Monitoring seismicity near an active CO_2 EOR injection

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Cataloging Earthquakes

- Events cataloged from April 2015 to April 2017
- 2133 earthquakes were located in Sumner County, KS
- Magnitudes range from M_w 0.4 to M_w 3.5
- P-wave velocity calculated from well logs of KGS 2-32
- S-wave velocity is calculated from a Vp/Vs ratio
- Moment Magnitude calculated from energy spectrum of event and distance to event
- Magnitude of Completeness
    - 1.5 M_w for Sumner County

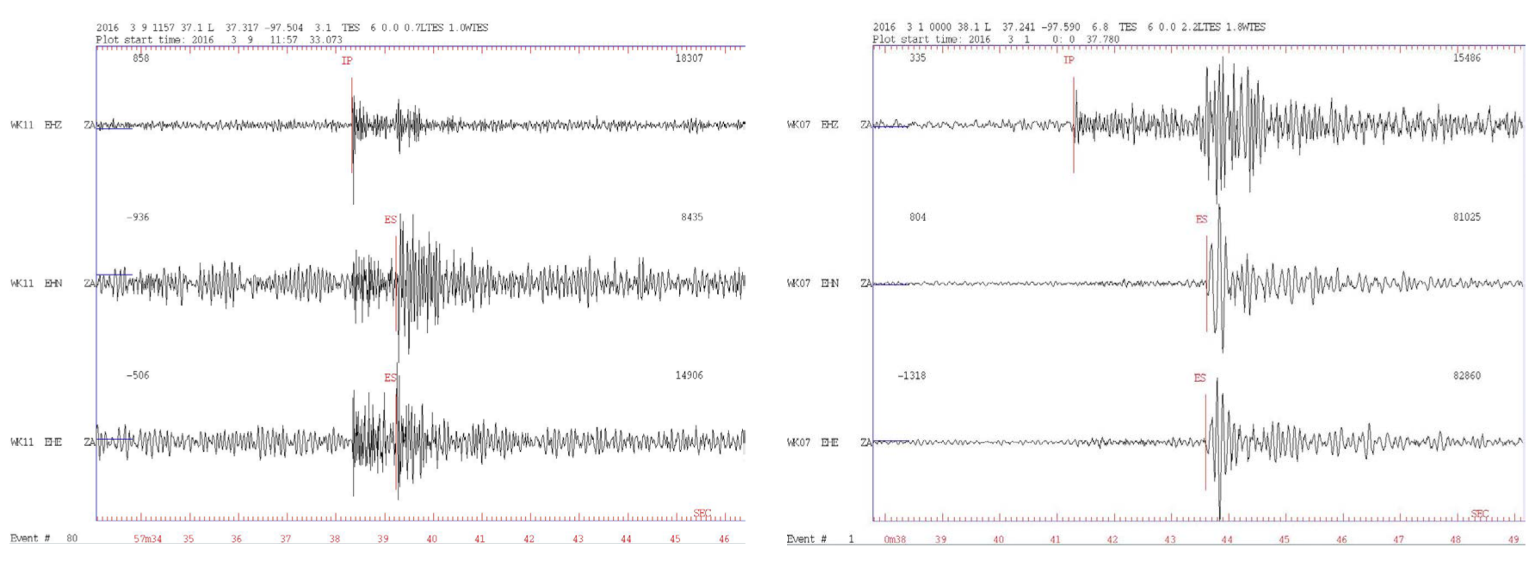

Figure 1. Comparison of small local event (left) of M_w 1.0 and large local event (right) of M_w 1.8 with vertical channel displayed on the top row and the two horizontal channels below. P and S arrivals are shown in red. Both events are from March of 2016.

