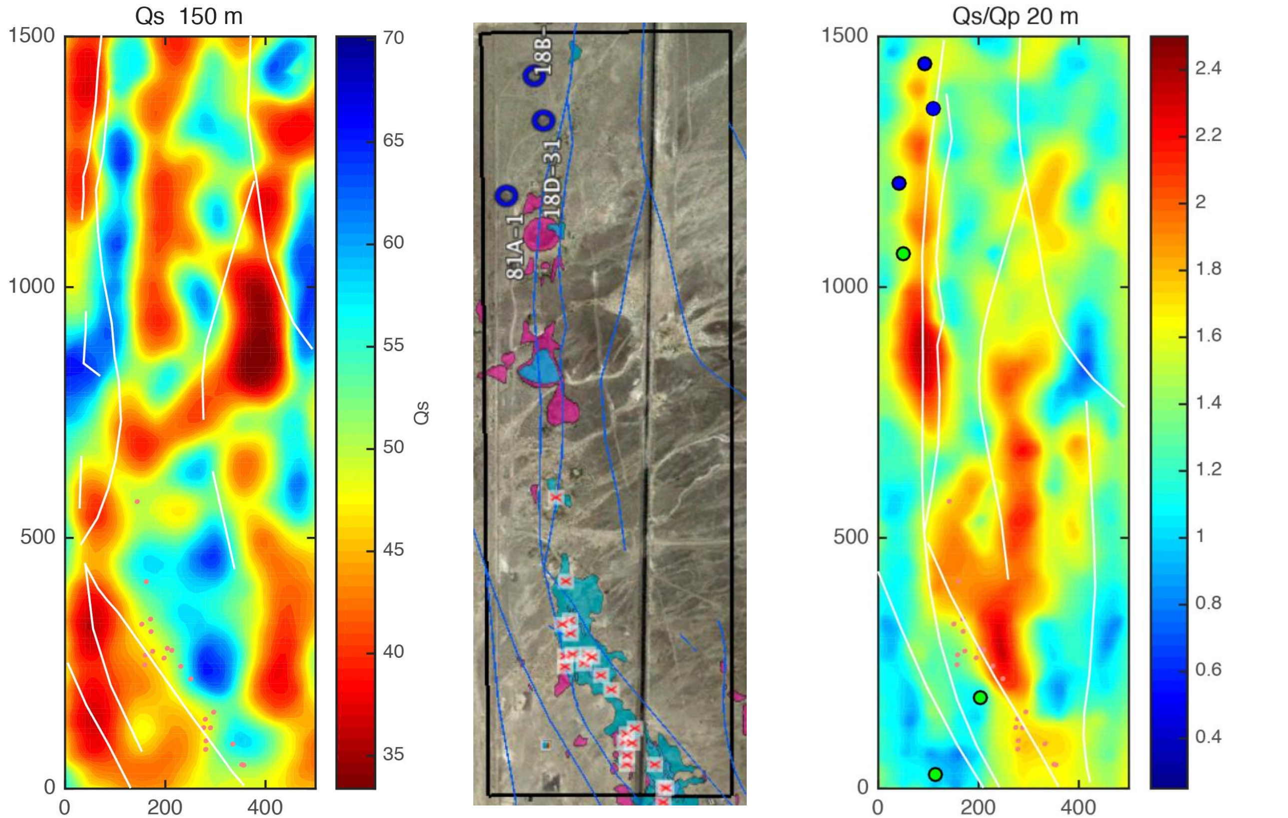
Imaging Seismic Attenuation at the Brady Geothermal Field Using Interferometry

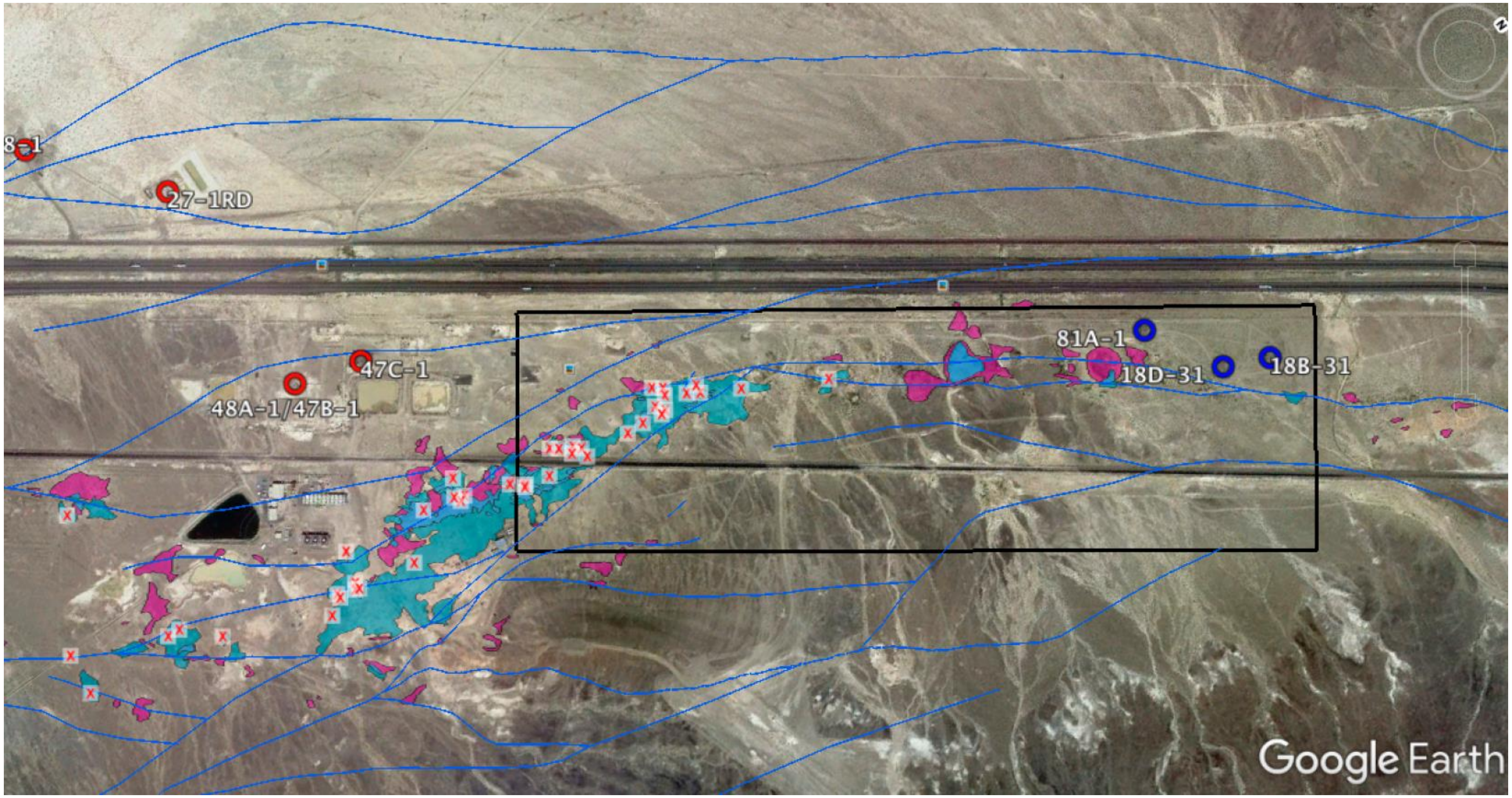
Eric Matzel, Christina Morency, Kurt Feigl, Clifford Thurber and the PoroTomo team



This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. The PoroTomo project was funded in part by the Office of Energy Efficiency and Renewable Energy (EERE), U.S. Department of Energy, under Award Numbers DE-EE0006760 and DE-EE0005510.

The PoroTomo "Natural Lab"

