Testing stimulation concepts for an Enhanced Geothermal System (EGS) in a deep mine: the U.S. EGS Collab Project

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A Diverse and Brilliant Team Coming Together to Answer EGS Questions

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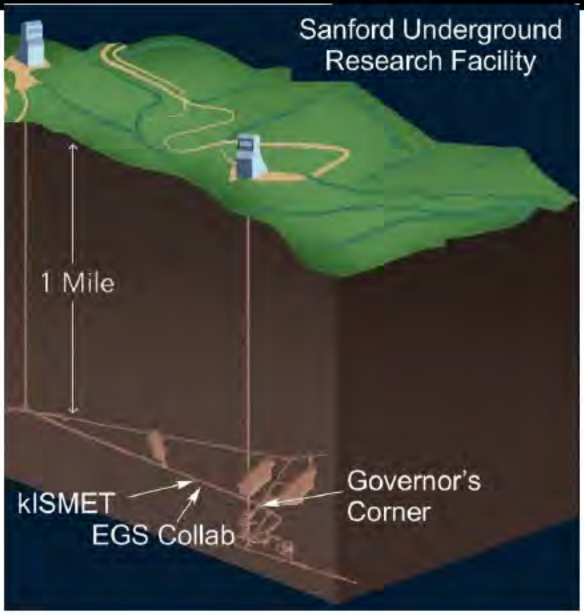
Leland Stanford Junior University
The Pennsylvania State University 1855
Colorado School of Mines
South Dakota School of Mines & Technology
The University of Wisconsin Madison
Berkeley Lab
Lawrence Livermore National Laboratory
Pacific Northwest National Laboratory
INL Idaho National Laboratory
Sandia National Laboratories
Los Alamos National Laboratory
NREL National Renewable Energy Laboratory
Oak Ridge National Laboratory
Sanford Underground Research Facility
TDoeGeo Rock Fracture Consulting
McClure Geomechanics

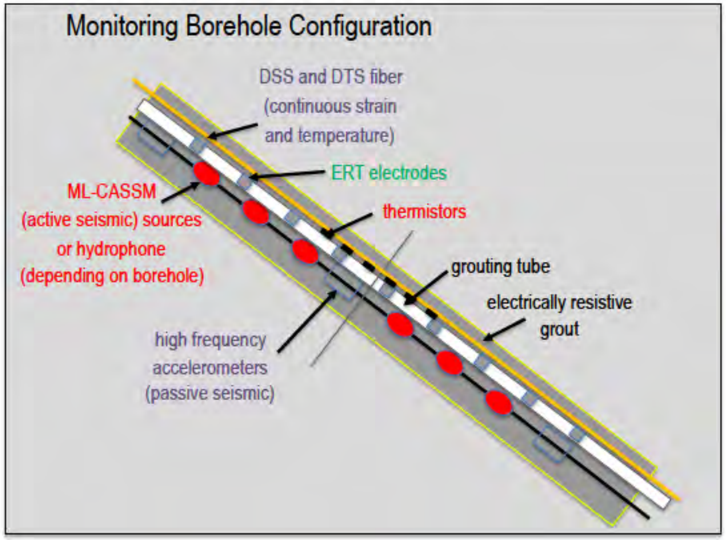
Department of Energy United States of America

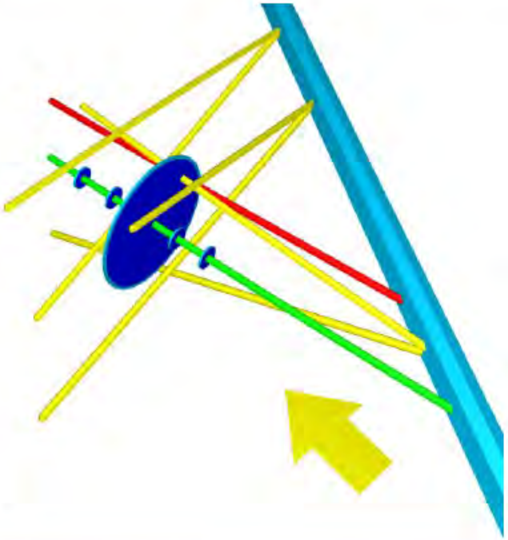
Additional collaborations with Schlumberger, LUNA, Georgia Tech, AIST, Sinopec, and Florian Amann

Overview of Project and Goals

- Demonstrate and set stage for validation of software essential for FORGE and commercial-scale EGS
- Experiment 1 will investigate hydraulic fracturing, and will be performed in the Sanford Underground Research Facility (SURF) at 1478 m depth.
- Experiment 2 will be designed to investigate hydroshearing.
- Experiment 3 will investigate changes in fracturing strategies.
- Each experiment will be heavily instrumented and will generate 10s TB data…







Challenges and opportunities…

- Siting and basic borehole layout
- Preliminary hydraulic fracture studies
- Completion design – notching to limit near wellbore tortuosity
- Thermal stress influence
- Monitoring
- Flow testing

→ Team approach has lead to solutions

Our objectives for Experiment 1

- Deliver a robust plan for stimulation and flow testing with minimal risk
  - Identify and resolve competing objectives
  - Identify/anticipate roadblocks and interdependencies

Our approach:

- Leverage multidisciplinary team across labs, industry, and academia
- Build a testbed for validation of stimulation, flow, and monitoring
- Take advantage of access to the rock

