Bridging Gaps in Induced Seismicity Hazard Forecasting in Alberta, Canada

Ryan Schultz, Steven Pawley, Tiffany Playter, Hilary Corlett, Todd Shipman, Steven Lyster, Tyler Hauck

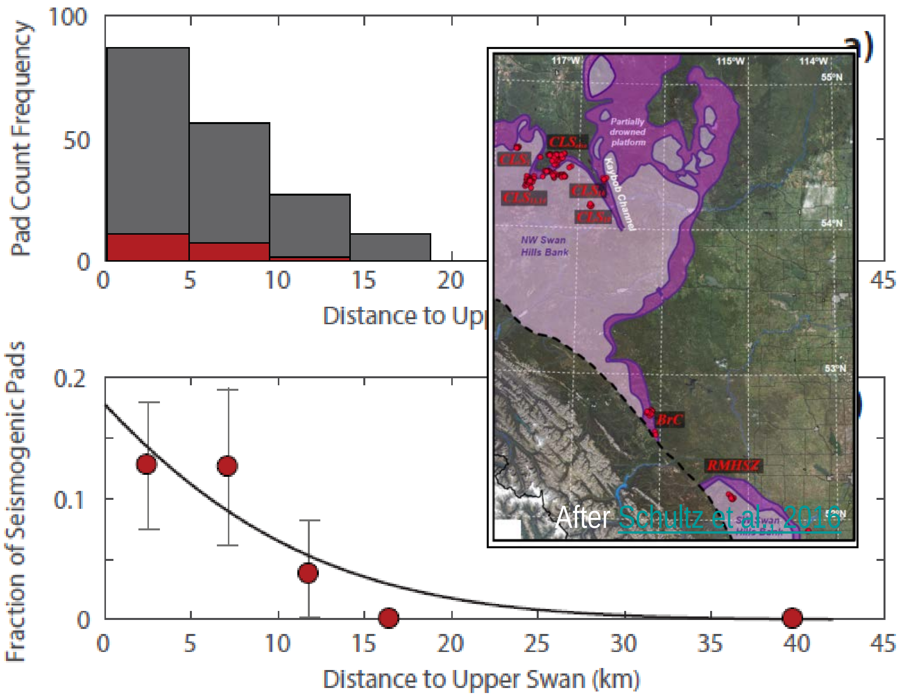
Alberta Energy Regulator

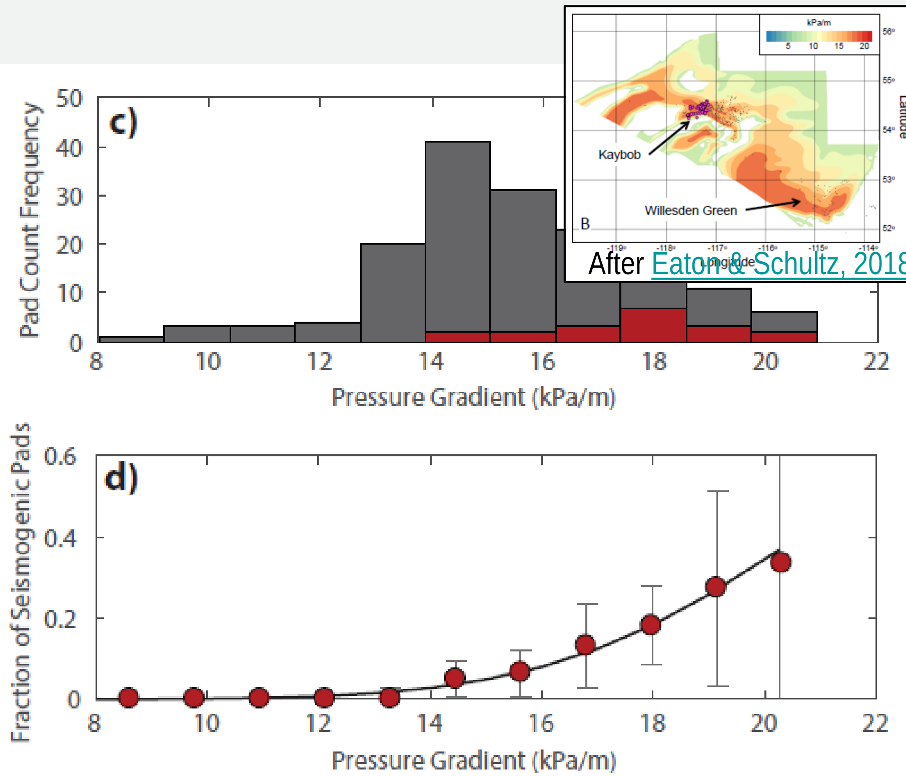
AGS ALBERTA GEOLOGICAL SURVEY

www.aer.ca
www.ags.aer.ca

Prior Evidence for Geological Susceptibilities: *Spatial Biases*

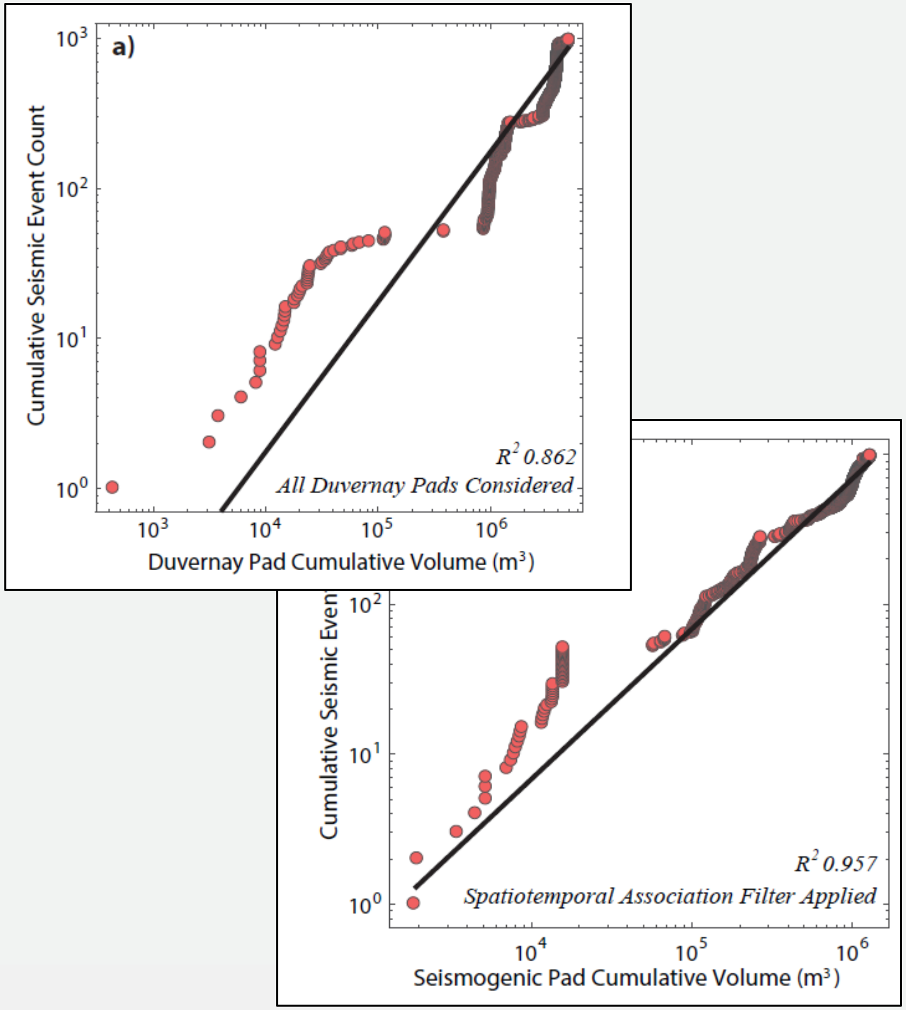
- Induced earthquakes locations in central Alberta have shown a spatial correspondence with carbonate reef margins.
- Induced earthquake locations have shown a spatial correspondence with relatively higher Duvernay formation overpressure.





