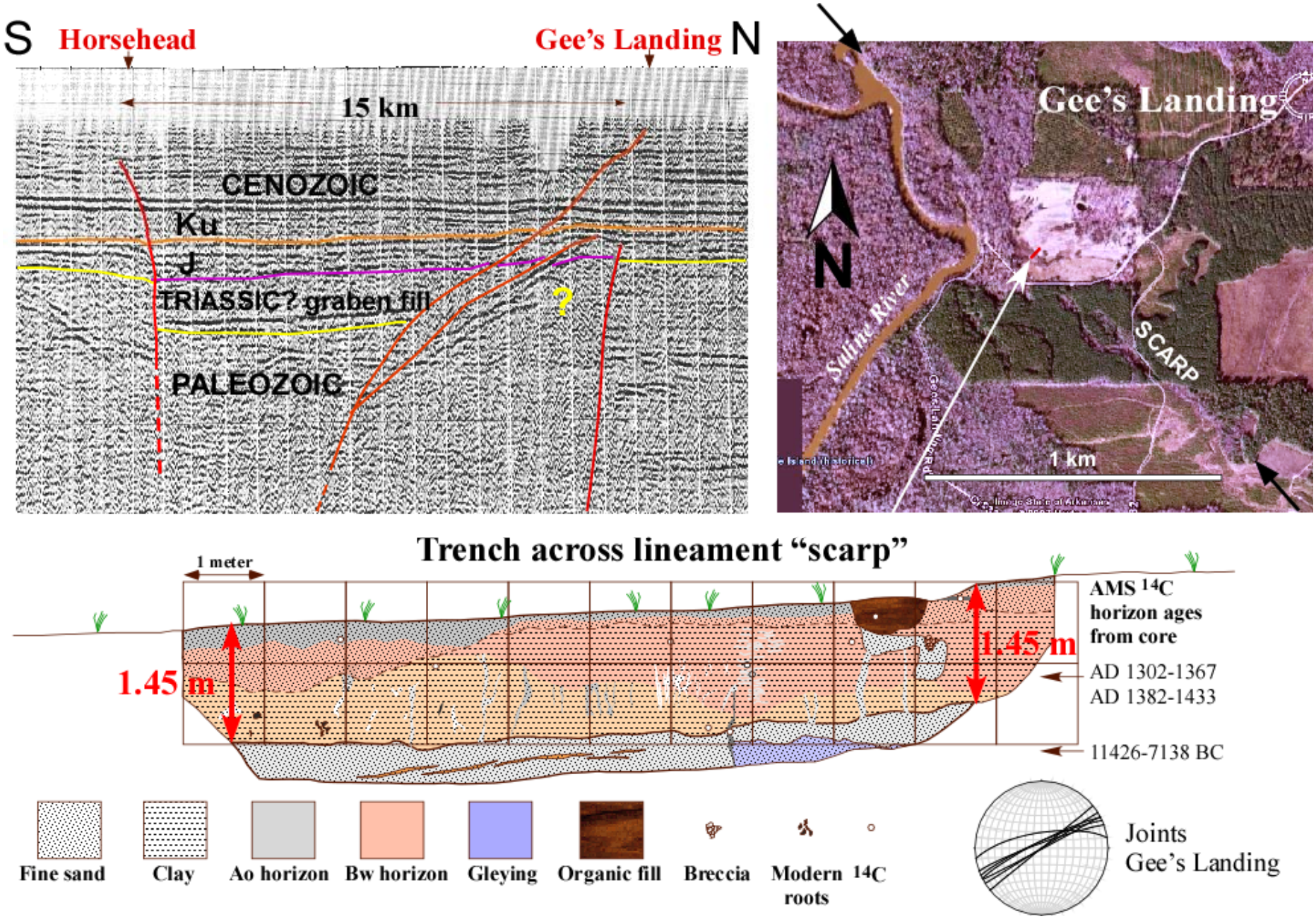


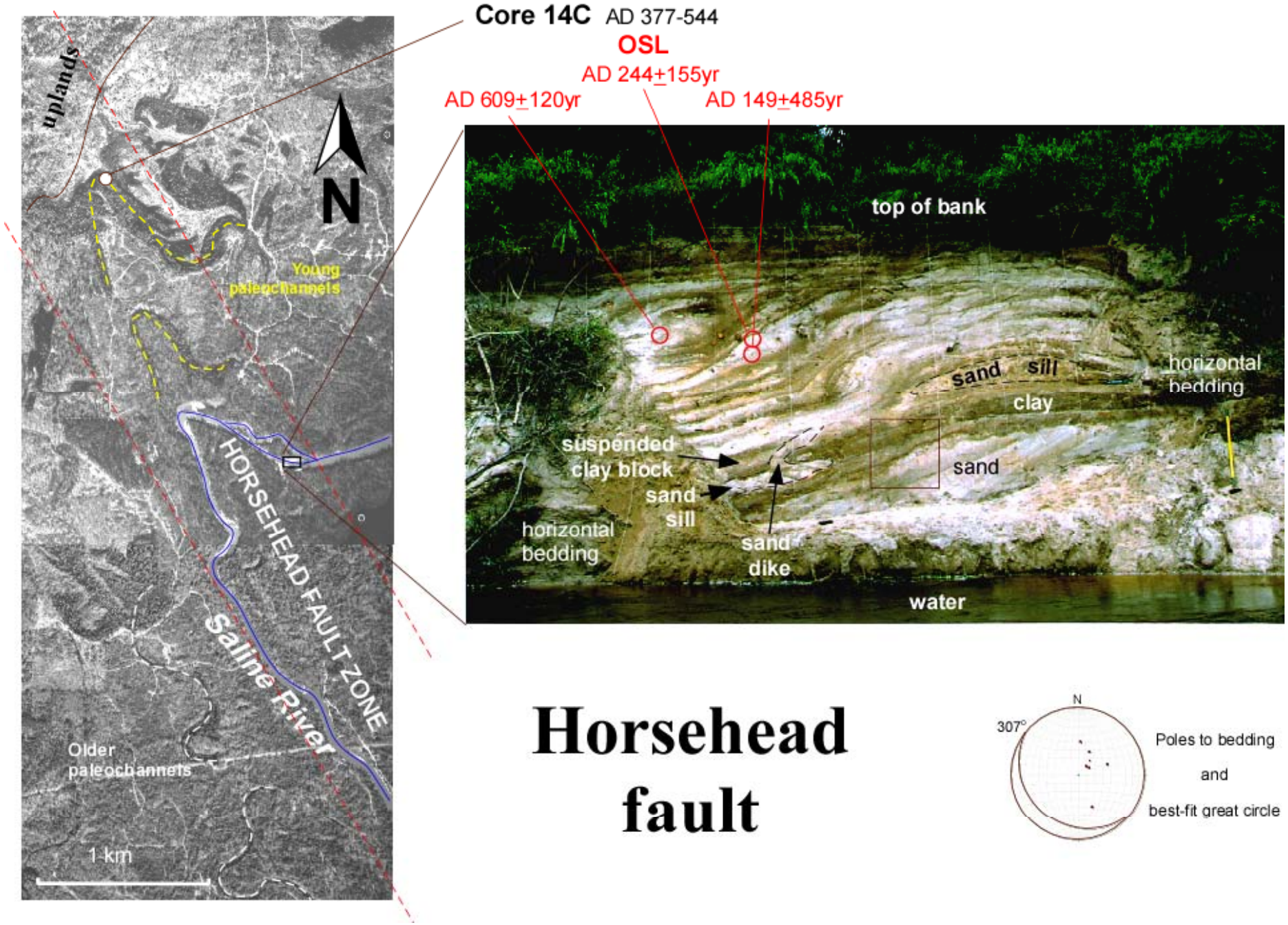
Left-lateral drag folding exposed in roadcut at Monticello involving Pleistocene alluvium





River cut through anticline lineament at Rison, Arkansas


S
Horsehead
Gee's Landing
N
15 km
CENOZOIC
Ku
J
TRIASSIC? graben fill
?
PALEOZOIC
Gee's Landing
N
Saline River
SCARP
1 km
Trench across lineament "scarp"
1 meter
1.45 m
1.45 m
AMS 14C horizon ages from core
AD 1302-1367
AD 1382-1433
11426-7138 BC
Fine sand
Clay
Ao horizon
Bw horizon
Gleying
Organic fill
Breccia
Modern roots
14C
Joints
Gee's Landing


Core 14C AD 377-544
OSL
AD 244±155yr
AD 609±120yr
AD 149±485yr
uplands
N
Young paleochannels
HORSEHEAD FAULT ZONE
Saline River
Older paleochannels
1-km
top of bank
sand
sill
horizontal bedding
clay
suspended clay block
sand
sand sill
horizontal bedding
sand dike
water
Horsehead fault
N
307°
Poles to bedding
and
best-fit great circle

Bob Hatcher

Department of Earth and Planetary Sciences, UT, Knoxville

Paleoseismic Investigation of the East Tennessee Seismic Zone: Preliminary Results

Stephen F. Obermeier
USGS Emeritus

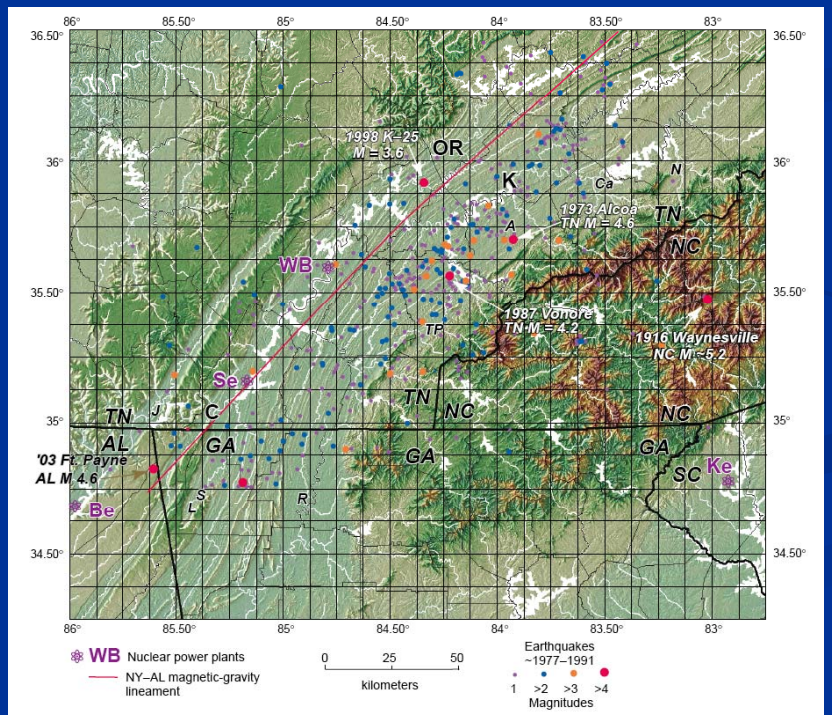
James D. Vaughn
MO Geological Survey (retired)

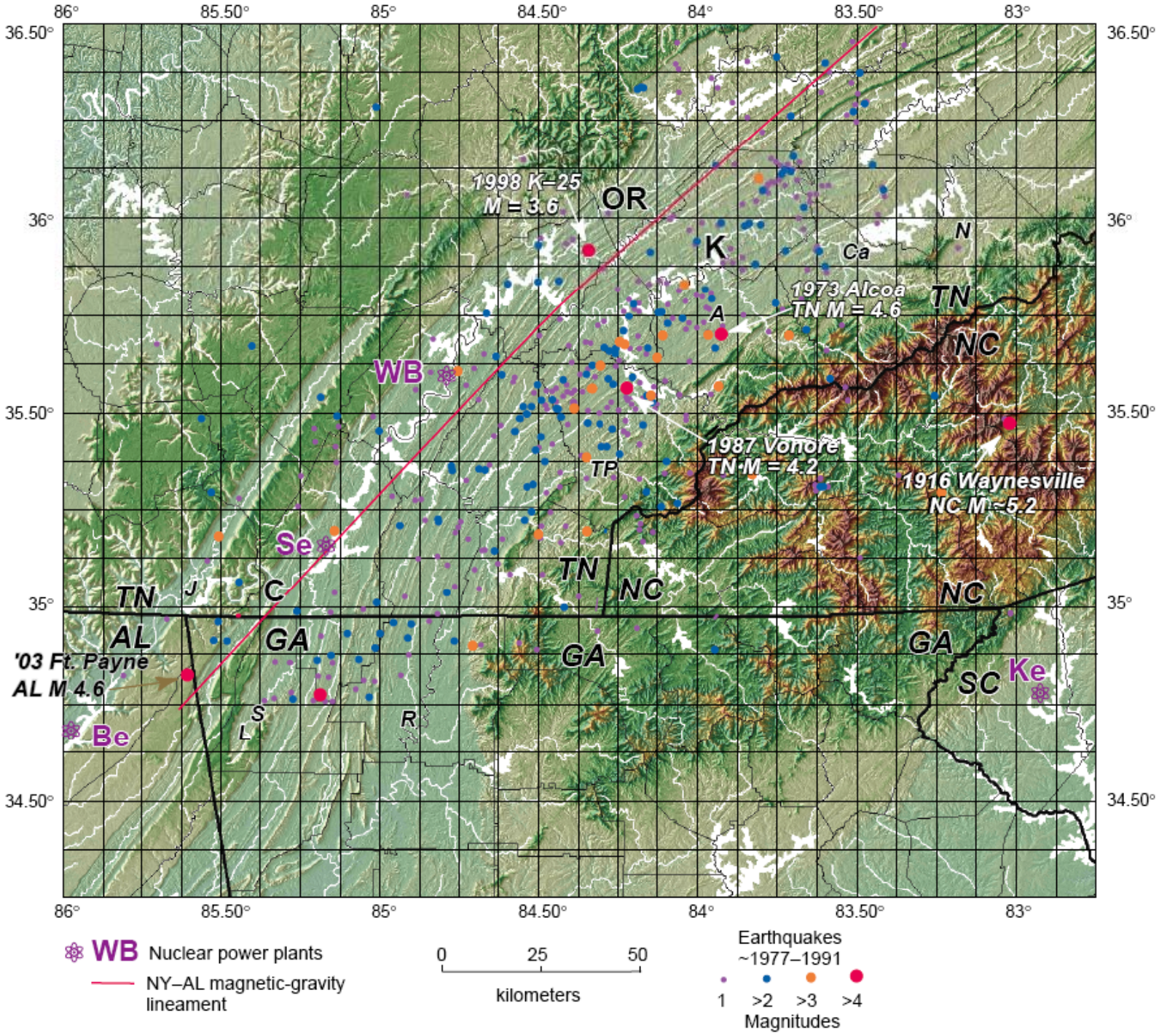
Robert D. Hatcher, Jr.
Univ. of Tennessee–Knoxville

Hugh H. Mills
Tennessee Tech Univ.

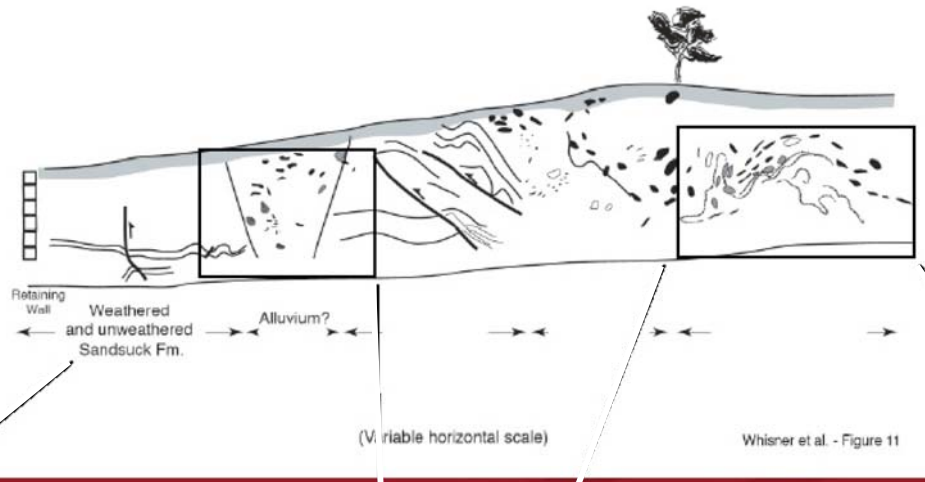
S. Christopher Whisner
Bloomsburg Univ.

Christopher W. Howard
Univ. of Tennessee–Knoxville




86°
85.50°
85°
84.50°
84°
83.50°
83°
36.50°
36°
35.50°
35°
34.50°
1998 K–25
M = 3.6
OR
K
Ca
N
1973 Alcoa
TN M = 4.6
A
TN
NC
WB
1987 Vonore
TN M = 4.2
TP
1916 Waynesville
NC M ≈ 5.2
Se
TN
J
C
NC
NC
AL
GA
GA
GA
'03 Ft. Payne
AL M 4.6
SC
Ke
S
L
R
Be
WB Nuclear power plants
NY–AL magnetic-gravity lineament
0
25
50
kilometers
Earthquakes
~1977–1991
1
>2
>3
>4
Magnitudes

Possible ETSZ Liquefaction/Deformation-Related Structures



Tellico Plains, TN

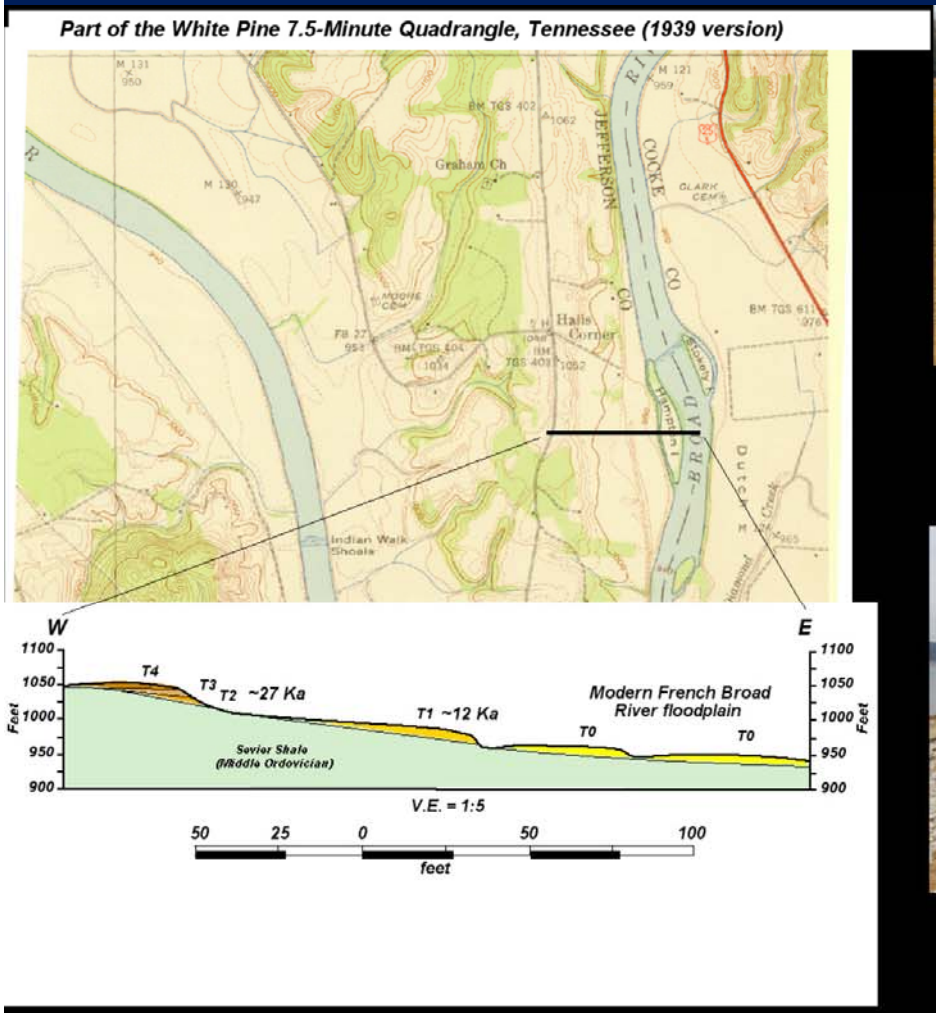
Possible ETSZ Liquefaction/Deformation-Related Structures

Tellico Plains, TN

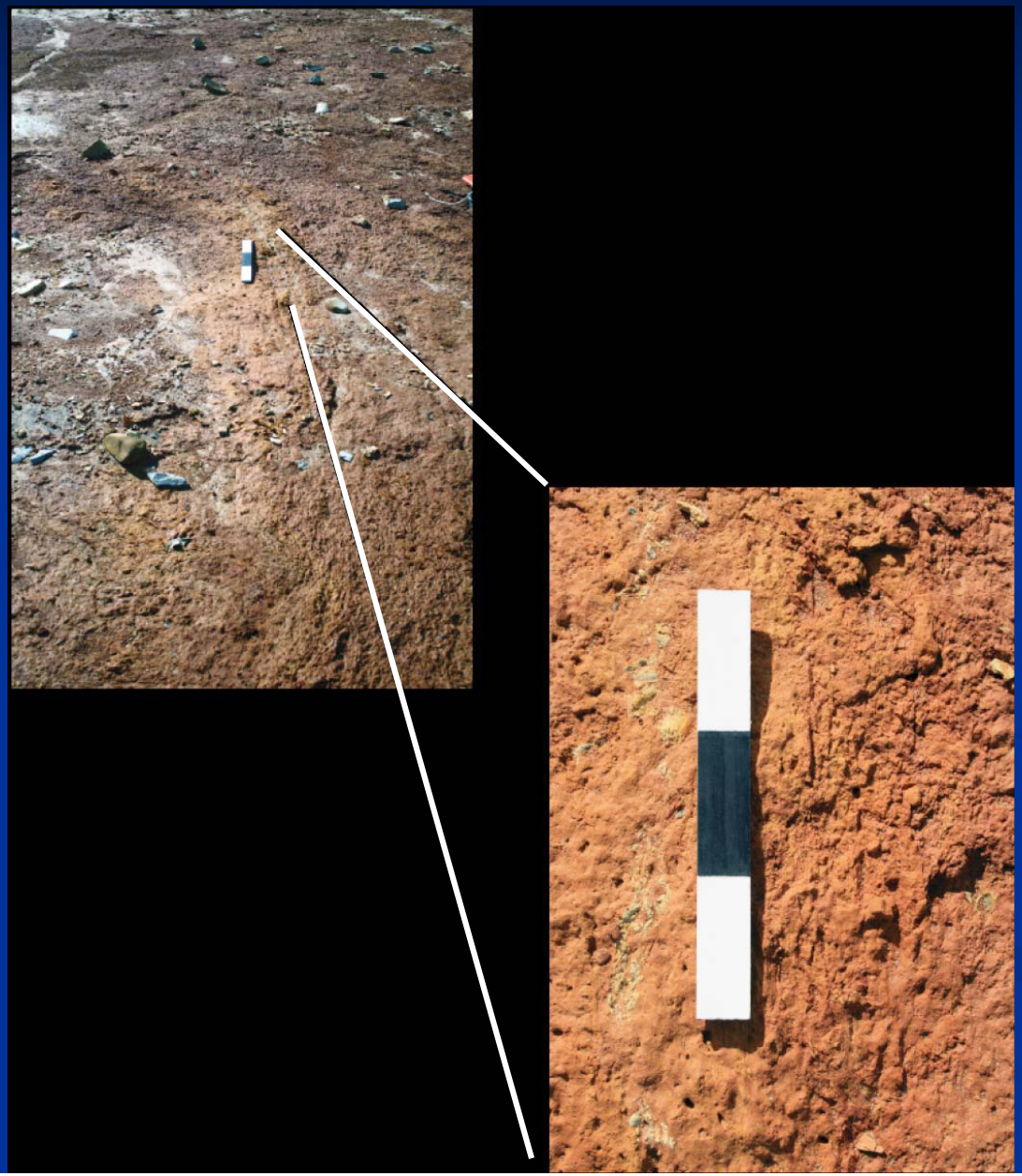
Possible ETSZ Liquefaction/Deformation-Related Structures

Deformed alluvium, Tellico Plains, TN

Terraces and Possible Paleoseismic Features Around Douglas Reservoir



Terraces and Possible Paleoseismic Features Around Douglas Reservoir

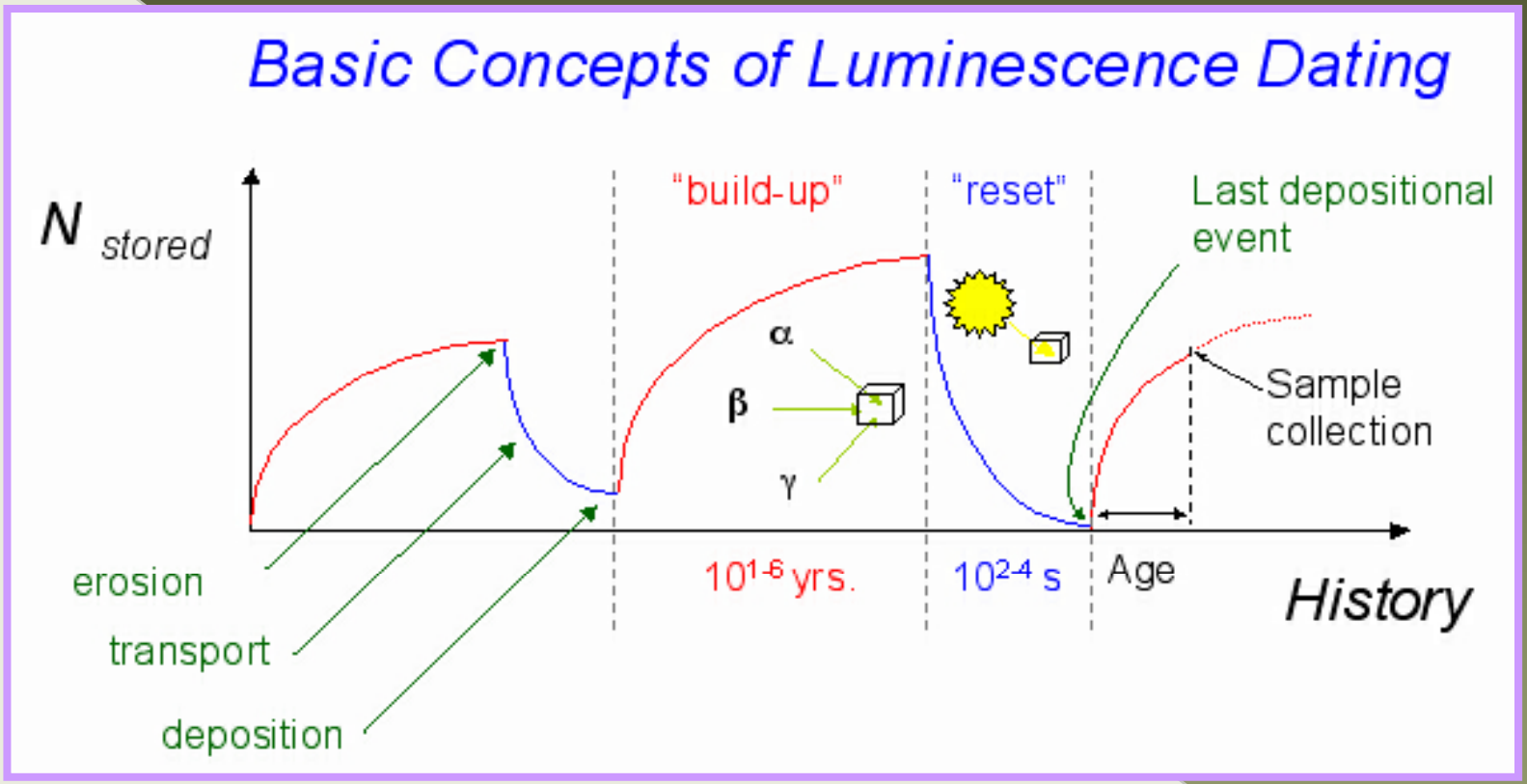


Clay-filled fracture near Dandridge, TN

Photos by Jim Vaughn
October 22, 2009

Shannon Mahan

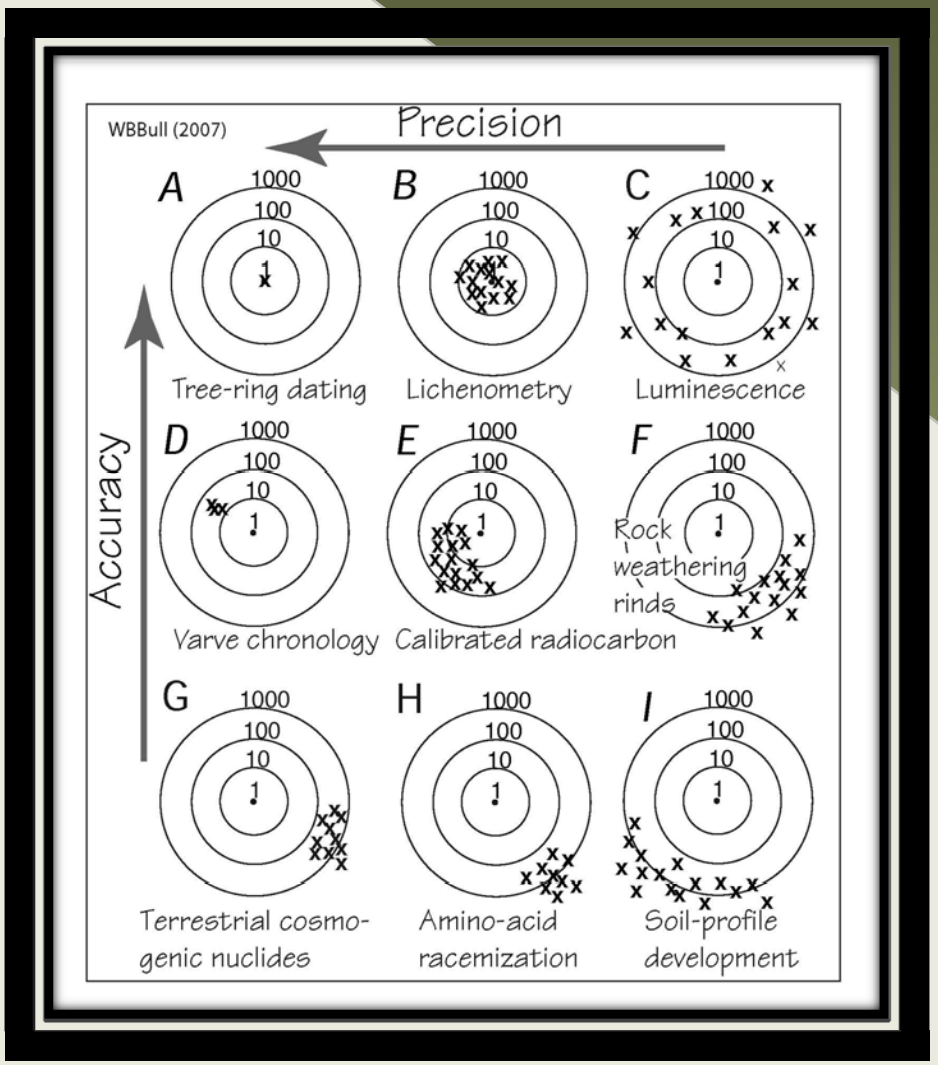
US Geological Survey

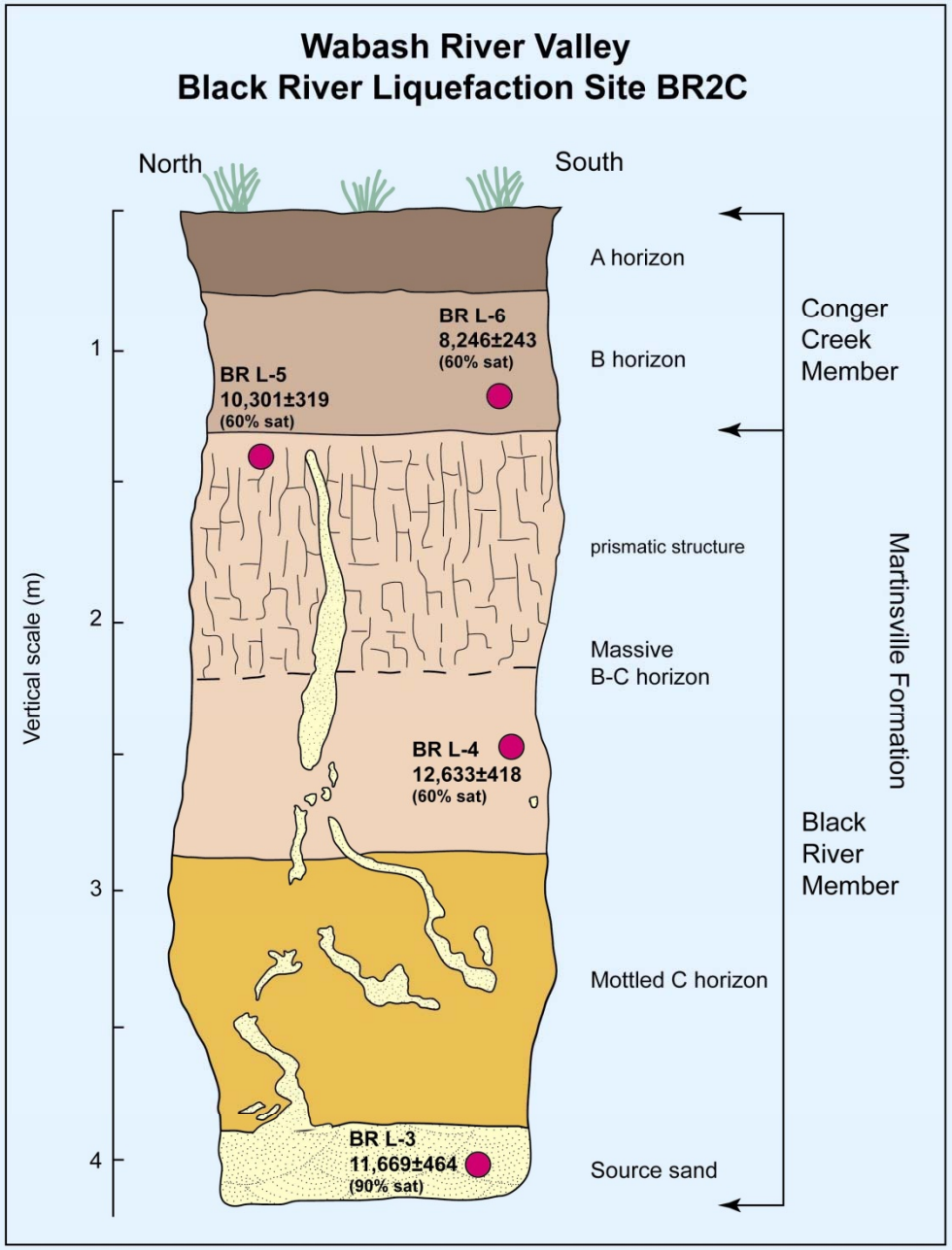


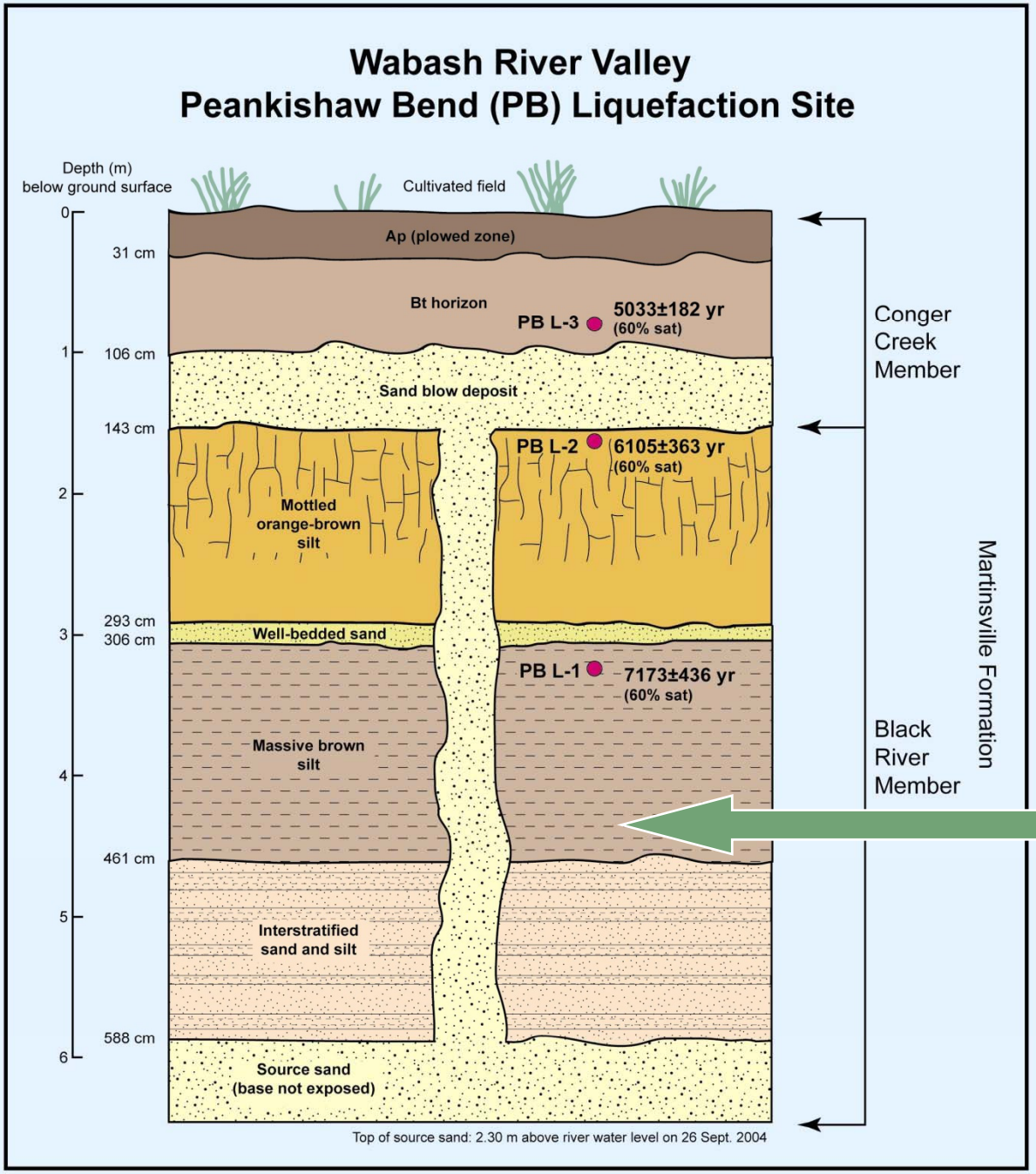
$$\text{Age (ka)} = \frac{\text{Equivalent Dose (Grays/ka)}}{\text{Dose Rate (Grays)}}$$

USGS

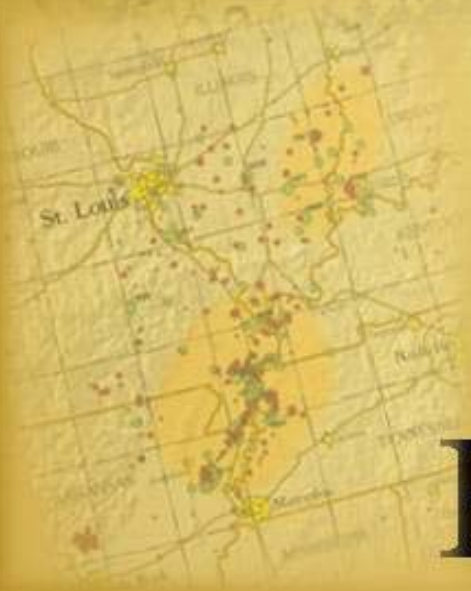
Where does OSL stand with regards to other young deposits dating methods?




