Concept Testing and Development at the Raft River Geothermal Field, Idaho

Project Officer: W. Vandermeer

Total Project Funding: $10,214,987

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Principal Investigators: J. Moore and J. McLennan

Presenter Name: J. Moore

Organization: University of Utah

Track Name: EGS Demonstration Projects

Relevance/Impact of Research: 1

Technical challenges and barriers to EGS development:

- Creation and sustainability of EGS reservoirs
- Optimizing potential stimulation methods (e.g. thermal stimulation, high and low pressure hydraulic stimulations, propellants)
- Importance of preexisting structures
- Minimizing undesirable seismic activity
- Stimulating wells at low wellhead pressures
- Mapping fluid flow patterns
- Numerical modeling of stimulated reservoir volume

- Operational in January 2008
- Maximum resource T ~150 C
- Produces ~10.5-11.5
- 4 Production Wells; 3 Injection Wells
- Production: ~ 5,000 gpm (individual wells produce 850-2,200 gpm
- 433 gpm per MWe

Project will:

- Stimulate large-scale development of readily accessible low permeability hot rock
- Reduce costs of EGS development by optimizing techniques for reservoir creation
- Improve performance of existing sub-commercial wells

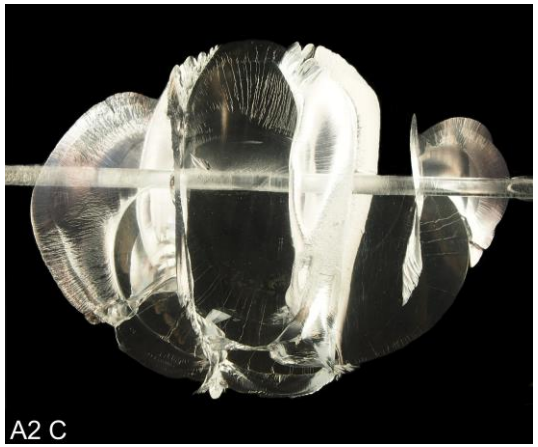
Relevance/Impact of Research: 2

Innovative Aspects

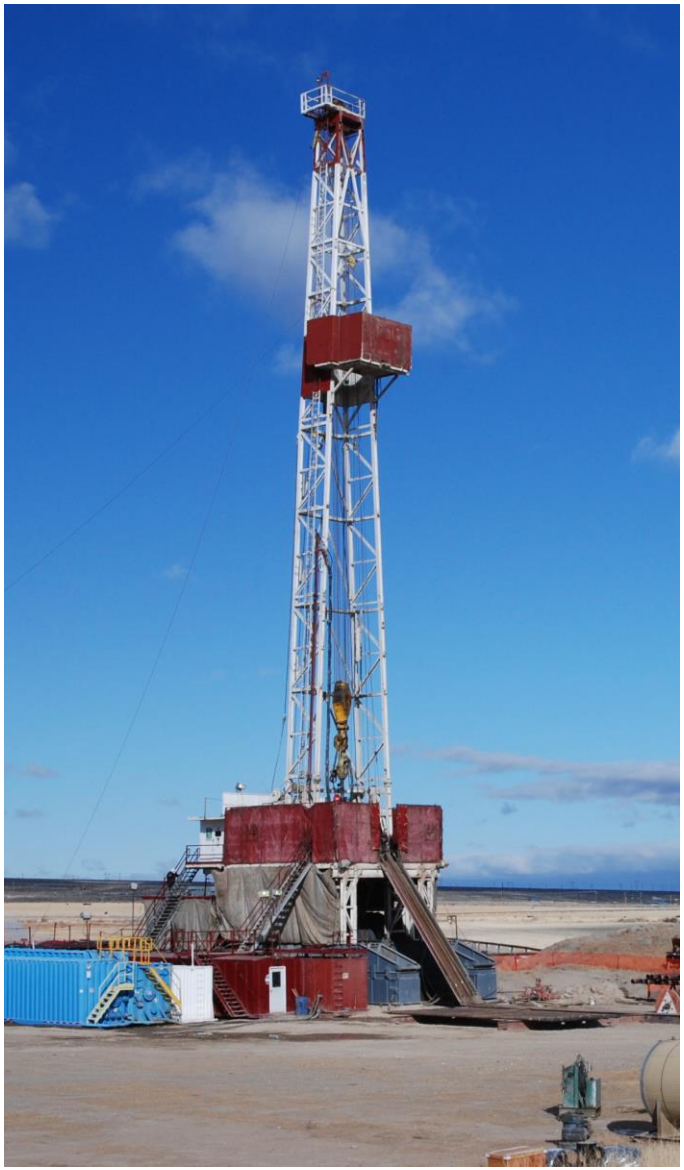
- Application of thermal and hydraulic stimulations
- Application of low and high pressure stimulations
- Application of INL's THMC program Falcon
- Documentation of injectivity changes over time

How is success impacting DOE goals

- Successfully stimulated RRG-9 ST1 at low wellhead pressures, which minimizes seismicity
- Provides a successful demonstration case of turning a low-permeability well into a commercial well
- Project demonstrates importance of thermal stimulation



Hydraulic (E-W) and Thermal Fractures in an Acrylic Block



Scientific/Technical Approach: 1

Project consists of 3 phases:

- Phase 1: Prestimulation Activities
  - Establish the geologic setting and characteristics of the faults and rocks that make up the target zone
  - Characterize the permeability, mechanical properties and in-situ stresses of the zone to be stimulated
  - Establish background microseismicity levels
  - Formulate a stimulation plan
- Phase 2: Stimulation
  - Well stimulation
  - Microseismic monitoring
  - Tracer monitoring
  - Analysis of downhole temperature and televiewer surveys
  - Numerical modeling of injection data
- Phase 3: Long Term Monitoring

Stimulation 3

Scientific/Technical Approach: 2

Key Issues and Highlights (achieved successful results in red):

