Geothermal Energy
Utah FORGE

NATIONAL ASSOCIATION OF
STATE TRUST LANDS
Helping States Fund Education

John McLennan
University of Utah

EGI Energy & Geoscience Institute
... the science to find energy

Since 1972

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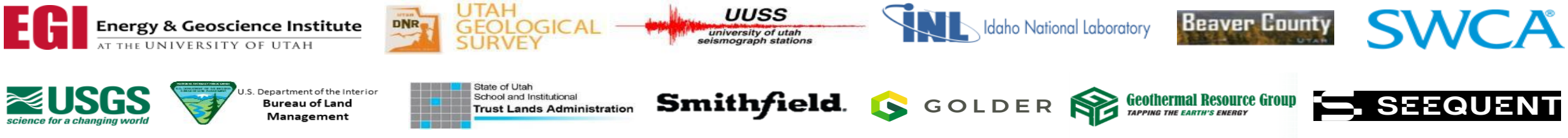
U.S. Department of Energy

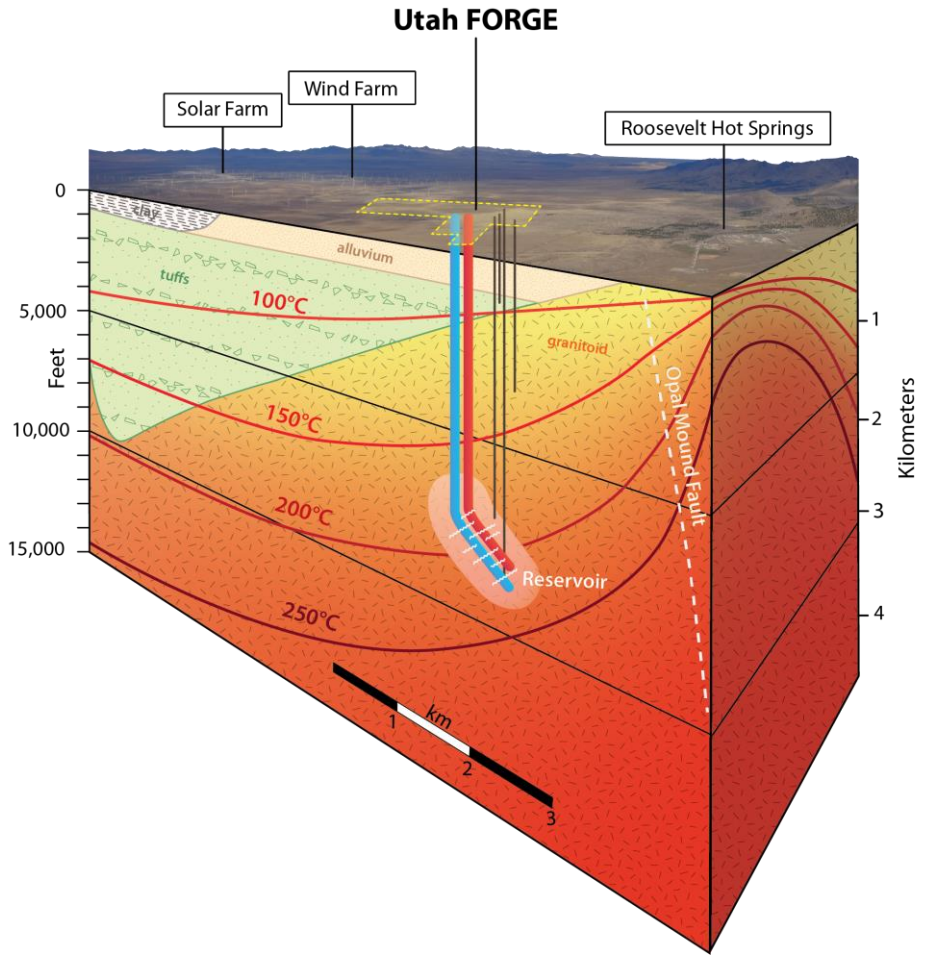
Funding for this work was provided by the U.S. DOE under grant DE-EE0007080 "Enhanced Geothermal System Concept Testing and Development at the Milford City, Utah FORGE Site"

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



What is Utah FORGE?

- **FORGE:** Frontier Observatory for Research in Geothermal Energy
- Underground field laboratory sponsored by the Department of Energy (DOE)
- Developing, testing, and accelerating breakthroughs in Enhanced Geothermal Systems technologies to advance the uptake of geothermal resources around the world
- Located near Milford in Beaver County, UT



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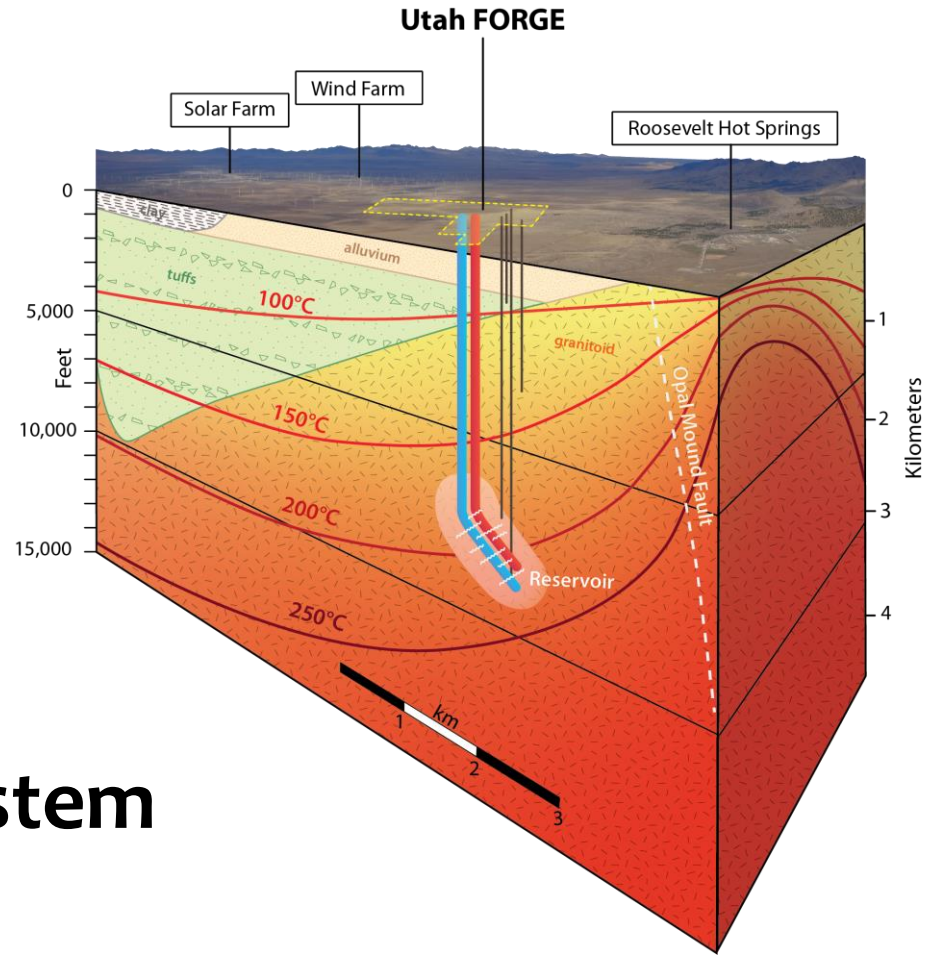
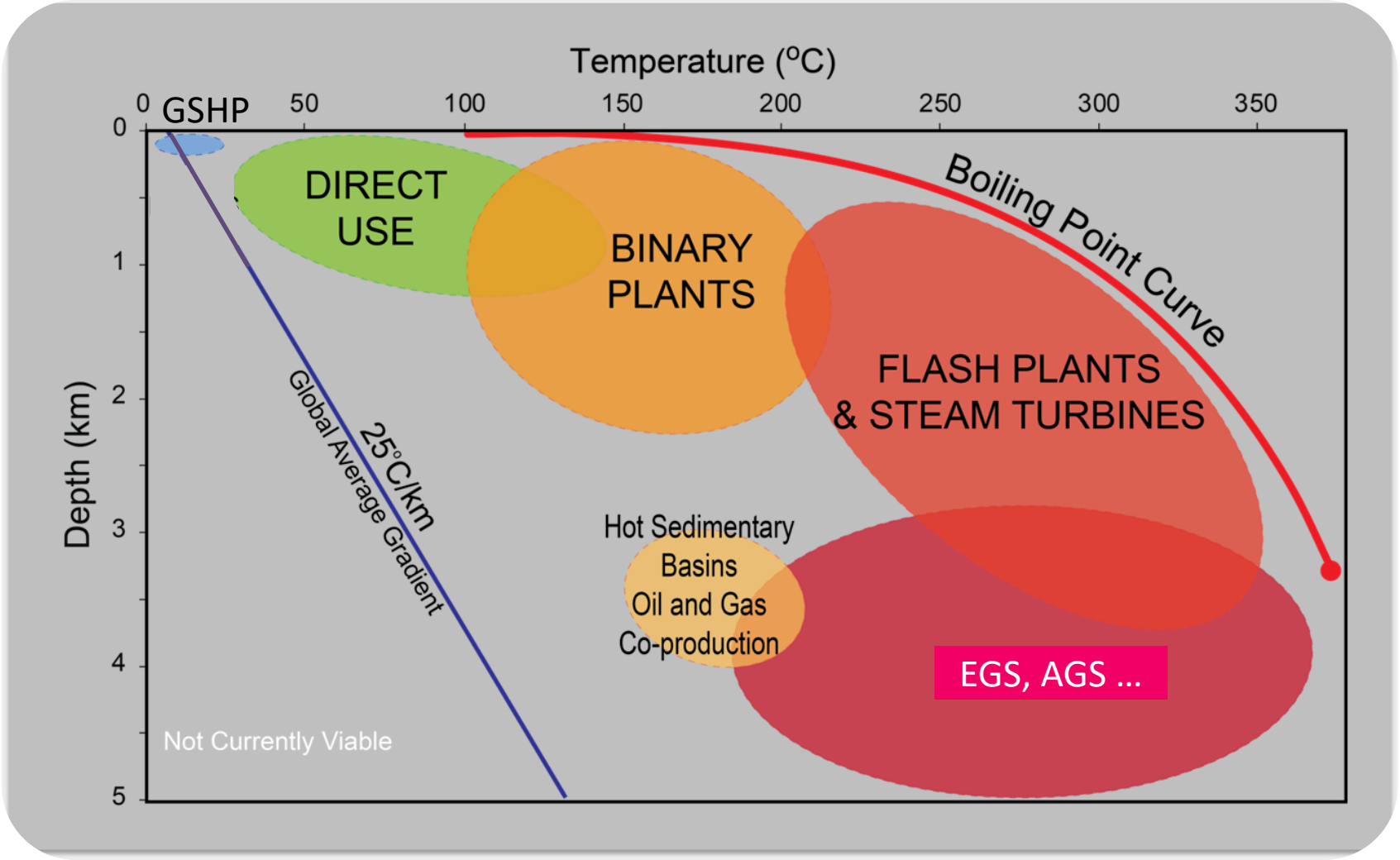
www.UtahFORGE.com

Attributes of FORGE?

- Temperature >350°F and <450°F
- Depth Exceeding 5,000 ft
- Reservoir in low permeability crystalline rocks (granite)
- Low risk of seismic hazards
- No environmental risks to groundwater, flora, fauna
- No connection to hydrothermal system



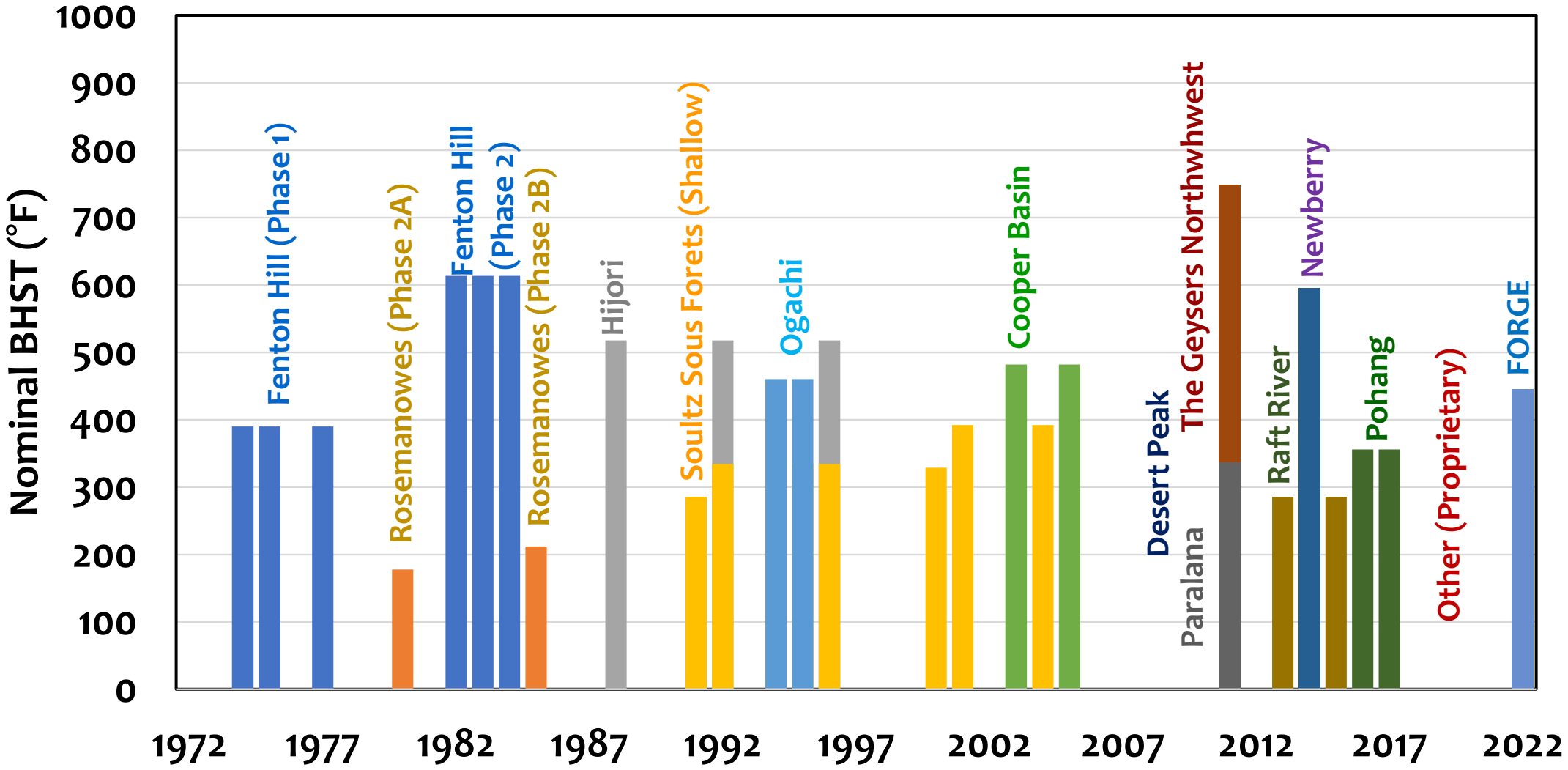
What Technology Gaps Does FORGE Address?



