



UNCONVENTIONAL RESERVOIR ENGINEERING PROJECT
COLORADO SCHOOL OF MINES



Research Summary

Hydraulic Fracturing Modeling of an Enhanced Geothermal System

Kagan Kutun



UNCONVENTIONAL RESERVOIR ENGINEERING PROJECT
Advisory Board Meeting, November 3, 2017, Golden, Colorado

Presentation Outline

- Introduction
- Overview FORGE & SIGMA-V
- Motivation & Outcomes
- Task 1: Underground Research Laboratory (URL), Manitoba – Code Verification
- Future Work & Planned Schedule



UNCONVENTIONAL RESERVOIR ENGINEERING PROJECT
Advisory Board Meeting, November 3, 2017, Golden, Colorado

2

Introduction

- NREL contract. Started September 2017
- Hydraulic fracturing (HF) and geomechanical modeling for SIGMA-V
- Well drilled horizontally into a mine drift. Scale is larger than lab but still smaller than HF in oilfield.
- Assist using commercial/proven software and contemporary understanding of hydraulic fracturing
- Team members:
 - CSM: Jennifer Miskimins, Kagan Kutun
 - NREL: Henry "Bud" Johnson, Koenraad Beckers
- Another team from CSM lead by Dr. Wu – Tracer Modeling

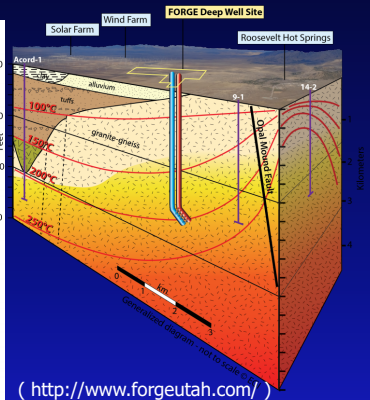
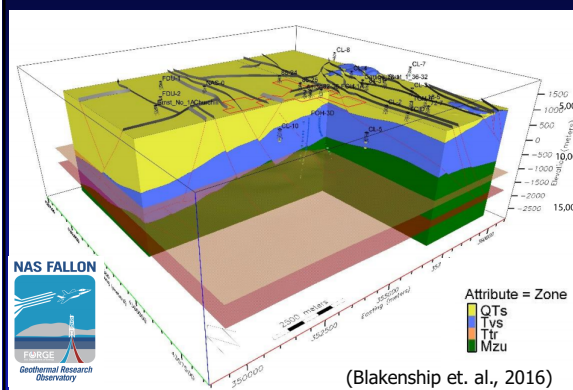


UNCONVENTIONAL RESERVOIR ENGINEERING PROJECT
Advisory Board Meeting, November 3, 2017, Golden, Colorado

3

Overview FORGE & SIGMA-V

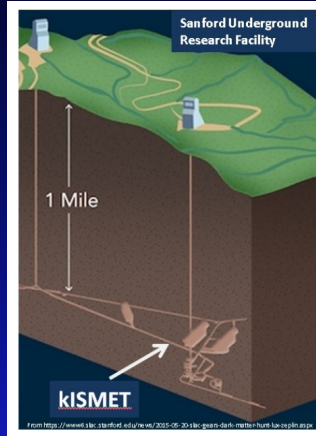
- Frontier Observatory for Research in Geothermal Energy (FORGE)
- Fully instrumented research site to enable a commercial pathway for EGS technologies



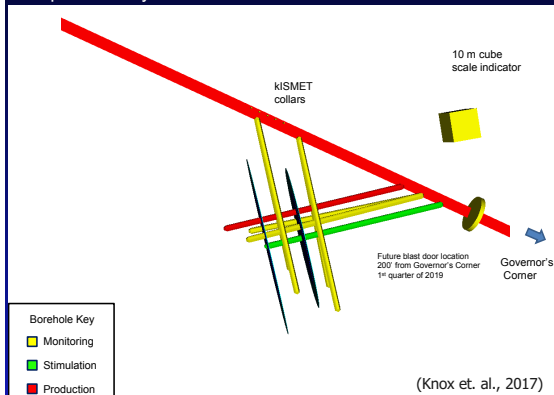
UNCONVENTIONAL RESERVOIR ENGINEERING PROJECT
Advisory Board Meeting, November 3, 2017, Golden, Colorado

