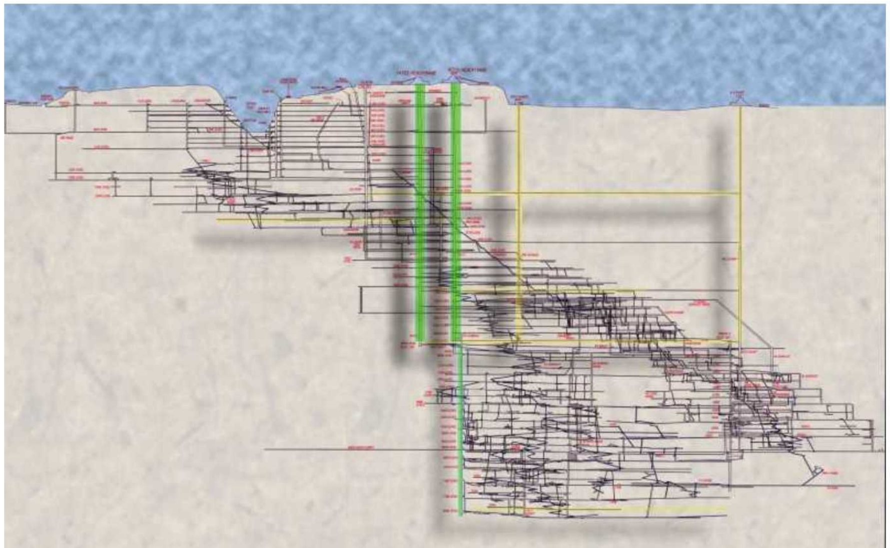
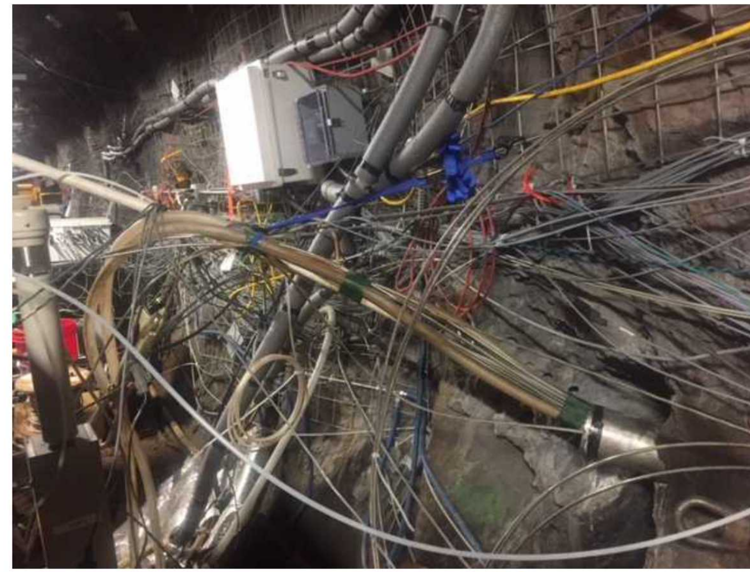
Overview of Sandia National Labs and the EGS Collab Project

SAND2019-3449PE

MD Ingraham





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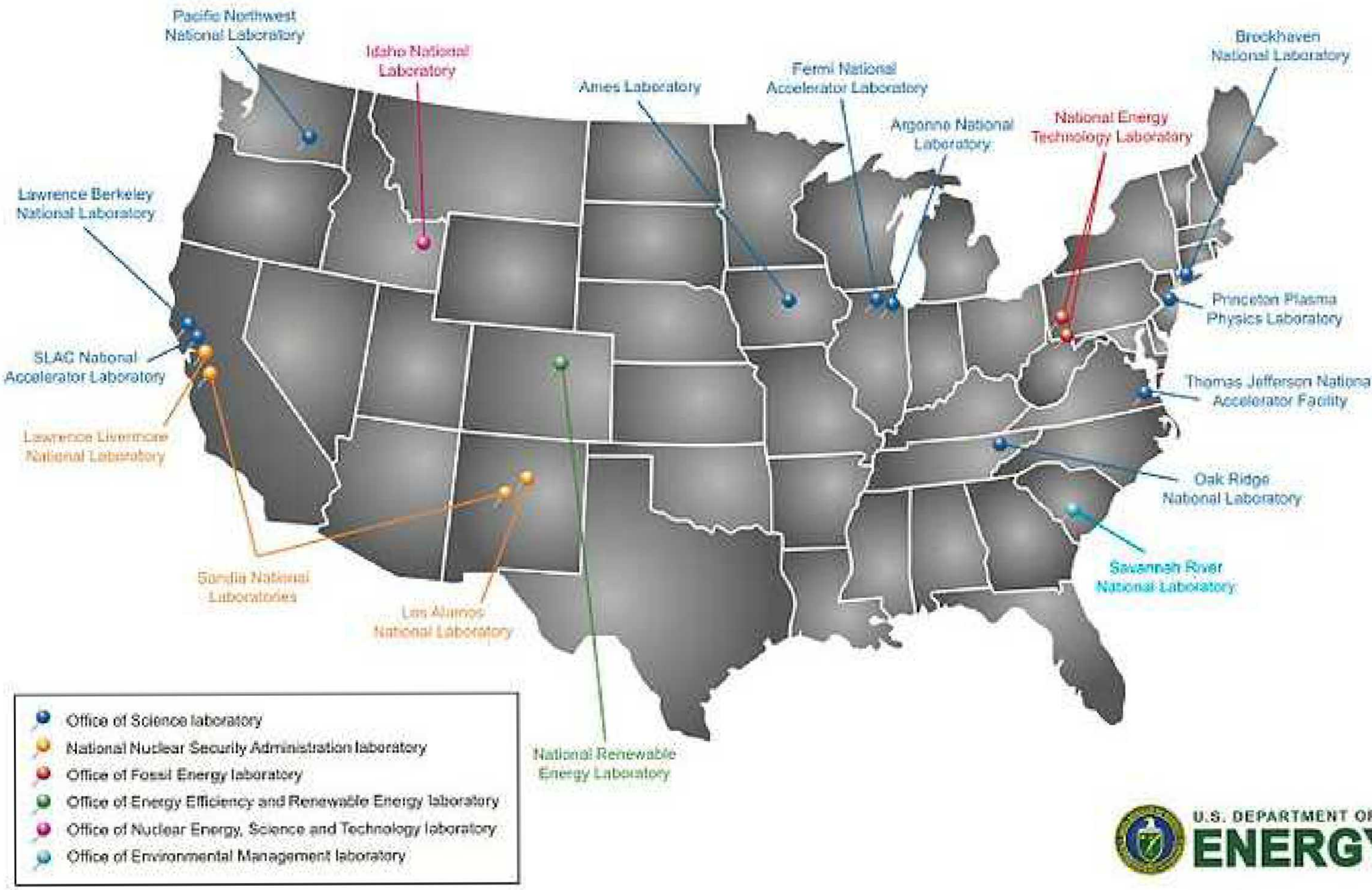
Introduction

- Sandia National Laboratory
- EGS Collab Project Overview
    - Background
    - Site Layout
    - Modeling and Monitoring
    - Results to date
    - FORGE
- Other areas of research
    - Shale Proppant Interactions
    - Salt Characterization
    - Material Properties
    - High Profile Work

Department of Energy National Labs



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Sandia National Laboratory

Sandia National Laboratories

- ~13,000 employees (Largest of the National Labs)
- ~$2.6 billion annually
- Research areas
  - Nuclear Weapons – sustain secure and modernize the US nuclear arsenal
  - Defense Systems and Assessments – design and develop defense and national security capabilities
  - **Energy and Climate** – Ensure secure and stable supply of energy and resources and protection of infrastructure
  - International, Homeland and Nuclear Security – Protection of nuclear material/assets, nuclear emergency response and nonproliferation

Collab Team

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

OU

MINES

SOUTH DAKOTA M SCHOOL OF MINES & TECHNOLOGY

THE UNIVERSITY of WISCONSIN MADISON

Sanford Underground Research Facility

TDoeGeo Rock Fracture Consulting

NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

RESFRAC

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Collab Team

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Y. Zhang
Y.Q. Zhang
Q. Zhou
M.D. Zoback

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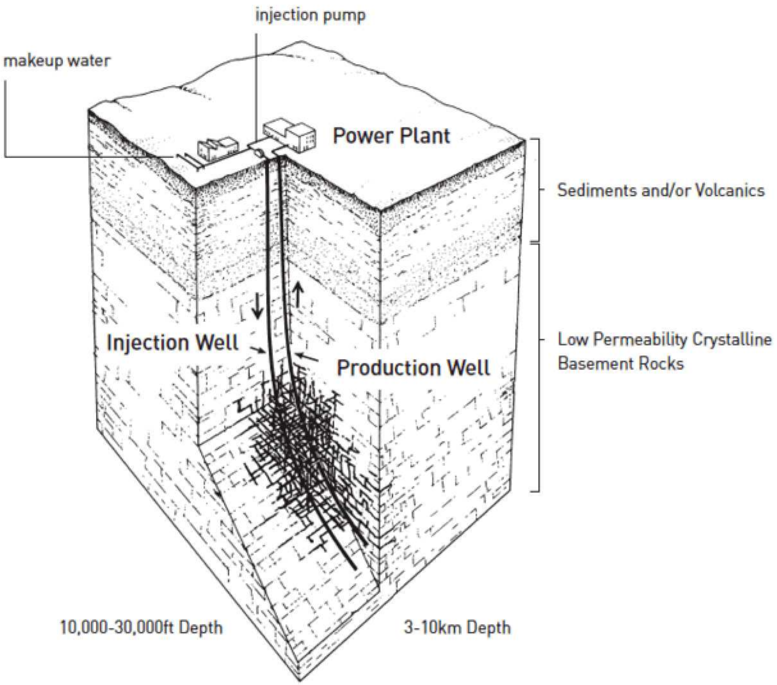
Background

- Motivation - What is EGS?
- How do you make an EGS?
- The EGS Collab project
  - Experiment 1 (of 3)
- Challenges/considerations

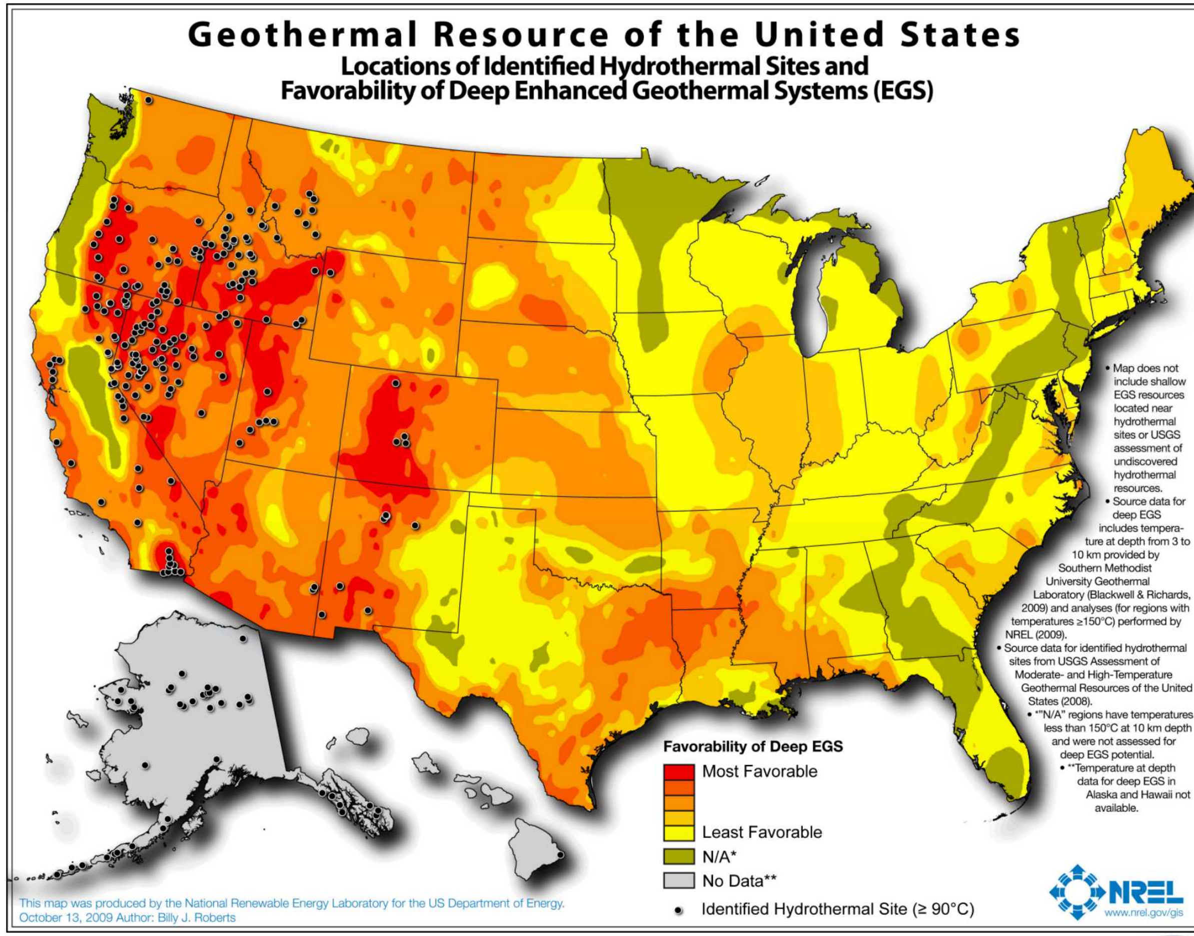


Tester (2006)

Geothermal Power in the US

Geothermal power plants require high-temperature (300°F to 700°F) hydrothermal resources that come from either dry steam wells or from hot water wells

US has predicted geothermal reserves on the order of 700,000 MW accessible with EGS



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EGS Collab Project Challenge

Establish a collaborative **experimental and model comparison** project to **elucidate the basic relationship between stress, seismicity, and permeability enhancement.**

- Develop ~10 m-scale field sites, perform well-monitored experiments and collect **high-quality data** with **comprehensive instrumentation**.
- Identify and quantify the **nature of stimulation** and other key governing parameters that impact permeability.
- Challenge and constrain models with data.
- **Prepare, validate, and improve tools** for FORGE and EGS.

