Understanding the Correlation Between Induced Seismicity and Water Injection in the Fort Worth Basin*

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Search and Discovery Article #80481 (2015)**
Posted October 19, 2015

*Adapted from oral presentation given at AAPG Annual Convention & Exhibition, Denver, Colorado, May 31-June 3, 2015

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Abstract

Starting in the mid-2000s, there has been an increase in seismic activity around areas where fluid injection was expanding because of shale development. As the injection rate increased, so did occurrences of earthquakes in the surrounding area. Extensive studies have been done regarding the correlation between injection wells and induced seismicity (Frohlich 2012, Davis 1995). However, many injectors don't cause earthquakes, and the boundaries between safe and high risk practice have yet to be defined. Also, there is often a time lag between the onset of injection and the occurrence of seismic activities – what controls that timescale? In order to encompass areas of injection with and without seismic activity, a reservoir simulation model was built for most of the Fort Worth Basin (FWB), including 374 wells with available relevant data located in the following counties: Denton, Ellis, Erath, Hill, Hood, Jack, Johnson, Palo Pinto, Parker, Somervell, Tarrant, and Wise. The data needed for the simulation include minimum and maximum injection depths, monthly injection pressures, and monthly volumes. The locations of major faults in the basin are being worked into the model to include the effects of transsmissive versus sealing faults on flow patterns. Preliminary simulation results show that where earthquakes occur, there is some spatial correlation with injection well locations. Furthermore, the modeling shows the quake areas have substantial increases in pore pressure due to injection. However, not all areas of increased pore pressure have induced earthquakes. Preliminary analysis suggests absence of induced seismicity in areas of elevated pore pressure might be attributed to shallow depth and lack of large pre-existing faults. Similar correlation difficulties are seen between the timing of injection and earthquake occurrence. The distance between the

injector and the fault as well as the permeability-thickness (kh) of the injection formation are being investigated as controls on this time lag effect.

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Hornbach, M.J., H.R. DeShon, W.L. Ellsworth, B.W. Stump, C. Hayward, C. Frohlich, H.R. Oldham, J.E. Olson, M.B. Magnani, C. Brokaw, and J.H. Luetgert, 2015, Causal Factors for Seismicity Near Azle, Texas: Nature Communications, 6:6728, p. 1-10. doi: 10.1038/ncomms7728

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AAPG Annual Convention & Exhibition 2015

TEXAS
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Understanding the Correlation Between Induced Seismicity and Wastewater Injection in the Fort Worth Basin

AAPG Annual Convention & Exhibition 2015

June 3rd, 2015

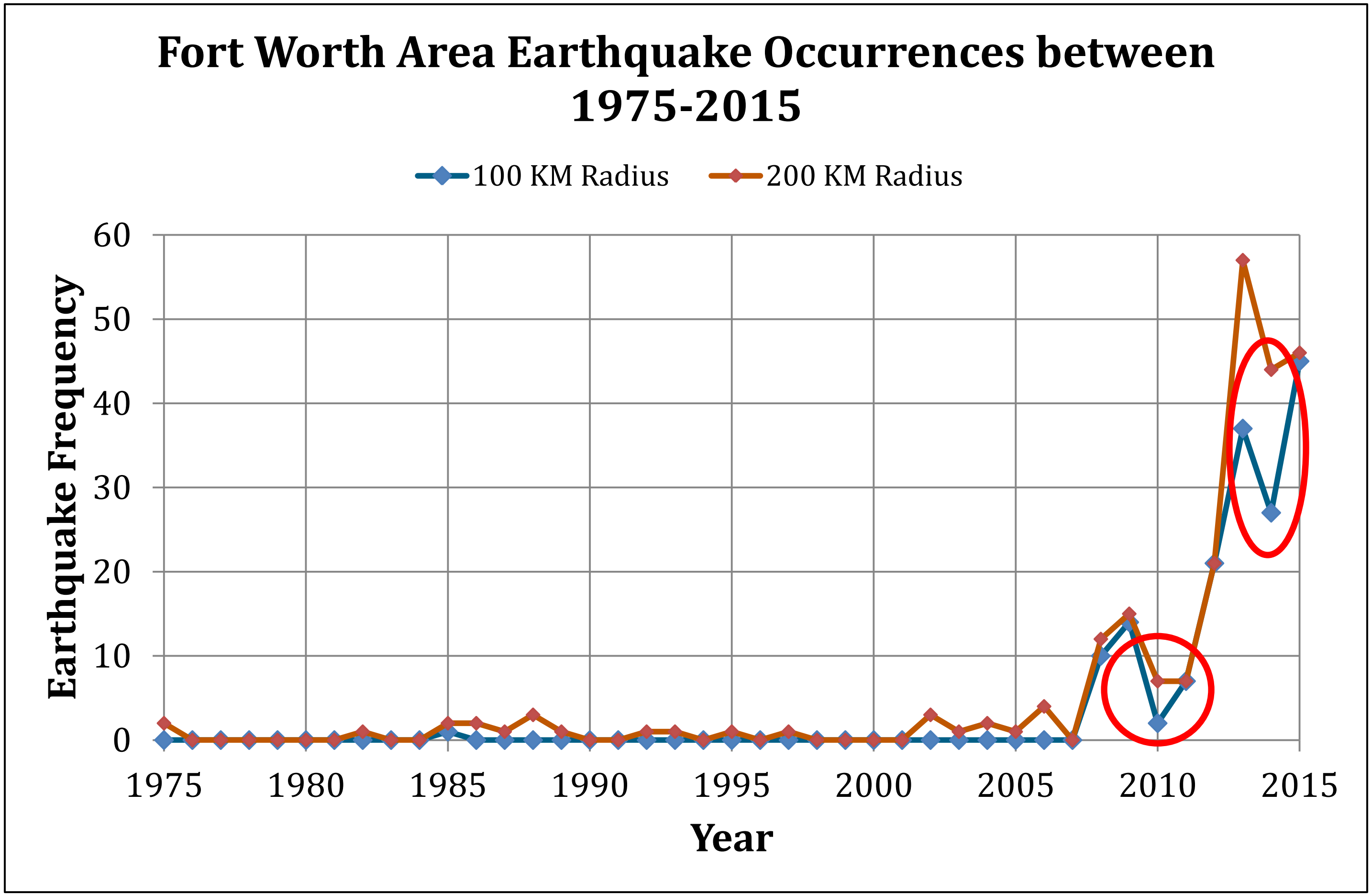
Denver, CO

Valerie Gono, Dr. Jon Olson & Dr. Julia Gale

The University of Texas at Austin

Motivation

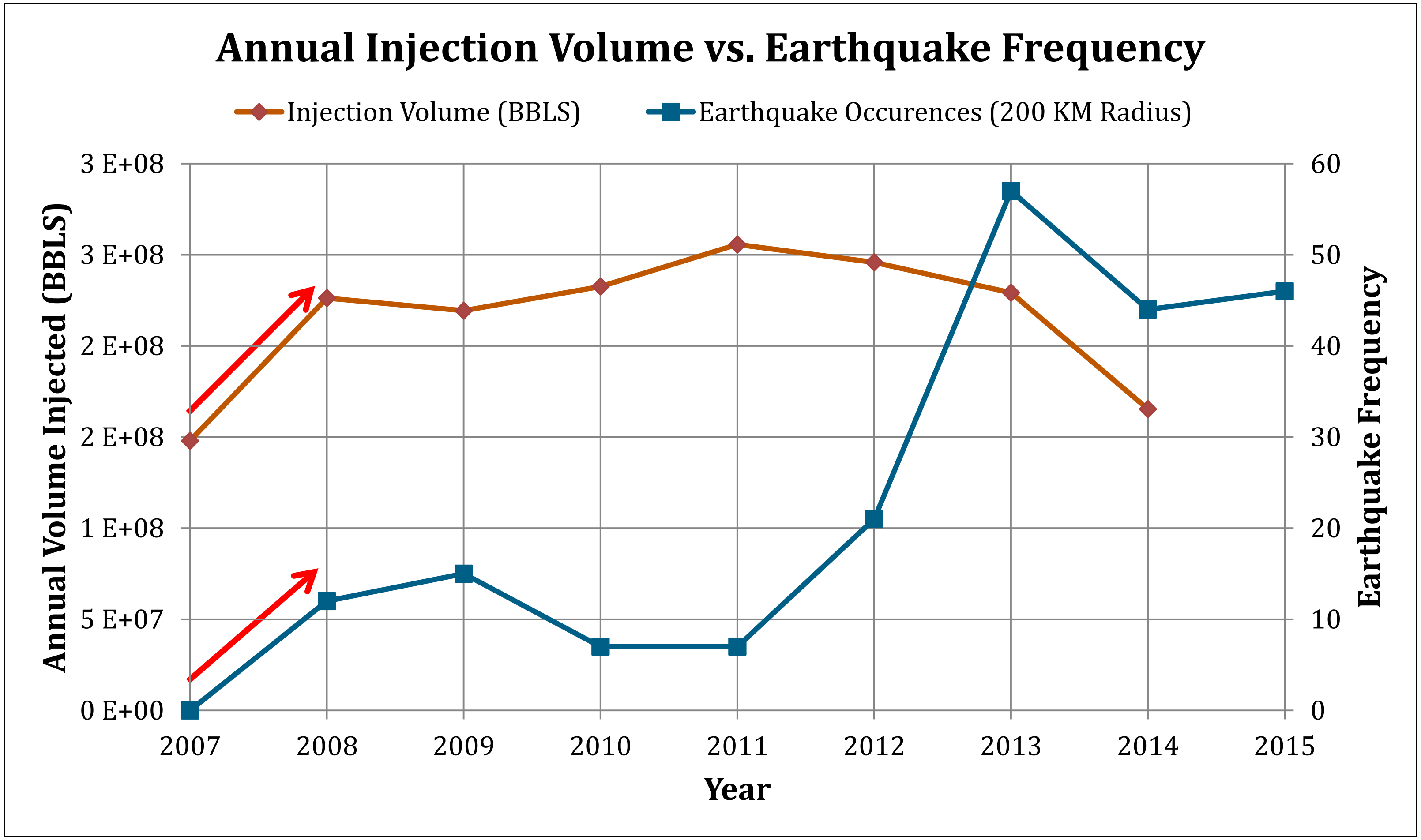
Number of earthquakes that occurred around the Fort Worth area has drastically increased in the past 10 years.



Motivation

The University of Texas at Austin

Total injected fluid volume and earthquake occurrences cannot be easily correlated.



Motivation

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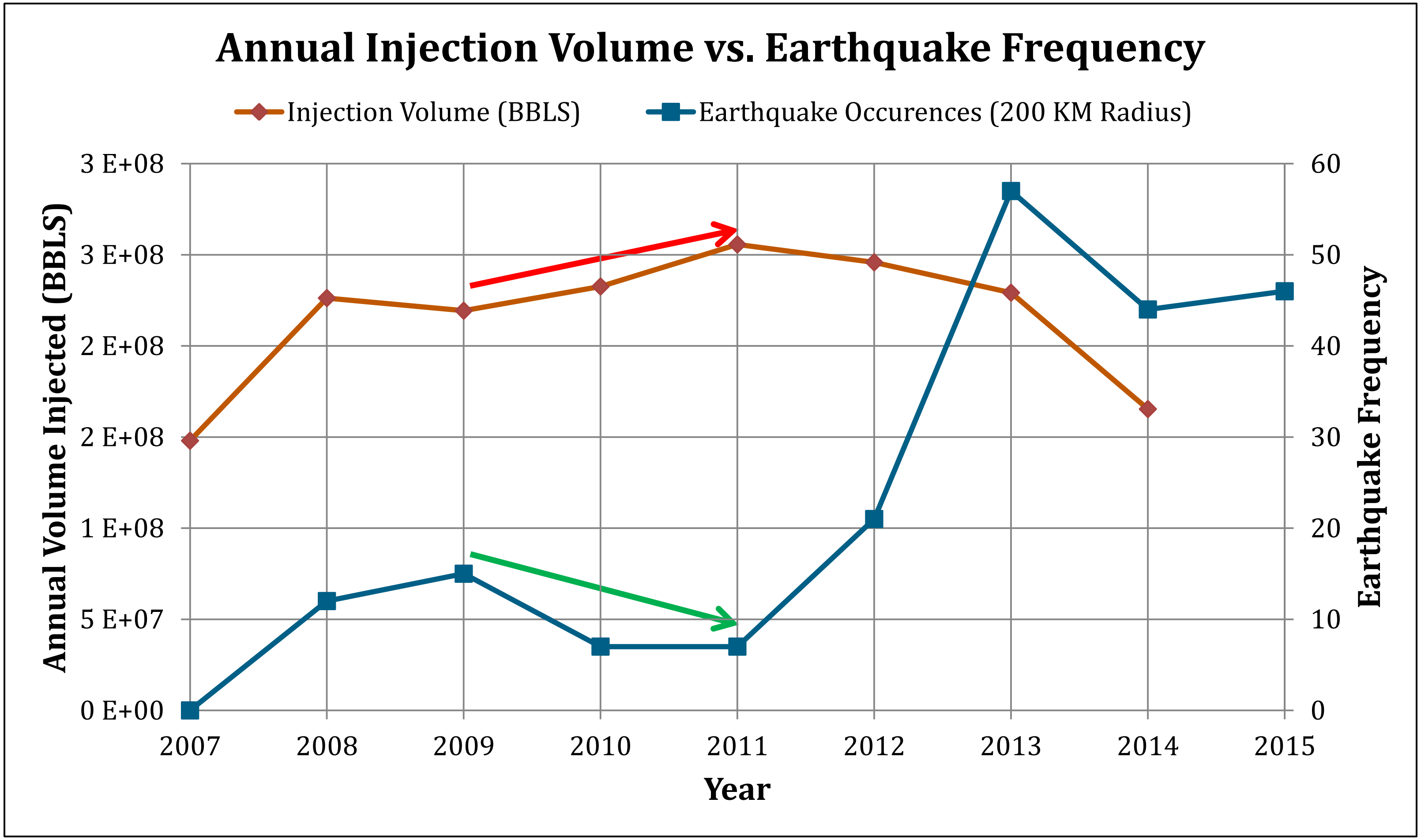

