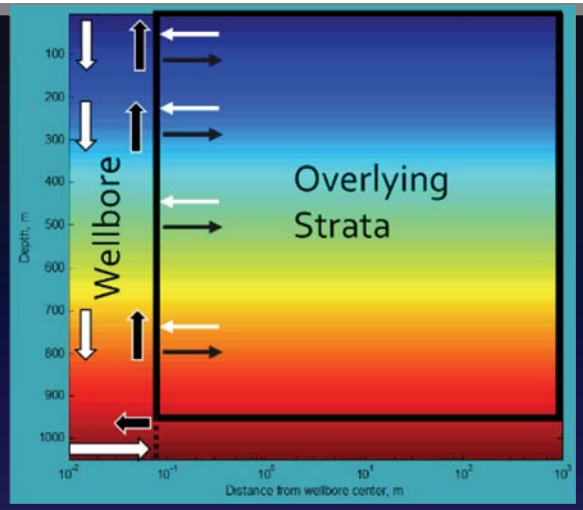
Research Summary

Hydraulic Fracturing Modeling of an Enhanced Geothermal System

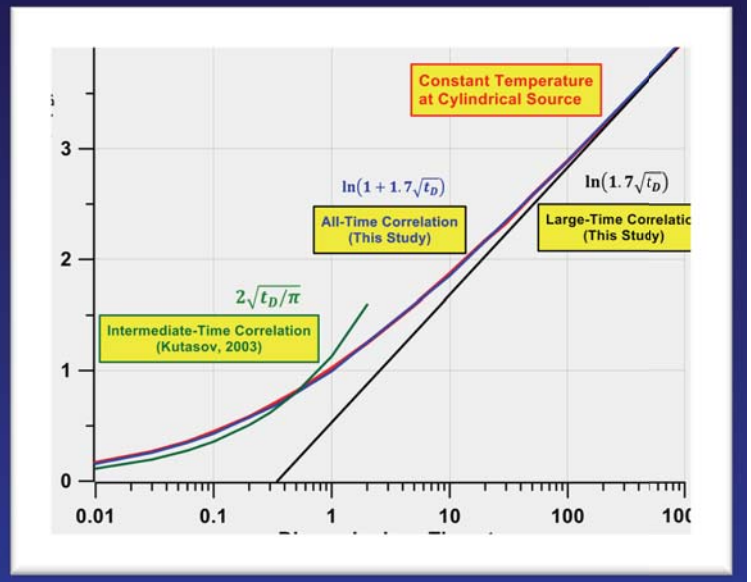
Kagan Kutun

About Me

- Istanbul Technical University
  - B.S. in Petroleum Engineering
  - M.S. work: Heat Loss in Geothermal Wellbores



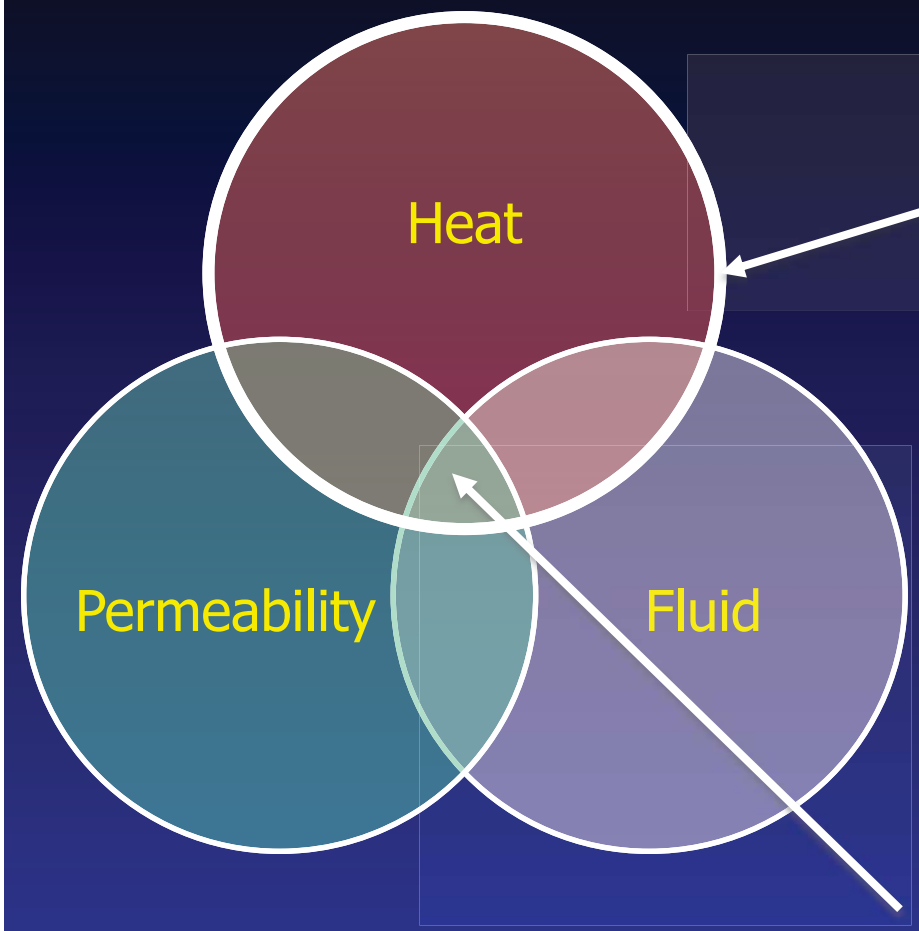
- Colorado School of Mines
  - M.S. – Fracture Modeling for EGS Collab
  - Ph.D. – Experimental Fiber Optics DTS, DAS



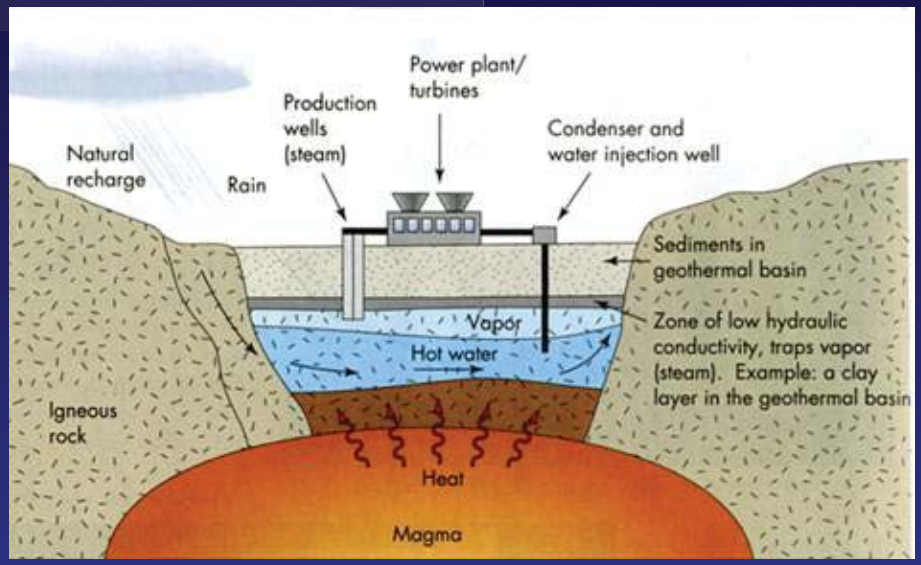
Outline

- Enhanced Geothermal Systems
- FORGE
- EGS Collab
- Challenges/Complexities
- Modeling
- Future Work
- Fiber Optics Flow Loop

EGS - Comparison



Enhanced Geothermal Systems

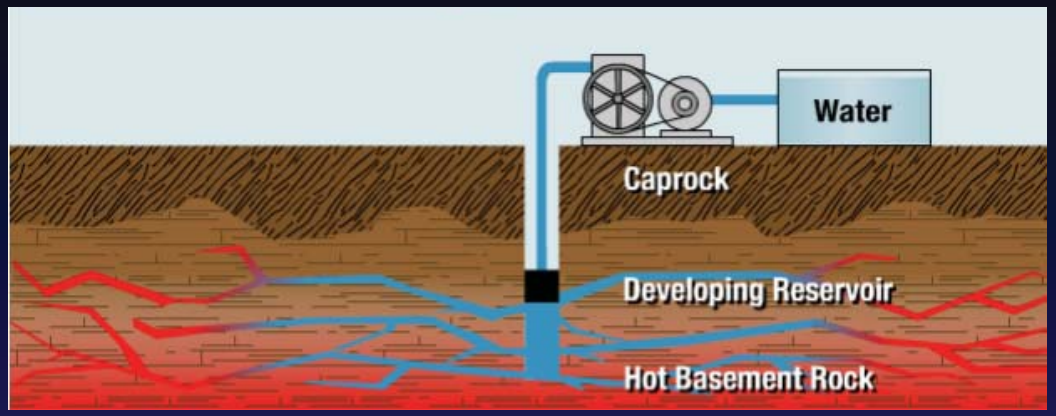


Geothermal (Hydrothermal)

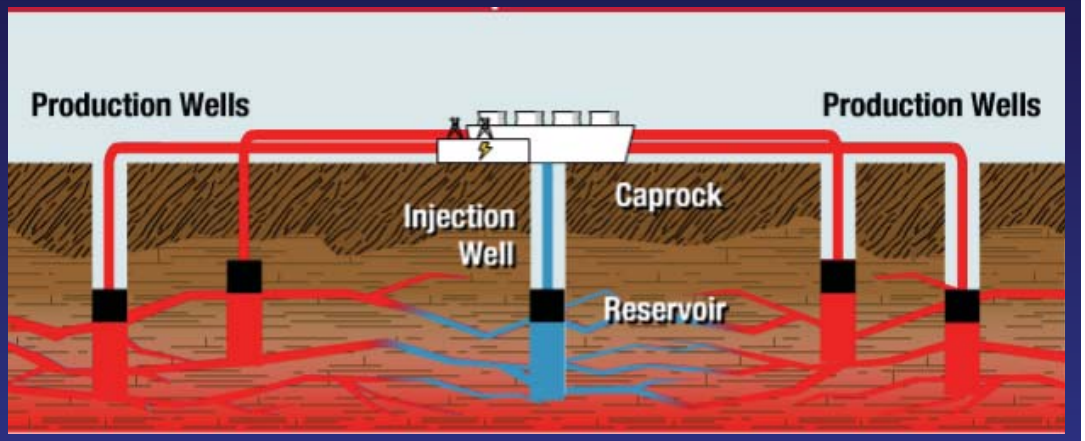
(Keller, 2010)

