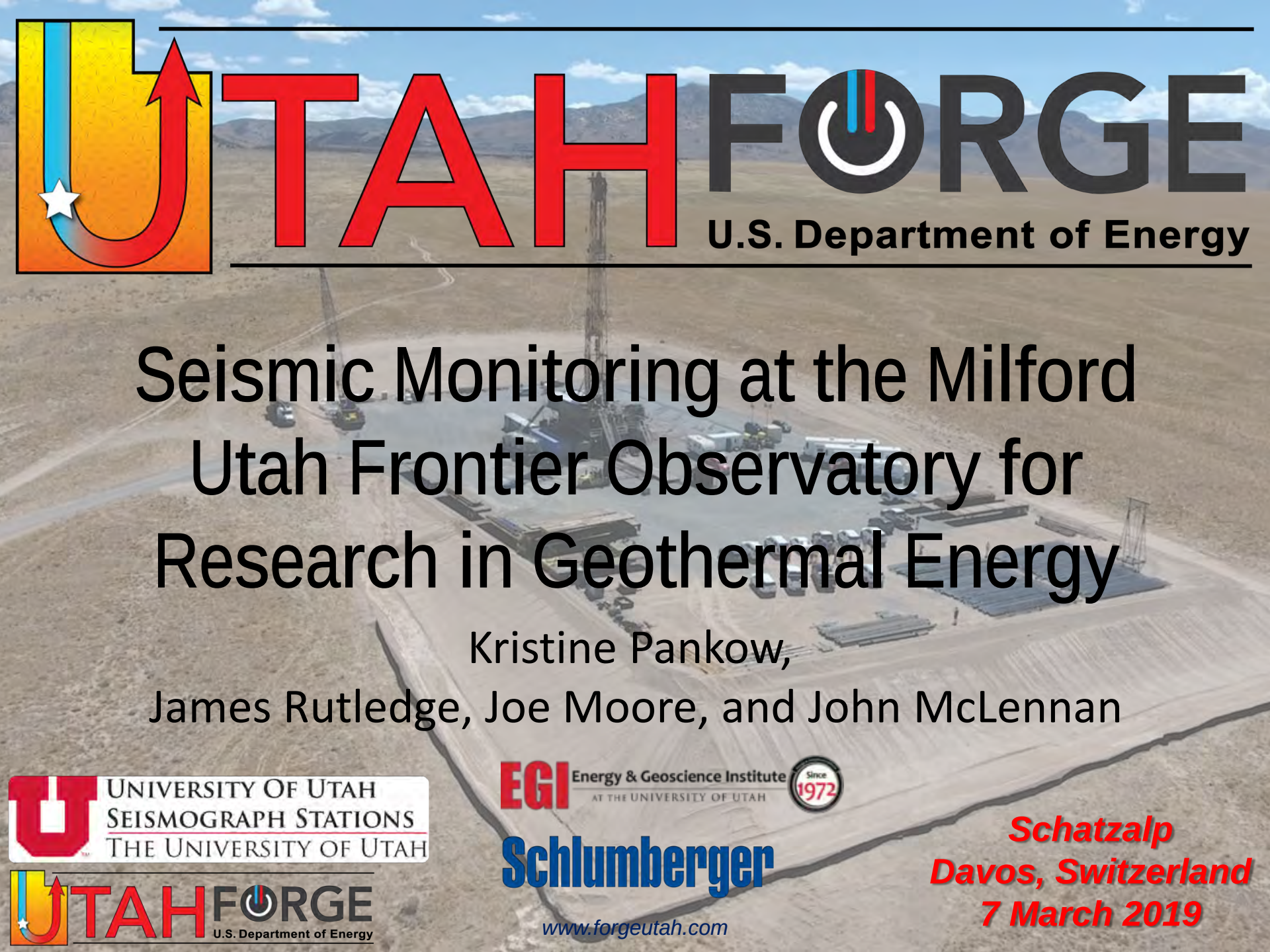


Seismic Monitoring at the Milford Utah Frontier Observatory for Research in Geothermal Energy

Kristine Pankow,
James Rutledge, Joe Moore, and John McLennan

University Of Utah Seismograph Stations
The University of Utah

EGI Energy & Geoscience Institute at the University of Utah Since 1972

Schlumberger

UTAH FORGE U.S. Department of Energy

www.forgeutah.com

Schatzalp
Davos, Switzerland
7 March 2019

FORGE
U.S. Department of Energy

Mission

FORGE's mission is to enable cutting-edge research and drilling and technology testing, as well as to allow scientists to identify a replicable, commercial pathway to EGS

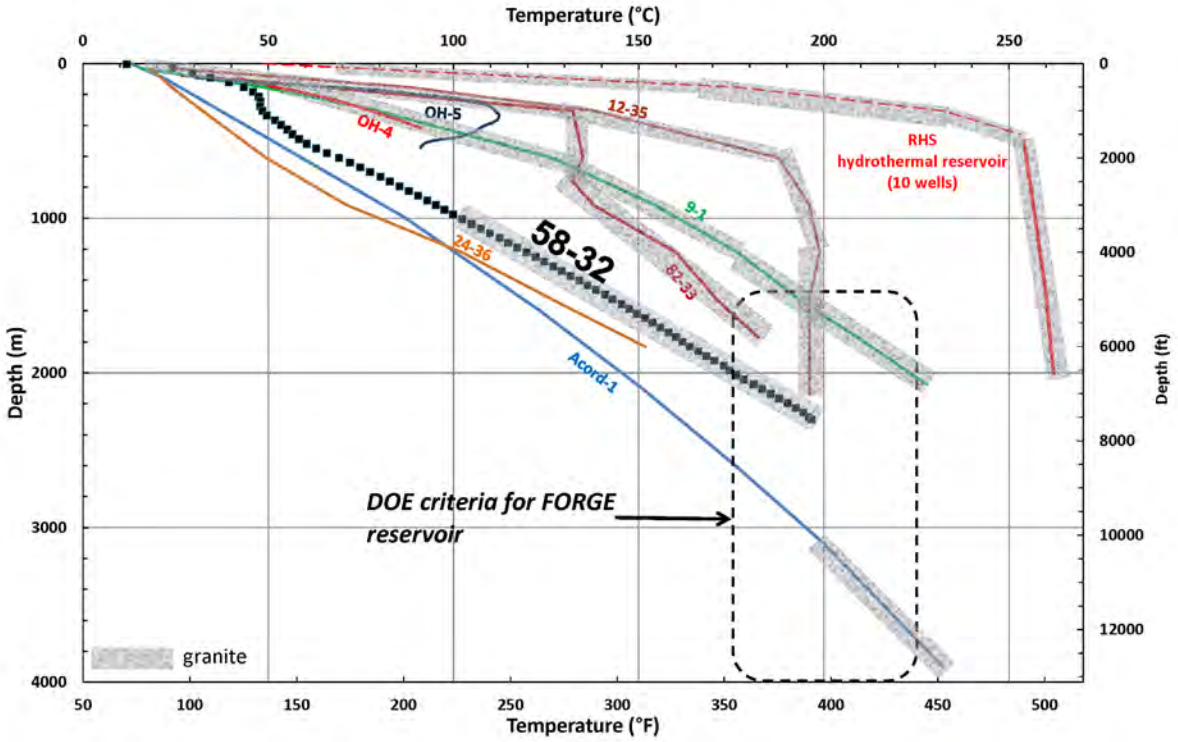
R&D Activities

All R&D activities at FORGE will focus on strengthening our understanding of the key mechanisms controlling EGS success--specifically, how to initiate and sustain fracture networks in basement rock formations.