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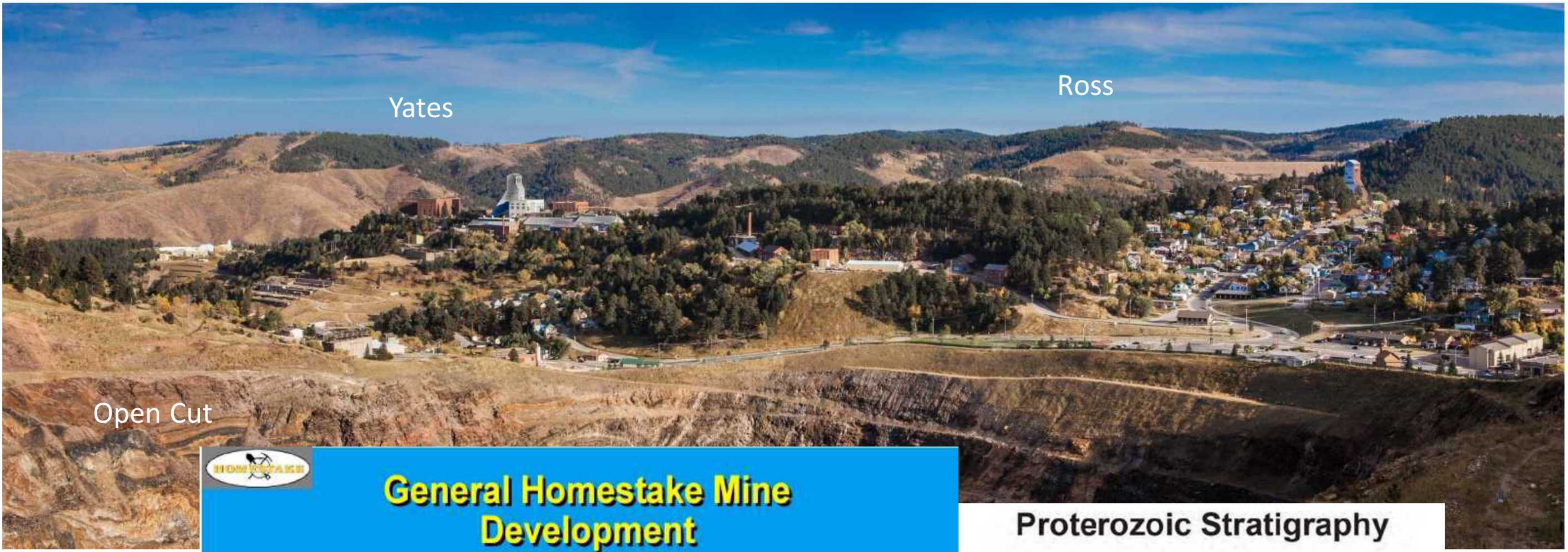
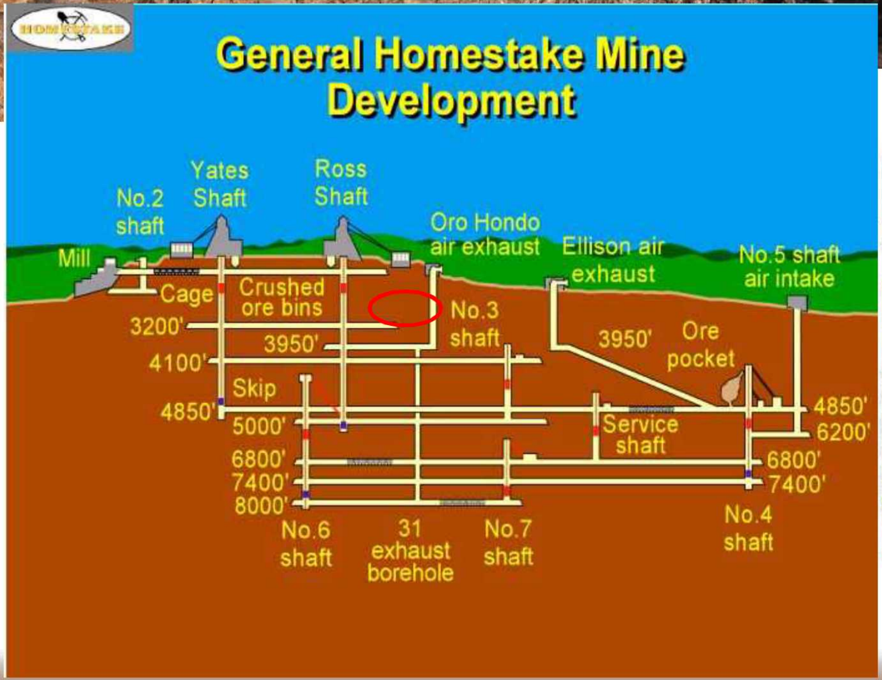
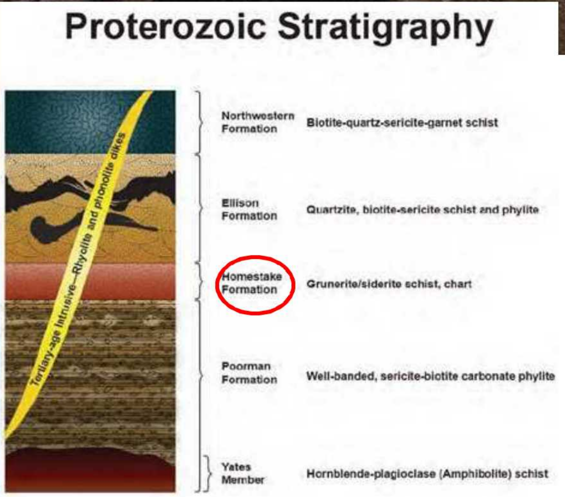
Sanford Underground Research Laboratory







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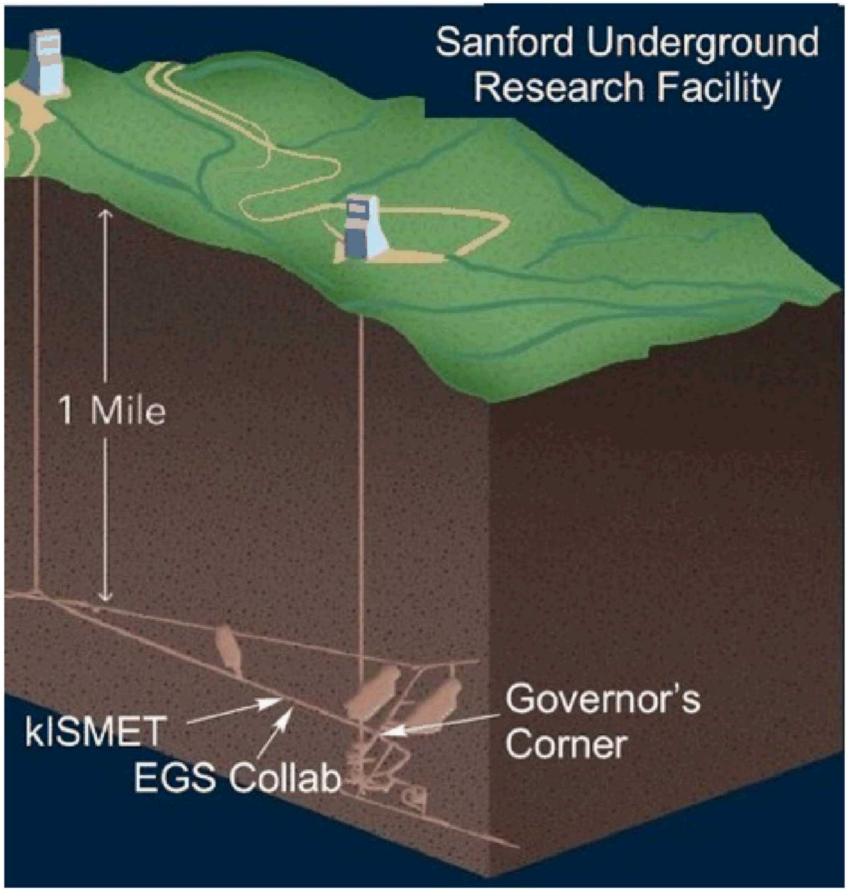

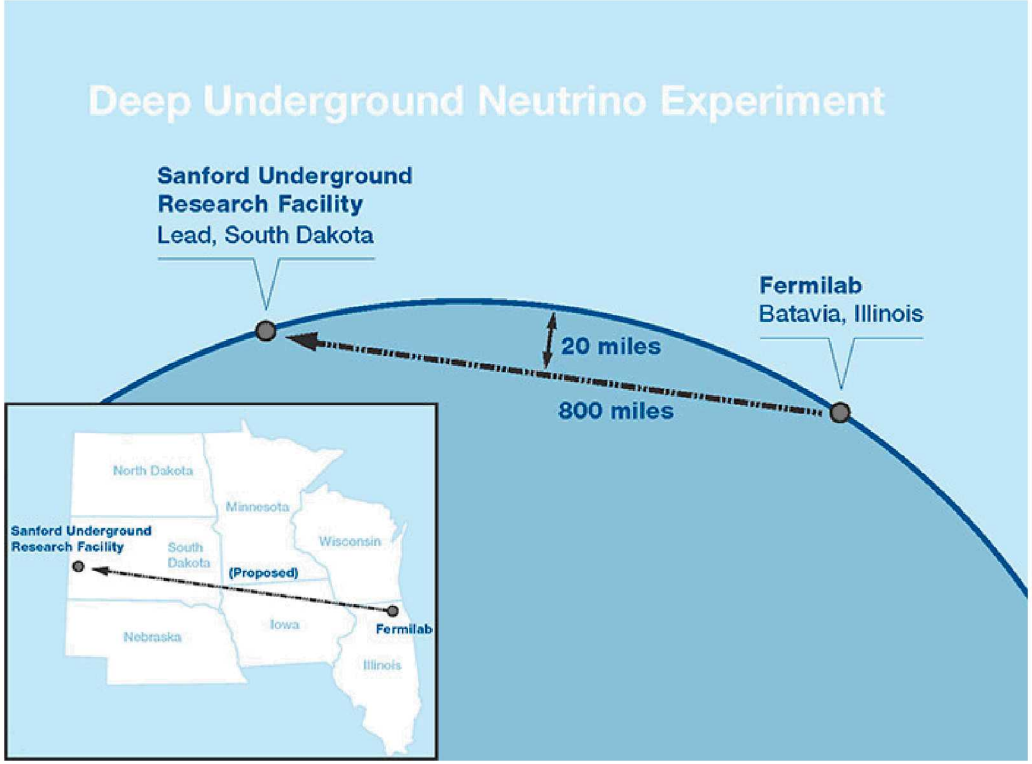

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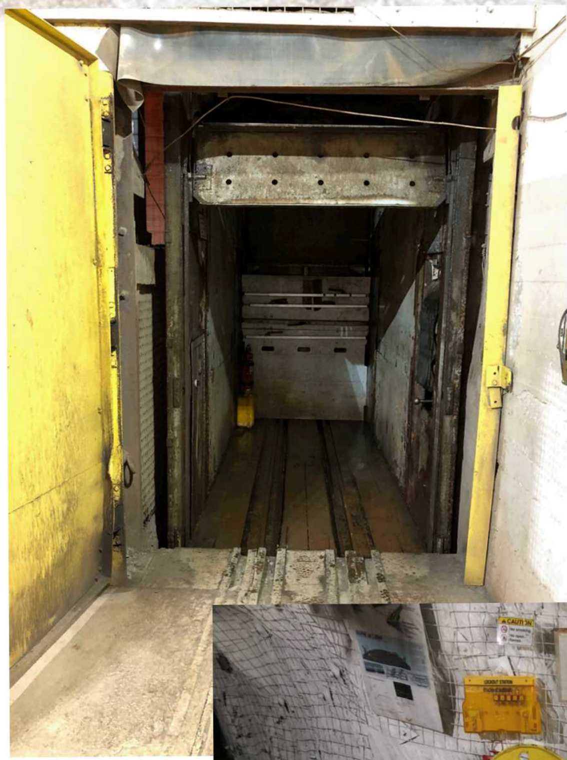
The Morning Commute



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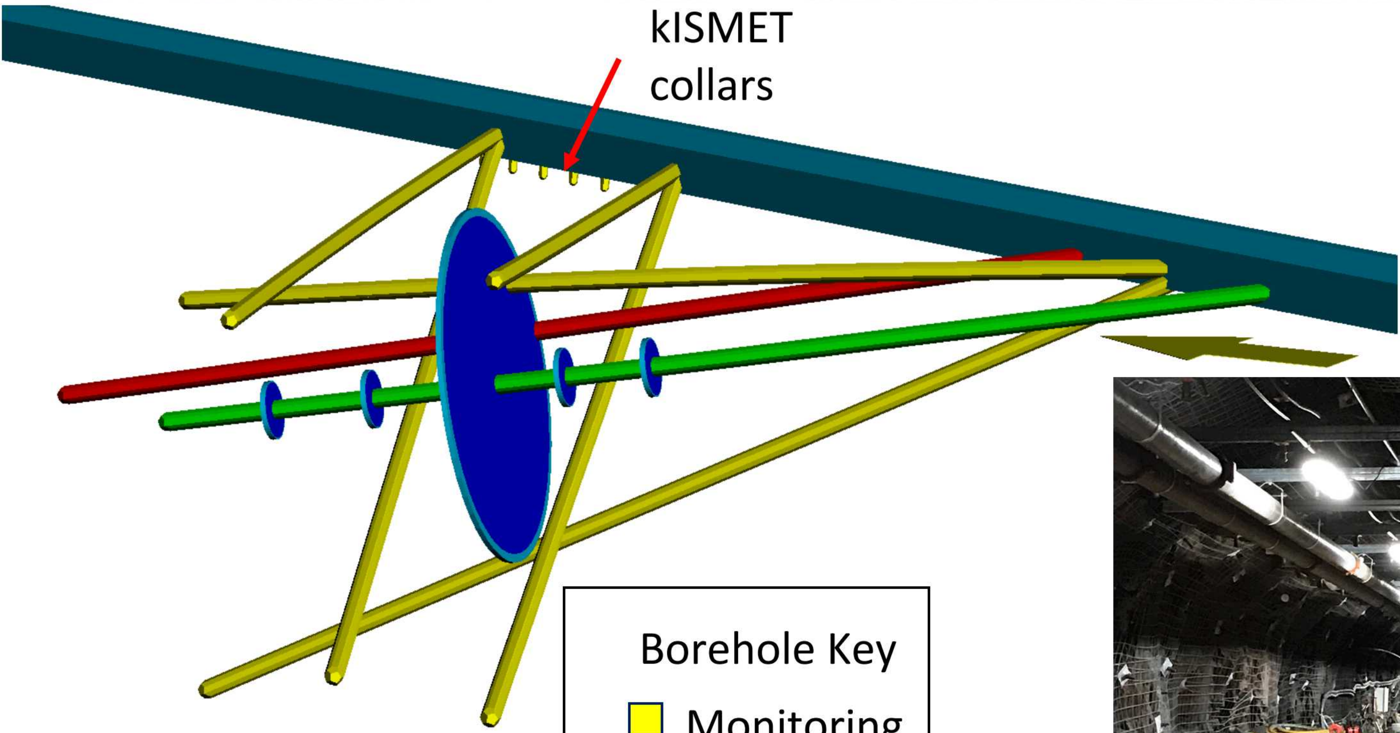
EGS Collab Experiments

- **Experiment 1**, intended to investigate **hydraulic fracturing***, at the Sanford Underground Research Facility (SURF) at 4,850 ft. 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.