- Commercial Temperatures
- Developing Improved Well Construction Methods
- Improved Reservoir Characterization in Extreme Environments
- Developing Surface Area for Heat Transfer

Moore and Simmons, 2013

Nearly 50 Years of EGS Evaluations



Compiled from Tester et al., 2006 and Breede et al., 2013

New Technologies? Revitalizing Classical EGS

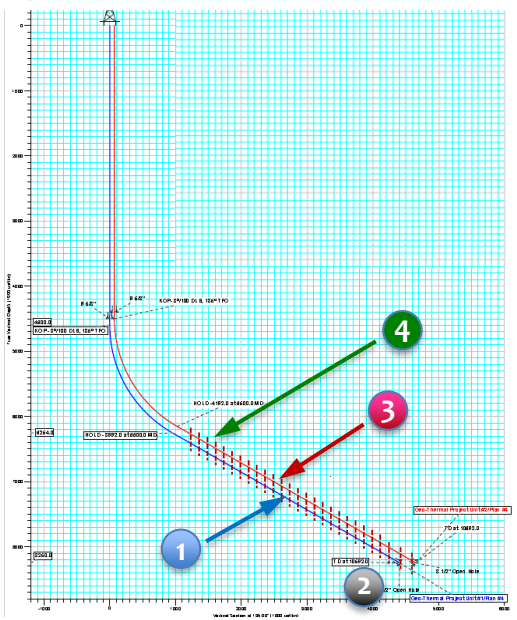
Conceptual Reservoir Development

1. Drill Injection Well
2. Hydraulically Fracture (Multiple Stages)
3. Drill Production Well to Intersect Fractures
4. Populate Well with Frac Stages

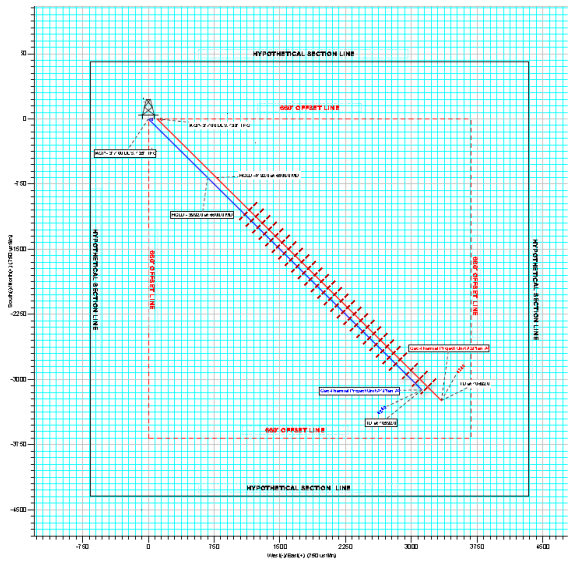
Conceptual Commercial Agenda

- Injected Cold Water Circulates Through Hydraulic Fractures
- Hot Water Brought to Surface Through Production Well
- Flashed to Steam and/or Run Through Organic Rankine Cycle Binary Plant

Classical EGS Conceptual Schematic



Elevation (Side) View



Plan (Map) View

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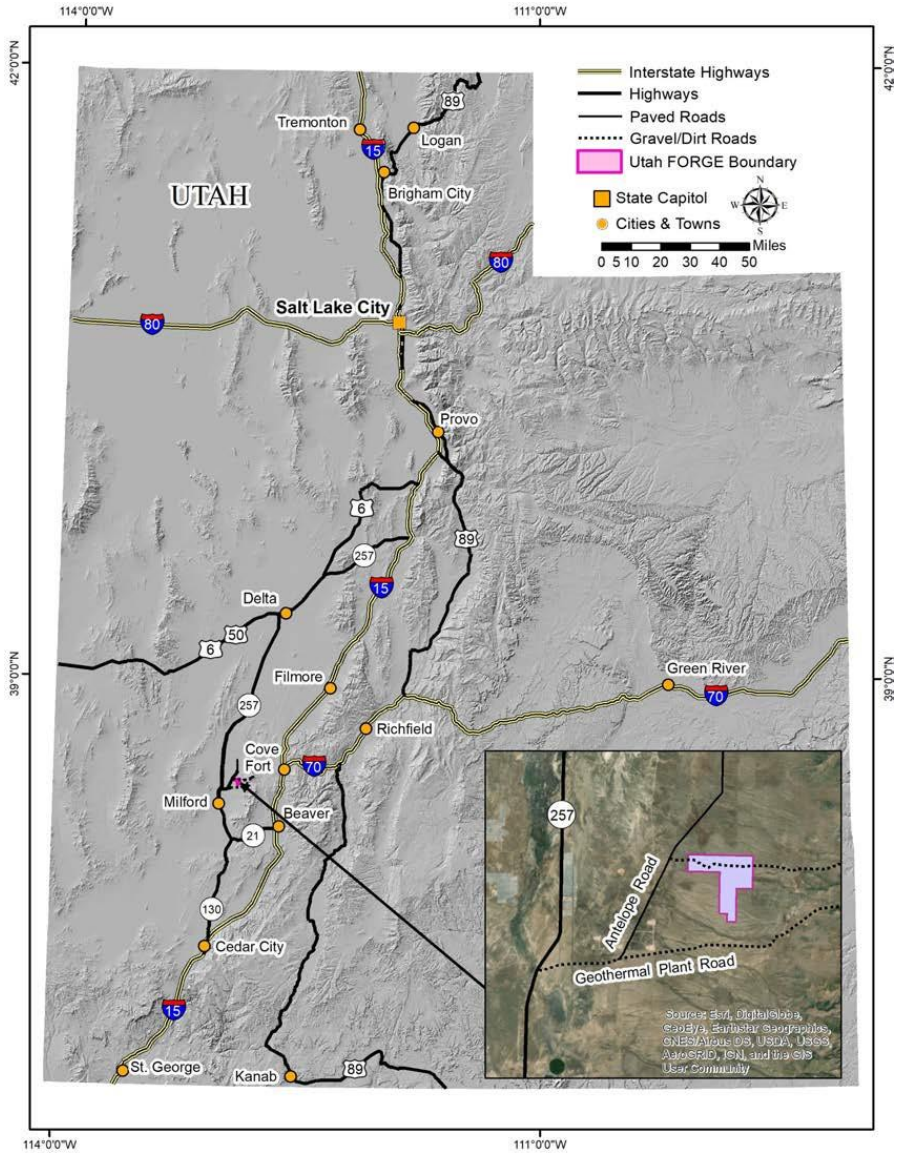
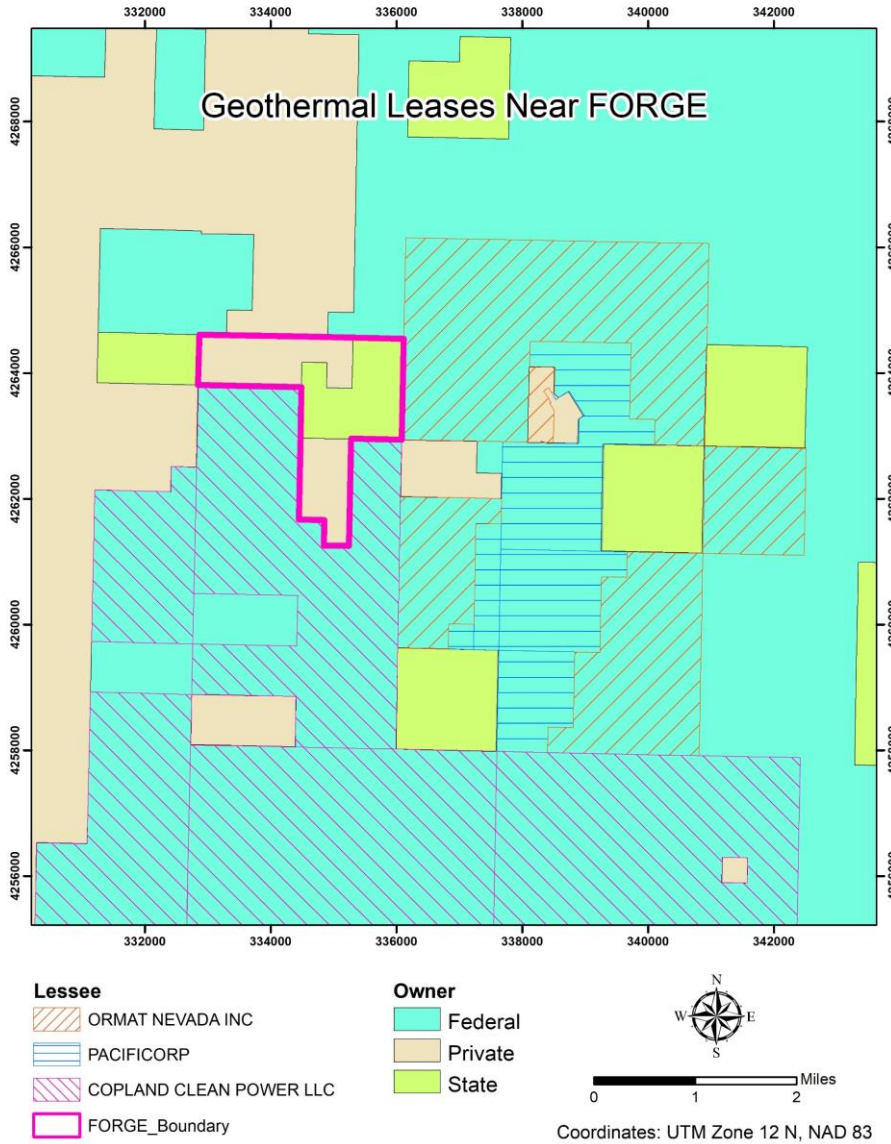
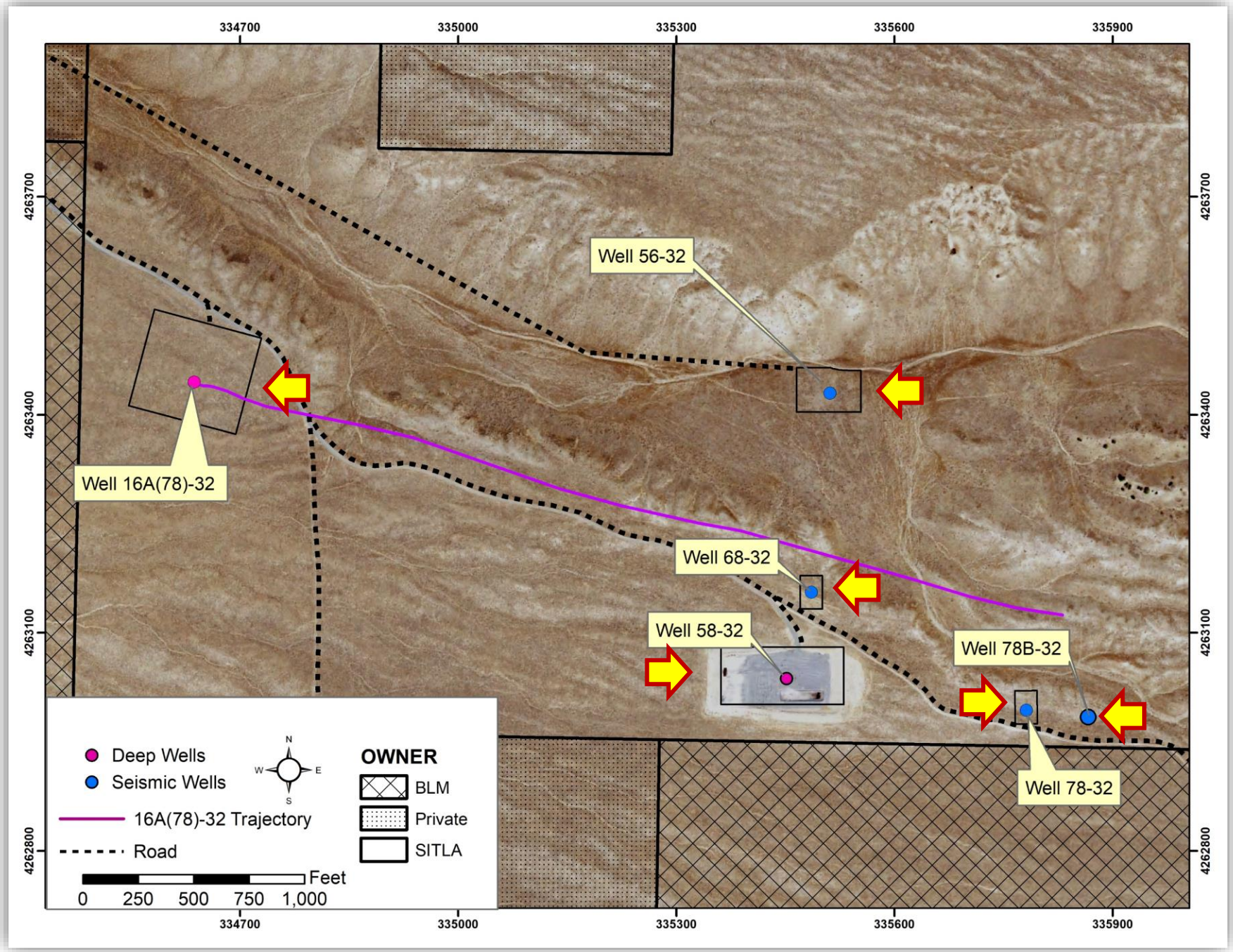

