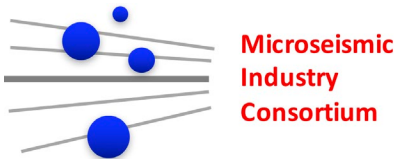# Insights from joint interpretation of dense array observations and 3D multicomponent seismic: The ToC2ME experiment, Fox Creek, AB
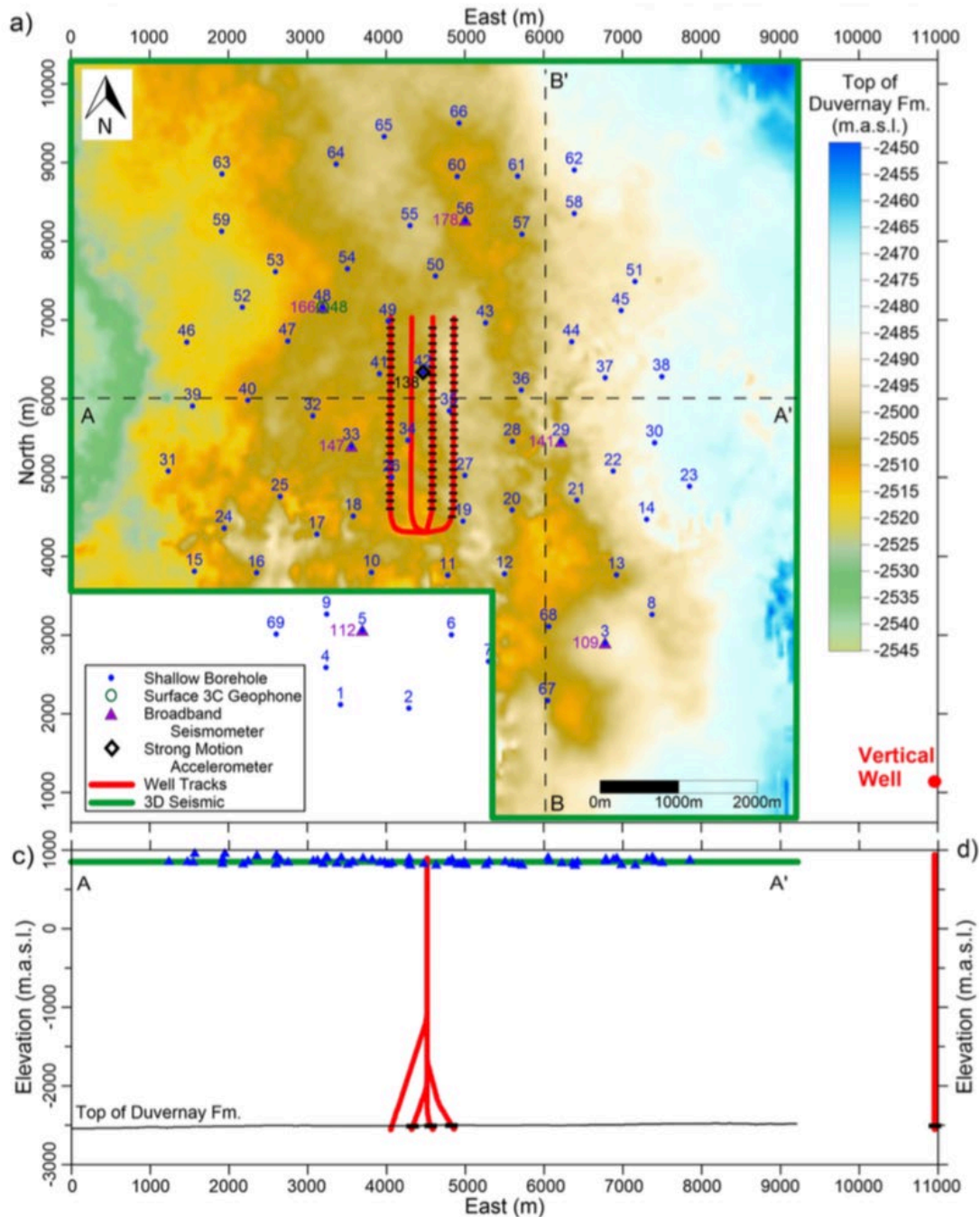
David Eaton, Nadine Igonin, Andrew Poulin, Ron Weir,
Hongliang Zhang, Scott Pellegrino, German Rodriguez & Rebecca Salvage

Department of Geoscience
University of Calgary

UNIVERSITY OF CALGARY

Microseismic
Industry
Consortium

ToC2ME Experiment

- Continuous monitoring (over the course of ~one month) of a 4-well Duvernay completion

- Sixty-eight station shallow-well geophone arrays (university operated) combined with six broadband seismometers and one accelerometer (Nanometrics)
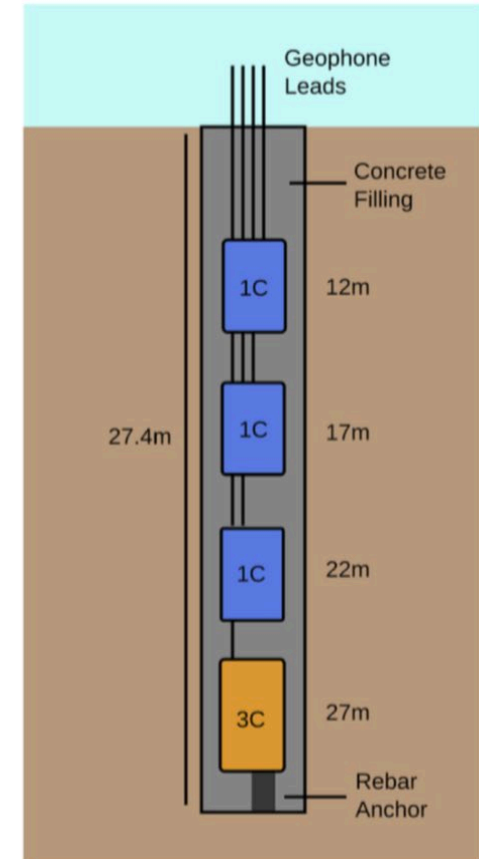
- Recorded 10,000's events, up to M_W 3.2

