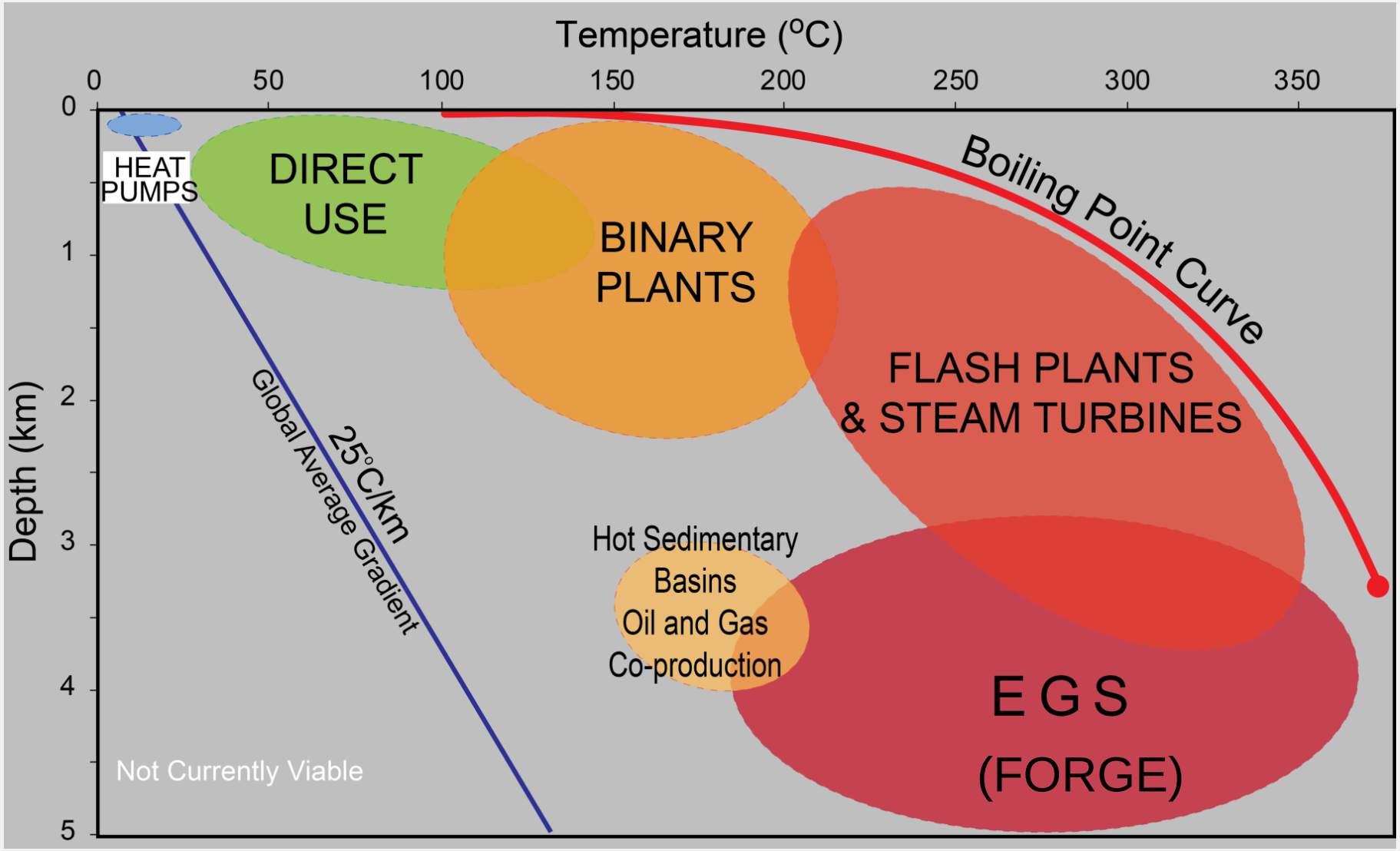
Utah FORGE: A Stepping Stone to EGS Development