114°0'0"W
111°0'0"W
42°0'0"N
39°0'0"N
Interstate Highways
Highways
Paved Roads
Gravel/Dirt Roads
Utah FORGE Boundary
State Capitol
Cities & Towns
Miles
0 5 10 20 30 40 50
UTAH
Tremonton
Logan
Brigham City
Salt Lake City
Provo
Delta
Filmore
Green River
Richfield
Cove Fort
Milford
Beaver
Cedar City
St. George
Kanab
Antelope Road
Geothermal Plant Road
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

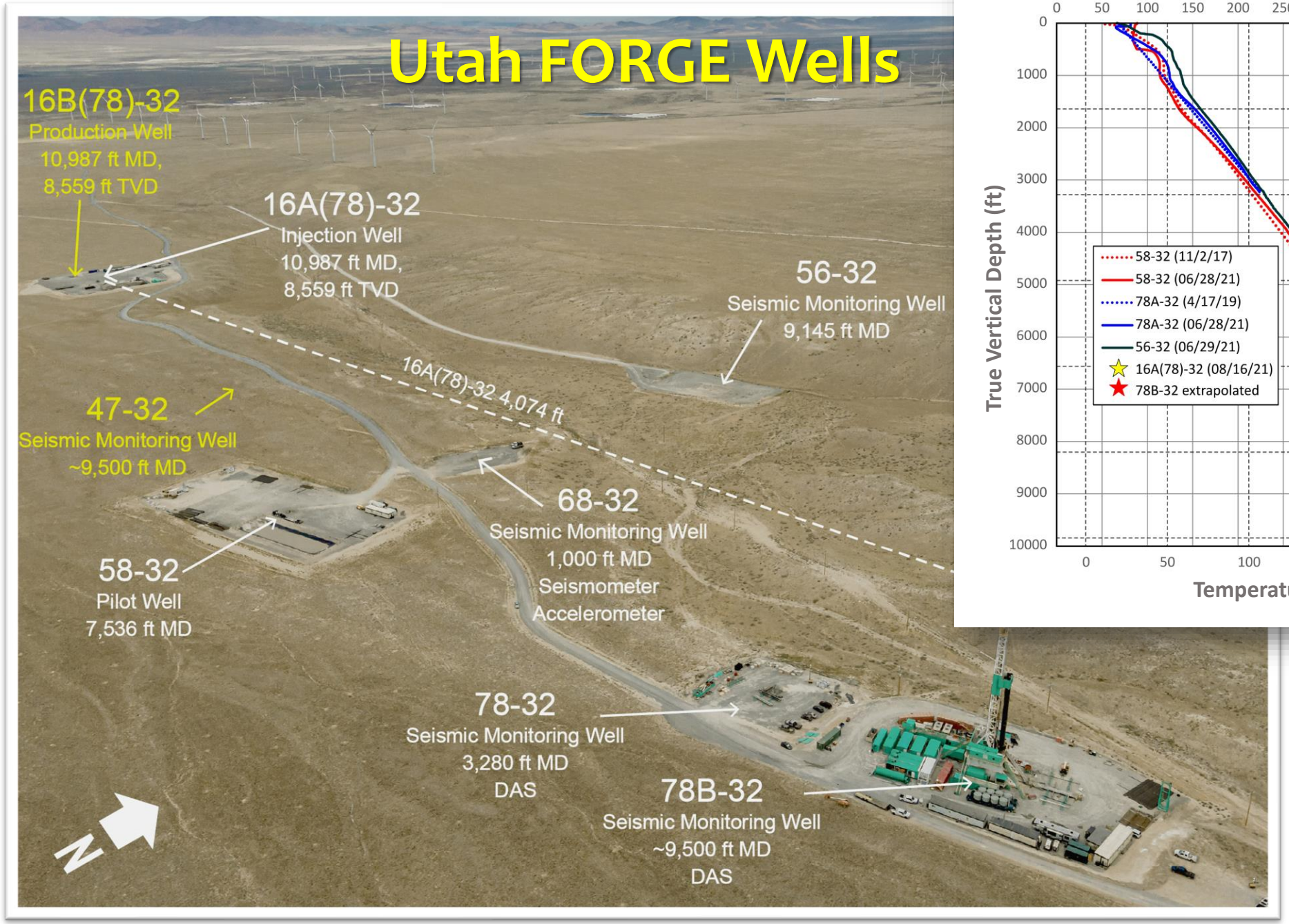

Geothermal Leases Near FORGE
332000
334000
336000
338000
340000
342000
4268000
4266000
4264000
4262000
4260000
4258000
4256000
Lessee
ORMAT NEVADA INC
PACIFICORP
COPLAND CLEAN POWER LLC
FORGE_Boundary
Owner
Federal
Private
State
N
W
E
S
Miles
0
1
2
Coordinates: UTM Zone 12 N, NAD 83

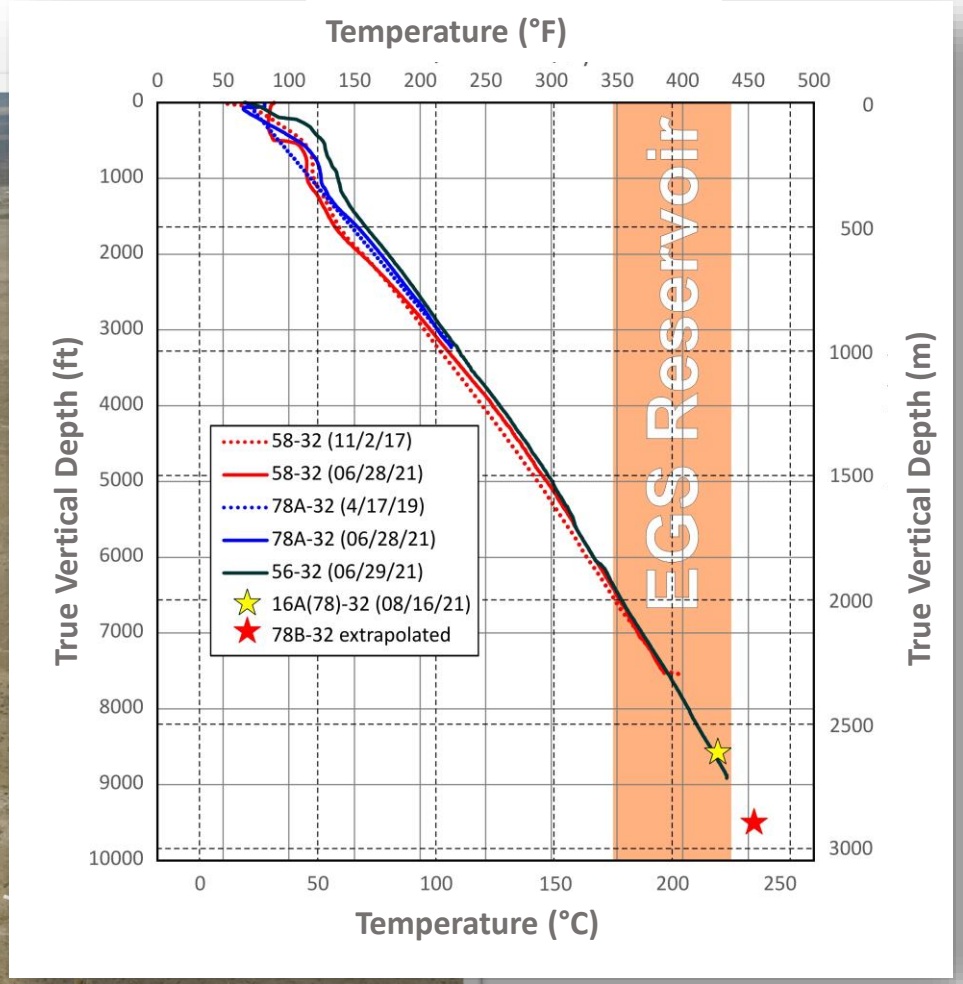
Chronology

1) 58-32 2017
2) 68-32 2019
3) 78-32 2019
4) 16A(78)-32 2020
5) 56-32 2021
6) 78B-32 2021
7) Stimulate 16A(78)-32 2020



Utah FORGE Wells

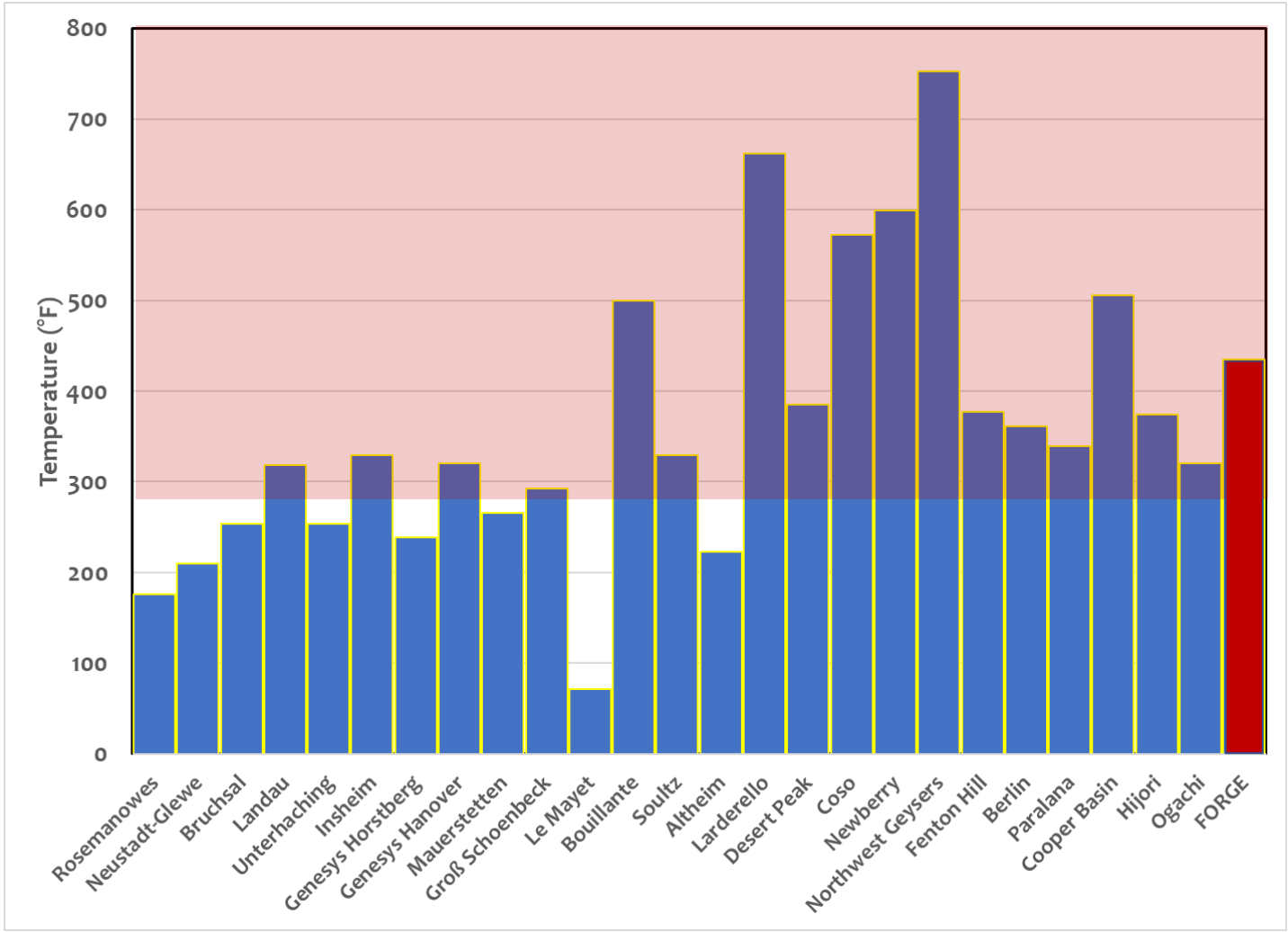




Why Problematic? Temperature

Need and motivation for products and services that can perform successfully at elevated temperature/time required