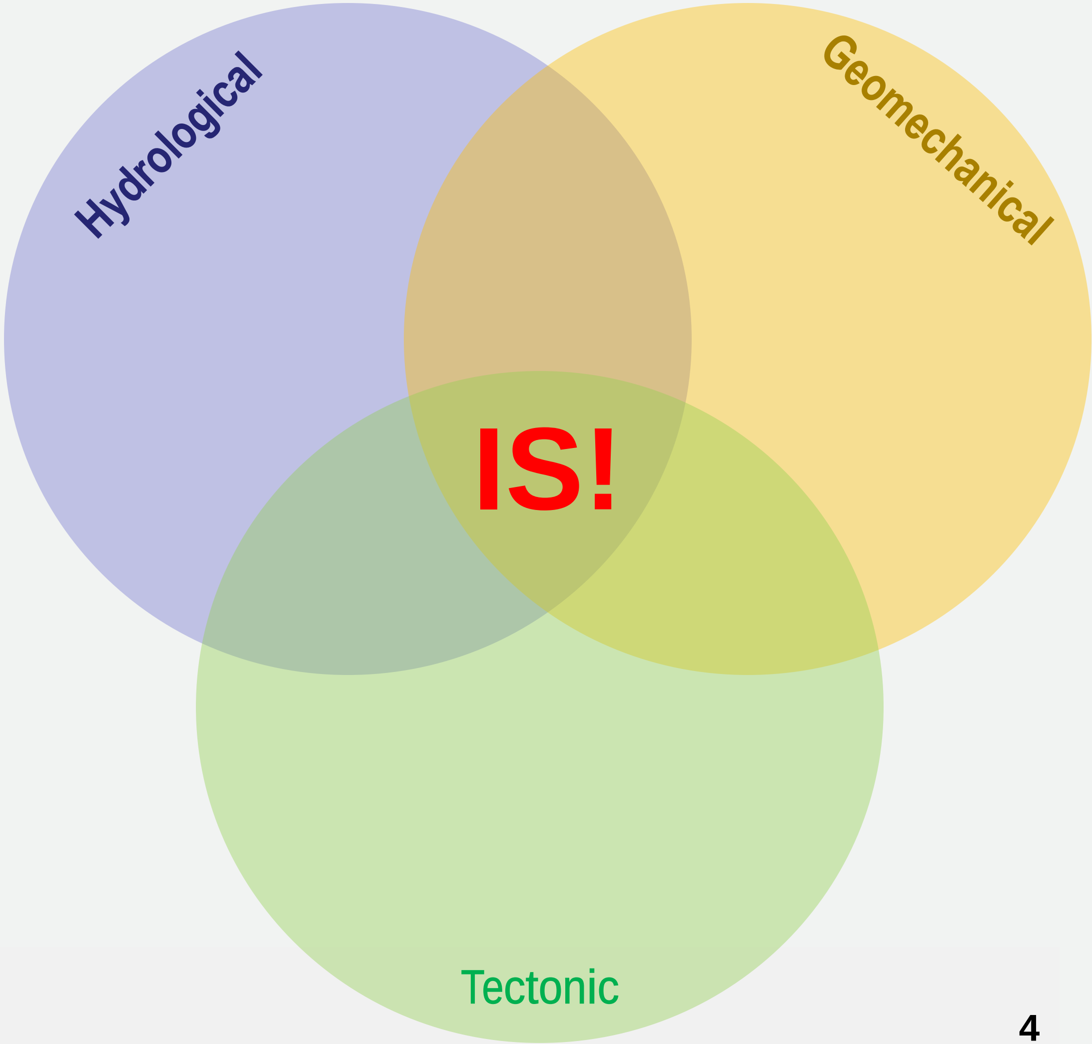
Prior Evidence for Geological Susceptibilities: *IS Rate Models*

- Prior study examined operational effects on HF IS in Kaybob Duvernay [Schultz et al., 2018].
- Decent linear fit. Noted systematic biases above or below best fit line.
- Systematic biases not strongly pronounced in single cluster/pad Σ fits.
- Significant improvement to goodness of fit (R^2 0.96) if only seismogenic wells are considered.
- Suggests presence of spatial biases.



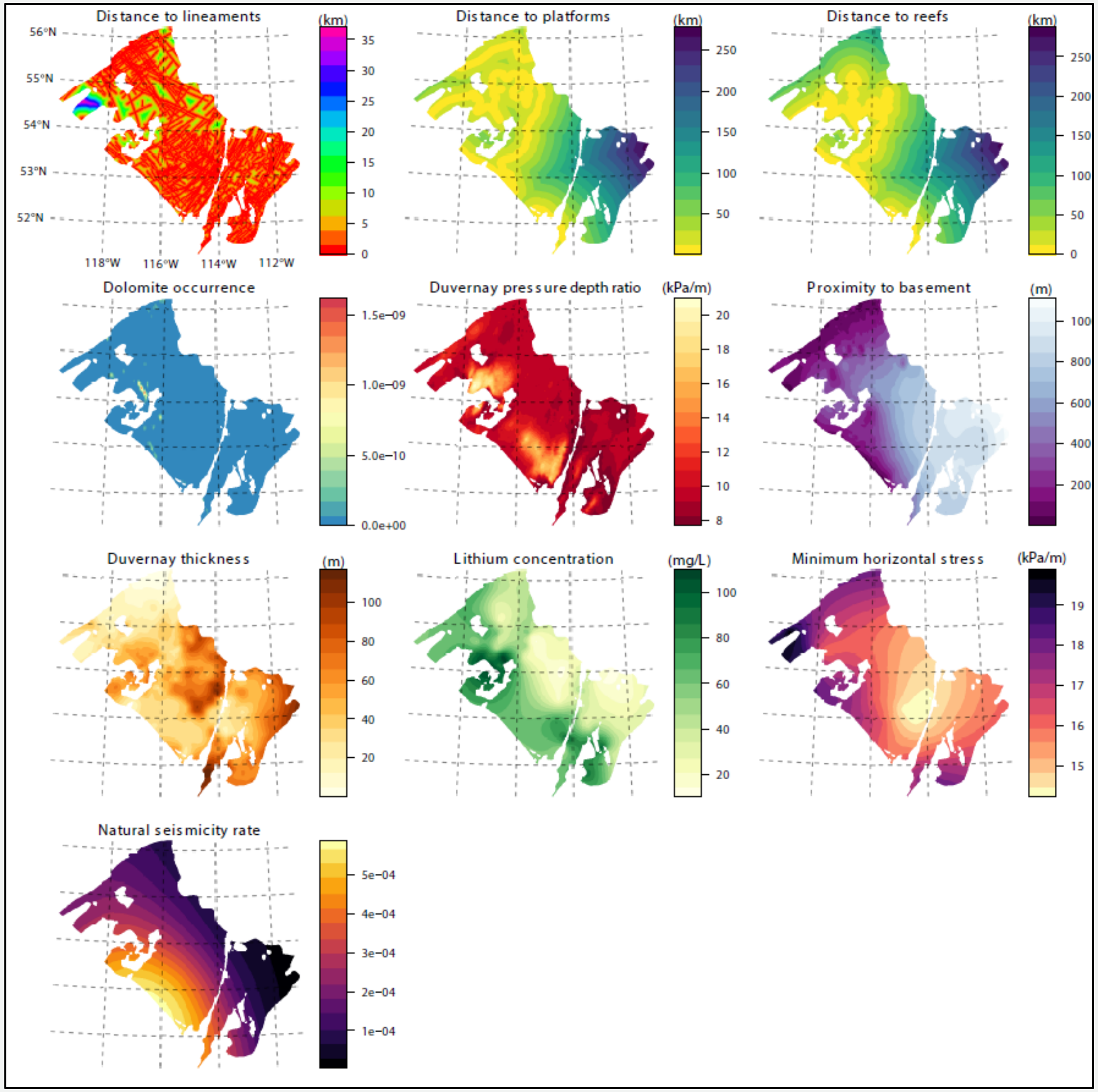
Understanding Geological Susceptibility

- What is the meaning of spatial biases?
- Can't be operational, stimulation volume accounts for the rate.
- Only geological factors remain.
- Likely the result of the probabilistic intersection of all contributing factors.
- Basin-wide estimate of this likelihood in viable HF plays is < 0.3% [Atkinson et al., 2016; Skoumal et al., 2015].



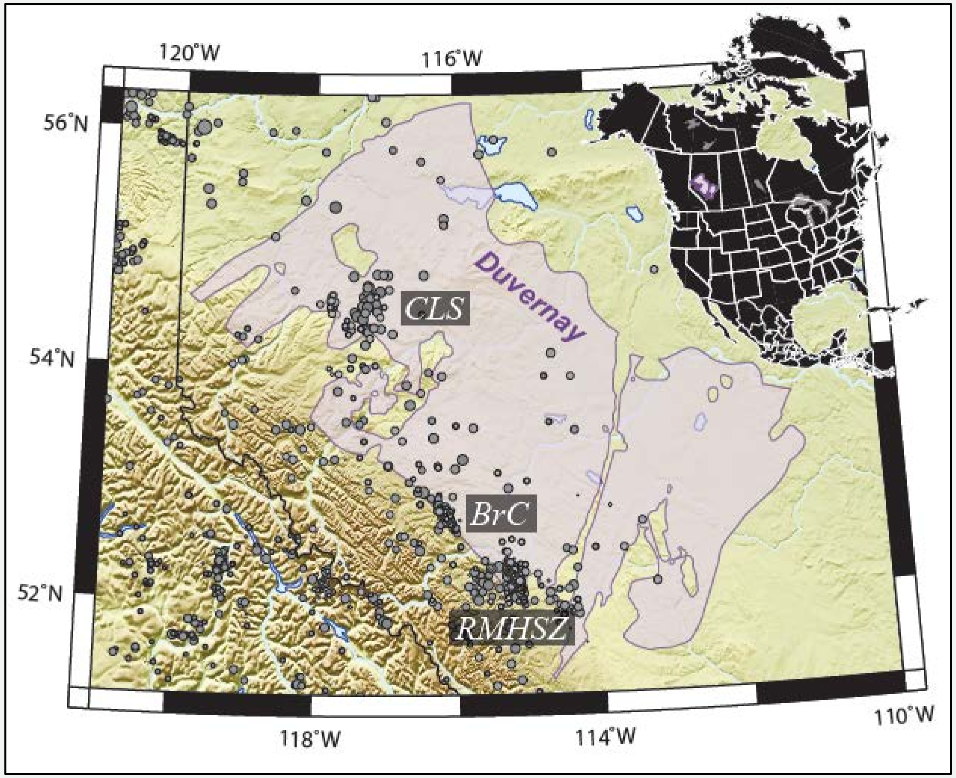
Quantifying Geological Susceptibility : *Input Geological Features*

