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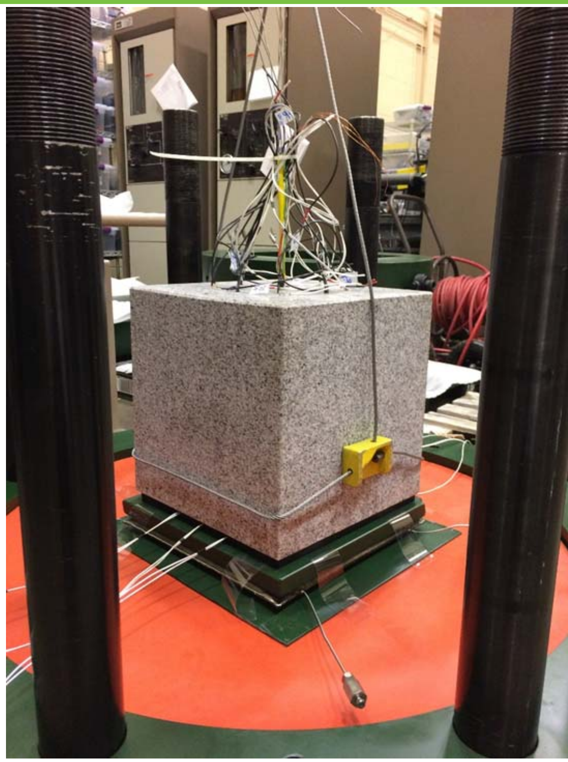

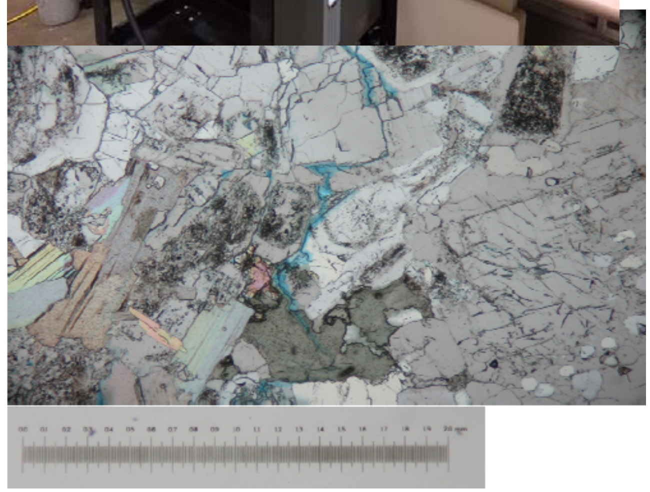

LABORATORY-SCALE CHARACTERIZATION OF EGS RESERVOIRS

Project Officer: Elisabet Metcalfe

Total Project Funding: $880K ($300 Leidos+$550 OU)

Duration: 2014-2017

Principal Investigator A. Ghassemi

University of Oklahoma

Garg and Pritchett Leidos Inc.

Track Name

[1]Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Objectives and purpose

1. Develop and operate a facility to investigate a variety of EGS issues on a laboratory scale, to complement DOE's new full-scale "FORGE" EGS observatory
2. Use a variety of techniques (acoustic emissions, tracers, SP, numerical simulation) to investigate fracturing, fracture area, and heat transfer processes in the laboratory with a view towards their application in the field

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Relevance to Industry Needs and GTO Objectives

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Objectives and purpose

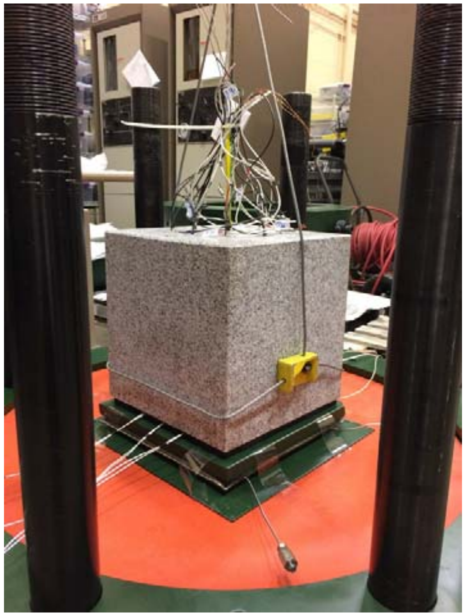
The permeable zones of an EGS must be created by stimulation, but several questions remain:

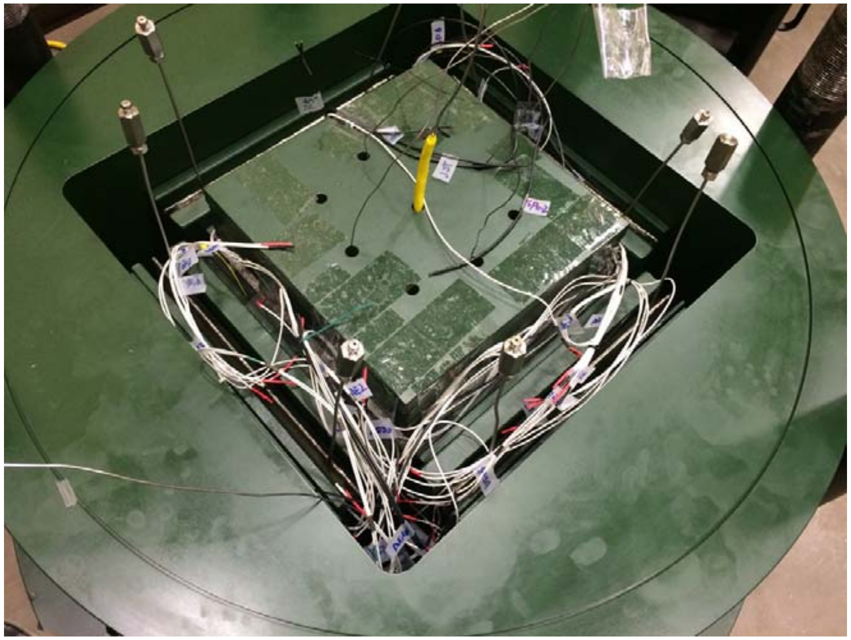
- The relation of the stimulated created fractures with seismicity
- The permeability of the fractures hosting the micro-seismic events
- The role of SP in fracture detection
- Tracer analysis for fracture area determination; heat extraction rates