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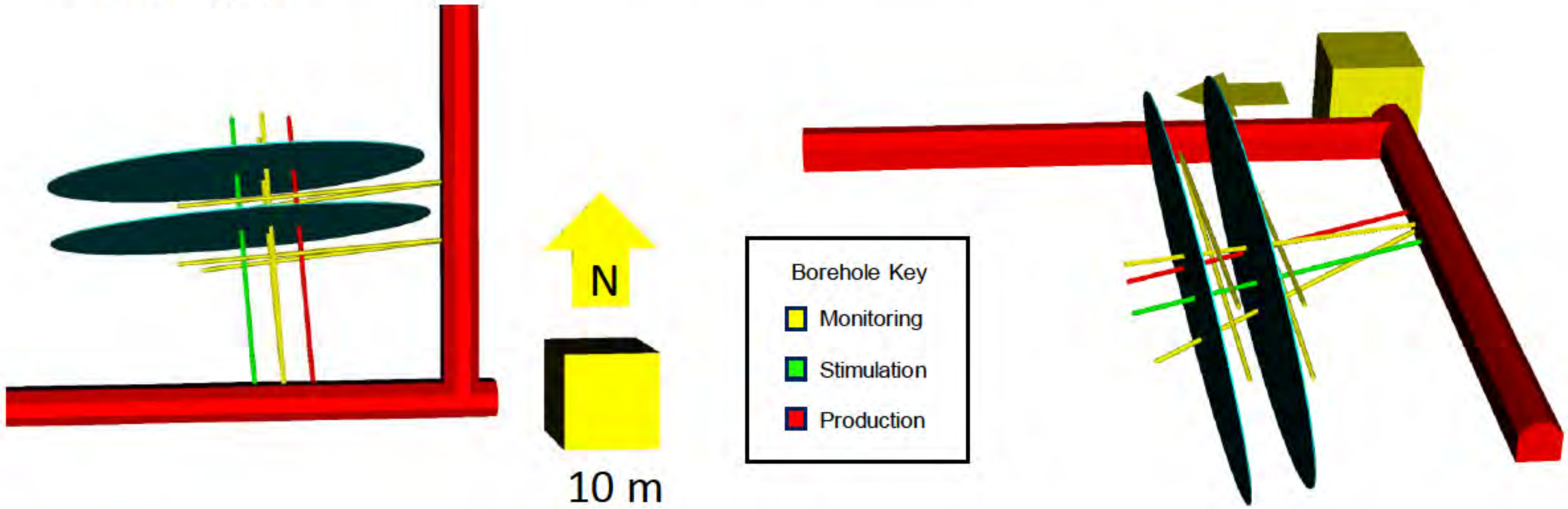
Siting of Experiment 1: The Dream

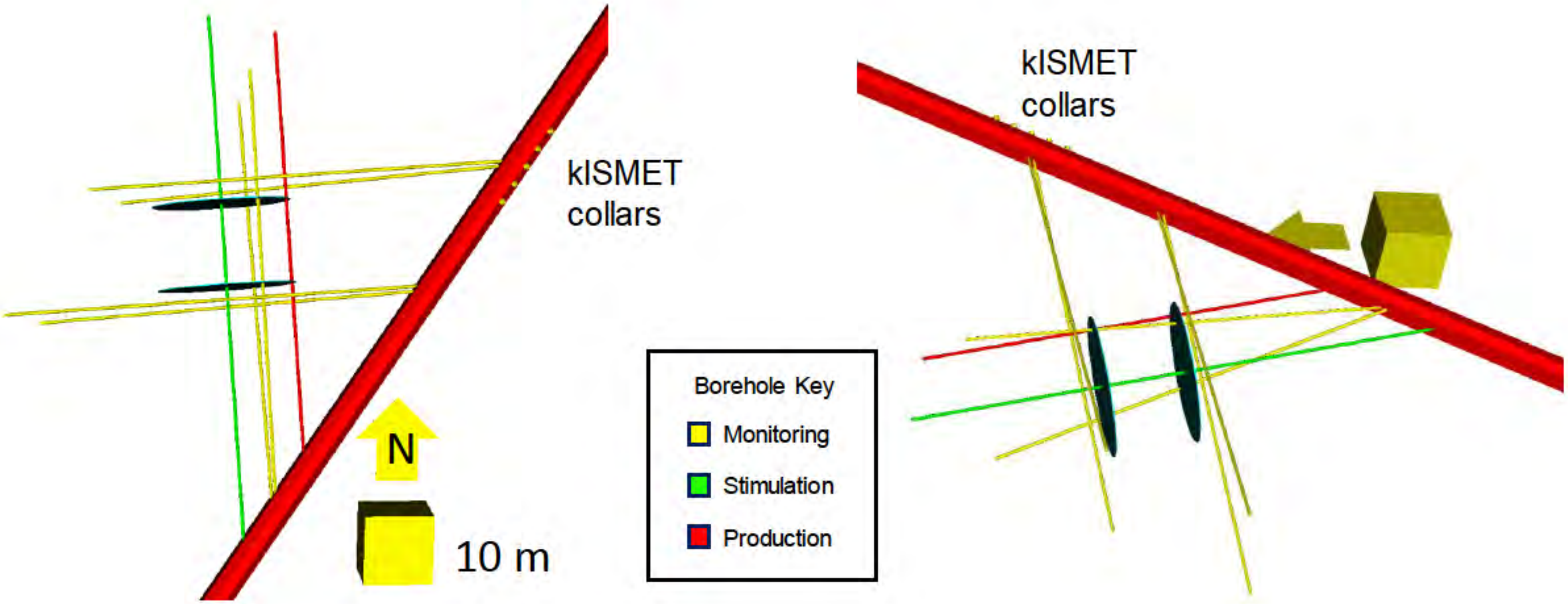
- Hydraulic fractures (HF) expected to open against minimum horizontal stress
  - HF strike at ~86 degrees
- Wouldn't it be great to access/monitor HFs from two drifts?



