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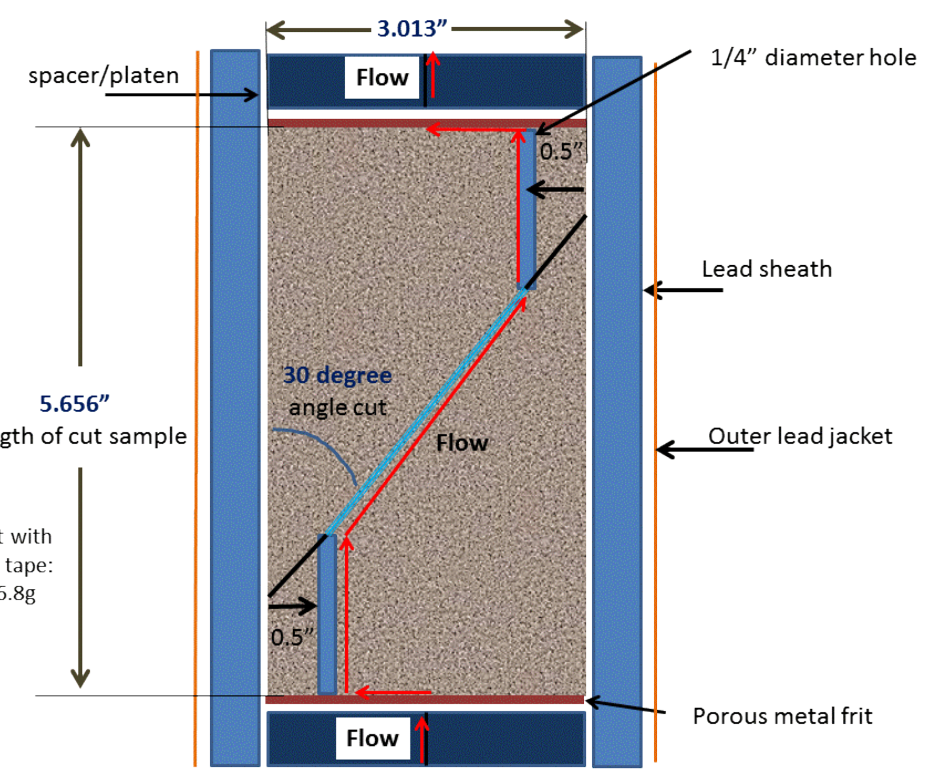

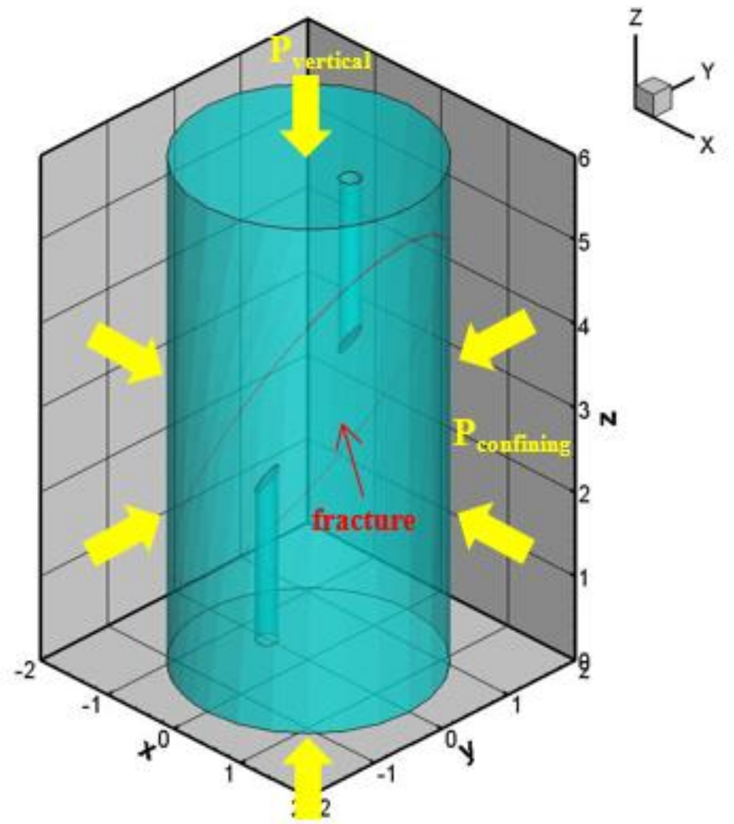

Laboratory Evaluation of EGS Shear Stimulation

Project Officer: S. Porse, D. King
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Sandia National Laboratories
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Oklahoma U

Track Name

This presentation does not contain any proprietary confidential, or otherwise restricted information.

Laboratory Evaluation of EGS Shear Stimulation

Organization: Sandia National Laboratories / Geothermal Research
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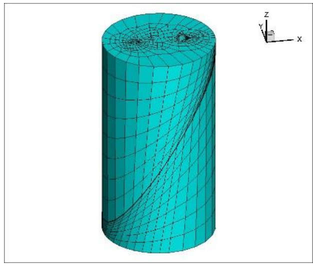
Project Team: Ahmad Ghassemi, Qinglu Chen University of Oklahoma, Perry Barrow, Sandia National Laboratories

To produce laboratory-based experimental and numerical analysis results that will provide a physics based understanding of shear stimulation phenomena (hydroshearing) and its evolution during stimulation. Water will be flowed along fractures in hot and stressed fractured rock, to promote slip.