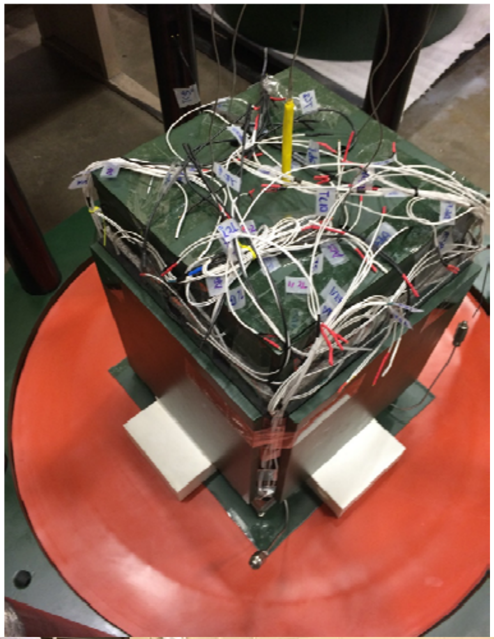
This work would provide insight into fracture propagation in EGS

- Develop a better understanding of the relation of fractures with AE
- Characterize the induced fracture permeability and fluid/heat flow using SP and tracer analyses
- Use numerical simulation techniques to interpretation various laboratory determinations
- Study the role of rock and stress on the induced fractures

System components



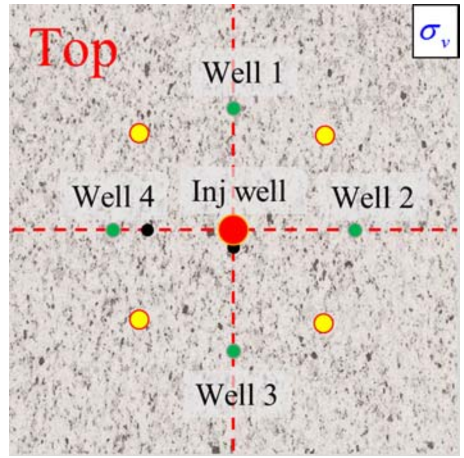




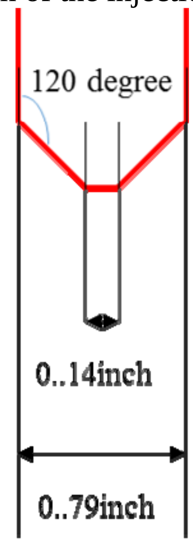
- Polyaxial frame, flatjacks
- Block size up to 18"
- Pore pressure up to 1000-1500 psi; Conf. Stress up to 7000 psi
- Heat to 90C, SP measurements, AE

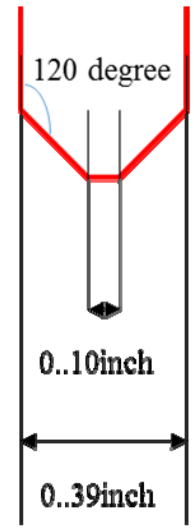
Rock Block, Wells, Sensors Layout

- 13’’ cubic Sierra White granite blocks with five wells drilled from the top surface
- Four production wells drilled around the injection well (3.5” away from the center)
- Injection wells have a diameter of 0.79” and a depth of 7.5”.
- Production wells have a diameter of 0.39” and a depth of 9.0”.



Bottom of the injection well



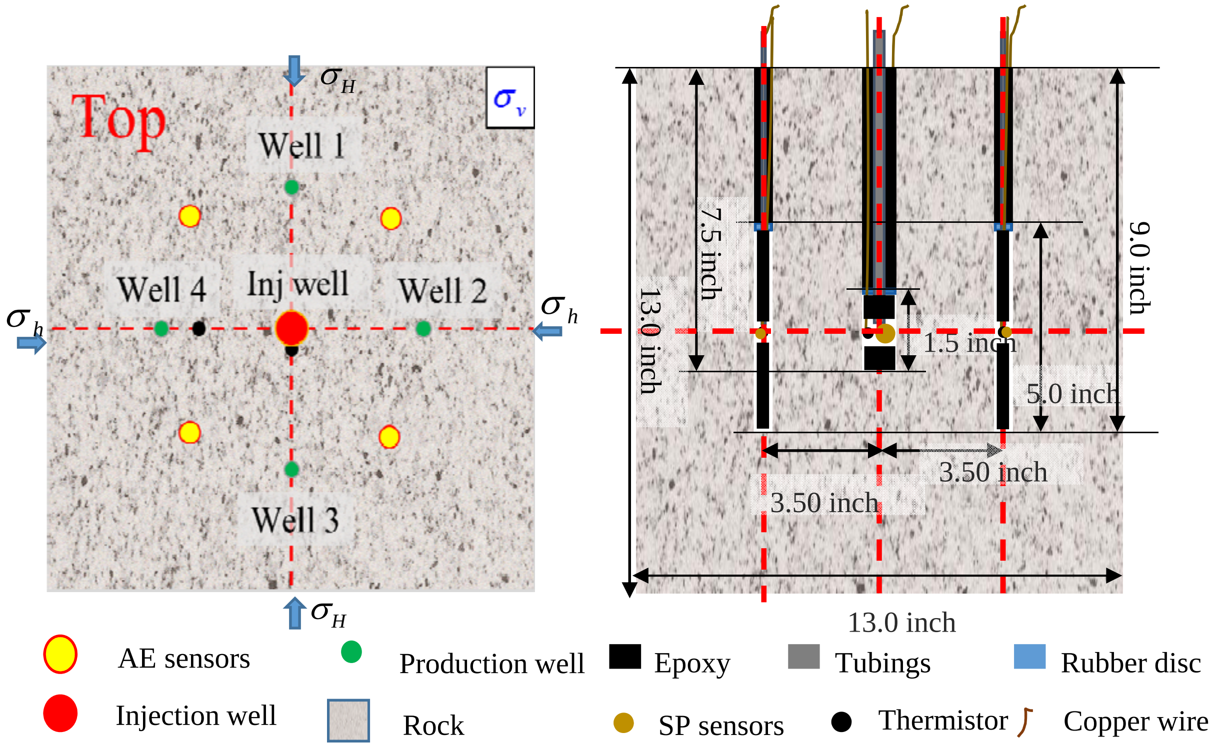


Bottom of the production well

Property	Value	Property	Value
Density	2.65 g/cm^3	Elastic modulus	9427452 psi
Permeability	518 nD	Poisson’s ratio	0.25
Compressive strength	25400 psi	Porosity	0.8%
Tensile strength	1280 psi	P-wave velocity	153234 inch/s
		S-wave velocity	87286 inch/s

Wells, sensor layout, test stages

Test Stage	Recorded information
Sample preparation, system assembly (drill holes, place sensors, connect wires, etc.)	Location of sensors, sample & system components , etc.
Injection index test, hydraulic fracturing	AE, SP, flow rate, pressures
Heat the rock	Temperature history
Injection index test, Circulation test	Temperature, AE, pressure flow rate
Tracer test, Injection index test	Pressure, flow rate, AE tracer concentration
Fracture geometry reconstruction	3D fracture geometry



