FORGE: Frontier Observatory for Research in Geothermal Engineering

Efficient Energy: Observations, Monitoring, & Diagnostics
2019 HFC Workshop, June 27, 2019

www.UtahFORGE.com

Acknowledgements

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We thank the many stakeholders who are supporting this project, including Smithfield, Utah School and Institutional Trust Lands Administration, and Beaver County as well as the Utah Governor's Office of Energy Development.

The DOE FORGE Program

Phase 1
- Five sites selected; $400,000 awarded to Utah for "desktop" characterization (Completed)

Phase 2 Underway (2016-2019)
- 2A/B: $10 awarded for permitting and proving resource (Completed)
- 2C: Milford chosen for the laboratory ($10,000,000 available)

Phase 3 (2019-2024)
- Drill, stimulate and flow test two deep wells; ~ $130 million over the five years for testing and research

Utah's Renewable Energy Corridor

- Geothermal fields (three)
- Windfarm
- Solar fields
- Biogas facility

Current Physical and Data Assets

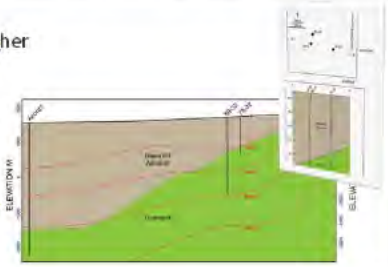
- FORGE Site and Surroundings
  - Modern Seismic, LIDAR
  - Offset Logs and Drilling Reports
- Well 58-32 – Vertical to ~7500 ft
  - Drilling Records, Bond Logs
  - QuadCombo Logging Suite
  - Repeat FMI, Two Cores
  - Series of Barefoot Injection Tests for Stress and Permeability
  - Mechanical Properties Data
  - Mineralogy, Permeability …

Current Physical and Data Assets

- Well 68-32 – Vertical to ~1,000 ft
  - Pair of Geophones at TD
- Well 78-32 – Vertical to ~3200 ft
  - Distributed Acoustic Sensors(DAS) Cemented In
  - 12 Geophones

What is Missing? Operations for April 2019

- Stimulation at Higher Rate
- Initiation Considerations
- Natural Fracture Capture Potential
- Aseismicity
- Additional Uphole Quantification



Borehole Instrumentation

- Well 68-32 (~ 925')
  - 3C 15 Hz geophone (4 sensors per component)
  - 3C Silicon Audio accelerometer
- Well 78-32 (Top of granite 2615'; TD 3280')
  - 12 3C geophones, 100' spacing, straddling granite contact
  - Distributed Acoustic Sensor (fiber optic cable) cemented in annulus

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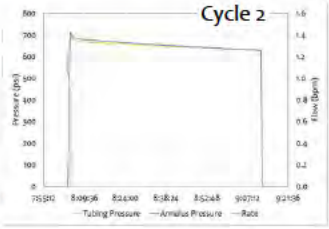
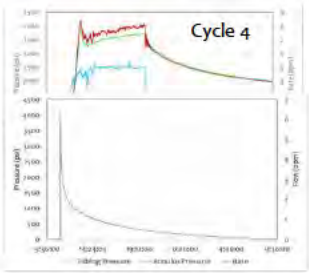
Operations in April 2019

- Treat Three Zones: Openhole and Two Perforated Sections
- Nine Injection Cycles Per Zone
- Cycle 1: Stepped Impulse Test (250, 500, 750, 1000, and 1250 psi Surface Pressure with Shut-Ins)
- Cycle 2: Small Volume, Low Rate (~1 BPM, 1 BBL)



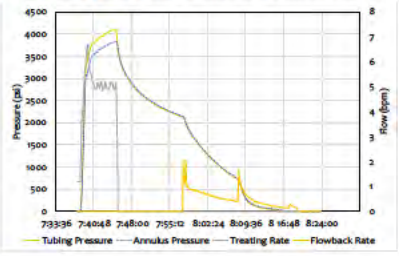
Operations in April 2019

- Cycle 3: Double Rate, Small Volume
- Cycle 4: Relatively Standard DFIT
- Packer Failed Earlier, Bridge Plug Intact
- Pumped Down Casing
- Dead String
- Shut-In Until Nominally Complete Pressure Decay



