Passive Seismic Monitoring of CO_2 Storage Sites

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UKCCSRC Geophysical modelling for CO2 storage, monitoring and appraisal meeting

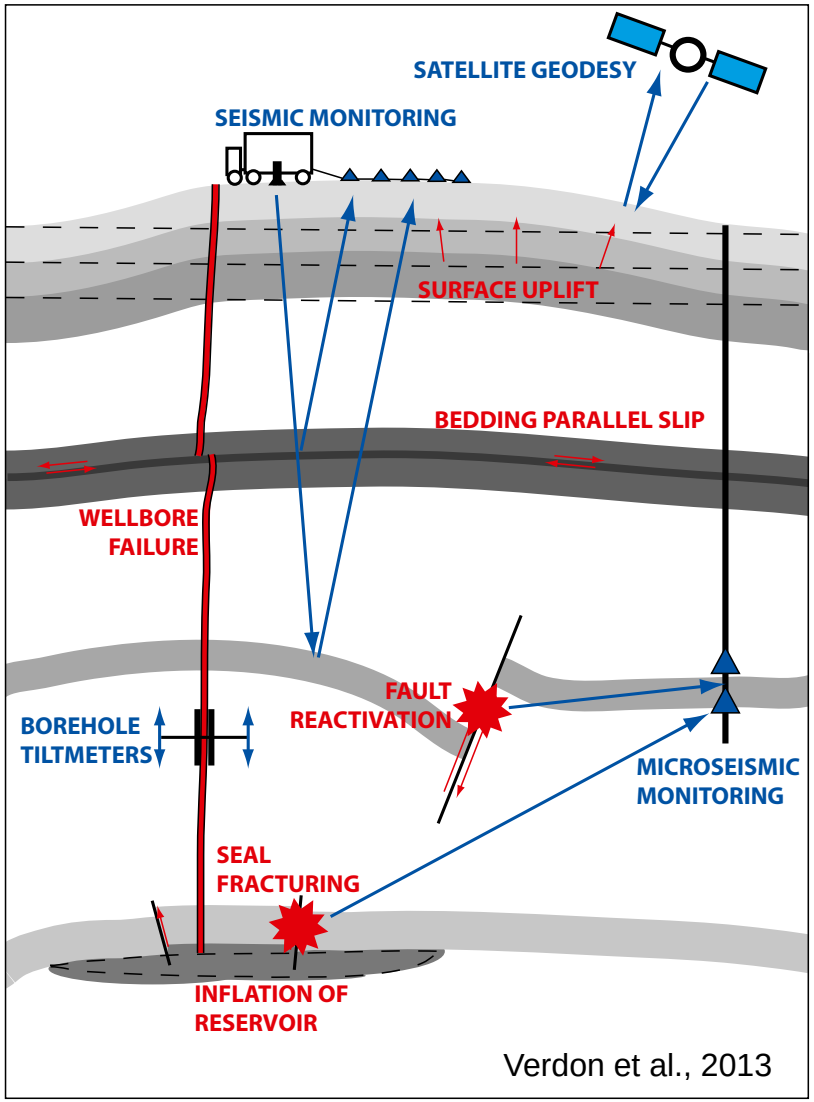
Leeds

3 November 2015

1. University of Bristol
2. University of Edinburgh
3. Geological Survey Canada

Passive seismic monitoring

- Generally small magnitude, M<0,
- Identify potential leakage pathways,
- Near real-time analysis to provide early-warning,
- Understand geomechanical response & verify models,
- Aid seismic hazard assessment.



Major CCS projects

1. Weyburn, Saskatchewan
   - >30 Mt since 2000
   - Constraining geomechanical models with microseismic observations
2. In Salah, Algeria
   - ~4 Mt 2004-2011
   - Changes in fracture characteristics during injection
3. Aquistore – Boundary Dam, SK
   - Began injection April 2015
   - Using ambient noise to determine seismic velocities

