Earthquake Hazards in the Central and Eastern U.S.

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Earthquake Hazards Program

U. S. Geological Survey

Reston, VA

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Main Points

- Central U.S. seismic zones: Faults and Earthquake history.
- Earthquakes in central and eastern U.S. affect a much larger area than western U.S. earthquakes.
- Shallow deposits can amplify ground shaking and cause liquefaction.
- Impacts of a large central U.S. earthquake (analog, Christchurch, NZ).
- USGS products for monitoring earthquakes and mitigating damage.

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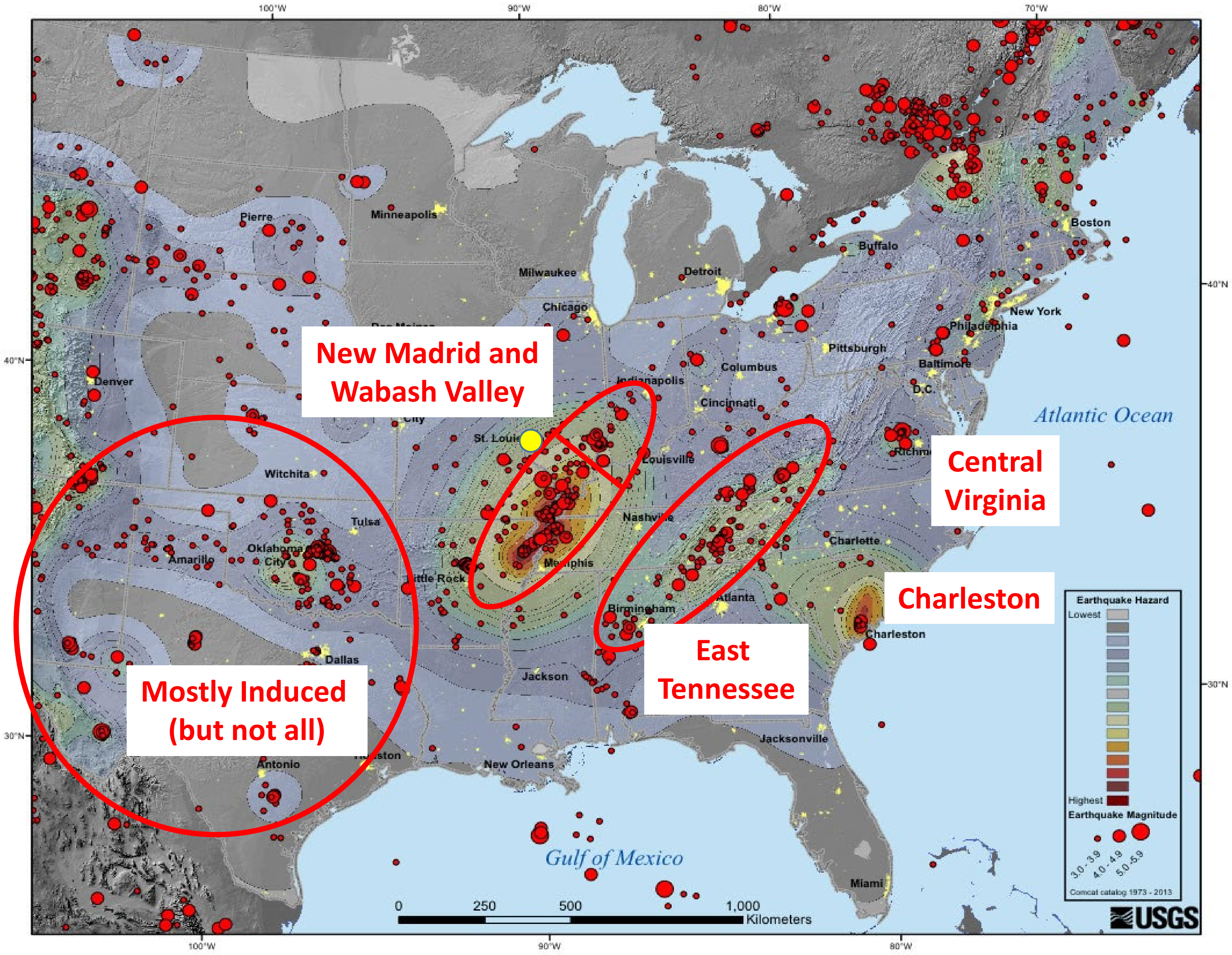
15 largest earthquakes in the continental United States (outside of Alaska)
(They're not just in California!)

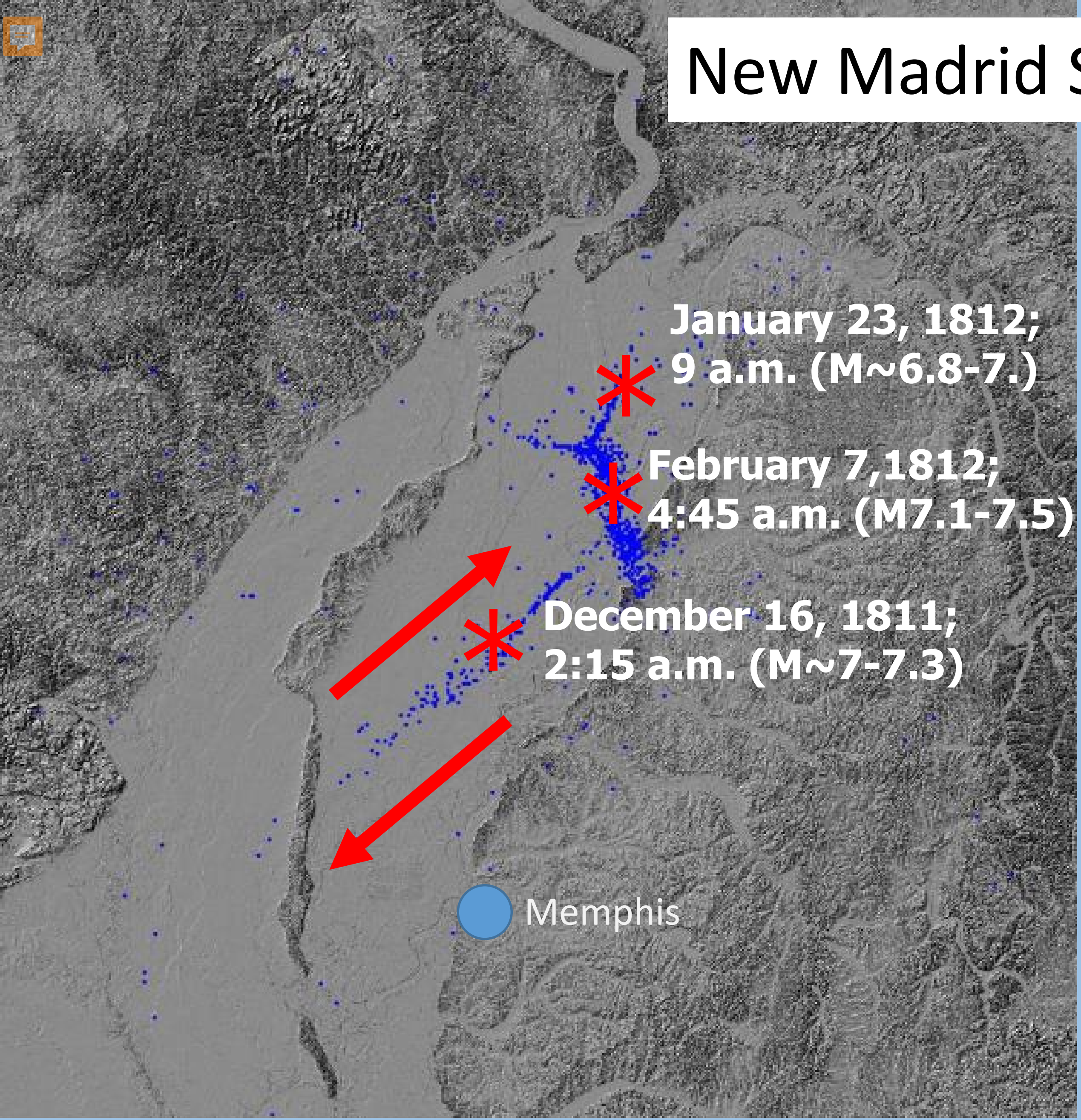
Rank	Magnitude	Date	Location
1	~9	Jan. 26, 1700	Cascadia Subduction Zone
2	7.9	Jan. 9, 1857	Fort Tejon, California
3	7.7	April 18, 1906	San Francisco, California
4	7.8	Feb. 24, 1892	Imperial Valley, California
5	**7.5**	**Dec. 16, 1811**	**New Madrid, Missouri**
6	**7.5**	**Feb. 7, 1812**	**New Madrid, Missouri**
7	7.4	Mar 26, 1872	Owens Valley, California
8	**7.3**	**Jan. 23, 1812**	**New Madrid, Missouri**
9	7.3	June 28, 1992	Landers, California
10	7.3	Aug. 19, 1959	Hebgen Lake, Montana
11	7.3	July 21, 1952	Kern County, California
12	7.3	Jan. 31, 1922	Offshore Eureka, California
13	**7.3**	**Aug. 31, 1886**	**Charleston, South Carolina**
14	7.3	Nov. 23, 1873	Oregon-California border
15	7.3	Dec. 15, 1872	N Cascades, Washington

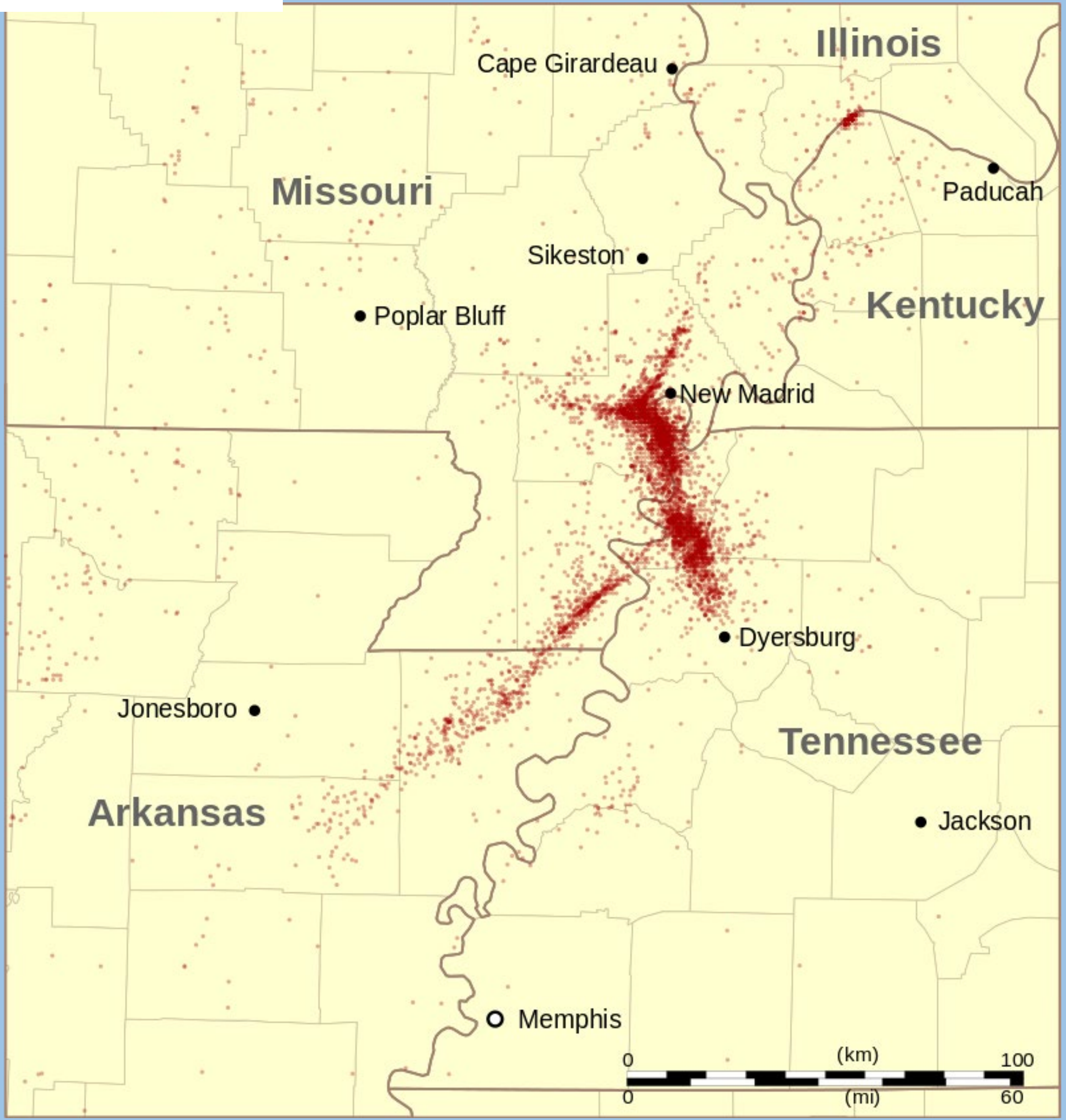
Seismic zones in the central and eastern U.S., plotted on top of the National Seismic Hazard Model