Relevance/Impact of Research

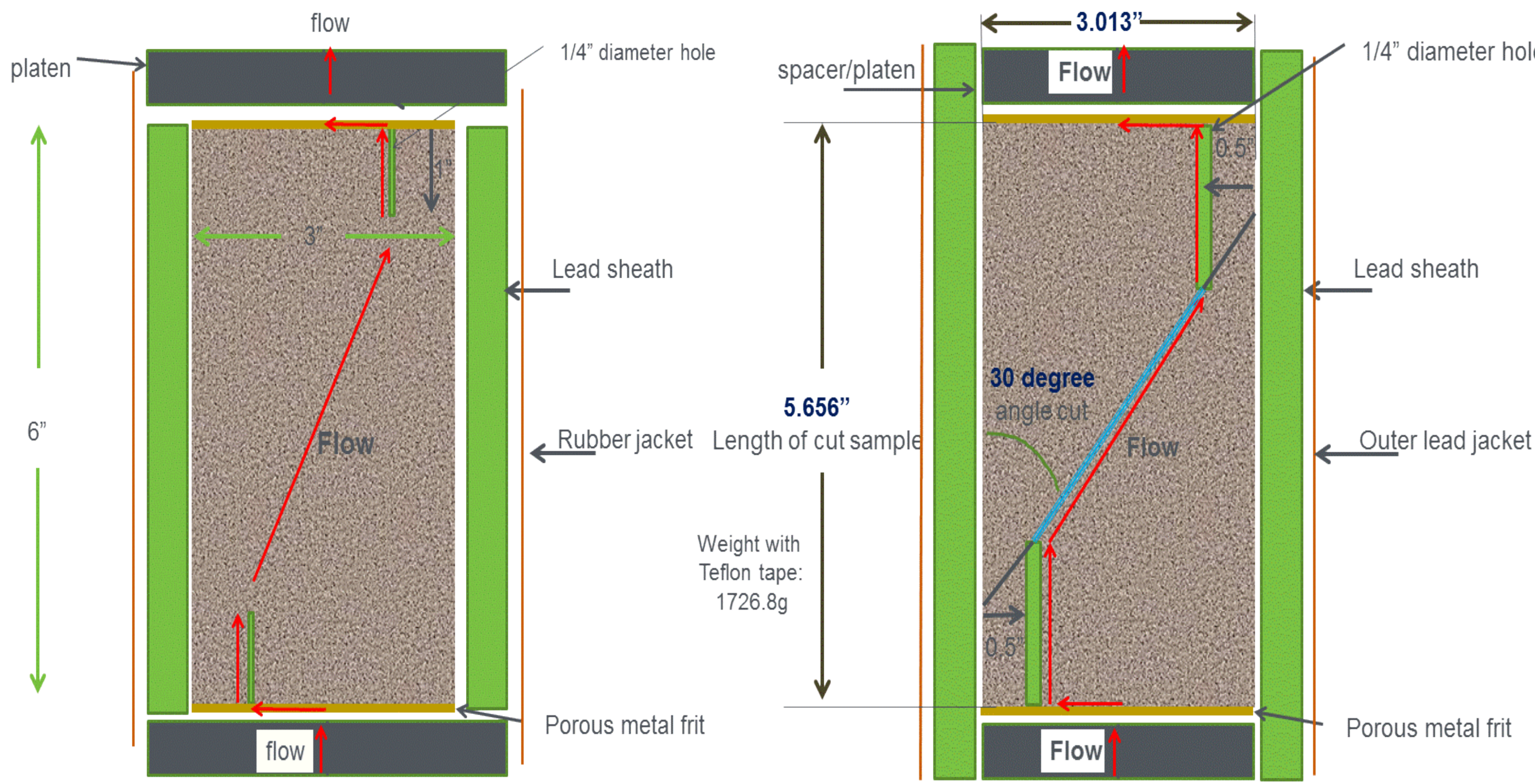
- **Provide insight to the role of fracture slip on permeability enhancement- "hydroshear"**
- **Provide insight toward the relationship between pore pressure and thermal stress and fracture shear deformation, fluid flow and AE.**
- **The goal of the project is to study the response of fracture shear deformation induced by fluid flow resulting from pore pressure changes and cooling in reservoir stimulation using laboratory experiments and modeling**

The work will provide valuable input data for stimulation models, thus helping design effective EGS.