First round of FOAs will be released in Fall 2019

DOE Mandated Direct Measurements in Test Well

- Temperature: 175° to 225°C at 1.5 to 4 km
- Lithology: crystalline (granitic) rocks with volume greater than 1 km^3
- Stress orientations and magnitudes
- Permeability and porosity



Confirmation of Required Temperatures and Depth

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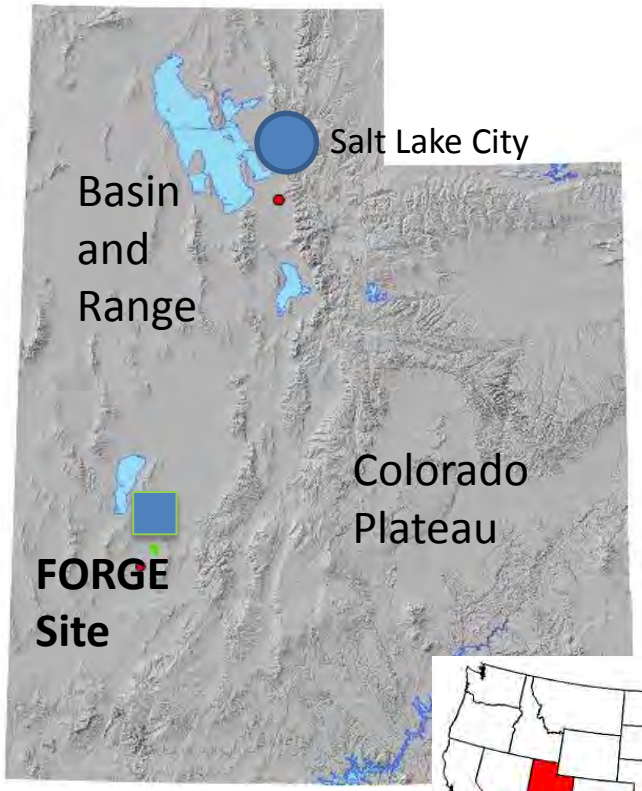
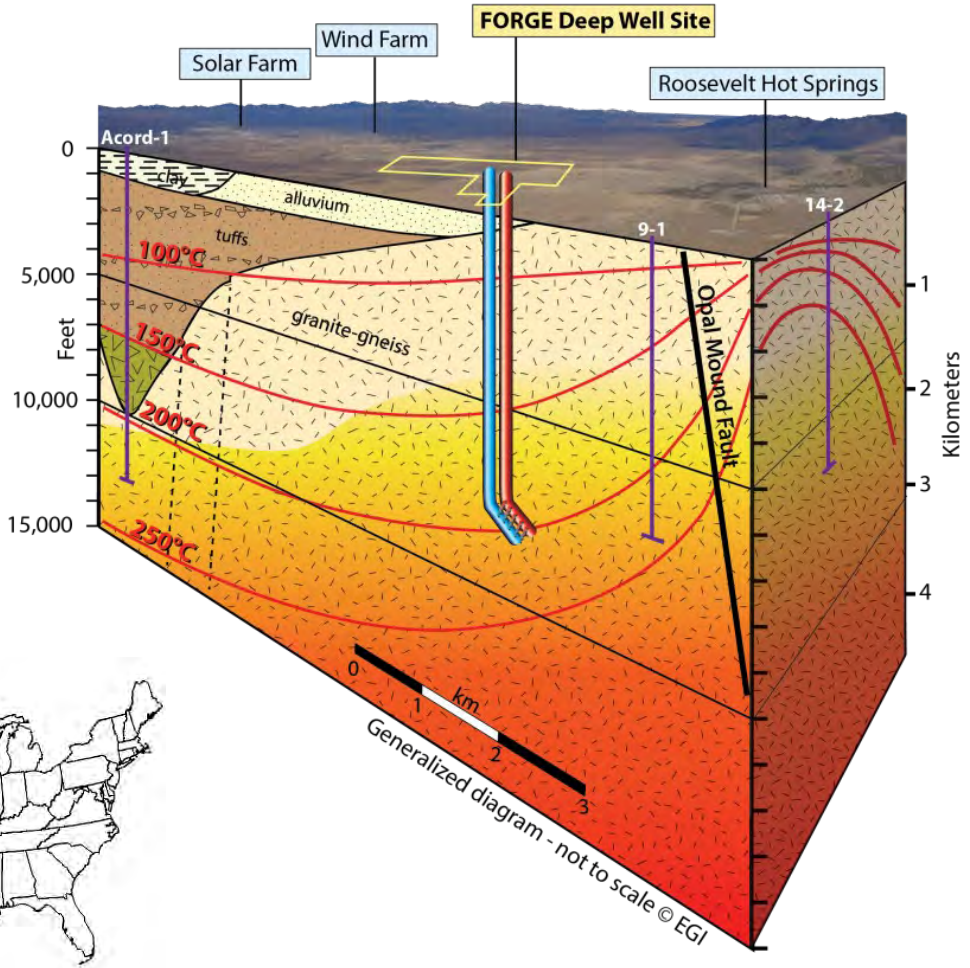
Milford Utah FORGE Site





