The Evolving Earthquake Hazard near Cushing, Oklahoma

William L. Ellsworth, Martin Schoenball, Matthew Weingarten

Stanford University

and

Robert Skoumal and David R. Shelly

U. S. Geological Survey

Stanford | Stanford Center for Induced and Triggered Seismicity

School of Earth, Energy & Environmental Sciences

USGS science for a changing world

Outline

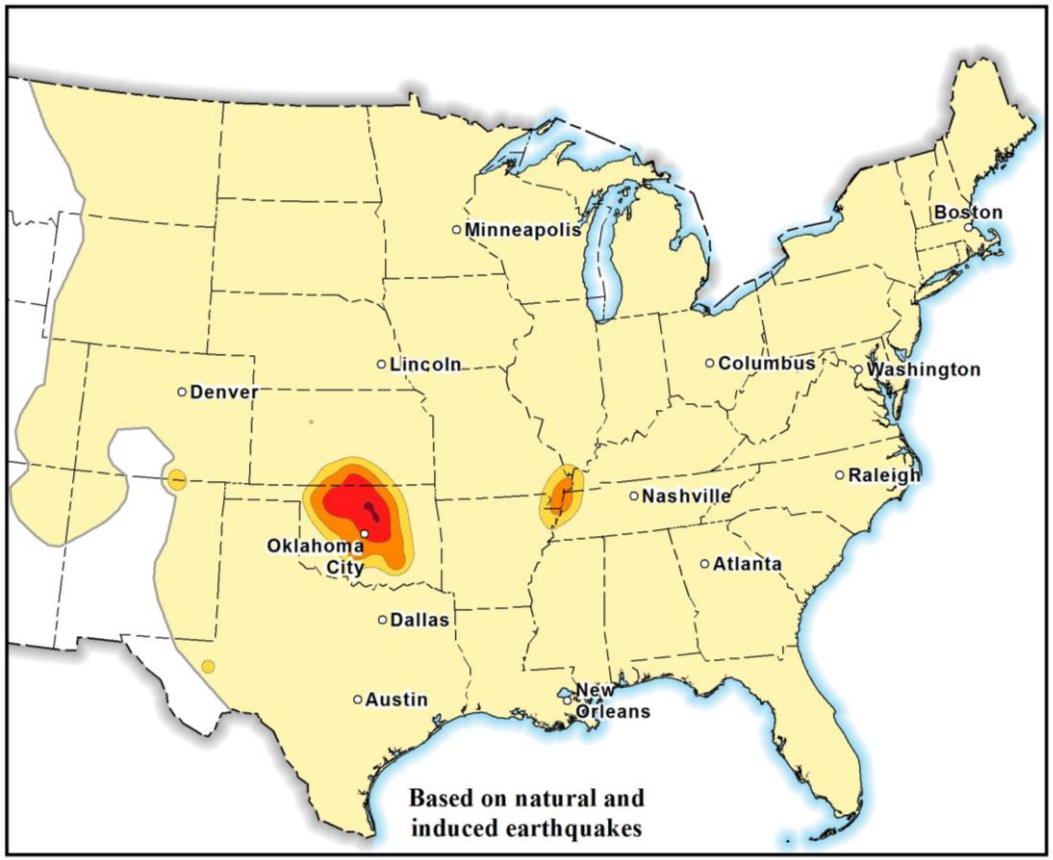
Induced earthquake forecast for 2017

Evolving hazard in Oklahoma

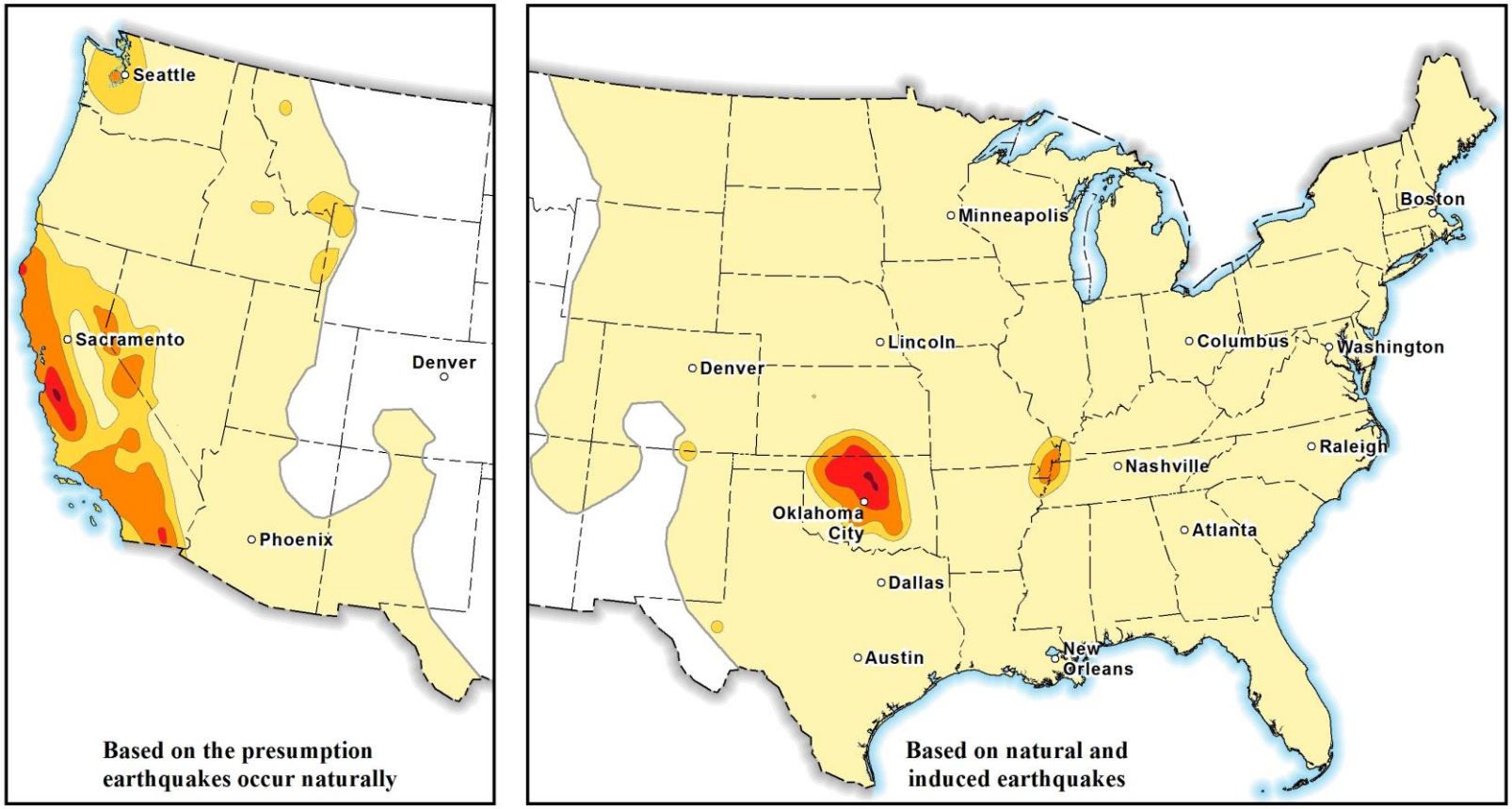
Induced earthquakes are not weak

The 2014 and 2015-2016 Cushing earthquake sequences: Two faults waking up

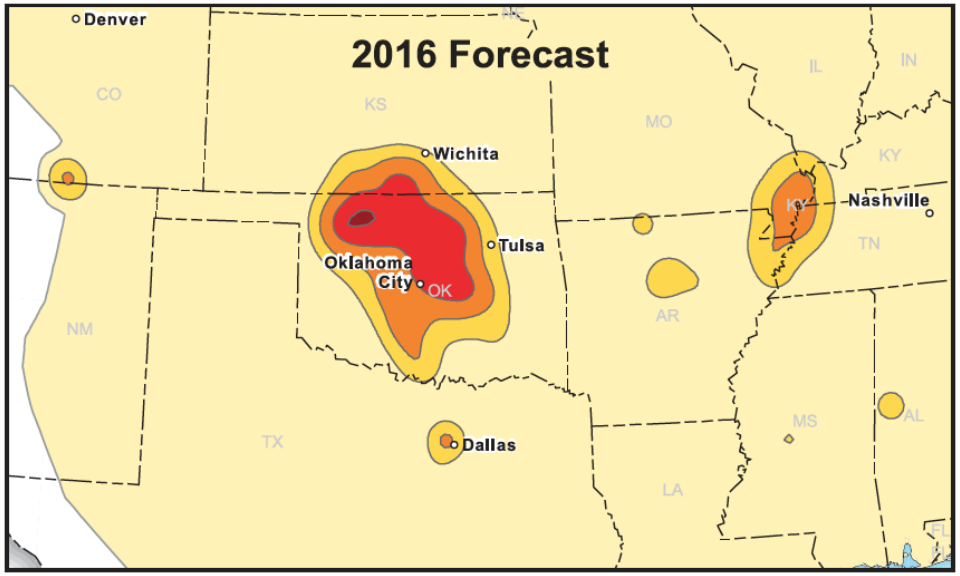
Summary

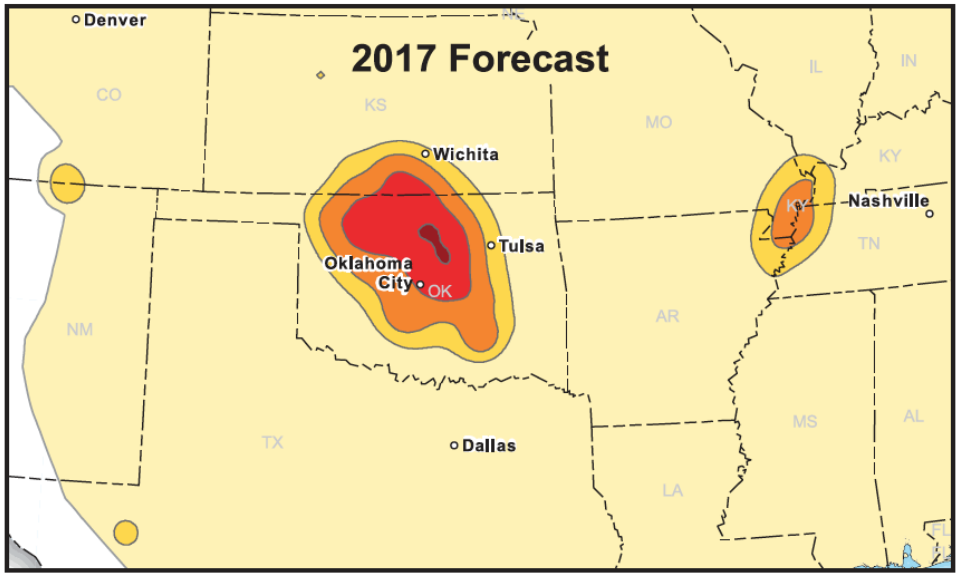


USGS Forecast for Damage from Natural and Induced Earthquakes in 2017



USGS map displaying potential to experience damage from natural or human-induced earthquakes in 2017. Chances range from less than 1 percent to 12 percent.

