Monitoring induced seismicity in southern Sumner County, South Central Kansas

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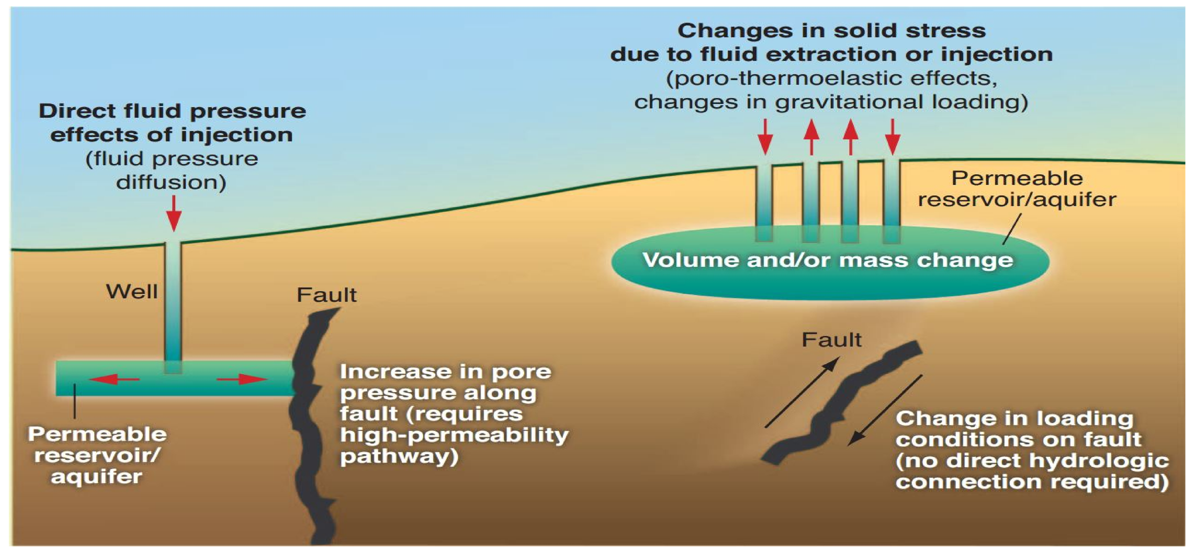


Figure 1. Left: The increase in pore pressure or the change in load on a fault can cause an earthquake to be induced. Earthquakes in Kansas and Oklahoma are induced by reinjection of fluids produced from oil and gas operations.

Figure 2. Right: A fault scarp occurs when a single side of a fault moves vertically to offset the earth surface. The three main components of an earthquake are the epicenter, the fault, and the focus (hypocenter).