- Evaluation of the injection history and numerical modeling of the injection program. *Developed a reservoir model for numerical simulations utilizing INEL's THMC program FALCON, modified to incorporate pressure dependent permeability and a distributed fracture network (DFN)*.
- Determining the impact of injection into RRG-9 ST1 on the field's performance *using routine production and injection data as well as tracer injection.*
- Evaluation of the evolution and origin of the microseismicity *through continued monitoring of an installed geophone network and correlation/assessment of their relationship to injection activities and large scale geologic structures.*
- Improve injectivity and assess of potential stimulation strategies *(e.g. thermal and hydraulic stimulation, propellants, Haliburton's Surgifrac technique).*
- Evaluation of the viability of distributed temperature sensor installations (DTS) for inferring flow patterns in the near-wellbore environment through analysis of long-term DTS data *(collaboration with B. Freifeld, M. Plummer).*
- Determining the fluid pathways and direction of fluid movement *through microseismic data and MT surveys (collaboration with E. Majer and G. Newman).*

♦ The project has achieved its target objective of an injection rate >500 gpm.

Accomplishments, Results and Progress: Key Milestones to Date

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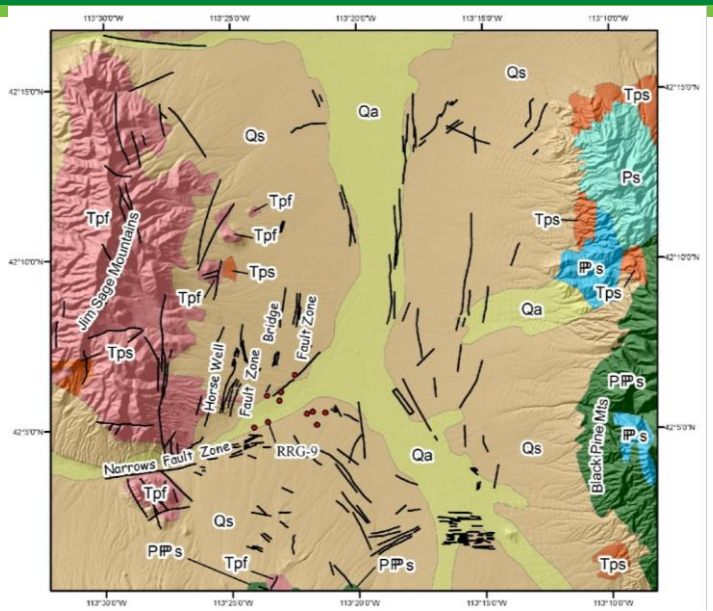
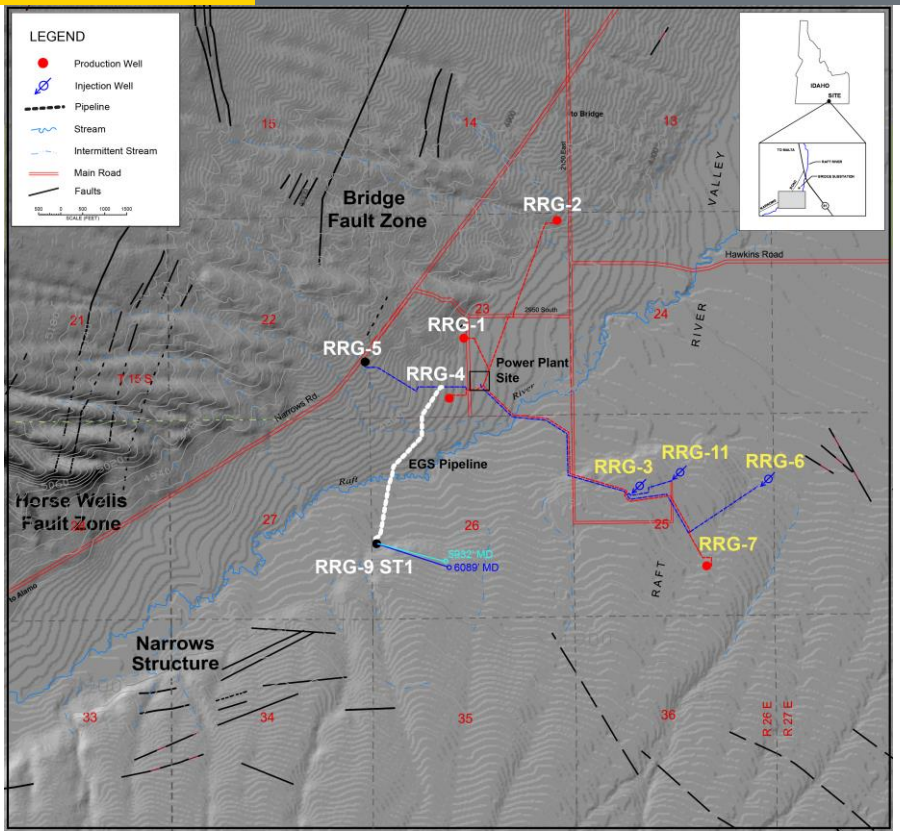
Original Planned Milestone/ Technical Accomplishment	Actual Milestone/ Technical Accomplishment	Date Completed
Conduct VSP and MT surveys	Completed as planned	2010
Complete RRG-9 for stimulation	RRG-9 sidetracked; RRG-9 ST1 completed as planned	2/2012
Conduct Stimulation 1 and televiewer survey	Completed as planned	2/2012
Install 10” 1 mile pipeline	Completed as planned	10/2011
Stage Gate presentation	Completed as planned	10/2012
Initiate injection through 10” line	Completed as planned	6/2013
Install 3” bypass line	Completed as planned	7/2013
Conduct Stimulation 2	Completed as planned	8-9/2013
Run televiewer, PTS, video camera survey	Completed as planned	10/2013
Initiate numerical simulations	Completed as planned	6/2014
Conduct Stimulation 3, time-lapse MT survey	Completed as planned	4/2014
Reach target injection rate (500 gpm)	Successfully achieved	2/2015
Reconnect 10” flow line, inject tracer	Completed as planned	1/2015