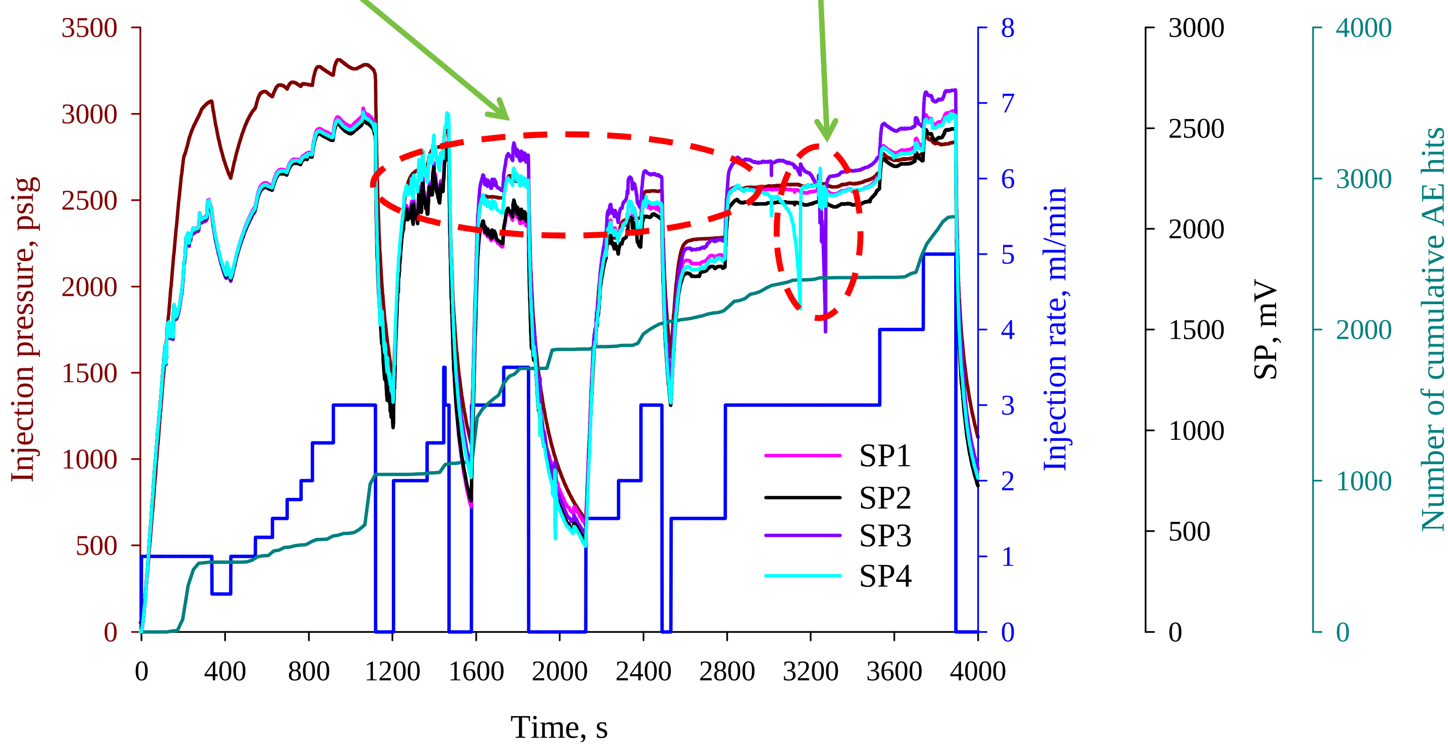
Hydraulic fracturing stage

Principal stress: $\sigma_V = 500\,\text{psi}; \sigma_h = 1000\,\text{psi}; \sigma_H = 1500\,\text{psi};$

Near wellbore saturated; Room temperature

SP in well 3 and well 4 is higher, since the fracture propagated close to these two wells more and thus a higher Cc in these two directions

Drop in SP for well 3 and well 4 when the fracture intersected them (pressure difference drops significantly).



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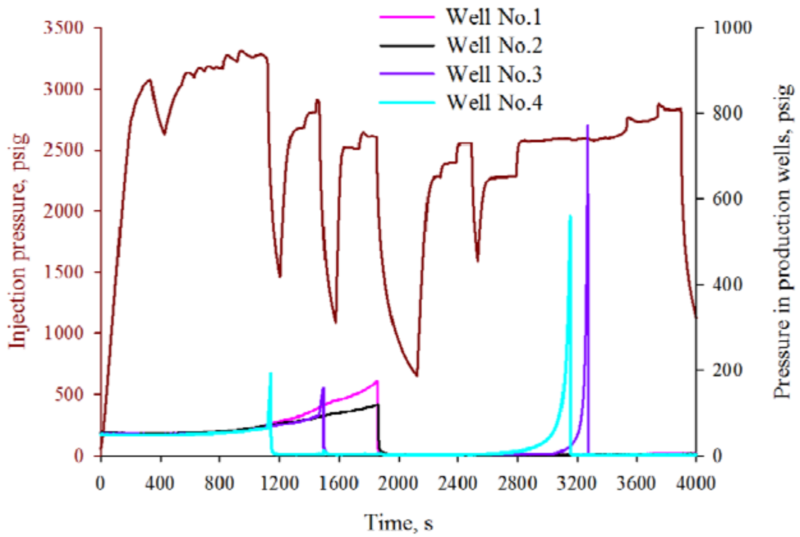
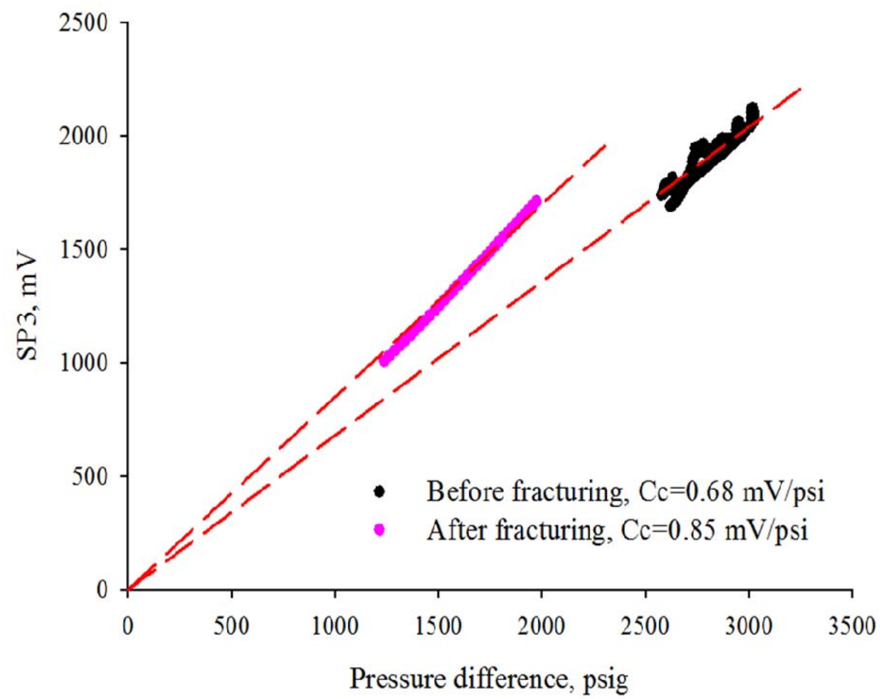
Test (SWGB8) Results-Hydraulic Fracturing