EGS

- Create permeability

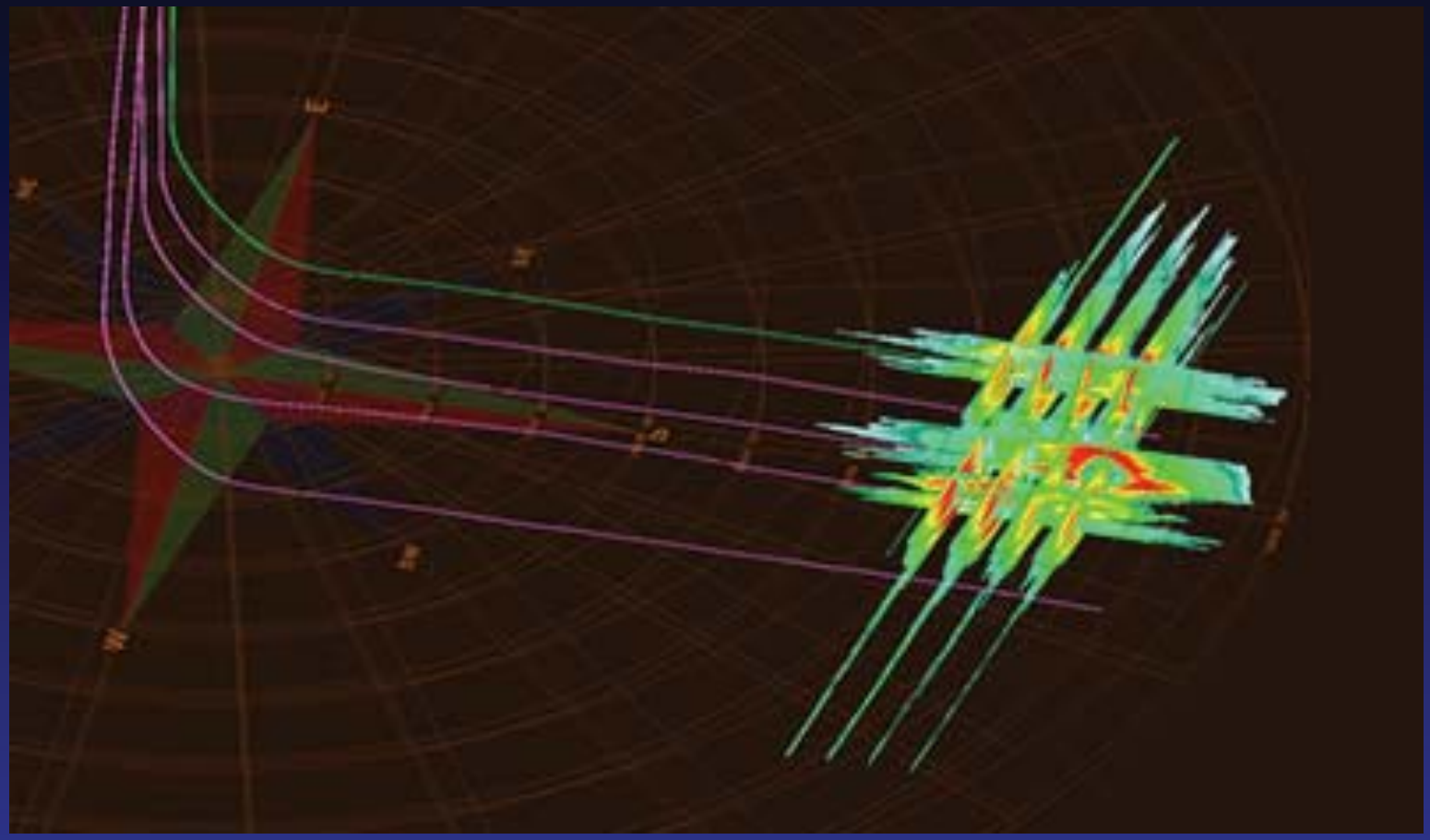


- Create fluid system



(DOE , 2018)

EGS



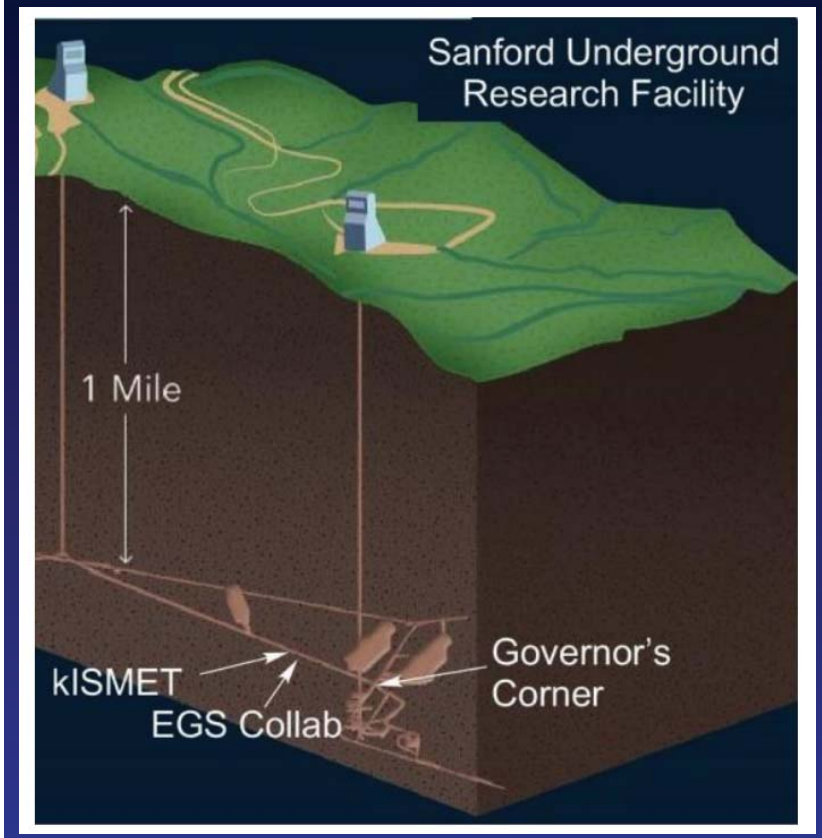
(Barree & Associates , 2018)

EGS

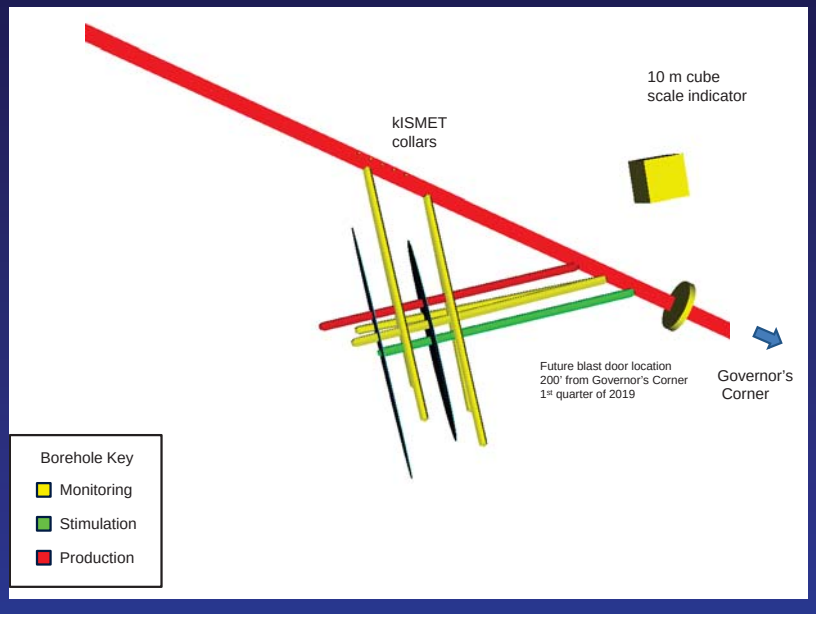
- Not a new idea - Hot Dry Rock
  - Fenton Hill, New Mexico, 1977
  - 2.6 km deep, 185°C
- EGS – Jason Report (Jeanloz and Stone, 2013)
  - Findings
    - Additional reserves possible
    - Drilling costs, stimulation uncertainties, well lifetime
  - Recommendation
    - Start a research program!

EGS Collab – Sigma V

(Kneafsay et. al., 2018)



- Stimulation Investigations for Geothermal Modeling Analysis and Validation
- Hydraulic fracturing and circulation experiments in SURF.
- Act as the bridge between laboratory scale stimulation/rock mechanics studies and the large field scale FORGE sites
- Relation between stress, induced seismicity, permeability enhancement

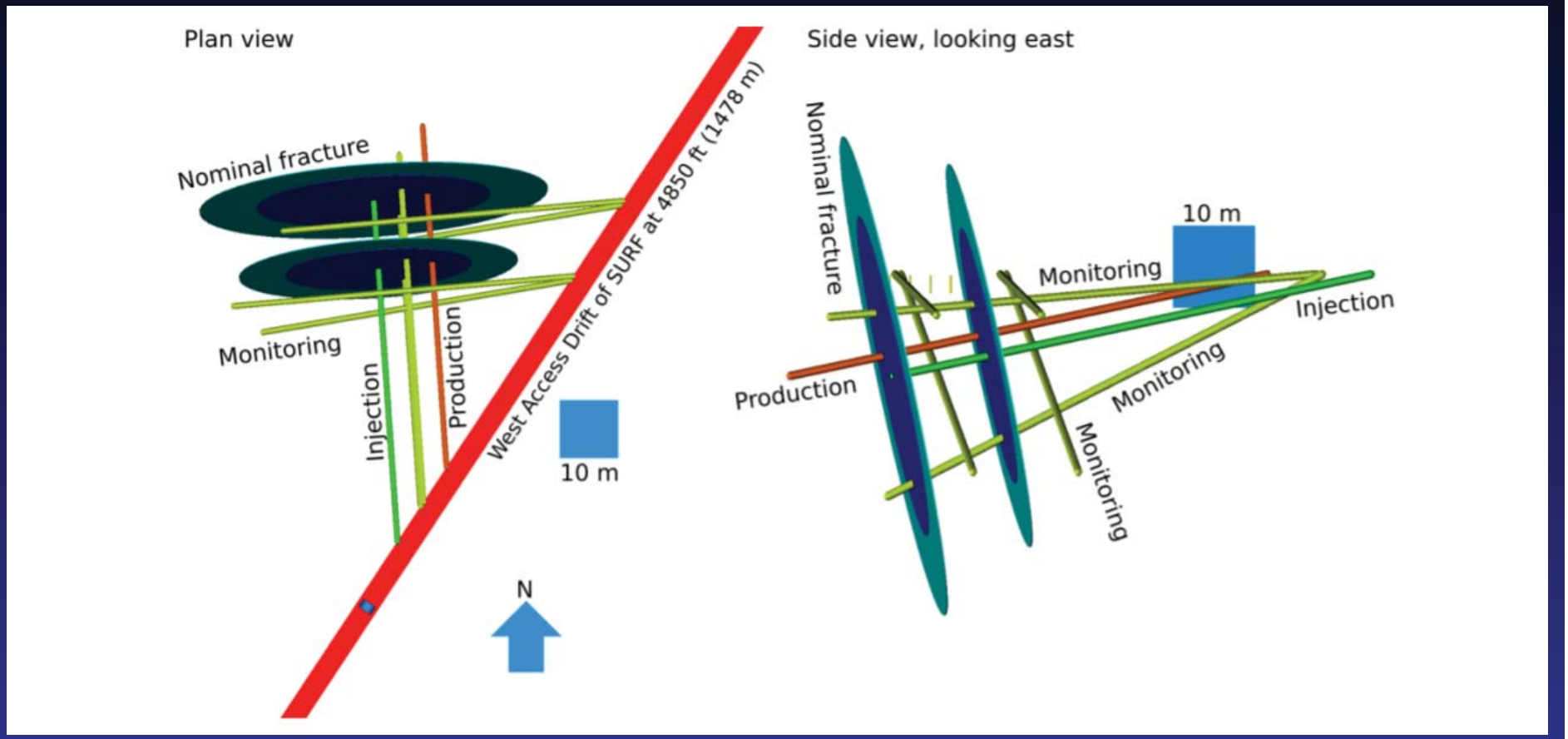


(Knox et. al., 2017)

EGS Collab – Sigma V

- Stress conditions allow a vertical fracture:
  - Min horiz. stress = 21.7 Mpa (3146 psi)
  - Vertical stress = 42 Mpa (6092 psi)
  - Max horiz stress = 35 Mpa (5076 psi)
- Temperatures cannot be replicated. 19-36°C (66-97 ^{o}F)
- Scale is much smaller than field.