- Such locations lack necessary infrastructure

Siting of Experiment 1: The Reality

- If the drift runs at an angle to the principal stresses…



…you can deploy parallel and perpendicular observation holes by ***moving down the drift***

- kISMET location meets geometric and infrastructure requirements

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Preliminary Analysis: Toughness Dominated

$$\mathcal{K} = K' \left(\frac{t^2}{\mu'^5 Q_0^3 E'^{13}} \right)^{1/18} \qquad \mathcal{M} = \mu' \left(\frac{Q_0^3 E'^{13}}{K'^{18} t^2} \right)^{1/5}$$

$$K' = 4(2/\pi)^{0.5} K_{IC} \qquad E' = E/(1-\nu^2) \qquad \mu' = 12\mu$$

Detournay (2004)

Property	Value
Rock Young's modulus, E	71.4 GPa
Rock Poisson's ratio, ν	0.22
S_{hmin}	20 MPa

Property	Value
K_{IC}	1.0 MPa(m)$^{0.5}$
Fluid viscosity, μ	0.001 Pa s
Fluid density, ρ	1000 kg/m^3

0.1 L/s → $\mathcal{K}$=1.44 and $\mathcal{M}$=0.24 → **Toughness dominated**

10 min/60 L → 15.5 m and an aperture of 118 microns

17 min/100 L → 19.8 m

Note: Consistent with Äspö (Zang et al., 2017) observations in similar rock

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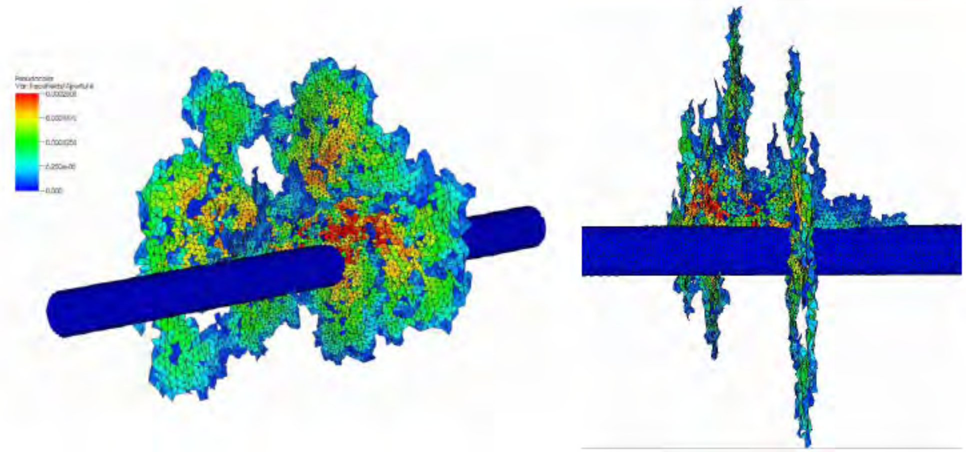
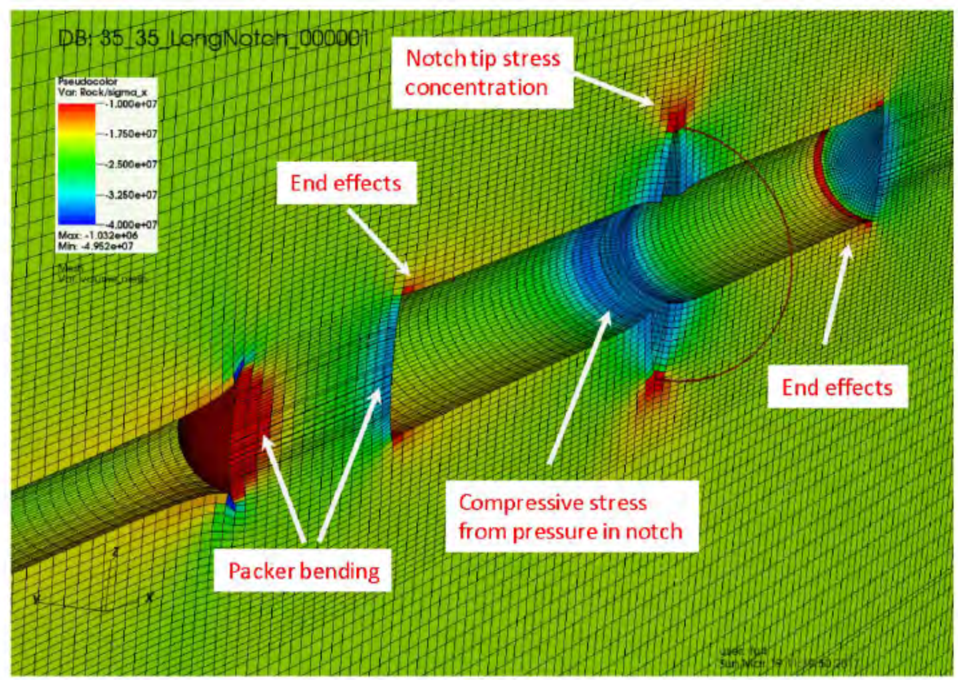
HF Initiation is a Challenge…