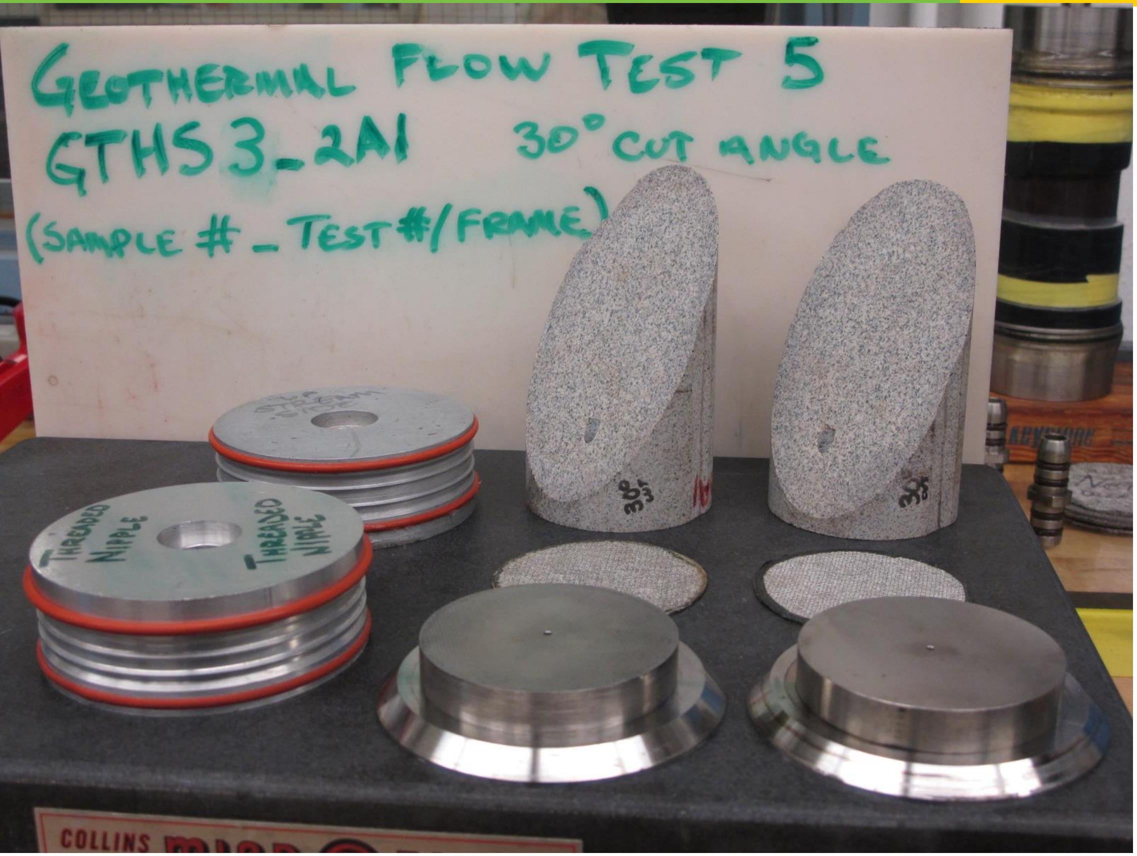
Scientific/Technical Approach

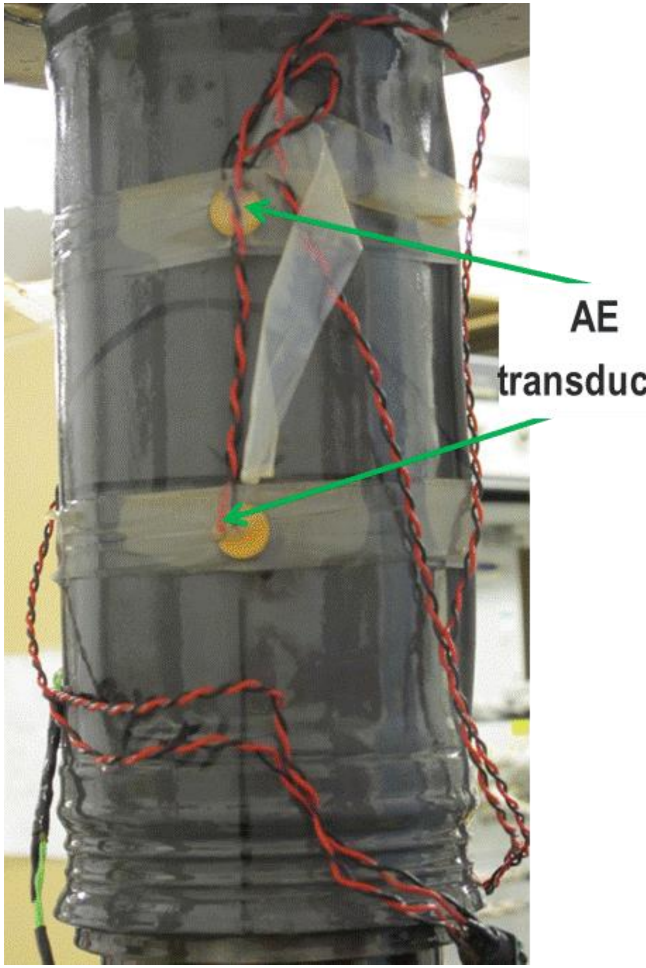
- **Development of a laboratory based experimental system**
- **Development of analysis methods to model experiments**
- **Cross pollinate results between experiment and analysis**
- **Better understand hydroshear phenomena**