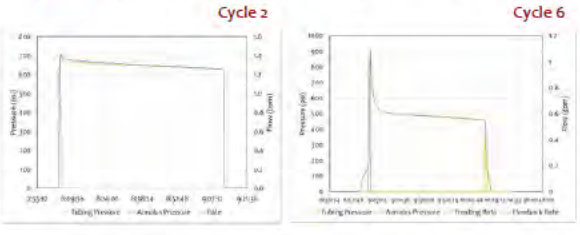
Operations in April 2019

- Cycle 5: Repeat Cycle 4 with Flowback Rather Than Shut-In



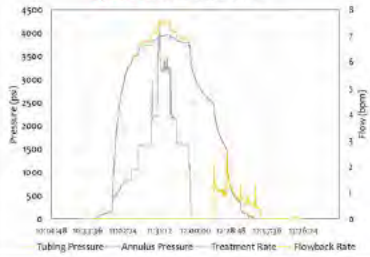
Operations in April 2019

Cycle 6: Repeat Cycle 2 to See If Treating Pressure Has Changed



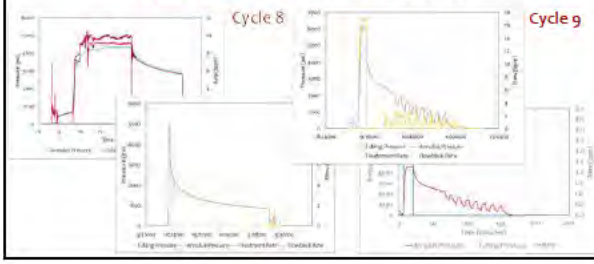
Operations in April 2019

Cycle 7: SRT and SDT



Operations in April 2019

Cycles 8 and 9: Increase Treating Rates



Phase 2C – Scientific Measurements – Zone 1

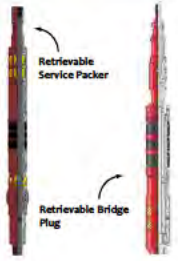
Openhole Injection Program

- Confirmation of Stress Field and Longer Shut-Ins
- Assessment of Monitoring and Degree of Aseismicity
- Continuing Effort to Assess Role of Shear Fracturing
- Temperature Profiles to Comprehend Height Growth
- Assessment of Flowback as a Measurement Technique
- Impulse Testing for Measuring Conductivity and Longevity?
- Higher Rates and Fracture Evolution
- Platform and Data for Numerical Simulations

Phase 2C Scientific Experiments – Zone 1

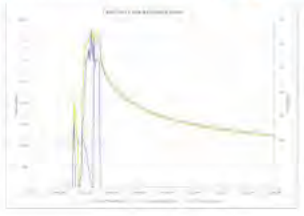
Openhole Injection Measurements

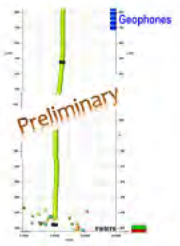
- Repeat stress, DFIT and permeability measurements from Sept 2017
- Injection tests and shut-in/ flowback cycles may generate useful microseismic response with small injection fluid volumes(?)



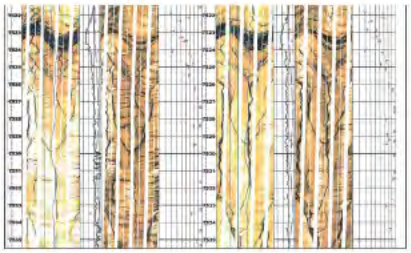
Phase 2C – Scientific Measurements – Zone 1

Openhole Injection Program





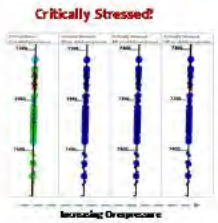
Before **After**



Phase 2C – Scientific Measurements – Zone 2

Cased Hole 1: Critically Stressed Fractures

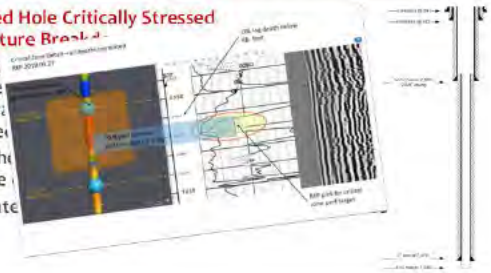
- Reactivate Critically Stressed Fractures
- Baseline for Hydroshearing Evaluations
- Baseline for Establishing Influence of Pre-Existing Fractures
- Baseline for Considering Implications of Horizontal Stress Anisotropy
- Assess Near-Wellbore Pressure Losses



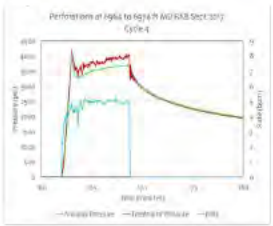
Phase 2C – Scientific Measurements – Zone 2

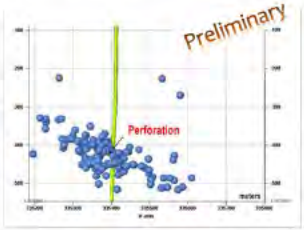
Cased Hole Critically Stressed Fracture Breakd...