Challenge: Near wellbore tortuosity can prevent effective initiation

Solution:

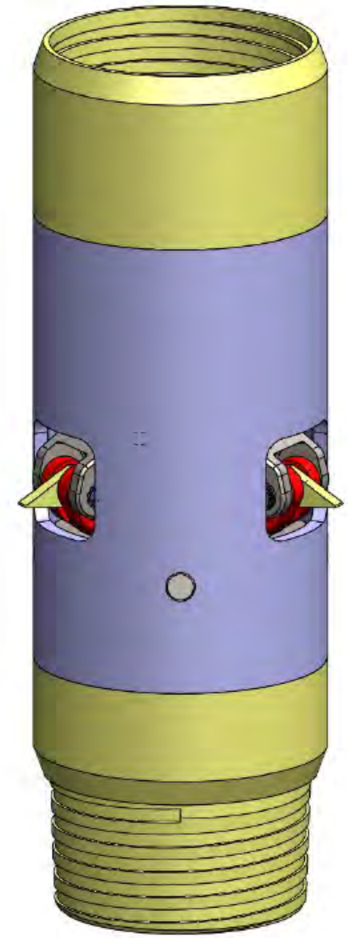
- Notching encourages perpendicular fracture
- Models quantified notch geometry required to overwhelm such effects





A New Notching Tool was Developed

- Extend carbide/polycrystalline-diamond cutters into borehole wall
- Deployed on HQ-sized coring rod
- Rotated by the rig to notch.
- Notch cutters extend diametrically using water pressure supplied by drilling system.



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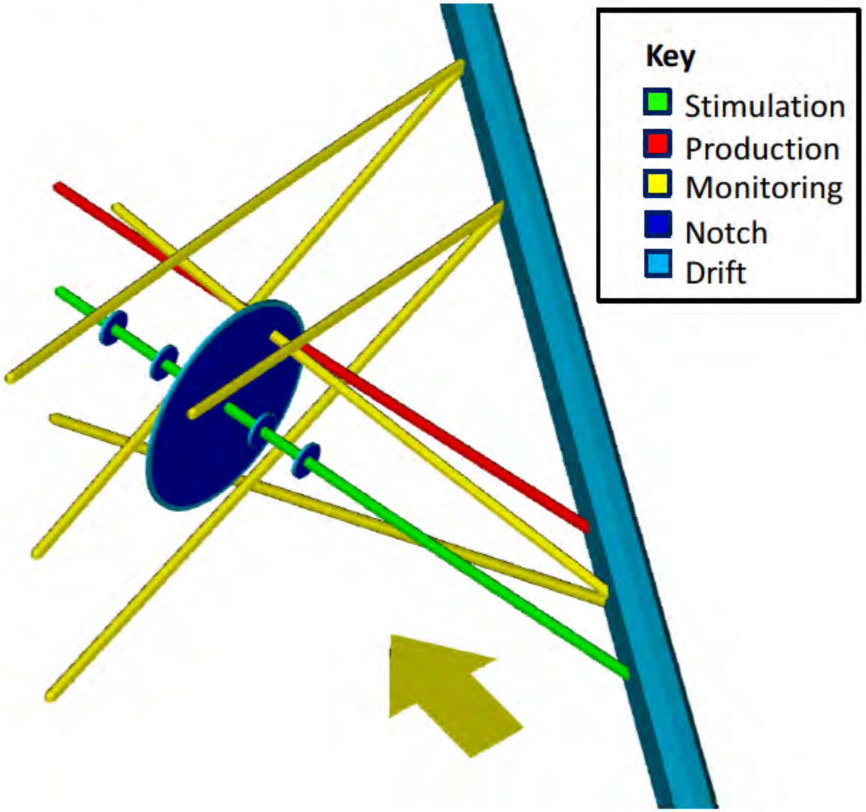
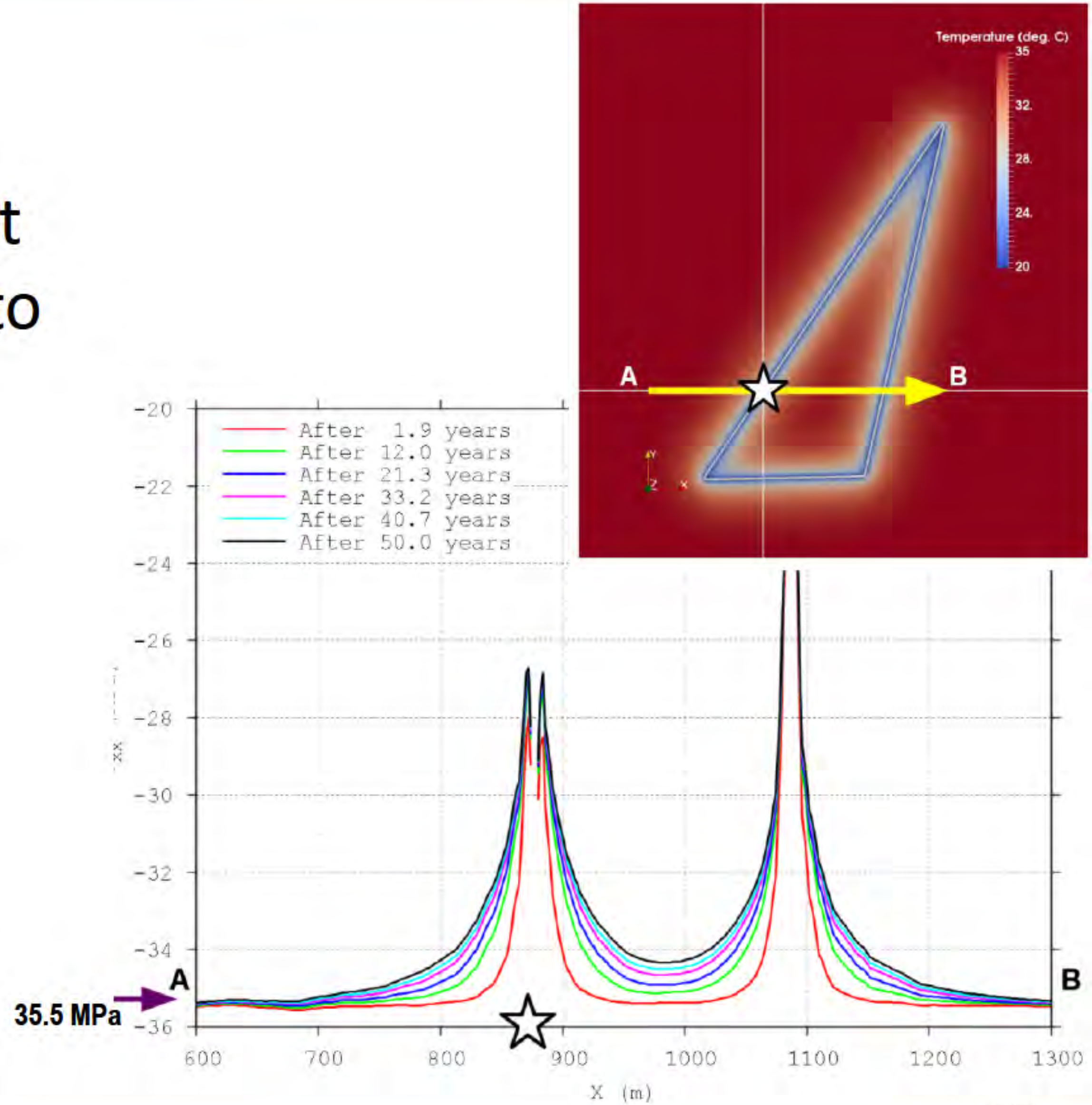
Several Notches were placed