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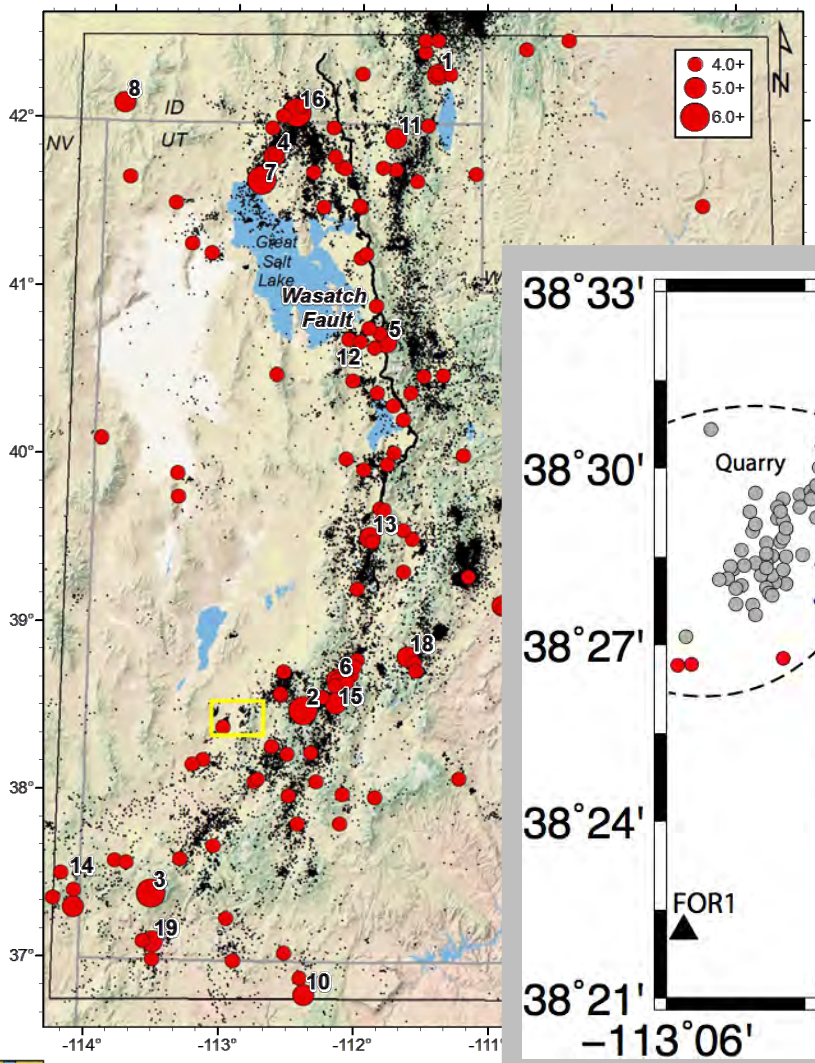
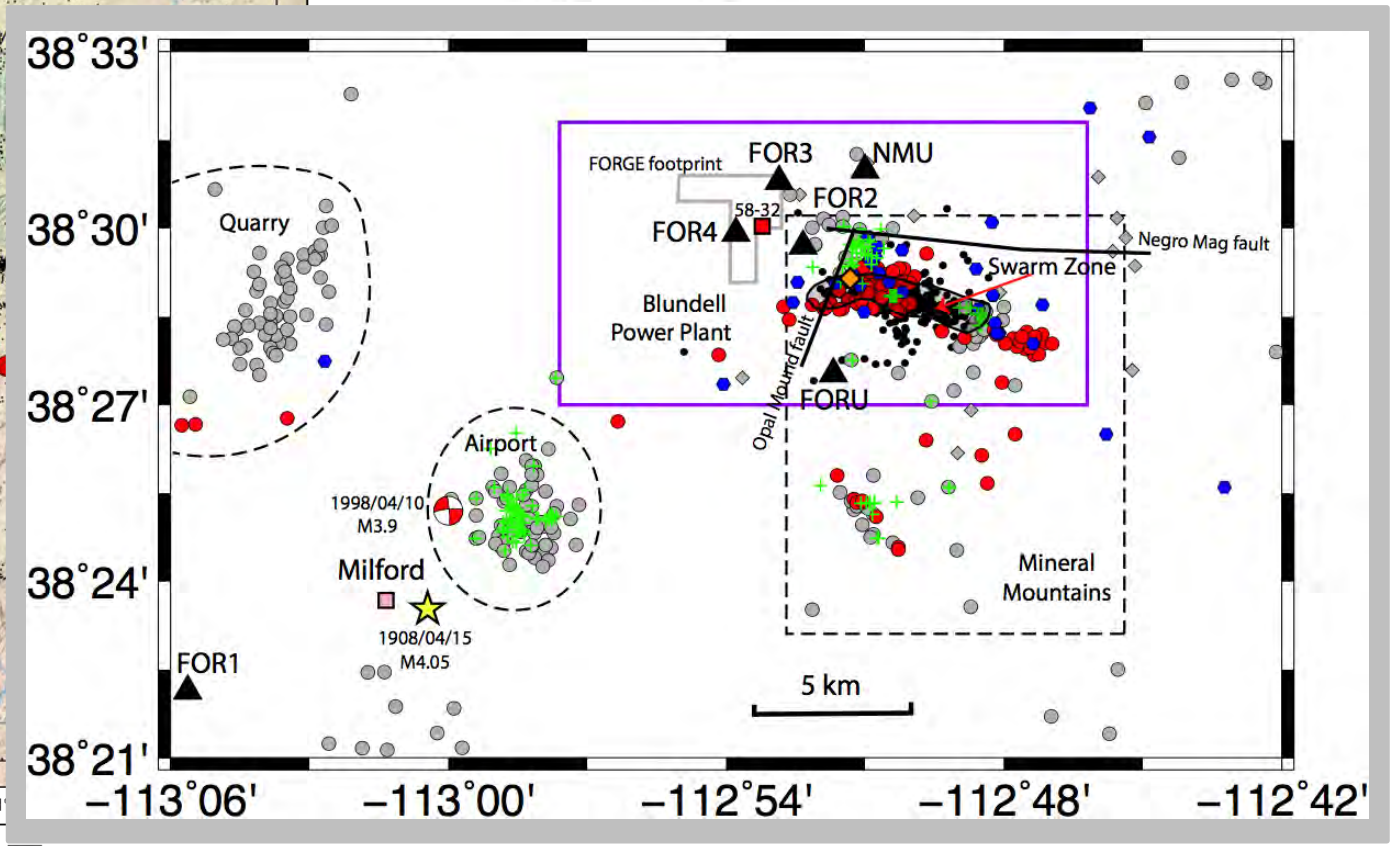
Summary of Seismicity