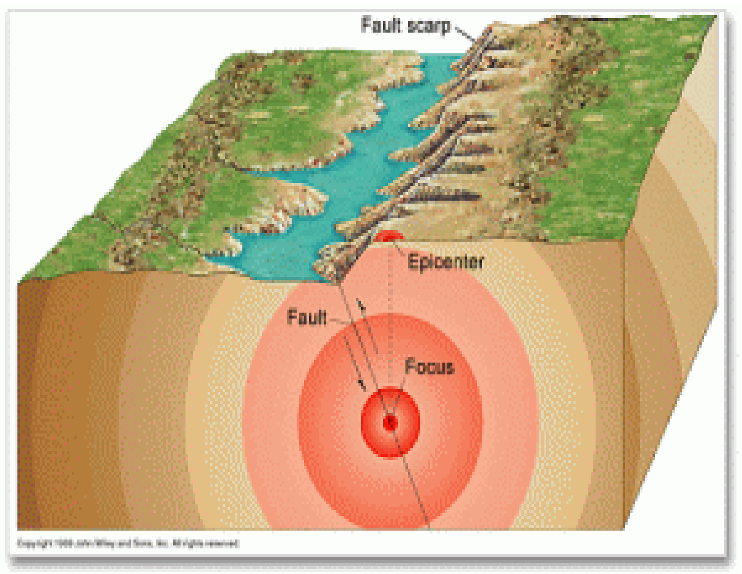
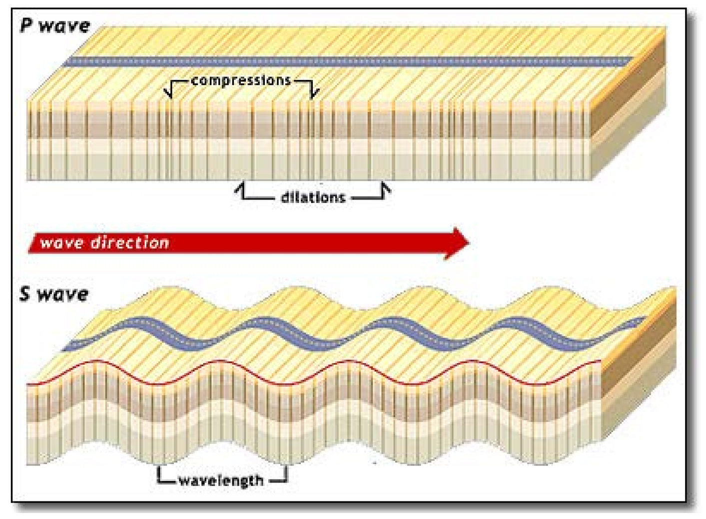


Figure 3. Bottom: Energy that travels through the earth is referred to as seismic waves. The most common types are body waves and surface waves. Body waves travel at a higher velocity than surface waves since they pass along the interior of the earth. P waves and S waves are the two types of body waves and produce different motions. P waves are considered the primary waves because they are the fastest and pass through rocks and fluids. Particles travel in the same direction as the P waves when energy is released. S waves are known as secondary waves because they are much slower and arrive after the P waves. These waves move particles perpendicular to the direction the wave is traveling.



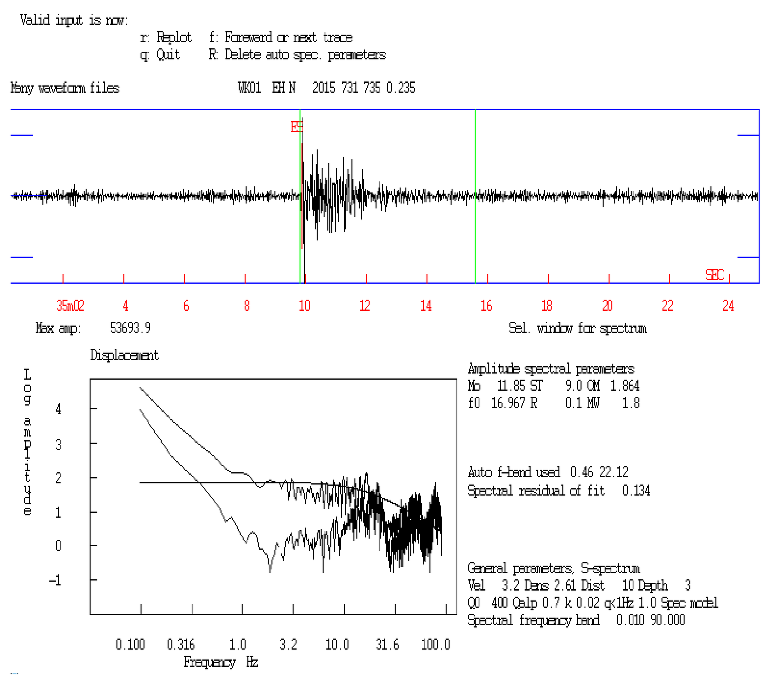


Figure 4. Top Right: Everything in between the two green lines represents a "window of spectrum"
Bottom Right: Event frequency (top line) can be separated from background noise (bottom line) up until about 90 Hz.