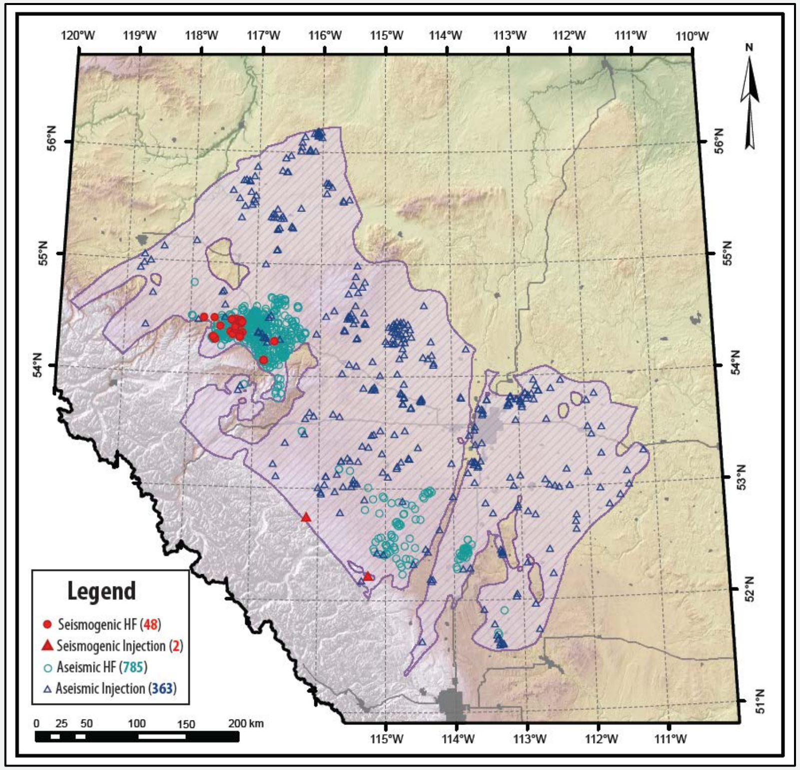
- Can δ be quantified spatially?
- What factors contribute to it?
  - Tectonic
  - Geomechanical
  - Hydrological
- What factors are publicly available?
- Collect all and see what the machine comes up with.