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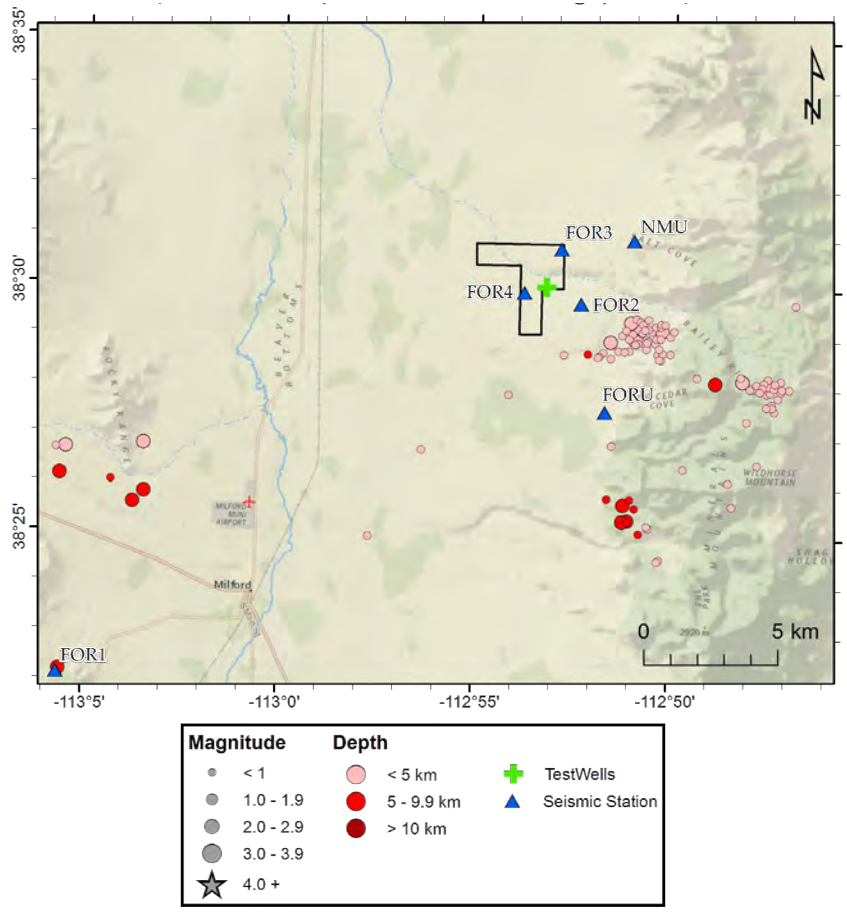
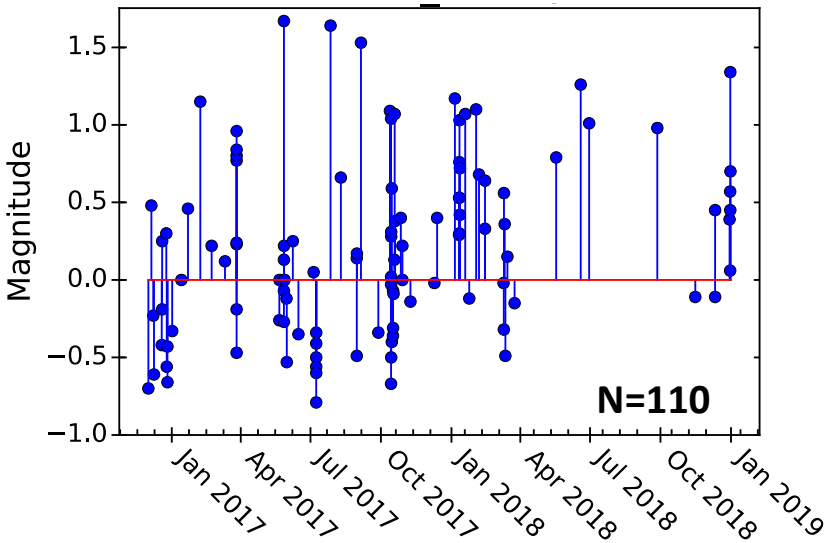
FORGE Seismic Monitoring

November 1, 2016 – December 31, 2018





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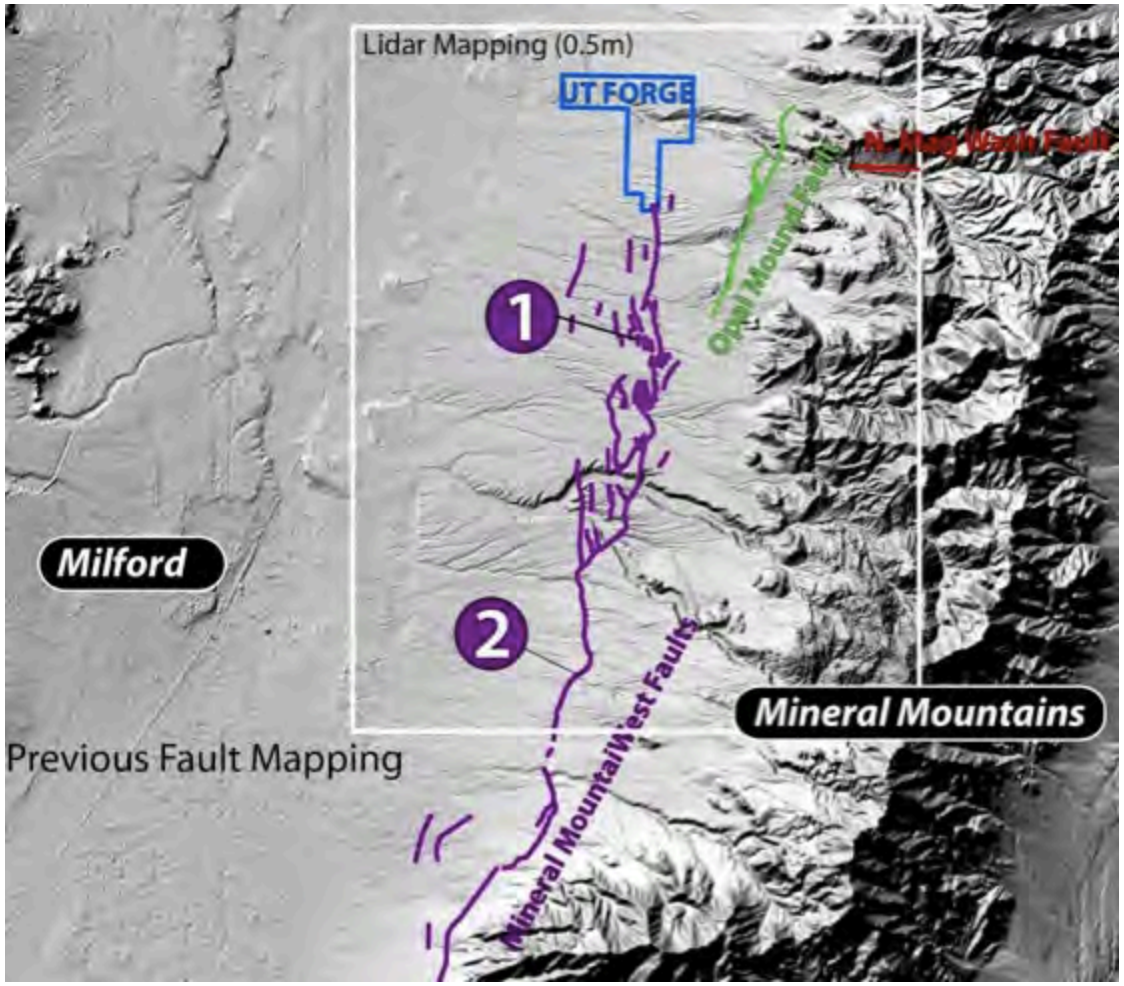
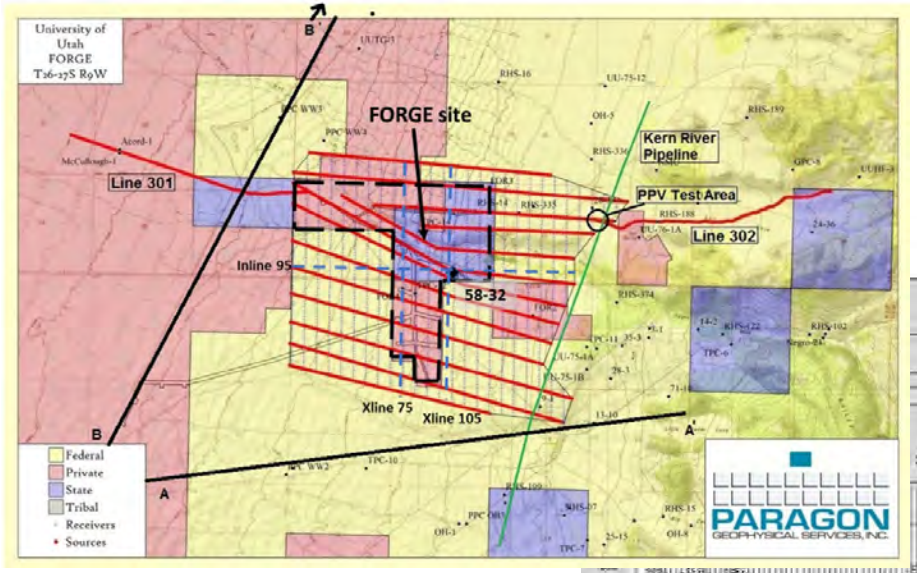
Faults

