Geothermal Technologies Office 2017 Peer Review

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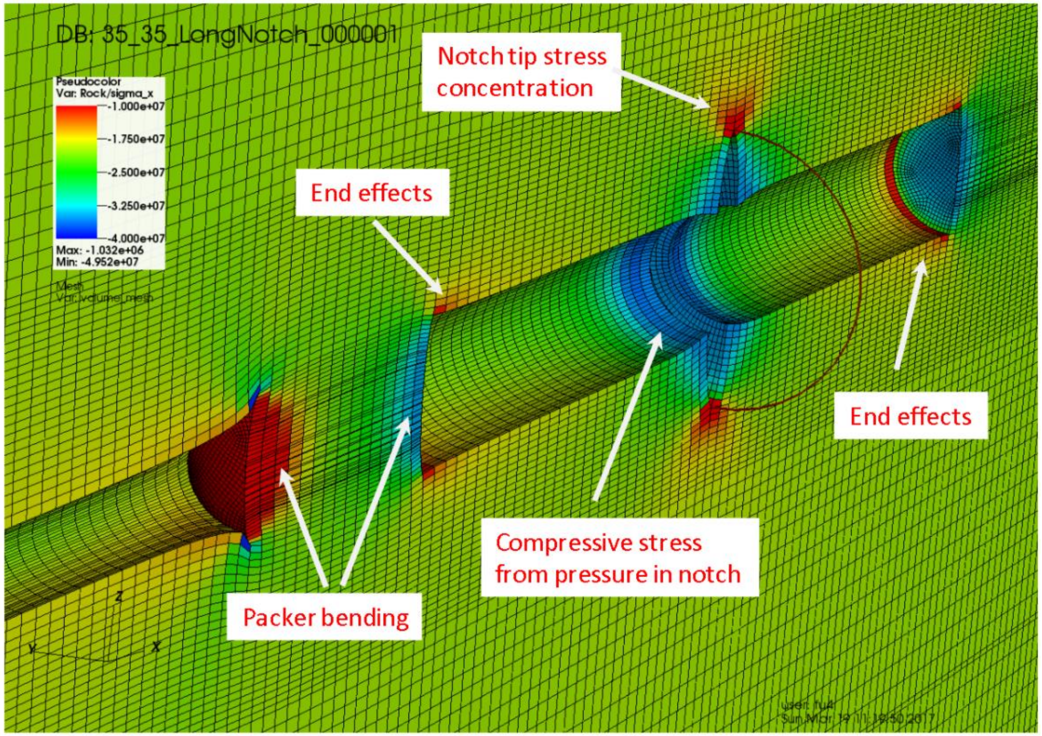

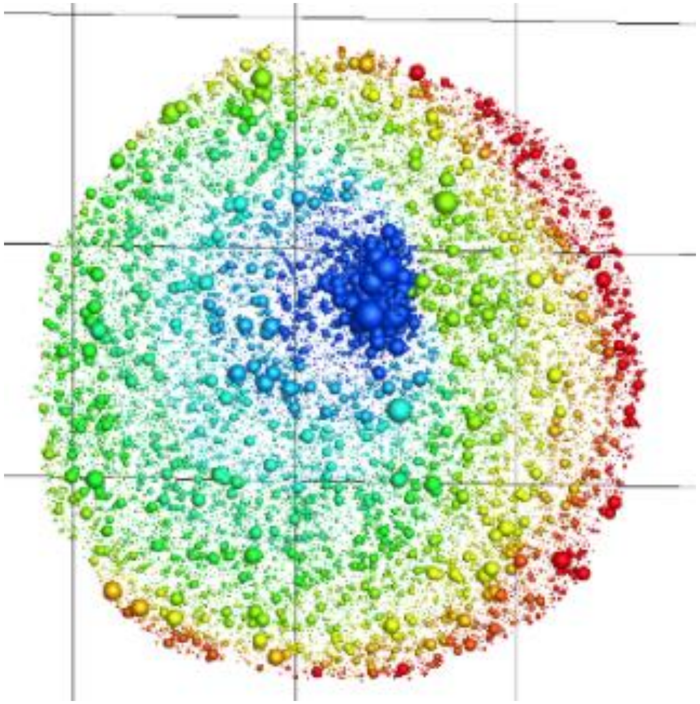

EGS Collab Project (Task 3/9): Refine Stimulation Test Design, Preliminary THMC Test Design Modeling, and Monitoring Design and Installation (EGS Experiment 1)

Project Officer: Lauren Boyd

Total Project Funding: $9M FY17

November 13, 2017

Principal Investigator:
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Lawrence Livermore Nat. Lab.
EGS Collab

Prepared by LLNL under Contract DE-AC52-07NA27344.

Relevance to Industry Needs and GTO Objectives

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Objective

- The focus of EGS Experiment 1/Task 3 will be upon delivering a robust plan for stimulation and flow testing with minimal risk
  - Identify and resolve competing objectives
  - Identify/anticipate roadblocks and interdependencies
- Demonstrating and setting stage for validation of software essential for FORGE and commercial-scale EGS

Innovation and novelty:

