Summary and Lessons from the North Texas Earthquake Study, 2013-2020

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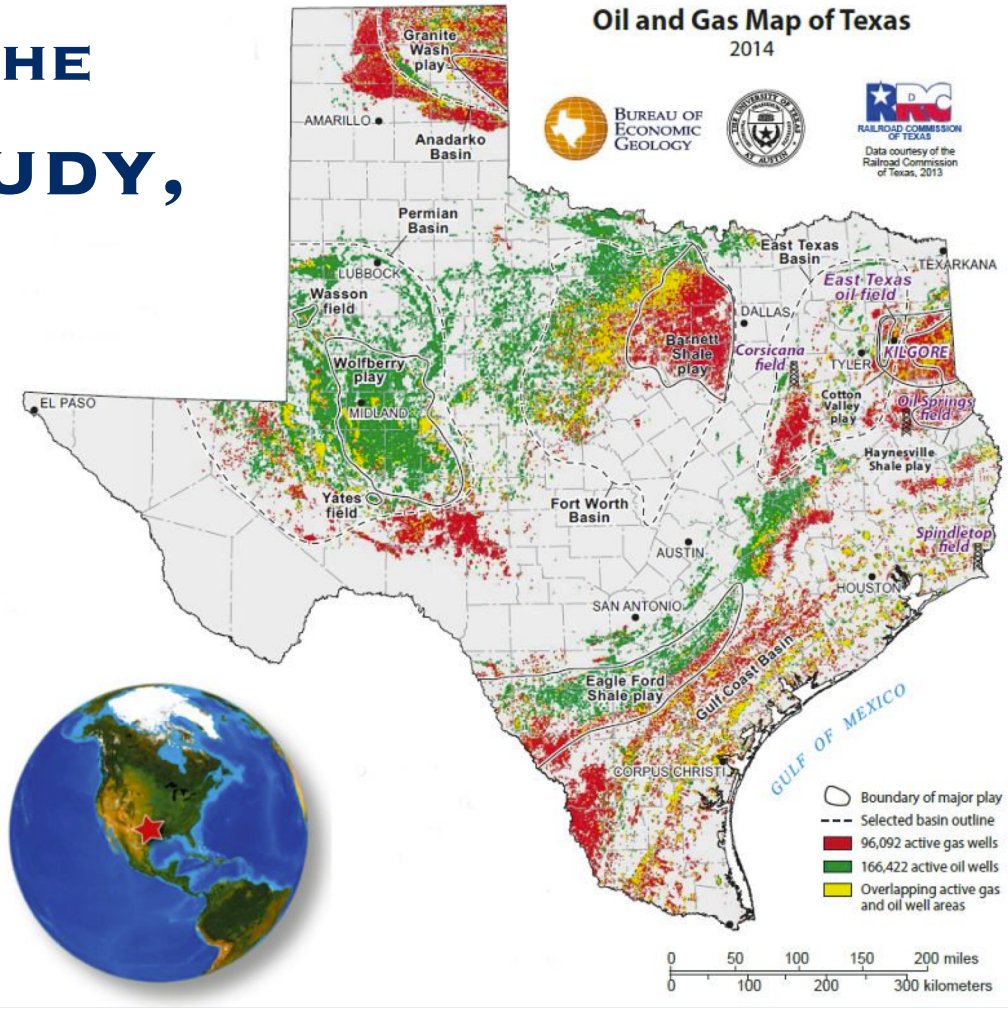
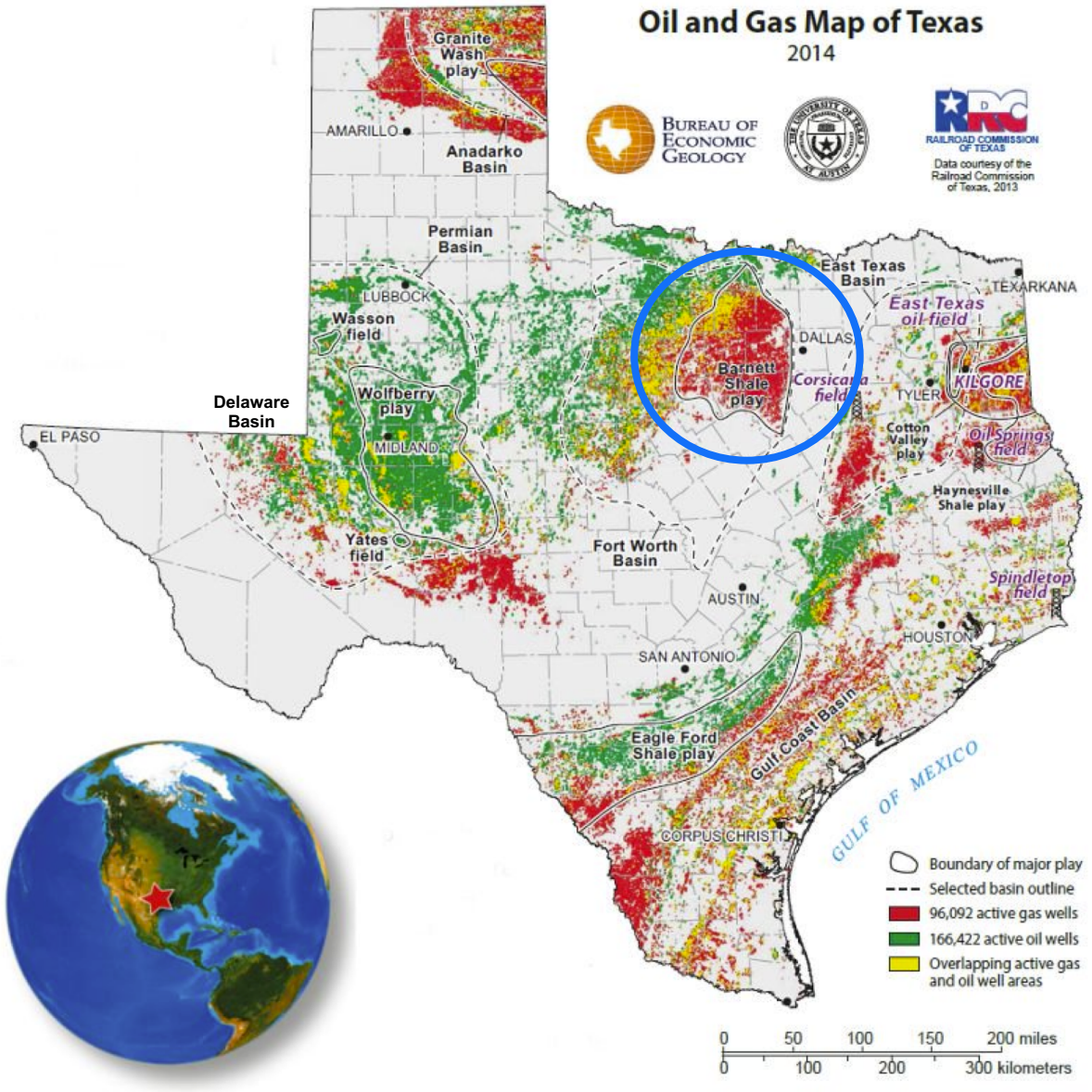
Contributions from L. Quinones, S. Jeong, and others

Regional Induced Seismicity Collaborative Webinar
June 18, 2020



Questions addressed

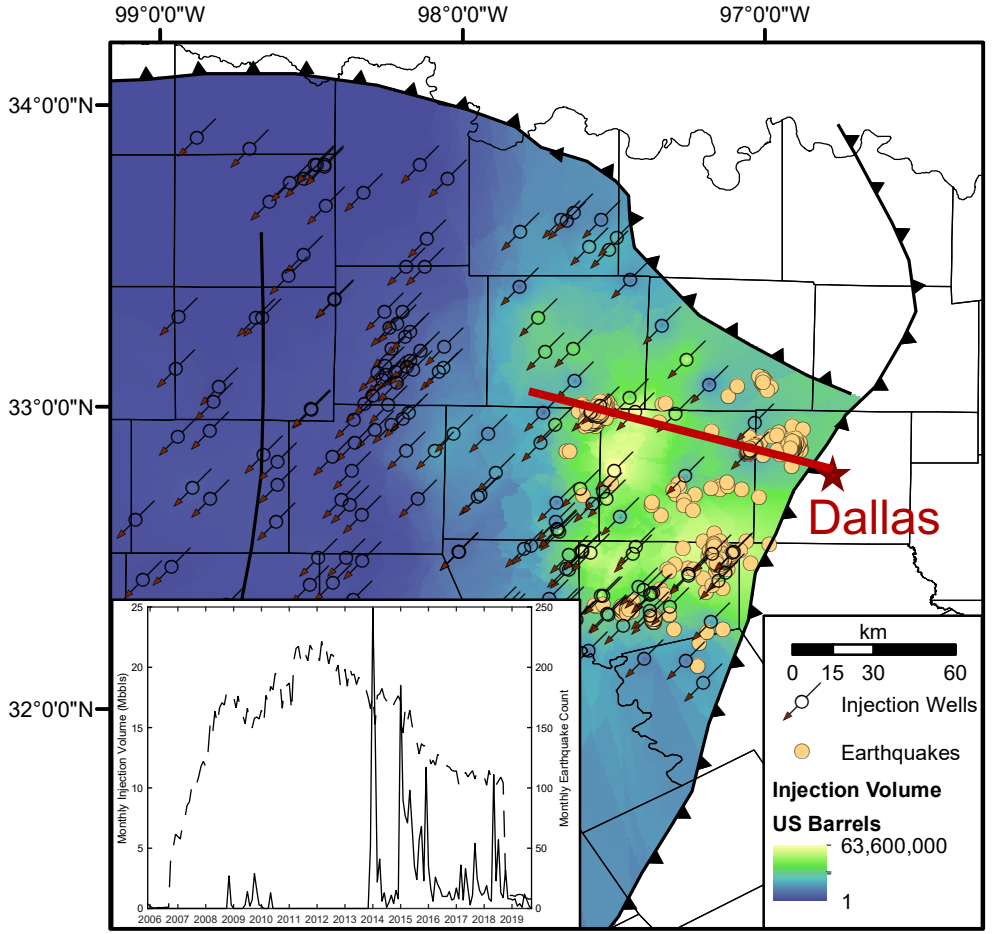
- What do high-resolution local-scale networks reveal about induced earthquakes?
- How were the SMU earthquake catalogs developed and where does monitoring merge into research?
- What do studies of the Fort Worth Basin uniquely reveal about induced earthquakes?
- What are some remaining questions and key missing data needed to effectively design mitigation strategies?



Earthquakes in the Fort Worth Basin are primarily induced by wastewater disposal practices

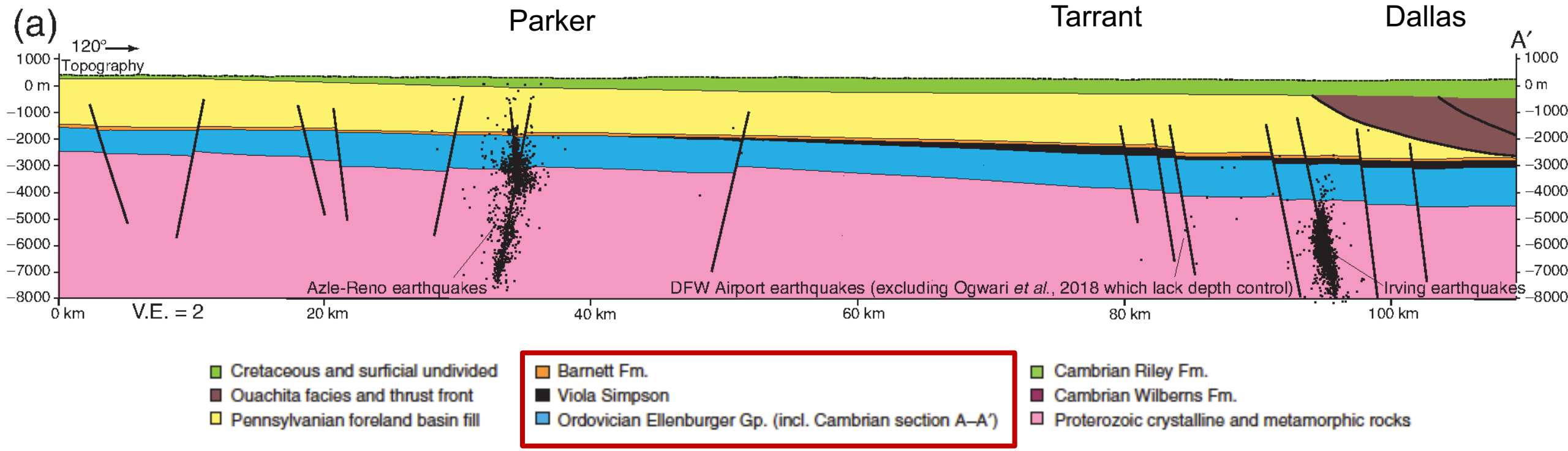
- No known earthquakes in this region prior to 2008
- Earthquakes are spatially & temporally associated with the shale gas play
- North Texas Earthquakes by the USGS numbers:
  - ➡ 1 M4.0, the 2015 Venus earthquake
  - ➡ 35 M3.0+

Cumulative Wastewater Injection: 2005-2019



Quinones et al. 2019 updated from Hornbach et al. 2016

Shale gas is extracted from the Barnett Shale and waste fluids are injected into the Ellenburger formation.



Faults link to the crystalline basement, where most earthquakes occur.

