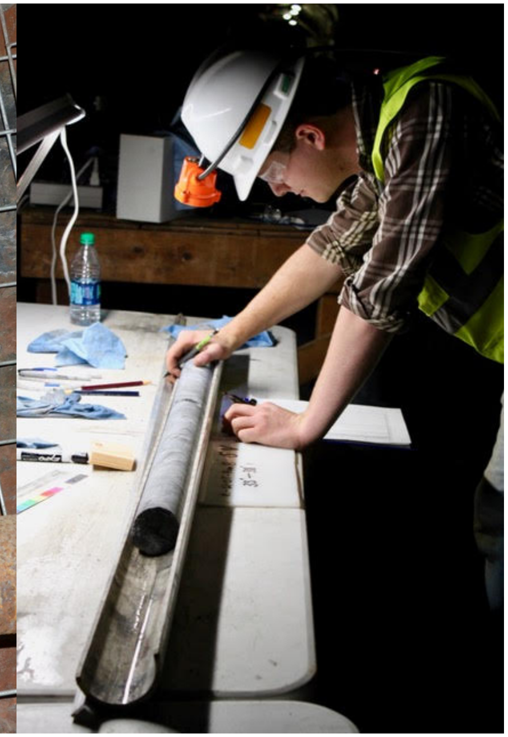

The EGS Collab Project: Stimulation Investigations for Geothermal Modeling Analysis and Validation

Project Officer: Lauren Boyd

Total Project Funding: PY1 - $9M, PY2 – $10.7M

November 13, 2017

Tim Kneafsey (LBNL)

EGS Collab team

Track EGS Collab

EGS Collab Team

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
McClure Geomechanics
Tom Doe
Sanford Underground Research Facility

Building collaborations with Schlumberger, Luna, AIST, GTS, Florian Amann

COLLAB
A PATH TO FORGE
U.S. DEPARTMENT OF ENERGY

Relevance to Industry Needs and GTO Objectives (1)

Enhanced Geothermal Systems (EGS) hold the potential to power tens of millions of American homes and businesses. There are knowledge gaps in processes related to creation and sustaining reservoirs, and few comprehensive data sets are available to validate EGS codes. The EGS Collab project will generate data sets specifically targeted to constrain and validate predictive tools for EGS commercialization. Validated models will reduce reservoir production costs by optimizing the number of wells and stimulations and providing the scientific bases for engineering solutions.

The EGS Collab project will enhance understanding of reservoir creation processes including stimulation, monitoring, flow, and heat exchange, **and** the ability to accurately simulate these processes.

EGS Collab Challenges

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- Develop ~10 m-scale field sites where the subsurface modeling and research community will establish validations against controlled, small-scale, in-situ experiments focused on rock fracture behavior and permeability enhancement.
- Provide the opportunity for reservoir model prediction and validation and in-depth fracture characterization, with an ultimate goal of further elucidating the basic relationship between stress, seismicity and permeability enhancement.
- Identify and quantify the nature of stimulation (e.g., hydraulic fracturing, shear stimulation, mixed-mode fracturing, thermal fracturing) and other key governing parameters that impact permeability.
- Apply comprehensive instrumentation and data collection.
- Prepare, validate, and improve tools for FORGE and EGS.

Methods/Approach

Specifically we will:

- Establish a collaborative experimental suite of intermediate-scale (~10-20 m) field test beds coupled with stimulation and interwell flow tests. Tests will be specifically designed to compare measured data to models to improve the measurement and modeling toolsets that will be available for FORGE.
- Perform pre- and post-test modeling of each test for model prediction and validation.
- Perform well-controlled, *in situ* experiments focused on rock fracture behavior and permeability enhancement.
- Collect high-quality, high-resolution geophysical and other fracture characterization data using comprehensive instrumentation. These data will rapidly become available to the community.