Motivation

TEXAS
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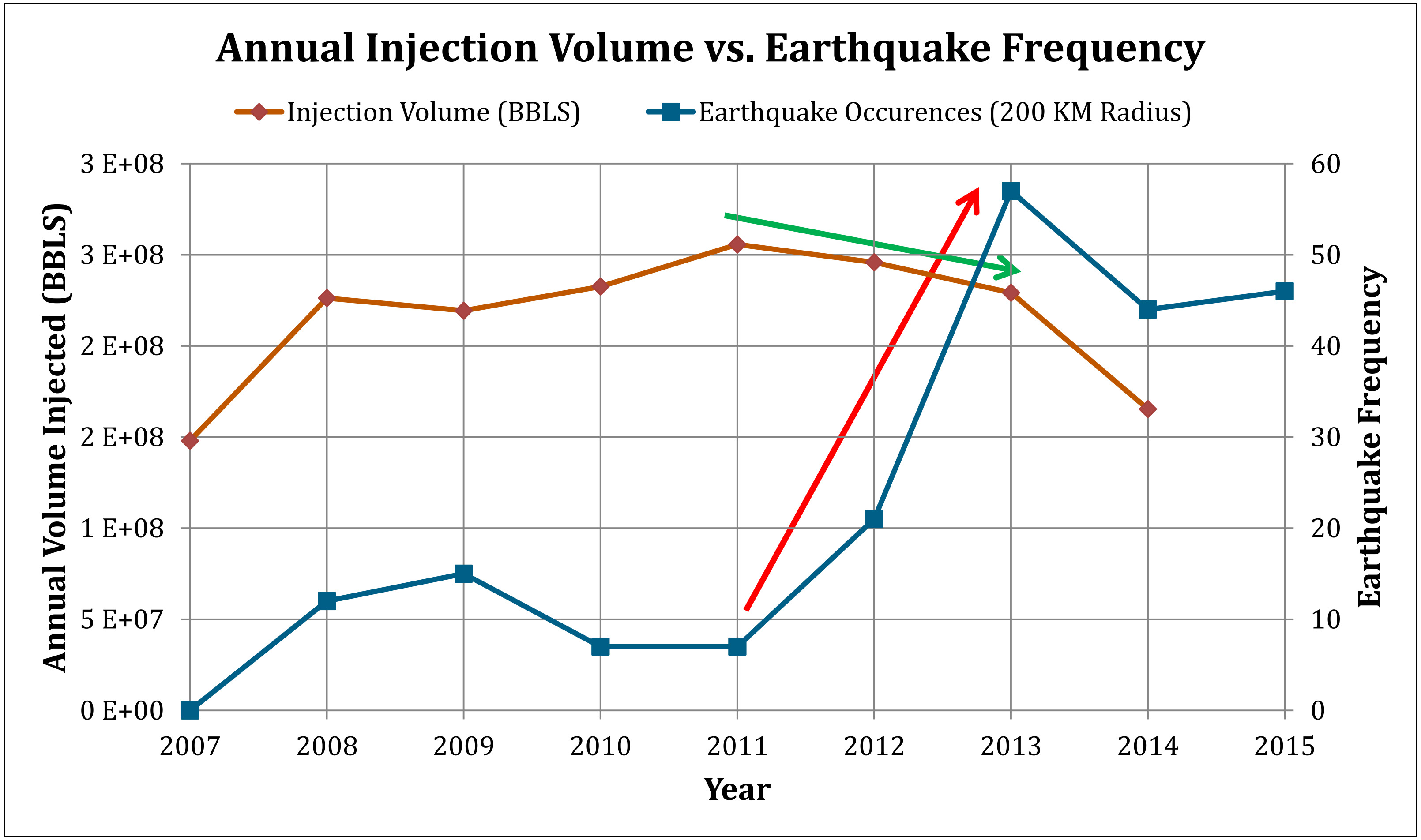
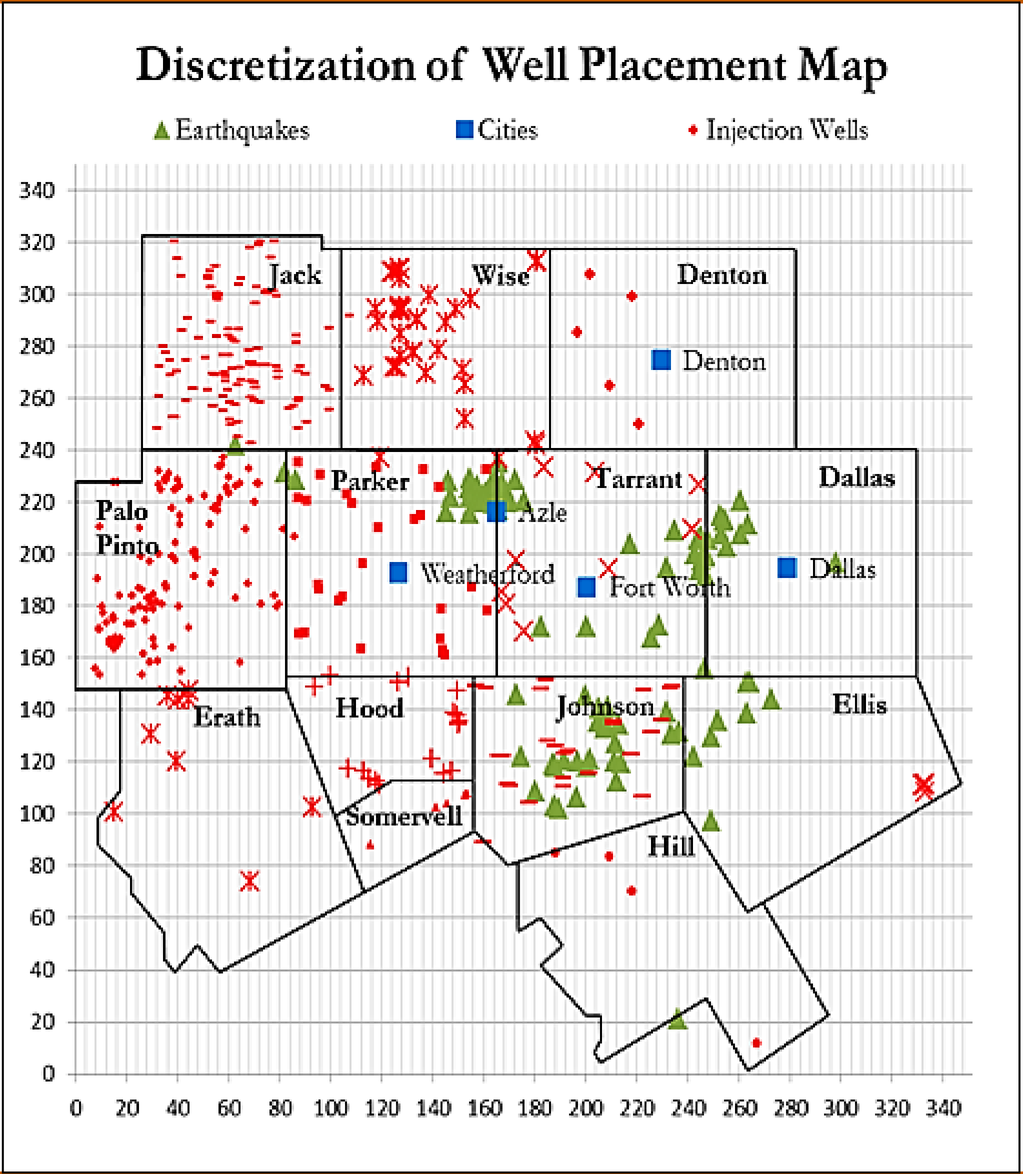


Current Research

- Focus simulation on a basin scale (Fort Worth Basin)
- Total number of injection wells modeled: 374/1095
- Goal: To understand both positive and negative pressure response in correlation to seismic activities



Simulation Domain

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- Simulator: Computer Modeling Group (CMG) Implicit Explicit Black Oil (IMEX) finite difference simulator

- # of blocks in x-direction: 342 cells @ 2,000 ft each
  # of blocks in y-direction: 330 cells @ 2,000 ft each
  # of blocks in z-direction: 9 layers @ variable thicknesses

- Total x-direction distance: 684,000 ft = 129.55 miles
  Total y-direction distance: 660,000 ft = 125 miles
  Total z-direction depth: 14,346 ft

- Reference pressure = hydrostatic

- Injection length: 199 months (start date: 1997-12-01)

Data Sources

- IHS Petra: Formation Tops Data

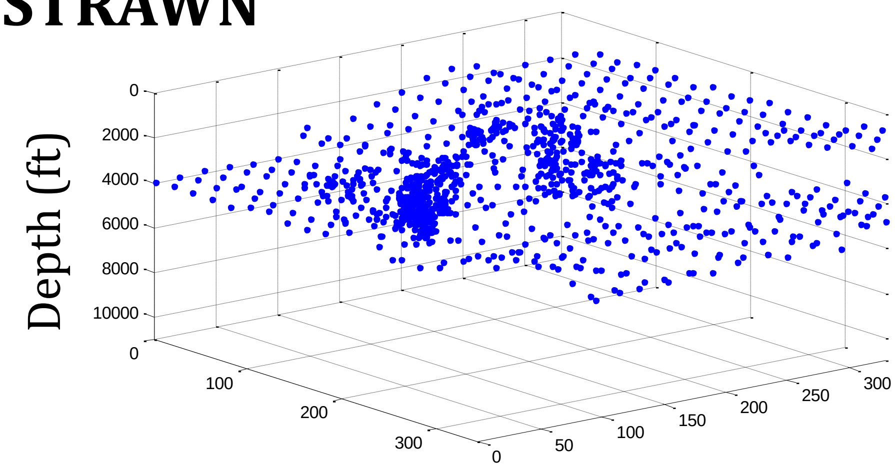
  Formation tops available and their corresponding layer in the model: Strawn (Layer 2),
  Marble Falls (Layer 4),
  Barnett (Layer 6)
  Ellenburger (Layer 8)

- Railroad Commission of Texas (TX RRC): Injection Volume, Injection Depth, Injection Pressure

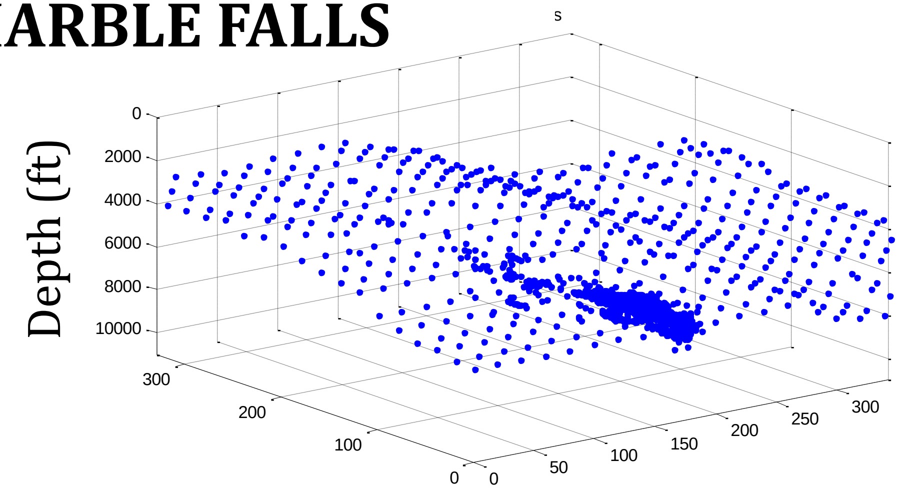
- U. S. Geological Survey (USGS) National Earthquake Information Center (NEIC): Earthquake Data

Formation Tops Data

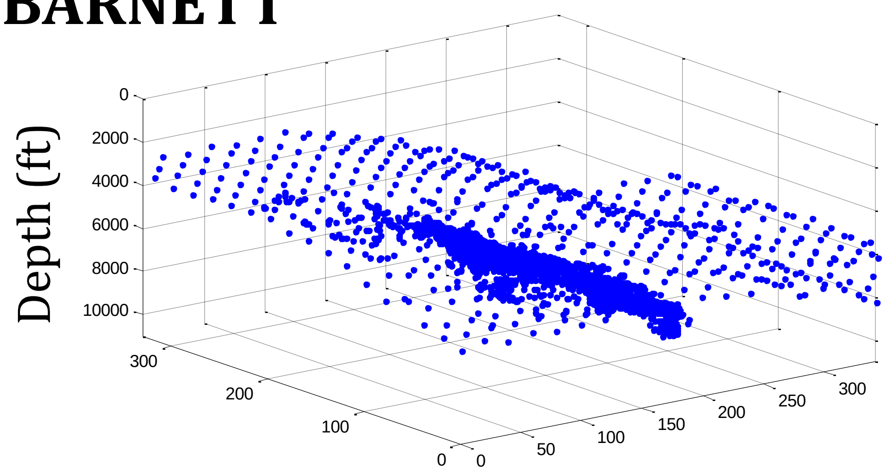
STRAWN



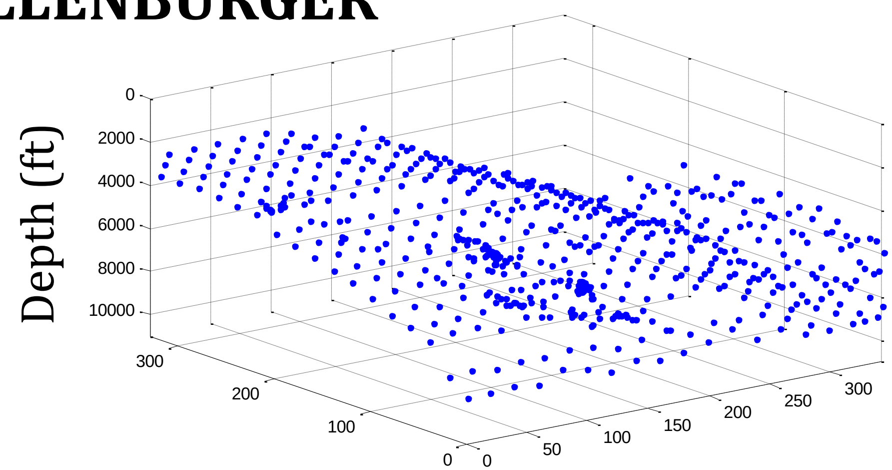
MARBLE FALLS



BARNETT



ELLENBURGER



Interpolated Formation Tops

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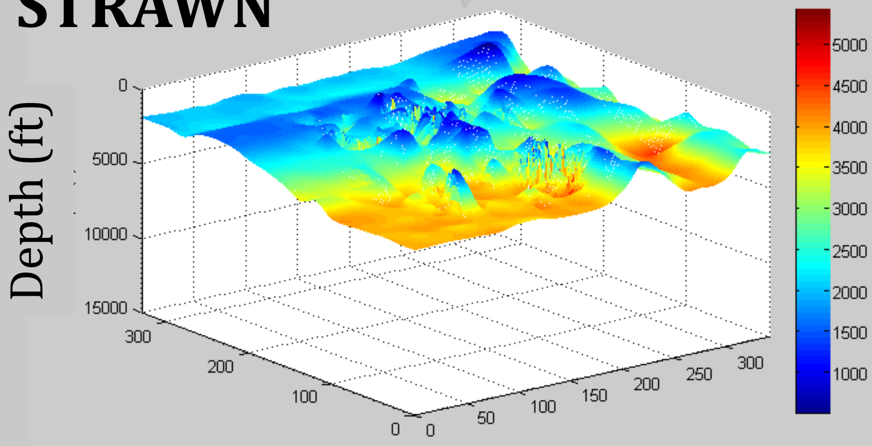
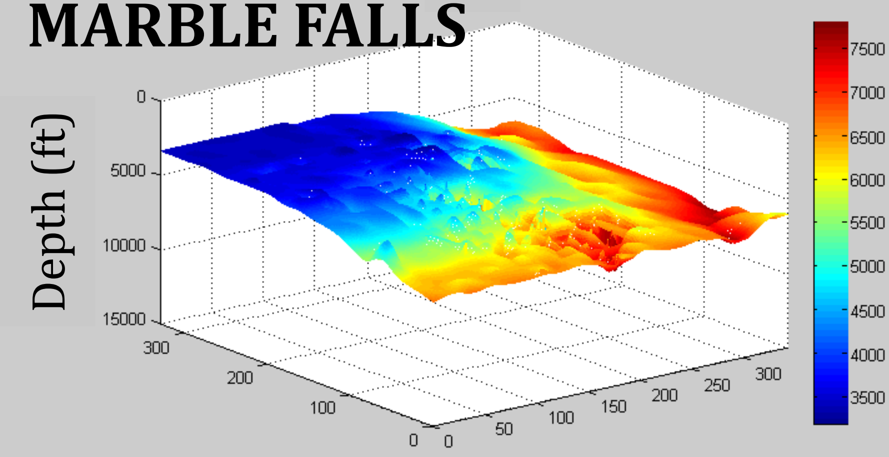
STRAWN



MARBLE FALLS



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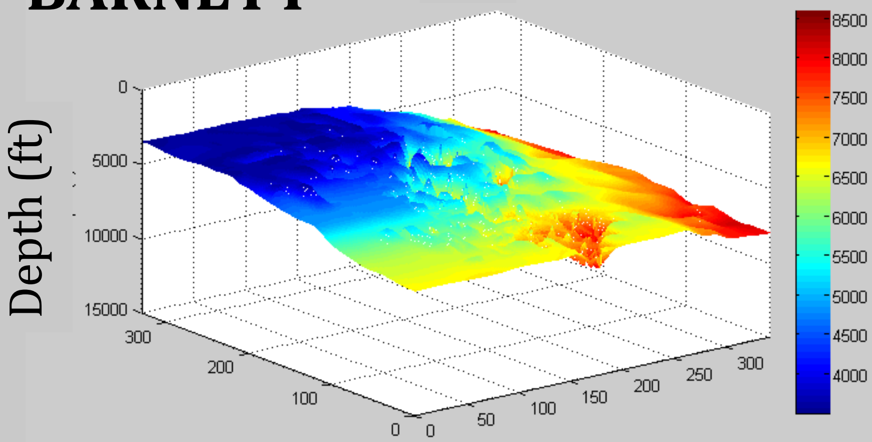
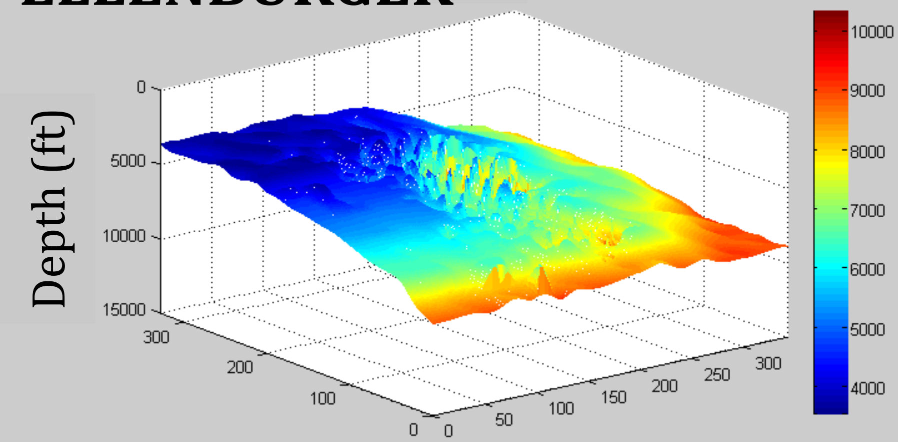