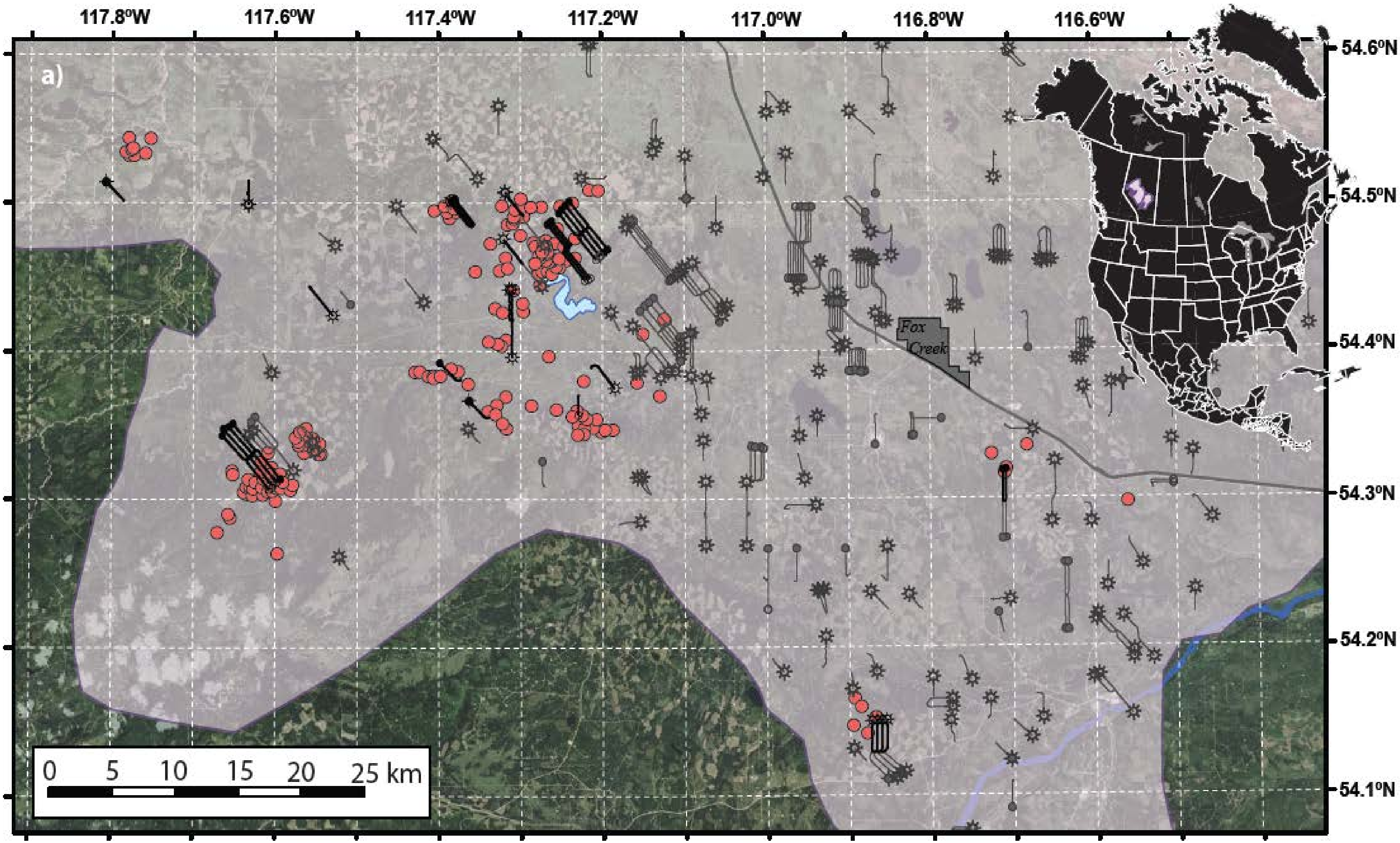
AGS

Quantifying Geological Susceptibility:
Identifying IS

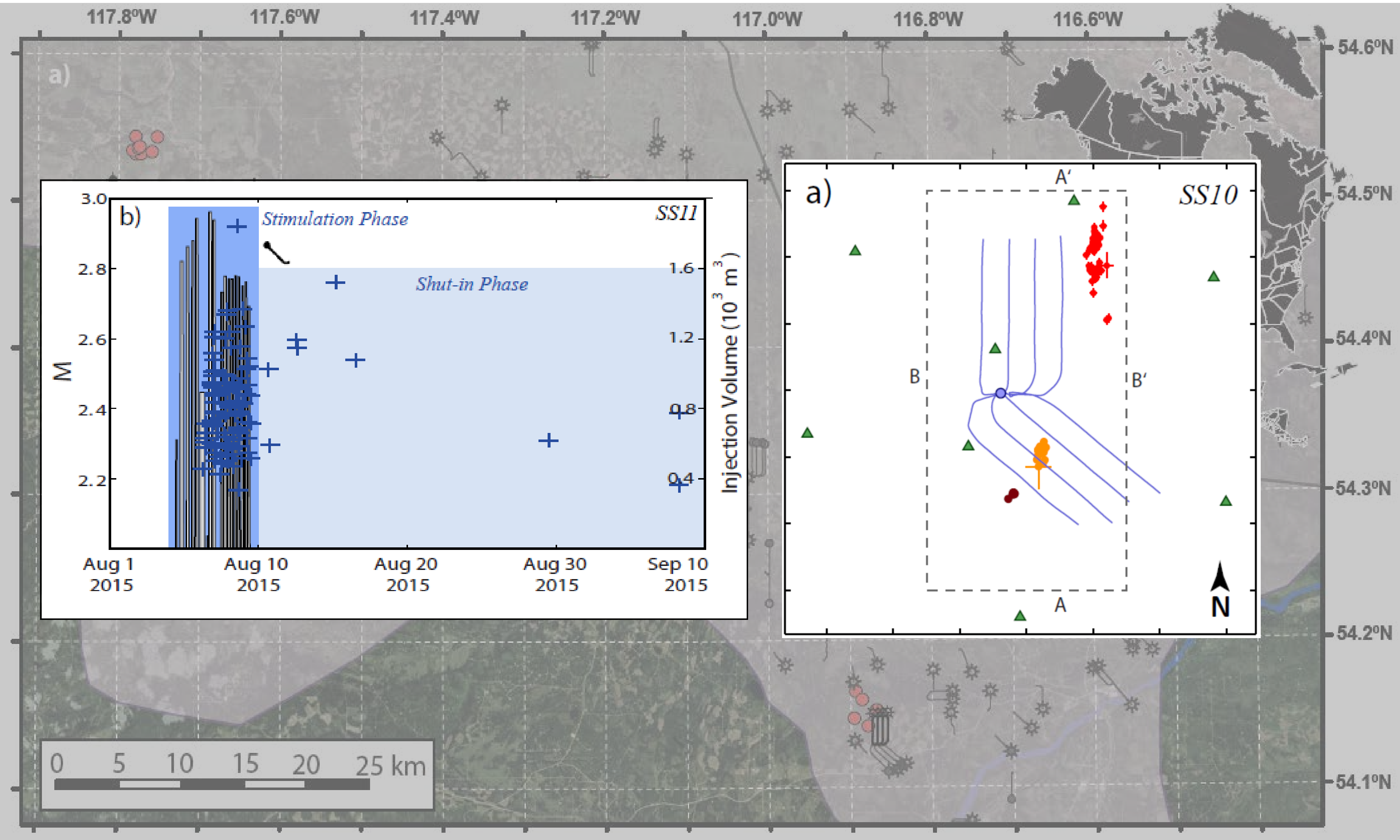




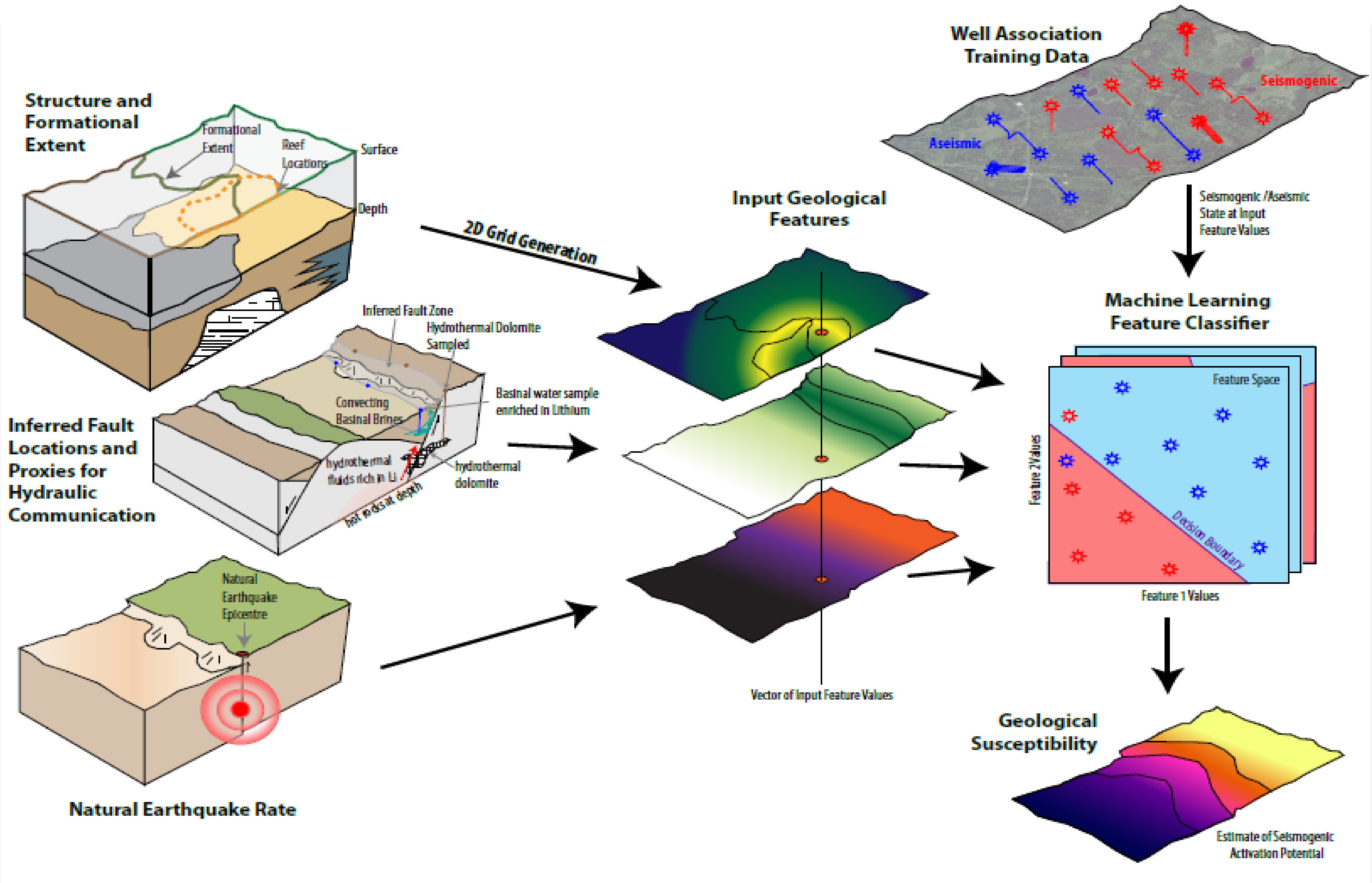
Spatiotemporal Association Filter



Spatiotemporal Association Filter

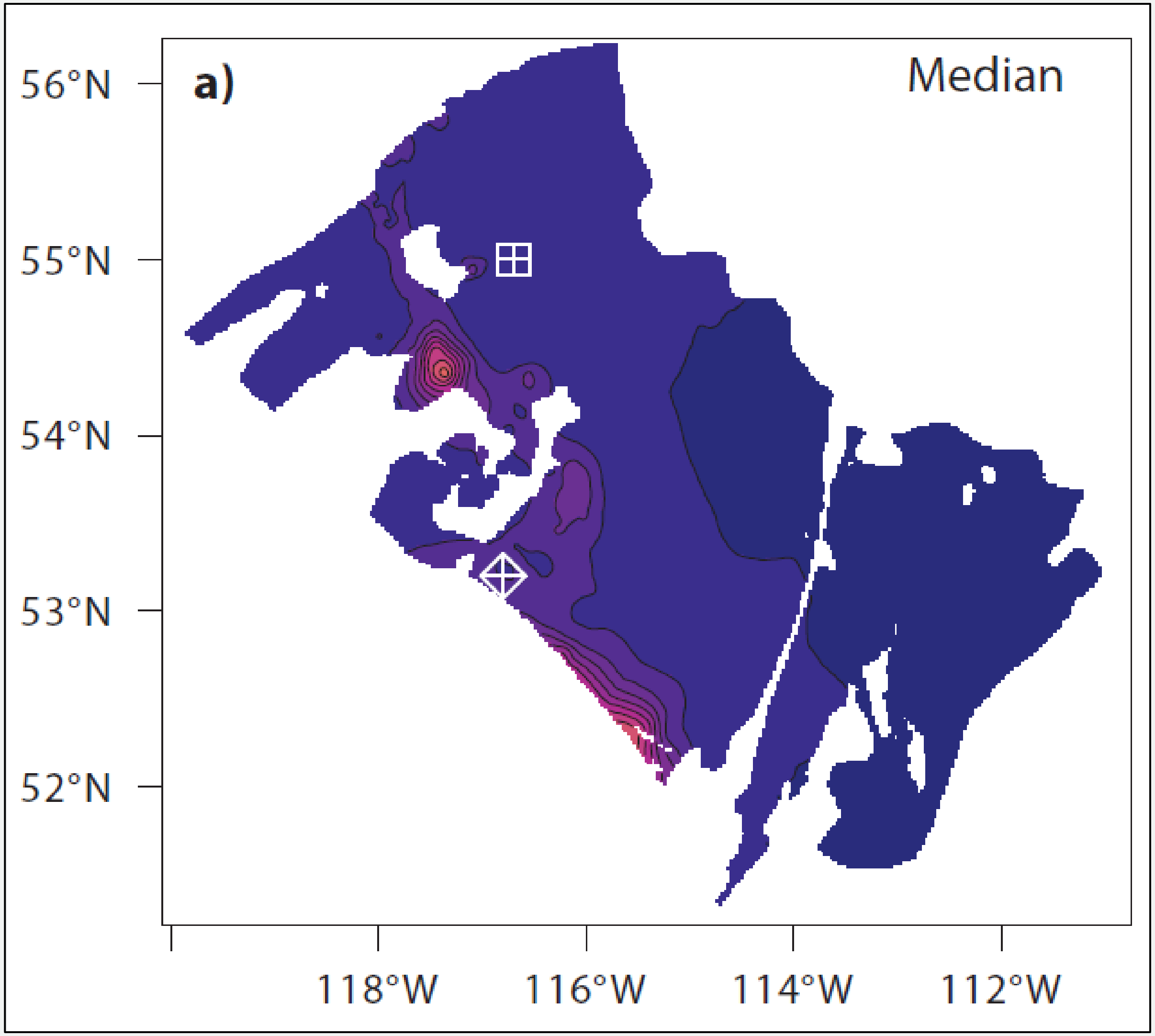


Quantifying Geological Susceptibility:
Binary Classification Problem



Geological Susceptibility Model

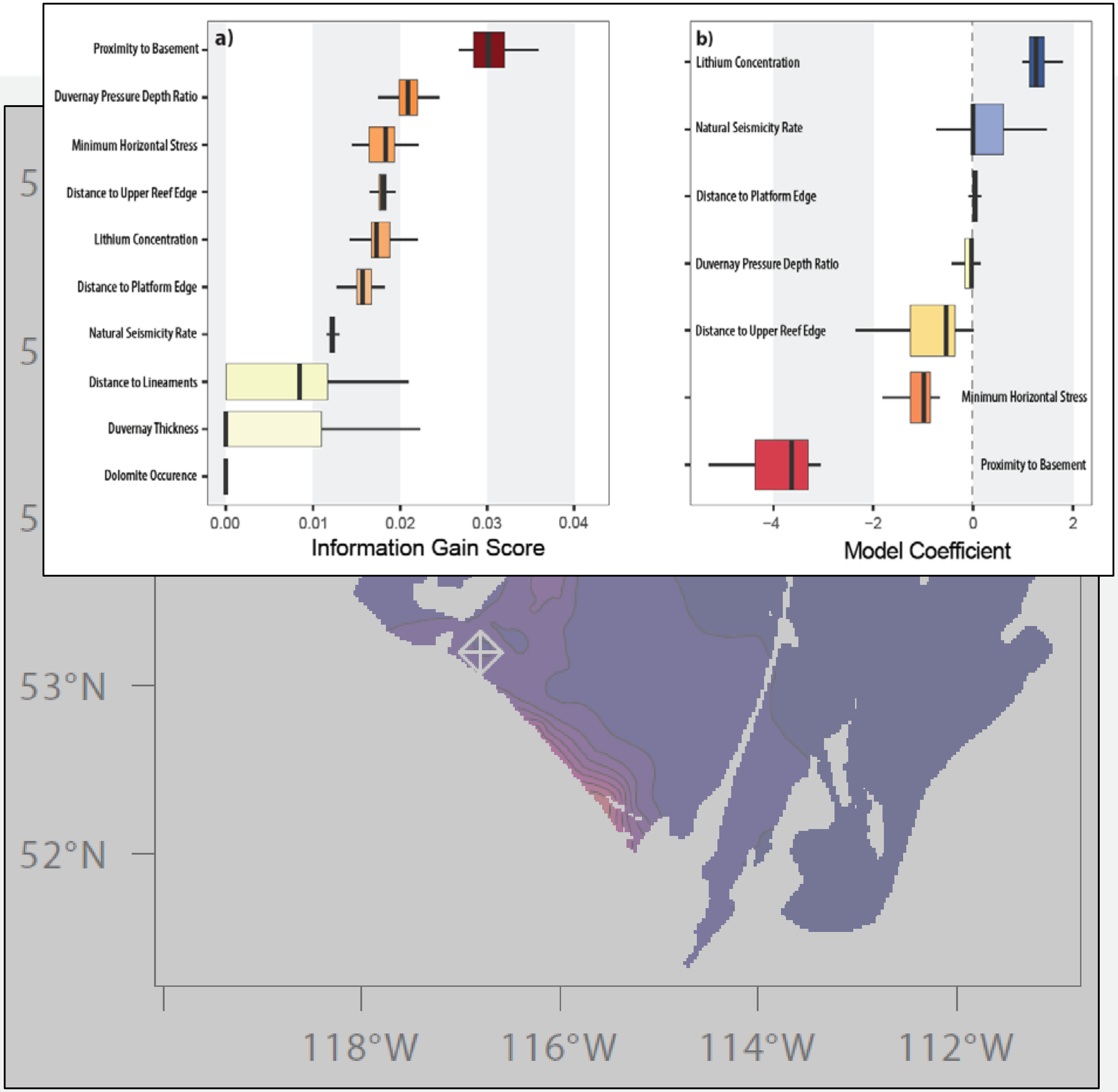
- Quantifies the likelihood of encountering an earthquake if a well is drilled in a given region.
- Allows for extrapolation to regions as of yet undrilled.



AGS