Induced Seismicity

- Events cataloged from August to October 2016
- Magnitudes range from M_w 0.4 to M_w 3.6
- Distance to the event is calculated from a predefined velocity model
    - 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
    - 1.1 M_w for Area of Interest

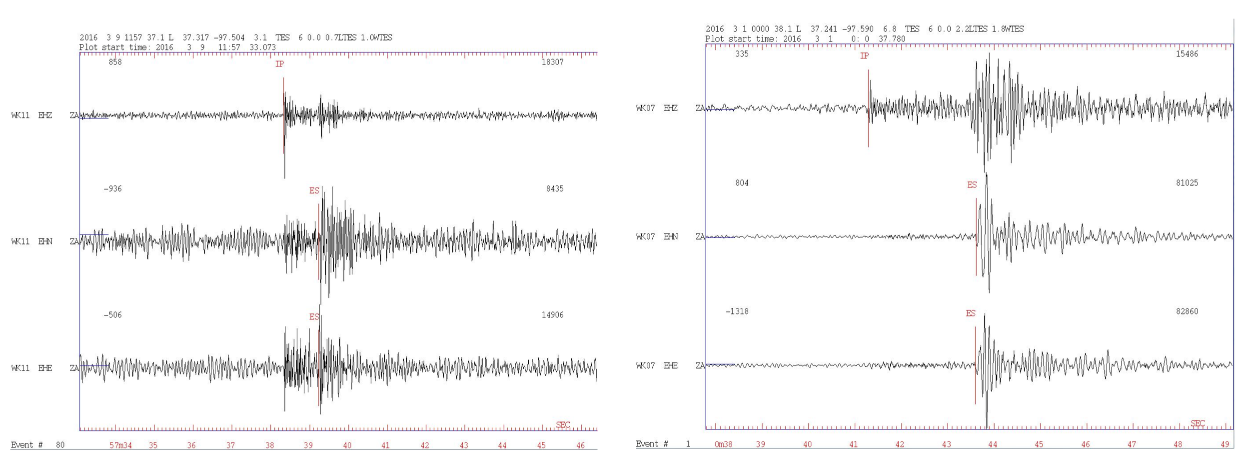


Figure 1. Comparison of small local event (left) of M_w 1.0 and larger local event (right) of M_w 1.8 with vertical channel displayed on the top row and the two horizontal channels below. P and S arrivals are shown in red. Both events are from March of 2016.

Objective

The objective of the earthquake monitoring program at Wellington Oilfield is to ensure safe CO_2 injection in the Mississippian and Arbuckle reservoirs 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.