4

Overview FORGE & SIGMA-V



- Hydraulic fracturing and circulation experiments in Sanford Underground Research Facility.
- 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



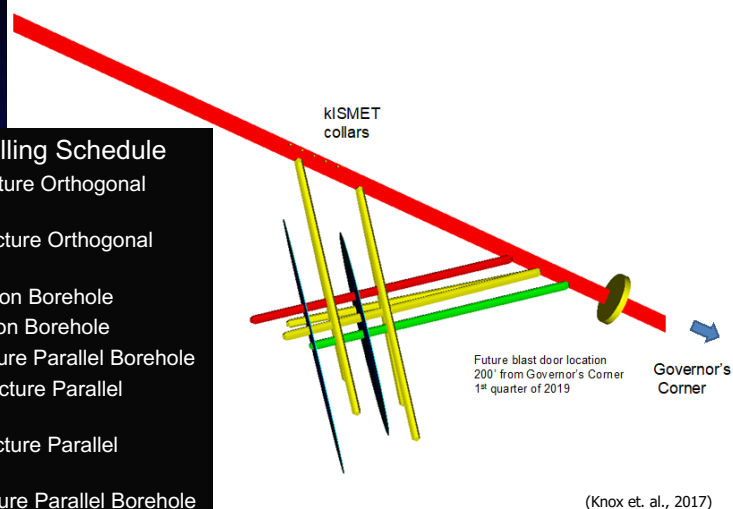
UNCONVENTIONAL RESERVOIR ENGINEERING PROJECT
Advisory Board Meeting, November 3, 2017, Golden, Colorado

5

Overview FORGE & SIGMA-V

Anticipated Drilling Schedule

- Oct. 13 - 1st Fracture Orthogonal Borehole
- Oct. 20 - 2nd Fracture Orthogonal Borehole
- Oct. 27 - Production Borehole
- Nov. 2 - Stimulation Borehole
- Nov. 9 - 1st Fracture Parallel Borehole
- Nov. 16 - 2nd Fracture Parallel Borehole
- Nov. 23 - 3rd Fracture Parallel Borehole
- Dec. 5 - 4th Fracture Parallel Borehole

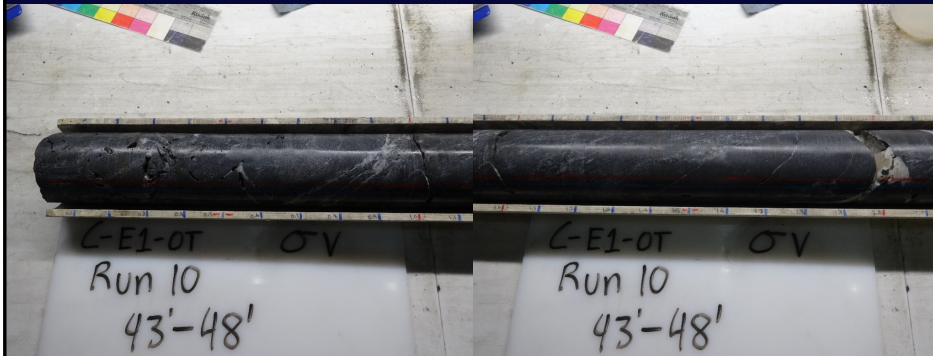


UNCONVENTIONAL RESERVOIR ENGINEERING PROJECT
Advisory Board Meeting, November 3, 2017, Golden, Colorado