Wabash River Valley
Black River Liquefaction Site BR2C
North
South
A horizon
B horizon
prismatic structure
Massive
B-C horizon
Mottled C horizon
Source sand
Conger
Creek
Member
Black
River
Member
Martinsville Formation
Vertical scale (m)
1
2
3
4
BR L-6
8,246±243
(60% sat)
BR L-5
10,301±319
(60% sat)
BR L-4
12,633±418
(60% sat)
BR L-3
11,669±464
(90% sat)



7,570 ± 130 yrs BP
Consistent with 10,500
To 6,500 yrs BP range



Robert Williams

US Geological Survey

Deformation Observed in Seismic-Reflection Profiles Across the Blytheville Arch and Crowley's Ridge, Northeast Arkansas

Robert Williams – USGS, Golden, Colorado

Presented at the University of Memphis, October 28, 2009

West East

Reflection profile location

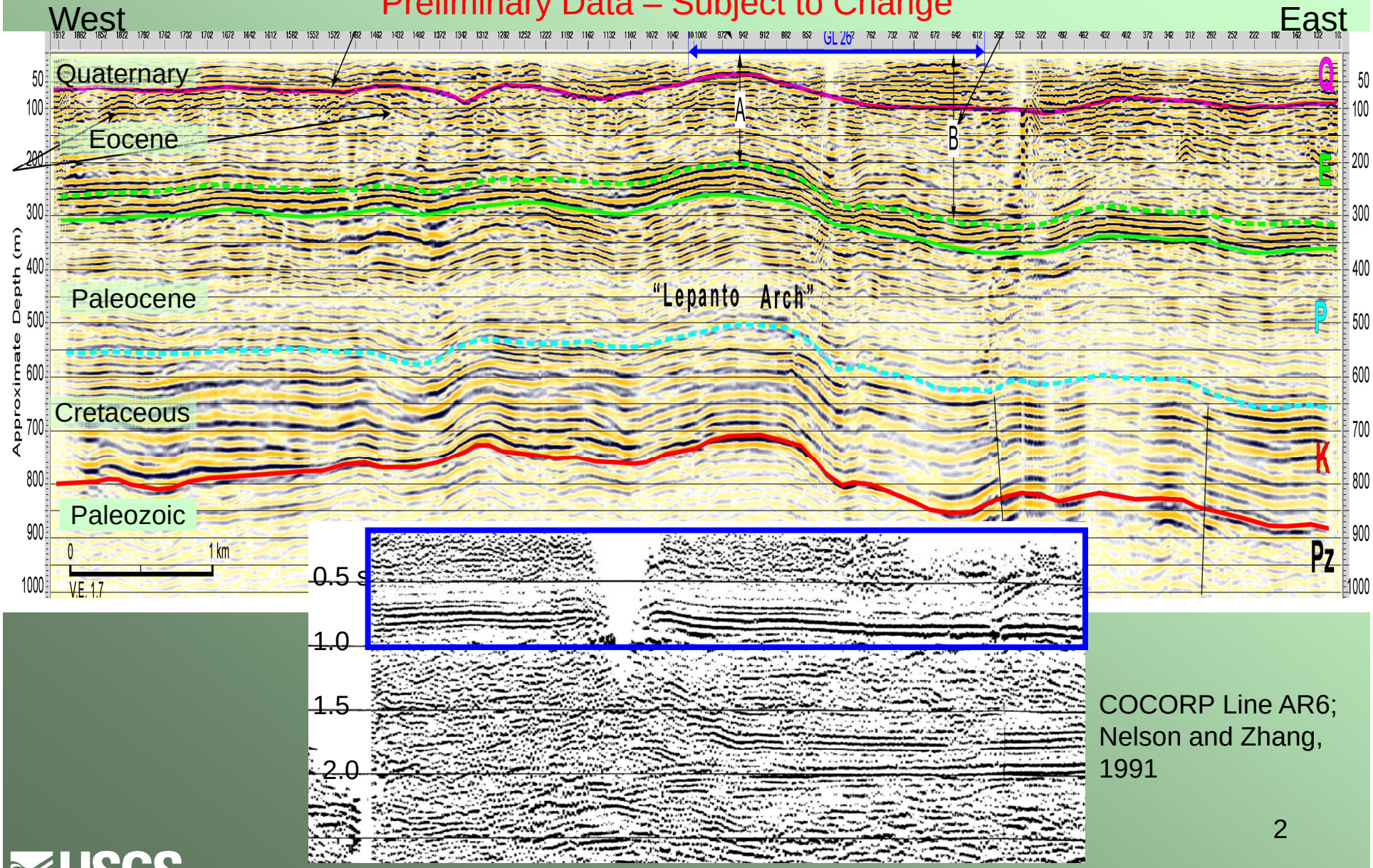
USGS

NSF

nees@UTexas

Lepanto, Ark., Mini-vibe profile over the Blytheville Arch

Preliminary Data – Subject to Change

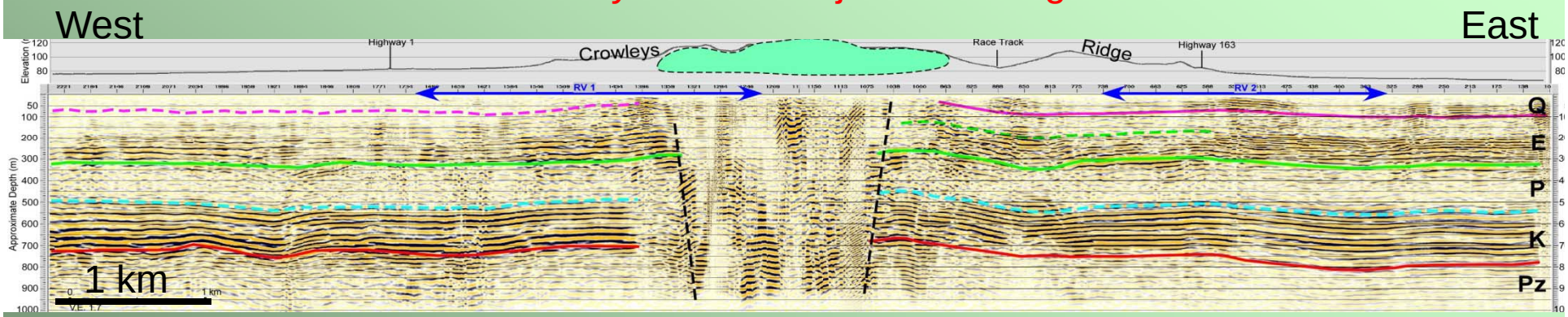


COCORP Line AR6; Nelson and Zhang, 1991

USGS

Mini-vibe profile across Crowleys Ridge, Arkansas

Preliminary Data – Subject to Change



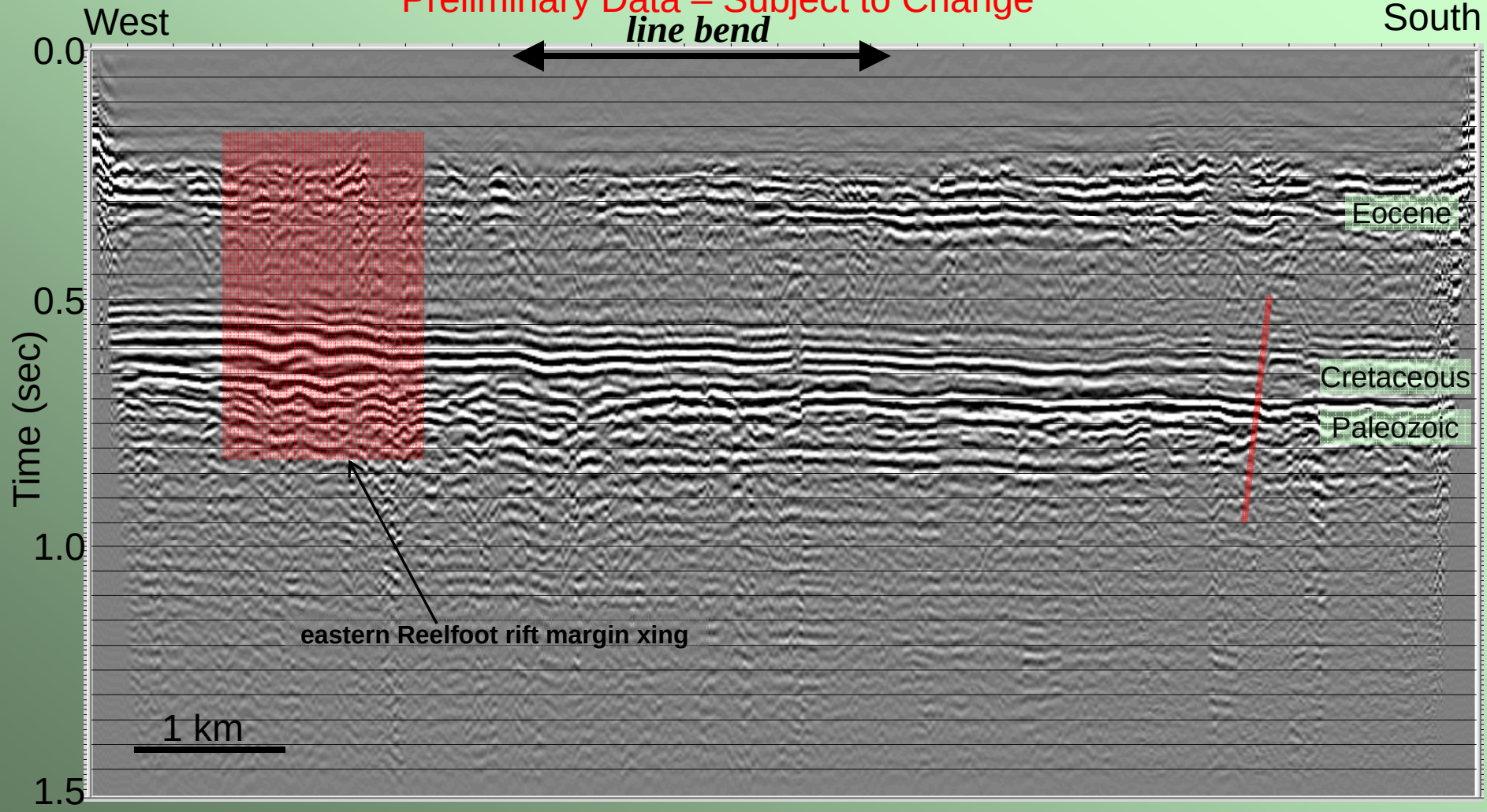
Elevation of Crowleys Ridge relative to Eastern and Western Lowlands (~50 m) is comparable to the fold amplitude of ~75 m seen in the subsurface on Q – Pz reflectors. This suggests that Crowleys Ridge is in part due to uplift by folding and possibly faulting.

In contrast to Q-E section near Lepanto, the Q-E section on Profile 2 does not appear to thicken west of the Crowley's Ridge fold.

USGS

Mini-vibe profile across the Western Reelfoot Rift Margin, Arkansas

Preliminary Data – Subject to Change



Stk6 with post stack trace mix, fxdecon, bp and eigen filter 0-10 eigen images 10-22-09

USGS

Preliminary Conclusions

Interpretation supports previous explanations (e.g., Van Arsdale et al., 1995) for Crowley's Ridge: that it is partly due to tectonic deformation.

Profiles show improved images of folding, and possibly faulting, that deforms the Quaternary section. Folding on Lepanto profile overlies the southeastern side of the Blytheville Arch, but the connection between the two structures is unclear.

Relatively constant thickness of reflections into the Eocene on Lepanto profile suggests that folding began after that time. An absence of Eocene thickening on Crowleys profile suggests that deformation may have started in the Quaternary.

Tectonic deformation at these locations may be contemporaneous with deformation that occurred (occurring?) at the Crittenden County fault zone and the Meeman-Shelby fault west and north of Memphis, respectively.

USGS

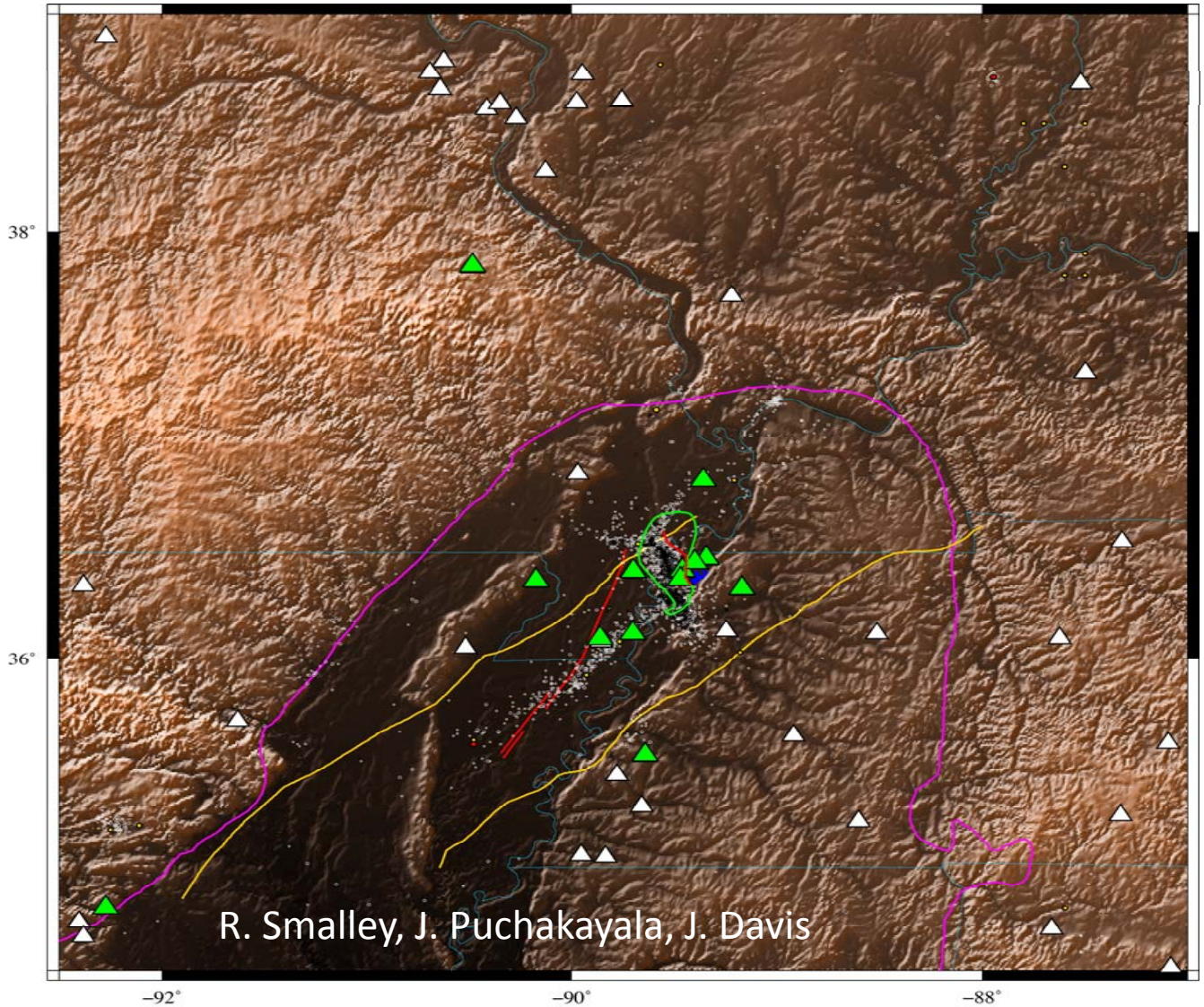
Robert Smalley

University of Memphis (CERI)

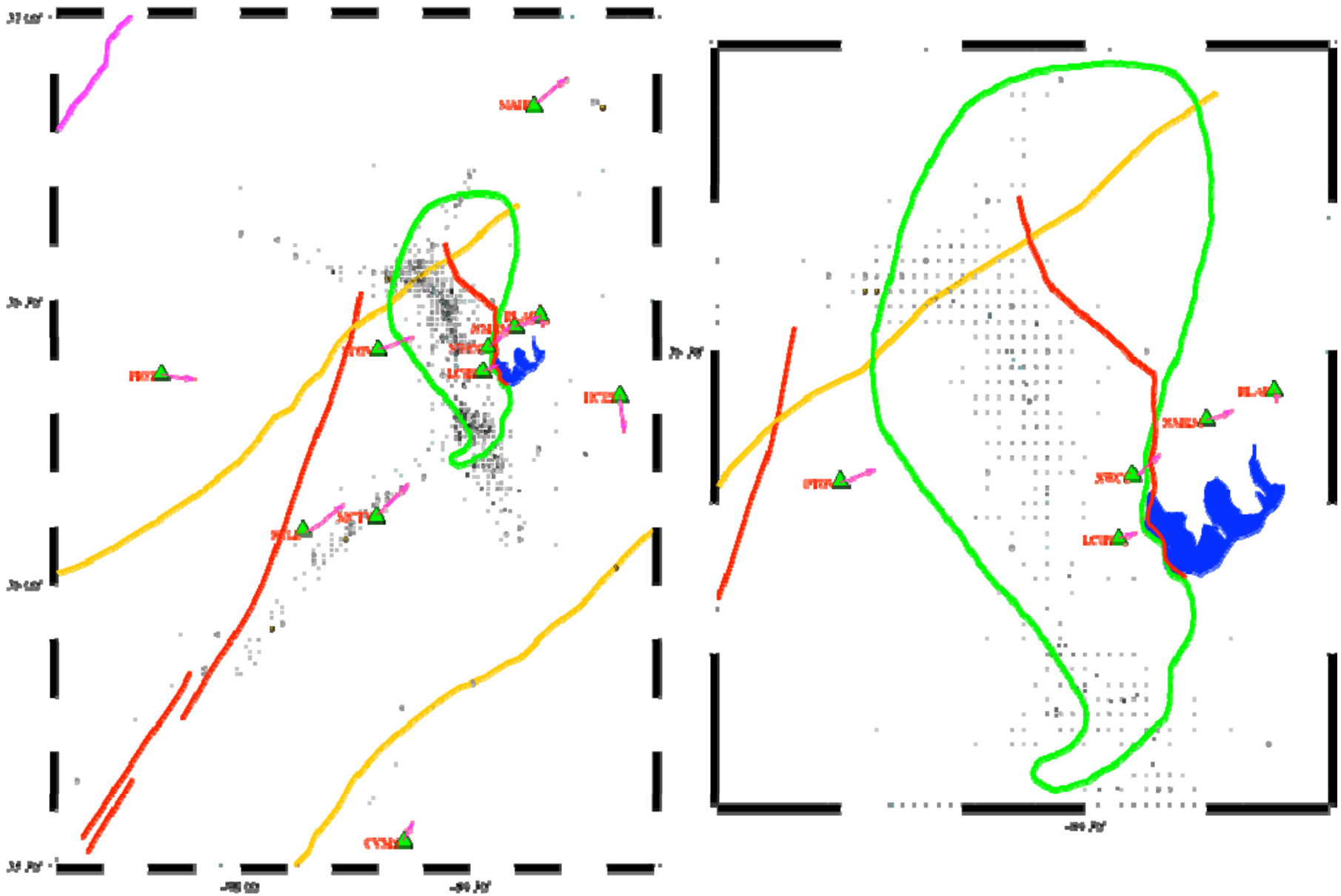
Current state of GAMA network

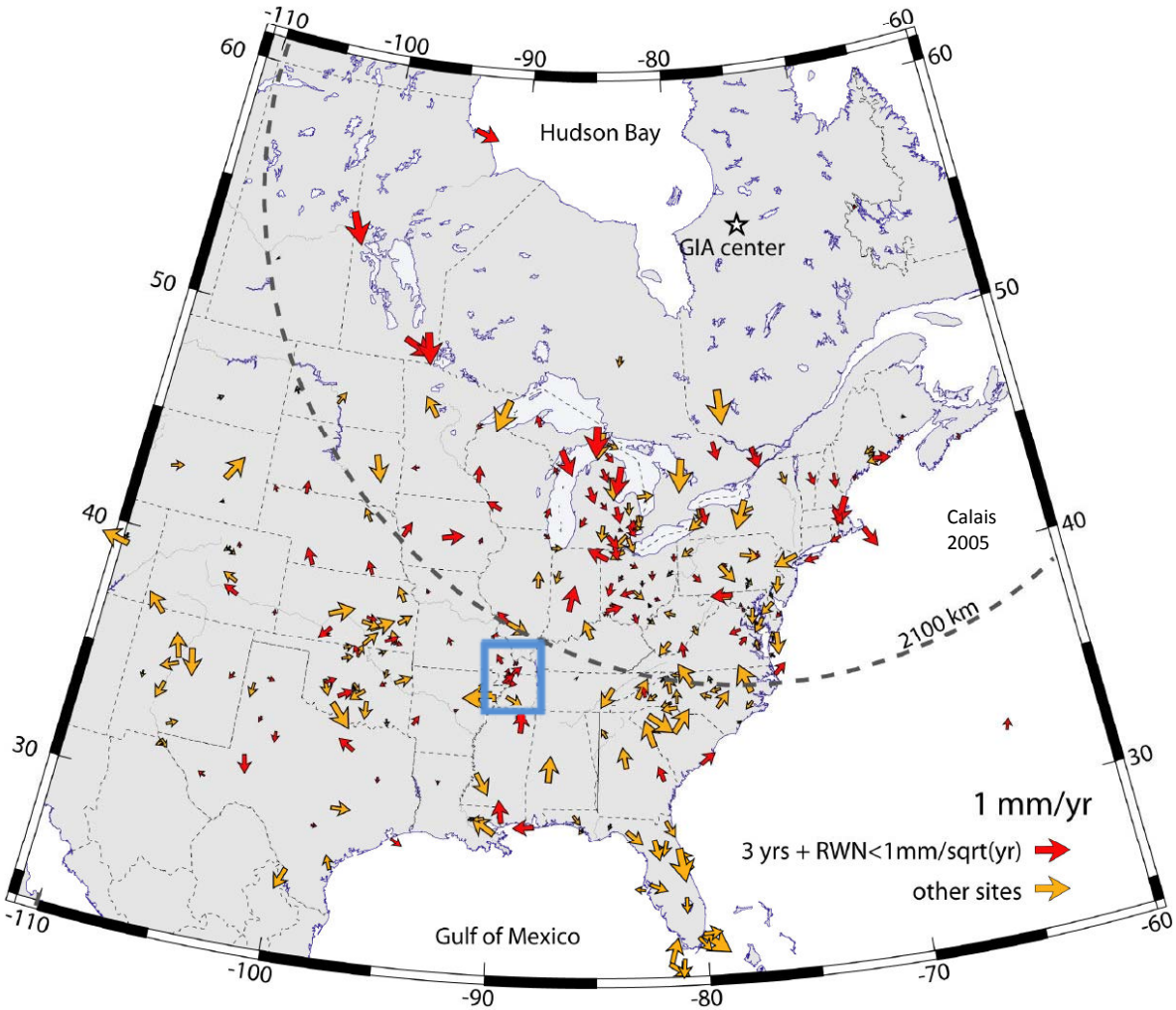
13 CGPS stations, 11 in NMSZ. Choke ring antennas, geodetic monuments.

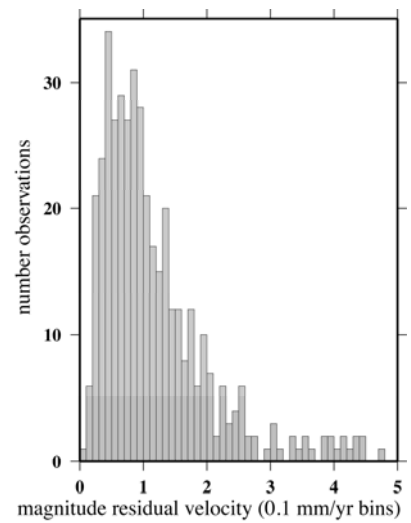
~35 open stations in the region for surveying support and other uses. Various antennas mounted on buildings, fences, towers.



Residual velocities (North America removed)



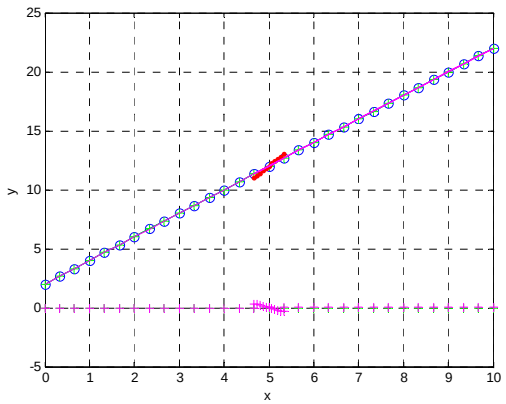


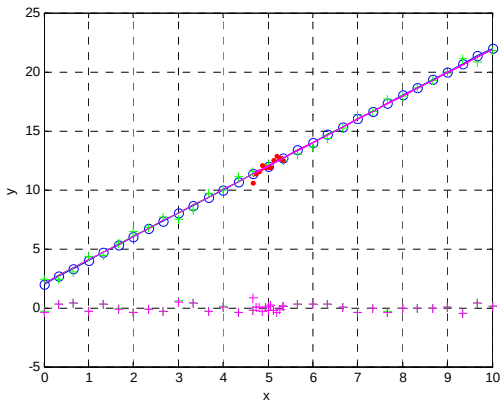


Is the New Madrid seismic zone deforming with respect to North America?
How can one tell?

Separating two signals:

New Madrid – small region with small signal. Need high quality data from small region.





Left – no noise,

Right – with noise.

Eric Calais

Purdue University

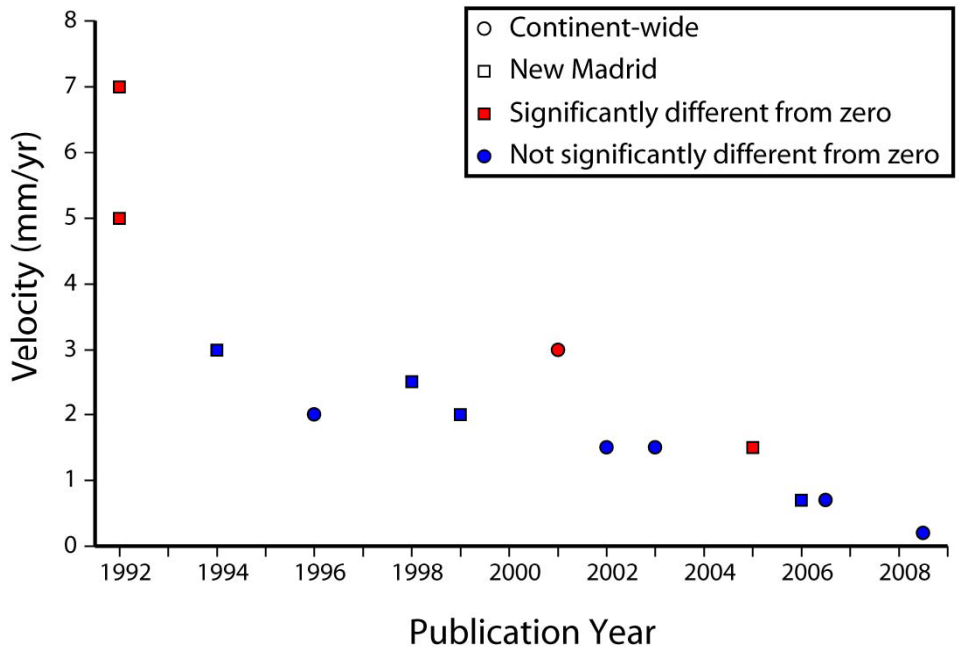
Time-variable Deformation in the New Madrid Seismic Zone

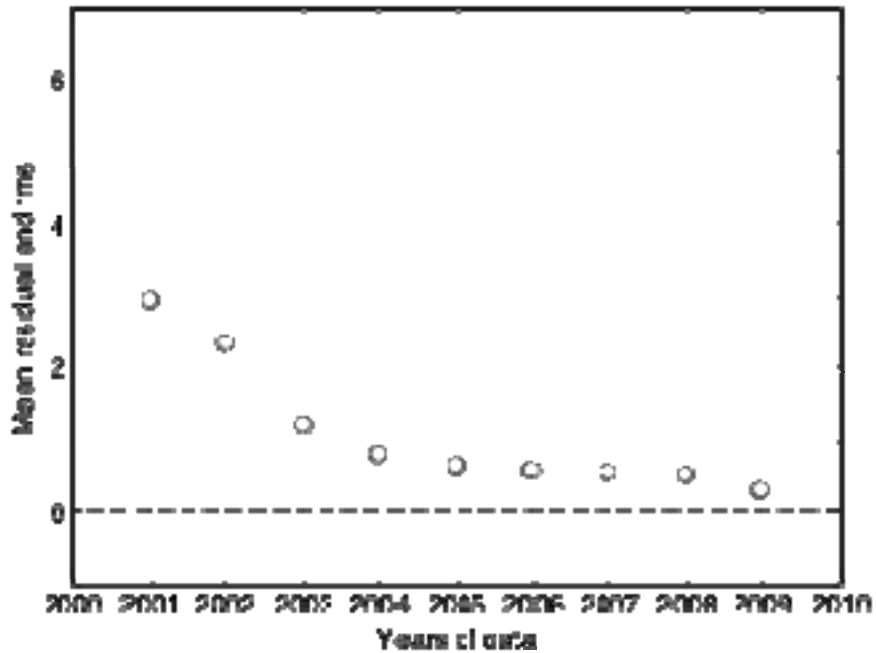
Eric Calais, Andy Freed - Purdue University

Roy van Arsdale - University of Memphis

Seth Stein - Northwestern University

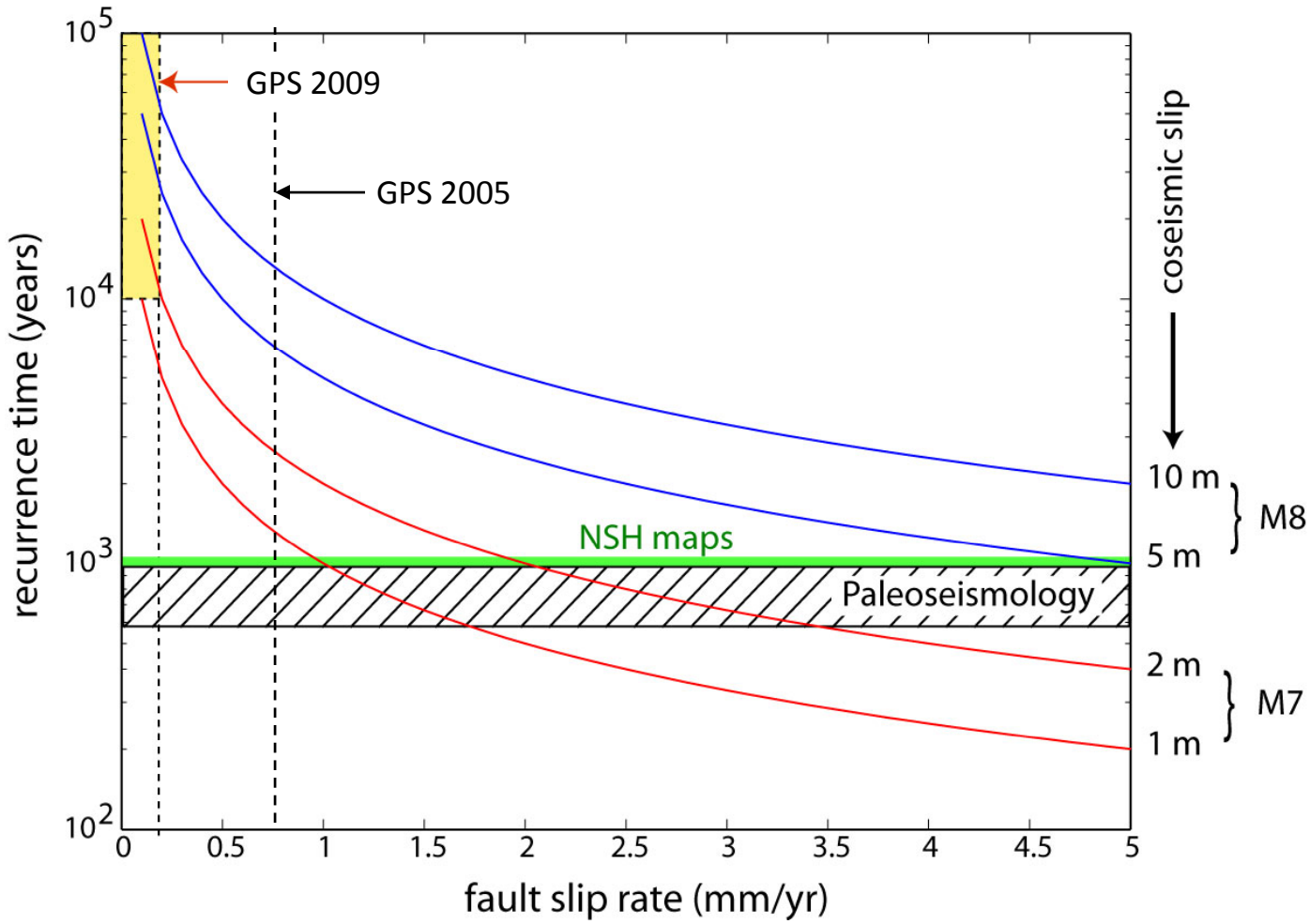
Current strain rate in the NMSZ is less than 0.2 mm/yr over 100 km





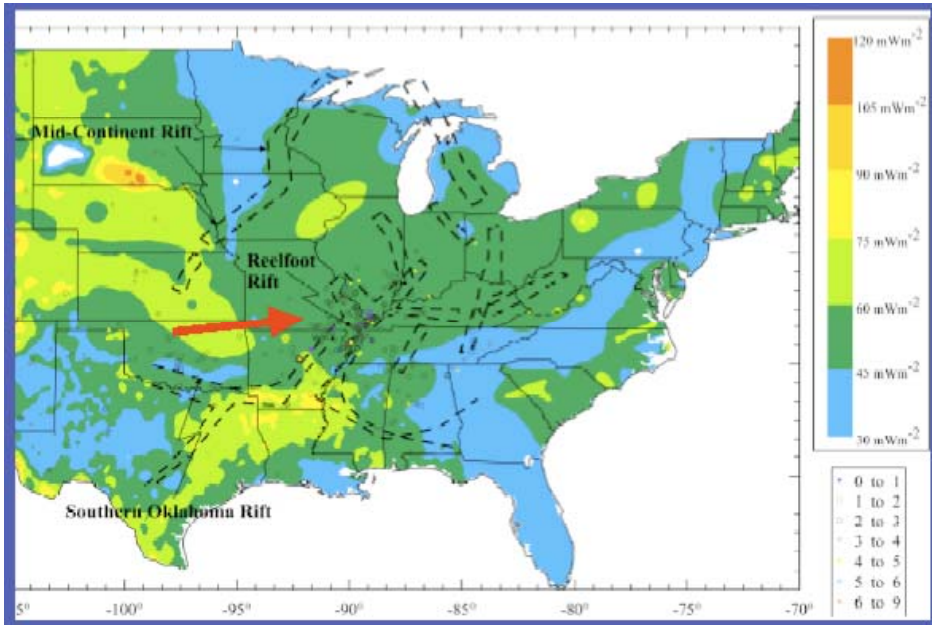
The longer we measure, the smaller the uncertainties,
the smaller the signal.

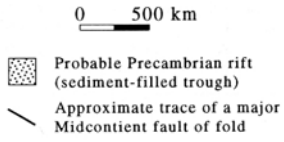
The NMSZ in not in steady-state

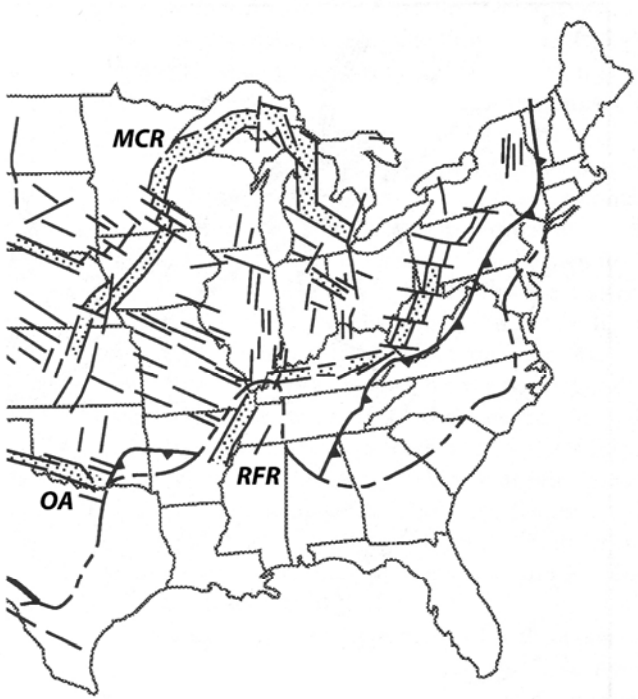


0.2 mm/yr => minimum repeat time = 10,000 years for low M7.
=> current strain accumulation rate in the NMSZ cannot sustain the ~5,000 yr seismicity rate.

Why there, why then?