1500-by-500 meter natural laboratory at the Brady EGS field

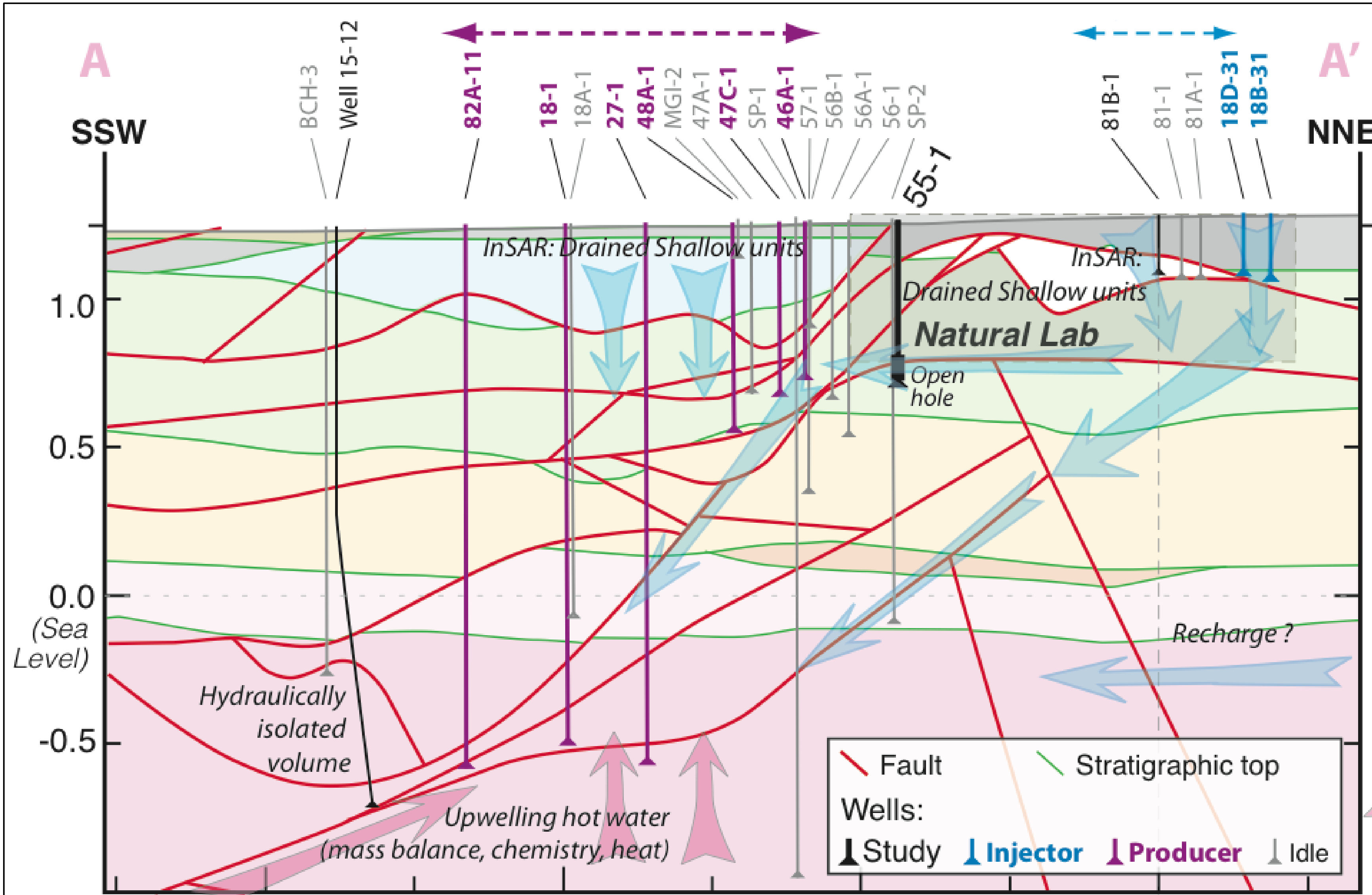


geologic obstacles by Coolbaugh

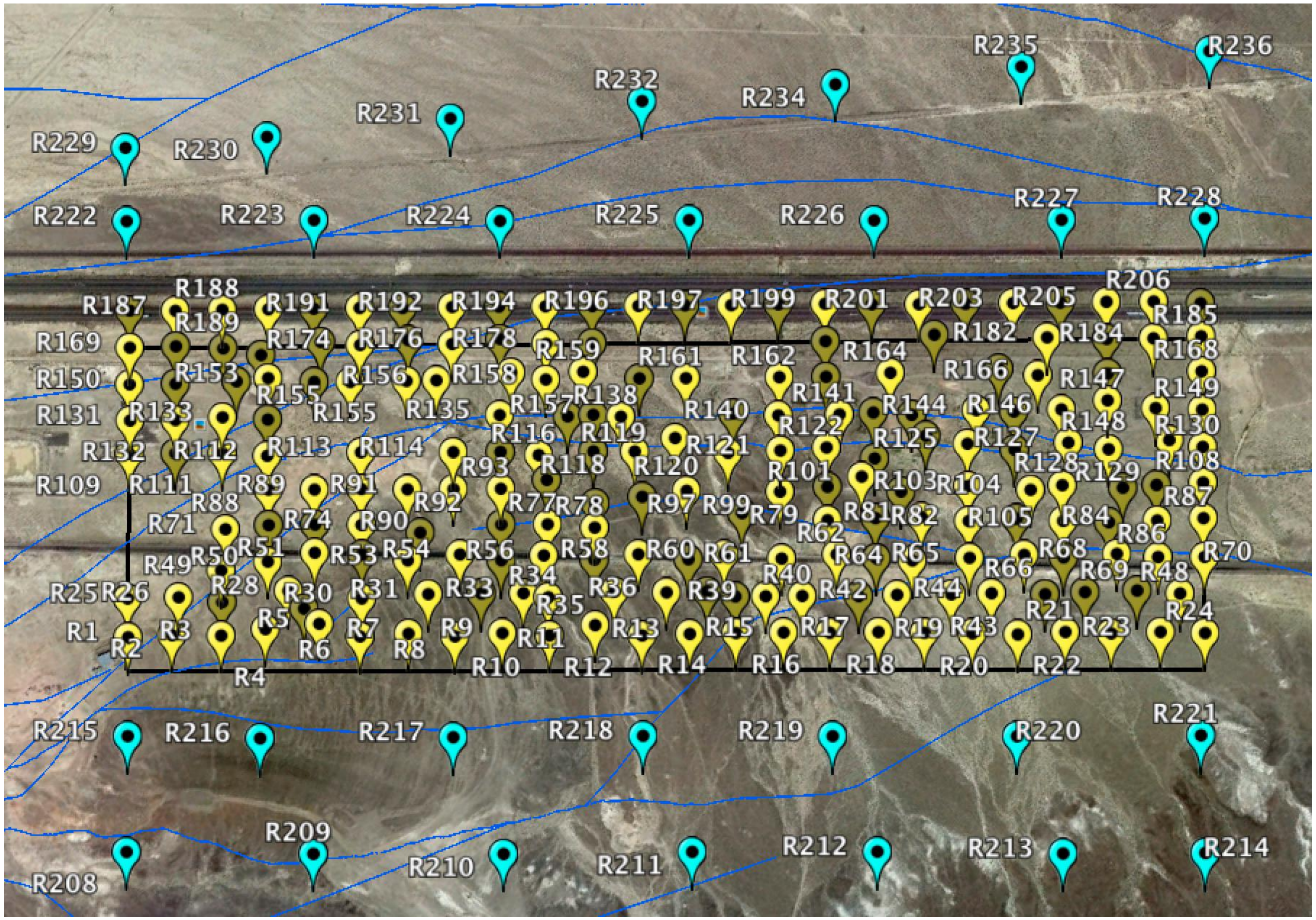
Key goal: understand how fluids travel from shallow aquifers, through faults and fractures, to deep geothermal reservoirs.

Seismic, geodetic, and hydraulic technologies are applied to fully characterize the rock mechanical properties.

Conceptual model: Highly permeable conduits along faults channel fluids from shallow aquifers to the deep geothermal reservoir tapped by the production wells.



A large seismic array was deployed over the geothermal field.