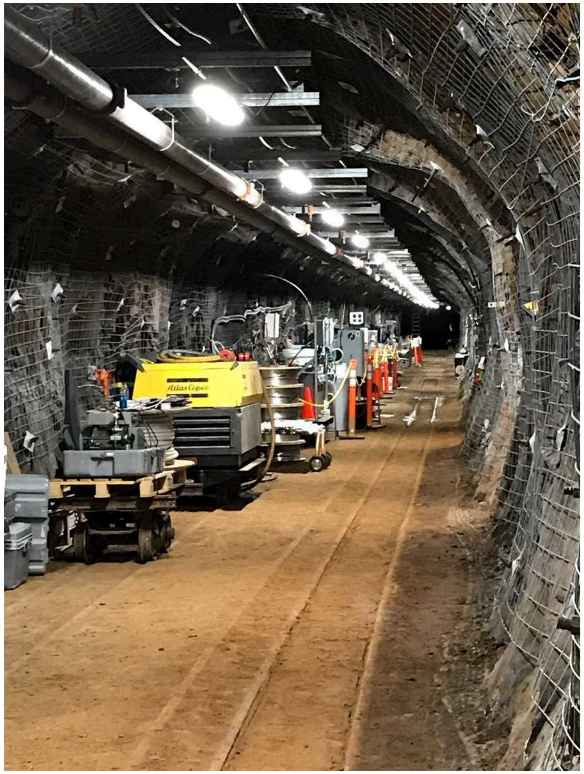
Each experiment consists of multiple stimulations; and characterizations of flow, tracer, and heat transfer behavior.

Experiment 1



Borehole Key
- Monitoring
- Stimulation
- Production

Joe Morris (LLNL)



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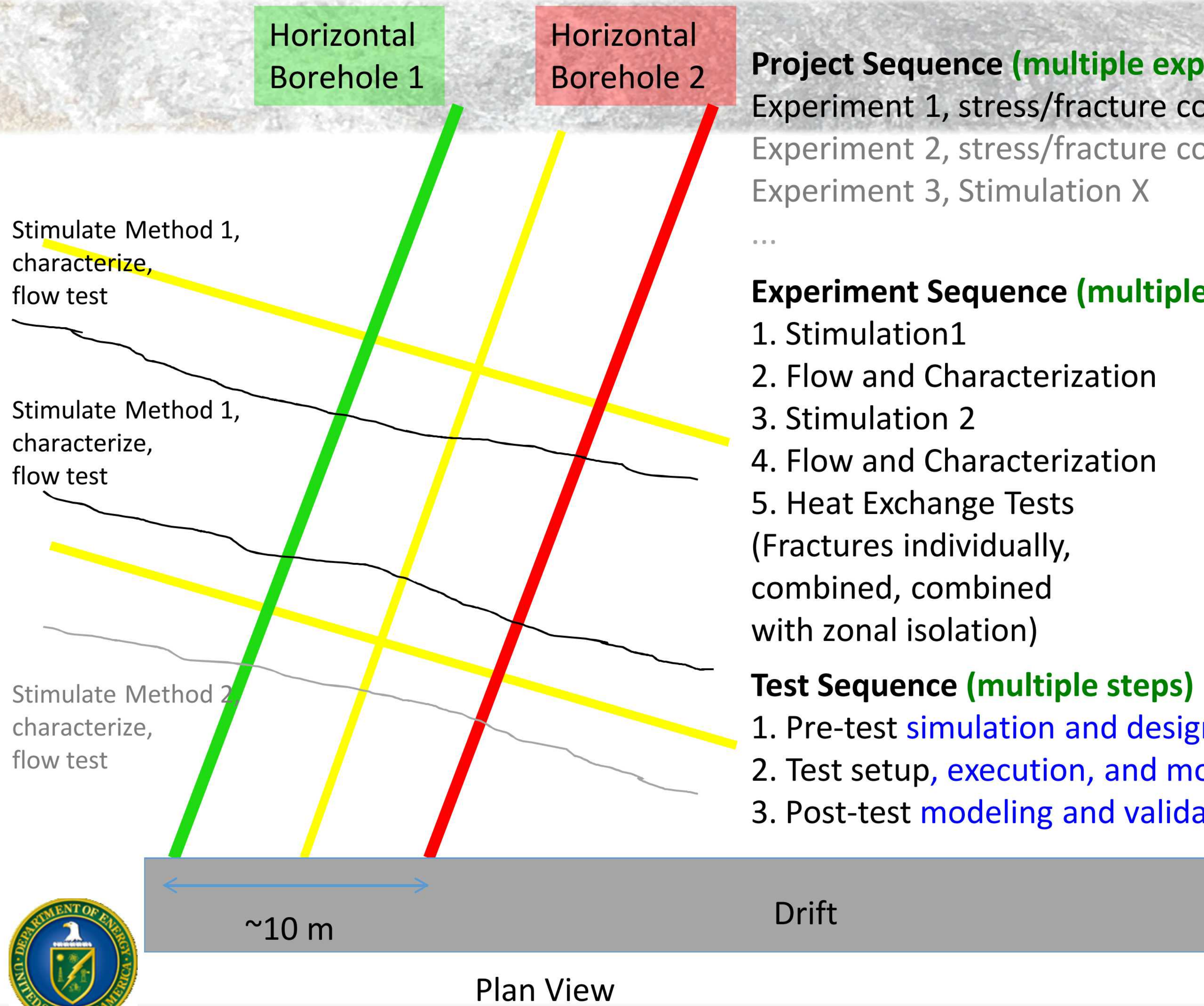

Project Sequence (multiple experiments)

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

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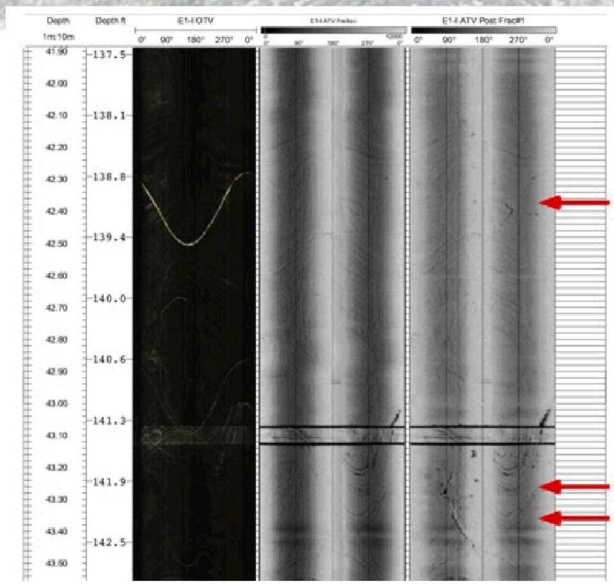
Testbed Characterization

Borehole

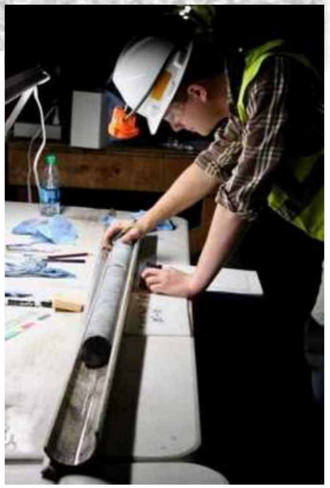
- Optical and acoustic televiewer
- Full waveform seismic
- Electromagnetic
- Gamma
- Temperature

Test “block”

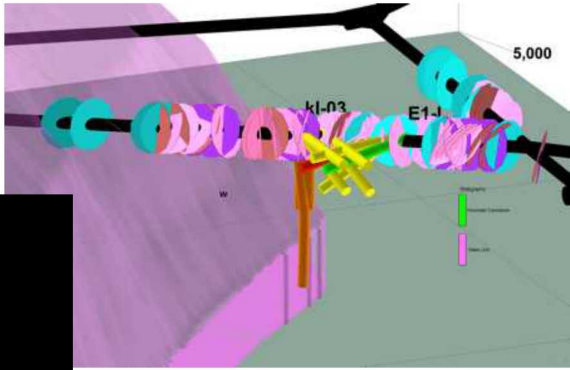
- P- and S-wave characterization using mobile and grouted borehole sensors, grouted and mobile sources
- Extended hydrologic characterizations
- Electrical Resistance Tomography (ERT) baseline and flow



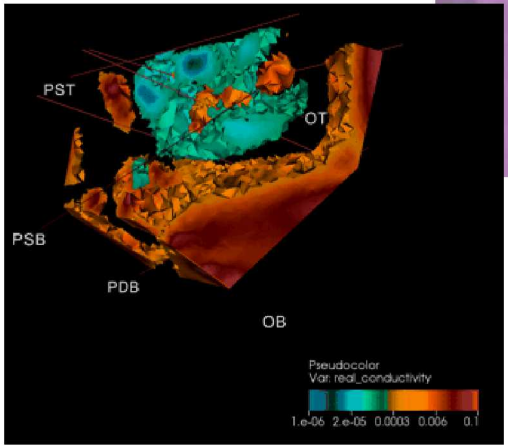
Craig Ulrich (LBNL)



Sterling Richard (SDSMT)



Hari Neupane (INL)



Tim Johnson (PNNL)

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Monitoring during stimulation and flow

- Acoustic emissions (AE)*
- Continuous Active Source Seismic Monitoring (CASSM)*
- MicroEarthquake (MEQ)*
- Electrical Resistance Tomography (ERT)
- Temperature by fiber distributed temperature sensing (DTS)
- Strain by fiber distributed strain sensing (DSS)
- Direct 3-D fracture displacement using SIMFIP at injection and production boreholes

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On-Line Communication

Monitoring during stimulation and flow

Fracture Pe

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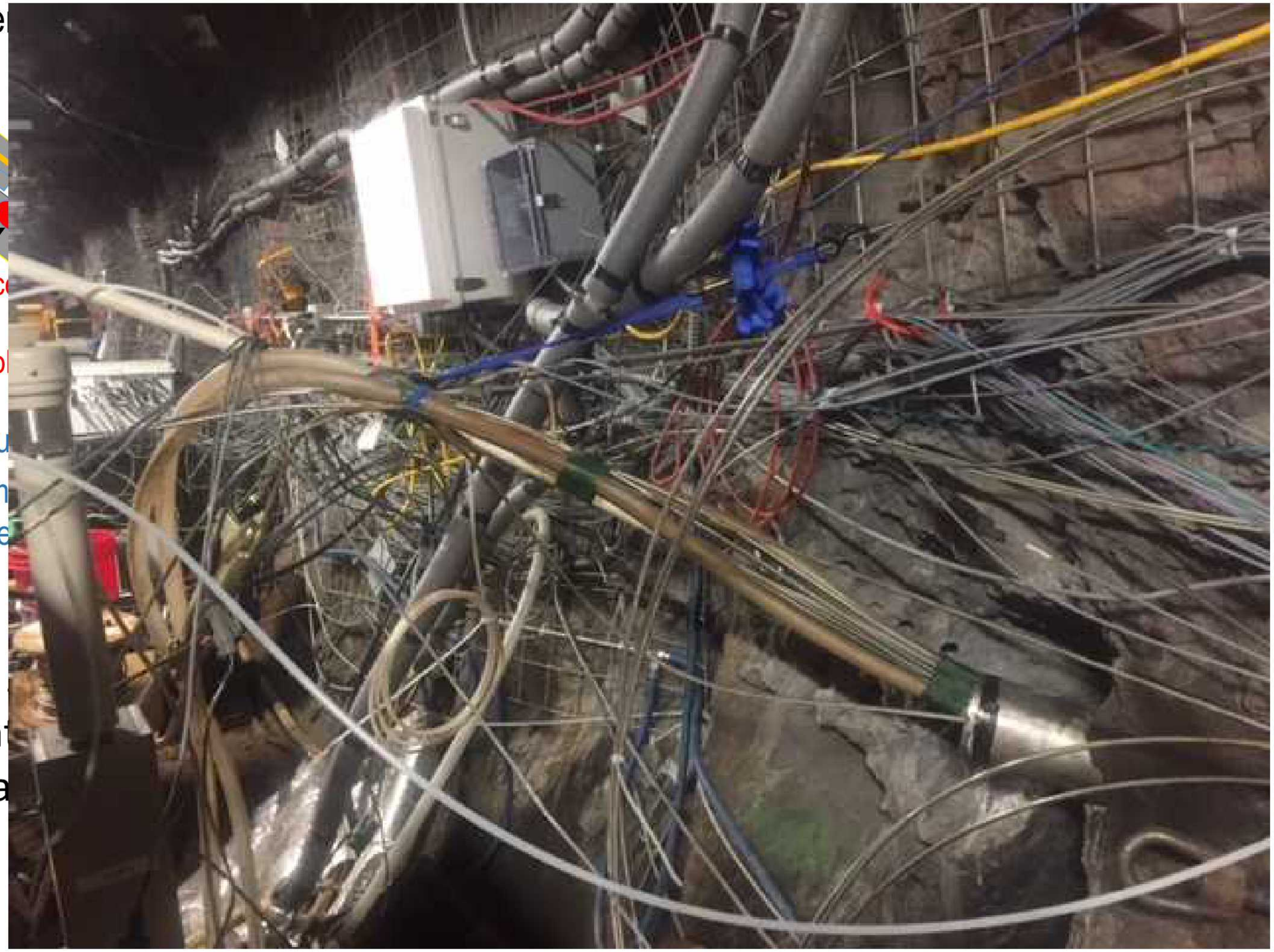

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Fracture Characterization

BNL)