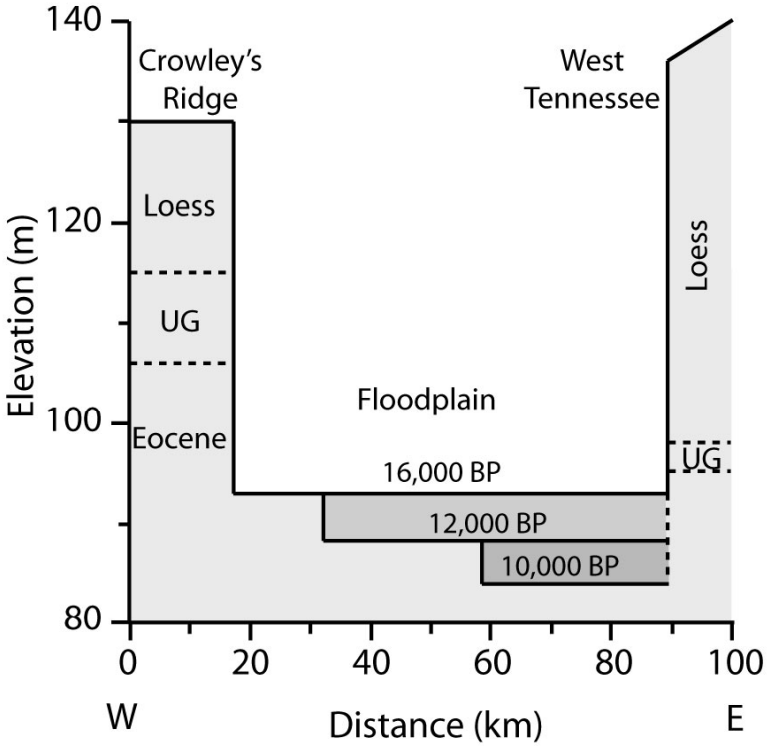


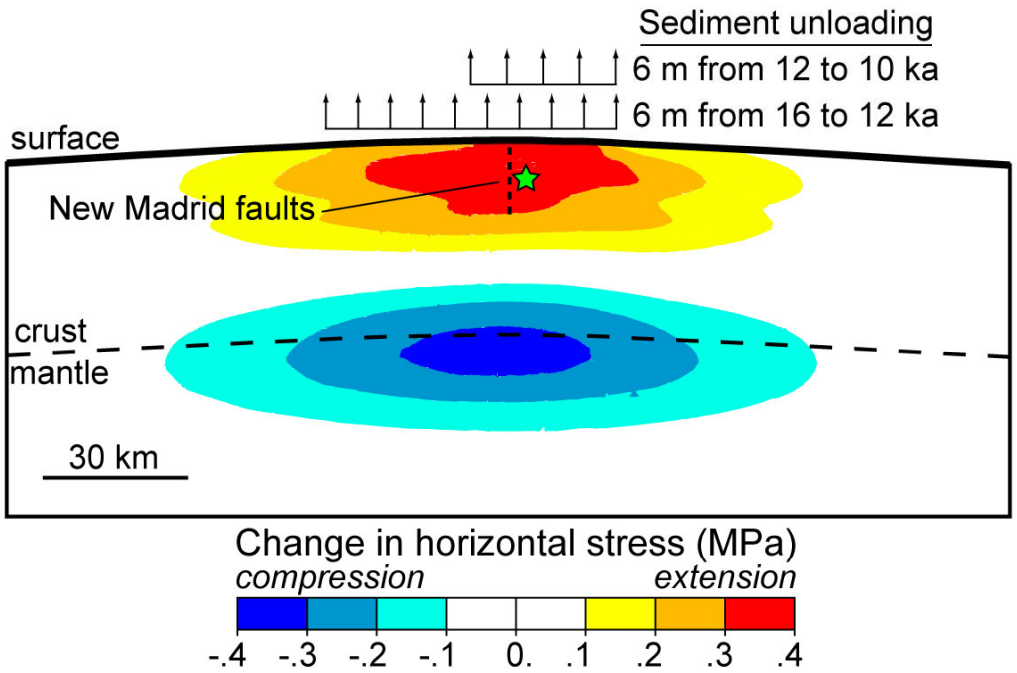


Displacement history and slip rate on the Reelfoot fault of the New Madrid seismic zone

Geologic time	Radiometric time	Slip magnitude (m)	Slip rate (mm year^{-1})
Late Cretaceous–present	80 my	73	0.0009
Late Cretaceous	80–65 my	10	0.0007
Paleocene	65–54 my	21	0.002
Late Paleocene–Eocene	54–45 my	11	0.001
Late Eocene–Holocene	45 my–9 ka	15	0.0003
Holocene	9000–present	16	1.8
Late Holocene	AD 900–1812	5.4	6.2

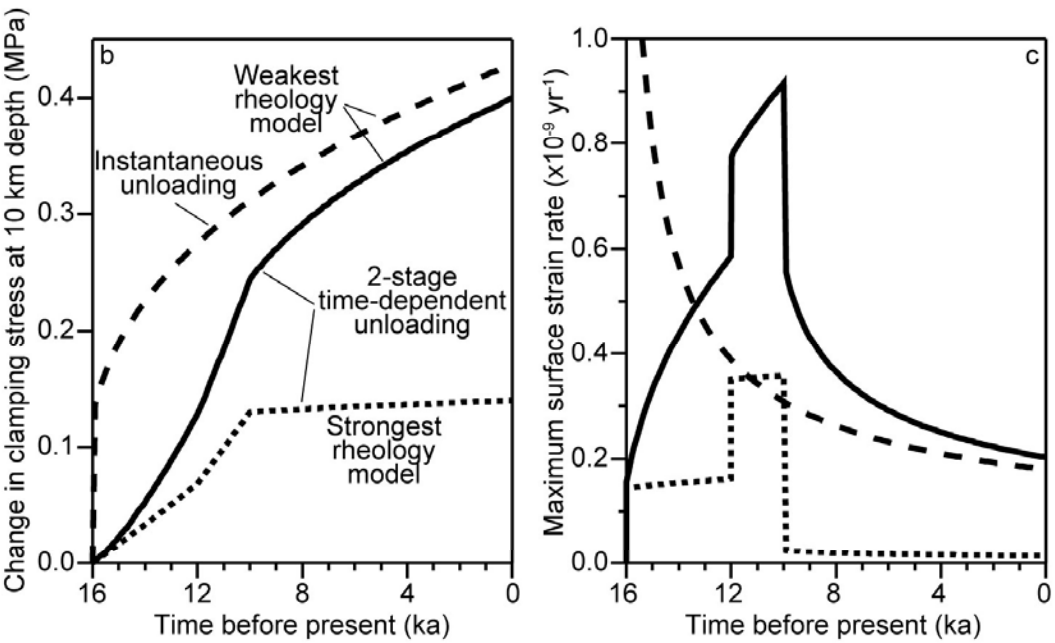
Late Pleistocene erosion triggered NMSZ seismicity





Upward flexure of the lithosphere caused by unloading from river incision between 16,000 and 10,000 years ago caused a reduction of normal stresses in the upper crust sufficient to unclamp pre-existing faults close to failure equilibrium.

Fault segments that have already ruptured are unlikely to fail again soon



- Faults continue being unclamped today, but at a slow and decaying rate.
  - Viscoelastic relaxation from previous events can contribute up to 0.1 MPa over 1,000 years
  - Far-field plate motions contribute ~nothing (~10 MPa per 1,000 years for the San Andreas fault).
- Fault segments that have already ruptured are unlikely to fail again soon.
- Stress changes (incl. from previous earthquakes) may however bring other nearby segments to failure

Michael Hamburger

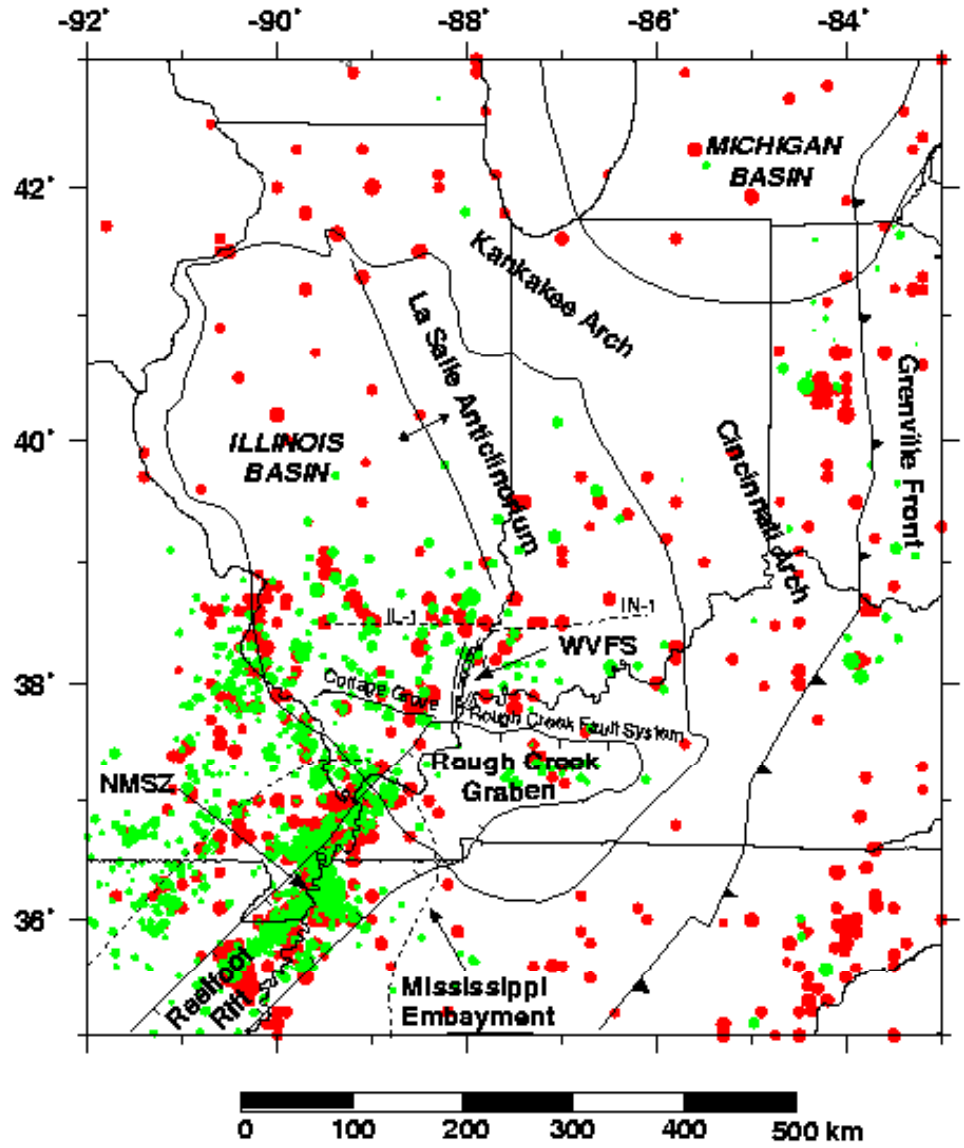
Indiana University

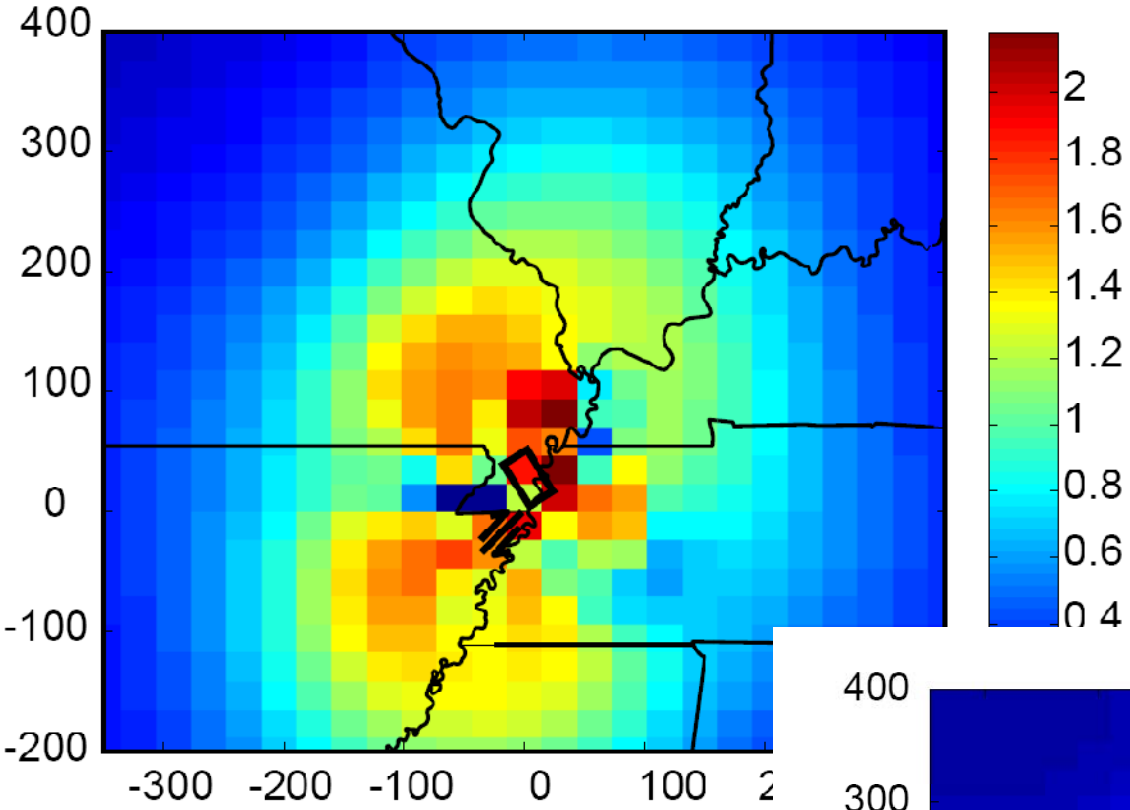
Is There a Connection Between Seismicity and Deformation in the New Madrid and Wabash Valley Seismic Zones?

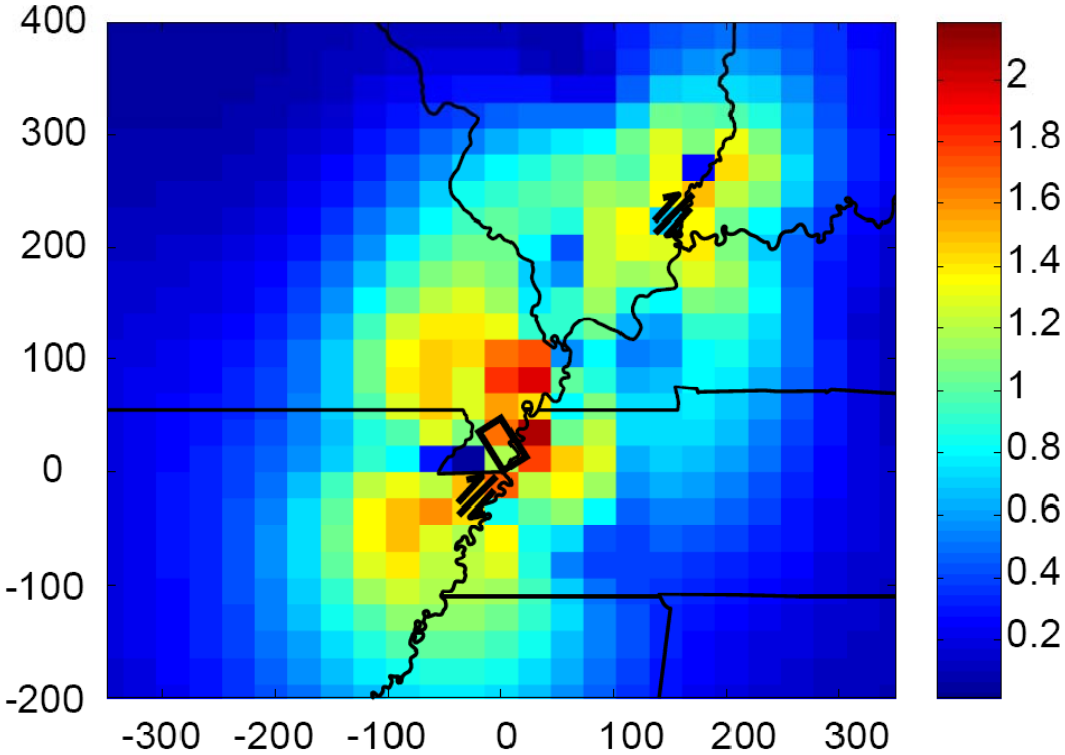
Michael Hamburger
(Indiana University)

Kaj Johnson
(Indiana University)

Gerald Galgana
(Lunar Planetary Science Institute)




400
300
200
100
0
-100
-200
-300
-200
-100
0
100
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4


400
300
200
100
0
-100
-200
-300
-200
-100
0
100
200
300
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2

TECTONIC TARGETS FOR EARTHSCOPE IN THE OZARK-PLATEAU –ILLINOIS BASIN REGION

Steven Marshak

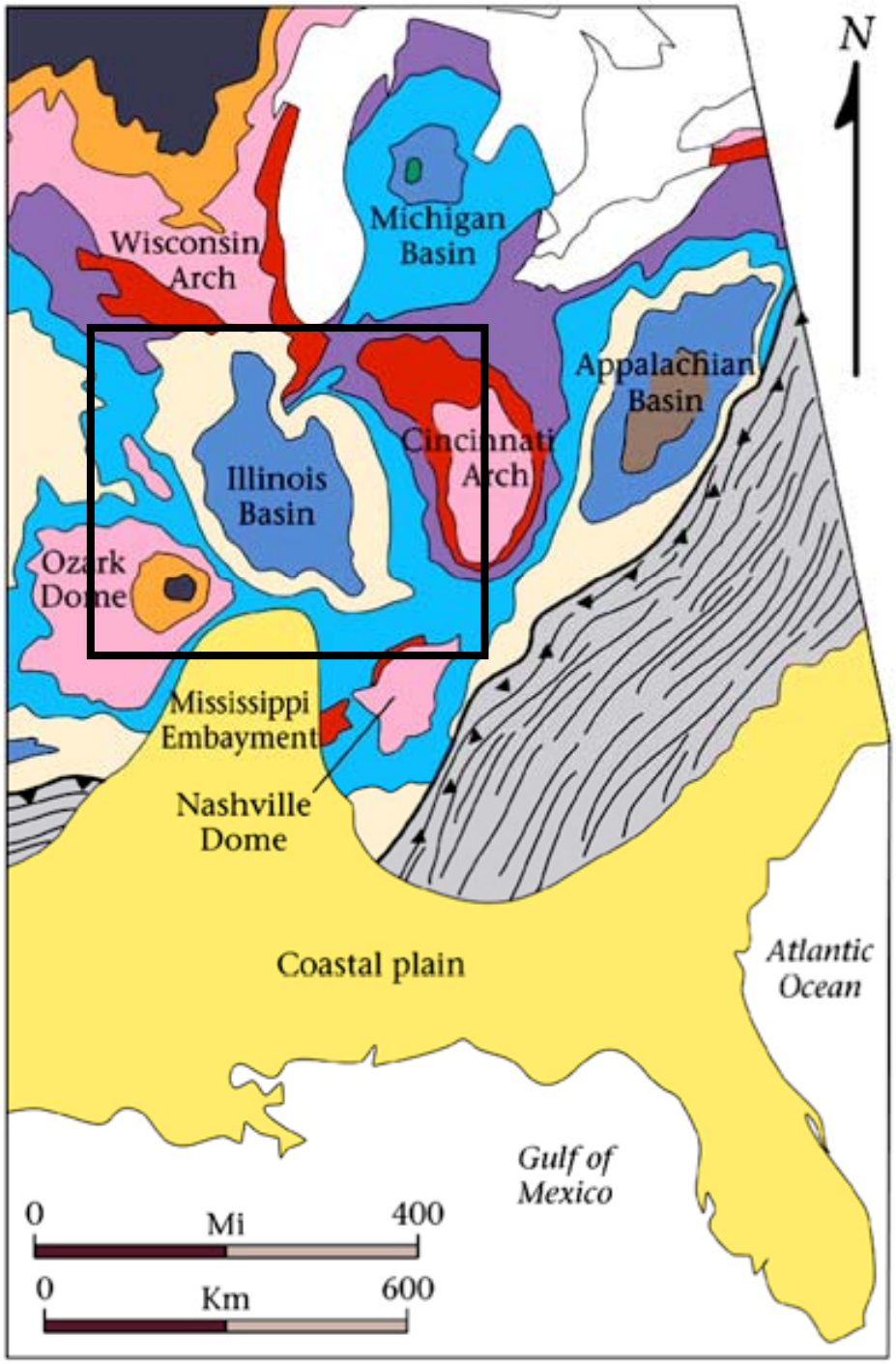
(University of Illinois Urbana-Champaign)

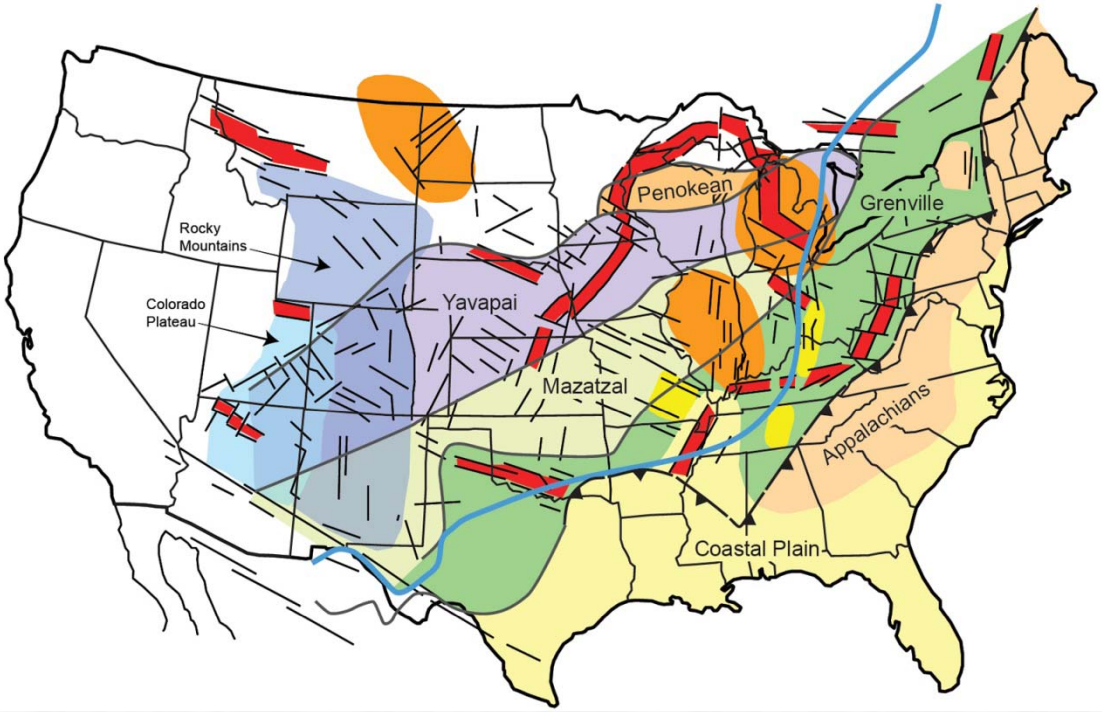
Michael Hamburger

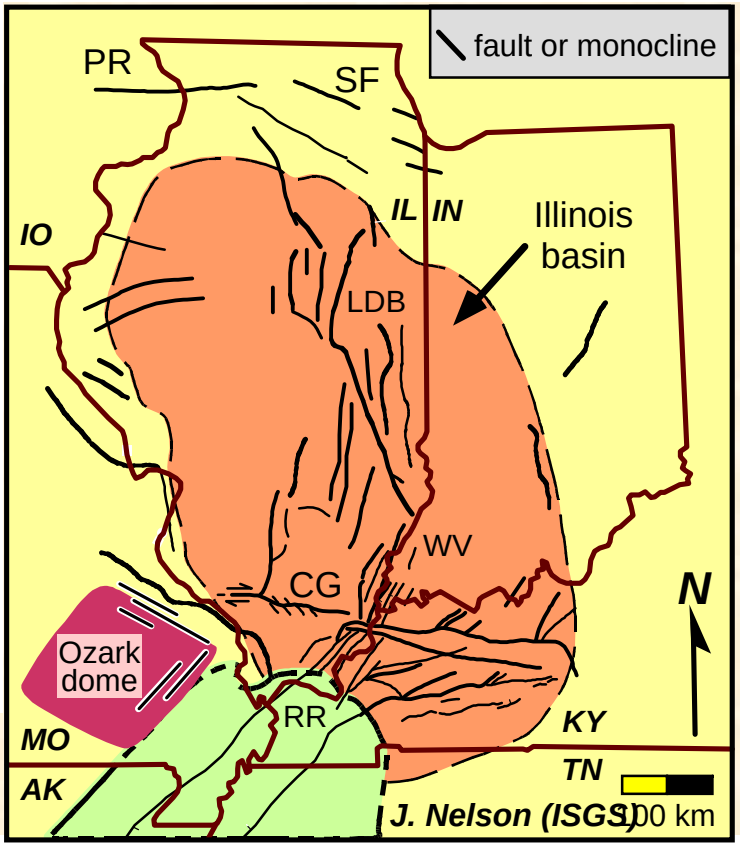
(Indiana University)

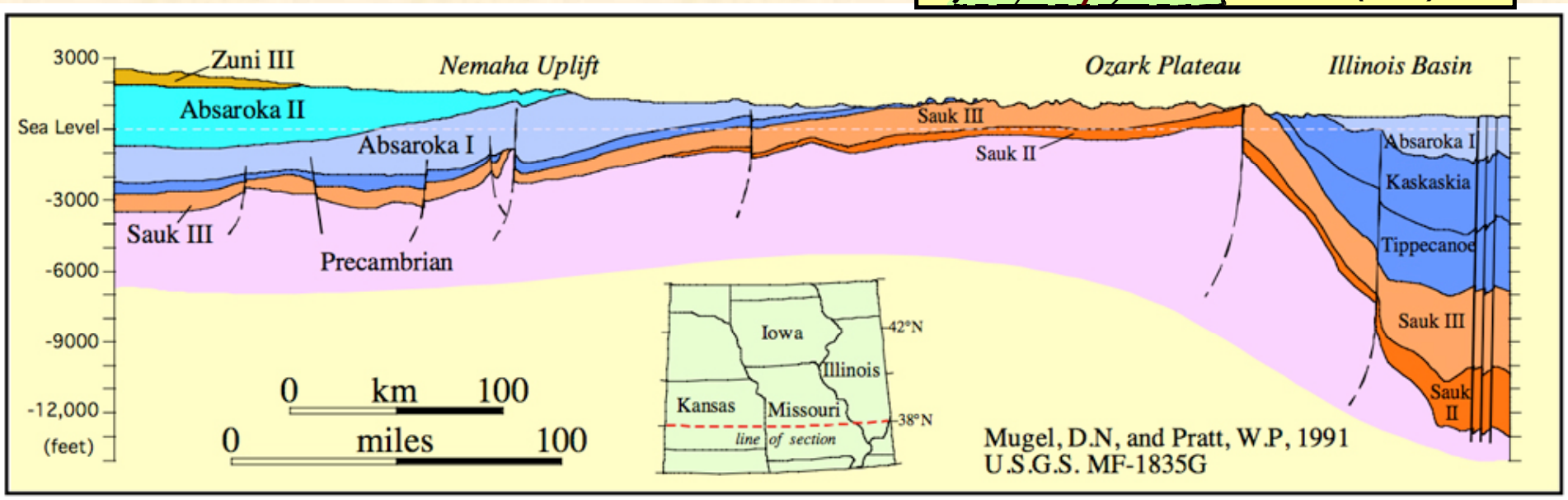
Mary Parke

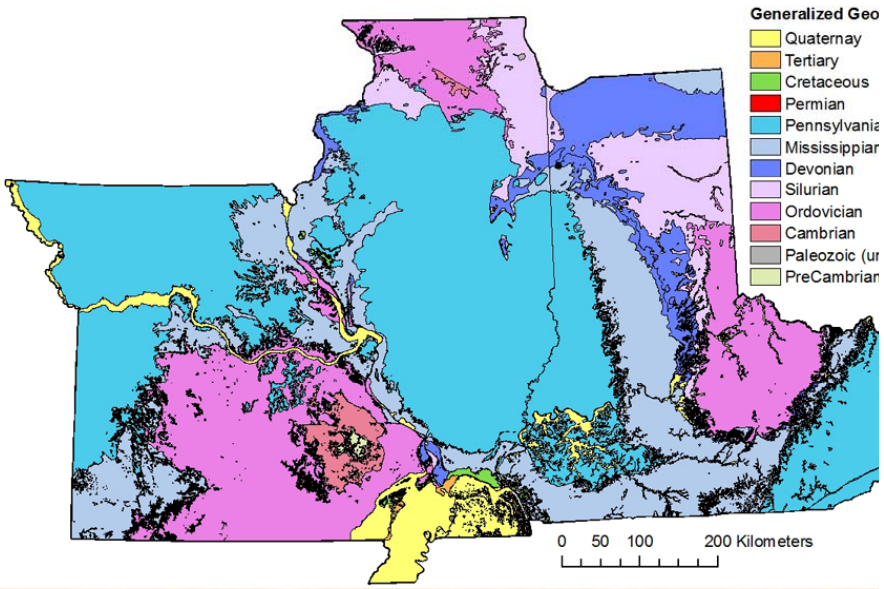
(Indiana Geological Survey)

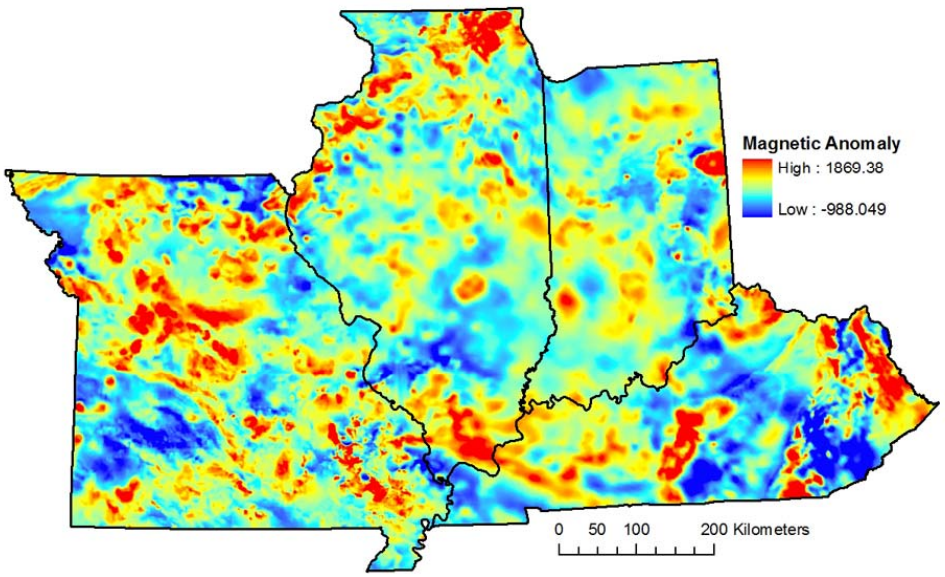


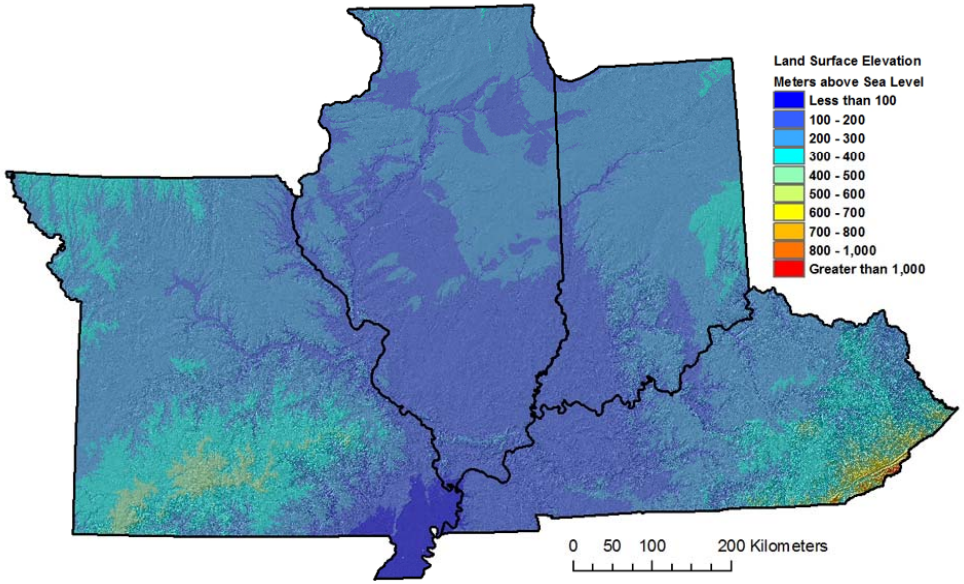

Rocky Mountains
Colorado Plateau
Yavapai
Penokean
Grenville
Mazatzal
Appalachians
Coastal Plain

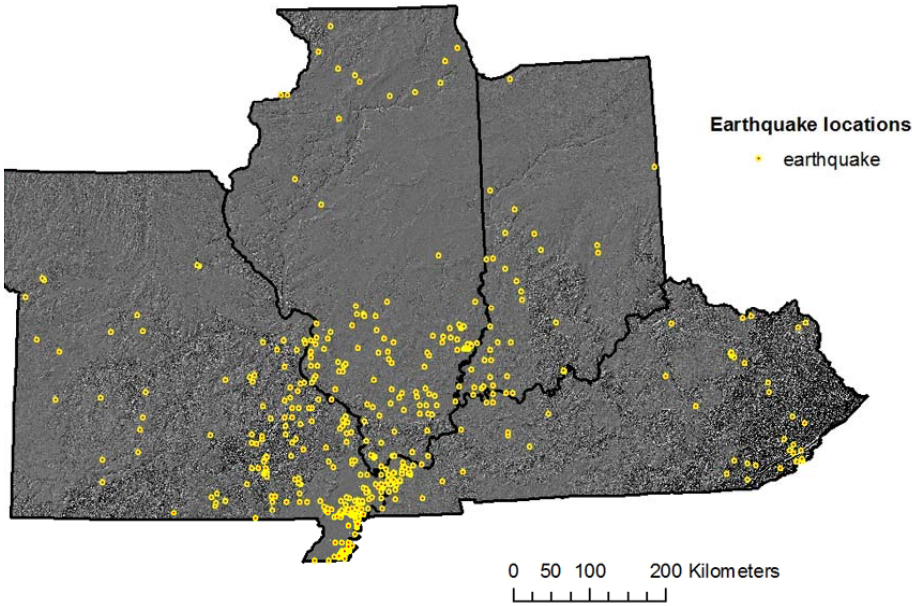

fault or monocline
PR
SF
IO
IL
IN
Illinois basin
LDB
WV
CG
N
Ozark dome
RR
MO
KY
TN
AK
J. Nelson (ISGS)
100 km


3000
Sea Level
-3000
-6000
-9000
-12,000
(feet)
Zuni III
Absaroka II
Absaroka I
Sauk III
Precambrian
Nemaha Uplift
Ozark Plateau
Illinois Basin
Sauk III
Sauk II
Absaroka I
Kaskaskia
Tippecanoe
Sauk III
Sauk II
0 km 100
0 miles 100
Iowa
Illinois
Kansas
Missouri
42°N
38°N
line of section
Mugel, D.N, and Pratt, W.P, 1991
U.S.G.S. MF-1835G


Generalized Geo
Quaternay
Tertiary
Cretaceous
Permian
Pennsylvania
Mississippiar
Devonian
Silurian
Ordovician
Cambrian
Paleozoic (ur
PreCambrian
0 50 100 200 Kilometers


Magnetic Anomaly
High : 1869.38
Low : -988.049
0 50 100 200 Kilometers


Land Surface Elevation
Meters above Sea Level
Less than 100
100 - 200
200 - 300
300 - 400
400 - 500
500 - 600
600 - 700
700 - 800
800 - 1,000
Greater than 1,000
0 50 100 200 Kilometers

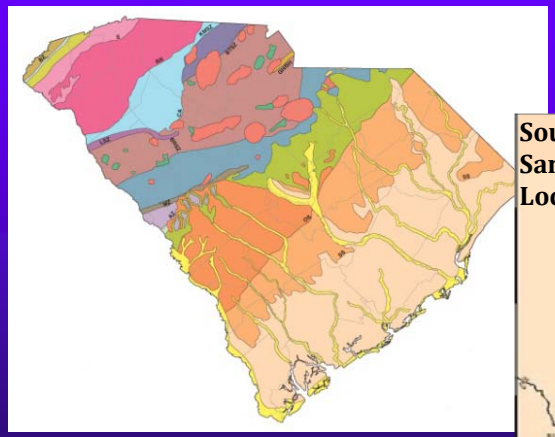

Earthquake locations
earthquake
0 50 100 200 Kilometers

Sarah Gassman

University of South Carolina

Maximum Magnitudes of Charleston, South Carolina Earthquakes from In Situ Geotechnical Data

S. Gassman, P. Talwani, and M. Hasek
University of South Carolina

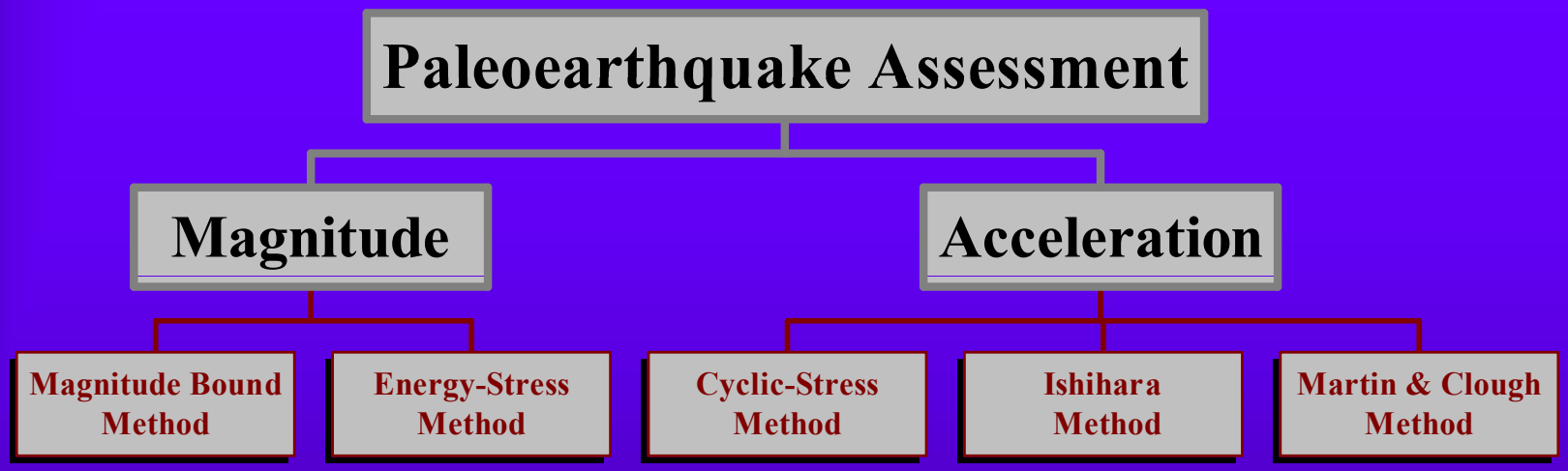


Geotechnical Field Investigations

- Seismic Cone Penetrometer Tests
- Standard Penetration Tests
- Dilatometer Tests

- Cross-hole Seismic Tests
- High Quality Sampling with Ground Freezing

Methods Used to Back-Calculate Earthquake Magnitudes and Accelerations



Methods based on in situ geotechnical data:

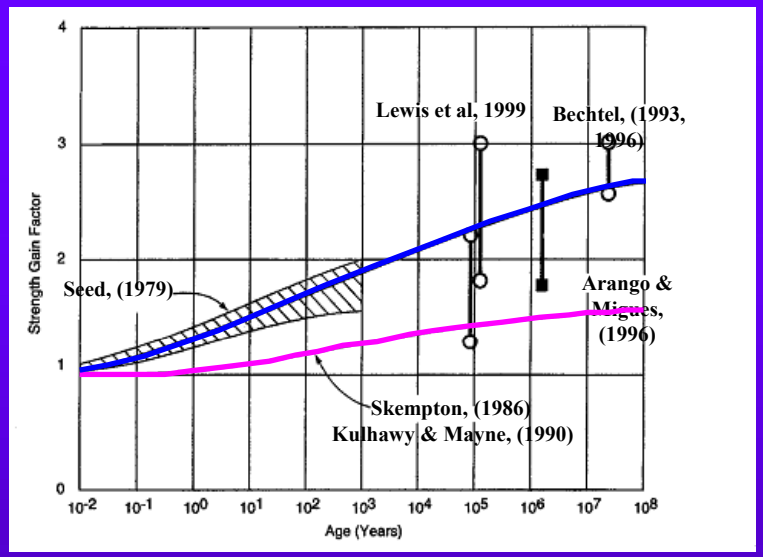
Energy-Stress Method (Pond, 1996)