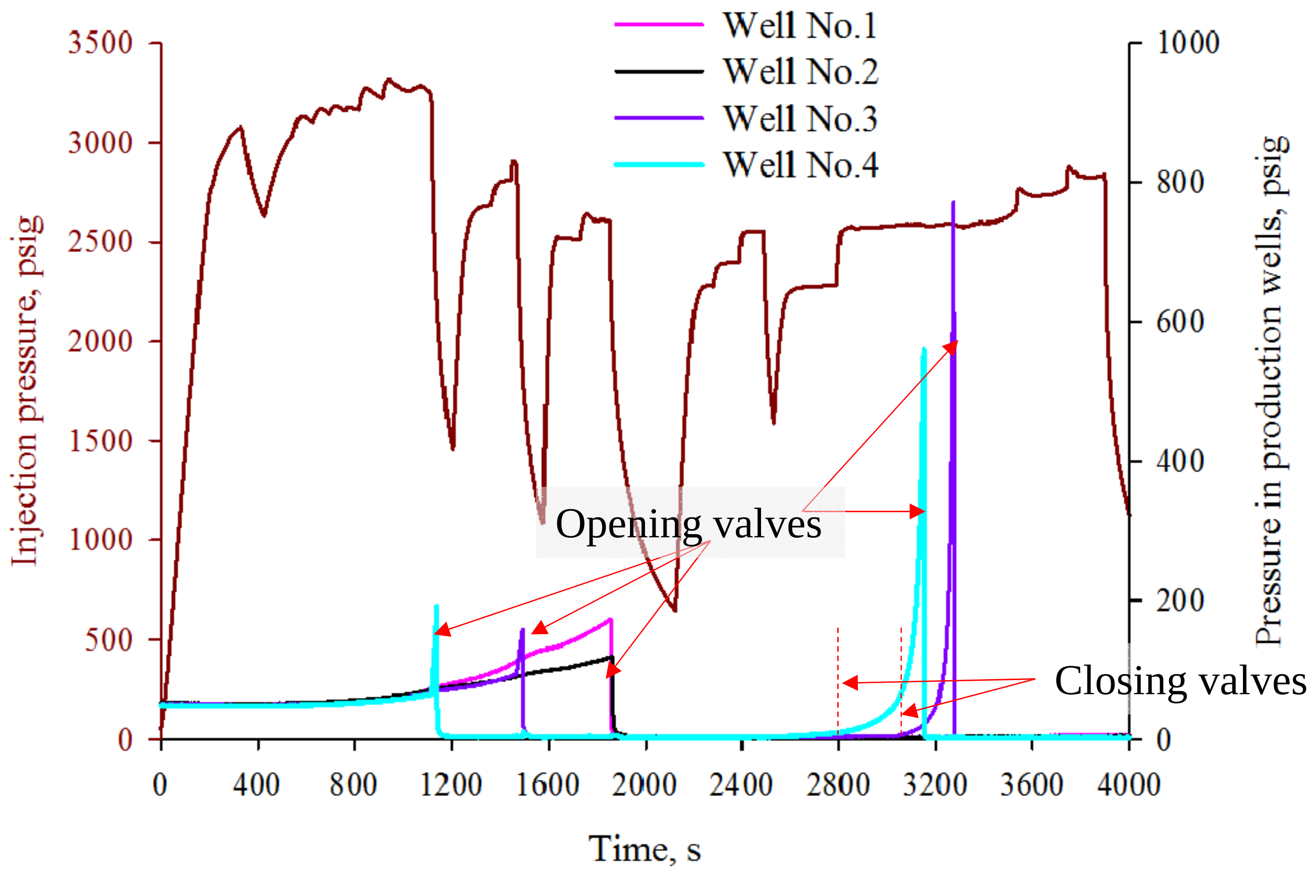
- Electrokinetic coupling coefficient for fracturing (well 3)