And – multiple stimulation stages envisioned



Modified from Breede et al., 2013

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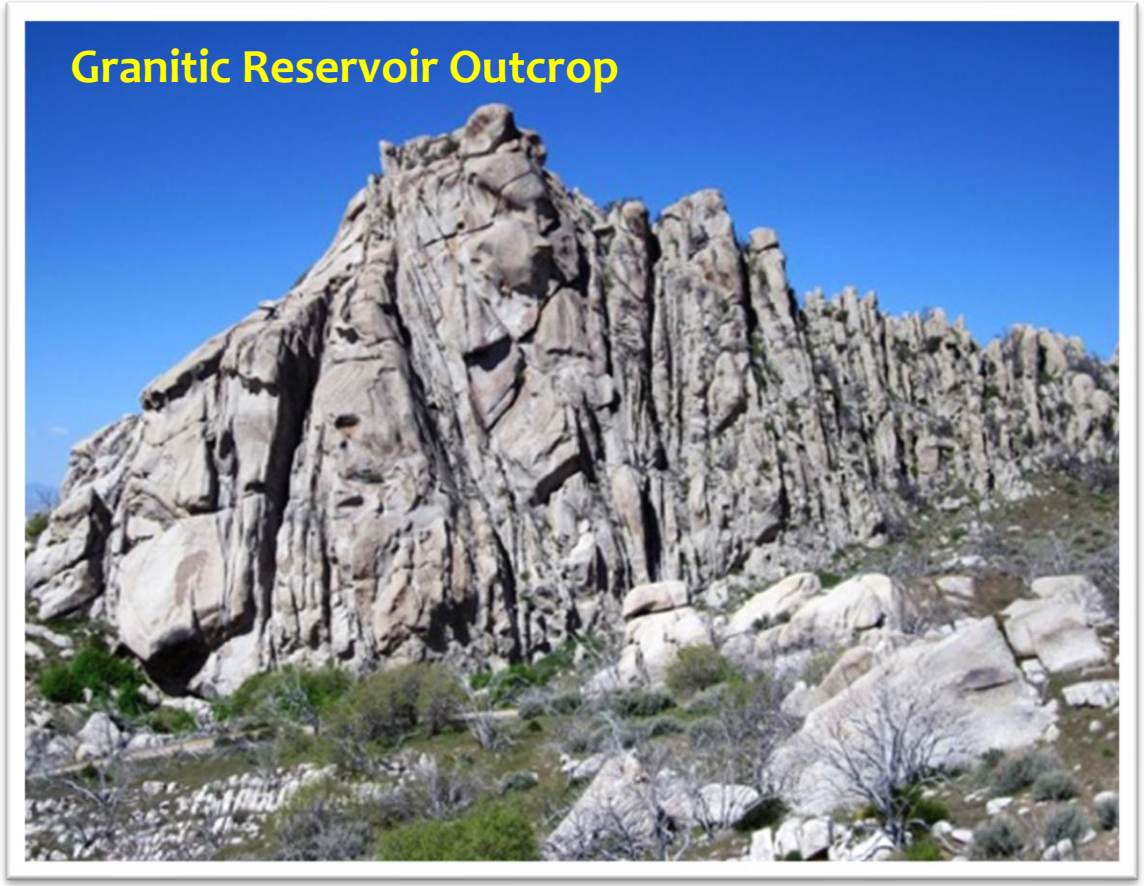
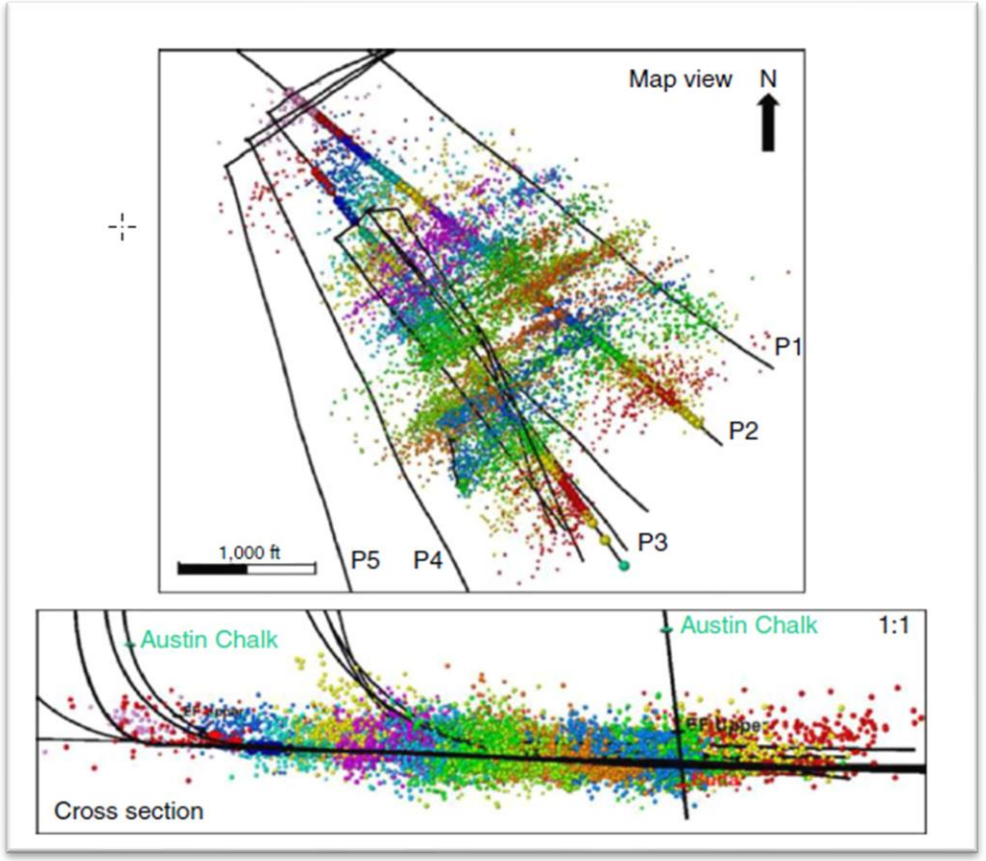
Why Problematic? Reservoir Characteristics?



Courtesy Bartley 2019



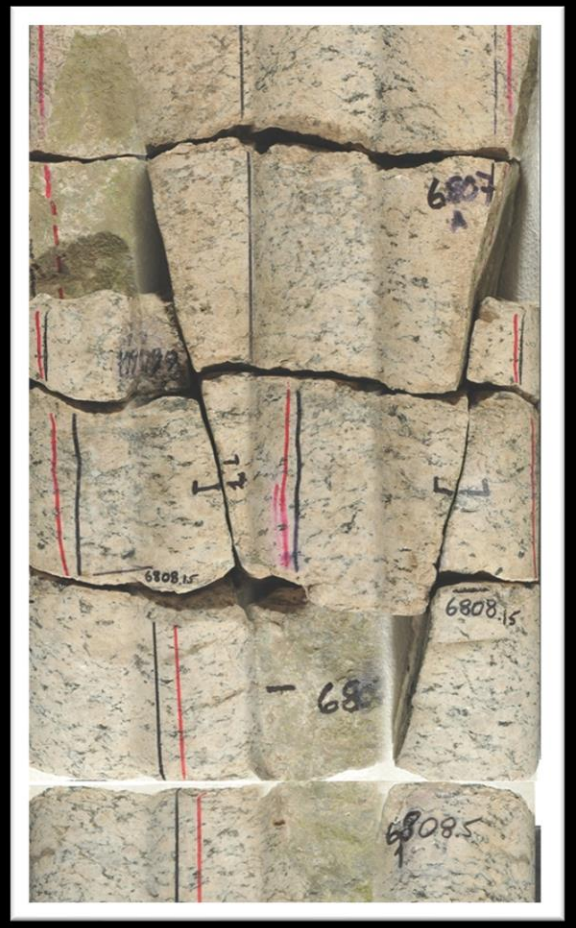
Raterman et al. 2018. Sampling a Stimulated Rock Volume : An Eagle Ford Example, SPE 191375, SPE Reservoir Evaluation & Engineering

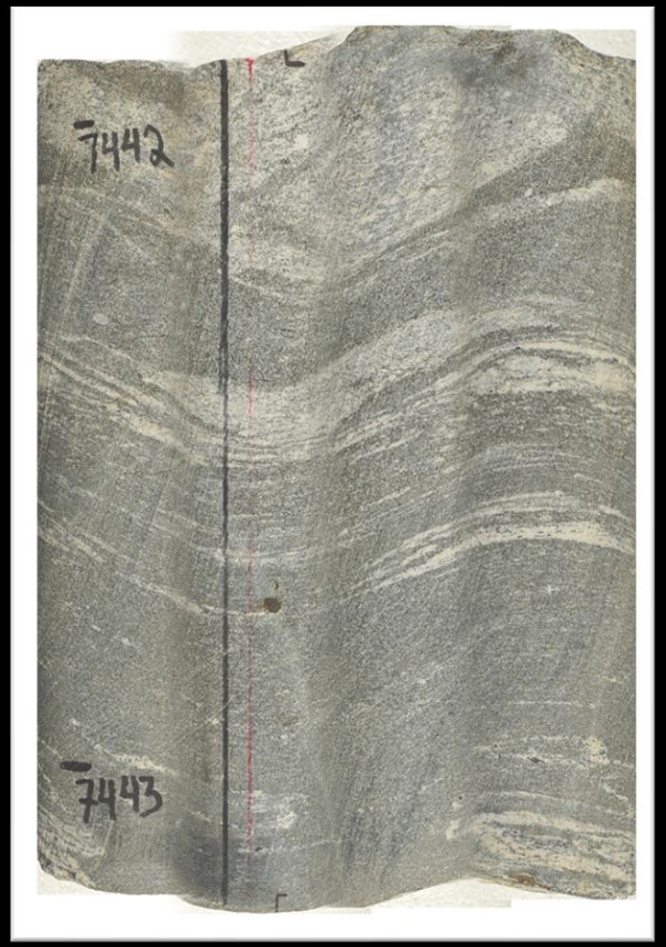
Why Problematic? Operational Limitations

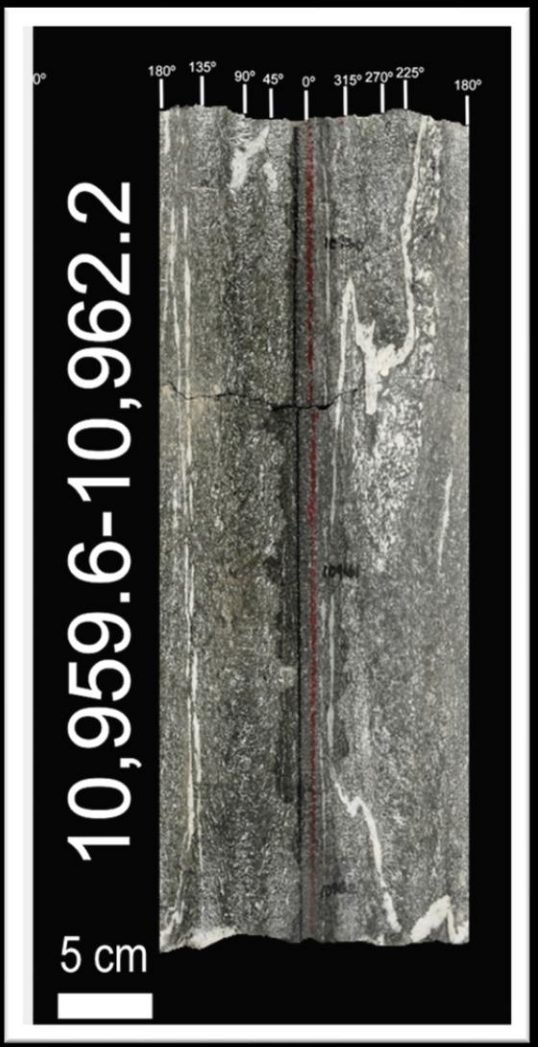
Zone 2 Packer Failure

"When packer pulled above the slips, the broken ring [Zone 3] fell into our hands"