Geological Susceptibility Model

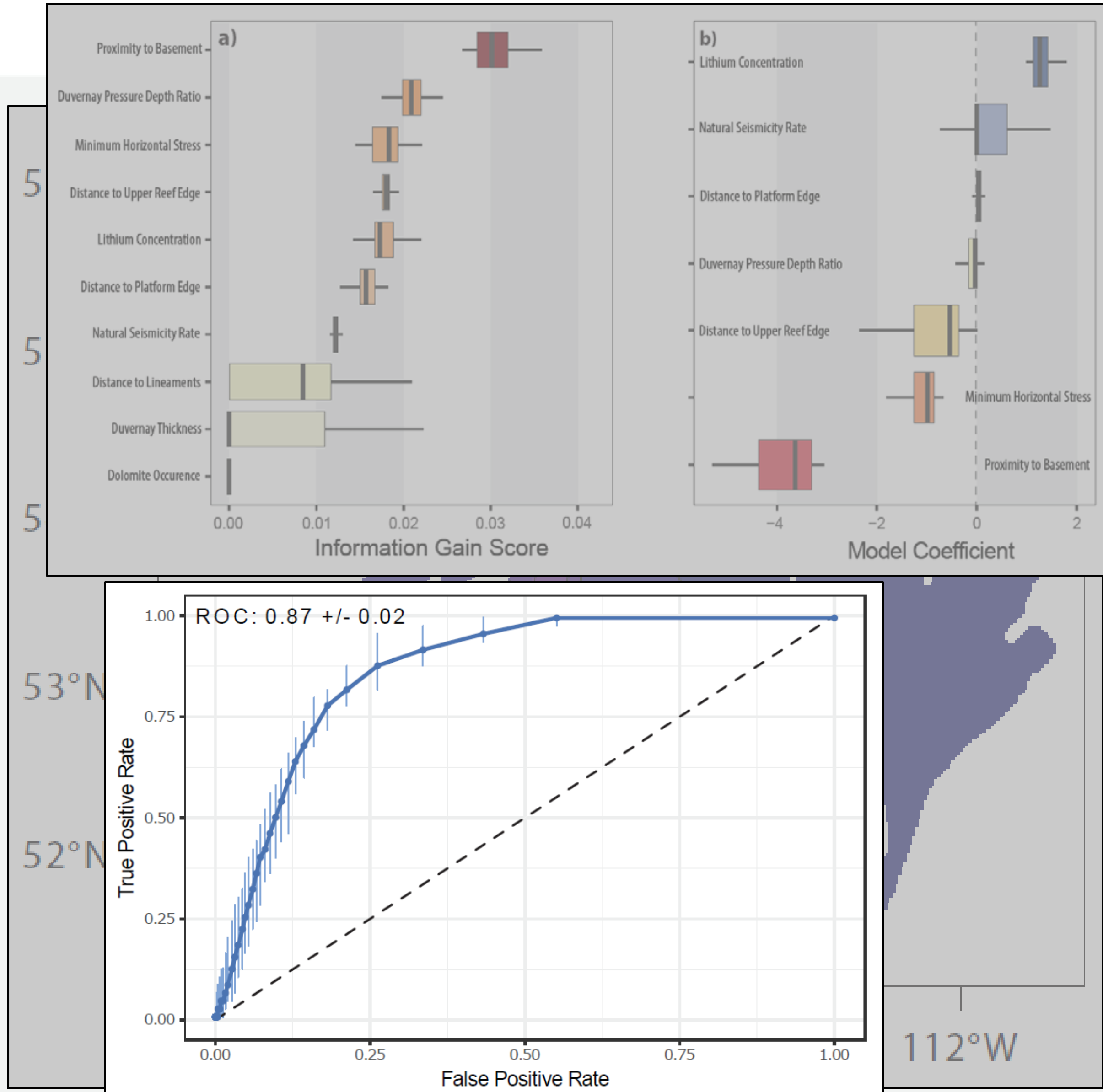
- Allows for extrapolation to regions as of yet undrilled.
- Appears to be producing geologically intuitive results: previously identified proxies are still important.
- proximity to basement is the most important, similar to consensus and other regions [Skoumal et al., 2018].



AGS

Geological Susceptibility Model

- proximity to basement is the most important, similar to consensus and other regions [Skoumal et al., 2018].
- Appears to be producing statistically robust results.
- AUROC is better than random guessing (0.87).