Model results indicate notching should be sufficient to limit near wellbore tortuosity

Ventilation May Induce Stress Gradients

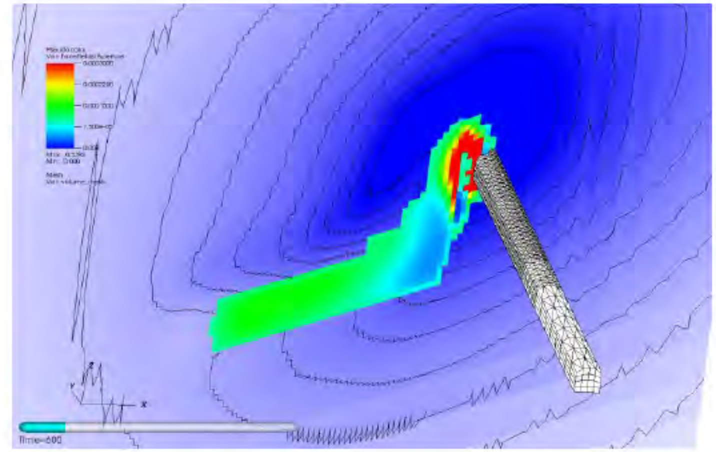
- Analysis indicates potential for significant thermal gradient due to cooling from drift
- 3D stress modeling quantifies the stress gradient

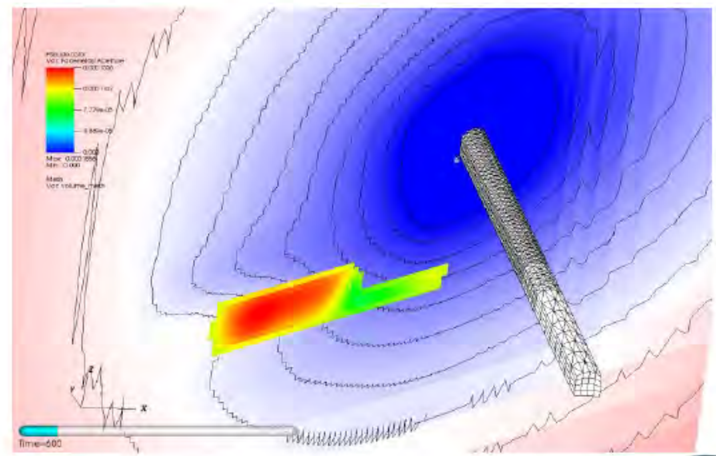


Thermal Gradient May Offer V&V Opportunity

How might thermal stress influence stimulation?