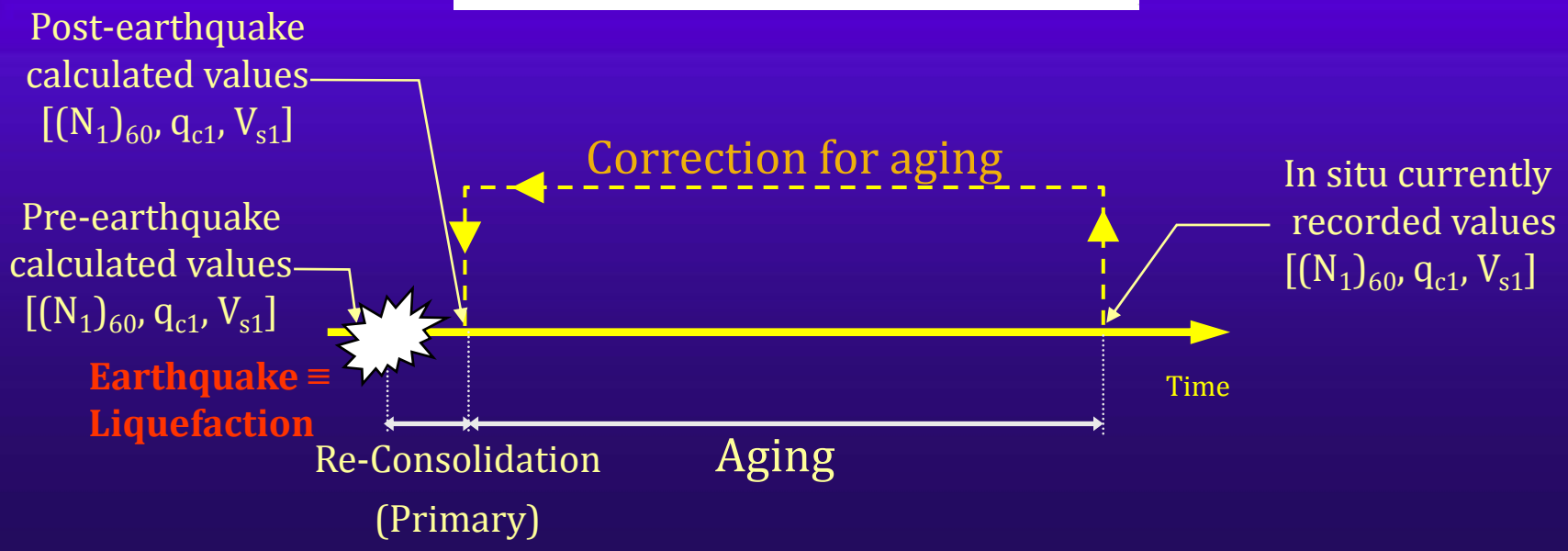
Cyclic-Stress Method (SPT, CPT, V_s), (Seed and Idriss, 1971)

Ishihara Method (1985)

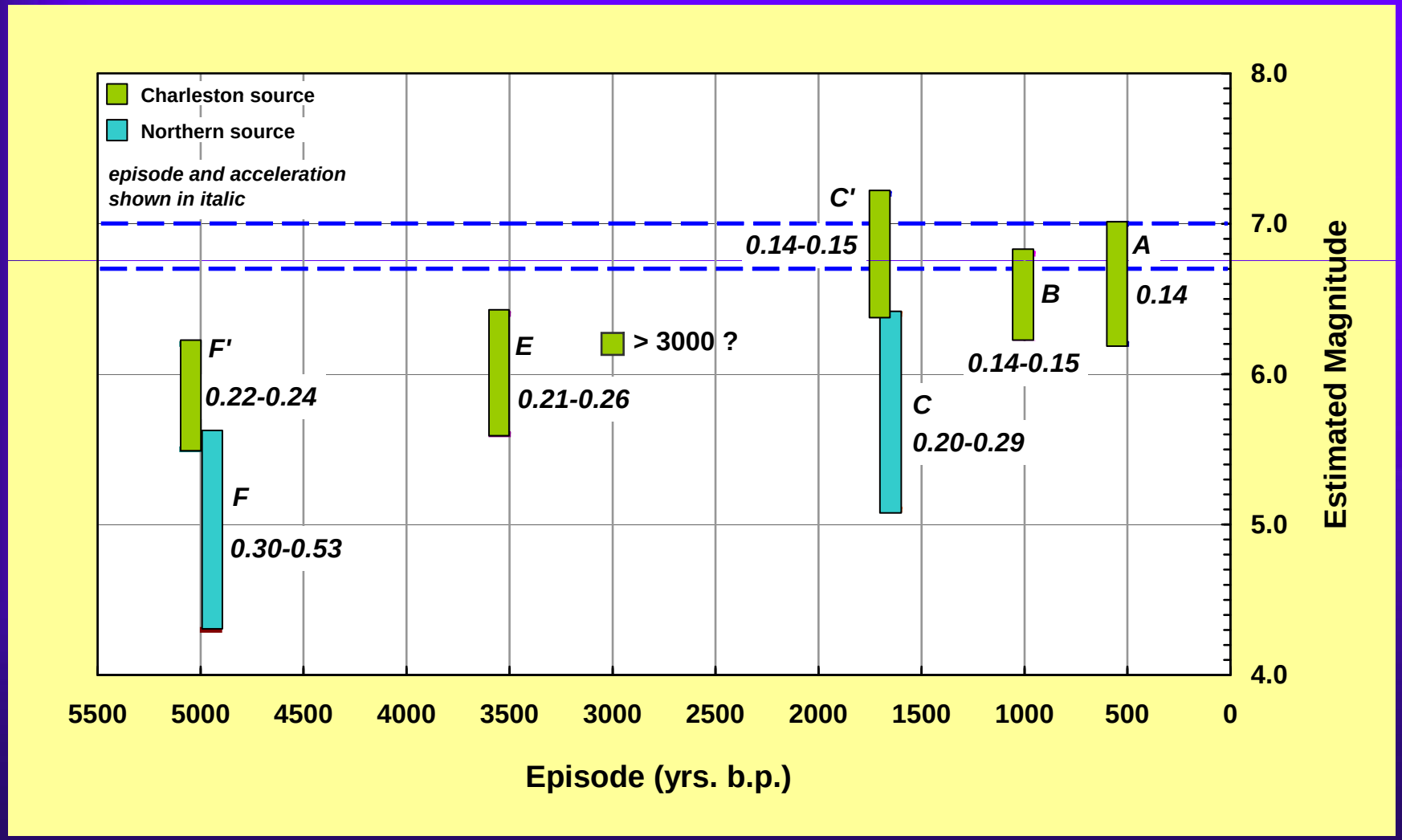
Martin & Clough Method (1994)

Correction for Aging





Historical Magnitudes and Accelerations



Martin Chapman

Virginia Polytechnic Institute and State University

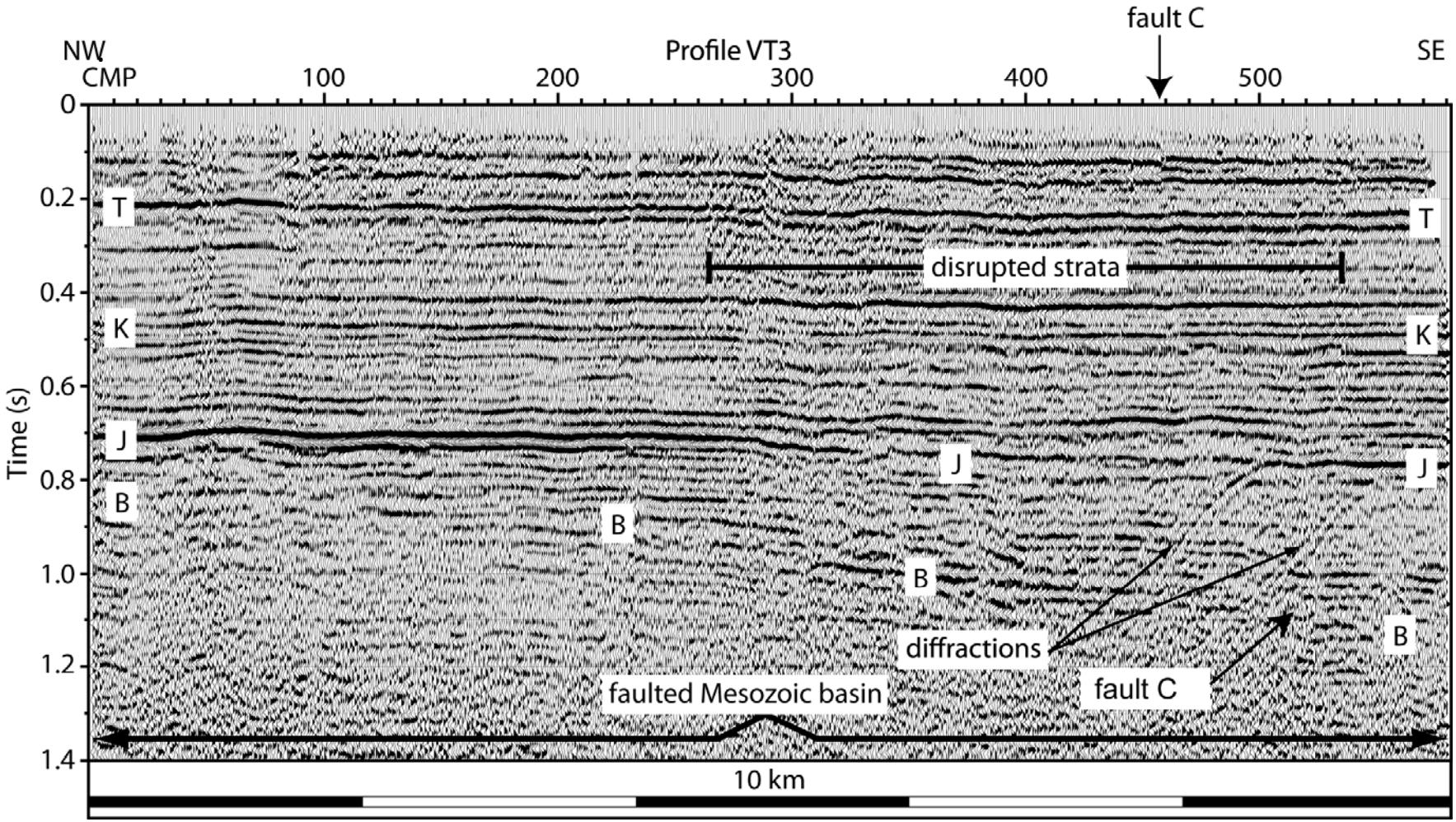
Results of Reprocessing Seismic Reflection Data Collected Near Summerville, South Carolina

Martin Chapman and Jacob Beale

Department of Geosciences
Virginia Tech

Earthquake Hazards Program Meeting
October 28-29 2009
Memphis, TN

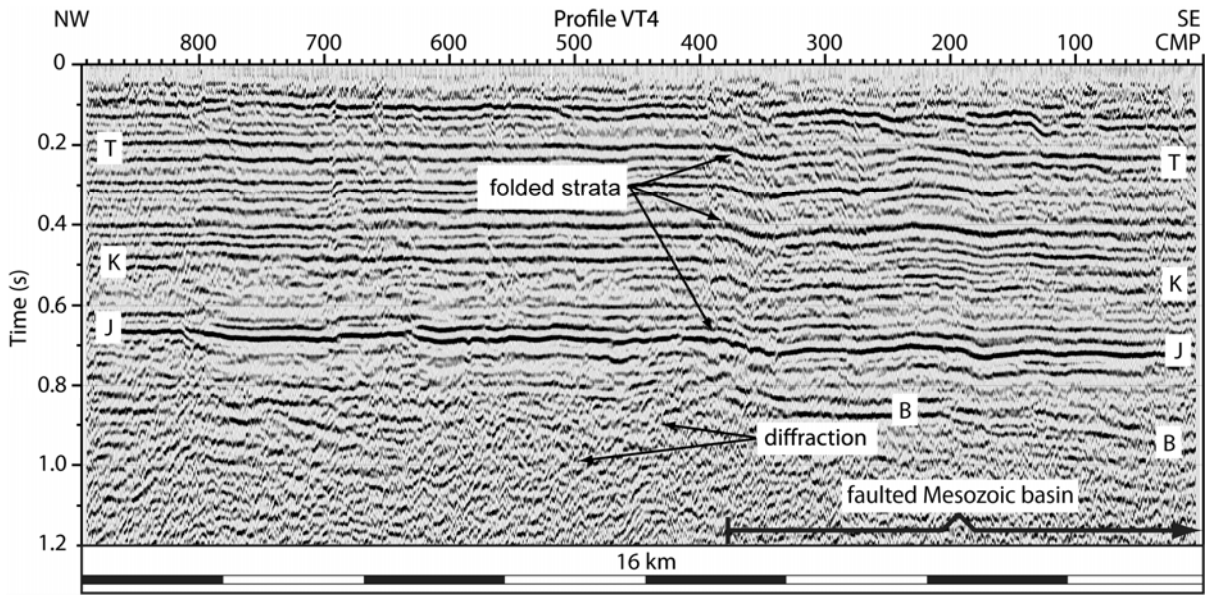
Seismic Profile VT3: Highest Resolution Data Collected in the Study Area



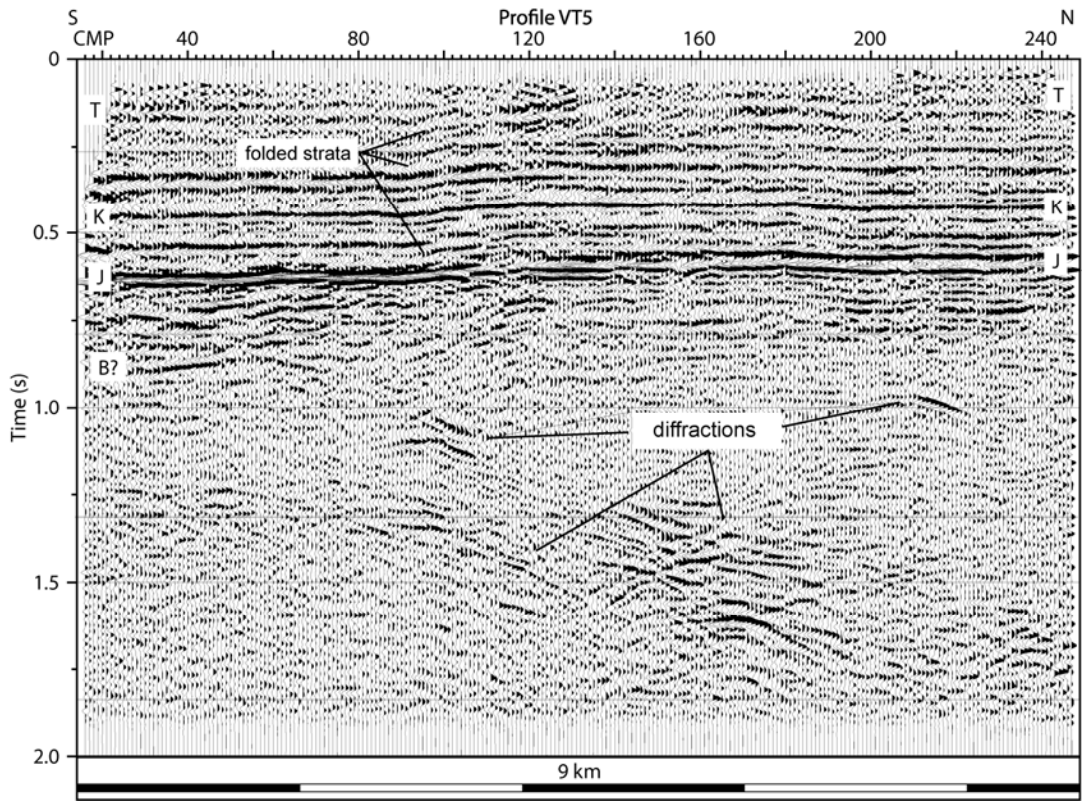
The "J" reflection marks the top of the Mesozoic basement and is an early Jurassic basalt flow

From: Chapman, M.C. and J.N. Beale (2008). Mesozoic and Cenozoic Faulting Imaged at the Epicenter of the 1886 Charleston, South Carolina Earthquake, *Bull. Seism. Soc. Am.*, 98, 2533-2542.

VT4


NW
Profile VT4
SE
CMP
800
700
600
500
400
300
200
100
0
0.2
0.4
0.6
0.8
1.0
1.2
Time (s)
T
K
J
B
folded strata
diffraction
faulted Mesozoic basin
16 km

VT5

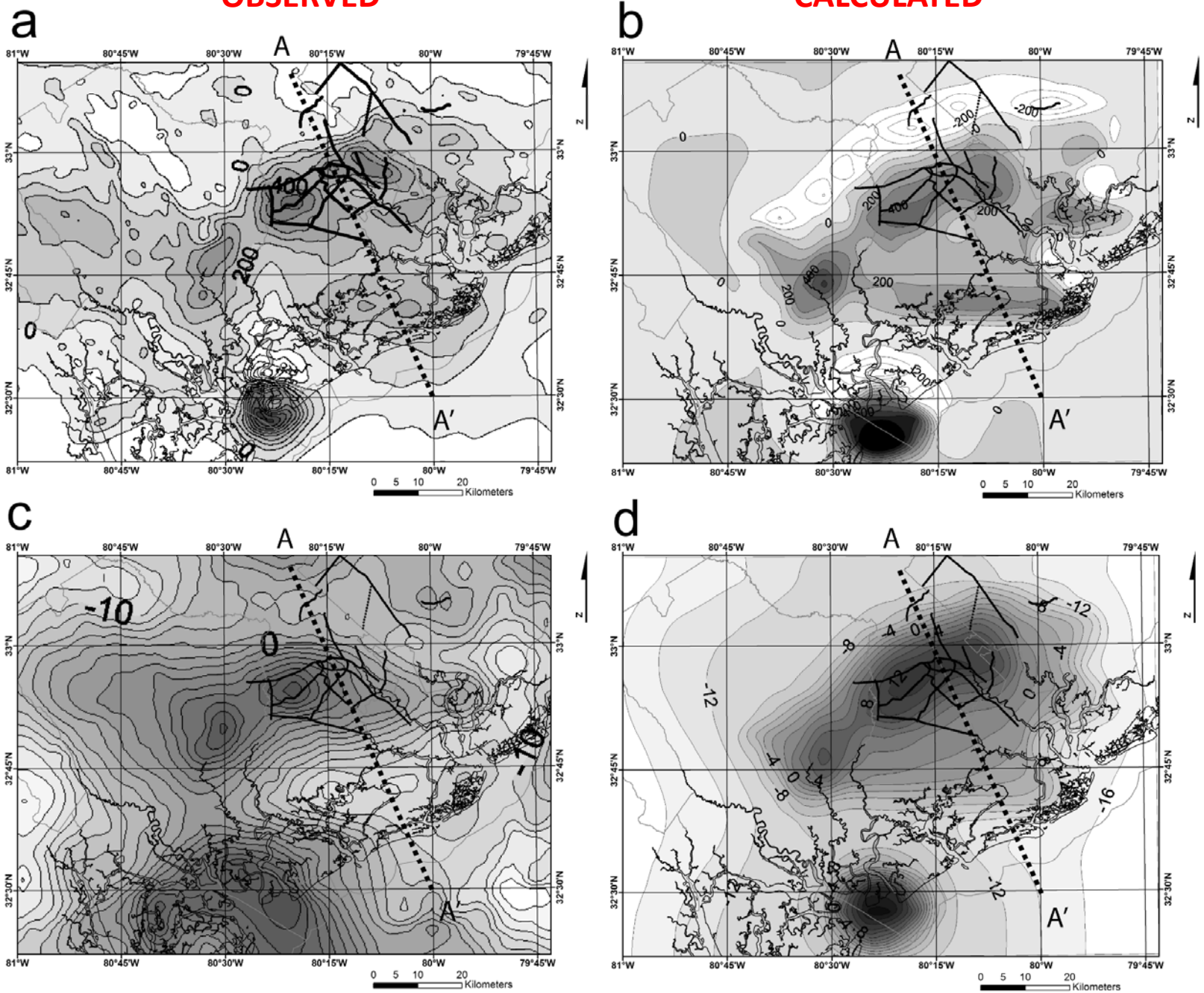

S
Profile VT5
N
CMP
40
80
120
160
200
240
0
0.5
1.0
1.5
2.0
Time (s)
T
K
J
B?
folded strata
diffractions
9 km

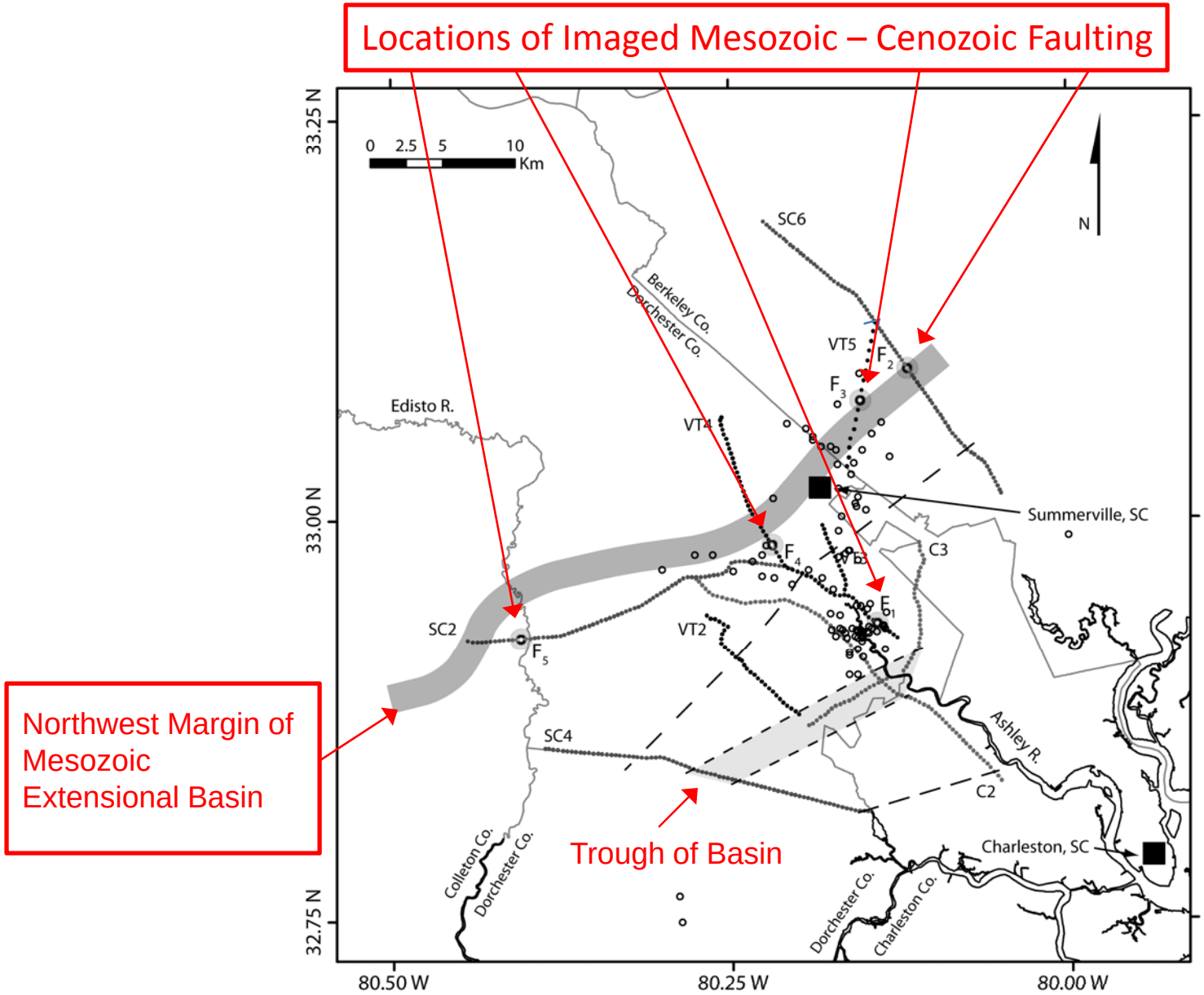
OBSERVED

CALCULATED

Total Intensity Magnetic Anomaly

Bouguer Gravity Anomaly





The area between Summerville and Charleston is the site of intense Mesozoic crustal extension. Mafic rocks are present to a depth of at least 4 km, in a fault-bounded basin. The 1886 earthquake represents reactivation of this faulting.

Ronald Andrus

Clemson University

Liquefaction Potential of Aged Soil Deposits in Charleston, South Carolina

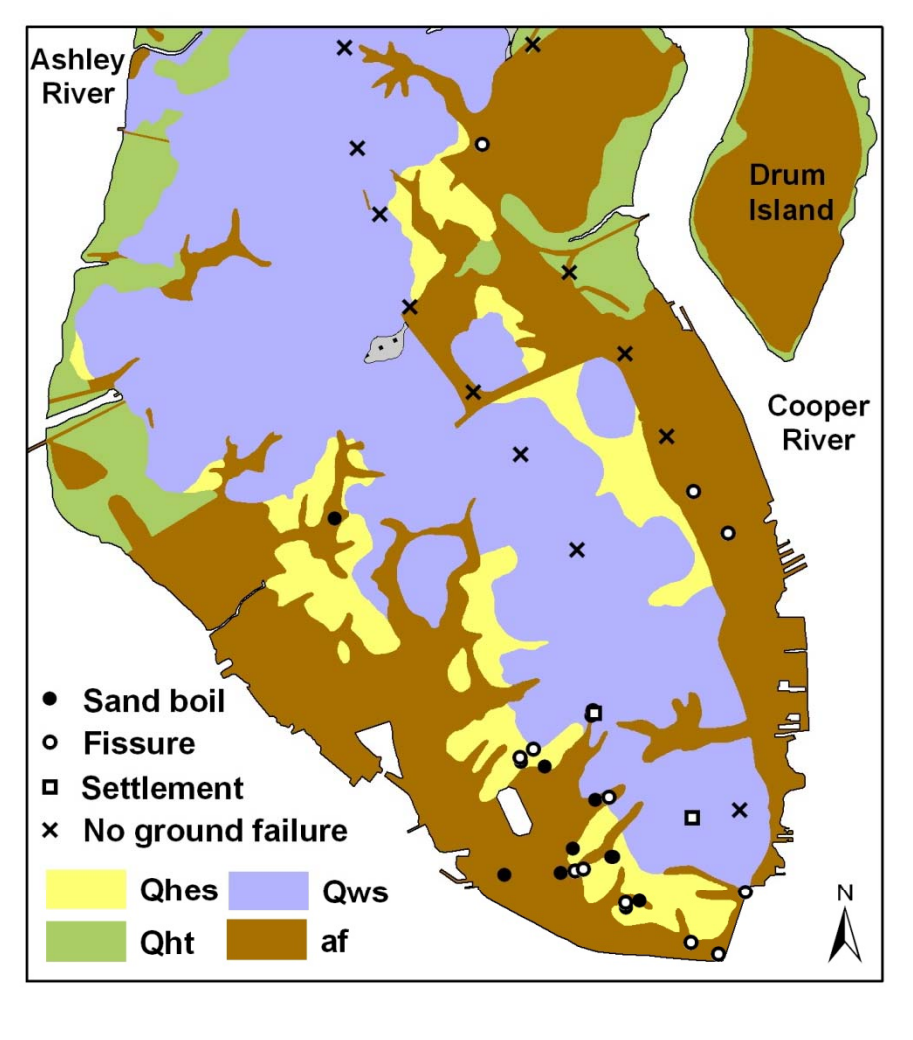
Ronald Andrus, Tahereh Heidari, and Hossein Hayati
Clemson University

CEUS Earthquake Hazards Meeting
October 28-29, 2009
University of Memphis
Memphis, TN

USGS
science for a changing world

CLEMSON
UNIVERSITY

1886 Historic Liquefaction Map of Charleston Peninsula

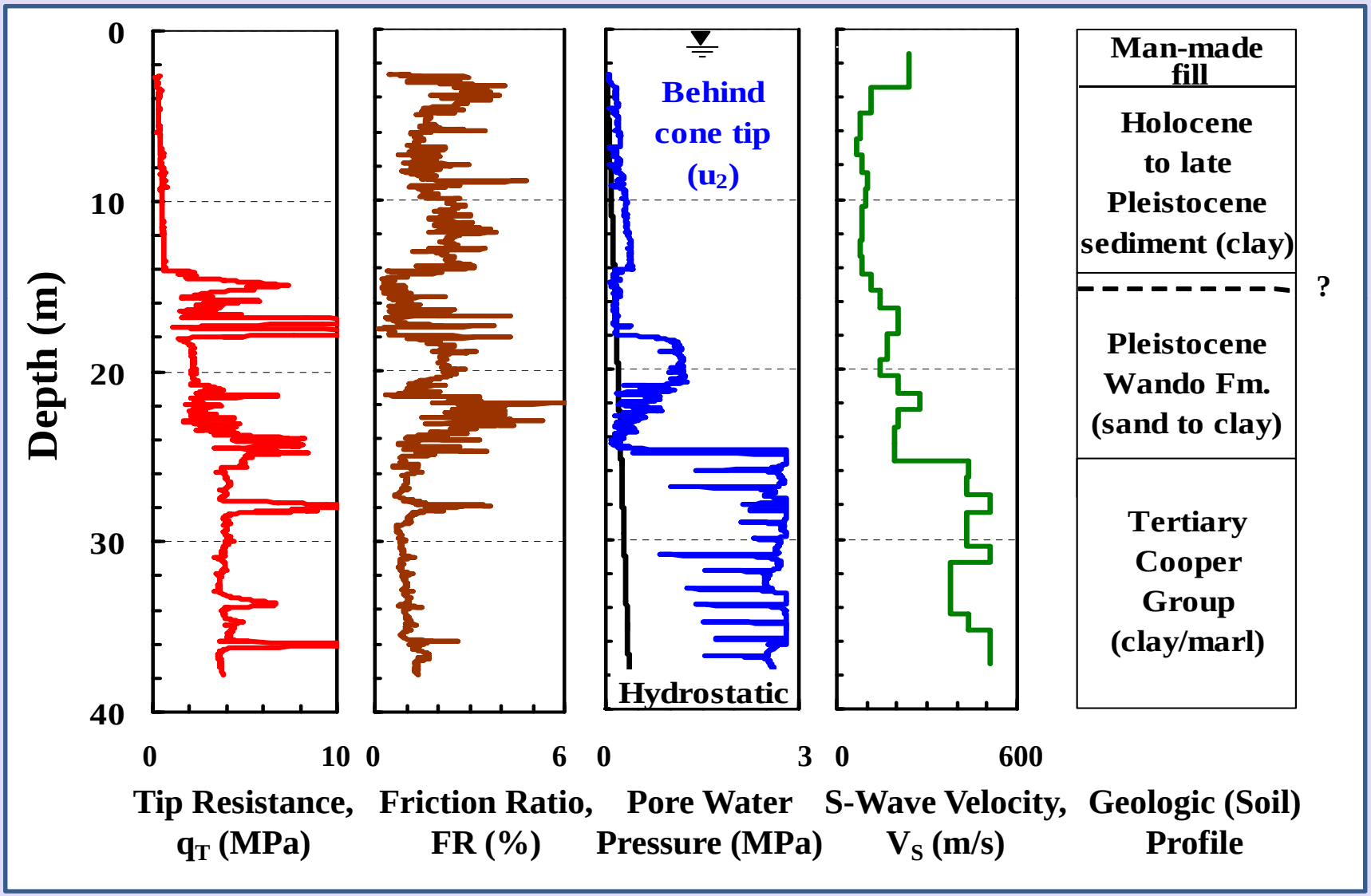


26 cases of liquefaction and ground failure associated with Qhes and younger sands.

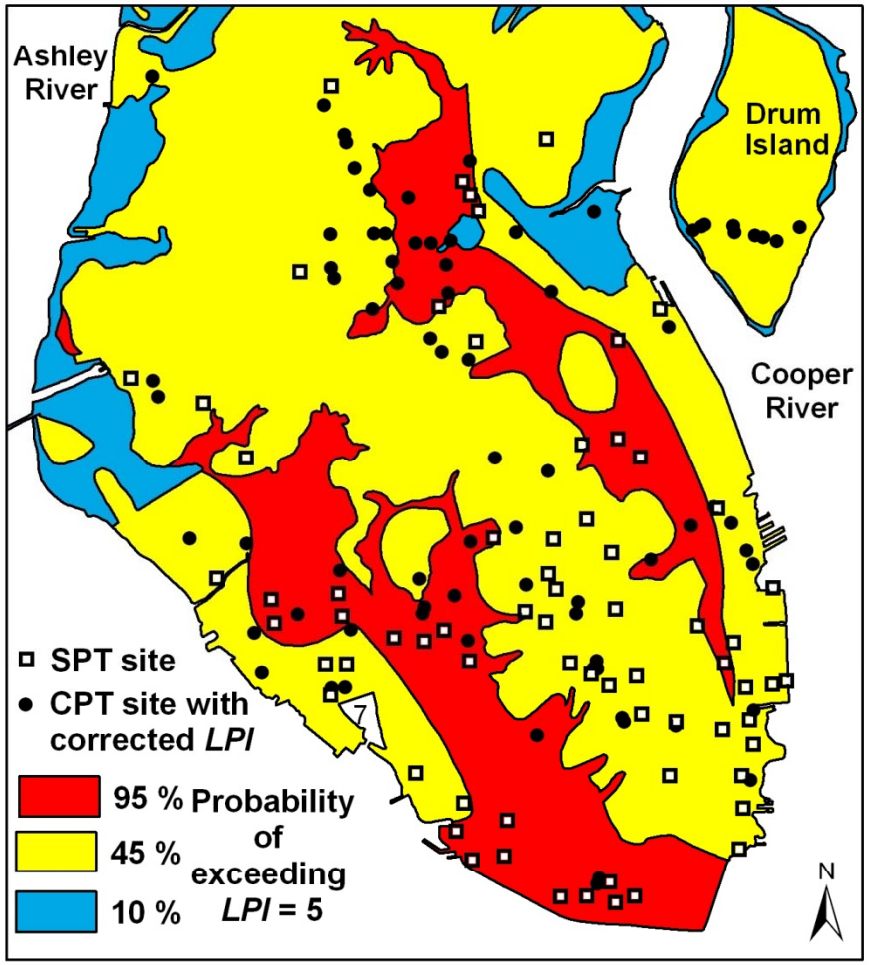
Only 1 case of marginal liquefaction associated with Qws (sand facies of the 100,000-year-old Wando Formation).

Geologic map by Weems and Lemon (1993) with 1886 ground behavior data from Hayati and Andrus (2008).

Sample CPT, V_S & Geologic Profiles



Liquefaction Potential Map of Charleston Peninsula



Followed mapping approach of Holzer et al. (2006), who assumed LPI = 5 to be the threshold for sand boil generation.

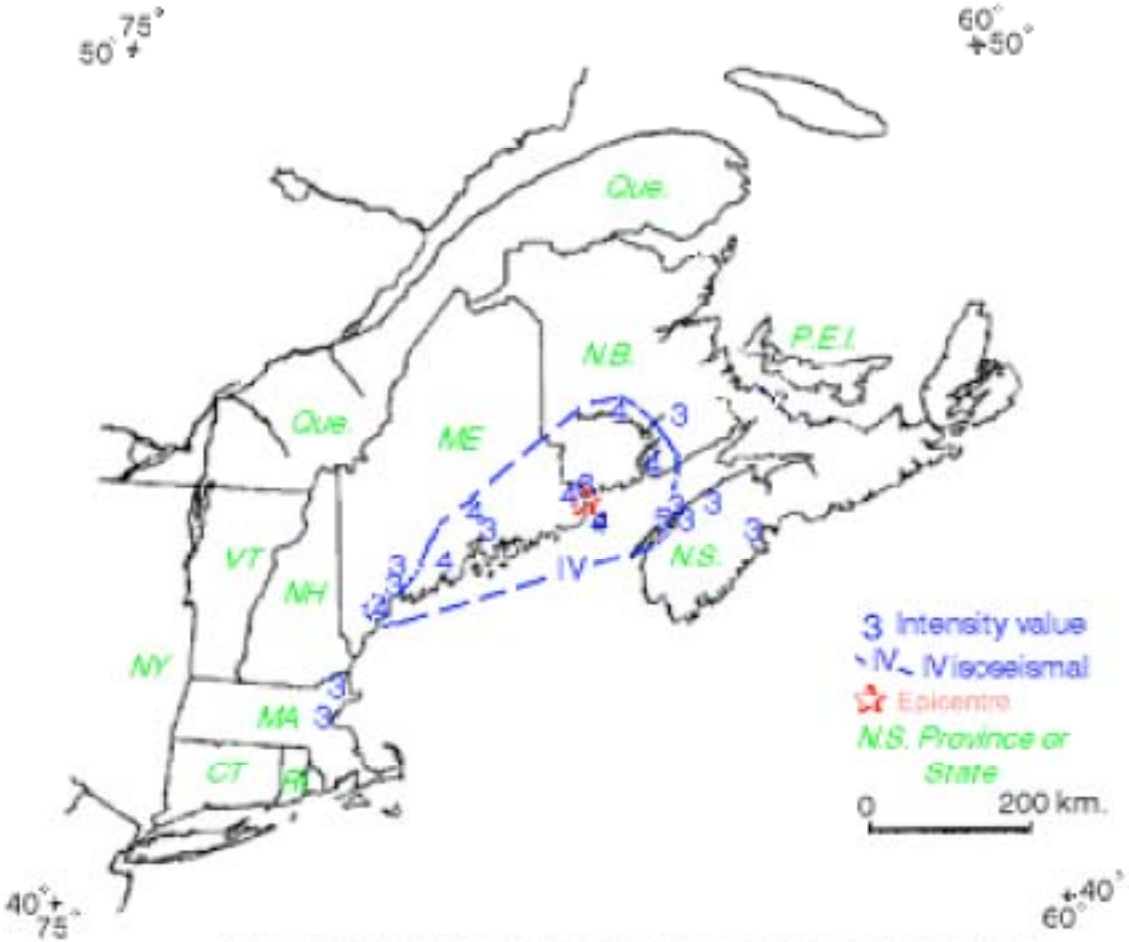
Similar results obtained for Mount Pleasant by Heidari and Andrus (2010).

Future work to include other areas in the greater Charleston region.