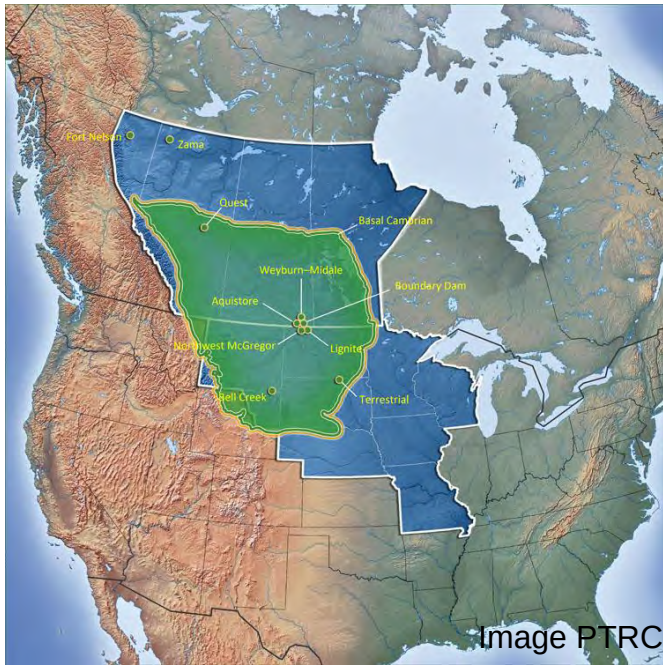


Image PTRC

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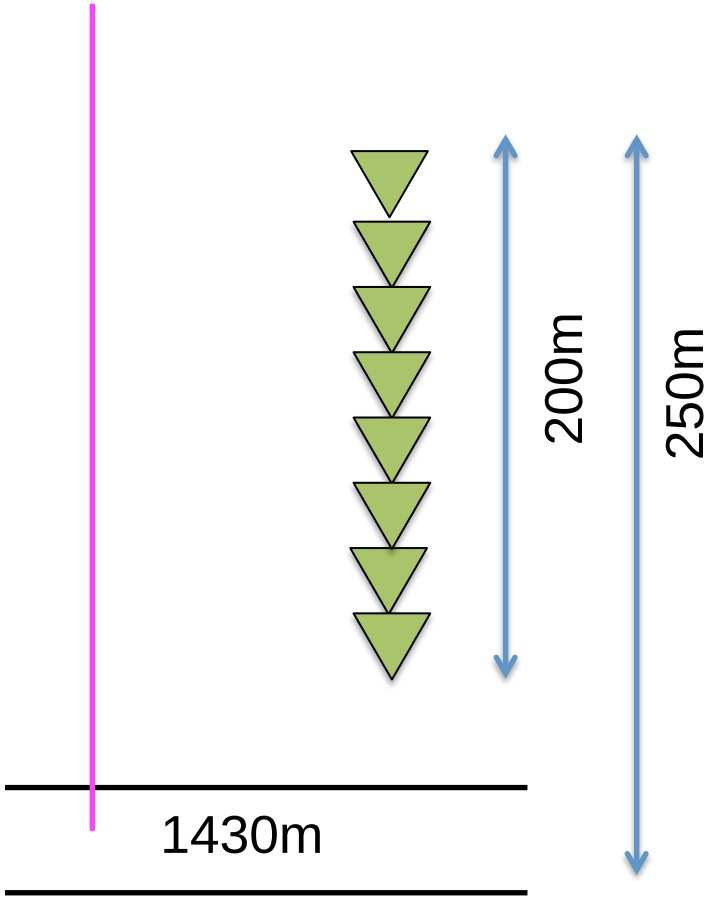
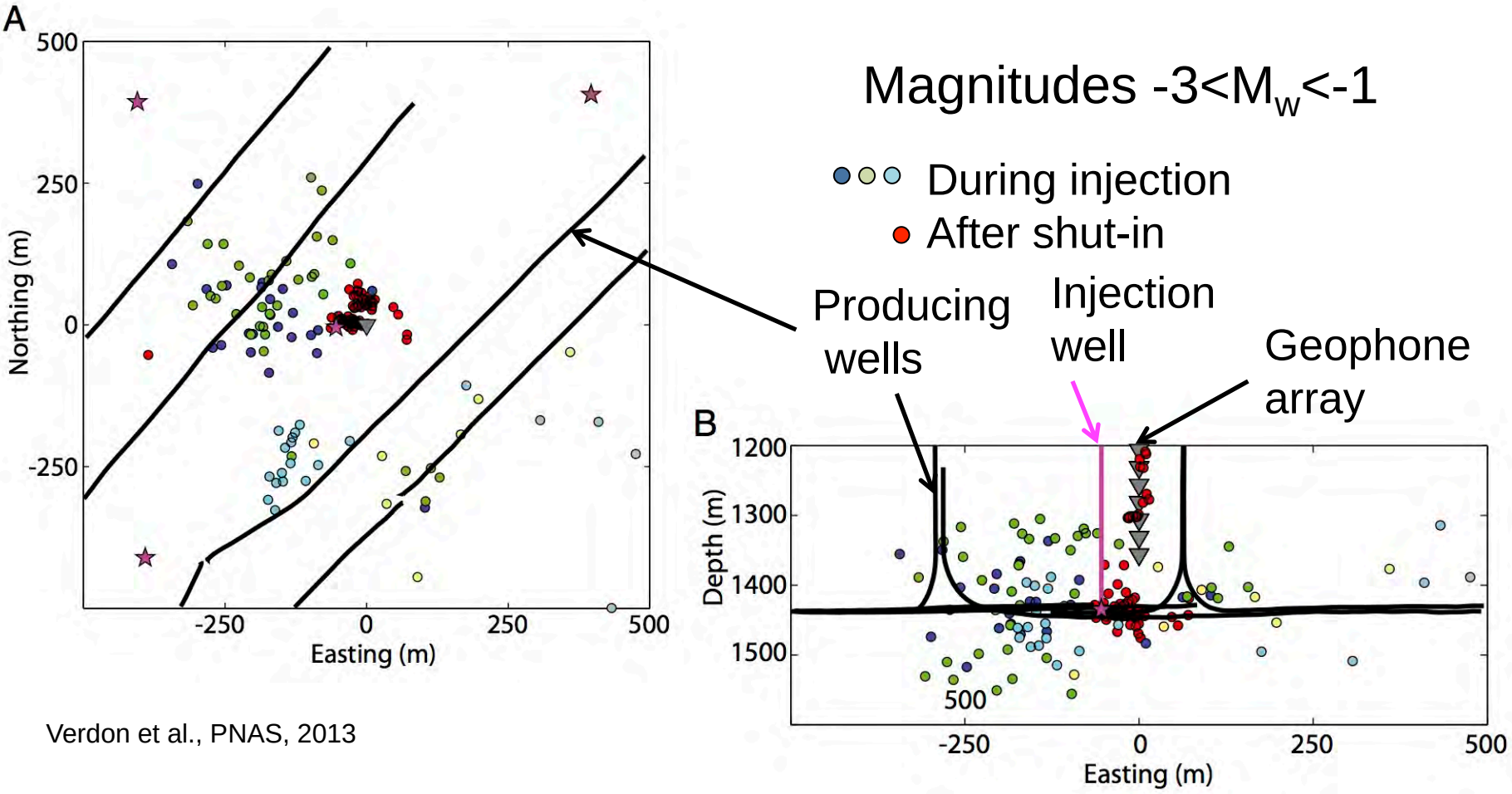
Weyburn passive seismic monitoring 2003 – 2011

Injection:
2000 – present



Weyburn microseismic event locations

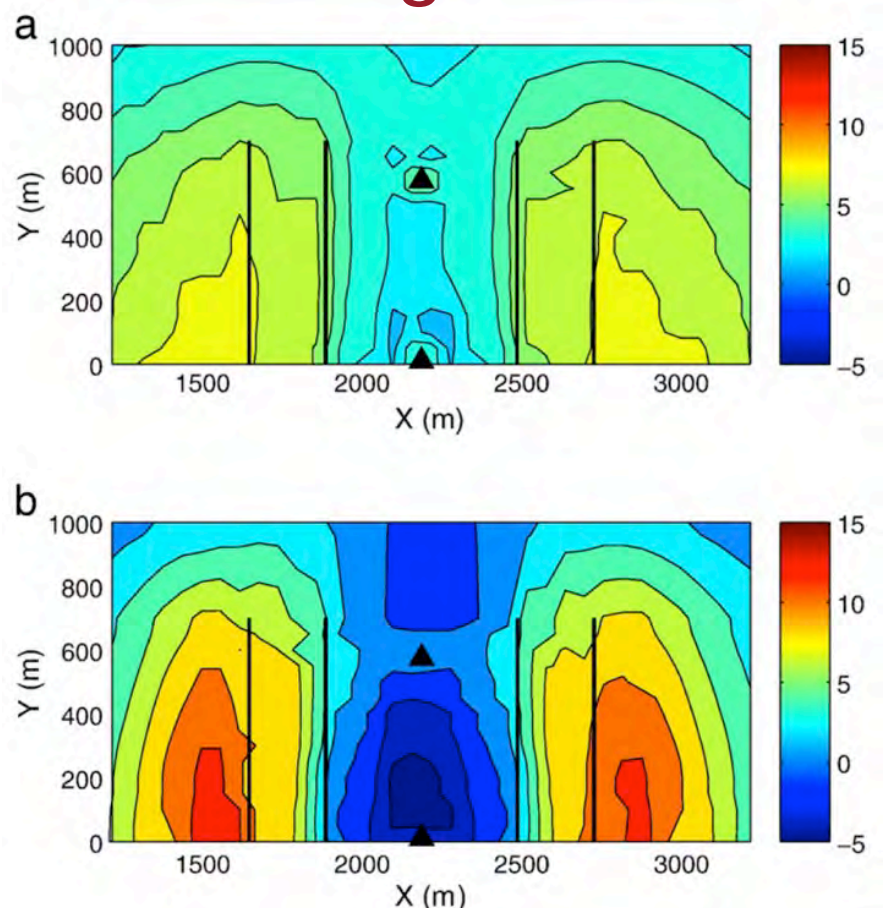


Verdon et al., PNAS, 2013

Modelling stress changes

Reservoir

Overburden



▲ Injection well

| Producing well

Verdon et al., EPSL, 2011

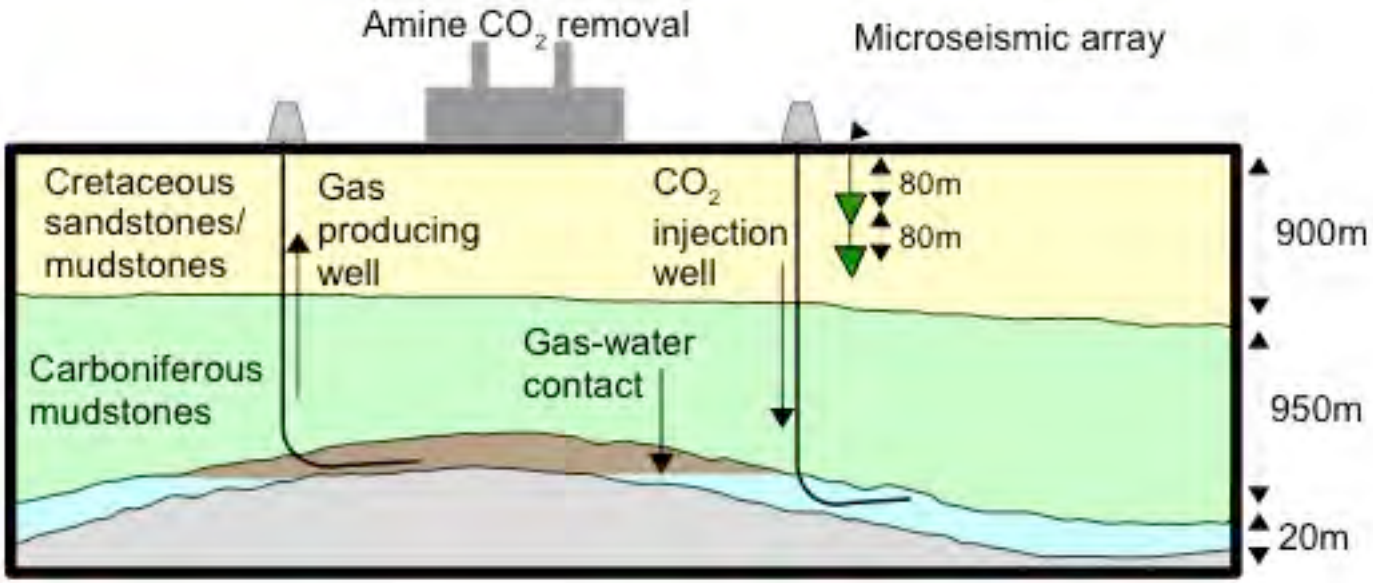
To match observed seismicity pattern an updated geomechanical model in required with a softer reservoir.