Methods/Approach (2)

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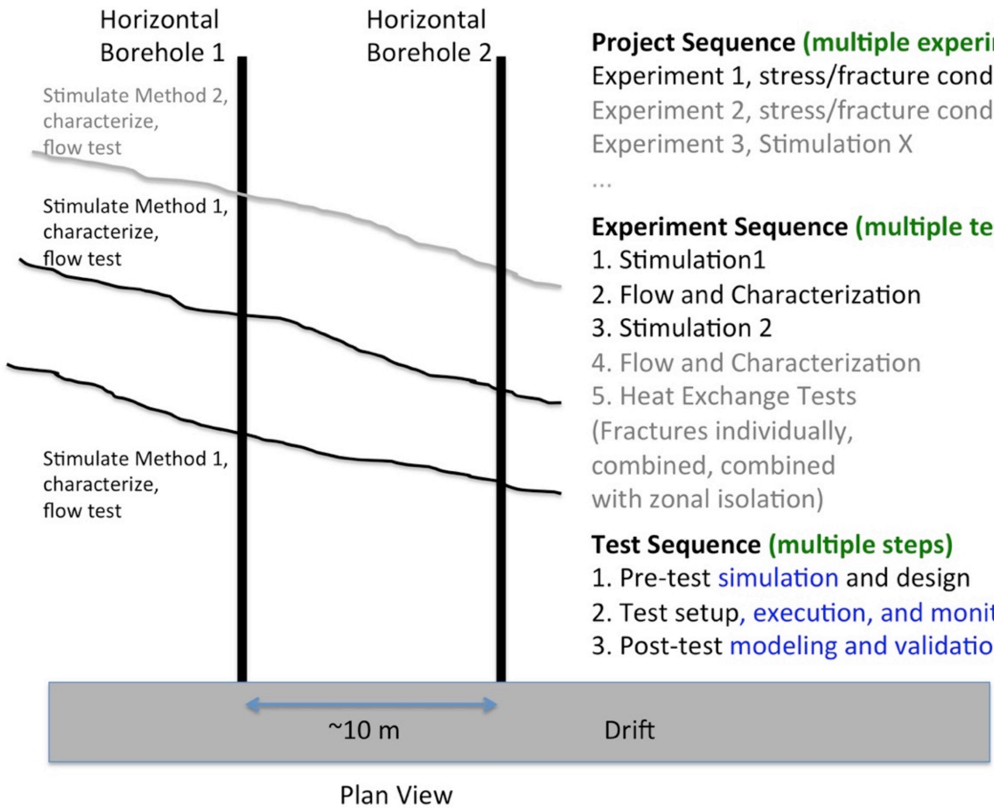
- Analyze data and compare to models and field observations to further elucidate the basic relationships between stress, induced seismicity, and permeability enhancement.
- Drill back through the stimulated zone to provide as-is fracture characteristics that can be compared to other monitoring data as well as predictions.
- Observe and quantify other key governing parameters that impact permeability and attempt to understand how these parameters might change throughout the development and operation of an EGS project with the goal of enabling the commercial viability of EGS.
- Operate openly, and disseminate data, information, and knowledge efficiently.

Methods/Approach (3)

- **Experiment 1**, intended to investigate **hydraulic fracturing**, at the Sanford Underground Research Facility (SURF) at 1,500 m depth
- **Experiment 2** will be designed to investigate **shear stimulation**.
- **Experiment 3** will investigate changes in fracturing strategies and will be further specified as the project proceeds.



Project Sequence (multiple experiments)
Experiment 1, stress/fracture condition A
Experiment 2, stress/fracture condition B
Experiment 3, Stimulation X
...

Experiment Sequence (multiple tests)
1. Stimulation1
2. Flow and Characterization
3. Stimulation 2
4. Flow and Characterization
5. Heat Exchange Tests (Fractures individually, combined, combined with zonal isolation)

Test Sequence (multiple steps)
1. Pre-test simulation and design
2. Test setup, execution, and monitoring
3. Post-test modeling and validation