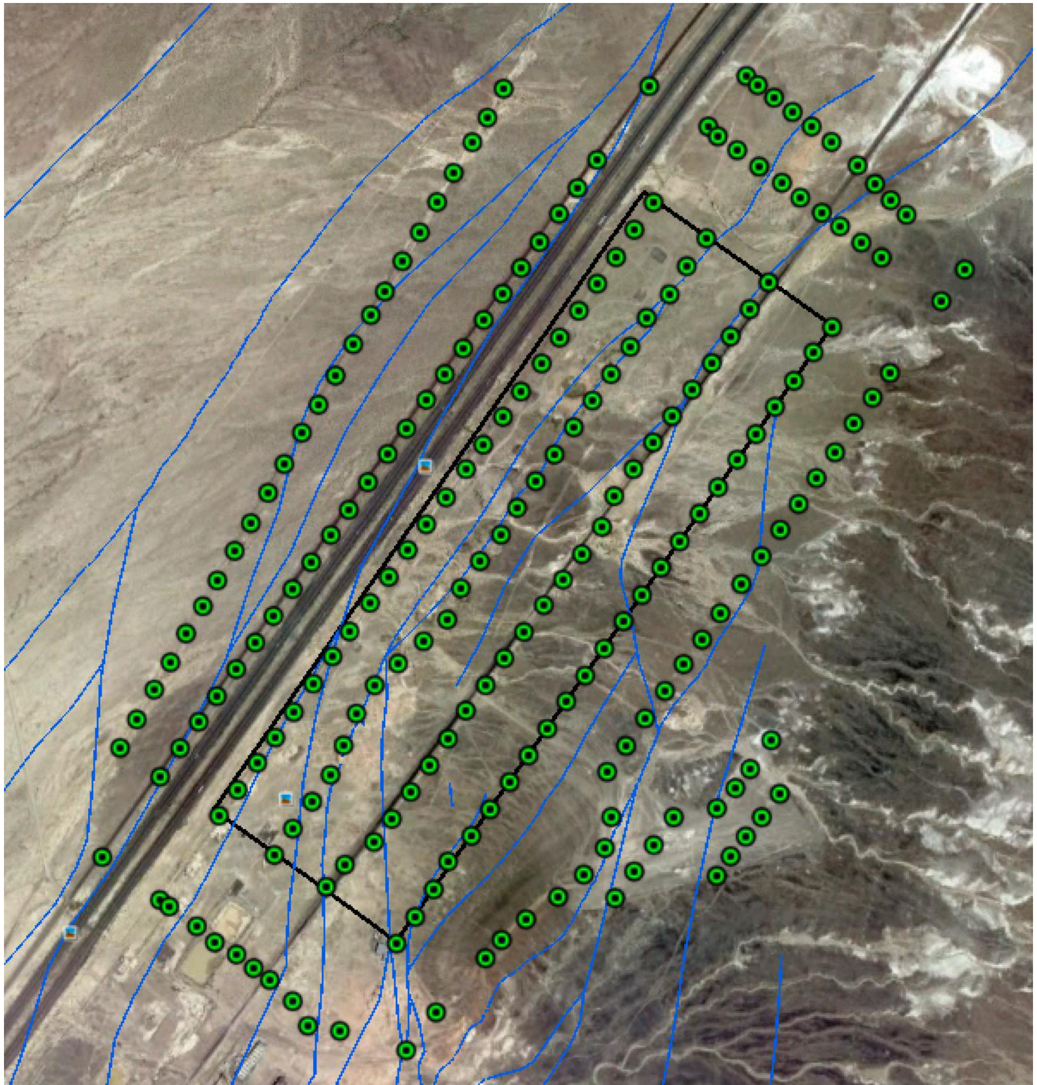


geophones (yellow in lab, cyan external to lab)

238 nodes recorded more than two weeks of continuous data

- local and regional earthquakes, vibroseis sweeps, local traffic noise, and the ambient seismic wavefield.

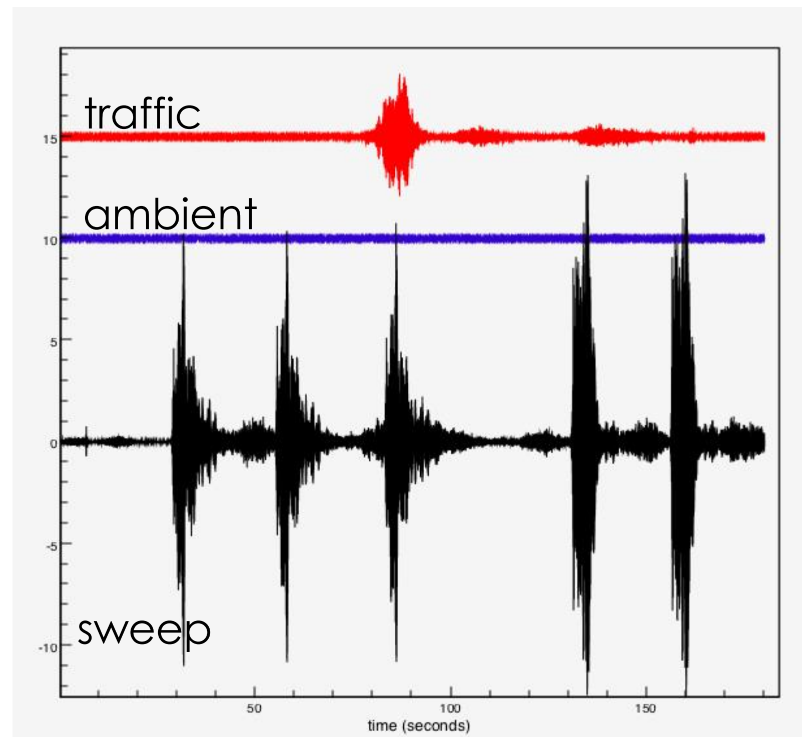
“Virtual Earthquakes”: sources of seismic energy



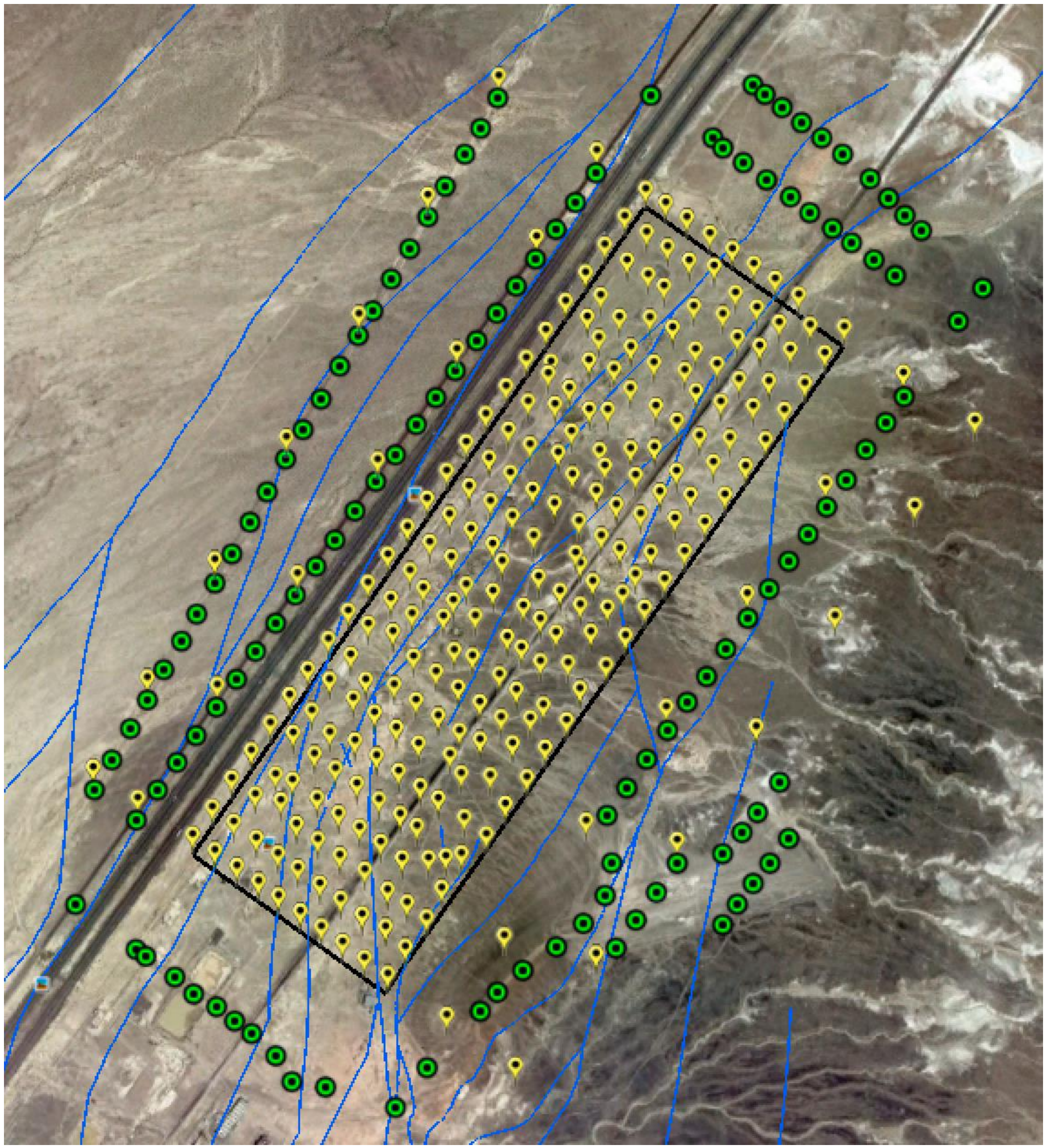
vibroseis points (green). Highway I-80 parallel to natural lab.
geologic obstacles from Coolbaugh, faults from Faulds

Types of data:
ambient noise, coda, active sources

- Focus – structure between seismometers
- Simple estimate of the GF
- Perfect location and timing constraints



Using Vibroseis Sweeps as a source of coherent energy

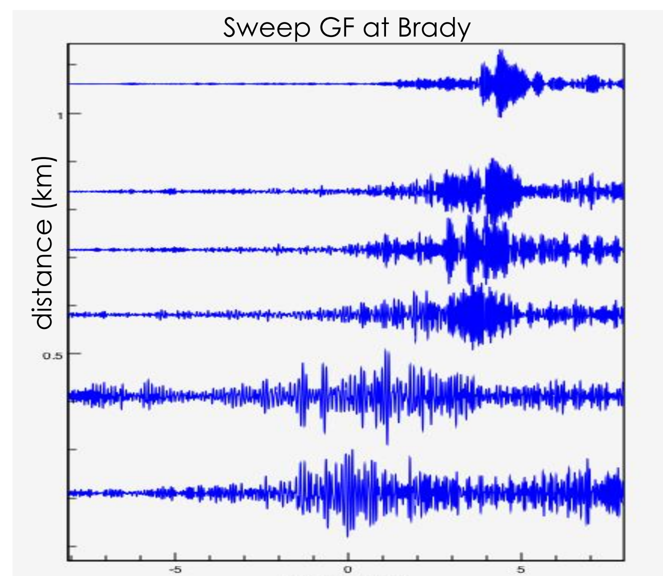


vibroseis points (green), geophones (yellow)
geologic obstacles from Coolbaugh, faults from Faulds