Weyburn - Summary

- Microseismic observations can provide important constraint on geomechanical models.
- Model with a softer reservoir than expected from core samples
  - Increases fracture potential in overburden above producing wells;
  - Decreases fracture potential in overburden above injection wells.
- Seismicity caused by stress transfer, *not* fluid migration.

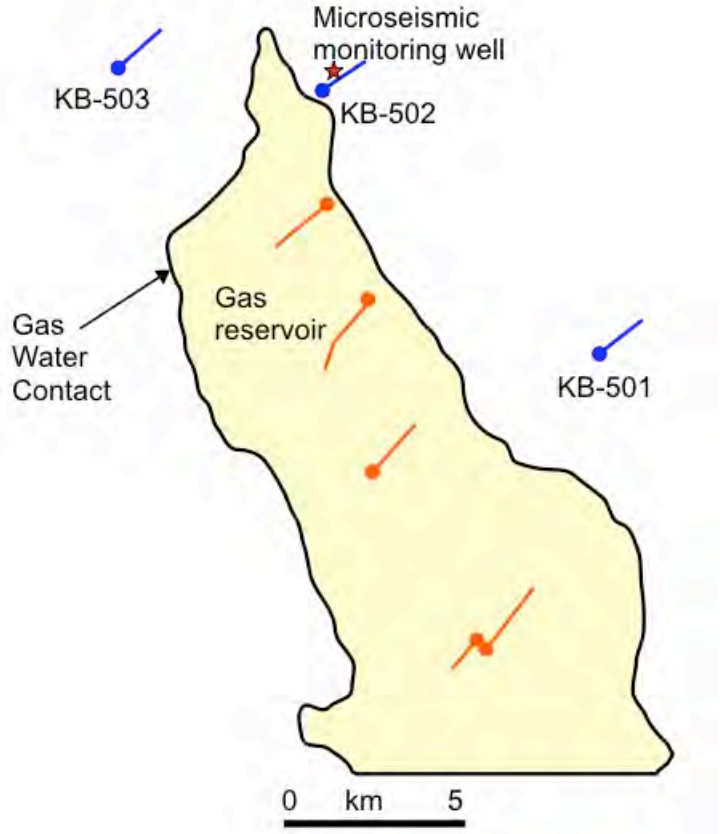
In Salah passive seismic monitoring 2009 – 2011

Injection 2004 – 2011



Stork et al., IJGGC, 2015

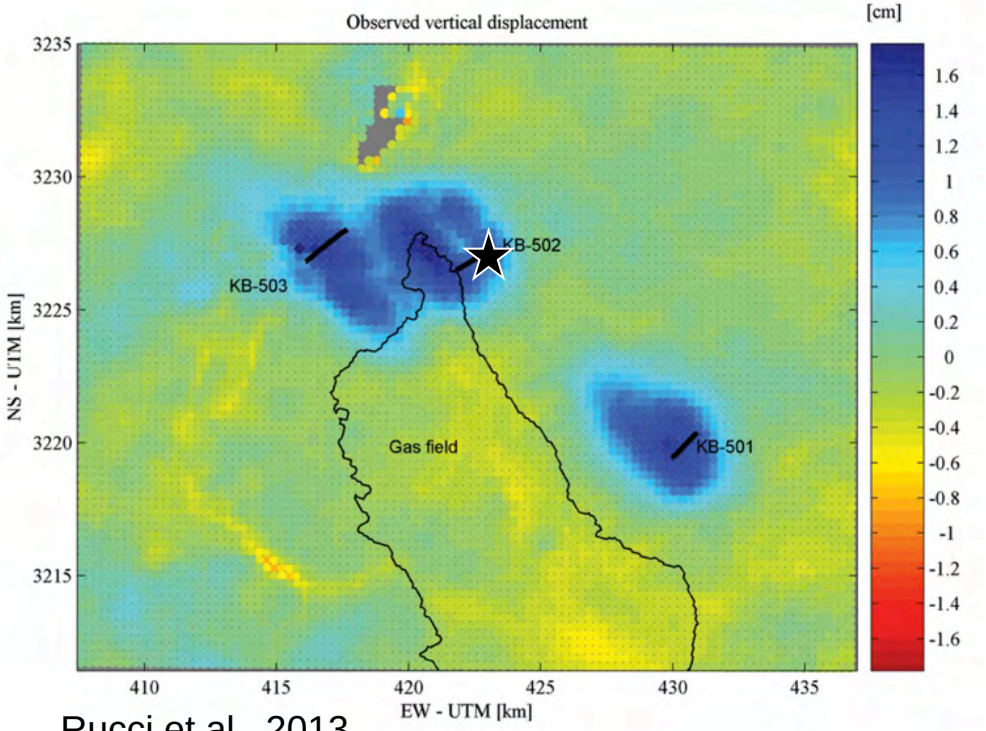
In Salah, Algeria



Stork et al., IJGGC, 2015

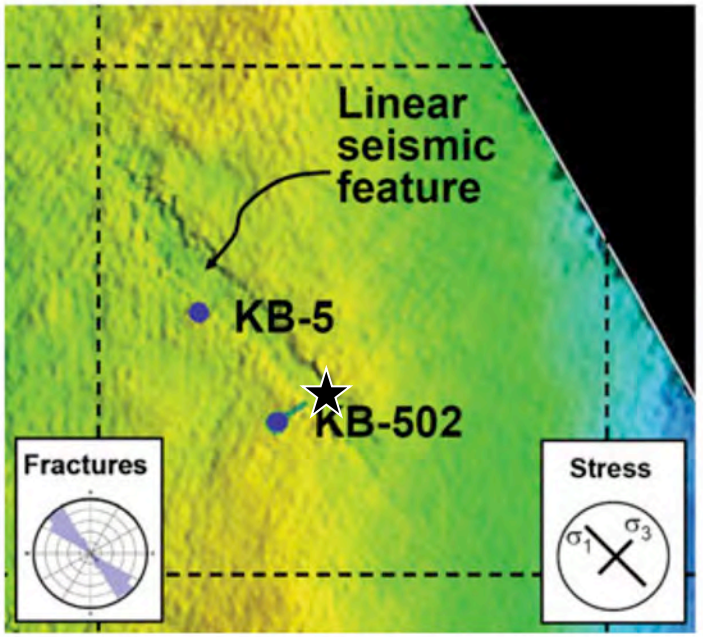
In Salah – Geophysical observations

Ground movement detected by satellites (InSAR)