Project Description

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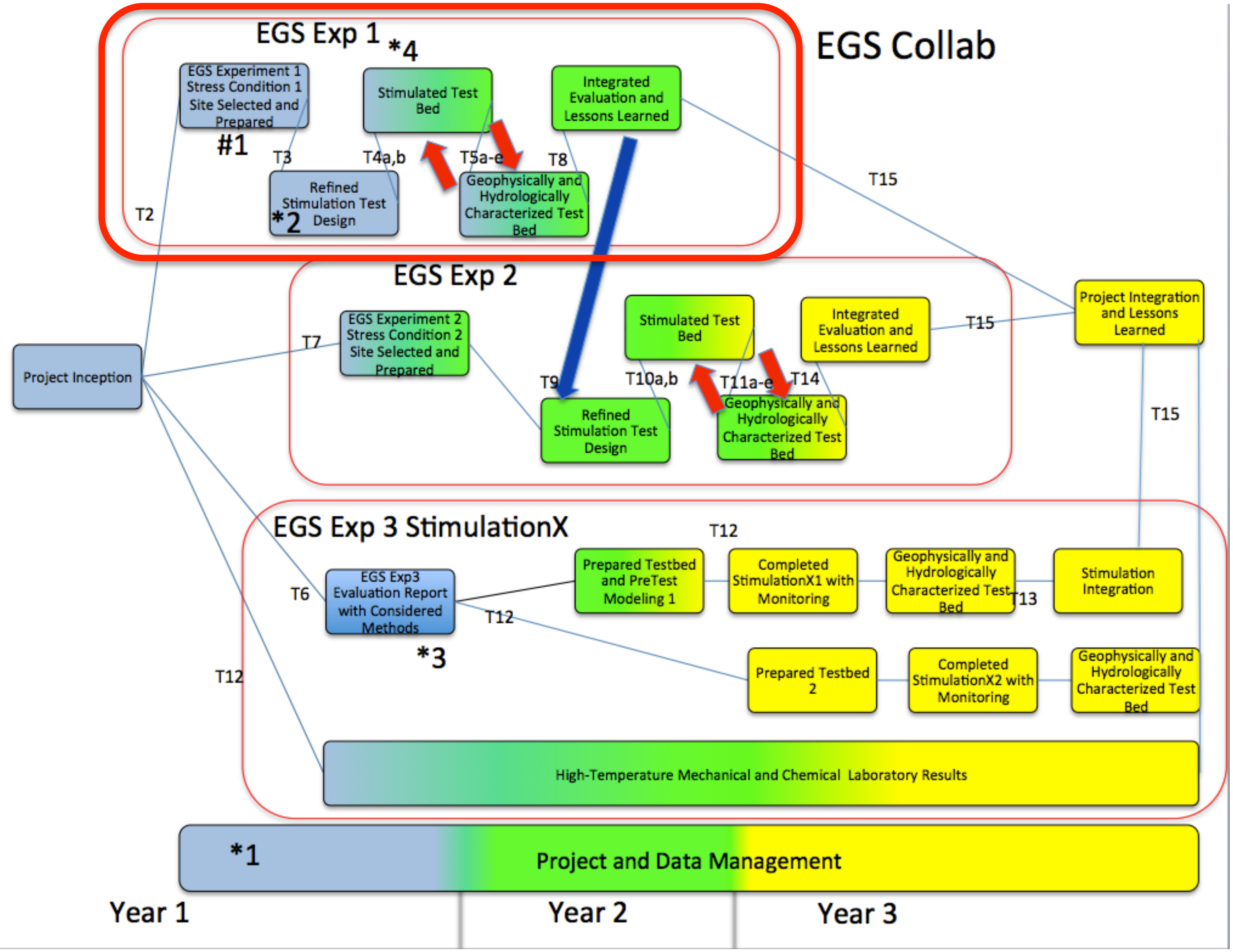

Project Organization

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PI
Tim Kneafsey (LBNL)
co-PI
Doug Blankenship (SNL)

Executive Committee
D.Blankenship[1,3] (SNL), A.Bonneville[1] (PNNL), L.Boyd[4], Z.Frone[4], L.Huang[1] (LANL), B.Johnston[1] (NREL), T.Kneafsey[1] (LBNL), J.McLennan[3] (Utah), R.Mellors[1] (LLNL), E.Metcalfe[4], A.Nieto[4], R.Podgorney[1] (INL), Y.Polsky[1] (ORNL), S.Porse[4], B.Roggenthen[2] (SDSMT), B.Vandermeer[4]
[1]National Lab, [2]Academic/Industrial, [3]FORGE, [4]DOE

Project Manager
Carol Valladao (LBNL)

Data Manager
Jon Weers (NREL)

Site Operations Coordinator
Dennis King (SNL)