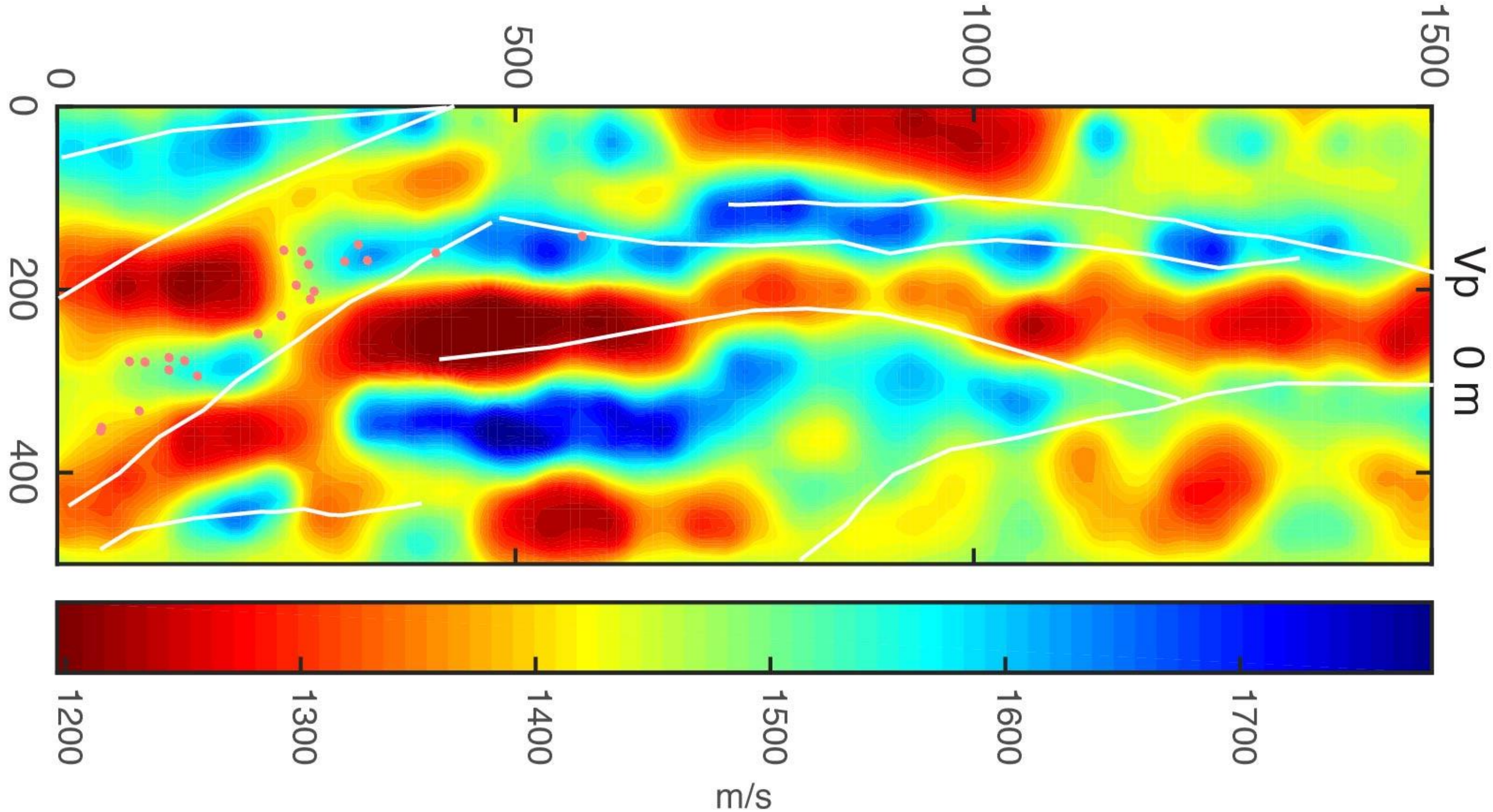
Vibroseis sweeps at points surrounding the site during the experiment.

Only short records of the active sweeps are required to estimate high frequency GFs (up to 30 Hz).

Computationally much less expensive than ANC.



We see large lateral heterogeneity in seismic velocity



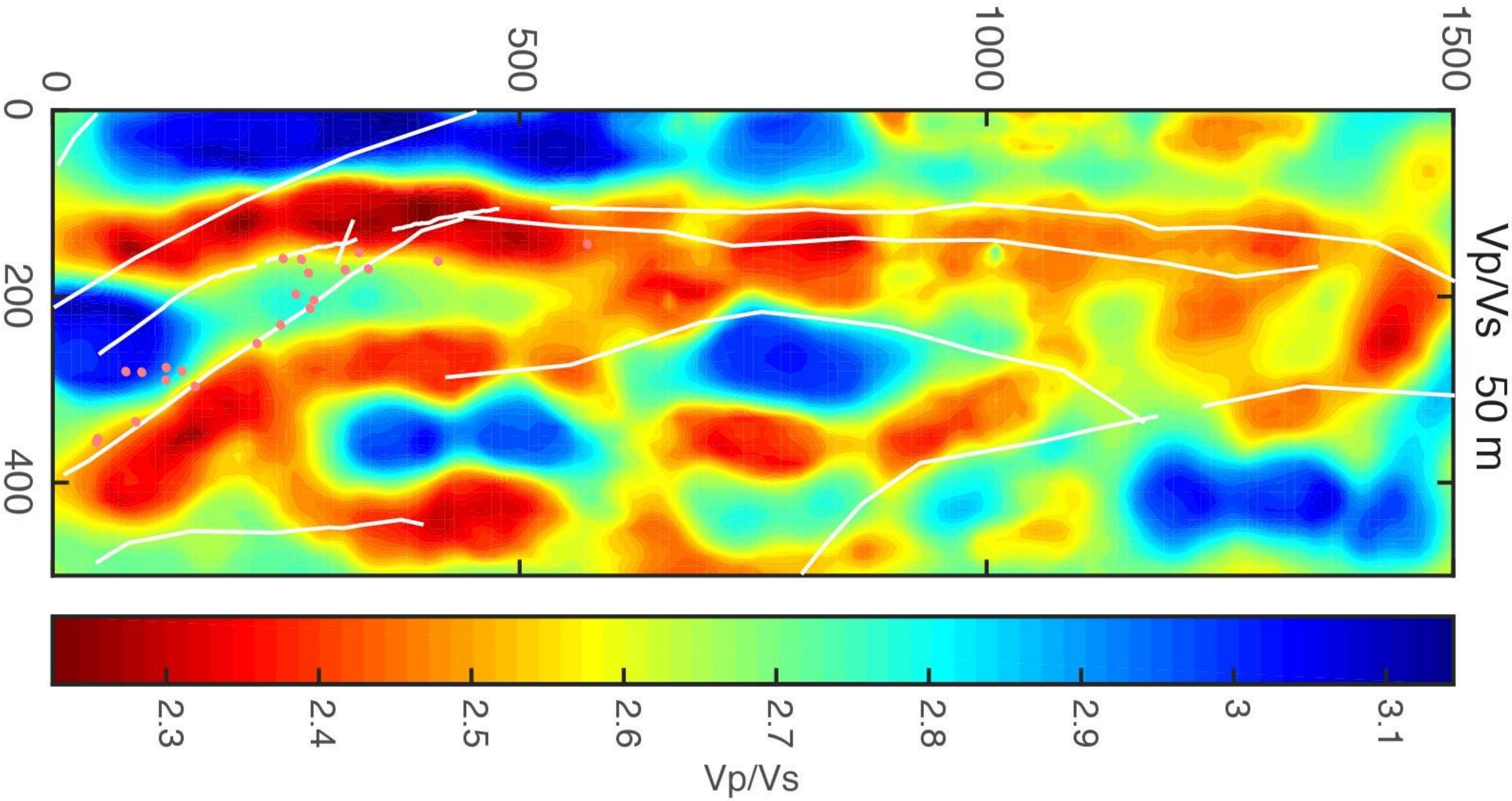
Vp (surface)

surface expression of faults in white, fumaroles (orange circles)

geologic obstacles from Coolbaugh, faults from Faulds

- Inverted for Vp, Vs, Qs, Qp
- At the surface Vp varies by more than 50%.
- Anomalies align with mapped hotspots and faults.