But: Notice the scattered seismicity throughout the region



New Madrid Seismic Zone





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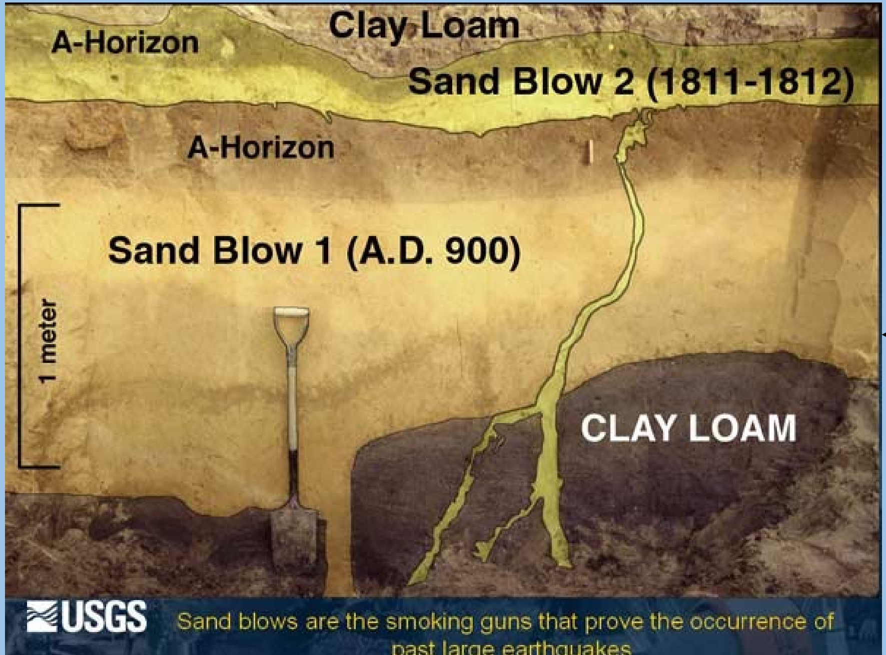
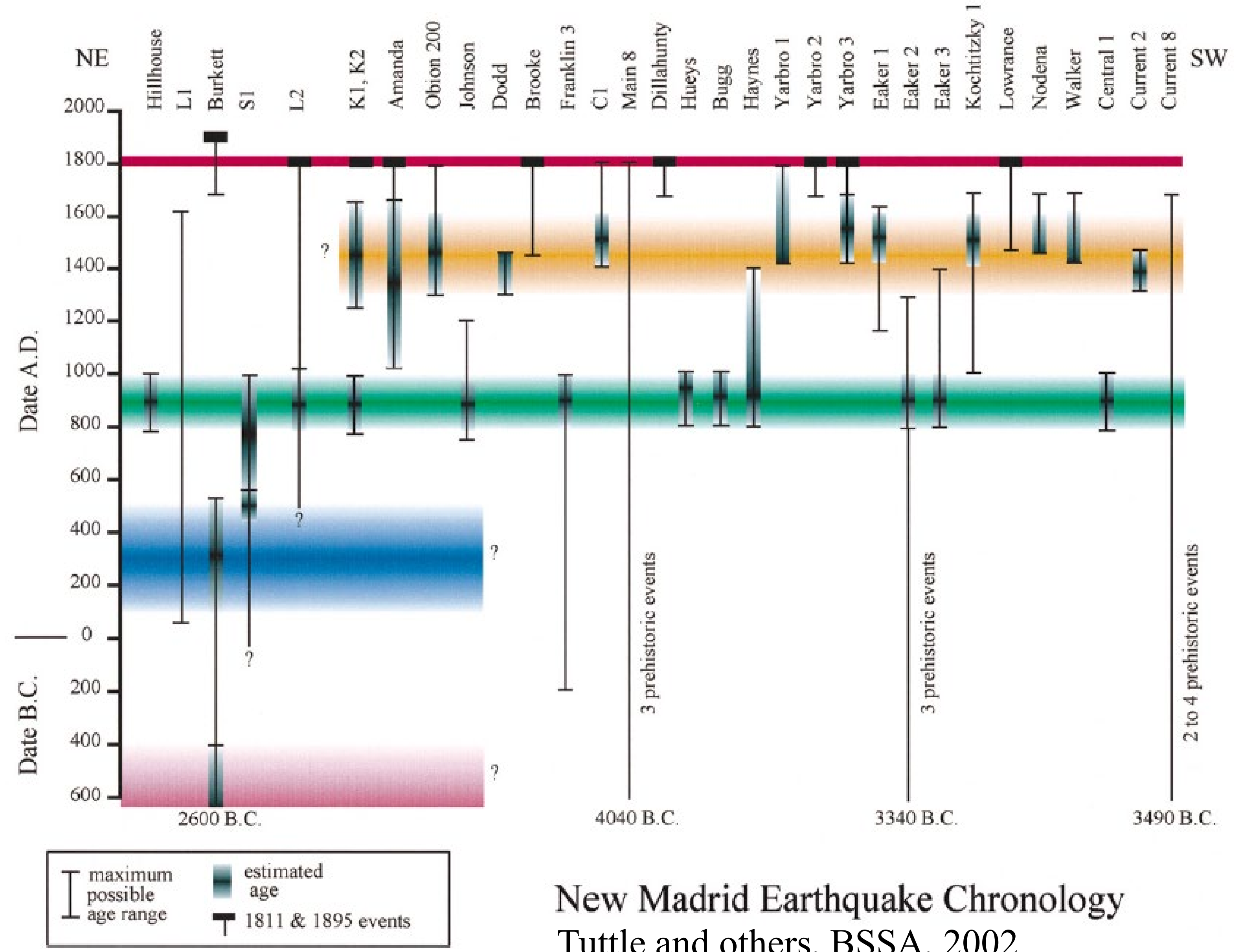


Tuttle and others, 2019, Paleoliquefaction Studies and the evaluation of seismic hazard, Geosciences, v. 9 p. 311.

History of New Madrid earthquakes from paleoseismic studies: 1811/1812, about A.D. 1500, about A.D. 900, perhaps earlier



New Madrid Earthquake Chronology

Tuttle and others, BSSA, 2002

Probabilities of Large New Madrid Earthquakes in the Next 50 Years

- **Magnitude ~ 7.5**
  (similar to 1811-1812 earthquakes)
  - Approximately 7-10%

- **Magnitude 6.0 or greater**
  (such as the 1843 Marked Tree, AR and 1895 Charleston, MO earthquakes)
  - Approximately 25-40%

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Fault scarps when earthquakes reach the near-surface

1999, Chi-Chi, Taiwan

https://research.engineering.ucdavis.edu/gpa/earthquake-hazards/surface-rupture-taiwan/

Seattle, WA

photo by Thomas Pratt, USGS

Santa Monica, CA

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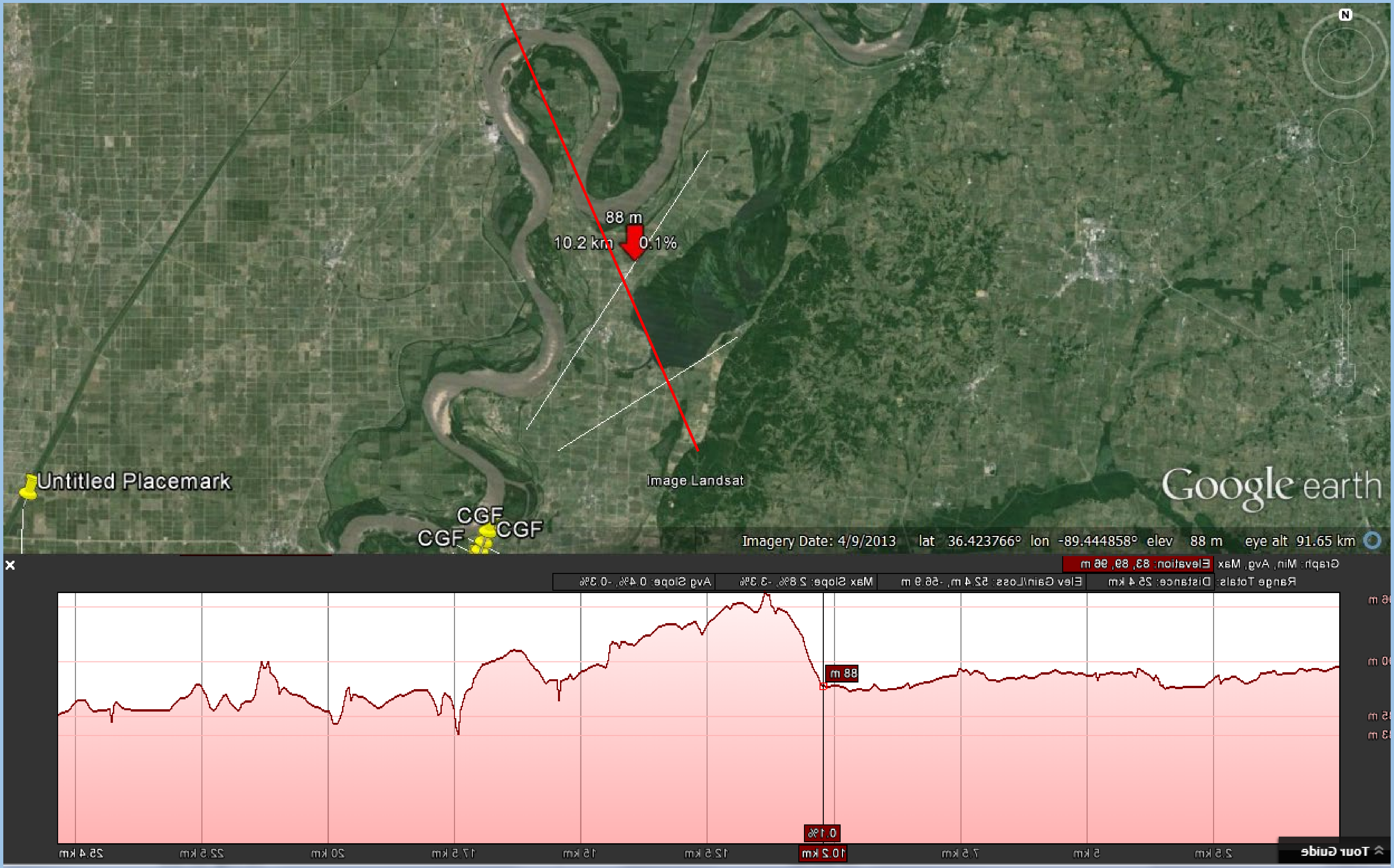
Reelfoot scarp – looks like a levee!

Photos by Thomas Pratt, USGS

Reelfoot scarp is evident on Google Earth, between Reelfoot Lake and the Mississippi River



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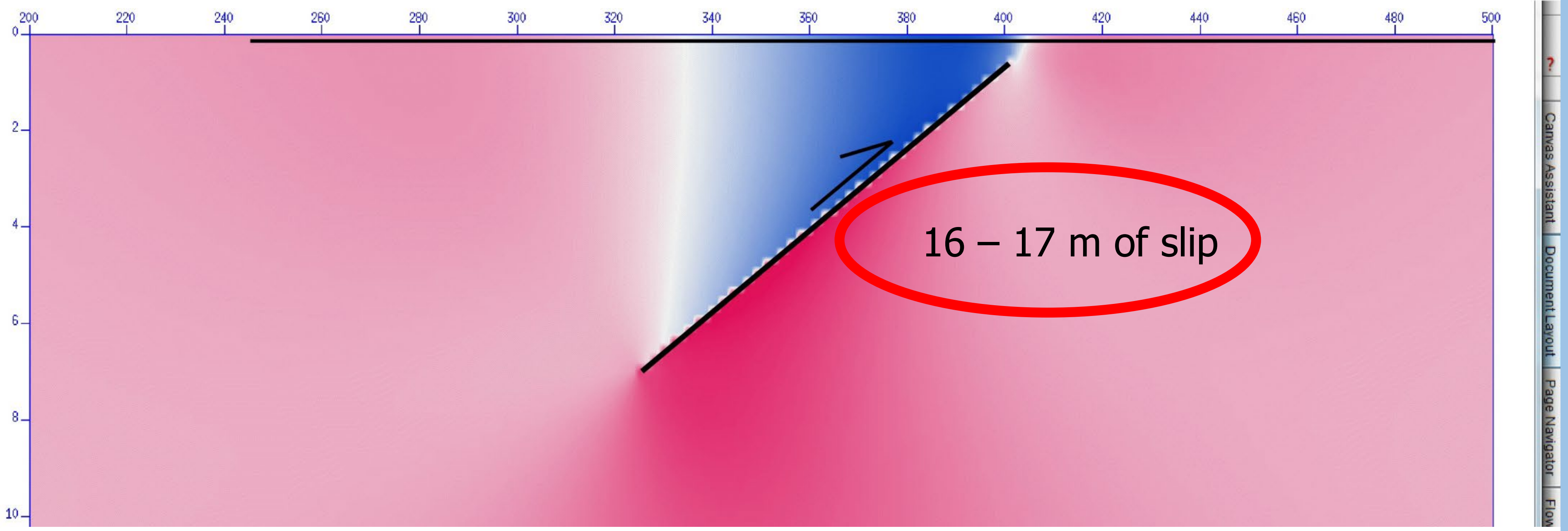
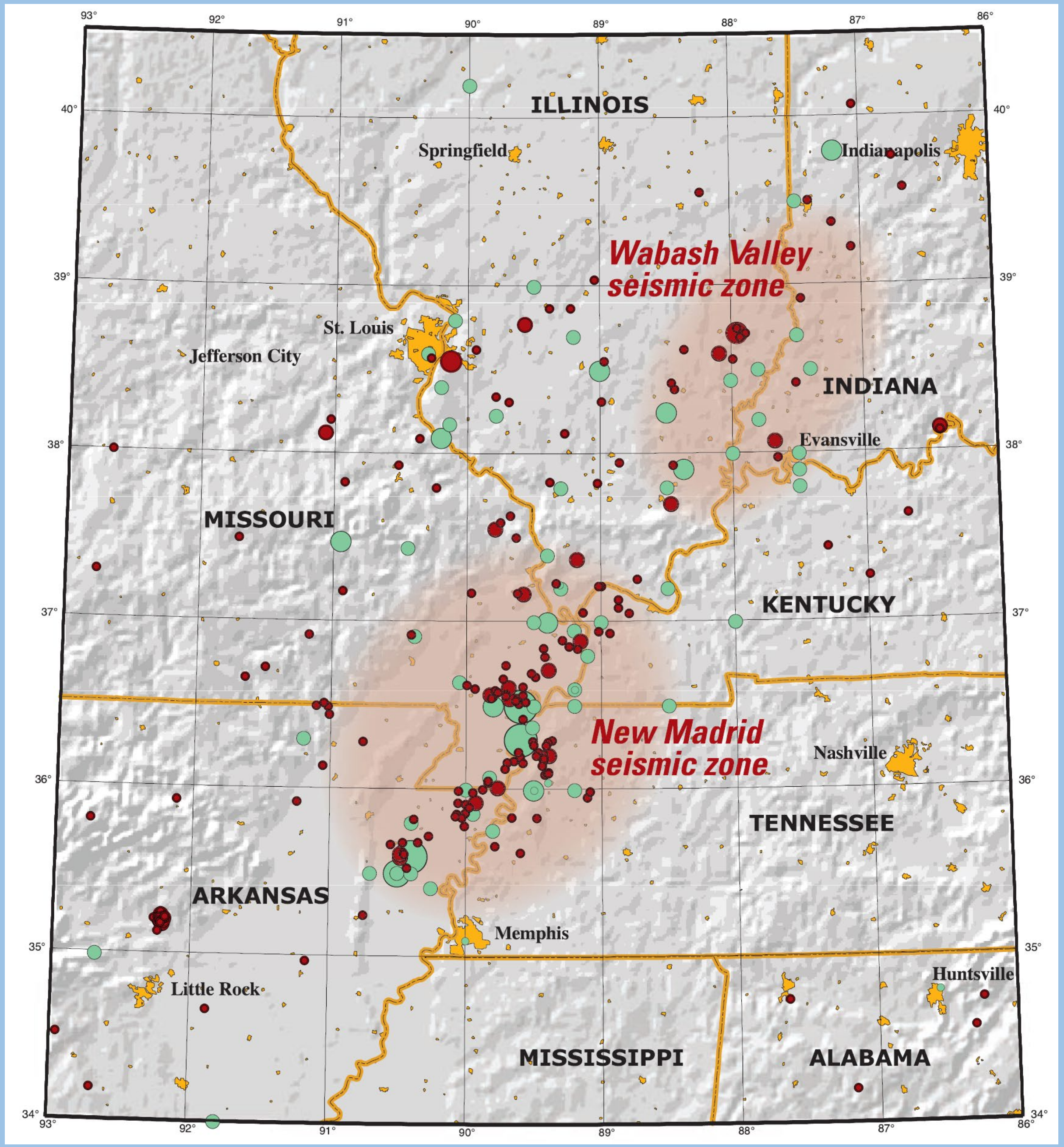
Topography of the Reelfoot Scarp matches what is expected above a thrust fault with about 16 to 17 m of slip.