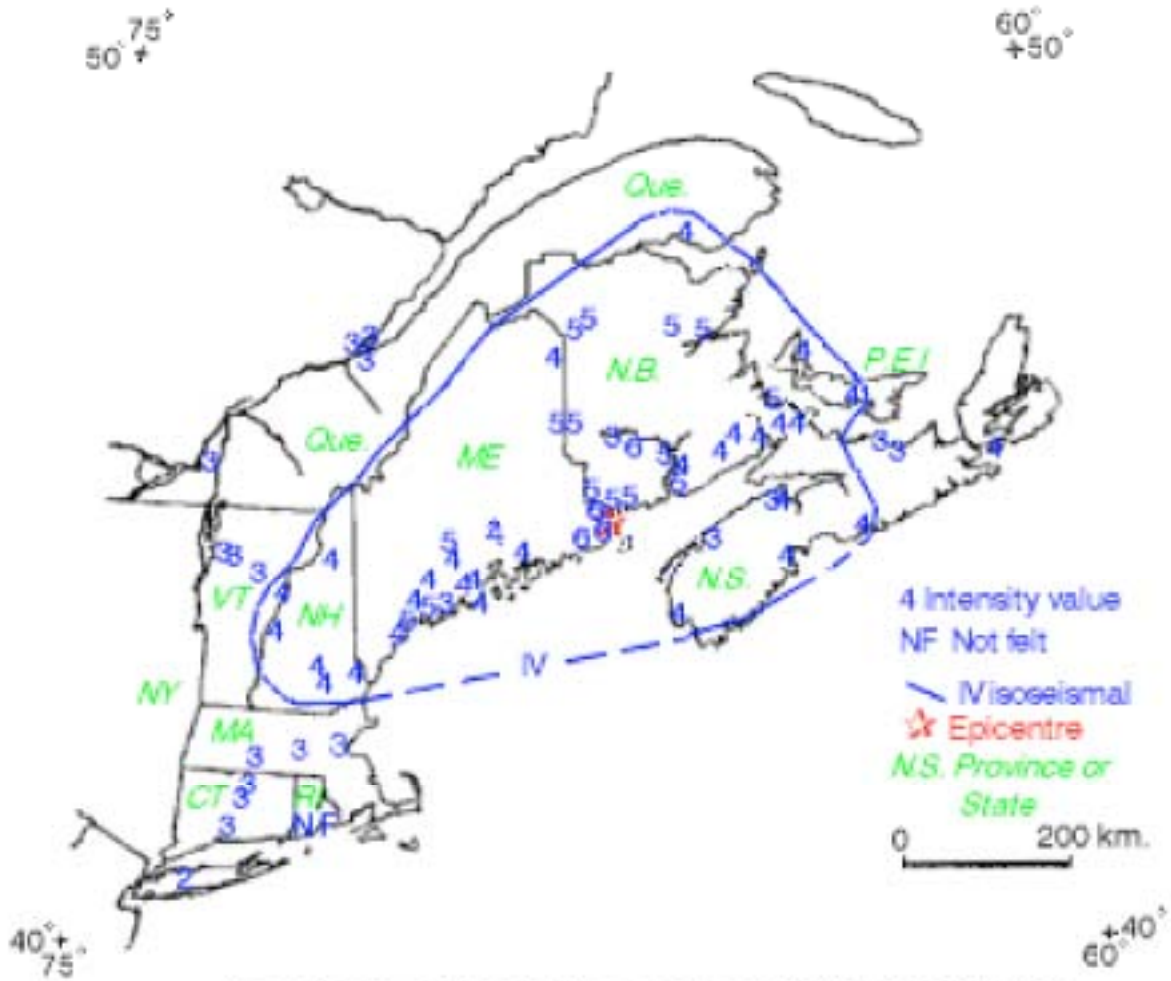
Hayati and Andrus (2008).

Alan Ruffman

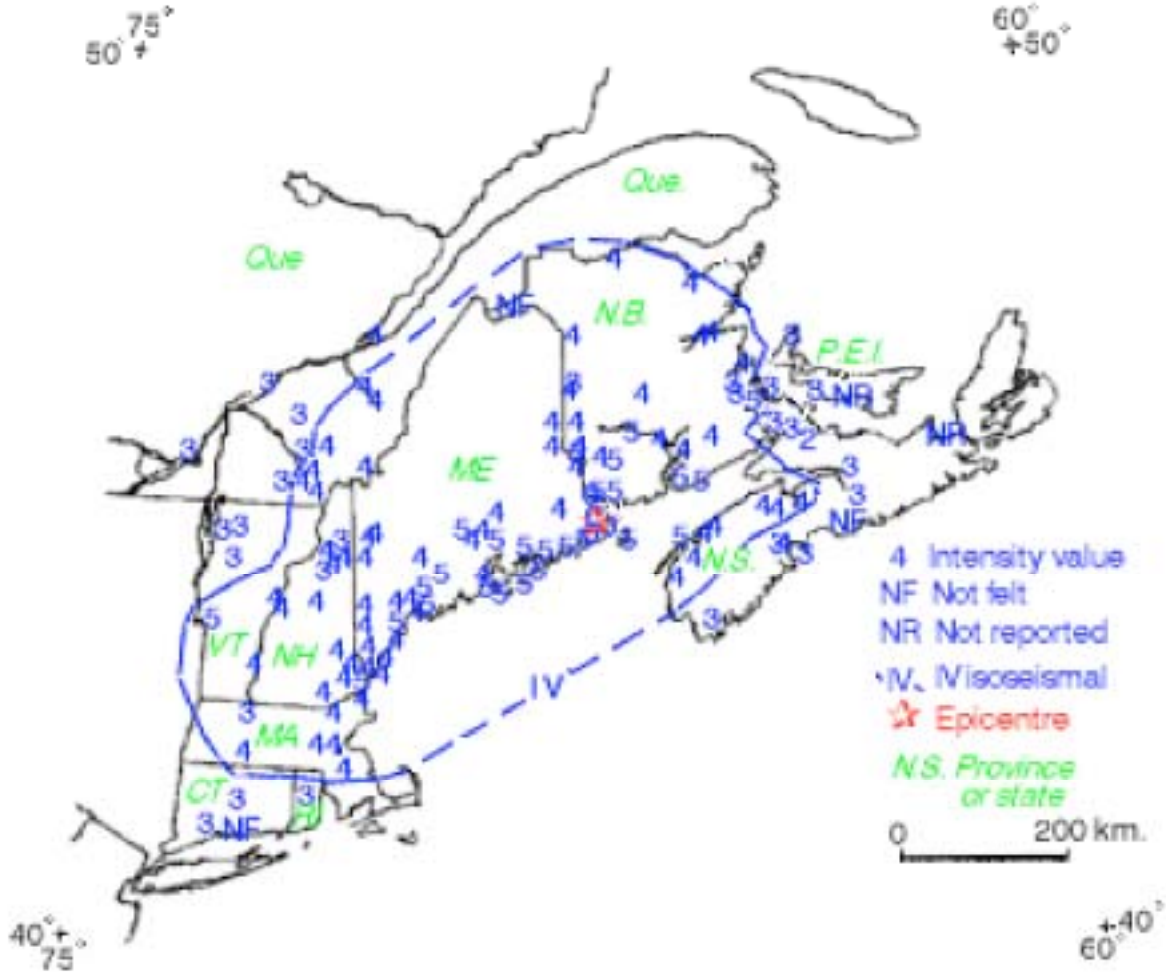
Geomarine Associates Ltd.



INTENSITY MAP FOR 1817 EARTHQUAKE



INTENSITY MAP FOR 1869 EARTHQUAKE



INTENSITY MAP FOR 1904 EARTHQUAKE.

Oshkosh Daily Northwestern.

A TIDAL WAVE.

A Visitor at New Haven, Conn., Which Followed an Earthquake—Damage to Shipping.

NEW HAVEN, Conn., Dec. 23.—An earthquake shock was felt here about eleven o'clock Sunday night. Fifteen minutes later a tidal wave eight feet high rolled into the bay from the south, traversing the entire length of the harbor—four miles. It had a speed of about twelve miles an hour. There are 200 vessels in the harbor bound eastwards. Several were torn away from their moorings. One ship loaded with coal and four heavily loaded barges were sunk. A three-masted schooner, 800 tons, was swept by the wave nearly a quarter of a mile like a cork, and now lies stranded on Sandy Point. Many other vessels were badly shaken and strained by the wave, but there is no means of communicating with them. Up the harbor the wave overturned small boats, parted the fastening of small vessels and did damage to the New Haven Yacht Club. An overturned yawl was found at Morris' Cove to-night, with a quantity of sailors' clothing, splintered spars and loose rigging, and thirty-two hatches swept from vessels' decks by the wave. It is now feared that other disasters have occurred.

Miguel Pando

University of Puerto Rico Mayaguez

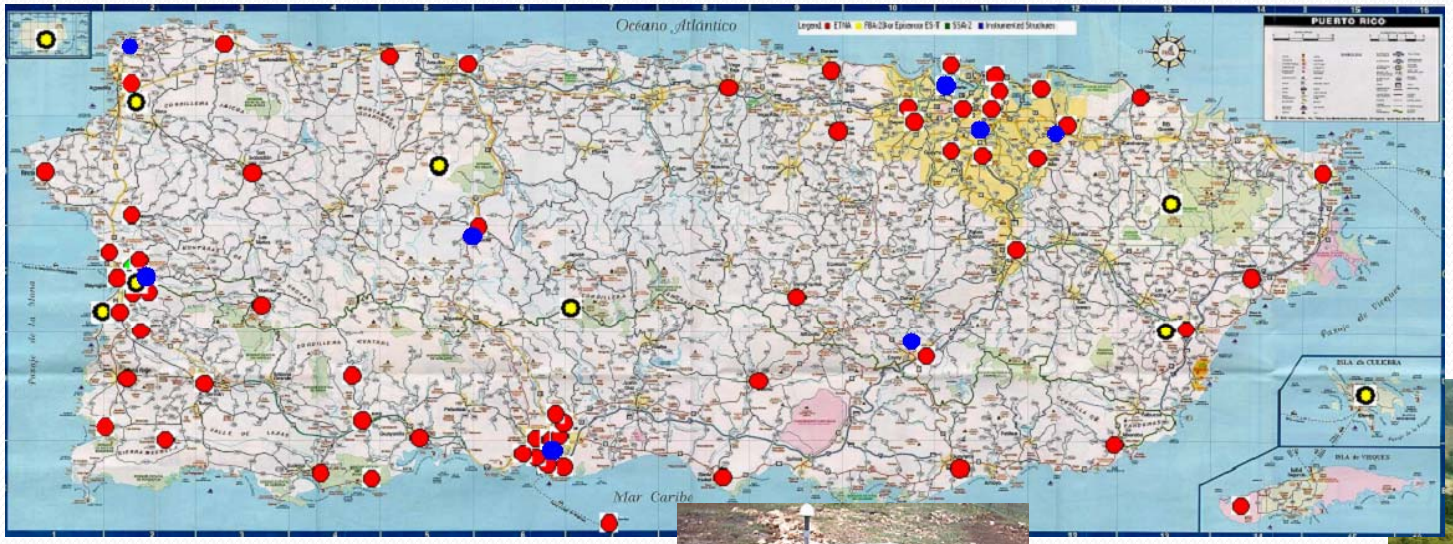
Overview of Recent and Current Earthquake Hazard Research at the Puerto Rico Strong Motion Program (PRSMP) at UPRM

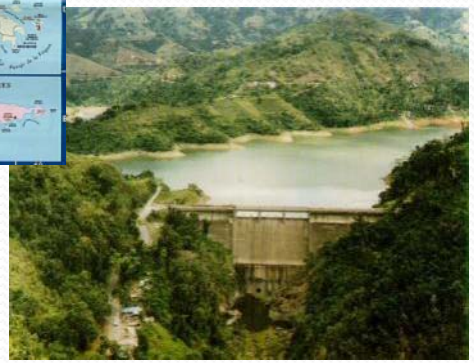
Dr. Miguel A. Pando, Researcher,
Dr. Carlos I. Huerta (Presenter), PRSMP, Eng. Seismologist,
Dr. José A. Martínez-Cruzado (Director PRSMP),
Dr. Luis E. Suárez, Researcher.

Meeting of the USGS CEUS Earthquake Hazards Program
October 28-29, 2009, Fogelman Conference Center, University of Memphis, Memphis, TN

PRSMP Current Instrumentation

- Instrumentation Network in PR: 90 free field.
- Stations in neighbor islands: DR (2), USVI (3), BVI (5).
- Instrumentation of Structures: 5 buildings, 3 bridges, 6 concrete dams, 1 earth dam (2 in progress).





PRSMP Recent Research (1/2)

- Instrumentation network: Most effort goes to build and maintain instrumentation network (Previous slide).
- Site effects and NEHRP soil mapping:
  - NEHRP soil maps for main cities of PR (San Juan, Ponce, Mayagüez, Arecibo, Caguas, Humacao).
    - Version 1 (**2003-2008**): Used existing geologic and geotechnical data (lots SPT data, some CPT, v. little Vs data)
    - Mayagüez: Detailed database with USGS NEHRP funds (2005) (Geophysical testing, ArcView GIS).
  - Liquefaction susceptibility maps for PR main cities
    - Simplified liquefaction method (liquefaction potential Index)

PRSMP Recent Research (2/2)

- Strong Motion Records:
  - Analysis of existing EQ recordings: Small to moderate (M: ≤ 5), attenuation, frequency contents, site periods, etc.
  - Design ground motions: (Problem: Lack of strong motion data in PR)
    - Development of estimated artificial design ground motions (compatible with design spectra) (Suárez et al.)
    - Applicability of scaling moderate PR records?
- Dynamic properties of PR soils:
  - Residual soils (Hoyos, 1999), Calcareous sands (Cataño & Pando, 2005)
- Liquefaction susceptibility of PR Calcareous sands:
  - 2007 USGS NEHRP joint project (Virginia Tech and UPRM)
  - Test results suggest that conventional liquefaction screening techniques do not apply to PR calcareous sands

PRSMP Current and Future Research (1/2):

- Detailed NEHRP soil maps and Seismic microzonation maps:
  - Expand efforts with geophysical testing in PR main cities (AV, SPAC, SASW, etc)
  - $Vs_{30\,m}$, Site and building periods, period matching, and estimation of damping
  - Develop maps of predominant site periods and building periods for main cities of PR (developed protocol & pilot study).
- Free field instrumentation:
  - Continue densification of the instrumentation network. For example for San Juan Metropolitan Area ANSS recommends ≈ 150 (currently in San Juan only 16 strong motion stations),
  - More instruments in neighboring islands,
  - Real-time monitoring (Antelope).
- Instrumentation of structures: (Continue ≈ 1 structure per year)

PRSMP Current and Future Research (2/2):

- Dynamic properties and liquefaction of PR soils:
  - Dynamic properties of PR residual soils, calcareous sands
  - Continue liquefaction study of PR Calcareous sands

<u>Future plans and wish list</u>:

- OBS instrumentation.
- Downhole array in PR
- Historic and Prehistoric Seismicity of PR:
  - Build on paleoseismology & Paleoliquefaction studies in PR (Tuttle et al. 2003)
- Ground Motion Attenuation Relationships for PR:
  - Update & build on study by Gail Atkinson & D. Motazedian (2005).
- Detailed geotechnical data for each free field PRSMP station.

Leo Ramirez-Guzman

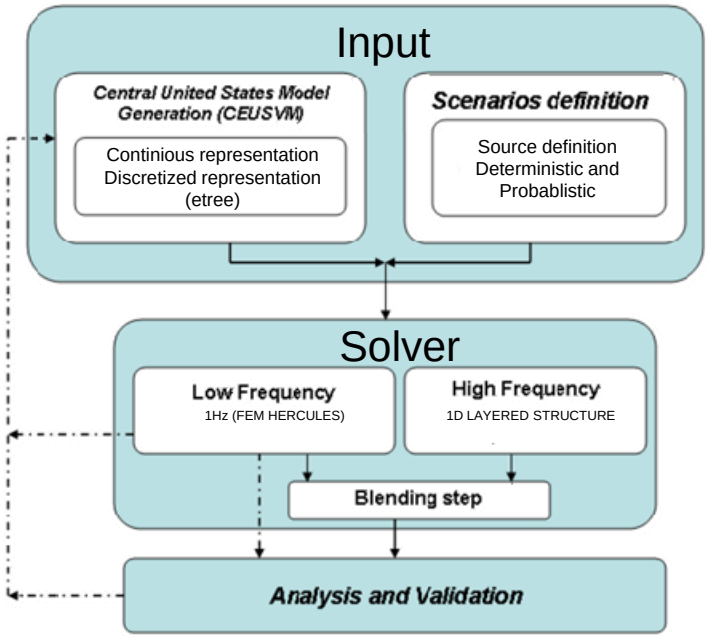
US Geological Survey

CENTRAL UNITED STATES VELOCITY MODEL VERSION 1: DESCRIPTION AND VALIDATION

Leonardo Ramirez-Guzman, Robert A. Williams,
Oliver Boyd and Stephen Hartzell (USGS).

A PIECE OF THE PUZZLE

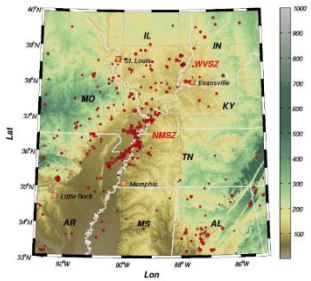
Project:
Earthquake simulations in the New Madrid Seismic Zone: The 1811–1812 Bicentennial.



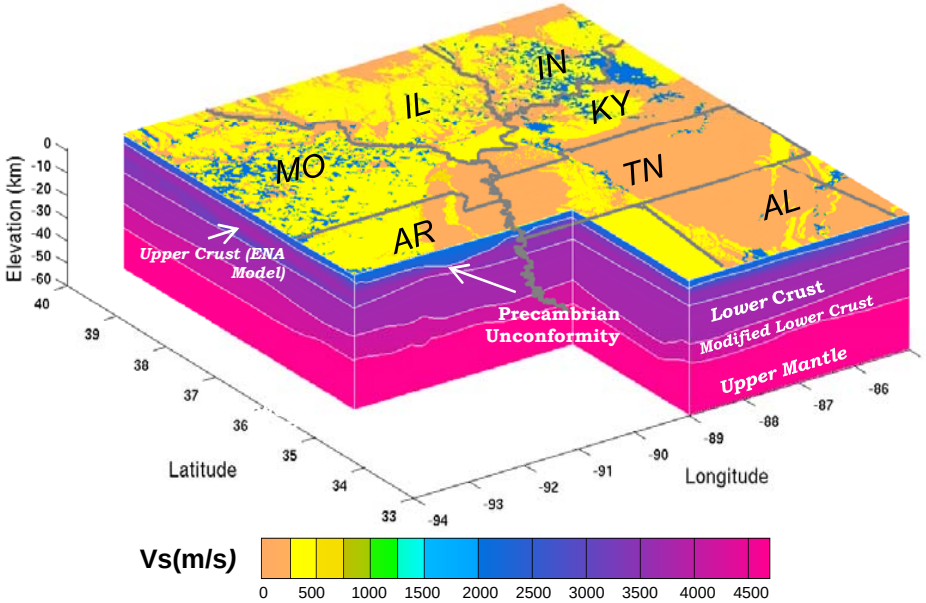
Conceptual framework similar to those already done for 1906 and 1868 Hayward (Bay Area) and Shakeout (Southern CA) scenarios.

Model Extension and Overview

Topographic map showing the extension of the CUSVM and earthquakes greater than magnitude 2.5 (red circles) that occurred after 1972.

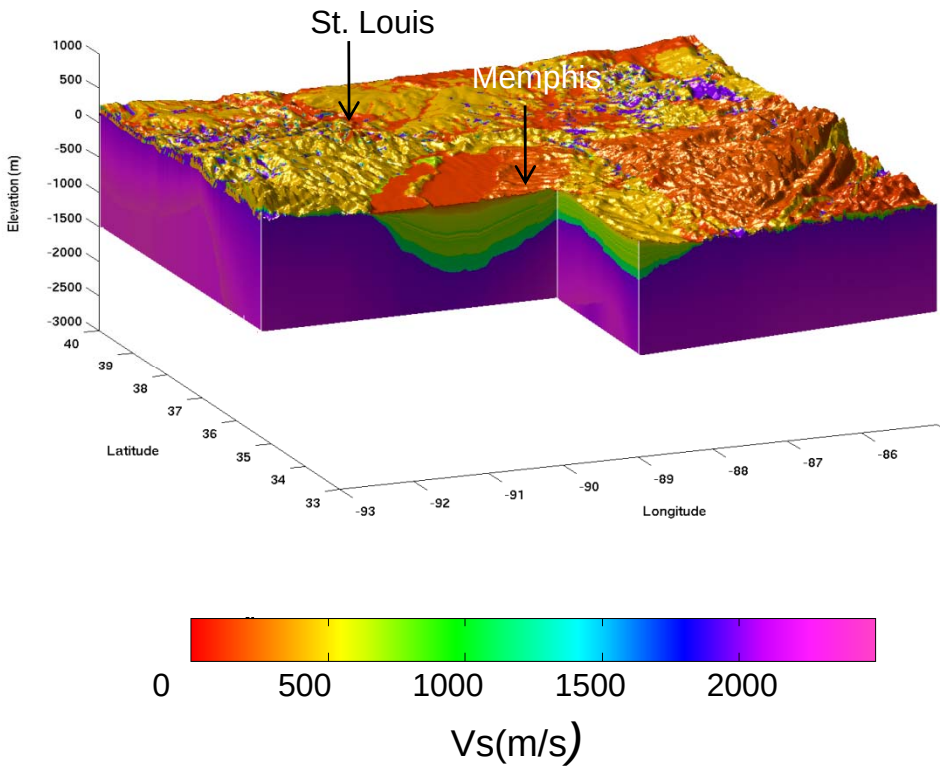


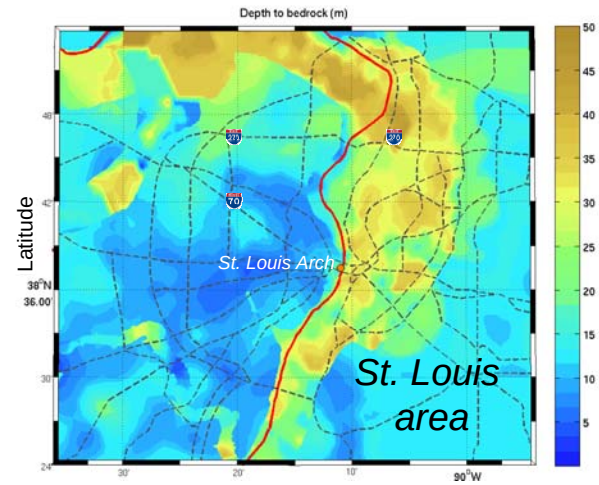
Model Overview. The white lines delineate the boundaries between the oldest units. The colormap indicates the Vs (m/s) distribution.

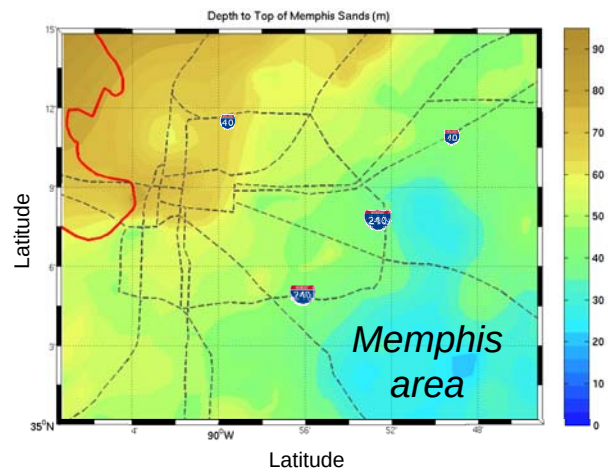


SHALLOW STRUCTURE

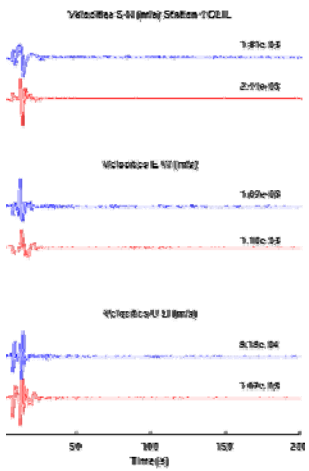
Shallow structure. Velocity and topography. The colormap indicates the Vs (m/s) distribution.

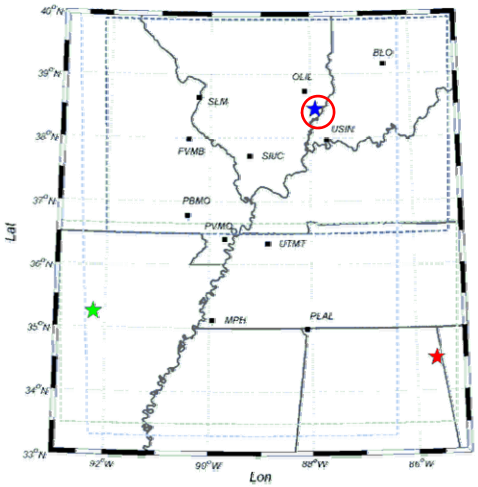




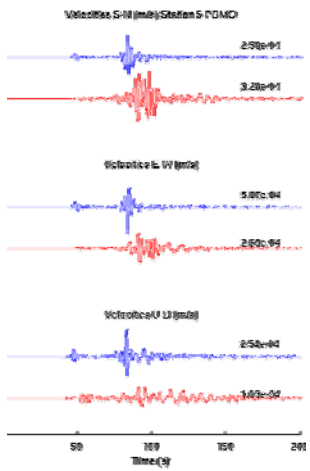


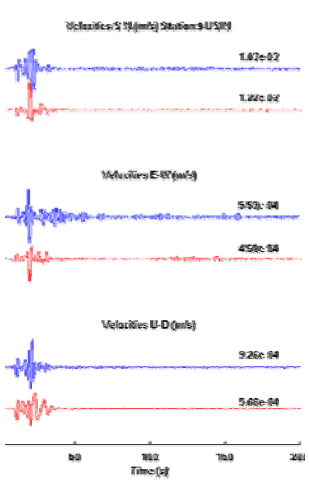
CUSVM TEST (Validations): Mt. Carmel Earthquake

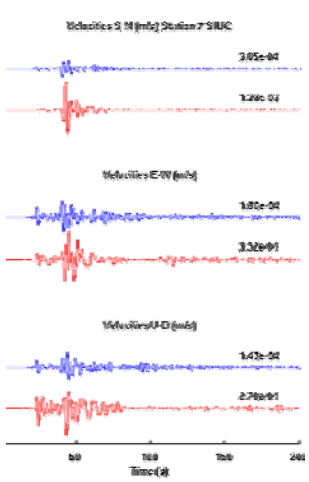


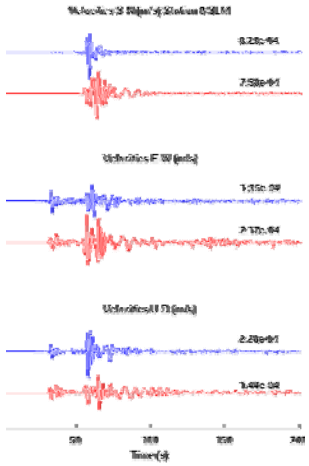


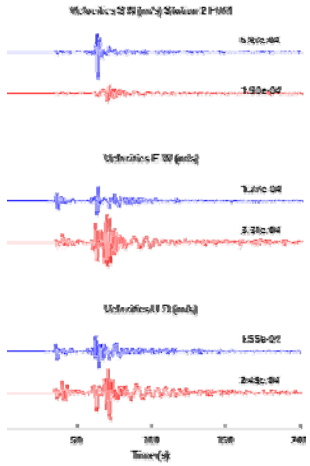
Three earthquakes were used to calibrate the model. Stars indicate locations. Synthetic (red) vs. observed (blue) velocity for the Mt. Carmel Earthquake. The location of each station is displayed. The frequency range is 0-0.75Hz.











POTENTIAL USAGE and CONTRIBUTIONS

Physics based simulation of the Ground Motion.

Influence of tridimensional effects.

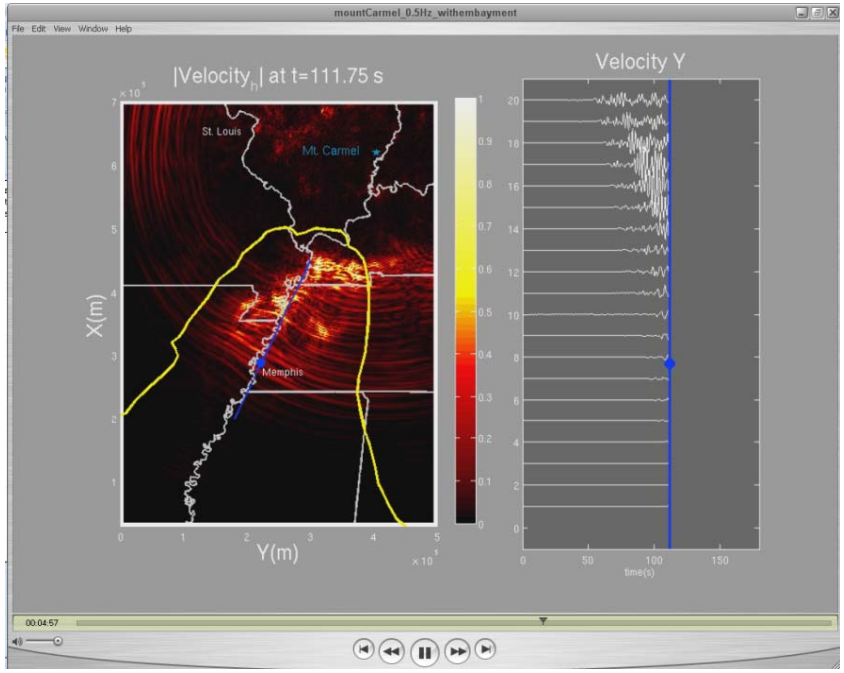
High frequency.

Loss estimates.

Emergency planning.

Raise awareness of the effects of large earthquakes in the region.

Crustal Deformation simulations.



Jer-Ming Chiu

University of Memphis (CERI)

High-resolution P- and S-wave Velocity Structure of the Post-Paleozoic Sediments in the Upper Mississippi Embayment

Jer-Ming Chiu [1], BiniamAsmerom[1]
Edward Woolery[2], ZhenmingWang [2], and Ron Street[2,3]

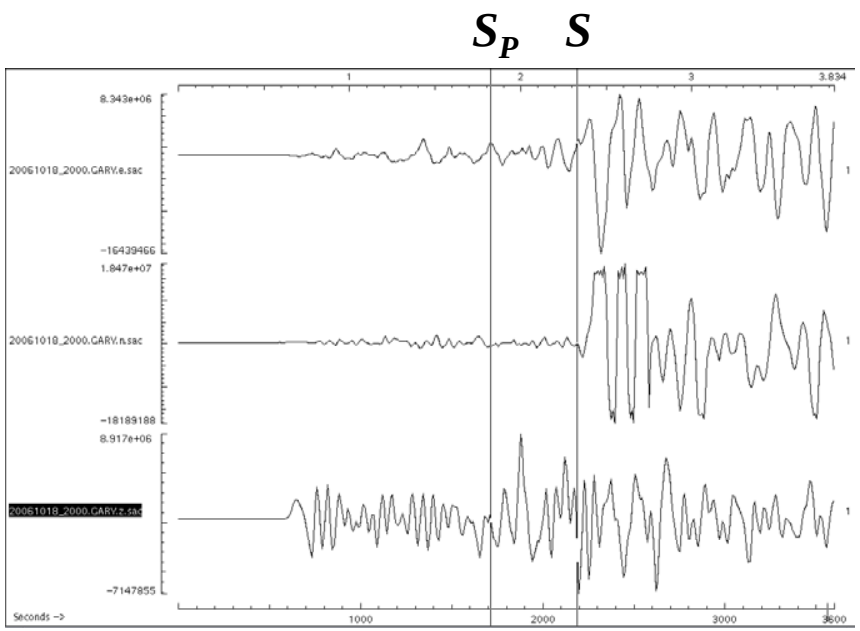
[1]CERI, The University of Memphis,
[2]Dept. of Earth and Environmental Sciences, University of Kentucky
[3]Retired

The main objective of this project is to explore spatial variations of Vp and Vs structures in the sedimentary basin to

- **Improve the resolution of local earthquake locations to quantify the 3-D characteristic features of active fault zones.**
- **Provide essential velocity information for site specific response assessment to allow a reliable evaluation of regional seismic hazard**

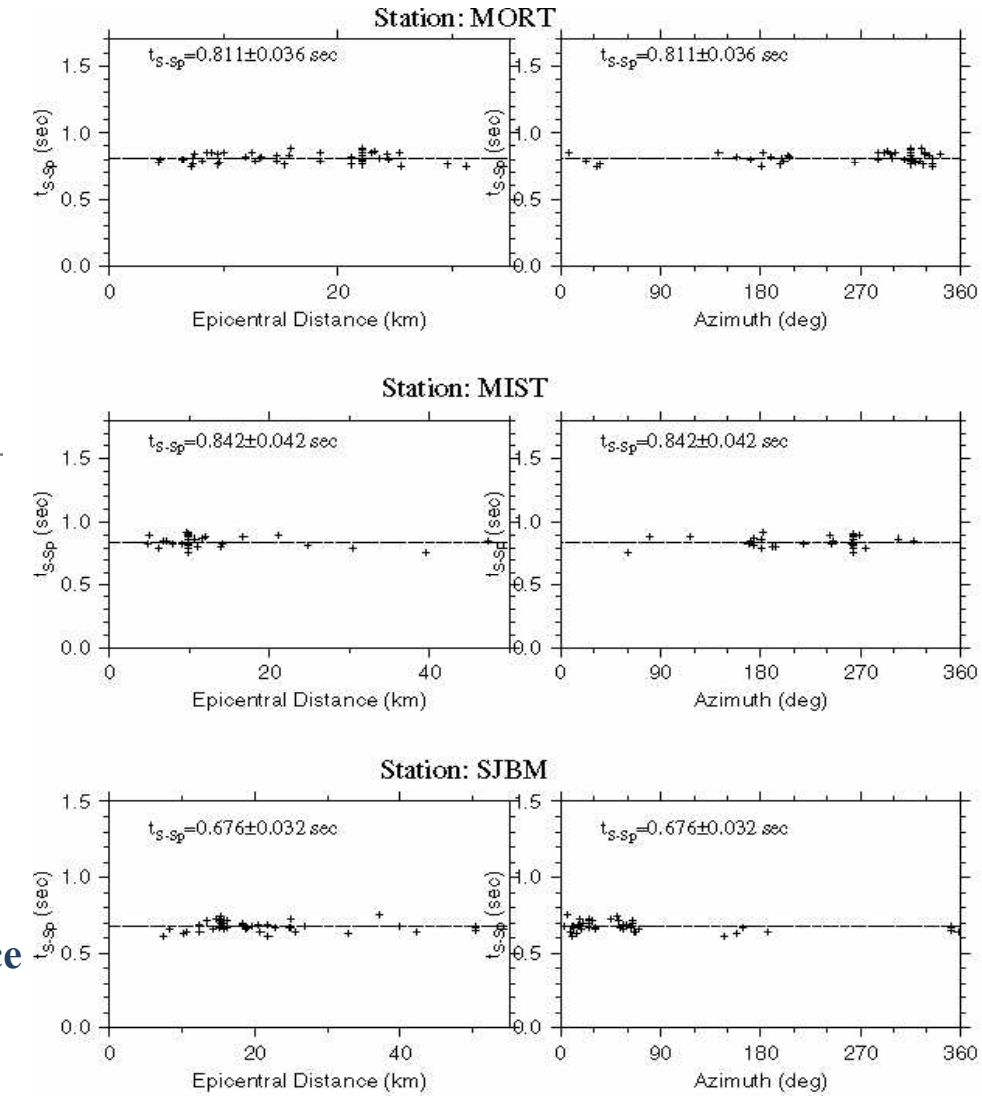
Our approaches:

1. **Select sites evenly distributed over the Upper Mississippi Embayment**
2. **Deploy BB station on each site to record local earthquakes**
3. **Conduct P and S seismic reflection/ refraction profiles at each site**
4. **Determine Vp and Vs structures underneath each site**



sediment

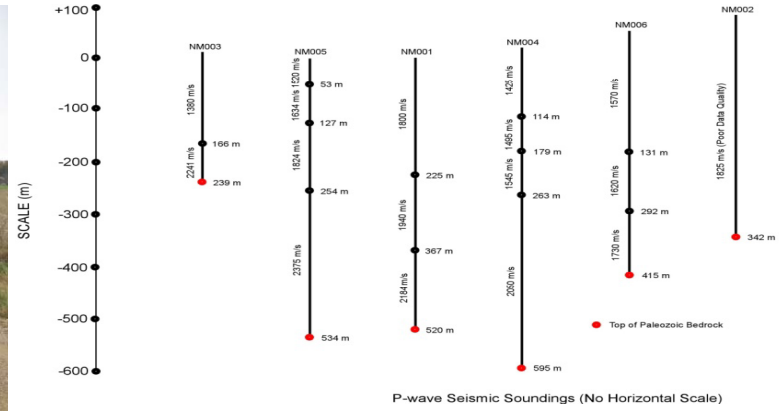
Δt_{S-S_p} is a constant at each station but is different at different station

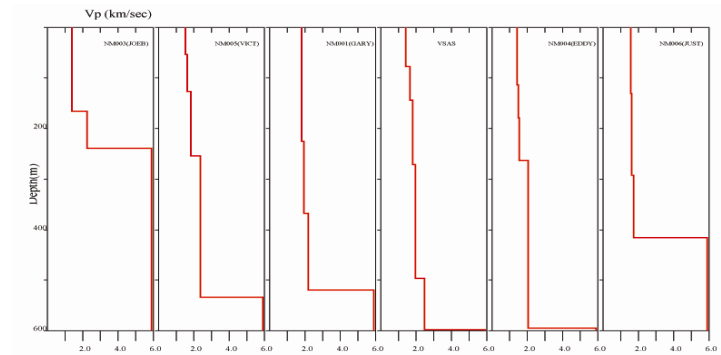


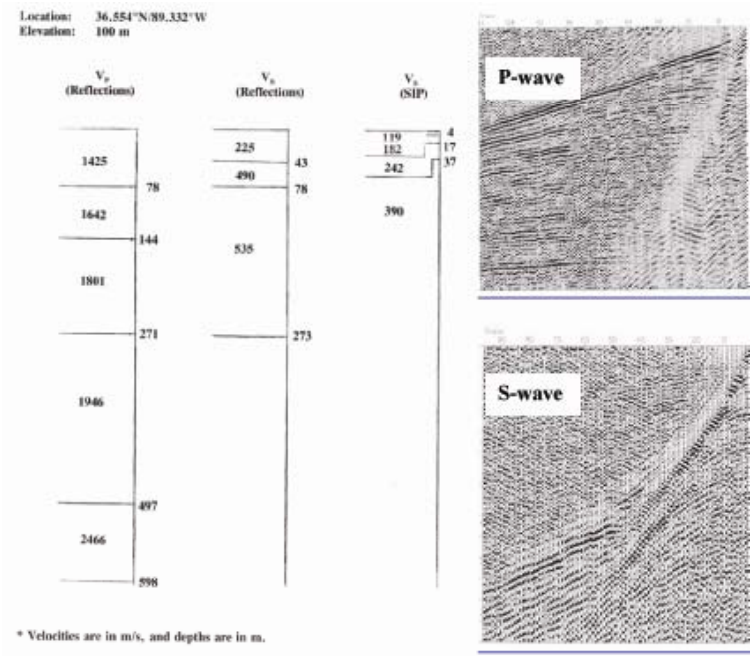
Δt_{S-S_p} represents the travel time difference between P and S waves traveling across the entire thickness of the sediments beneath each site