ELLENBURGER



Permeability and Porosity

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Formation	Layer	k_{horiz} (md)	k_{vert} (md)	Porosity
Strawn	**1**	75[1]	7.5	0.20[1]
Strawn	**2**	40	4.0	0.13
Marble Falls	**3**	1[2]	0.1	0.05[3]
Marble Falls	**4**	5	0.5	0.07
Barnett	**5**	9[4]	0.9	0.06[5]
Barnett	**6**	13	1.3	0.11
Ellenburger	**7**	16[6]	1.6	0.09[6]
Ellenburger	**8**	Varies	$0.1*k_{horiz}$	0.07
Basement	**9**	16	1.6	0.07

Sources: See Appendix A

Pressure-Matched Permeability of Layer 8

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Jack 6.51 mD	*Wise* 46.84 mD	*Denton* 21.50 mD	
Palo Pinto 21.50 mD	*Parker* 16.42 mD	*Tarrant* 20.29 mD	*Dallas* 21.50 mD
Erath, Hood, Somervell 21.50 mD	*Johnson* 16.25 mD	*Ellis, Hill* 21.50 mD	

Pressure-Matched Permeability for Layer 8

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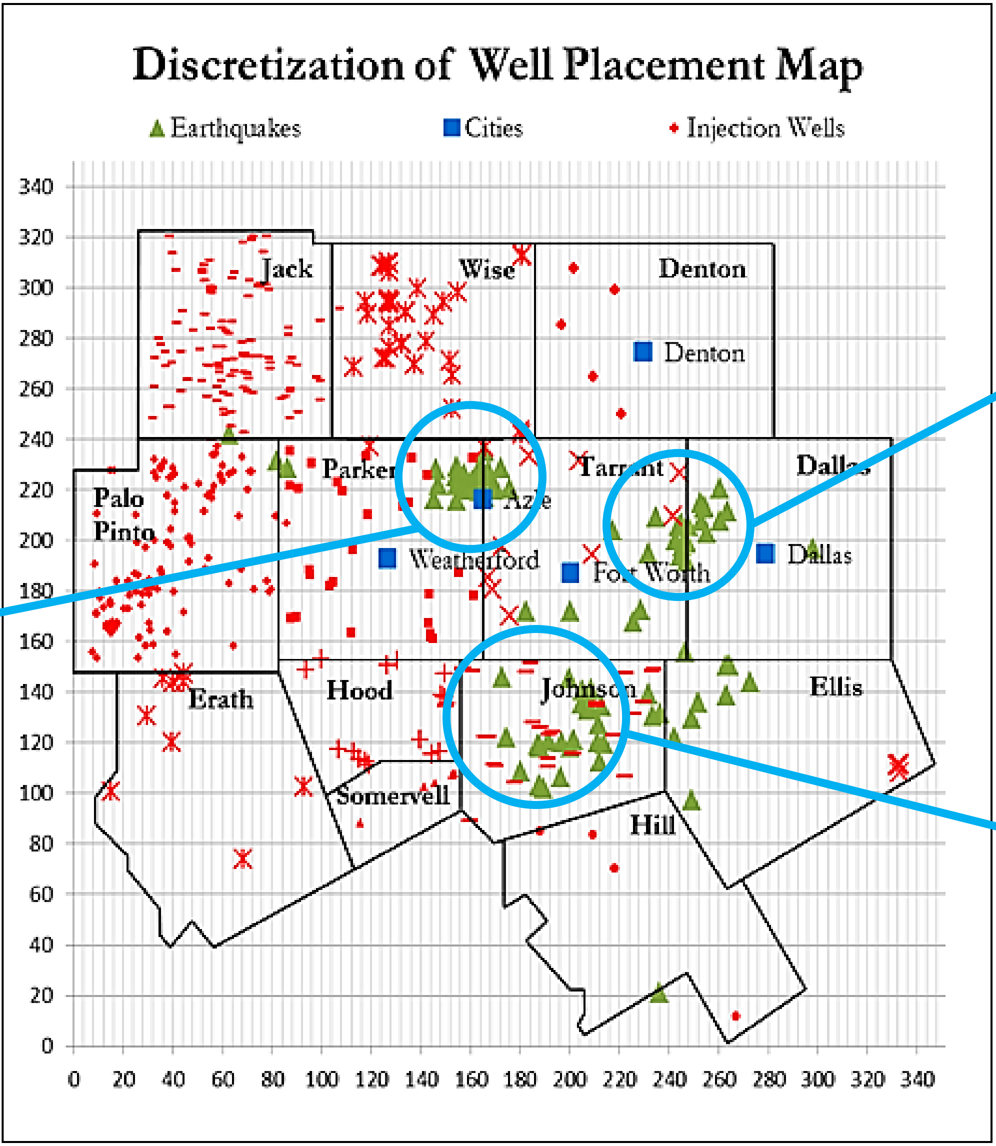
- Layer 8 is of interest for the following reasons:
  - High number of wells injecting into the layer (62 injection wells)
  - Based on preliminary modeling, pressure differential is the greatest

- Pressure-matched permeability for layer 8:
  - 38 out of 62 well's pressure data was matched to within an average of 10%
  - Average permeability was assigned by county
  - For counties with no well injecting into it, the average permeability of the whole layer was used

Areas of Interest



Azle Earthquakes

(Hornbach, et al., 2015)

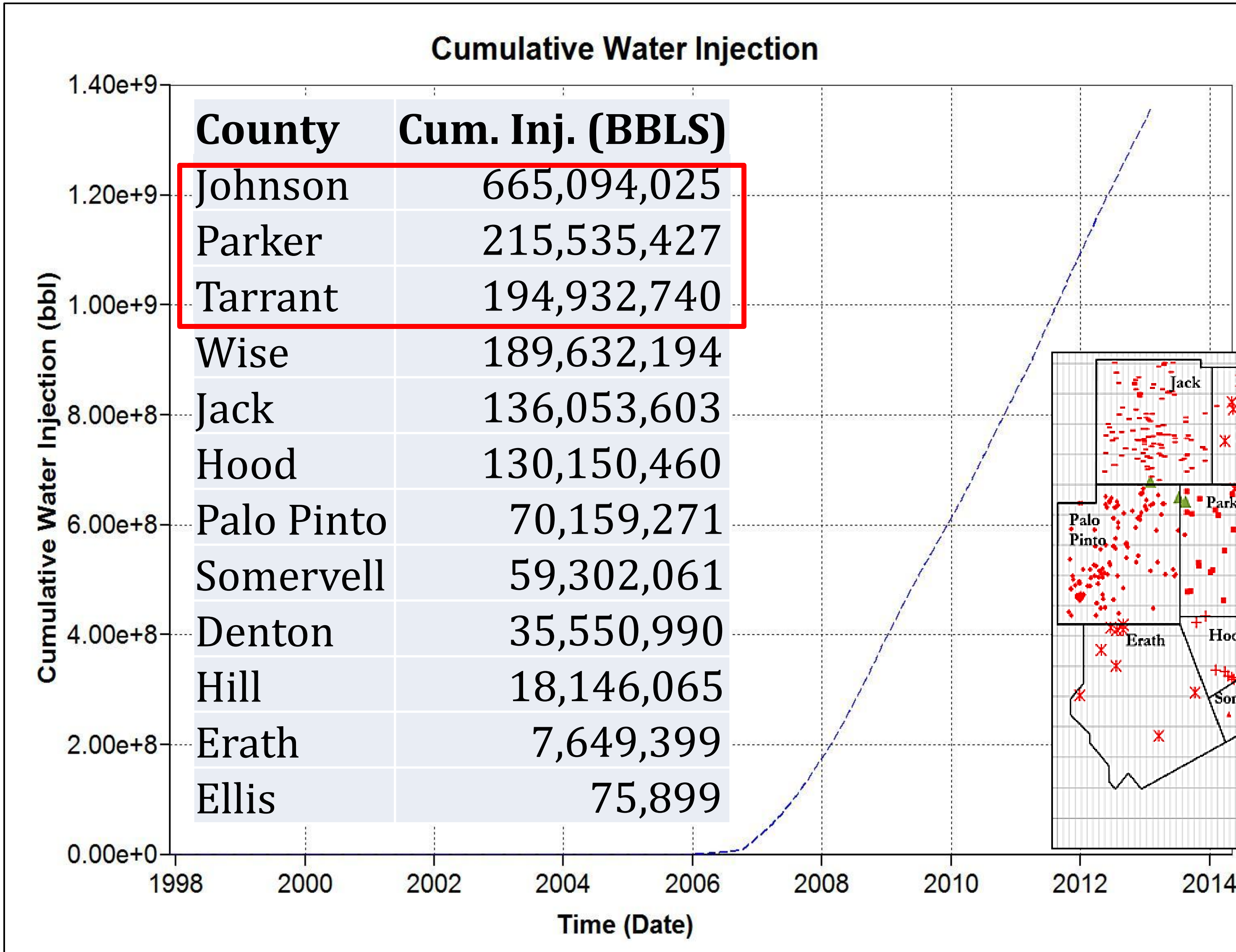
Dallas – Fort Worth Airport (DFW) Earthquakes

(Frohlich, et al., 2011)

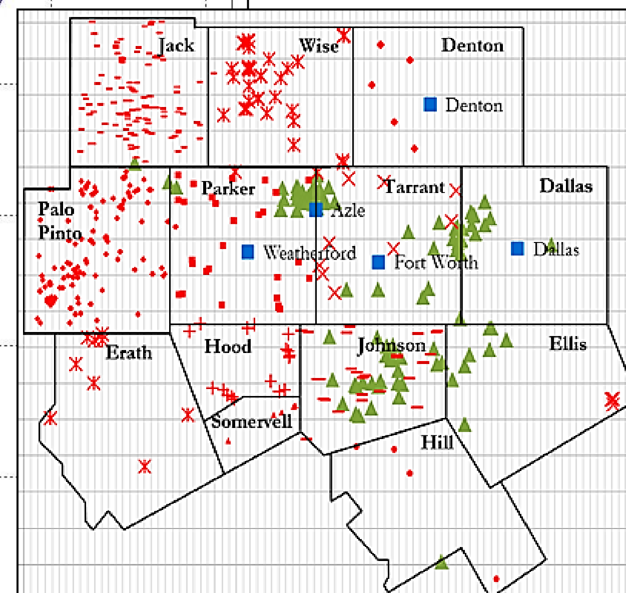
Cleburne Earthquakes

(Justinic, et al., 2013)

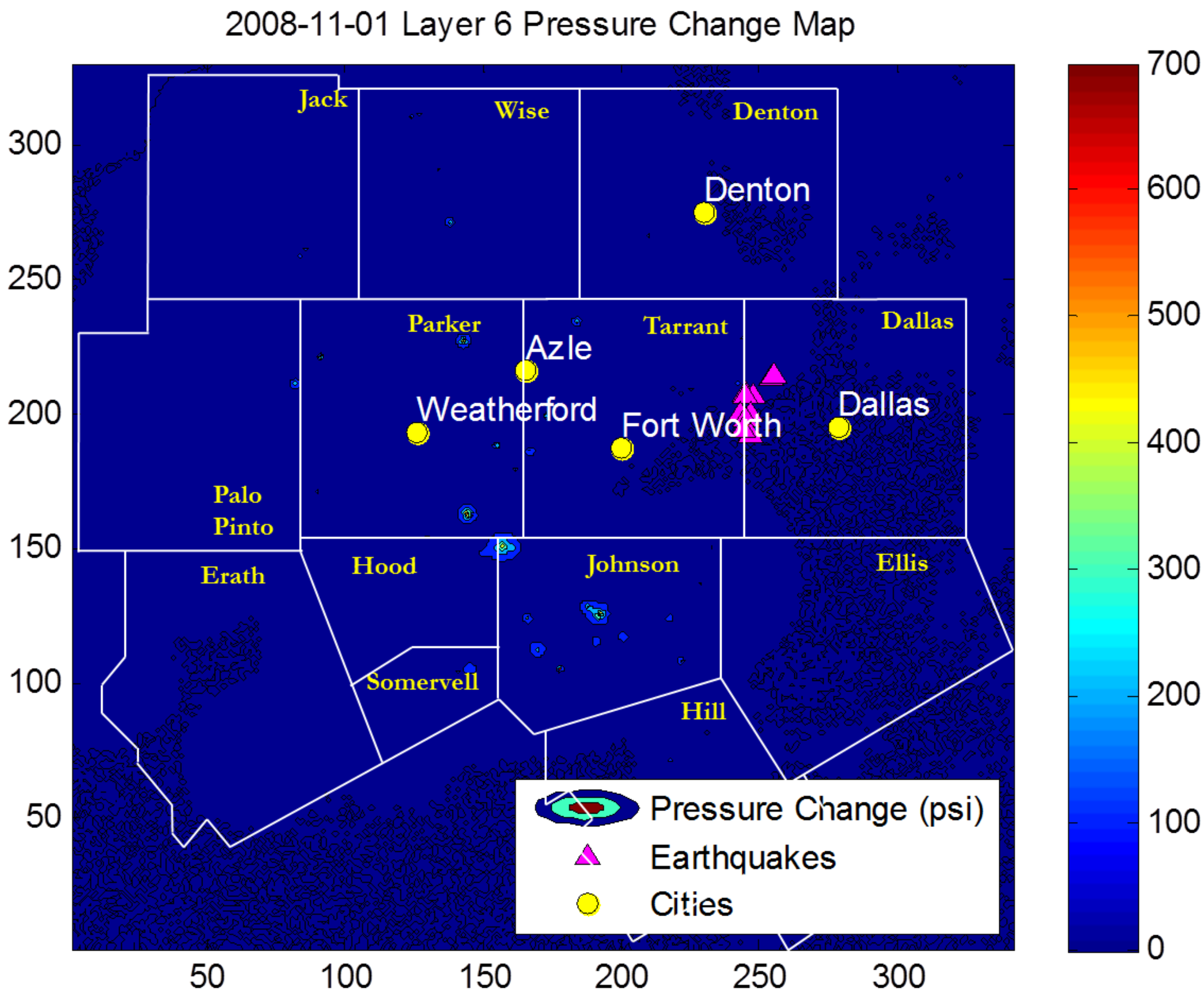
Cumulative Water Injection by County



County	Cum. Inj. (BBLS)
Johnson	665,094,025
Parker	215,535,427
Tarrant	194,932,740
Wise	189,632,194
Jack	136,053,603
Hood	130,150,460
Palo Pinto	70,159,271
Somervell	59,302,061
Denton	35,550,990
Hill	18,146,065
Erath	7,649,399
Ellis	75,899