Sample geometry

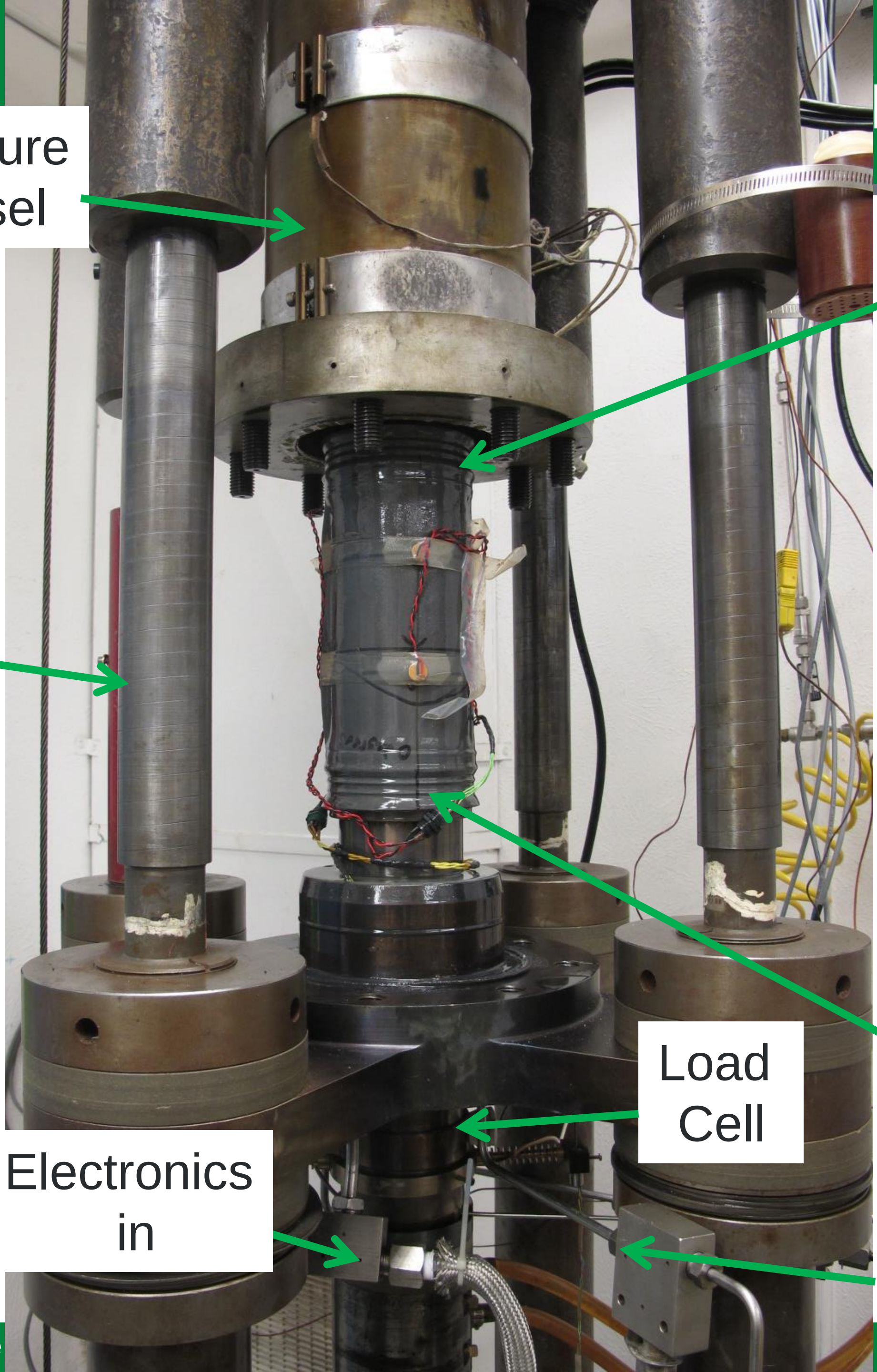


Accomplishments, Results and Progress



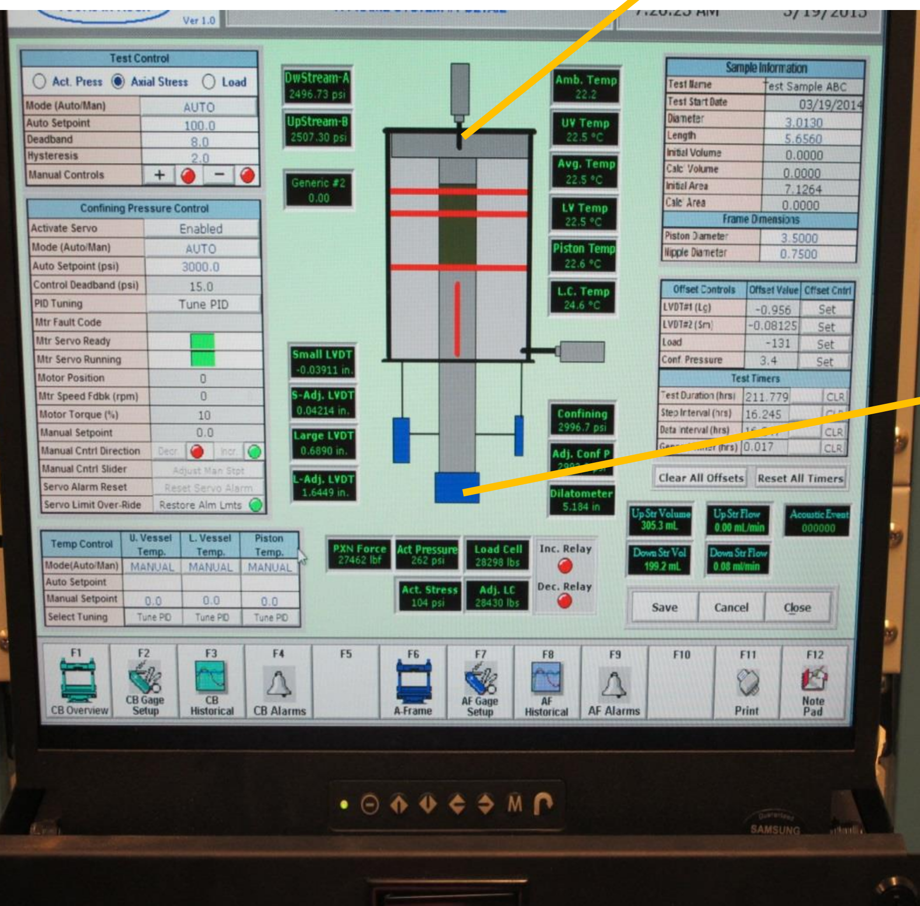


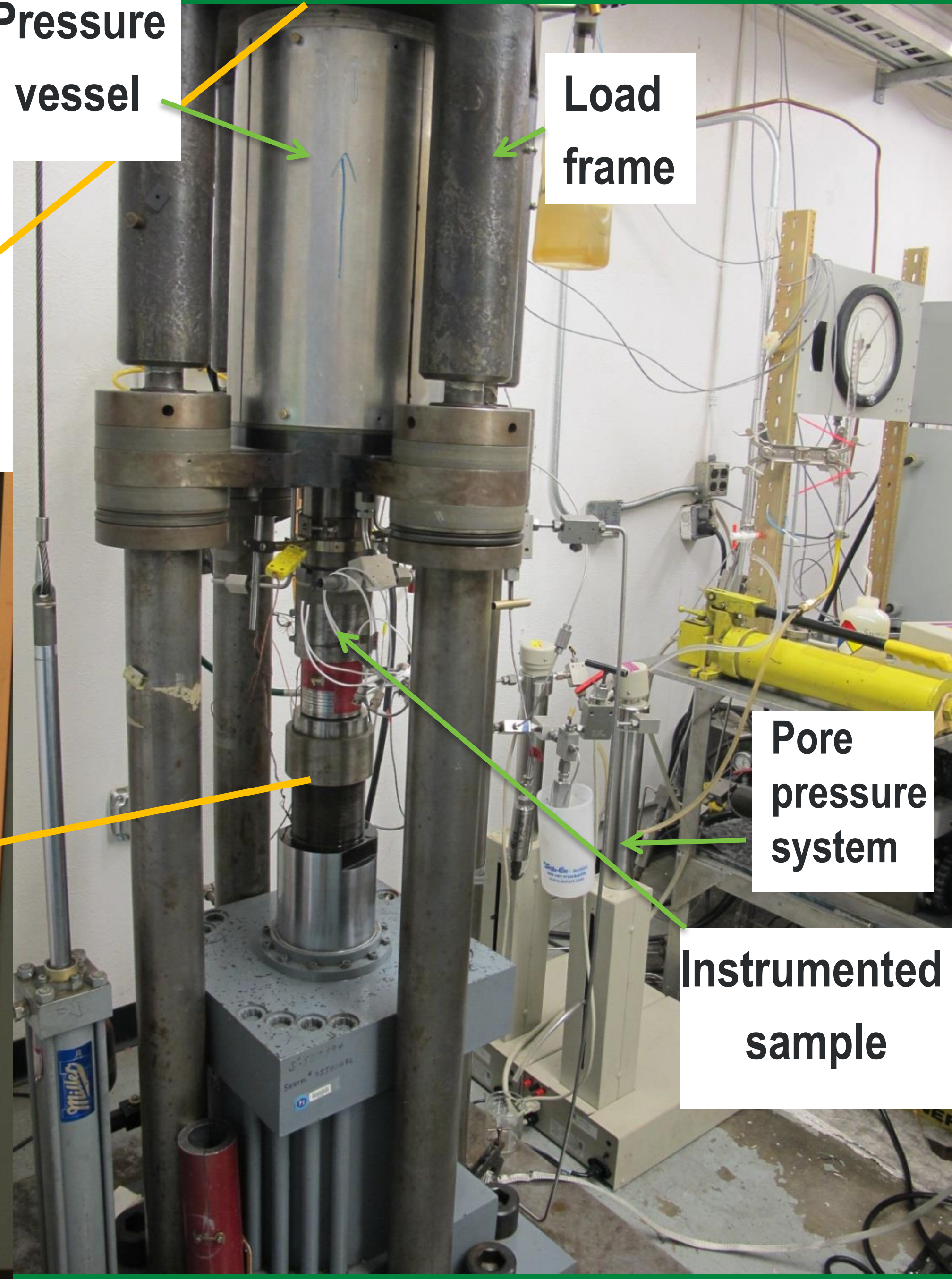
- **Confining pressure: 3000 psi**
- **Temp: 175ºC**
- **Differential Stress, Effective Stress, Pore Pressure: Varied**
- **Pore water temp 20ºC+**