ToC2ME Field Layout

- Combination of microseismic and induced-seismicity monitoring
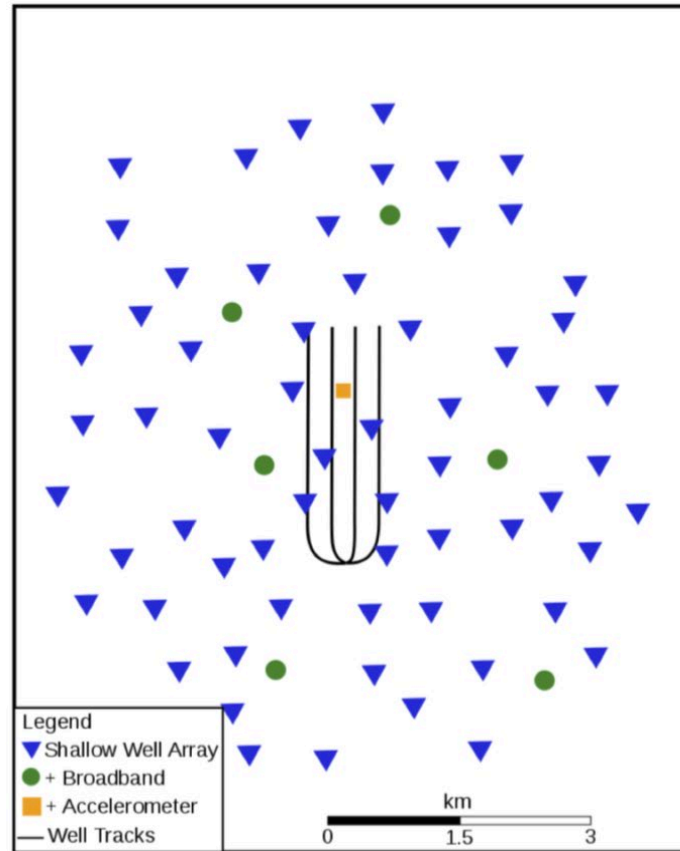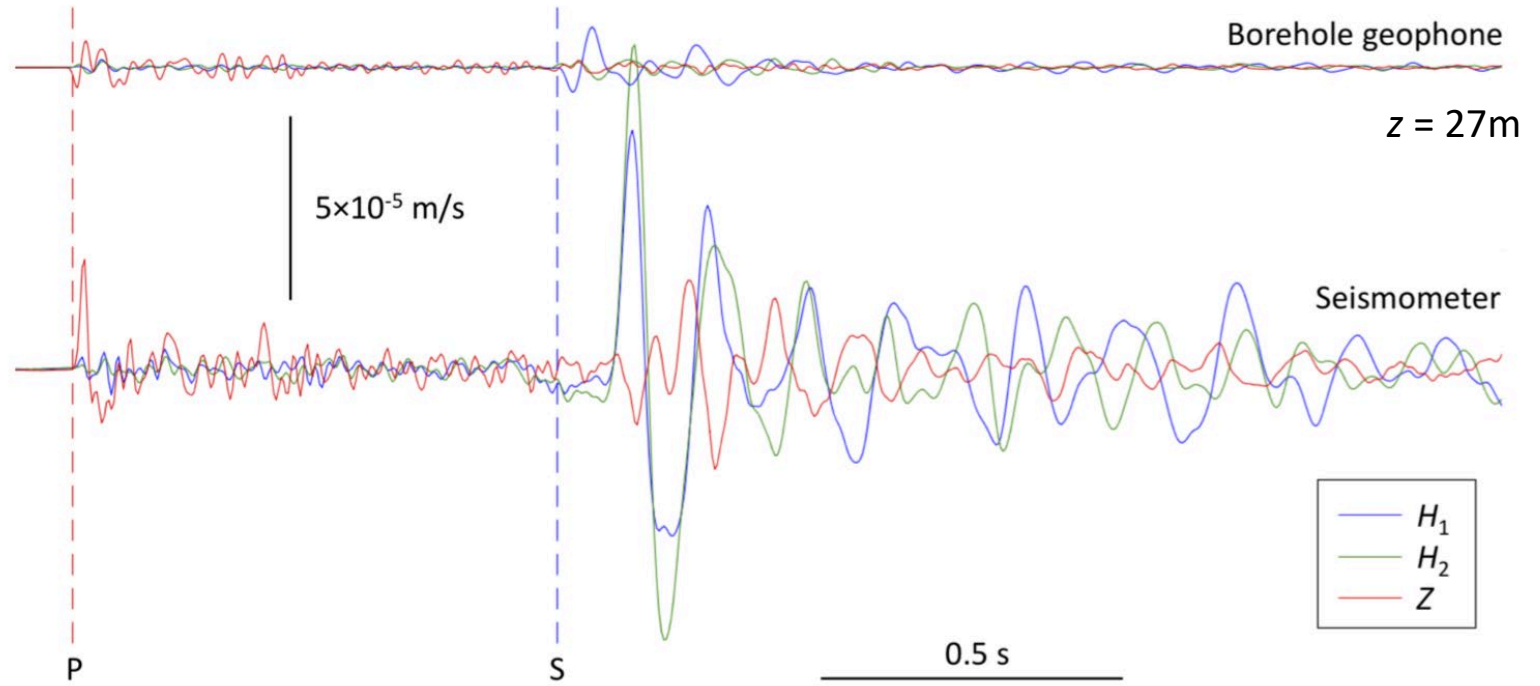

Station Map

Geophone Array

- Plus 3D multicomponent seismic volume (TGS)