Academic and Industrial Team
Roland Horne and Mark Zoback (Stanford), Herb Wang (Wisconsin), Ahmad Ghassemi (Oklahoma), Derek Elsworth (Penn State), Bill Roggenthen (SDSMT), Yu-Shu Wu (CSM), Tom Doe

Geologic, Geomechanical, and Hydrologic Characterization
Pat Dobson (LBNL)

Field Testing and Stimulation
Hunter Knox (SNL)

Experiment Design
Joe Morris (LLNL)

Monitoring (geophysics, hydrology, etc.)
Jonathan Ajo-Franklin (LBNL)

Laboratory Experiments and Measurements
Megan Smith (LLNL)

Modeling and Simulation
Mark White (PNNL)

Integration, Upscaling, Application to FORGE
Rob Podgorney (INL)

Task 1
Project Management

Task 2 – Site Selection, Preparation, Drilling and Coring, Characterization (EGS Experiment 1) Pat Dobson (LBNL)

Task 3 – Refine Stimulation Test Design, Preliminary THMC Test Design Modeling, and Monitoring Design and Installation (EGS Experiment 1) Joe Morris (LLNL)

Task 4 - Stimulation Test - Permeability Enhancement Execution and Characterization (EGS Experiment 1) Hunter Knox (Sandia)

Task 5 - Interwell Flow Test - Geophysical and Hydrological Characterization and Drillback (EGS Experiment 1) Tim Johnson (PNNL)

Task 6 - Feasibility Evaluation of Potential Stimulation Methods. (EGS Experiment 3) Earl Mattson (INL)

Task 12 - High Temperature Laboratory Experimentation to Support EGS Stimulations
Megan Smith (LLNL)

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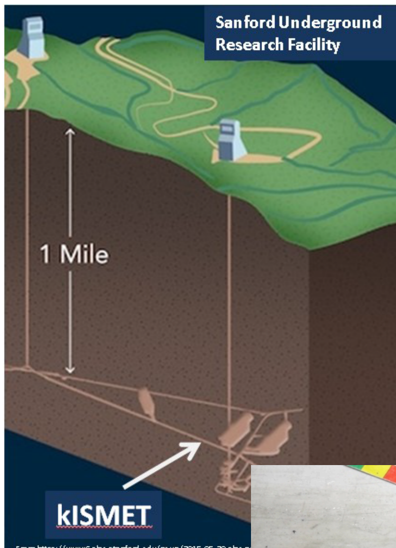
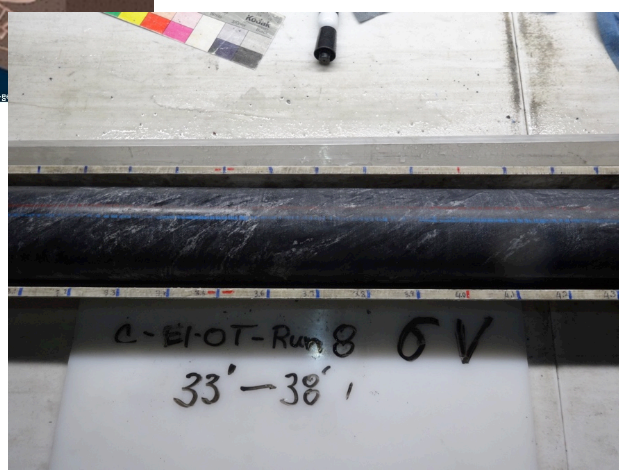
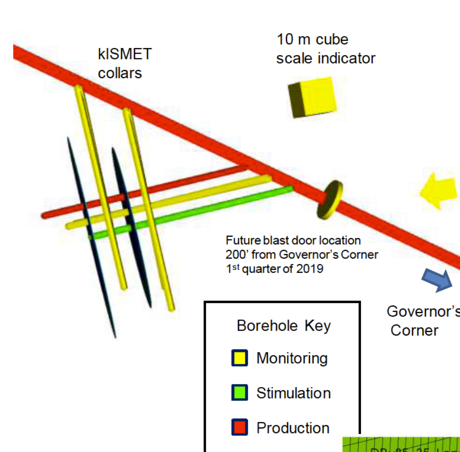
Tasks 2 (and 7): Site Selection, Preparation, Drilling and Coring, Characterization (EGS Experiment 1) - Pat Dobson