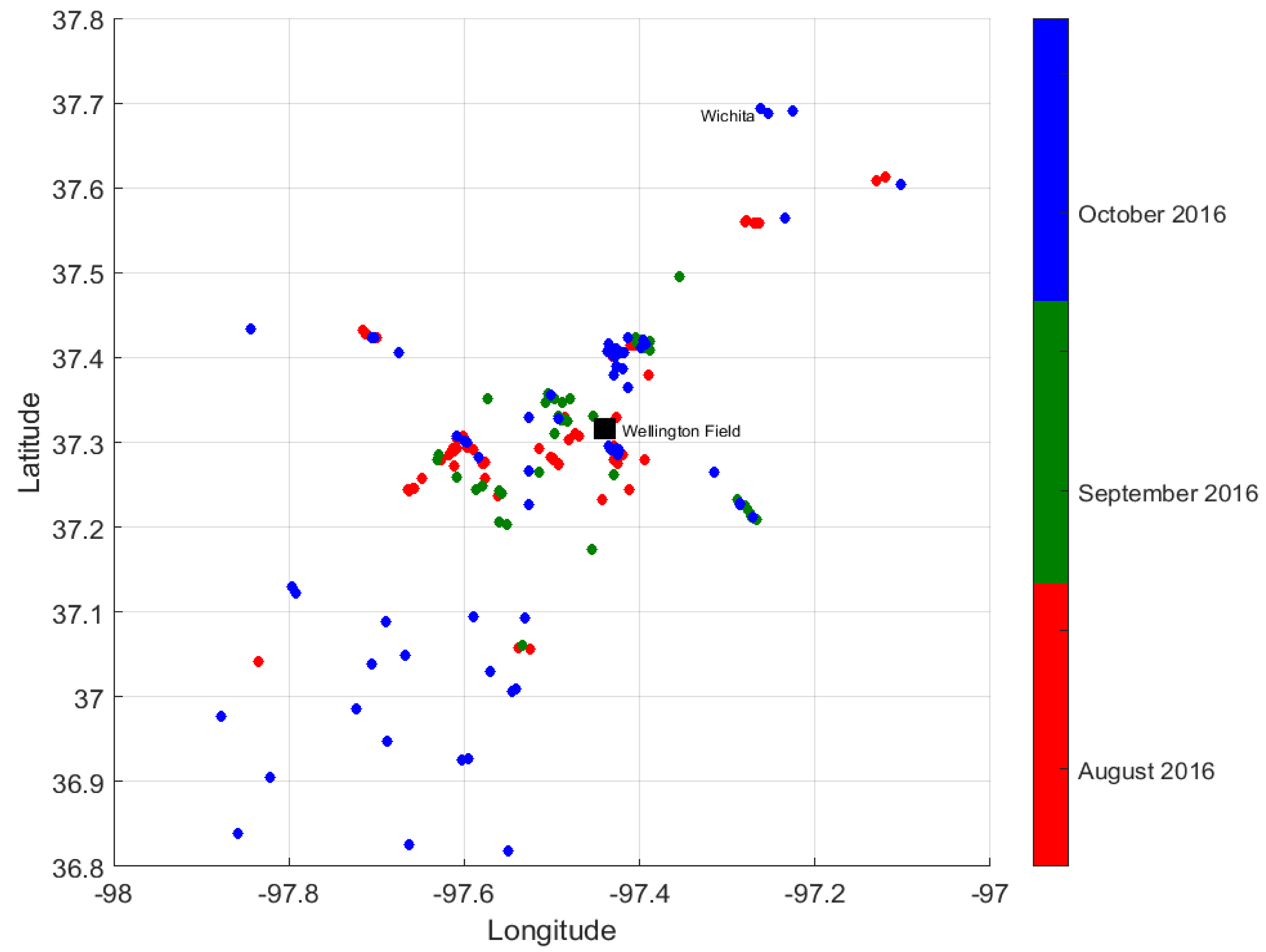


Figure 6. Map of all events observed between August 2016 and October 2016 in western Sumner County. Earthquakes are colored by their temporal variation. Blue colors are more recent and red colors are oldest.

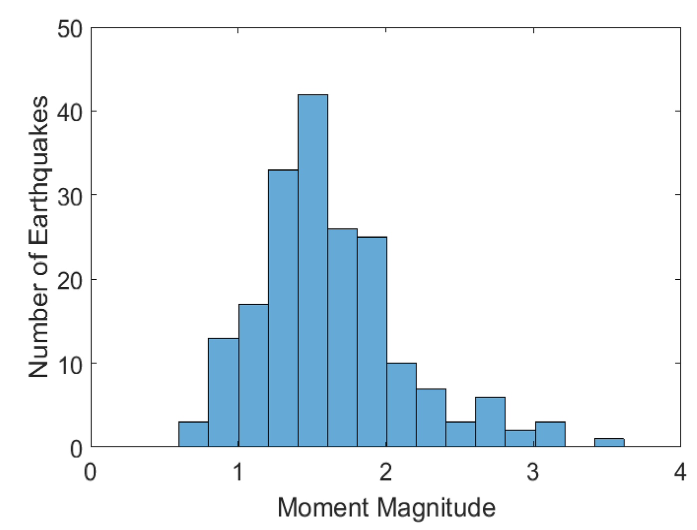


Figure 7. Histogram of earthquakes with a magnitude between 0 and 4. The quantity of each type of magnitude earthquake is identified on the y axis.