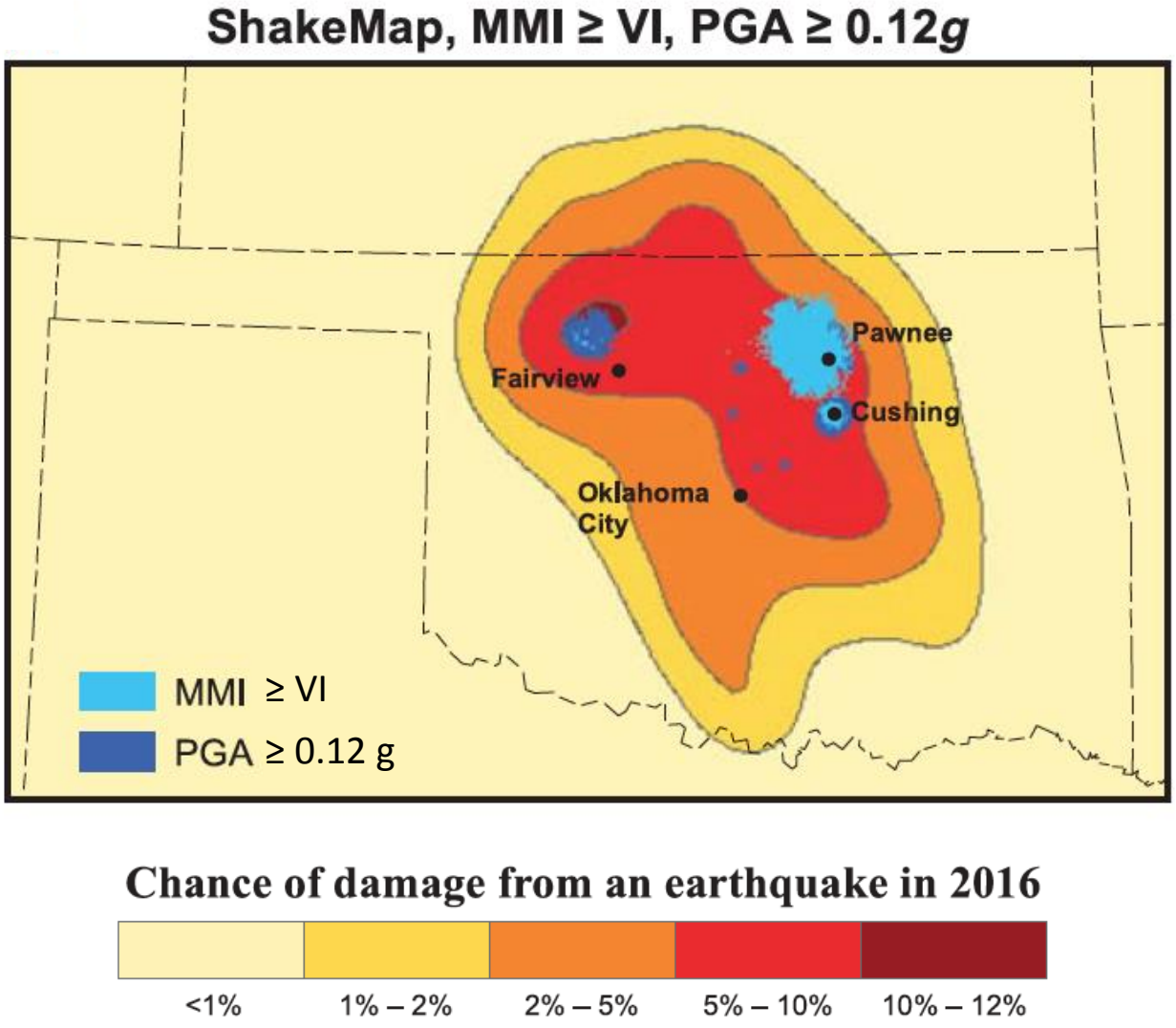




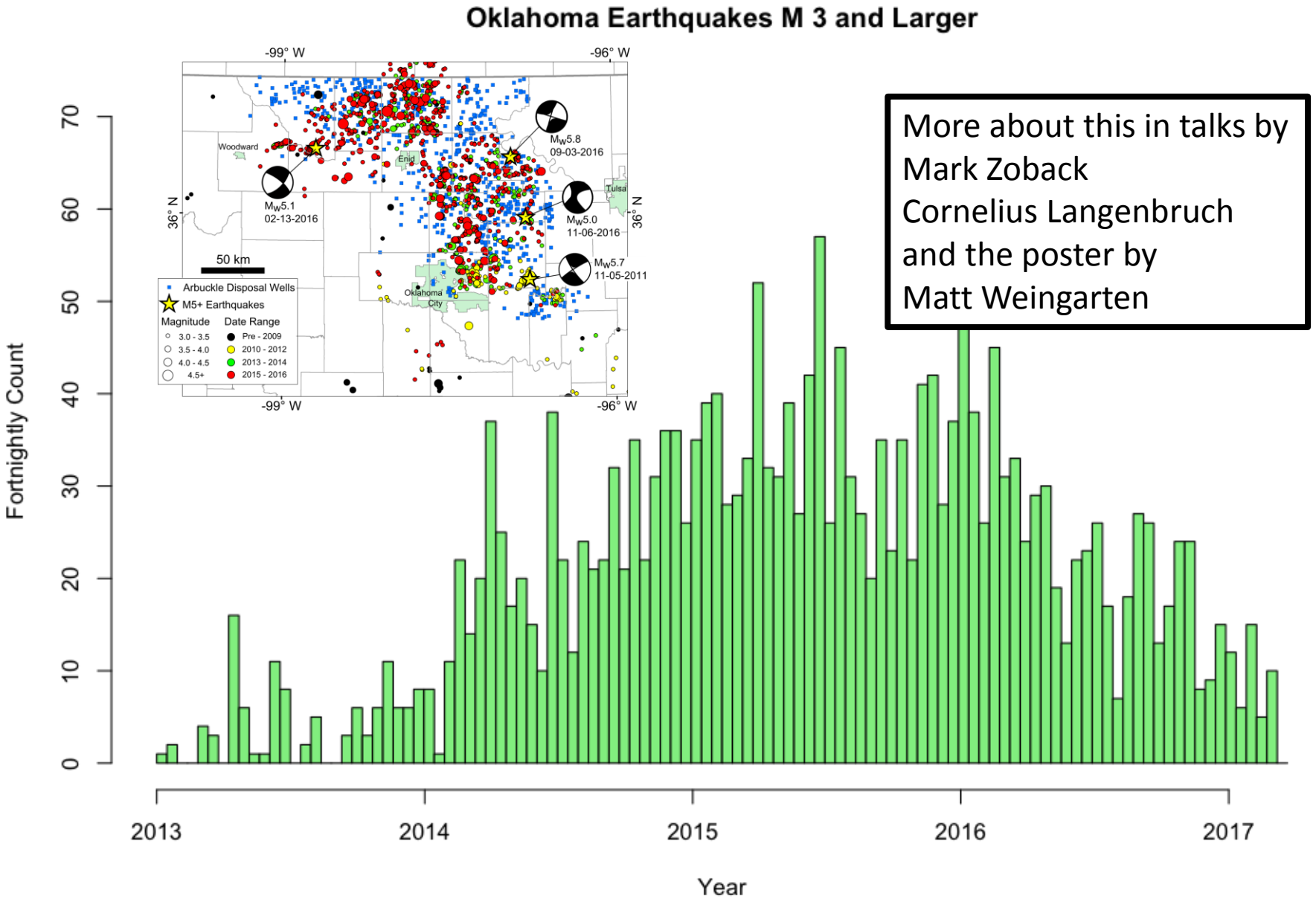
Chance of damage from an earthquake

Performance of the 2016 One-Year Hazard Map

Fairview (M_w 5.1), Pawnee (M_w 5.8) and Cushing (M_w 5.0)



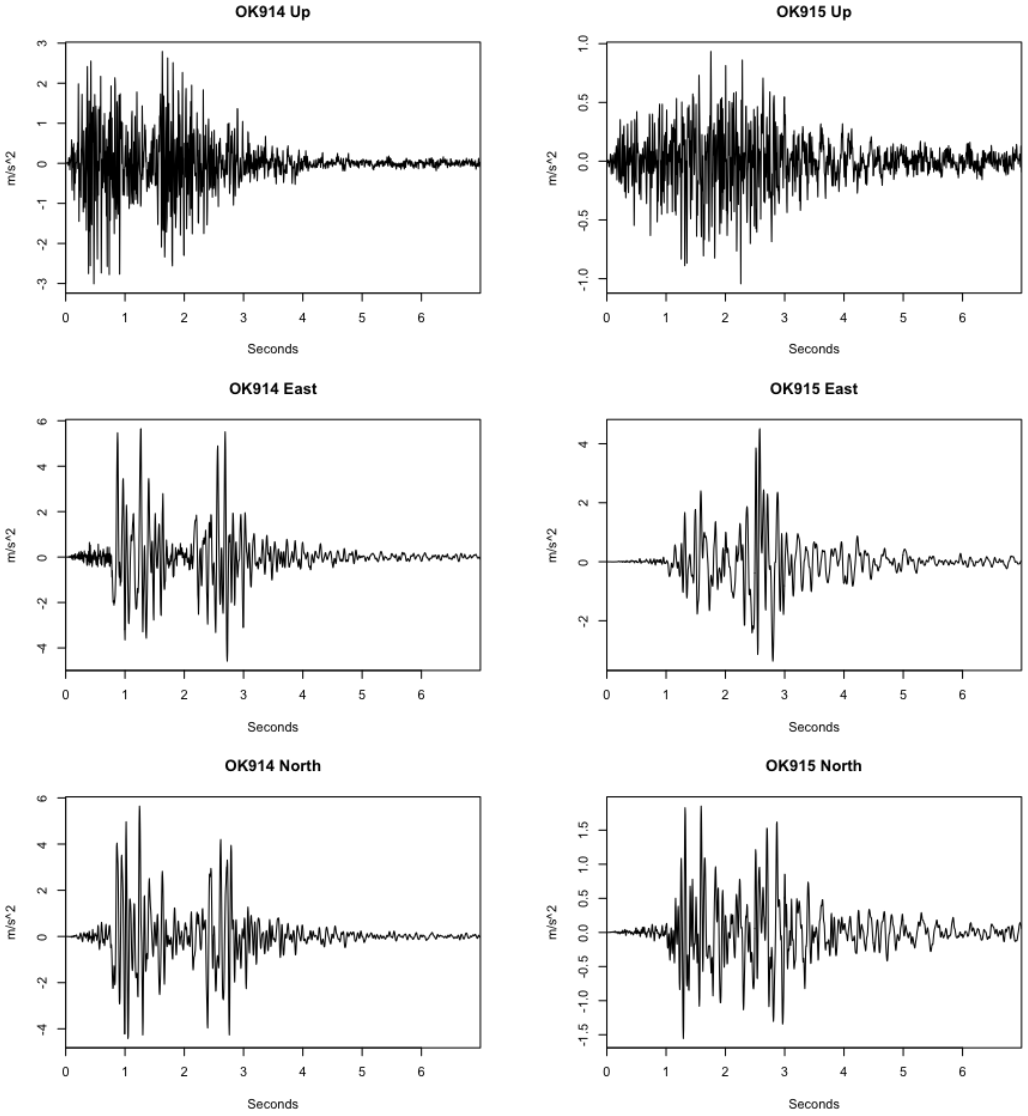
Evolving Hazard in Oklahoma



More about this in talks by
Mark Zoback
Cornelius Langenbruch
and the poster by
Matt Weingarten