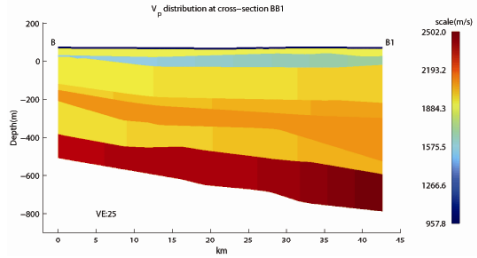
P-wave source

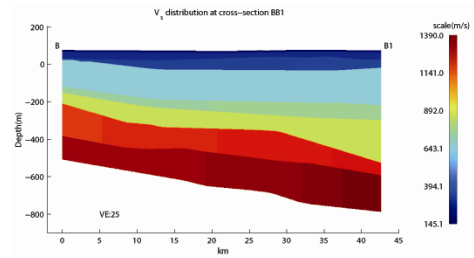
S-wave source



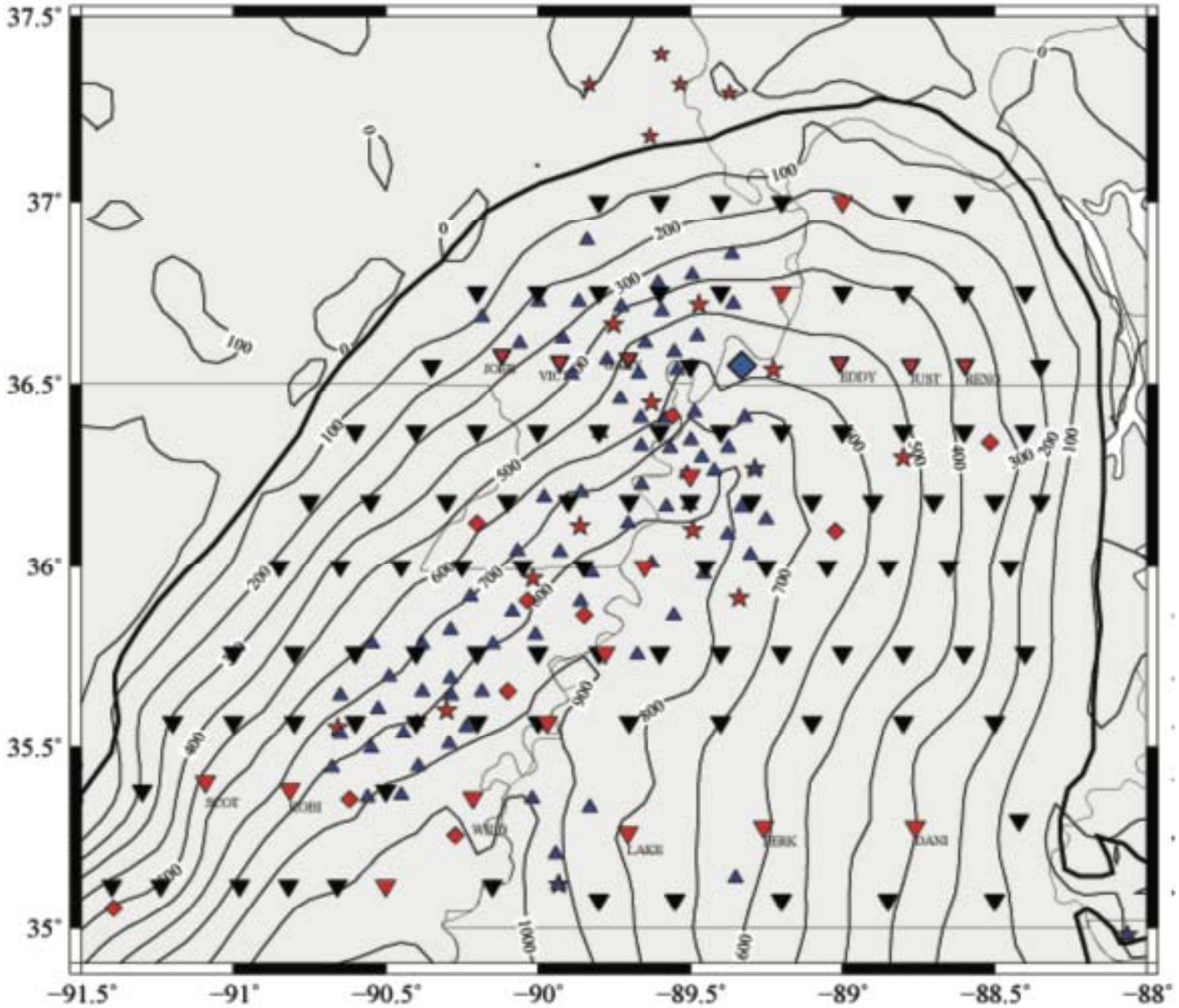








UoM and UK Mississippi Embayment Experiment (2009-2011)



Zhenming Wang

University of Kentucky

The Central United States Seismic Observatory (CUSSO) and Its Implication

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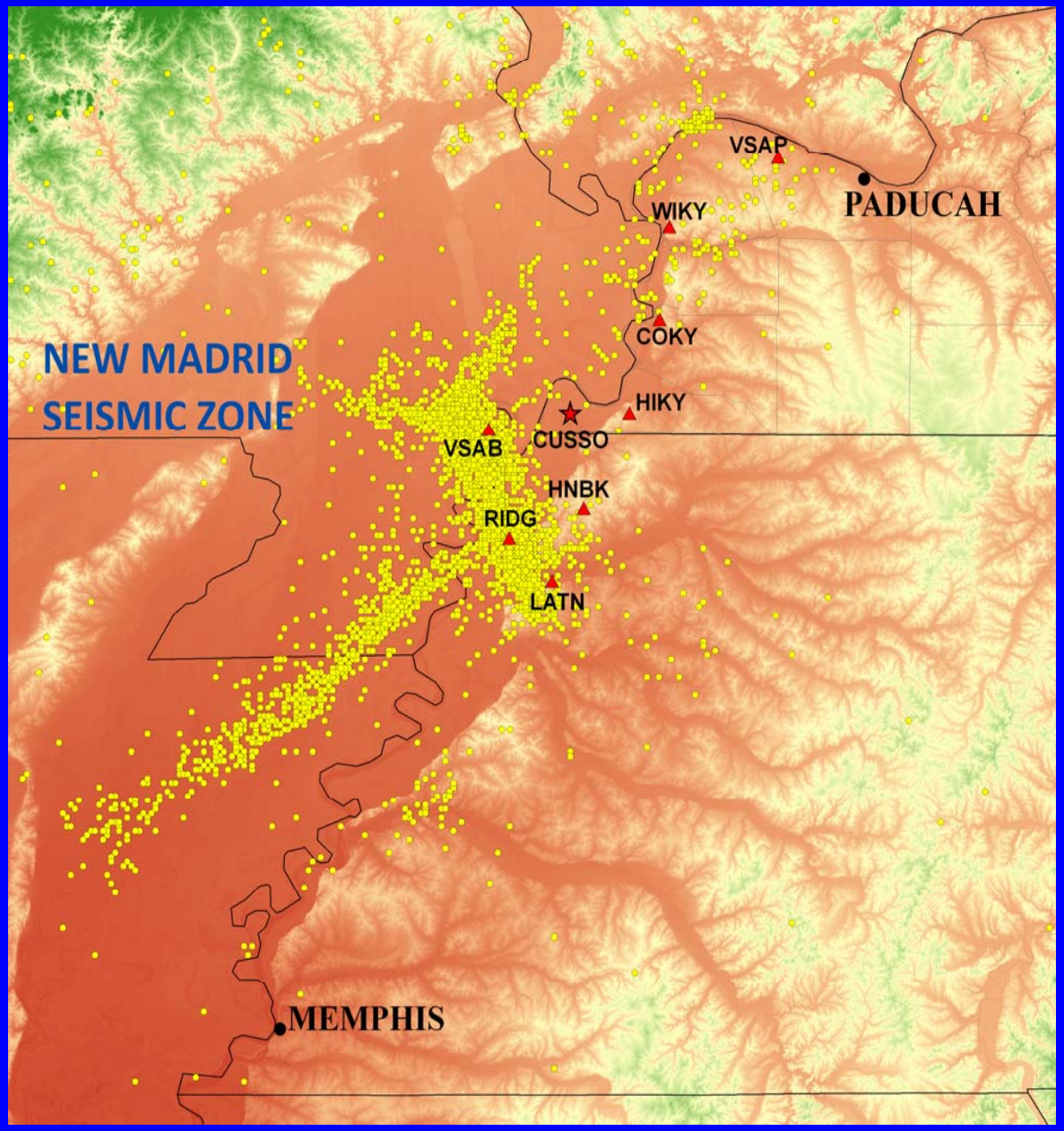
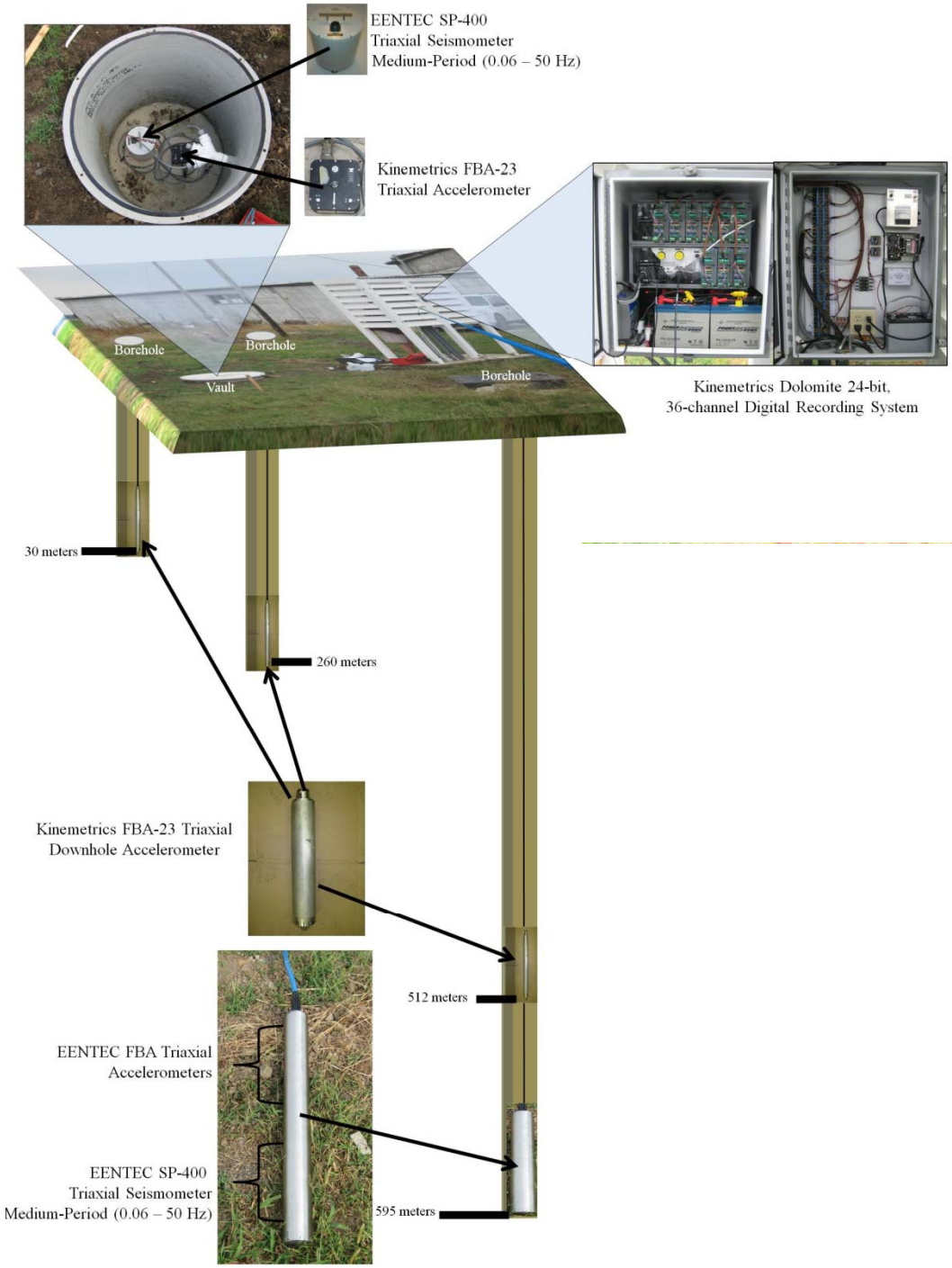
CEU Earthquake Hazards Meeting
October 28-29, 2009

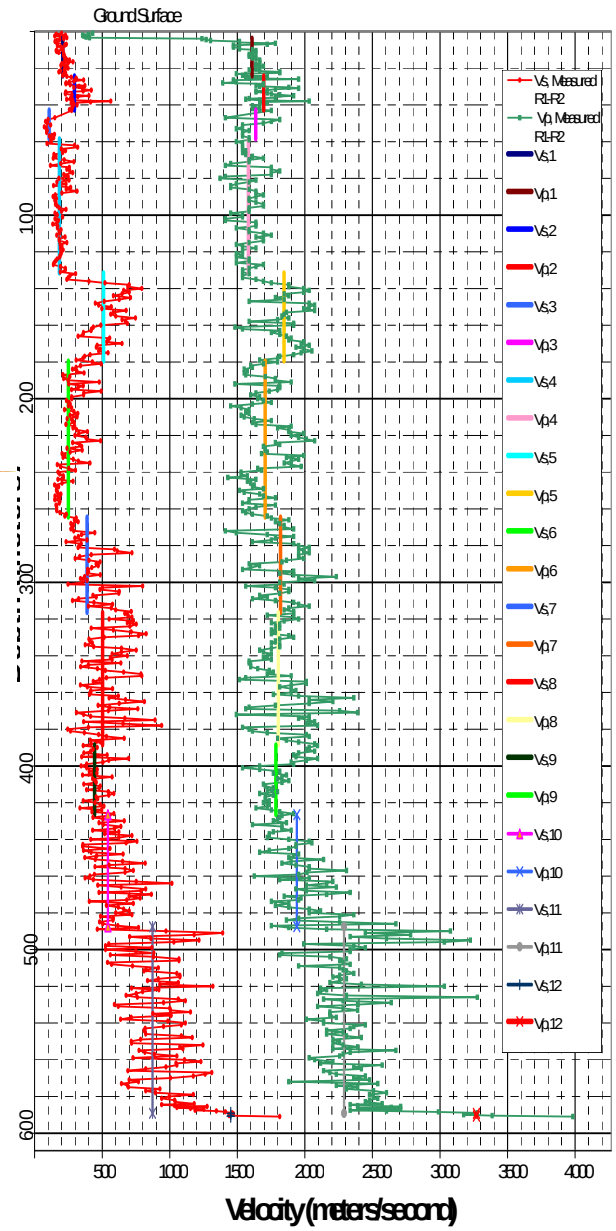
Acknowledgements

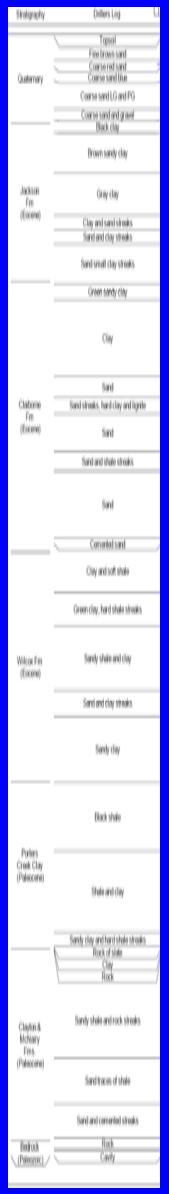
- A dedication to Ron Street's original idea
- The Department of Energy ($300,000)
- The United States Geological Survey ($100,000)
- The Kentucky Geological Survey ($200,000)
- Greg Steiner
- The Voorhees' family for providing the land for CUSSO

Location


VSAP
PADUCAH
WIKY
COKY
NEW MADRID
SEISMIC ZONE
HIKY
VSAB
CUSSO
HNBK
RIDG
LATN
MEMPHIS


EENTEC SP-400
Triaxial Seismometer
Medium-Period (0.06 – 50 Hz)
Kinemetrics FBA-23
Triaxial Accelerometer
Borehole
Borehole
Vault
Borehole
Kinemetrics Dolomite 24-bit,
36-channel Digital Recording System
30 meters
260 meters
Kinemetrics FBA-23 Triaxial
Downhole Accelerometer
512 meters
EENTEC FBA Triaxial
Accelerometers
EENTEC SP-400
Triaxial Seismometer
Medium-Period (0.06 – 50 Hz)
595 meters


Ground Surface
Vs, Measured R1-R2
Vp, Measured R1-R2
Vs1
Vp1
Vs2
Vp2
Vs3
Vp3
Vs4
Vp4
Vs5
Vp5
Vs6
Vp6
Vs7
Vp7
Vs8
Vp8
Vs9
Vp9
Vs10
Vp10
Vs11
Vp11
Vs12
Vp12
100
200
300
400
500
600
500
1000
1500
2000
2500
3000
3500
4000
Velocity (meters/second)



Goals

1. Evaluation of the effect of thick sediments on strong and week motions

2. Evaluation of current analytical and empirical methods for site amplification

3. Evaluation of soil dynamic properties of the sediments

4. Constrain on seismic hazard (strong motion) estimates in the New Madrid Seismic Zone

David Dolenc

University of Minnesota, Duluth

Effects of Shallow 3D Structure of the Mississippi Embayment on Ground-Motion Amplification

David Dolenc, University of Minnesota

Steve Horton, CERI

Funded by USGS NEHRP

Work Plan

Model well-recorded M4.0-5.2 earthquakes using:

- Finite-difference code
- Velocity and attenuation models

1D crust + 1D sedimentary model
+ 3D sedimentary model
3D crust + 3D sedimentary model

Evaluate:
- Effects of shallow structure on ground-motion amplification
- Trapping of surface waves in slow-velocity structures
- Focusing and interference effects at basin edge

Compare synthetic waveforms to observations

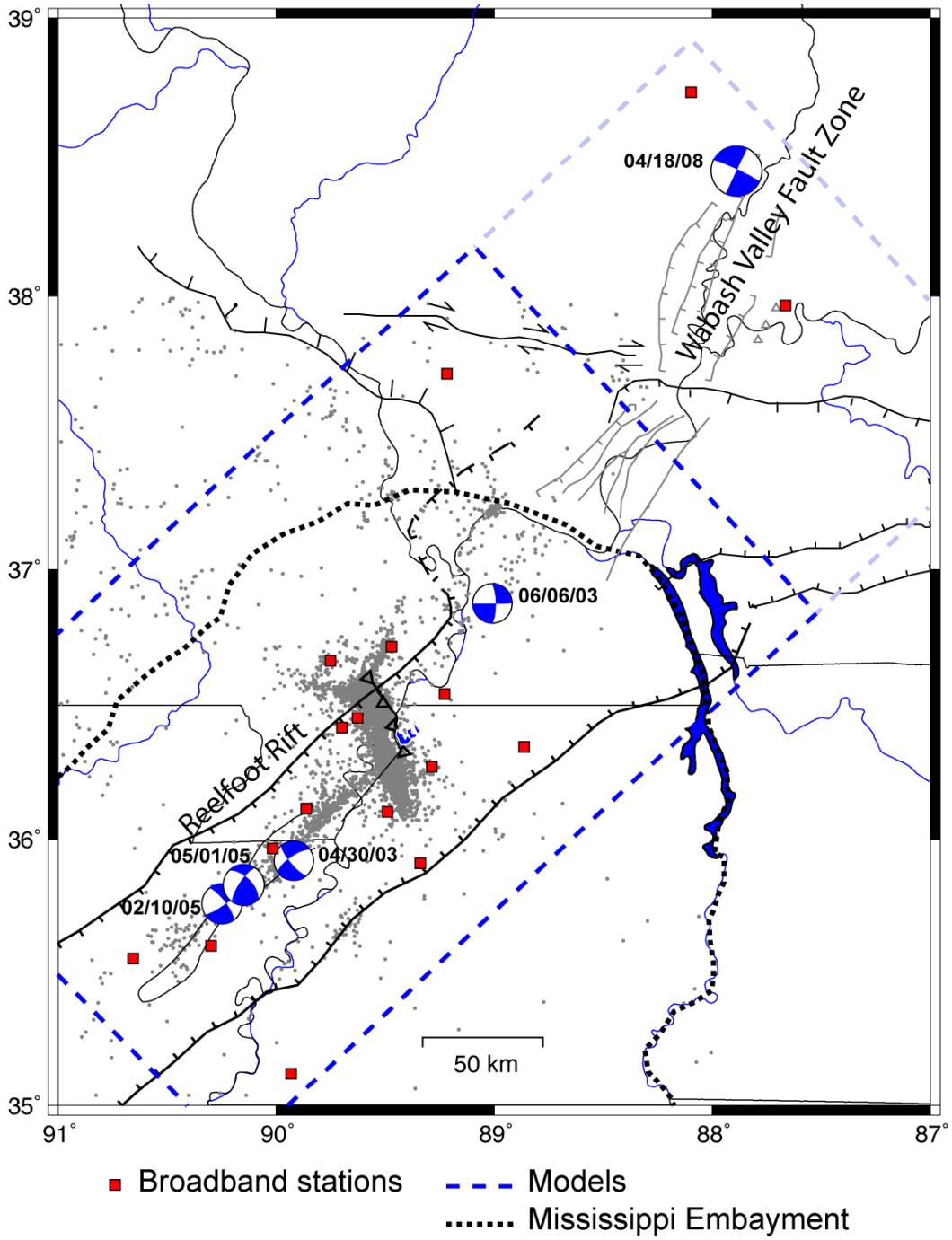
Evaluate 3D velocity model

Events

Bardwell	M4.0	06/06/2003
AR1	M4.0	04/30/2003
AR2	M4.1	02/10/2005
AR3	M4.2	05/01/2005
Mt. Carmel	M5.2	04/18/2008

Models

Small	345 x 230 x 50 km
Large	450 x 230 x 50 km



- Finite-difference code WPP (developed by LLNL)

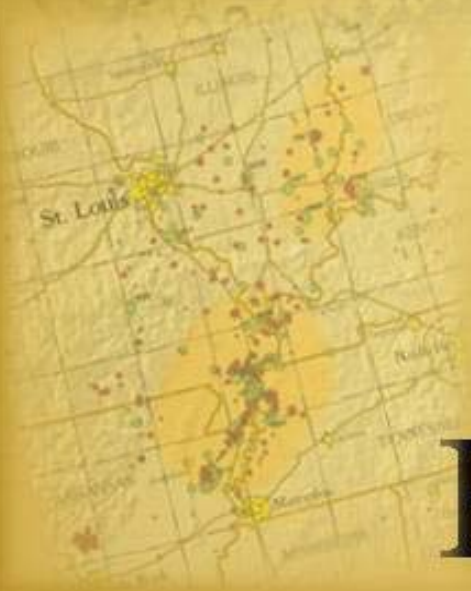
- Minnesota Supercomputing Institute — Linux cluster “Calhoun”
  2048 compute cores, 4TB memory

- Largest simulations

Model size	450 x 230 x 50 km
Variable resolution	62.5 m (shallow)
	1000 m (deep)
Minimum vs	250 m/s
Bandwidth	T > 0.6 s
Attenuation	Yes

- 3D Velocity model — CEUSVM (Ramirez-Guzman et al.)
  + its variations for shallow layers

- Preliminary simulations – POSTER
- Final results expected by June 2010

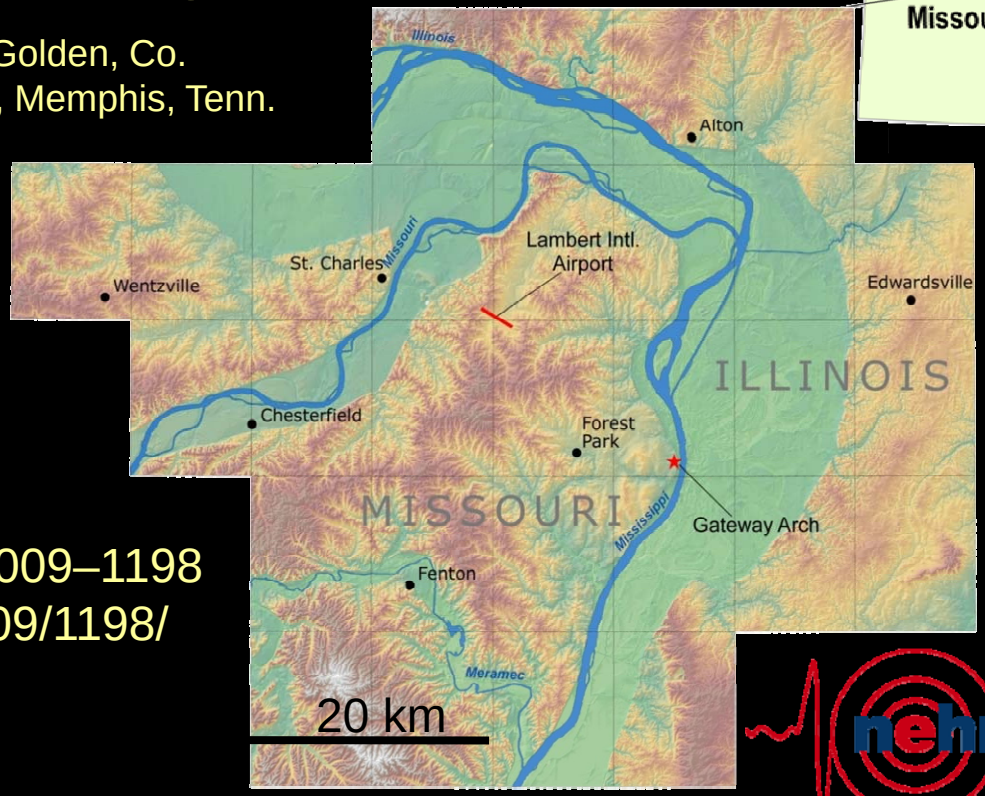


Robert Williams

US Geological Survey

St. Louis Area Earthquake Hazards Mapping Project

Robert A. Williams, USGS – Golden, Co.
Presented October 29, 2009, Memphis, Tenn.

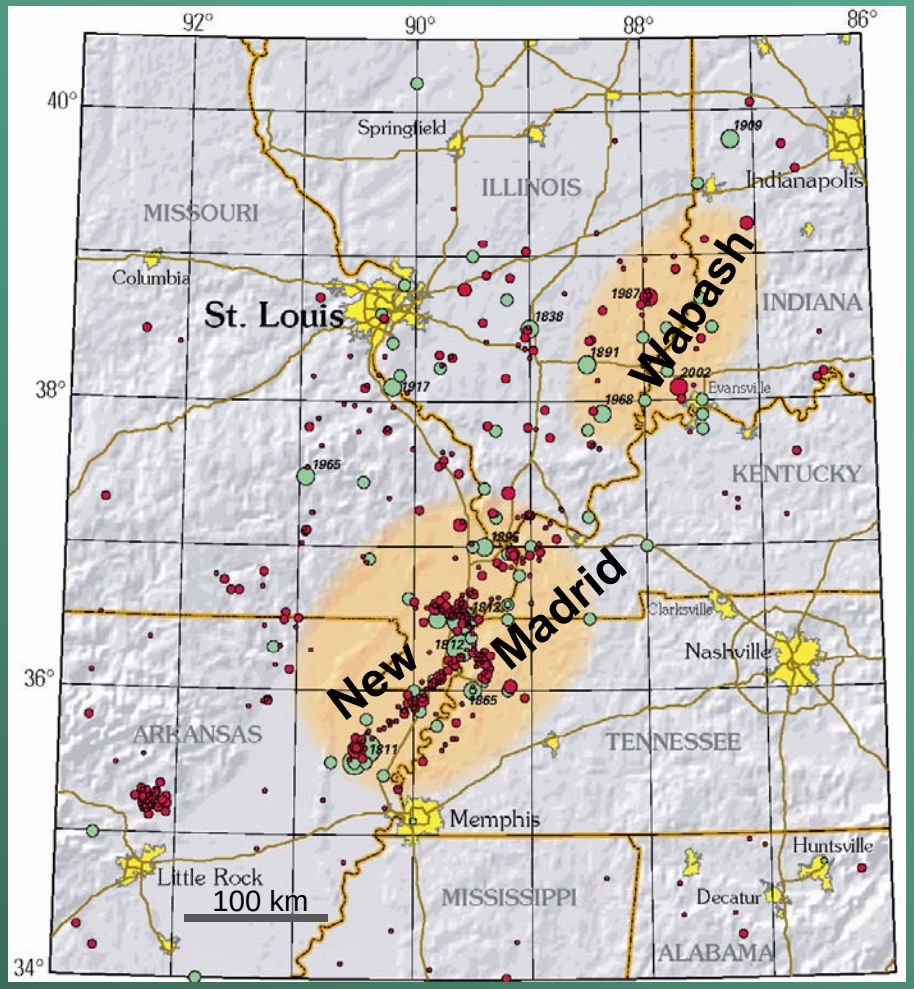


Excerpted from:
USGS Open-File Report 2009–1198
http://pubs.usgs.gov/of/2009/1198/

Why study St. Louis earthquake hazards?

Proximity to seismic zones:
New Madrid and ***Wabash Valley.***
Scattered seismicity east and south of St. Louis.

Since 1811 at least a dozen earthquakes have caused minor damage in St. Louis.
(Public domain information: Saint Louis University Earthquake Center, St. Louis, Mo., 1999, http://www.eas.slu.edu/Earthquake_Center/EQInfo/Flyers/central_u.html)



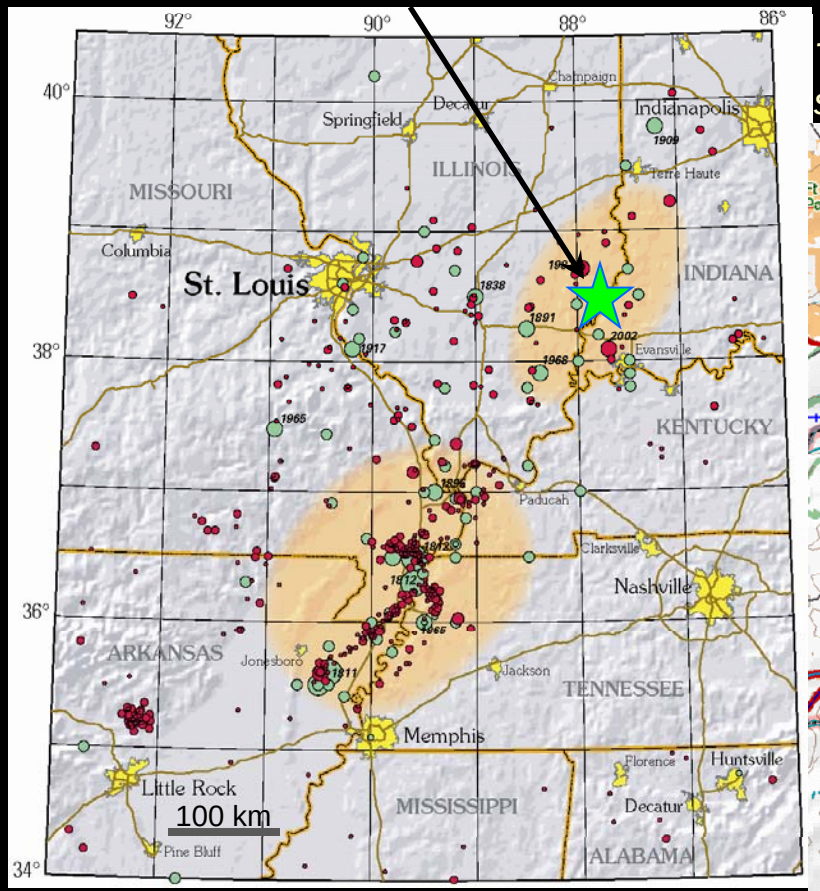
Topographic map showing earthquakes greater than magnitude 2.5 (circles) of the central United States. Red circles are earthquakes that occurred after 1972 (U.S. Geological Survey Preliminary Determination of Epicenters (PDE) catalog). Green circles are earthquakes that occurred before 1973 (USGS PDE and historical catalog). Larger earthquakes are represented by larger circles. Yellow patches show urban areas.

USGS

SLAEHMP

A look at earthquake ground motions in St. Louis:

M5.4 Mt. Carmel Earthquake epicenter–April 18, 2008



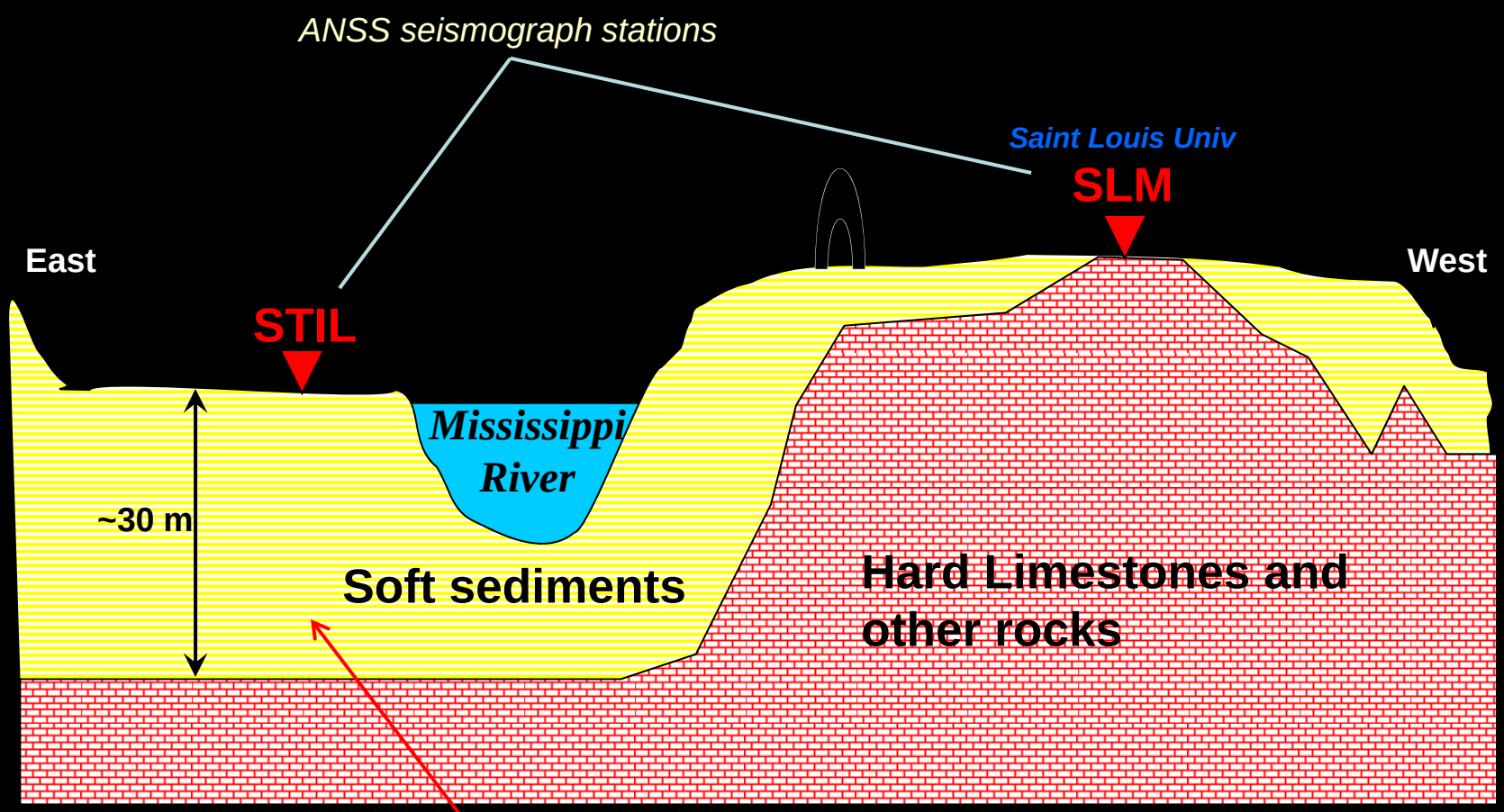
Earthquake travel time to St. Louis: ~30 seconds

The seven Advanced National Seismograph System (ANSS) stations in the St. Louis region

Figure from St. Louis University ANSS Web site information page:
http://www.eas.slu.edu/Earthquake_Center/ANSS/slmmap.html

USGS

Generalized site condition comparison for STIL and SLM



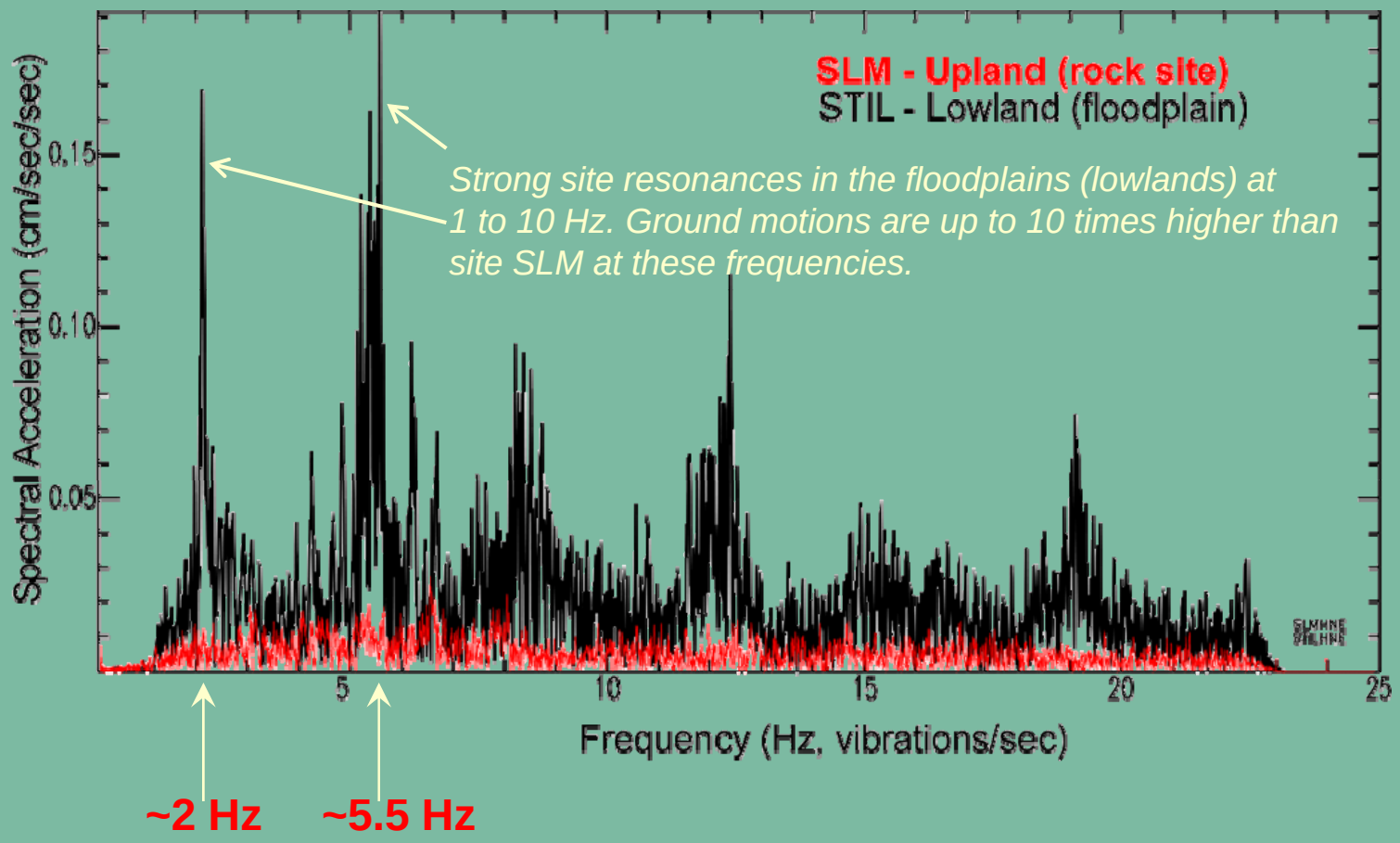
There is concern about the possibility of strong site resonances in the floodplains (lowlands) at 1 to 3 Hz.