- Multiple analyses indicate stress gradient will encourage growth toward drift
- Suitably placed producing borehole for drainage may arrest fracture growth





V&V: Well-characterized stress gradient rather than “statistical” heterogeneity

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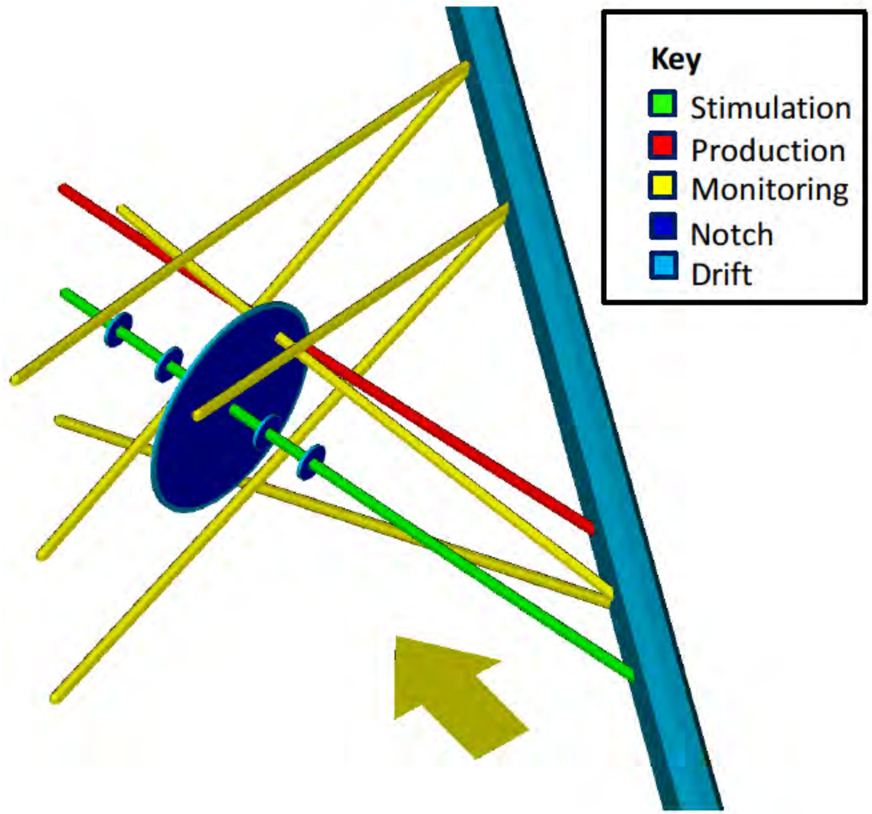
Monitoring: Multiple methods

- Multiple methods will be employed to monitor the hydrofracture and flow-through experiments
- ***This will help quantify fracture area***
- Leverage the different borehole orientations



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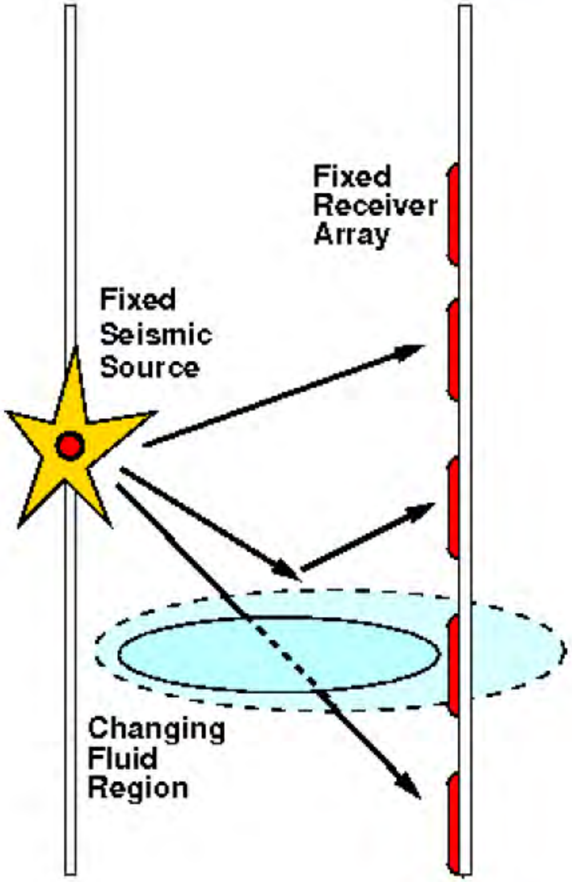
Monitoring: CASSM

Continuous Active Source Seismic Monitoring

- **Concept** : Fully automated seismic acquisition system with stationary S/R geometry.

- Rapid switching allows fast acquisition of tomographic datasets (< 1 minute).

- Stationary components increases measurement repeatability & detection of subtle signatures.



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Monitoring: Passive Microseismic

- Can help to understand patterns of fracture developments, connectivity and the impacts from in-situ stress, rock fabric and existing fractures or discontinuities.
- MEQ monitoring at the EGS Collab site will be carried out using high sensitivity three component (3C) accelerometers that will be installed in the monitoring boreholes

Monitoring: Acoustic Emissions

- Similar to MEQ monitoring
- Targets very high frequencies
- Requires
  a) faster recording rates, often including triggering,
  b) special purpose transducers tuned to AE band
  c) special attention to transducer installation to preserve higher frequency coupling
- Can provide time-resolved image of fracture advancement and failure modes