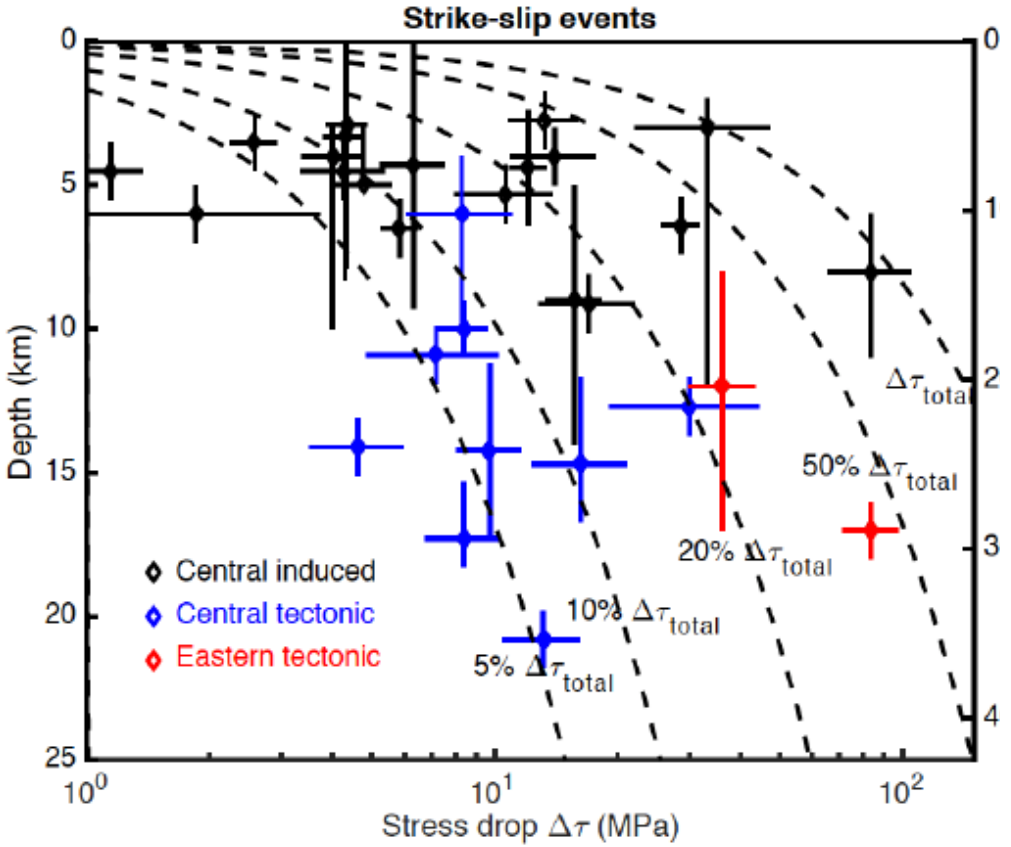
Induced Earthquakes are as strong as Tectonic Earthquake

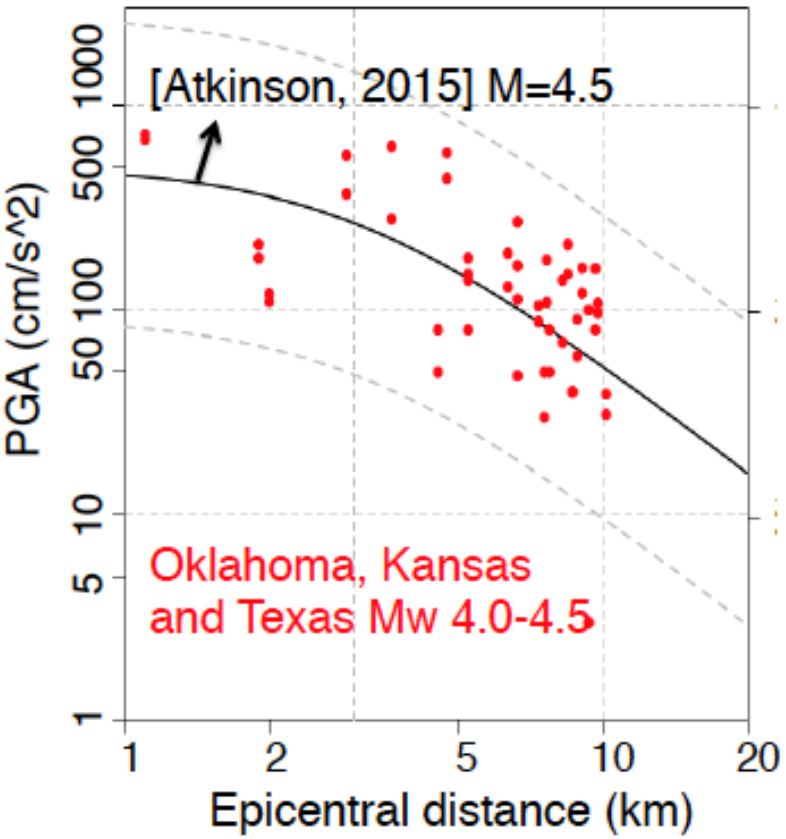
Downtown Cushing after 2016 Mw 5.0 (J. Beckel AP)



November 7, 2016 Cushing M_w 5.0

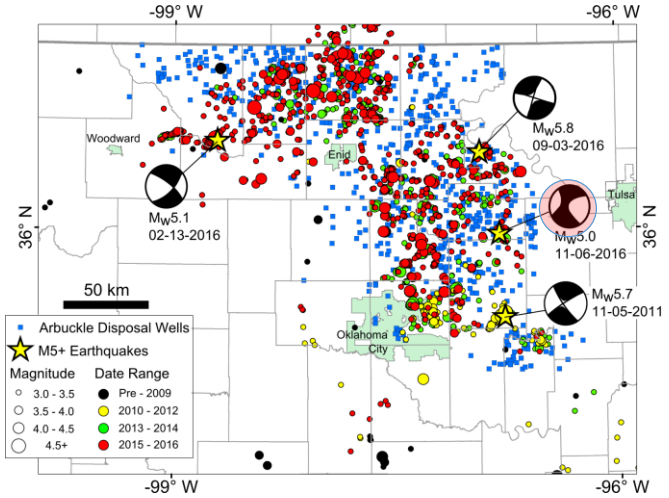
Induced Earthquakes are as strong as Tectonic Earthquake

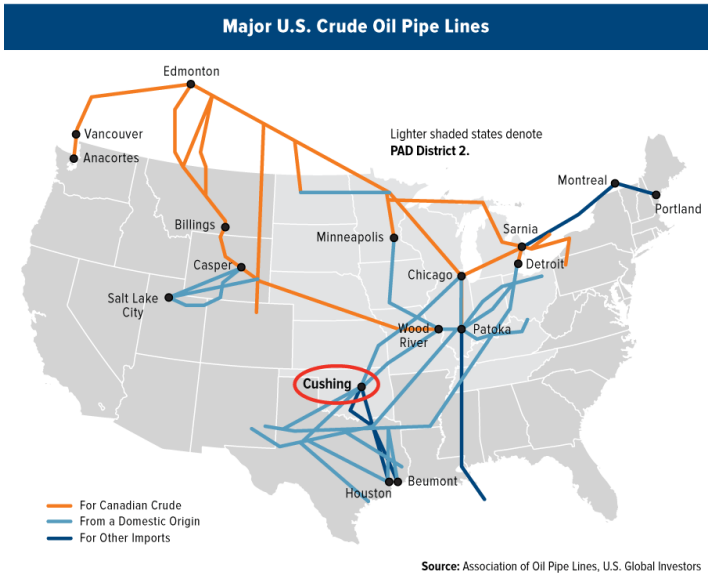




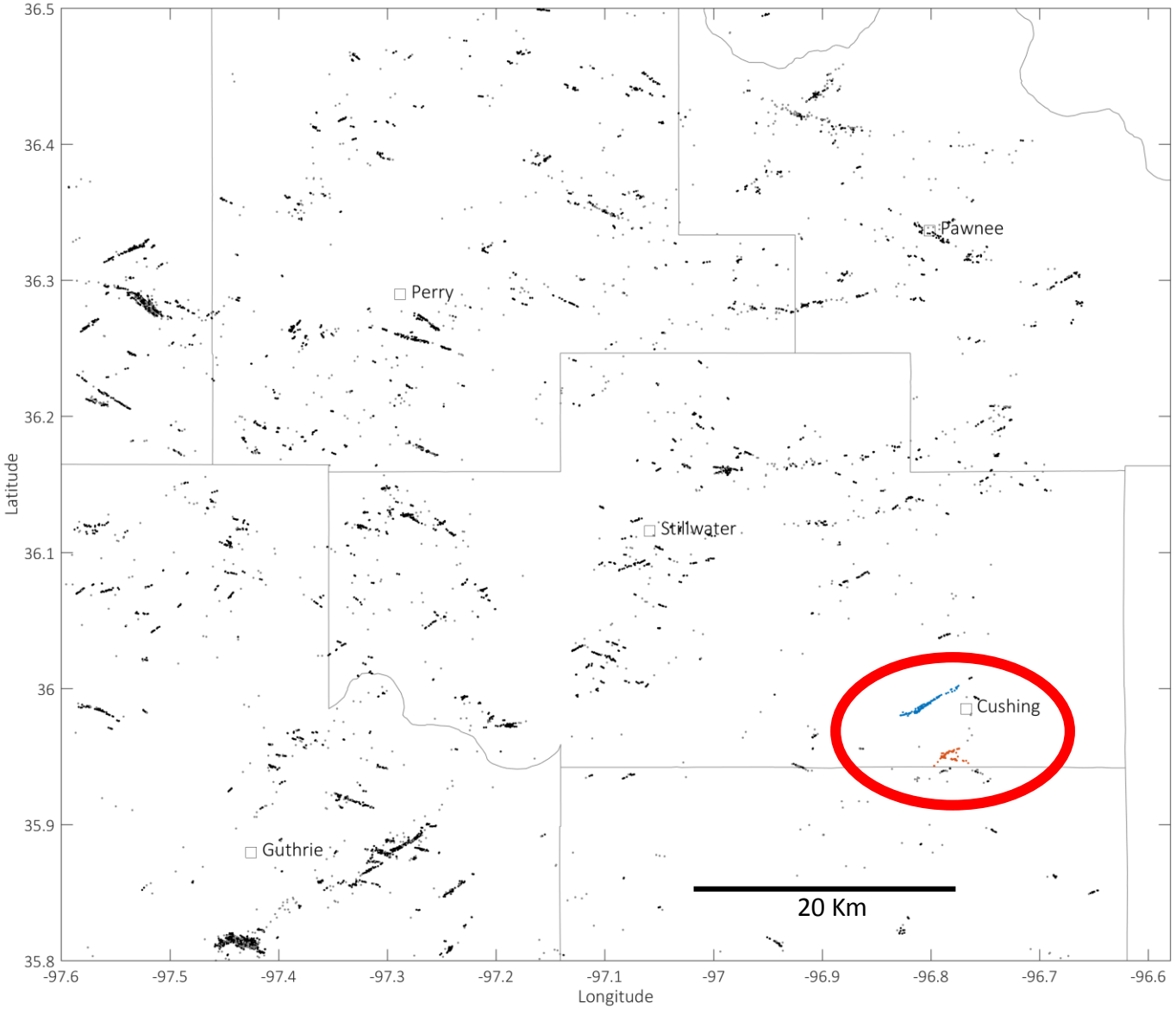
Huang, Ellsworth, Beroza (submitted)