Vp/Vs contrasts appear to map subsurface fabric



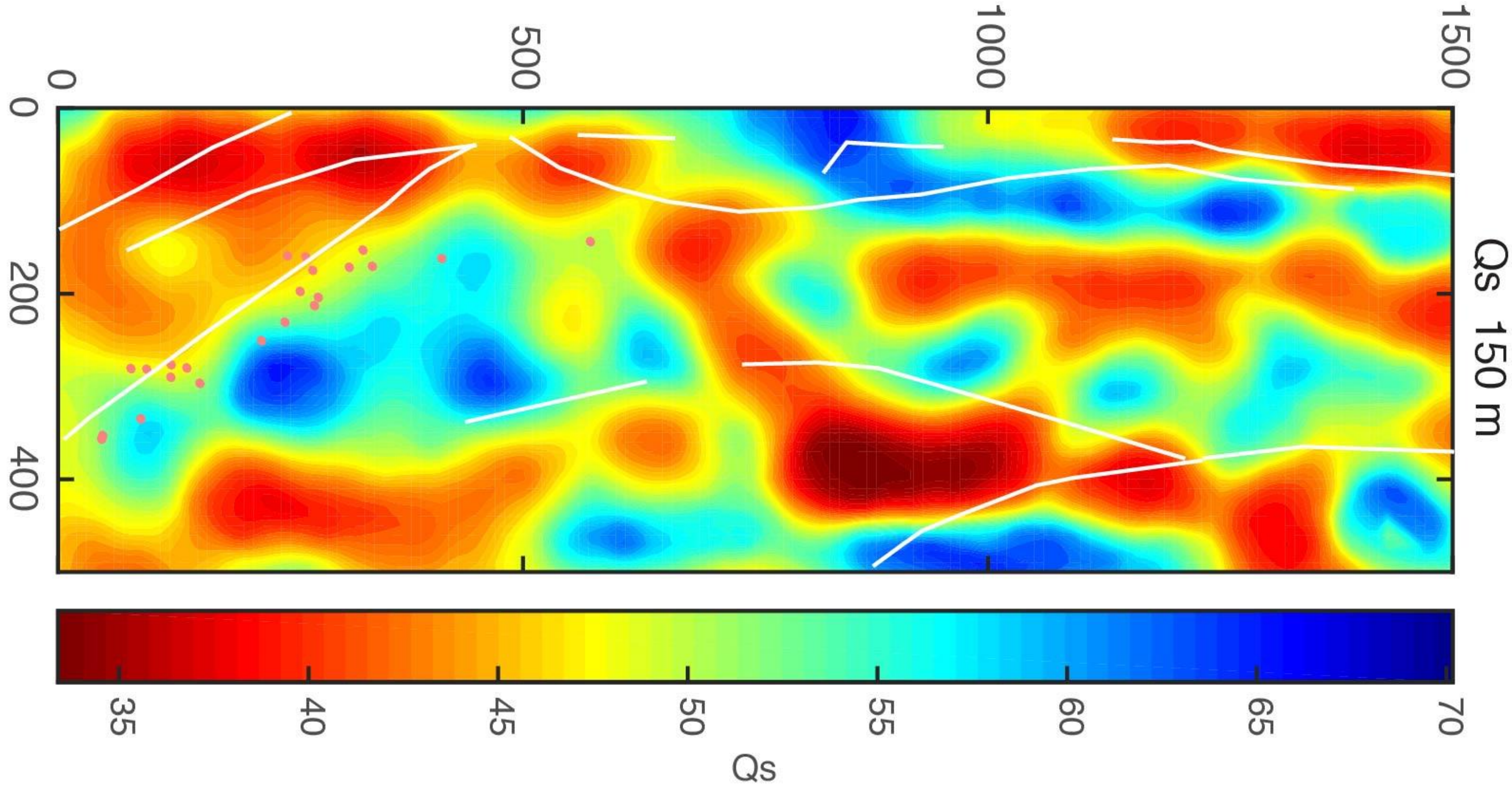
Vp/Vs (50 m)

50 m depth of faults in white, fumaroles (orange circles)

geologic obstacles from Coolbaugh, faults from Faulds

- Inverted for Vp, Vs, Qs, Qp
- Max Vp/Vs decreases rapidly with depth in the top 100 m.
- Surface Vp/Vs varies between 3.5-7.

Attenuation of seismic energy increases in regions that are hot or heavily fractured.



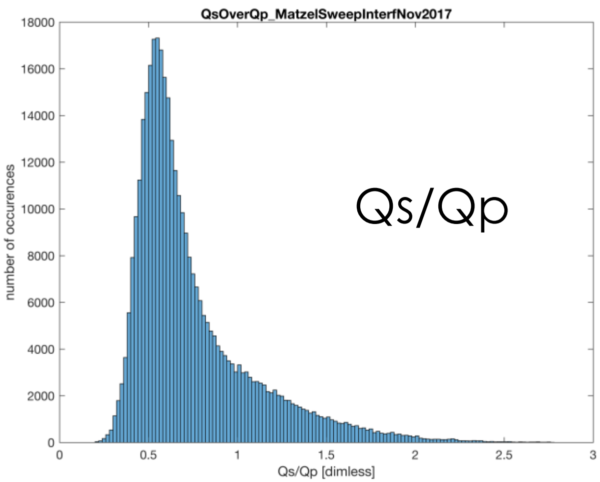
Qs (150 m)

150 m depth of faults in white, fumaroles (orange circles)

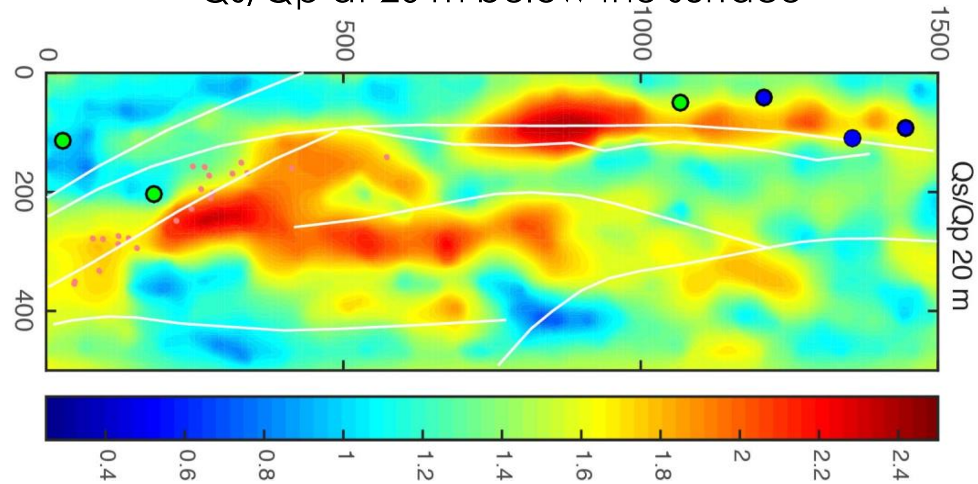
geologic obstacles from Coolbaugh, faults from Faulds

- Inverted for Vp, Vs, Qs, Qp
- Each has different sensitivity to material properties (temperature, porosity, fluid content and composition.)