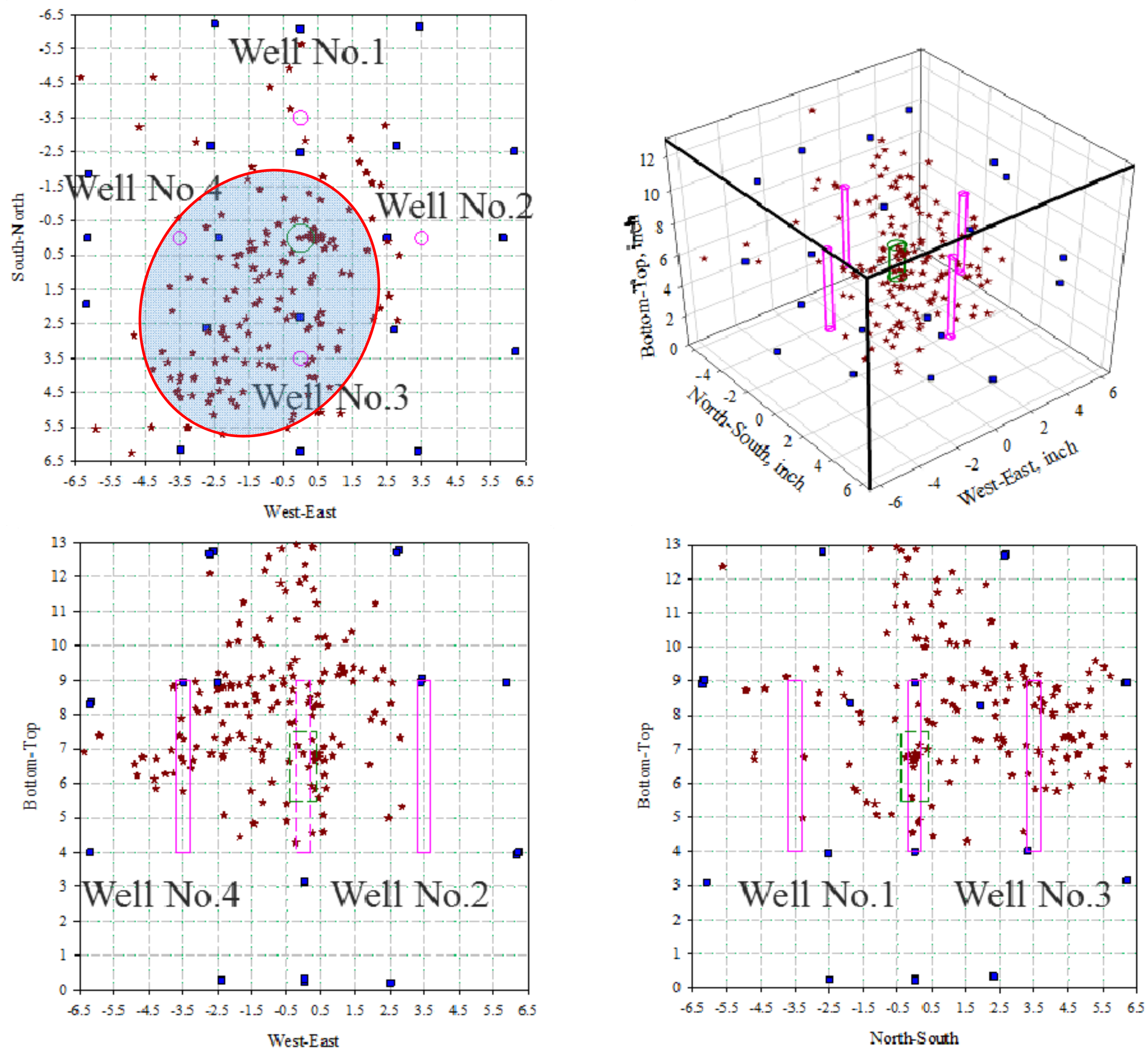
The coupling coefficient increased about 25% after the hydraulic fracturing test.

- Pressure in the wells



It is apparent that Well No.4 and Well No.3 was connected and the connection of Well No.3 is better than that of the Well No.4. It also can be seen that the fracture also propagated towards Well No.1 and No.2 too, since we also have some pressure increasing in these two wells.

- Acoustic emission events



Side View
Looking North

Side View
Looking East

Hydraulic Fracture

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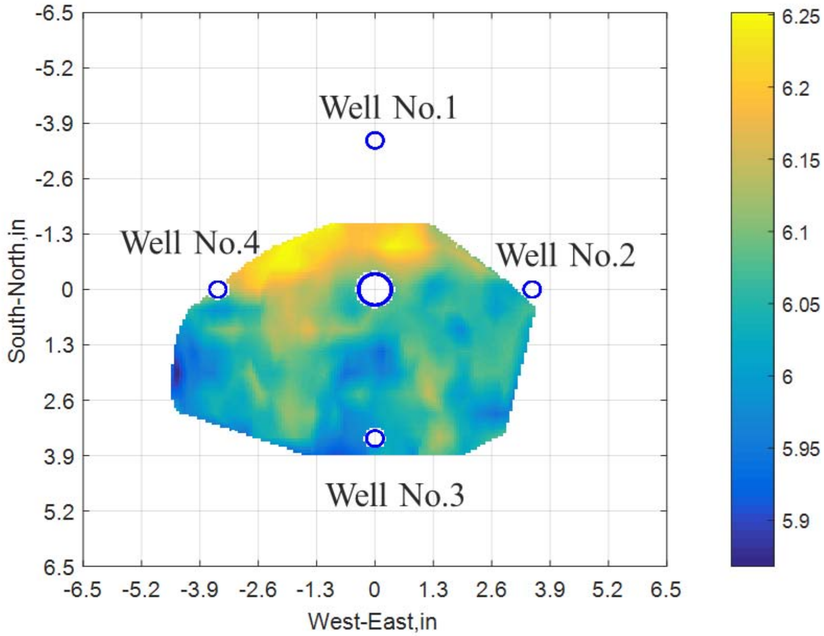
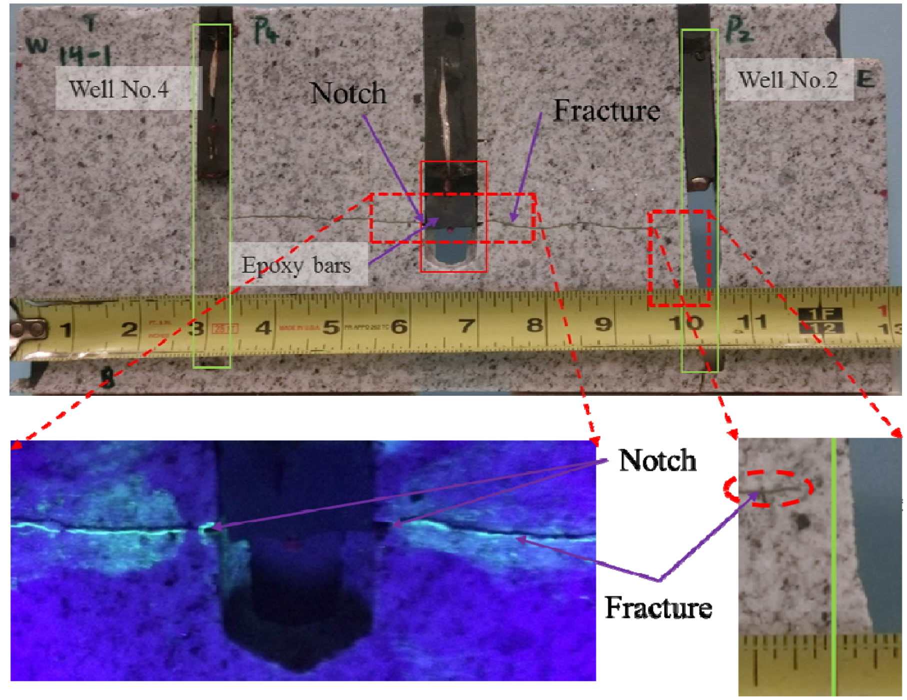
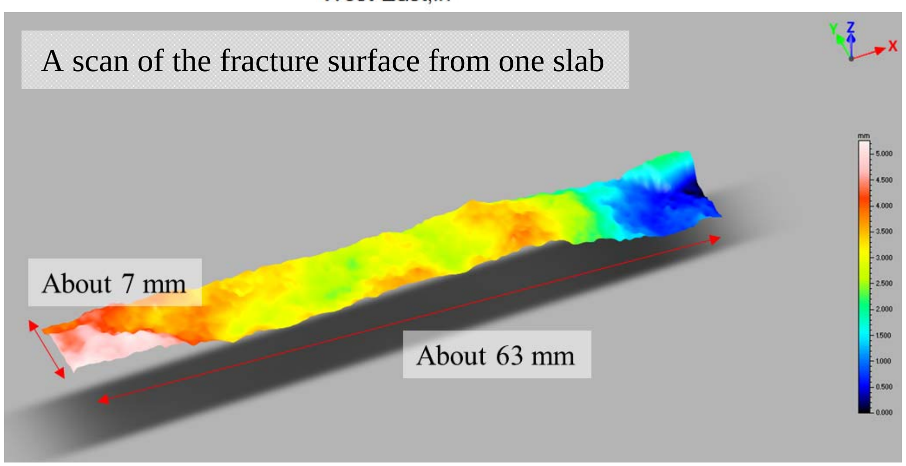
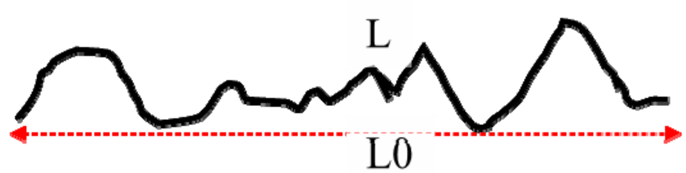