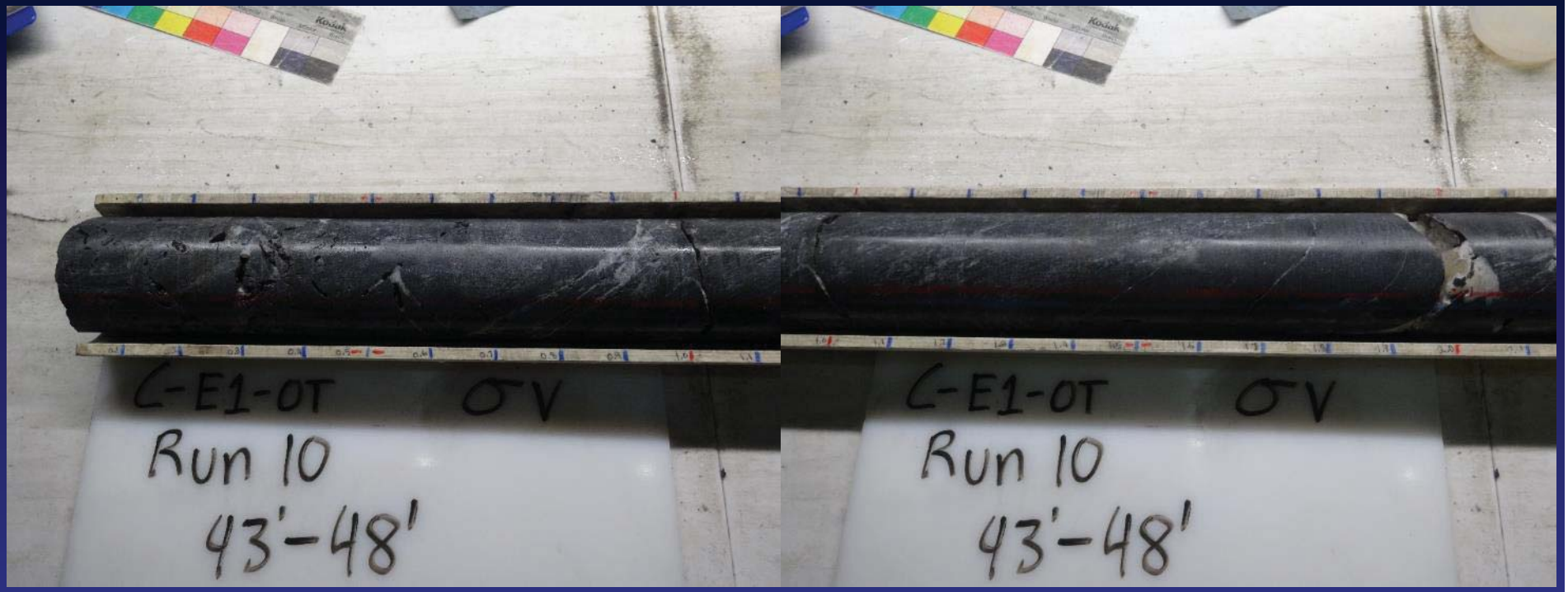
EGS Collab – Sigma V



(Fu et. al., 2018)

EGS Collab – Sigma V

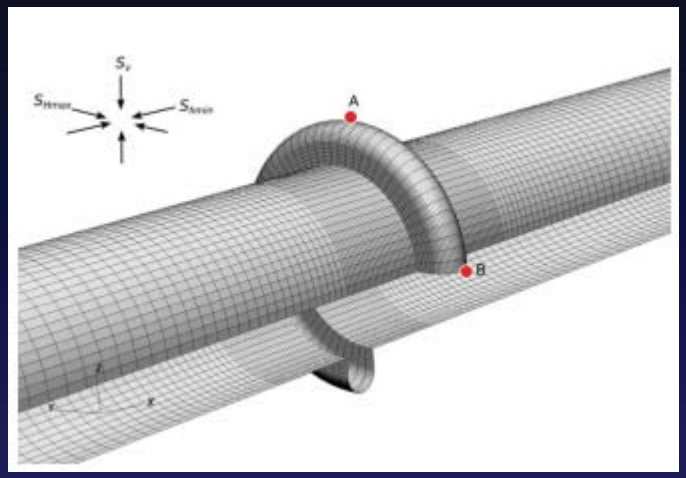
- Rock type matches. Crystalline igneous.

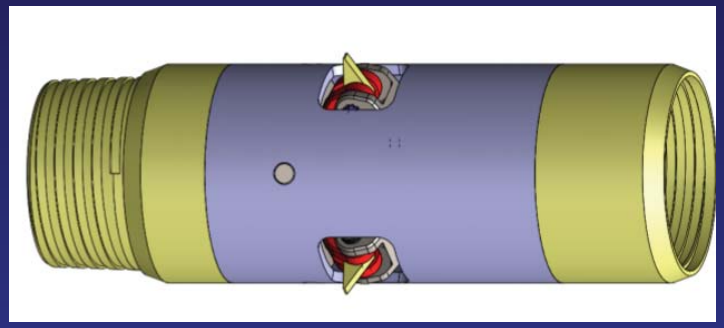


Challenges/Complexities

Challenges/Complexities – Fracture Initiation

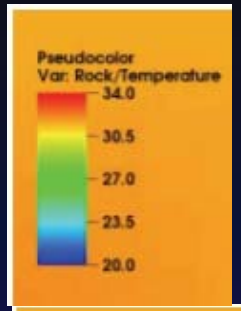
- Fracture Initiation
  - Horizontal Wellbore – Fracture tries to initiate along the wellbore
  - Notching had to be introduced





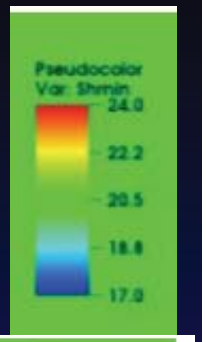
(Morris et al., 2018)

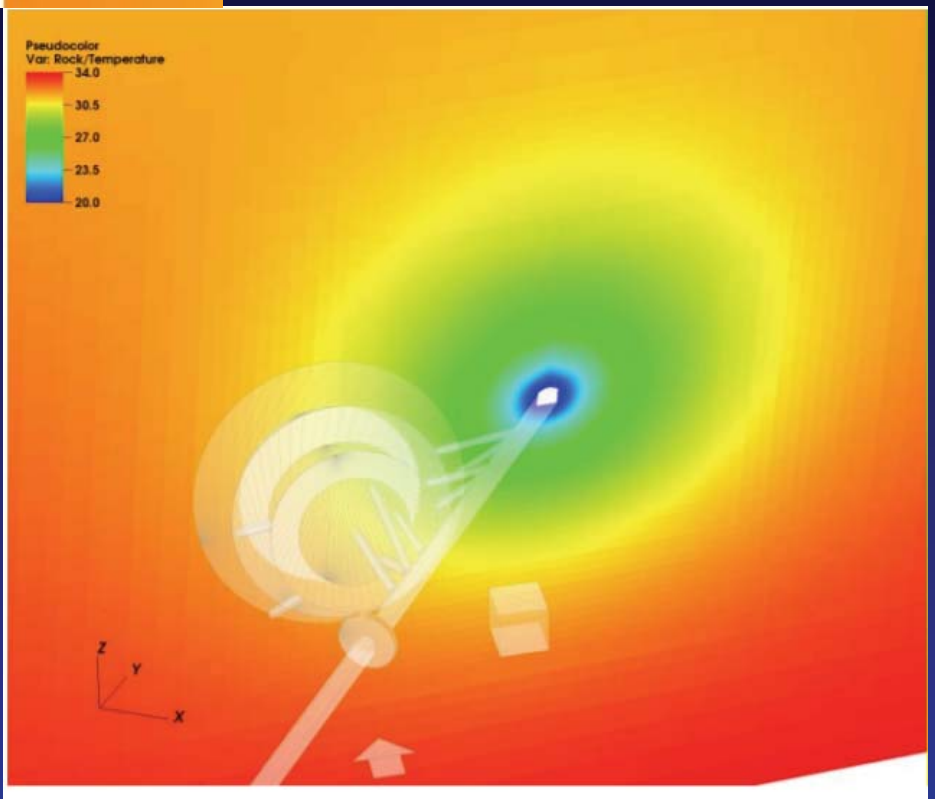
Challenges/Complexities – Stress Heterogeneity

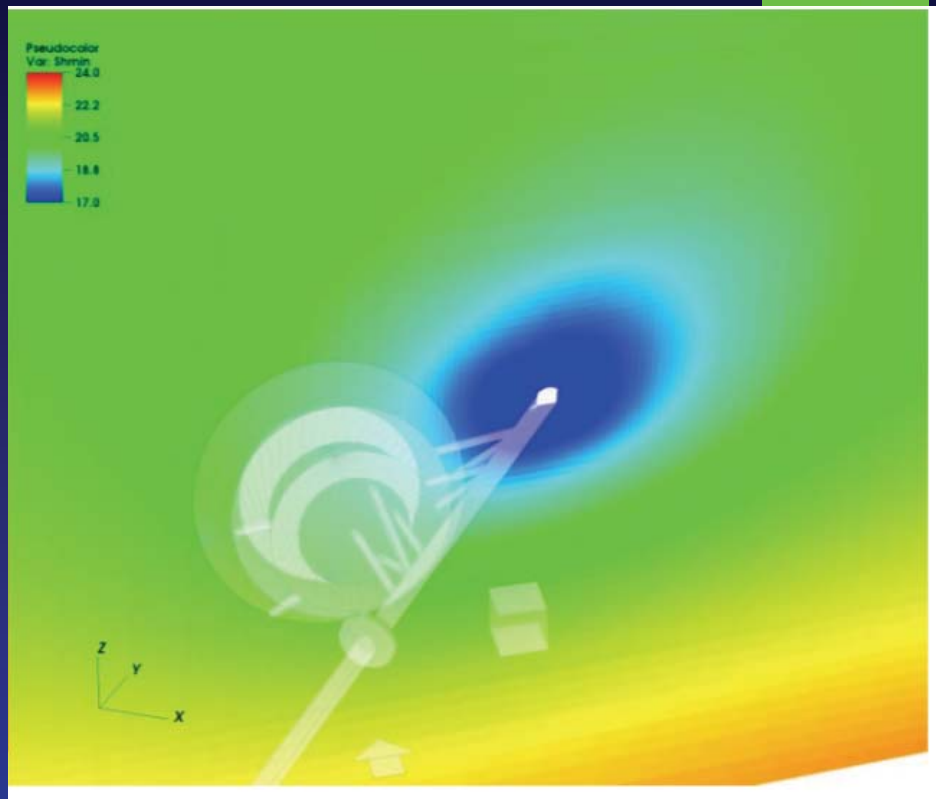


Presence of the Drift

- Mechanically alters the stress
- Cooling causes another alteration to stress
- Limits experiment size