Zone 3 Packer. Rings and slips caused significant drag

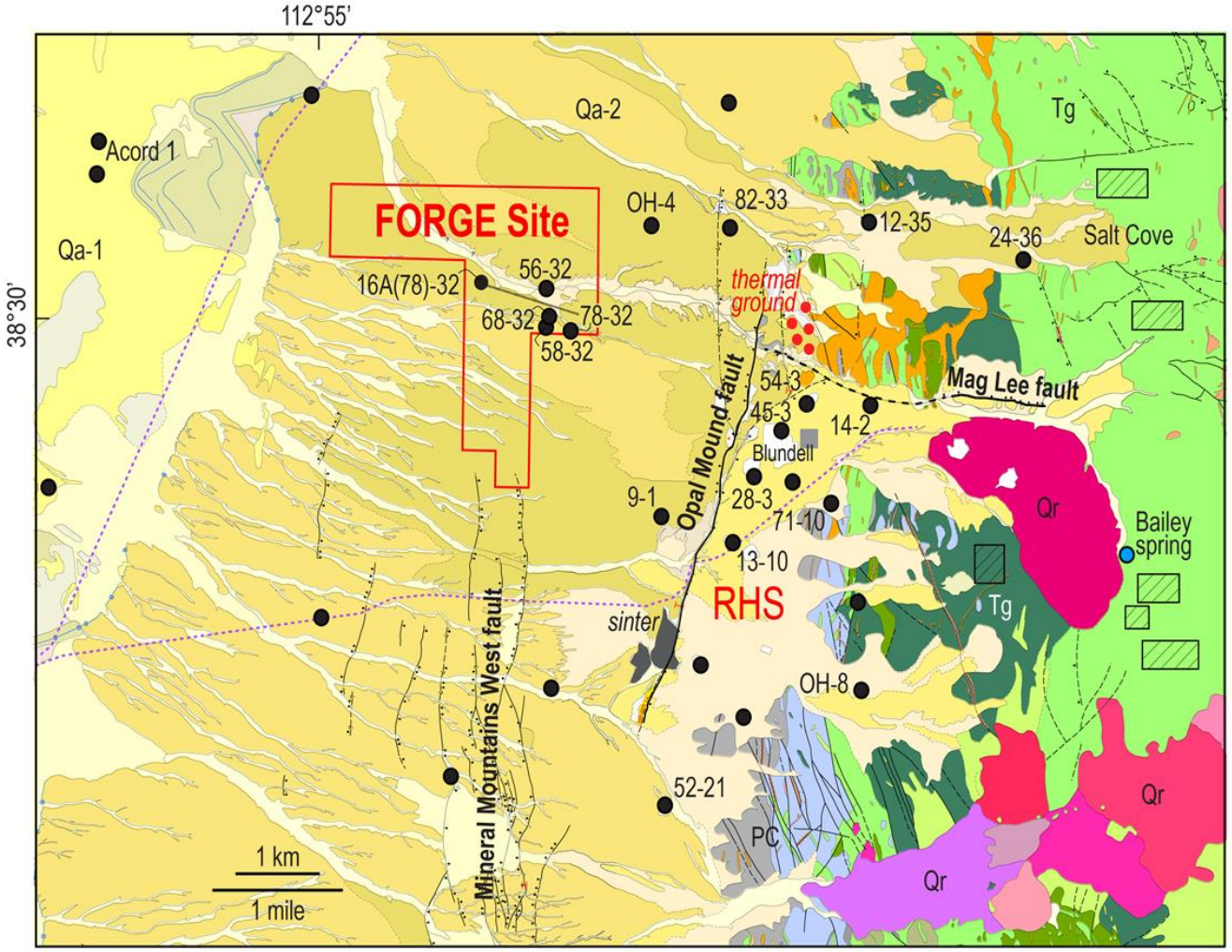




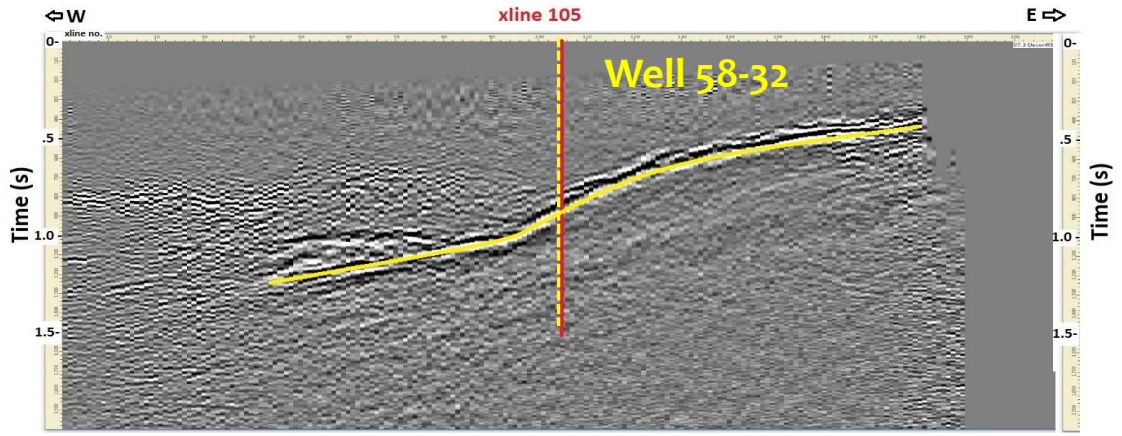


Reservoir Characterization

Geologic Setting

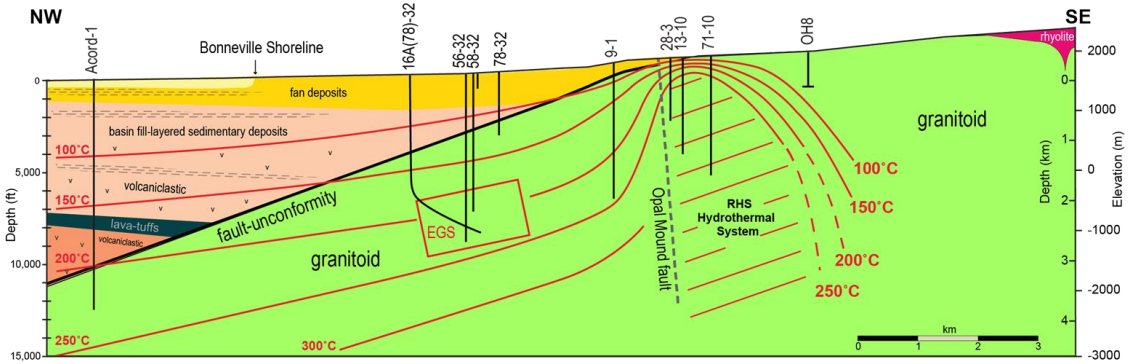


Kirby et al., 2018

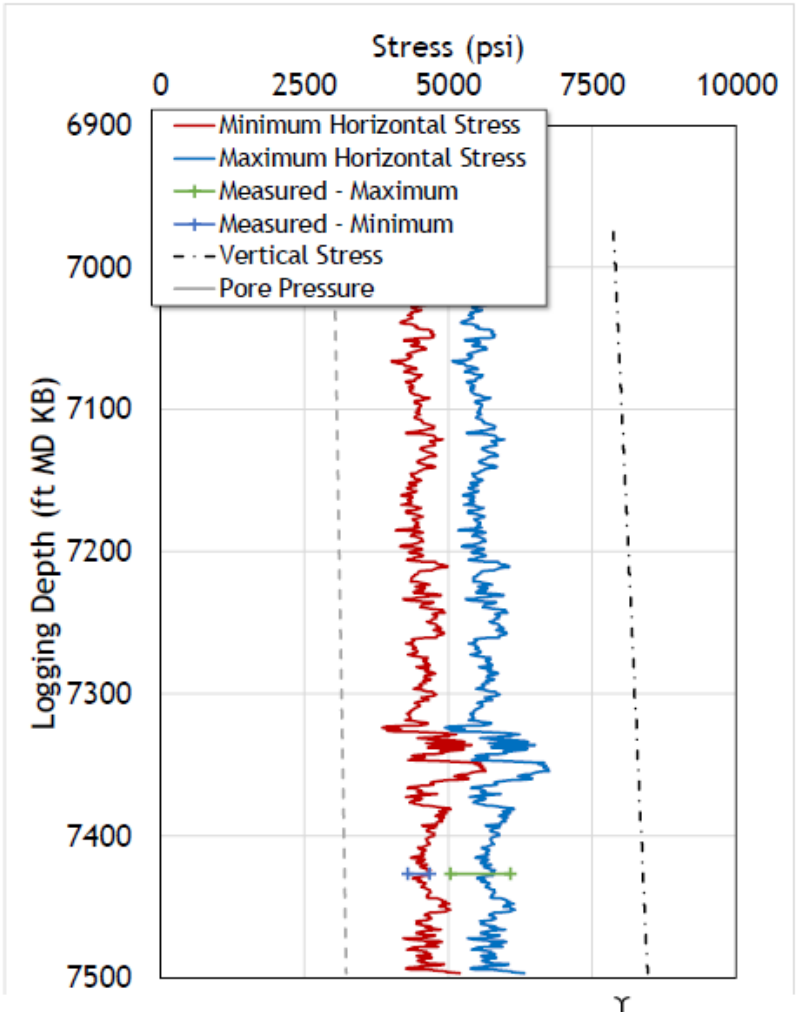


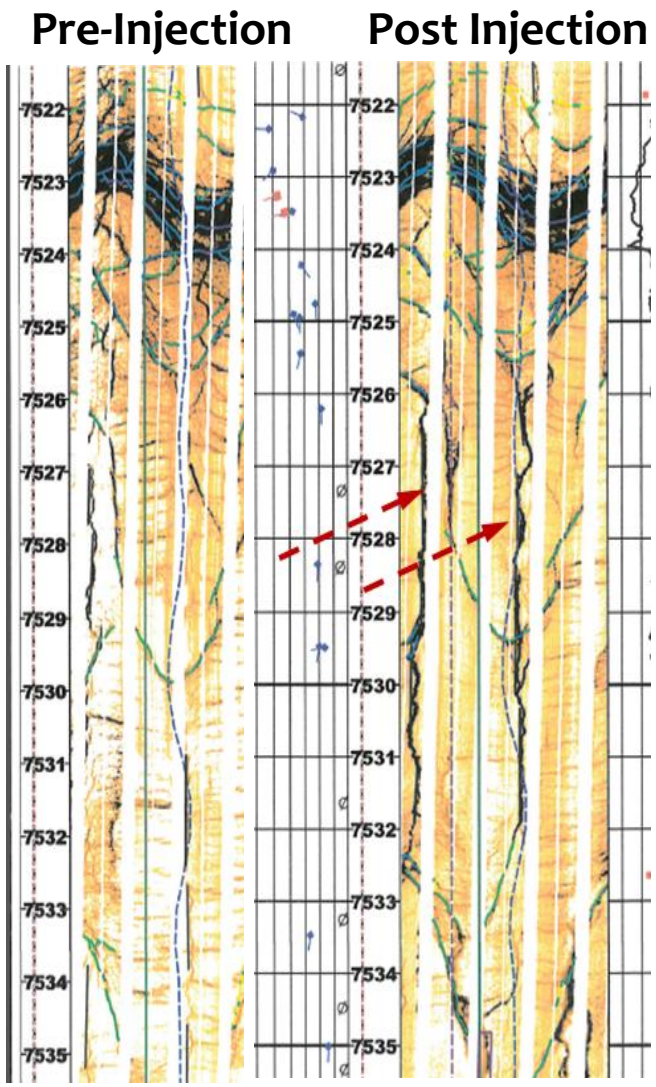
Basement top interpreted as exhumed footwall of rotated Basin and Range fault