Fluid flow property (tortuosity)

$$\text{Tortuosity} = L/L_0 \approx 1.022$$



$JRC = 12.08$

Circulation Phase

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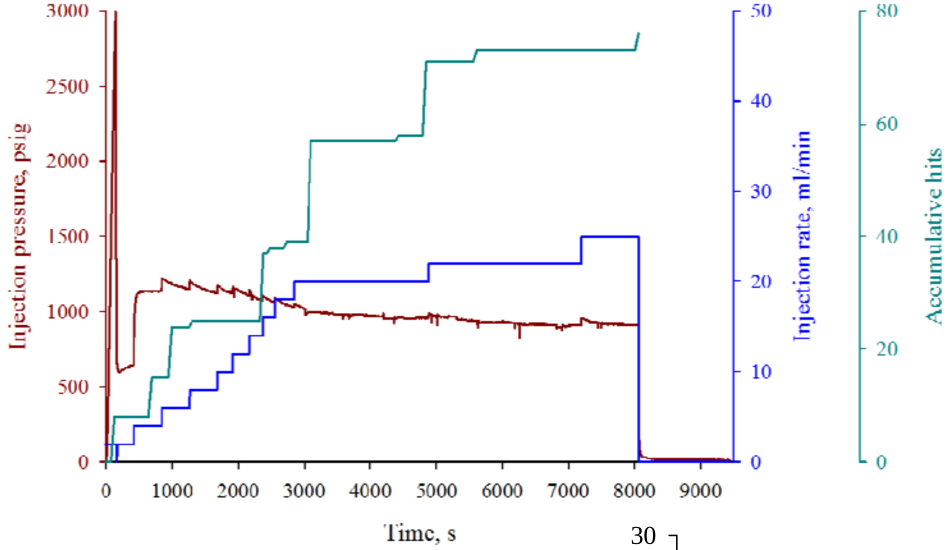
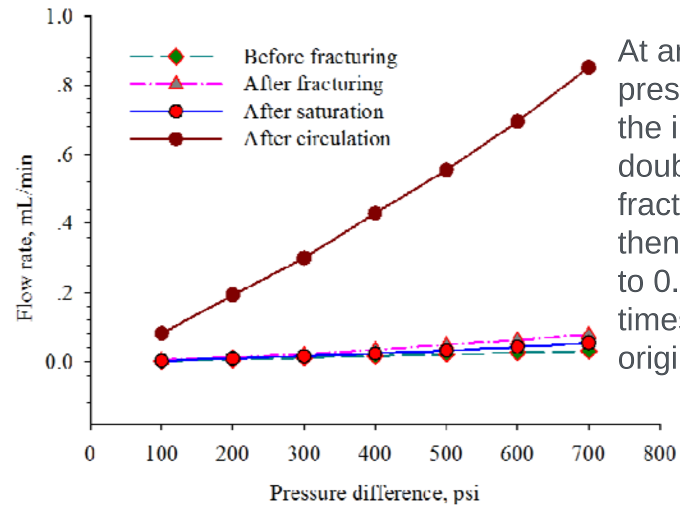
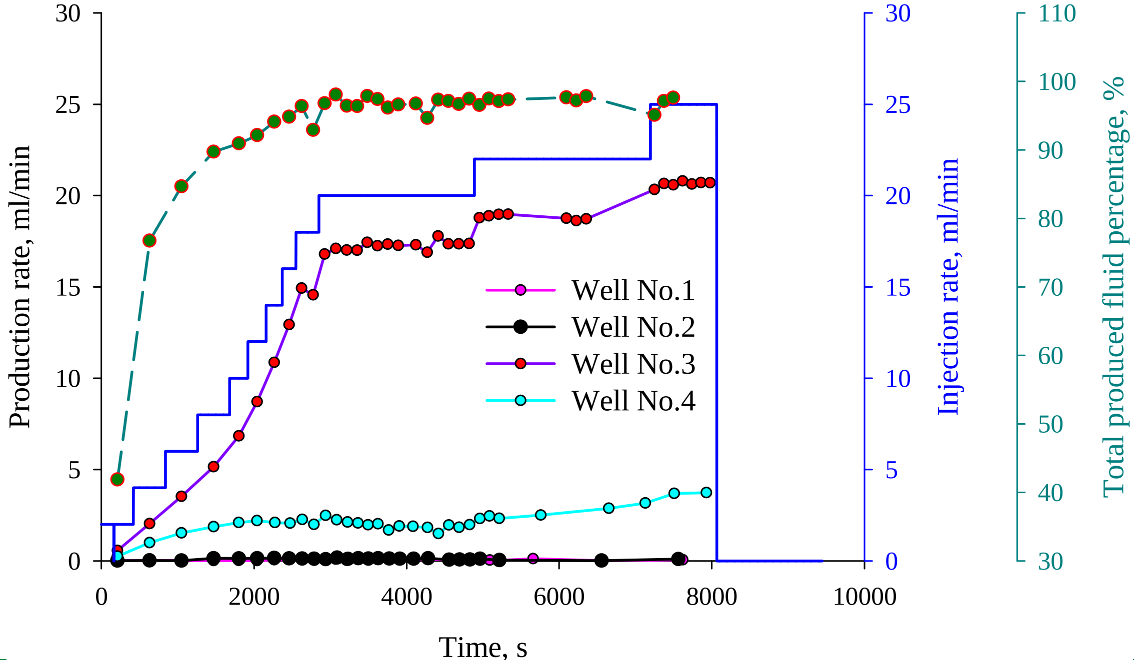
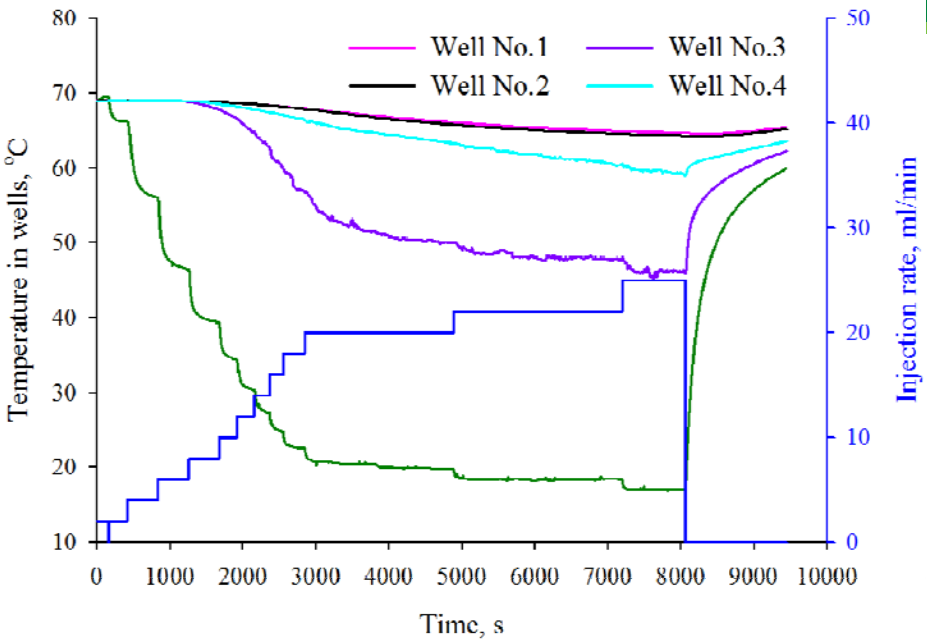