Geophone vs. seismometer
Waveform comparison

Borehole geophone

z = 27m

5×10^{-5} m/s

Seismometer

	H_1
	H_2
	Z

P   S   0.5 s

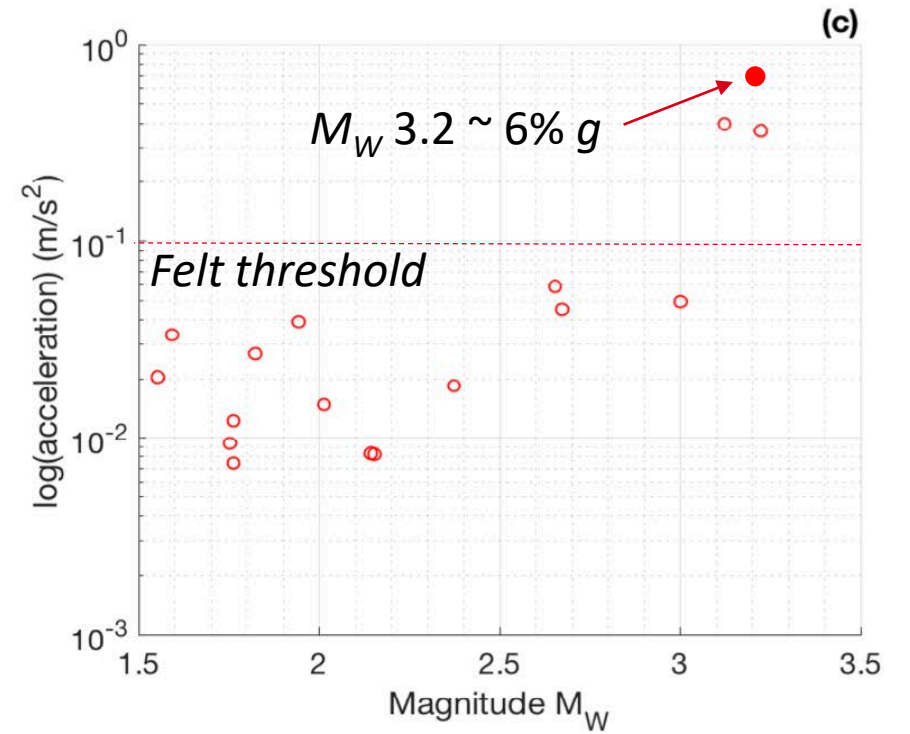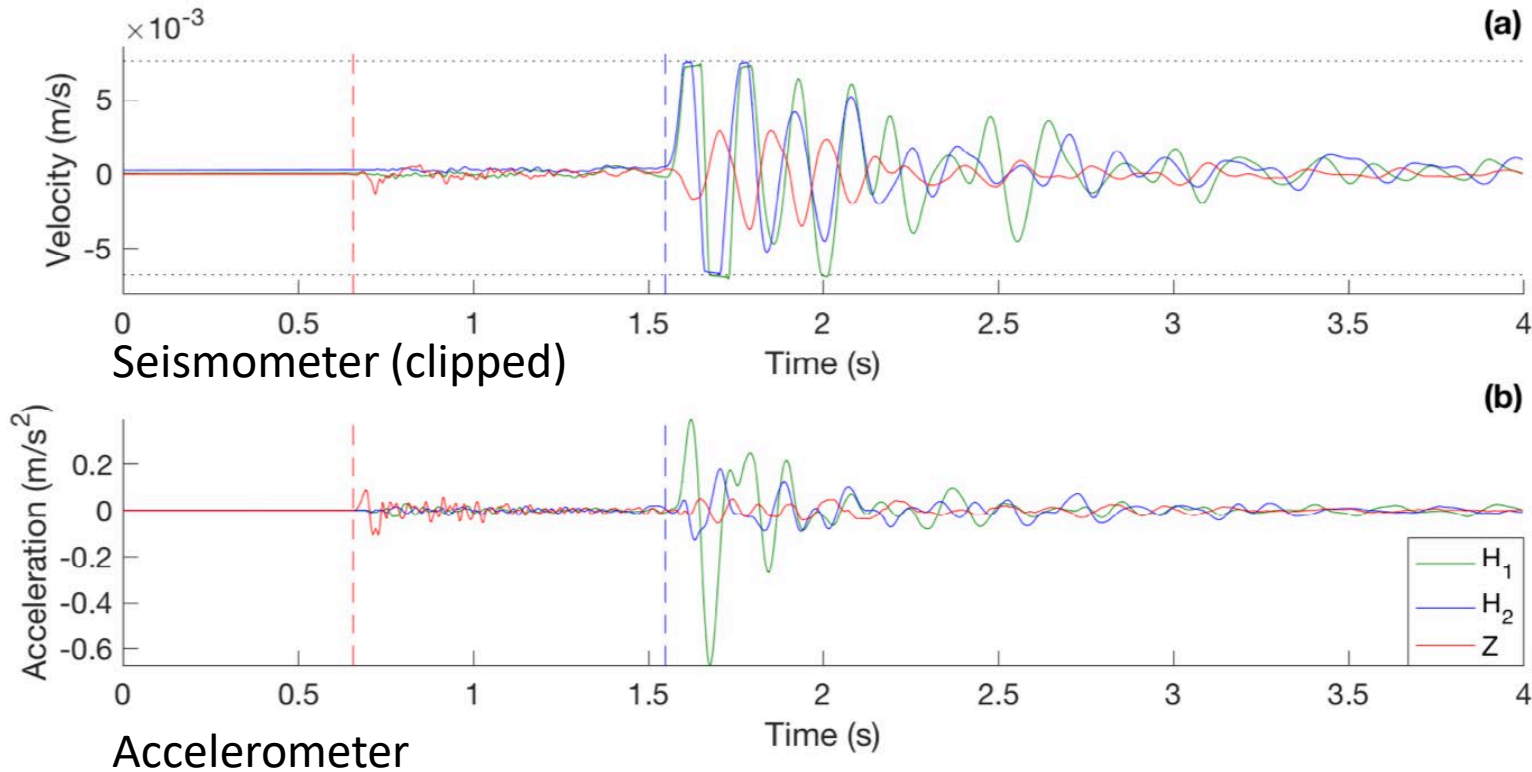- Example response-corrected waveforms (velocity) for a M_W 1.76 event

Eaton et al., SRL 2018

Ground motions and waveform clipping

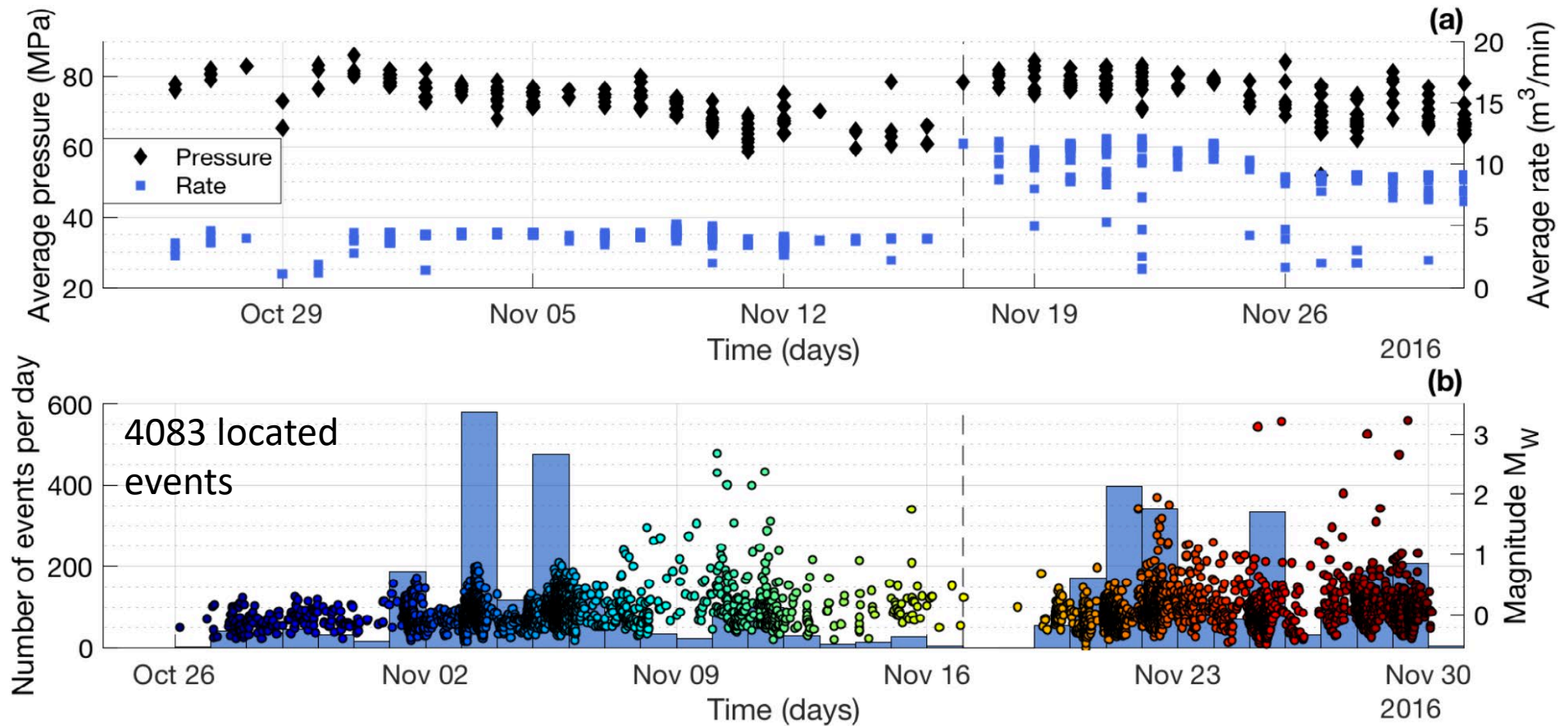(a) Seismometer (clipped)