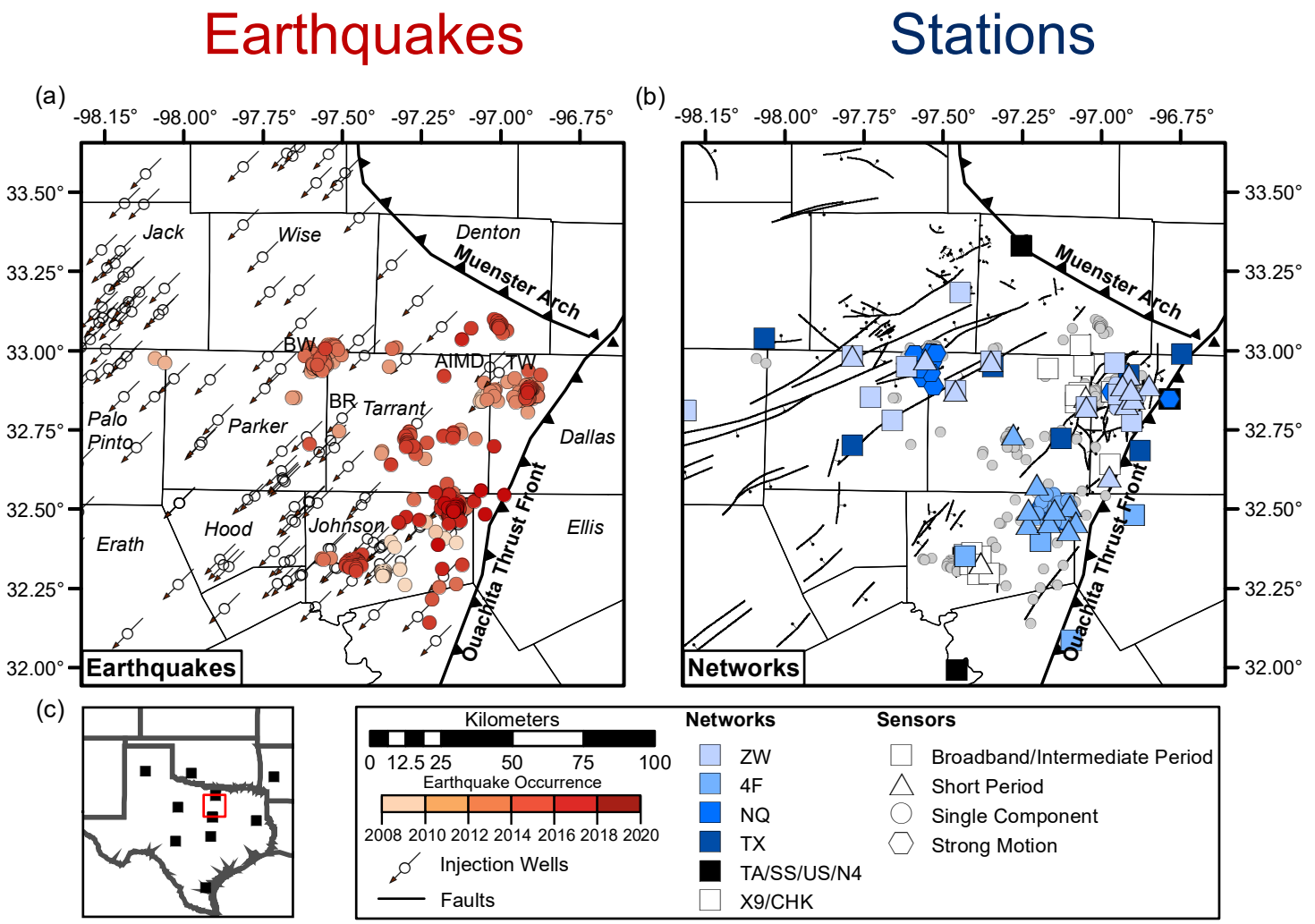
Where are the faults? How can we tell which faults can host earthquakes?

Hennings et al. 2019 from multiple sources

Network Operations & Catalogs in the FWB

- NTXES Network and Catalog
  - Combines early 2008-2009 work with focused study 2013-present
  - Peak at 40 SMU stations in 2016
- Texas Seismic Network & Catalog
  - Online January 2017

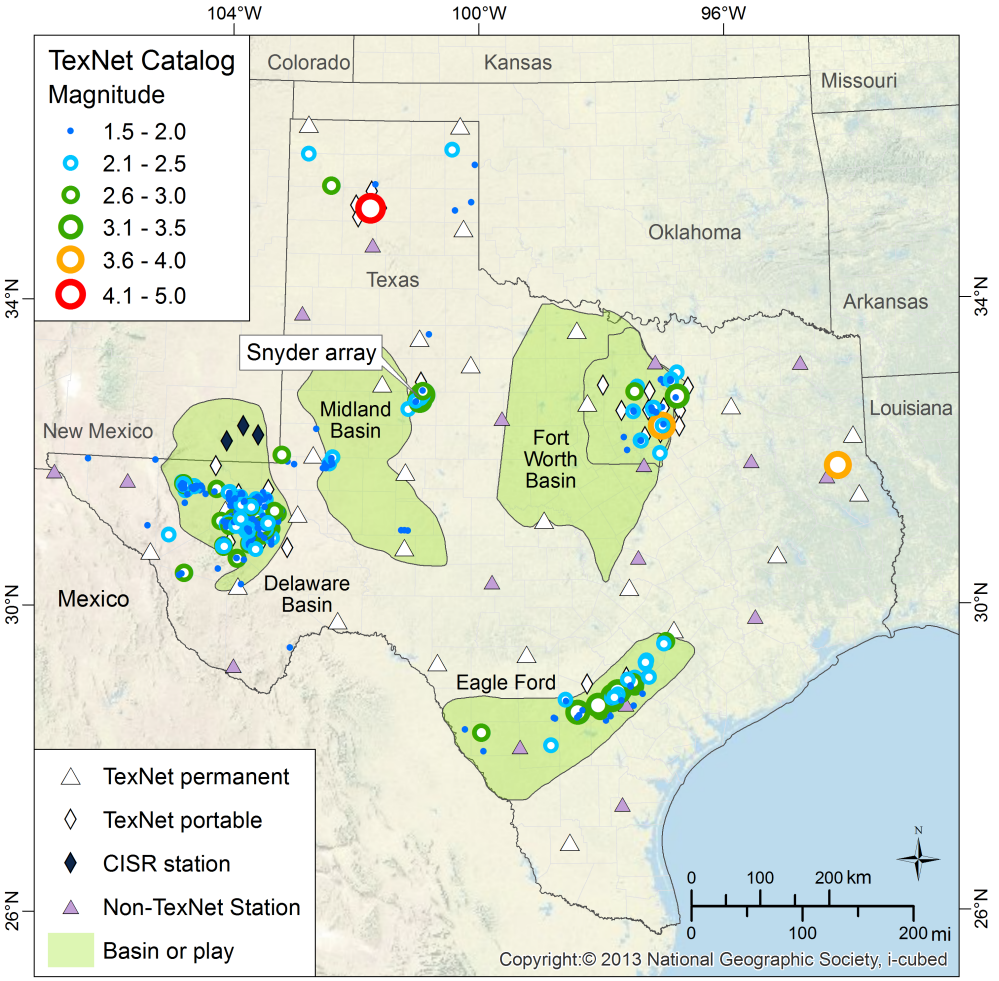
~40 stations monitoring the basin, combined between TexNet and SMU



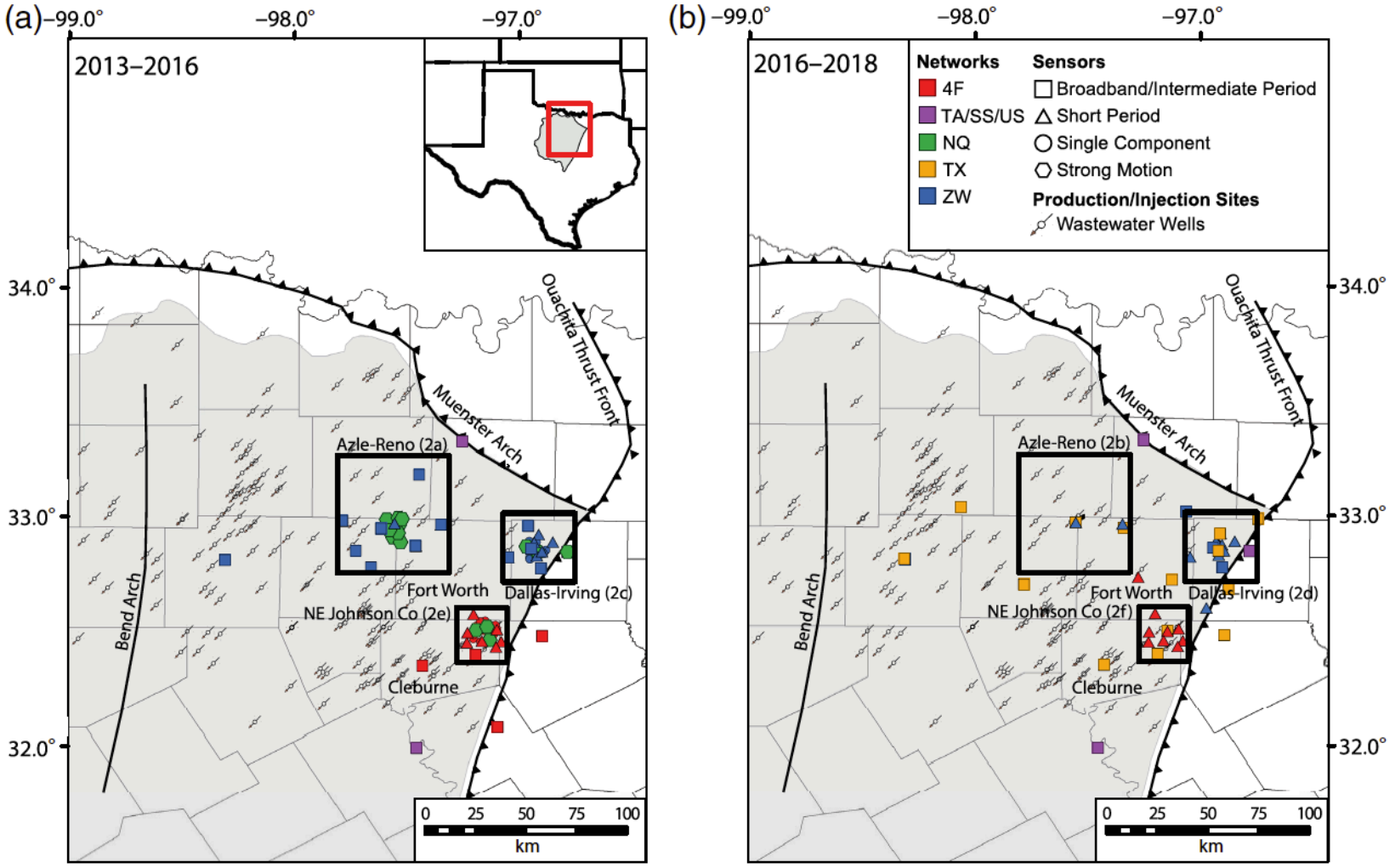
DeShon et al. (2018)

TexNet:
Texas funded a state-wide seismic network in 2015

- Estimated magnitude of completeness in the USGS ComCat for Texas is ~M2.7
  - 18 broadband stations in Texas prior to 2017
- TexNet added & reduced sensitivity to M1.5
  - 25 permanent broadband seismometers
  - 33 portable systems (broadband+strong motion)
- Temporary networks supplement in areas of interest ➡ SMU research networks



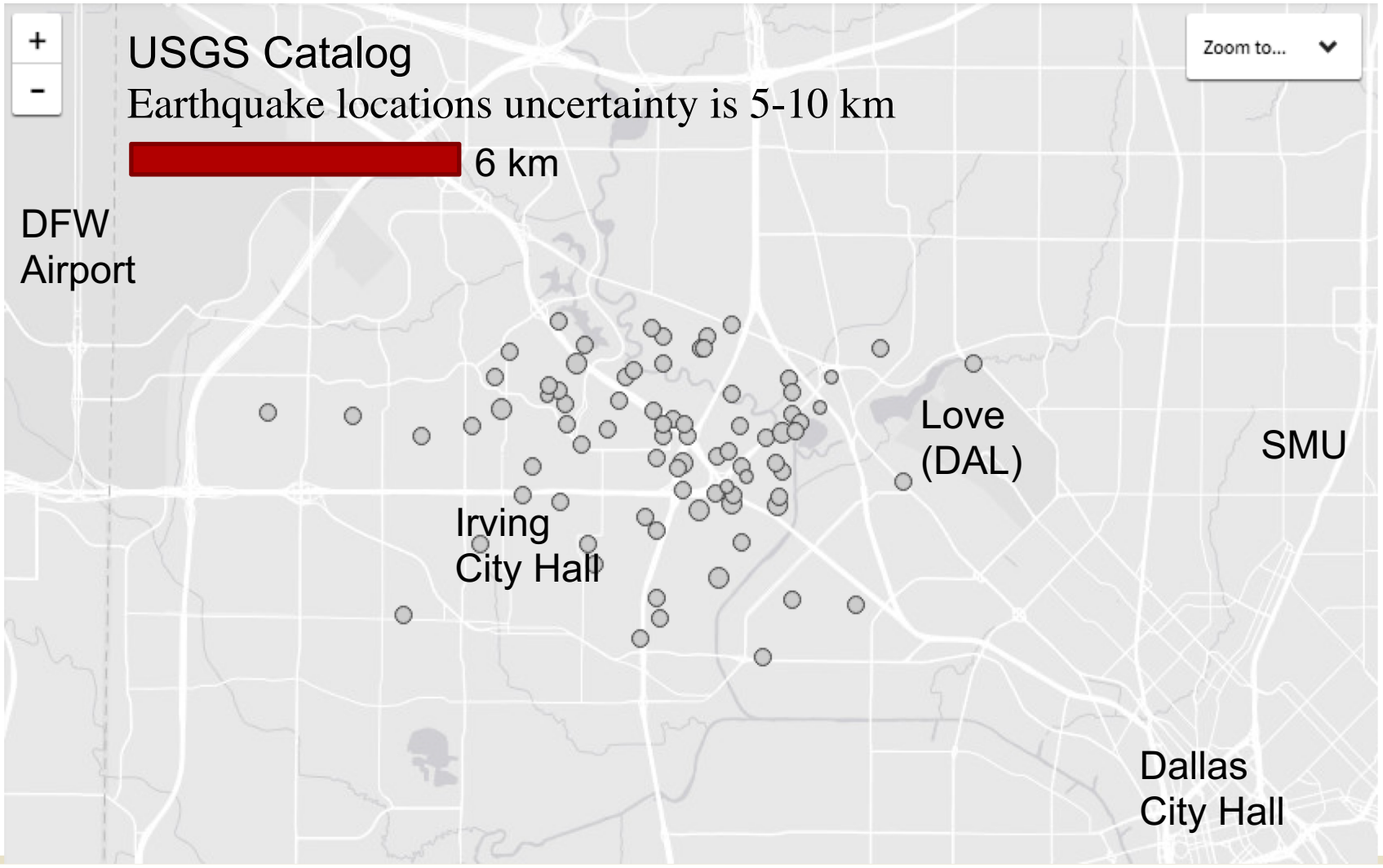
What do local and near-regional studies reveal about induced earthquakes relative to regional networks?