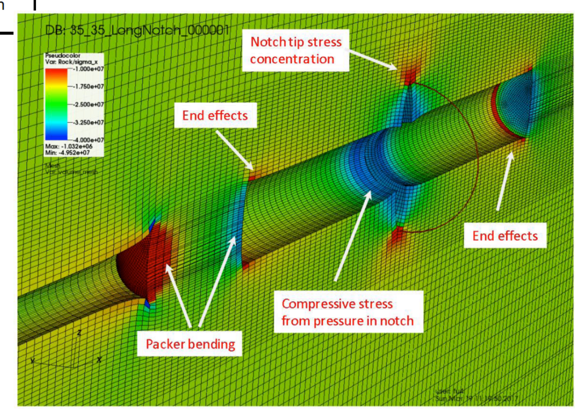




Tasks 3 (and 9): Refine Stimulation Test Design, Preliminary THMC Test Design Modeling, and Monitoring Design and Installation (EGS Experiment 1) – Joe Morris



Fat Crayon to Refined Layout



Methods/Approach Tasks 4, 5

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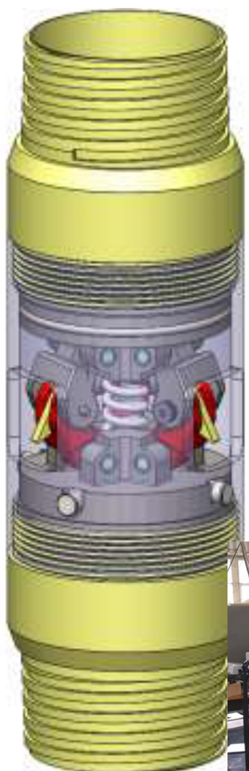
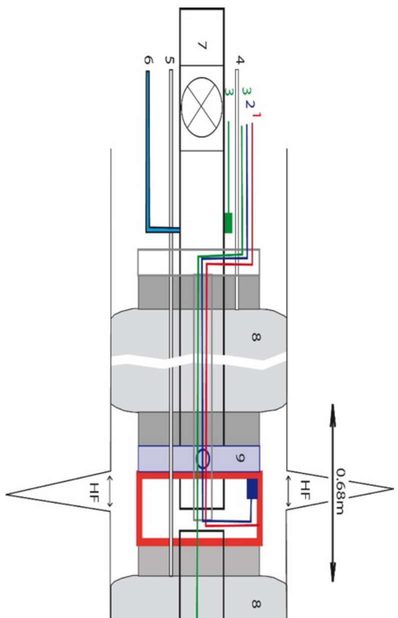
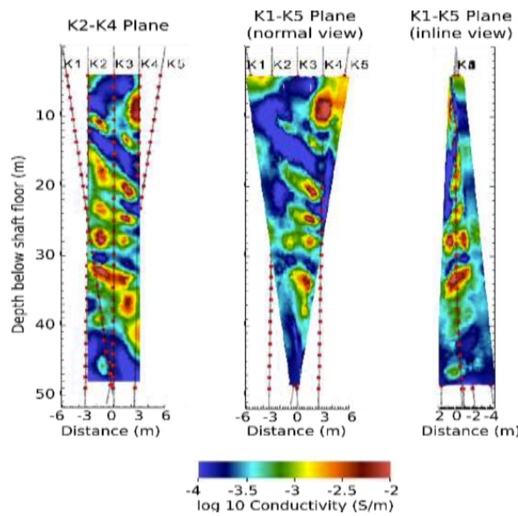
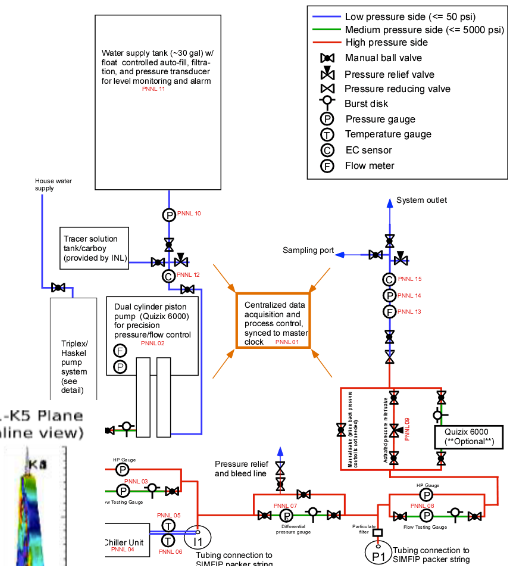
Task 4: Stimulation Test - Permeability Enhancement Execution and Characterization (EGS Experiment 1) – Hunter Knox