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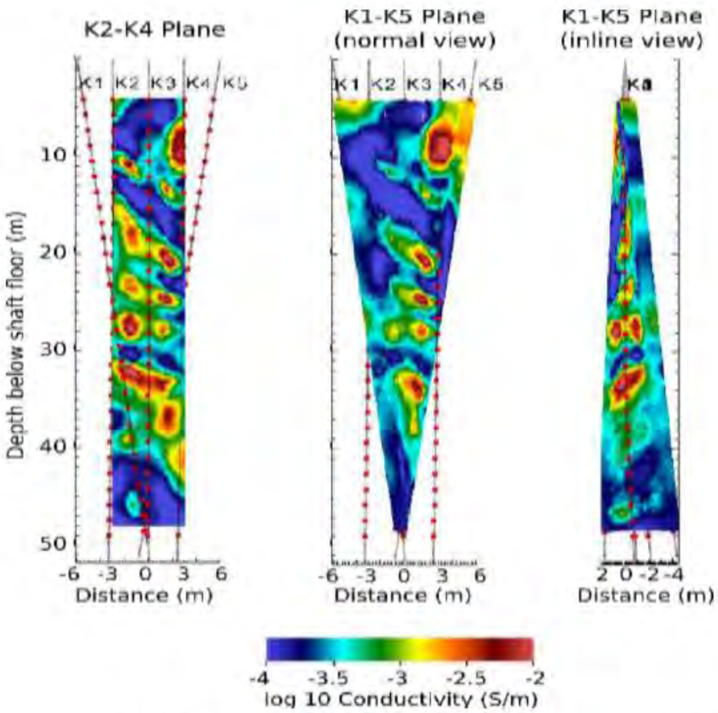
Monitoring: ERT

- Sensitive to changes in temperature, fluid saturation and fluid conductivity
- Seek to image
  - baseline conductivity
  - fracture geometry
  - fluid transport
  - temperature changes



kISMET ERT (Oldenburg et al, 2016)

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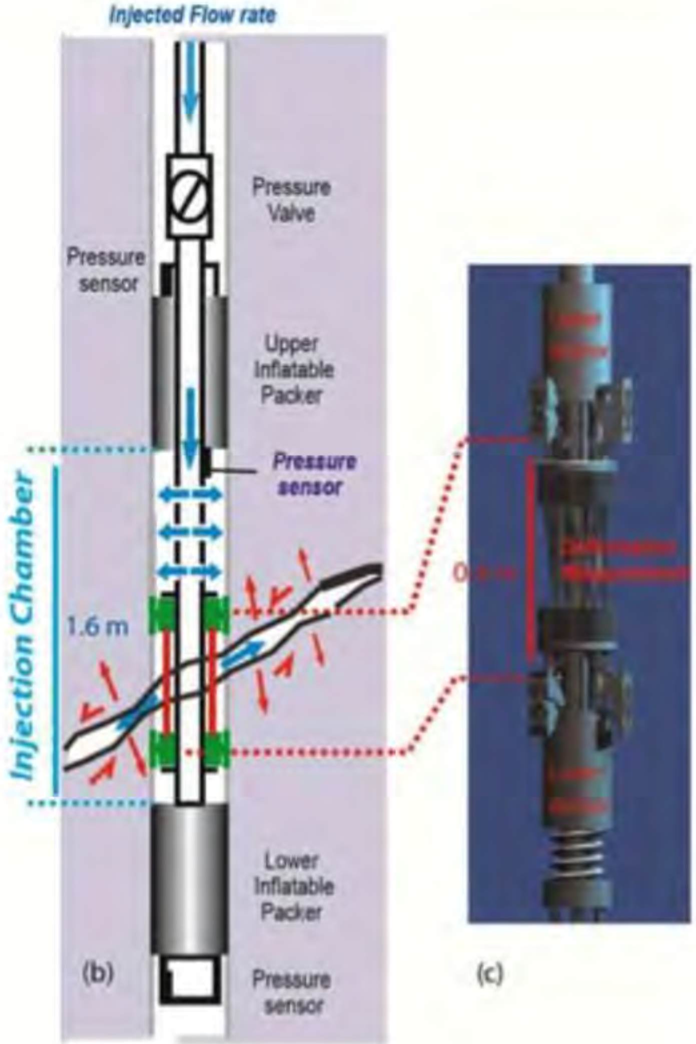
Monitoring: Borehole Deformation

- Step-rate Injection Method for Fracture In-situ Properties (SIMFIP) tool
- 6-component optical strain system
- Allows hydraulic isolation and deformation measurement during injection



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Monitoring: DTS, DSS, DAS

- Distributed temperature (DTS), strain (DSS), and acoustic (DAS)
- Low deployment cost
- Excellent performance at high temperatures when appropriate packaging is chosen
- DSS provides constraints on fracture intersection the 6 monitoring boreholes
- DTS provides additional constraint on evolving temperature field during thermal tests