- Earthquakes in space to <1 km epicentral uncertainty
- Earthquake depth
- Earthquake source parameters (stress drop, moment, etc.)
- Earthquake recordings to lower magnitudes
- Ground motions at finer scales

DeShon et al., 2018

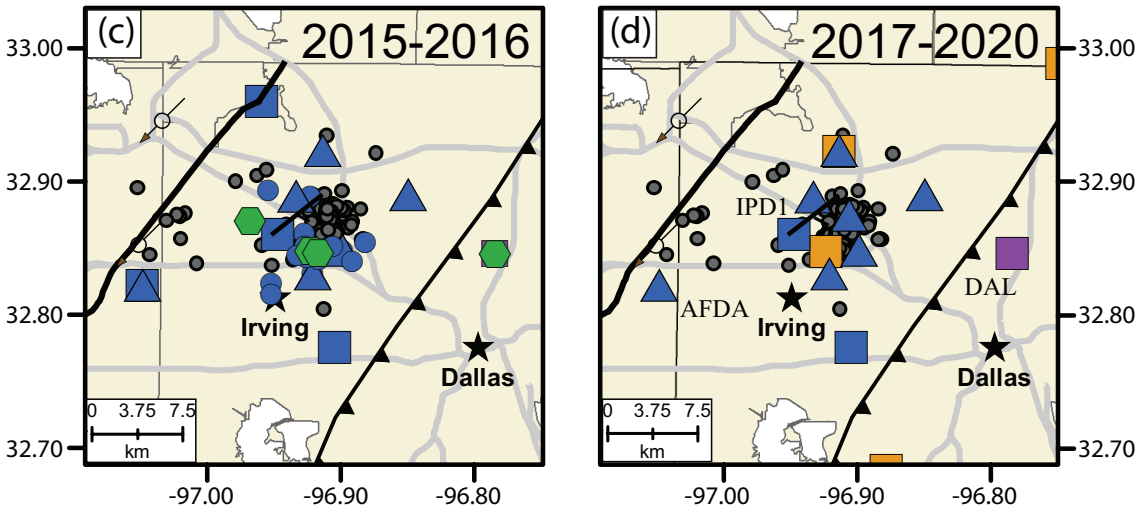
Local seismic data resolves faults and fault behavior



Building a catalog:

Install stations ➡ Resolve depth, smallest size, azimuthal coverage

Example: Irving-Dallas Eq Sequence

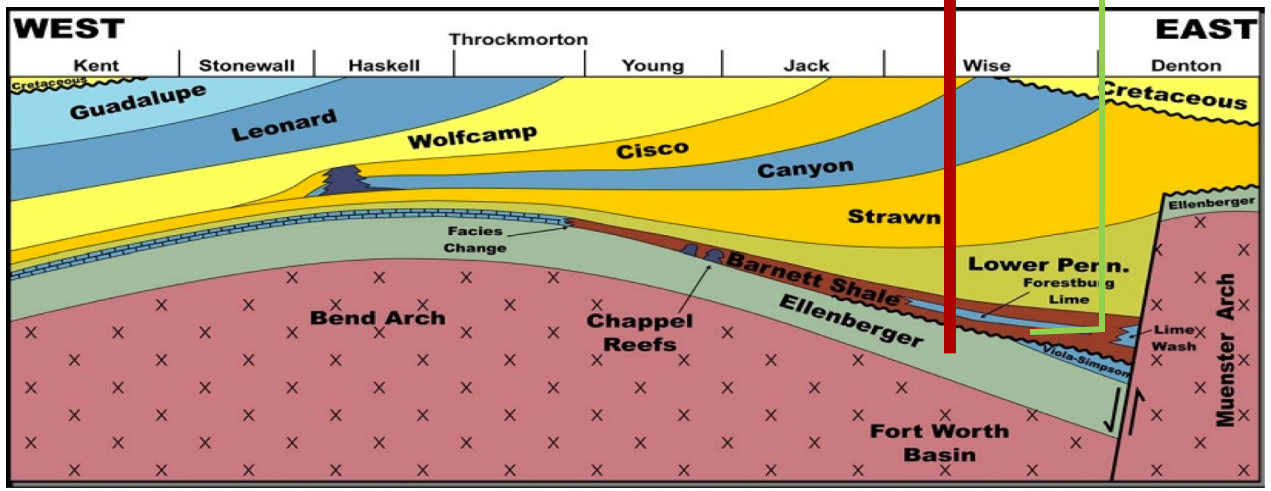


- Constraints at SMU for NTXES 4F & ZW
  - Limited choice in sensor type
  - Rapid response deployments – speed matters
- Stage 1: Texans (<10 days operation)
- Stage 2: Concentric circles, telemetered
  - 1 station within a focal depth (<5 km)
  - Short-periods & strong motion within 5-10 km
  - Broadbands at 10-25 km

DeShon et al. (2018)

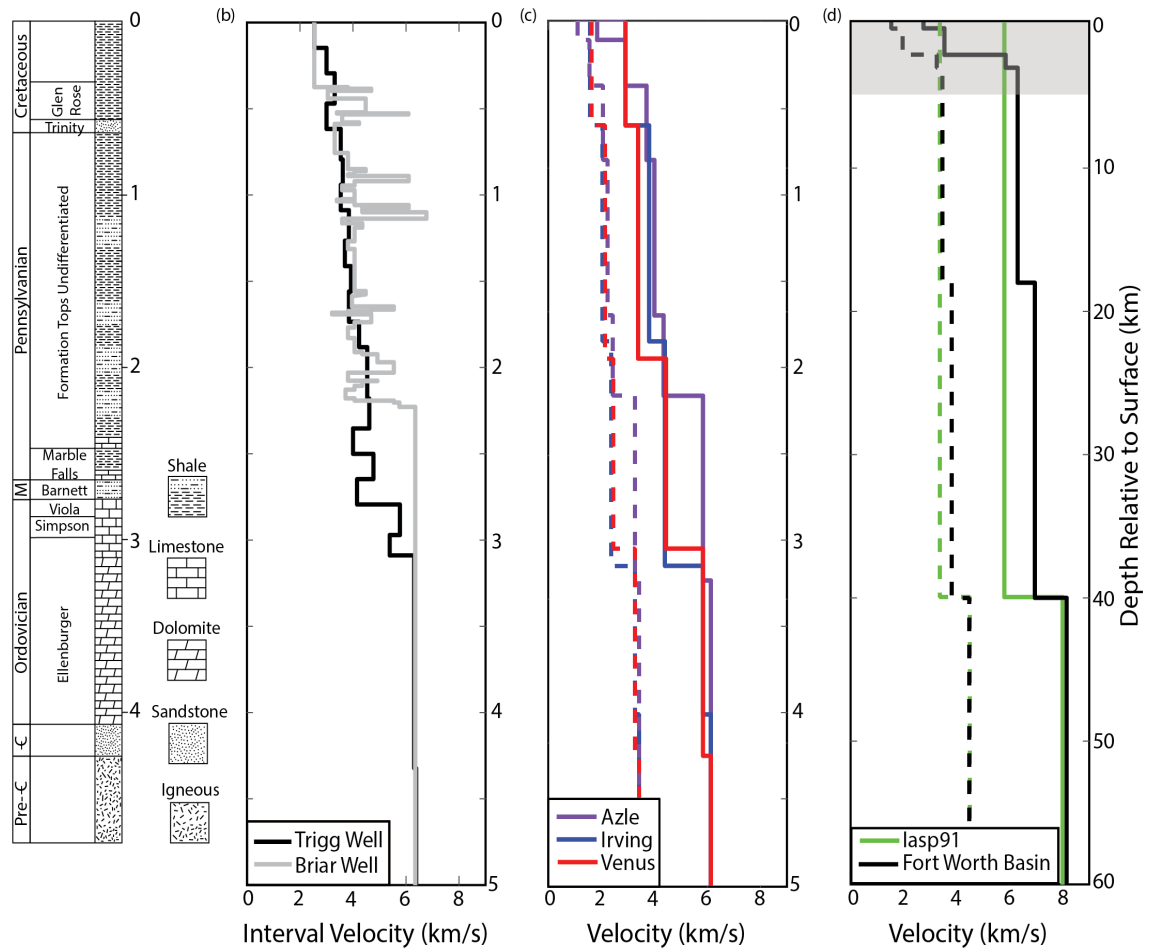
Building a catalog:
Characterize the subsurface geology and velocity

Fort Worth Basin



SWD Producer

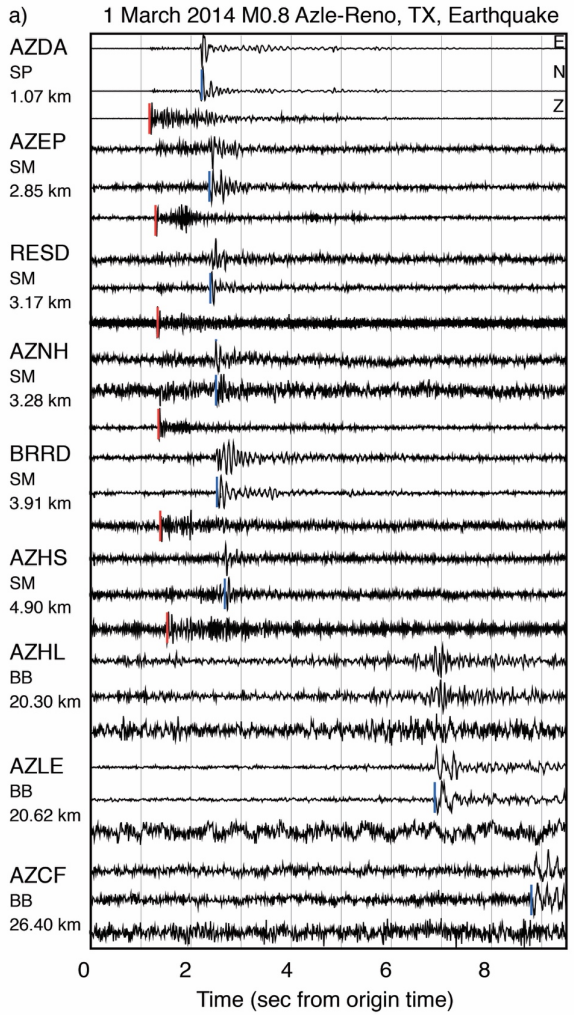
Stratigraphy Logs Network Operations



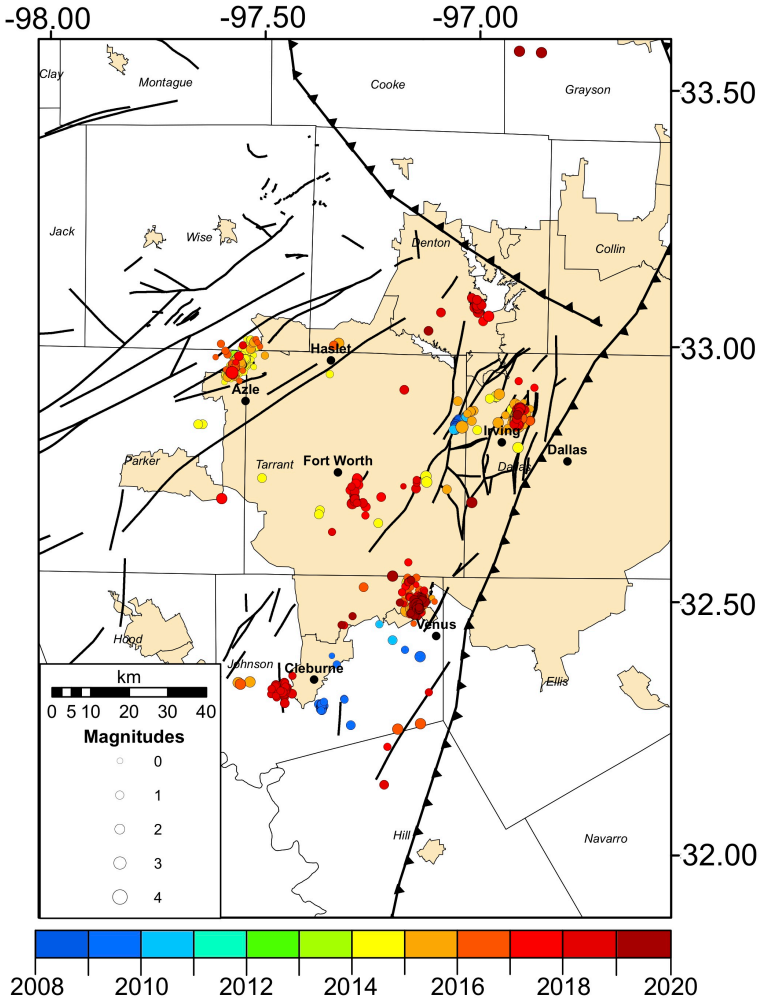
- Well log information can inform:
  - 3D petrophysical models
  - Compressional and shear velocity models
  - Pore pressure and poro-elastic modeling