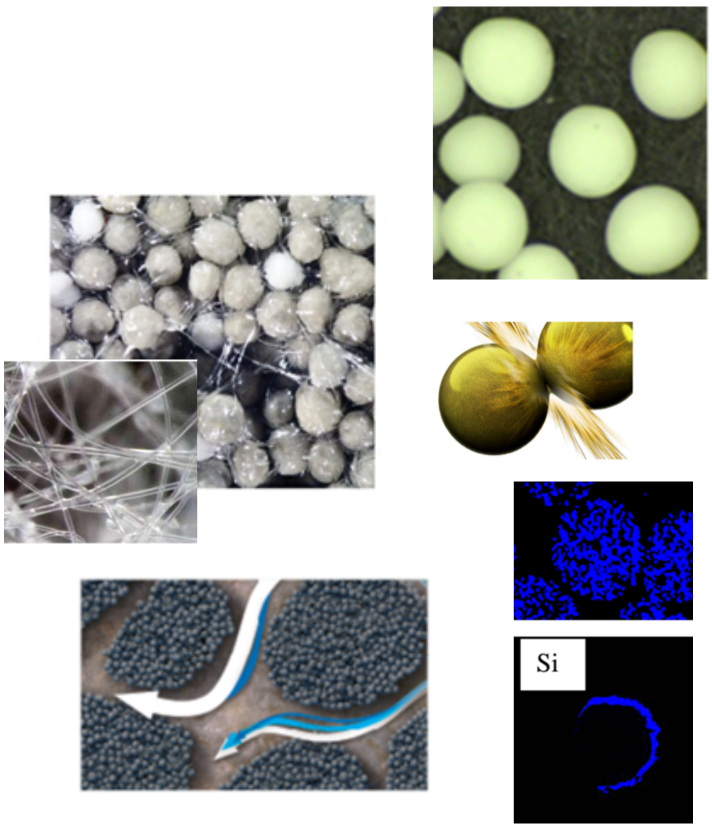


Task 5: Interwell Flow Test - Geophysical and Hydrological Characterization and Drillback (EGS Experiment 1) – Tim Johnson