- 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

Relevance to Industry Needs and GTO Objectives

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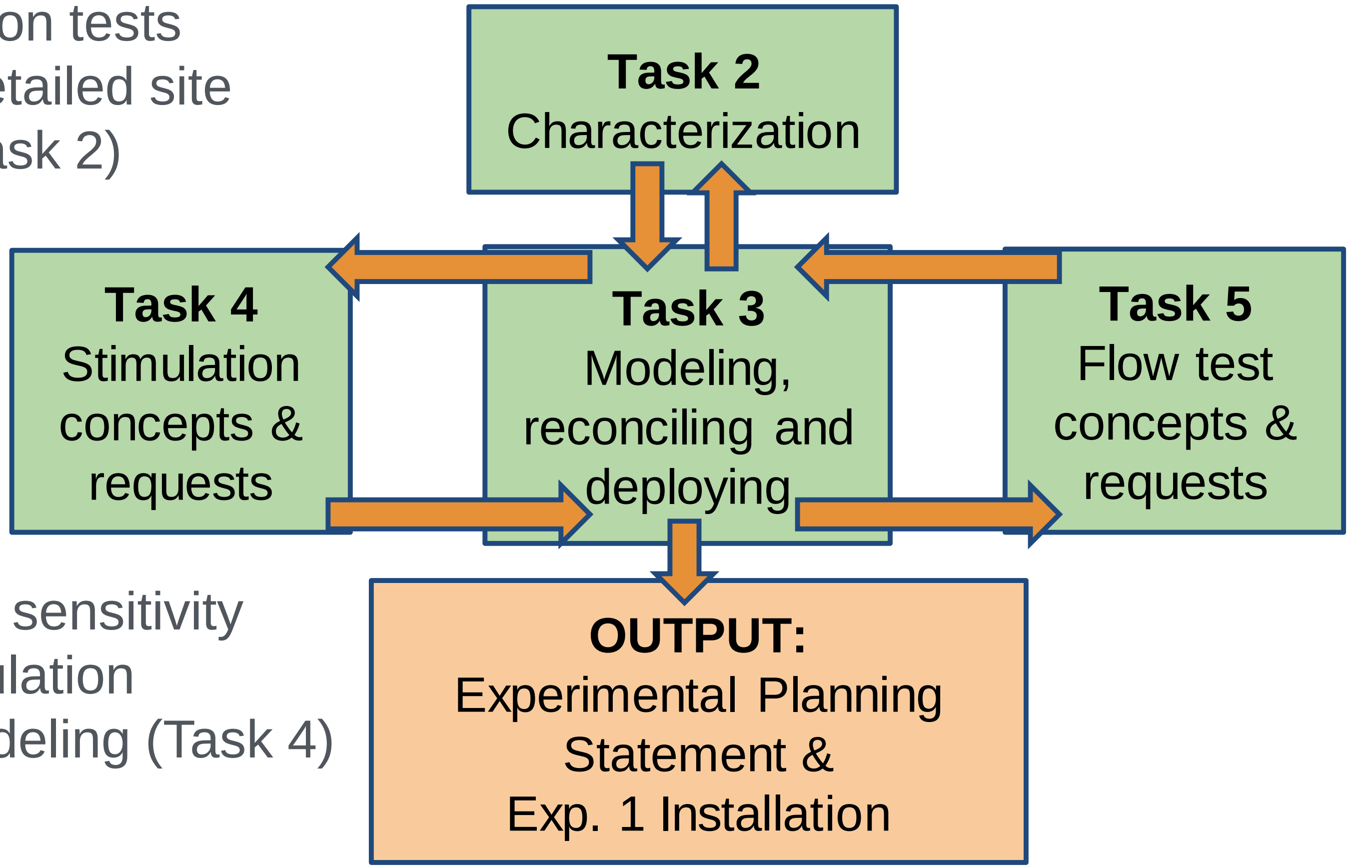
Task 3 is a Nexus for Exp. 1 Planning:

- Refine the stimulation tests design based on detailed site characterization (Task 2)



- Perform systematic sensitivity studies of pre-stimulation (fracturing) test modeling (Task 4)

- Perform initial THMC modeling of desired tests to support (Task 5)

Methods/Approach

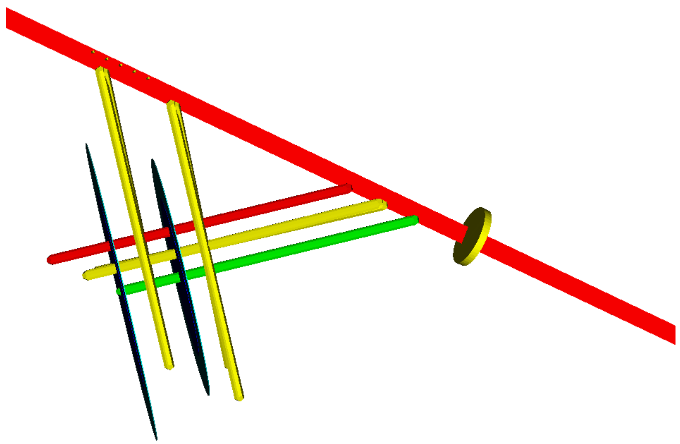
- Utilize modeling and peer review across the Collab team to address every step of the experimental design
- To the extent possible, confidence is built through repeated analyses with
  - Different modeling approaches
  - Different contributors across the Collab team
  - Utilize COTS and research tools as appropriate
- Key issues:
  - Control near-wellbore tortuosity to ensure stimulation
  - Predict geometry of stimulation
  - Predict performance of flow test
  - Predict performance of monitoring systems

Milestone: Refine Stimulation Test Design:

Refined the test design based on available and collected information.