Dallas – Fort Worth Airport (DFW) Earthquakes



Dallas – Fort Worth Airport (DFW) Earthquakes

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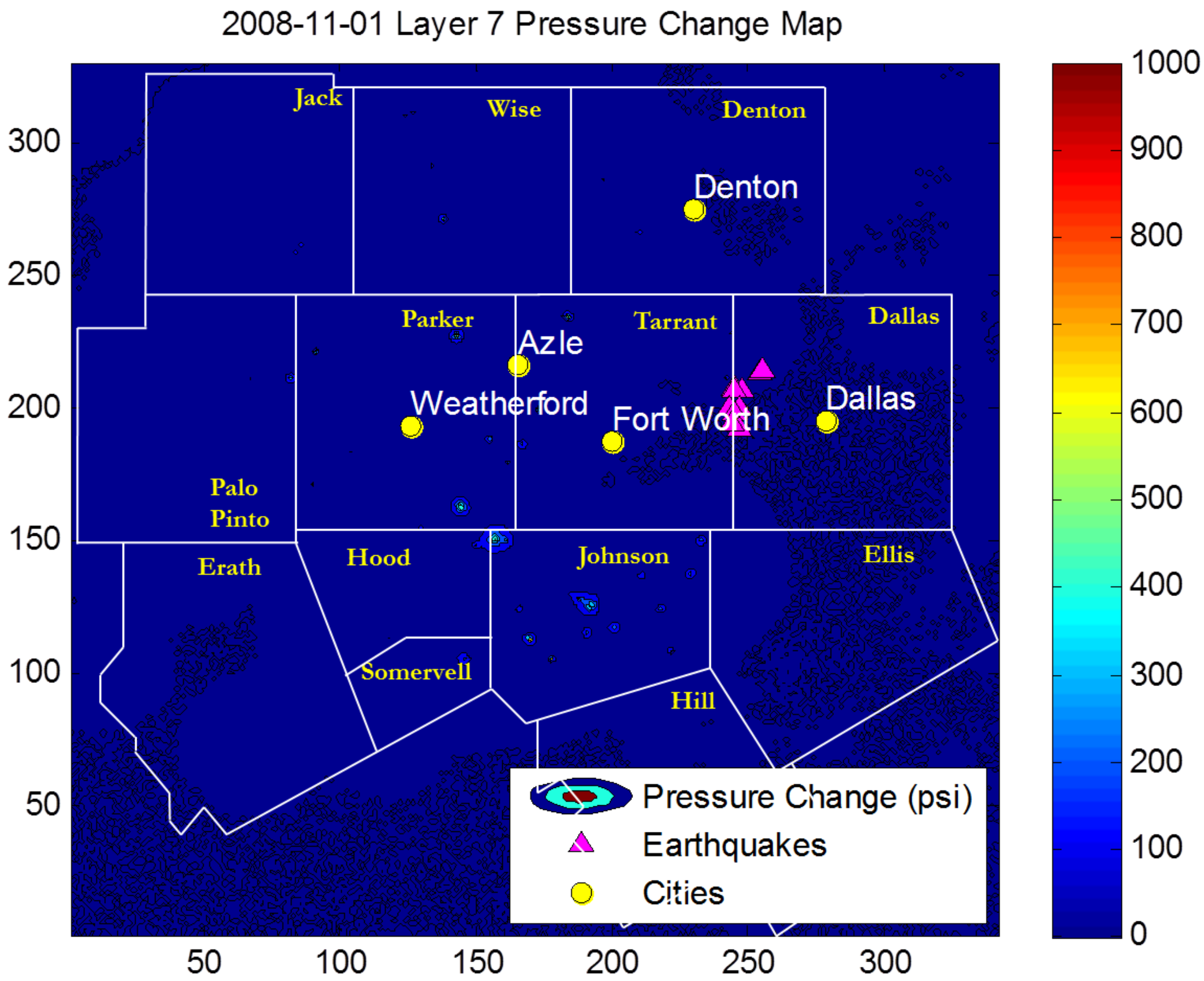
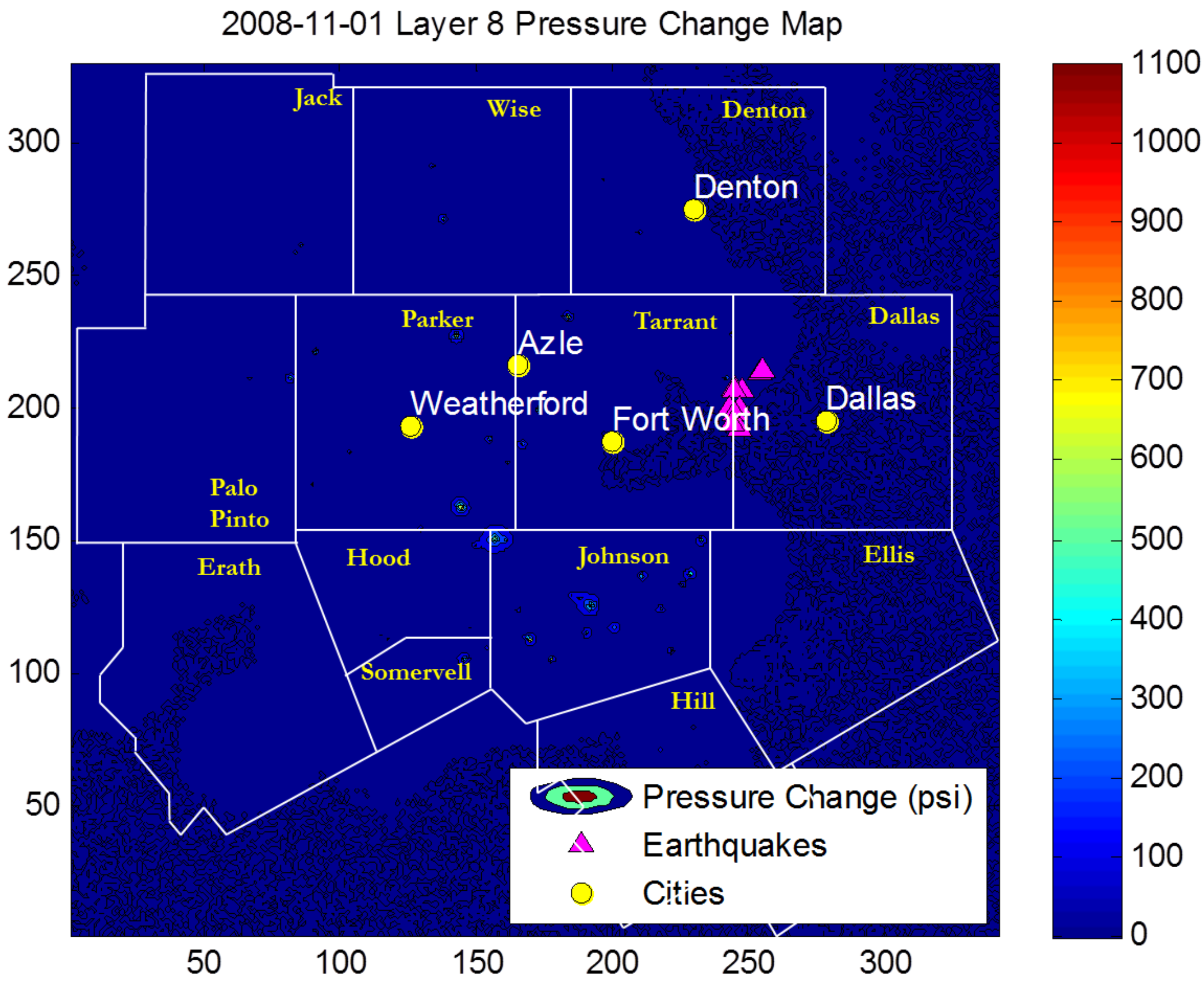


Dallas – Fort Worth Airport (DFW) Earthquakes



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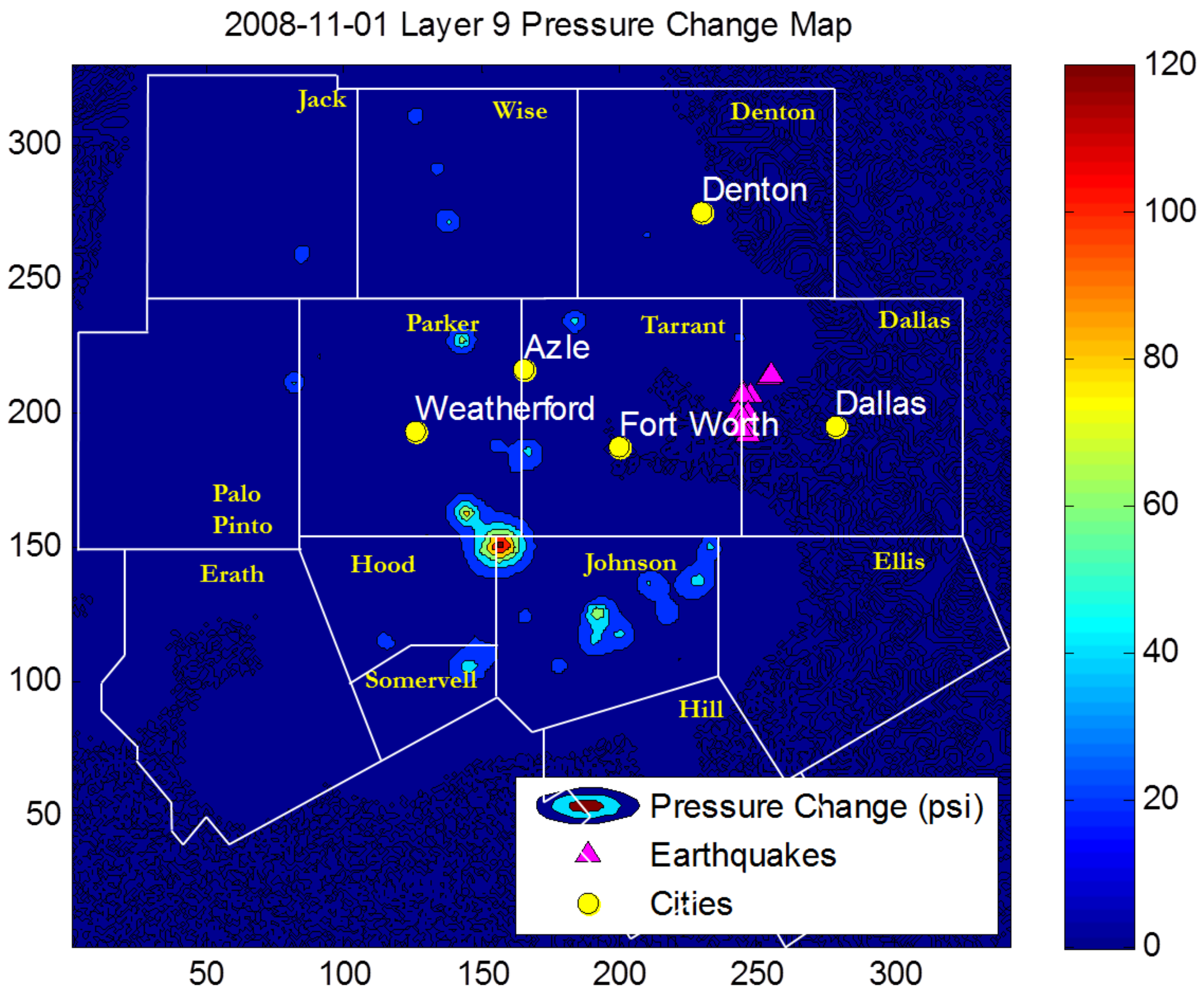

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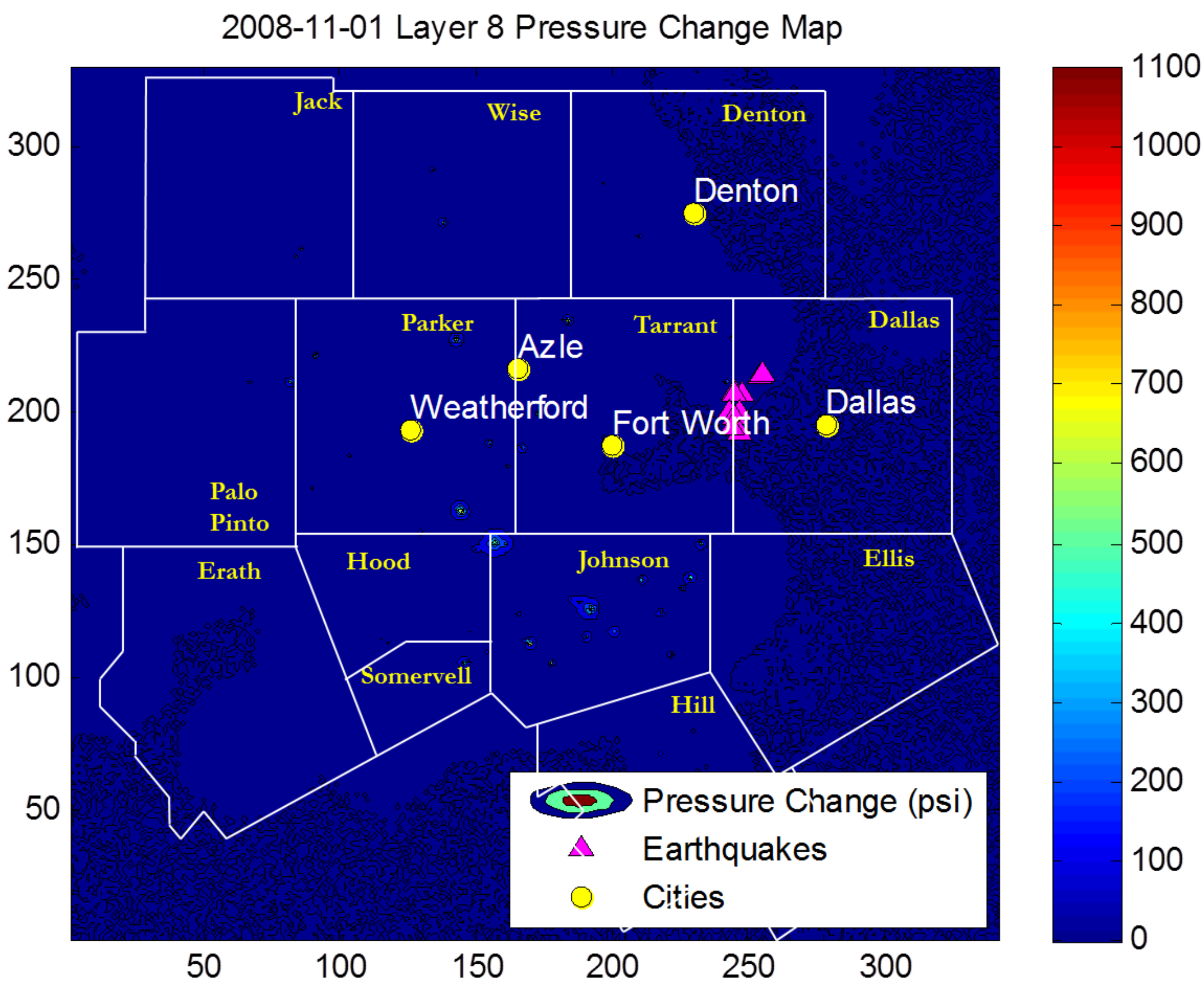