Pressure vessel
Reaction Frame
Load Cell
Electronics in
Flow in

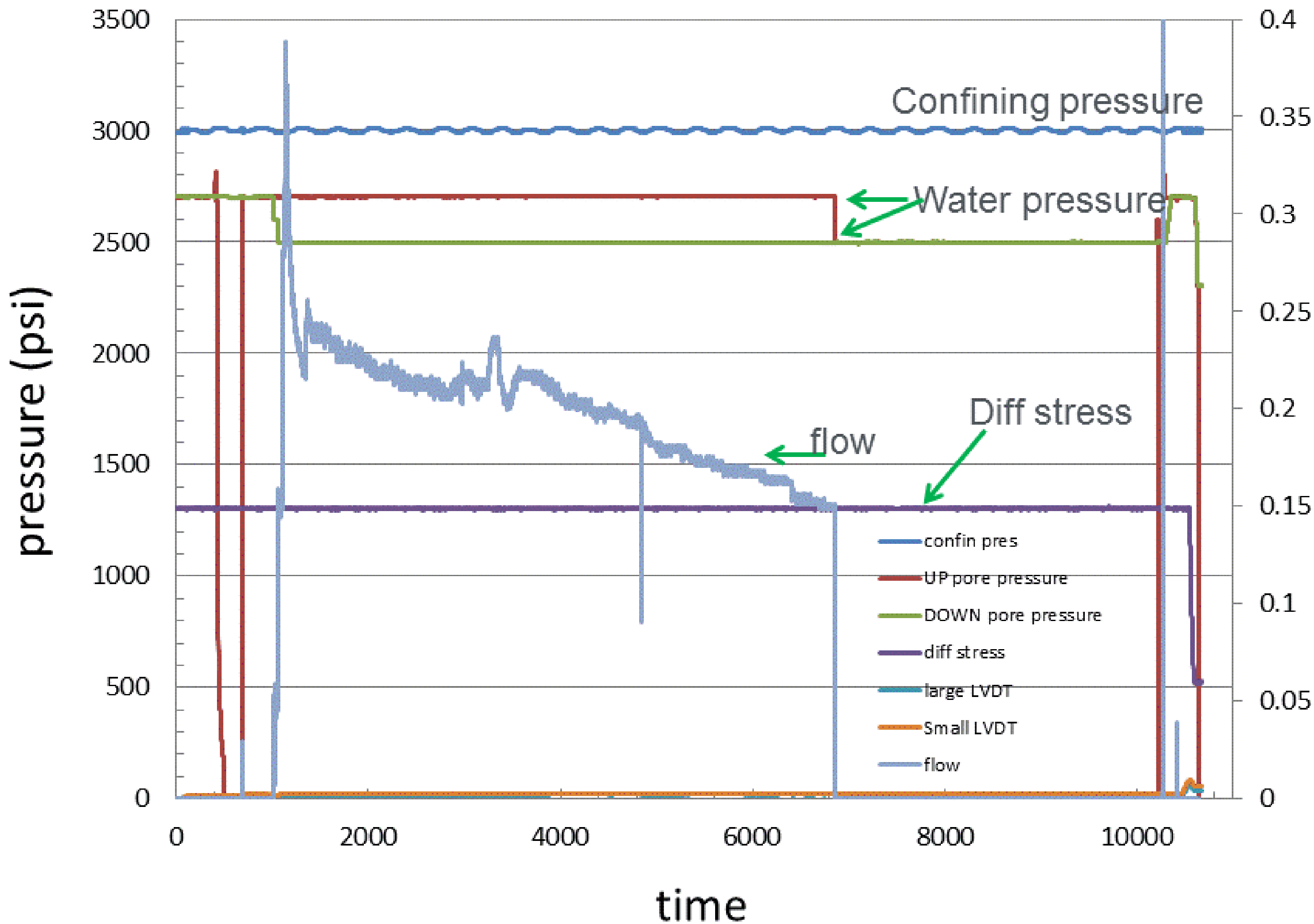
Test system

DAS/GUI

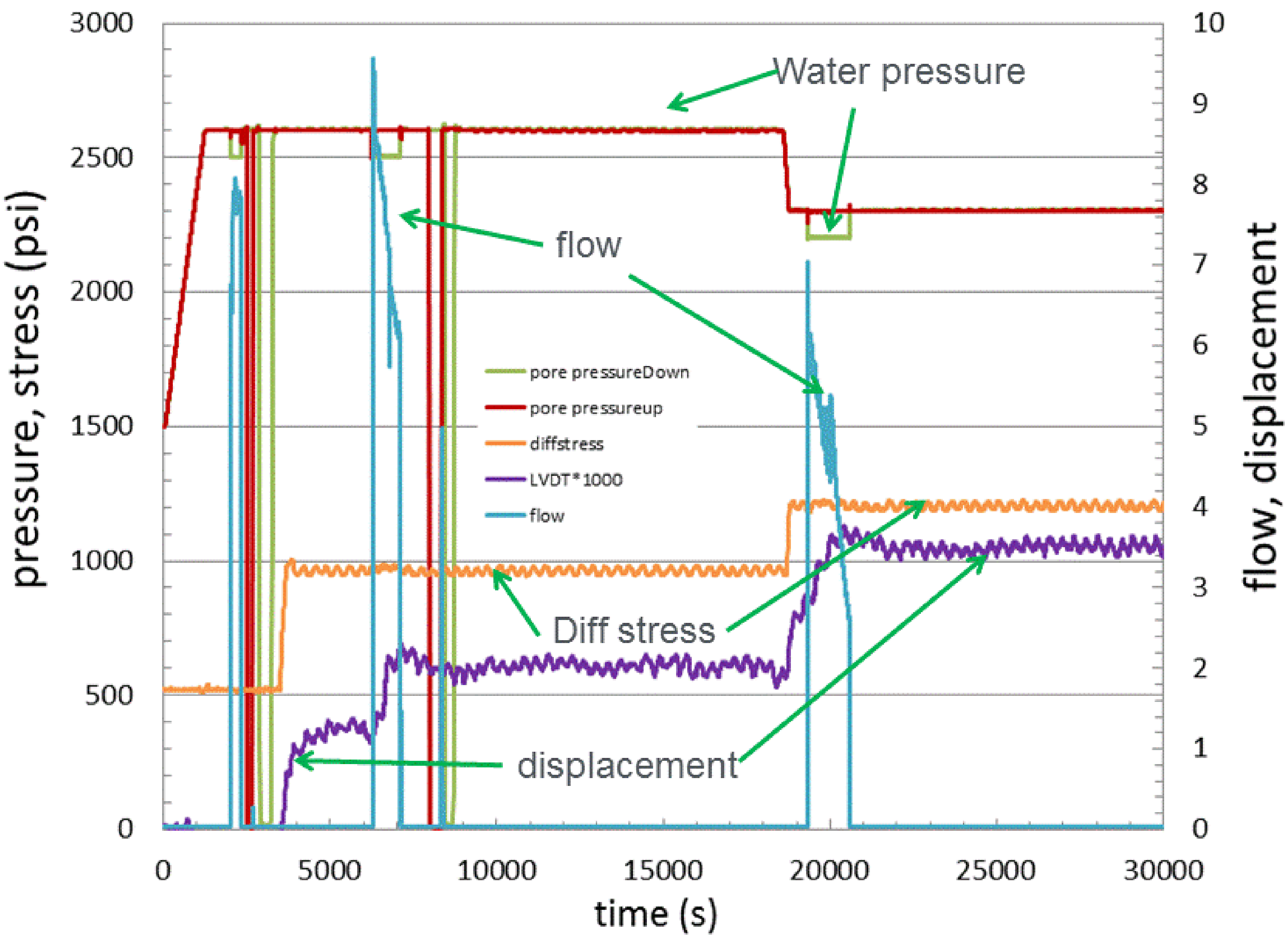




Test Conduct



Test results during flow



Numerical Simulation of Laboratory Flow Test

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Problem Description

This study involves a thermos-poroelastic analysis of a lab experiment in which a granite core specimen is subjected to water injection. The diameter and length of the specimen is 3 inch and 6 inch, respectively. Two boreholes of 0.25 inch diameter are drilled on the sample as shown in Figure 1. A diagonal fracture is introduced to simulate a fractured system. The sample is under 3000 psi confining pressure, and 4300 psi vertical stress. The initial pore pressure is 1000 psi. The pressure on the surface of the boreholes is controlled in 3 stages: 2700 psi, 2500 psi, and 2700 psi, according to experimental data (TA GTHS3_2A1-5-SlipTest-11-03-14sjba (2)). The initial temperature of the sample is 175° C and it is fixed on sample surface to simulate a constant temperature boundary. During the simulation, the heat source at the upstream borehole is held at 20° C. The properties used in the simulation are summarized in Table 1. Fracture permeability is assumed to be $1x10^5$ larger than matrix permeability.