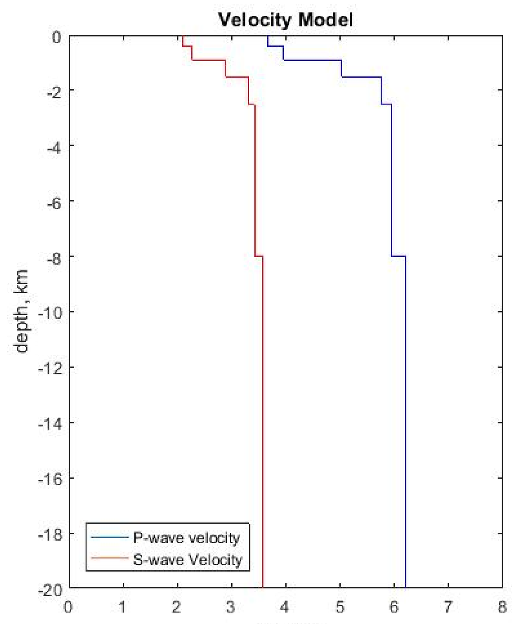

Figure 2. Velocity model was used in calculating locations of events near the Wellington Array. The model was derived from well logs of the KGS 2-32 well, calculated to the bottom of the well. Deeper velocities were constrained through 1-D velocity inversion

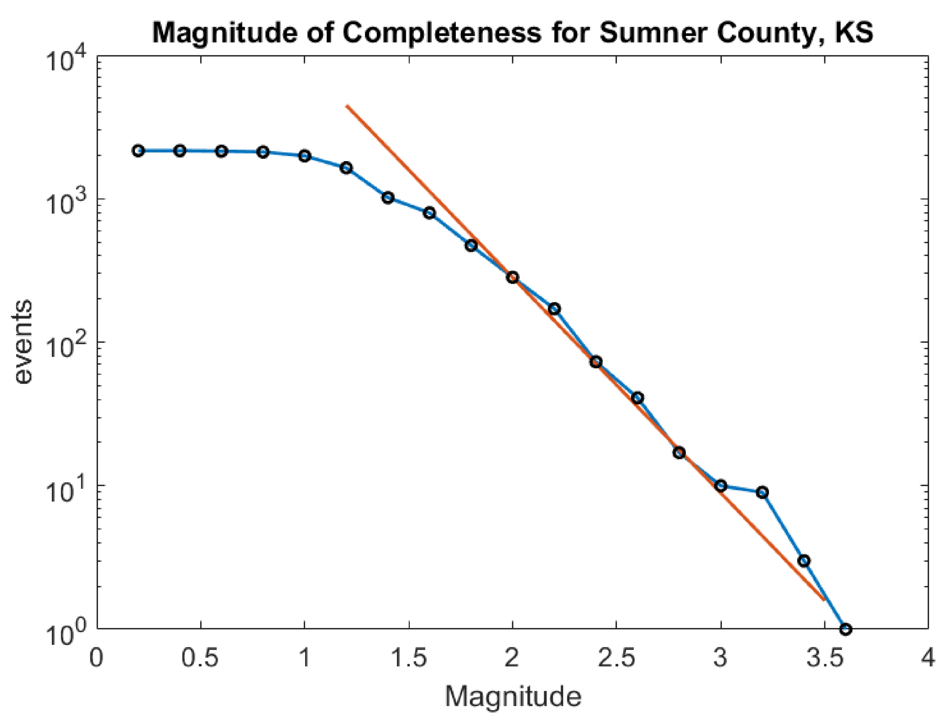

Figure 3. The graph is showing the Magnitude of completeness calculated from the Gutenberg-Richter law. The blue line with black circles represents events recorded from the seismometer array, and the orange line represents predicted events using the Gutenberg-Richter law, with a b-value of 1.5. The two curves diverge at a magnitude Mc = 1.1.

Magnitude of Completeness:

- Magnitude of Completeness (M_c) is the earthquake magnitude for which an array can confidently pick all events of that magnitude and larger in a certain area [Vorobieva, 2012]
- M_c for the Wellington array is ~1.5 M_w for Sumner County
- Increase b-value of 1.5 indicative of pore fluid pressure increase as cause of seismicity

Objective

The objective of the earthquake monitoring program at Wellington Oilfield is to ensure safe CO_2 injection in the Mississippian and Arbuckle with regards to induced seismicity. The research also provides information on the stress field of the shallow basement and the location of faults. This data can be used to advance the understanding of induced seismicity in the region as well as inform the regulation of fluid injection in the midcontinent.