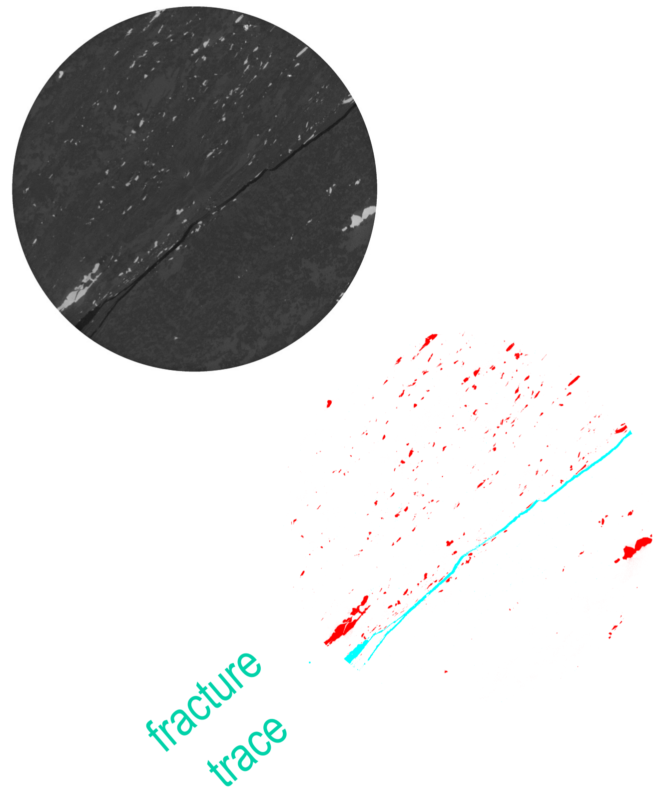




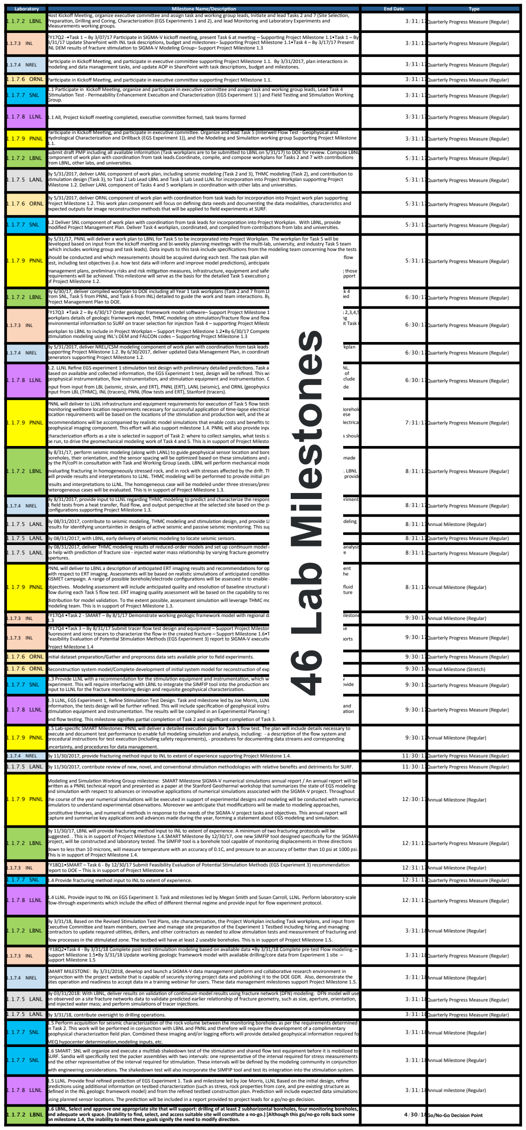
Task 6: Feasibility Evaluation of Potential Stimulation Methods. (EGS Experiment 3) – Earl Mattson



Task 12: High Temperature Laboratory Experimentation to Support EGS Stimulations. – Megan Smith



Technical Accomplishments and Progress



Project Milestone	Progress	Date
1.1 All, Project kickoff meeting completed, executive committee formed, task teams formed	**Completed**	**3/31/17**
1.2 LBNL, Detailed Work Plan and Project Management Plan prepared to reflect DOE and reviewer input.	**Completed**	**6/30/17**
1.3 LLNL, EGS Experiment 1, Refine Stimulation Test Design. Based on available and collected information, the tests design will be refined. This will include specification of geophysical instrumentation, flow instrumentation, and stimulation equipment and instrumentation. This milestone signifies partial completion of Task 2 and significant completion of Task 3.	**Completed**	**9/31/17**
1.4 INL, EGS Experiment 3, EGS Exp3 Evaluation Report with Considered Methods. This milestone signifies completion of Task 6.	On Schedule	12/30/17
1.5 LBNL, Prepared test bed suitable to perform stimulation tests. This milestone signifies completion of Task 2.	Anticipated 12/17	3/31/18

Research Collaboration and Technology Transfer

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CSM (Wu, Winterfield)

Simple numerical simulation models to predict thermal breakthrough and conservative tracer concentrations at various injection rates.

- Fracture apertures equal to 100 microns with variable injection rates - 0.4, 1.5, and 6.0 L/min.
- Conservative tracer simulations used various fracture apertures – 10, 55, and 100 microns - with lower injection rates - 0.10, 0.22, and 0.40 L/min.