Quinones et al. (2019); Smye et al. 2019

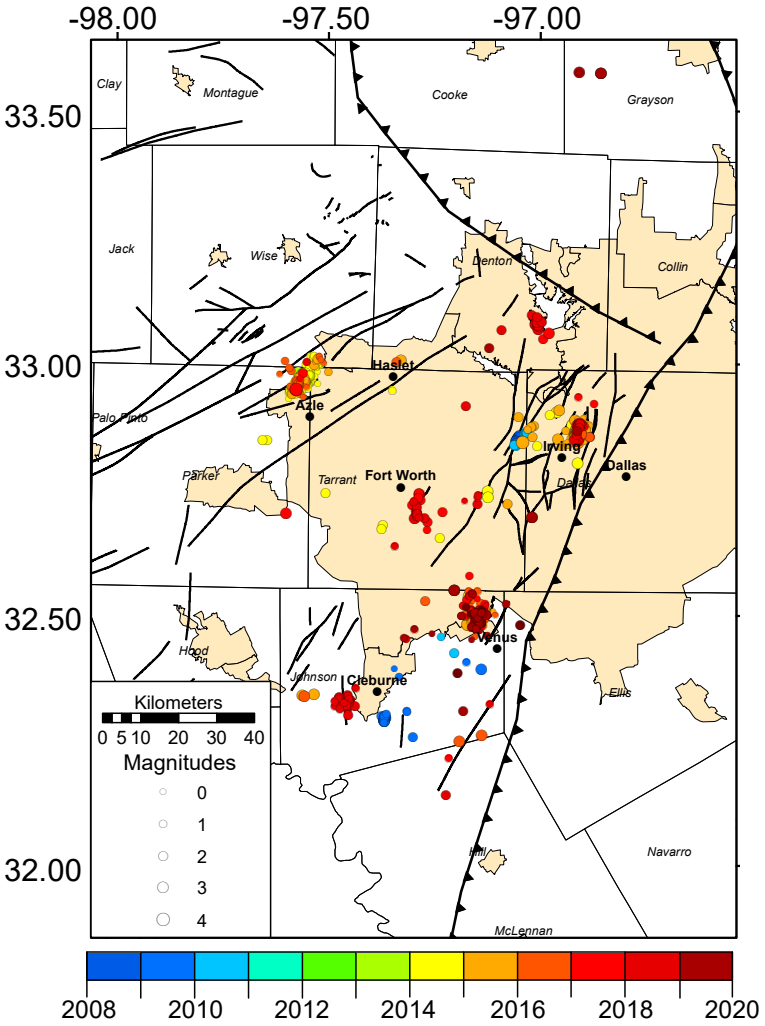
Building a catalog:
Automated and manual review of onset times & initial location

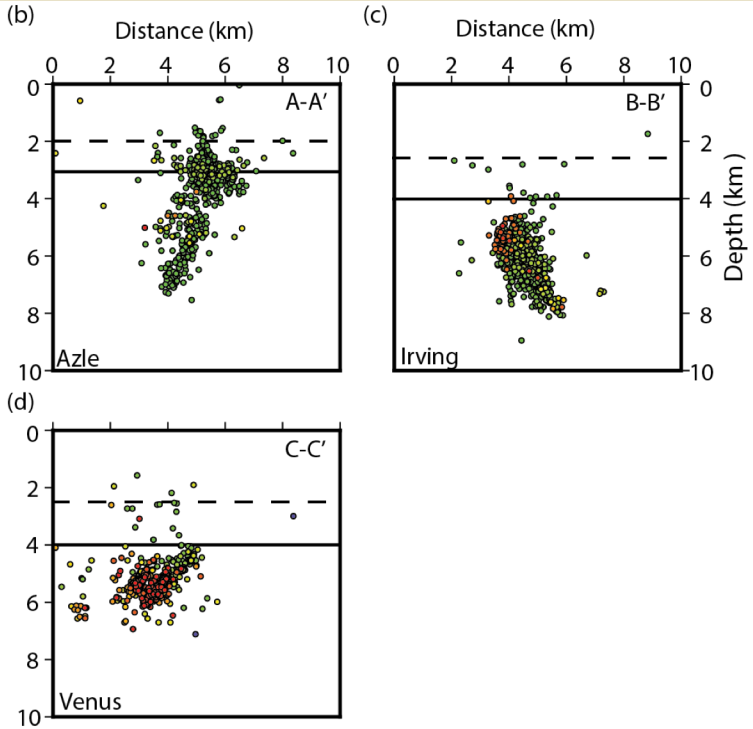


Over 2100 earthquakes in the NTXES catalog



We have 5 named sequences but many more source zones!



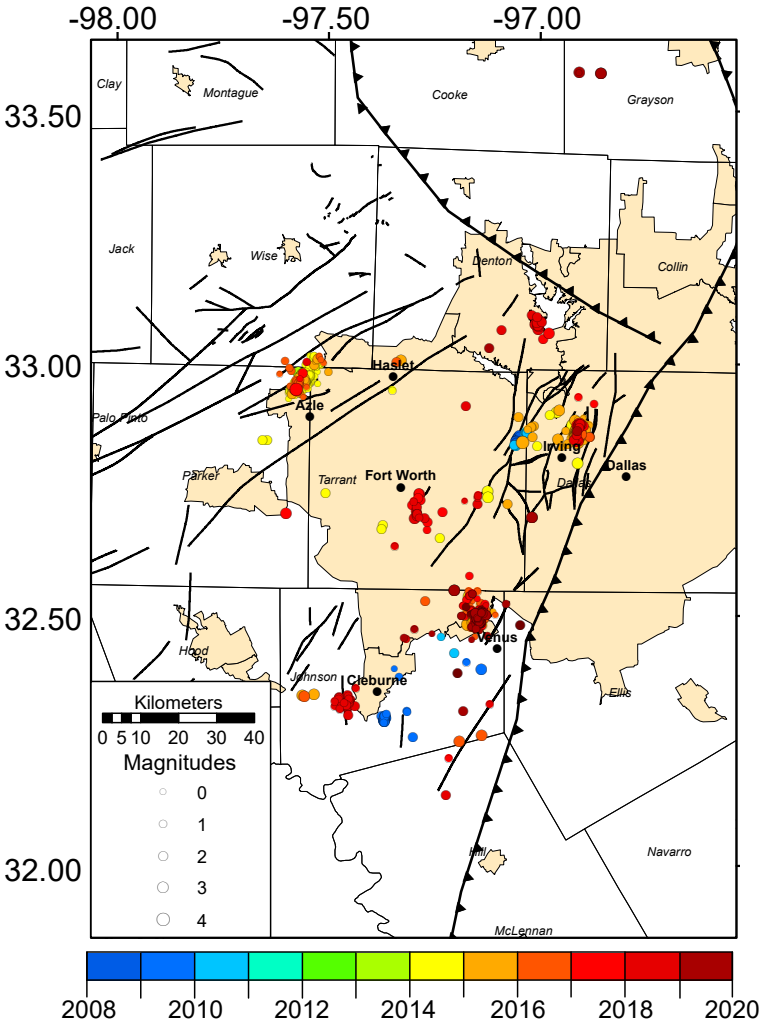


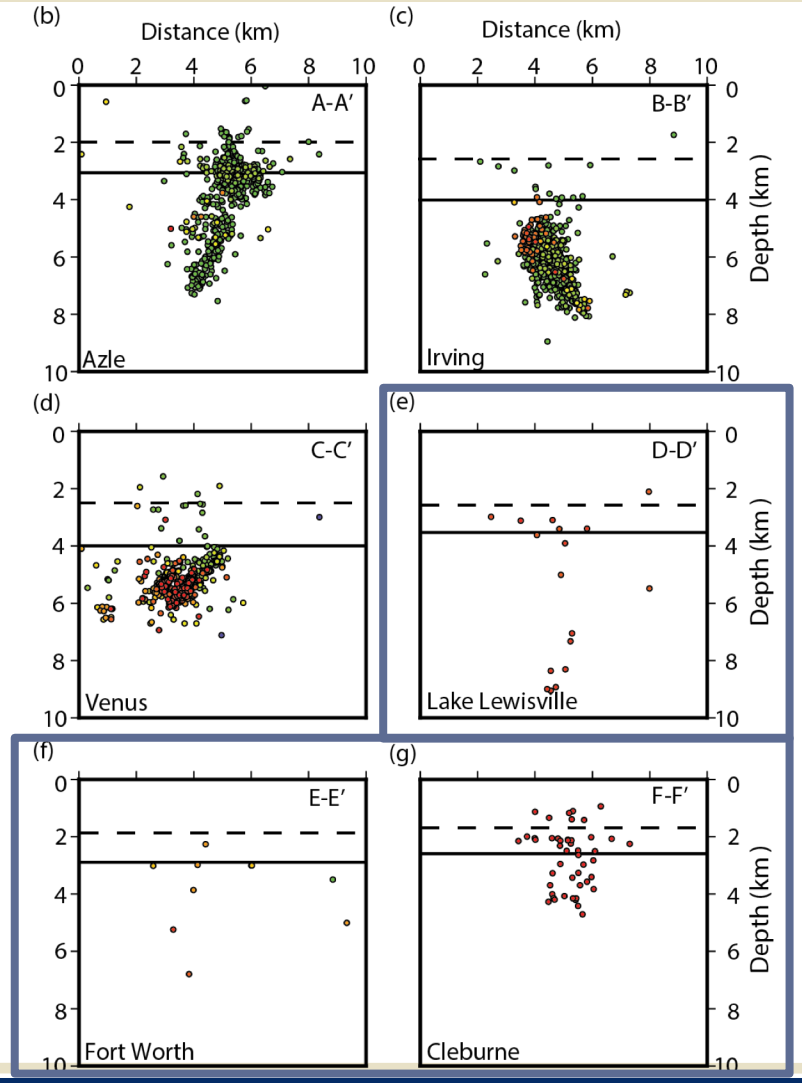
2008 DFW Airport
2009 Cleburne
2013 Azle-Reno
2015 Irving-Dallas
2015 Venus

- Primarily in the crystalline basement with limited Ellenburger activation in Azle (b)
- NE-SW trending, steeply dipping normal faults

Quinones et al. (2019) and update

We recorded 3 newly active faults over 2017-2019





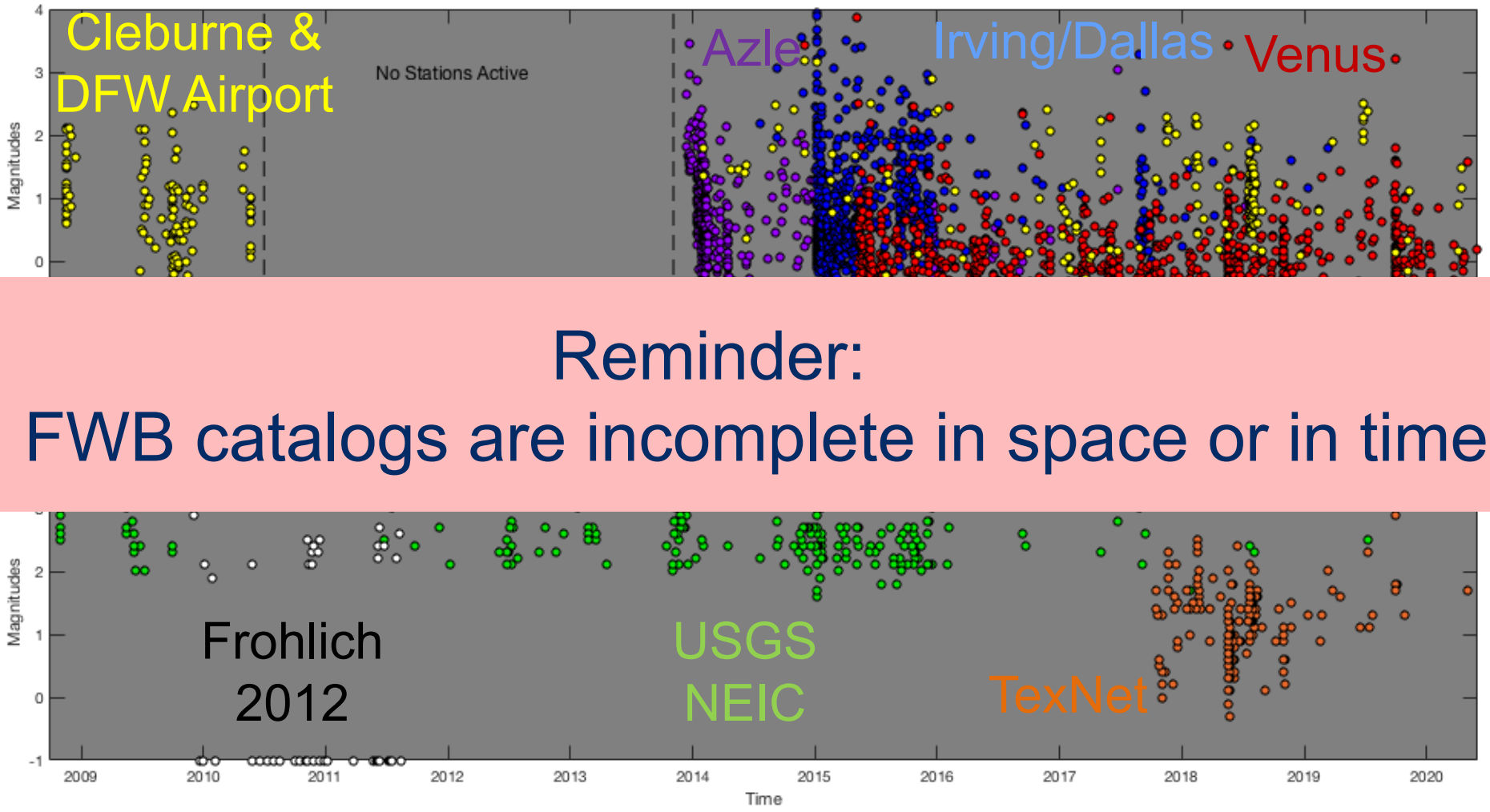
- Earthquakes occur primarily in the crystalline basement with limited Ellenburger activation in Azle (b)
- New source zones in Fort Worth, Lake Lewisville and west of Cleburne
- **Depths for newer sequences remain poorly constrained due to lack of station within a focal depth distance upon onset**

Quinones et al. (2019) and update

Building a catalog but sliding toward research: Establishing a local magnitude calculator