Joseph Moore on behalf of the Utah FORGE Team
Utah FORGE PI

Geothermal Systems

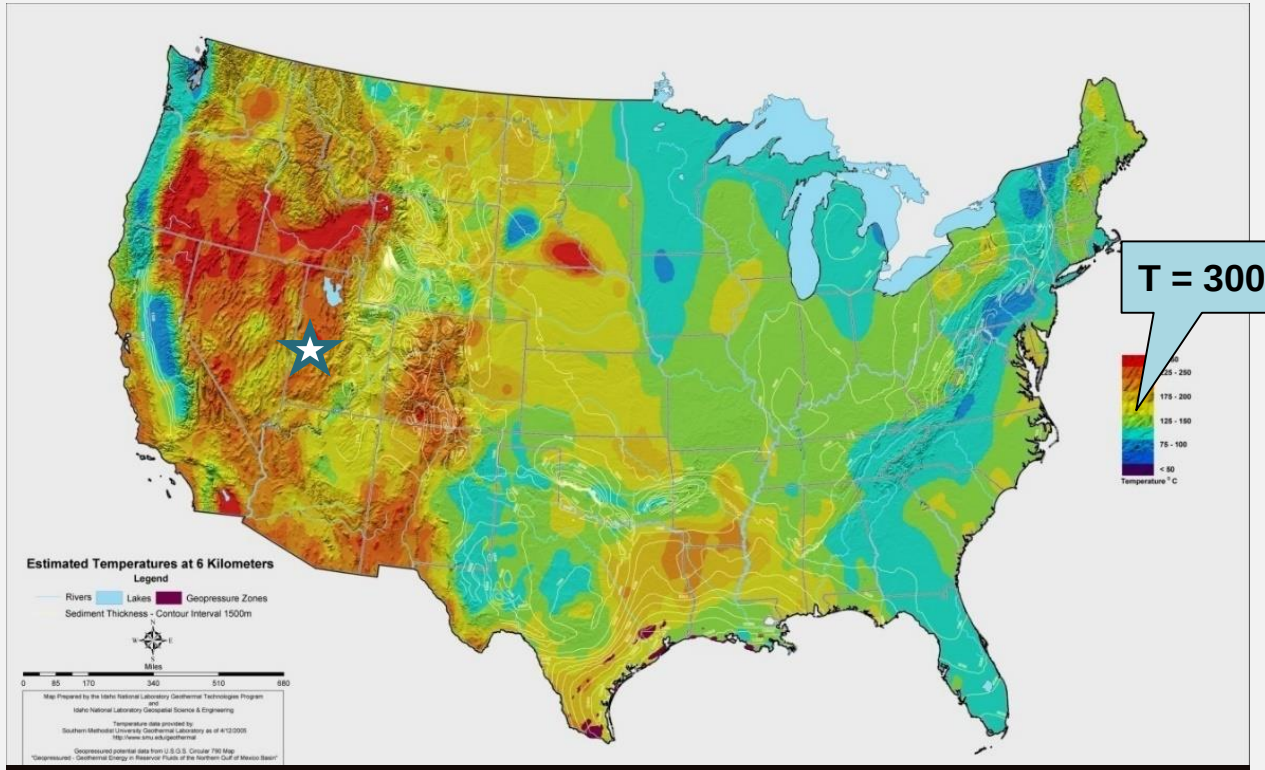


Moore and Simmons, 2013

US Enhanced Geothermal System Resource Base

- The US currently produces ~3700 MWe. Continued development of natural hot spring systems cannot meet DOE's programmatic goals of:
  - 90,000 MWe by 2050
  - Reducing cost of EGS by 90% to $45 per MW hour
- Requires the creation of geothermal reservoirs where none exist naturally.
- **Tapping even 2% of the energy between 2 to 4 miles, would provide more than 2000 times the yearly US energy needs (Tester and others, 2006).**

The heat beneath our feet is inexhaustible



Temperatures at ~4 miles

Data from SMU; from Tester and others (2006)

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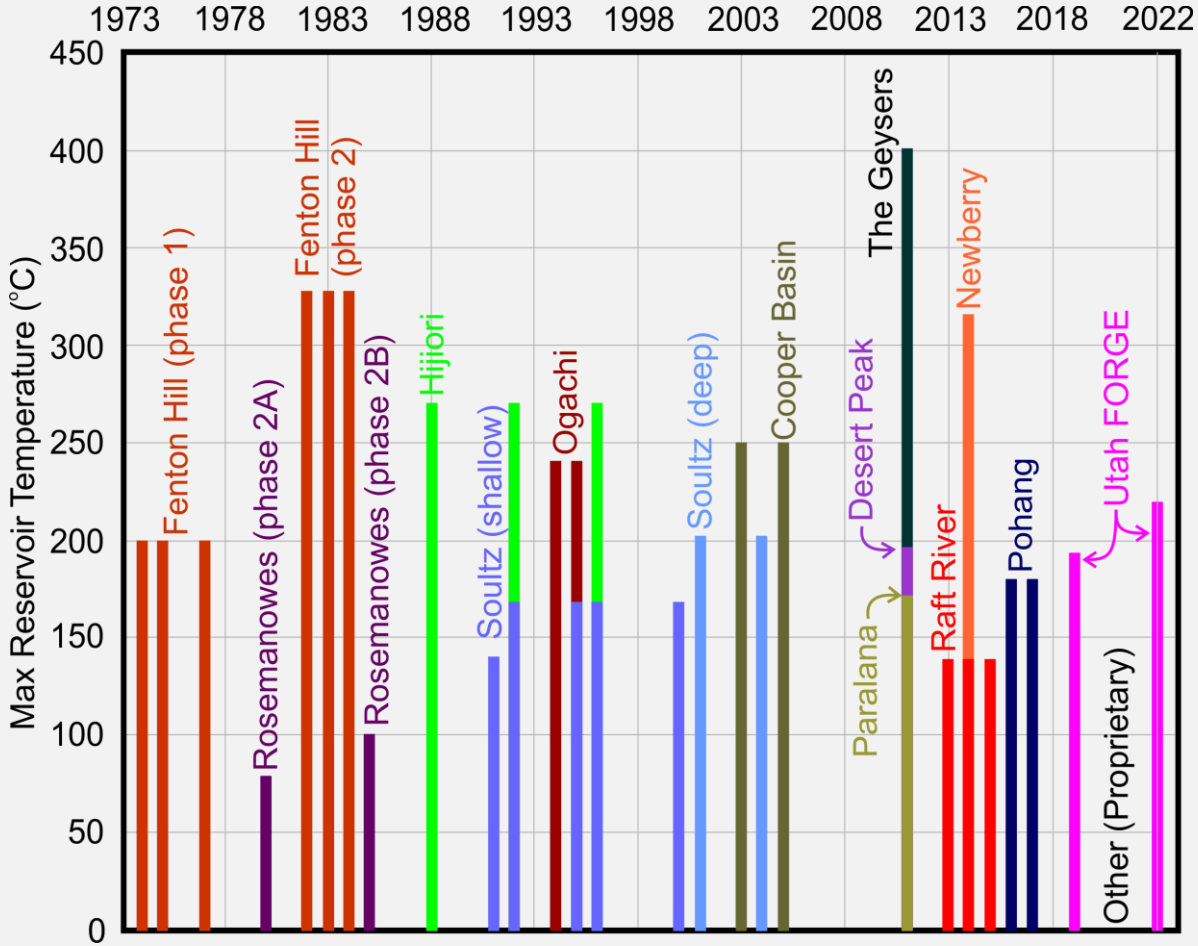
Current State of Enhanced Geothermal System Development

- Over a dozen EGS projects have been conducted worldwide since the 1970s
- No EGS systems >few MWe developed by hydraulic stimulation
  - Subeconomic flow rates (<40 L/s)
  - Low heat recoveries (<few percent)
- Unacceptable levels of induced seismicity
- Flow from a few natural fracture zones dominate
- Commercial projects underway