Step-rate Injection Method
for Fracture In-situ Properties

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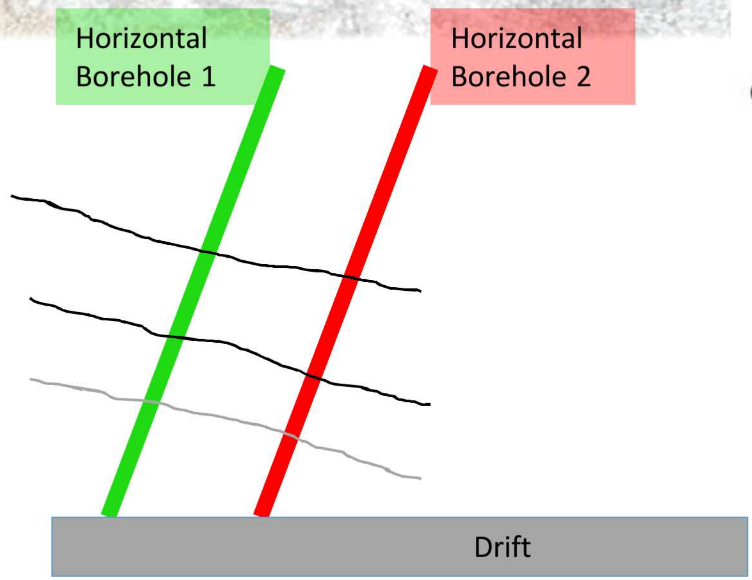
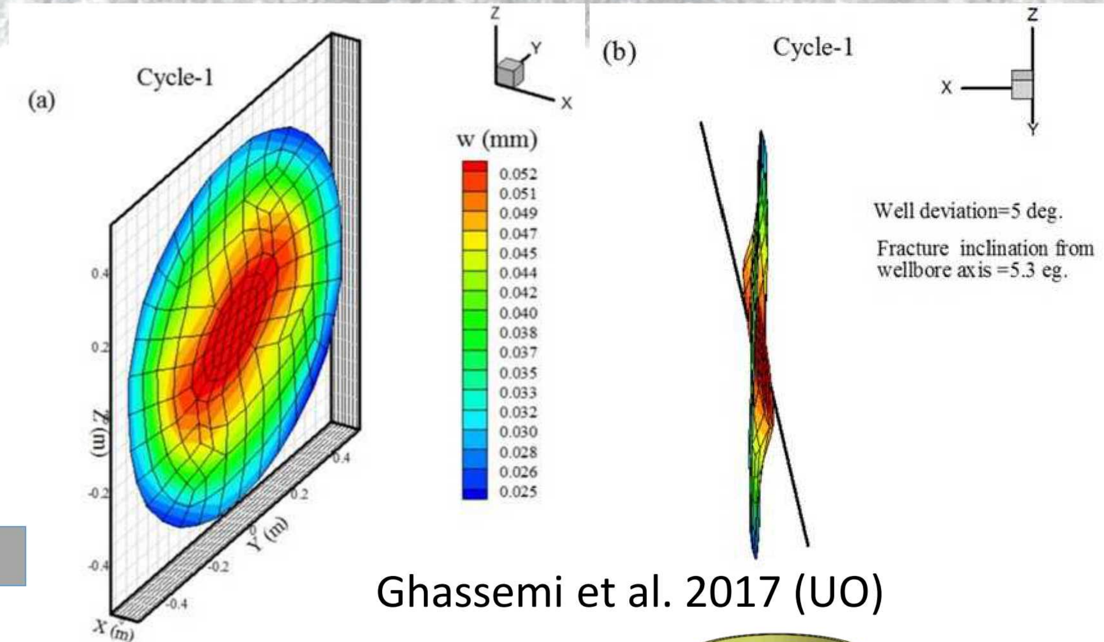
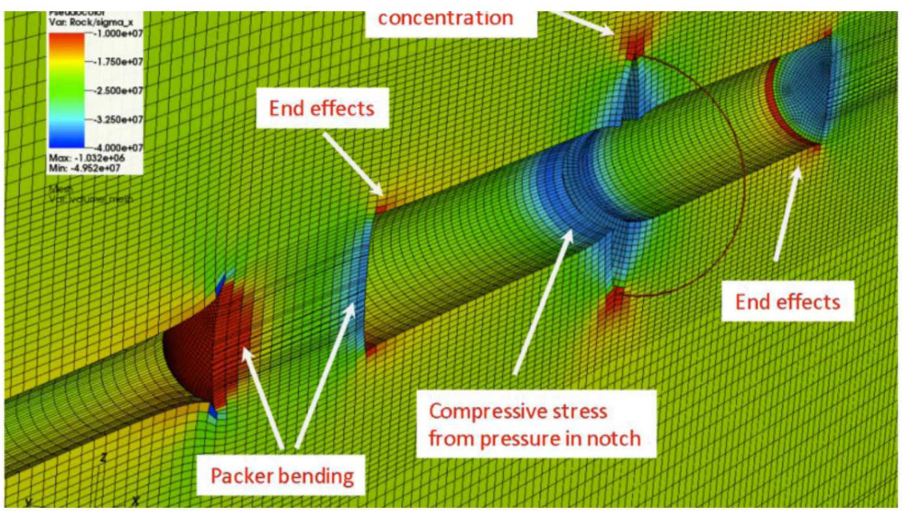
Fracture Configuration



Plan View

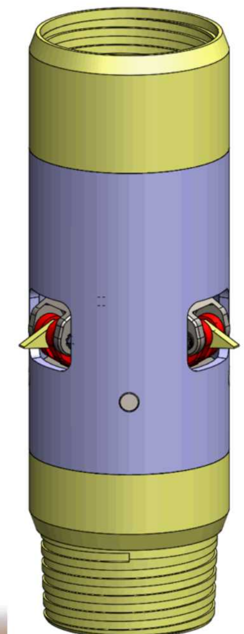


Ghassemi et al. 2017 (UO)



Pengcheng Fu (LLNL)

Jiann-cherng Su (SNL)



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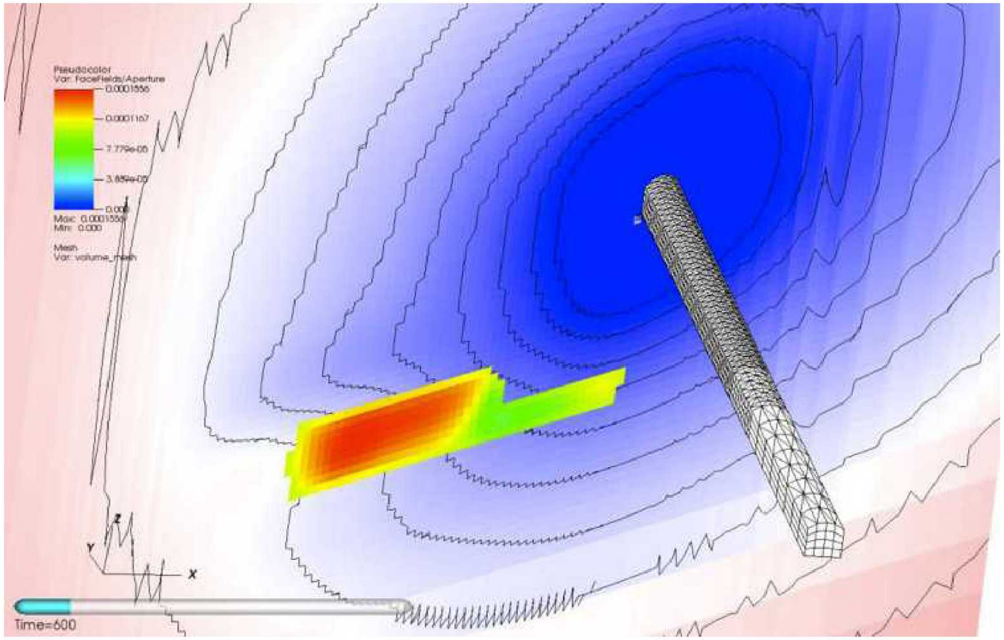
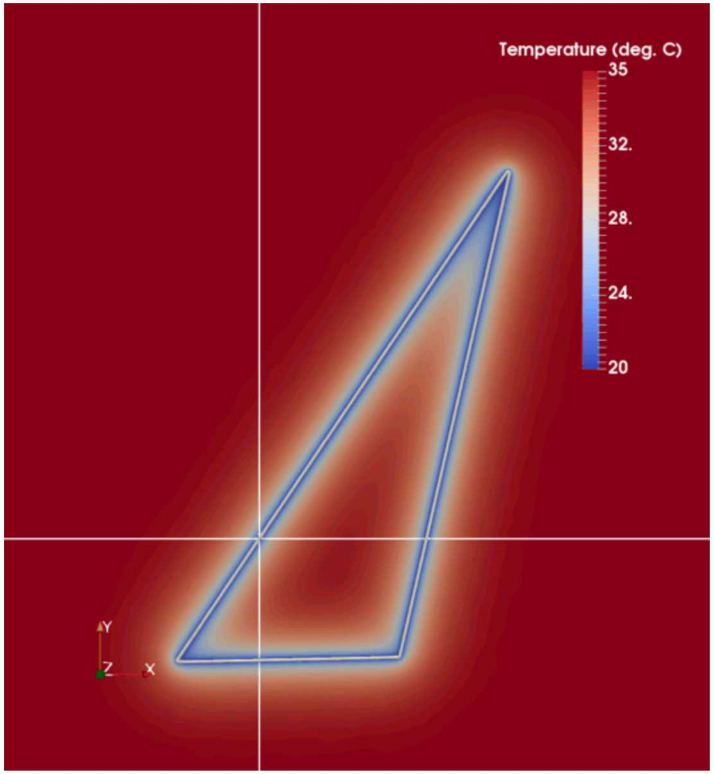
Rock temperature gradient

- Mined in mid 1970s and ventilated
- Flooded and drained in 2000s



Stress gradient attracts fractures to drift.
Production hole halts fracture propagation.

Pengcheng Fu (LLNL)



2-D cross section of temperature field

Yidong Xia (INL)

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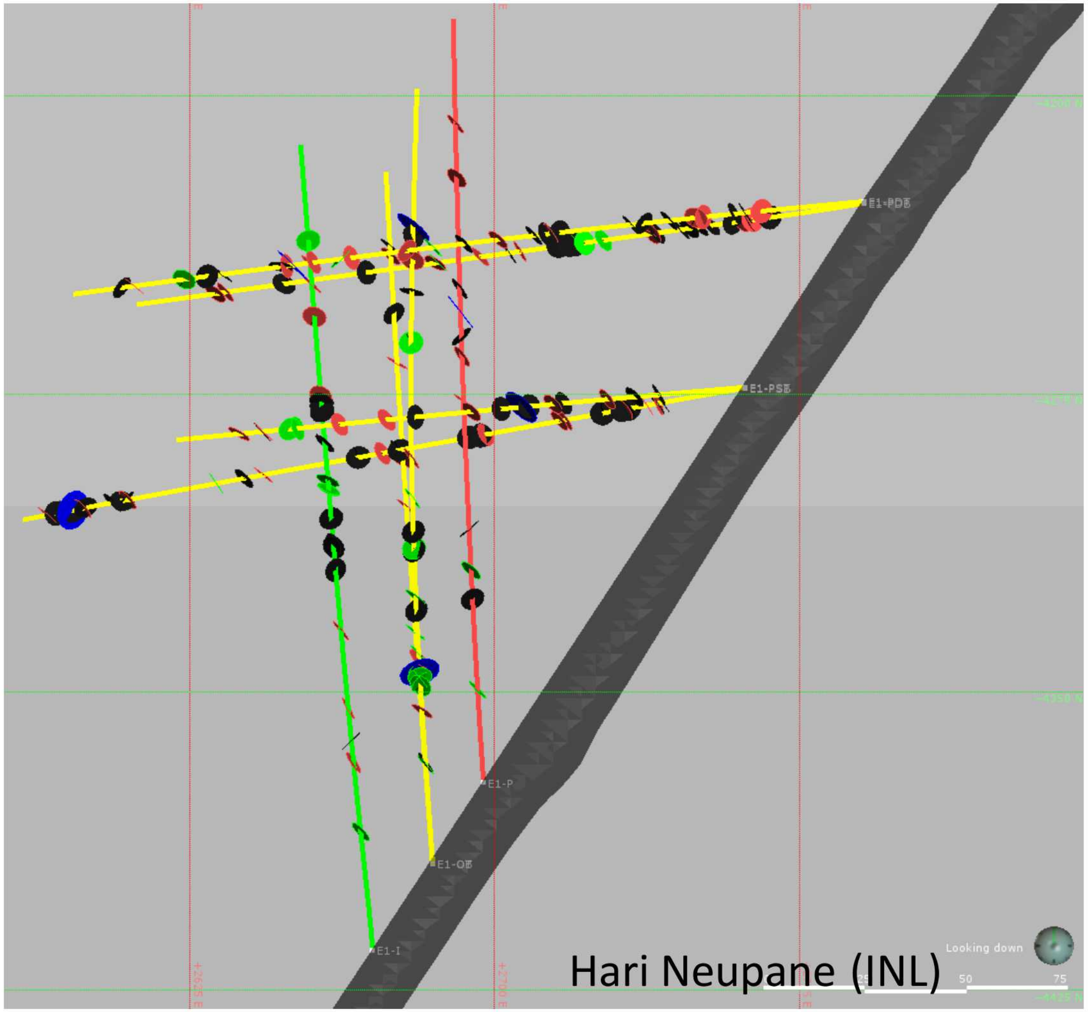
Geologic Framework Model
Common Discrete Fracture Network Model



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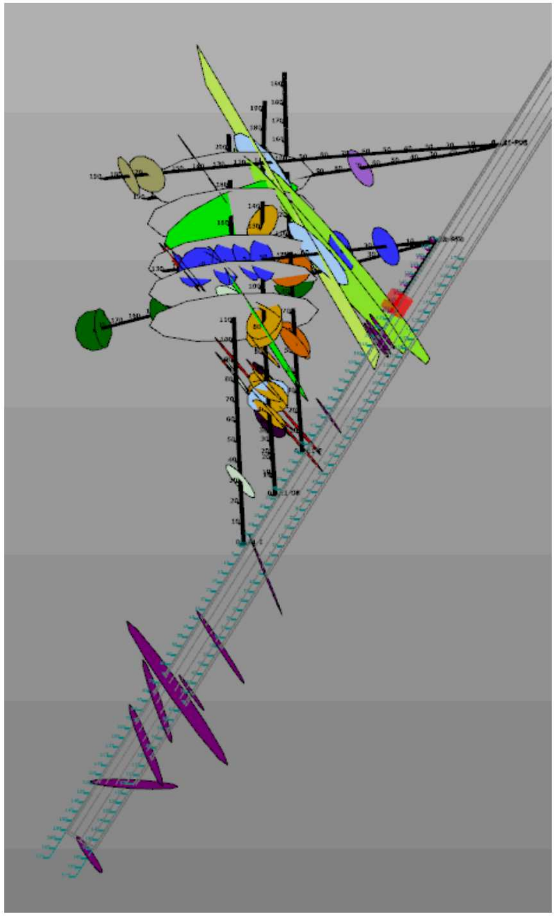