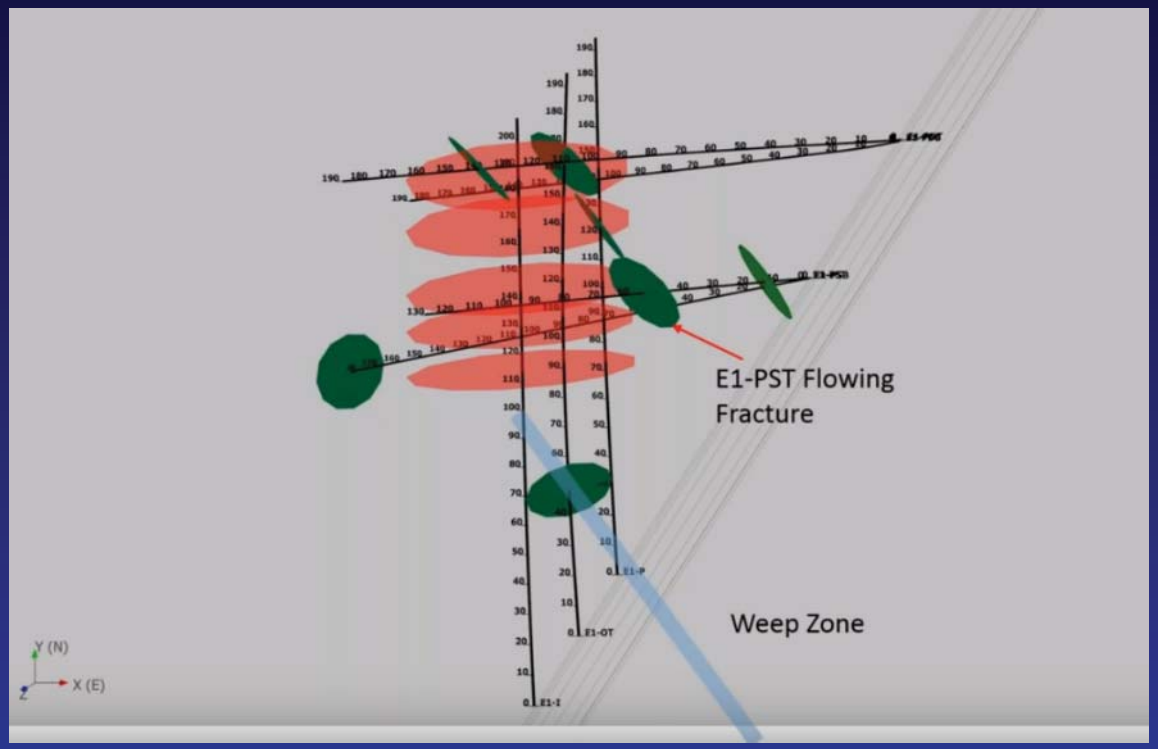






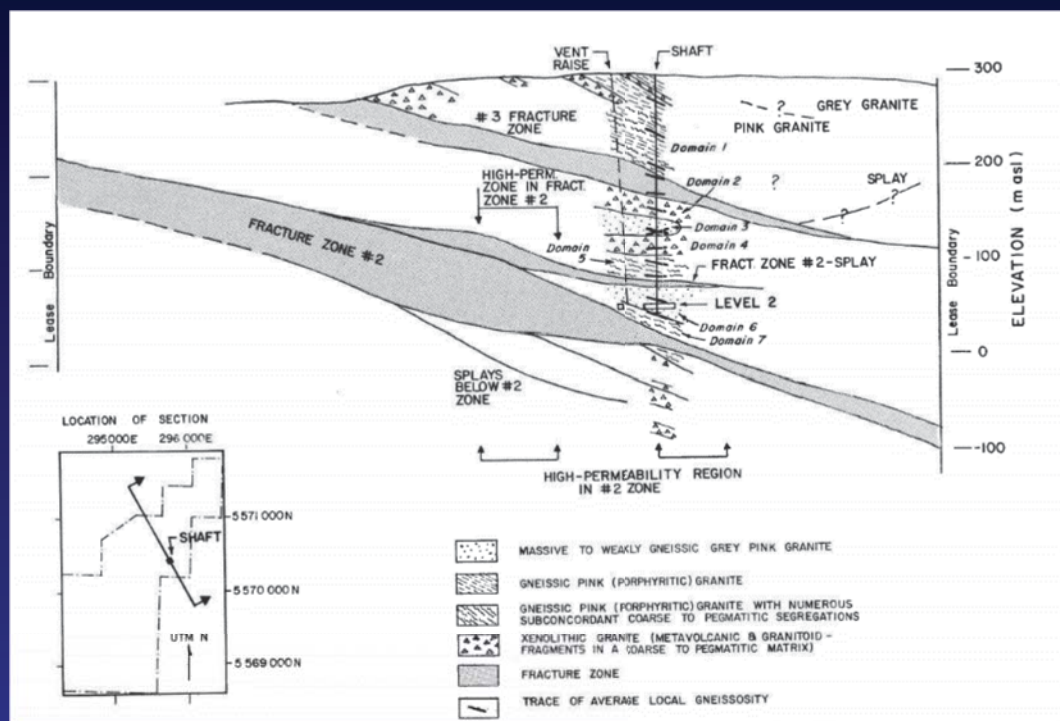
Challenges/Complexities – Natural Fractures

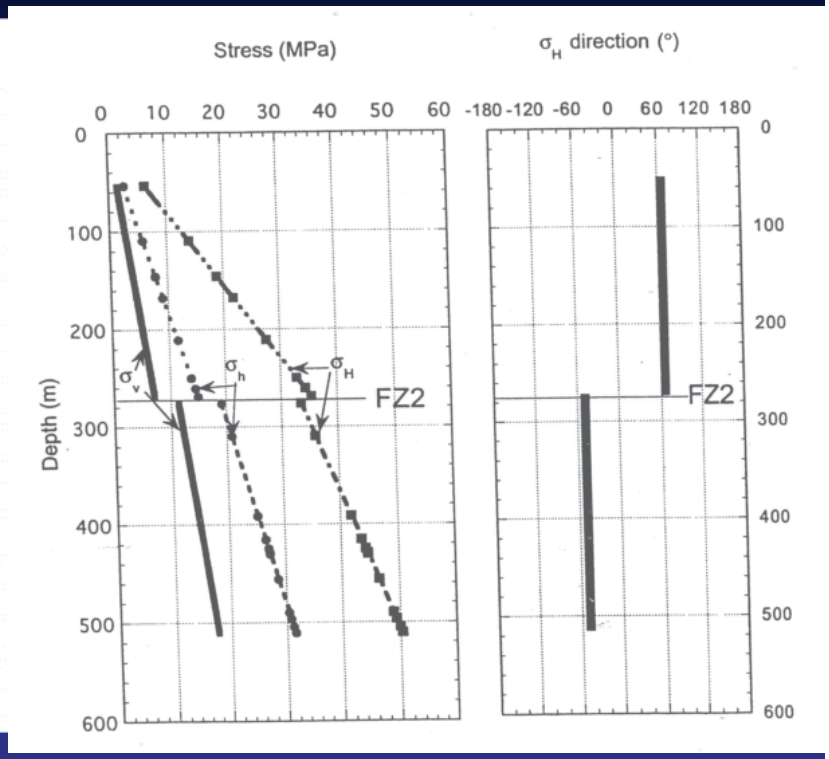
- Rock Complexities
  - There are a couple of identified natural fractures on planned fracture's path.



Complexities - Example

- Underground Research Lab – URL (Manitoba, Canada)
- 10+ year stress measurement campaign





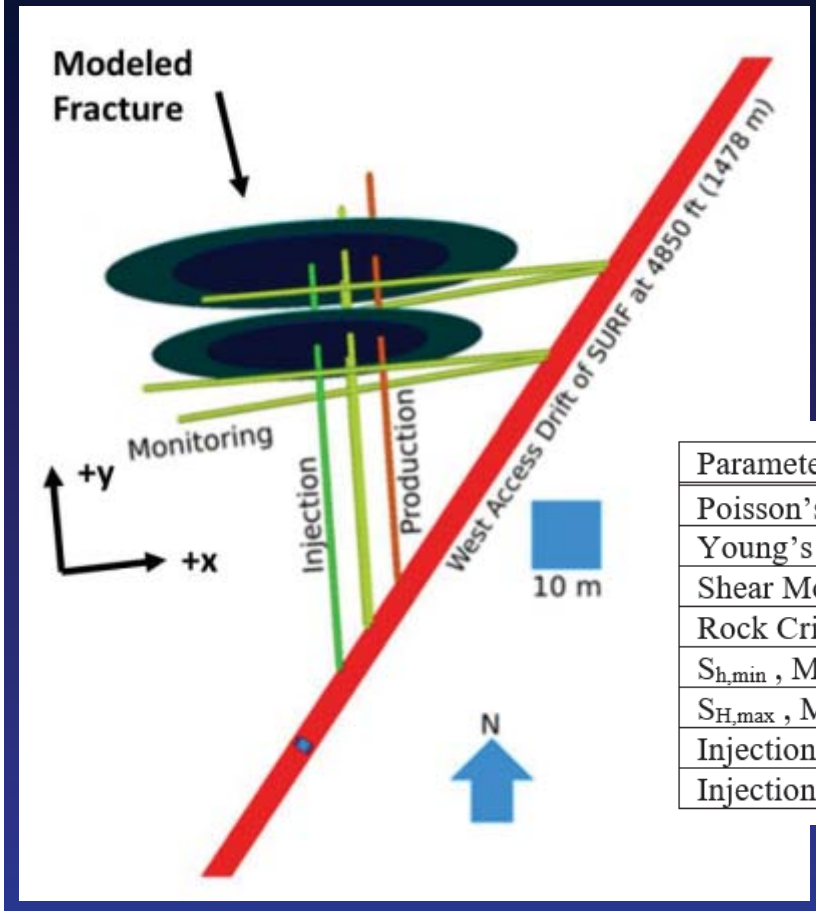
(Brown et. al., 1988)