USGS

SLAEHMP

M5.4 Mt. Carmel Spectra Comparison at STIL and SLM

These are so-called "weak" motion (low strain) responses; ground motion behavior will probably be different under stronger ground shaking.



USGS

SLAEHMP

Where are we headed?

- We are seeking to refine the geologic model and continue to collect and compile new data–especially through donated data and geologic mapping.
- A 2011 public release of St. Louis earthquake hazard and liquefaction-potential maps:
  - PGA, plus Probabalistic 1-sec and 0.2-sec Spectral Acceleration
- The 2011-12 New Madrid Earthquake Bicentennial
  Commemorated with scientific meetings and public events

Project data available at: http://earthquake.usgs.gov/regional/ceus/urban_map/st_louis/index.php

USGS

SLAEHMP

Chris Cramer

University of Memphis (CERI)

Time Histories and Hazard Model Updates for SLAEHMP

By Chris H. Cramer, CERI, U. of Memphis

An Overview Presentation at the

USGS NEHRP Workshop

October 29, 2009

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Center for Earthquake Research and Information

Database of ENA Time Histories

- M 5-6 < 50 km; M 7 ~200 km
- Time Histories from
  - ENA (M < 6)
  - Outside ENA (M 5-7; good signal up to 25 Hz)
  - Synthetic (Atkinson and Beresnev, 2002; SMSIM)
  - Spectrally Matched for ENA
- For soil amplification, the choice of time-history source had little effect within uncertainties.

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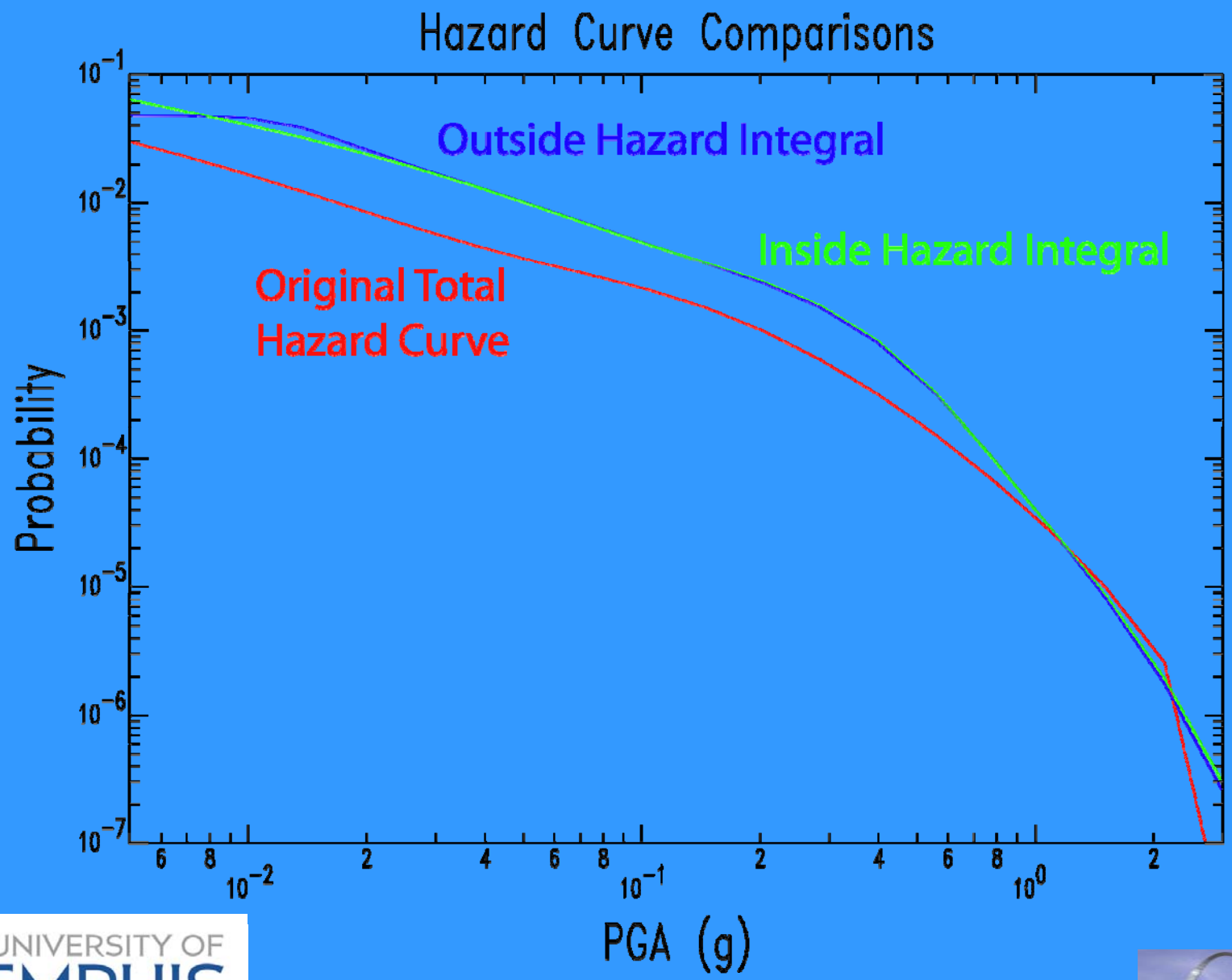
SLAEHMP

Model and Methodology Update

- Seismic Model Updated from USGS 2002 to USGS 2008 (some reduction in hazard).

- Modification for Effect of Local Geology moved from Inside the Hazard Integral to Outside (site amplification distribution is independent of magnitude and distance).



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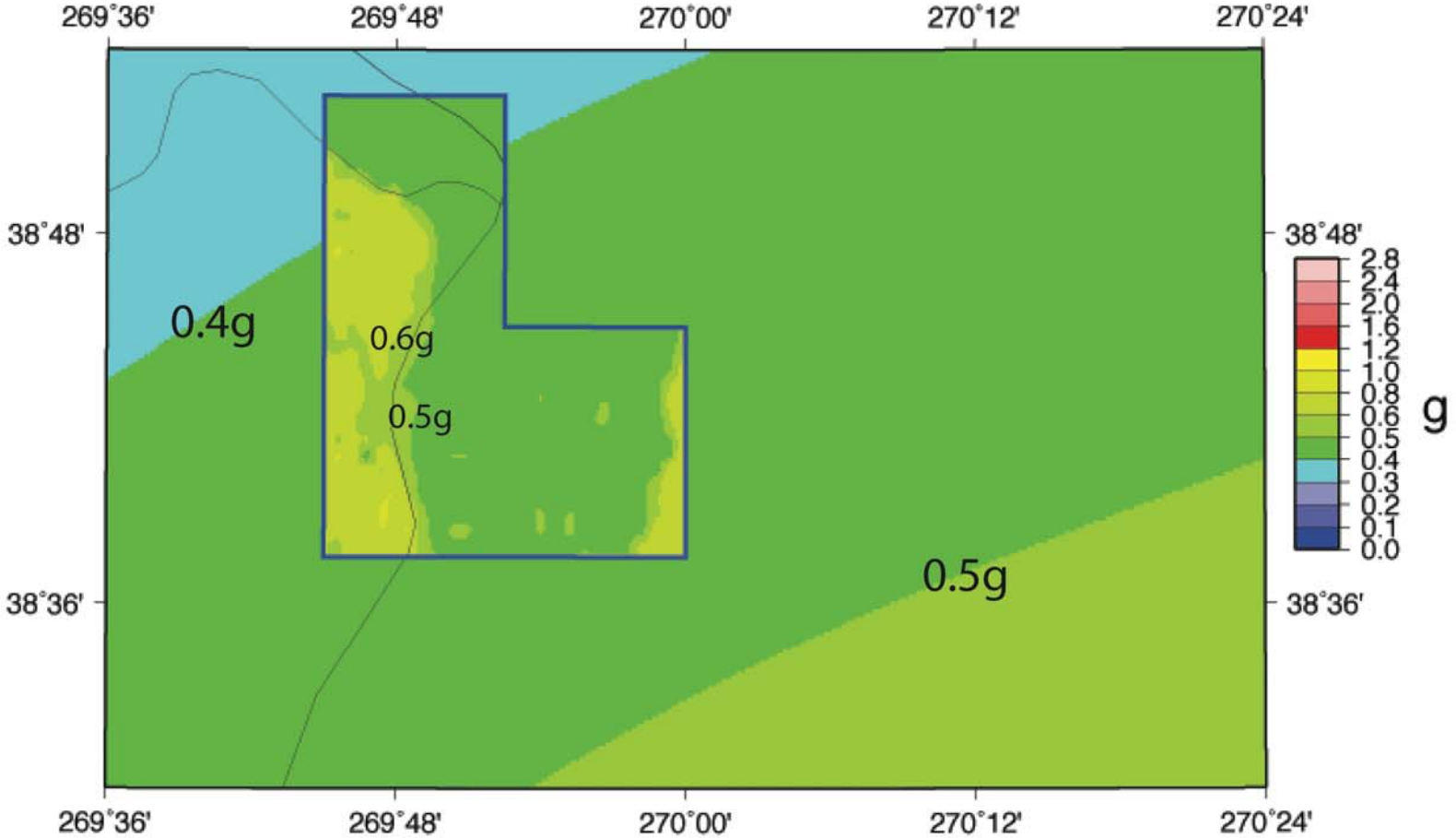
St. Louis Pilot 2008 0.2s Sa Hazard



2% in 50 year, Petersen et al., 2008

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Center for Earthquake Research and Information

Please see Posters!

Jae-Won Chung

Missouri University of Science and Technology

Geodatabase for Earthquake Hazards Mapping in the St. Louis Metro Area

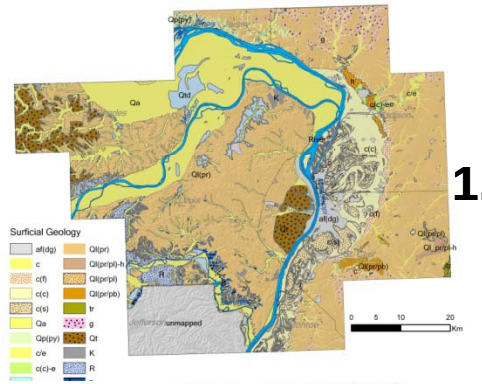
Jae-Won Chung and J. David Rogers

Geological Sciences and Engineering
Missouri University of Science & Technology

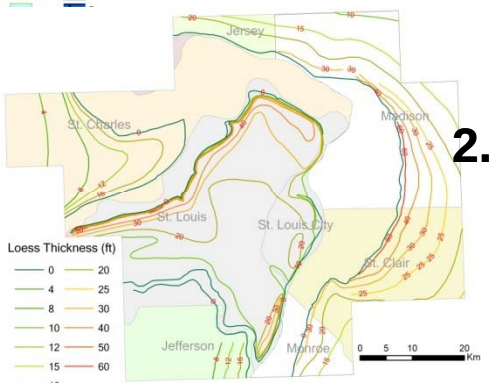
October 29, 2009

MISSOURI S&T MISSOURI UNIVERSITY OF SCIENCE AND TECHNOLOGY USGS

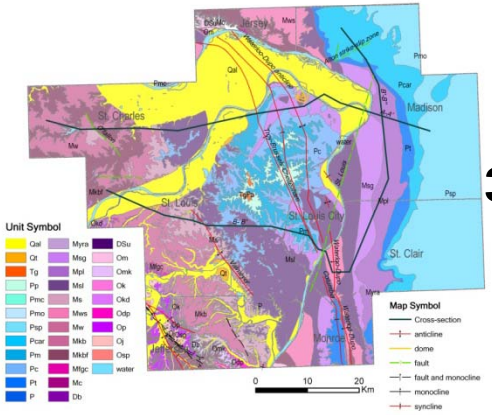
GIS Data Layers for the St. Louis Metro Area



1. Surficial Geology

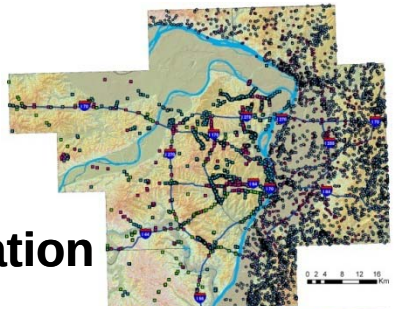


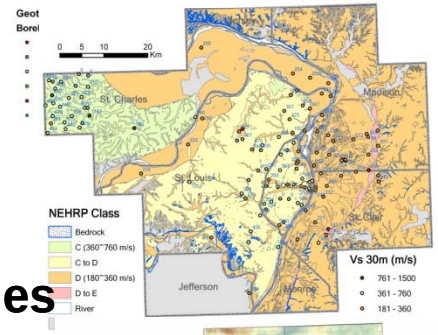
2. Loess Thickness



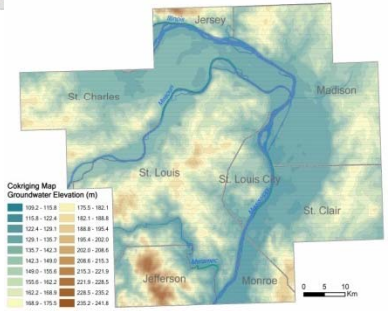
3. Bedrock Geology

4. Borehole Information

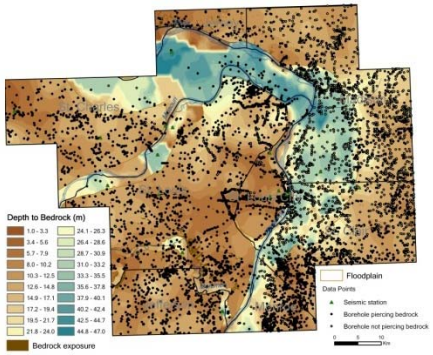




5. Shear Wave Velocities



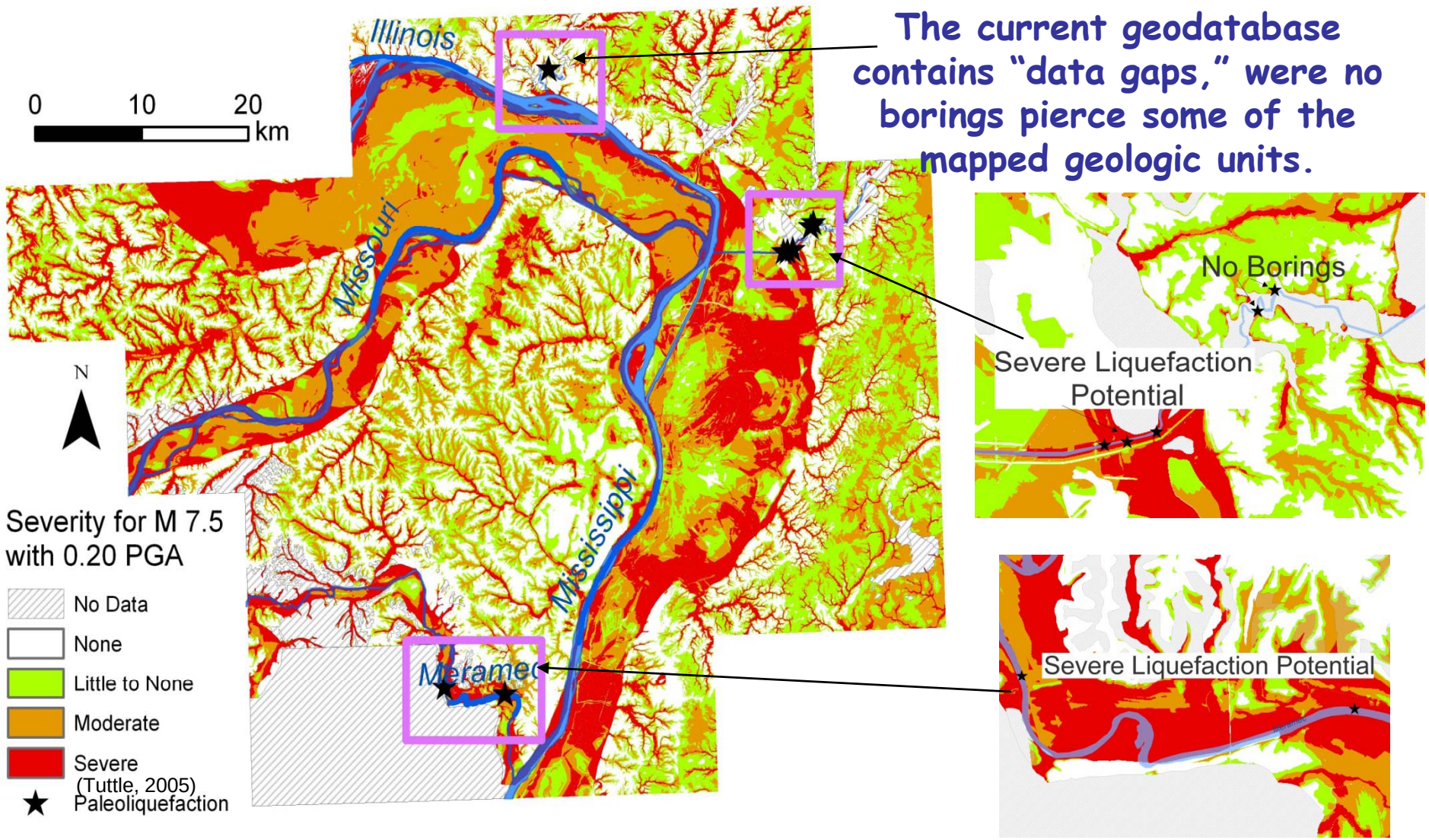
6. Groundwater Table



7. Depth-to-Bedrock

Sample Product of GIS-Geodatabase

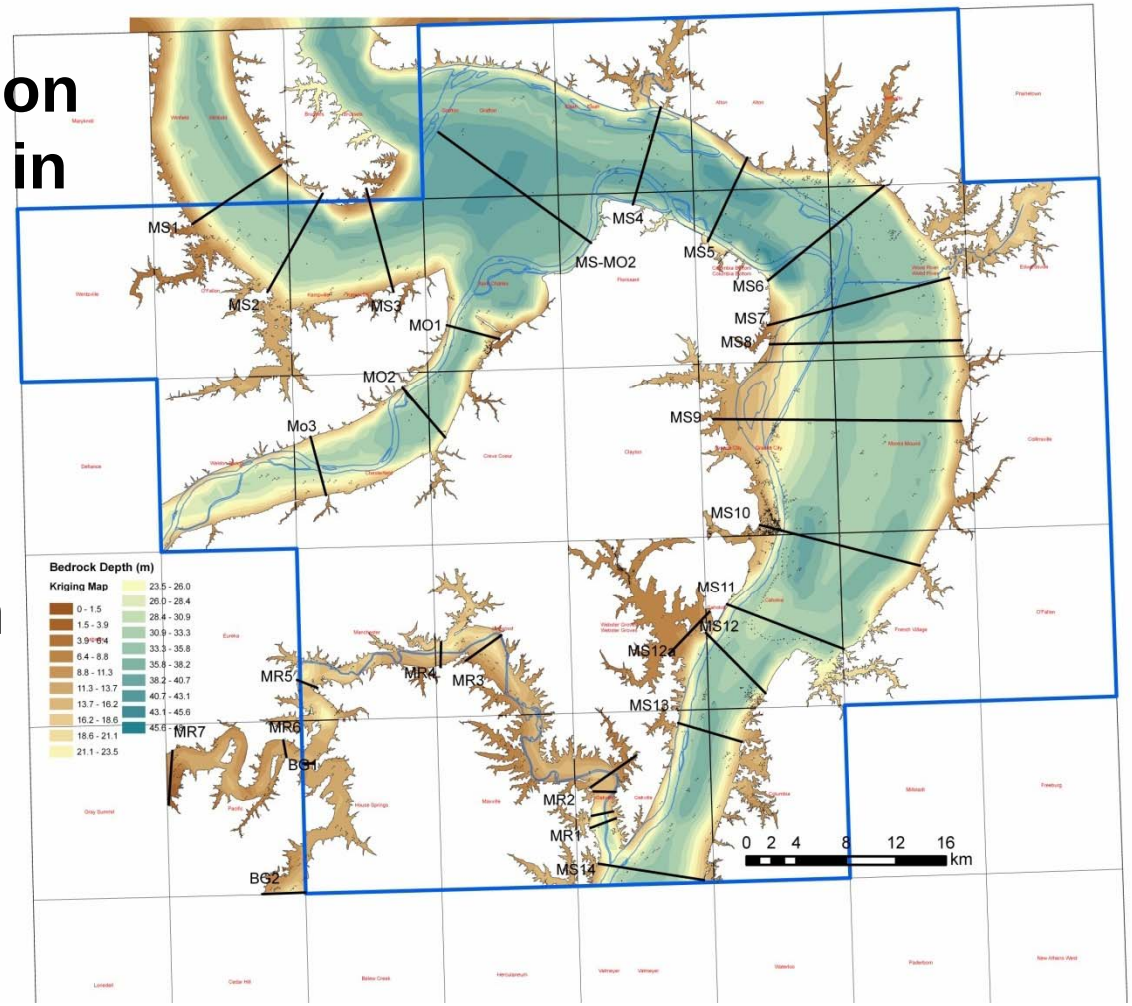
- Liquefaction Potential Map -



Future Plans

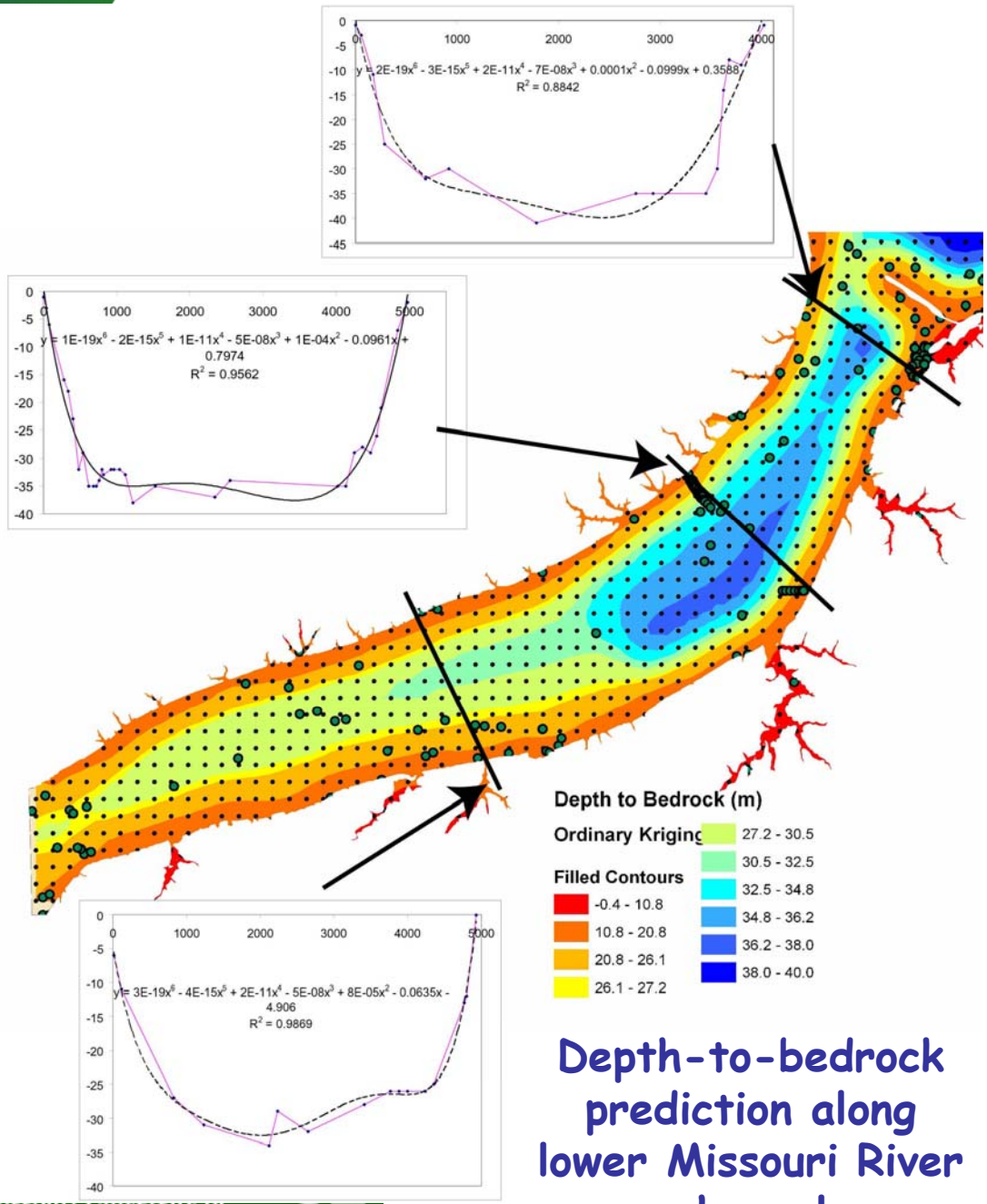
- **Publishing comprehensive article on "Geology of St. Louis" in AEG Geology of Cities volume**

- **Mapping Depth-to-Bedrock in the modern floodplains using statistical models**



Missouri University of Science and Technology

Estimating channel geometry



Depth-to-bedrock prediction along lower Missouri River channel

We hope to write a software subroutine to interpolate between adjacent 2D channel cross sections, to estimate the 3D surface between adjacent cross sections. The predicted 3D bedrock surface between adjacent cross sections will be generated on 250m grid spacings, to allow construction of isopleths defining the contact between the alluvium and the underlying bedrock. This adjustment allows a more realistic prediction of the "average" depth-to-bedrock.

Conor Watkins

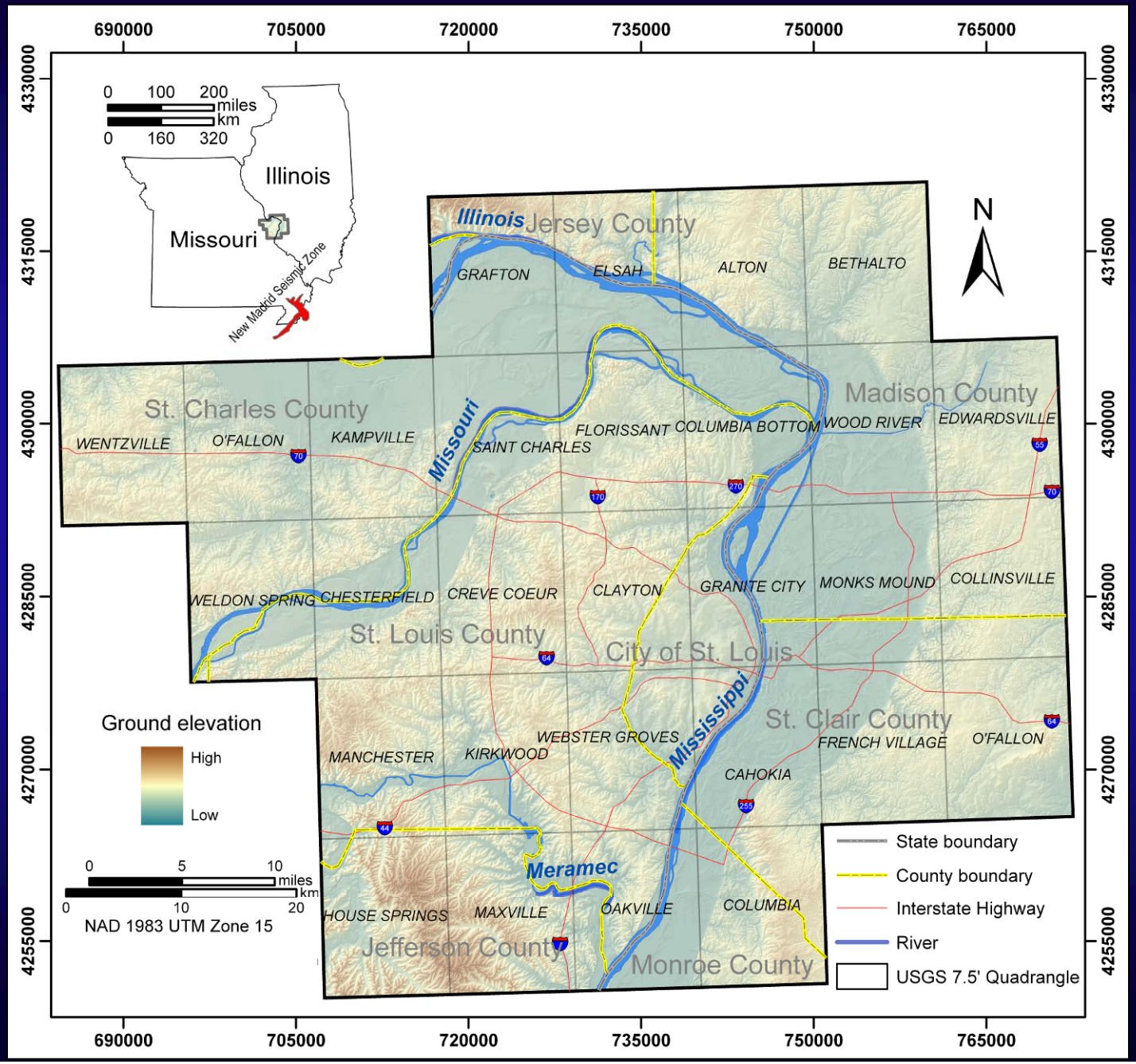
US Geological Survey

Status of Data Collection for the St. Louis Earthquake Hazards Mapping Project in 2009

Conor Watkins
USGS Mid-Continent Geographic Science Center
Rolla, MO 65401
October 28-29, 2009

U.S. Department of the Interior
U.S. Geological Survey

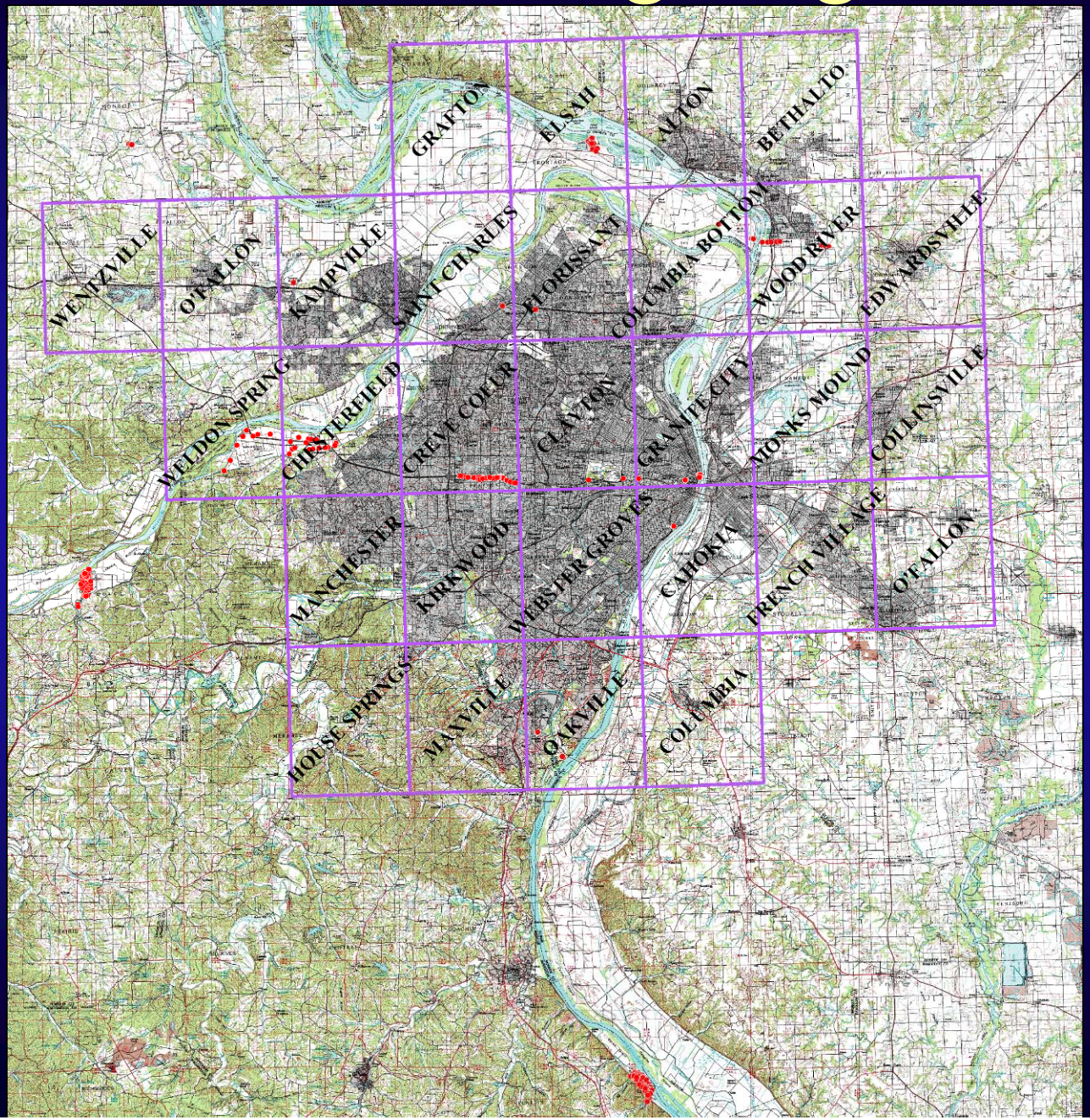
29 7.5 Minute Quadrangle Project Area Extent



Subsurface Information

Subsurface and geospatial data were collected throughout the St. Louis Earthquake Hazards Mapping Project (SLEAHMP) area and distributed to project partners. Collection of subsurface data including borehole logs and geophysical data from private and public sources focused on areas of data gaps, such as those in the vicinity of the confluence of the Missouri and Mississippi Rivers, the lower Meramec River, and urban areas developed prior to large scale collection of subsurface information. For example, the Missouri Department of Natural Resources has collected subsurface borehole and geophysical data in the vicinity of the confluence of the Missouri and Mississippi Rivers, which suggests that buried bedrock river channels occur at depths of up to 60 meters below the ground surface in parts of northeastern St. Charles County.

New Boring Logs

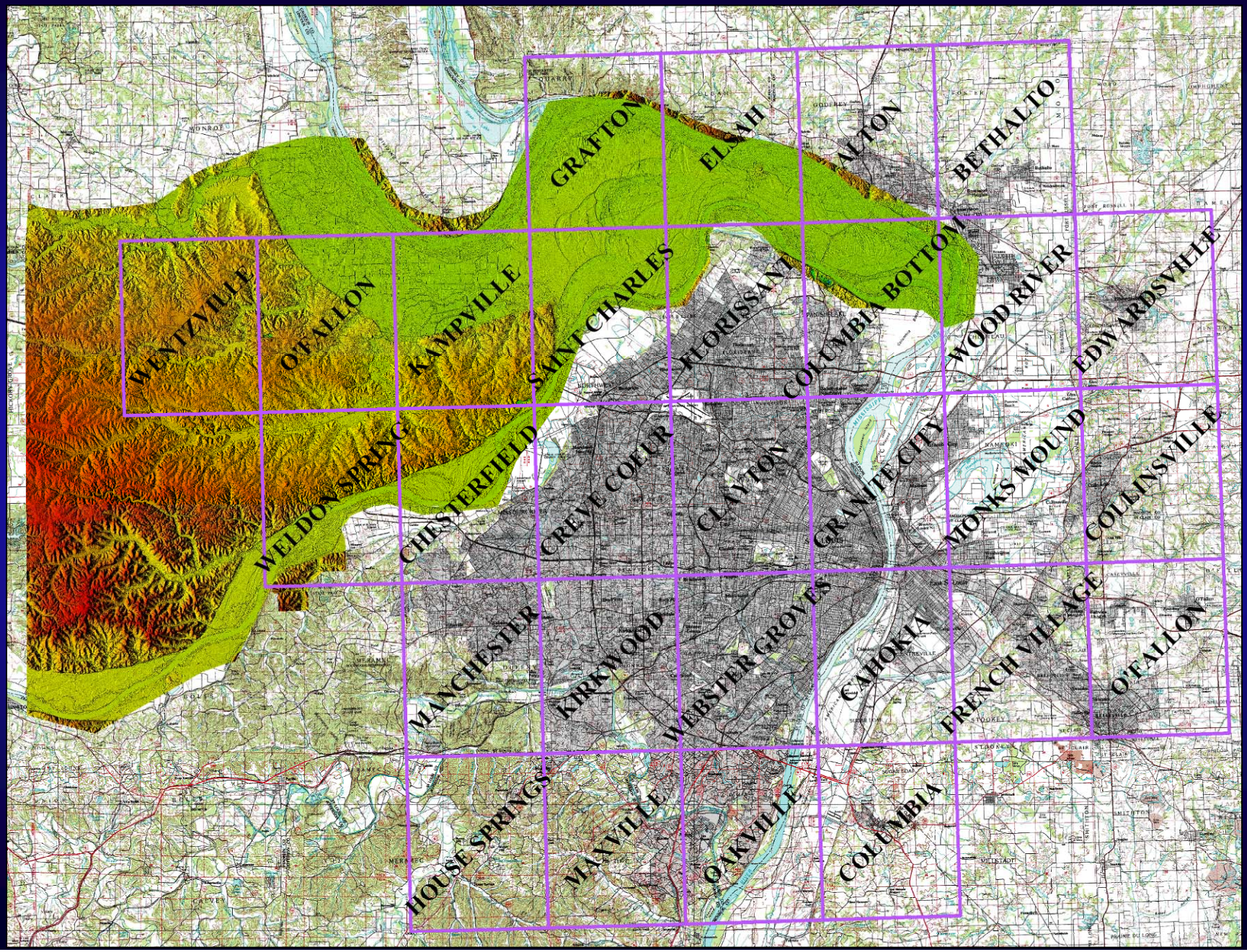


St. Charles County 1m LiDAR Data

The Missouri State Emergency Management Agency (SEMA) provided a 1 meter LiDAR dataset of St. Charles County, Missouri, flown in 2008, covering the northern and western portions of the project area including the confluence of the Missouri and Mississippi Rivers. This dataset extends a few kilometers into Illinois, providing valuable information in the vicinity of Alton and Wood River, Illinois.

USGS

St. Charles County, Missouri 1 meter LiDAR



NGA 133 Urban Areas Imagery

National Geospatial Agency (NGA) 133 Urban Areas Project images with a resolution of 0.3 meters covering the St. Louis metropolitan area for years 2004, 2006, and 2008 were acquired for use by SLEAHMP partners. These images cover the majority of the SLEAHMP project area. The NGA plans to collect imagery with a 0.15 meter spatial resolution in 2010.