The CDFNM Team

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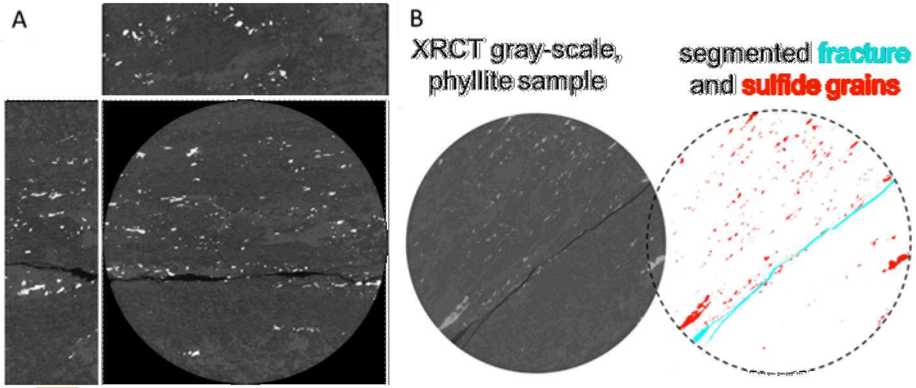
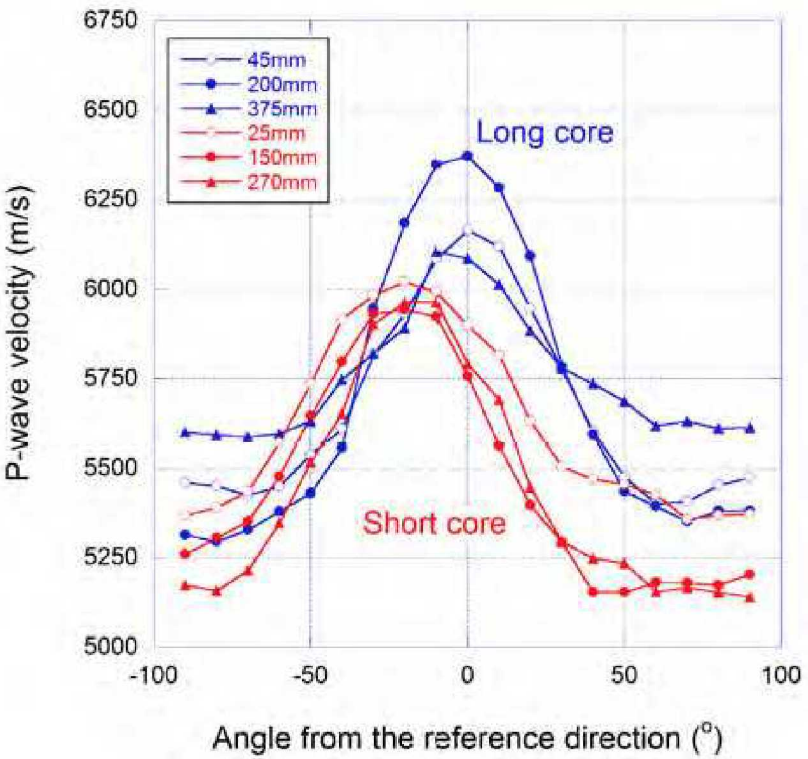
Laboratory Measurements

- Seismic anisotropy
- Anisotropic thermal conductivity
- Elastic constants
- Fracture toughness
- Microbiology
- High-Temperature flow/geochem

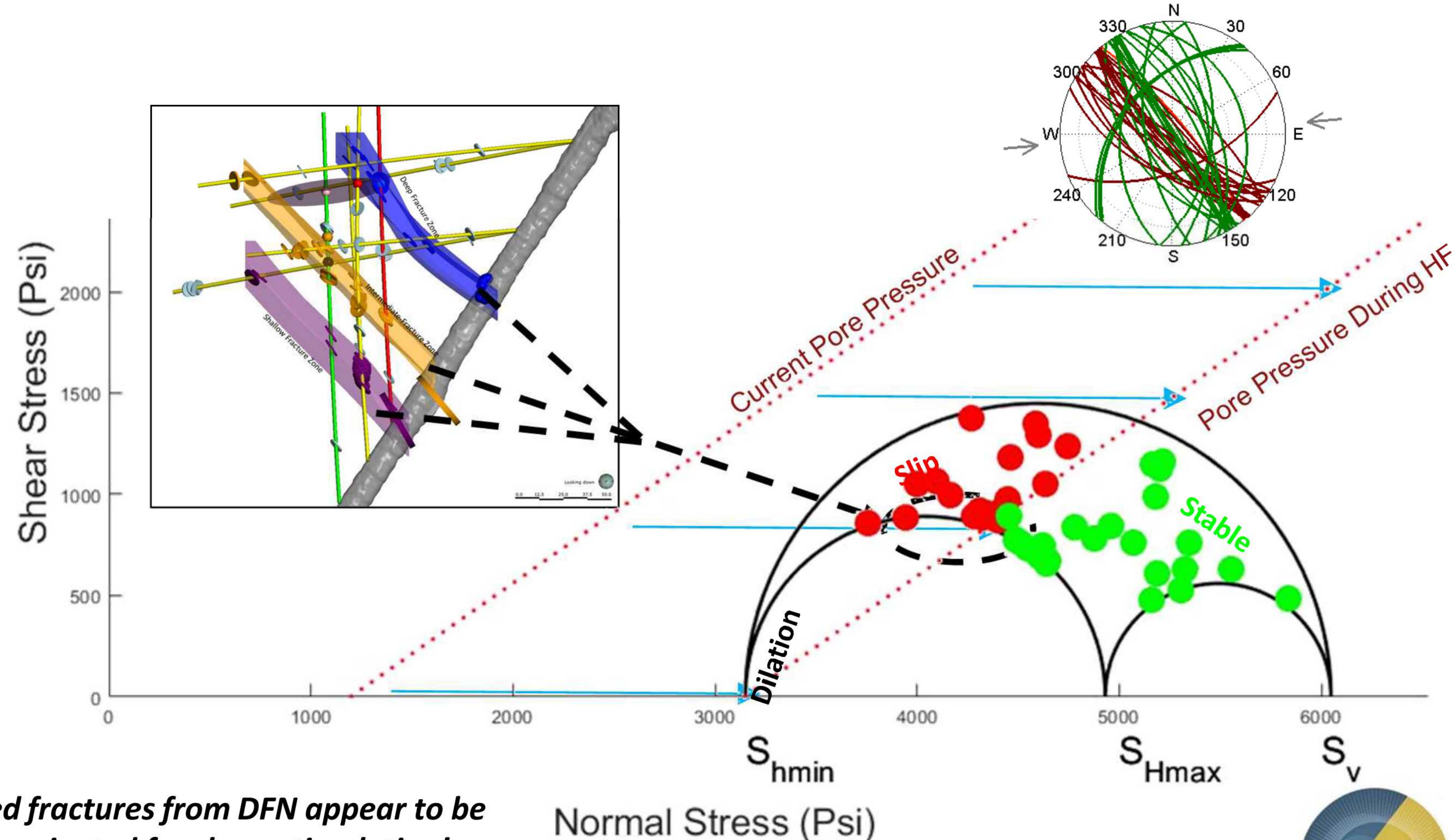


Megan Smith (LLNL)



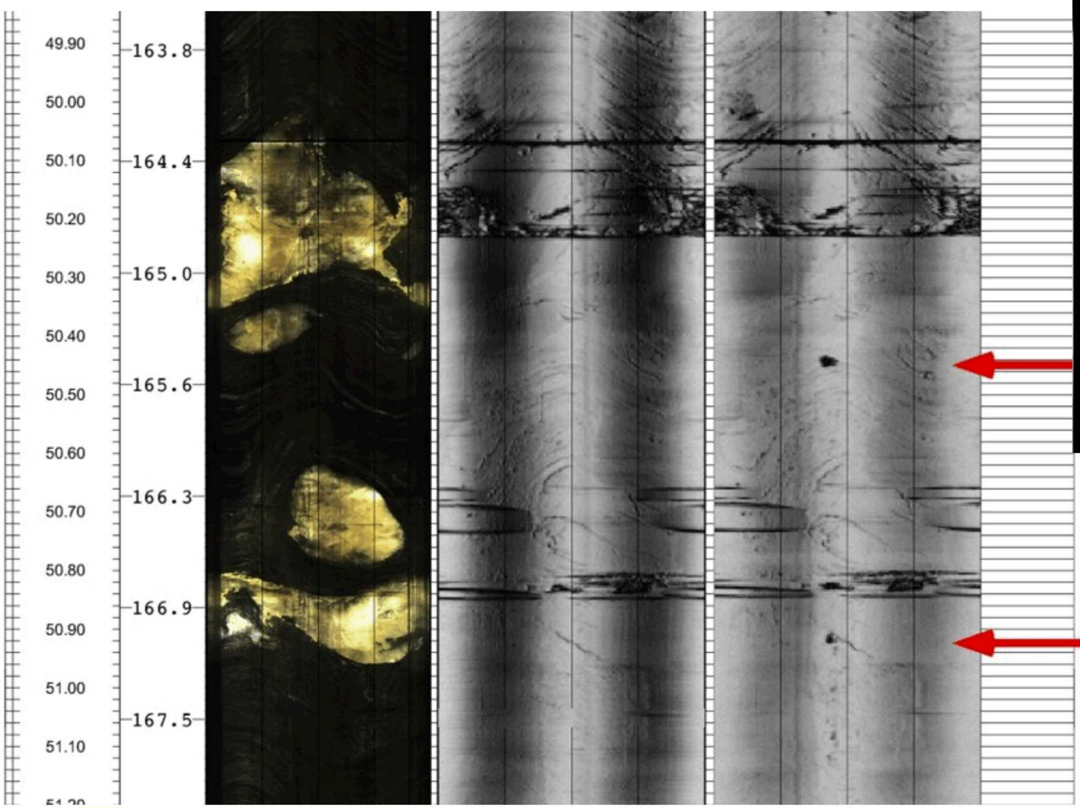
Seiji Nakagawa (LBNL)

Stimulation Tendency Analysis



Connected fractures from DFN appear to be favorably-oriented for shear stimulation!

Results – Borehole logging, Inflow



Craig Ulrich (LBNL)

Paul Schwering (SNL)

Flow tests

- Quantify fracture opening versus working pressure
- Find a working pressure to contain fracture
- Flow versus fracture pressure
- Conservative, nonconservative, and DNA tracers
- Thermal tests and interpretations

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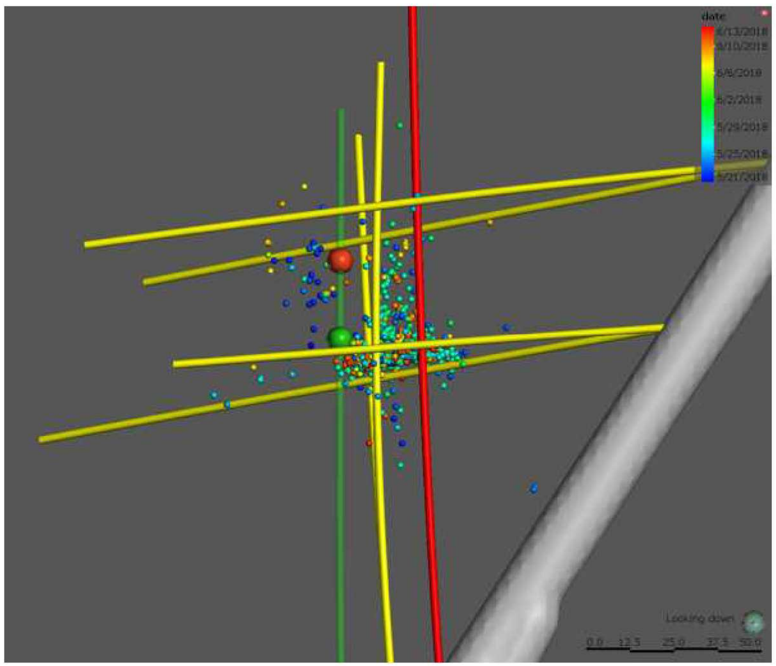
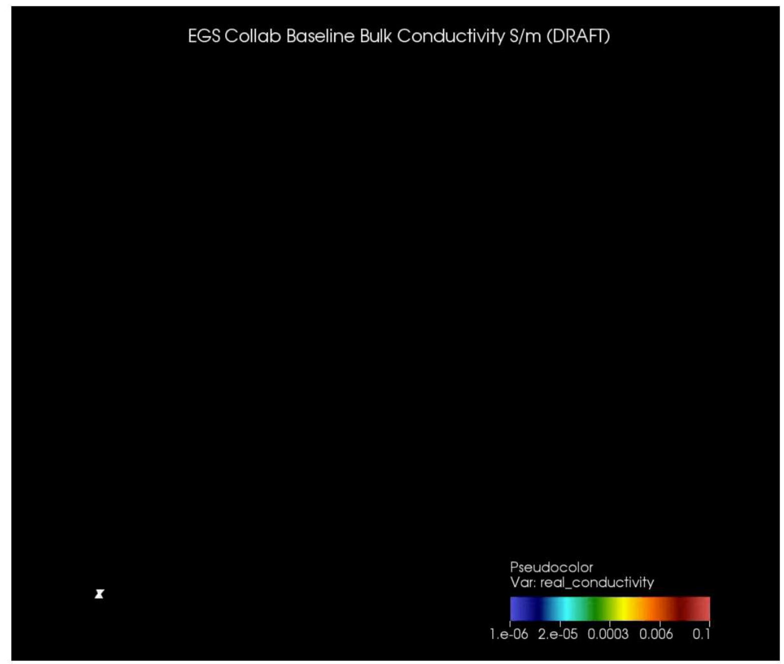
Results – Induced Seismicity, ERT