At an injection pressure of 700 psi, the injection rate doubled after fracturing test, and then further increased to 0.85 ml/min (26 times higher than the original value)

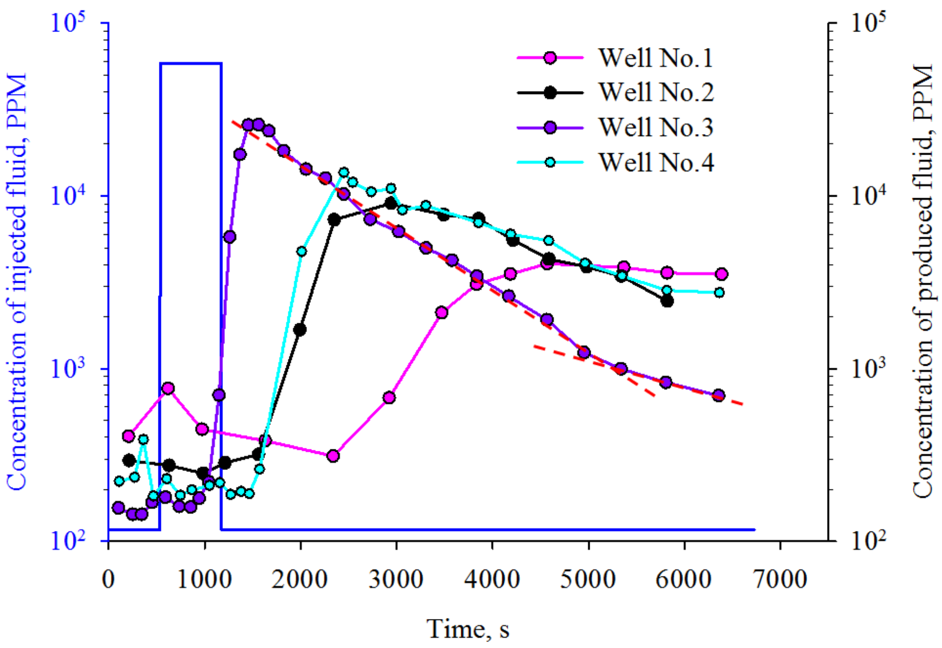
At high injection rates indicate more than 97.5% of injection fluid was recovered from production wells. Well No.3 and No.4 produced 82.8% and 14.8% of the injected fluid at the later stage. And total flow in other two production wells was less than 1.0% of the injection rate.





74 percent (295kJ) of the heat extracted by water flow in the fracture

In Well No.3, we observed the two apparent linear relationships of trace tail in semi-logarithmic coordinates.



Technical Accomplishments and Progress

1. Have developed a polyaxial system for EGS testing
   - Pore pressure, temperature, polyaxial stress
2. Have conducted small-scale stimulation experiments
   - Applied AE and SP, tracer to characterize stimulation
   - Excellent correlation between SP and pressure drop
   - Very good agreement between AE cloud and the overall fracture shape
   - Fracture mechanic and fluid flow properties, heat extraction

Our work may represent one of the 1st of its kind in terms of stimulating, SP, AE, Heat, Tracer

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Acquire rock samples, test set up	Acquire rock samples, modified/redesigned test set up	3/2015
Carry out unconfind/confined tests	Carried out unconfind/confined tests on cement blocks/rocks	9/2015
Carry out confined test at elevated Temps	Carry out confined test at 65 C	3/2016
Carry out circulation and tracer tests/analyze all data	Carried out circulation and tracer tests/analyze all data	5/2017
Carry out analysis, modeling		ongoing

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Research Collaboration and Technology Transfer

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Strong collaboration between OU and Leidos, and also Sigma-V project

- Lessons learned can be applied to Sigma-V
  - Control fracture propagation by production well temperature manipulation
  - Notch granite to facilitate transverse fracture formation
  - Determine fracture roughness coefficient
  - Study impact of scale on fracture creation and related AE, and permeability
  - Collaboration with Oil/Gas industry.