Dallas – Fort Worth Airport (DFW) Earthquakes

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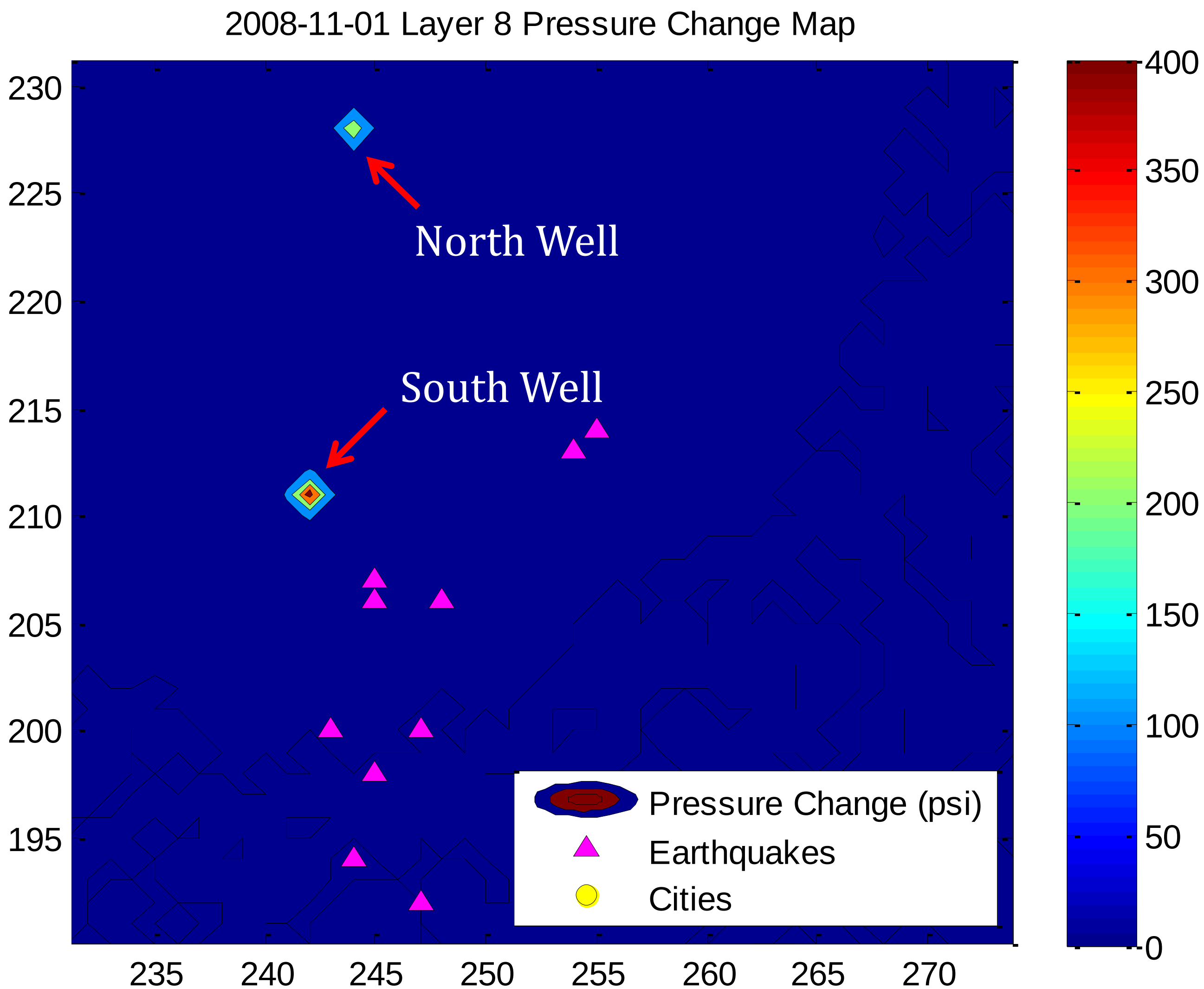

Dallas – Fort Worth Airport (DFW) Earthquakes

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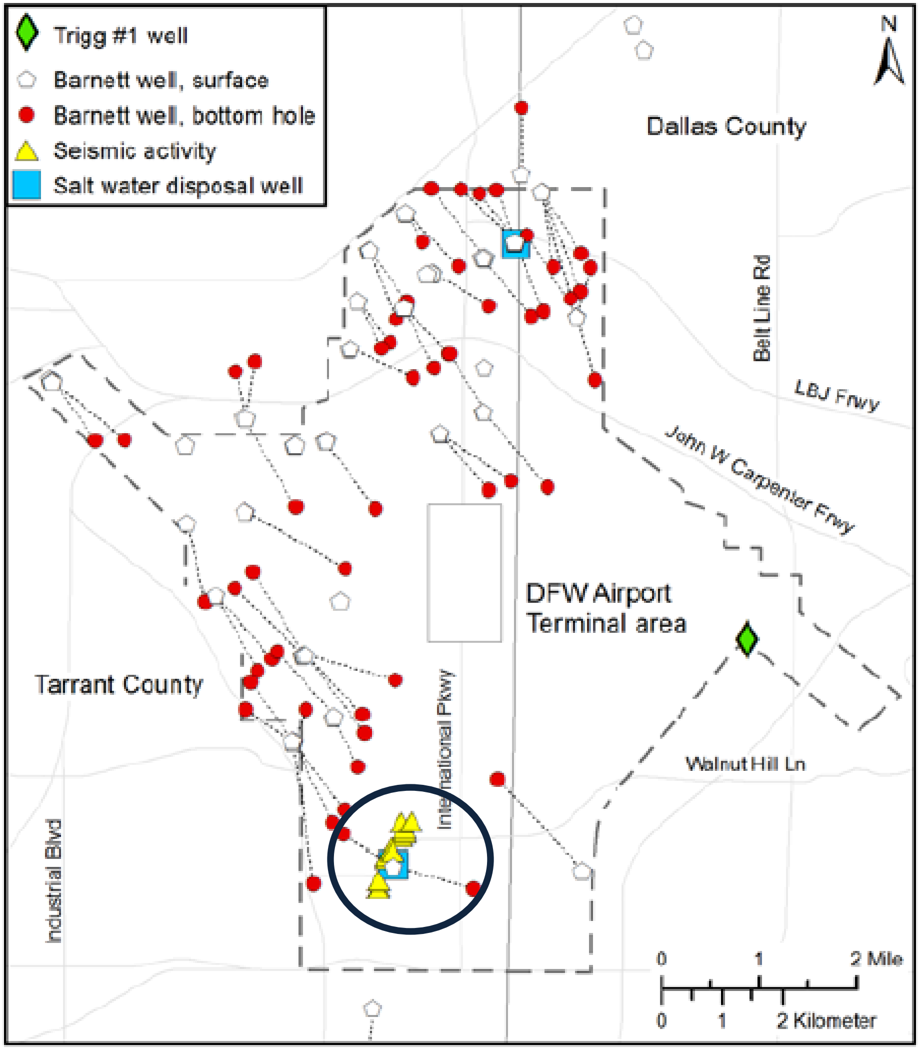
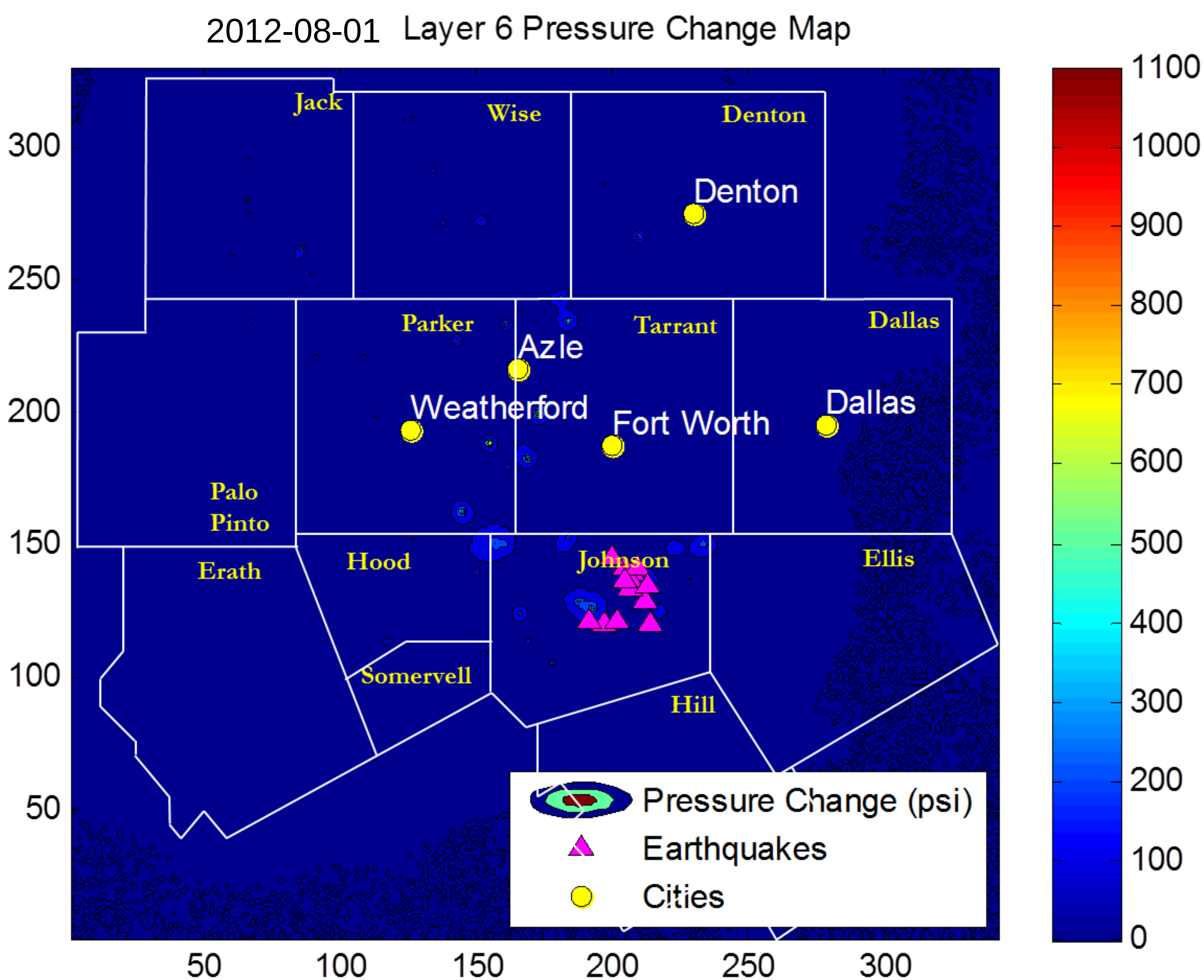
- Frohlich, et al., relocated the earthquakes, and now they coincide directly above South Well
- Pore pressure change is confined to an area of roughly 3500 ft x 4000 ft.
- Pore pressure increase of approximately 150 psi – 400 psi

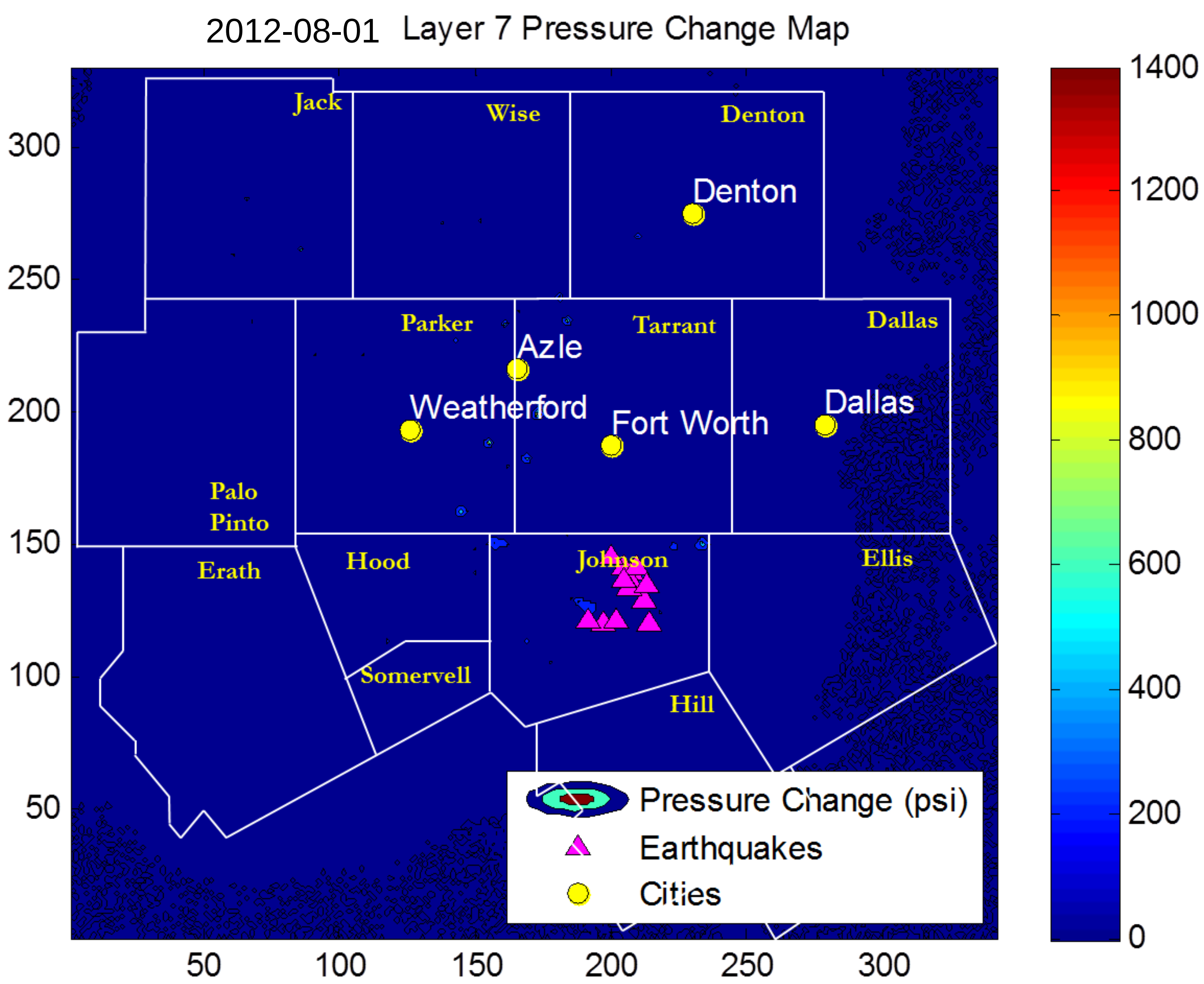


Frohlich, C., C. Hayward, B. Stump, E. Potter. 2011. The Dallas-Fort Worth Earthquake Sequence: October 2008 through May 2008. *Bulletin of the Seismological Society of America*. 101: 327–340.