Qs and Qp have different sensitivity to fluid saturation

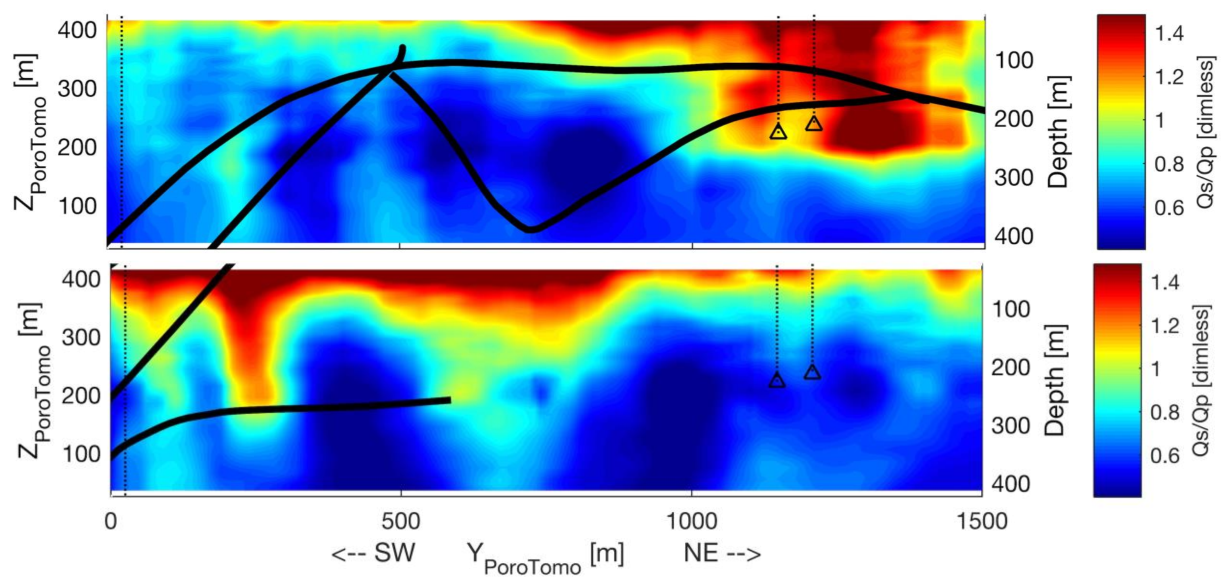


Qs/Qp at 20 m below the surface

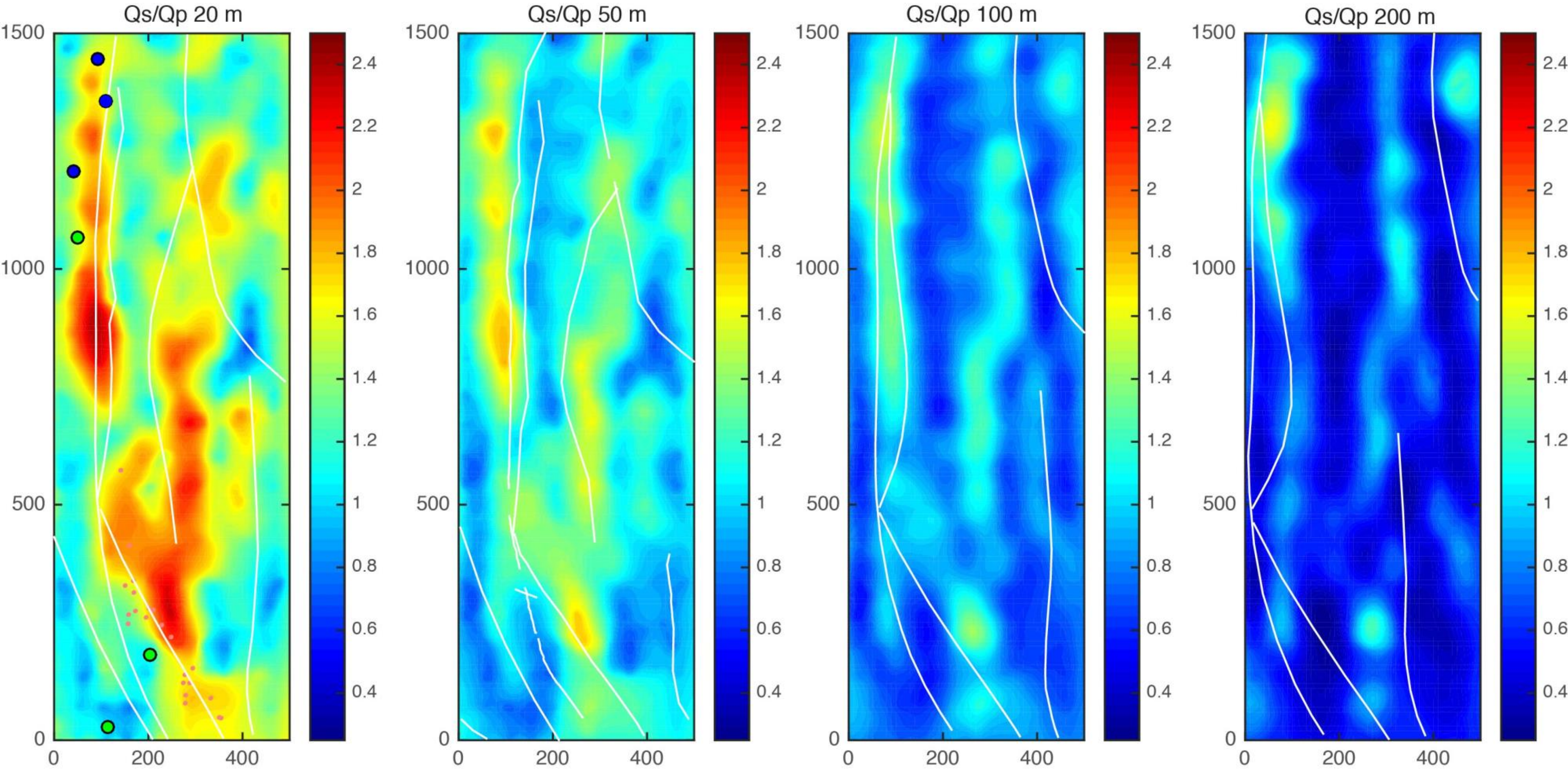


Cross section through injection point x= 50m

Cross section through fumaroles x=270m

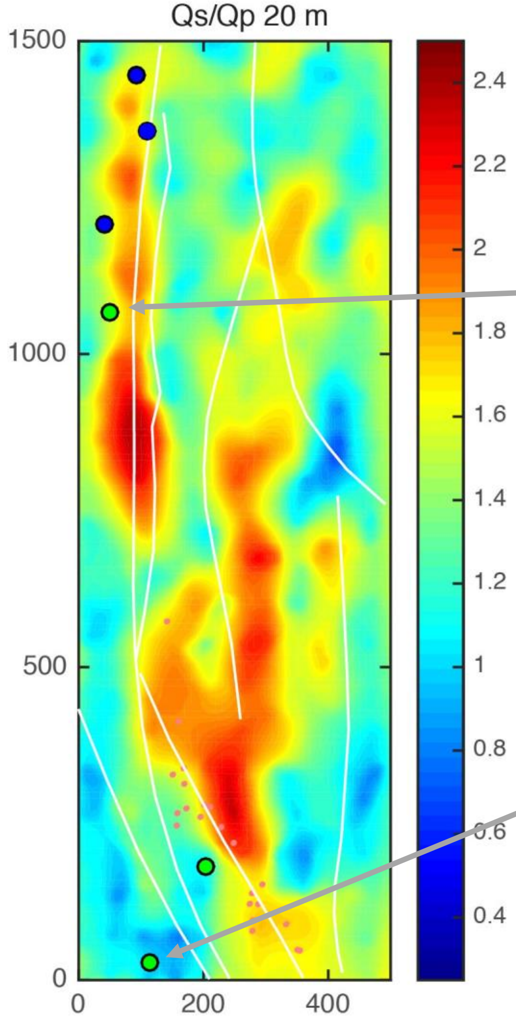


Qs/Qp anomalies align on faults



geologic obstacles from Coolbaugh, faults from Faulds

Pressures were changed in four stages over the two week experiment.