2014 – 2016 Cushing, OK, Earthquake Sequences



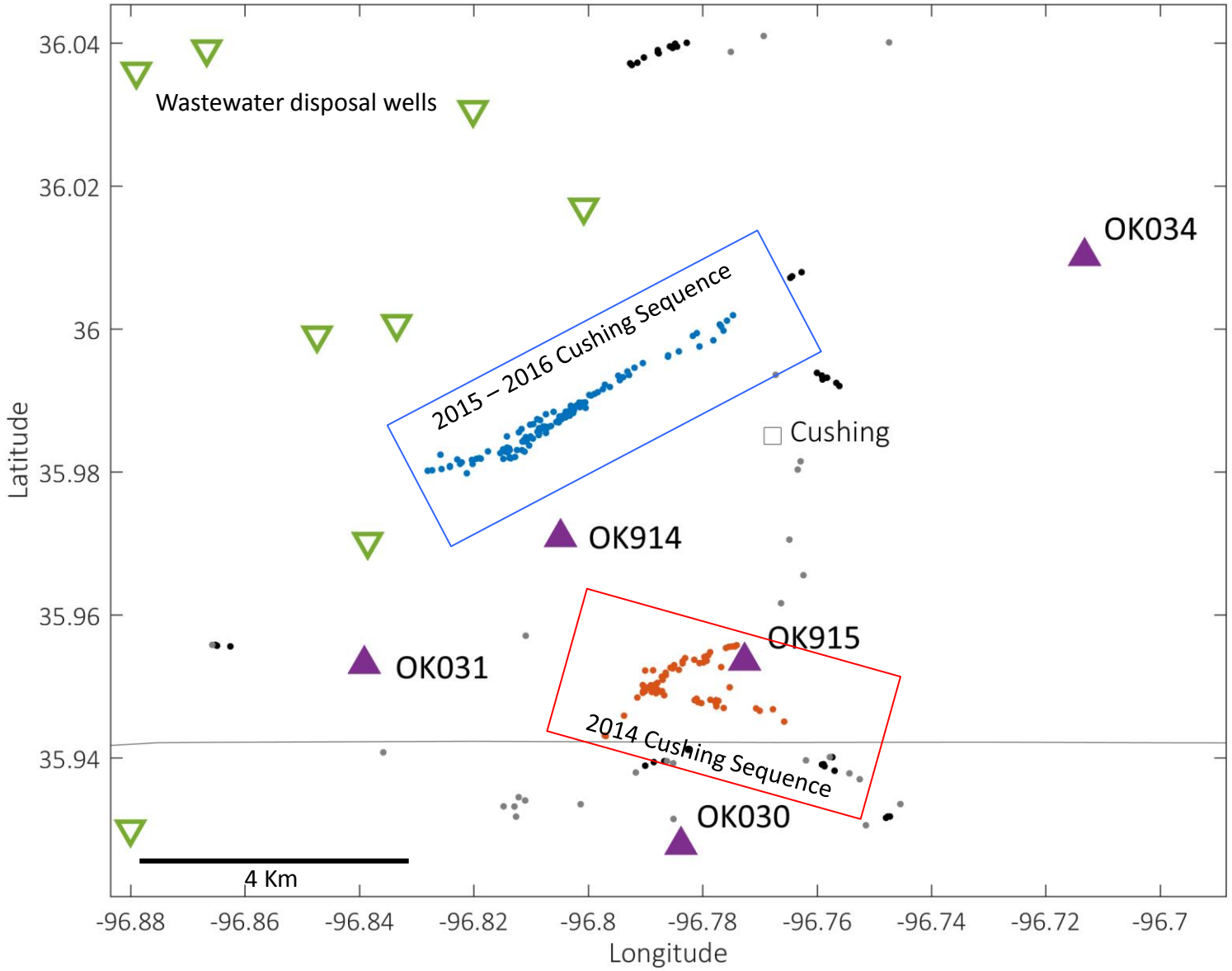


Oklahoma Basement Faults Revealed

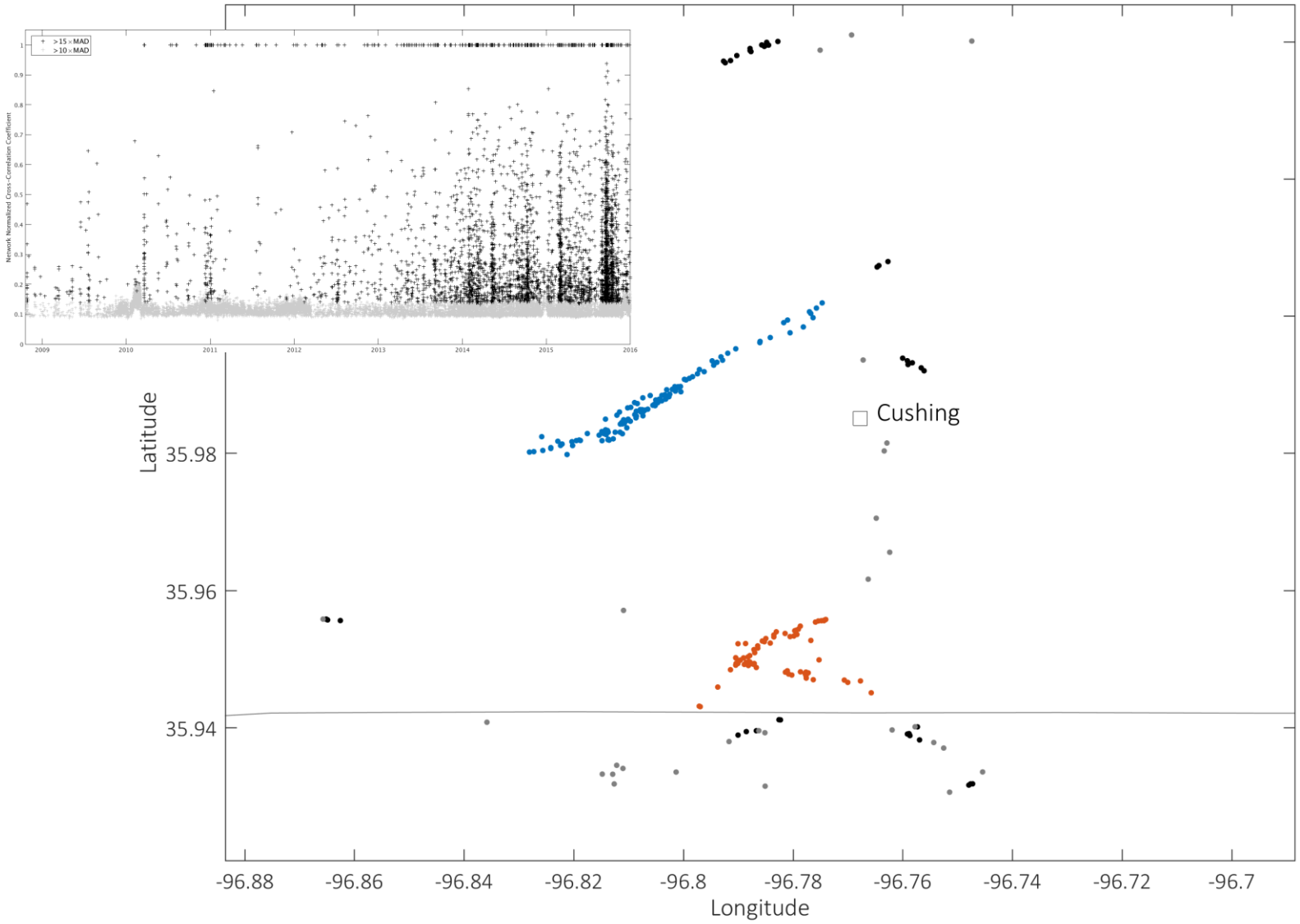


Much more about this in Martin Schoenball's talk

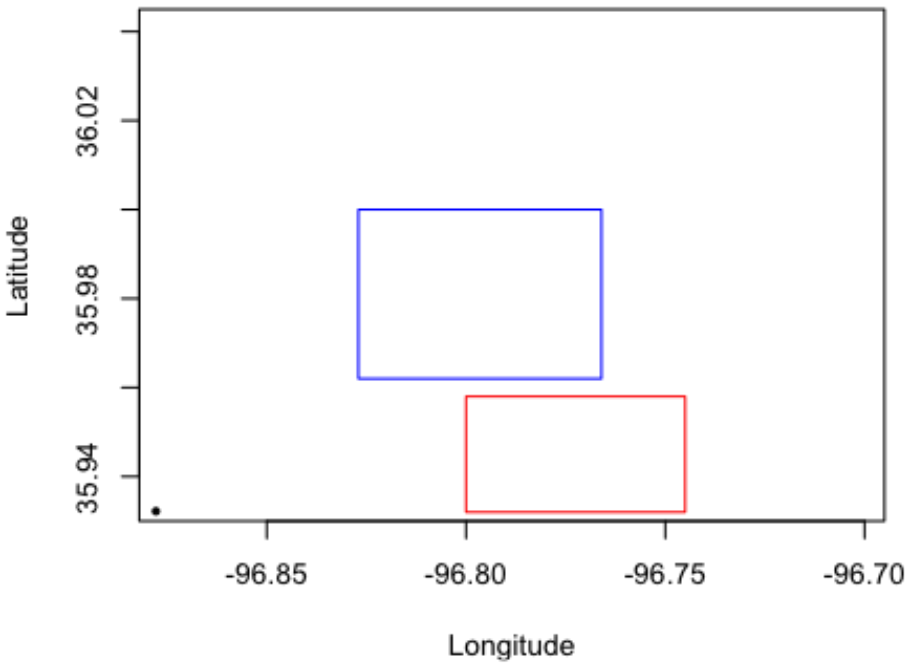
2014 and 2015-2016 Cushing, OK, Earthquake Sequences