All fractures were expected to be horizontal

Modeling

EGS Collab – Sigma V – Modeling

- CFRAC – Complex Fracturing Research Code

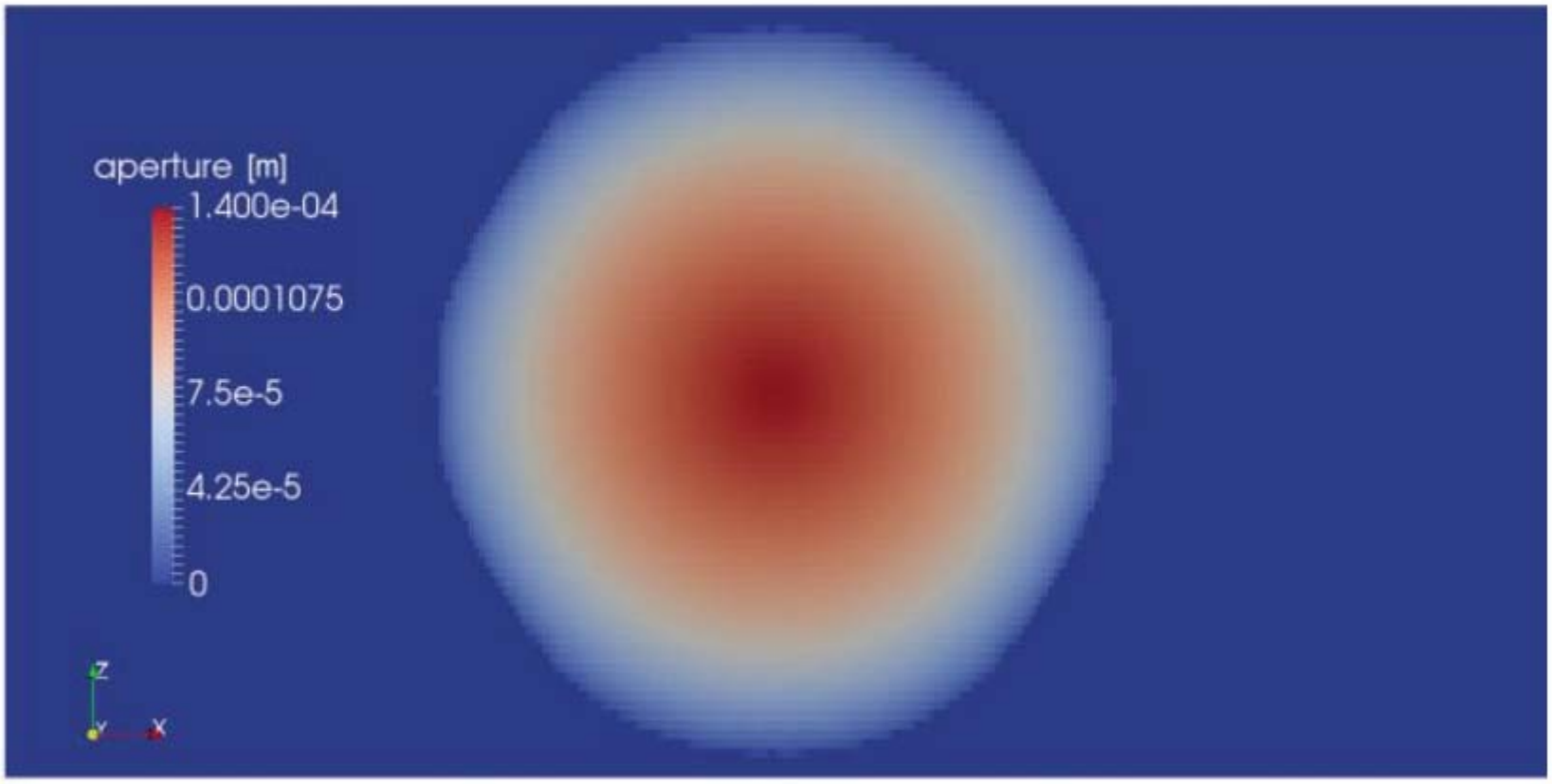


- Model single fracture and investigate:
  - Stress gradient towards the drift
  - Presence of a natural fracture

Parameter	Value	Source/Comments
Poisson's Ratio	0.22	Oldenburg et al. 2016
Young's Modulus, GPa (psi)	71.4 (10.3E6)	Oldenburg et al. 2016
Shear Modulus, GPa	29.26 (4.2E6)	Calculated
Rock Critical Stress Intensity Factor, MPa-m$^{1/2}$	1.0	Morris et al. 2018
$S_{h,min}$, MPa (psi)	20.0 (2900)	Fu et al. 2018
$S_{H,max}$, MPa (psi)	35.0 (5076)	Fu et al. 2018
Injection rate, kg/s	0.1	Assumed
Injection time, s	180	Assumed

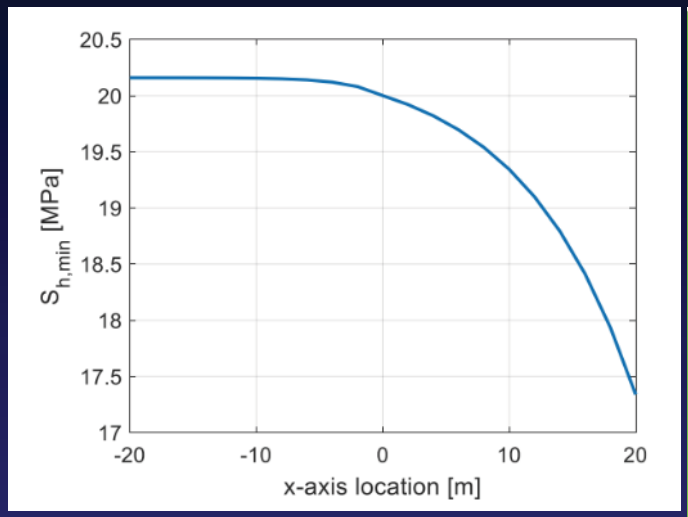
EGS Collab – Sigma V – Modeling

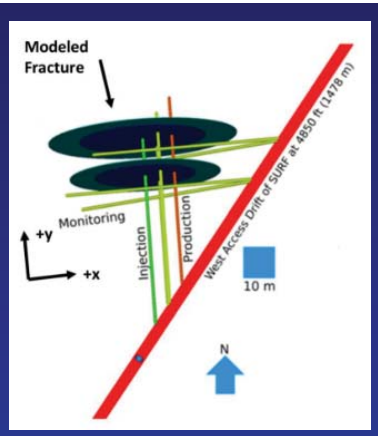
- Base Case – No heterogeneities
- 3.09m half length, 0.14mm max aperture
- 0.1mm aperture cutoff