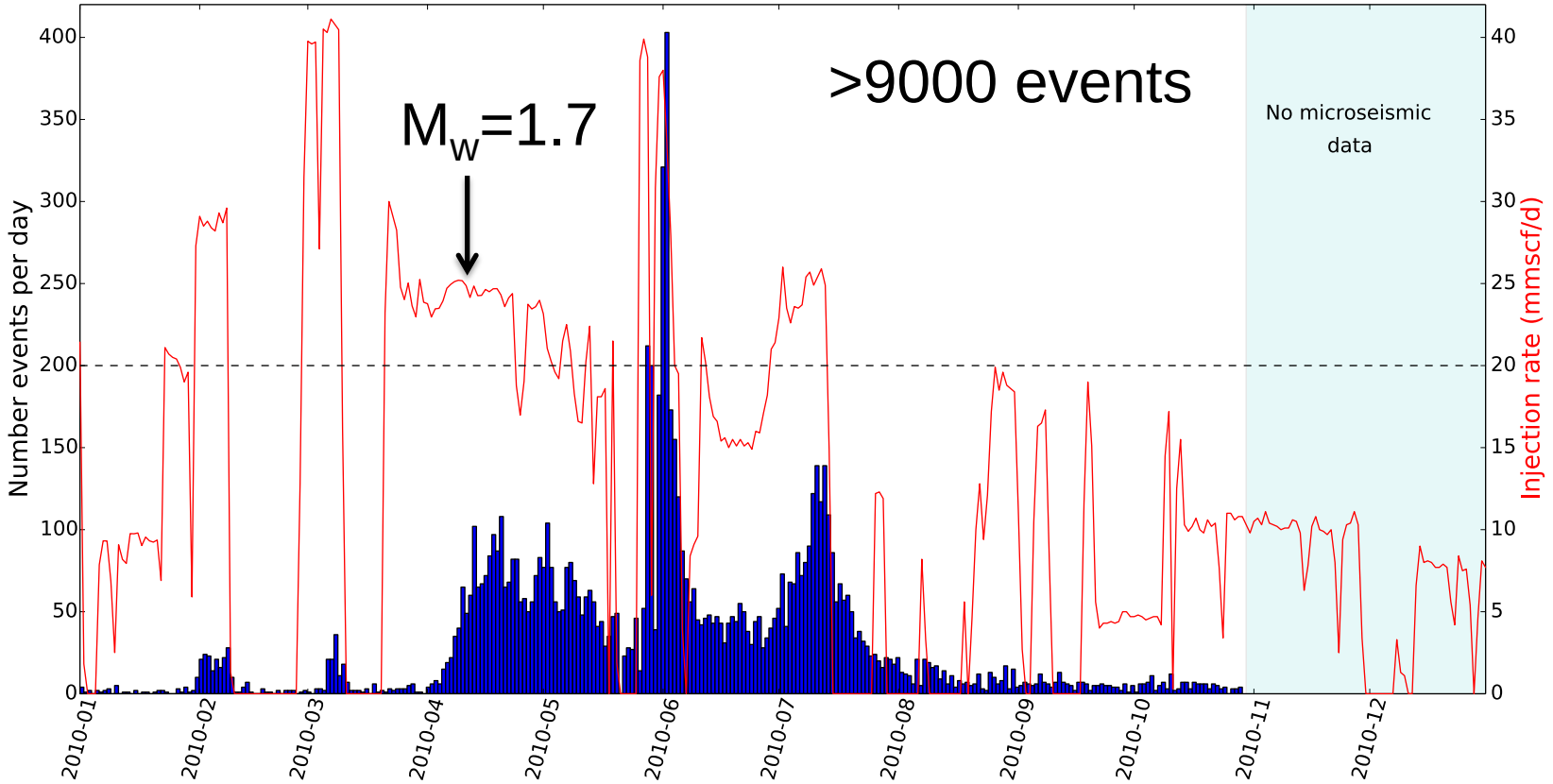
Rucci et al., 2013

Fracture zone detected at injection depth (2km)



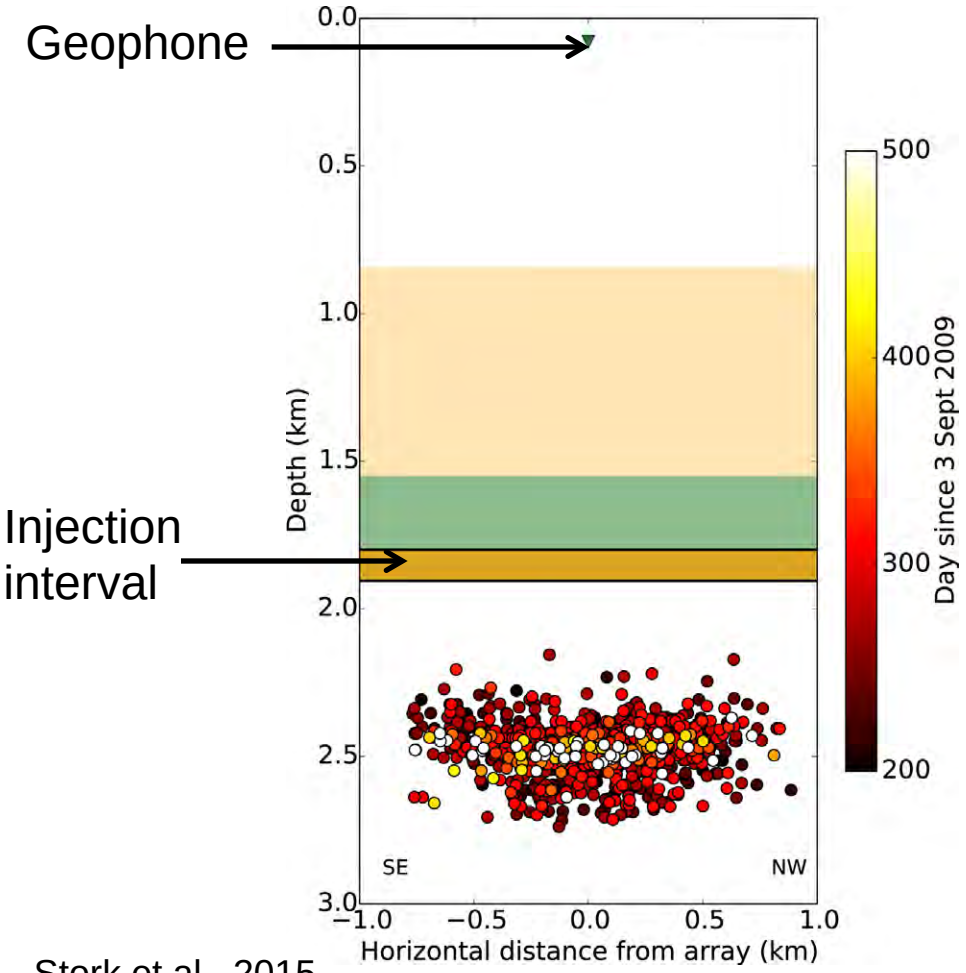
Rutqvist, 2012

In Salah – Passive seismic observations



Stork et al., 2015

In Salah – Event locations

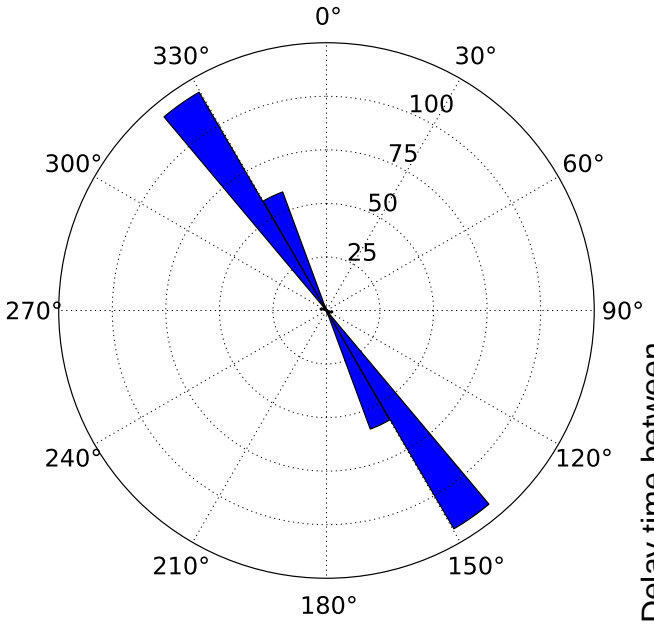


Stork et al., 2015

- Constant depth events
  - No evidence of migration to surface.