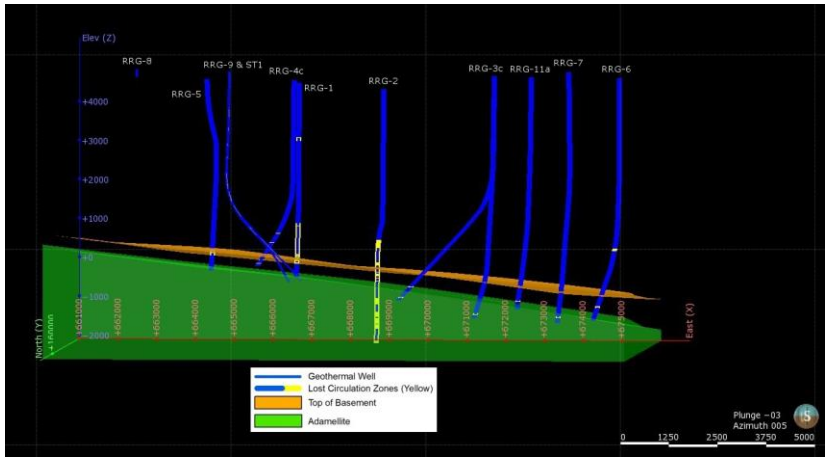
Key Challenges: Numerical simulation of injectivity data; costs of additional stimulations

Geologic Setting

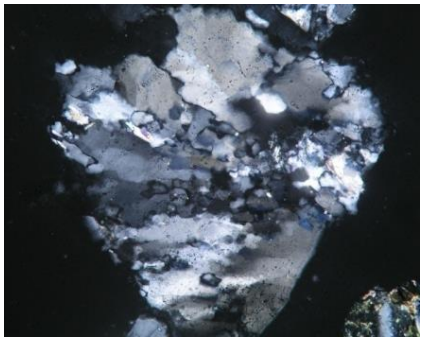


Pink/orange = Tertiary volcanic rocks; blue/green = Paleozoic rocks





Looking northeast from RRG-9 ST



White: low salinity

Yellow: high salinity

Elba Quartzite

Fractures at Reservoir Depth

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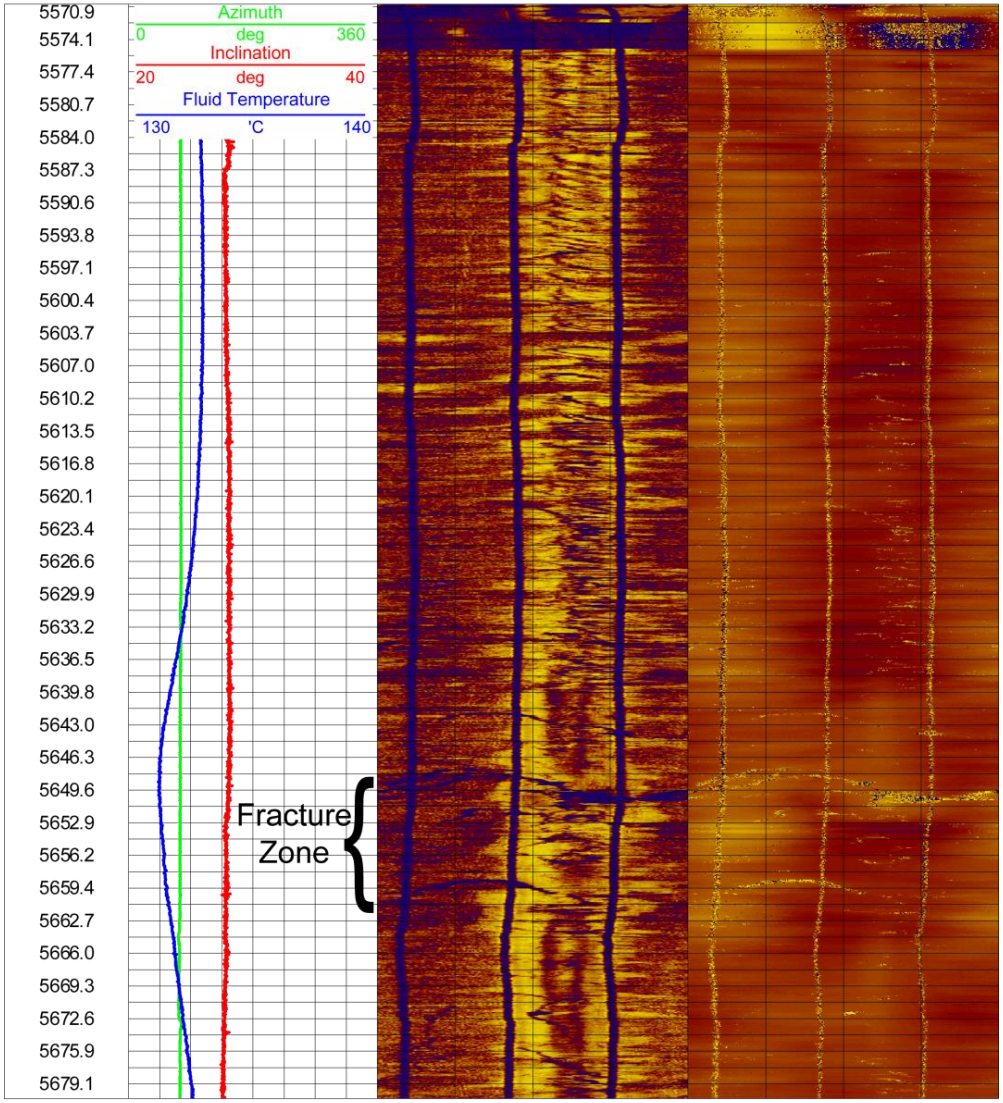
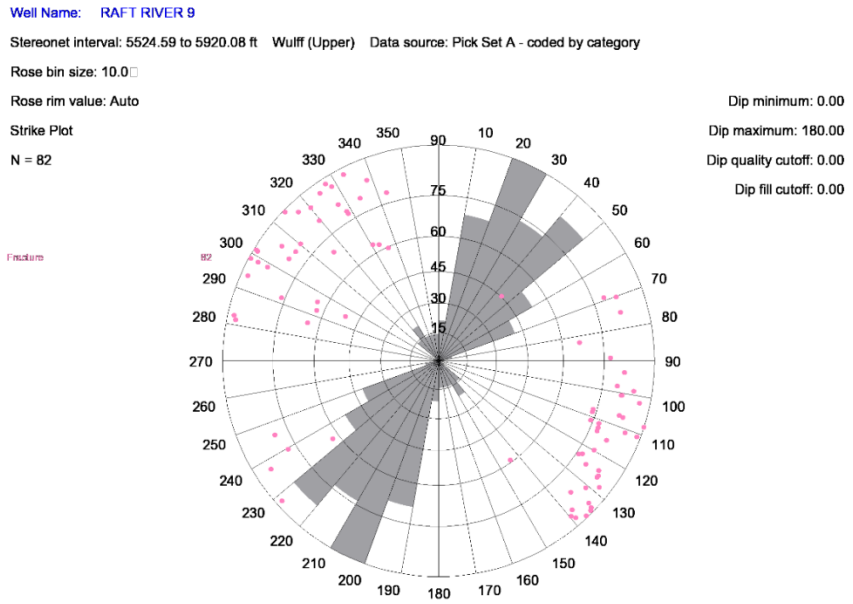
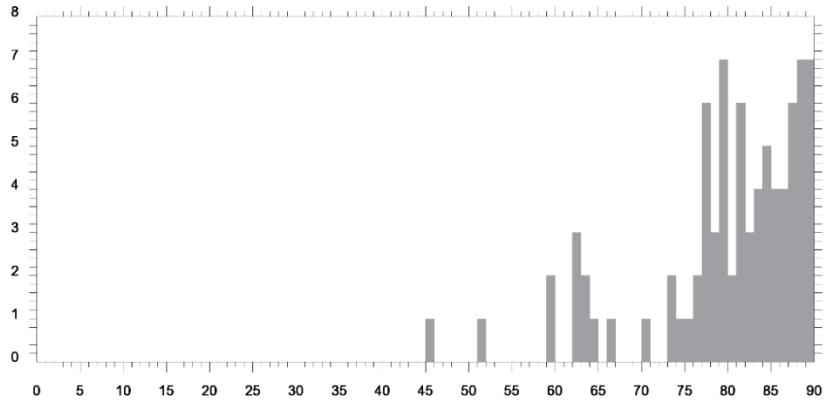