- T... re... fra... se...
- Th... be...
- Inte...

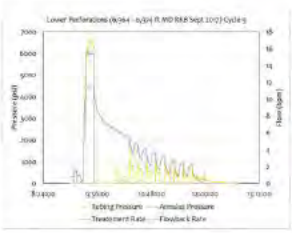


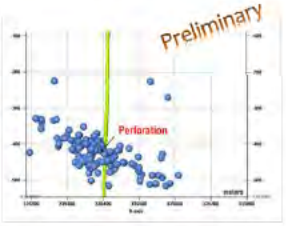
Phase 2C – Scientific Measurements – Zone 2





Phase 2C – Scientific Measurements – Zone 2





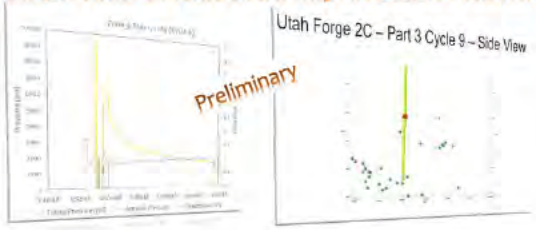
Phase 2C – Scientific Measurements – Zone 3

Cased Hole 2: Non-Critically St... Fractures

- Reacti...
- "End P...
- "End P... Fractures
- "End Pc... l Stress Anisotr...
- Assessm...

Phase 2C – Scientific Measurements – Zone 3

Cased Hole 2: Non-Critically Stressed Fractures



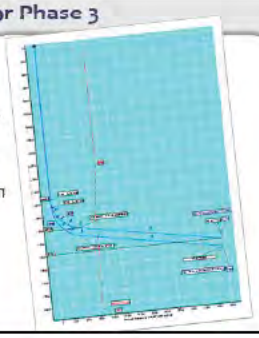
Phase 3 Activities

- Create and map wellbore connections
- Test and prove multistage stimulation technologies
- Effective, safe and environmentally benign
- Research Facility

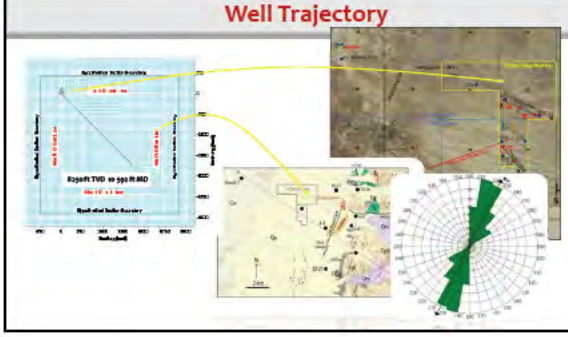
Vision for Phase 3

Objective

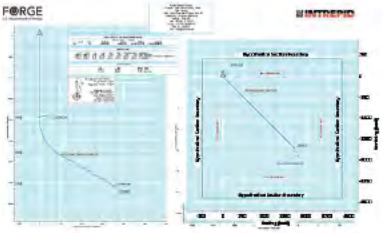
Drill and geosteer two highly deviated wells into granitic rocks with a temperature of ~175 to 225°C in the 1.5 to 4 km depth range.