Computer model by Thomas Pratt, USGS. Preliminary Information-Subject to Revision. Not for Citation or Distribution.

The neighbor to the north:
The Wabash Valley seismic zone

Note, however, that the Wabash
Seismic zone is not as well
Defined by earthquakes as the
New Madrid seismic zone



https://pubs.usgs.gov/fs/2006/3125/pdf/FS06-3125_508.pdf

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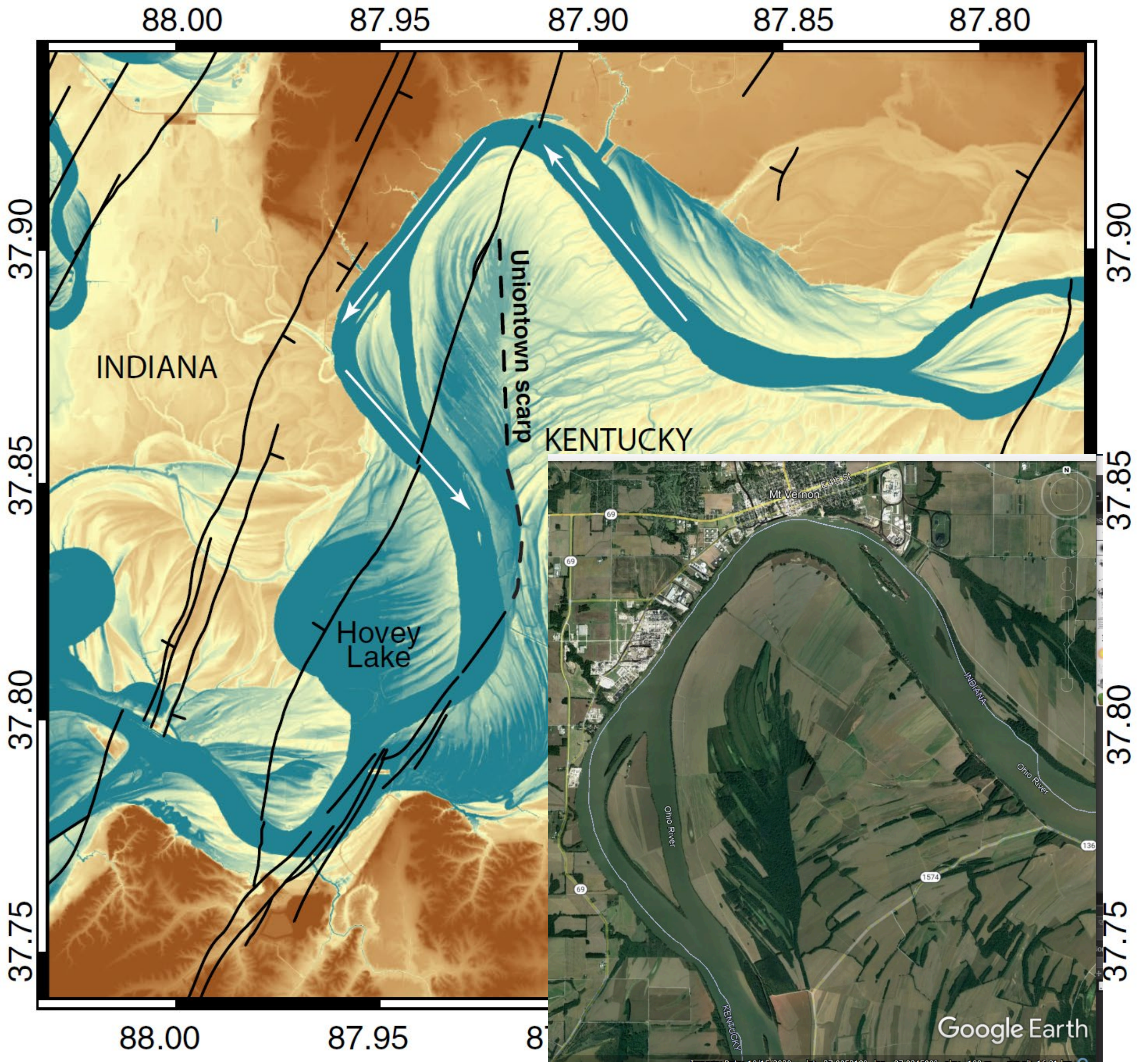
Wabash Valley Seismic Zone

-recent fault scarp
(earthquake about 3500 years ago)



Counts, R. C., R. V. Arsdale, E. Woolery, M. K. Murari, L. A. Owen, E. Glynn Beck, S. Mahan, and J. Durbin (2021). Late Holocene Deformation near the Southern Limits of the Wabash Valley Seismic Zone of Kentucky and Indiana, Central United States, with Seismic Implications, Bull. Seismol. Soc. Am. 111, 1154–1179, doi: 10.1785/0120190089

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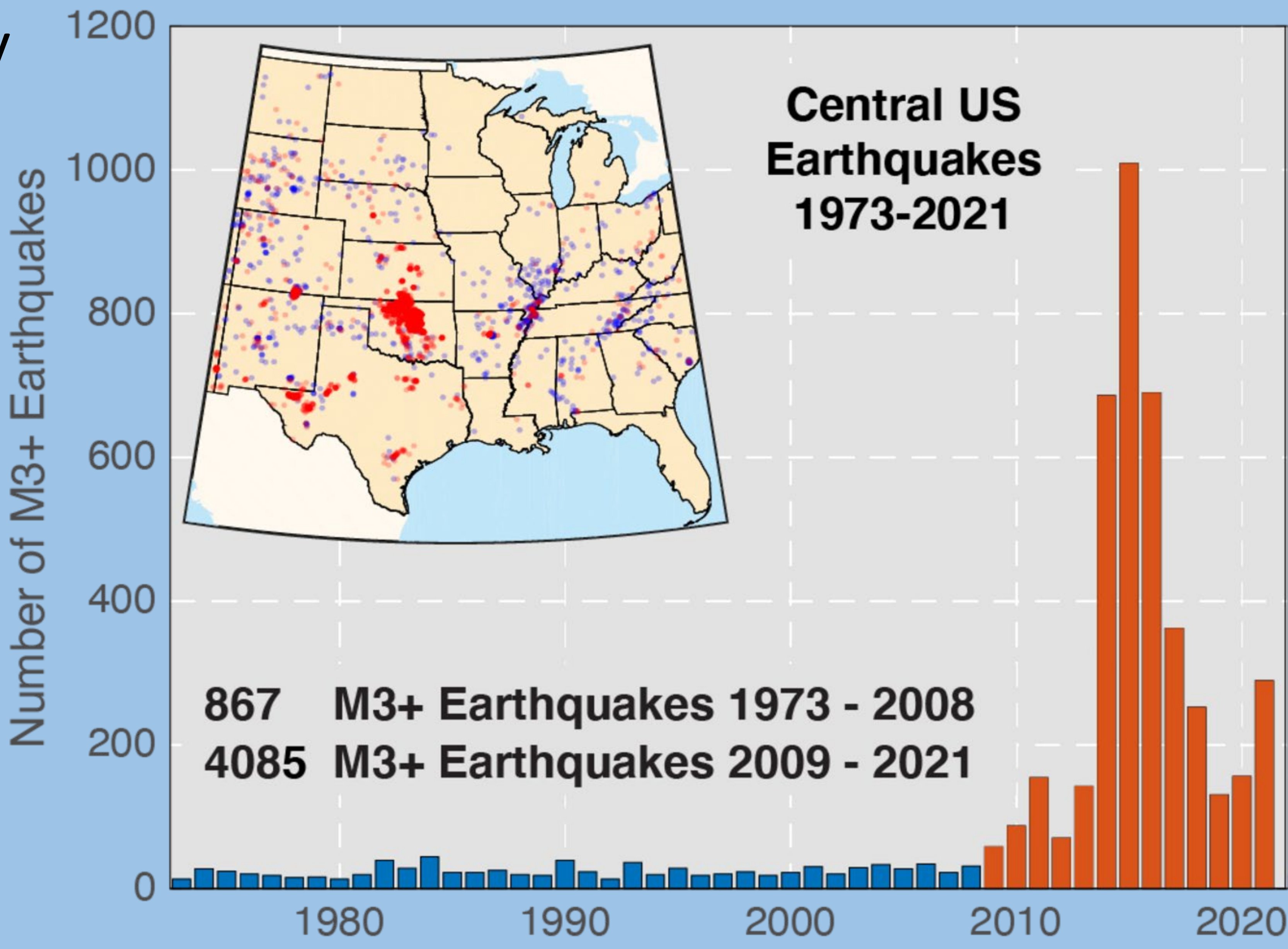
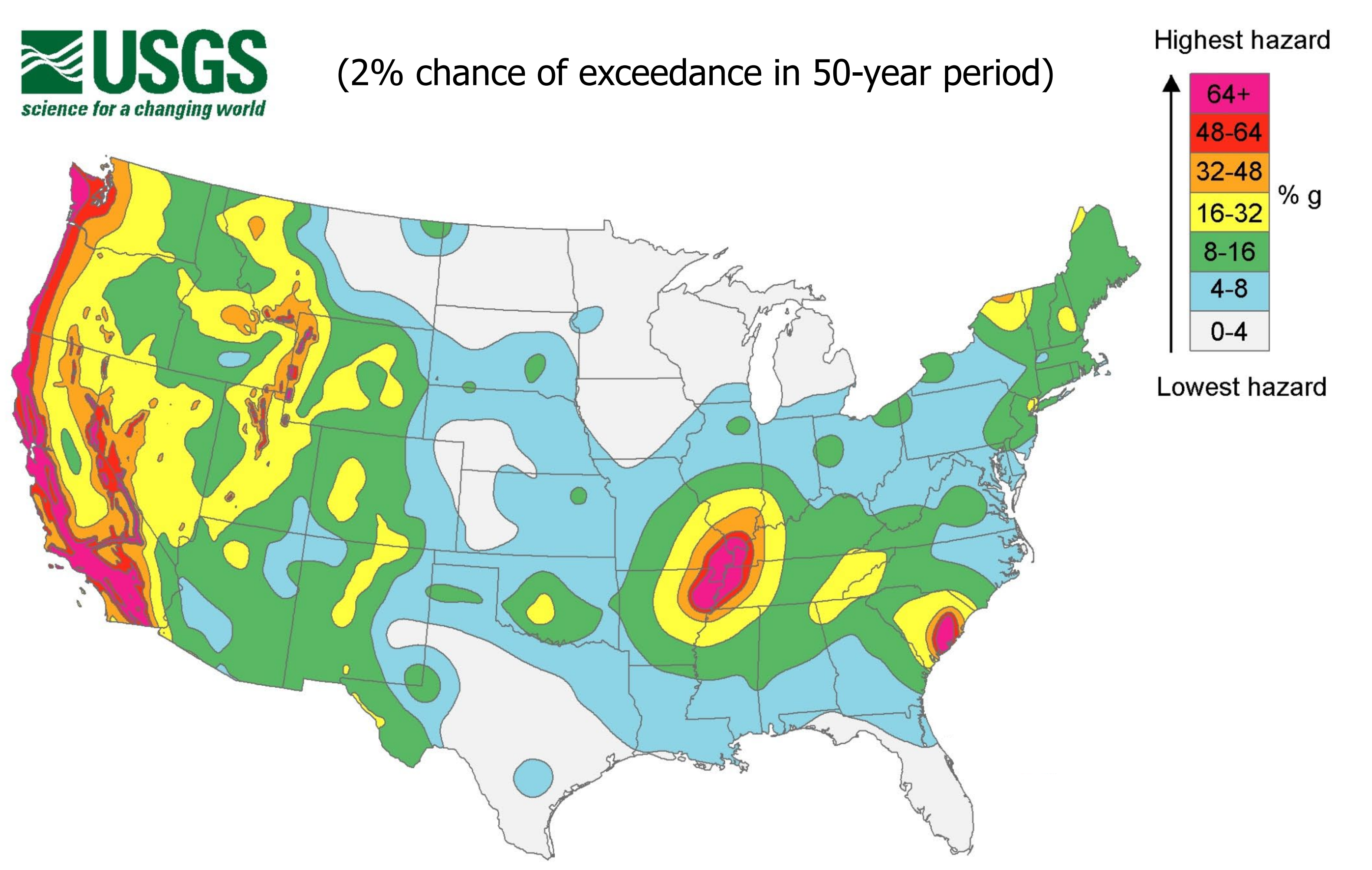
Induced seismicity