133 Urban Areas Imagery – St. Louis

Youssef Hashash

University of Illinois Champaign-Urbana

Conditional mean spectra as a bridge between probabilistic and deterministic seismic hazard assessment

Youssef M. A. Hashash , Scott Olson and

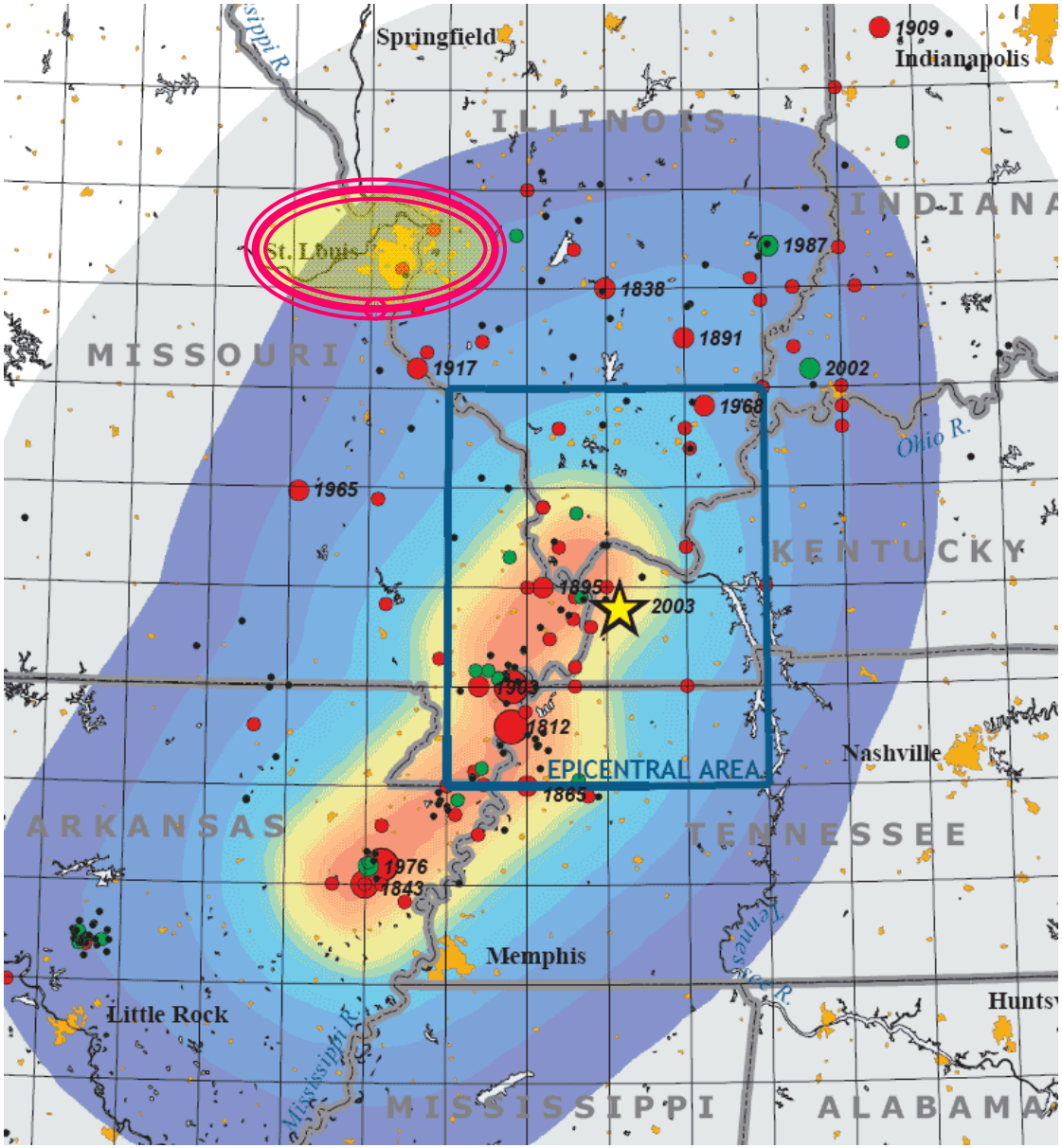
Department of Civil and Environmental Engineering
University of Illinois at Urbana-Champaign

and Norm Abrahamson

CEUS Earthquake Hazard Meeting, Memphis, TN

October 29, 2009

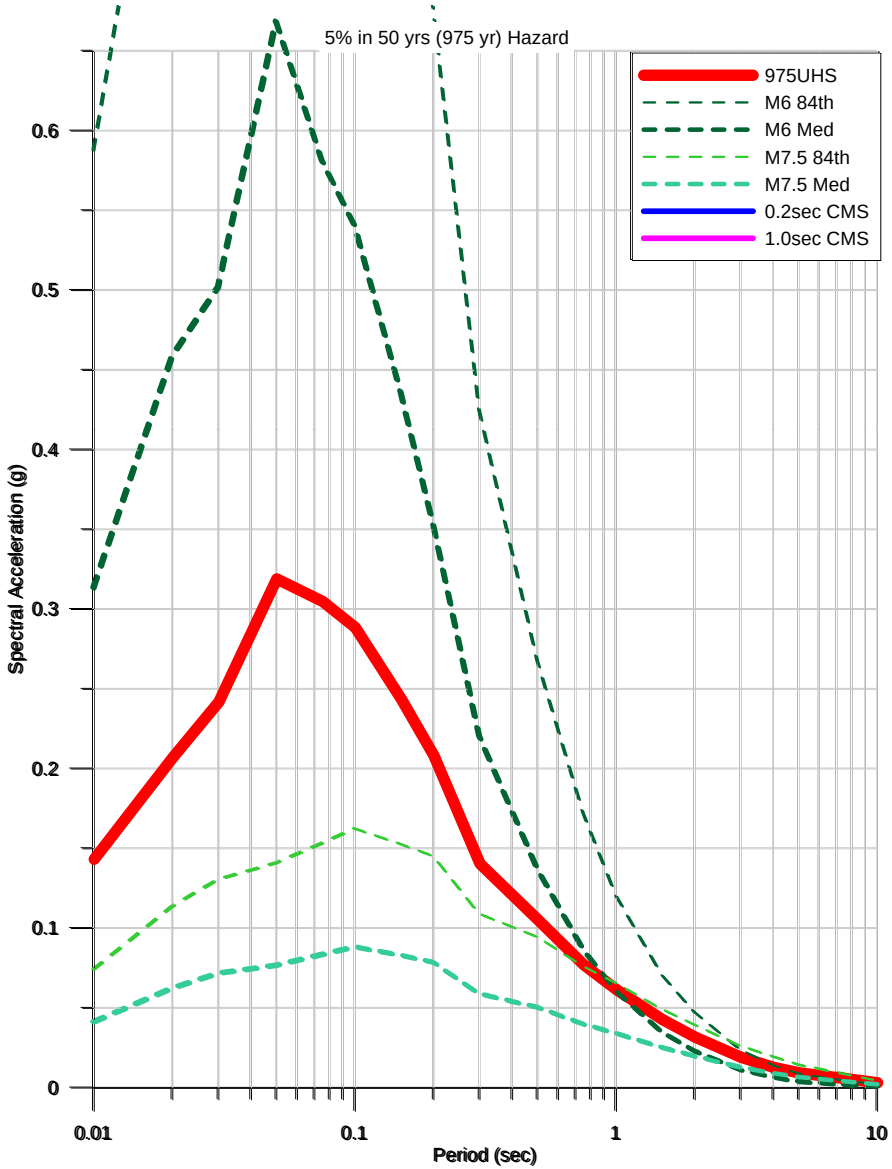
Hazard at some distance- NMSZ

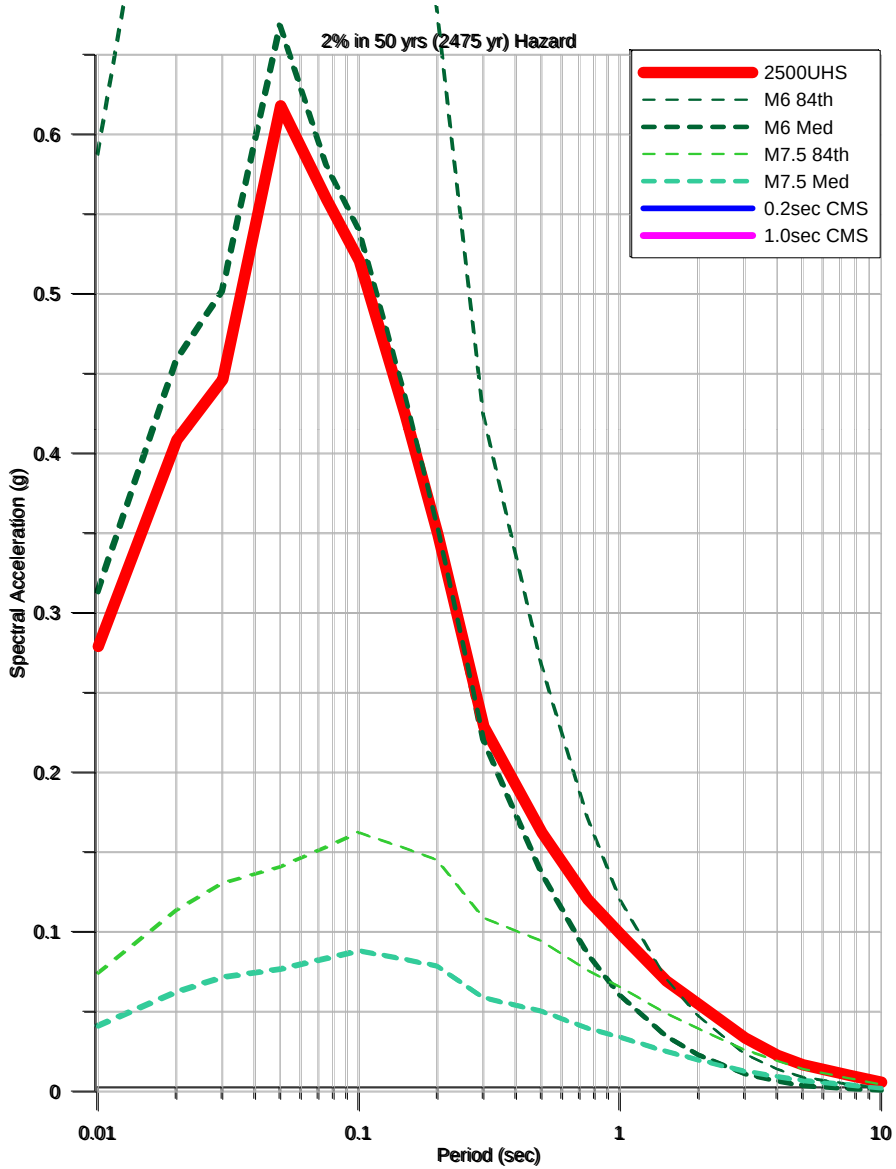


USGS

Deterministic Seismic Hazard Analysis

Bi-modal hazard reconcile with PSHA?



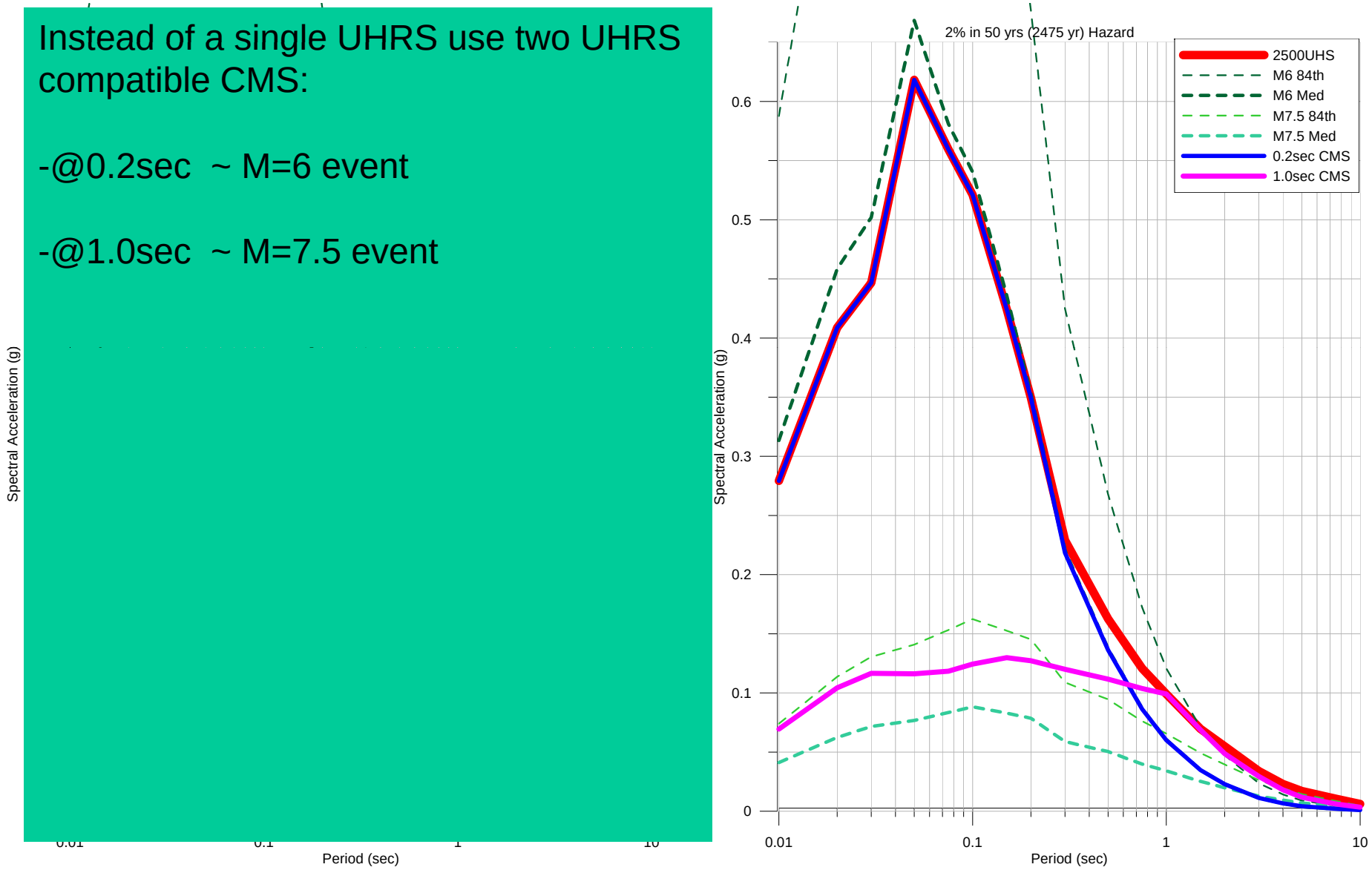


Conditional Mean Spectra for St. Louis

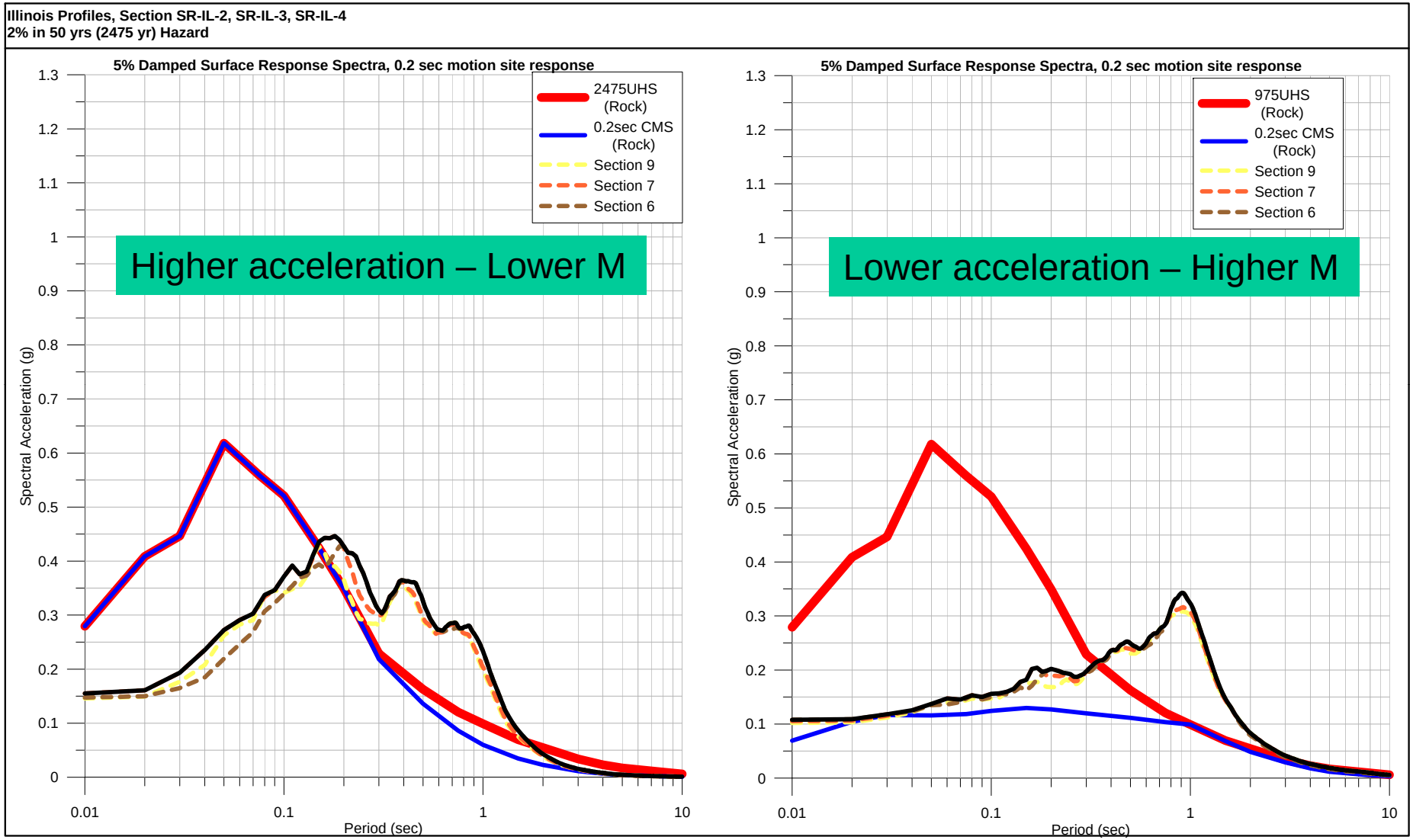
Instead of a single UHRS use two UHRS compatible CMS:

-@0.2sec ~ M=6 event

-@1.0sec ~ M=7.5 event



Site response for deep sections



Implication => very limited liquefaction v.s. extensive liquefaction without CMS

Nicolas Luco

US Geological Survey

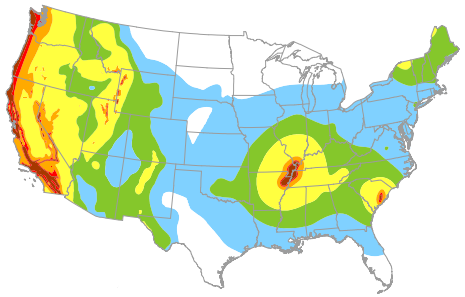
New Seismic Design Maps and Associated Web Products for the 2012 IBC and IRC

Nicolas Luco (& Charlie Kircher, Andrew Whittaker)
Research Structural Engineer
National Seismic Hazard Mapping Project
Golden, Colorado

U.S. Department of the Interior
U.S. Geological Survey

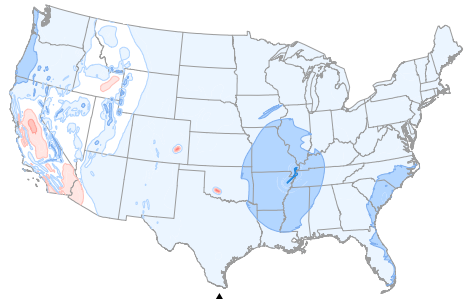
29 October 2009

Hazard Map (2%-in-50yrs P.E.)



×

Risk Coefficient Map



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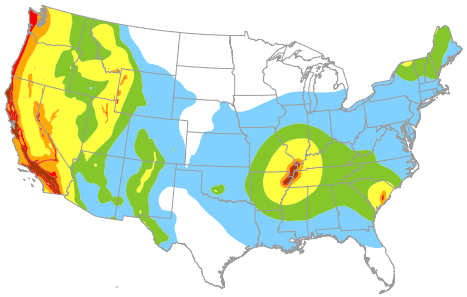
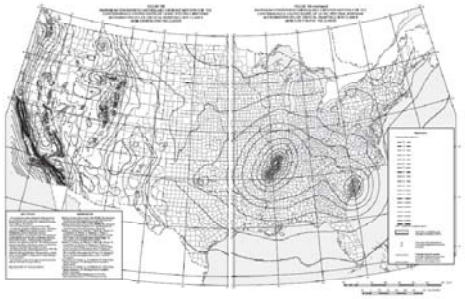
Risk-Targeted Map (1%-in-50yrs P.C.)



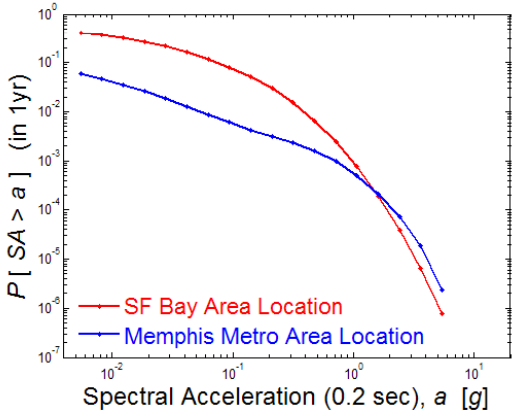
Deterministic Map

(min)

MCE Map (≤'09 IBC)



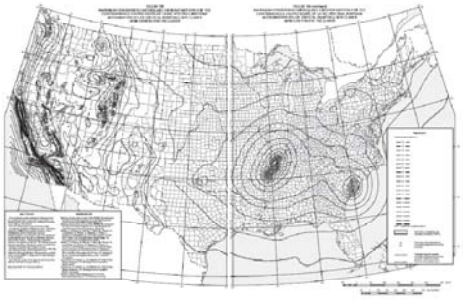
Hazard Curves



Deterministic Map

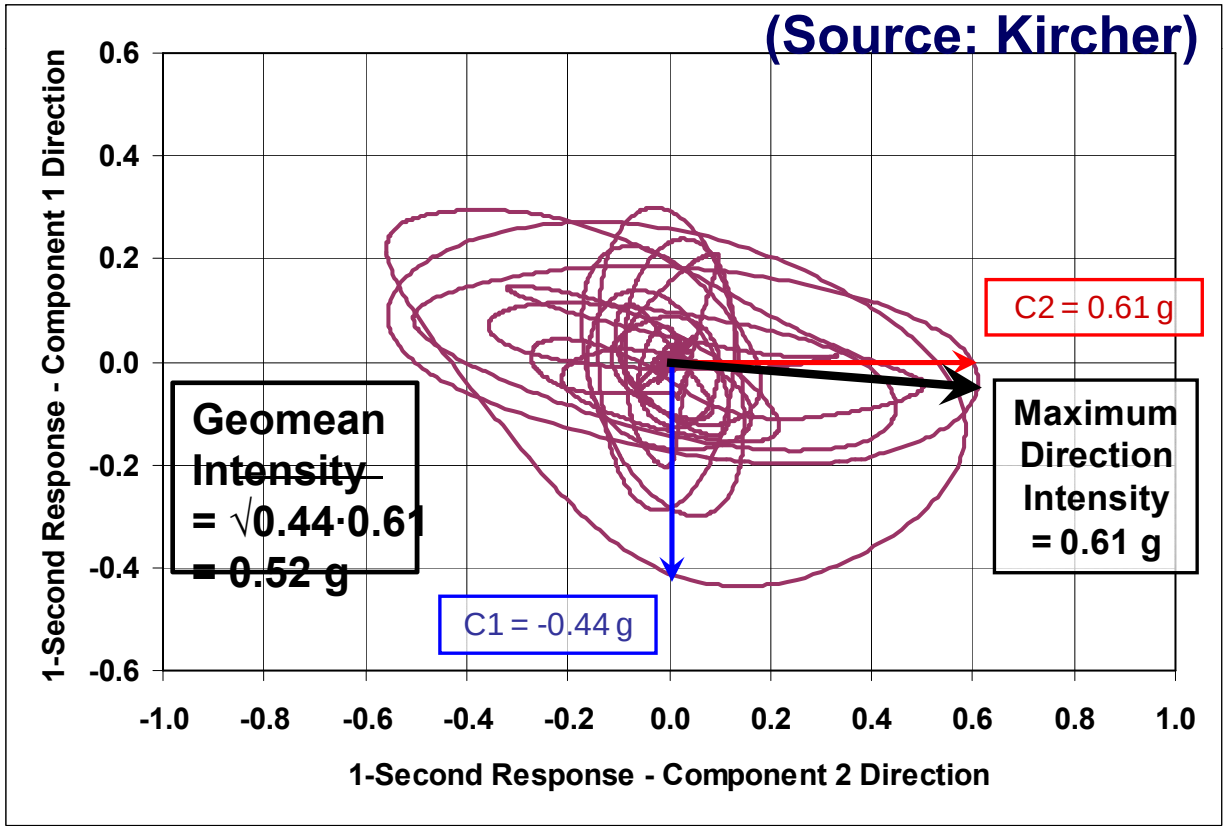
(min)

MCE_R Map ('12 IBC)



2nd Change to Design Map Derivation

- New design maps use hazard curves for max-direction rather than geometric-mean S_a, est. via factors of 1.1 & 1.3 for 0.2 & 1.0 sec



3rd Change to Design Map Derivation

- **Deterministic S_a values are 84th-percentile (est. as 1.8*median) rather than 1.5*median, but still no less than 1.5 & 0.6 g for 0.2 & 1 sec**

$$\text{Det. GM} = \max(\underline{1.1} \text{ x } 1.8 \text{ x Med. GM}, \underline{1.5}g) \text{ for } \underline{0.2}\text{s}$$

$$\text{Det. GM} = \max(\underline{1.3} \text{ x } 1.8 \text{ x Med. GM}, \underline{0.6}g) \text{ for } \underline{1.0}\text{s}$$

Preparation of Seismic Design Maps for Codes [DL-NGA01-NL] - $45.00 : EERI - Windows Internet Explorer

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Preparation of Seismic Design Maps for Codes $45.00

[DL-NGA01-NL]

Presented by:
Nicolas Luco, Research Structural Engineer
USGS, Golden, Colorado

Click to enlarge

About this Seminar Series

Next Generation Attenuation (NGA) Models
This seminar informs structural and geotechnical engineers about the implications for engineering practice of the recently developed next generation attenuation (NGA) models. Significant changes are coming to the USGS Hazard Maps and Seismic Design Maps that are part of the ASCE 7 and IBC design process. These changes need to be understood by geotechnical, seismological, and structural engineers; not only will they impact site-specific studies, but they will also become a part of the 2010 ASCE 7 and 2012 IBC design provisions. This seminar provides the background and basis for the NGA models and how they impact the new USGS Hazard Maps. It also summarizes the technical basis of the three major changes to Seismic Design Maps. It provides examples of applications of the new NGA models.

The NGA models that are now incorporated in the new USGS Hazard Maps were developed by the Pacific Earthquake Engineering Research (PEER) Center over a five-year period to update the ground motion predictive equations for shallow crustal earthquakes in the western United States and similar active tectonic regions. The expansion of the strong motion database

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Preparation of New Seismic Design Maps for Building Codes

EERI Seminar on Next Generation Attenuation Models

Nicolas Luco, Research Structural Engineer

USGS, Golden, Colorado

USGS science for a changing world · FEMA · Building Seismic Safety Council · ASCE · EERI

Google "EERI NGA Seminar Presentations"
or email nluco@usgs.gov for PowerPoint alone

Phillis Steckel

Independent

The New Madrid Field Trip Guidebook

Phyllis Steckel, RG
Earthquake Insight LLC
Washington, Mo.

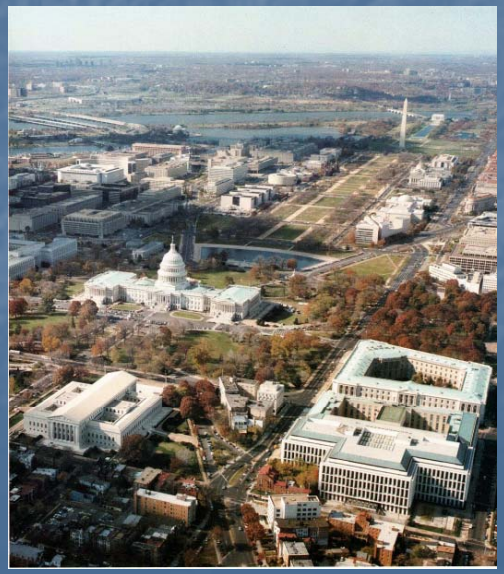
The Earthquake Trail

Field Trip Guidebooks – USGS Publications

- "Recycled" ***Earthquake Insight Field Trip*** stops
- Business/Private sector
- 60-100 stops
- St. Louis to Memphis
- Earthquake features, EQ hazards, historic sites, EQ engineering projects, vulnerable infrastructure

The Earthquake Trail

Field Sites – Feasibility Study



- St. Louis
- *New Madrid Historical Museum*
- New Madrid I-55 Rest Stop & Info Center
- Blytheville area
- Memphis
- Washington DC

Target Audiences

- USGS Publications
  - Geoscientists
  - Educators
  - Elected & community leaders
  - Engineers
  - Historians
  - Hobbyists
  - Media
- Field Sites
  - General public
  - Educators
  - Business leaders
  - Elected & community leaders
  - Congressional staffers
  - Lobbyists
  - Media

Gary Patterson

University of Memphis (CERI)

The Public Earthquake Resource Center at CERI

A system for the development and transfer of non-technical and technical information related to earthquake research, earthquake hazards, Earth Science, and earthquake engineering.

Focus areas:

•Host K-16 tour groups, teacher workshops, and civic groups

•☐Provide technical information and support for professional development and training for engineers and emergency managers

*Develop, support, and implement earthquake awareness and mitigation programs (West TN EQ AWARE)

•Develop and maintain rapid earthquake information tools for emergency managers and public information officers in the Central US

•Develop public information products to promote Earth Science and earthquake hazard research (displays, videos, animations, public service announcements, presentations, etc.)

•Support media response to CEUS earthquakes and research

•Technical advice for emergency management scenarios and building codes

•Coordinate CERI E and O efforts with major science organizations and facilities

More than just a cool place for kids to visit….

…….a system of partnerships

West Tennessee Seismic Safety Commission

USGS science for a changing world

The University of Memphis Center for Earthquake Research and Information

Emergency Management Association of Tennessee

Mid-America Earthquake Center
Headquartered at the University of Illinois at Urbana-Champaign

nehrp National Earthquake Hazards Reduction Program

Tennessee Homeland Security

MLGW Hometown Energy Working for You

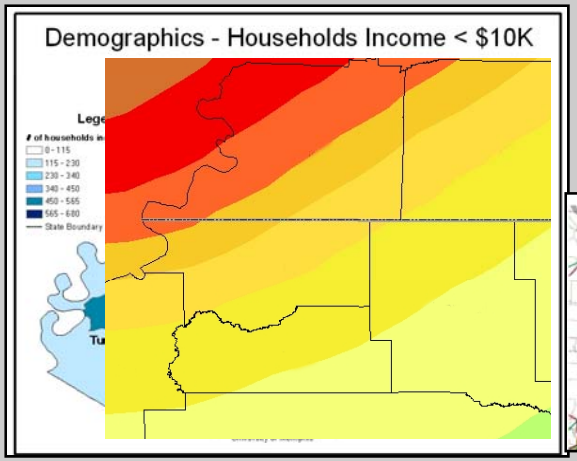
NGO's

Academia

State and federal agencies

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

…..to develop and distribute products that address specific needs and audiences



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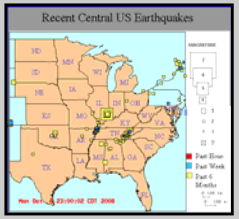

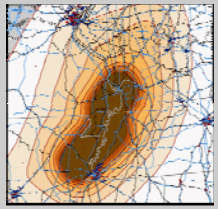

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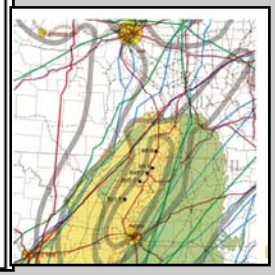
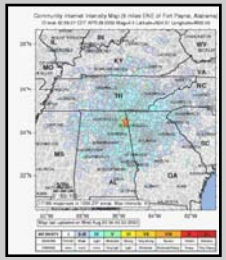
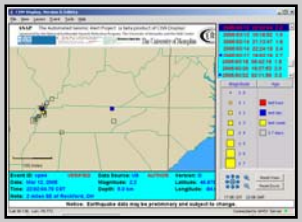




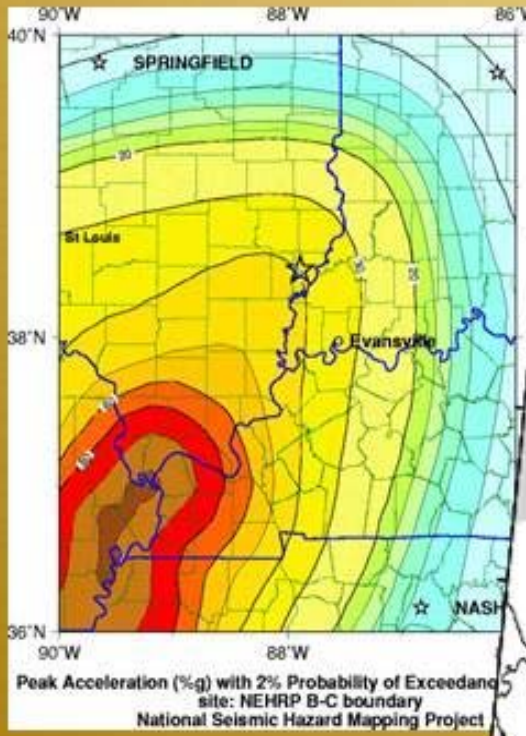


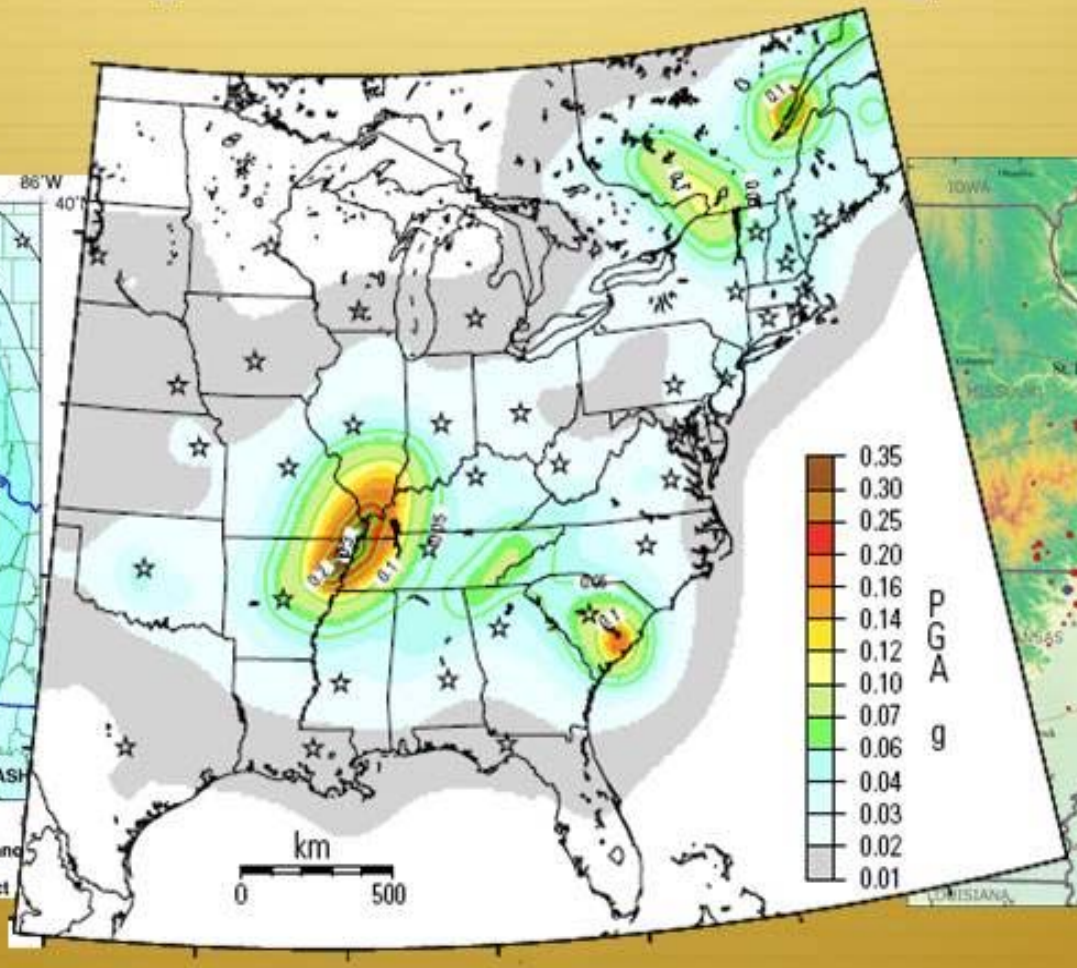
Current PERC/USGS efforts

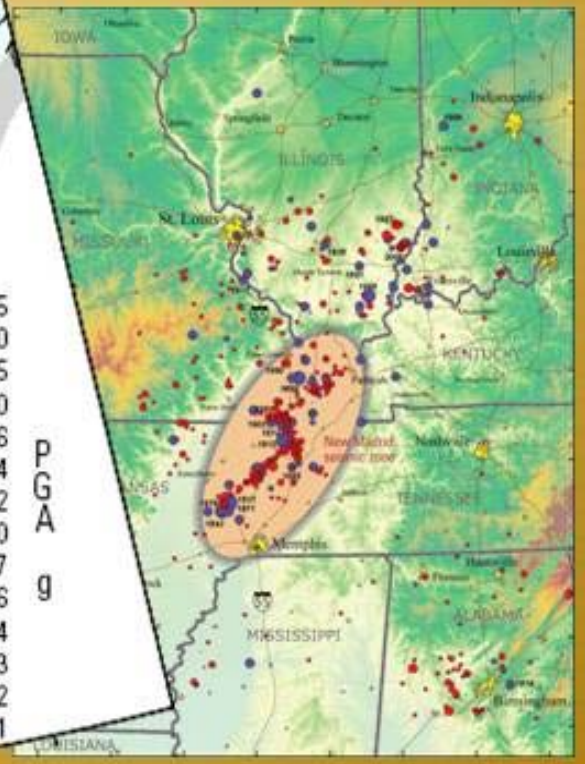
- Develop a framework of projects to promote the major science and awareness opportunities that arise from EarthScope and the Bicentennial in the Central US.
  - Develop a scientifically appropriate New Madrid documentary based on a “Hidden Fury” story line
  - Develop videos for distribution on the Web and PSA’s for regional distribution
  - Develop and new public display area at CERI
  - Support SSA and NEC meeting planning and NLE activities
  - Support awareness and distribution of USGS products (Rover, Pager, etc)
  - Promote earthquake drills in schools
  - Organize business continuity planning meetings
  - Support EarthScope deployment and station adoption

THANK YOU

Meeting of Central and Eastern U.S. (CEUS) Earthquake Hazards Program







October 28-29, 2009 USGS Memphis, TN