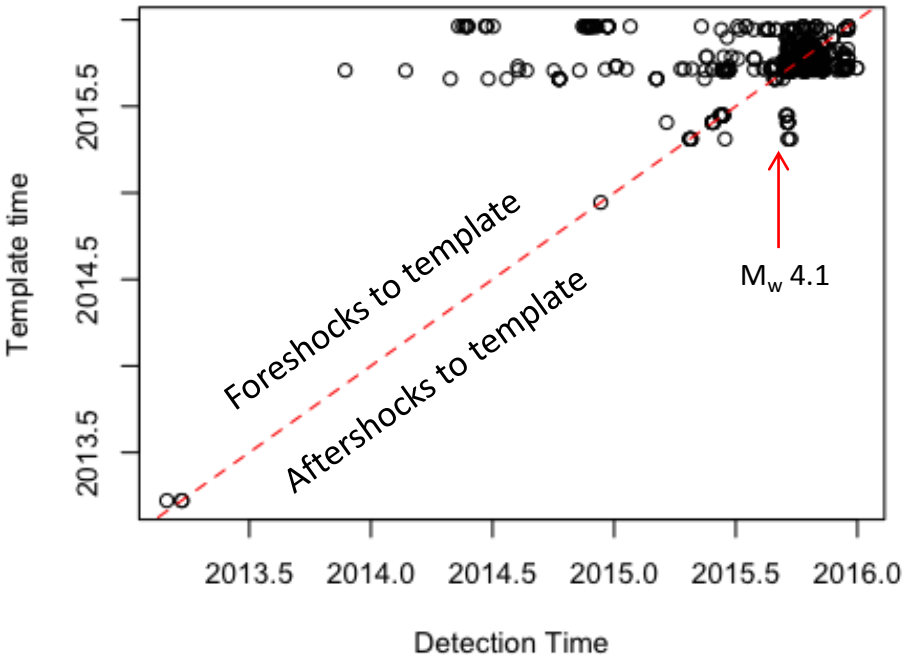
Use Templates to Explore Sequence Initiation

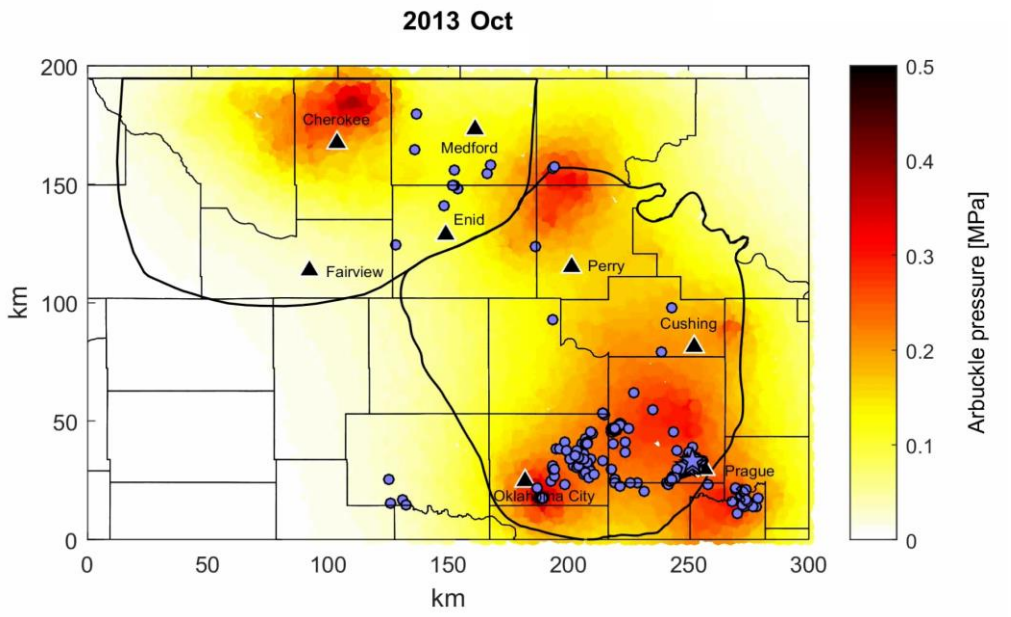


Nothing detected in 2008 – 2012



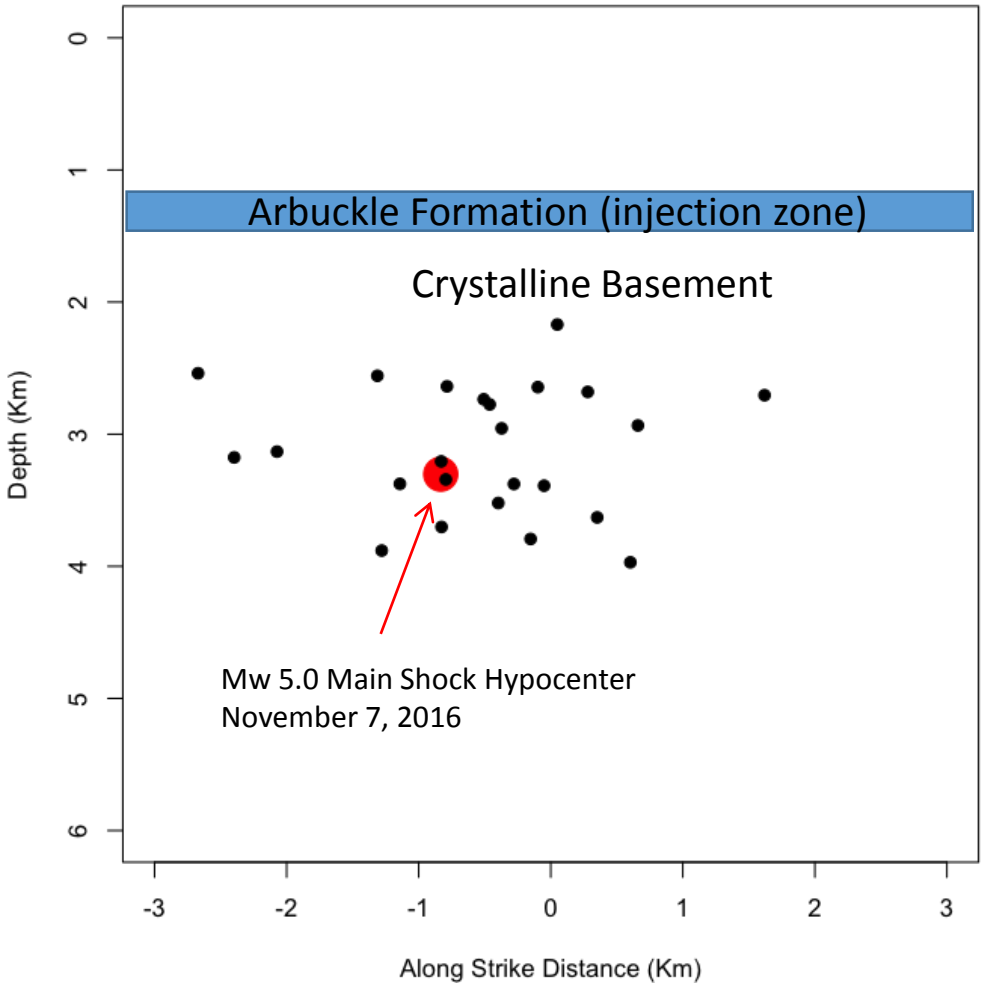
West Cushing templates

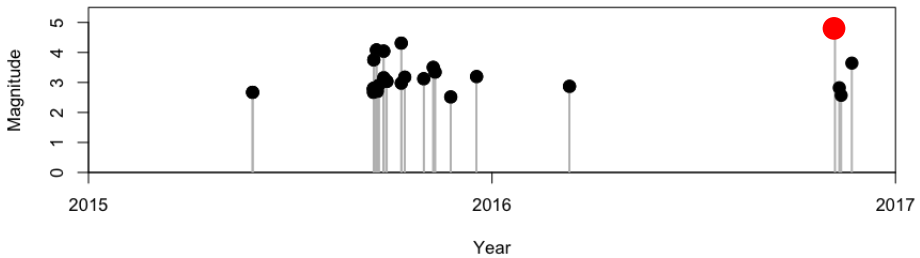




Visit Matt Weingarten's poster for more information

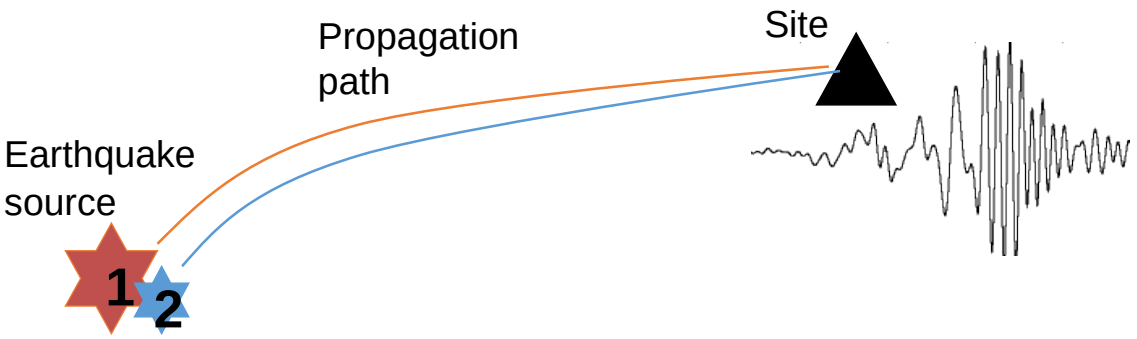
Seismicity Leading Up to the M_w 5.0 West Cushing Earthquake

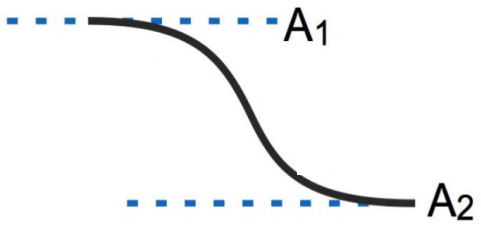




Along-fault cross section with hypocenters determined with hypoDD using cross-correlation timing