(b) Accelerometer

(c) M_W 3.2 ~ 6% g

Felt threshold

Eaton et al., SRL, 2018
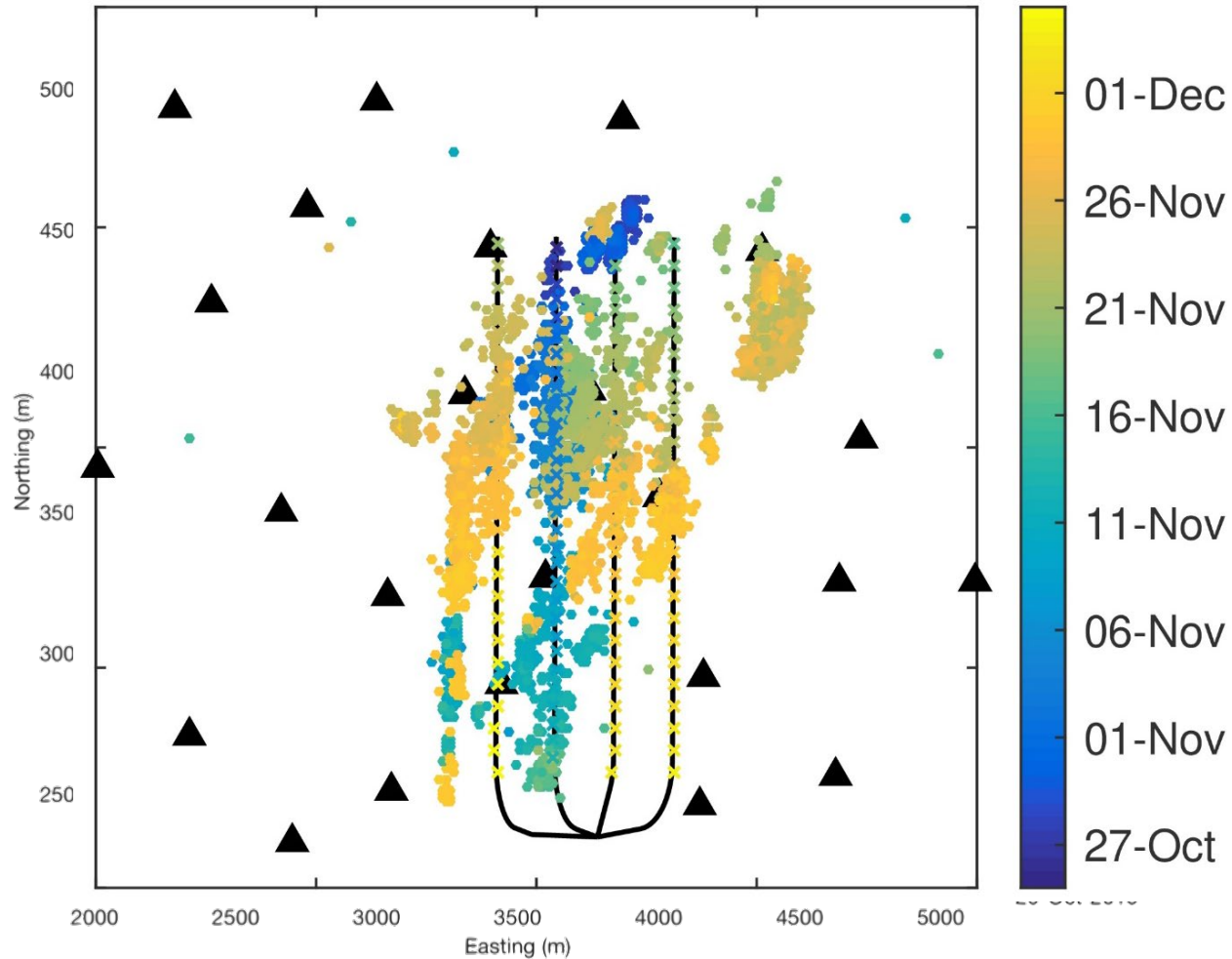
Seismicity vs. treatment parameters

4083 located events

Eaton et al., SRL, 2018

Spatiotemporal event clusters

- Highest magnitude events (4083) reveal 6 distinct clusters
- Matched-filtering method used
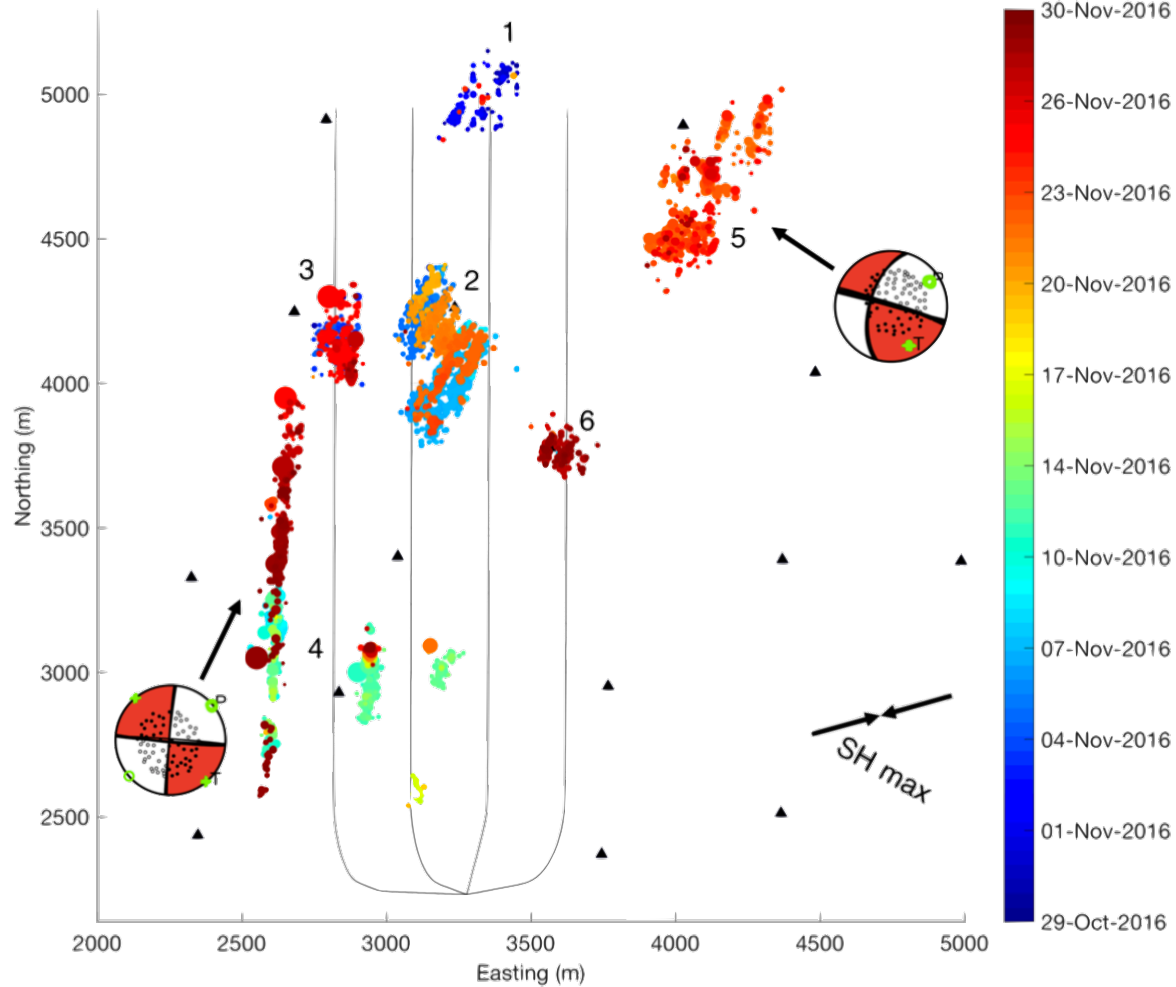- Absolute locations of parent events, child event relative locations anchored to parent