Fracture characterisation from shear-wave splitting

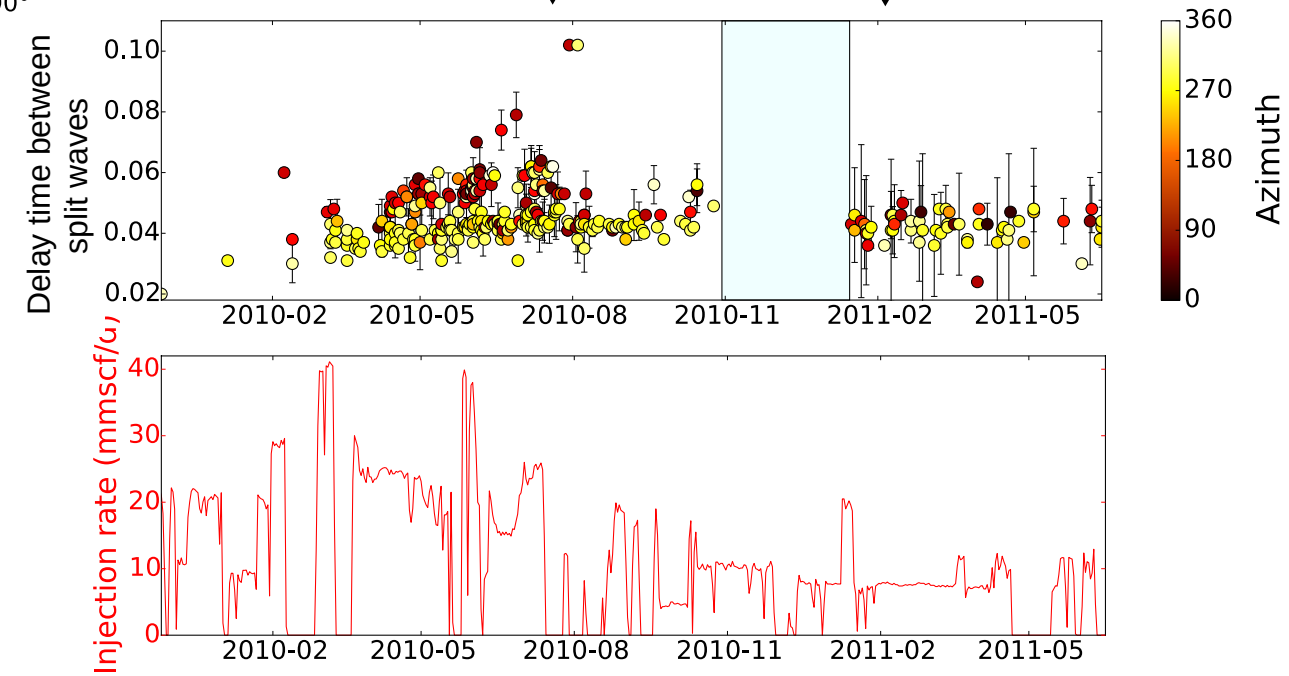
Concern: Is injection creating new fractures, allowing CO_2 migration?



Dominant fracture orientation in direction of σ_H

Delay time increases after high injection

Returns to original value



Stork et al., IJGGC, 2015

In Salah - Summary

- Proof-of-concept
  - Limited array but provides useful results
- No evidence of shallower seismicity with time
  - No evidence of shallow migration of CO_2
- CO_2 injection opens fractures that close when pressure decreases
  - Limits potential of CO_2 leakage

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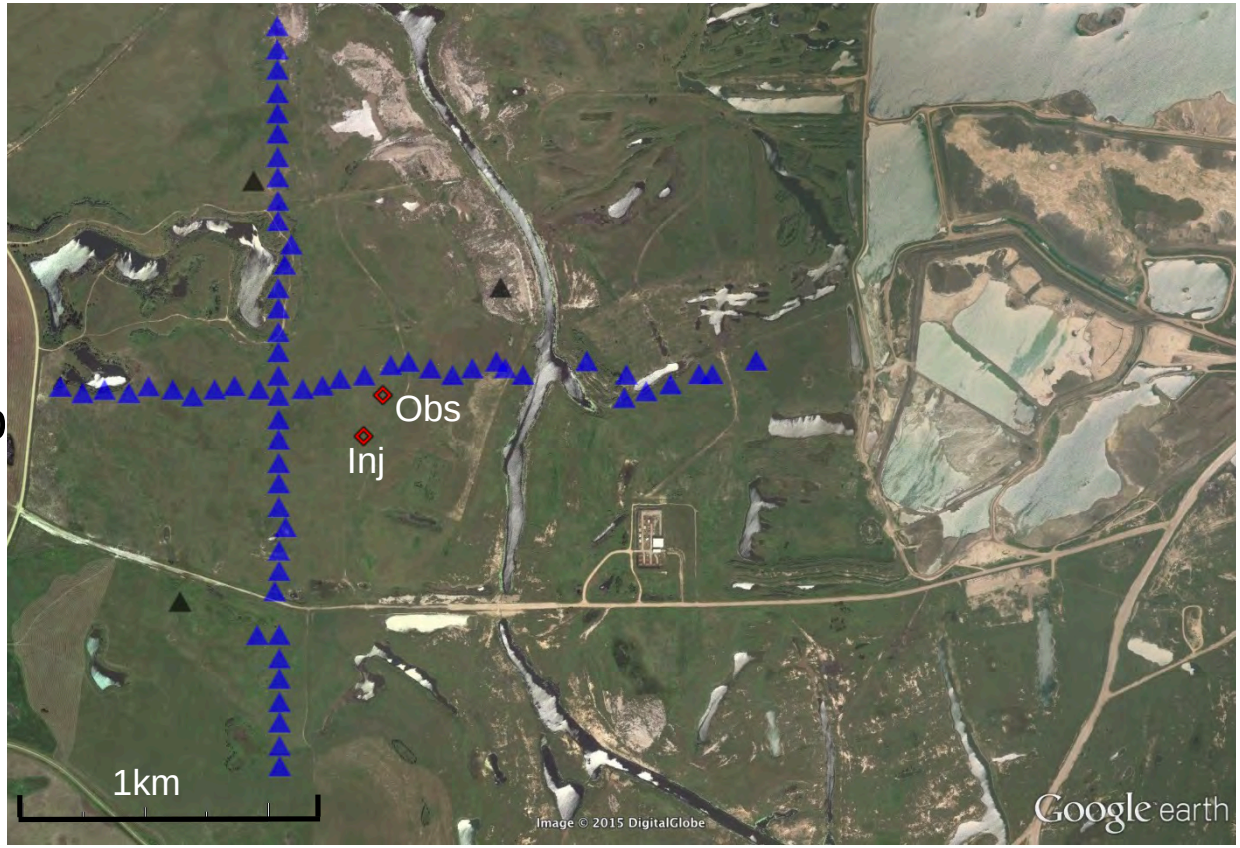
Aquistore passive seismic monitoring 2012 – 2015