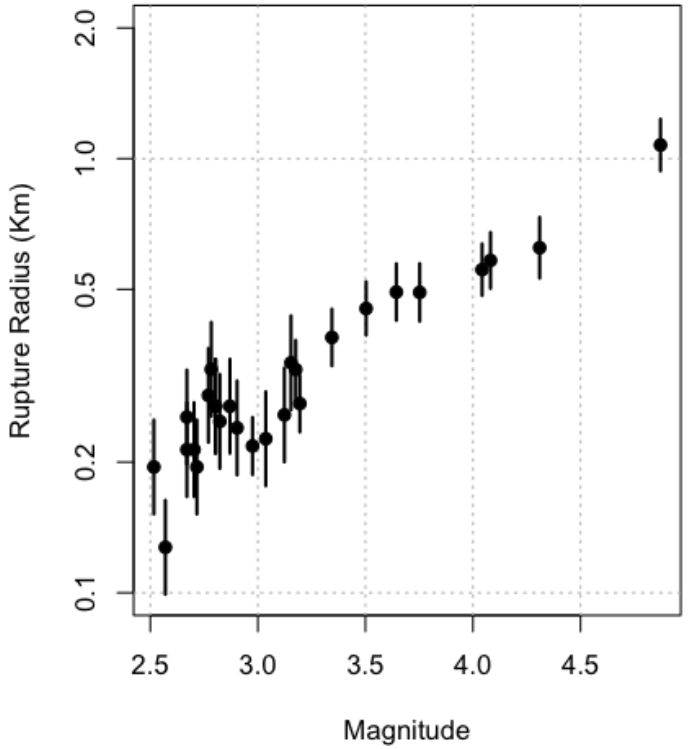
Measure Source Parameters Using The Asymptotic Spectral Ratio Method

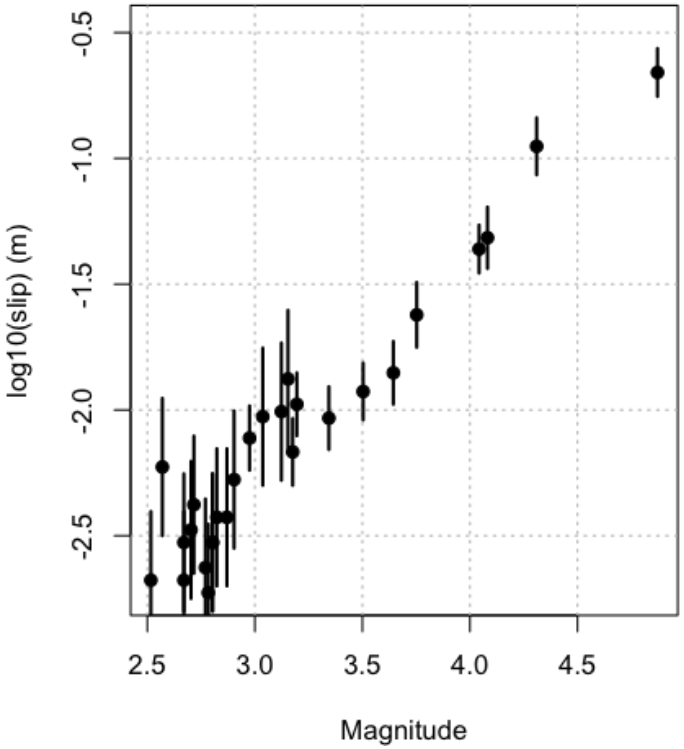




Spectral Ratio

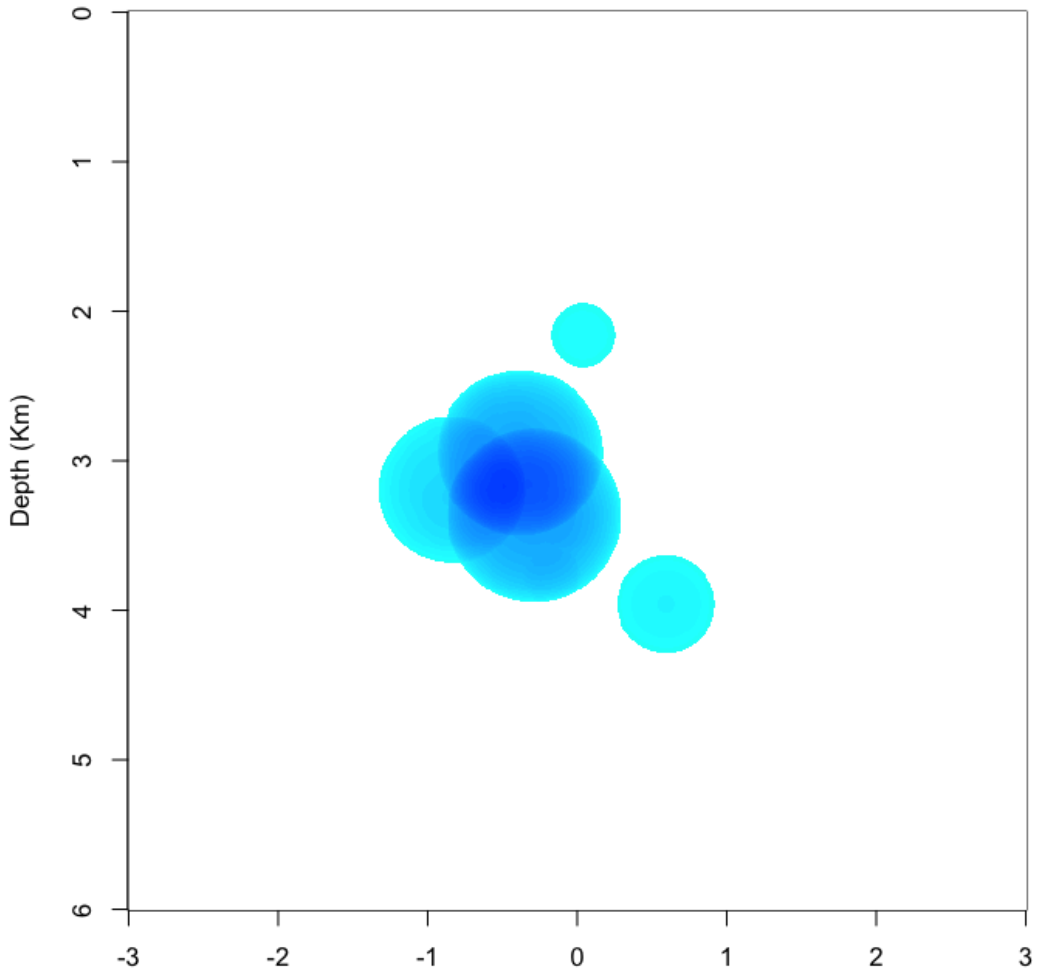
(Irikura and Kamae, 1994)
(Shaw, et al., in prep.)

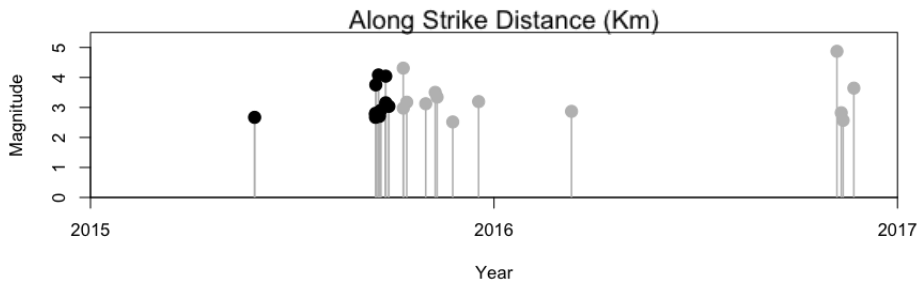




Source Dimension and Slip for West Cushing Sequence

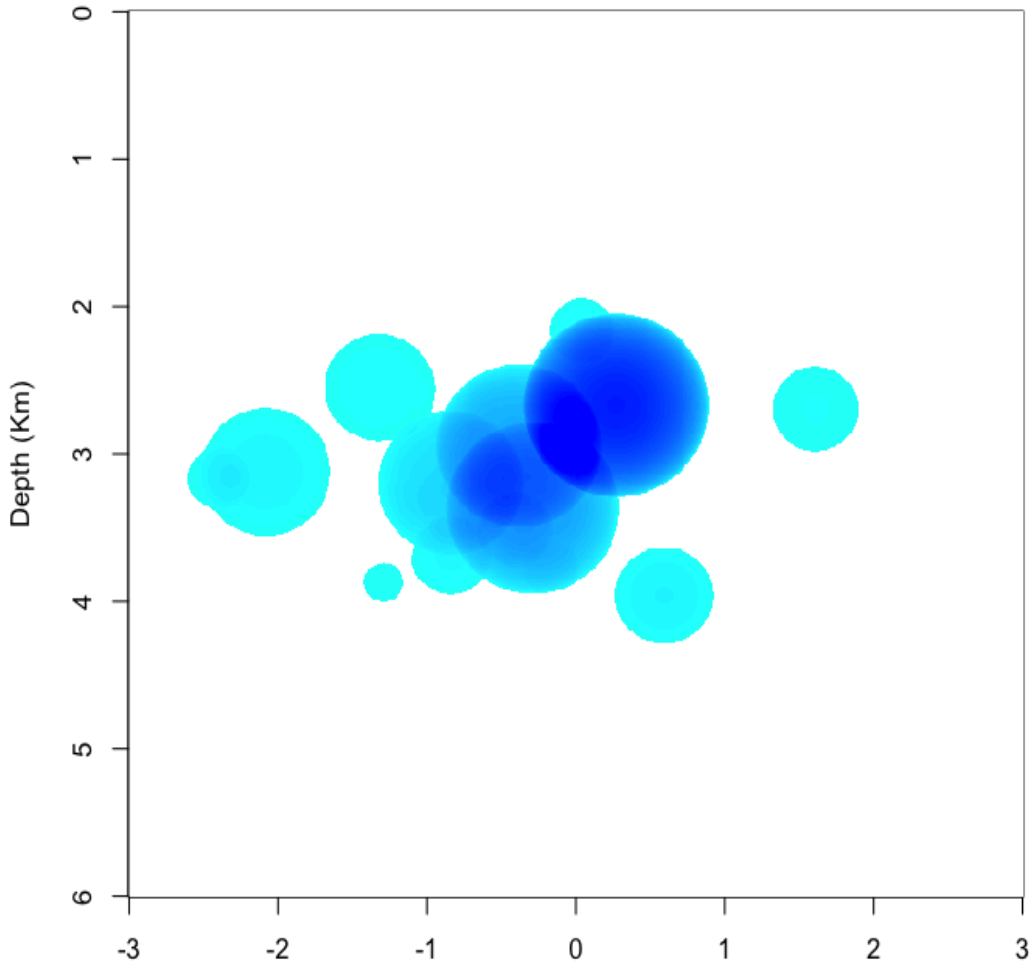
Along Fault Cross Section through September 2015