Hydraulically Stimulated Sites

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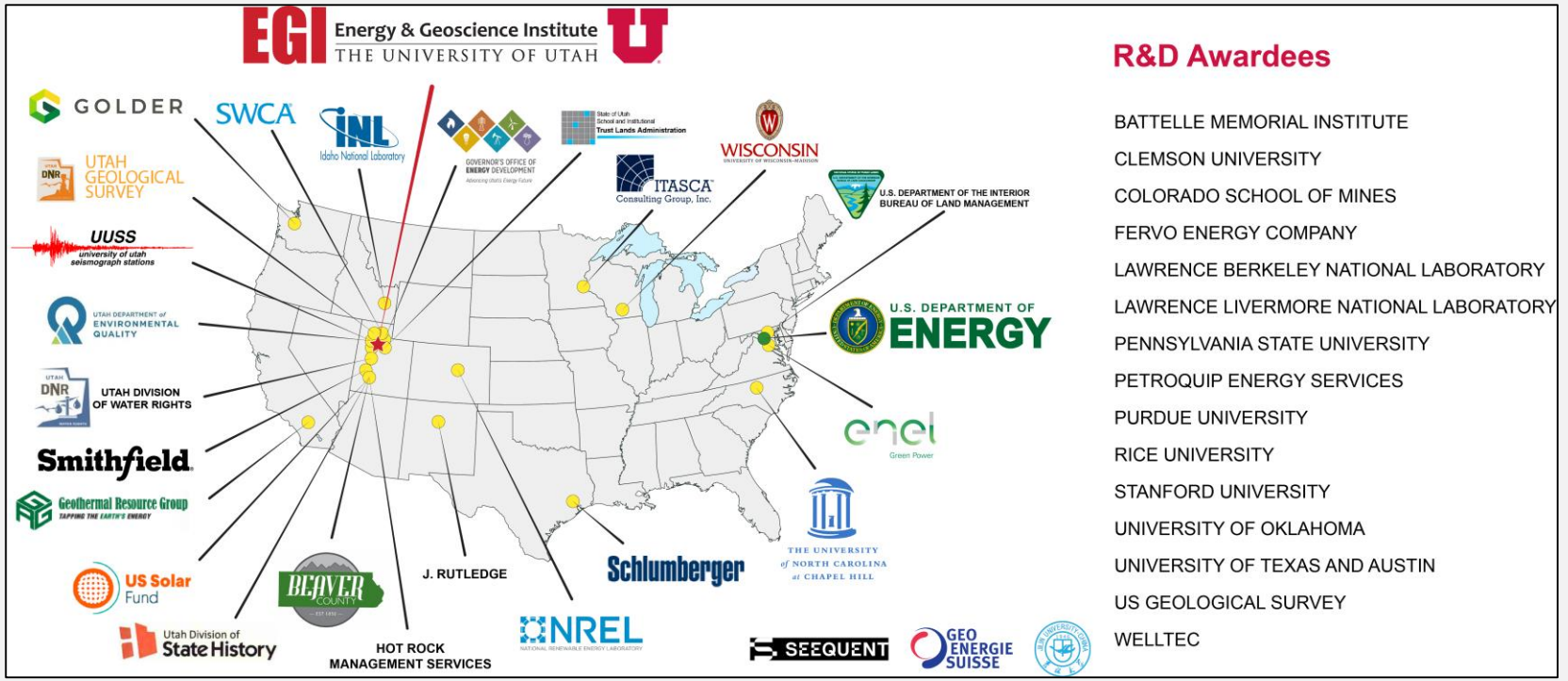
Challenges

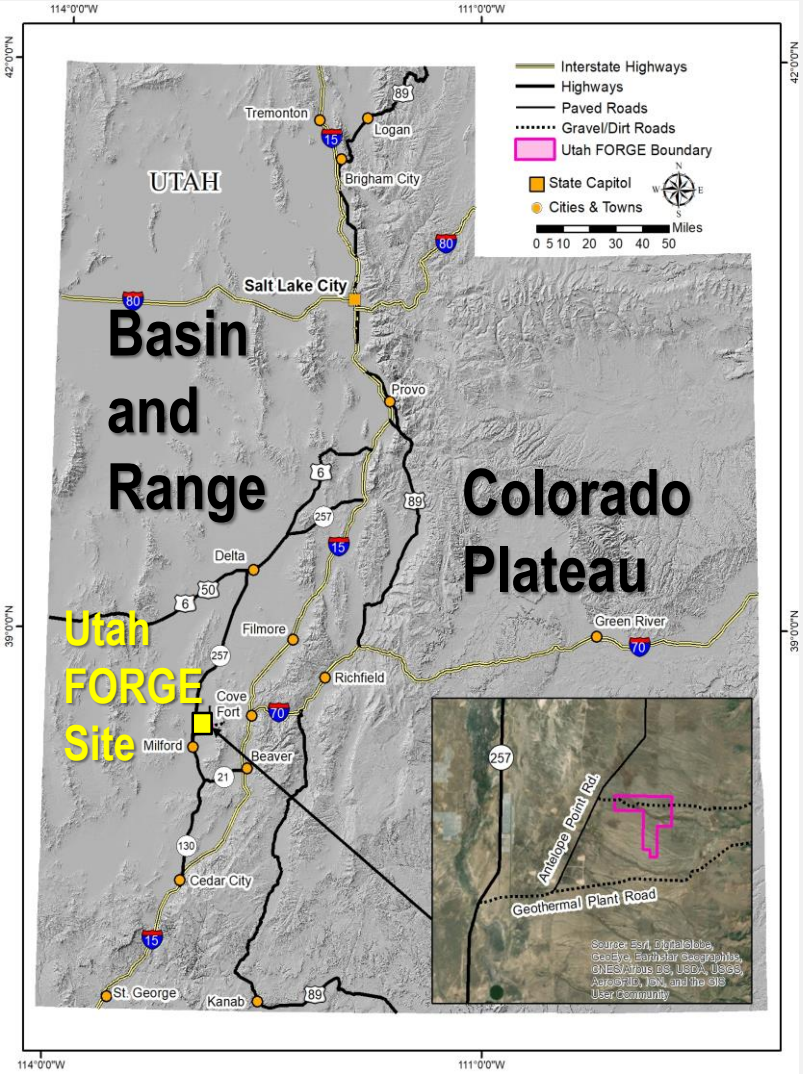
- Create **interconnected fracture networks** for long term (>15 years) injection and heat extraction with minimal temperature declines
- Develop sufficient permeability to achieve **economic flow rates** (>40 L/s)
- **Controlling fluid flow** at high temperature (plugs, packers, sliding sleeves)
- **Mitigate** sensible induced **seismic events**
- Develop a **roadmap** for creating, monitoring and sustaining EGS reservoirs