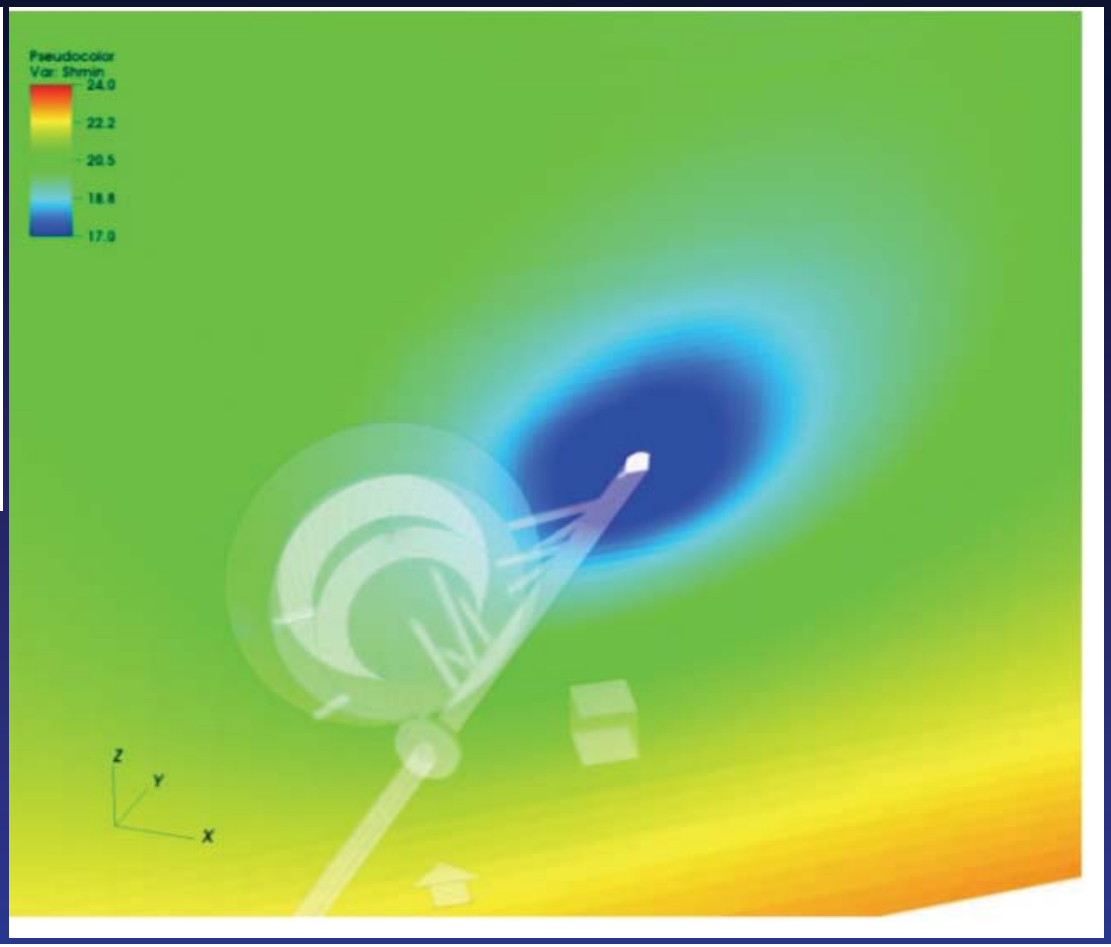


EGS Collab – Sigma V – Modeling

- Case 2 – Decreasing stress towards the drift

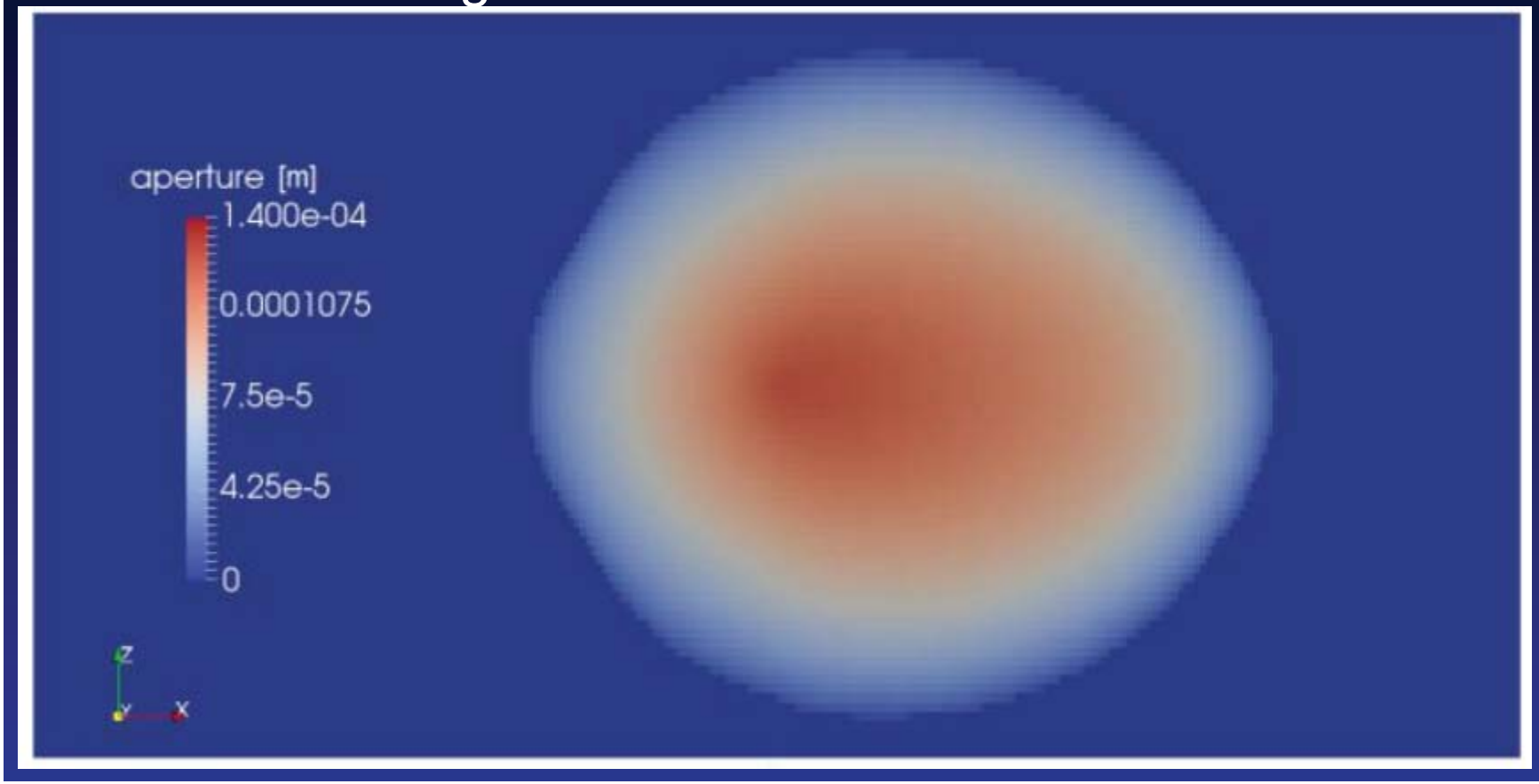






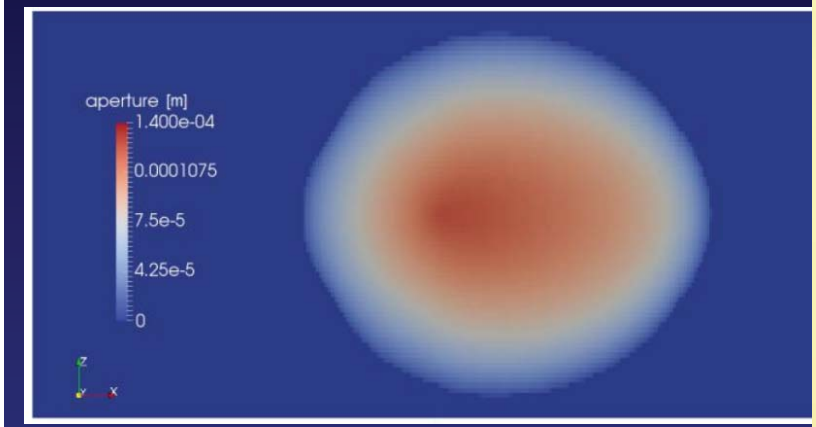
EGS Collab – Sigma V – Modeling

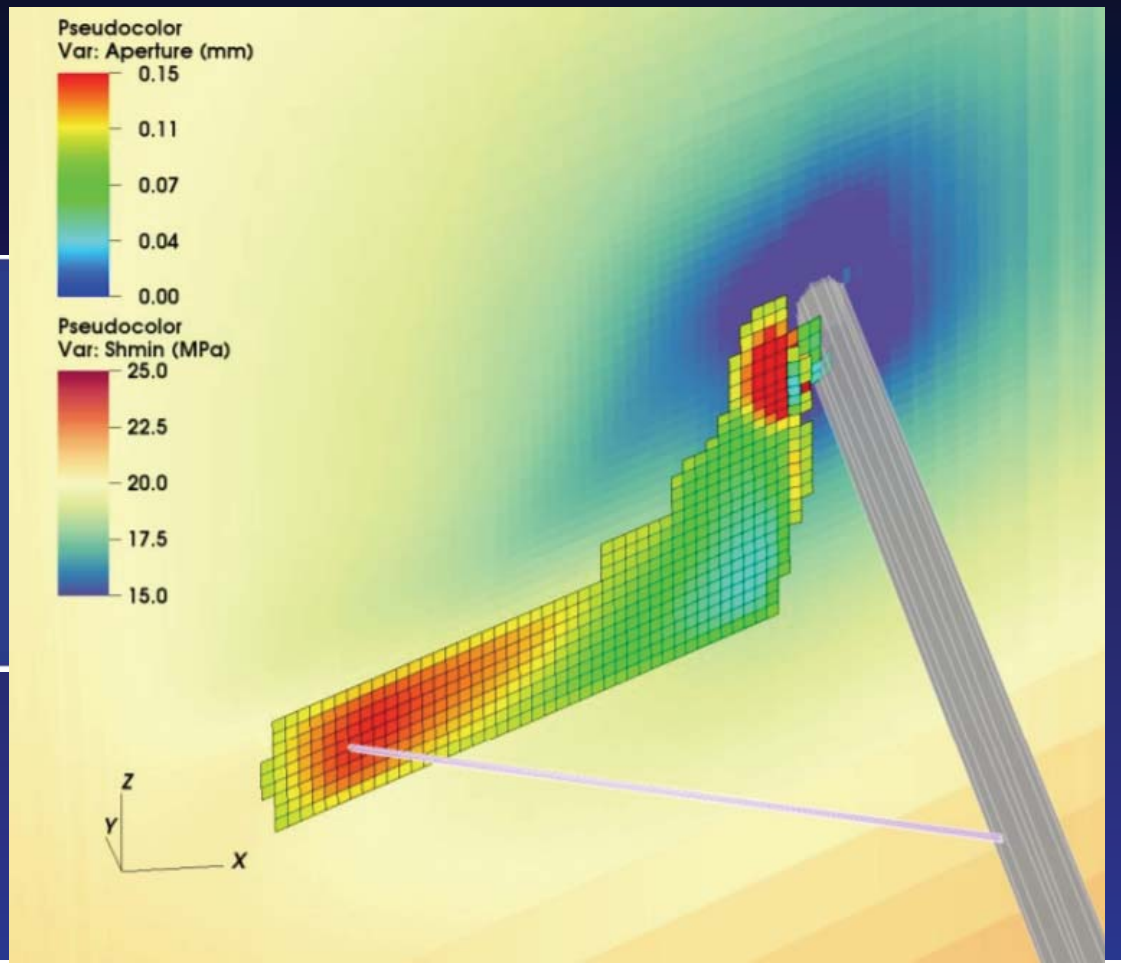
- Case 2 – Decreasing stress towards the drift
- 5.56m half length



EGS Collab – Sigma V – Modeling

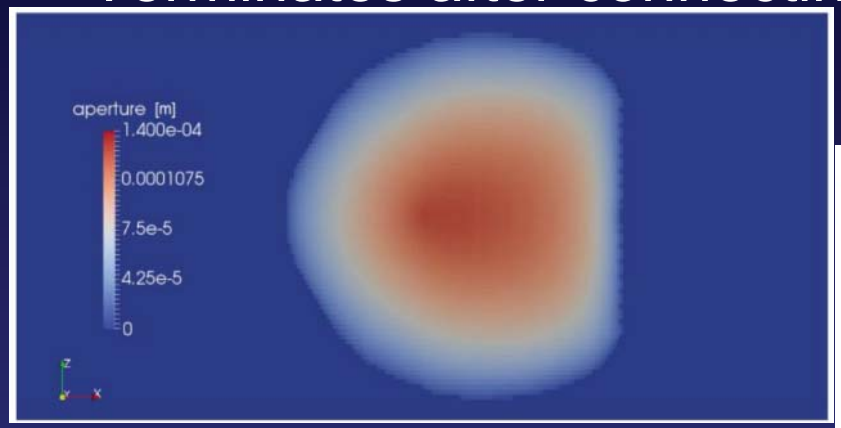
- Case 2 – Comparison against other EGS Collab models
- 3D stress gradient
- 3 min vs 6 min

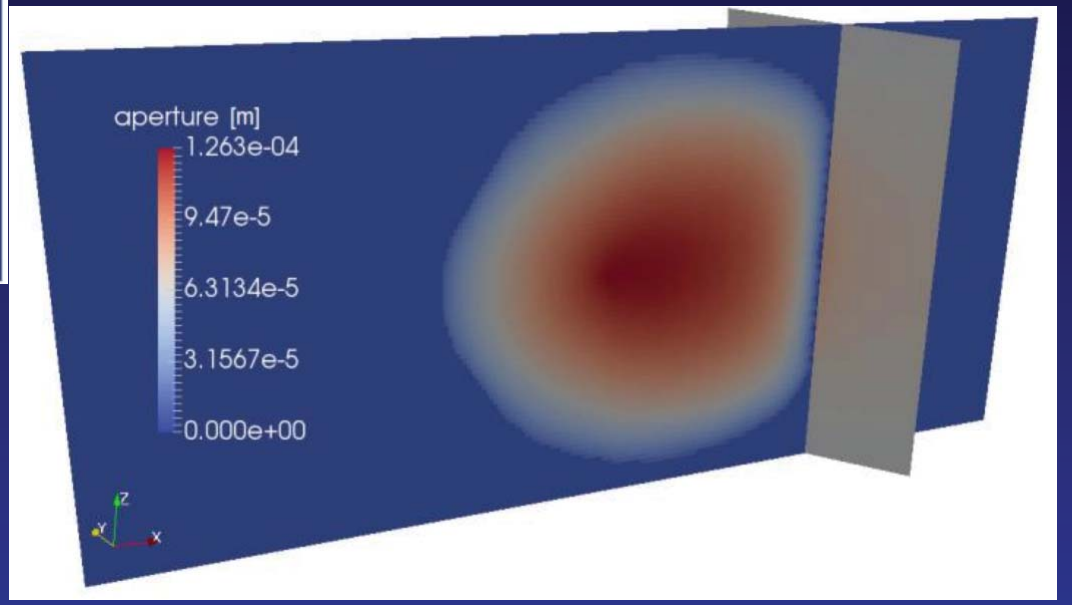




EGS Collab – Sigma V – Modeling

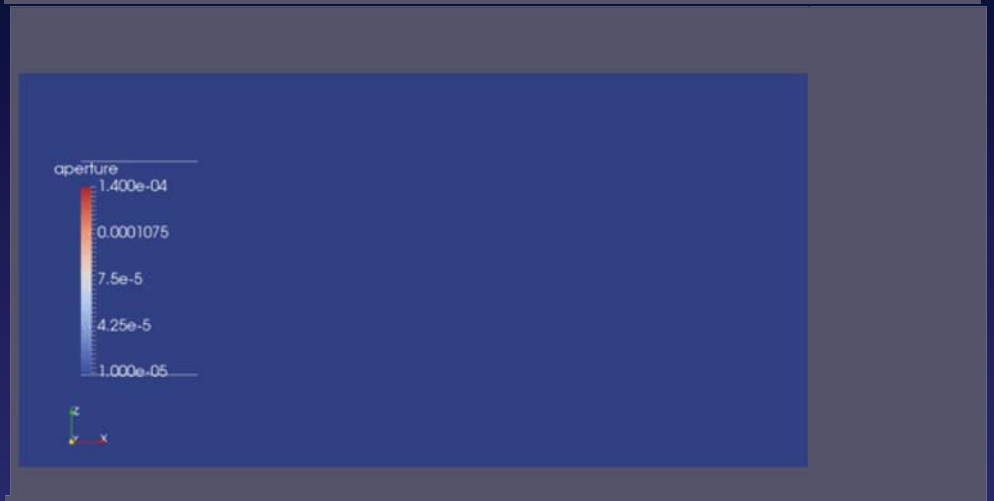
- Case 3 – Decreasing stress + Natural Fracture
- 4.07m half length
- Terminates after connecting with NF