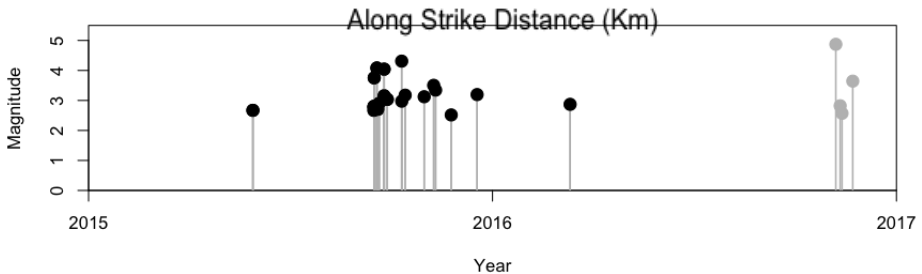




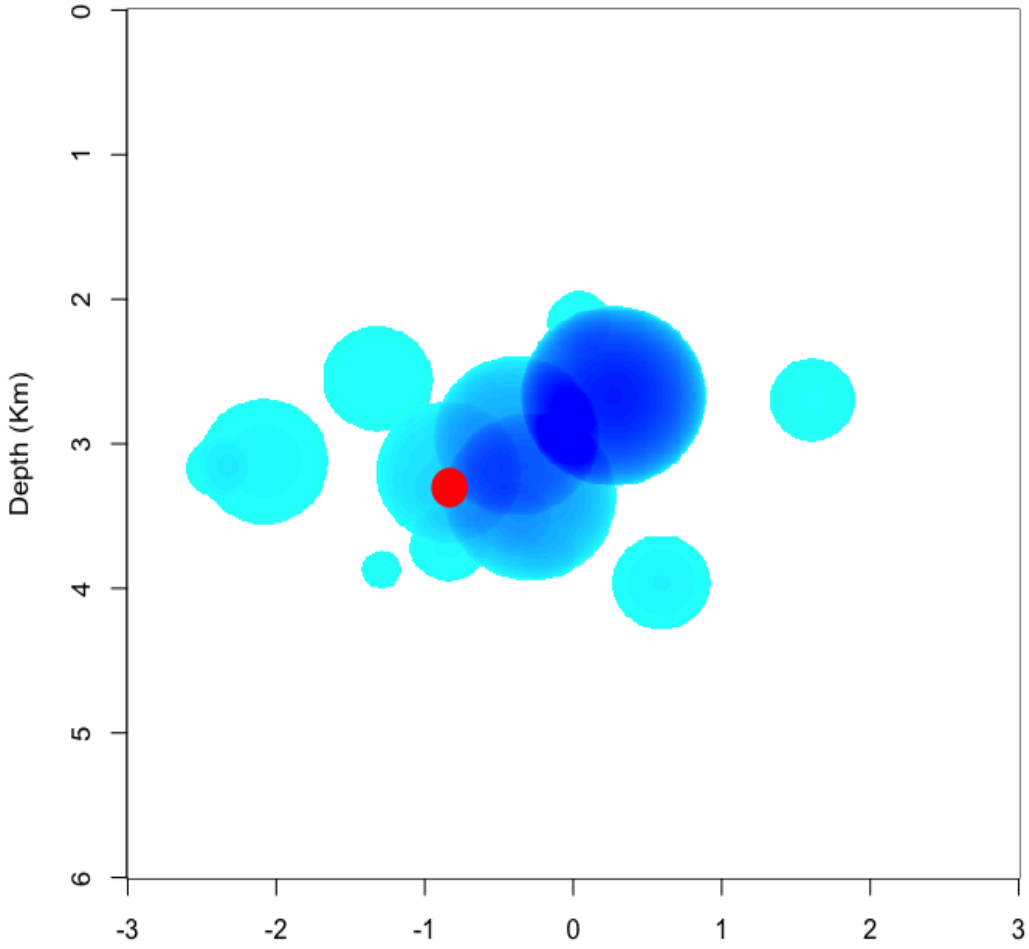
Slip distributed over circular fault using constant stress drop model

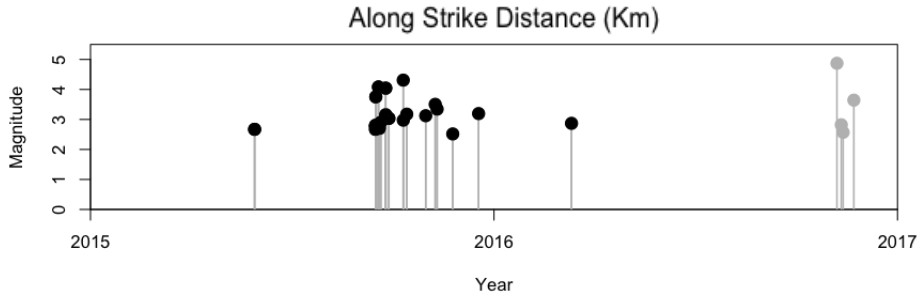
Along Fault Cross Section up to November 2016 Main Shock