Utah FORGE Partners and R&D Recipients



R&D Awardees

BATTELLE MEMORIAL INSTITUTE
CLEMSON UNIVERSITY
COLORADO SCHOOL OF MINES
FERVO ENERGY COMPANY
LAWRENCE BERKELEY NATIONAL LABORATORY
LAWRENCE LIVERMORE NATIONAL LABORATORY
PENNSYLVANIA STATE UNIVERSITY
PETROQUIP ENERGY SERVICES
PURDUE UNIVERSITY
RICE UNIVERSITY
STANFORD UNIVERSITY
UNIVERSITY OF OKLAHOMA
UNIVERSITY OF TEXAS AND AUSTIN
US GEOLOGICAL SURVEY
WELLTEC



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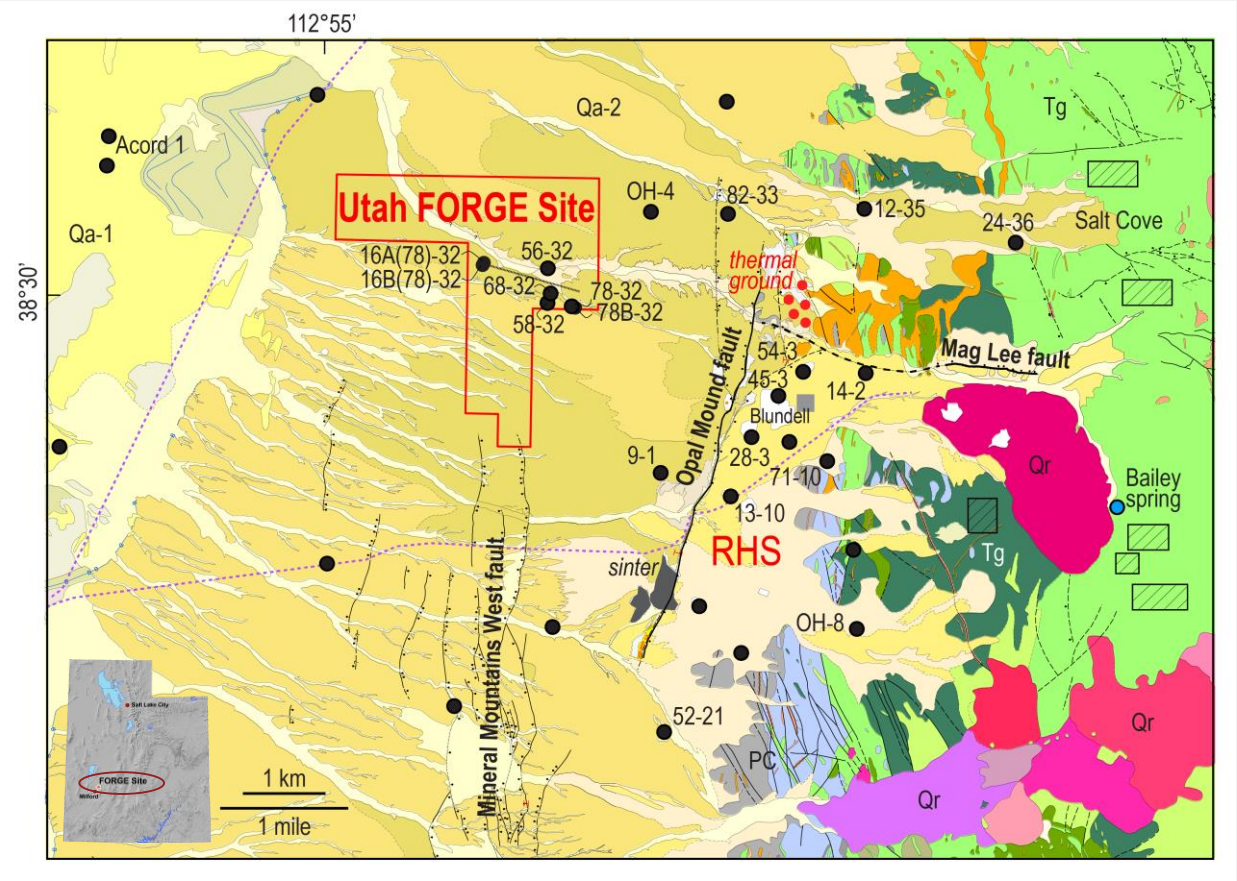
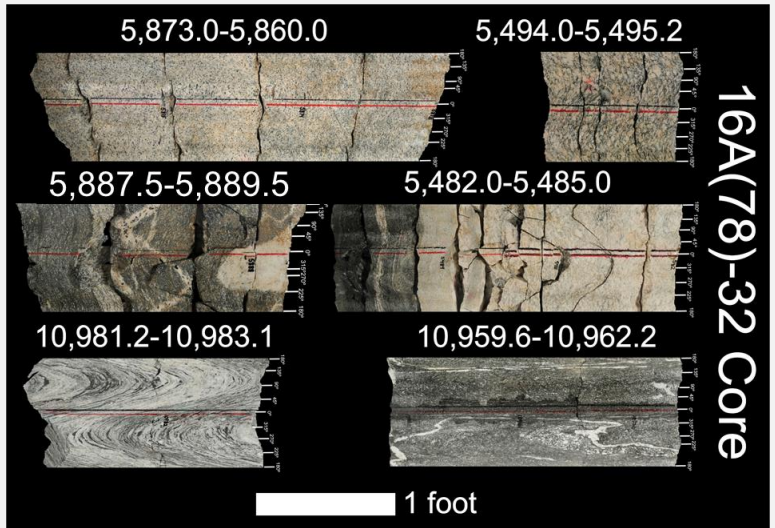
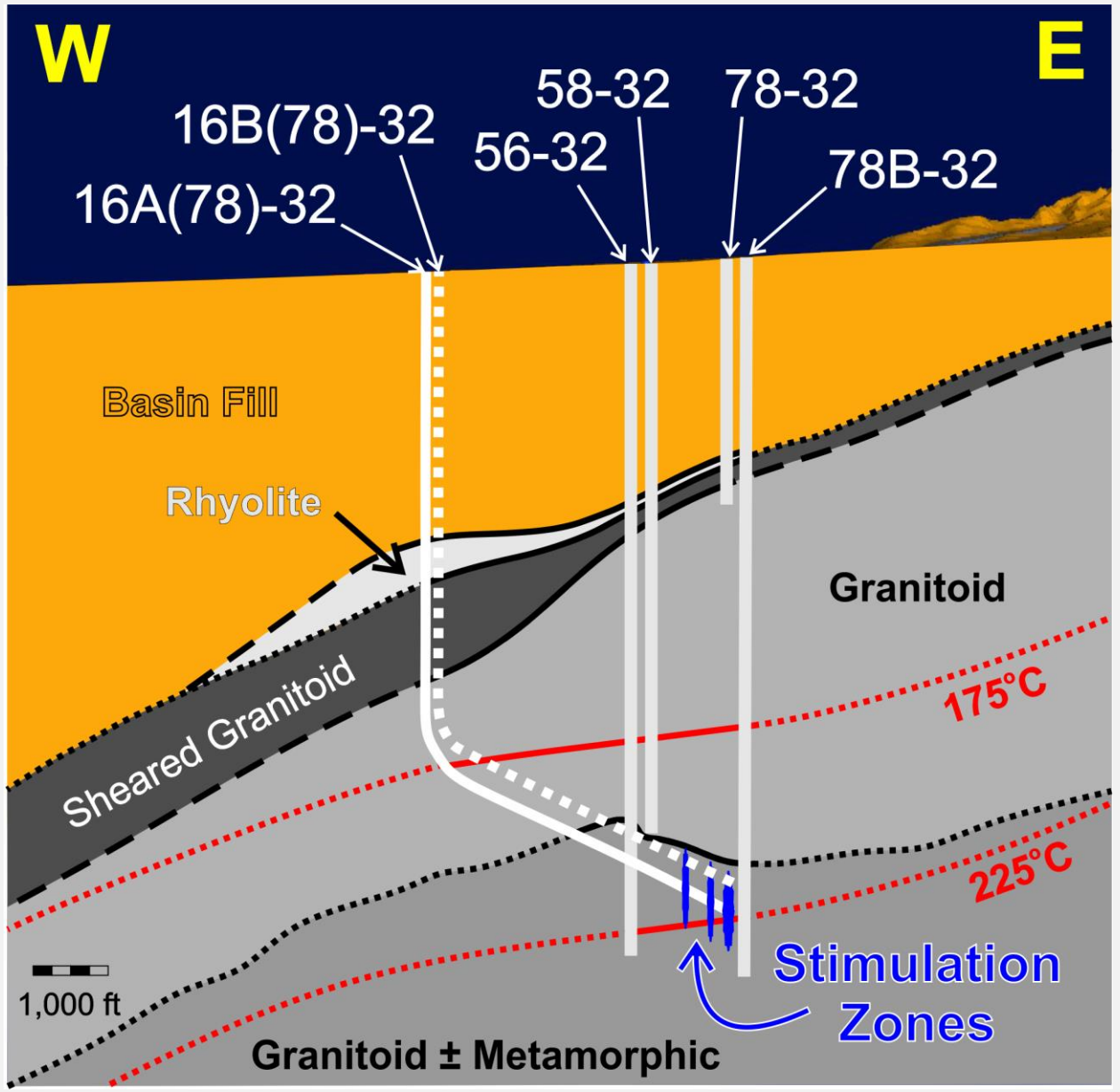
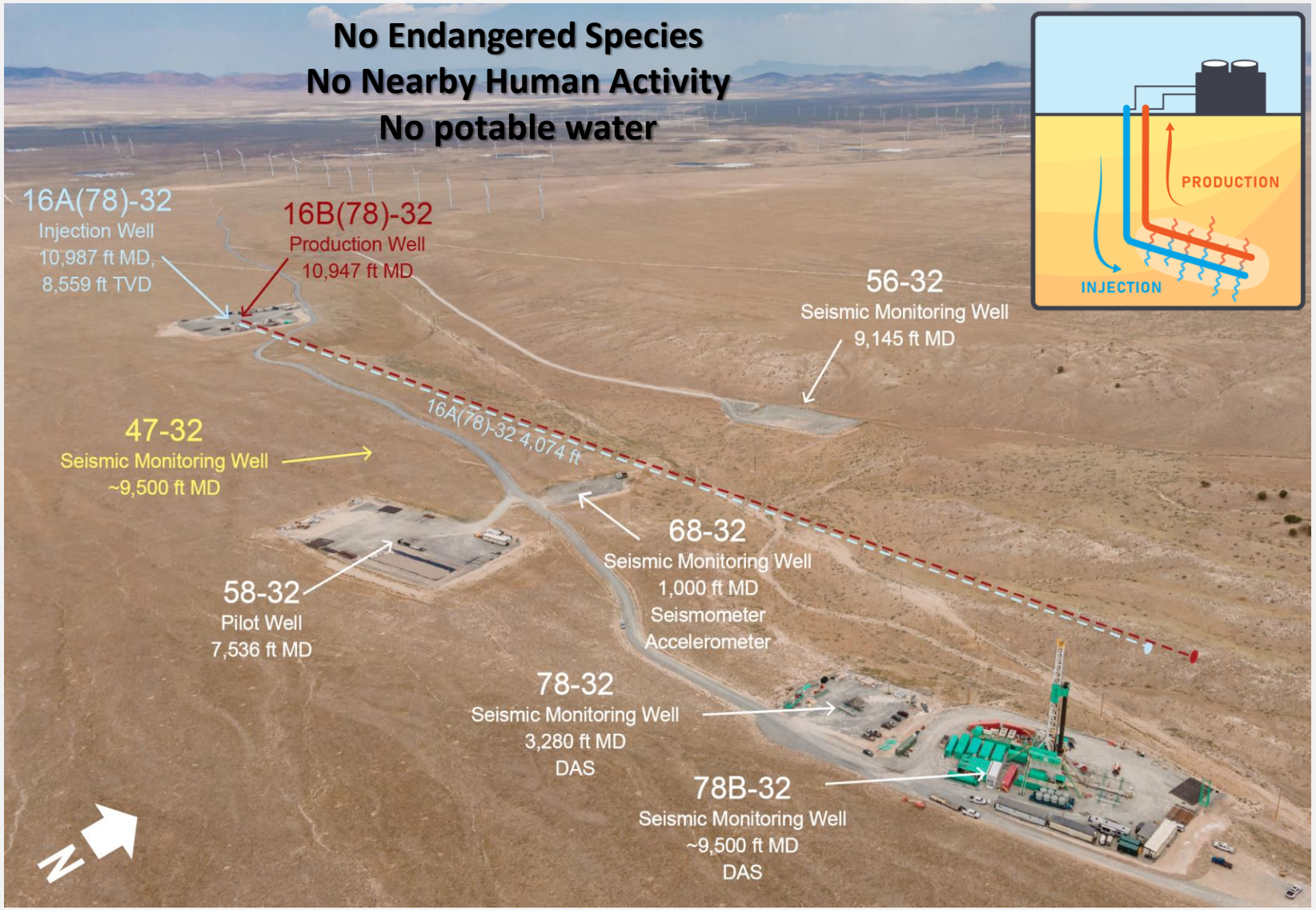
Geologic Setting