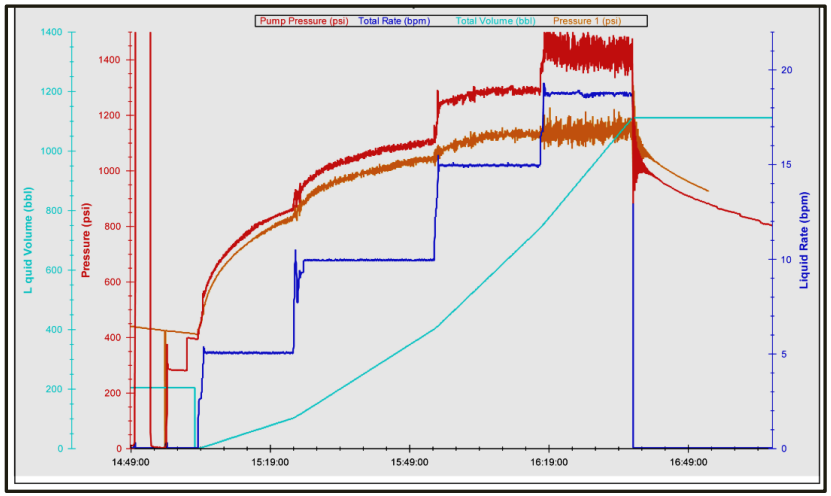


Fracture Strikes



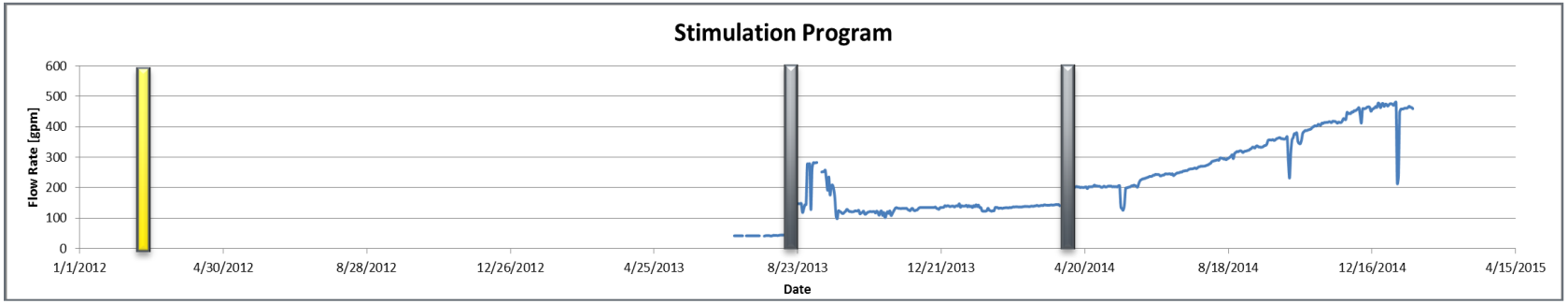
Fracture Dips

Stimulation 1



Injection Parameters/Results

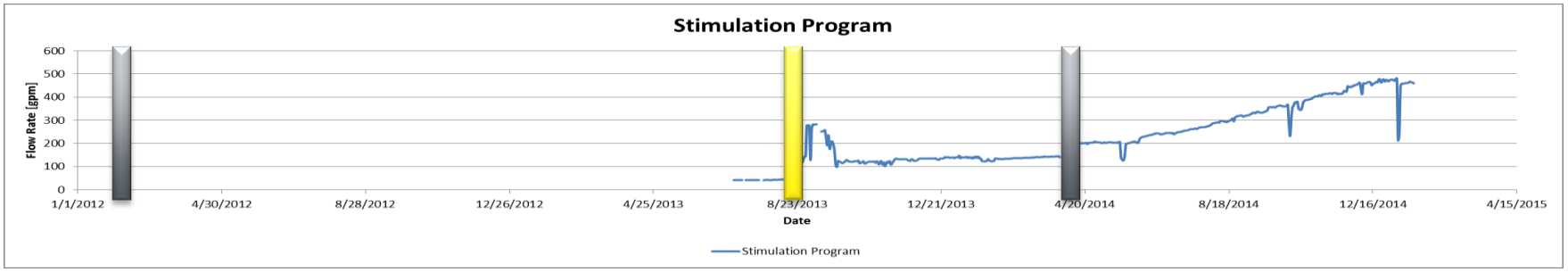
- Injection rates of 11 to 756 gpm
- Max wellhead pressure: 1150 psig
- Frac gradient: 0.59 to 0.62
- Total injected volume 81,648 gal



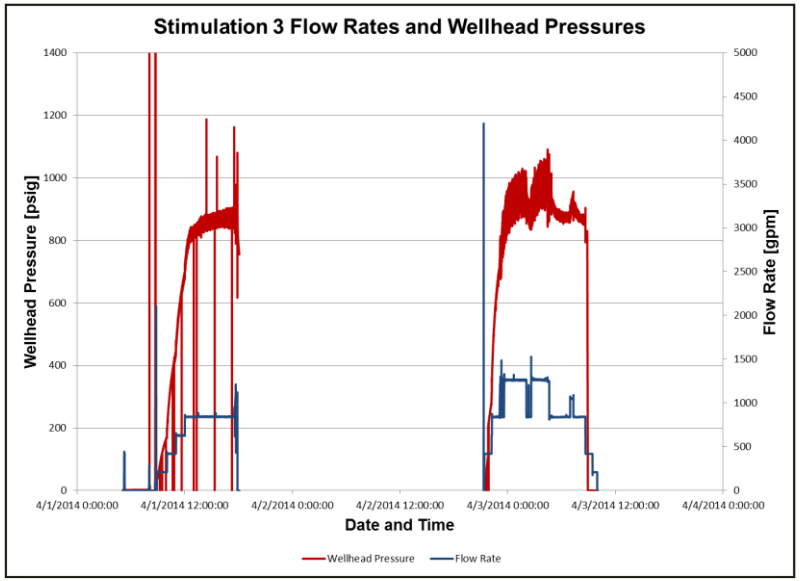