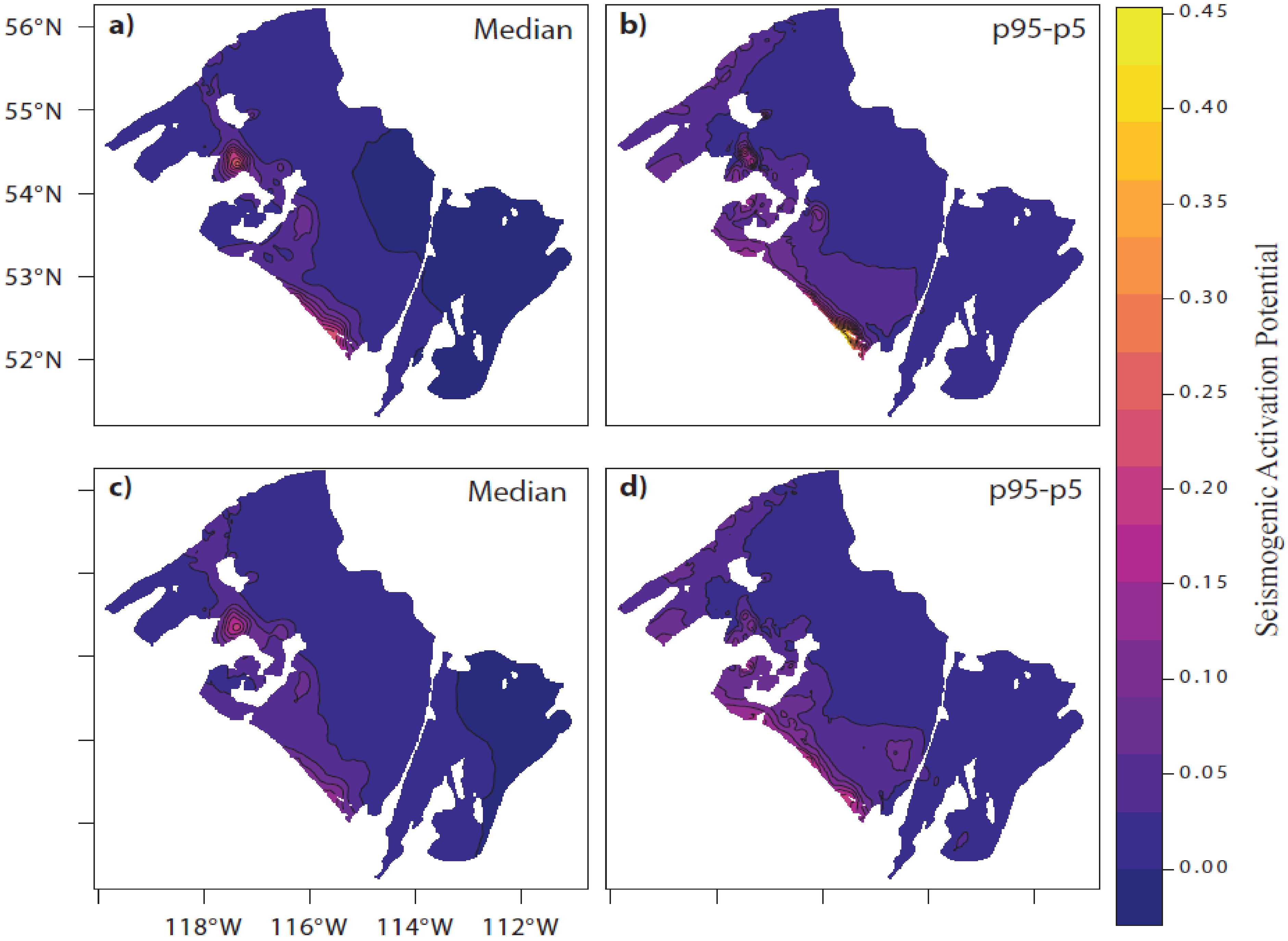
Summary

- Spatial biases in a Σ GR-FMD model account for 96% of variability in the IS rate.
- Model appears to be performing better than just guessing.
- Modelled weights to proxies makes intuitive sense.
- New δ parameter suggested to account for spatial biases, interpreted as the geological susceptibility to IS. Can be estimated by machine learning methods.
- Proposed model could help bridge knowledge gap for forecasting IS hazard .

Questions

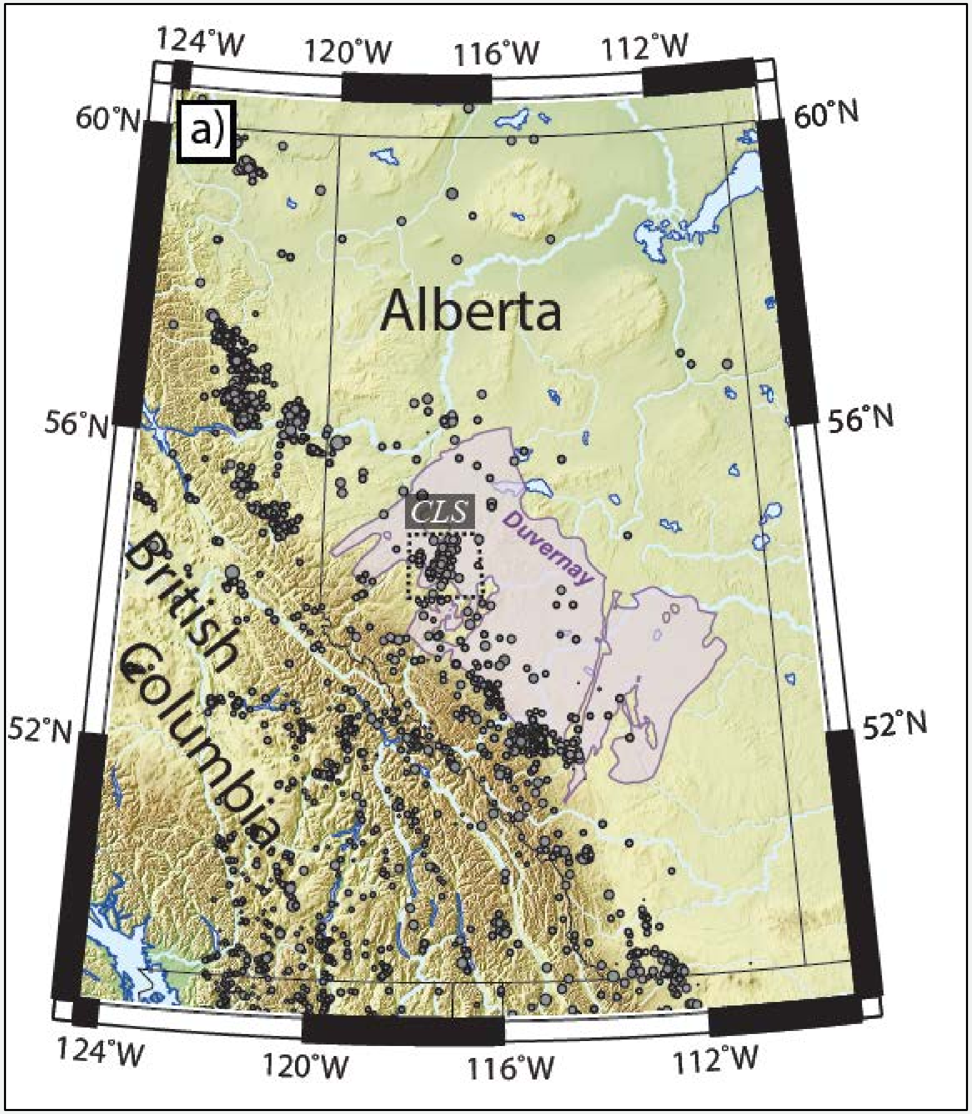
Pawley, Schultz, Playter, Corlett, Shipman, Lyster, & Hauck, (2018).
The Geological Susceptibility of Induced Earthquakes.
Geophysical Research Letters, doi: 10.1002/2017GL076100.

Thank you


a)
Median
b)
p95-p5
c)
Median
d)
p95-p5
56°N
55°N
54°N
53°N
52°N
118°W
116°W
114°W
112°W
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Seismogenic Activation Potential

Seismicity in the WCSB

- Seismicity in the WCSB is sparse and relatively quiescent.
- Long-lasting clusters have been recognized.
- Three clusters account for the majority of Albertan seismicity: RMHSZ, BrC, CLS.
- CLS is known to be related to HF of the Duvernay Formation [Schultz et al., 2017].