Injection:
Since April 2015

2.5km x 2.5km array

50 – 64 1C/3C
geophones 6m/20m deep

3 broadband stations



BOUNDARY DAM - AQUISTORE CO_2 INJECTION PROJECT

World's first commercial power plant CCS project

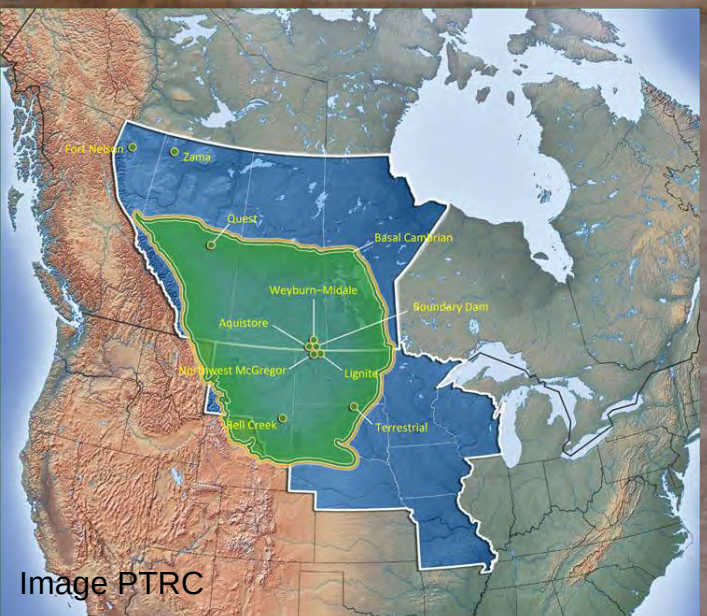
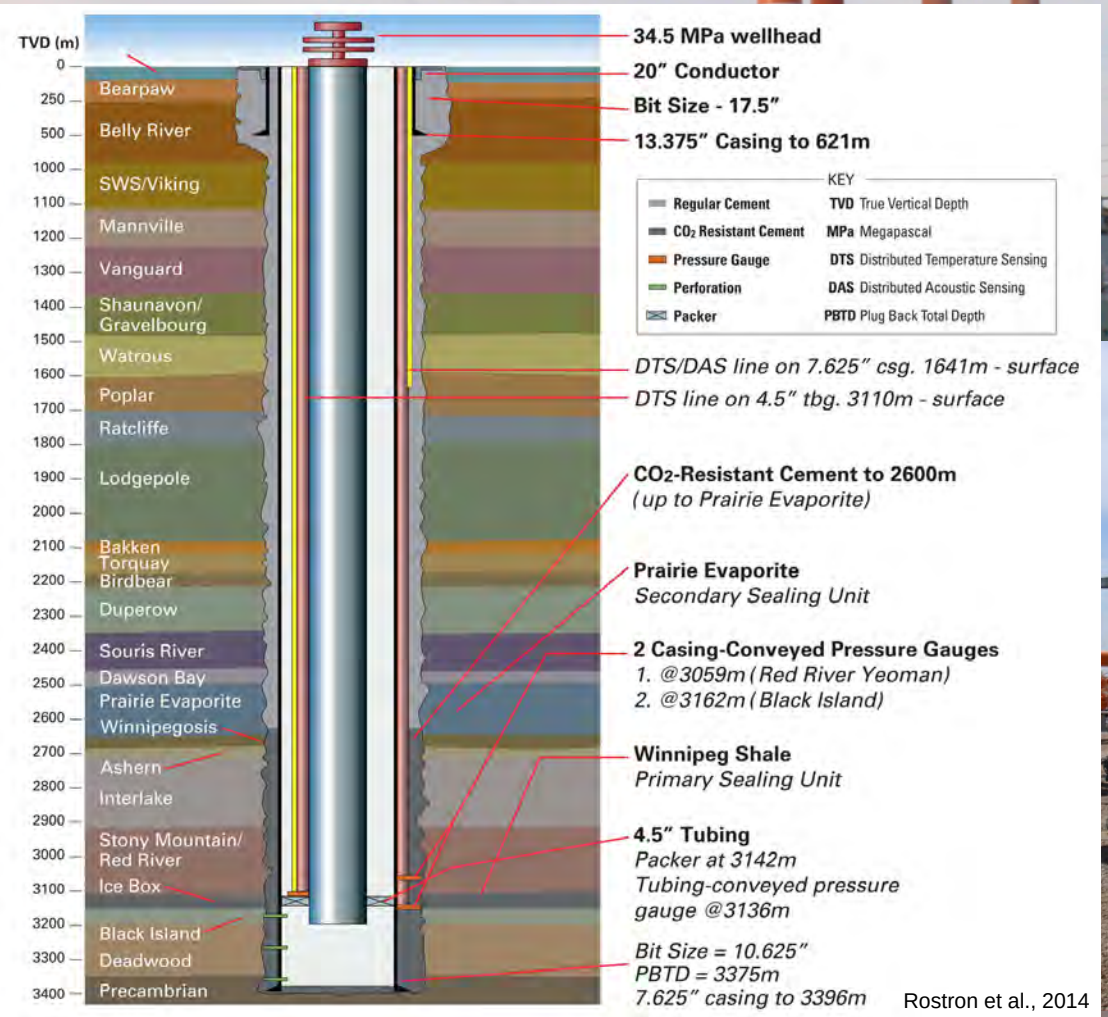