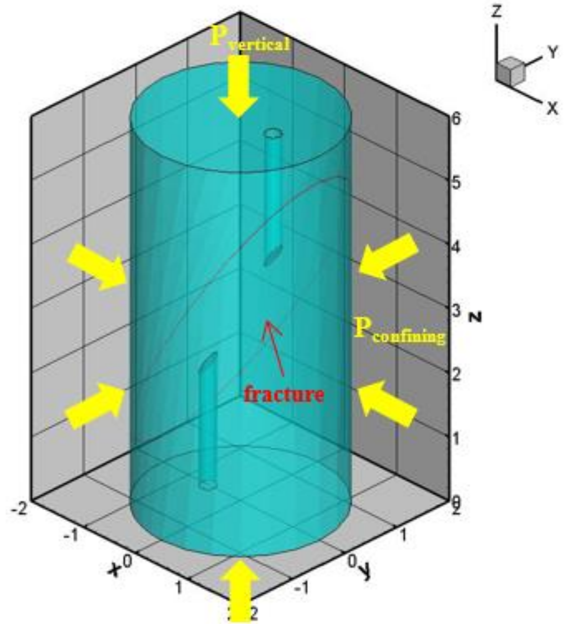

Figure 1. Specimen geometry

Young's modulus E	15.0 GPa
Biot's coefficient α	0.44
Drained Poisson's ratio ν	0.25
Undrained Poisson's ratio ν_u	0.33
Permeability coefficient k	$4\times10^{-19} m^2$
Porosity ϕ	0.01
Skempton's coefficient B	0.81
Fluid viscosity μ	$3\times10^{-4} Pa\cdot s$
Fluid diffusivity c	$7\times10^{-5} m^2/s$

Table 1. Rock properties.

Finite Element Model

Finite element formula of the governing field equations are derived using Galerkin's discretization in the space domain and Crank-Nicolson approach in the time domain. In this simulation, Cartesian mesh is used, and the specimen is discretized into 5730 hexahedral elements and 6527 nodes, as shown in Figure 2.

$$\begin{bmatrix} K & -C_{up} & -C_{uT} \\ C_{pu} & K_p + \Delta t C_{pp} & -C_{pT} \\ 0 & 0 & C_{TT} + \Delta t (K_{cdT} + K_{cvT}) \end{bmatrix} \begin{bmatrix} \Delta u \\ \Delta p \\ \Delta T \end{bmatrix} = \begin{bmatrix} \Delta t \dot{F}_u \\ \Delta t F_{qin} - \Delta t C_{pp} p_{t-\Delta t} \\ \Delta t F_{hin} - \Delta t (K_{cdT} + K_{cvT}) T_{t-\Delta t} \end{bmatrix}$$