Stimulation 2

Injection parameters:

- max flow rate: 333 gpm
- max well head pressure: 908 psig
- temperature: 40-46°C
- frac gradient: 0.56

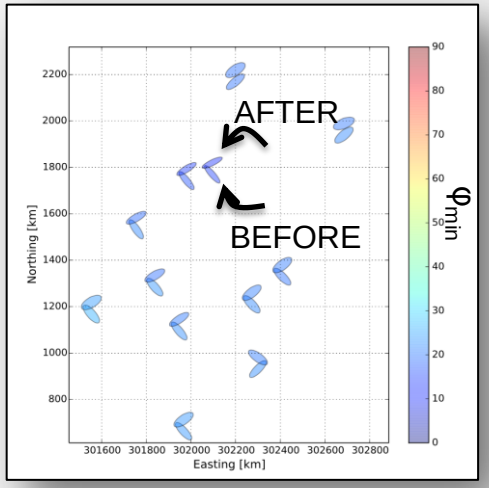


Stimulation 3



Injection parameters:

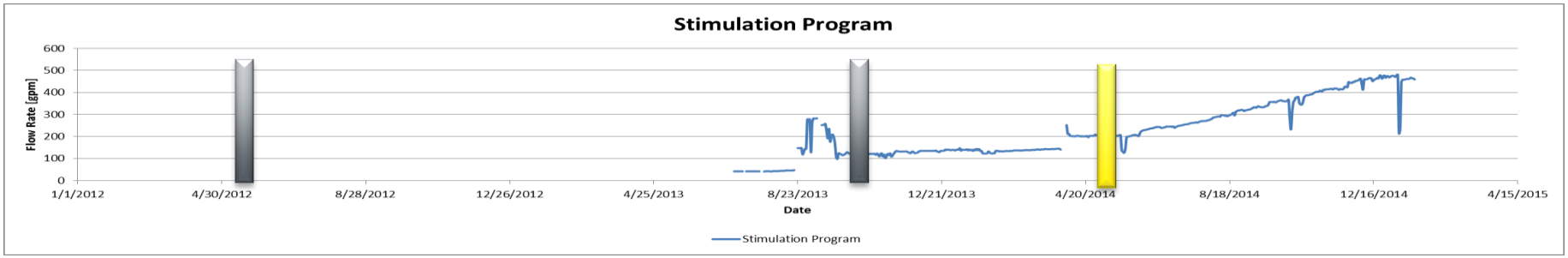
- Flow rate: 840 gpm for ~15 hrs; 1260 gpm for ~6 hrs
- Wellhead pressure: 850-980 psig
- Temperature: 10 -15°C