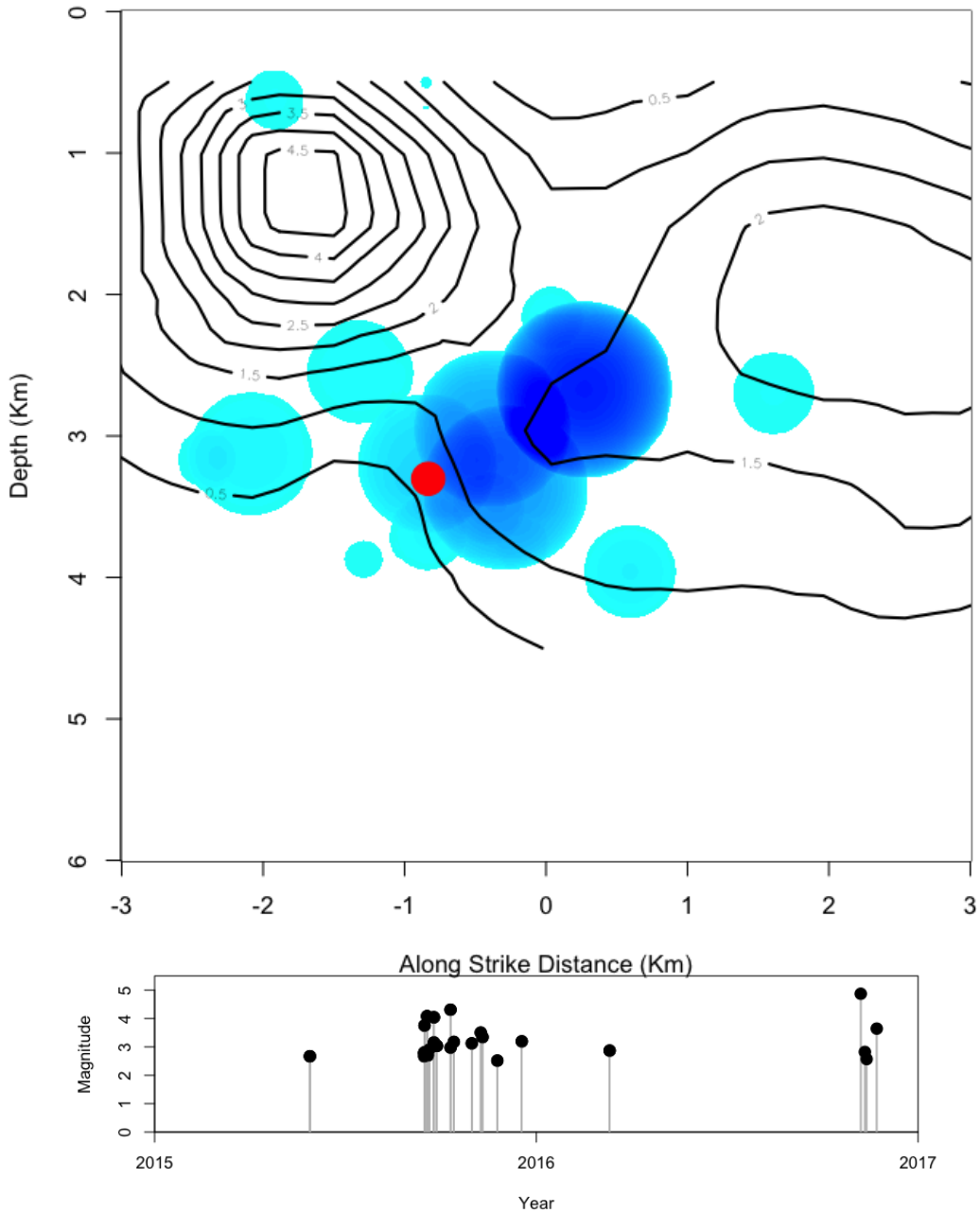


Along Fault Cross Section up to November 2016 Main Shock





Along Fault Cross Section with Main Shock Rupture Contours

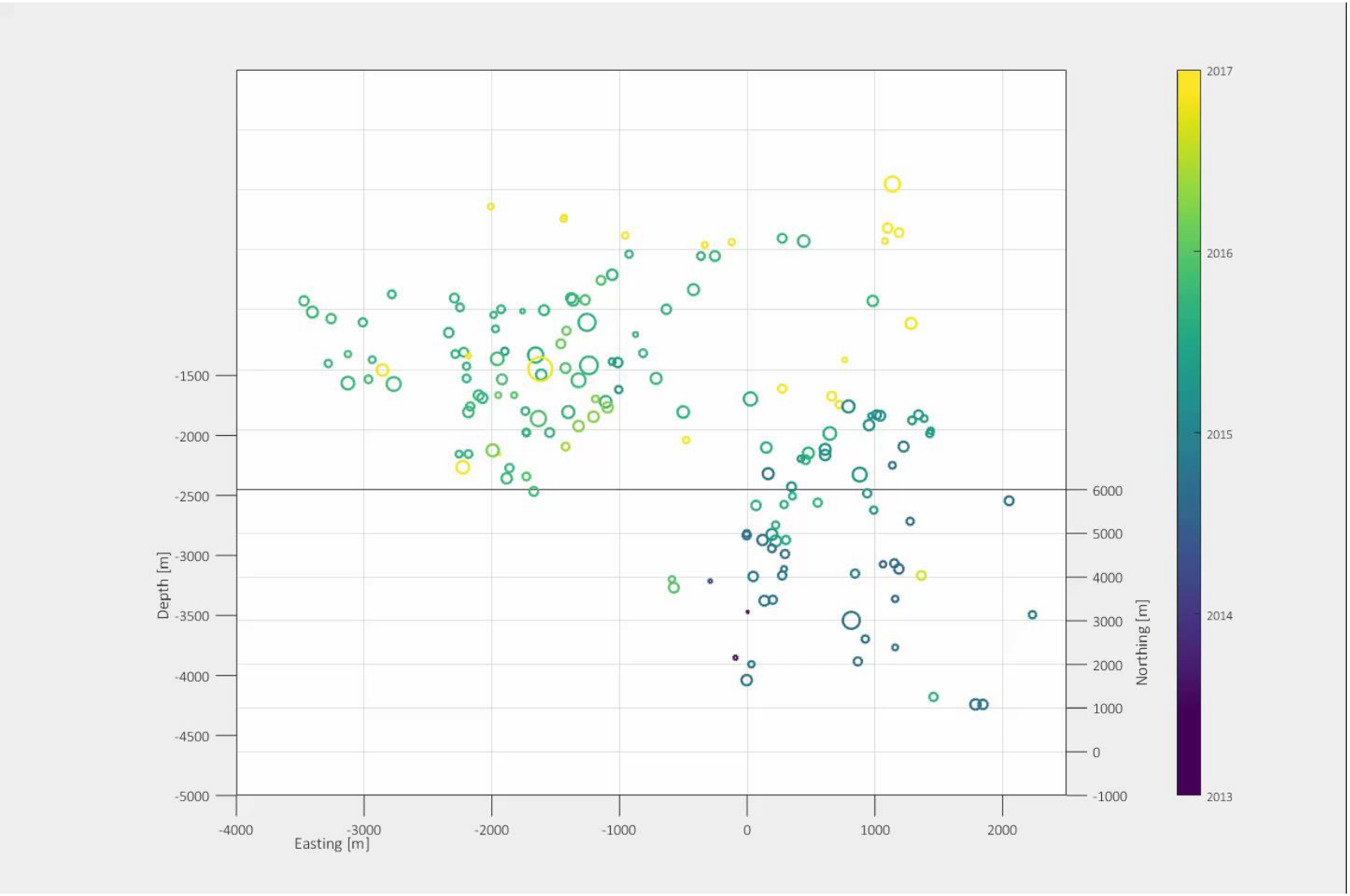


Slip contours of $_{Mw}$ 5.0 derived from kinematic source inversion

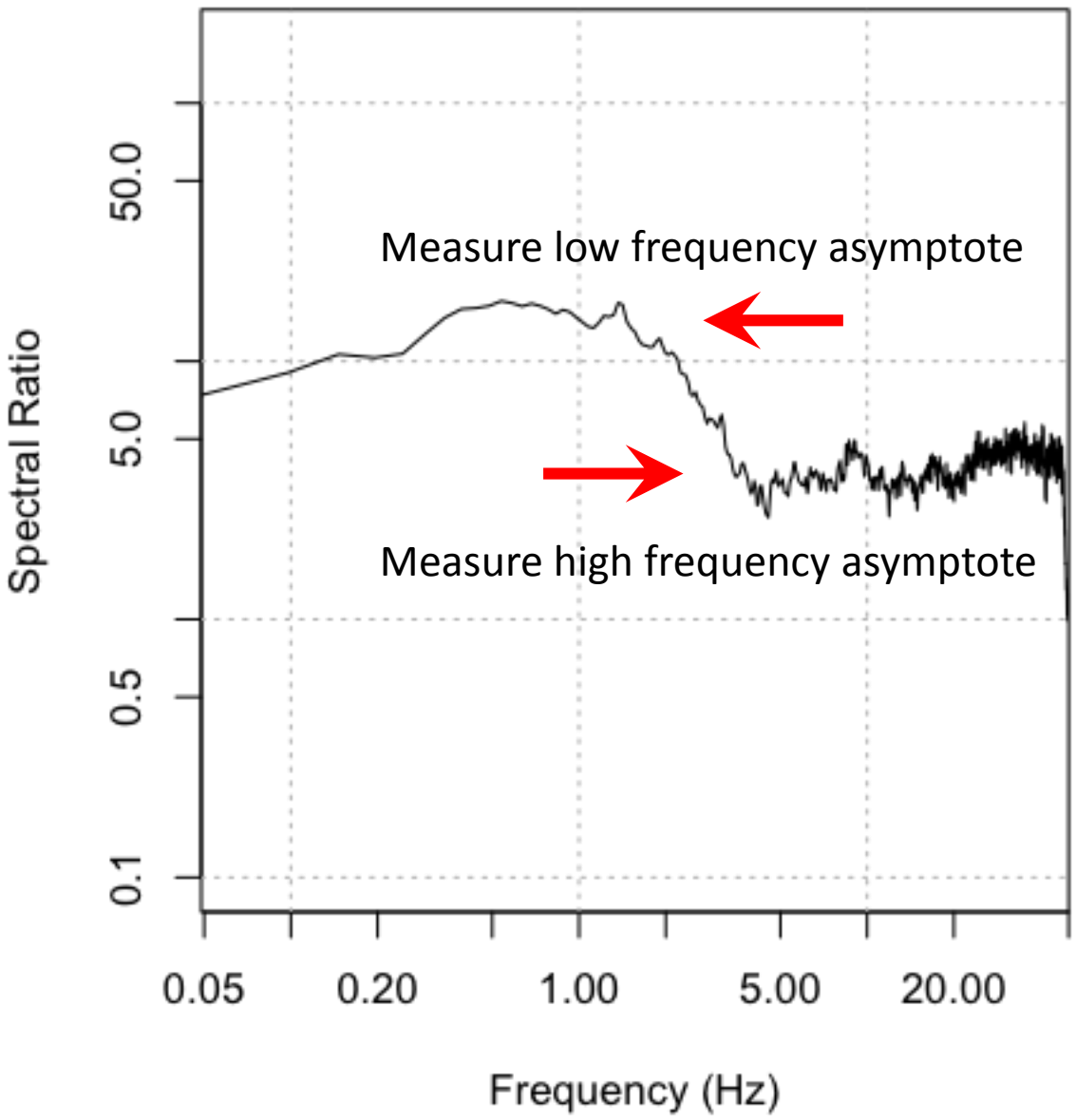
Summary

- The Cushing earthquakes activated strike slip faults in the shallow basement.
- Template detections show that each sequence had measurable activity for over a year before the occurrence of M_w 4+ earthquakes.
- Seismicity initiated at Arbuckle pressure < 0.5 MPa and built as pressure rose..
- The initial activity on the West Cushing fault was highly concentrated, including the ruptures of the Mw 4.1, 4.0 and 4.3 earthquakes in September – October 2015.
- The November 7, 2016 M_w 5.0 main shock hypocenter locates in the same zone.
- Rupture in the M_w 5.0 main shock propagated around the previously ruptured area, spreading both upward and along the fault.
- Shaking in the epicentral region from these earthquakes exceeded 0.5 g, in line with expectations for both induced and tectonic earthquakes in the central U.S.

2014 and 2015-2016 Cushing, OK, Earthquake Sequences



Spectral Ratio for M 3.5 and M 2.7

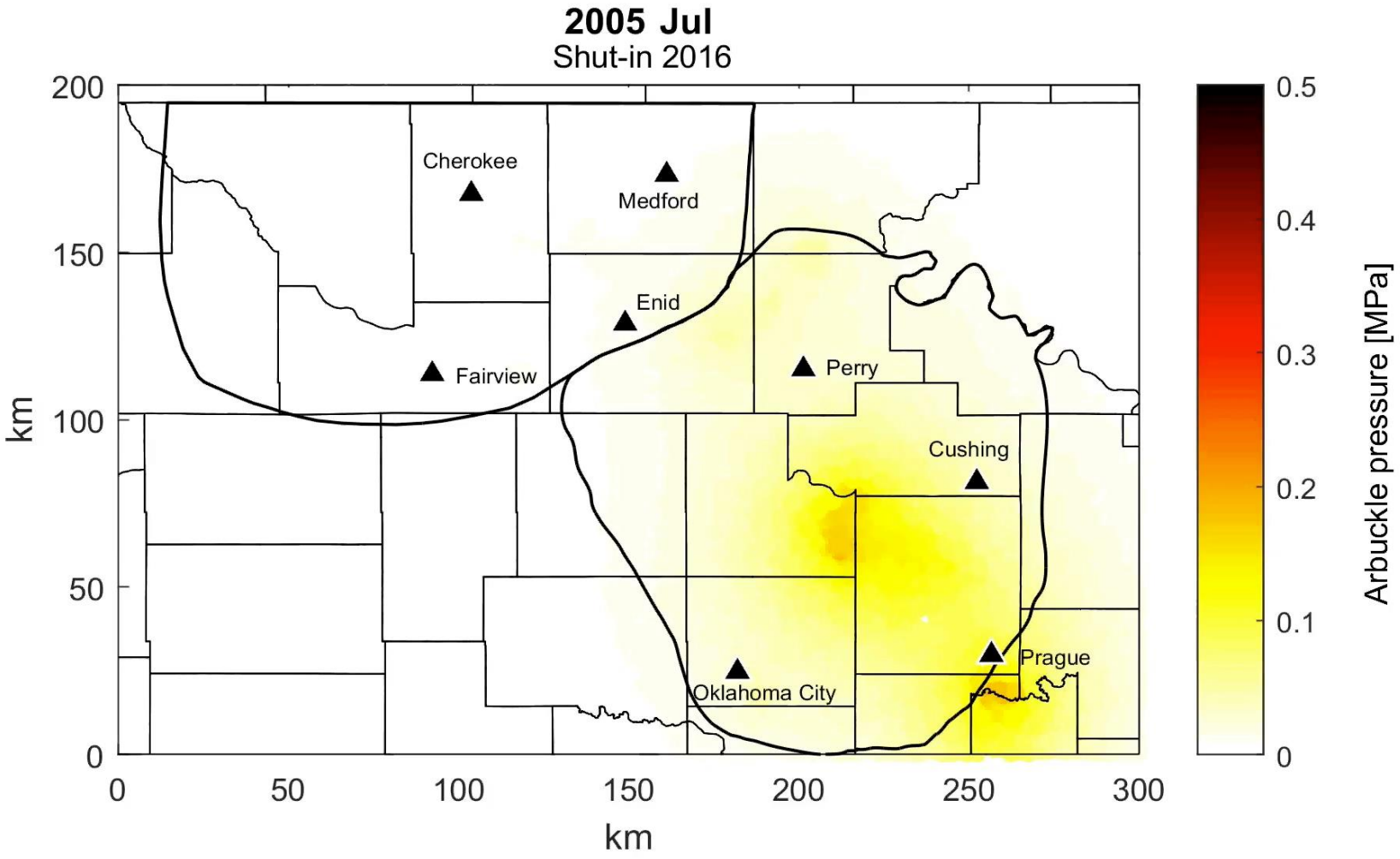


$$\log(Moment\ ratio) = \log(\Omega_0)$$

$$\log(stress\ drop\ ratio)$$
$$\frac{3}{2}\log(\Omega_\infty) - \frac{1}{2}\log(\Omega_0)$$

$$\log(rupture\ length\ ratio)$$
$$[\log(\Omega_0) - \log(\Omega_\infty)]/2$$

$$\log(slip\ ratio) = \log(\Omega_\infty)$$



Weingarten (in preparation)