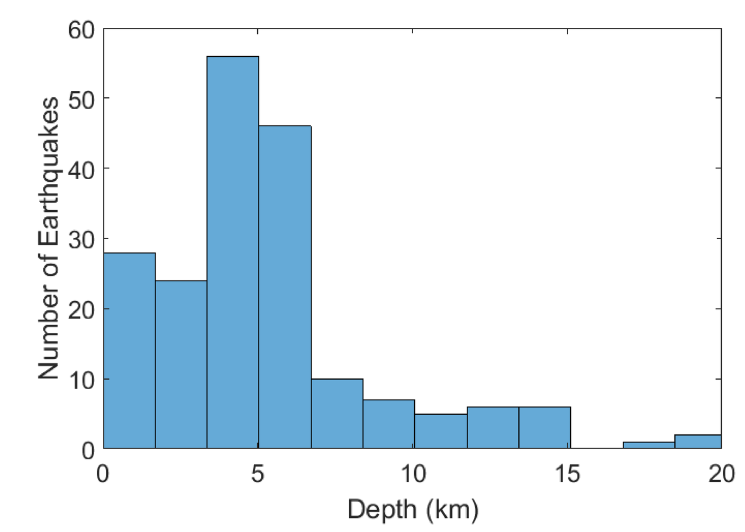


Figure 8. Histogram of the number of earthquakes that occurred at a certain depth ranging from 0 to 20 kilometers.

Results

- **Stress analysis from focal mechanisms correlates well to in-situ well measurements**
- **CO_2 injection at Wellington Field completed in summer 2016 did not cause seismicity**
- **Regional seismicity likely caused from increased pore fluid pressure in basement and Arbuckle from wastewater injection in Oklahoma and Kansas oil fields**
- **The regions affected by induced seismicity are growing**