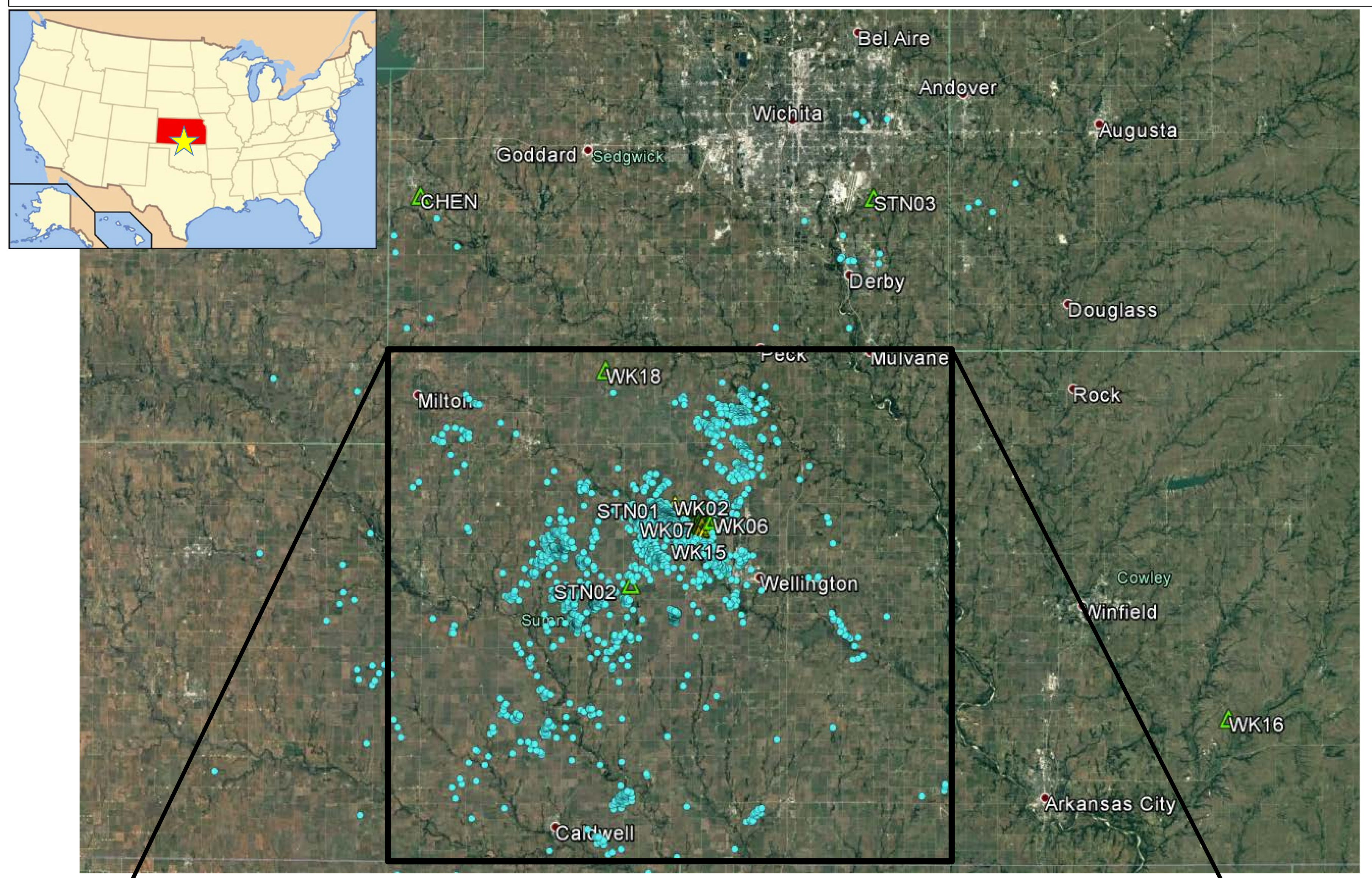

Figure 4. Map of Sumner County, KS, showing the earthquake catalog and station locations.