Eaton et al., SRL, 2018

Updated: 13,106 events located using nonlinloc
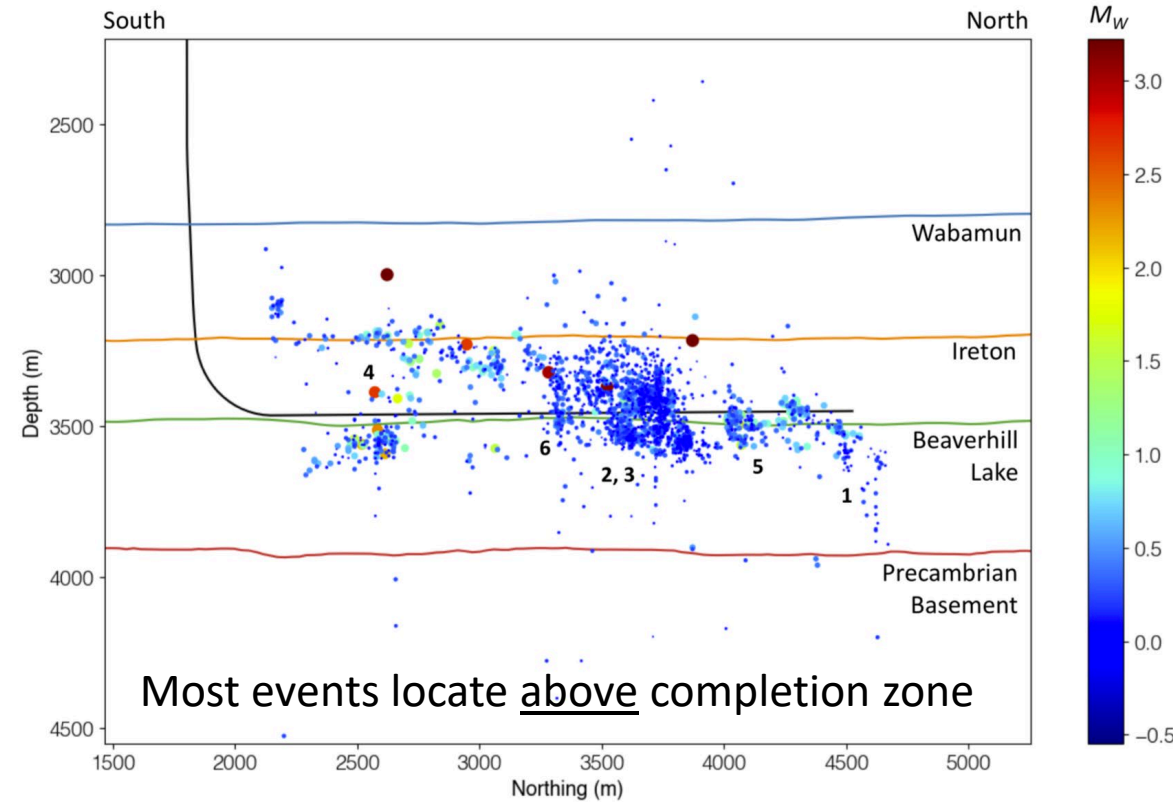
Spatiotemporal event clusters
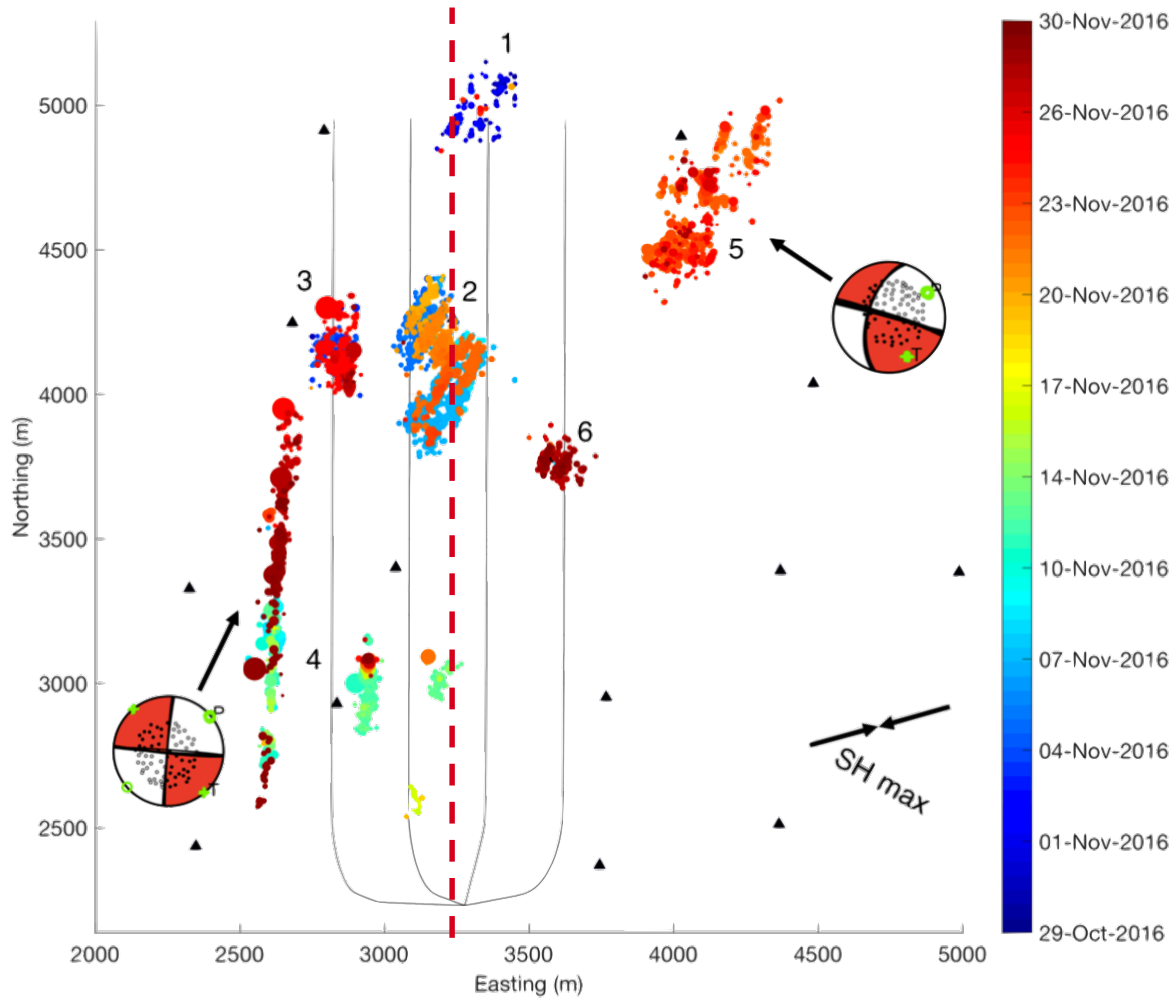

- Largest events occur on west side (3,4) along a north-south trending feature

- Episodically activated

- One cluster east of treatment program

- Focal mechanisms show strike slip mechanisms (typical of this area)