No offset of basement top observed

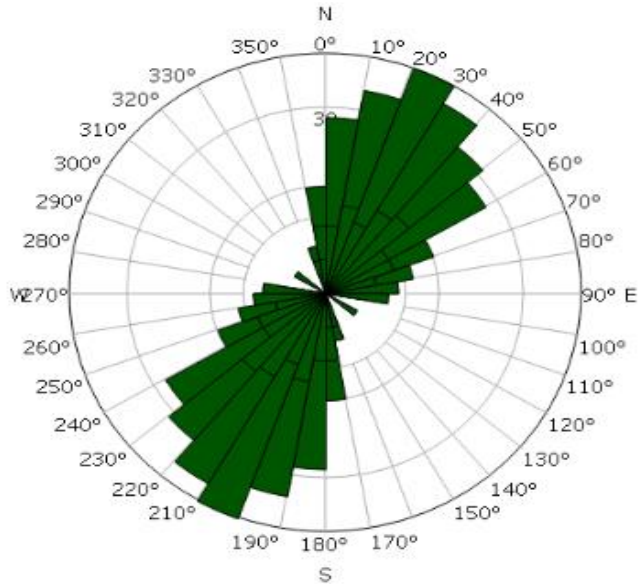


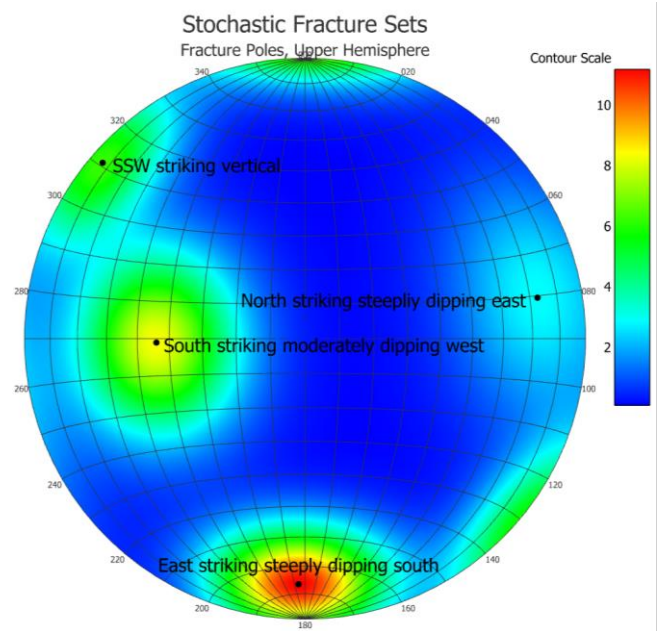
In Situ Stress and Fractures





Azimuth Induced Fractures: Well 58-32





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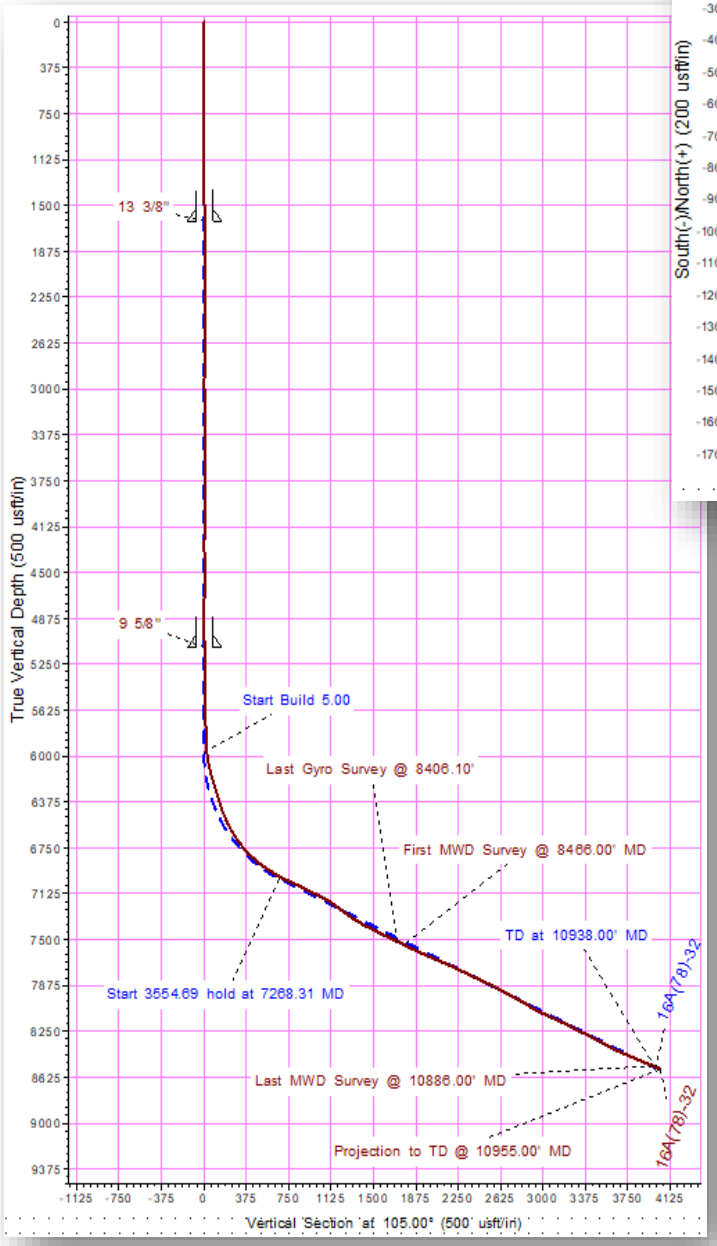
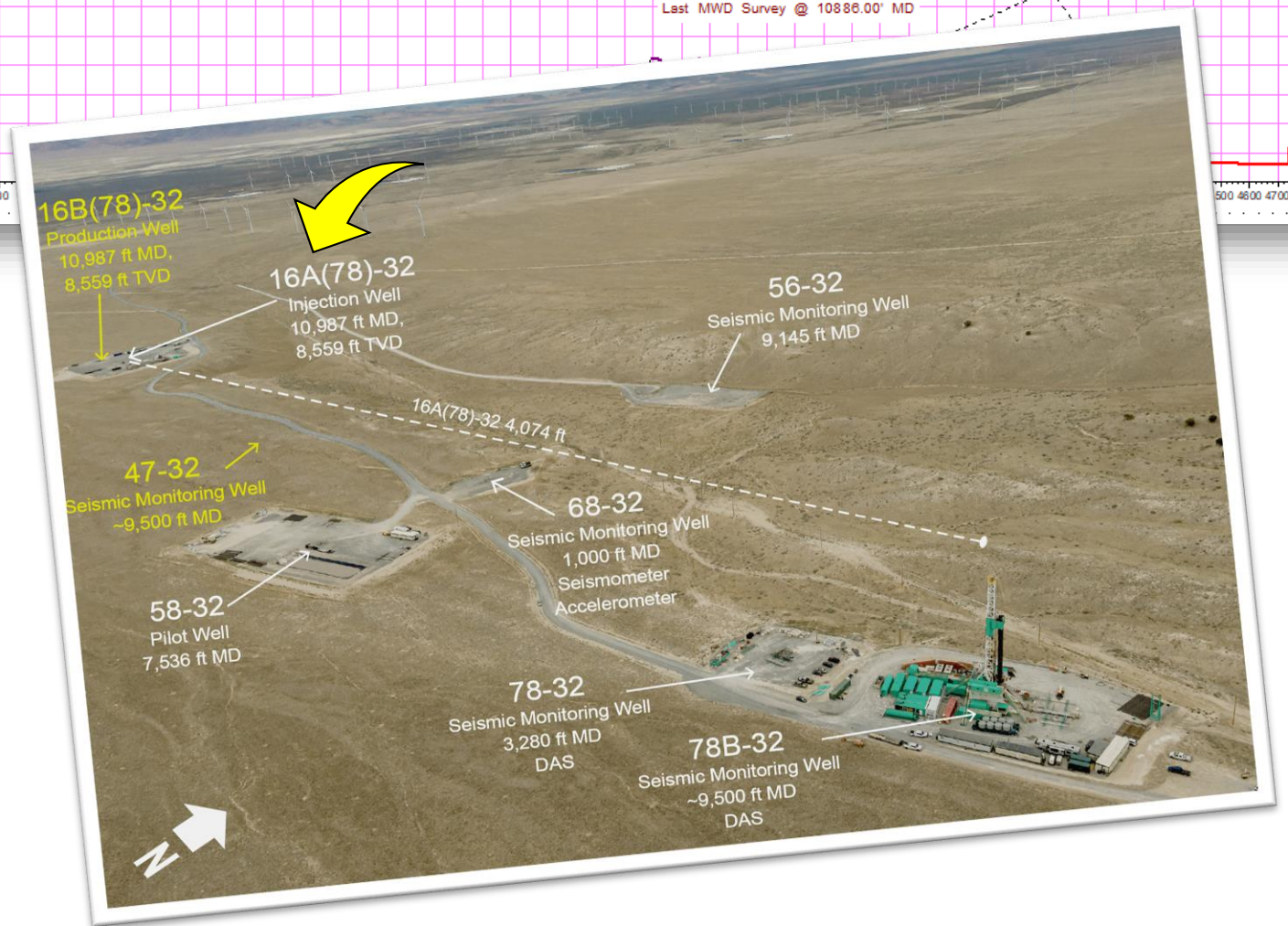
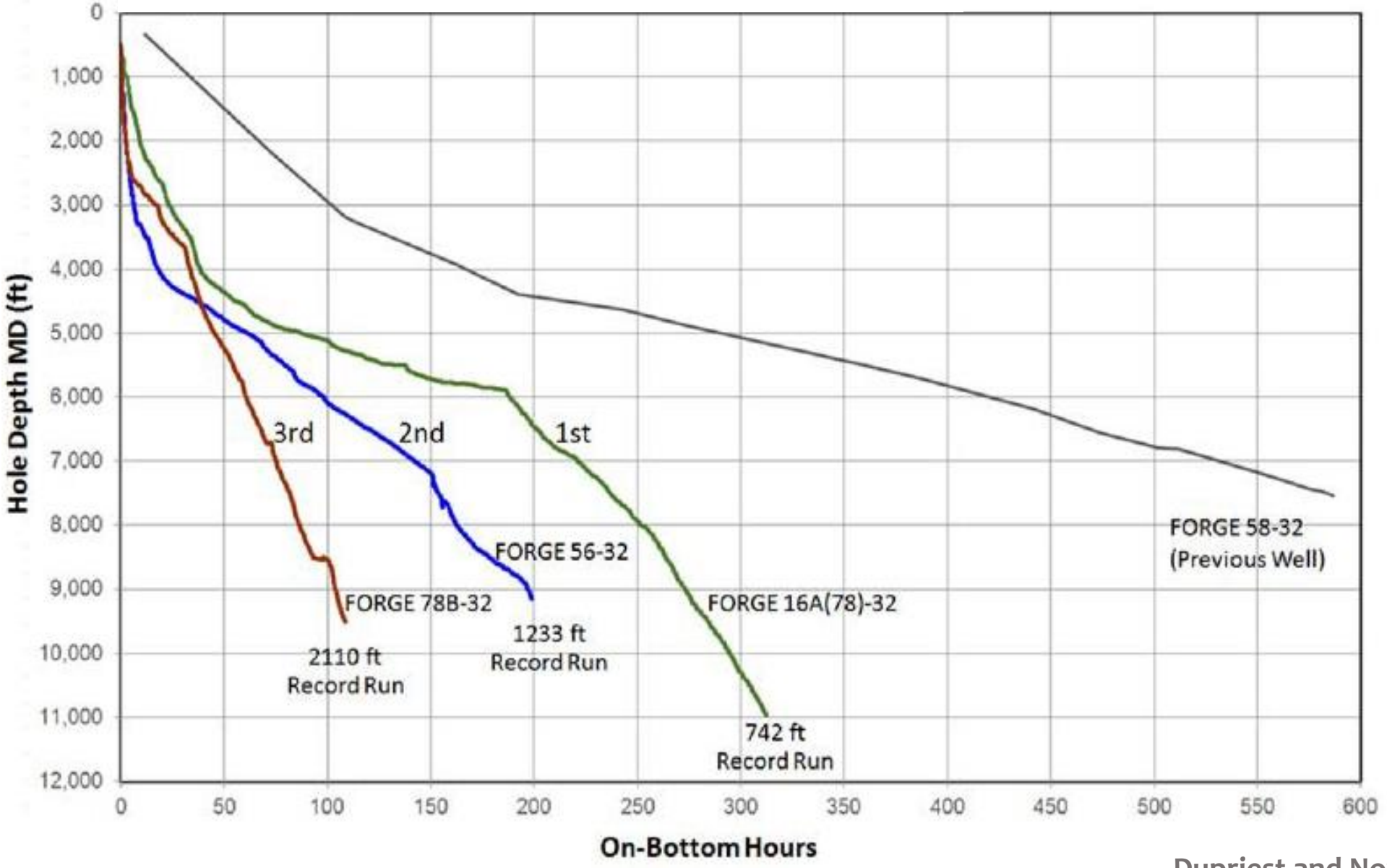
Well Construction

Well 16A(78)-32





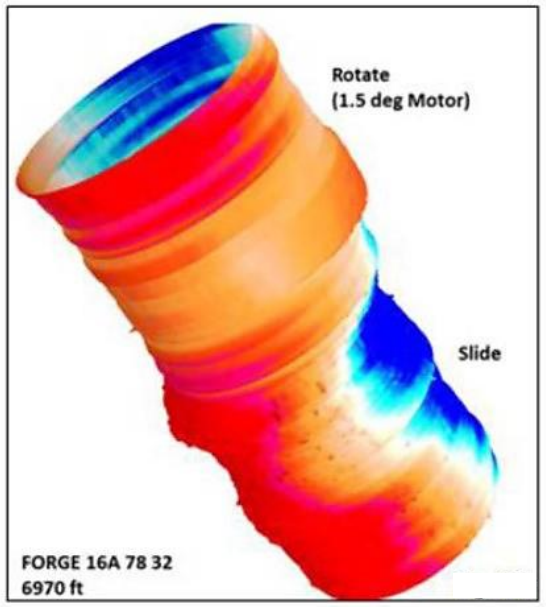
Improvements in Drilling

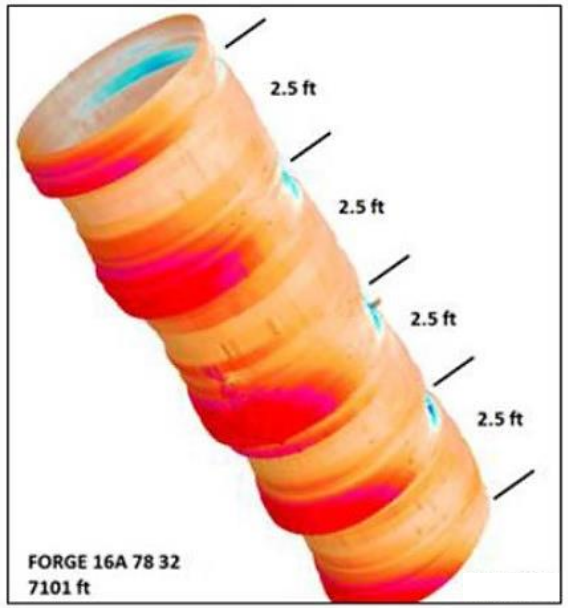


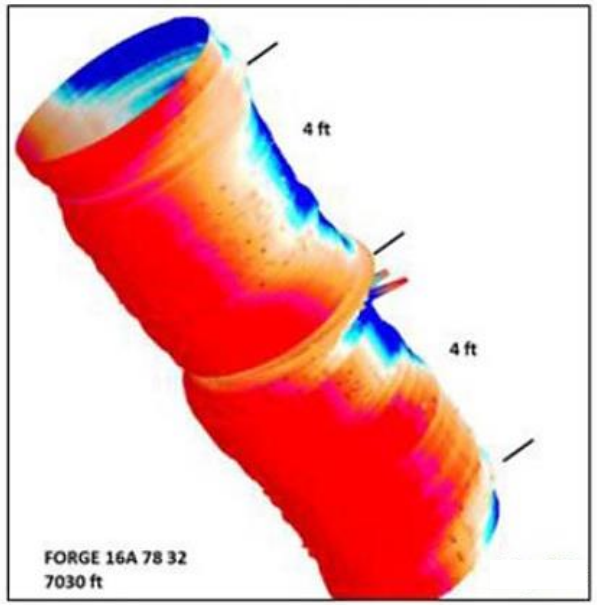
Dupriest and Noynaert, 2022

Yet to Learn?