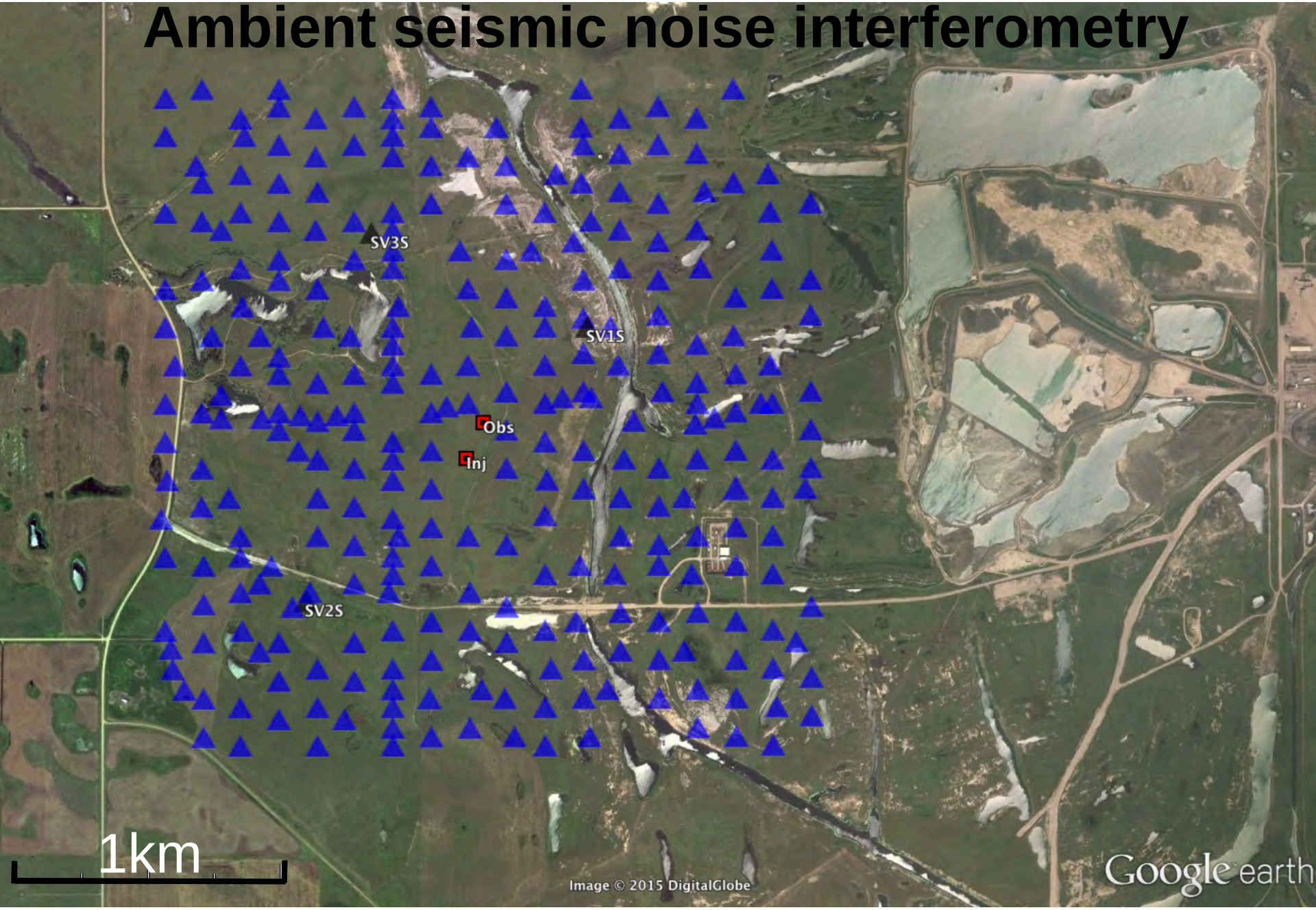
Image PTRC

BOUNDARY DAM - AQUISTORE CO_2 INJECTION PROJECT



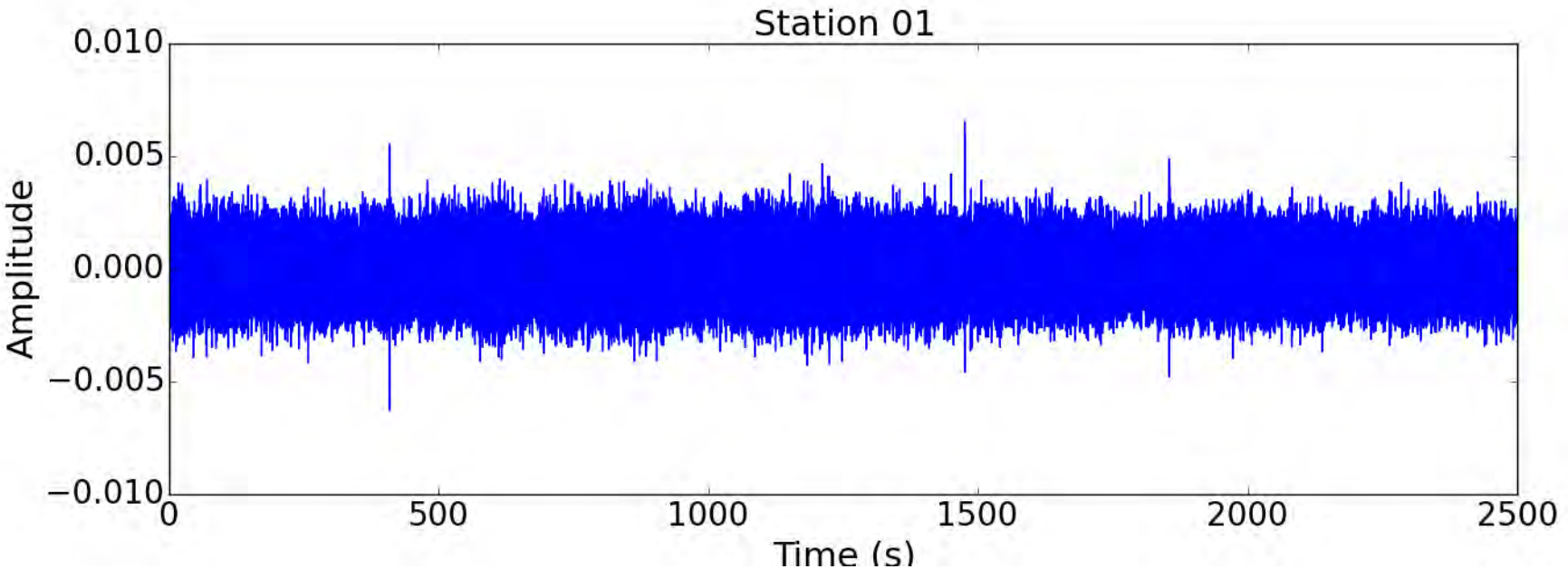
Rostron et al., 2014

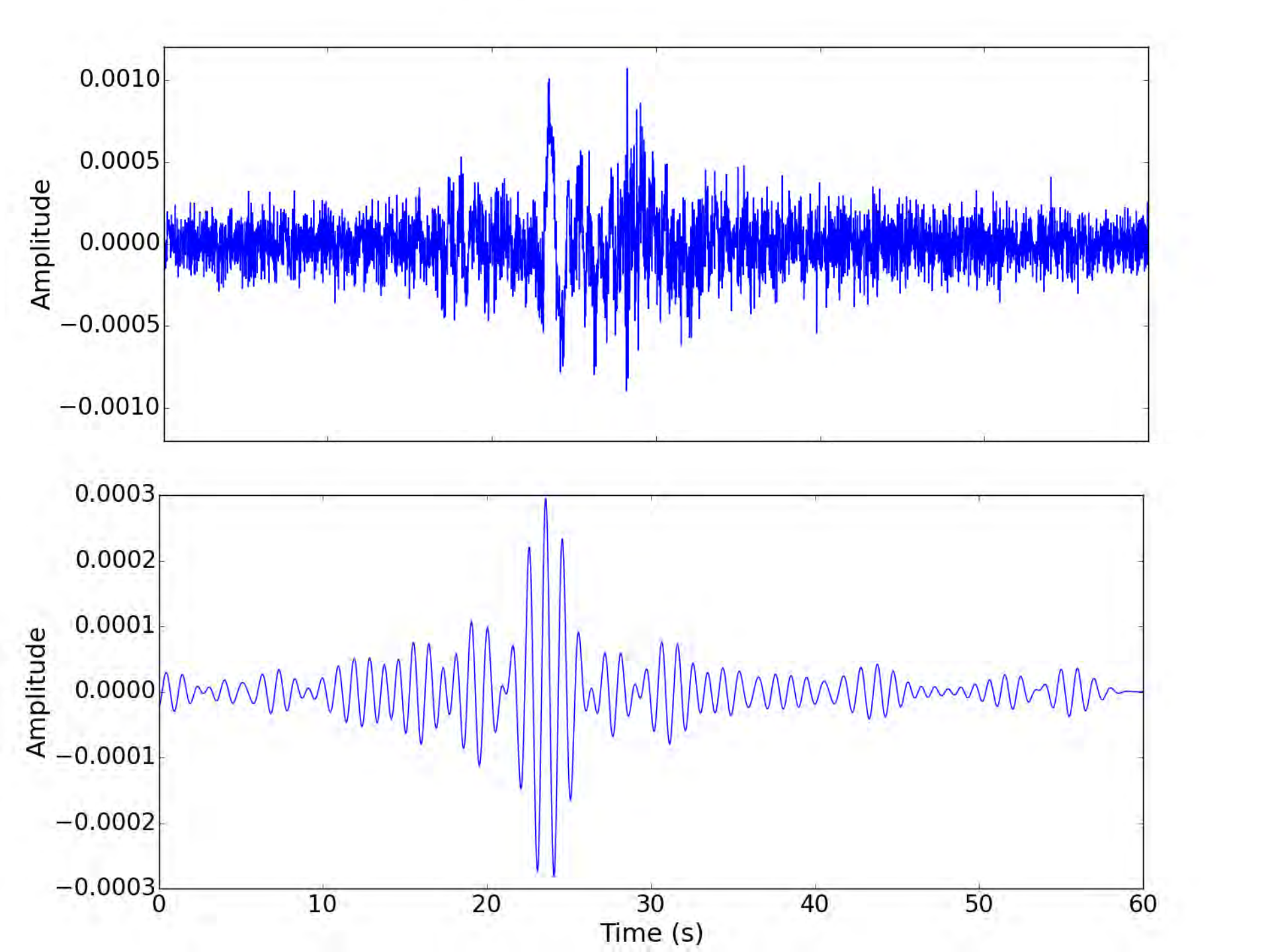
Ambient seismic noise interferometry



Ambient seismic noise interferometry

- Use noise recorded at receivers to produce velocity map
- Cross-correlate noise at pairs of receivers (Bensen et al., 2007)
  - Create virtual source at one receiver




0.0010
0.0005
0.0000
−0.0005
−0.0010
Amplitude
0.0003
0.0002
0.0001
0.0000
−0.0001
−0.0002
−0.0003
Amplitude
0
10
20
30
40
50
60
Time (s)