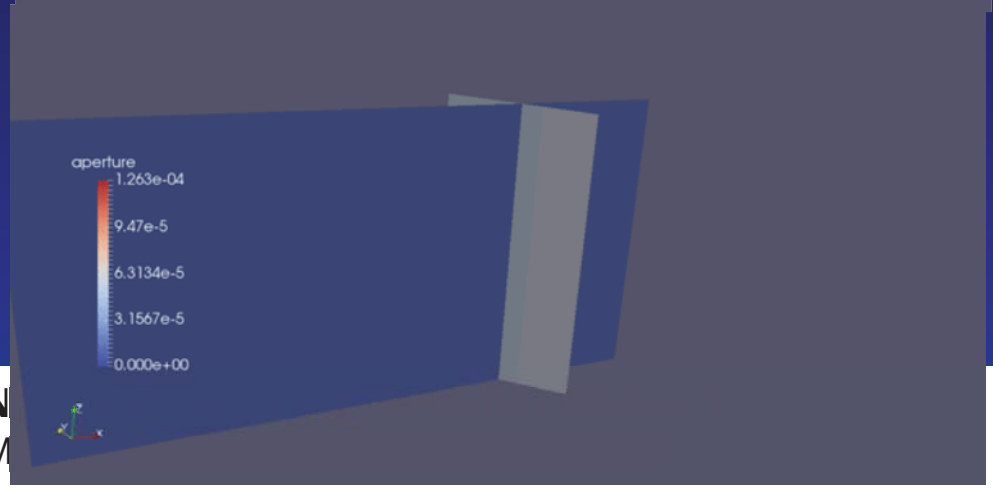


Case 1

Case 2



Case 3



EGS Collab – Sigma V – Future Work

- Pre-Job
  - Model more natural fractures and run sensitivity analysis on friction, leakoff, and toughness
  - Model changing rates and shut-in times to match experiment design.
- Post-Job (May 22nd 2018)
  - Model and match the falloff signals following every shut-in
  - Match observed fracture geometry

Research Summary

Development of a Fiber-Optic Instrumented Flow Loop System

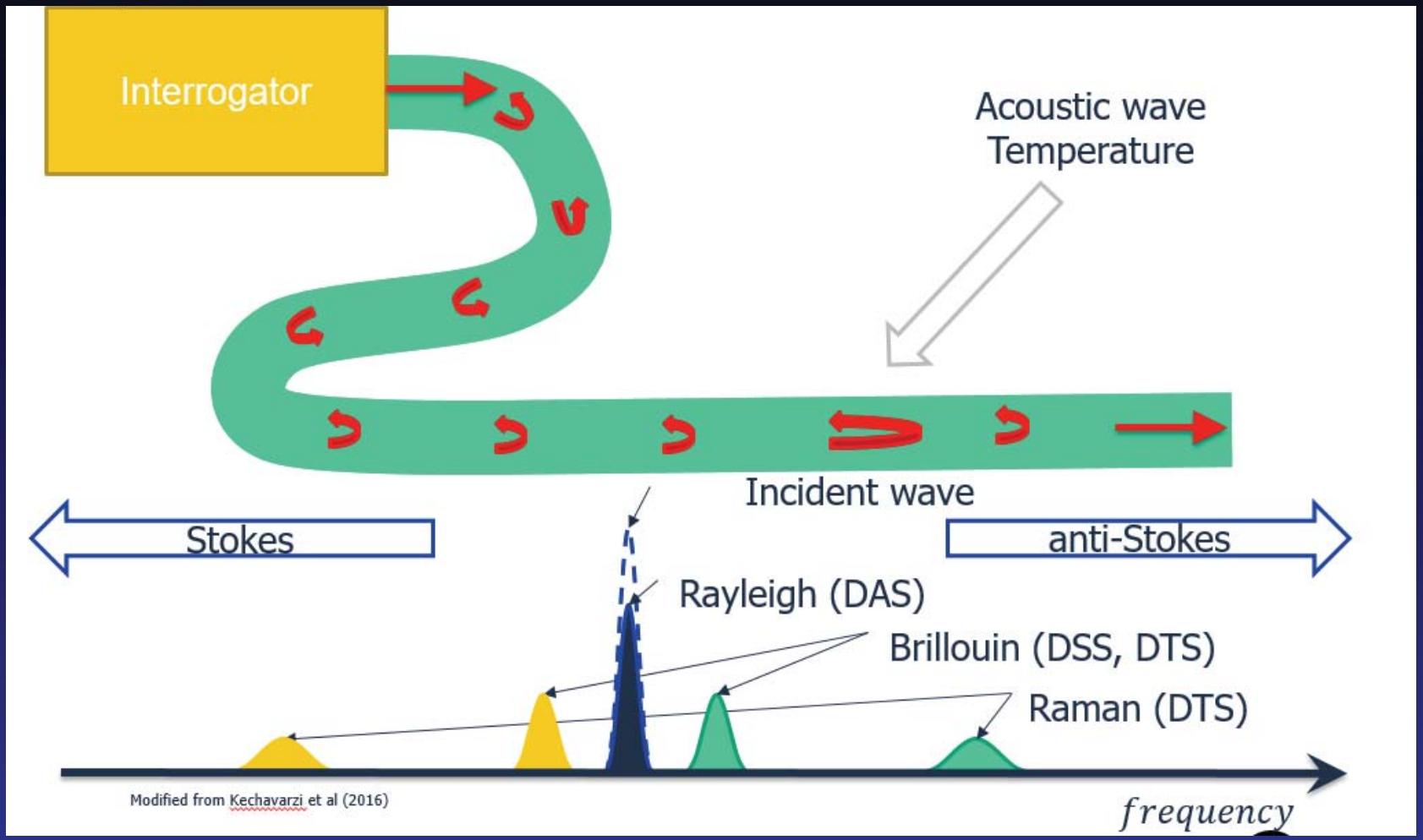
Kagan Kutun

Introduction

- Fiber Optics Research Program
  - CSM PE (FAST) – Dr. Jennifer Miskimins
  - CSM Geophysics (RCP) – Dr. Ali Tura

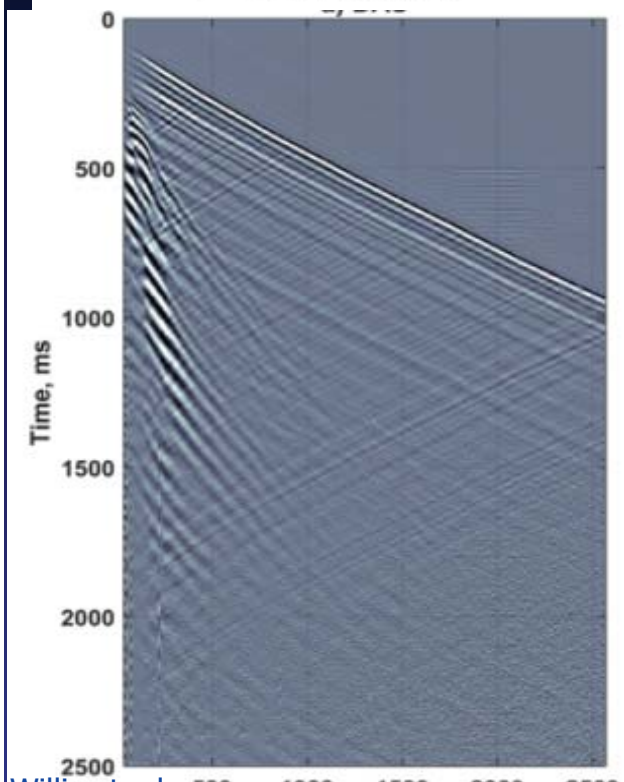
- Investigating distributed fiber optics sensing technology using experiment and field acquired data

Fiber Optic Sensing: Principles



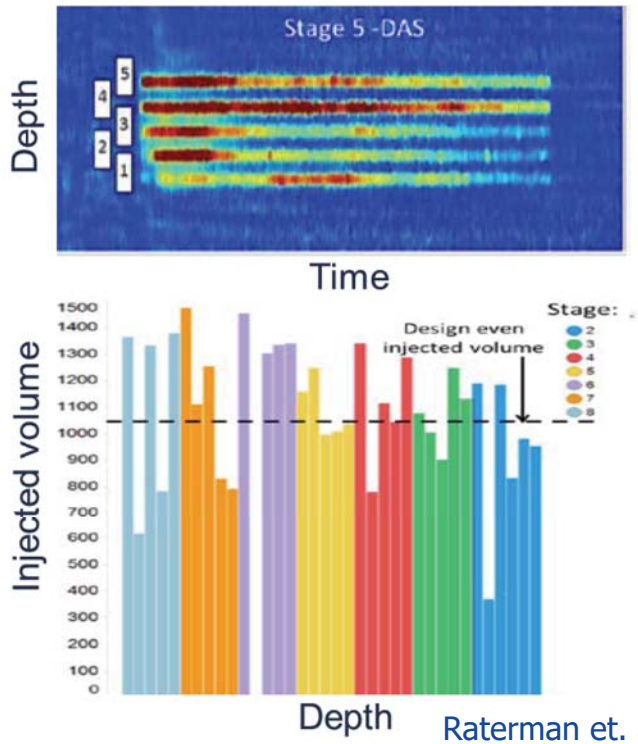
DAS Applications in Oil and Gas Industry

Seismic



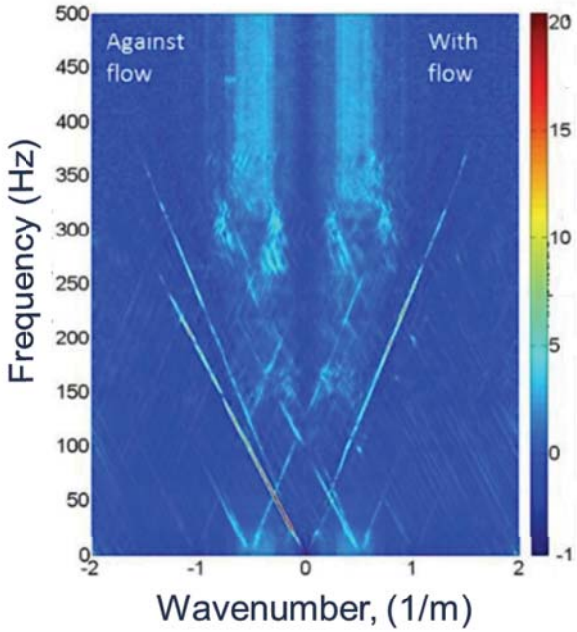
Willis et. al. (2016)

Completions



Raterman et. al. (2017)