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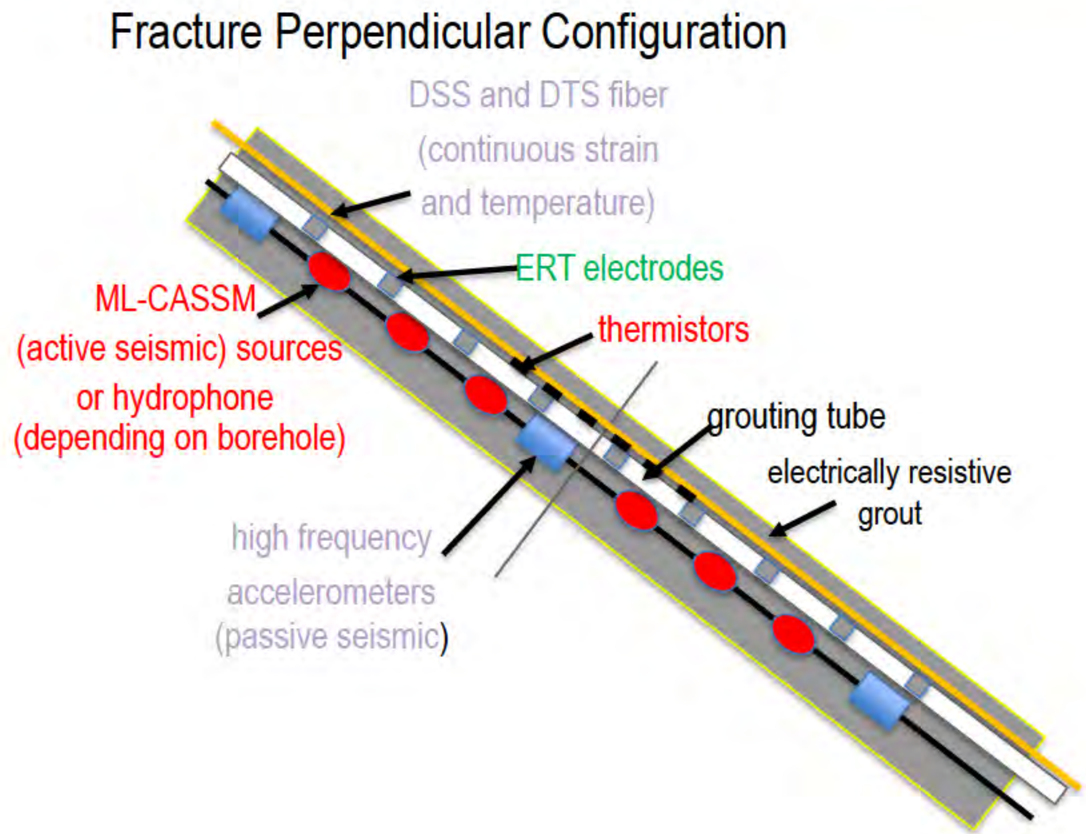
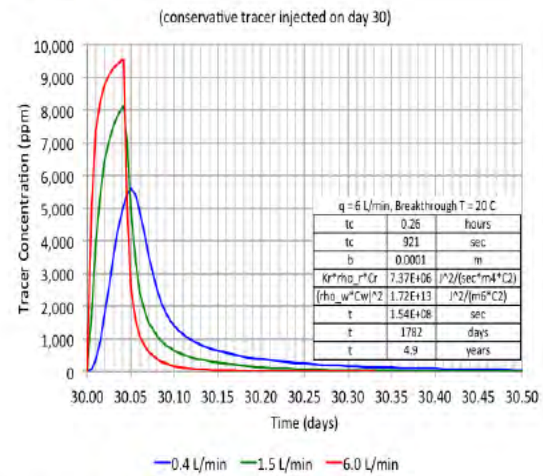
Monitoring: Multiple methods

- Deployment involves complex cabling and emplacement considerations



Flow Testing Sequence

1. Determine the fracture propagation pressure (to reduce risk of further propagation)
2. Isothermal step pressure test, (aperture/flow vs pressure)
3. Constant rate flow test with both conservative and reactive tracers.
   - Interrogate fracture residence time and surface area



4. Cold water injection to investigate thermal transfer and stress effects over several weeks

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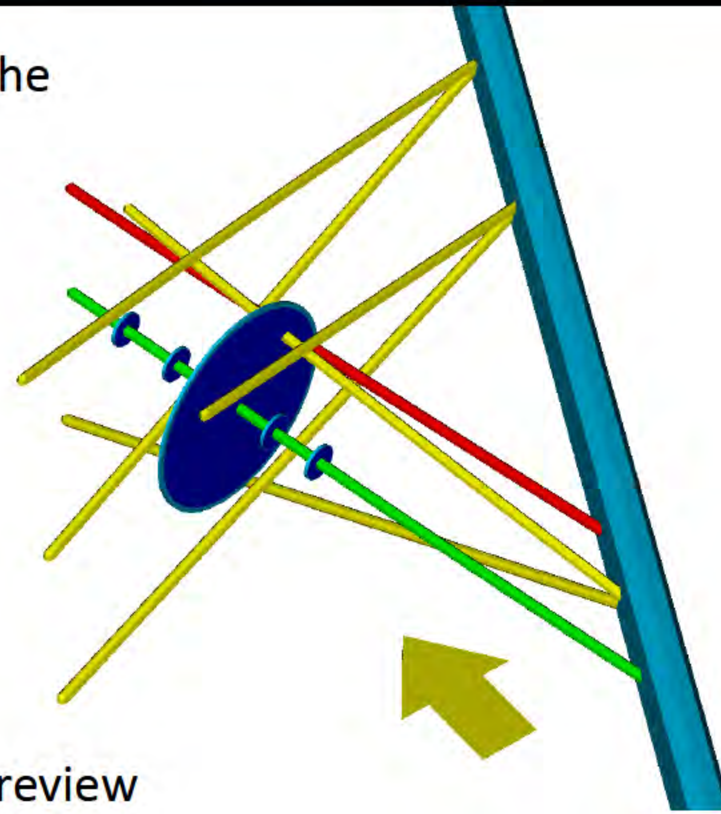
Summary

- We have effectively engaged as a team to guide the design of a robust, relevant test bed
- Design is balanced:
  - Validation goals of the experiment
  - Successful stimulation
  - Fracture intersection with producer well
  - Successful monitoring of fracture growth and subsequent flow
- This has required close teamwork among stimulation, flow, and modeling teams
- Benefited from rapid cross-verification and peer-review
- Demonstrating and setting stage for validation of software essential for FORGE and commercial-scale EGS



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