Preliminary Tomography Results

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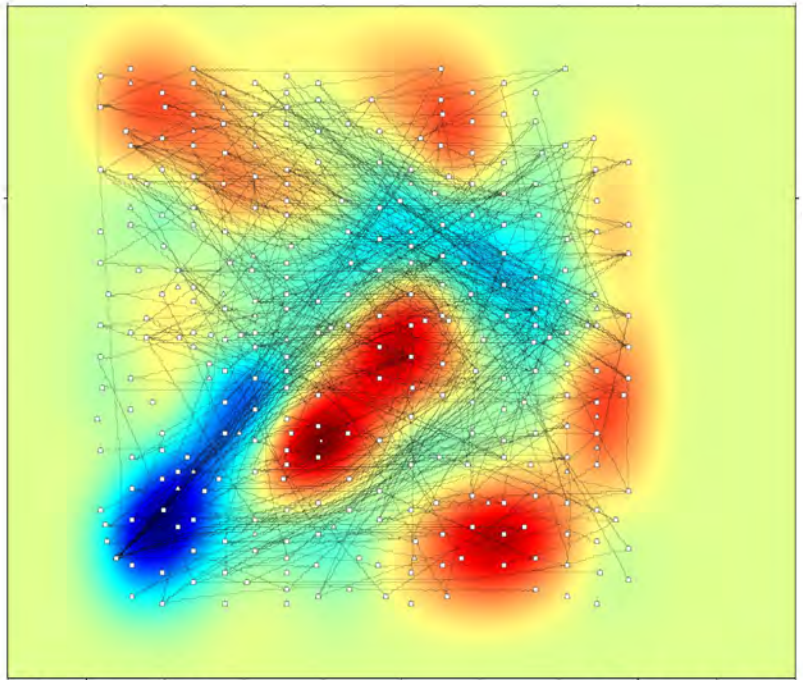
Rayleigh wave group velocity
0.7s period



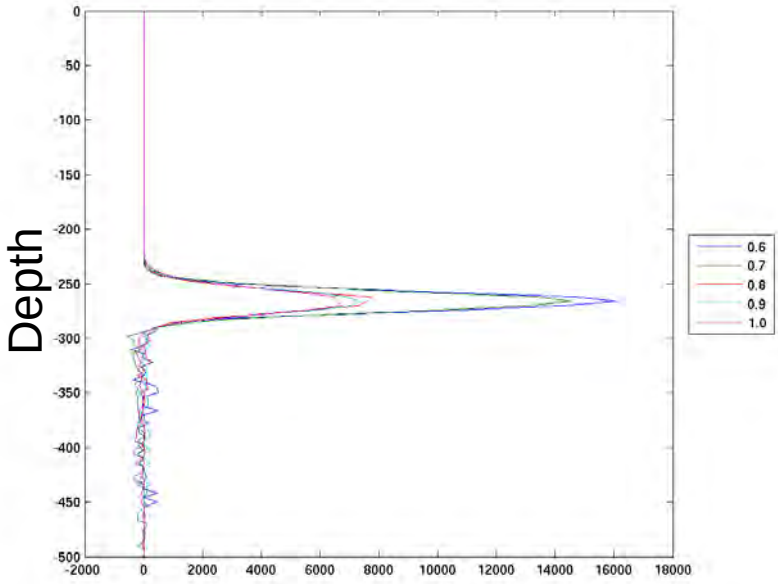
49.10

256.90 256.95

0.24 0.33

Velocity km/s

Depth sensitivity for periods 0.6 – 1.0s



Fast Marching Surface Wave Tomography
(Rawlinson et al., 2008)

Preliminary Tomography Results

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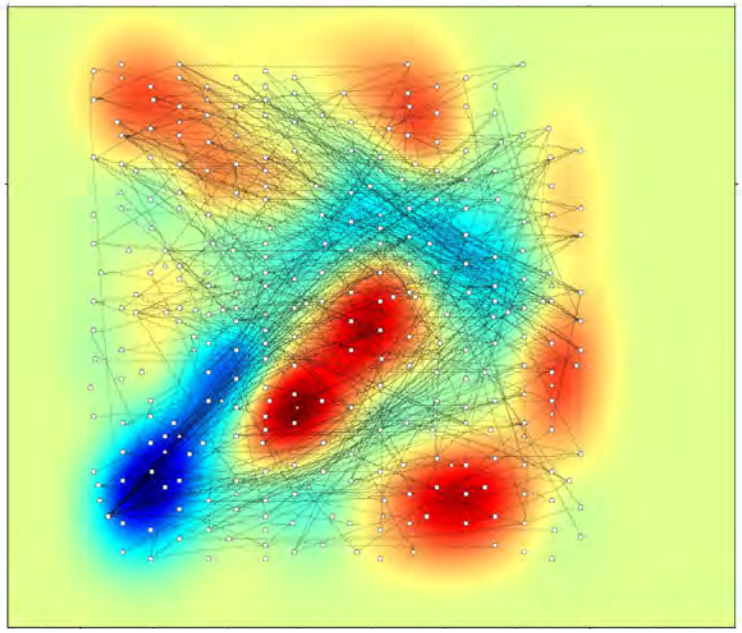
Rayleigh wave group velocity
0.7s period



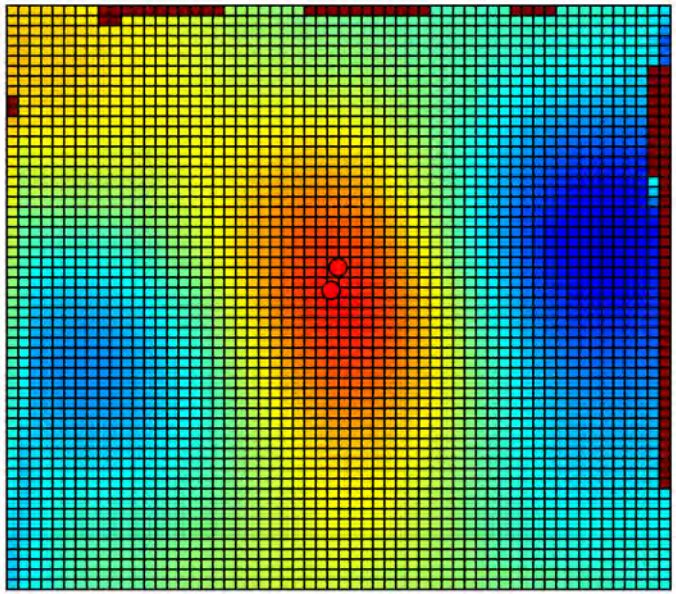
49.10

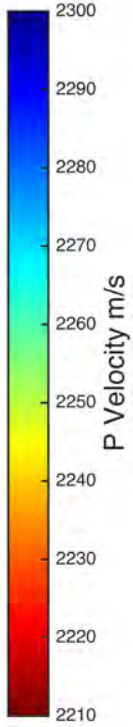
256.90 256.95

0.24 0.33

Velocity km/s

Depth 300 m

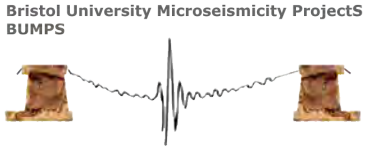




Aquistore – Summary

- Excellent baseline
  - Background seismicity
  - Near-surface characterisation
  - Allows time-lapse studies
- On-going array detection and location studies
- Broadband vs near-surface geophones vs downhole geophones vs fibre optic
- Similar geology to Weyburn – similar response?

Conclusions



- Large CCS sites exhibit differing microseismic responses.
  - Weyburn 100s seismic events up to M_W = -1.0
  - In Salah 1000s seismic events up to M_w~ 1.7
  - Aquistore?
- Baseline data is crucial to
  - Highlight any active structures;
  - Evaluate effect of injection.
  - In Salah – active fracture zone identified if earlier installation.
- Use passive seismic monitoring to
  - Calibrate geomechanical models;
  - Determine fracture characteristics;
  - Observe changes in seismicity, velocity, fracture characteristics.
- Conduct careful array design appropriate for purpose.

We thank the In Salah JIP, BP, Statoil and Sonatrach, for providing the microseismic data recorded at the In Salah site & for their permission to present this work.

We thank the PTRC for providing permission to work with and present the Weyburn and Aquistore microseismic data.

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