SMU NTXES Catalog

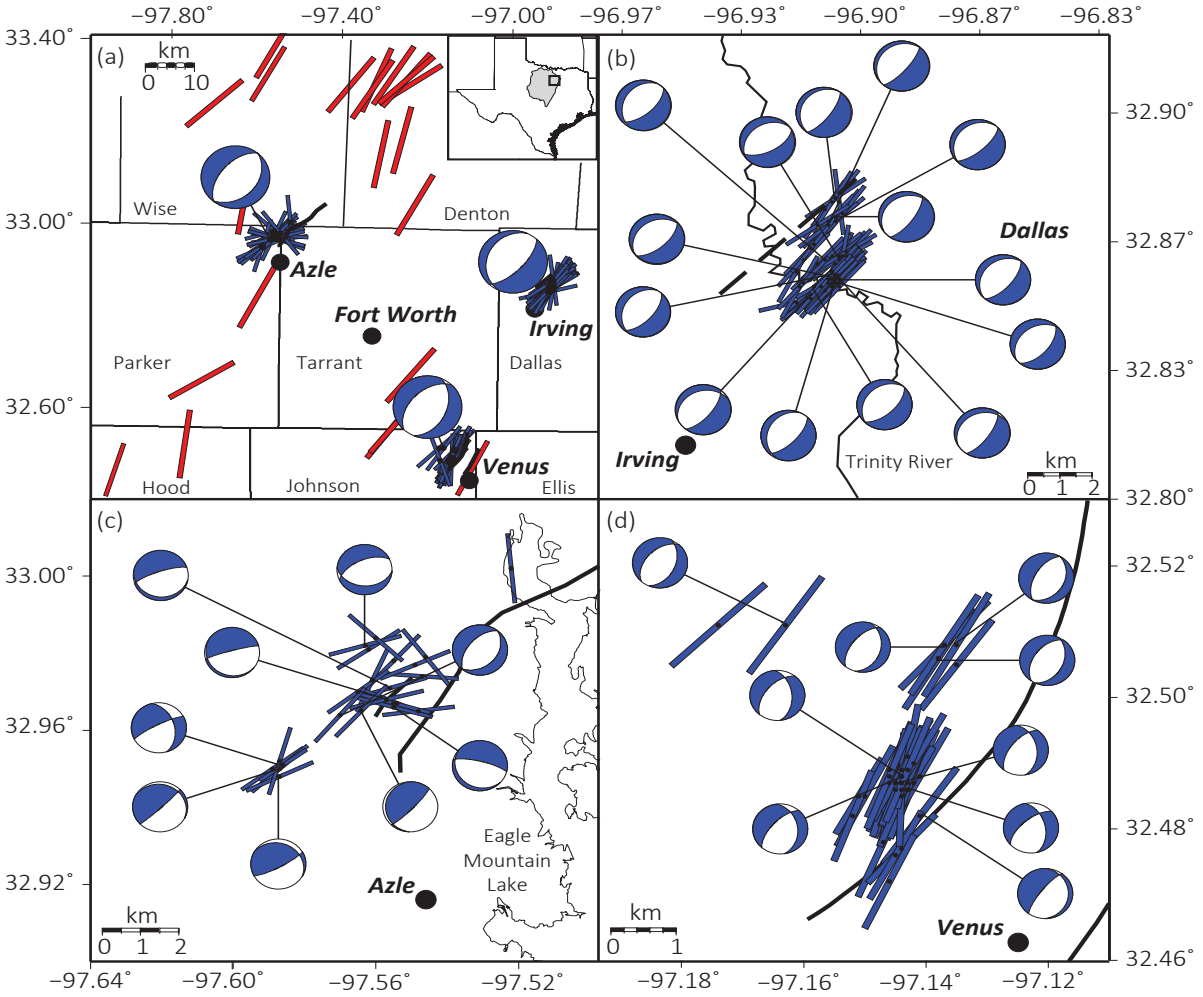
Other Catalogs



Reminder:
All FWB catalogs are incomplete in space or in time

Quinones et al. (2019) and update

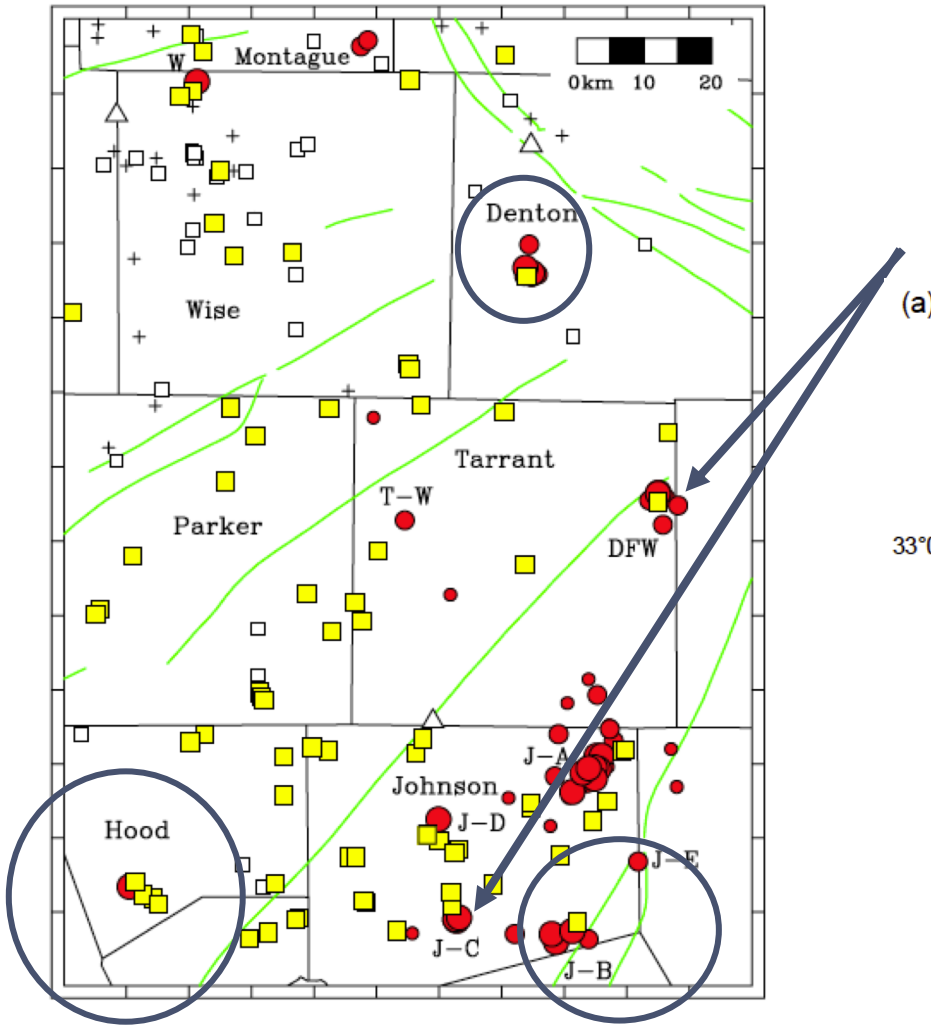
Building a catalog but sliding toward research: Establishing focal mechanisms



- P-wave first-motion and S-to P-wave (S/P) amplitude ratio data ➡ stabilizes the calculation with a low number of stations
- The mechanism solutions describe primarily NE–SW trending normal faults
- Display a surprising lack of intersequence variability
- Stress inversions indicate maximum stress in the basement strikes 20°–25°east of north

Quinones et al. (2018)

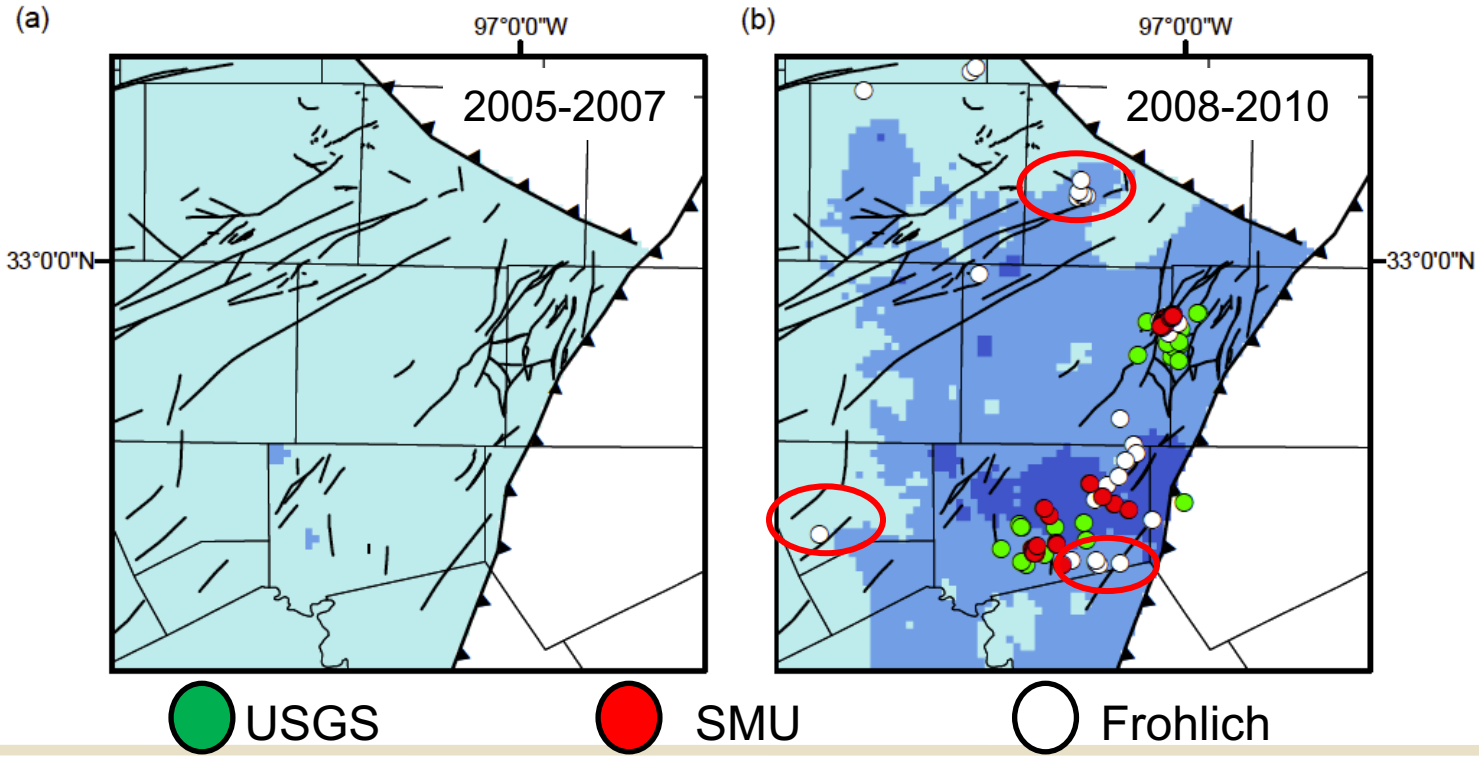
Research with catalogs:
Early indicators of induced earthquakes near wells



US Transportable Array Study of the FWB – Frohlich 2012 EQs

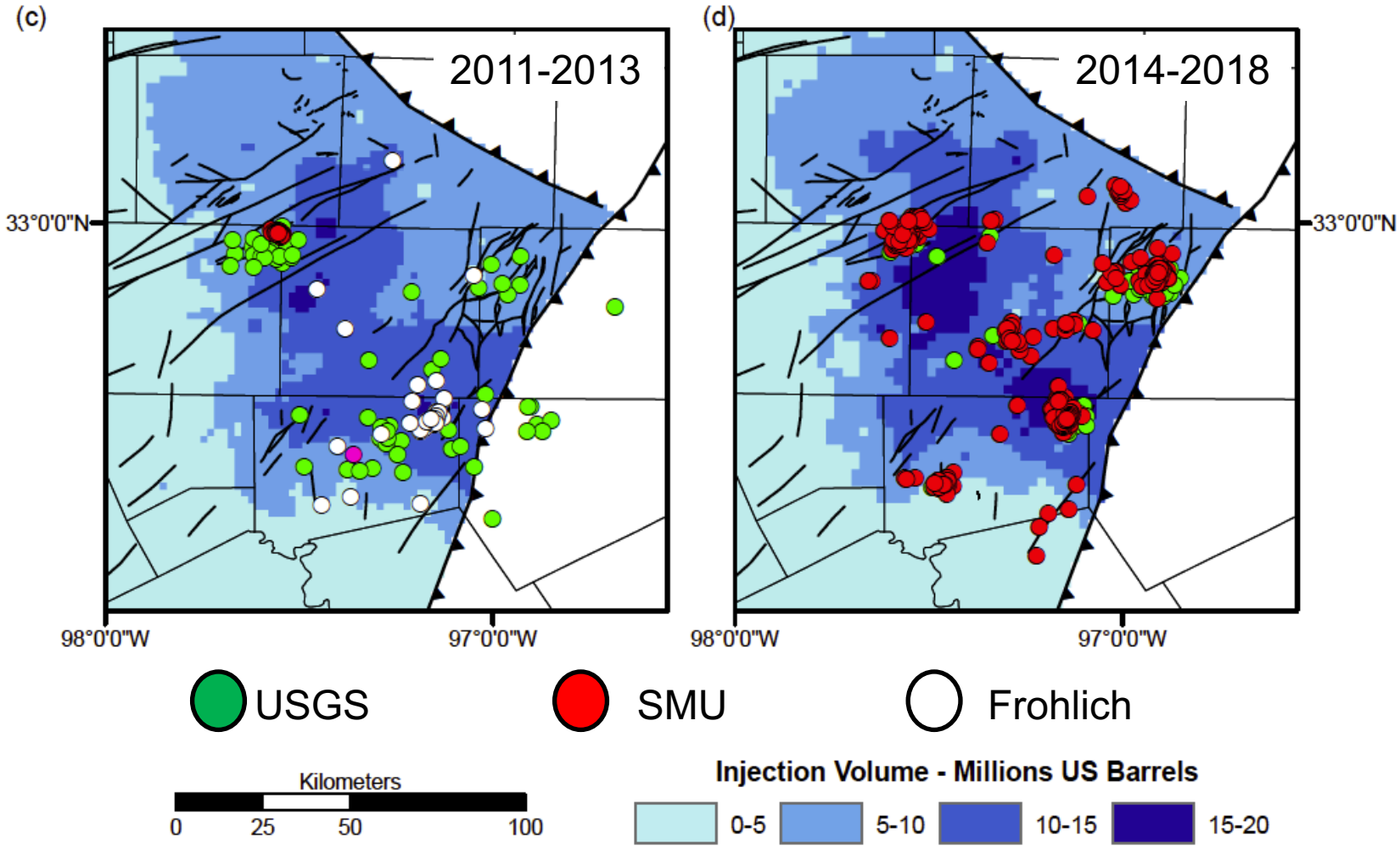
△ Stations were located around the basin from 2010-2011