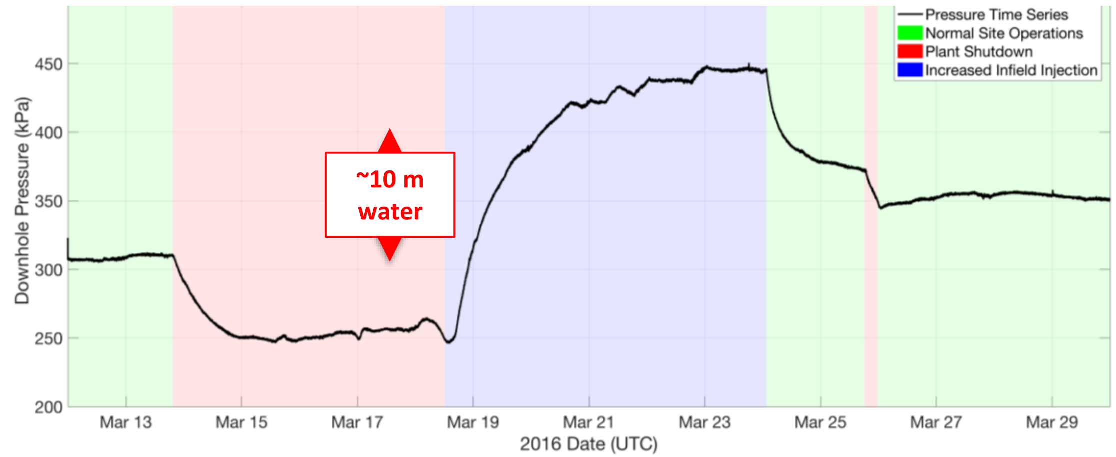


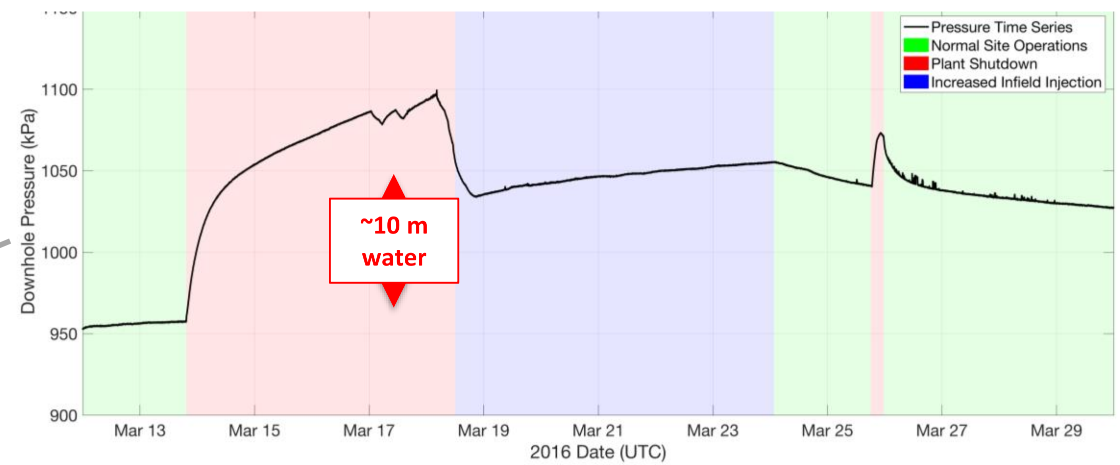
Stage 1: Normal Operations

Stage 2: Site Shutdown

Stage 3: Increased Injection & Pulsing

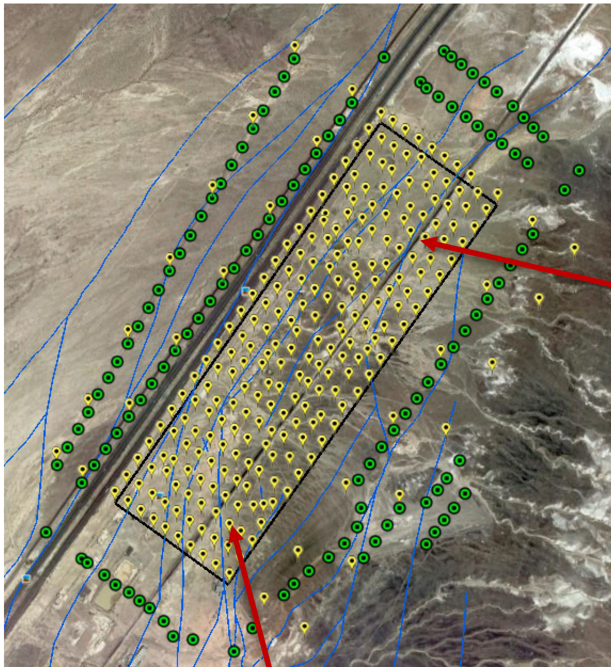
Stage 4: Normal Operations

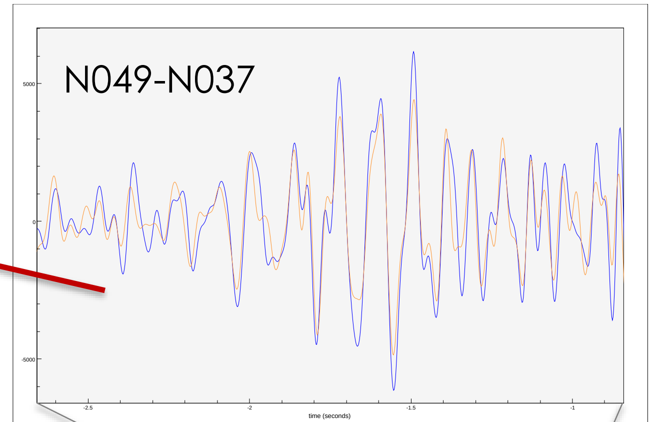




Time series of pressure records showing the response to four stages of pumping operations at recorded in three monitoring boreholes (Feigl, 2017)

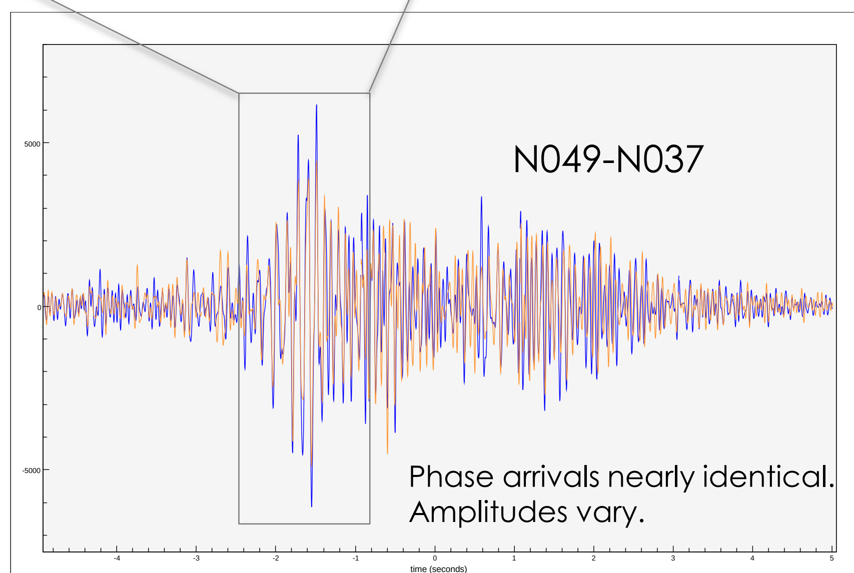
Phase arrival times are nearly identical, but amplitudes changed measurably after site shutdown



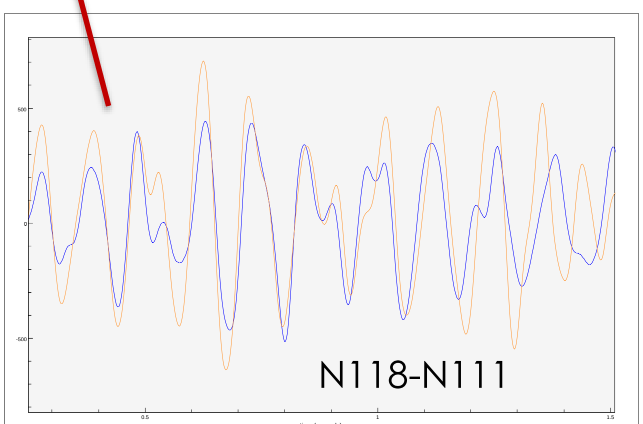


Amplitudes in the North decreased after shutdown

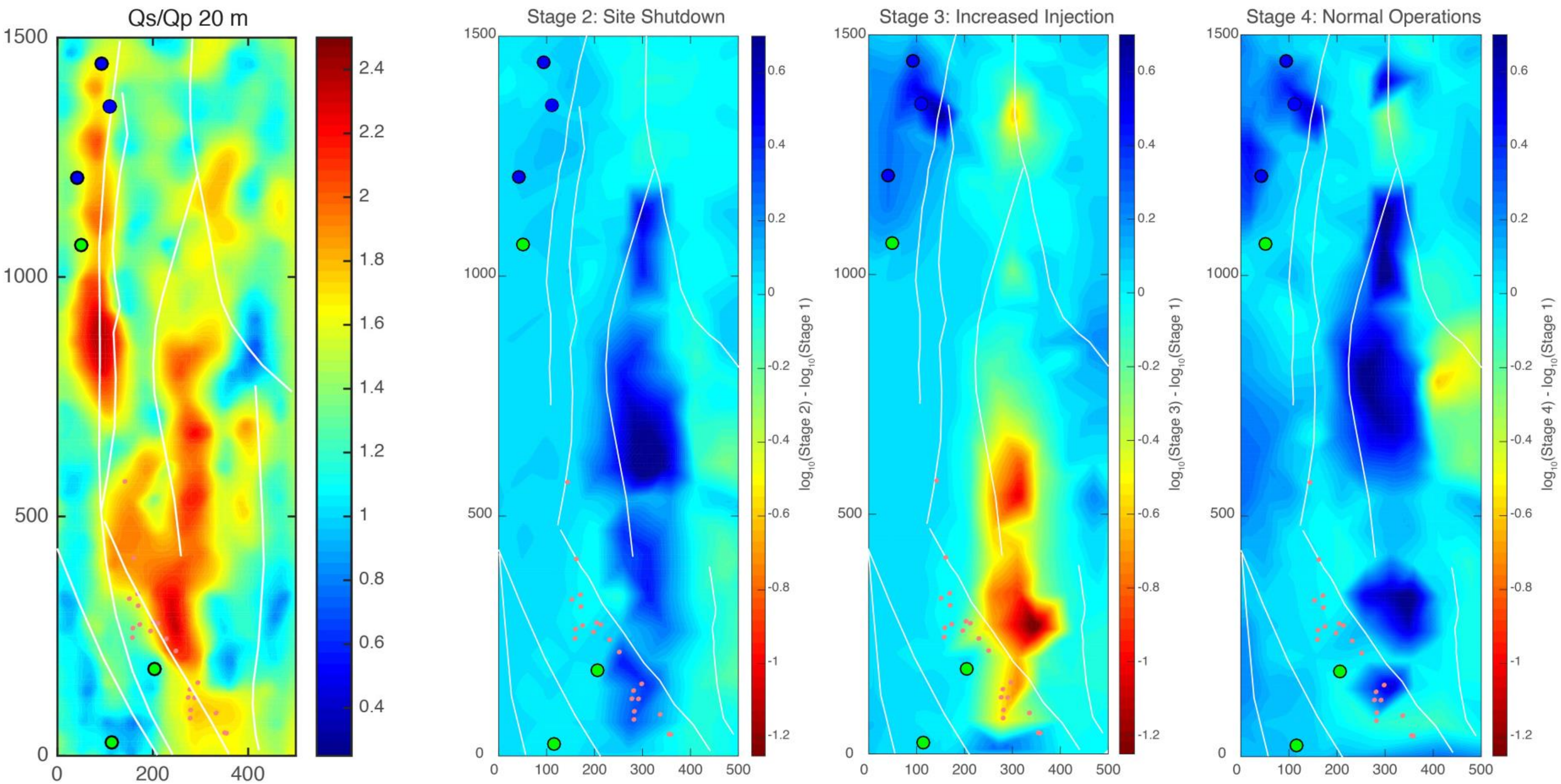
Normal Ops: Blue
Site Shutdown: Orange



Amplitudes in the South increased after shutdown



Changes in amplitude are concentrated in fault bounded blocks.