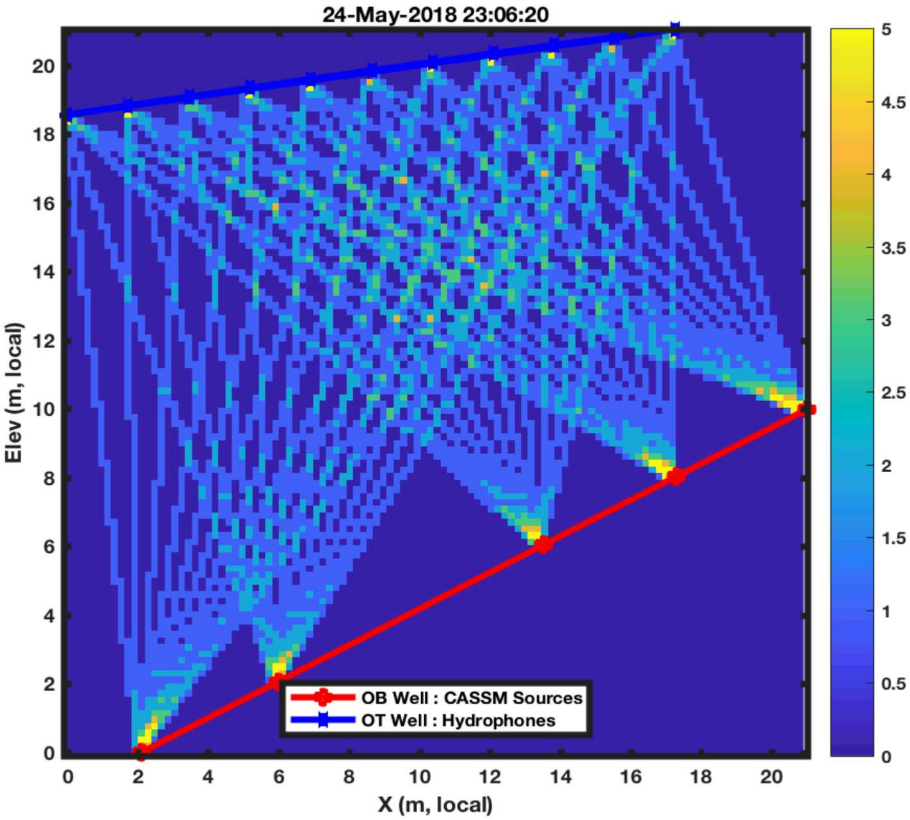


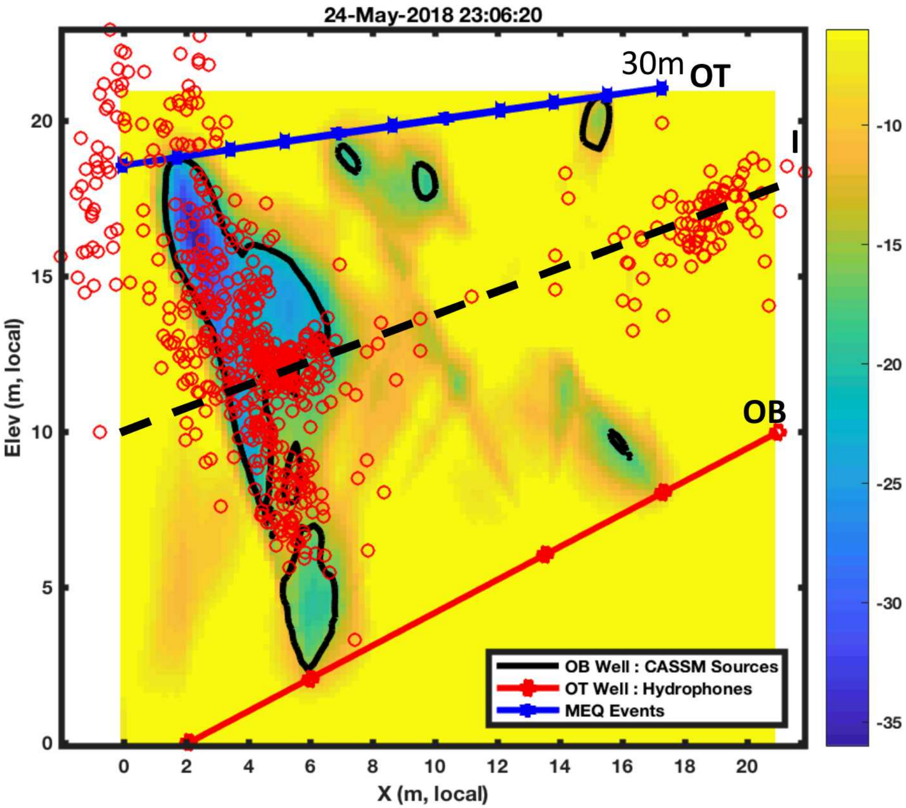


Martin Schoenball (LBNL)
Jonathan Ajo-Franklin (LBNL)
Hari Neupane (INL)

Tim Johnson (PNNL)

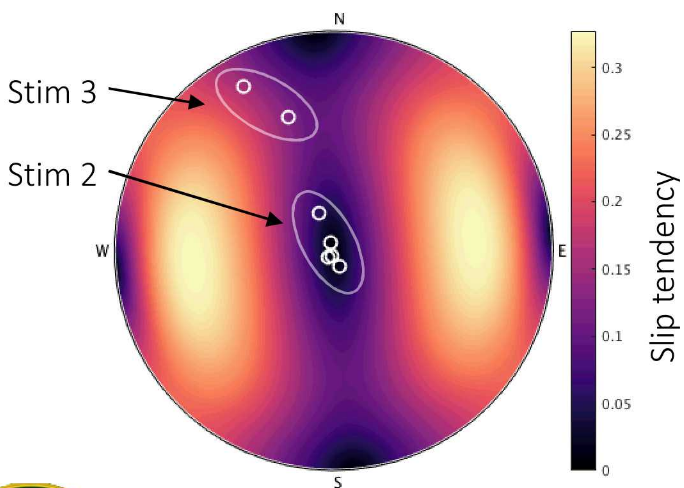
Comparison between P-wave tomography (CASSM) and MEQ (+ DTS)

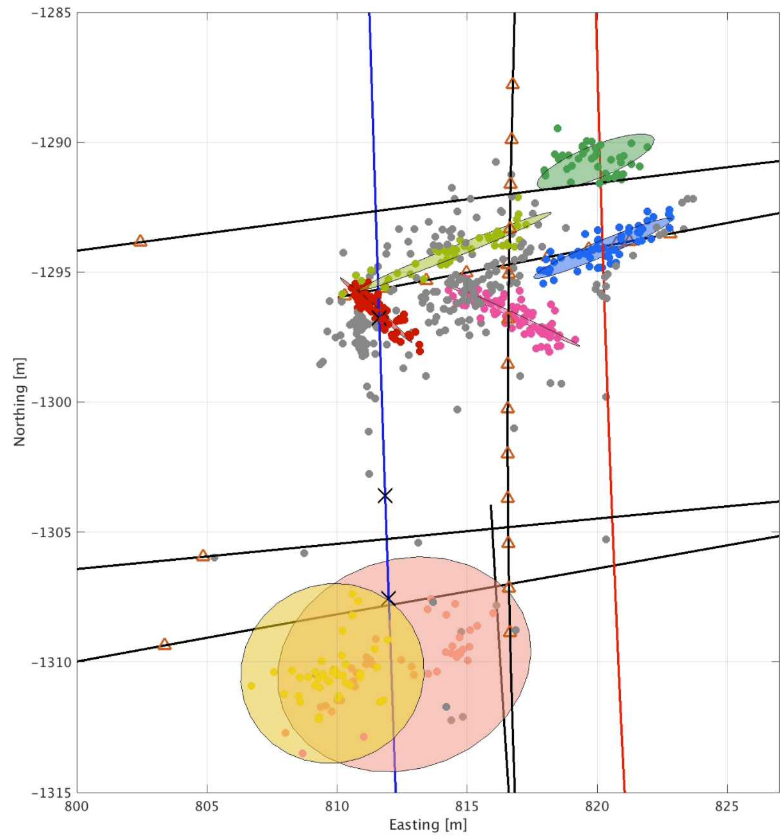




Fracture network

- 8 distinct fault planes identified fr MEQ
- Interception points with borehole consistent with distributed tempe (E1-OT) and in-situ conductivity measurements (E1-P)
- Very low slip tendency, consistent tensile opening in Stim 2
- Slightly higher slip tendency for St fractures but higher breakdown pressure





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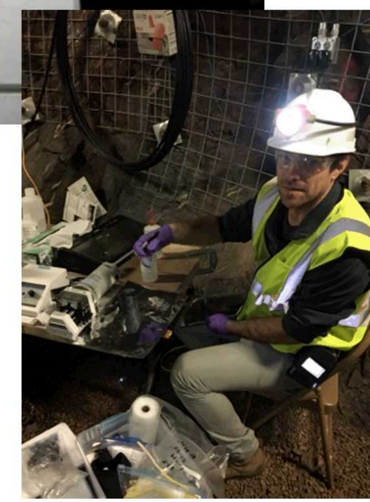
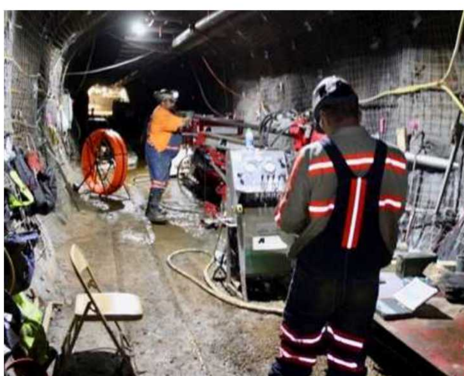
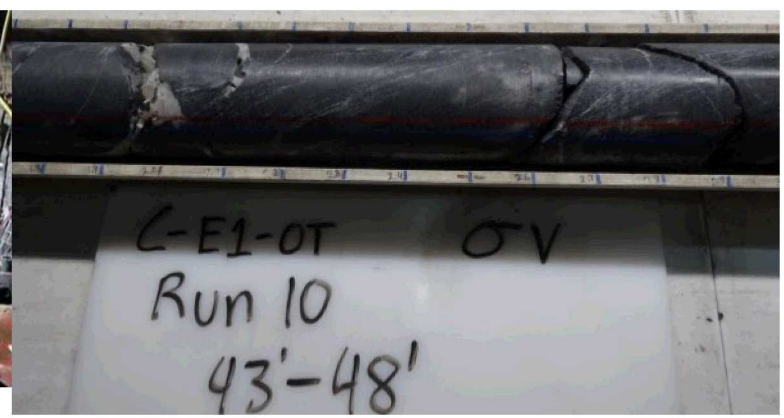
EGS Collab Project

- Project kicked off March 2017
- Numerous simulations and measurements have been performed
- Experiment 1 stimulations/ characterizations under way
- Tests performed with immediate feedback
- Data will be made available ASAP
- Evaluating locations for Experiment 2







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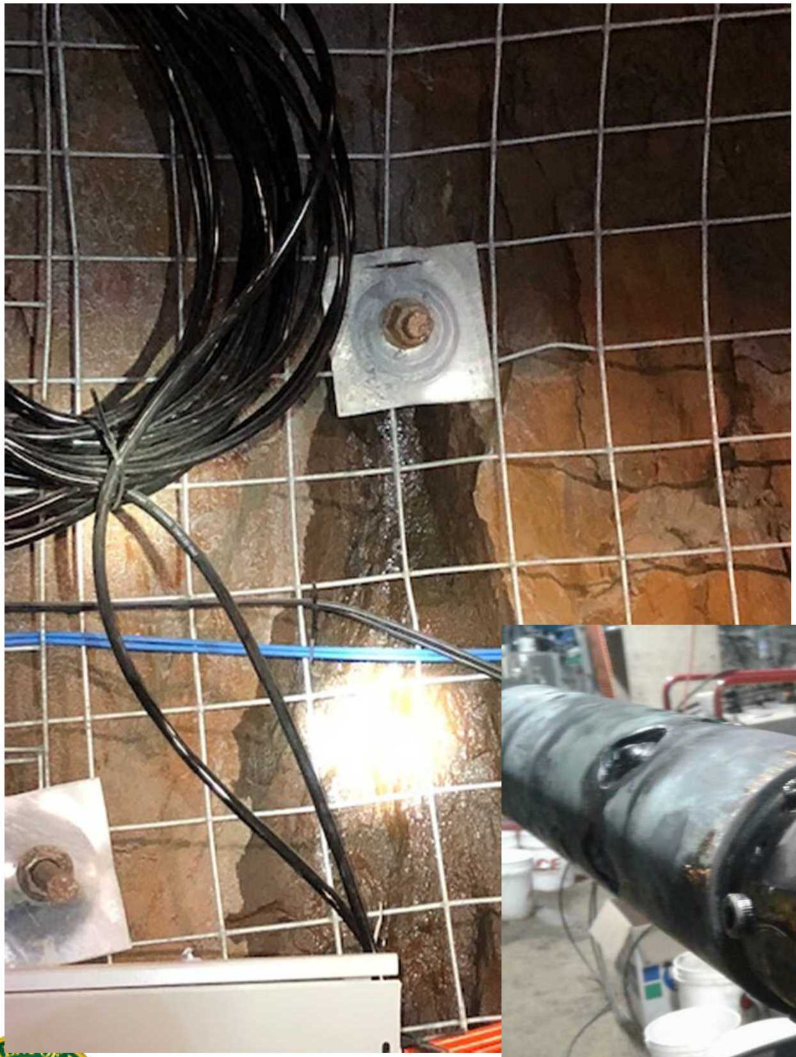
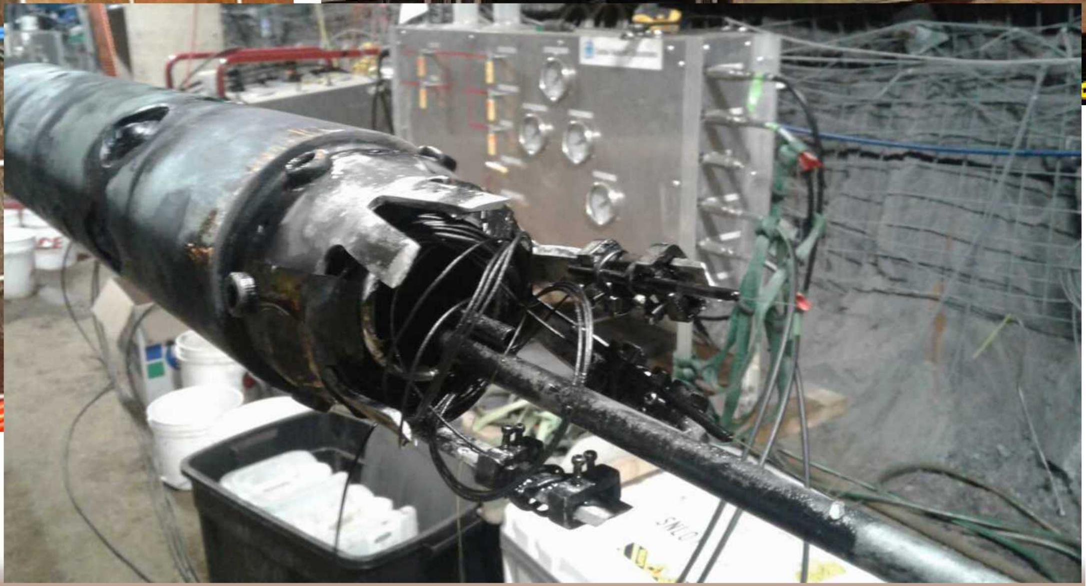
Sometimes things go sideways





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Path to FORGE

FORGE U.S. Department of Energy

- FORGE -Frontier Observatory for Research in Geothermal Energy
- Full-Scale Testbed being built in Milford, UT