- Primarily in Oklahoma, Texas and Kansas;
- but also in Arkansas, Colorado, New Mexico and Ohio.
- Mostly due to injection of fluids at high pressures deep into the Earth



https://www.usgs.gov/media/images/increasing-rate-earthquakes-beginning-2009

U.S. National Seismic Hazard Model (Map)



Main Points

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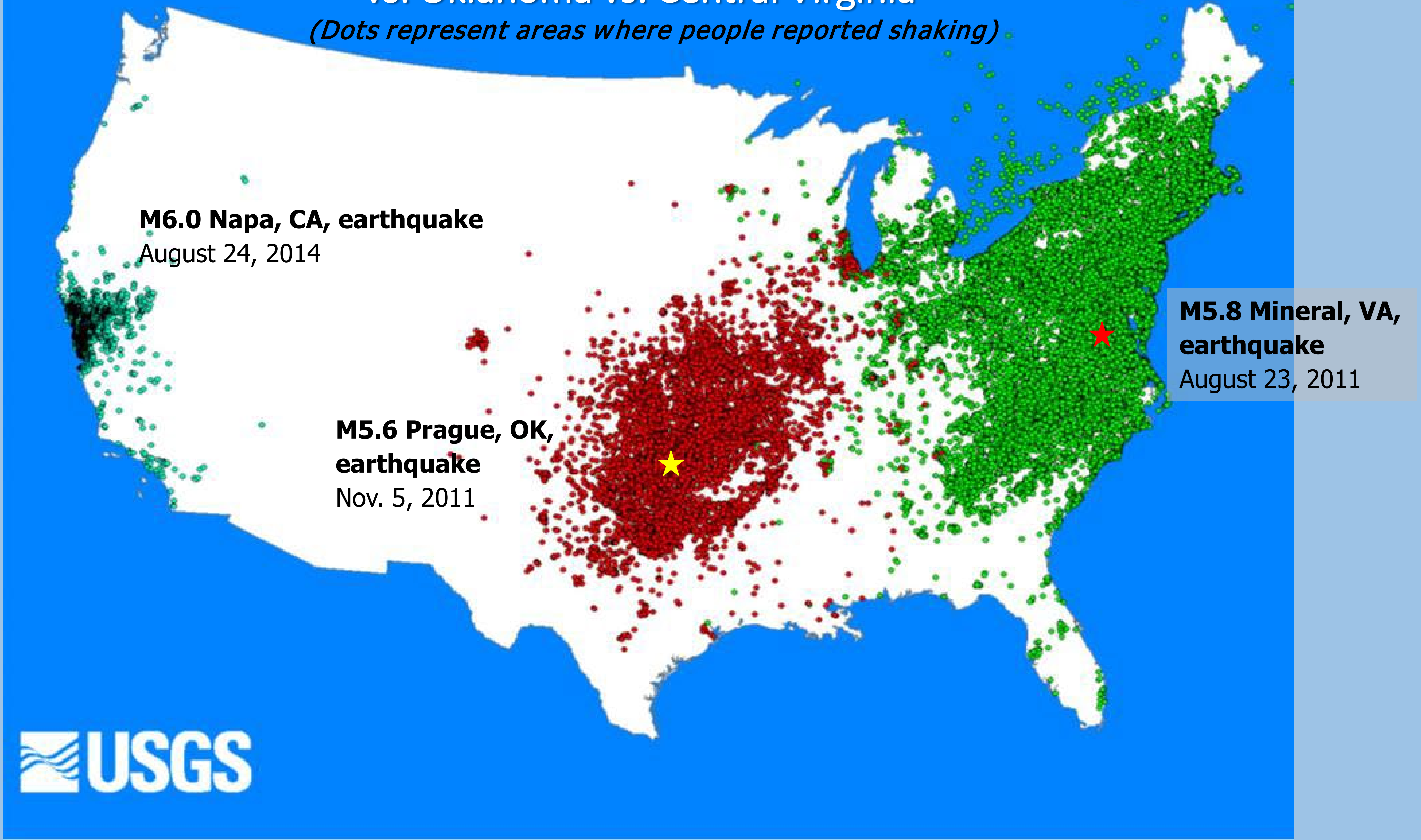
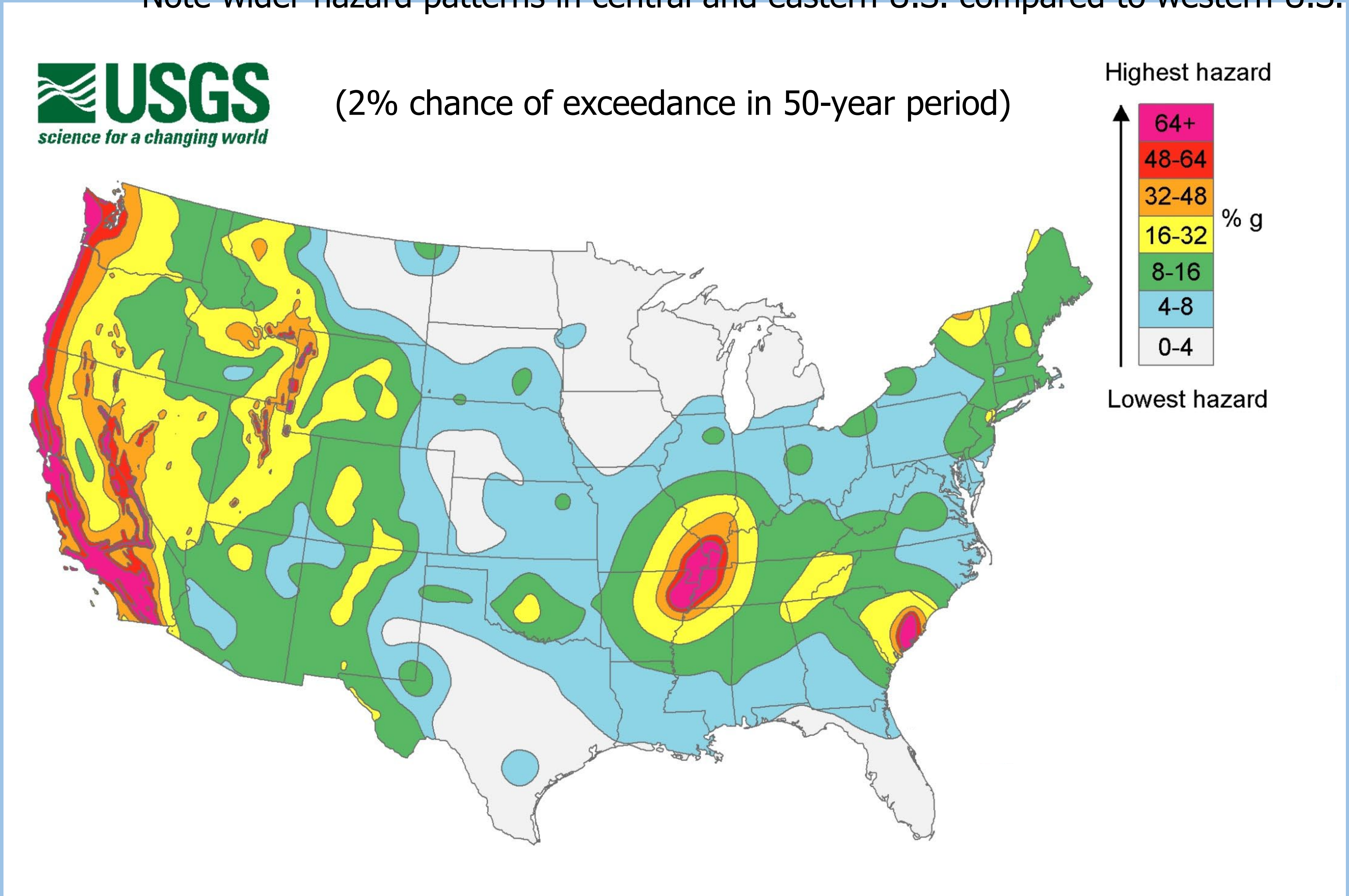
"Did You Feel It?" Comparison Napa vs. Oklahoma vs. Central Virginia

(Dots represent areas where people reported shaking)



U. S. National Seismic Hazard Map

Note wider hazard patterns in central and eastern U.S. compared to western U.S.



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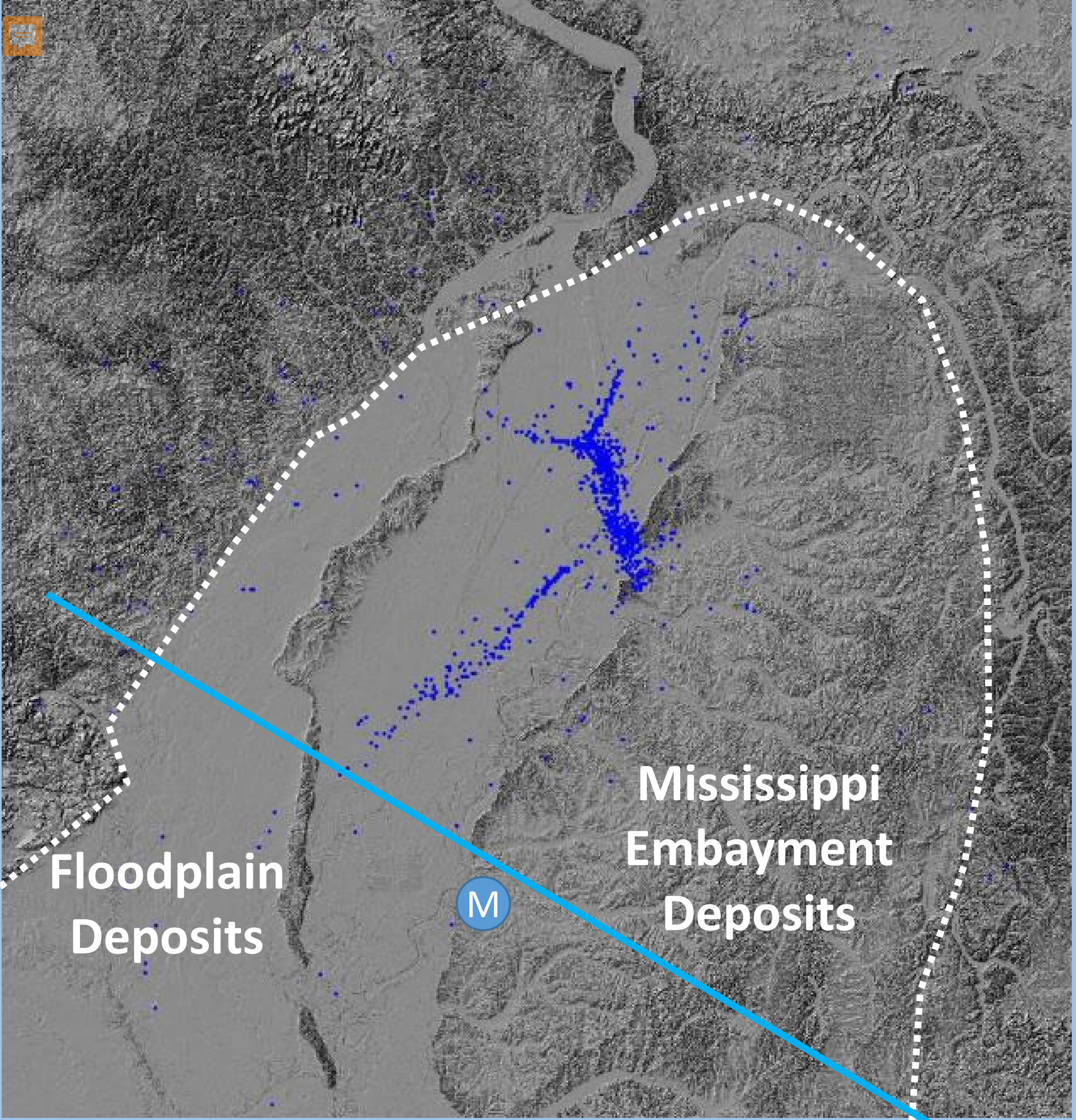
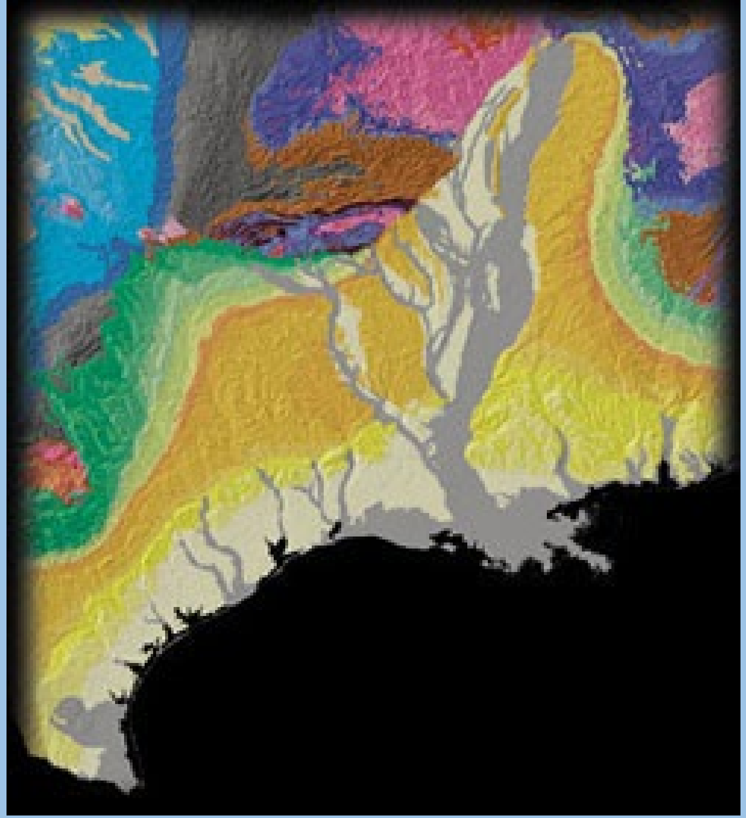
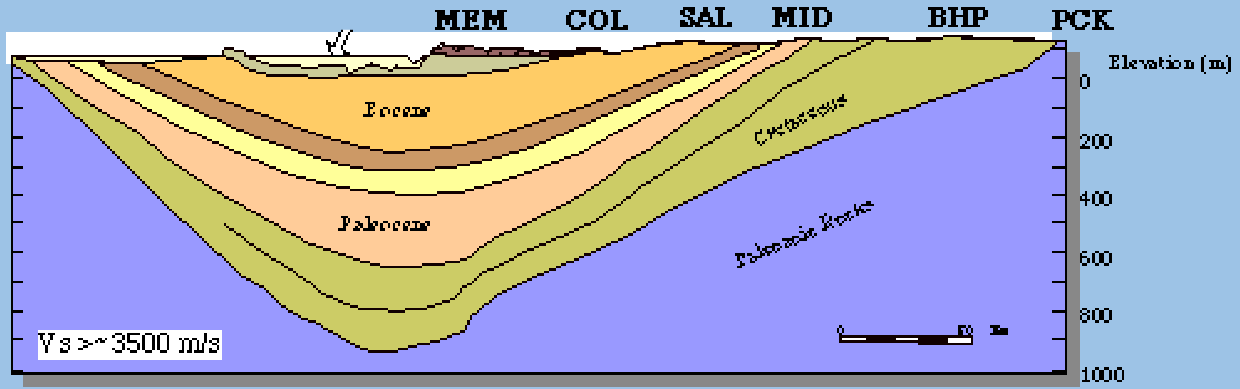