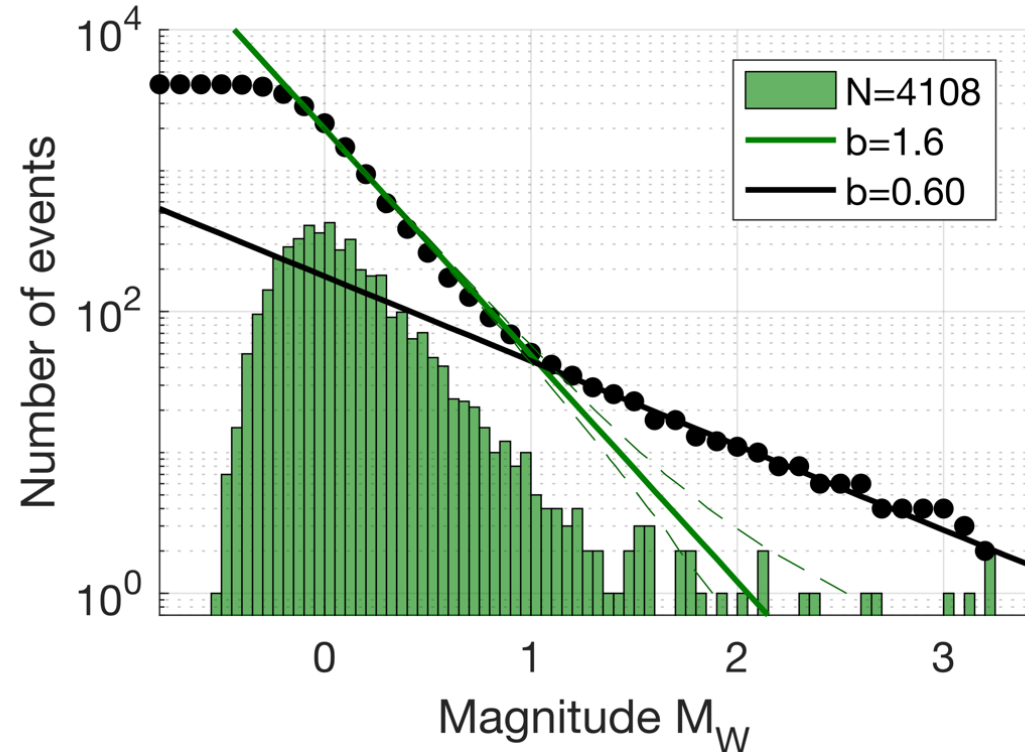Eaton et al., SRL, 2018

Spatiotemporal event clusters

Most events locate <u>above</u> completion zone

→ Eyre et al. poster

Magnitude distribution

- Moment-magnitude distribution exhibits a bilinear character

- Interpreted as superposition of distinct clusters with different distributions

- Characteristic earthquake model?

Igonin et al., GRL, in review

Source Mechanisms of Hydraulic-Fracturing Induced Event Sequences in the Fox Creek Area

- 530 moment tensors reveal predom-inantly double-couple strike-slip, with some more exotic mechanisms
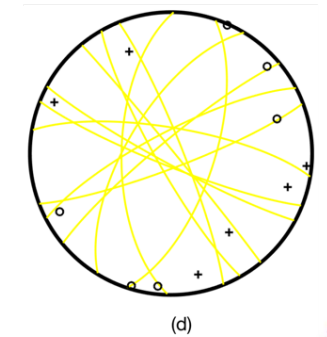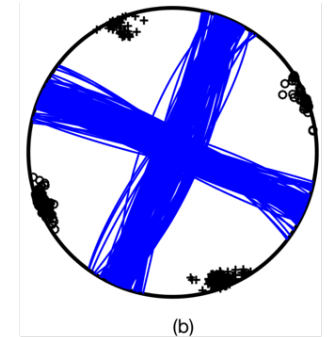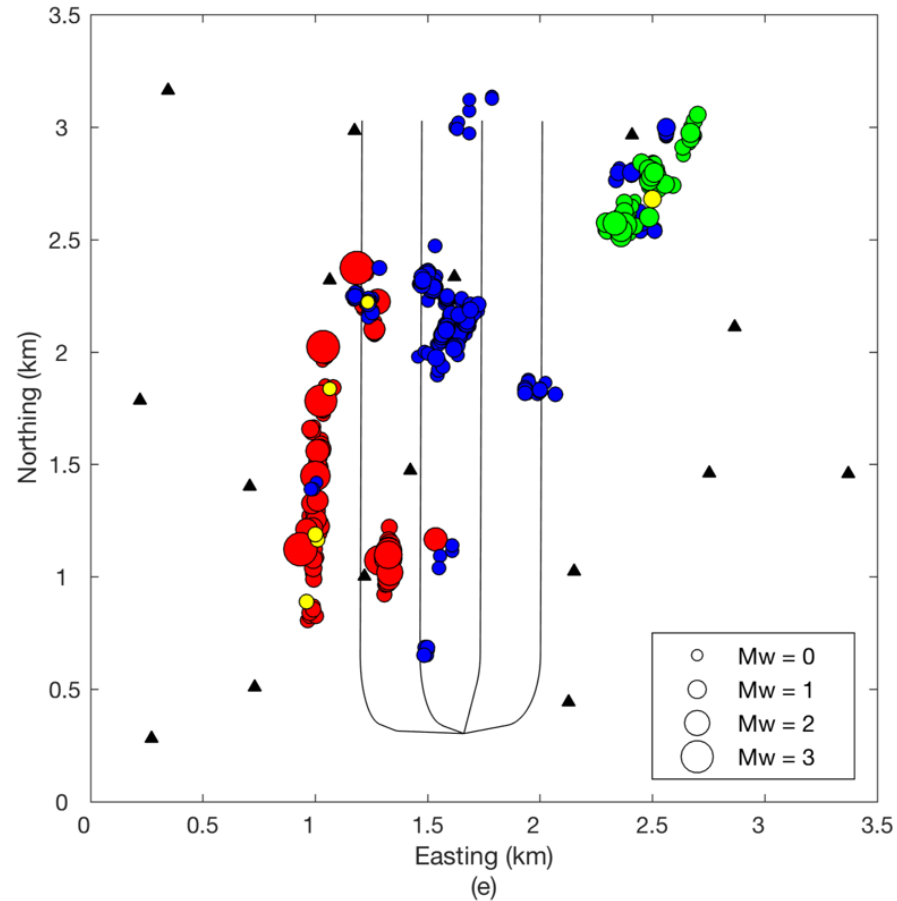
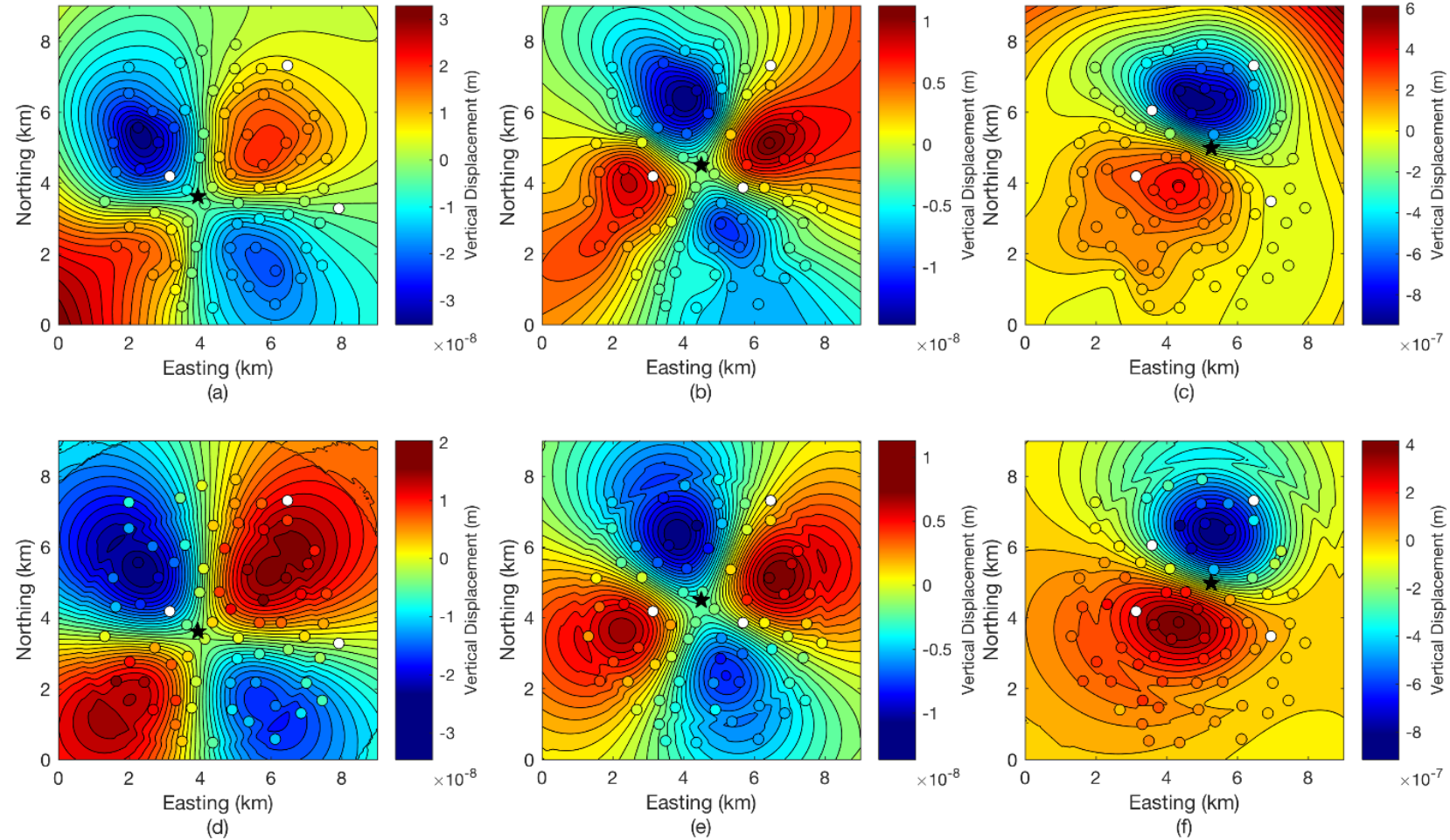# Observed vs. Predicted P-wave Amplitude Maps