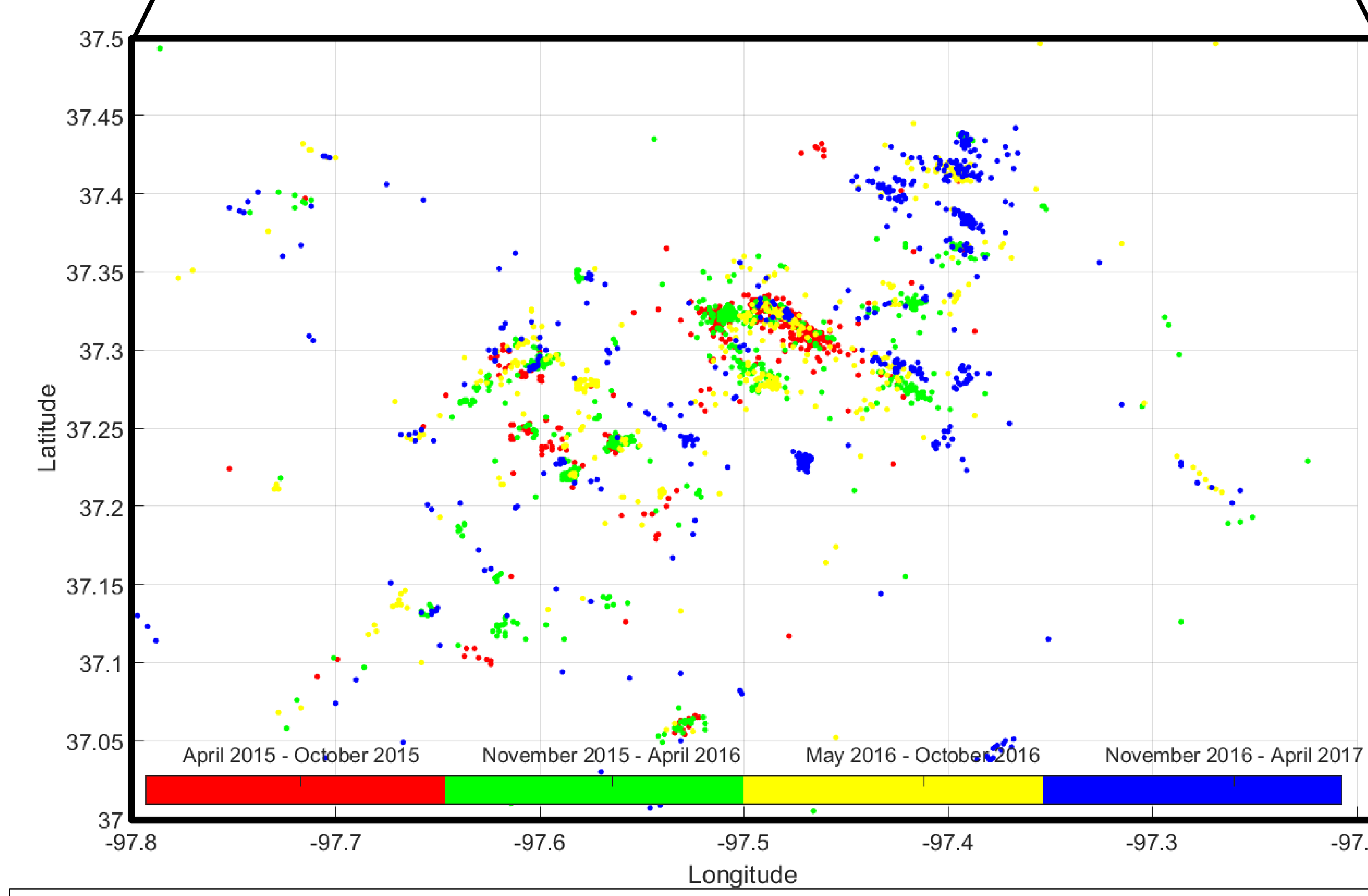

Figure 5. Map of Sumner County, KS, showing the earthquake progression through time,with red being the oldest (2015) and blue being the newest (2017).