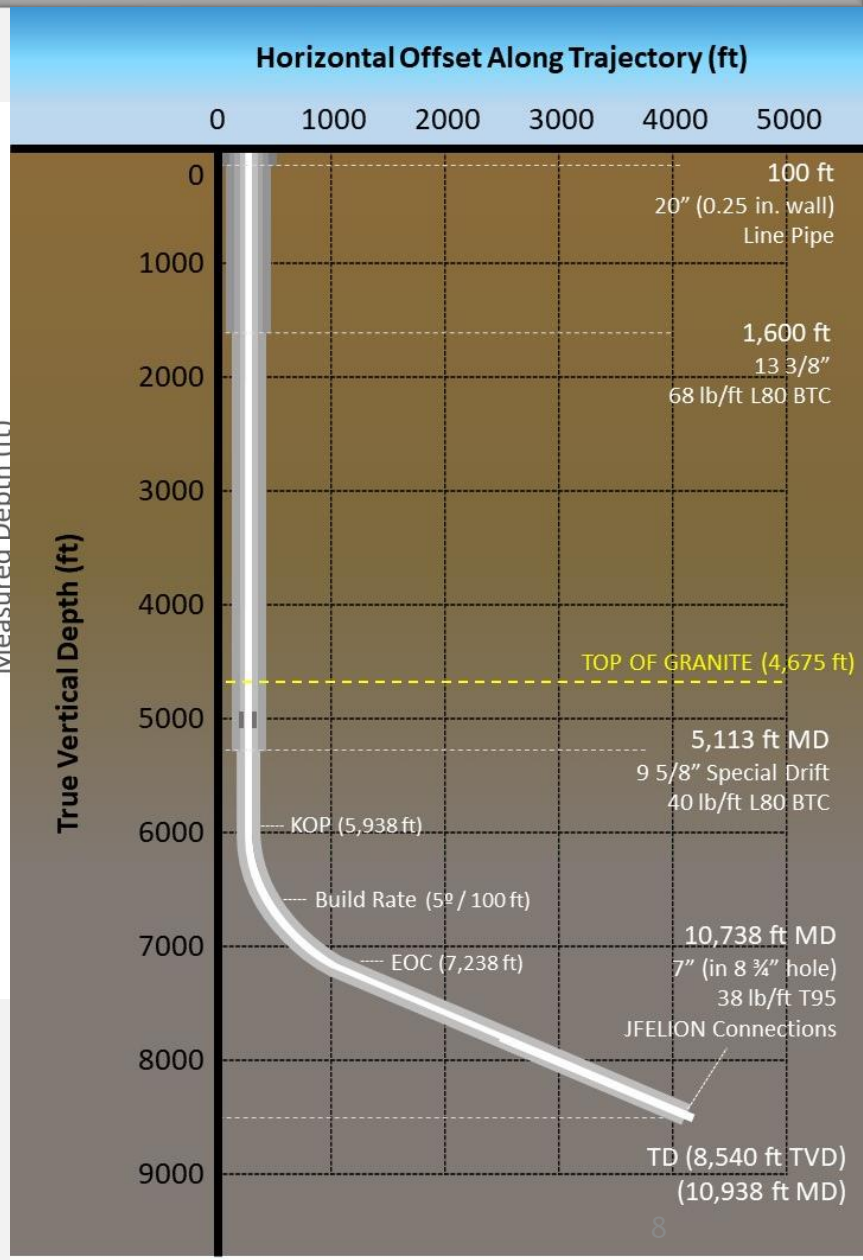






Utah FORGE Wells





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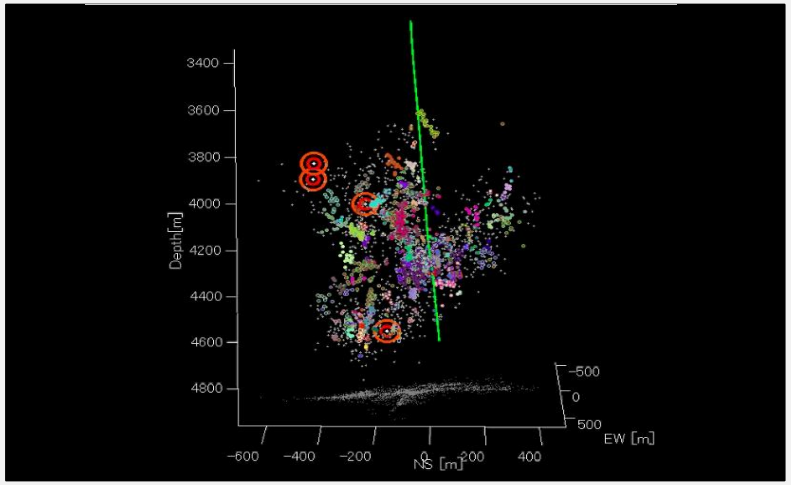
Induced Seismicity

- Several projects have generated seismic events exceeding M 3 (max M 5.5)
- Seismic activity minimized by:
  - Avoiding injection into large through going faults
  - Low-pressure hydroshearing of critically stressed fractures