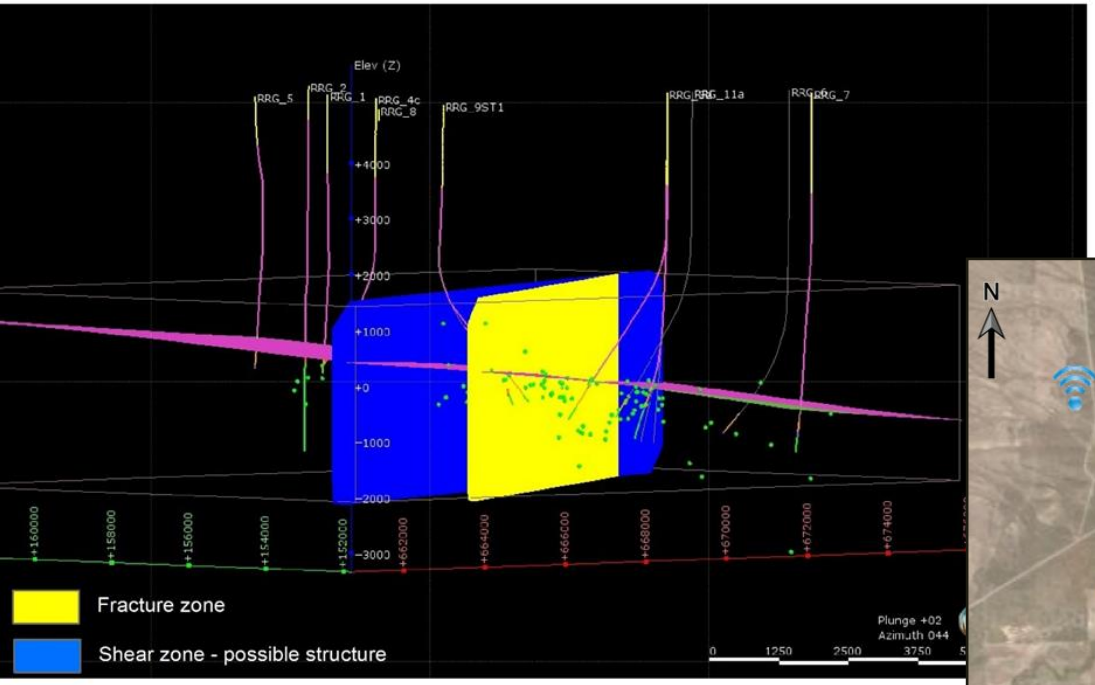
Time Lapse MT Survey

Injection @ 1.7 km depth
MT Response @ 0.176 Hz

Courtesy G. Newman

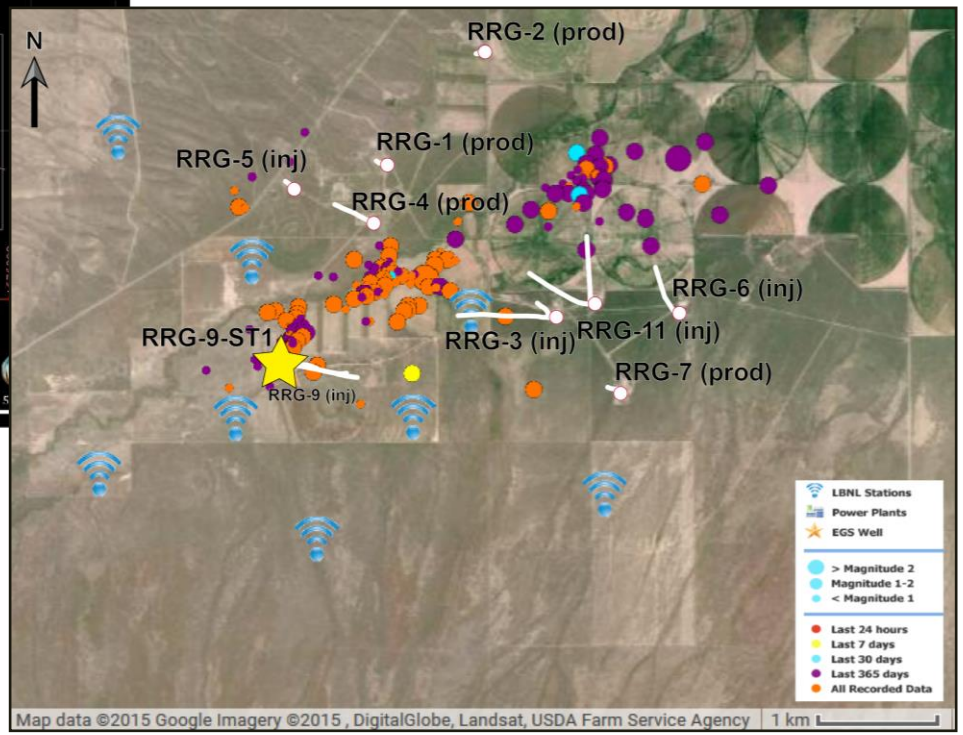


Seismic Monitoring



4 surface seismic stations

4 seismometers in 300 ft boreholes



Courtesy E. Majer

Microseismic Activity from 10/2/2010 to 3/23/2015

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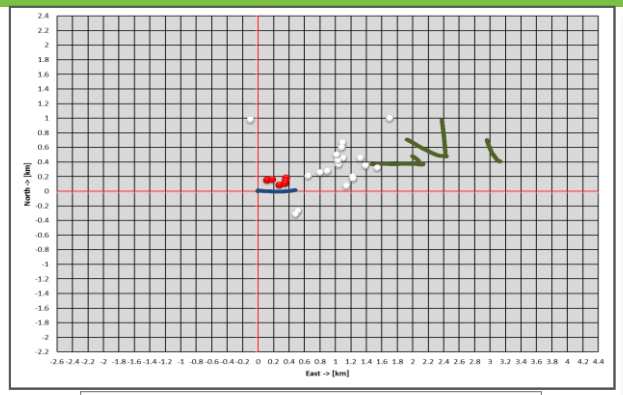
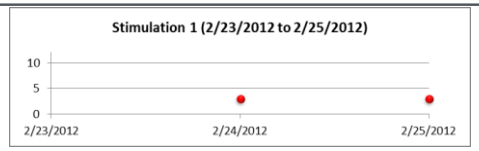
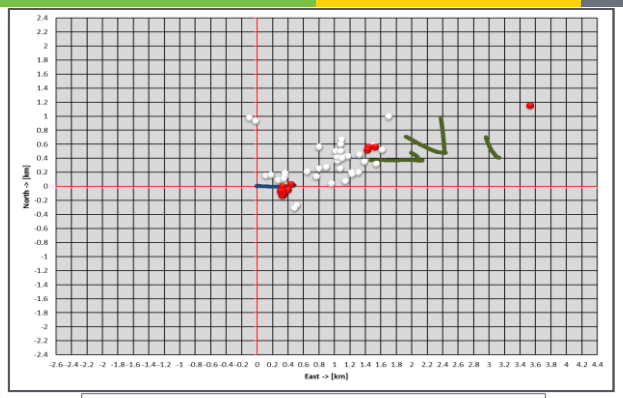
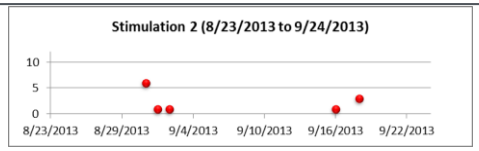
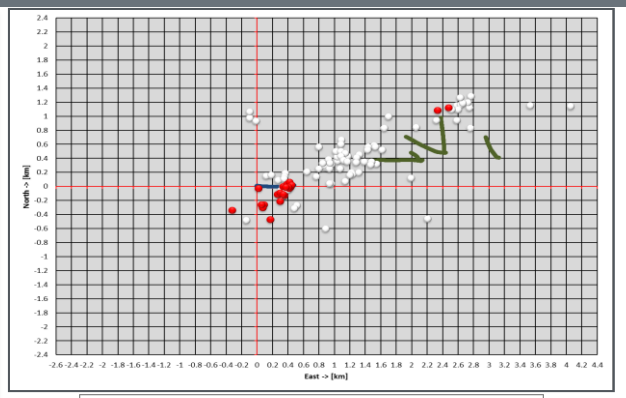
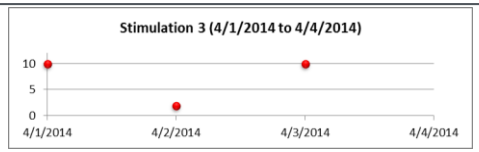