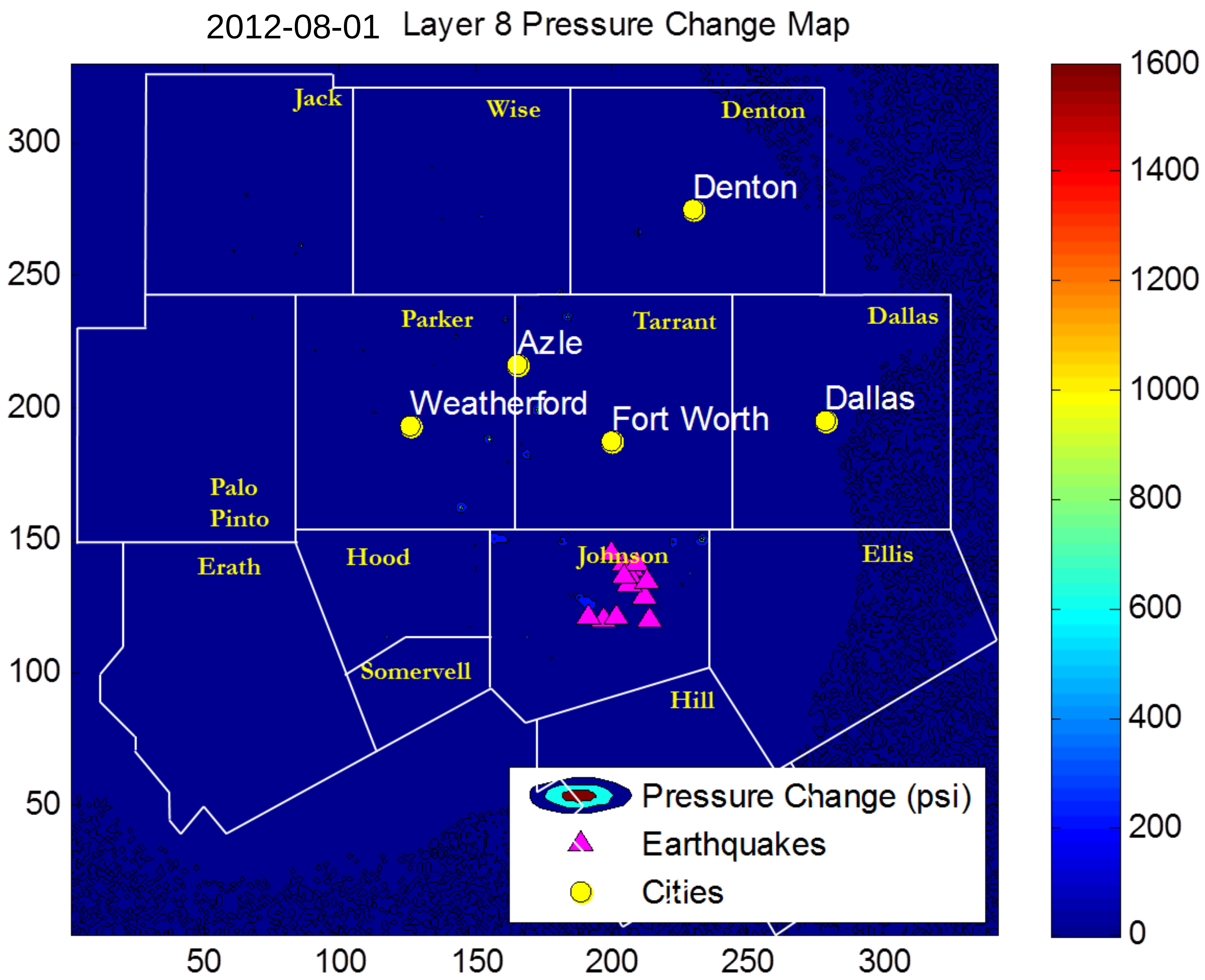
Cleburne Earthquakes



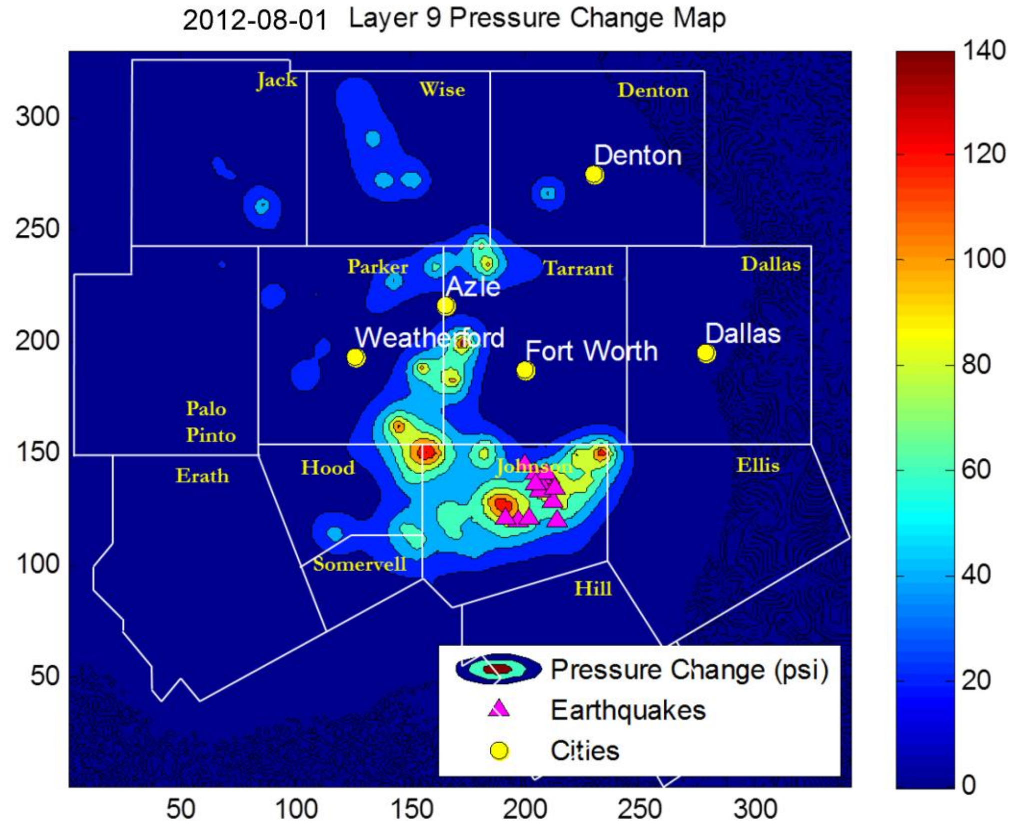
Cleburne Earthquakes



Cleburne Earthquakes

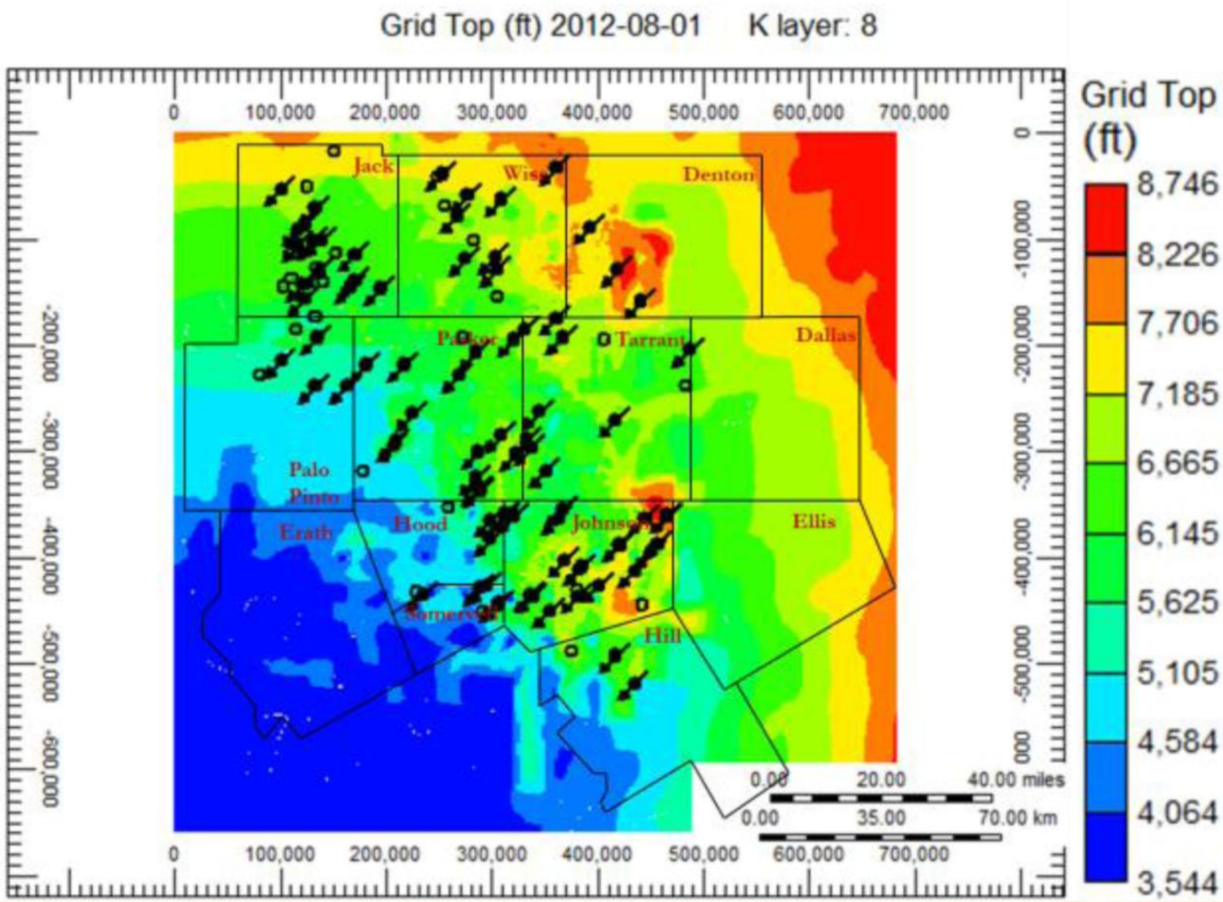


Cleburne Earthquakes



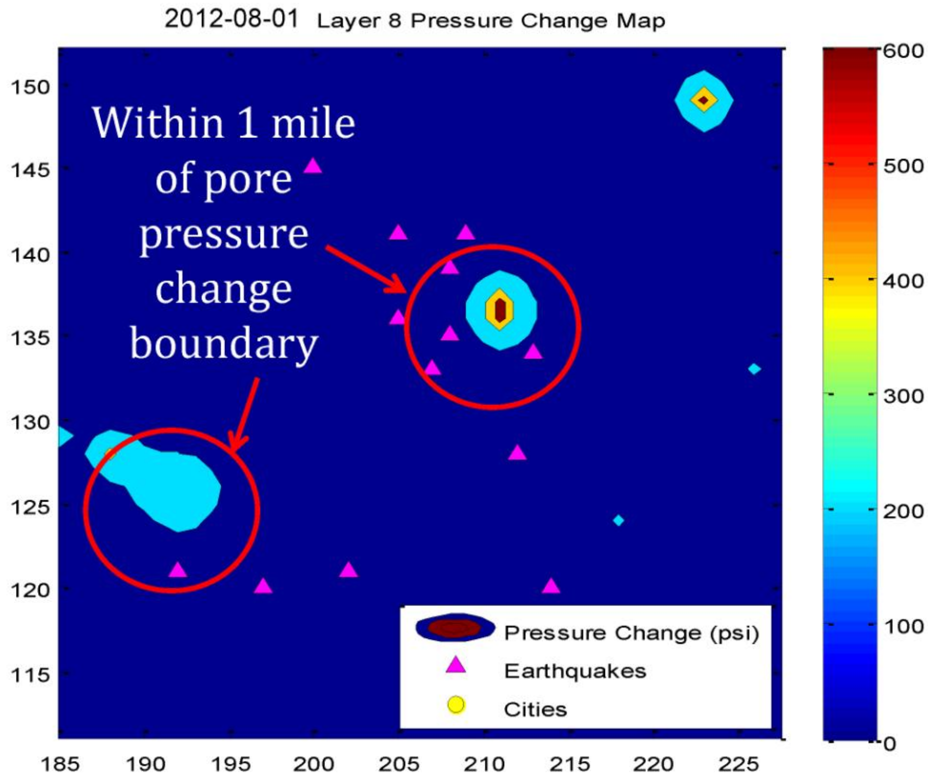
Presenter's notes: Point out the clear correlation between Layer 9 increased of pore pressure area and the location of earthquakes But also, point out that Wise and Jack has some increased in pore pressure, yet it doesn't experience any earthquakes

Cleburne Earthquakes



Presenter's notes: Even though, layer 9 has the most significant pressure differences, but layer 8 is of interest, since most of the injection at that time occurred in layer 8.

Cleburne Earthquakes



Presenter's notes: Looking at layer 8, there is a weak spatial and temporal correlation between the location of the earthquakes and the area of increased pore pressure. There are 5 wells located within 1 mile of the pore pressure change boundary. It should be pointed out that these earthquakes are not relocated, and the earthquake location from the NEIC database is only accurate to within a few miles.

Cleburne Earthquakes

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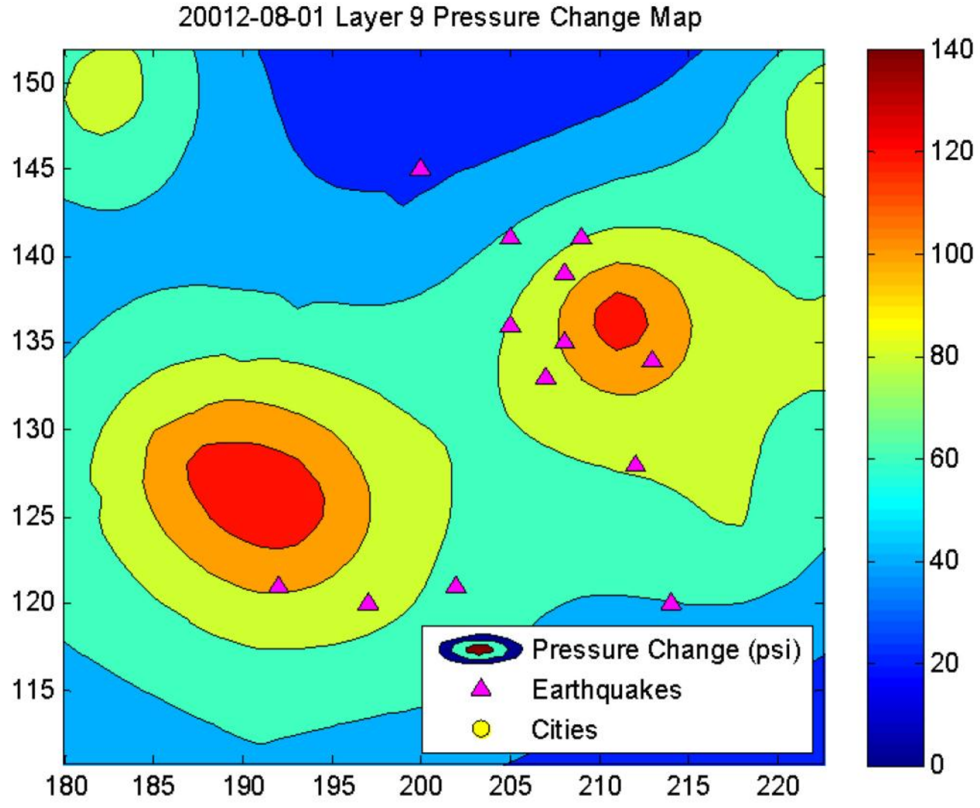


Presenter's notes: And if we look at layer nine, where the pressure increase is the most prominent, all the earthquakes fell within the areas of pressure increase.

Cleburne Earthquakes

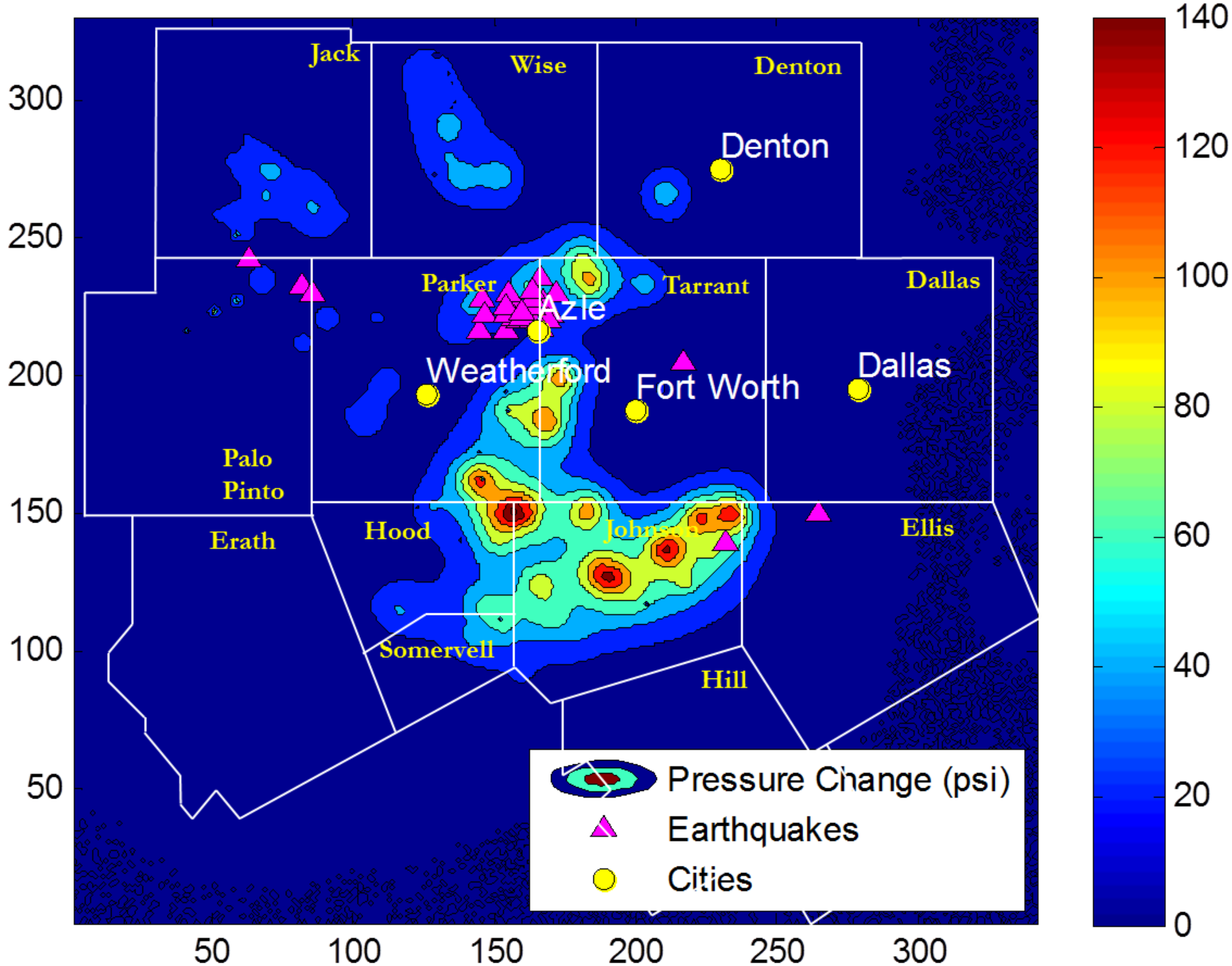
- NEIC database is only accurate to within a few mile (1 – 6 miles)