AGS

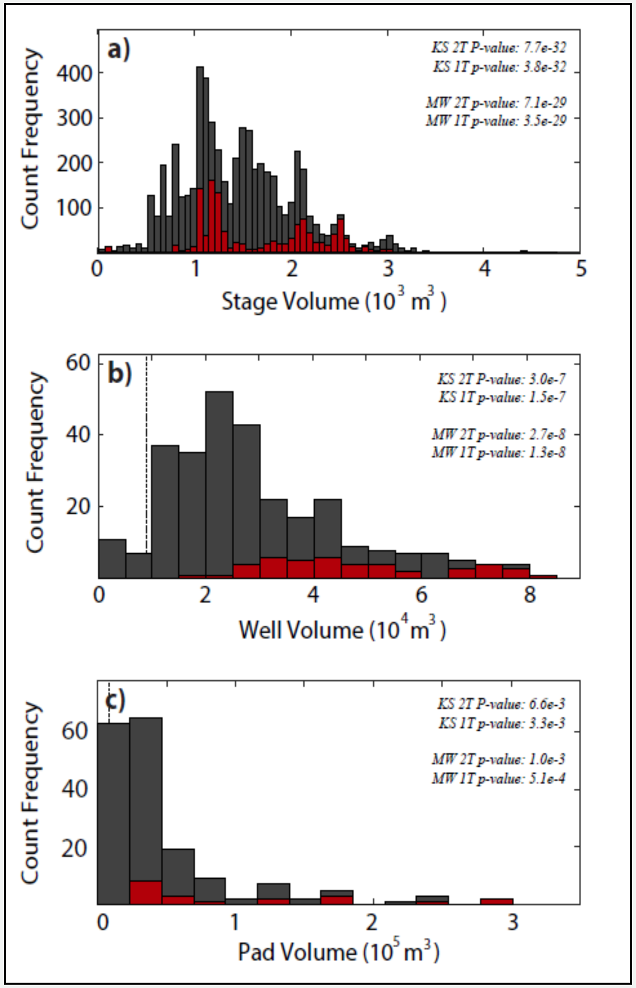
Statistical Tests:

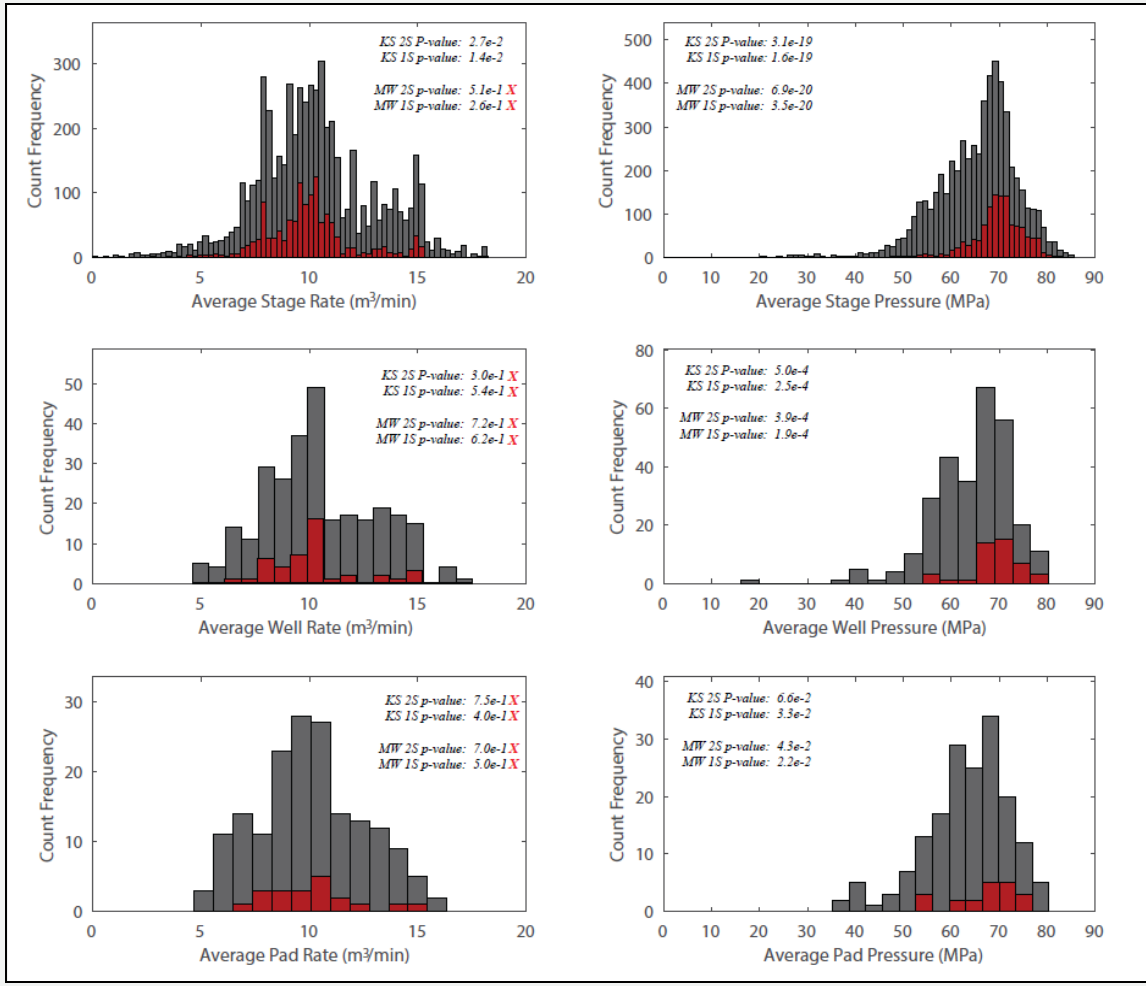
Kolmogorov-Smirnov & Mann-Whitney U test

Volume

Rate

Pressure

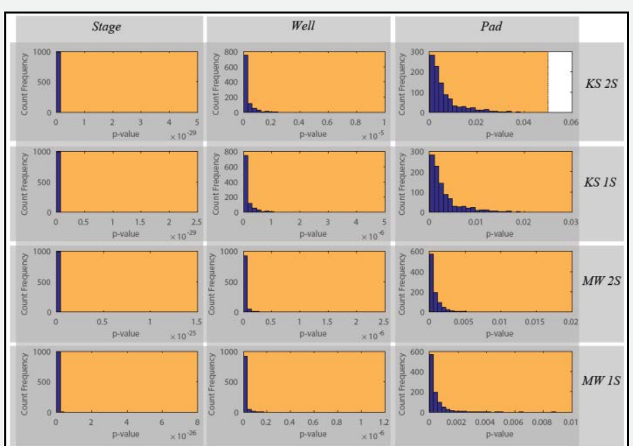




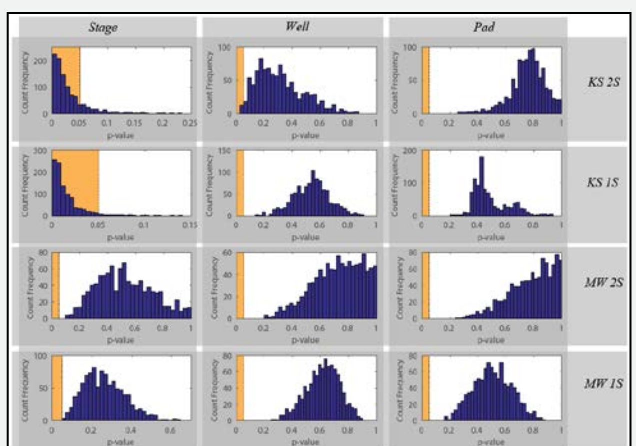
Bootstrap Resampling

- Repeat KS & MW tests for 10^5 trials.
- Randomly remove 10% of pads.
- Randomly flip seismogenic association state of 1% of pads.
- Compute distribution of test p-values (**blue**).
- Areas shaded **orange** indicate statistical significance.
- Reconfirms prior result is robust, and gives a sense of sensitivity to missed associations.
- **Seismogenic pads tend to be higher volume operations in the Kaybob Duvernay.**