6

Overview FORGE & SIGMA-V

1st Fracture Orthogonal Borehole Core Photos



(SIGMA-V Modeling Group Meeting Slides, October 2017)



UNCONVENTIONAL RESERVOIR ENGINEERING PROJECT
Advisory Board Meeting, November 3, 2017, Golden, Colorado

7

Overview FORGE & SIGMA-V

SIGMA-V Modeling Workgroup



**Lawrence Livermore
National Laboratory**



**Sandia
National
Laboratories**

**McCLURE
GEOMECHANICS**



**Los Alamos
NATIONAL LABORATORY**
EST. 1943

**Pacific Northwest
NATIONAL LABORATORY**



Idaho National Laboratory



UNCONVENTIONAL RESERVOIR ENGINEERING PROJECT
Advisory Board Meeting, November 3, 2017, Golden, Colorado

8

Motivation

- Take advantage of high resolution monitoring and characterization
- Knowledge transfer
- Access to insider details
- Develop a better understanding of HF in low perm crystalline rocks
- Master's thesis

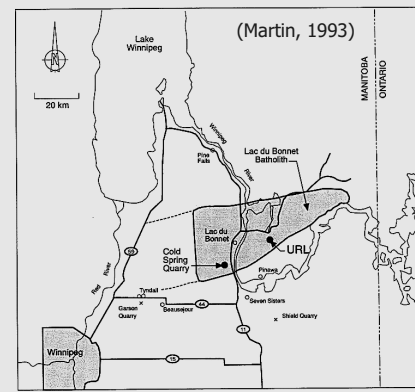
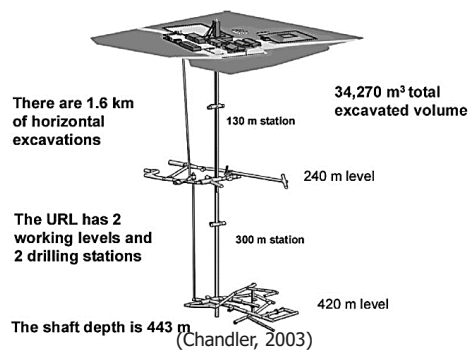


UNCONVENTIONAL RESERVOIR ENGINEERING PROJECT
Advisory Board Meeting, November 3, 2017, Golden, Colorado

9

Task 1: URL Manitoba – Code Verification

- Underground Research Laboratory, Manitoba, Canada
- Radioactive waste research
- Six HF stress measurement campaigns between 1981-1992



- Model using:
 - GOHFER (Commercial)
 - CFRAC_STANFORD (Research)
- Determine software capabilities and provide recommendations for future modeling work



UNCONVENTIONAL RESERVOIR ENGINEERING PROJECT
Advisory Board Meeting, November 3, 2017, Golden, Colorado

10

Task 1: URL Manitoba – Code Verification

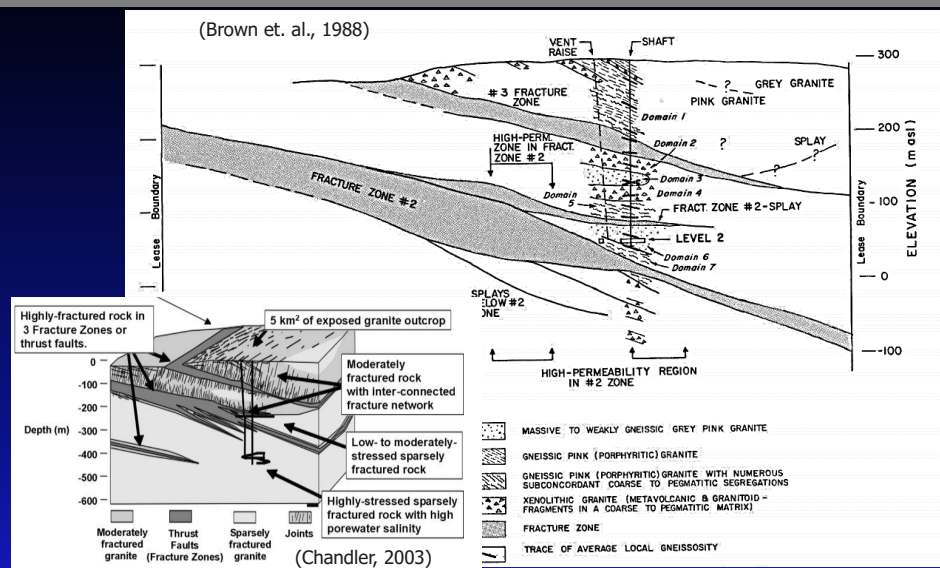
- Initial challenges:
 - Dataset = Four papers
 - Three decades
 - Understanding, nomenclature
 - Mining / rock mechanics measurement
 - Objective and scale
 - Very different results across the board
 - Closure, orientation, dip