Results

- **CO_2 injection at Wellington field well KGS #2-32 did not cause observable seismicity**
- **Seismicity likely caused from increased pore fluid pressure in basement and Arbuckle**
- **Over the last two years earthquakes have been advancing northward, from northern Oklahoma to southern Kansas**
- **Shear- wave anisotropy analysis presented here is the first direct evidence provided by seismological observations relating increase in pore fluid pressure to earthquakes in KS and OK**
- **Pressure monitoring in well KGS 1-28 confirms the pressure increase in KS and OK**
- **Shear-wave splitting methods can be used to mitigate seismic hazard associated with injection induced seismicity**

Shear-Wave Splitting

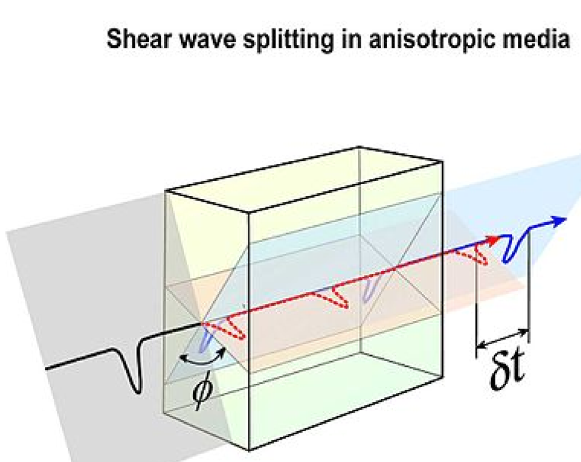

Figure 6. Example of how a shear-wave separates into a fast and slow component in an anisotropic medium. From Garnero, 2017.

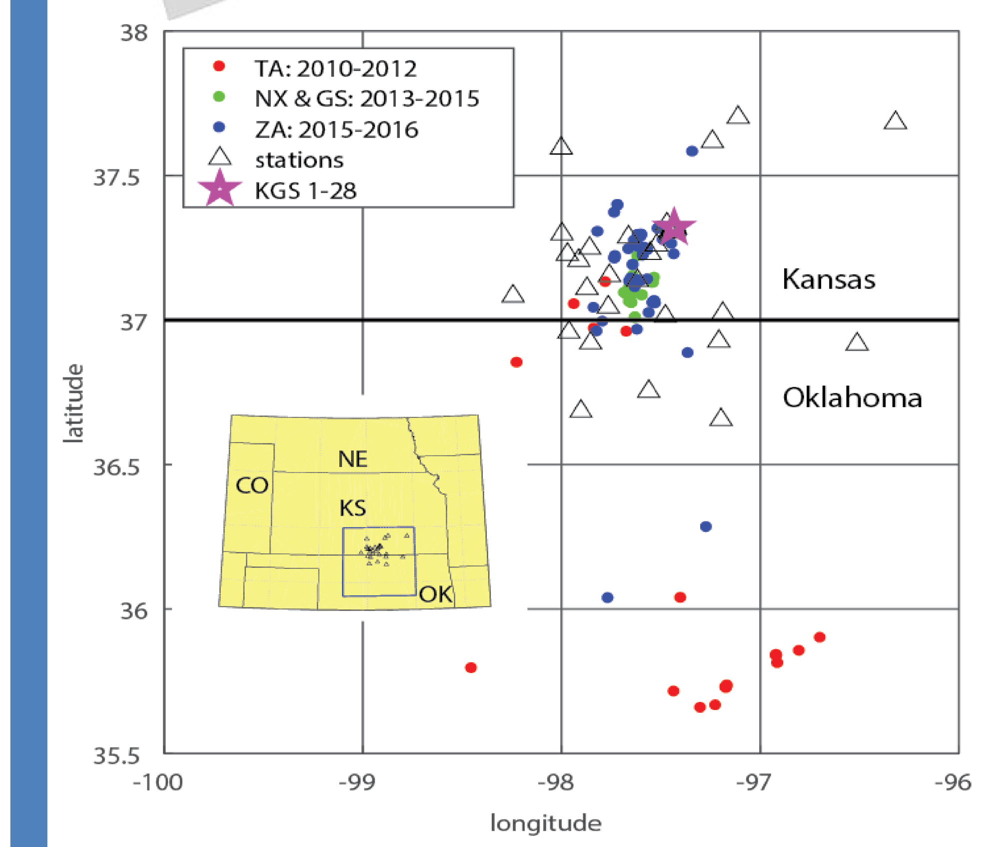

Figure 7. Map of the study area in south-central Kansas and northern Oklahoma. Black triangles are seismometer station locations, colored circles are earthquake epicenters where color identifies the time period of the earthquake and the source of the data. Red circles: 2010-2012 Earthscope Transportable Array (TA); Green circles: 2013-2015 Nanometrics Research Network (NX) and the USGS network (GS); Blue circles: 2015-2016 Wellington, Kansas CO_2 sequestration monitoring network (ZA). Arbuckle pressure measured in well KGS 1-28.