Eliminate Drilling-Related Rugosity







Images Courtesy of Dupriest and Noynaert
IADC/SPE-208798-MS, 2022

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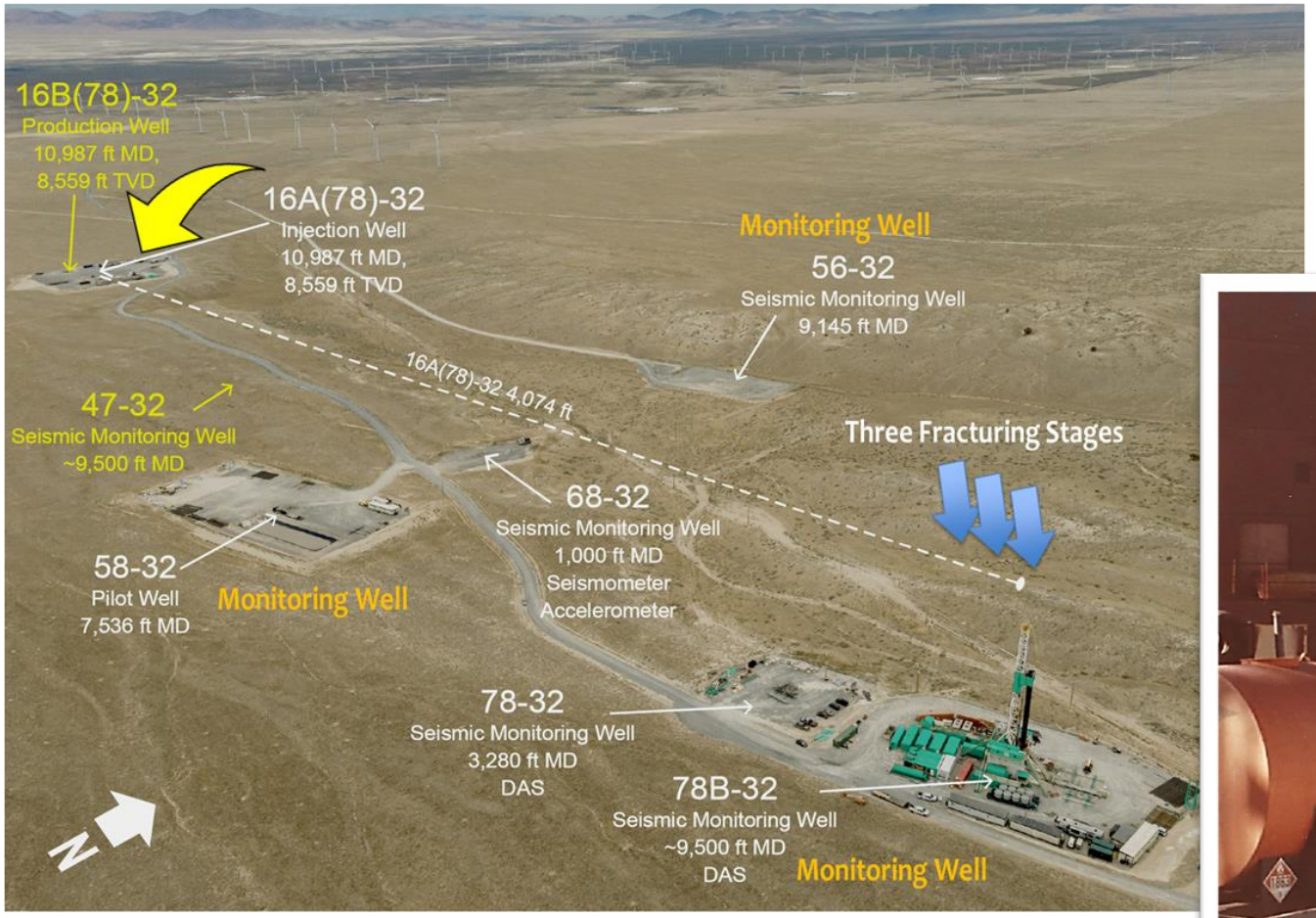
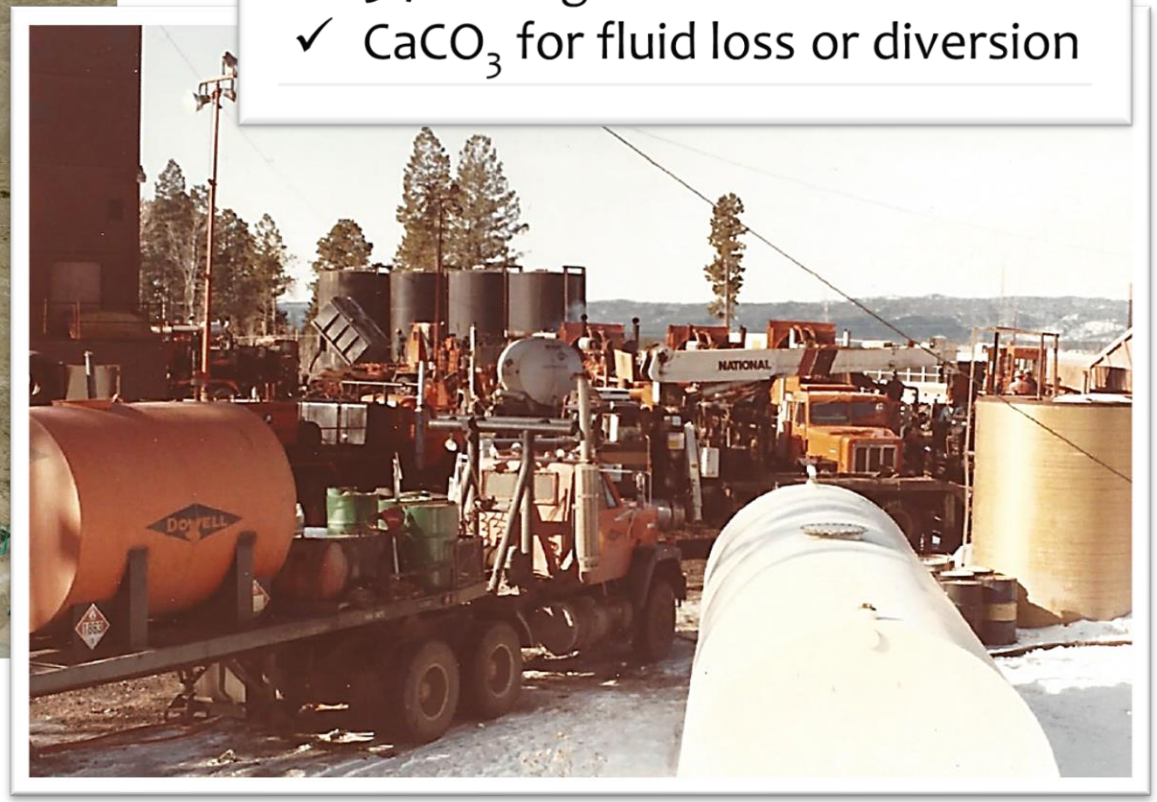
What Stimulation Was Used for 16A(78)-32?



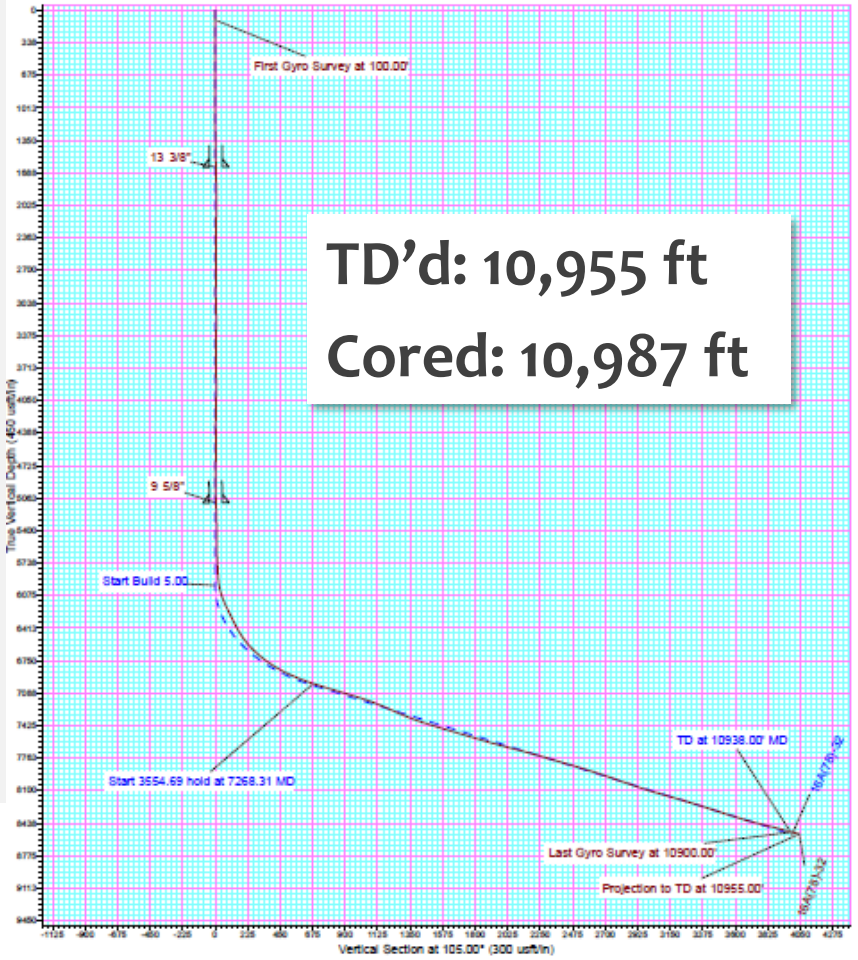
Fenton Hill, December 1983

- ✓ Slickwater
- ✓ 50 bpm
- ✓ 5.7×10^6 gal
- ✓ $CaCO_3$ for fluid loss or diversion



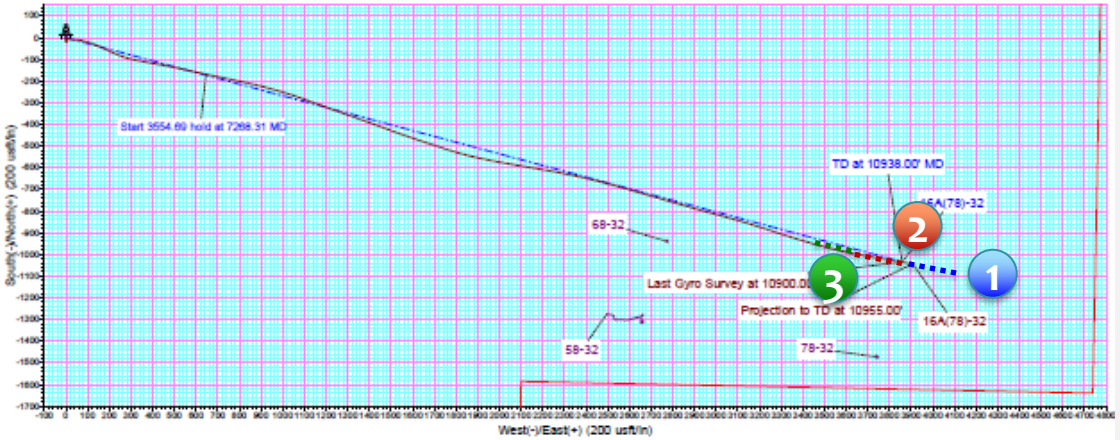
Treatments: Well 16A(78)-32

Project:	Forge
Site:	Beaver County, UT
Well:	16A(78)-32
GL:	GE + RKB (5414' + 30') @ 5444.00usft (Frontier 16)
SHL Northing:	13987645.20
SHL Easting:	1097896.92
Rig:	Frontier 16
Plan:	Design: 16A(78)-32 plan 1



TD'd: 10,955 ft

Cored: 10,987 ft

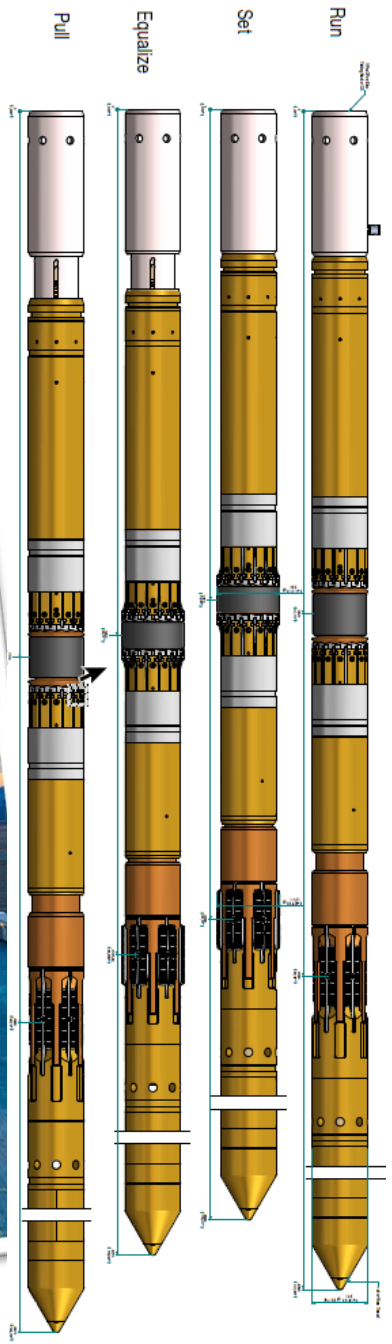


Stage 1: Openhole portion of the well below ~10,787 ft – **Slickwater, Tagged**

Stage 2: Cased and perforated – above 7-inch shoe – **Slickwater, Tagged**

Stage 3: Move slightly uphole from Stage 2 – **Crosslinked, Tagged**

Treatments: Well 16A(78)-32



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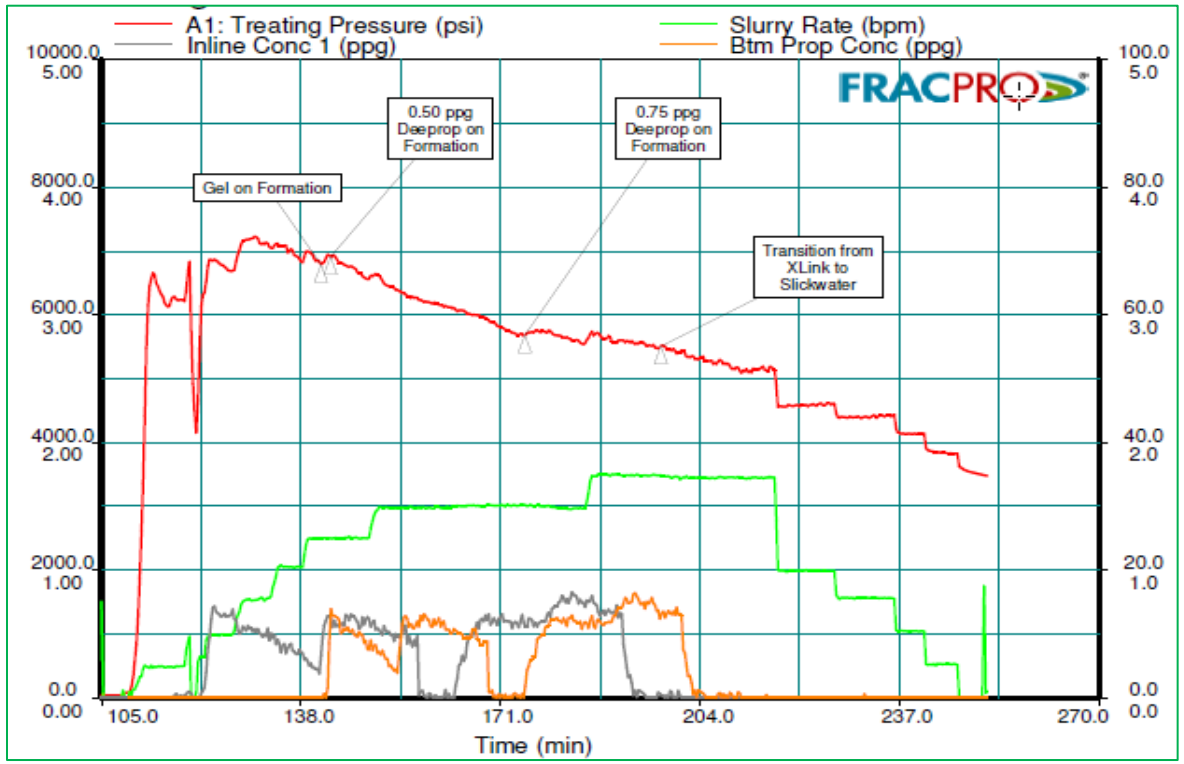
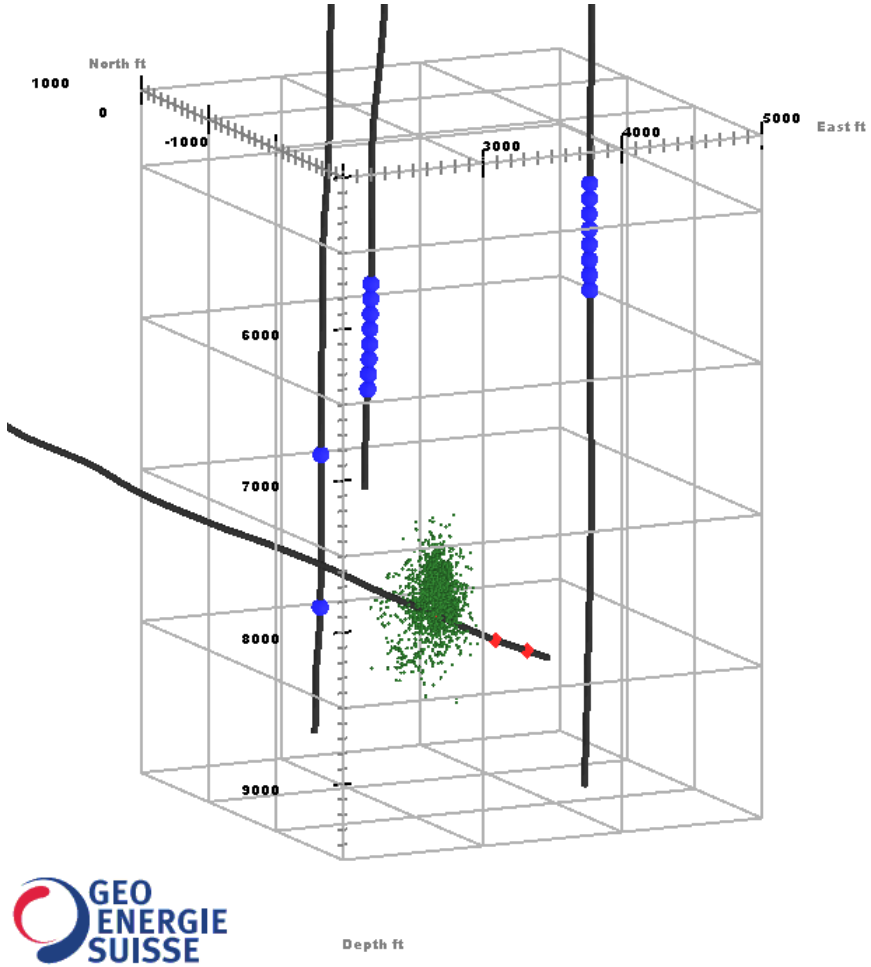
Stage 3