Verification Method:

Site 1 selected and testbed preparation initiated



Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Refine Stimulation Test Design	Refine Stimulation Test Design	9/30/17

Technical Accomplishments and Progress
Borehole layout – Refined "Fat crayon design"

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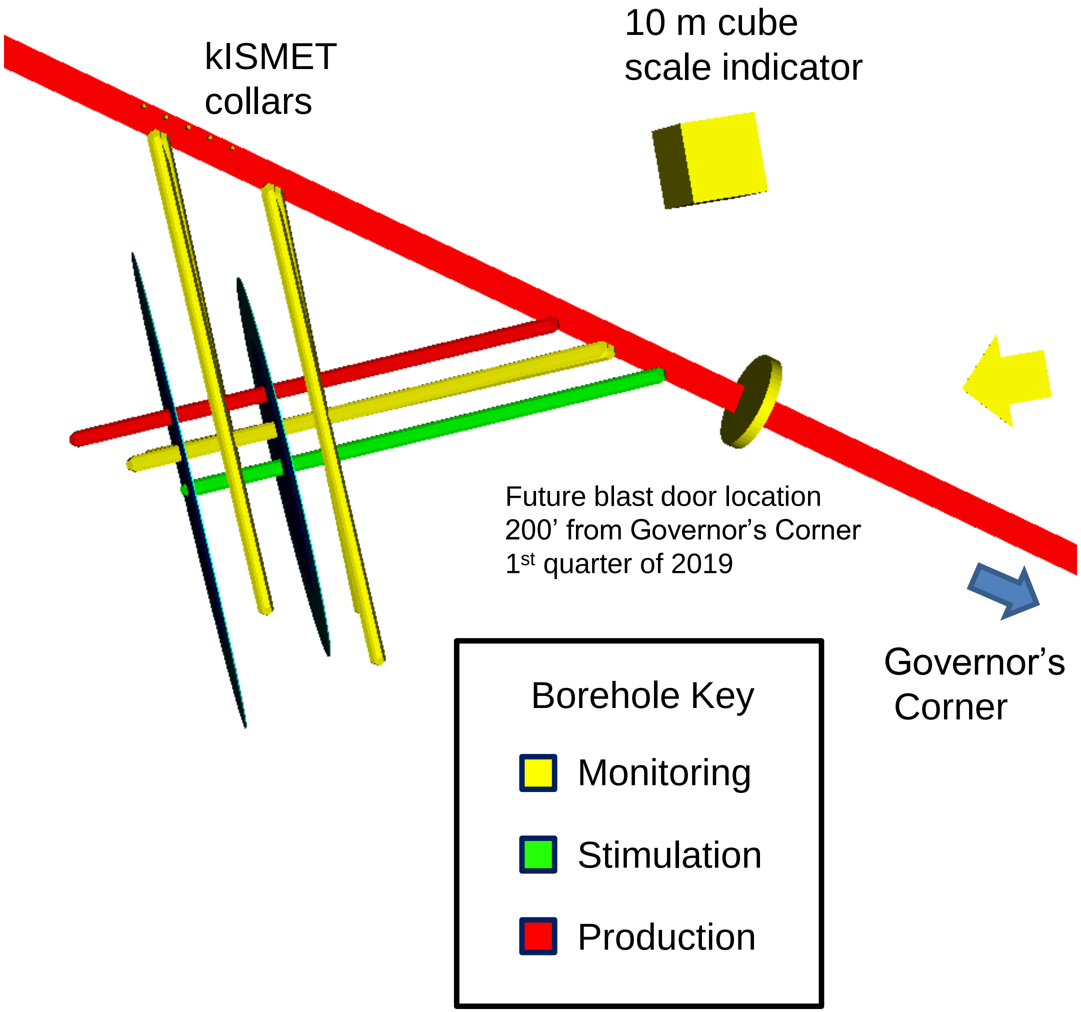
Challenge: Balancing readiness, availability, and characterization of test site with drift and stress orientation

Solution:

- Place boreholes according to stress state and model results
- Extensive modeling demonstrates system robustness

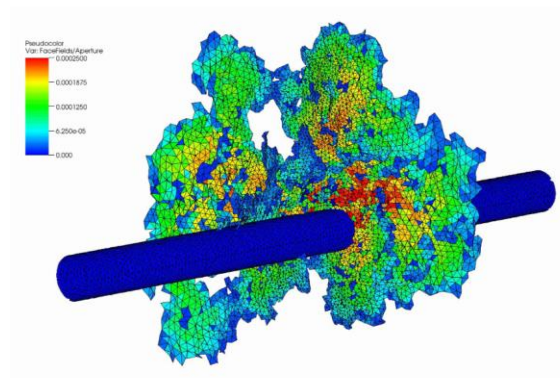


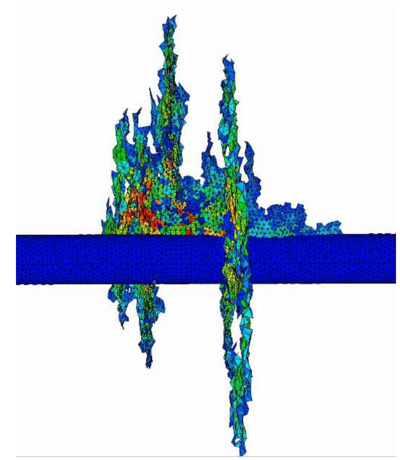
Evaluating notching to control stimulation