- Array aperture provides exceptional control on focal mechanisms
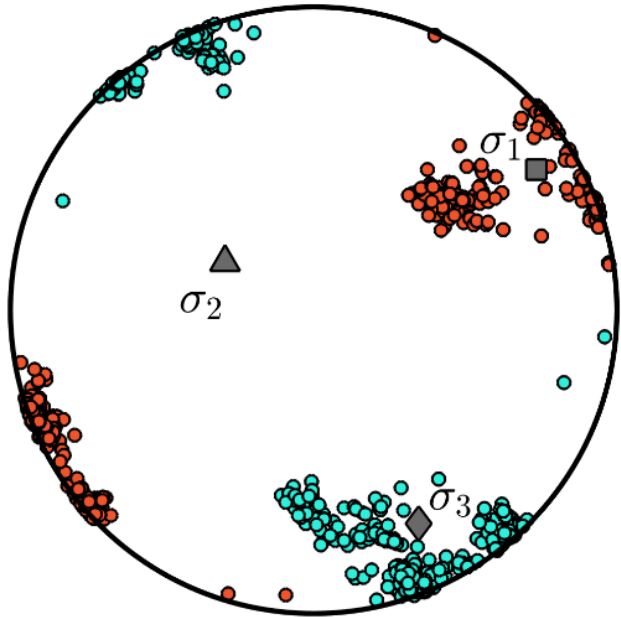
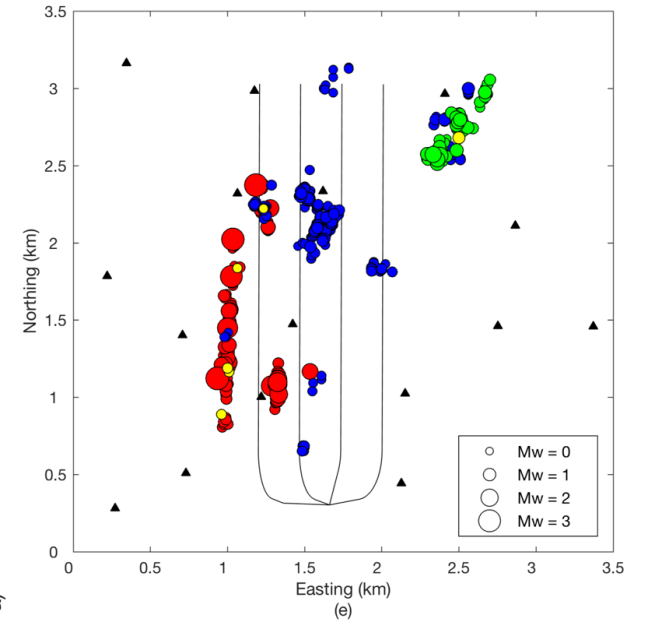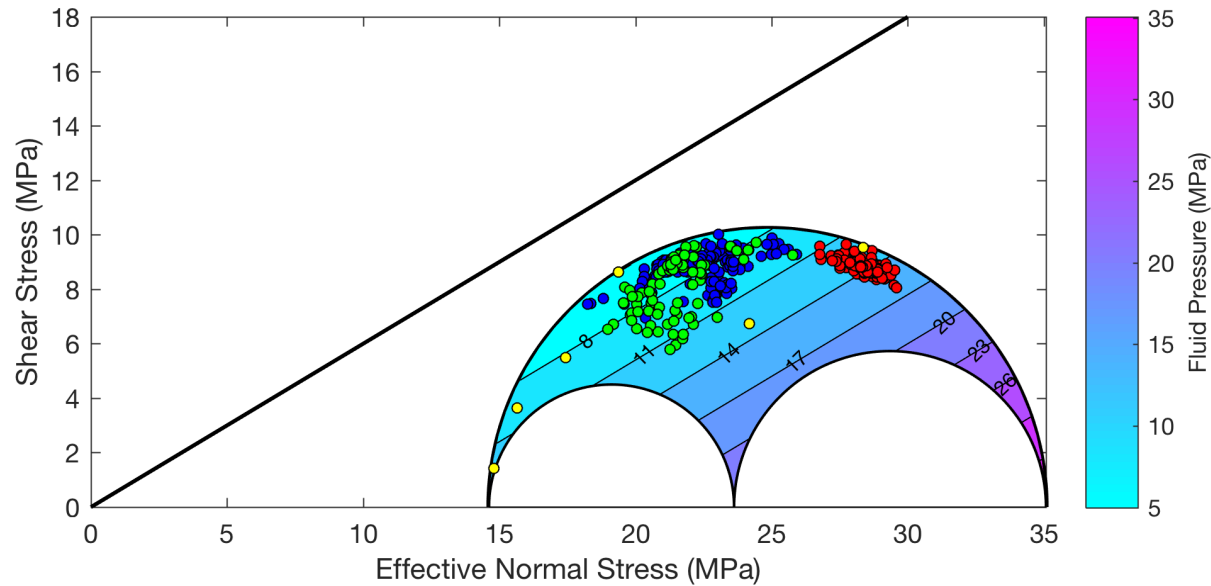- Clear selection of nodal plane