Some results in this study were also obtained under the support of the Haute-Sorne EGS project (Switzerland) that benefits from an exploration subsidy of the Swiss Federal Office of Energy (contract number MF-021-GEO-ERK

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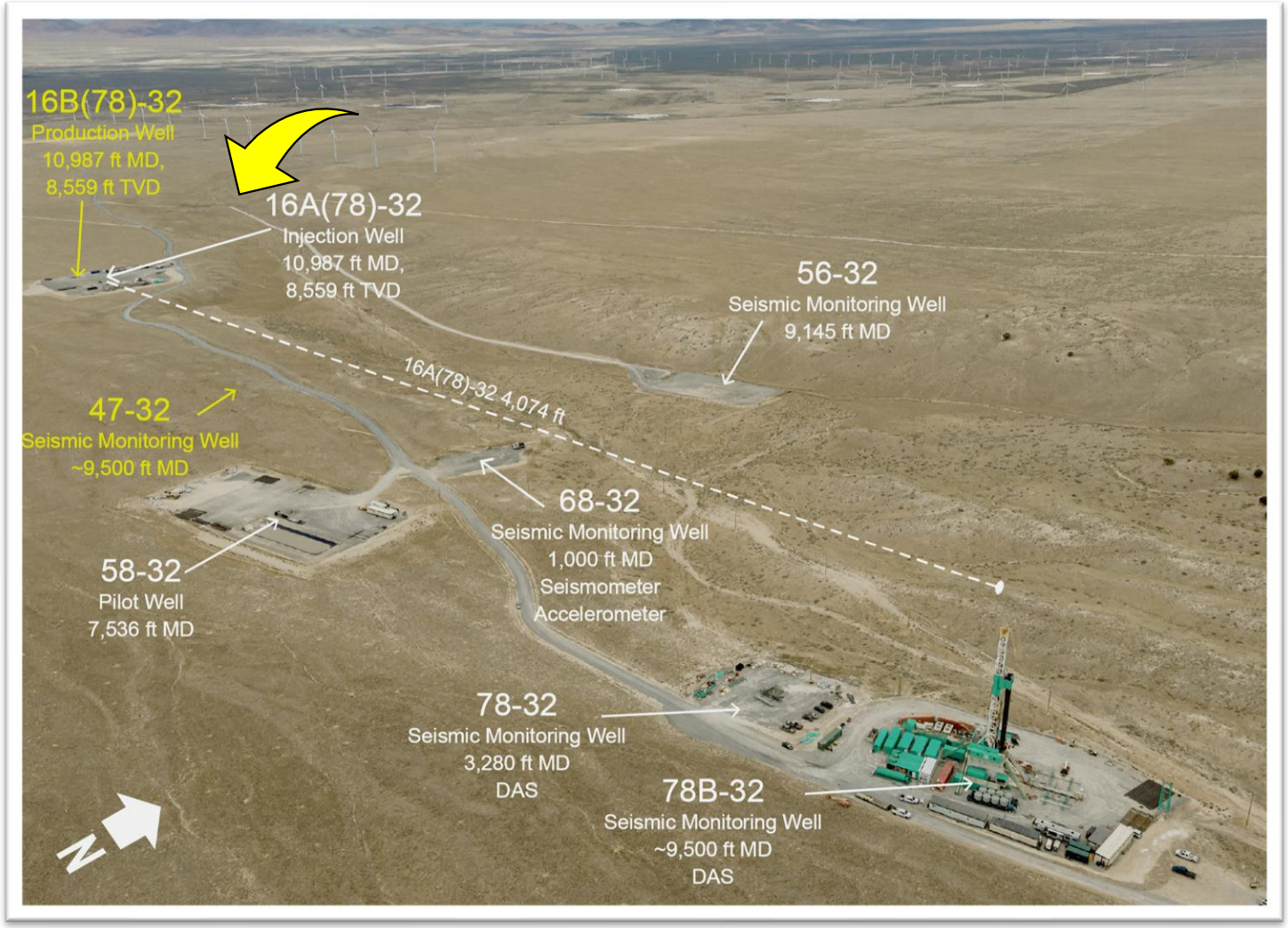
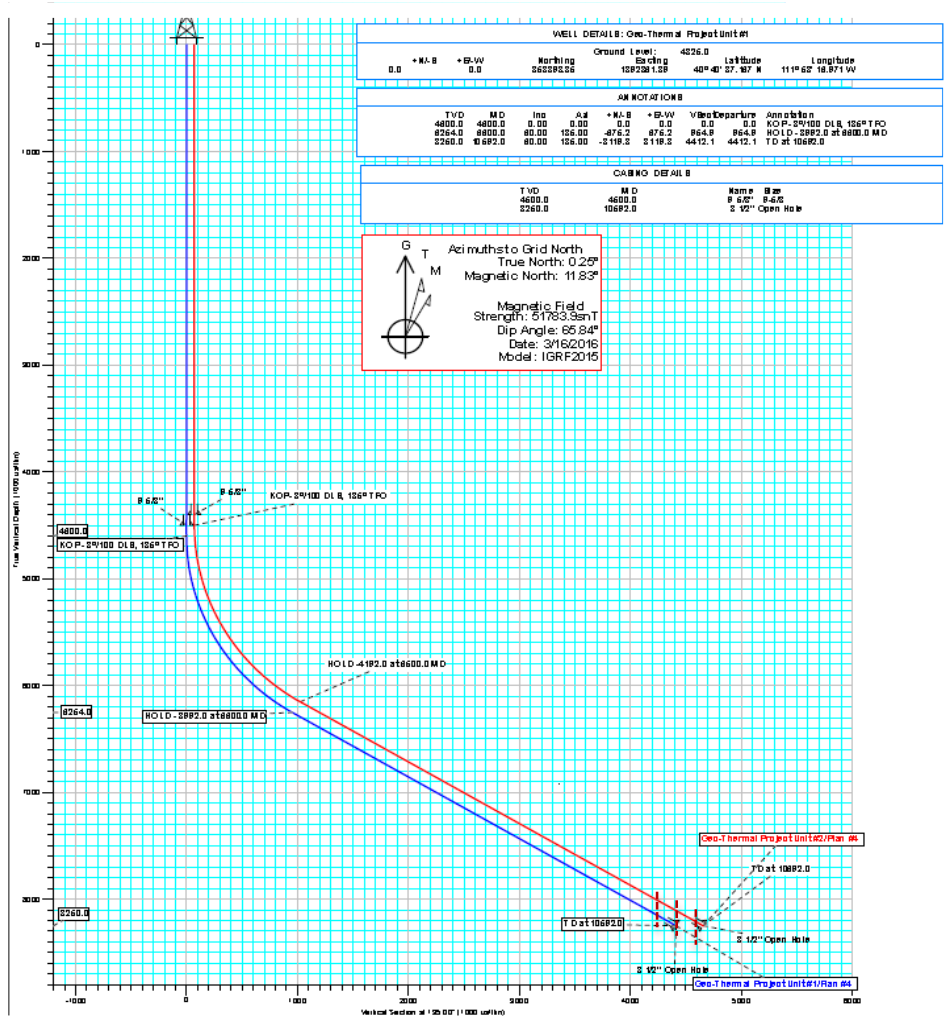
Operational Considerations

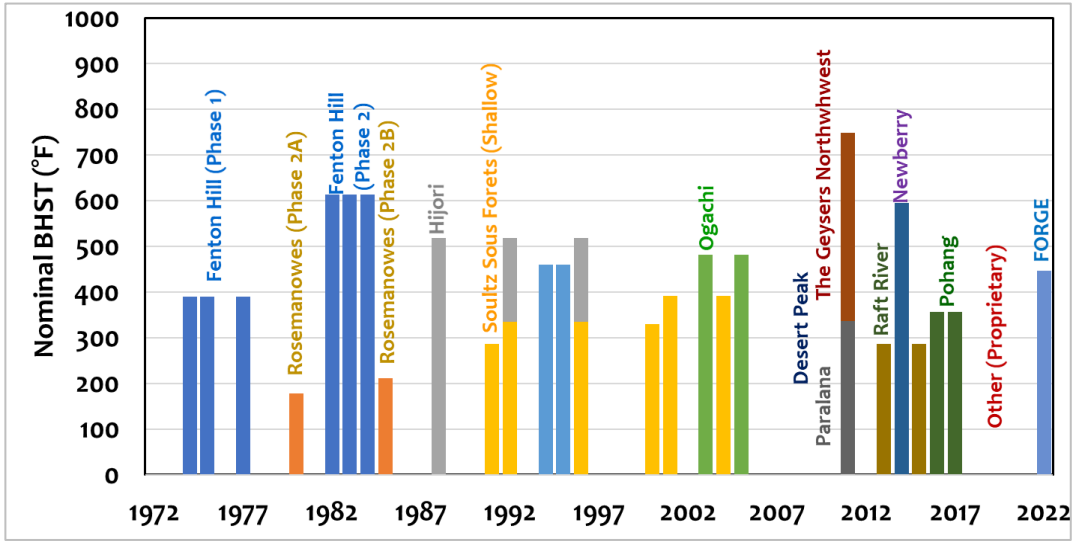
Interactions with Well 16B(78)-32

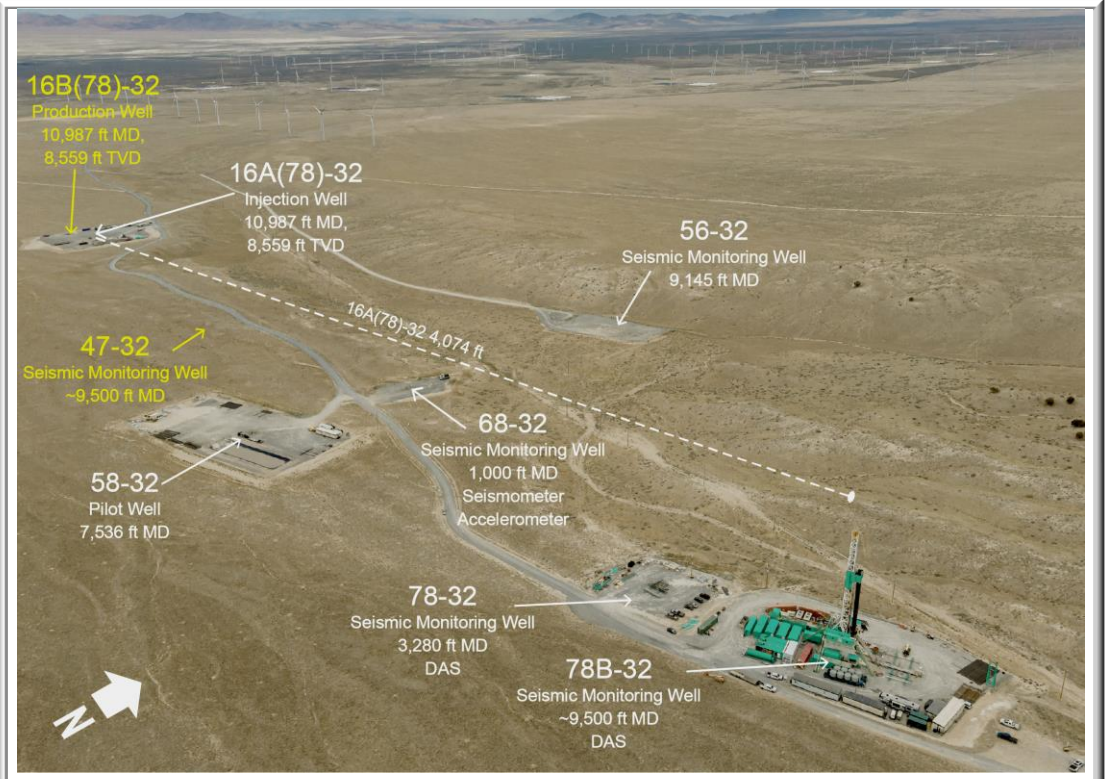




Connectivity – Conductivity – Conformance - Circulation

From Fenton Hill – to – FORGE (Frontier Observatory for Research in Geothermal Energy)





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