Static image of attenuation during normal operations (Stage 1)

Dynamic changes in seismic amplitudes as operations changed

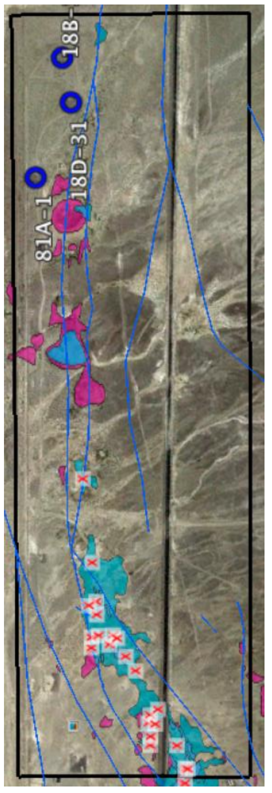
- blue: more efficient propagation
- red: more attenuated

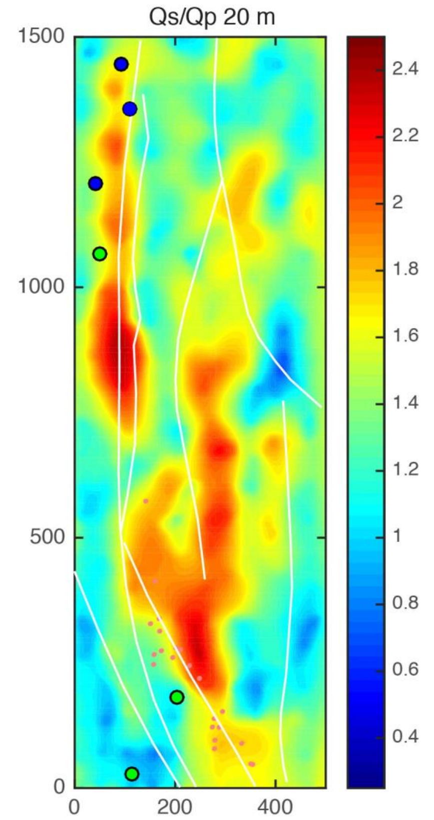
Conclusions

PoroTomo objective:

- Characterize spatial distribution and monitor temporal changes rock mechanical properties of EGS reservoir in 3D.
- Infer Young's modulus, Poisson's ratio, saturation, porosity density. (ref. Kurt Feigl SGW 2017).

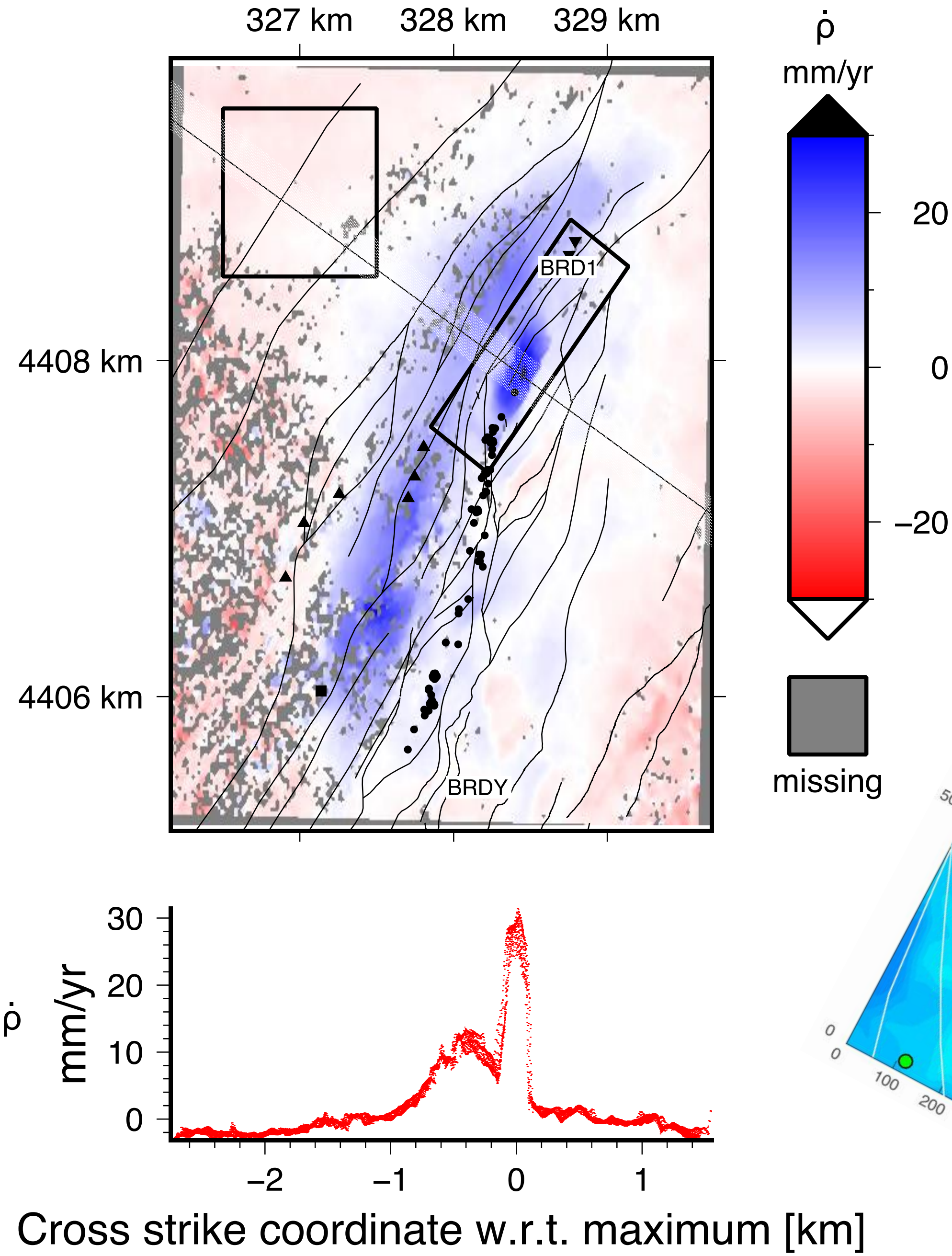
- Using interferometry we obtain images of Vp, Vs, Qp and Qs at high resolution.
- Brady geothermal field is highly heterogeneous in the top 100 m.
- Vp/Vs anomalies largely follow fault structure.
- Qs/Qp is largest following major faults and to greatest depth beneath the injection point and near the fumaroles.
- Changing pressures appear immediately in the seismic amplitudes, concetrated in fault bounded blocks.

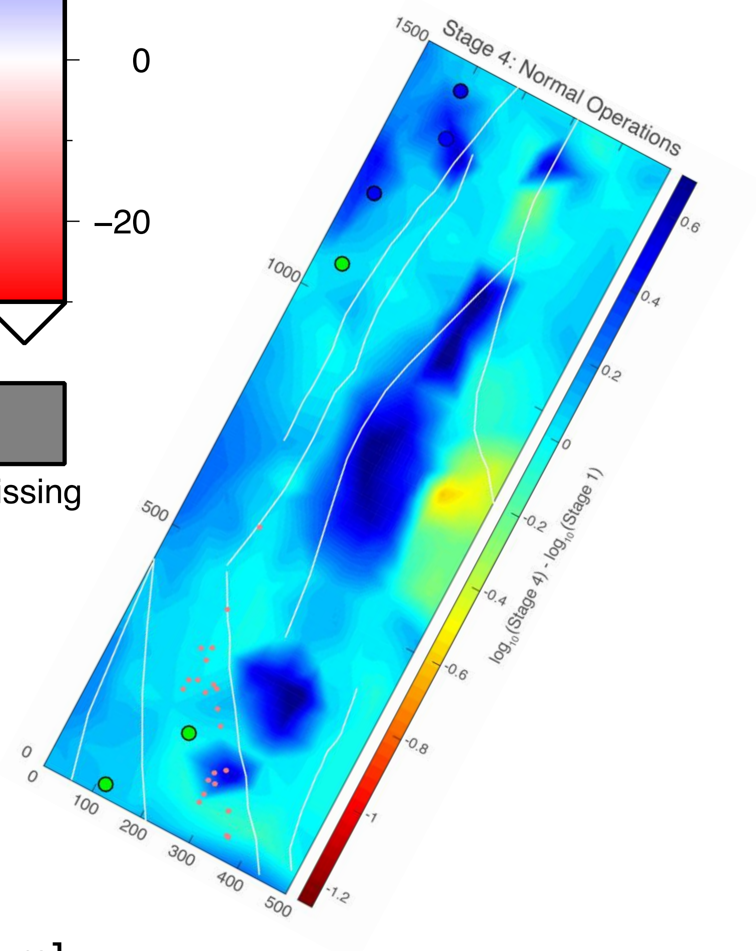




Poster presentation SSA:
Seismic Tomography at Brady Geothermal Field, Nevada with Dense Nodal and Fiber-Optic Seismic Arrays, Nayak et al.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. The PoroTomo project was funded in part by the Office of Energy Efficiency and Renewable Energy (EERE), U.S. Department of Energy, under Award Numbers DE-EE0006760 and DE-EE0005510.





Reinisch et al. in prep

Comparison with conceptual model