- Relocation of the earthquakes may result in a much clearer spatial correlation between earthquakes and pore pressure increase in layer 8

- On layer 8, the pore pressure increase that correspond to earthquake location is approximately between 200 psi – 600 psi, while on layer 9, it is approximately between 20 psi – 100 psi

Azle Earthquakes

2014-01-01 Layer 6 Pressure Change Map



Azle Earthquakes

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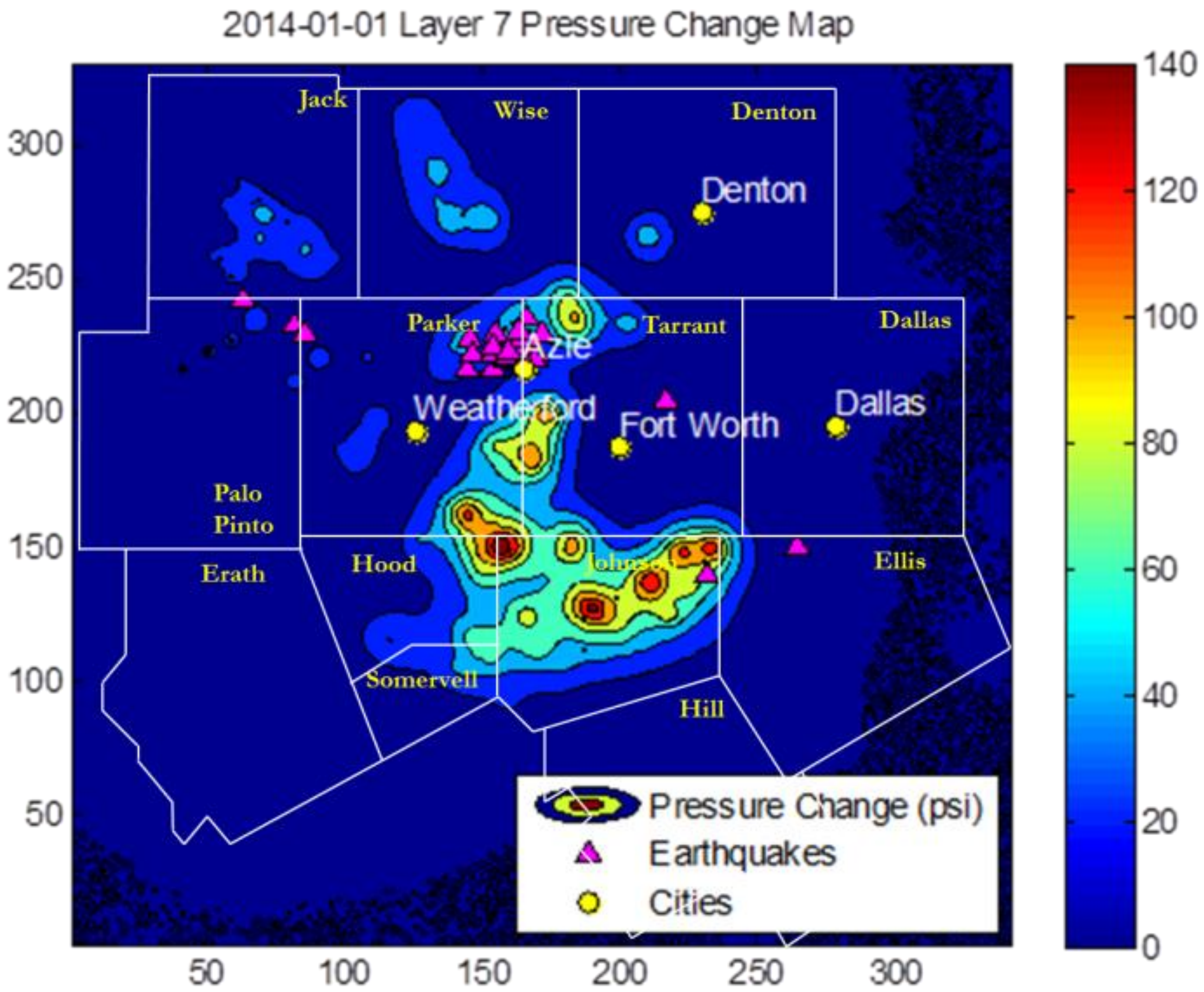

Azle Earthquakes

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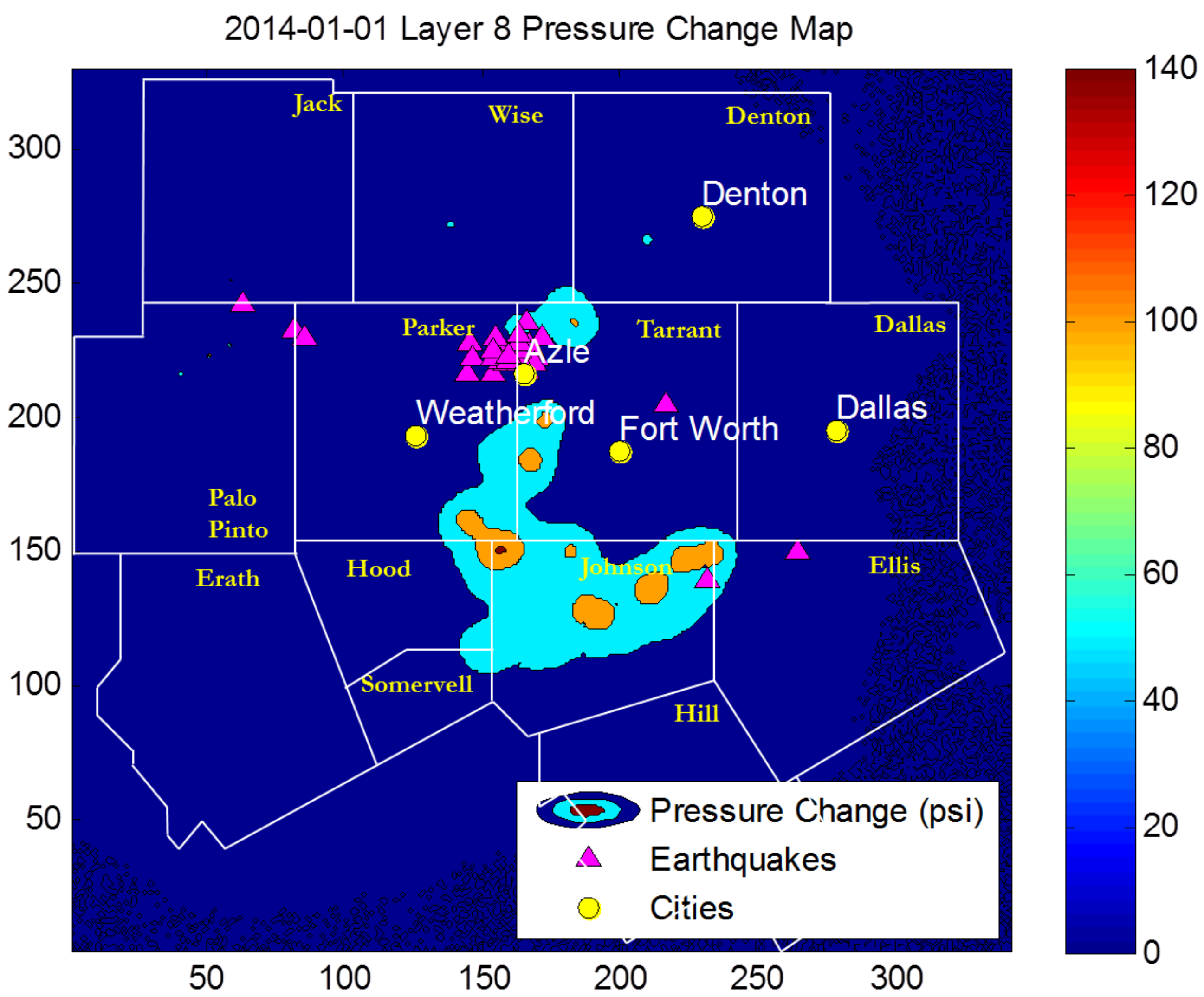
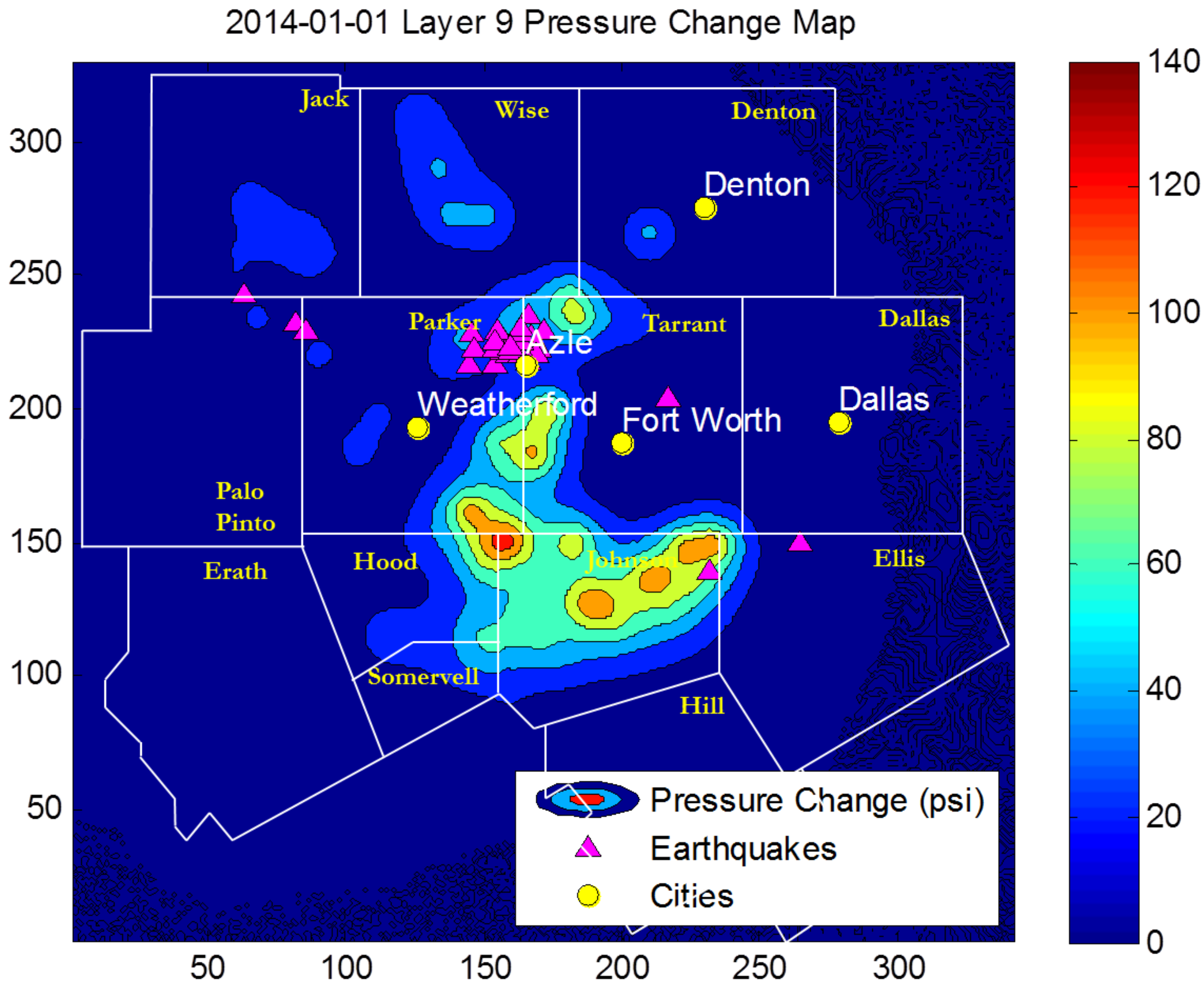


Azle Earthquakes



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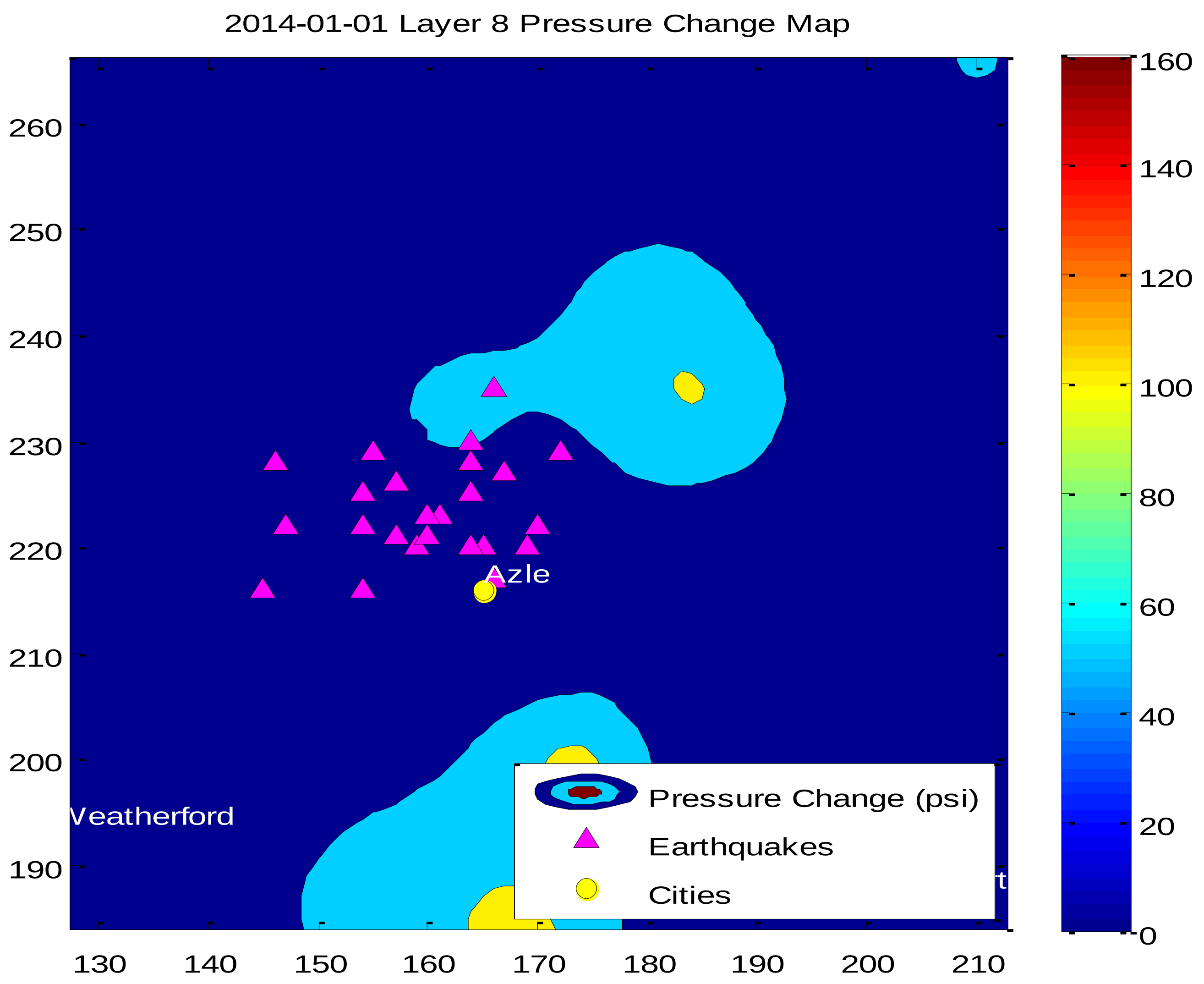
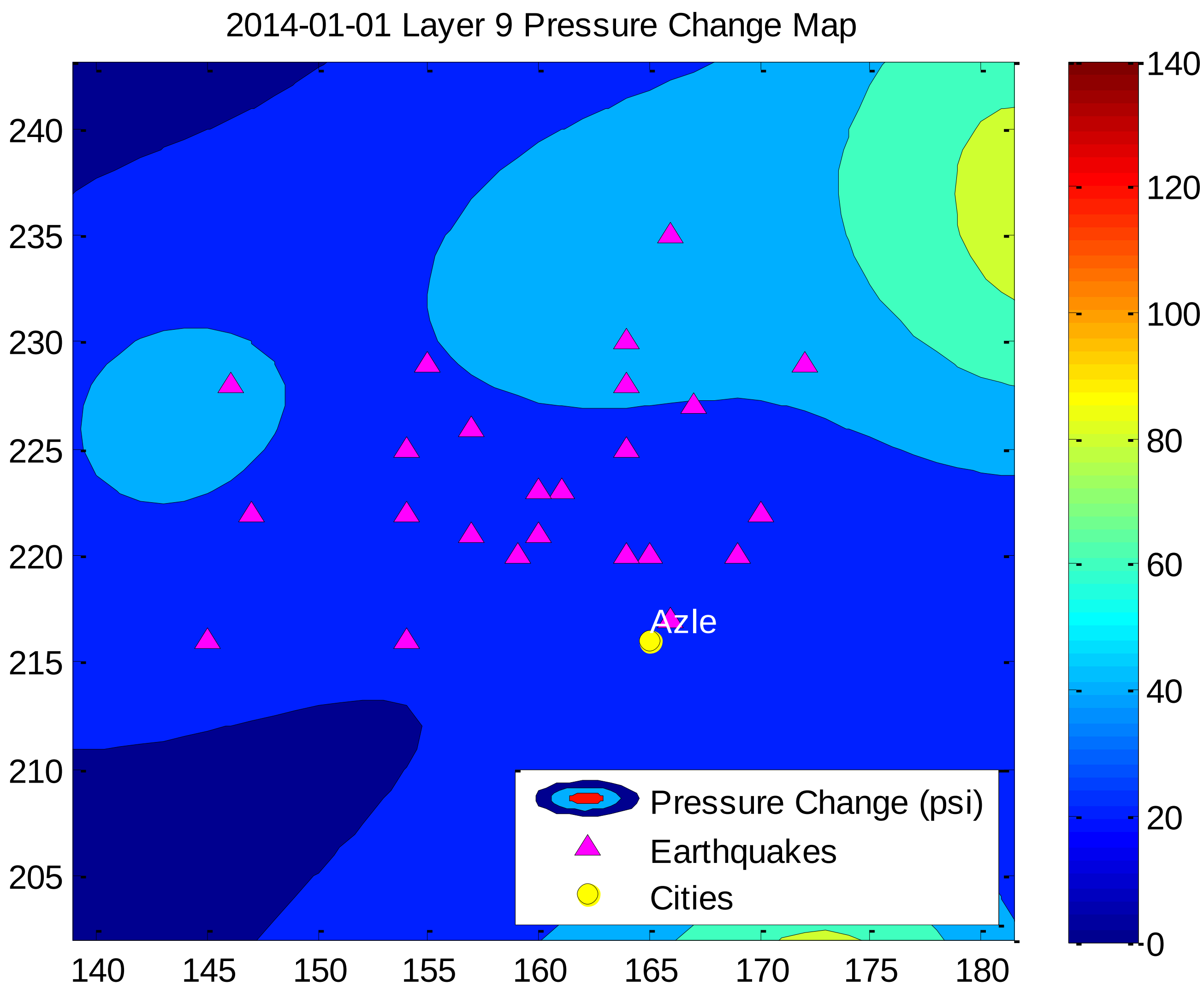