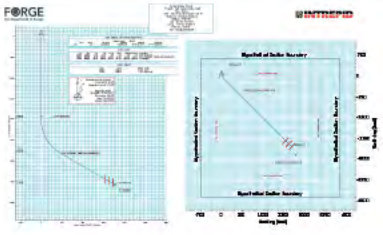
Well Trajectory



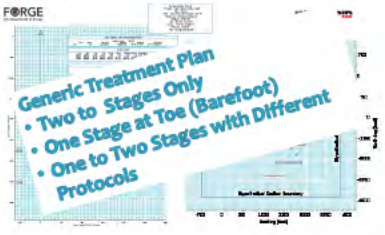
Drill and Complete "Active" Well



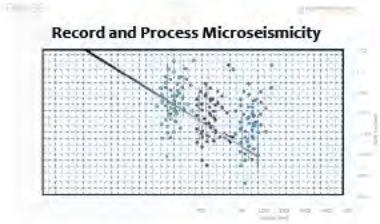
Stimulate Active Well at Toe



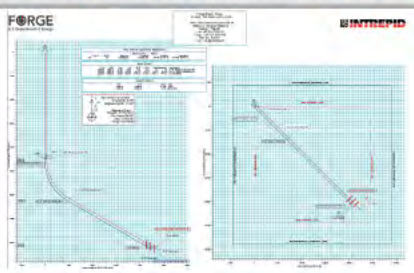
Stimulate Active Well at Toe



Stimulate Active Well at Toe



Geosteer Passive Well to Intersect Fractures



Laboratory Development and Testing: 2019-2024

- **Manage FORGE site**
- Drill Injection-Production Well Pair and Interconnect
- Continue Environmental Monitoring
- Release FOAs (Fund Opportuni… and …ojects
- Ma… …earch Contracts
- Con…nue Outreach Activities

Phase 3

- R&D projects solicited, reviewed, selected and incorporated in activities
- Develop new and novel tools and methods for drilling, stimulation and maintenance of EGS reservoirs.

- Exploration Technologies
- Reservoir Characterization
- Lower Cost Drilling
- Zonal Isolation/Packers
- High Temperature Tools
- Stimulation Procedures
- Modeling
- Diagnostics and Monitor
- Heat Management
- Induced Seismicity
- Equitable Flow Distribution

Short-Term Geothermal Drilling Research

- **Cutting:**
  - Drilloffs in new drills for monitoring wells
  - Including percussion
- **Bits and Motor Comparisons:**
  - Slotted into drilling horizontals.
  - Try out advanced technologies in wells of opportunity
- **Measurement:**
  - Evaluating advanced at-bit technologies for drilling and for reservoir characterization (MWD, LWD, MSE)
- **Other:**
  - Wired pipe, communication of data to surface …

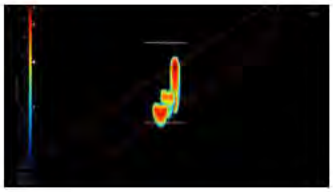
Breakdown Technologies

Connecting Wellbores

- **Early time testing** at heel of first well before drilling ahead
- **Communicating with the reservoir** (perforations, cyclic injection, propellant, other ...)
- **Stimulation technology and monitoring** (fluids, proppant, rates, cyclicity ... .)
- Measurements and validation of predictions of **fracture geometry and interaction** (i.e., using tracers, ERT, proppant tracking ...)
- Options for **detailed well design** - Trajectory and offset of well 2 from well 1

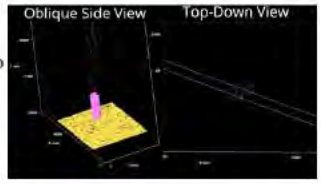
Scientific and Engineering Questions

Can discrete conductive fracture networks be generated at multiple locations along the length of a cased and cemented injection well?



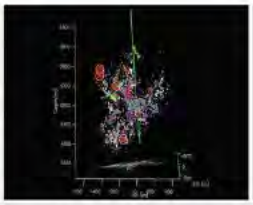
Scientific and Engineering Questions

Can these conductive fracture networks propagate from injector to producer, without significant interference, crossflow or short circuiting?



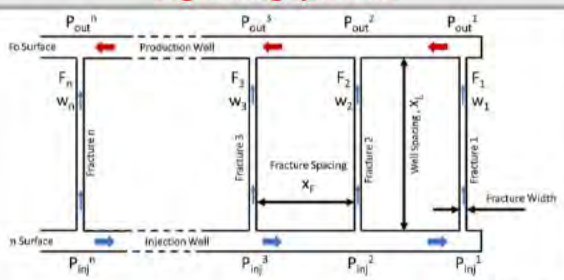
Lessons Learned and Vision: Seismicity

Basel, 1356 - Karl Jauslin



Basel, 2009 - Meir et al., 2015

Engineering Questions



After Asai et al., 2018

Hypotheses Evaluated in Phase 2C

- **Hypothesis 1:** Best available technology is available to monitor microseismicity and fracture growth with enough certainty that research in Phase 3 can reasonably be expected to fulfill the FORGE mission.
- **Hypothesis 2:** Reliable numerical simulations, using the available information about formation properties, will show a reasonable likelihood of establishing adequate well connectivity through hydraulic network development.

... continued

Phase 2C - Hypotheses

- **Hypothesis 3:** Reliable numerical simulations will show that adequate vertical growth can be established in a fracture network by a combination of extensile fractures, wing cracks that evolve into tensile-dominated fractures and hydraulically-induced shearing.
- **Hypothesis 4:** Fracture initiation in cased hole is possible in well 58-32.