UNCONVENTIONAL RESERVOIR ENGINEERING PROJECT
Advisory Board Meeting, November 3, 2017, Golden, Colorado

11

Task 1: URL Manitoba – Code Verification



UNCONVENTIONAL RESERVOIR ENGINEERING PROJECT
Advisory Board Meeting, November 3, 2017, Golden, Colorado

12

Task 1: URL Manitoba – Code Verification

- Modeling Phase 1: Above FZ 2
- Three wellbores
 - URL-1 (Inclined 15° to 19°)
 - URL-6 (Vertical)
 - SEPH (Inclined 11°)
- Only three vertical fractures (URL-6)
 - Discrepancies in closure and orientation
 - Measurements do not directly match calculations
 - Some vertical fractures were excluded from calculations
- Measurement error?
- Effect of changing rock fabric?

Depth*	Hole plunge	P _r	P _s	Hydrofrac orientation	
				Dip	Dip direction
m		MPa	MPa		
URL-1					
54 (64)	75°	6.3	4.3	58°	58°
146 (173)	74°	10.3	9.8	75°	146°
211 (250)	72°	15.9	15.1	73°	166°
261 (310)	71°	26.8	22.9	45°	39°
URL-6					
12.5	90°	6.2	4.2	83°	150°
109.5	90°	8.1	7.0	77°	8°
167.5	90°	4.6	6.9	90°	163°
203.0	90°	4.1	4.2	90°	176°
222.0	90°	14.8	14.9	90°	134°
250.0	90°	15.1	13.9	77°	5°
Shaft Extension Probe Hole (SEPH), 240 Level					
241.8	79°	20.3	18.0	70°	110°
247.8	79°	24.2	20.7	67°	112°
260.4	79°	23.5	21.1	77°	112°
269.2	79°	27.1	24.2	84°	114°
278.2	79°	23.6	21.4	61°	298°