U Oklahoma (Ghessemi)

Future stimulation modeling and analysis - initiation of transverse fractures from a wellbore

Breakdown pressure calculations considering different pressure boundary conditions at the wellbore wall, and rock anisotropy to study conditions for transverse fracture initiation

Simulation of kISMET-003 hydraulic fracturing using "GeoFrac3D". Also, simulated near-wellbore tortuosity that might result from inclined transverse fractures

Will carry out experiments to measure important rock mechanical properties

Stanford (Horne)

Investigate the microbial structure in a reservoir, to determine the possible impact on a DNA tracer test and how it could possibly guide fracture characterization. Specifically, we are looking into the use of indigenous microbial 16S profile as unique barcodes for each well or fracture, and how it could possibly be correlated to interwell connectivity and fracture effectiveness.

Conduct synthetic DNA tracer test to characterize the flow properties of synthetic DNA and evaluate its potential use as unique artificial tracers.

PSU (Elsworth, Marone)

Friction-stability-permeability experiments throughout the seismic cycle.

Preliminary results - key influence of healing and sealing during interseismic repose in conditioning reactivated permeability:

- Interseismic permeability decreases proportional to power-law in time.
- Reactivated permeability evolution is dependent on repose time.
  - Short repose – compaction and permeability reduction upon reactivation.
  - Long repose – dilation and permeability increase upon reactivation.

Reactivated permeability increase scales with repose time.

SDSMT (Roggenthen)

Field-oriented activities to provide a backdrop for interpretation of data acquired during the drilling and subsequent fracturing/stimulation experiments. 1. Measurement of bulk acoustic velocity properties,2. kISMET core properties in support of the EGS Collab Project, 3. weep locations and orientations, 4. weeps using IR photography, 5. temperature measurements in the kISMET boreholes.

On-site participation in arrangements for drilling, preparation for core logging activities, core preservation, and sampling activities

Fracture mapping in the 4850 level

Stanford (Zoback)

•Kismet hydraulic fracturing tests indicate a normal faulting regime ($S_{hmin} < S_{Hmax} < S_V$

•S_{Hmax} orientation ~E-W, consistent with regional earthquake focal plane mechanisms.

•Wellbore breakouts indicate S_V tilts to the north about 12°

•Preliminary modeling indicates that $S_{Hmax} \sim 0.8\ S_V$.

UWisconsin (Wang)

Acquired kISMET core for anisotropic strength and modulus testing to constrain stress magnitudes inferred from borehole breakout analysis and hydraulic fracturing.

Acquired parts to construct tilt stage and cutoff jigs for preparing sample cores from kISMET and the EGS Collab Project at precise angles relative to foliation.

Considering creep test measurements on EGS Collab Project cores.

Research Collaboration and Technology Transfer

- Building collaborations with:
- Florian Amann – Similar tests at GTS
- Schlumberger – Infrequent callers (large time difference), interested in inverting seismic data
- Luna – Fracture Strain Measurements at SURF (*Rapid Distributed Sensing of Subsurface In-situ Stress* - high-resolution distributed strain measurements to enable direct measurement of rock fracture formation and propagation. Real-time information improving understanding of geological processes, and needed feedback for adaptive control of subsurface processes.
- AIST – Early discussions
- Sinopec – Gao Cheng

Future Directions

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Continue along planned research path.

- Finish Experiment 1 testbed and perform multiple stimulations and flow tests with associated measurements and pre- and post-test models
- Select site for Experiment 2, perform preliminary simulations, characterization, and begin testbed preparation.
- Perform stimulations for Experiment 2 and flow tests with associated measurements and pre- and post-test models
- Define Experiment 3 and plan for execution
- Make data available
- Publish results

Milestone or Go/No-Go	Status & Expected Completion Date
1.6 LBNL, Select and approve one appropriate site that will support: drilling of at least 2 subhorizontal boreholes, four monitoring boreholes, and adequate work space. (Inability to find, select, and access suitable site will constitute a no-go.) [Although this go/no-go rolls back some on milestone 1.4, the inability to meet these goals signify the need to modify direction.	**Substantially Completed 3/31/18**

Summary Slide

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- The EGS Collab project brings modelers and experimentalists together to perform tests and gather data to validate predictive tools that will be useful in FORGE and EGS.
- Three large experiments are planned over the three-year project duration to investigate hydraulic fracturing, shear stimulation, and a yet-to-be-determined stimulation strategy.
- The project has many participants and they are focused on succeeding in the simulations, field and lab experiments, and model validation.
- There are multiple lines of communication through the project and participants are responsive.