Some faults had already generated felt earthquakes



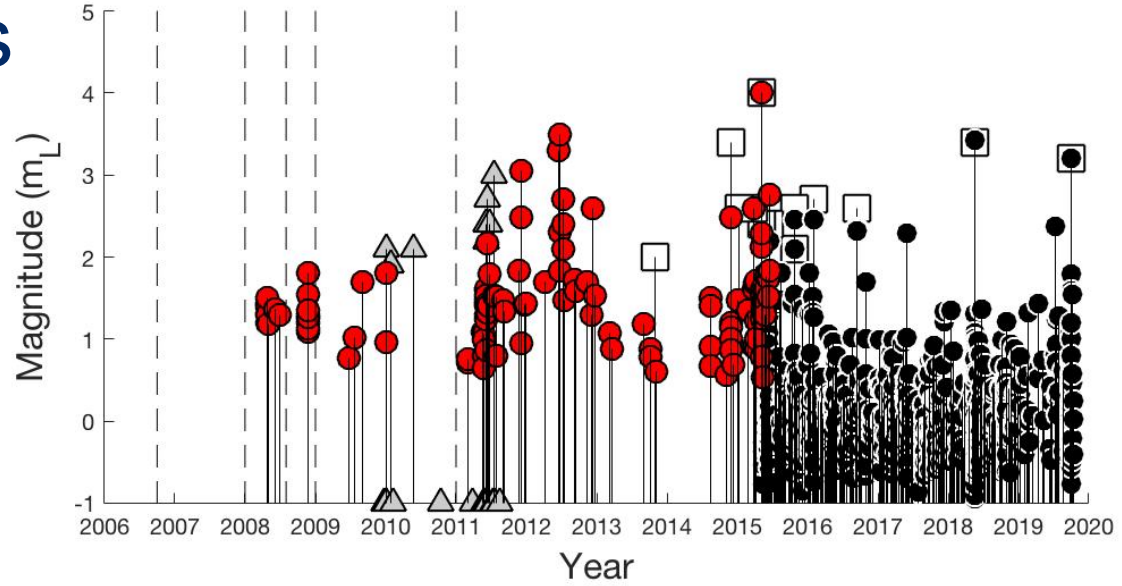
From Frohlich 2012

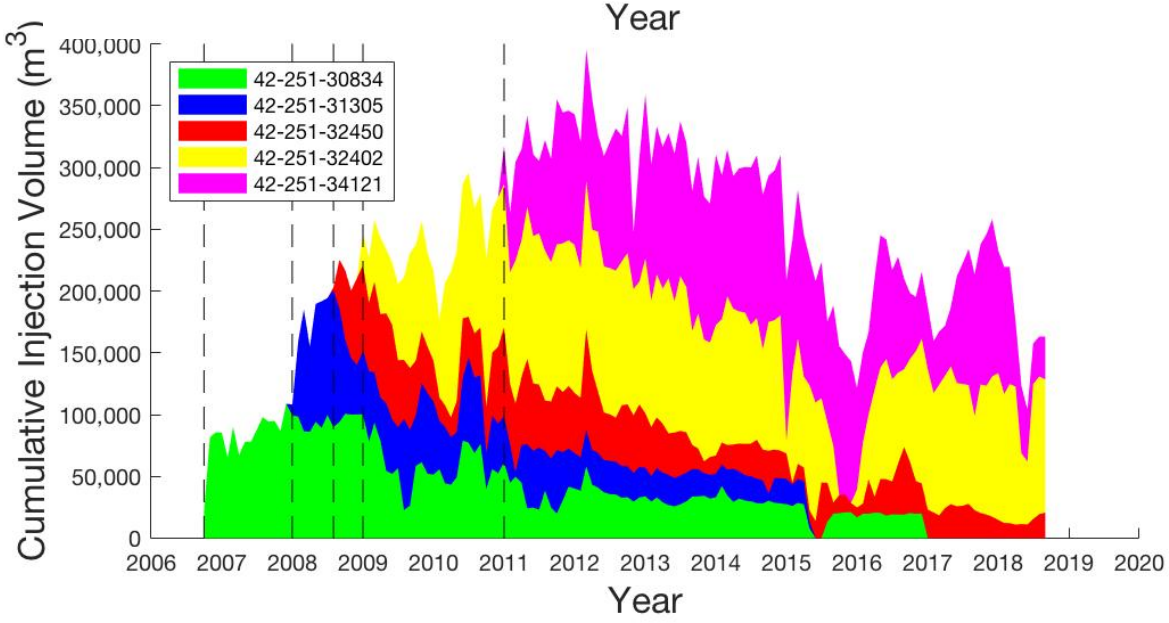
Over the last decade, earthquakes occurred on faults in areas of lower volume but with expected pore pressure change



Rebuilding catalogs to advance research: Template, correlation approaches

- Matched filter (template matching) allow us to expand the local catalogs in time but we lose resolution in space
- Example: Venus earthquake
  - The 2015 M4.0 was simply the largest earthquake.
  - The first earthquakes likely began back in 2008.
- Pressure data indicate a disposal formation that is 0.9–4.8 MPa above hydrostatic.

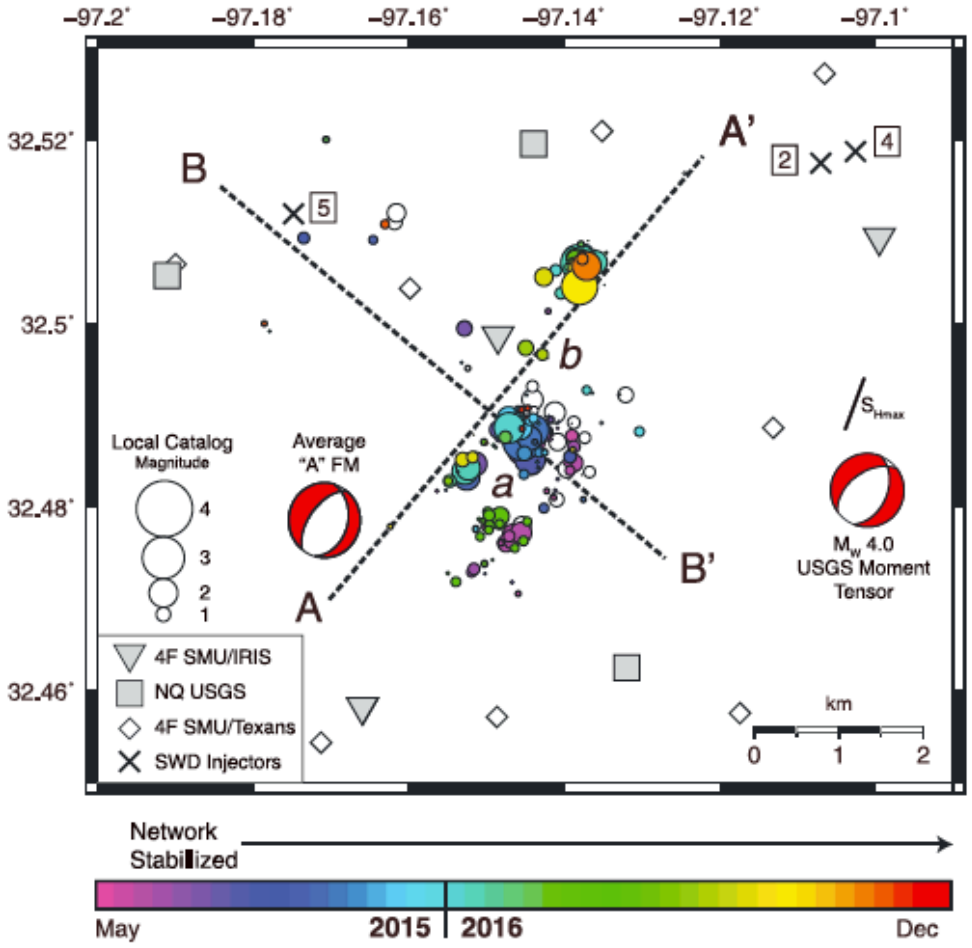


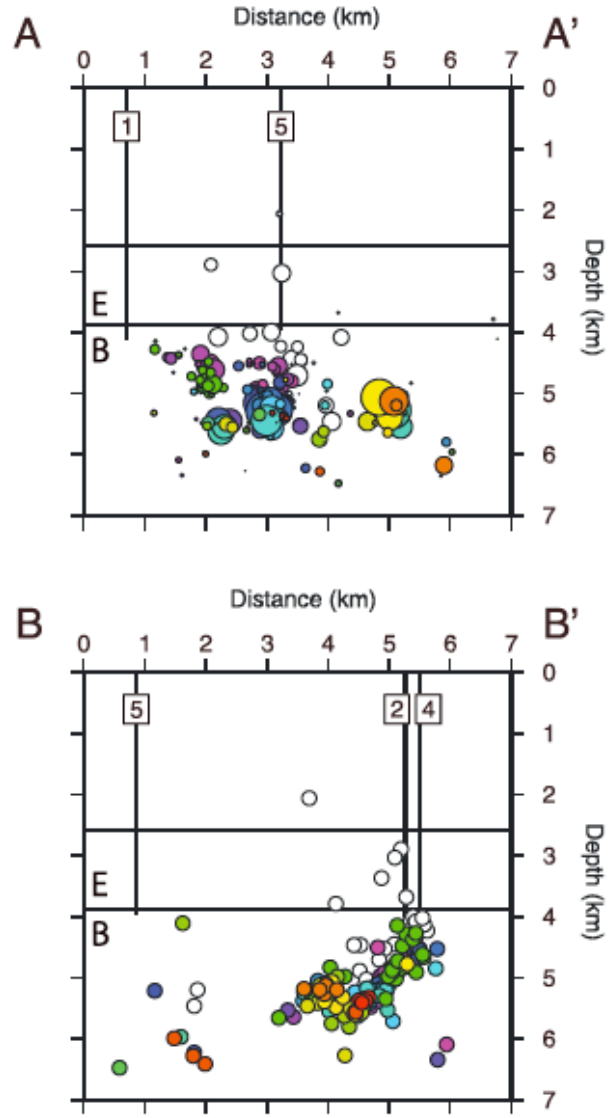


Updated from Scales et al. 2017

Rebuilding catalogs to advance research: Relative relocation

- Relocation relocation provides fine-scale structure
- Provides information below controlled source data resolution
- Identifies the active faults
- Better take-off angles
- Better facilitates exploration of cause

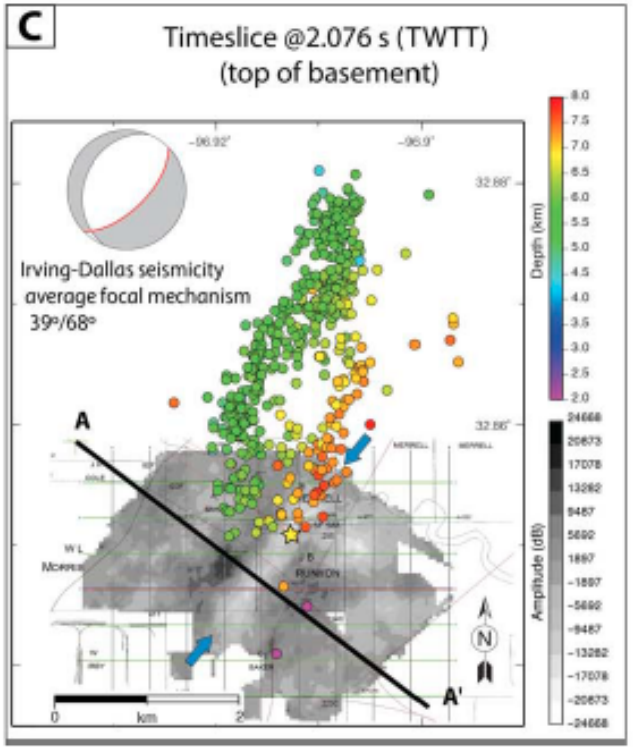




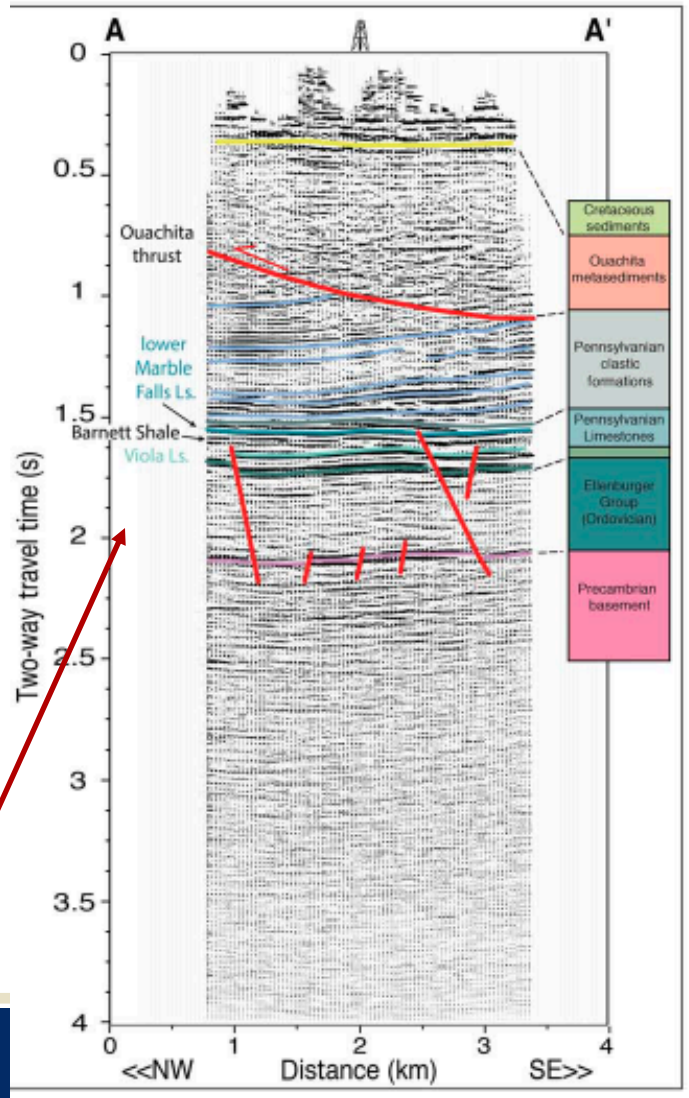
Updated from Scales et al. 2017

Collaborative research using the catalogs: Constraining fault geometry to study deformation history