USGS Open File Report 00-443



Cross section from Center for Earthquake Research and Information (CERI), University of Memphis.

Site Response – affect of local geology

- Soft sediments at the surface, or in basins, can dramatically increase the strength of ground shaking during earthquakes
- “bowl of Jello” model (example: Christchurch, New Zealand)

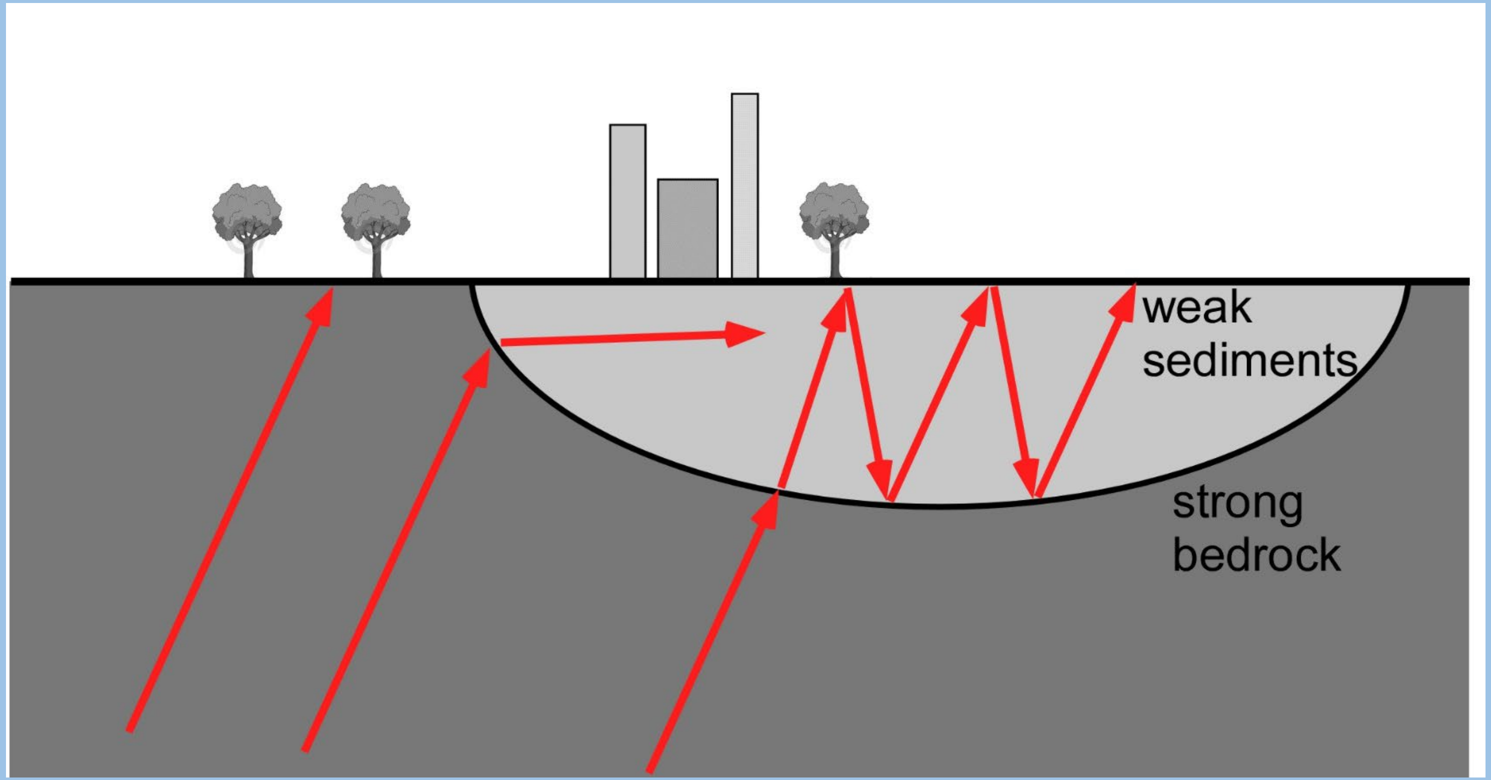


Diagram by Thomas Pratt, USGS

Site Response – affect of local geology

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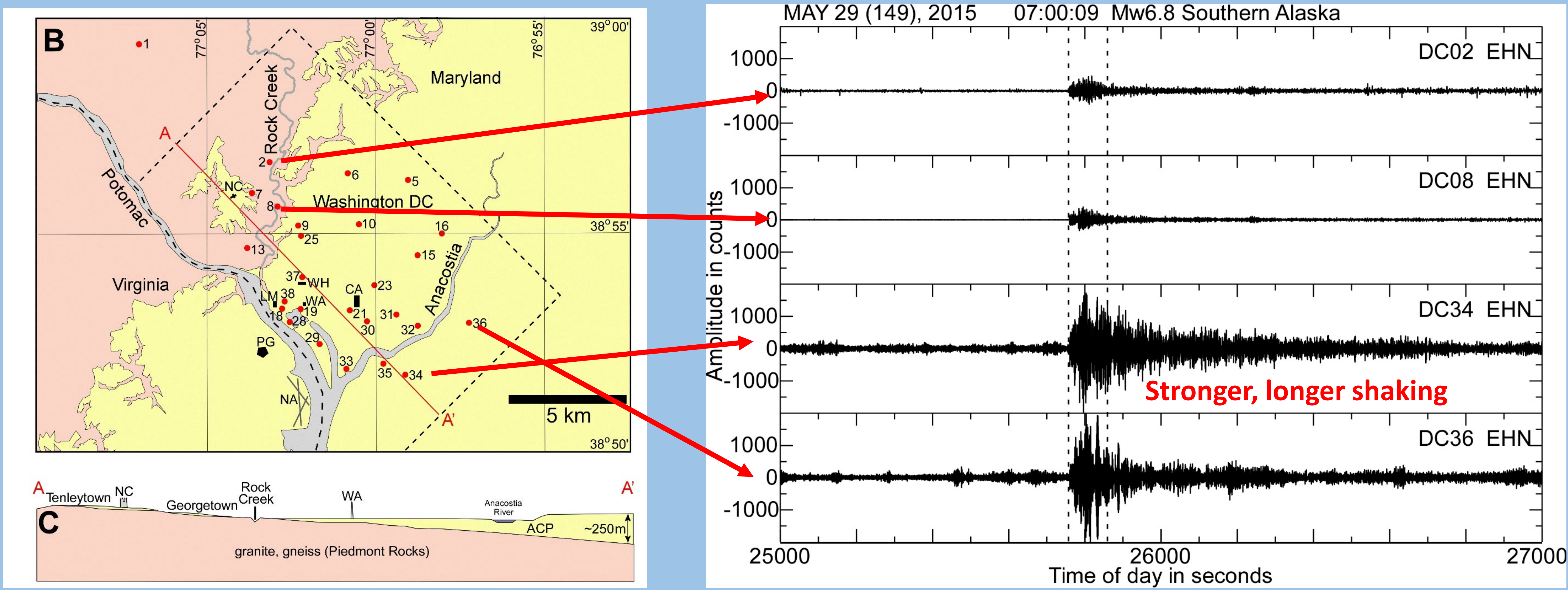
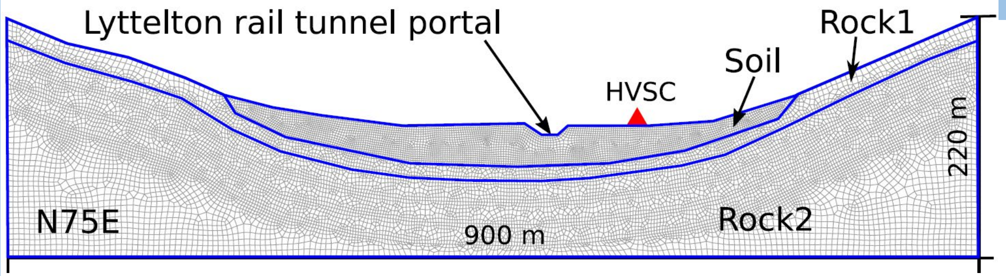
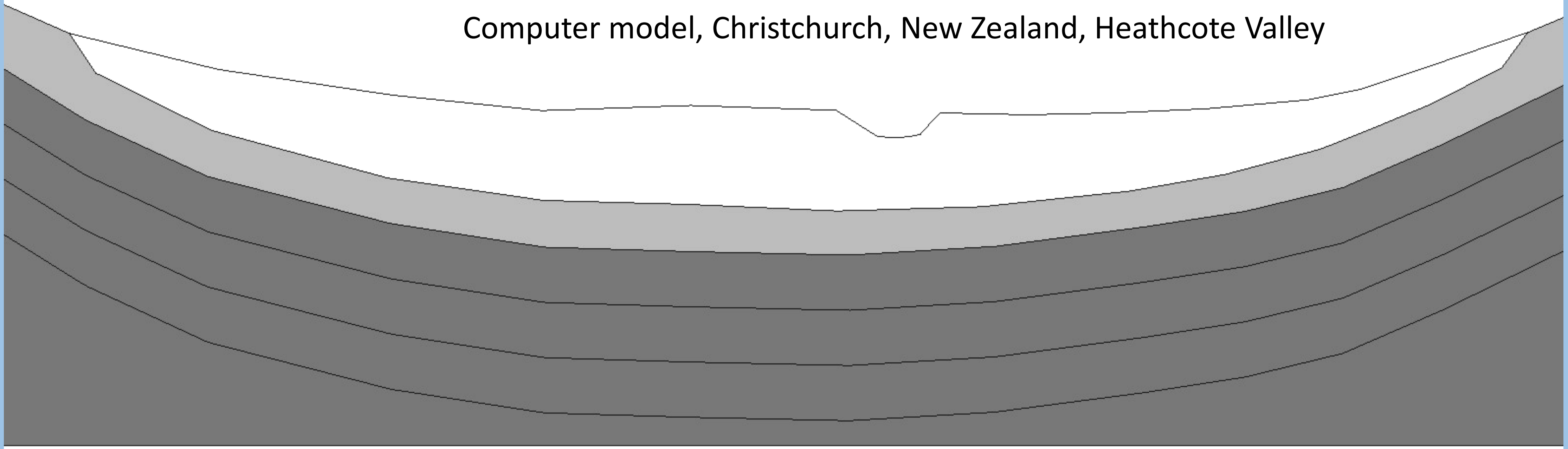


Pratt, T. L., J. W. Horton Jr., J. Muñoz, S. E. Hough, M. C. Chapman, and C. G. Olgun (2017). Amplification of earthquake ground motions in Washington, DC, and implications for hazard assessments in central and eastern North America, Geophys. Res. Lett. 44, 12,150–12,160, doi: 10.1002/2017GL075517.

Computer model, Christchurch, New Zealand, Heathcote Valley





Jeong, S., and B.A. Bradley (2017). Amplification of Strong Ground Motions at Heathcote Valley during the 2010–2011 Canterbury Earthquakes: The Role of 2D Nonlinear Site Response, Bull. Seismol. Soc. Am., 107(5), 2117–2130, doi: 10.1785/0120160389

y
x

step 2.71

Display Vectors of |a. Nodal Velocity| factor 10000 (0.0 3.05).