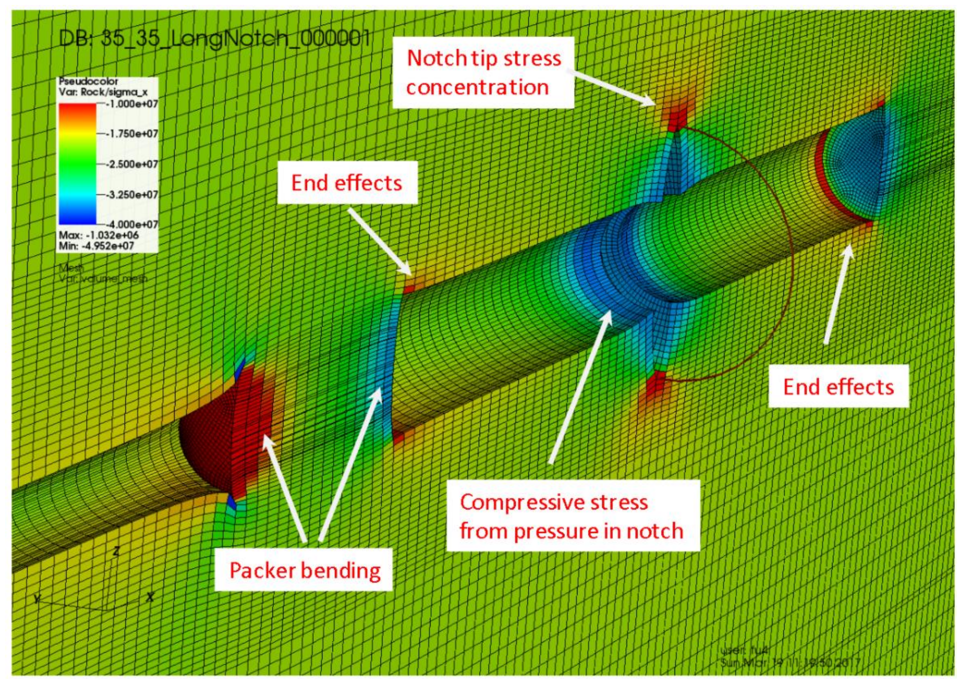
Challenge: Near wellbore tortuosity can prevent effective stimulation

Solution:

- Quantify notch geometry required to overwhelm such effects
- Results indicate notching apparatus should be effective





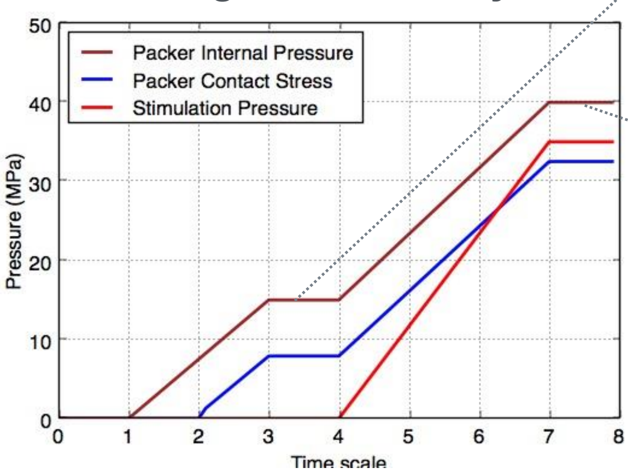


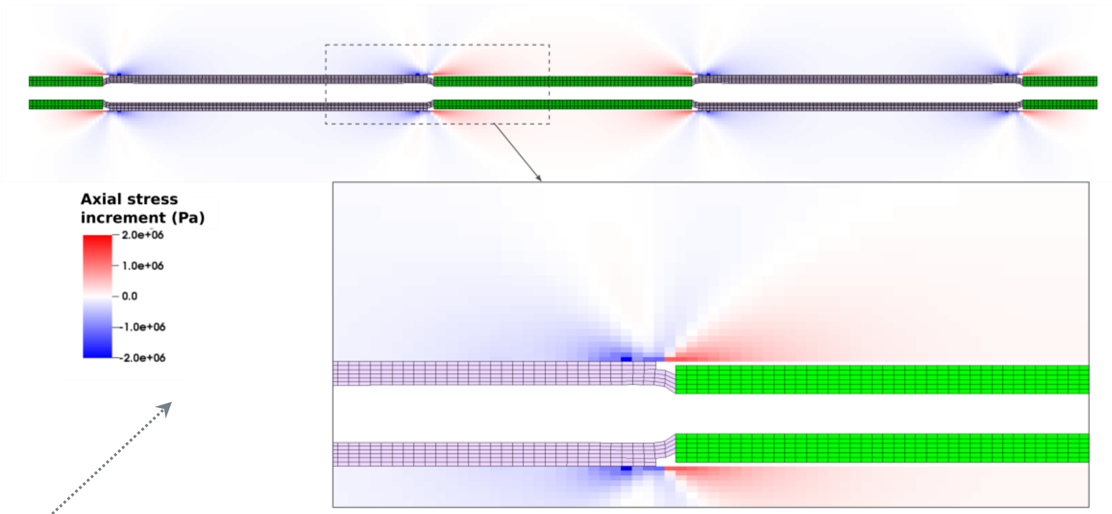
Predict performance of the packer system

Challenge: Will packer inflation impact fracture initiation?

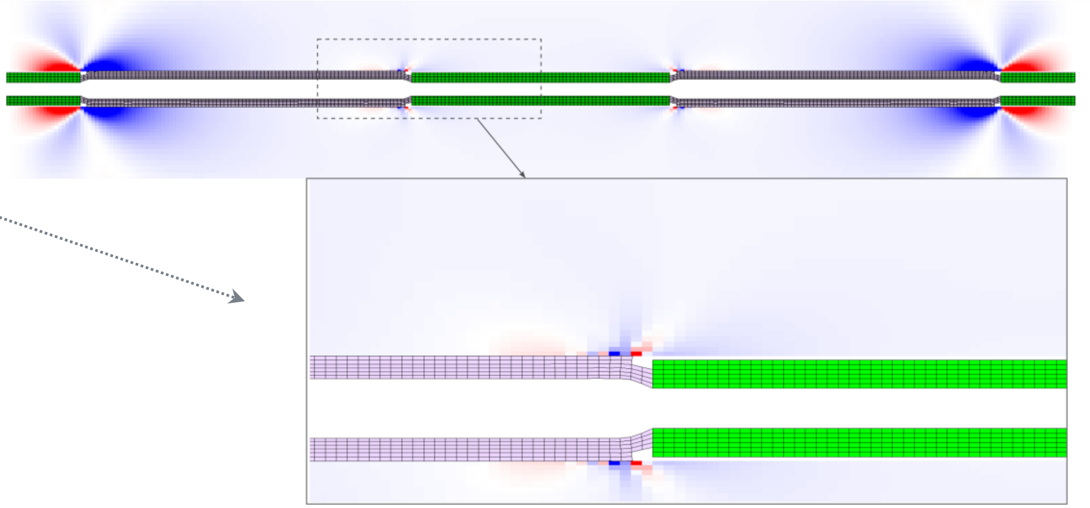
Solution:

- Finite element models indicate up to 2 MPa of axial tensile stress increment in the wellbore wall near the packer ends.
- Magnitude of this stress increment attenuates quickly.
- **Unlikely to affect fracture initiation from a notch**
- **Within range tolerated by tool**





(a) When packers are inflated with 15 MPa pressure



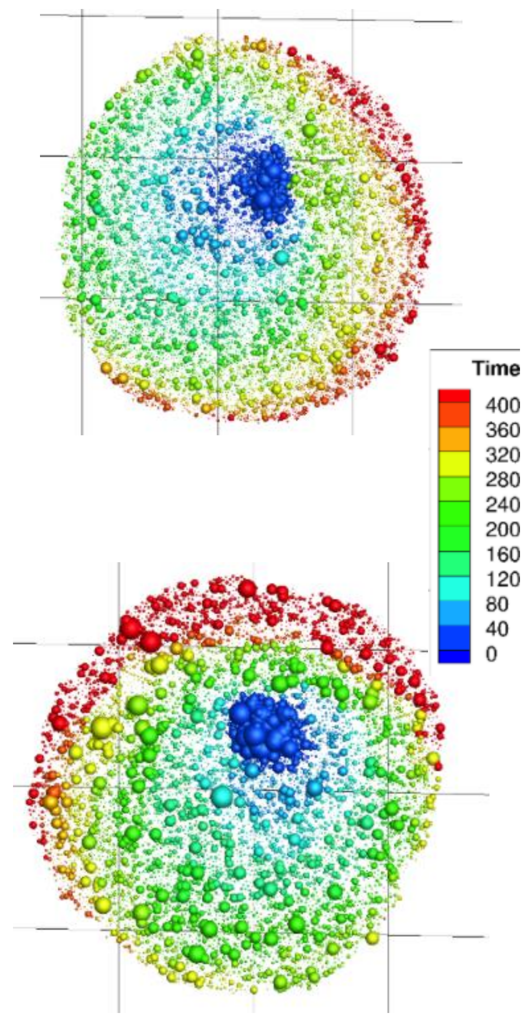
(b) When the packed-off test zone is pressurized with 35 MPa, and packer pressure reaches 40 MPa

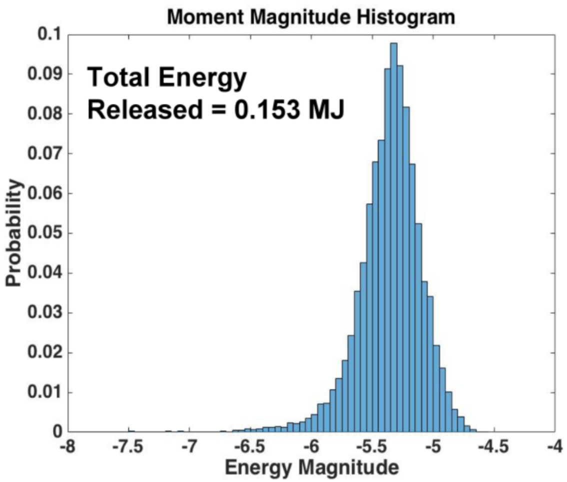
DEM indicates minimal seismic risk

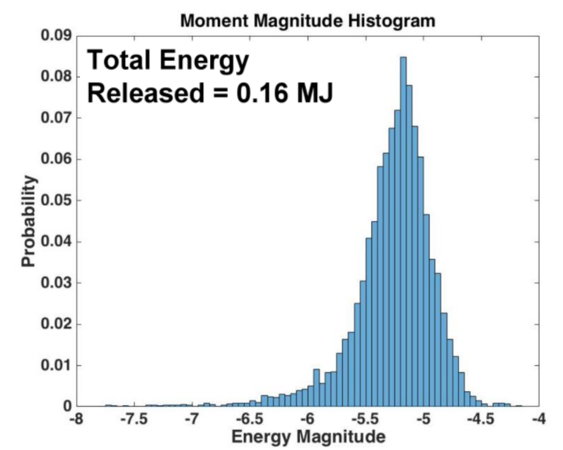
Challenge: Quantify seismic risk during stimulation

Solution:

- Multiple discrete element realizations build confidence
- Results consistent with and build upon kISMET experience