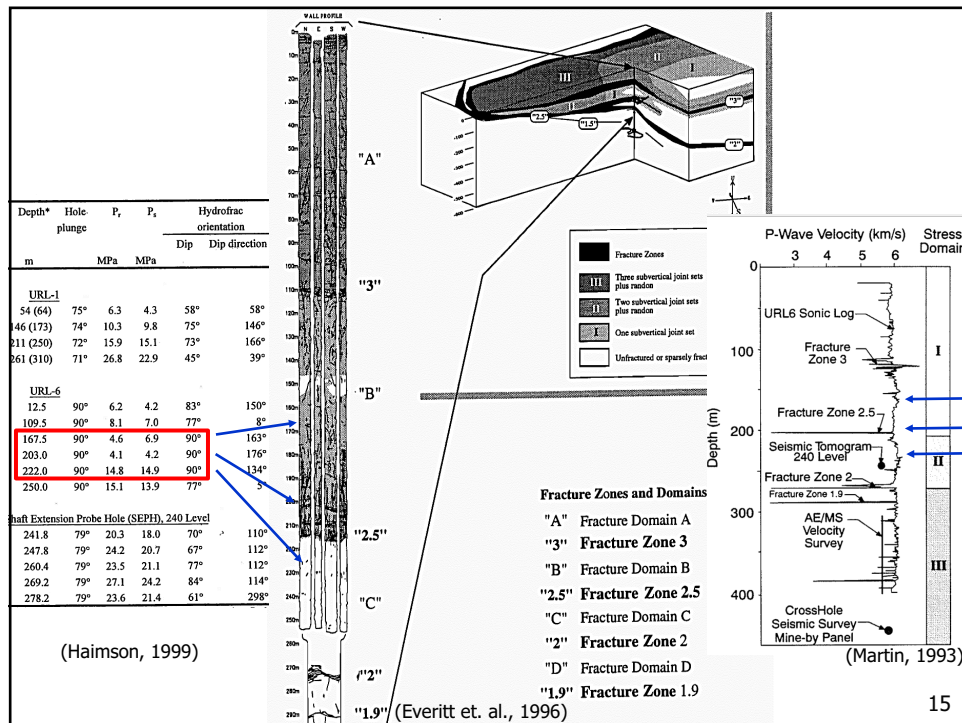
Task 1: URL Manitoba – Code Verification

Depth*	Hole plunge	P _r	P _s	Hydrofrac orientation	
				Dip	Dip direction
m		MPa	MPa		
URL-1					
54 (64)	75°	6.3	4.3	58°	58°
146 (173)	74°	10.3	9.8	75°	146°
211 (250)	72°	15.9	15.1	73°	166°
261 (310)	71°	26.8	22.9	45°	39°
URL-6					
12.5	90°	6.2	4.2	83°	150°
109.5	90°	8.1	7.0	77°	8°
167.5	90°	4.6	6.9	90°	163°
203.0	90°	4.1	4.2	90°	176°
222.0	90°	14.8	14.9	90°	134°
250.0	90°	15.1	13.9	77°	5°
Shaft Extension Probe Hole (SEPH), 240 Level					
241.8	79°	20.3	18.0	70°	110°
247.8	79°	24.2	20.7	67°	112°
260.4	79°	23.5	21.1	77°	112°
269.2	79°	27.1	24.2	84°	114°
278.2	79°	23.6	21.4	61°	298°

Loca- tion	Depth*	P _s *	Hydrofrac orientation*	σ _v **	σ _h **	σ _H **	σ _H direc- tion**
	m	MPa	Dip Dip di- rection	MPa	MPa	MPa	
URL-1	54.0	4.3	58°	58°	1.4	2.6	66°
URL-6	109.5	7.0	77°	8°	2.9	5.7	13.8
URL-1	146.0	9.8	75°	146°	3.9	7.8	18.7
URL-6	167.5	6.9	90°	163°	4.4	9.0	21.7
URL-1	211.0	15.1	73°	166°	5.6	11.5	27.5
URL-6	250.0	13.9	77°	5°	6.6	13.7	32.8
URL-1	261.0	22.9	45°	39°	6.9	14.4	34.3
SEPH	269.2	24.2	84°	114°	7.1	14.8	35.4

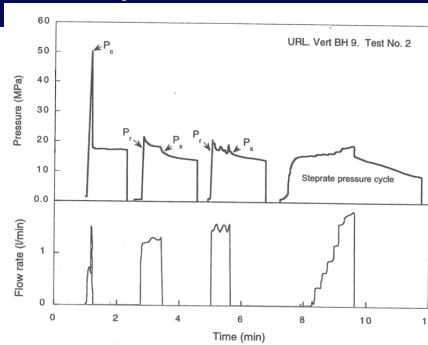
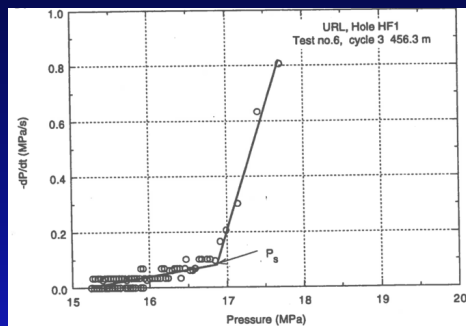
(Haimson, 1999)