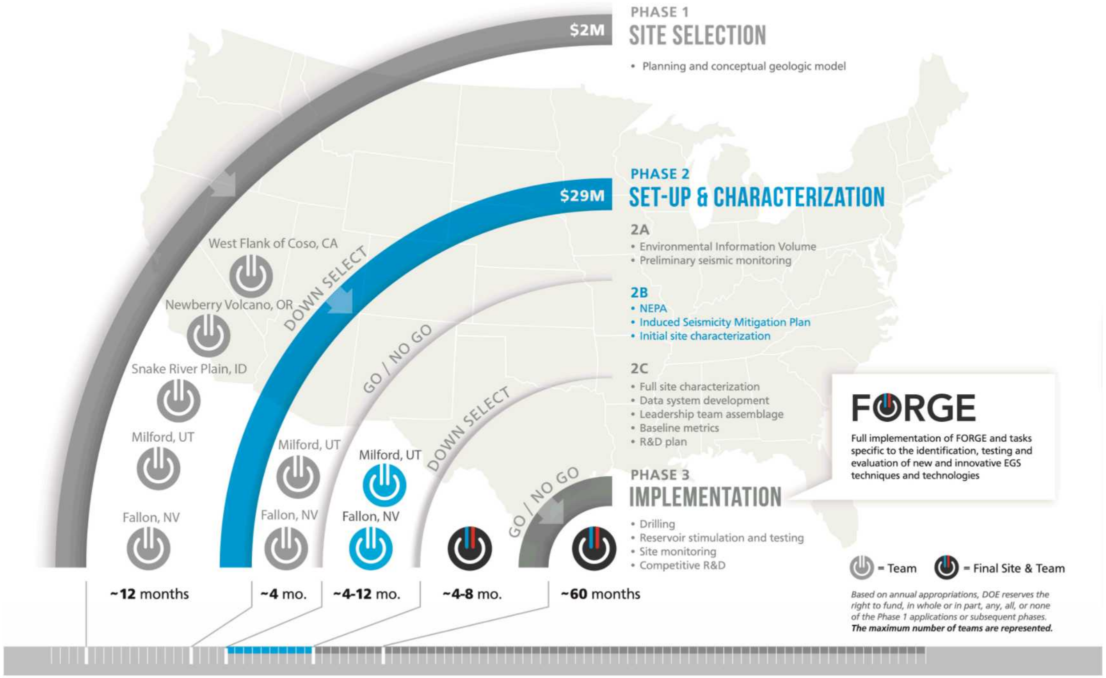

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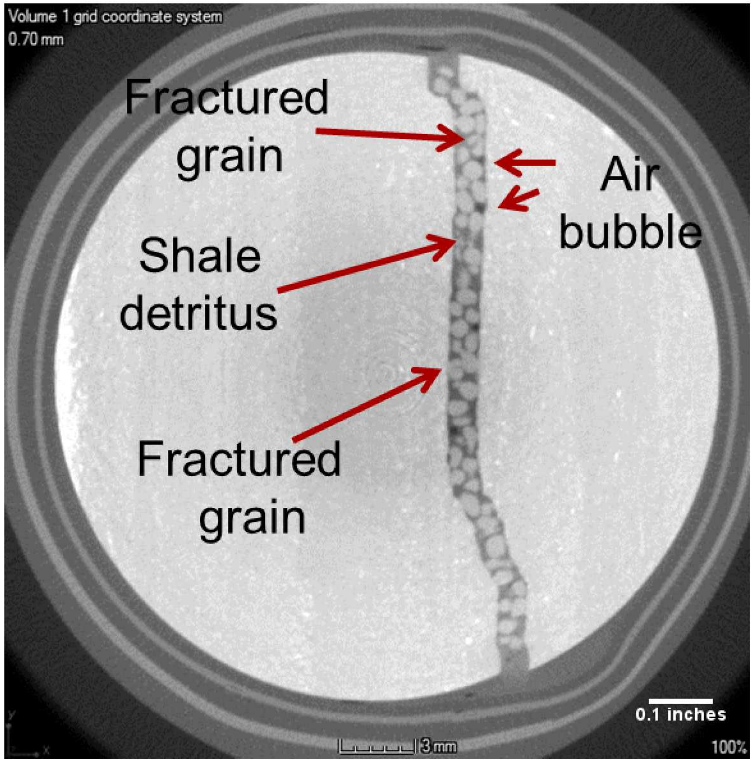
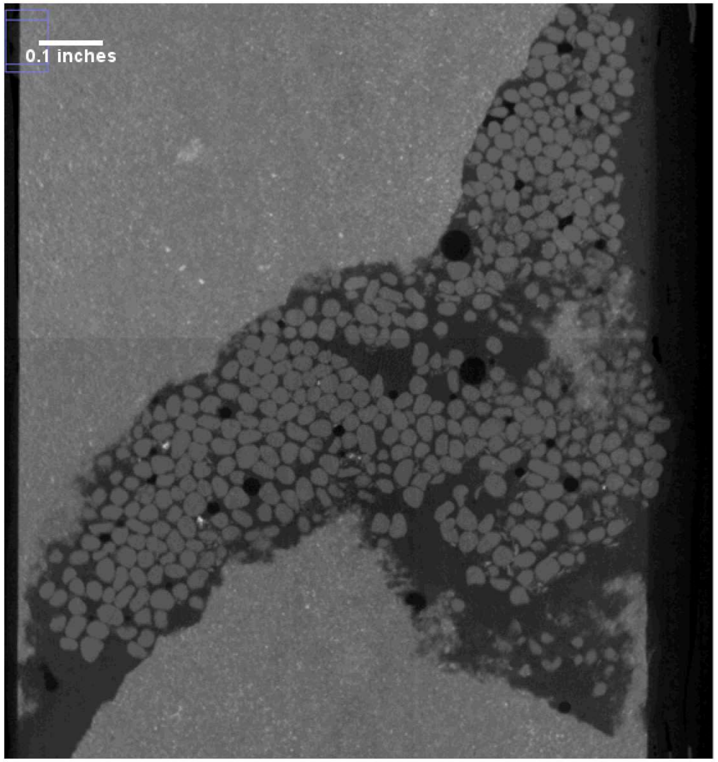
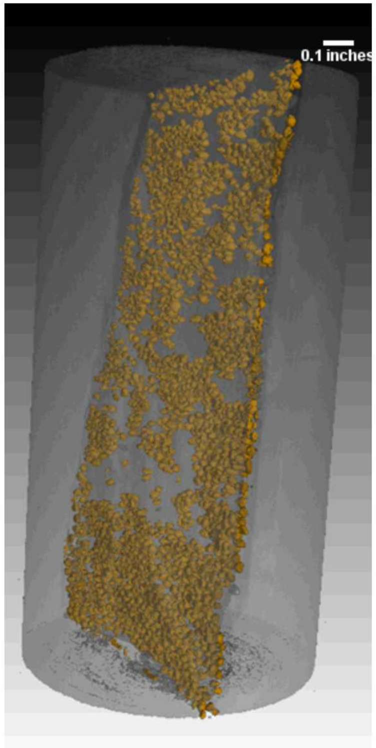
Image from www.energy.gov

Manual Fracturing Tests







X-ray µCT data allows us to investigate the effects of the application of pressure, temperature, and pore fluids on cracks and proppant particles. Grain fracturing, embedment and shale fracturing was observed.

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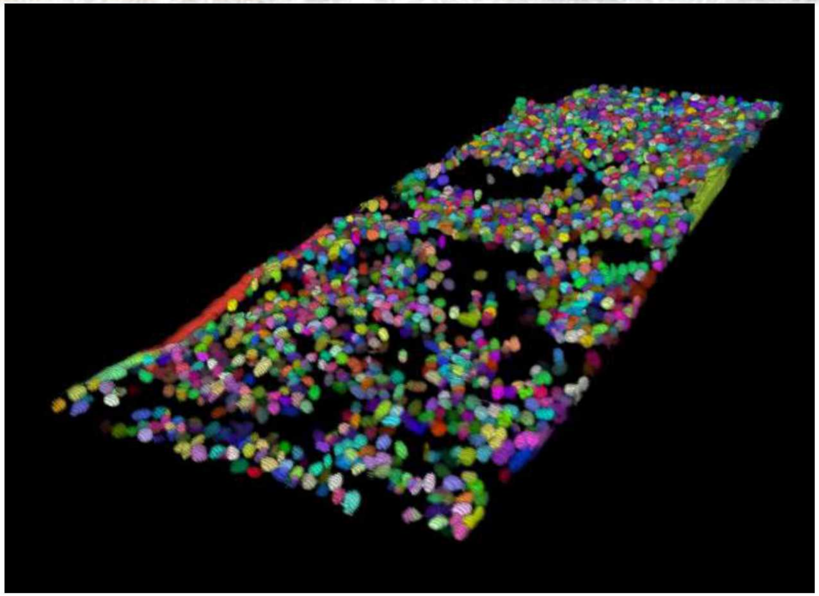
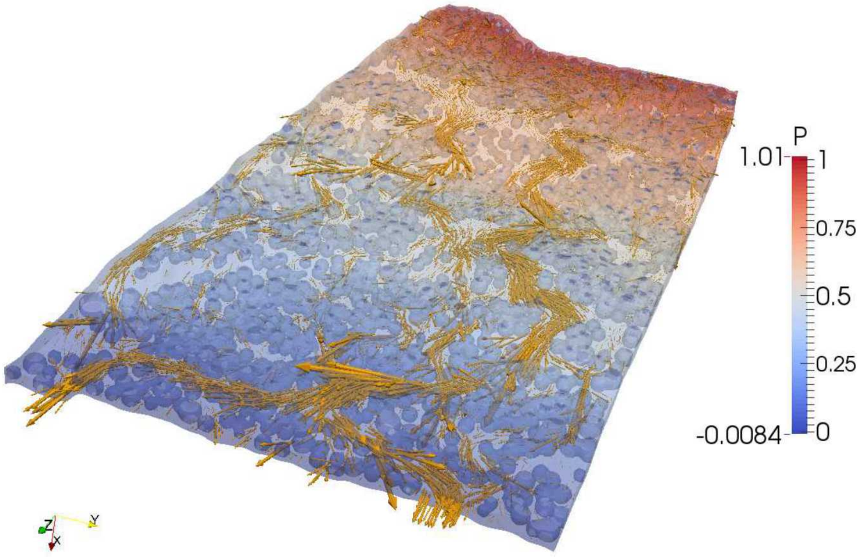
Mesh Generation/Flow Results





- Particles are identified by adaptive thresholding of the crack region (similar to determining crack space)
- Individual particles are identified with a 3D watershed algorithm

Combine particle size and location information with crack geometry by generating spheres at appropriate locations → possible to generate high-quality mesh that accounts for particles: (Still in progress)

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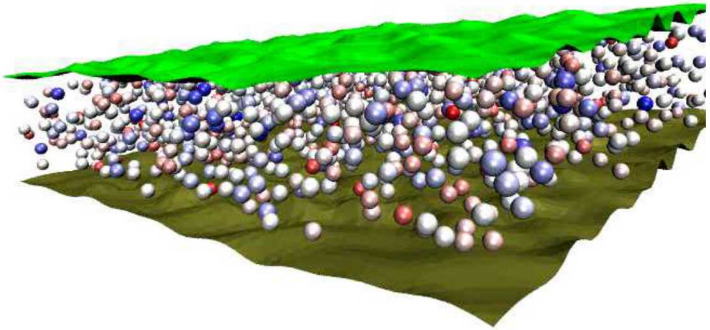
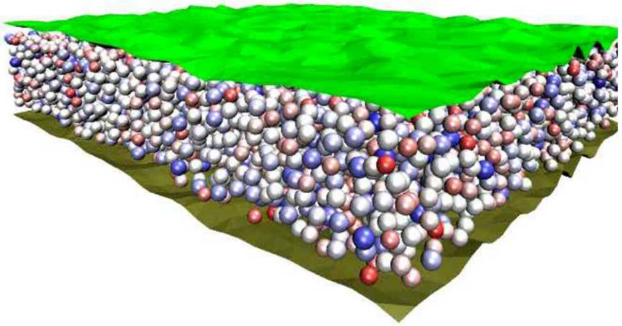
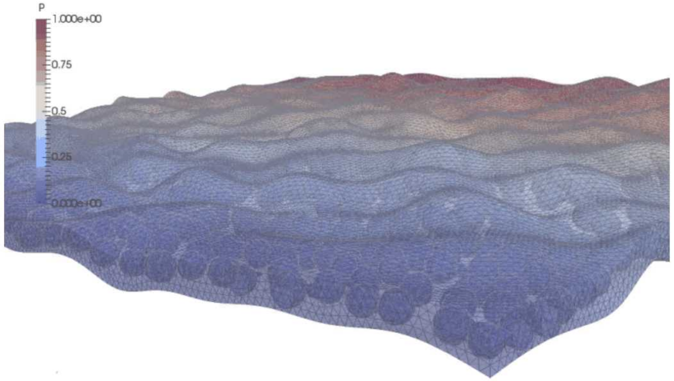
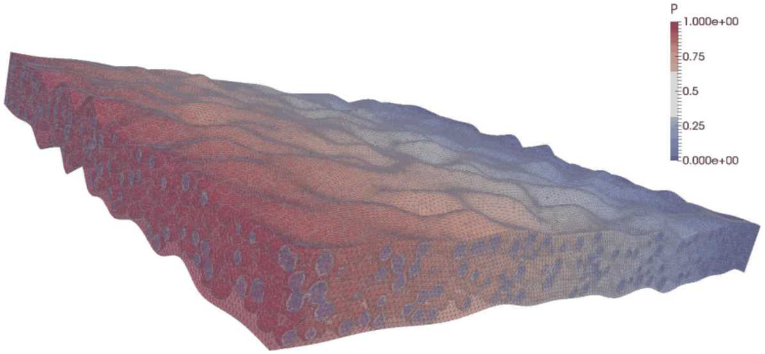
Simulation-based study





Generate mesh, compute permeability





- Computer-generated crack geometries with controlled tortuosity
- Particle placement is somewhat artificial (compression w/ periodic boundaries), but here we are only interested in final placement of particles
- Large number of simulations underway to study combined effects of particle size distribution, particle arrangement, number of particle layers and crack tortuosity on crack permeability and flow patterns
- Potentially analyze particle stress distribution → use simulations to find optimal particle characteristics that maximize permeability, minimize stress