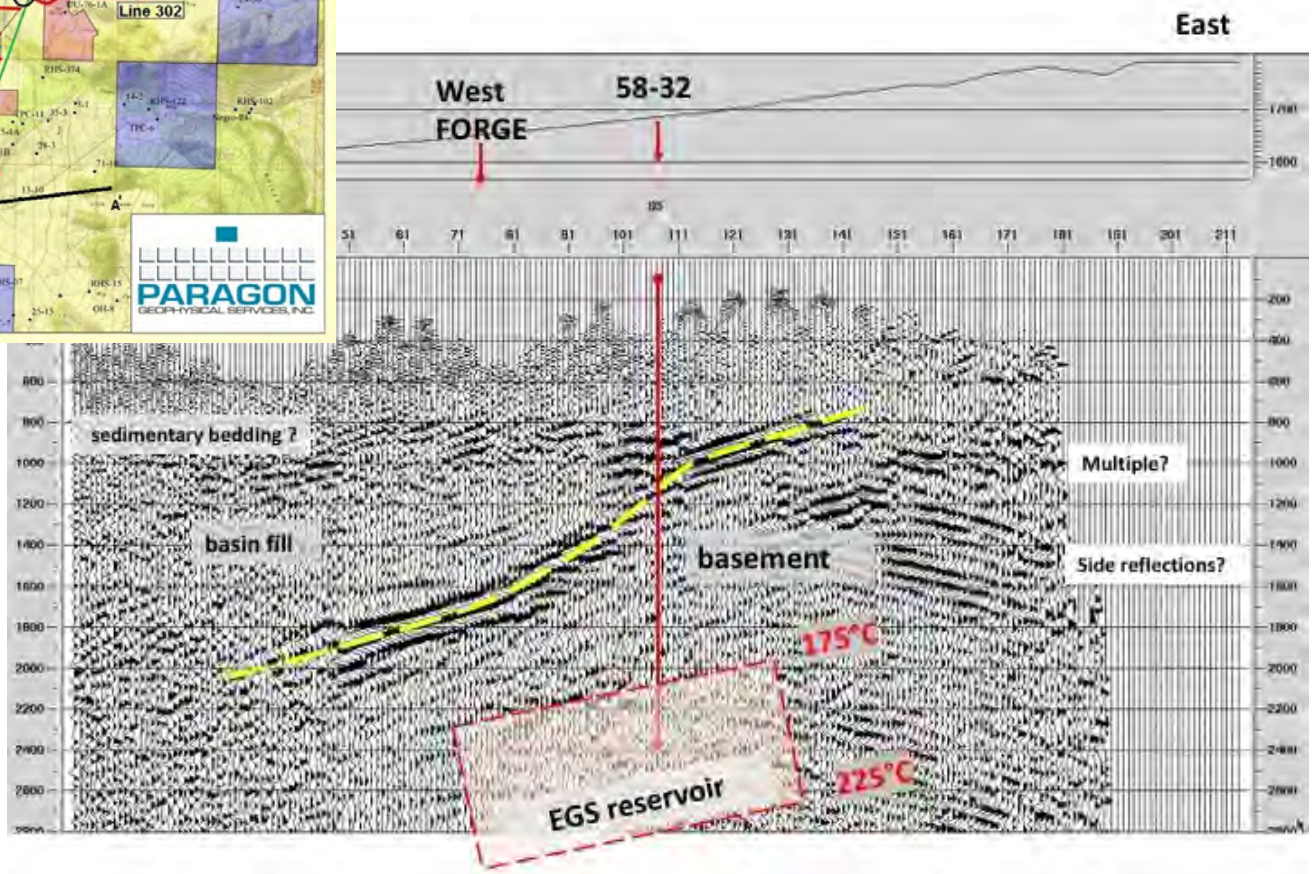


Kleber and Hiscock (2017)

- Top of basement defines a major detachment fault, accommodated >10 km Miocene extension
- Opal Mound fault small offset (<10 m?); subvertical; east-west flow barrier; thermal discharge
- Negro Mag fault small offset (<10 m?); E-W trending, subvertical
- Mineral Mountains West fault system, 3 km wide & 30 km long, but minor offsets (<5 m)
- Modern quiescent tectonic activity: basin profile, major fault scarps & faceted spurs are absent