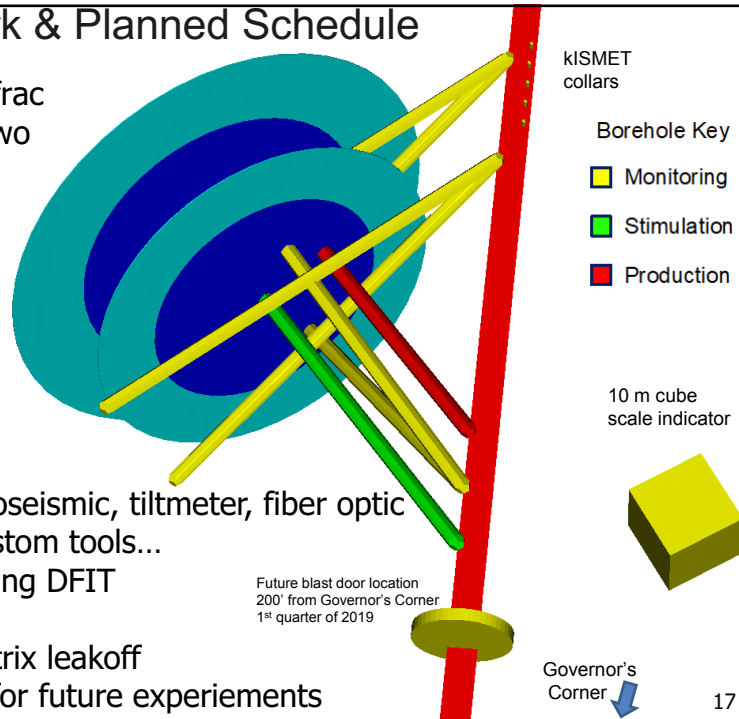


Task 1: URL Manitoba – Code Verification

- Orientation: Activating natural fractures?
- Closure pressure: Closure of HF vs natural fractures
- Scale: Total volume of the job is very small



Pre and post frac
modeling of two
fracture
experiments.



Cores, microseismic, tiltmeter, fiber optic sensing, custom tools...

Understanding DFIT

- Closure
- Non-matrix leakoff

Know-how for future experiments

Task Name

Task Name	2017			2018				
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
Literature Review								
Thesis Proposal								
Initial GOHFER Model/Match to URL								
GOHFER Sensitivity Runs for URL								
Finalize GOHFER Design for URL								
Initial CFRAC Model/Match to URL								
CFRAC Sensitivity Runs for URL								
Finalize CFRAC Design for URL								
Pre-Frac Modeling of Frac 1 SURF – GOHFER and CFRAC								
Post-Frac Modeling of Frac 1 SURF - GOHFER and CFRAC					?	?	?	
Thesis Writing								
Thesis Defense								



UNCONVENTIONAL RESERVOIR ENGINEERING PROJECT
Advisory Board Meeting, November 3, 2017, Golden, Colorado

Acknowledgements



- Henry "Bud" Johnston
- Neil Snyder
- Koenraad Beckers



UNCONVENTIONAL RESERVOIR ENGINEERING PROJECT
Advisory Board Meeting, November 3, 2017, Golden, Colorado

19



UNCONVENTIONAL RESERVOIR ENGINEERING PROJECT
COLORADO SCHOOL OF MINES



Thank You
Questions and Comments



UNCONVENTIONAL RESERVOIR ENGINEERING PROJECT
Advisory Board Meeting, November 3, 2017, Golden, Colorado

20