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Figure 15. The EERI Team studies the performance of this heavily damaged, retrofitted URM building that pounded against the building on the left and partially collapsed (photo: Turner).

Figure 18. Collapse of storage racks (photo: Elwood).

Figure 21. A house in Kaiapoi moved on its foundation in both the September and February earthquakes a total of 1.8m (photo: Lai).

Earthquake Engineering Research Institute, 2011;
The M6.3 Christchurch, New Zealand, Earthquake of February 22, 2011, EERI special Earthquake Report
https://www.eeri.org/site/images/eeri_newsletter/2011_pdf/EERI_NewZealand_EQRpt_web.pdf

80% of downtown buildings being rebuilt – photos from September, 2014

Photos by
Thomas Pratt
(USGS)

Cubrinovski, Green and others, 2010, Geotechnical Reconnaissance of the 2010 Darfield (Canterbury) Earthquake. Bulletin of the New Zealand Society for Earthquake Engineering, v. 43, no. 4.

Cubrinovski, Misko, "Liquefaction-Induced Damage in The2010-2011 Christchurch (New Zealand) Earthquakes" (2013). International Conference on Case Histories in Geotechnical Engineering. 1. https://scholarsmine.mst.edu/icchge/7icchge/session12/1

Mark Mitchell/New Zealand Herald/Associated Press; Boston.com
(http://archive.boston.com/bigpicture/2011/02/christchurch_earthquake.html)

(Brett Phibbs/AFP/Getty Images); Boston.com
(http://archive.boston.com/bigpicture/2011/02/christchurch_earthquake.html)

C.A. Davis, S. Giovinazzi and D.E. Hart, 2015, Liquefaction Induced Flooding in Christchurch, New Zealand,
6th International Conference on Earthquake Geotechnical Engineering, 1-4 November 2015, Christchurch, New Zealand

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Cubrinovski, Green and others, 2010, Geotechnical Reconnaissance of the 2010 Darfield (Canterbury) Earthquake. Bulletin of the New Zealand Society for Earthquake Engineering, v. 43, no. 4.

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Water System

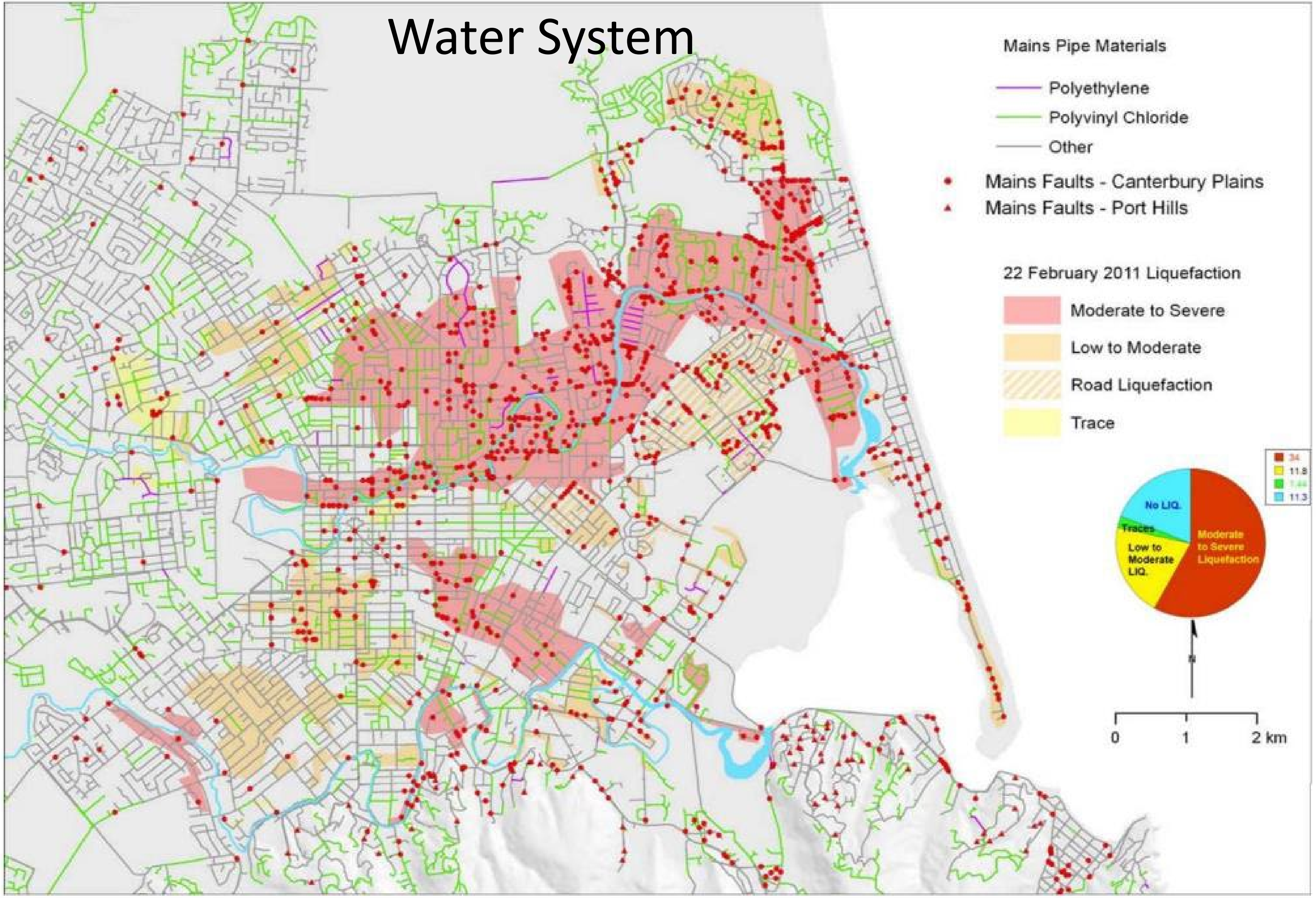
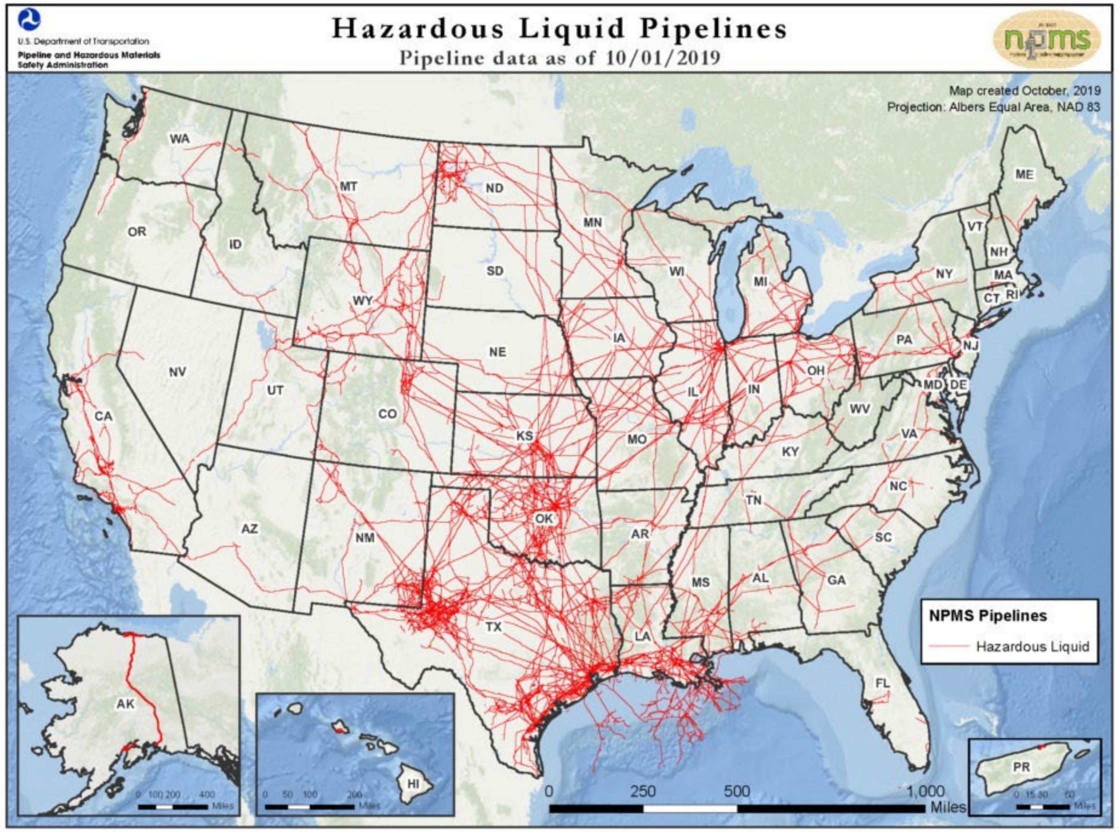
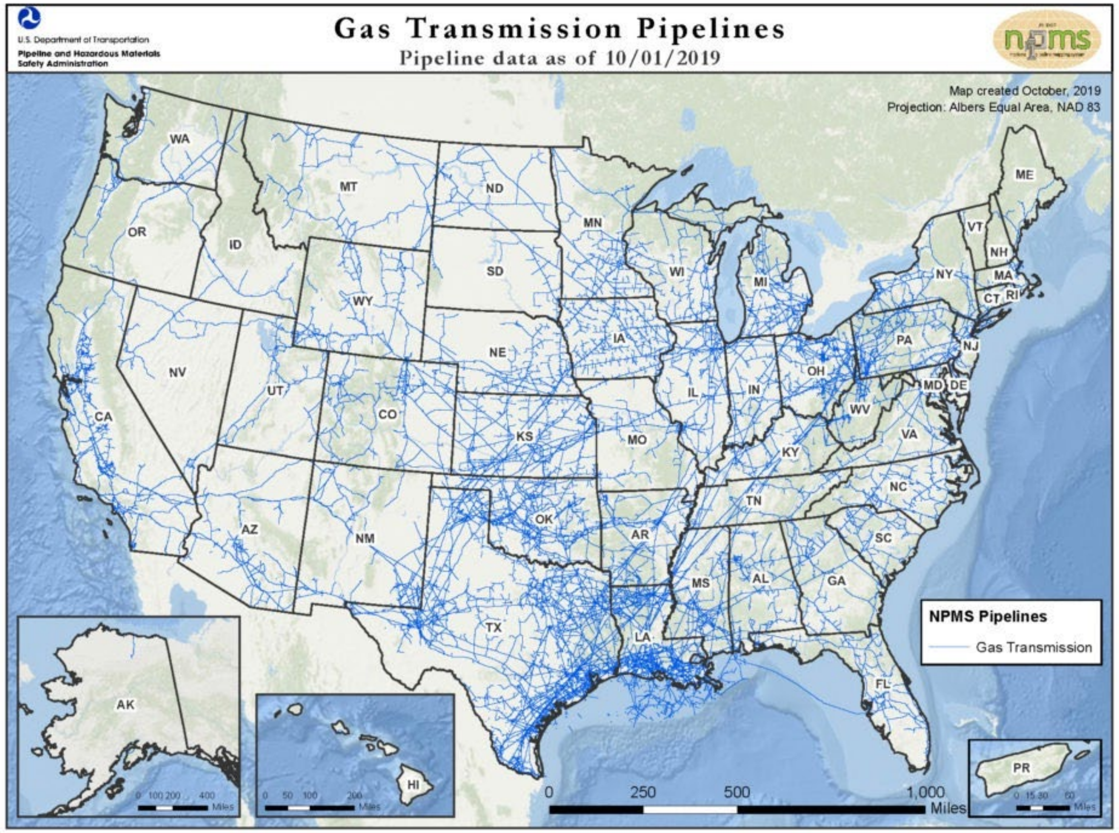


Figure 17. Locations of repairs/faults (red symbols) on the Christchurch watermains network and areas of liquefaction following the 22 February 2011 earthquake

Cubrinovski and others, 2011, Liquefaction Impacts on Pipe Networks, Research Report 2011-04 Civil & Natural Resources Engineering, University of Canterbury, Christchurch, NZ



Maps from the U.S. Department of Transportation,
National Pipeline Mapping System
https://pipeline101.org/topic/where-are-gas-pipelines-located/
https://pipeline101.org/topic/where-are-liquid-pipelines-located/