- Hu, L., Ghassemi, A. 2017. Reservoir Stimulation: Hydraulic Fracturing and Mixed-Mode Fracture Propagation. Second ARMA Workshop on Hydraulic Fracturing
- Hu, L., Ghassemi, A., Pritchett, J. and Garg, S., 2017. Experimental Investigation of Hydraulically Induced Fracture Properties in Enhanced Geothermal Reservoir Stimulation. Stanford University, Stanford, California, February 13-15, 2017
- Hu, L., Ghassemi, A., Pritchett, J. and Garg, S., 2017. Characterization of Hydraulically Induced Fracture in Lab scale Enhanced Geothermal Reservoir. 41st GRC Annual Meeting in Salt Lake City, Utah, USA
- Ghassemi, A. Hu, L., Ghassemi, A., Pritchett, J. and Garg, S., 2016. Laboratory Scale Investigation of Enhanced Geothermal Reservoir Stimulation. 41st Workshop on Geothermal Reservoir Engineering. Stanford University, Stanford, California, February 22-24, 2016
- Hu, L., Ghassemi, A., Pritchett, J. and Garg, S., 2016. Laboratory Scale Investigation of Enhanced Geothermal Reservoir Stimulation. 50th US Rock Mechanics/Geomechanics Symposium. American Rock Mechanics Association.
- Hu, L., Ghassemi, A ., Pritchett, J. and Garg, S., 2016. Experimental Simulation of Enhanced Geothermal Reservoir Stimulation. 40th GRC Annual Meeting in Sacramento, California, USA

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Future Directions

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- Lab facility and measurement/analysis methods developed and ready to be applied to other rock types
- Will test blocks from Sigma-V project, FORGE stimulation conceptual models
- Will test blocks for oil/gas operations

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Mandatory Summary Slide

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- Develop a facility to investigate a variety of EGS issues on a laboratory scale, to complement DOE's new full-scale "FORGE" EGS observatory
  - A polyaxial system for EGS testing
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- Used acoustic emissions, tracers, SP, numerical simulations to investigate fracturing, fracture area, and heat transfer processes in the laboratory with a view towards their application in the field:
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Additional Information

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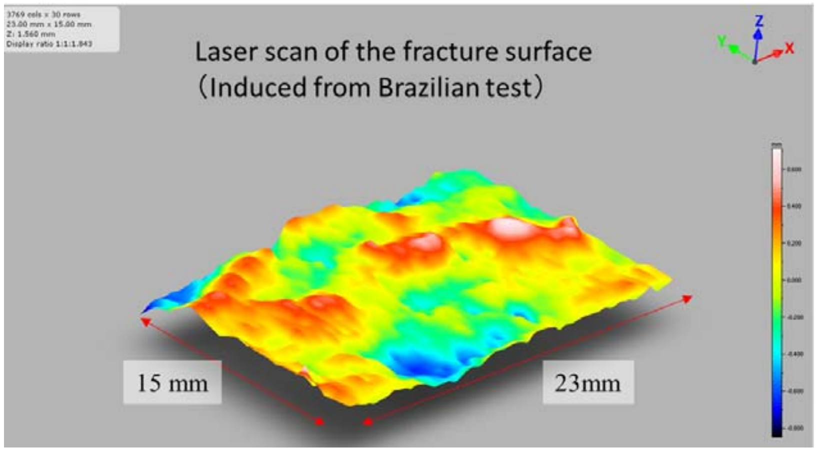
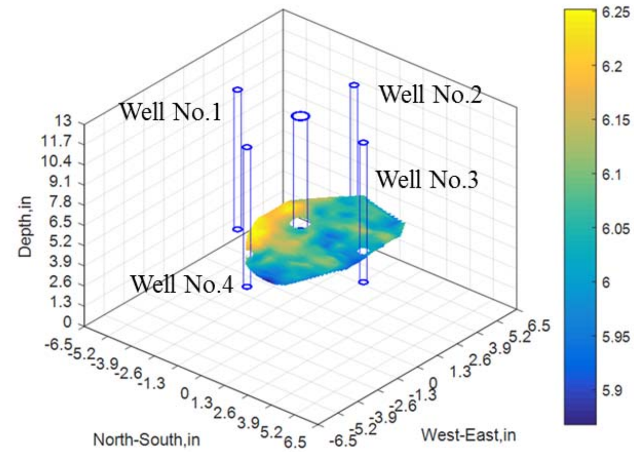
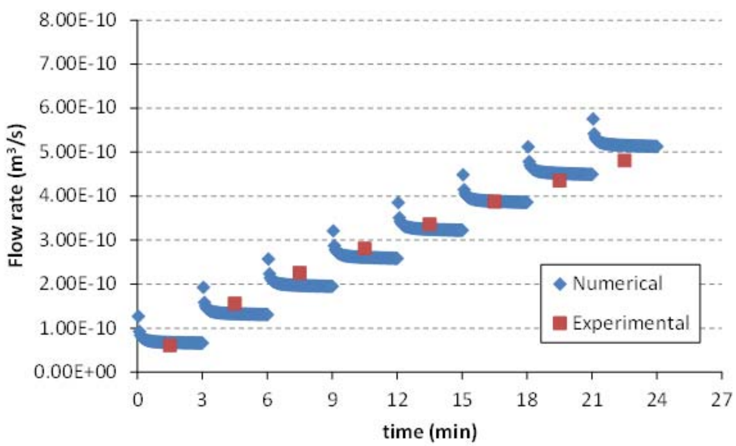


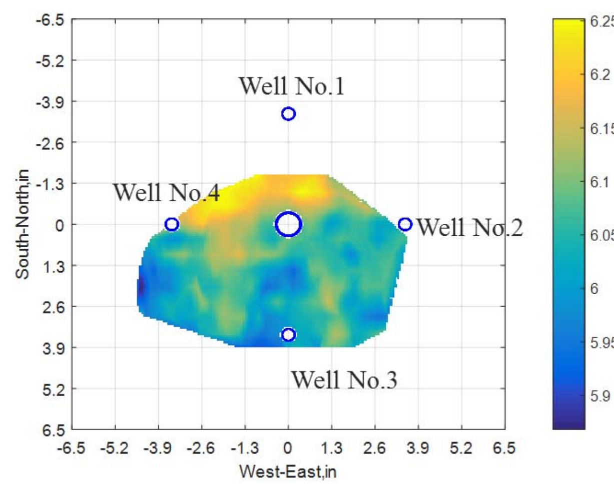
$$Z_2 = \left(\frac{1}{(N-1)(\Delta s)^2} \sum_{i=1}^{N-1} (y_{i+1} - y_i)^2 \right)^{1/2} \approx 0.1872;$$

$$JRC = 64.22 * Z_2 - 2.31 = 9.72$$





Numerical simulation: Flow rate plotted as a function of time for the case with permeability equal to 680 nD.



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