- Earthquakes occur on basement rooted faults that have not measurably deformed units younger than 300 MA
- The seismogenic faults look identical to neighboring faults that have no seismicity

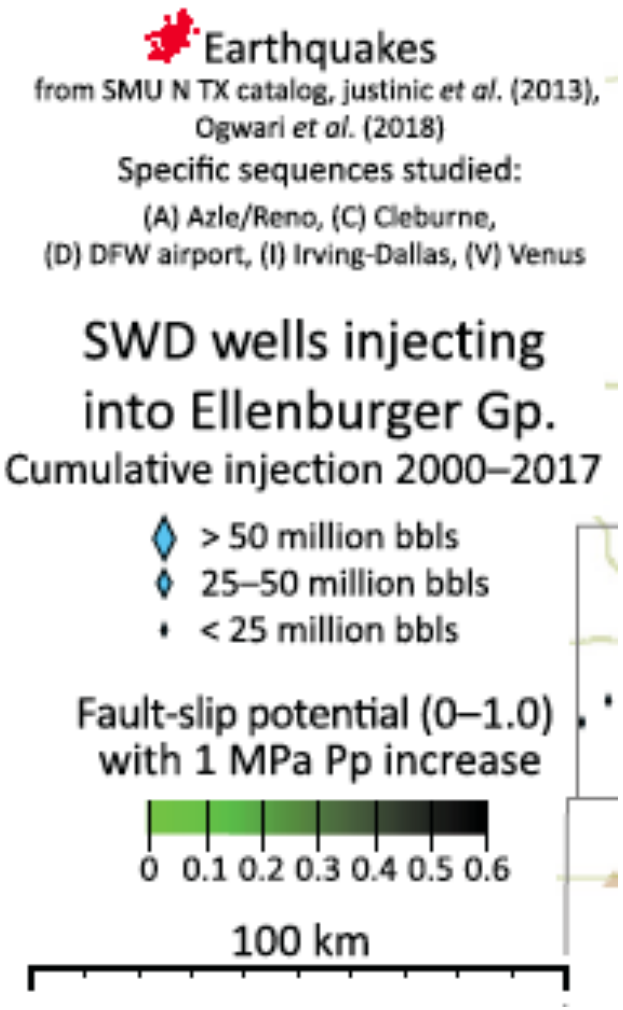


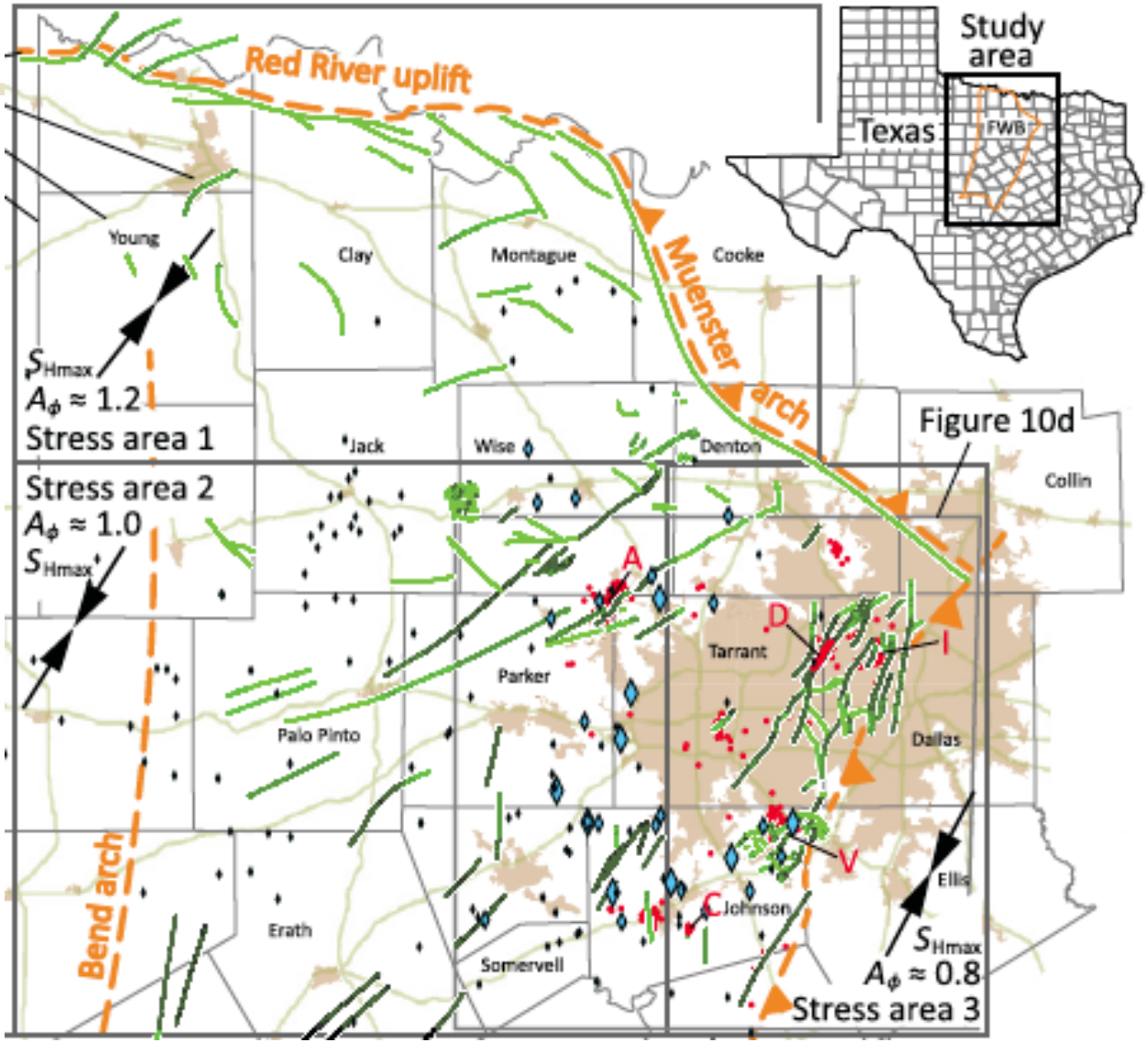
The fault generating Irving-Dallas earthquakes parallels these faults but lies off the NW edge of the 3D seismic data



Magnani et al., 2017

Collaborative research using the catalogs: Fault slip potential

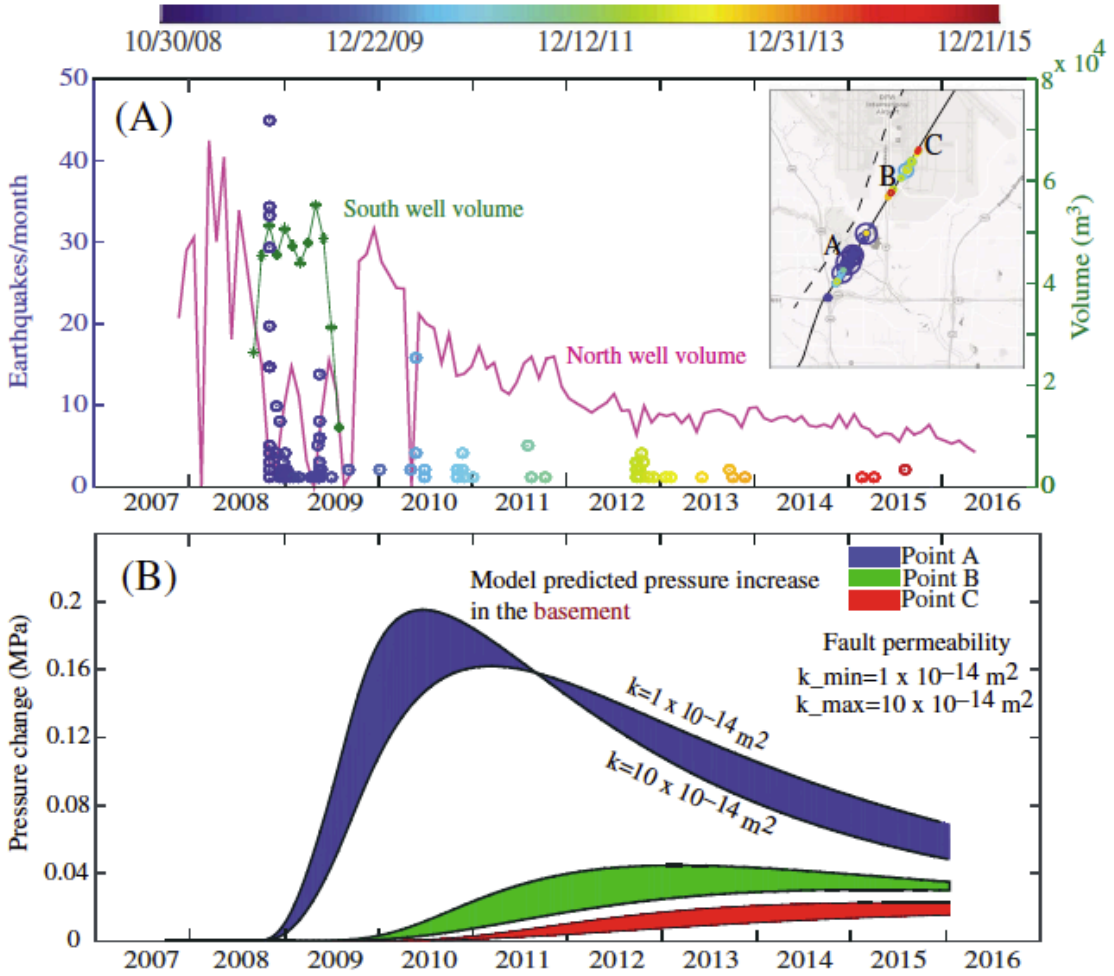




Hennings et al. (2019)

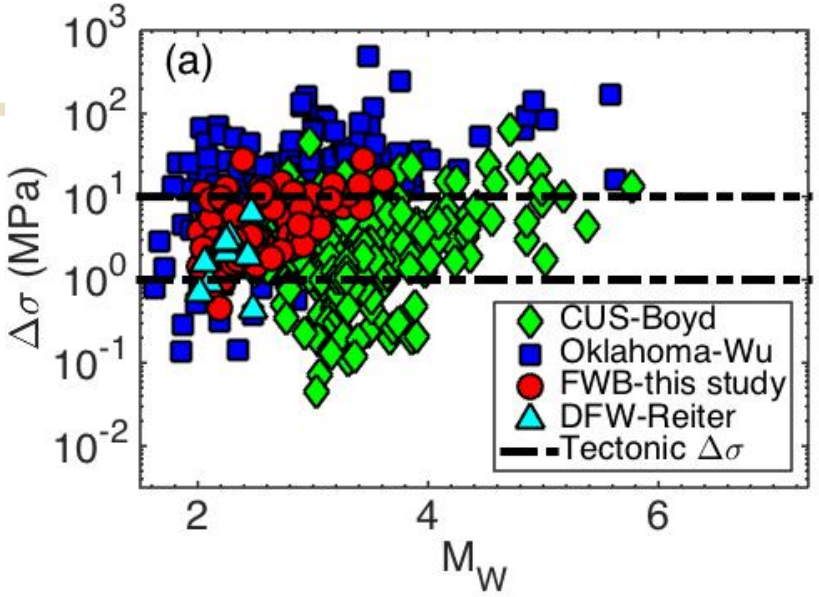
Collaborative research using the catalogs: Pore-pressure diffusion modeling [DFW Airport example]

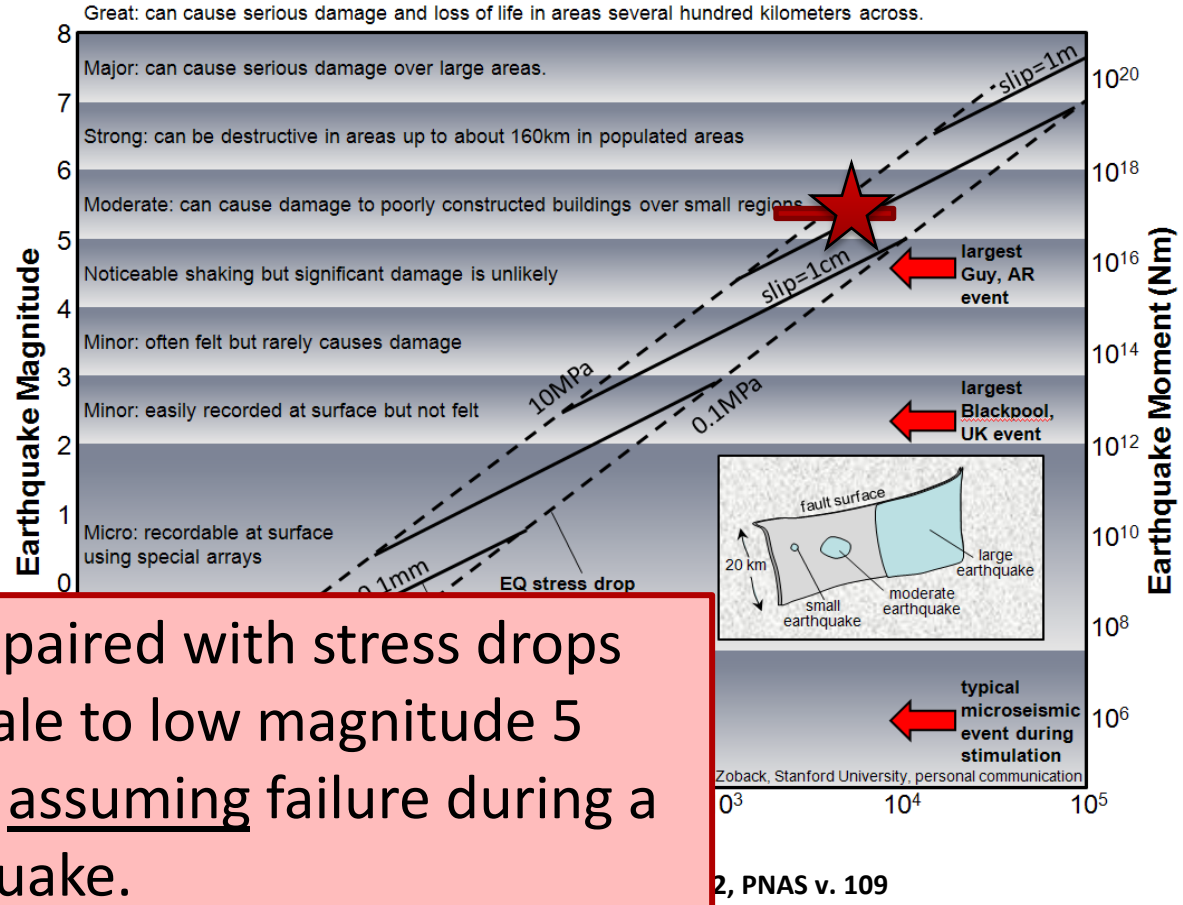
- At the DFW International Airport, wastewater was moved to a southern well
- While the 2008 Halloween earthquakes were felt, lower magnitude seismicity had continued into 2015
- Here, earthquakes spread north with time as pressure changes diffused from the injection point