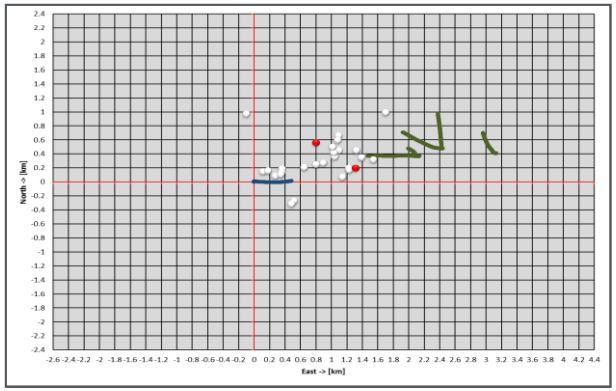


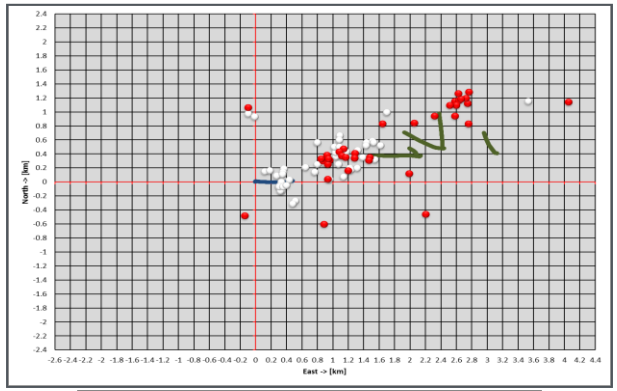


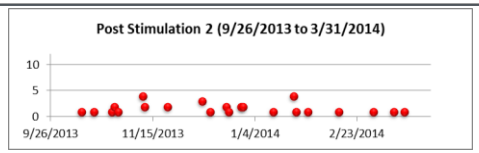


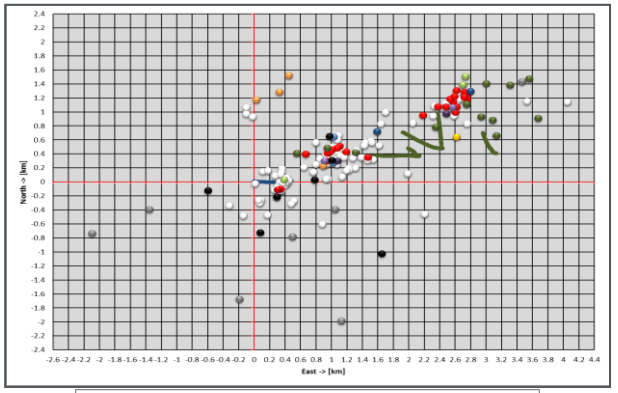


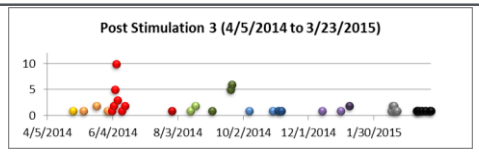






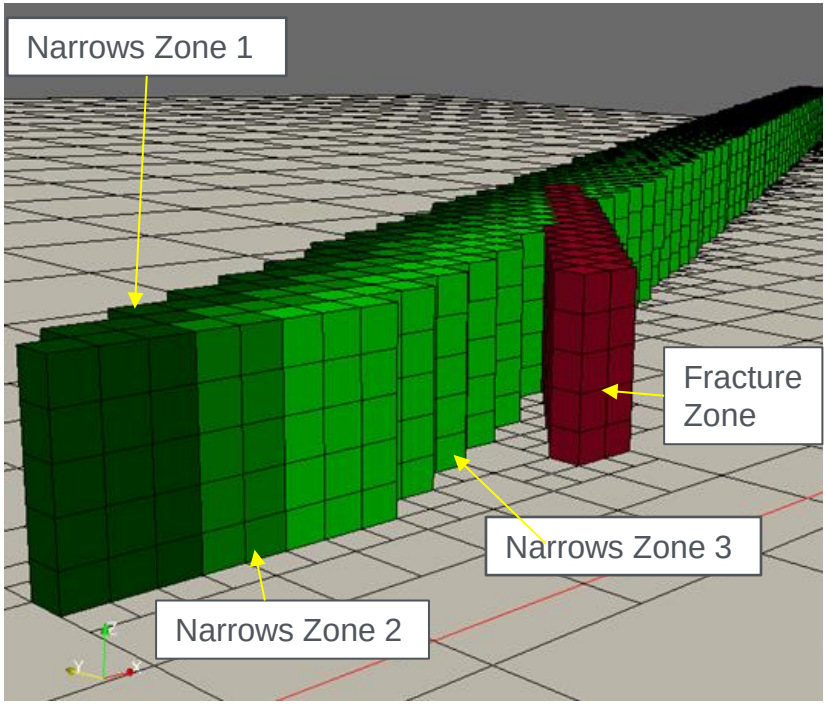


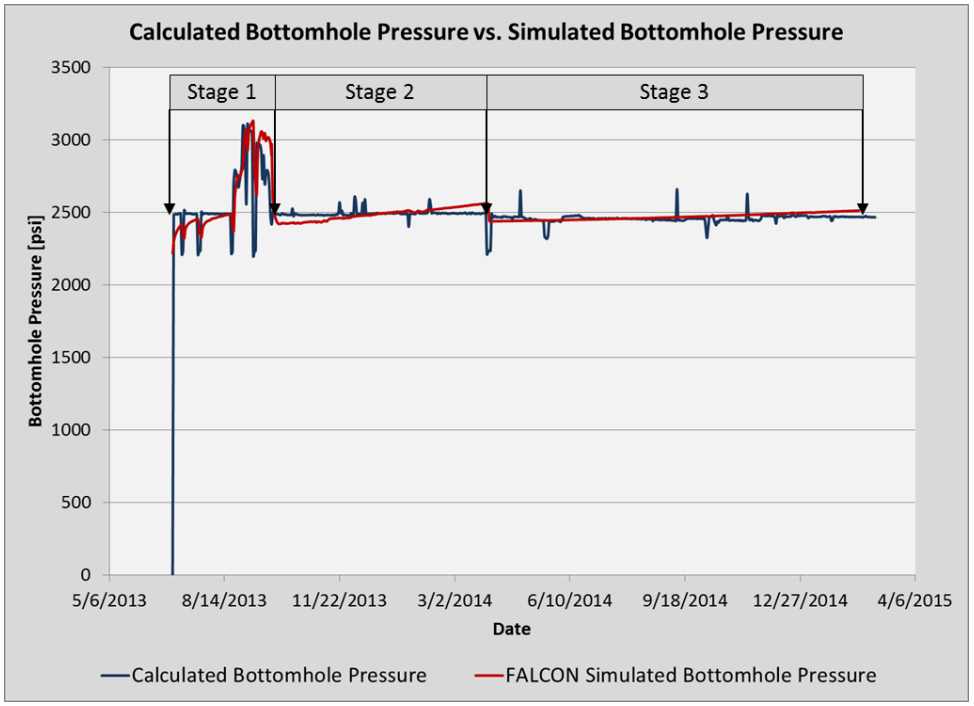




White dots: past earthquakes (M = -0.31 and 1.53) (E. Majer) / Blue line=RRG-9 ST1; Green lines = other injection wells

RRG-9 ST1 Stimulation Model





Parameter	Stage 1	Stage 2	Stage 3
Narrows Zone 1 Permeability [D]	10.1	50.5	50.5
Narrows Zone 2 Permeability [D]	10.1	50.5	50.5
Narrows Zone 3 Permeability [D]	10.1	50.5	50.5
Fracture Zone Permeability [D]	0.202	1.01	101
Aquifer Compressibility [1/Psi]	6.94×10^{-6}	6.94×10^{-6}	6.94×10^{-5}

Future Directions

- Expected outcomes:
  - Provide successful demonstration of combined hydraulic and thermal stimulation techniques (achieved)
  - Provide better predictive modeling of EGS reservoirs
- Significant issues:
  - Availability of funding for additional stimulations during project lifetime
- Future research, development or deployment needs:
  - Improved ability to track injected fluids through MT and seismic (VSP) methods (LANL)
  - Well documented tests of alternative stimulation techniques (propellants, proppant emplacement (Halliburton's Surgifrac))
  - Application of new proppant technologies (expandable proppants; BNWNL)

Milestone	Status & Expected Completion Date
Deploy pressure gauge in well	Activity initiated; planned completion: 4/2015
Conduct fall-off and build-up tests	To be initiated; planned completion: 5/2015
Conduct Stimulation 4 using propellant	Dependent on funding: Fall 2015
Complete numerical simulations	In progress; planned completion: 12/2015
Continue injection, seismicity and tracer monitoring	Activity initiated; planned completion: 6/2016

Summary

1. Conducted three stimulation campaigns; Injection rates increased from 20 to ~540 gpm (as of 4/2015), averaging an increase of 0.8 gpm/day at ~280 psig
2. RRG-9 ST1 put into commercial service; target rate of 500 gpm has been achieved
3. Documented utility of multiple, low-rate, low- pressure stimulations
4. Developed a new geologic model
5. History matched the stimulation program
6. Successfully tracked flow of injectate with time-lapse MT surveys
7. Recorded and located ~160 earthquakes (between -0.31 and 1.53 M) since 10/2010
8. Thermal modification of fracture apertures is primary cause of seismicity
9. Patience