New 2D and 3D Seismic Reflection





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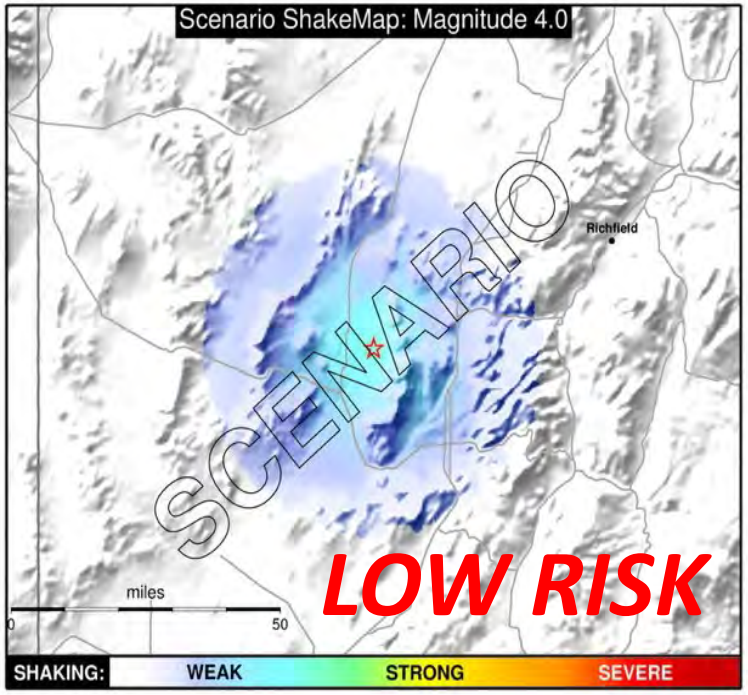
Potential Induced Seismic Events

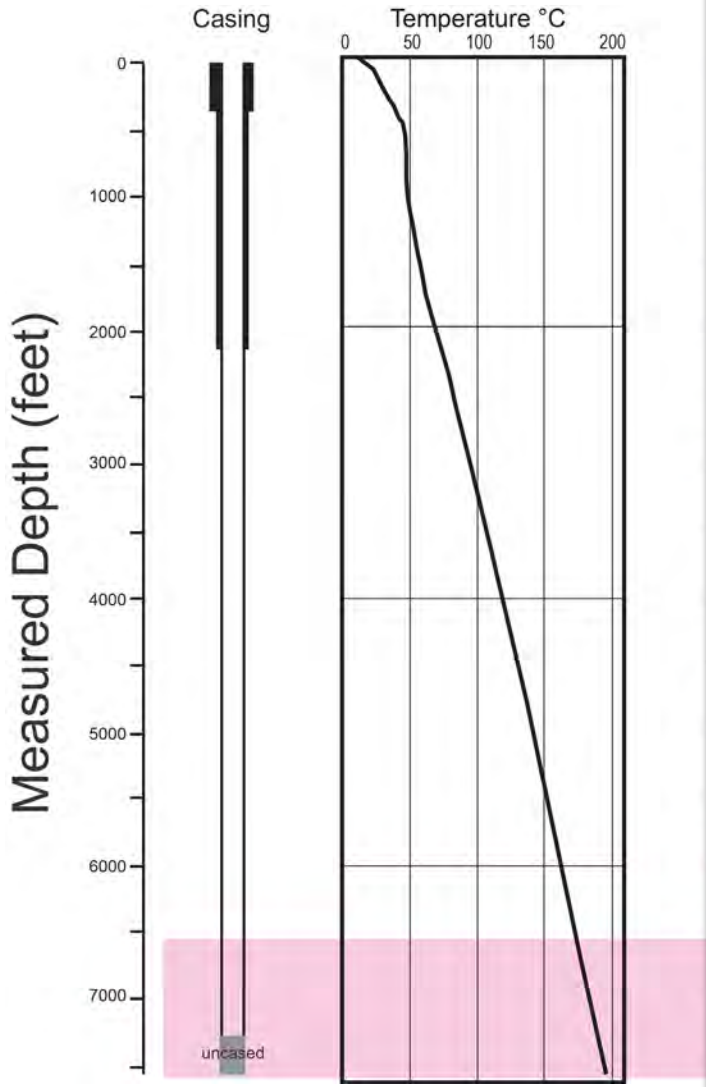
- Maximum Magnitudes
  - Schultz et al. (2018) hydraulic fracturing $M_{max} < 2$
  - McGarr (2014) total fluid injection volume M_{max} 3
- Key indicator for induced seismicity is a fluid pathway to basement faults