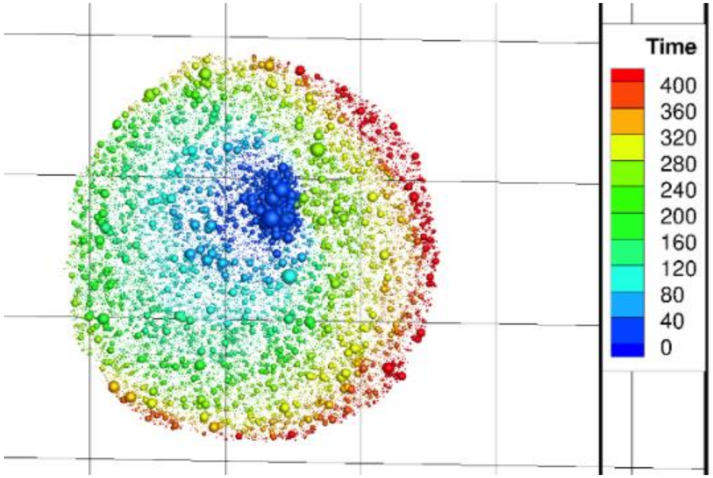


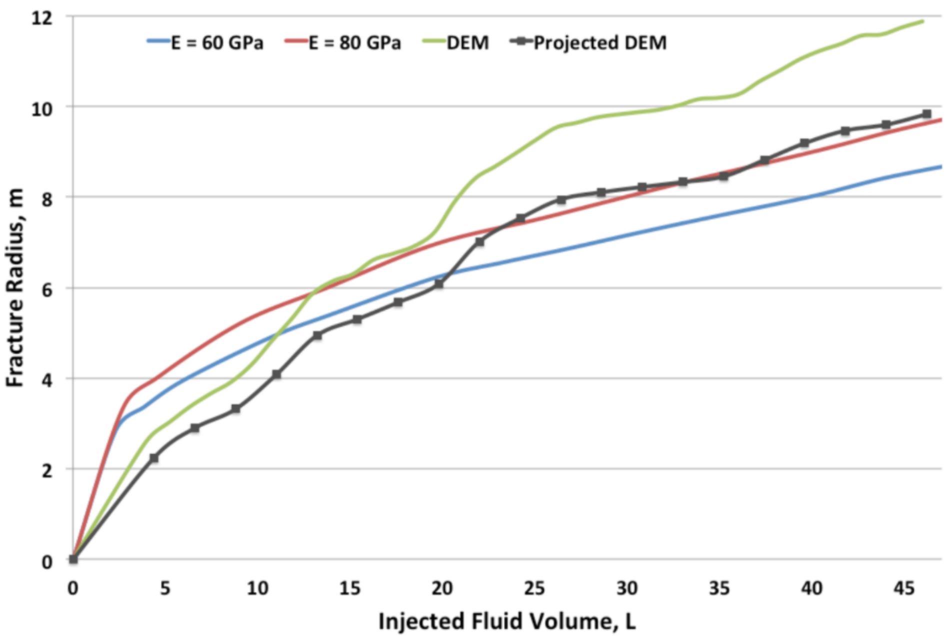




Built confidence in fracture extent

- **Challenge:** Predict expected aperture and fracture extent
- **Solution:** Compare multiple methods, range of assumptions
- Observe excellent agreement among radically different modeling approaches
  - DEM, FEM
  - Semi-analytic
- Aperture ~0.1 mm

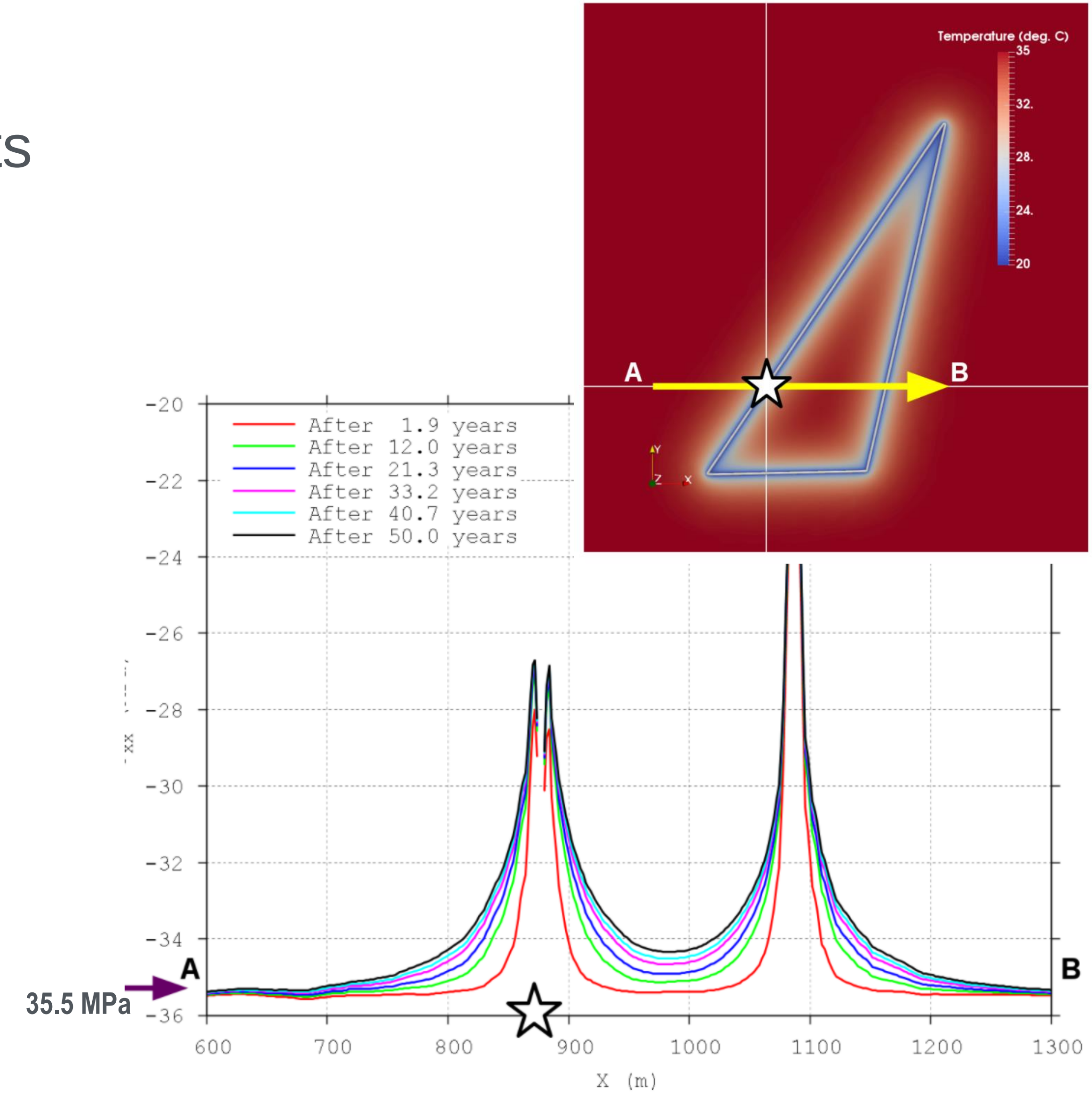




Challenge: Quantify the impact of thermal gradients due to ventilation

Solution:

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



Thermal stress: A validation opportunity

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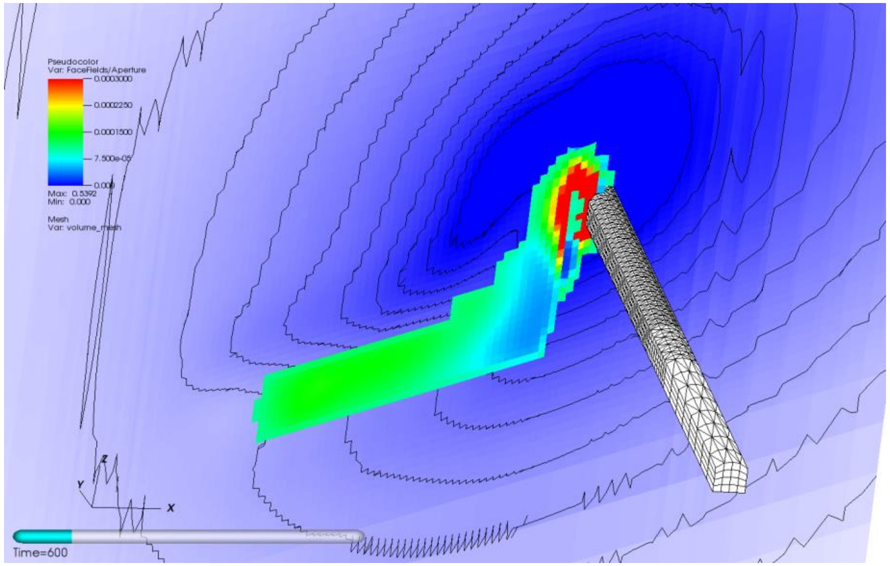
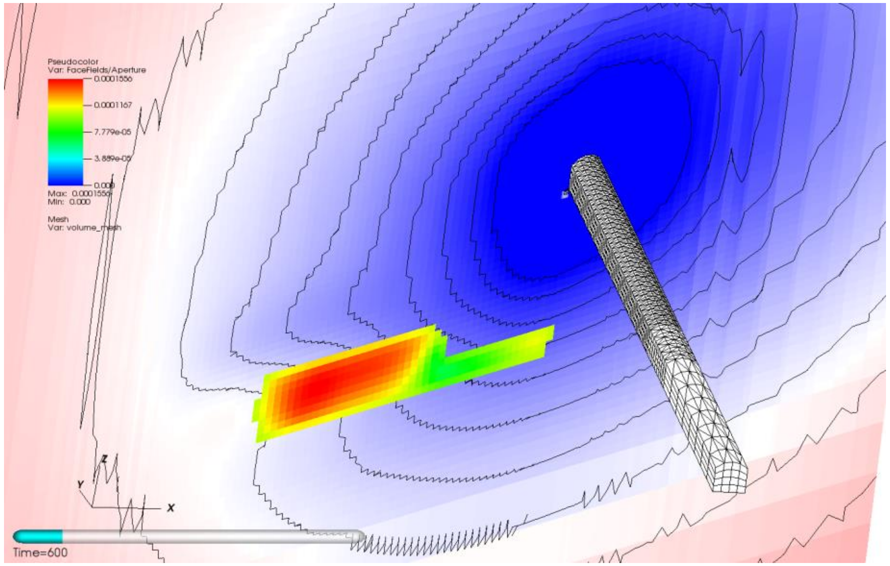
Challenge: How might thermal stress influence stimulation?

Solution:

- Multiple analyses indicate stress gradient will encourage growth toward drift
- Producer borehole well placed for draining and arresting fracture growth
- V&V: Well characterized stress gradient over “statistical” heterogeneity





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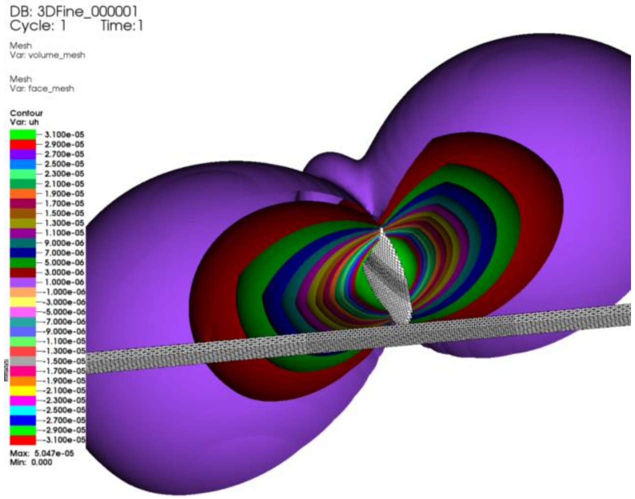
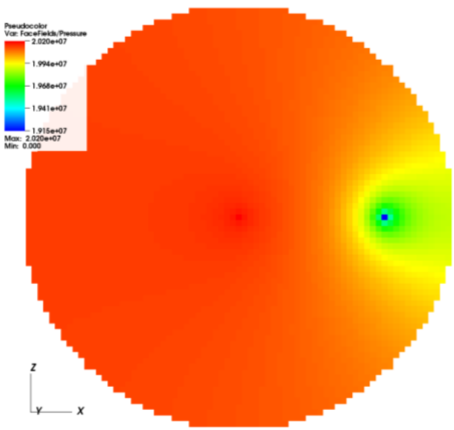
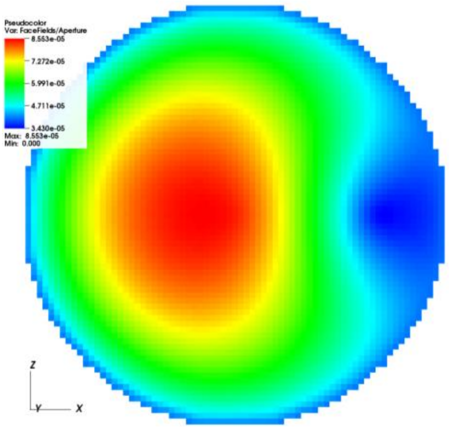
Challenge: Predict geophysical monitoring system performance