- Cycling and long-term low-pressure stimulation rather than short-term high-pressure injection (net zero) may be beneficial
- Thermal stimulation

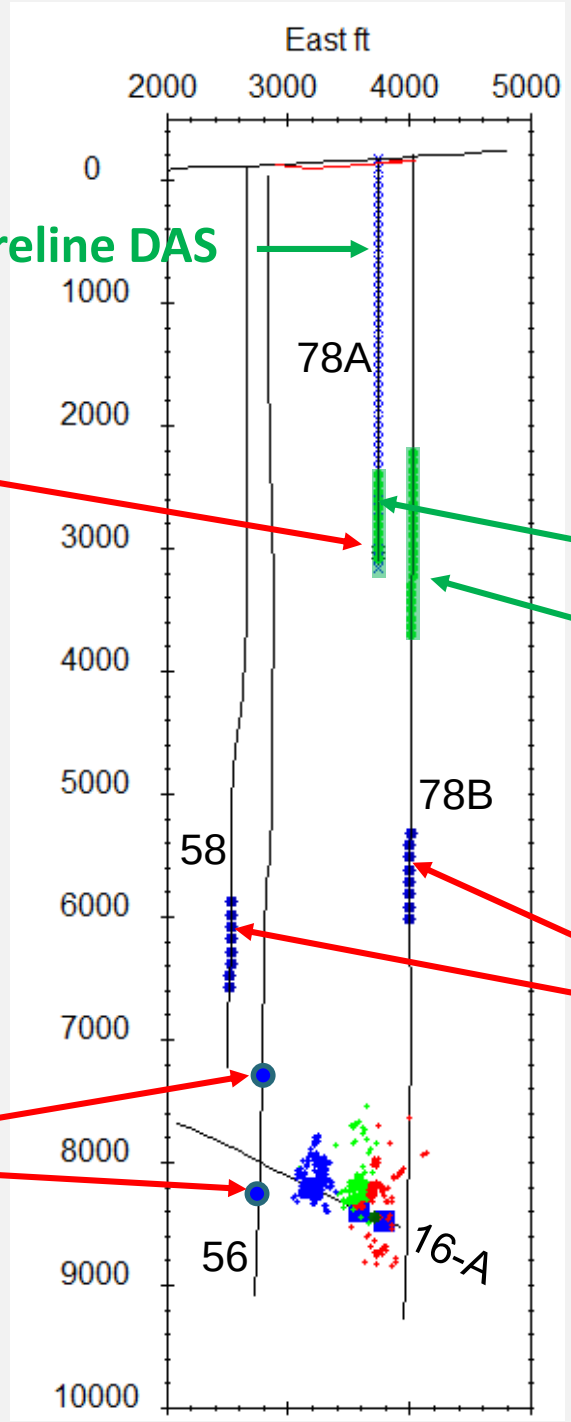
Basel, 1356 - Karl Jauslin



Basel, 2009 - Meier et al., 2015

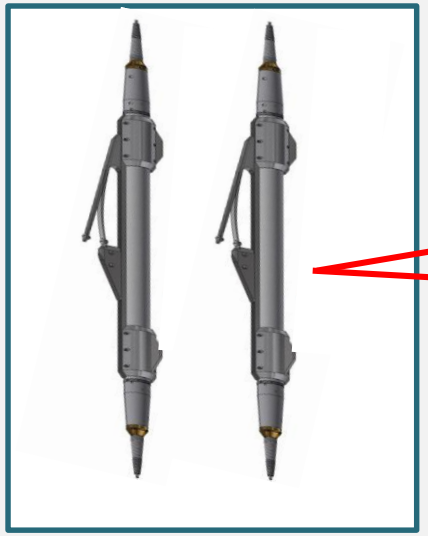
Deep-well receiver systems used for stimulation monitoring