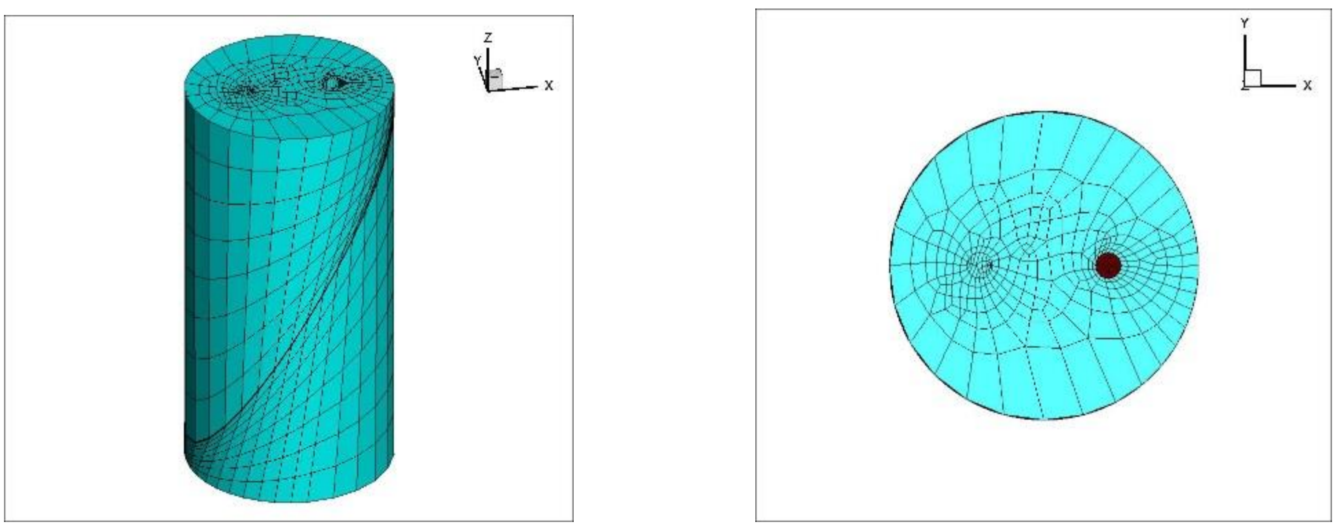

Figure 2. Finite element model

Simulation/experiment

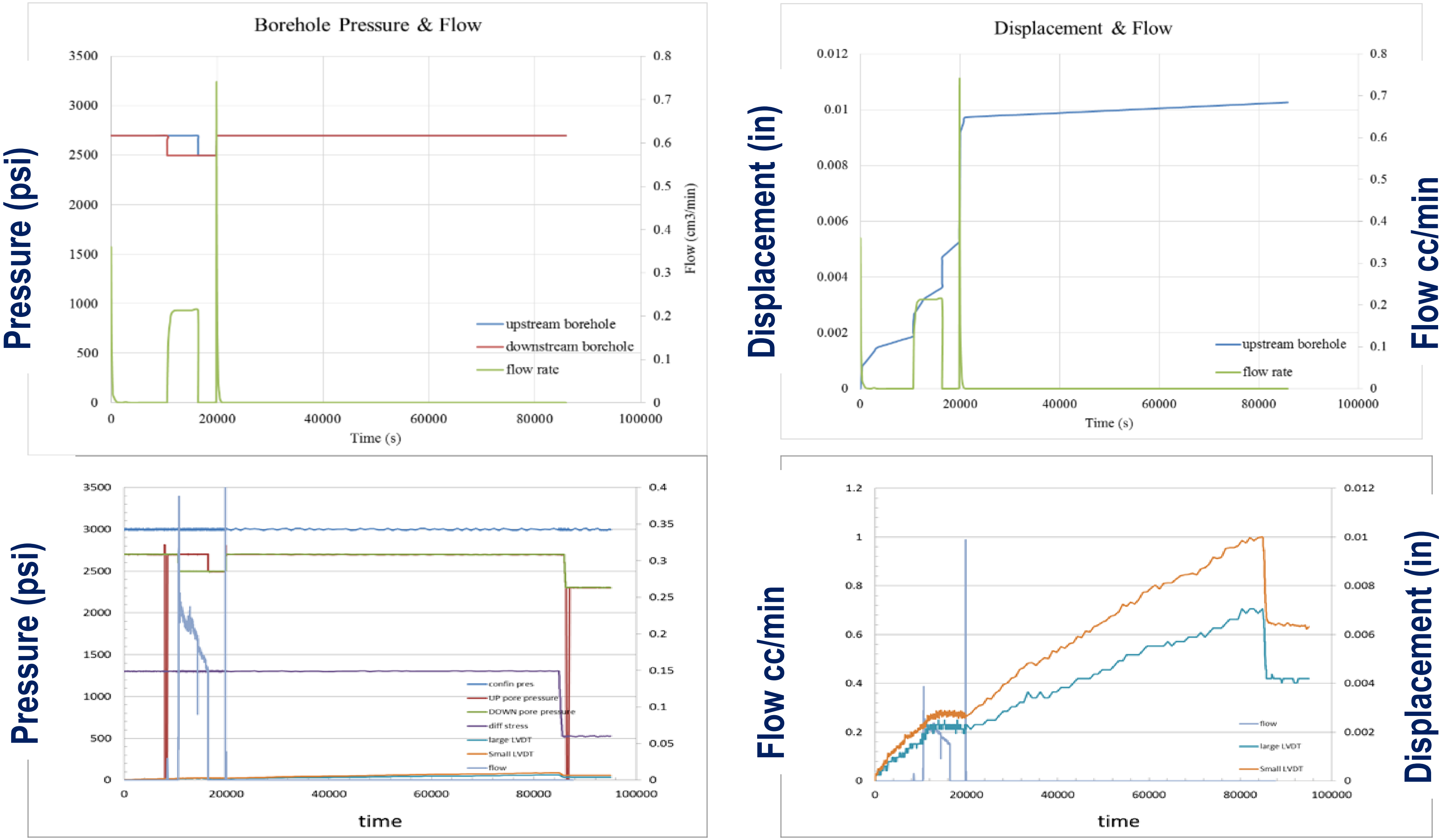

Figure 3. Borehole pressure, displacement, flow evolution with time.

Accomplishments, Results and Progress

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Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Milestone Name/Description	End Date	Type
Complete analysis based experiment design and select feasible experimental paths forward. In parallel, complete a portion of the first series of experiment(s) incorporating induced fractures. Tests will include fluid flow measurements at elevated temperatures and pressures (temperatures to be determined through preceding analyses). Parallel analysis and experimental work effort will help improve progress.	Designed and fabricated experimental system, system designed based on a combination of experience, and stretching of test system (flow through at high temperature, long test time duration, high temperature, pressure stable test environment	12/31/2014 (target) 11/30/2014-complete
Complete first series of experiments. Results from the experiments will be used to provide feedback to improve experimental design, experimental conduct, and data collected in the second series of experiments.	Check	3/31/2015 (target) 3/31/2015
Conclude and document first series experimental results.	6/30/2015	6/30/2015 (target) 9/15/2015-planned
(SMART) Assuming successful completion of go no go, Complete 2nd set of experiment(s) incorporating velocity measurements and AE transducers. Test will include fluid flow measurements at elevated temperatures and pressures (temperatures to be determined through analyses of preceding tasks). Report on FY15 activities through publication	9/30/2015	9/30/2015 (target) 12/30/2015-planned

Future Directions

- Measure AE events, correlate with slip events
- Determine surface profile
- Complete analyze of additional loading scenarios/boundary conditions
- Input to data repository
- Document results

Milestone or Go/No-Go			Status & Expected Completion Date
Test System Capability	Compare the test systems ability to conduct experiments with analysis based test requirements. If experiments cannot be performed to support the analytical activities the project should be ended.	See Above	6/30/2015

Mandatory Summary Slide

The experimental effort has developed a technique to conduct, observe and measure shear displacement resulting from introduction of cool water to a hot wet stressed fracture.

Induced displacement: flow, effective stress

The analysis effort has developed a method to model, observe and determine heat transfer, fluid flow and shear displacement shear displacement resulting from introduction of cool water to a hot wet stressed fracture.