Production



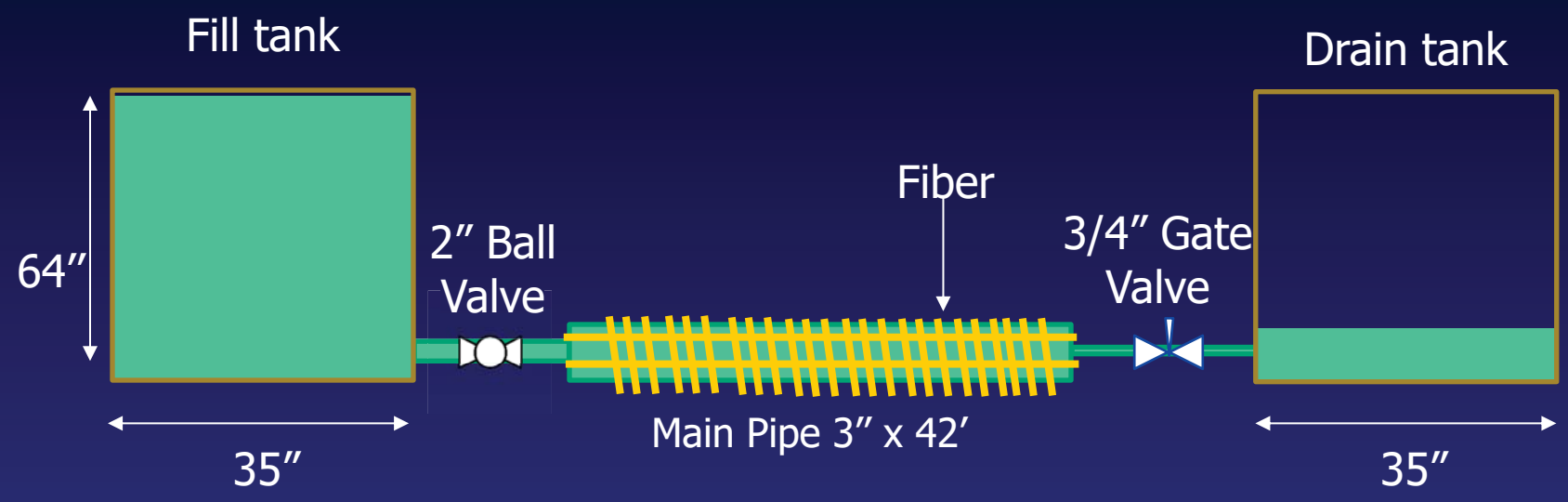
Xiao et. al. (2015)

Fiber Optics Research Program

- Full waveform seismic forward modeling and inversion of seismic DAS response
  - In progress
- CSM Campus Lab:
  - DAS in controlled environment: Flow loop
- CSM Edgar Research Mine – DAS/DTS:
  - In progress – Planning phase
- Field data (Devon):
  - FO in monitoring production
  - FO in understanding completion and reservoir

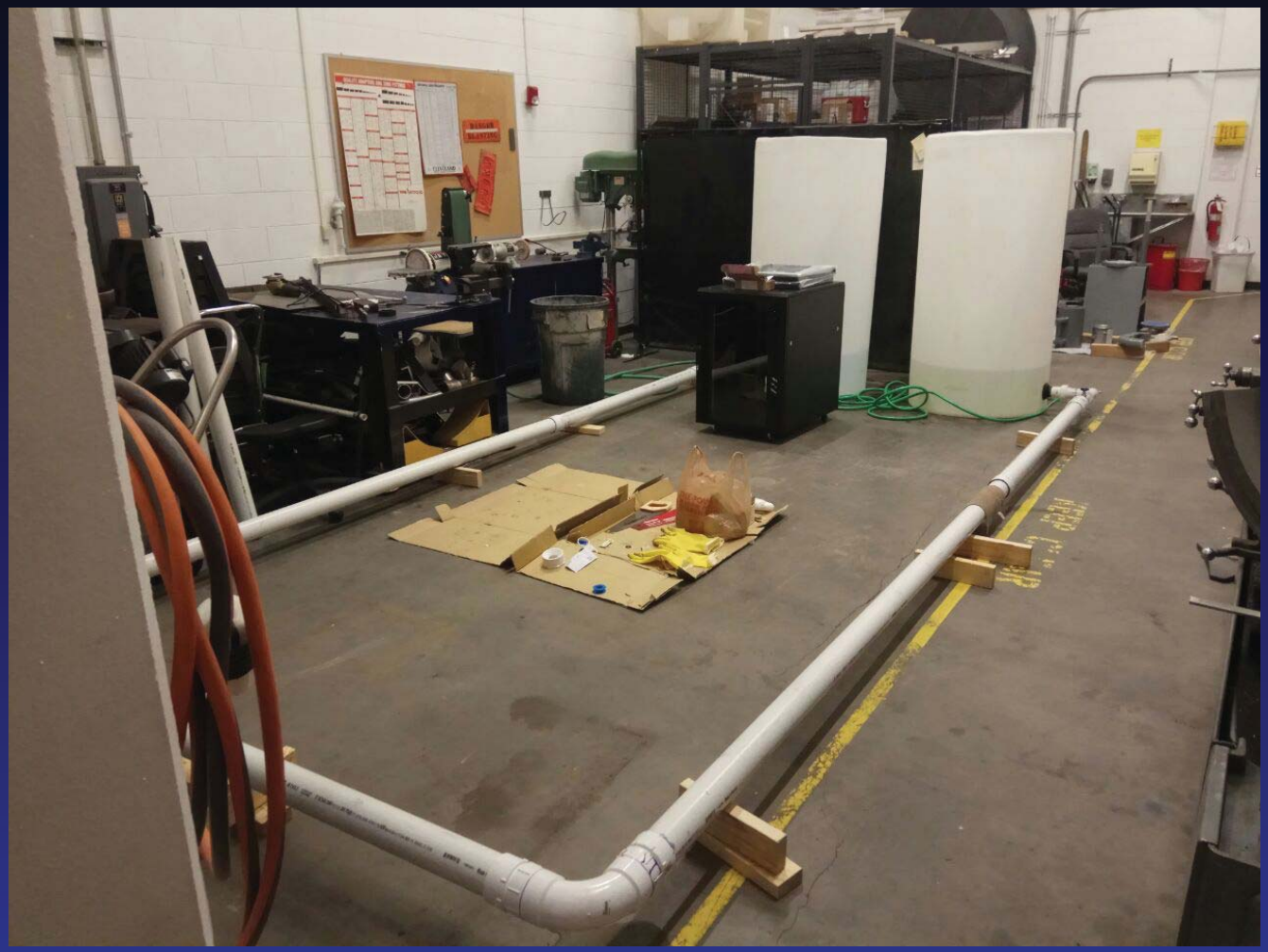
Flow Loop Design

- Gravity driven flow
- Water level drops at $1\ \mathrm{mm/s}$



- Estimated max. flow velocity in main pipe: $\mathrm{v} = 0.14\ \mathrm{m/s}$, flow rate: $Q = 0.6\ \mathrm{L/s}$
- Pressure in main pipe: $p = 2.3\ \mathrm{psi}$
- Reynold's number: $Re = 12000$

Flow Loop Design

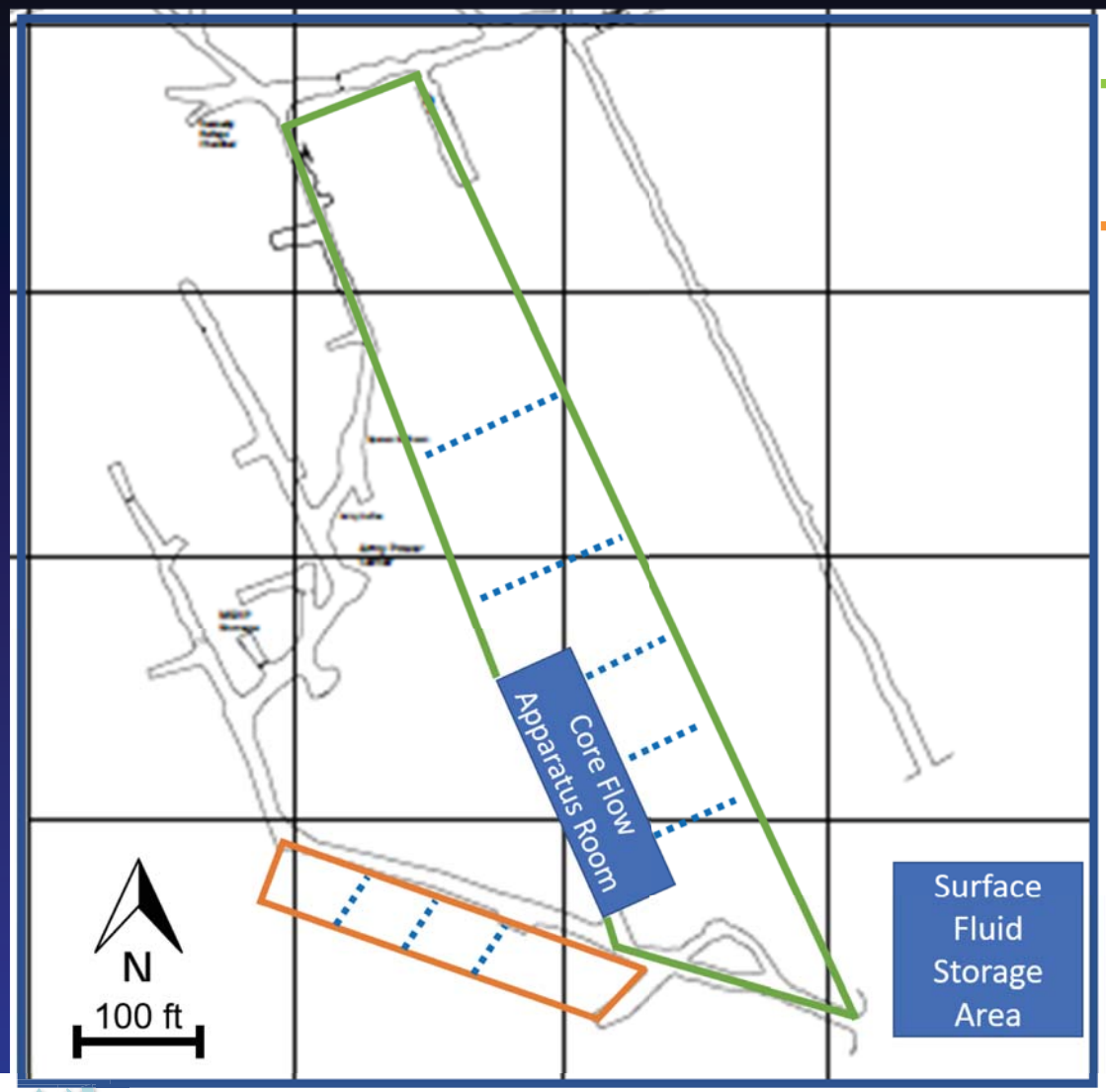


Flow Loop Design

Flow Loop Design

OptaSense®
a QinetiQ company

Edgar Research Mine Flow Loop



DOE Flow Loop (~1200 ft)

Current Flow Loop (~600 ft)

Future Work

- Effect of fiber installation
  - Coupling (epoxy, clamp …)
  - Location (Cemented behind casing, attached to tubing…)
- Perforation cluster behavior
  - Production
  - Stimulation
- Wellbore equipment
- Data analysis

Thank You
Questions and Comments