Zhang and Eaton, BSSA, submitted

Stress inversion indicates that N-S fault is not well oriented

… but good agreement with nearest observation from WSM
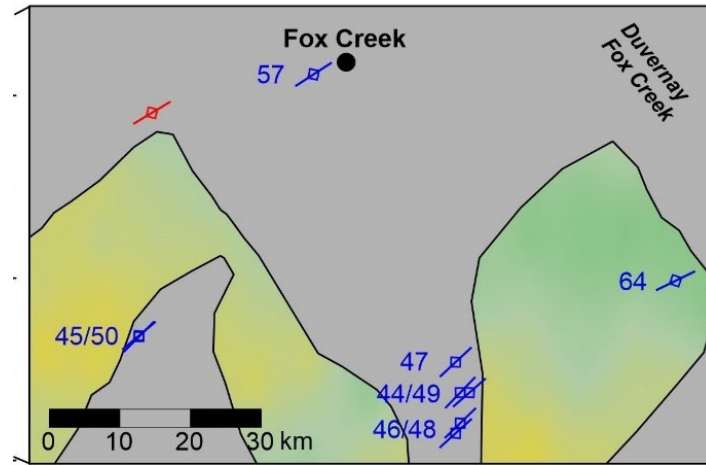
Zhang and Eaton, BSSA, submitted

Strategy for identifying faults in 3D seismic

Seismic expression of regional flower structure

Approximate extent of induced seismicity

Wabamun
Ireton
Duvernay
Beaverhill Lake
Precambrian Basement

F1 F2 F3 F4 F5 F6 F7

Section flattened on Wabamun horizon

~ 9 km

W / E

Time (s)

Generalized Lithology
Carbonate
Mixed shale + carbonate
Mixed shale + carbonate
Crystalline rock

Eaton et al., SRL, 2018
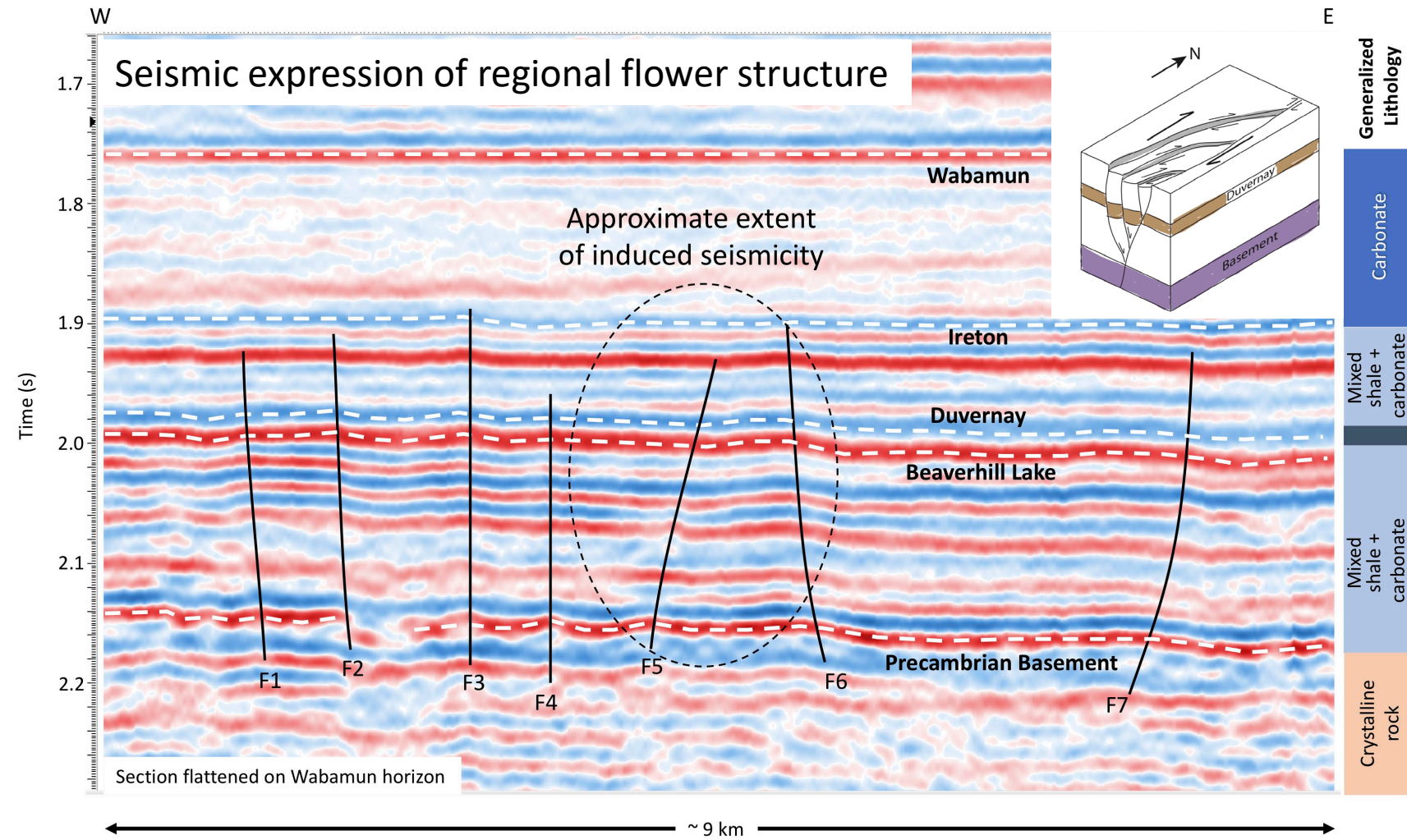
- Near-vertical faults are subtle (vertical exaggeration helps)
- Flatten on Wabamun horizon, connect ~vertically aligned curvature anomalies
- Take care to avoid conflation with other features (Gilwood channels, reef edges)

Takeaway Points

- ToC2ME experiment has enabled academic research innovation and new insights into fault activation in the Duvernay play

- Hypocentres of large events occur in the Wabamun Formation (well above the completion zone in the Duvernay), role of aseismic slip?

- Segmented magnitude-frequency distribution, consistent with characteristic earthquake model?

- Stress inversion using 530 well constrained mechanisms reveals that main north-south lineament is not favourably oriented for slip

- ToC2ME microseismic and induced seismicity data will be released through IRIS in 2020, providing a benchmark dataset for research

Acknowledgements

- Two anonymous companies for access to shallow-well array
- Nanometrics for installing and operating broadband stations + accelerometer
- TGS for providing multicomponent 3D seismic dataset
- Terra-Sine for permitting services, installing and operating digitizers
- CGG and Itasca for software
- Microseismic Inc. for license to use Buried Array method
- Chevron, NSERC, University of Calgary, ConocoPhillips Canada, Aqaua Terra Water Management, Nanometrics through IRC, VPR and CRD programs
- Other MIC sponsors for ongoing support