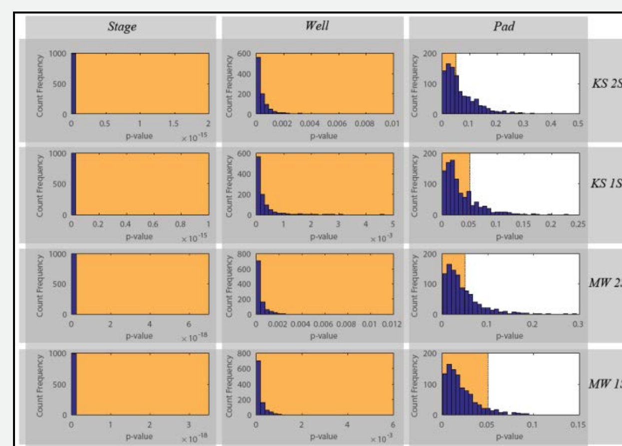
Volume



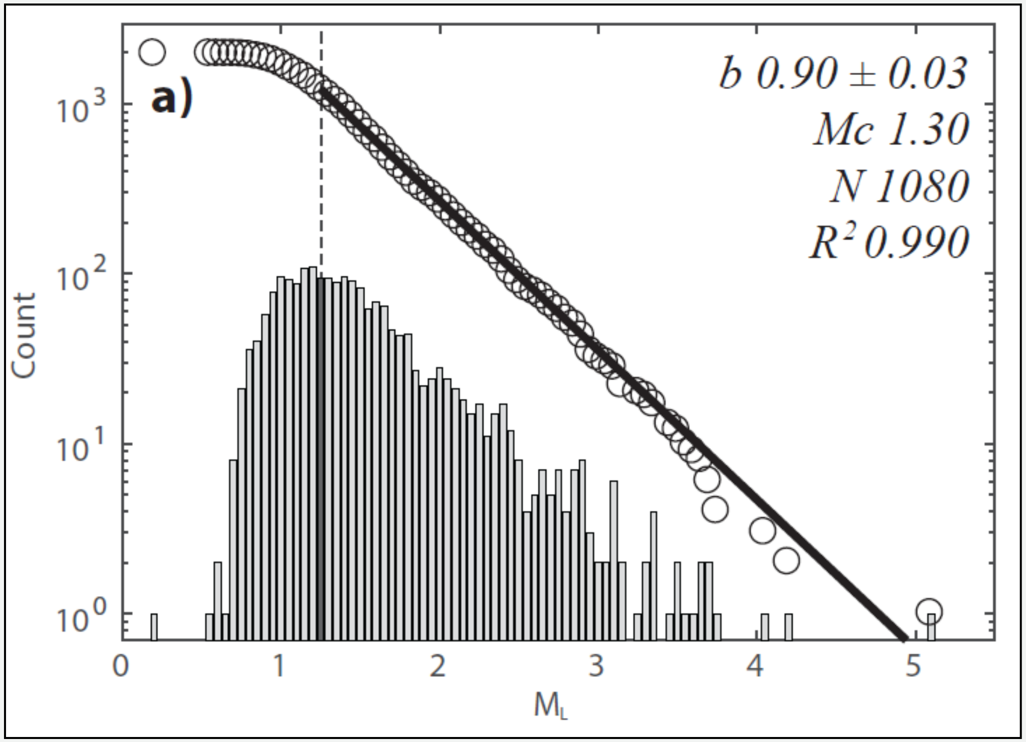
Rate



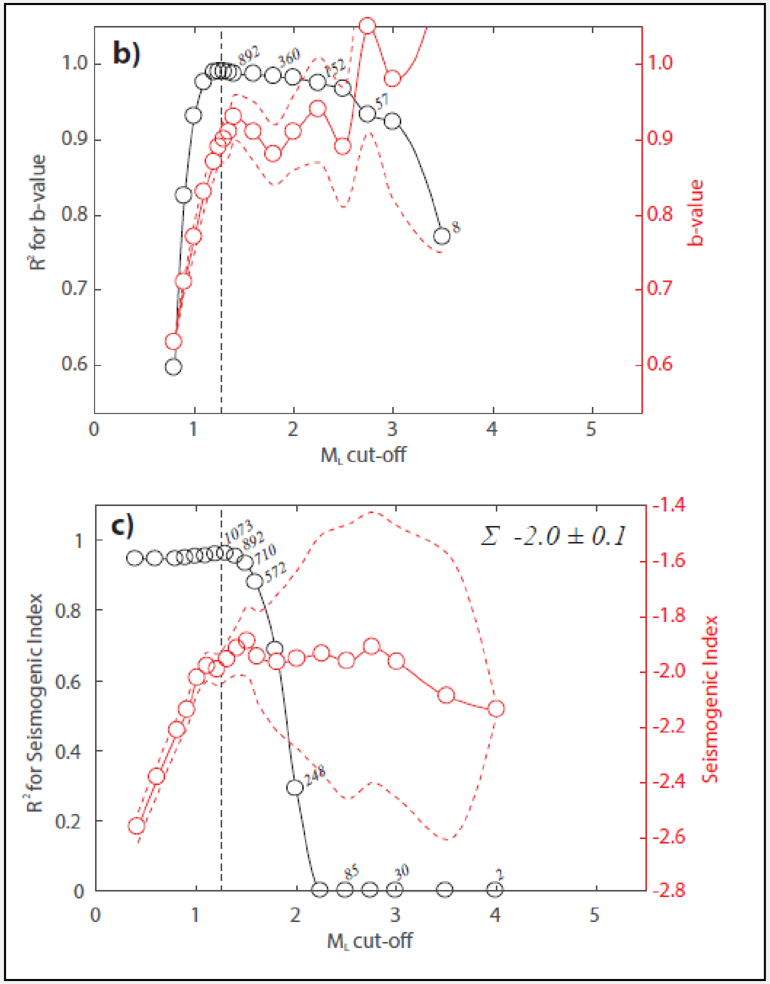
Pressure



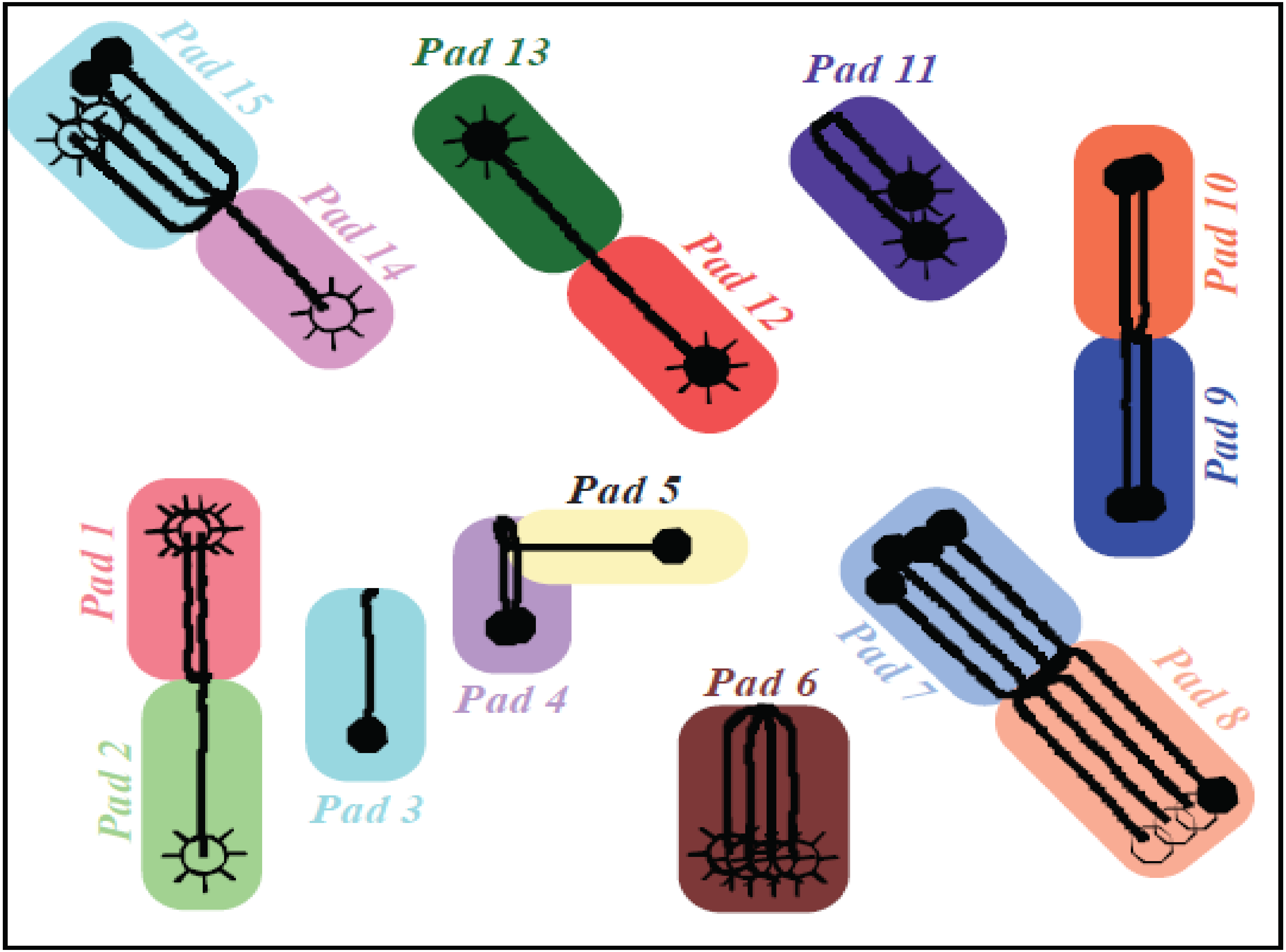
Σ GR-FMD Fit



a)
b 0.90 ± 0.03
Mc 1.30
N 1080
R² 0.990
Count
M_L



b)
R² for b-value
b-value
M_L cut-off
c)
Σ -2.0 ± 0.1
R² for Seismogenic Index
Seismogenic Index
M_L cut-off


Pad 15
Pad 14
Pad 13
Pad 12
Pad 11
Pad 10
Pad 9
Pad 1
Pad 2
Pad 3
Pad 4
Pad 5
Pad 6
Pad 7
Pad 8