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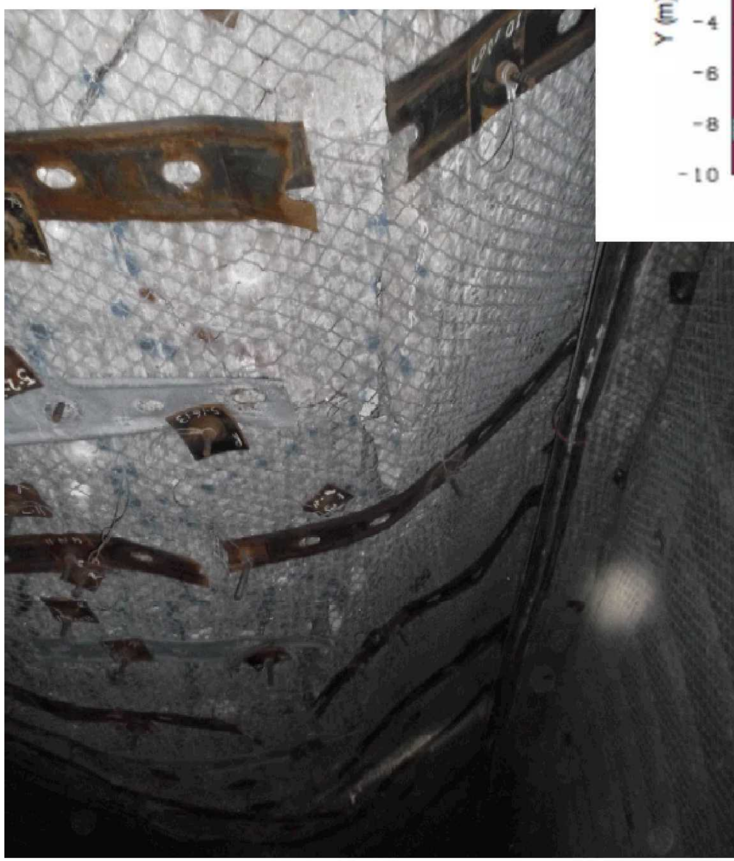
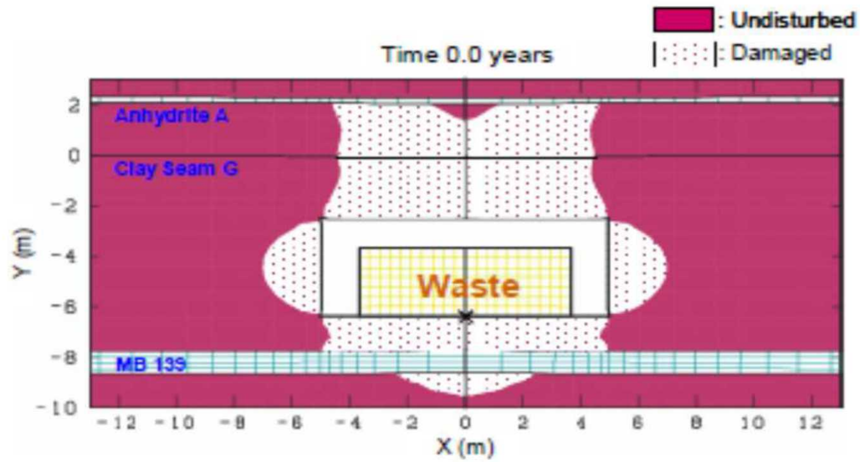
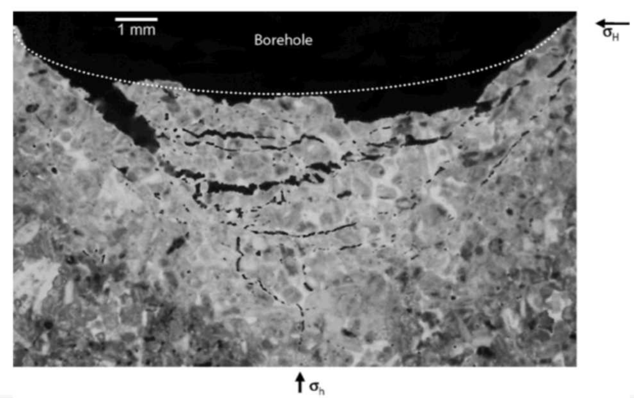
WIPP Closure

- DRZ
- Low stress creep





Herrick et al. 2009



Images courtesy of Courtney Herrick

Geomechanics Facilities

- 4 Uniaxial frames with pressure vessels (<1,000,000 lbs, <145,000 psi)
- Axial-Torsional frame (220,000 lbs, 7400 ft-lbs)
- True Triaxial system (σ_2<14.5 ksi + σ_3)
- 10^{-10} /s < Strain rate < 10^{2} /s
  - Creep Frames
  - Split Hopkinson Bar
- -65^{o}C < Temperature < 300^{o}C

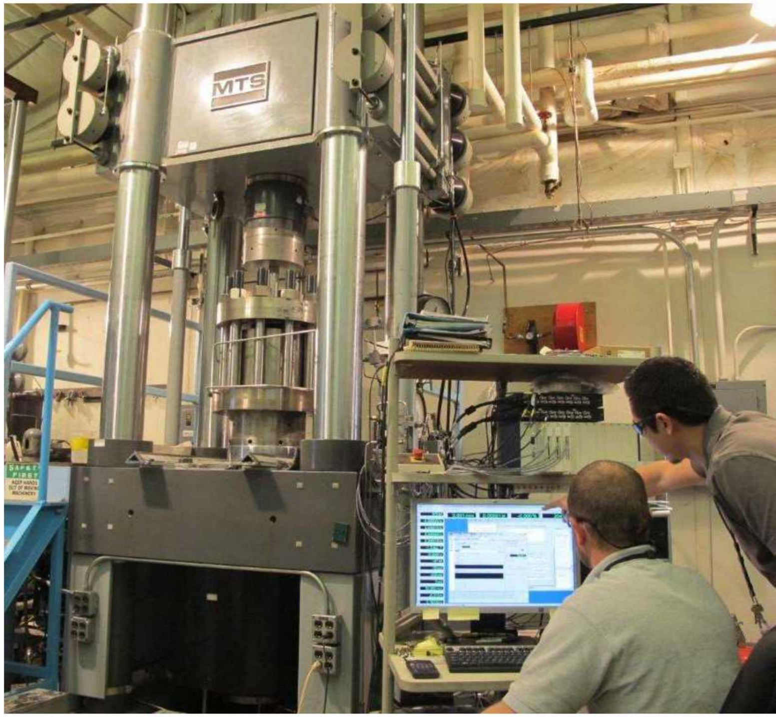


Image from Moo Lee

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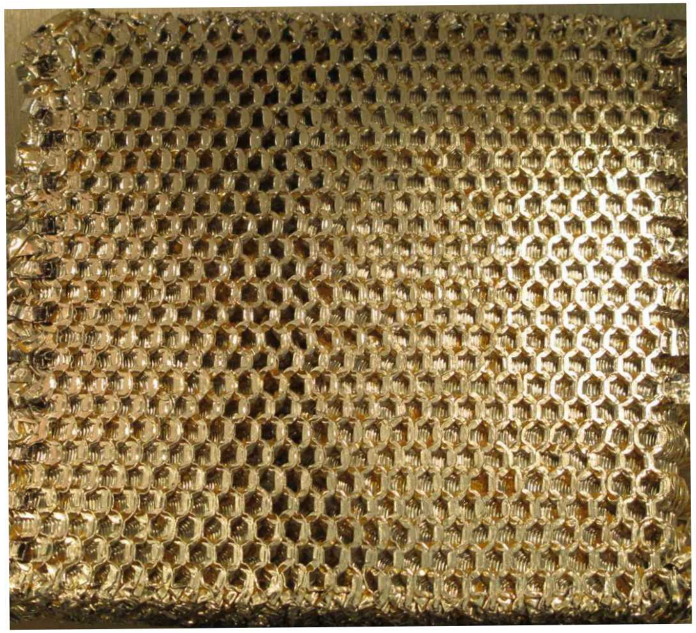
Materials Testing

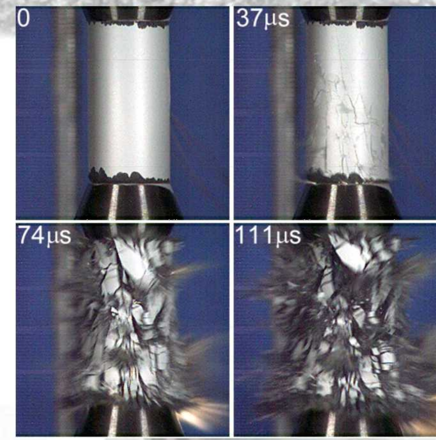
- 70% Geomaterials
  - Sandstone
  - Salt
  - Shale
  - Granite
  - Limestone
- 30% Engineering Materials
  - Bulk Metals
  - Honeycombs
  - Silicon Carbide
  - Ceramics
  - Carbon Composites

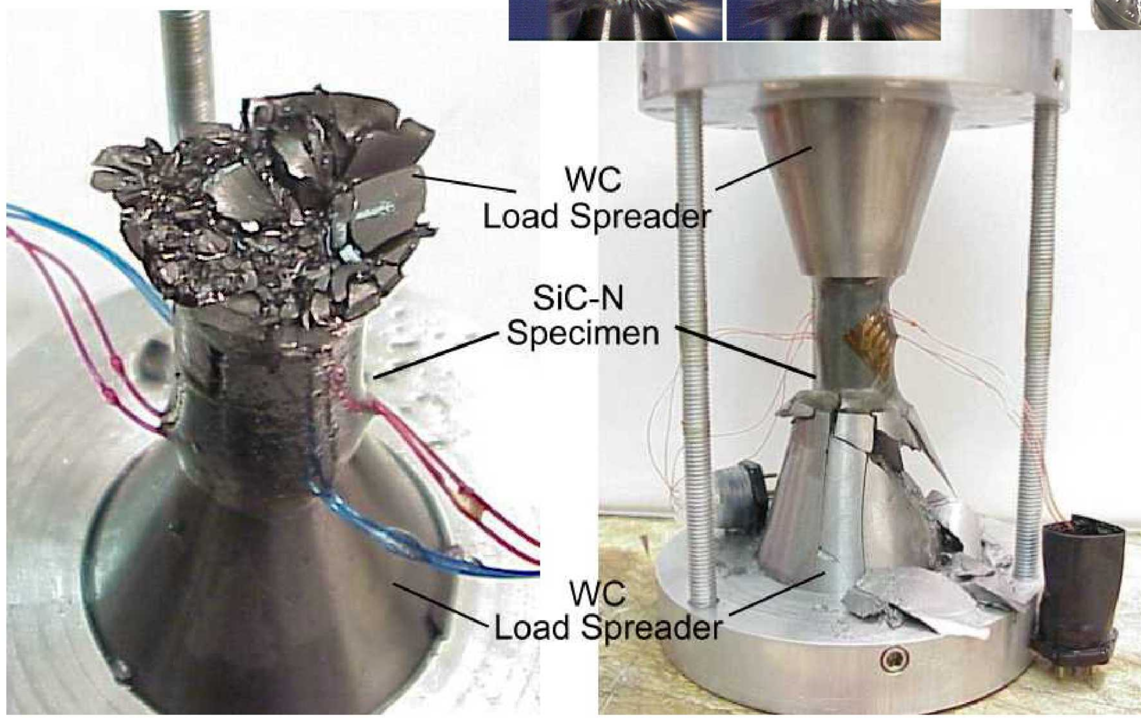


Materials Testing

- Uniaxial
- Axial – Torsion
- Hydrostatic
- Axisymmetric
- True Triaxial
- Active and Passive

  Acoustics
- Impact (Hopkinson Bar)
- Creep

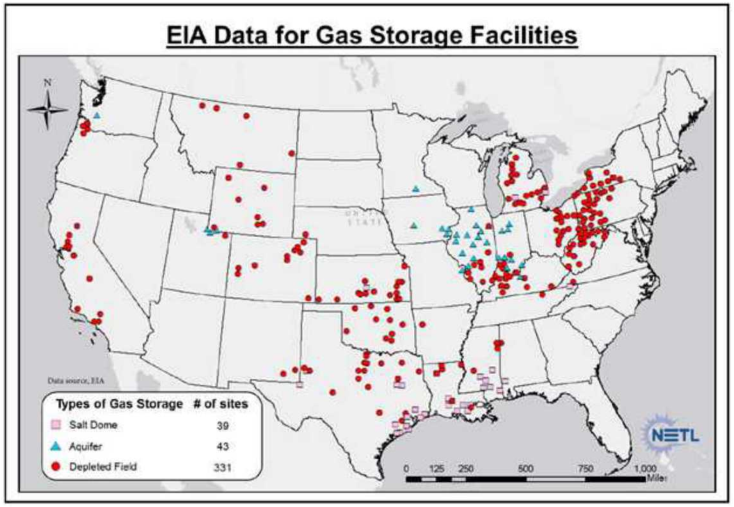




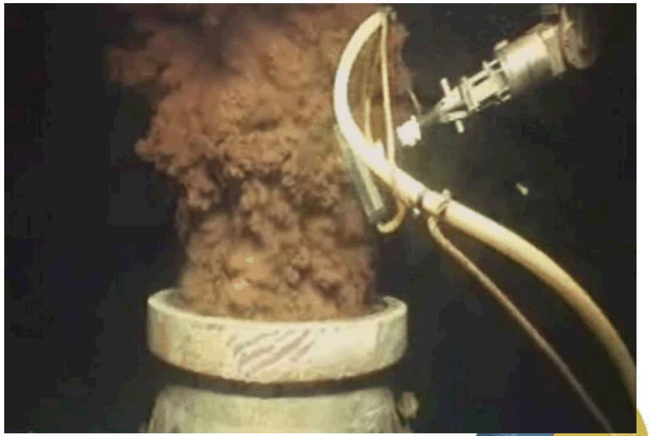
Thanks to Moo Lee for SiC-N Images

High Visibility Projects

- Aliso Canyon Blowout
  - ~100,000 tons of natural gas leaked from storage facility for ~3.5 months
- Deepwater Horizon oil spill
  - Estimated 4.9 million barrels of oil leaked over 87 days
- Both instances attempted top kills, which are commonly effective at stopping production.



U.S. EIA, 2015



Subsea World News

Thanks to Steve Bauer for information on these two events.

Acknowledgements

- EGS Collab Team
- Sanford Underground Research Laboratory
- Tim Kneafsey
- Hunter Knox
- Paul Schwering
- Jonathan Ajo-Frankin
- Martin Schoenball

This material was based upon work supported by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE), Office of Technology Development, Geothermal Technologies Office, under Award Number DE-NA0003525 with SNL. The United States Government retains, and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes. The research supporting this work took place in whole or in part at the Sanford Underground Research Facility in Lead, South Dakota. The assistance of the Sanford Underground Research Facility and its personnel in providing physical access and general logistical and technical support is acknowledged.

SAND2019-XXXX

Questions

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