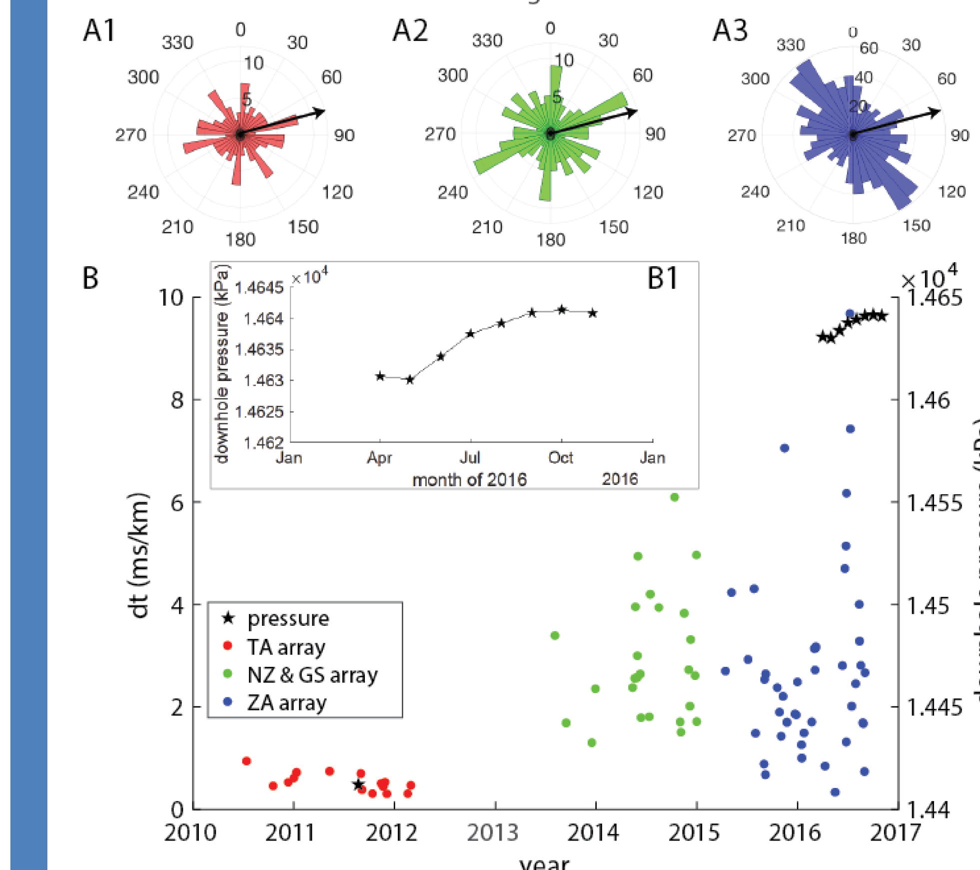

Figure 8. (A1) Polar histogram of ϕ from TA events 201-2012 (red). The most common ϕ value is near the maximum horizontal stress of ~75° along with flipped values at ~330°. Zero degree values are most often null solutions. (A2) Polar histogram of ϕ from NZ & GS events 2013-2015 (green) showing common solutions in line with maximum horizontal stress as well as solutions 90° off of maximum horizontal stress. (A3) Polar histogram of ϕ from ZA events 2015-2016 (blue) show the most common solution to be 90° off of the maximum horizontal stress, a direct indicator of critical pore fluid pressure. Arrows indicate the orientation of maximum horizontal stress at 75°. (B) Average dt/km of earthquakes from 2010 through 2016, showing a steady increase in magnitude over time as well as an increase in variance. Black stars correspond to average monthly pressure observations in well KGS 1-28, at Wellington Oil field. The initial pressure measurement in August 2011 was obtained when the well was drilled. Inset B1 is an expanded view of monthly average downhole pressures from April to November 2016.

Acknowledgements

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