M 4.0 Earthquake

Max PGA	~3 %g
Max PGV	1.5 cm/s

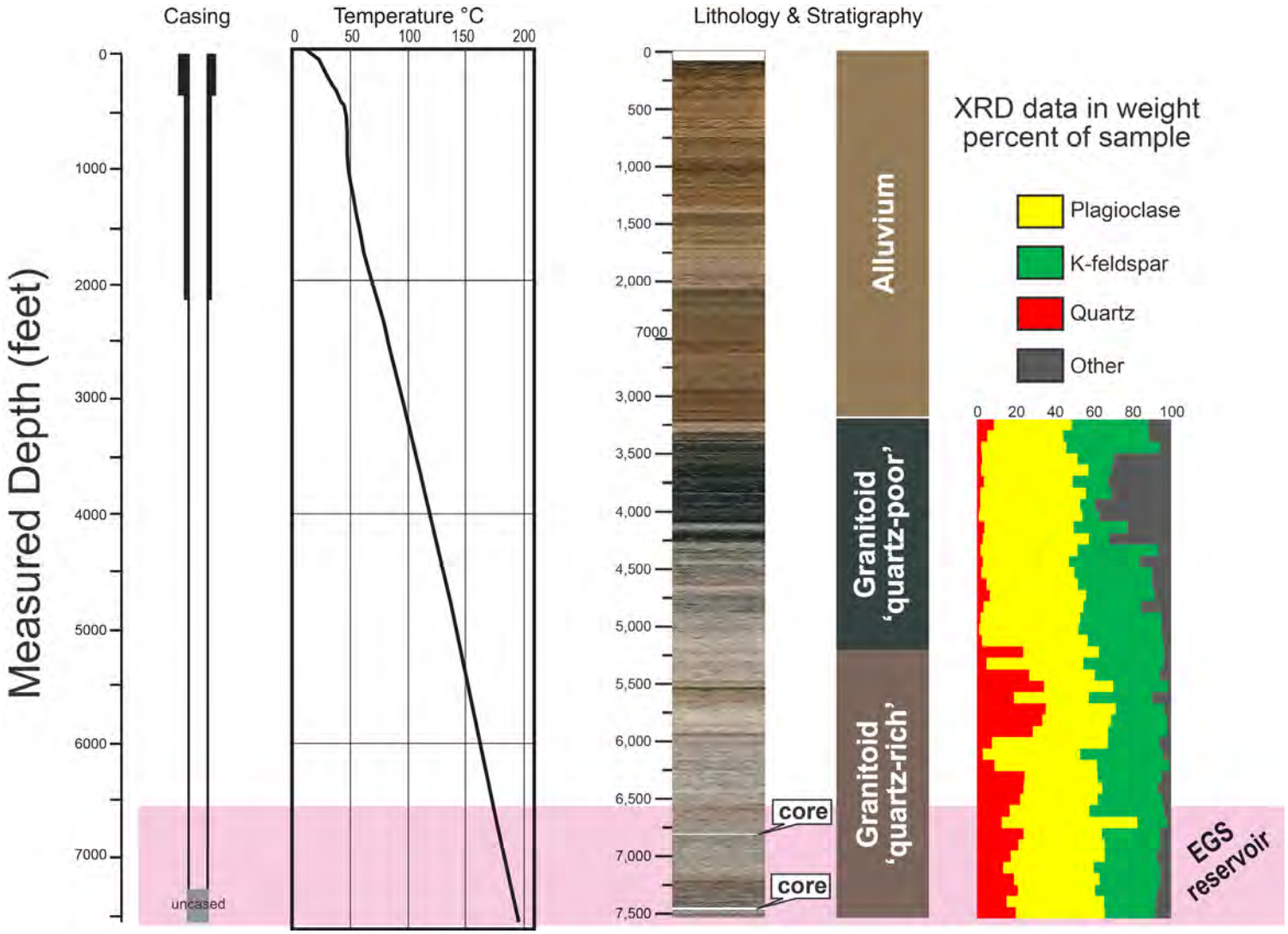
Current Project Phase



Stimulation Tests in Well 58-32

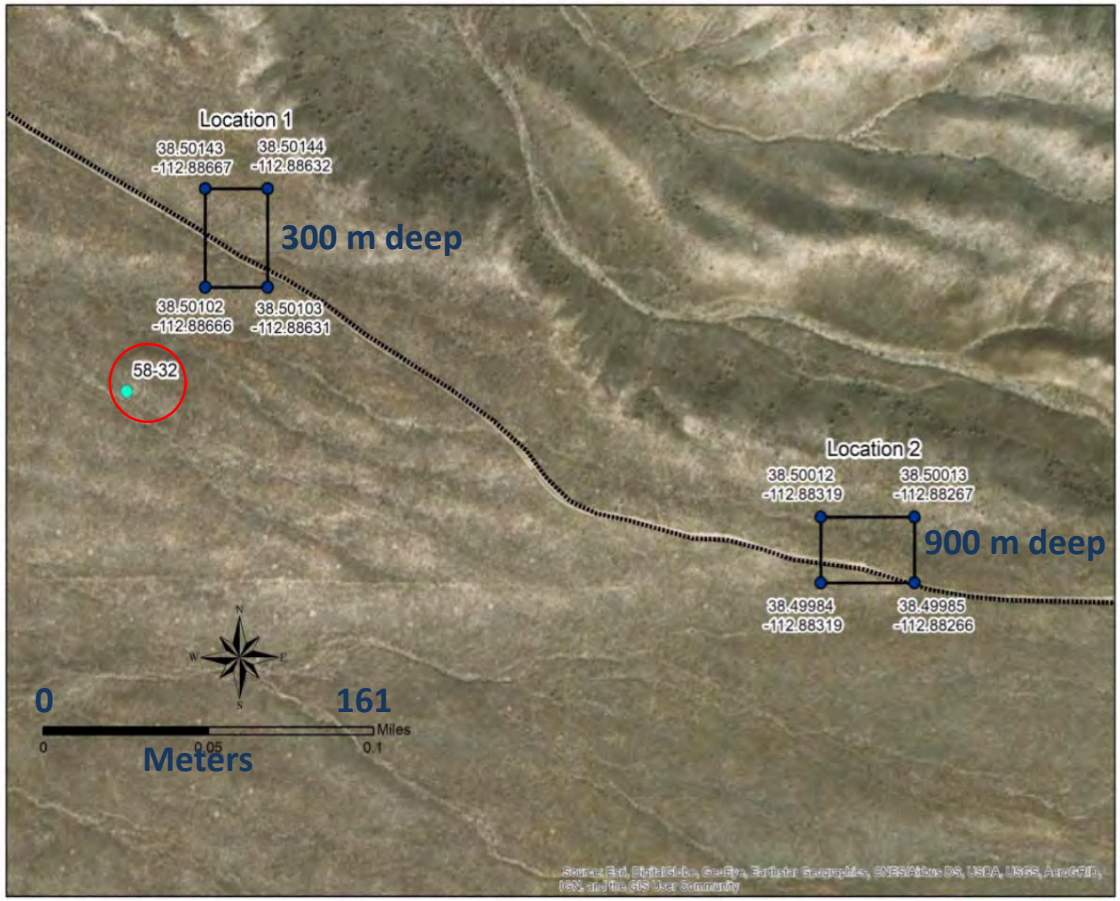
Cycle	Protocol for each zone - one openhole, two perforated	Time (hr)	Volume (bbl)
1	Increase pressure in 250 psi increments to 1000 psi and shut in (one hour with one hour shut-in, SI).	1	1
2	Pump at as low a rate as possible - e.g. 0.4± BPM - pump one to two bbl and SI (5 minutes pumping and one hour SI)	1.5	2
3	Repeat Cycle 2 at twice the rate (0.8± bpm) and SI (5 minutes pumping and one hour SI)	1.5	4
4	Carry out DFIT (diagnostic fracture injection test) - Pump 5 bbl at 5 bpm and shut-in (5 minutes pumping and 8 to 24 hours SI).	24	25
5	Repeat DFIT (diagnostic fracture injection test) but flow back rather than shut-in. Pump 5 bbl at 5 bpm and shut-in for 5 to 10 minutes (don't allow closure) and flow back to zero through ¼-in choke or similar (pump for 10 minutes, SI for ten minutes and flow back for two hours)	4	25
6	Repeat Cycle 2. Pump at as low a rate as possible - e.g. 0.4± BPM - pump one to two bbl and SI (5 minutes pumping and one hour SI)	1	2
7	Run an SRT (step rate test). Inject for one minute at each rate starting at 0.4 bpm and increase in 0.1 bpm increments up to 1 bpm and then increase in 0.2 to 0.5 bpm increments up to 5+ bpm. Run 5 increments of step down (progressive decrease in rate, used to calculate friction). Shut in and monitor for up to 8 hours. Flow back is possible	8	40
8	Inject at 8 to 10 bpm for 5 to 10 minutes (make decision on the fly). Shut-in for ten minutes and then flow back.	3	100
9	Inject at 15 bpm for 5 to 10 minutes and shut-in for 8 to 24 hours.	24	150
Repeat this at two zones that are perforated up hole.			