References

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Focal Mechanisms

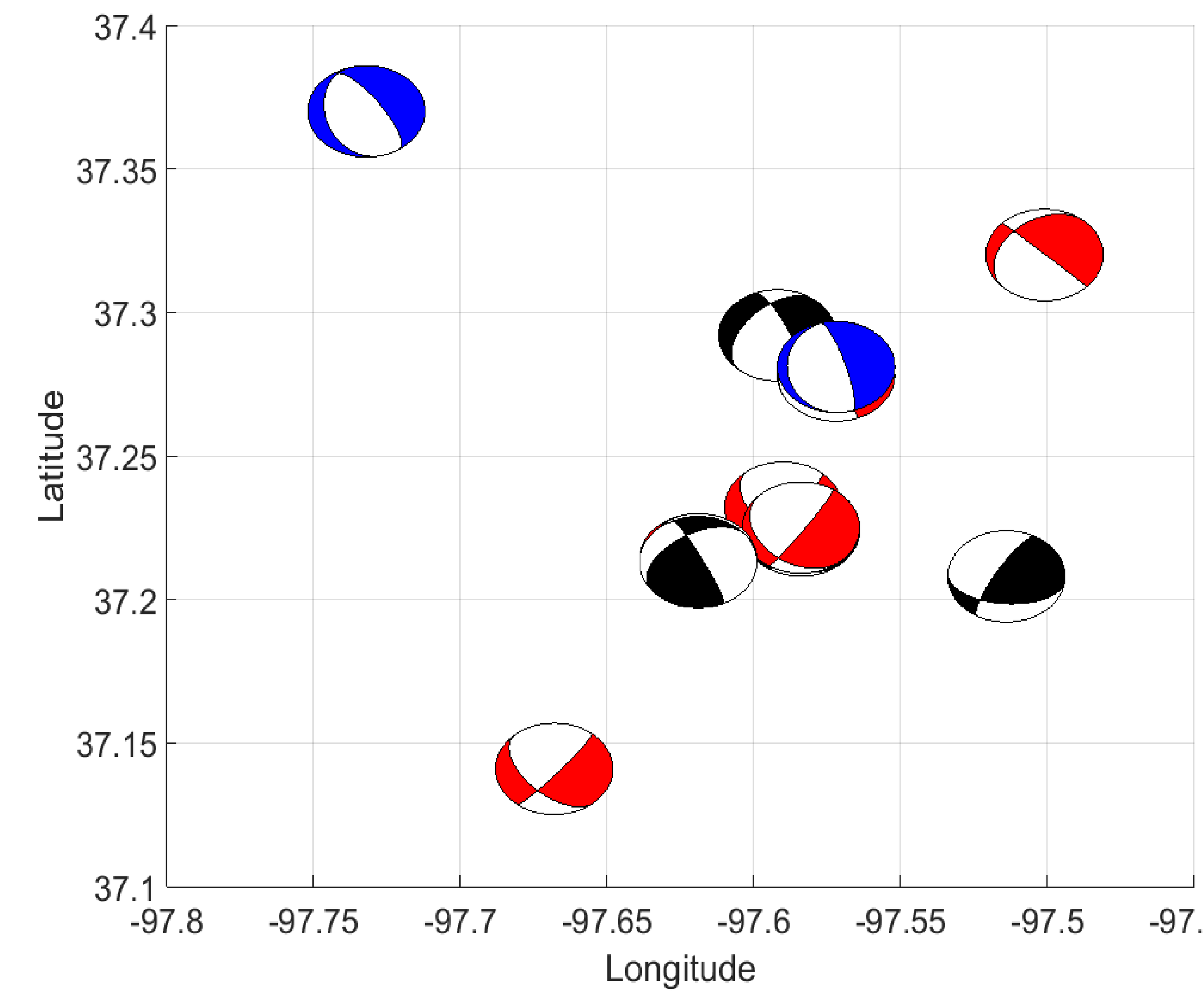

Figure 9. Top: Map showing the locations of earthquakes greater than Mw 2.0 with their respective focal mechanisms.

Earthquake focal mechanisms

A focal mechanism is a description of the subsurface ruptures.

- Strike-slip fault mechanisms are in red
- Normal slip fault mechanisms are in blue
- **Oblique slip** mechanisms are **black**

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 ~1.1 M_w for the Area of Interest

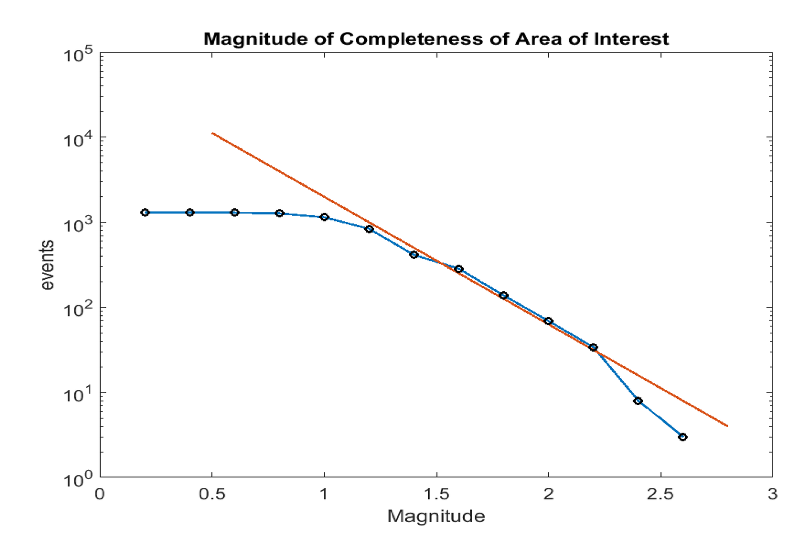

Figure 10. Left: The graph is showing the Magnitude of completeness calculated from the Gutenberg-Richter law. The blue line with black circles represents events recorded from the seismometer array, and the orange line represents predicted events using the Gutenberg-Richter law, with a b-value of 1.5. The two curves diverge at a magnitude Mc = 1.1.

Figure 11. Right: Photograph of the L-22 seismometer installed in the Wellington field.

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