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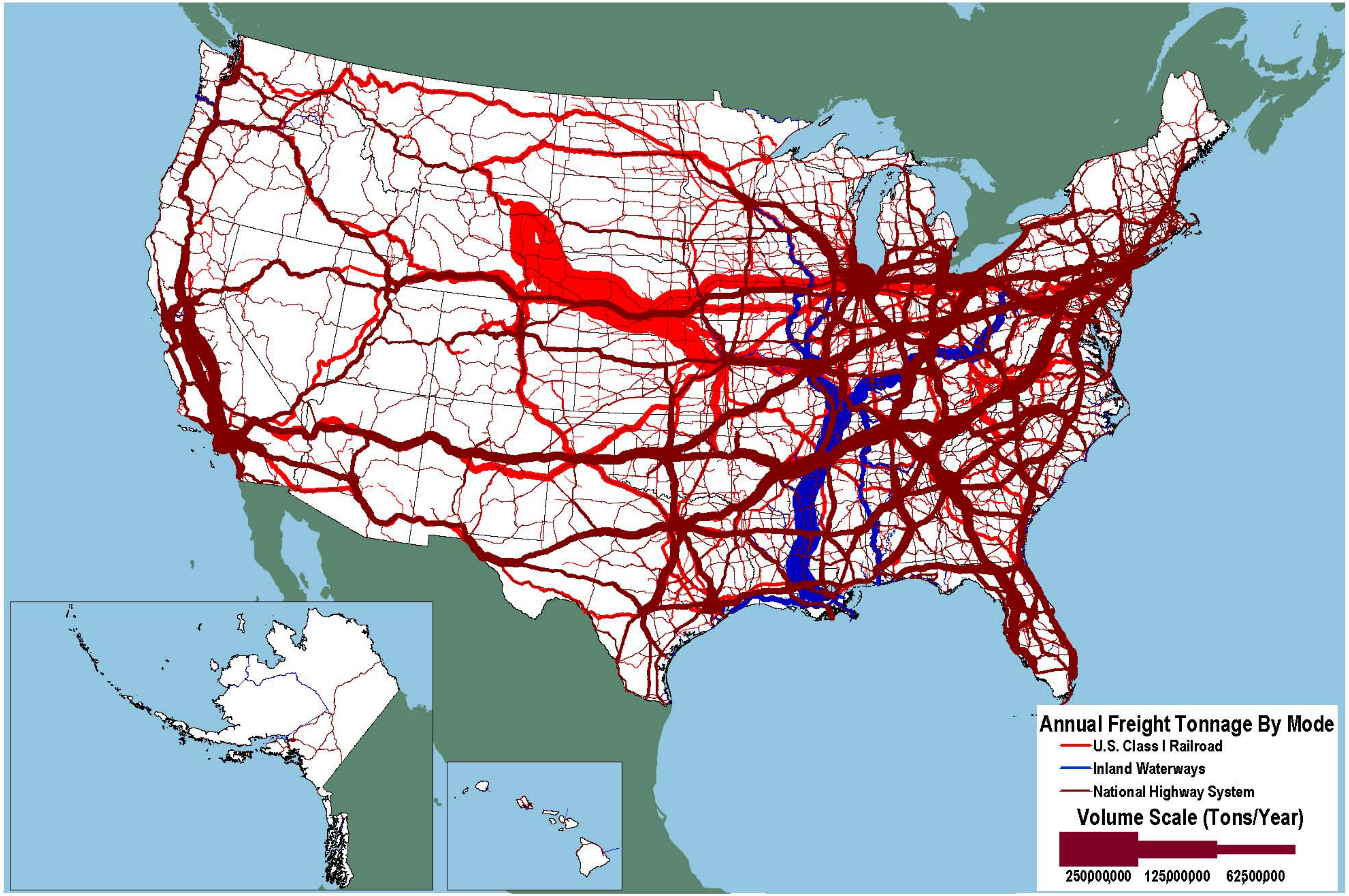
Tonnage on Highways, Railroads and Inland Waterways: 2002



Sources: Highways: U.S. Department of Transportation, Federal Highway Administration, Freight Analysis Framework, Version 2.2, 2007. Rail: Based on Surface Transportation Board, Annual Carload Waybill Sample and rail freight flow assignments done by Oak Ridge National Laboratory. Inland Waterways: U.S. Army Corps of Engineers (USACE), Annual Vessel Operating Activity and Lock Performance Monitoring System data, as processed for USACE by the Tennessee Valley Authority; and USACE, Institute for Water Resources, Waterborne Foreign Trade Data, Water flow asssignments done by Oak Ridge National Laboratory.

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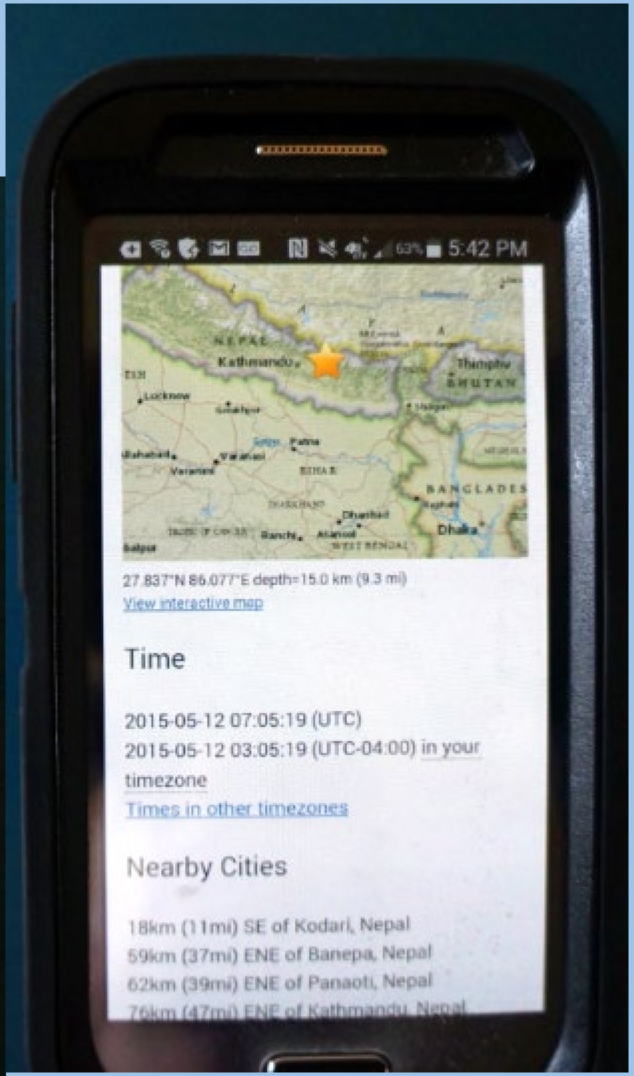
USGS Earthquake Response Products

- Earthquake Notifications (ENS)
- PAGER Loss Estimates
- https://earthquake.usgs.gov/ens/



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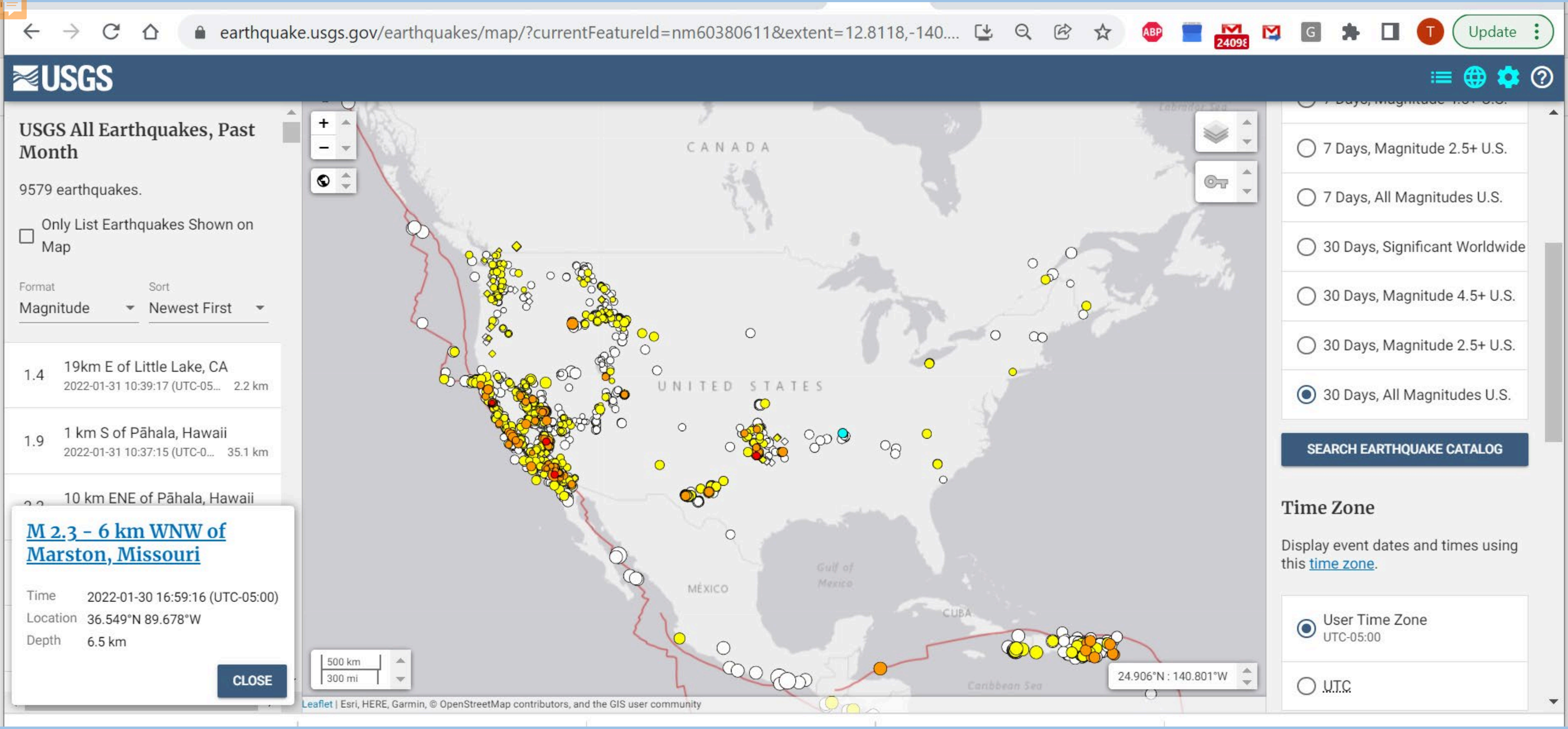

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earthquake.usgs.gov/earthquakes/eventpage/nm60380611/executive

← Latest Earthquakes

- Overview
- Interactive Map
- Regional Information
- Felt Report - Tell Us!
- Technical
- Origin
- Waveforms
- Download Event KML
- View Nearby Seismicity

- Earthquakes
- Hazards
- Data & Products

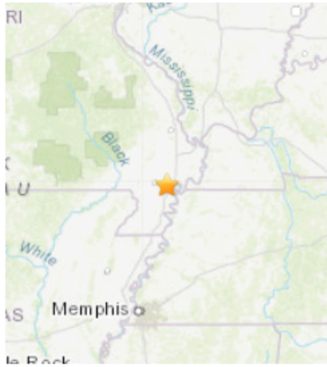
M 2.3 - 6 km WNW of Marston, Missouri

2022-01-30 21:59:16 (UTC) | 36.549°N 89.678°W | 6.5 km depth

Interactive Map

Contributed by NM [1]

Regional Information



Contributed by NM [1]

Felt Report - Tell Us!

0 0 0 0 0 0

Responses

Contribute to citizen science. Please tell us about your experience.

Citizen Scientist Contributions

Origin

Review Status
REVIEWED

Magnitude
2.3 md

Depth
6.5 km

Time
2022-01-30 21:59:16 UTC

Contributed by NM [1]

View Nearby Seismicity

Time Range
± Three Weeks

Search Radius
250.0 km

Magnitude Range
≥ 1.0

ANSS Comcat

For More Information

- Impact Summary
- Technical Summary

Contributors

1. New Madrid Seismic Network

Additional Information

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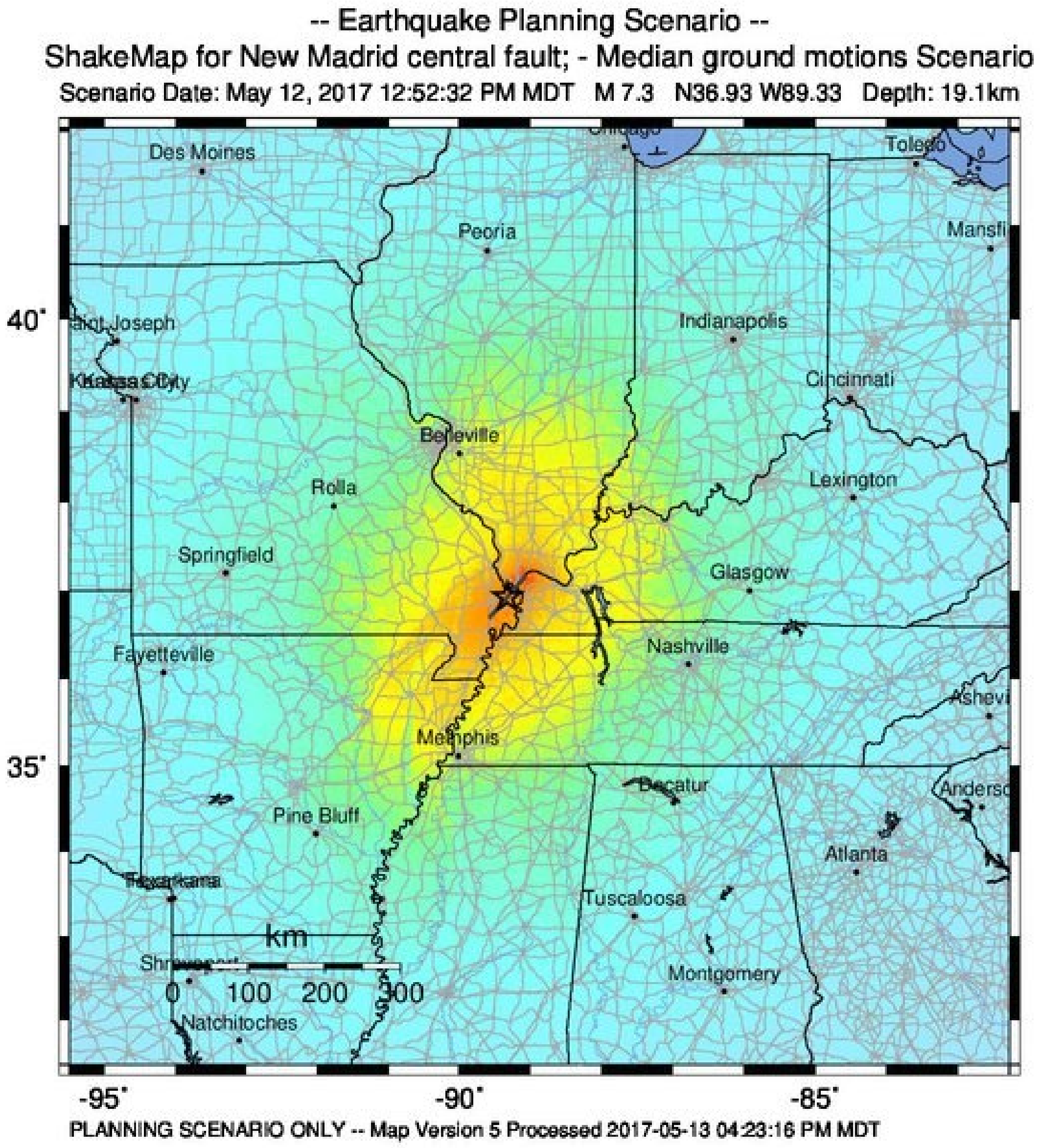
Other products:

- Shakemap (strength of ground shaking)
- Ground failure map (likely locations of landslides/liquefaction)
- “Did-you-Feel-It?” (DYFI?) map (strength of shaking reported by citizens)
- Aftershock forecasts (chances of different sized aftershocks)
- Earthquake scenarios (for response/recovery exercises)

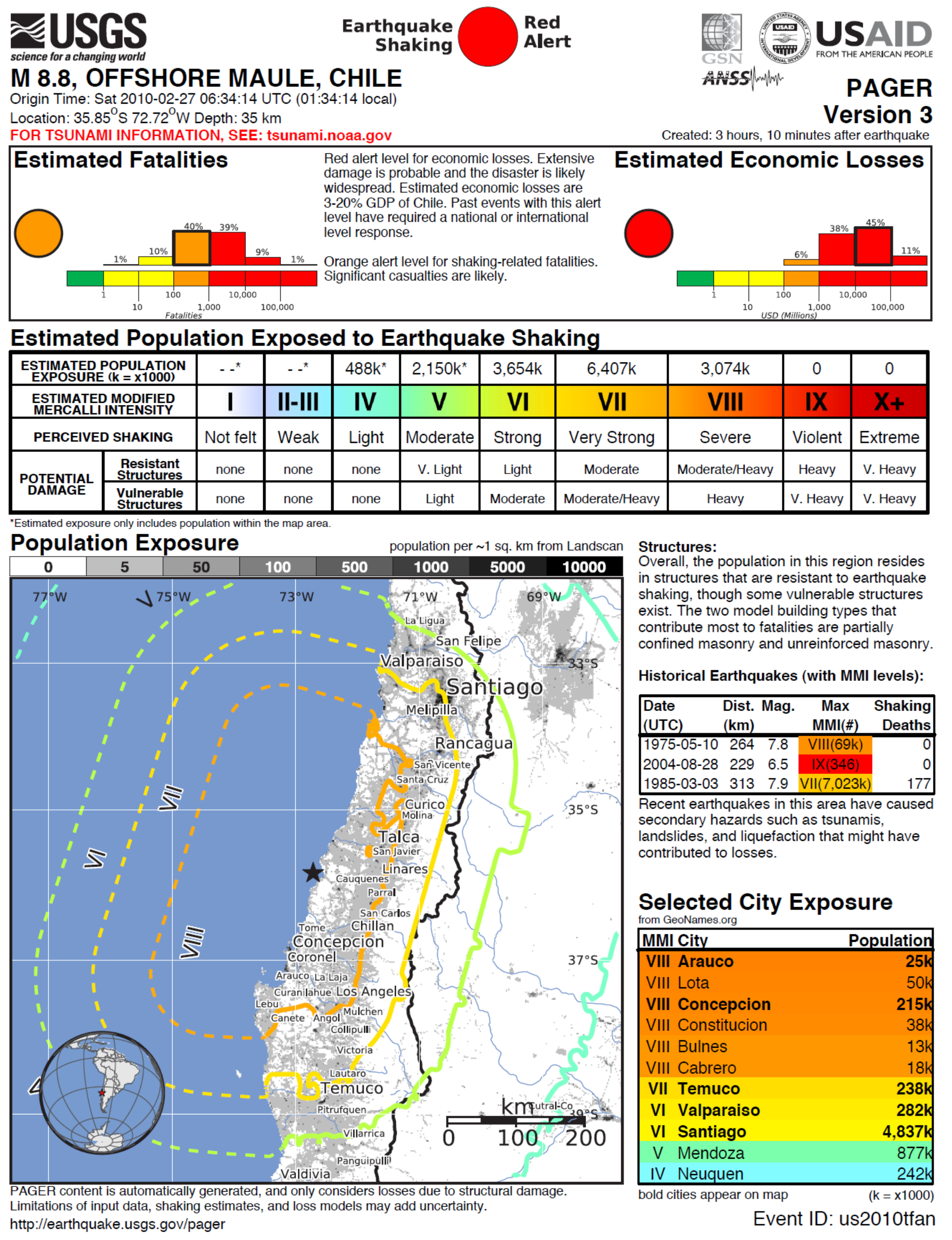


PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	<0.02	0.1	1.4	4.7	9.6	20	41	86	>178
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)

PAGER

- Gives a rapid assessment of estimated impacts of an earthquake (fatalities, economic damage)



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Earthquake Shaking **Red Alert**

GSN ANSS USAID FROM THE AMERICAN PEOPLE

M 8.8, OFFSHORE MAULE, CHILE

Origin Time: Sat 2010-02-27 06:34:14 UTC (01:34:14 local)

Location: 35.85°S 72.72°W Depth: 35 km

FOR TSUNAMI INFORMATION, SEE: tsunami.noaa.gov

PAGER Version 3

Created: 3 hours, 10 minutes after earthquake

Estimated Fatalities

Red alert level for economic losses. Extensive damage is probable and the disaster is likely widespread. Estimated economic losses are 3-20% GDP of Chile. Past events with this alert level have required a national or international level response.

Orange alert level for shaking-related fatalities. Significant casualties are likely.

Estimated Economic Losses

Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)	--*	--*	488k*	2,150k*	3,654k	6,407k	3,074k	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE: Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
POTENTIAL DAMAGE: Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

Structures:
Overall, the population in this region resides in structures that are resistant to earthquake shaking, though some vulnerable structures exist. The two model building types that contribute most to fatalities are partially confined masonry and unreinforced masonry.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1975-05-10	264	7.8	VIII(69k)	0
2004-08-28	229	6.5	IX(346)	0
1985-03-03	313	7.9	VII(7,023k)	177

Recent earthquakes in this area have caused secondary hazards such as tsunamis, landslides, and liquefaction that might have contributed to losses.

Selected City Exposure

from GeoNames.org

MMI	City	Population
VIII	**Arauco**	25k
VIII	Lota	50k
VIII	**Concepcion**	215k
VIII	Constitucion	38k
VIII	Bulnes	13k
VIII	Cabrero	18k
VII	**Temuco**	238k
VI	**Valparaiso**	282k
VI	**Santiago**	4,837k
V	Mendoza	877k
IV	Neuquen	242k

bold cities appear on map (k = x1000)

PAGER content is automatically generated, and only considers losses due to structural damage. Limitations of input data, shaking estimates, and loss models may add uncertainty.

http://earthquake.usgs.gov/pager

Event ID: us2010tfan

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Earthquake Early Warning/ Aftershock forecasting

- Alert system
- NOT Prediction!!

Wikipedia, Philpottm

Gary Larson, "The Far Side"

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Earthquake Early Warning

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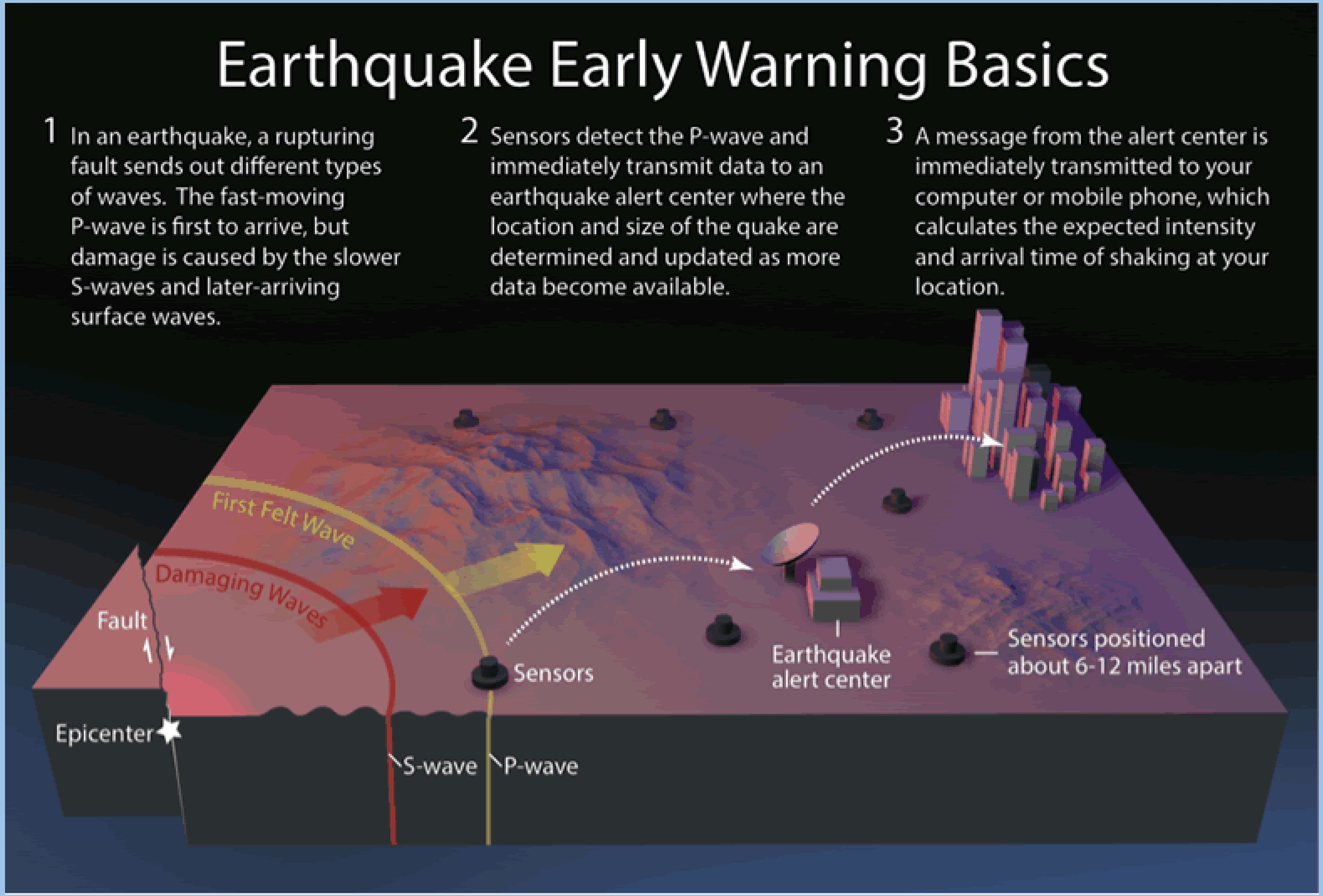

https://doi.org/10.3133/fs20143083

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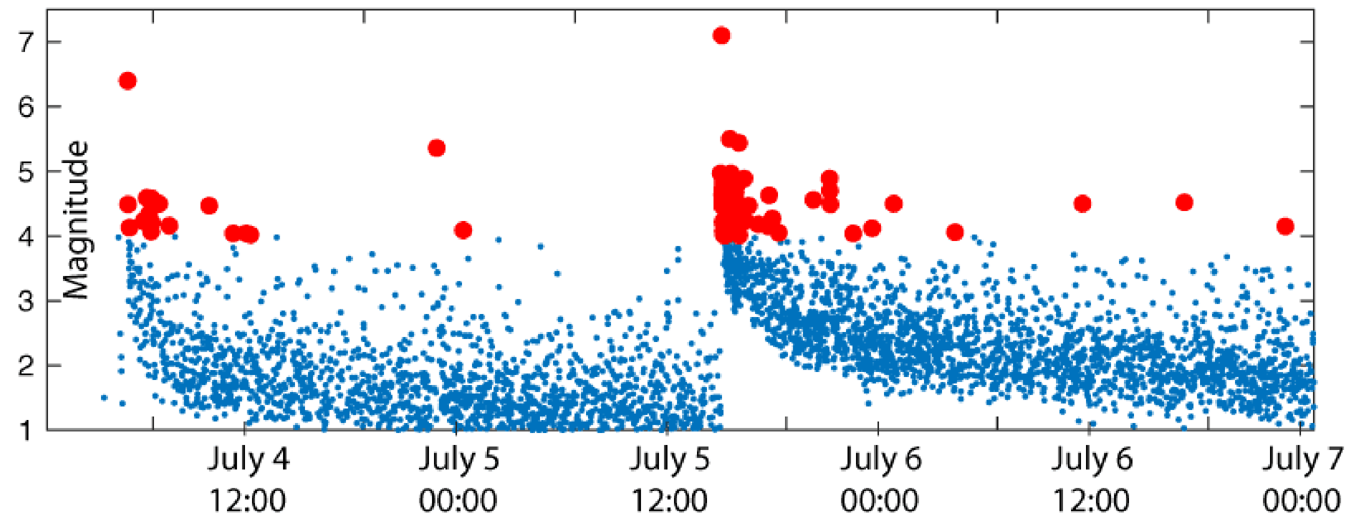
Aftershock forecasting



Ridgecrest, CA, Earthquake sequence (USGS)

https://www.usgs.gov/media/images/graph-2019-ridgecrest-earthquakes-function-time

Downs Collection, Winterthur Library
http://museumblog.winterthur.org/2016/08/31/the-day-the-earth-shook/

USGS science for a changing world

Summary

- The central and eastern U.S. are not immune to large earthquakes.
- Earthquakes in central and eastern U.S. affect a much larger area than western U.S. earthquakes.
- Shallow deposits can amplify ground shaking and cause liquefaction.
- Impacts of a large central U.S. earthquake can include extensive building damage and ground deformation such as liquefaction (analog, Christchurch, NZ).
- The USGS provides products summarizing the effects of an earthquake after one occurs, and providing information for earthquake emergency planning and mitigation.

END