58-32 Temperature & Stratigraphy



Borehole Instrumentation Phase 1

Drilling 2 boreholes for seismic instrumentation



Instrumentation

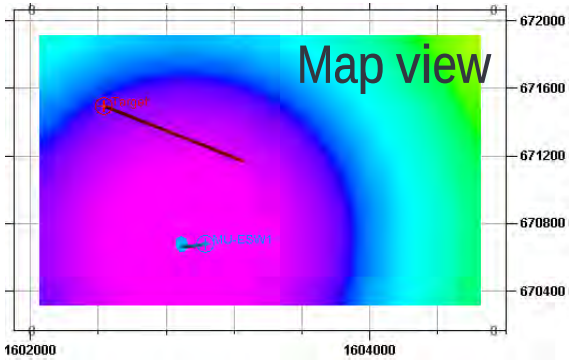
- Deep hole (Location 2):
  - Schlumberger 12 3C geophones, 15 m spacing
  - DAS cemented into annulus

- Shallow hole (Location 1):
  - 3C 15 Hz geophone (4 sensors/component)
  - 3C Silicon Audio broadband

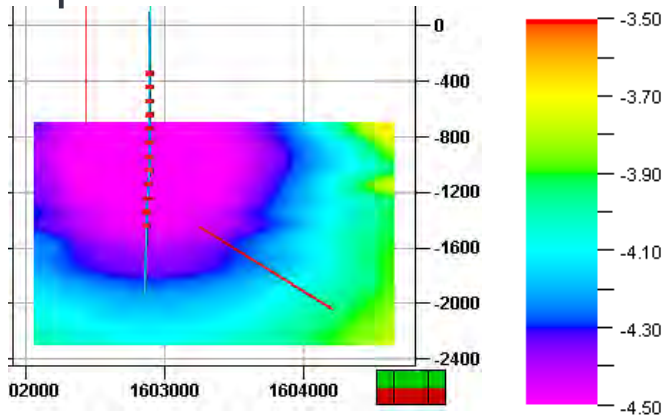
Example for Deep Wireline-Deployed System

Magnitude Detection

- Detect M ≧ -4



Depth view from south

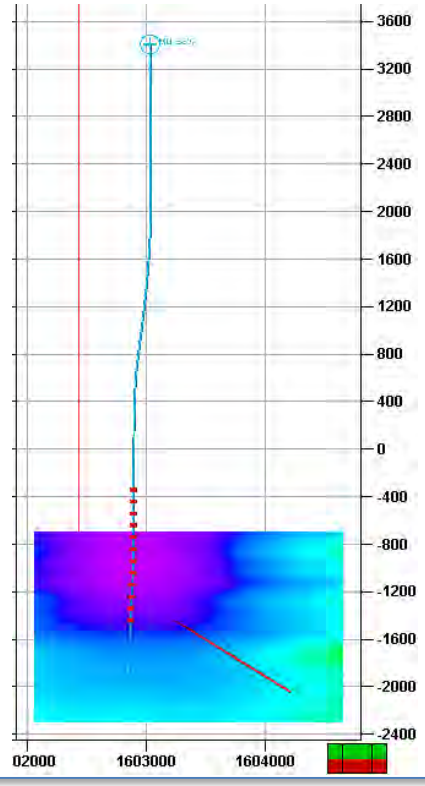


Location Accuracy (M -2)

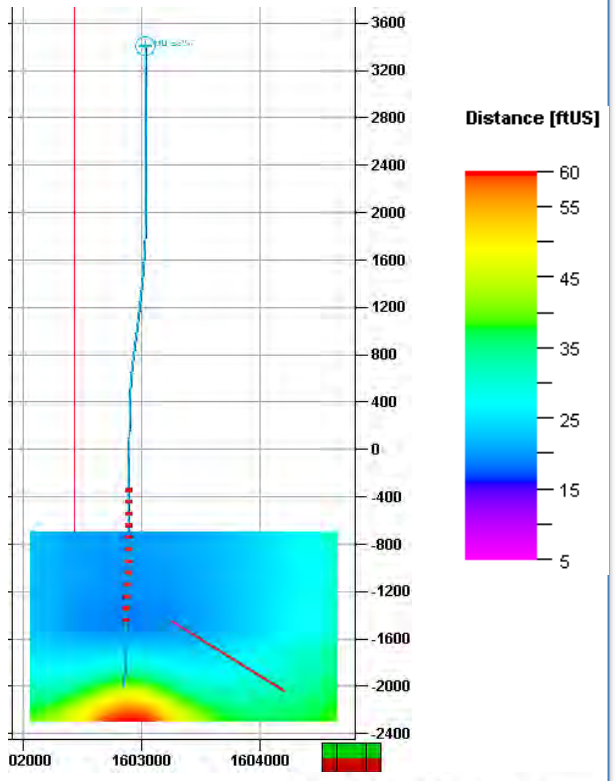
Vertical uncertainty 10-25’

Horizontal uncertainty 20-30’

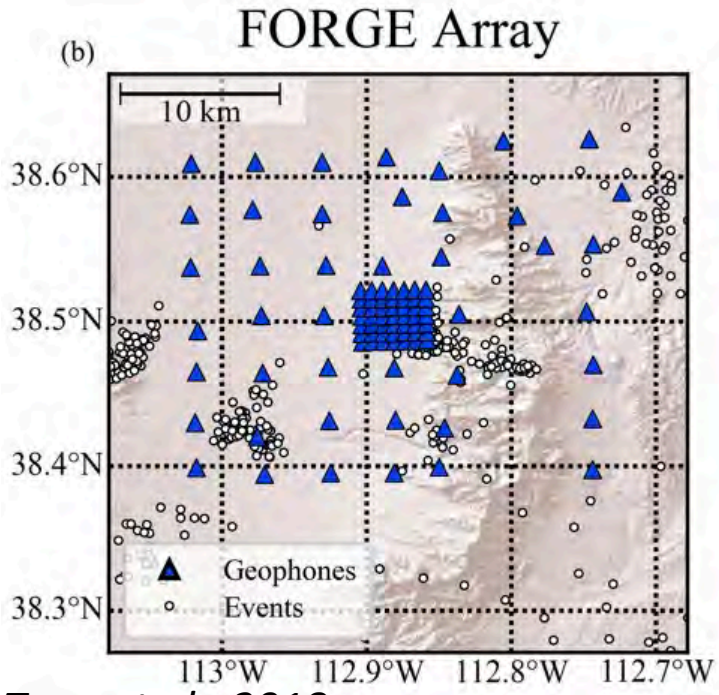
Vertical Uncertainty



Horizontal Uncertainty



Additional Seismic Monitoring



Trow et al., 2018

Experiments

2016 100 Nodes, 600 m spacing and ~4.5 km spacing

2017 49 Nodes, 600 m spacing

2019 150 Nodes varied geometry

Questions?