Ogwari et al. 2018

Collaborative research using the catalogs: Source studies and hazard





2, PNAS v. 109

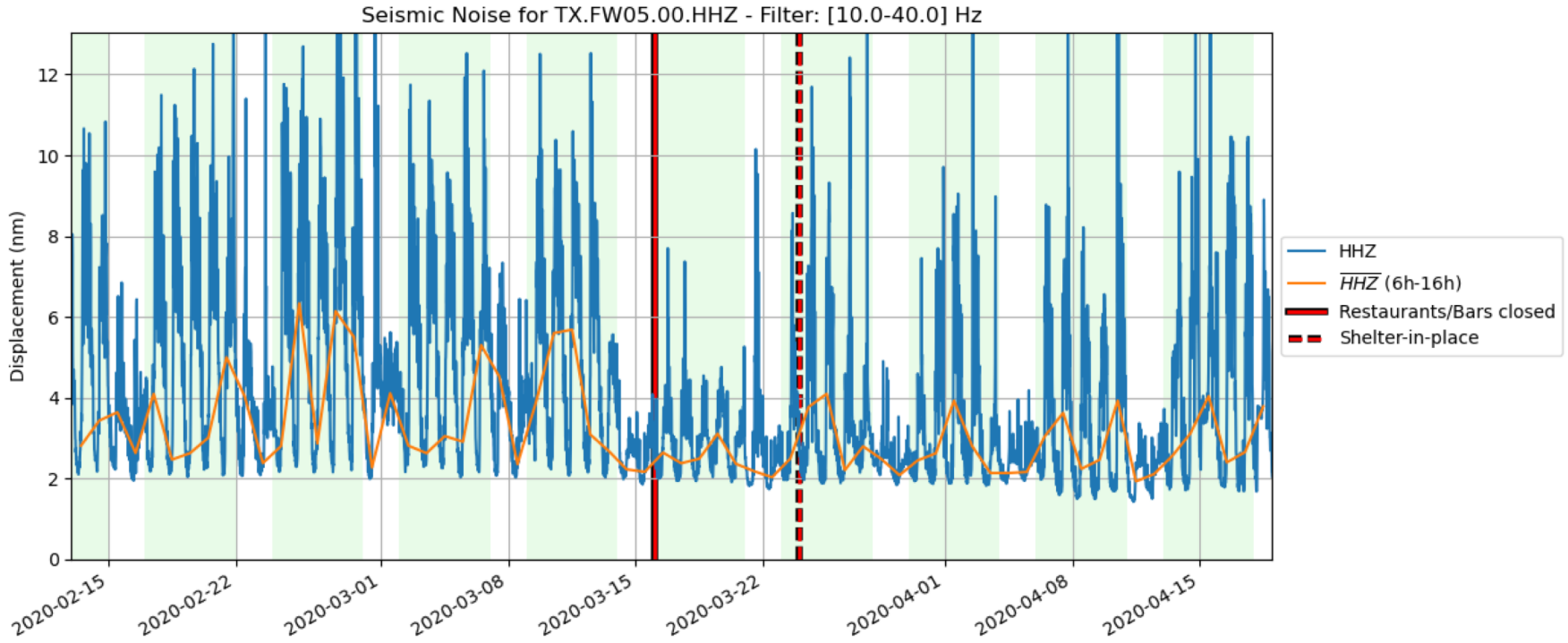
Fault lengths paired with stress drops (<10 MPa) scale to low magnitude 5 earthquakes, assuming failure during a single earthquake.

Multiple events are more common.

Jeong et al. (BSSA submitted)

Public real-time seismic data spurs societally-relevant research beyond induced earthquakes

North Texas seismometers record sudden reduced noise in Dallas associated with county stay-at-home order & the slower rise in noise with reopening



Data analysis provided by Stephen Arrowsmith, SMU

Lessons: What have we (re)learned in the FWB?

- Faults within the basement are near critically stressed & orientation within the current stress regime appears a critical predictor of reactivation
- Faults in naturally active seismic zones exhibit a long-lived history of reactivation
- Very small stress changes can trigger seismicity
- Maximum magnitudes appear different between the FWB and natural intraplate settings
- **The cumulative history of wastewater injection and fluid production within the Ellenburger, and the evolution of pressure in the injection formation and units in hydrogeological contact, appear to be key drivers of the seismogenic evolution of the basin.**

Many remaining questions

Why do only some faults generate earthquakes?

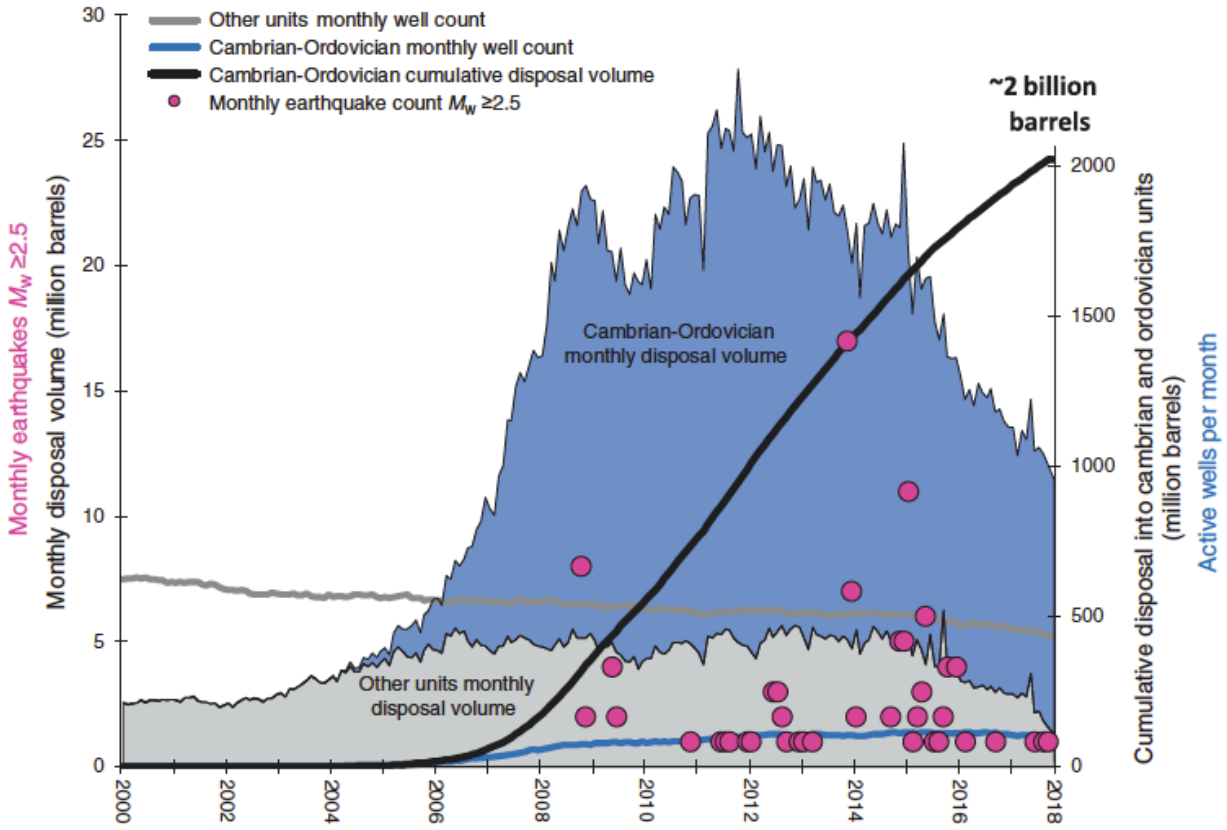
How sensitive are the FWB faults to pore pressure perturbations?

What is the permeability of these faults?

Some permeability and damage zone (fault width) is required to trigger basement faulting. How big are the damage zones after 300 Ma?

What are the best mitigation strategies?

Still missing key data: Injection and production data

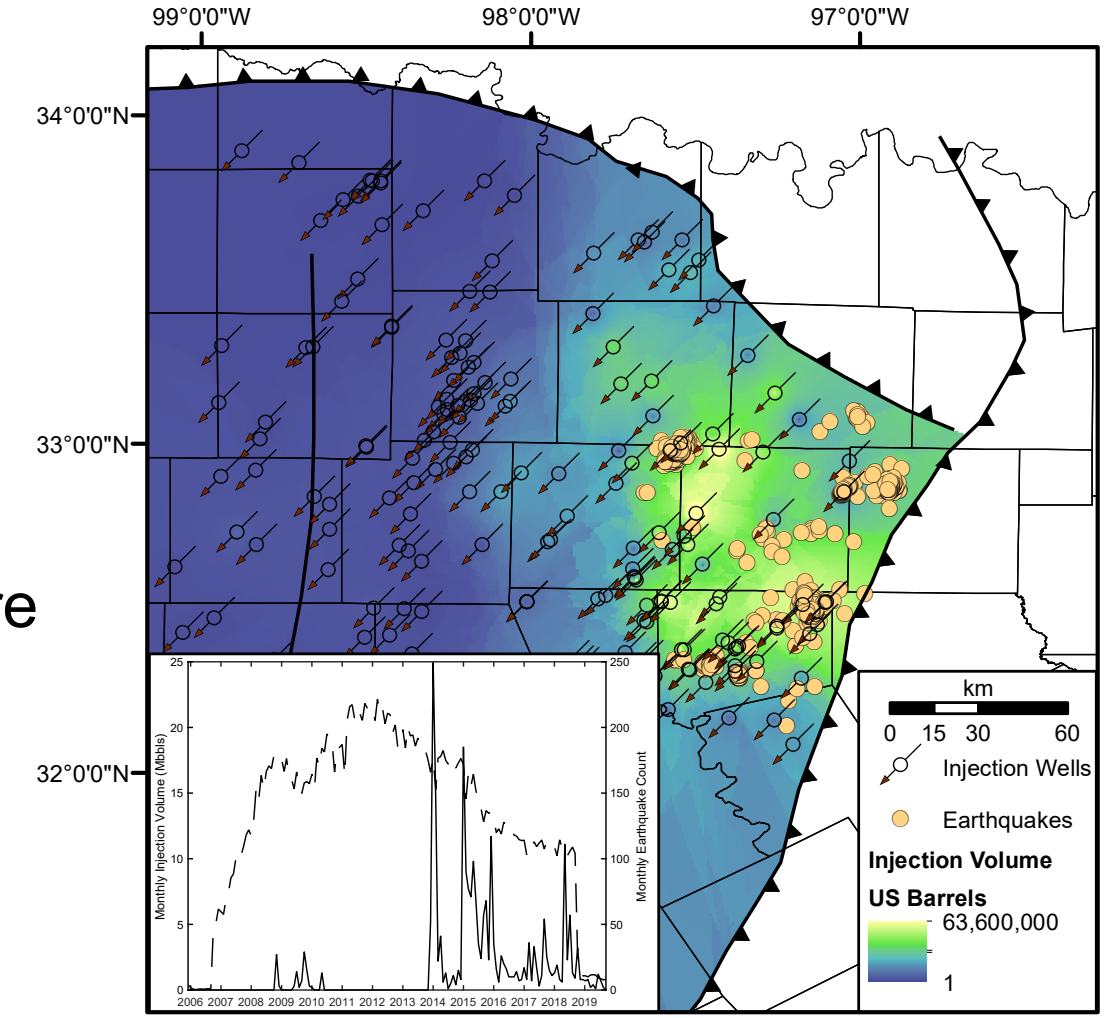


- Time and space correlation is not sufficient to understand physical processes in the subsurface
- Need to track local and regional subsurface pressure changes in both space and time
- Data needs include:
  - Daily injection volumes and pressures
  - Downhole pressure or fall-off tests
  - Fluid production information (oil, gas & water)
  - Properties of the fluids and the source rock

From Hennings et al. 2019

Summary

- Integrating geology, fault information, catalogs and modeling efforts with **timely** injection data provide necessary insights into physical mechanisms in the FWB
- Monitoring over the full life-cycle of a system is mandatory
- Improved knowledge of downhole pressure evolution, permeability and damage zone width is required
- Tracking the cumulative injection history and evolution of the basin remains key



Quinones et al. (2019), updated

Thank You!

Unlisted collaborators of FWB studies
Paul Ogwari, Monique Scales, Oner Sufri

Brian Stump, Matt Hornbach, Beatrice Magnani, Chris Hayward, Stephen Arrowsmith

Jake Walter, Cliff Frohlich, Peter Hennings, Alexandros Savvaidis, Patricia Martone, Mike Brudzinski, Jens Lund Snee, Michael Blanpied, Tom Pratt

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