Azle Earthquakes

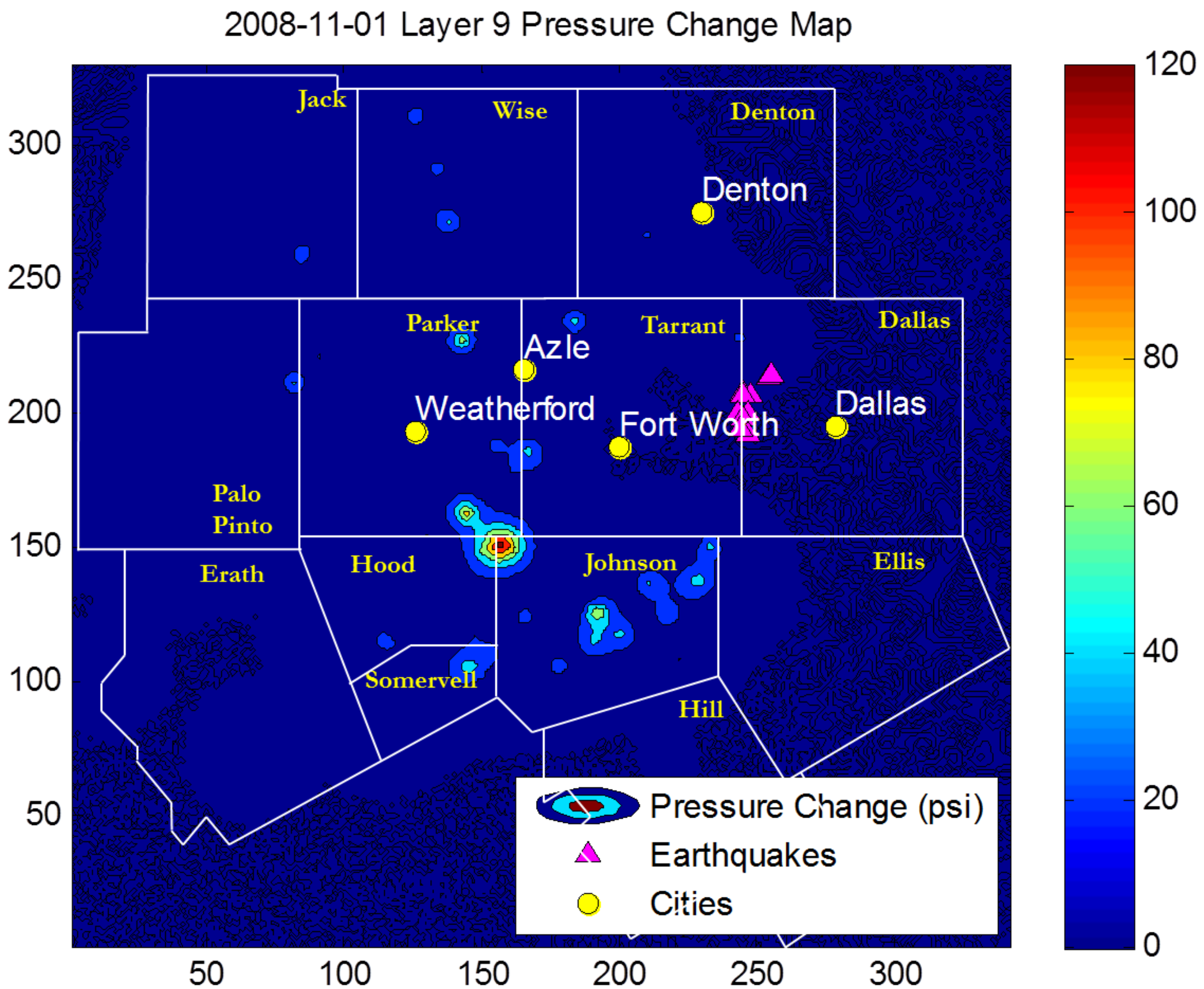


Azle Earthquakes

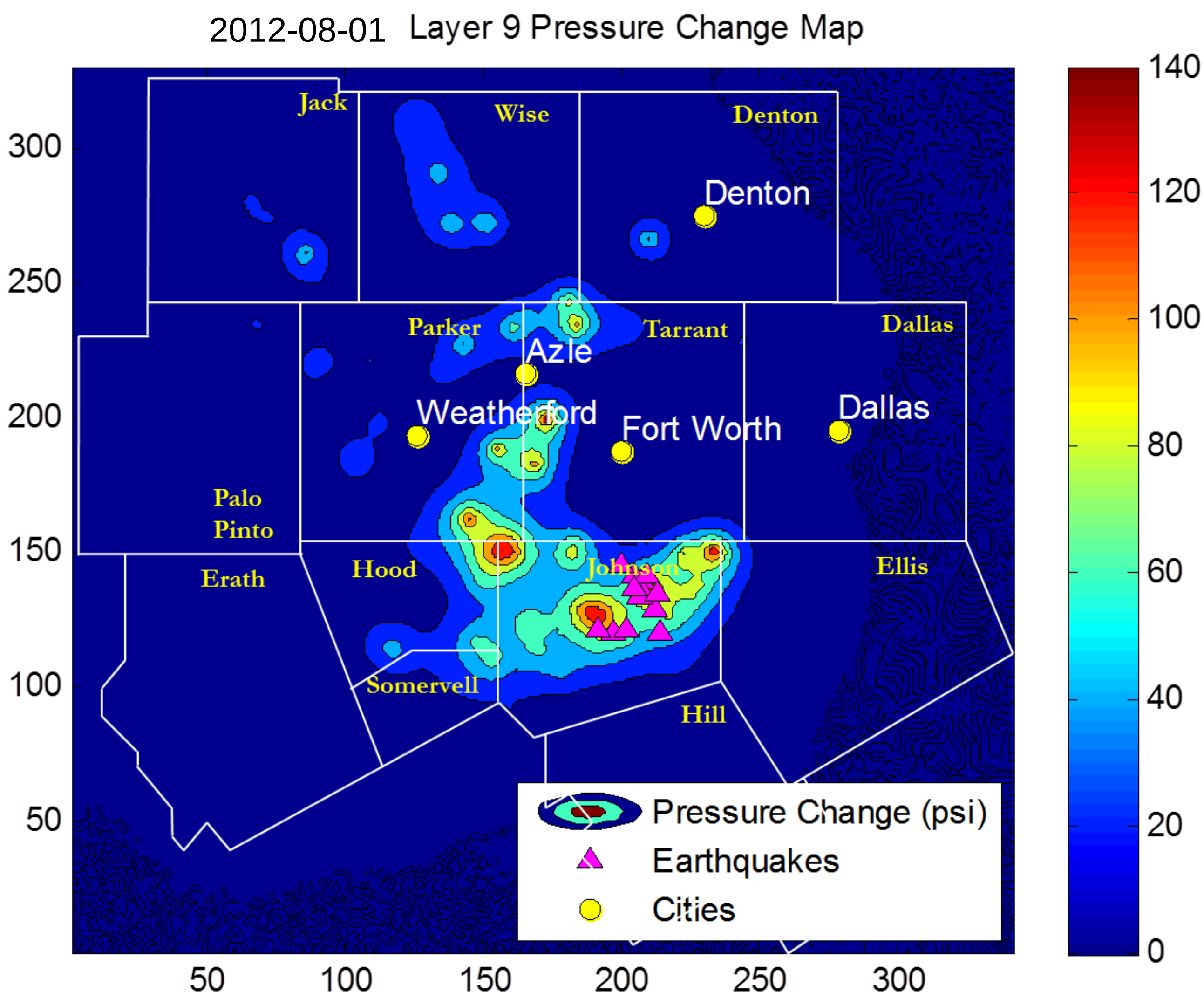
- From layer 8, it can be seen that the area of pore pressure increase of 60 psi is very close to the location of the earthquakes, and two events did occur in the area of pore pressure increase. However, correlation is pretty weak.

- On layer 9, the earthquakes are located within areas of pore pressure increase of approximately 20 psi – 40 psi

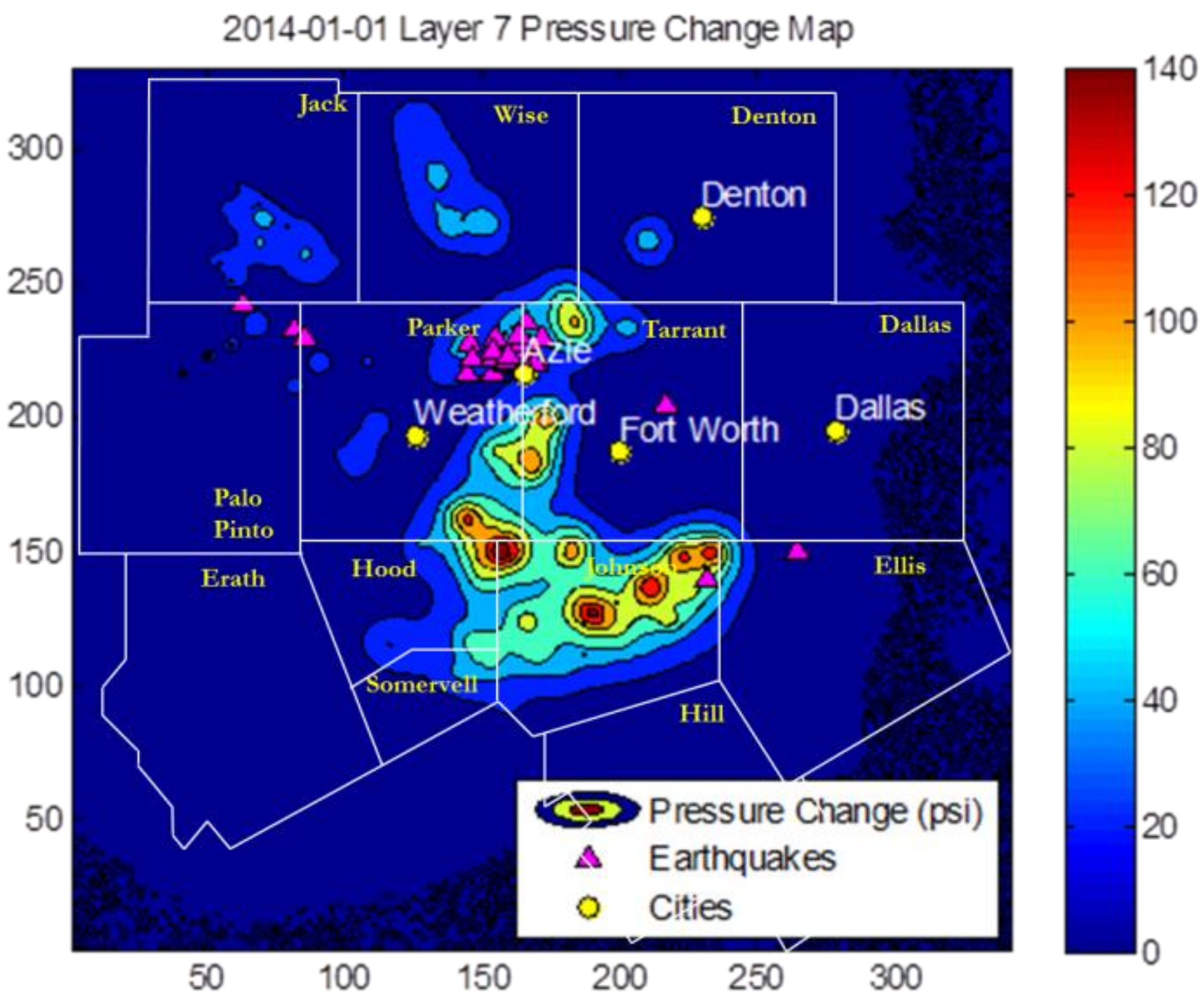
Area of Increased Pressure and No Earthquake



Area of Increased Pressure and No Earthquake



Area of Increased Pressure and No Earthquake



Conclusions

- On the area of interests, DFW, Cleburne, and Azle, there are some spatial and temporal correlation between the increase of pore pressure and occurrence of earthquakes

- An increase in pore pressure is required to slip the faults which in turn cause earthquakes. The increase needed to slip the fault may be quite small (Hornbach, et al., 2015)

- A more interesting result is that there are areas with high pressure changes but no earthquakes. This can be attributed to the lack of favorably oriented faults in the area or perhaps if there are faults, they are not critically stressed

Acknowledgements

The authors would like to thank Research Partnership to Secure Energy for America (RPSEA) for funding support of the project. Additionally, the authors would also like to thank *David Smith* and *Qilong Fu* of the Bureau of Economic Geology (BEG) at The University of Texas at Austin for the help with formation tops data gathering and determination.

RPSEA
Research Partnership to Secure Energy for America

Bureau of Economic Geology

Appendix A

TEXAS
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[1]Ball, M. M., W. Perry, Jr. Bend Arch-Fort Worth Basin Province. *United States Geological Survey.*

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[6]Holtz, M. H., C. Kerans. 1992. Characterization and Categorization of West Texas Ellenburger Reservoirs. *Permian Basin Section SEPM Publication*. 92–33: 31–44.