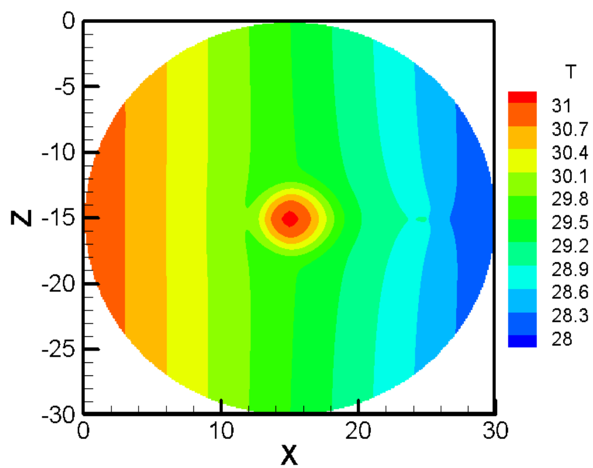
Solution:

- Rapid, multiple investigations and communication of results across the team
- Results inform placement of boreholes and geophysical layout









Research Collaboration and Technology Transfer

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- Design process directly involves academics and industry:
  - Mark Zoback (Stanford) – Stress measurement, stimulation borehole orientation, fracture geometry, breakout analysis
  - Tom Doe (Golder) – Stress measurement and hydraulic fracture growth
  - Mark McClure (McClure Geomechanics) – Hydraulic fracturing, diagnostic fractures, fast running analysis tools
  - Ahmad Ghassemi (OU) – Hydraulic fracture modeling
  - Participate/present in weekly project meetings
- Technology transfer is most immediately to FORGE
- Much of software used is available under license
- Learnings will influence the design of EGS in the future
- Conf. papers: GRC, Stanford Geothermal Workshop
- Journal publications planned

Future Directions: Exp. 2 with Task 9

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- Lessons learned from Exp. 1/Task 3 will influence Exp. 2/Task 9

Possible examples:

- Should spatial variability in temperature be a factor in site selection?
- Utilize viscous fluids and proppant to attain greater aperture for subsequent flow (also a consideration for Exp. 3)
- Will the notching technique need improvement?
- Should new monitoring be added, existing approaches modified, or dropped?

Go/No-Go	Status & Expected Completion Date
Site selected for Exp. 2	On track for "Go": Preliminary evaluation complete and expect site selection final by 3/31/18

Summary Slide

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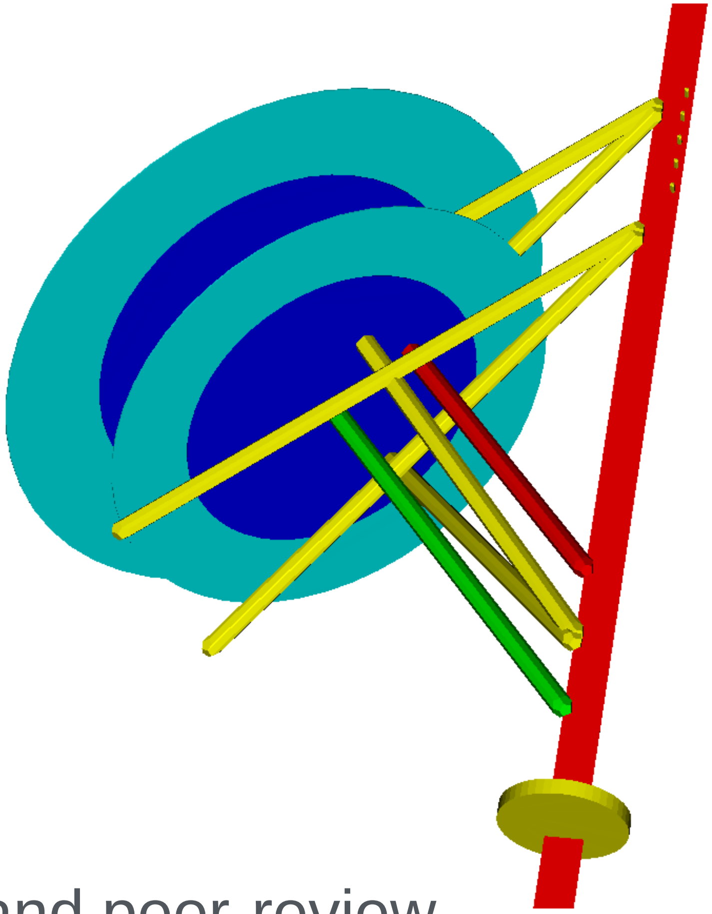
- We have effectively engaged as a team to guide the design of a robust, relevant test bed
- Design is balanced:
  - Validation goals of the experiment
  - Successful stimulation
  - Fracture intersection with producer well
  - Successful monitoring of fracture growth and subsequent flow
- This has required 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