3-level, 3C fiber optic string with wireline DAS



DAS behind casing

2-level analog 3C geophone string

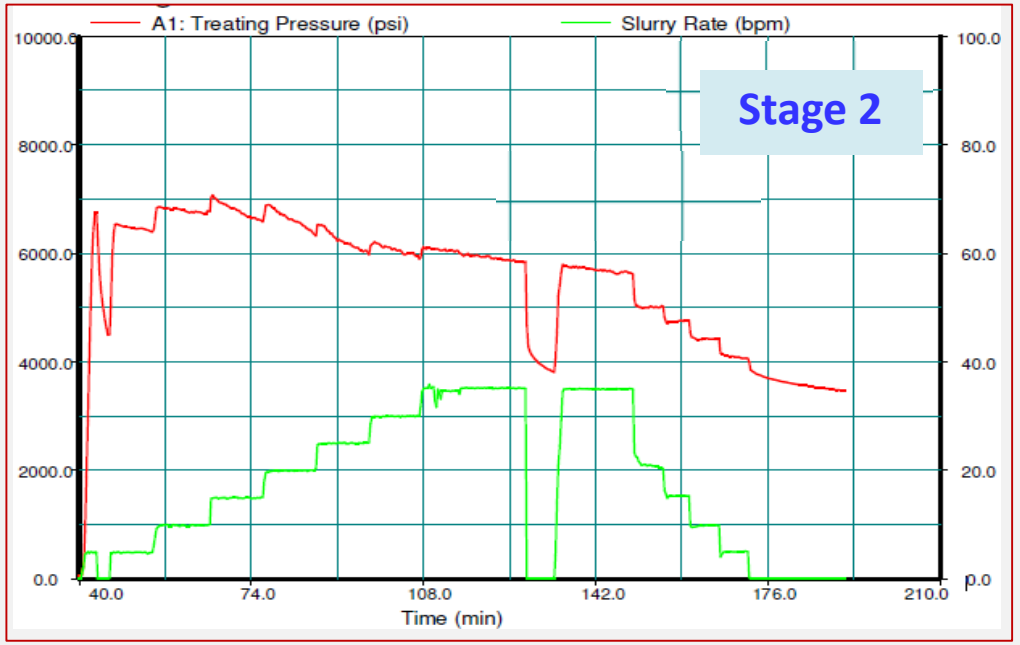


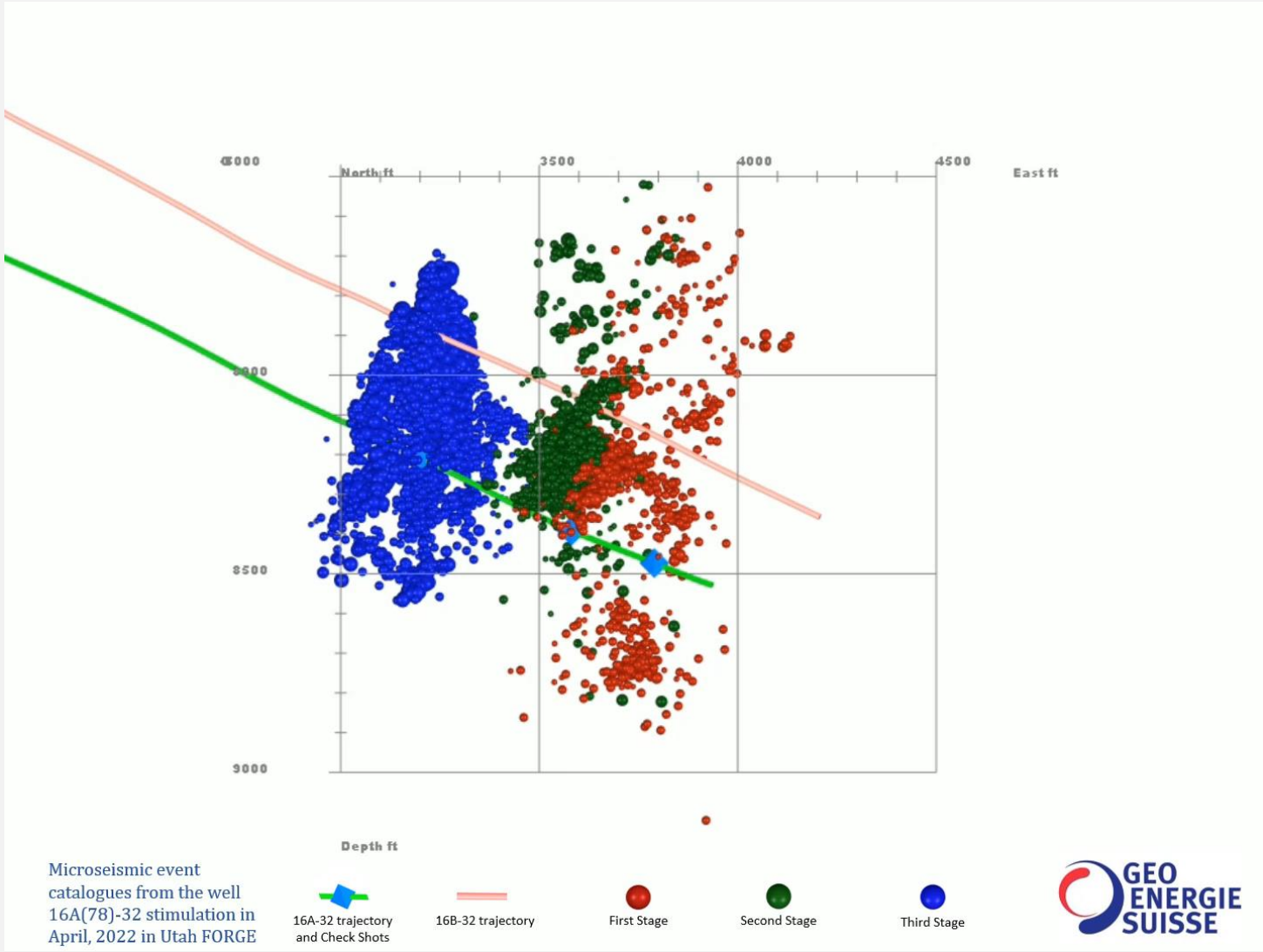
8-level, digital 3C geophone strings

Reservoir Creation: Seismic Events

April 2022: Stimulated 3 Stages in 16A(78)-32 (injection well)

- Pumped 10,054 bbl (1599 m^3) at 35-50 bpm
- Stage 1 in open hole; Stages 2-3 in casing
- Stage 1,2 slickwater; Stage 3 viscosified fluid
- Recovered ~50% during backflow; fluid increased in salinity with time
- Unique tracer injected in each stage





Microseismic event catalogues from the well 16A(78)-32 stimulation in April, 2022 in Utah FORGE

GEO ENERGIE SUISSE

Accelerating Commercial Development

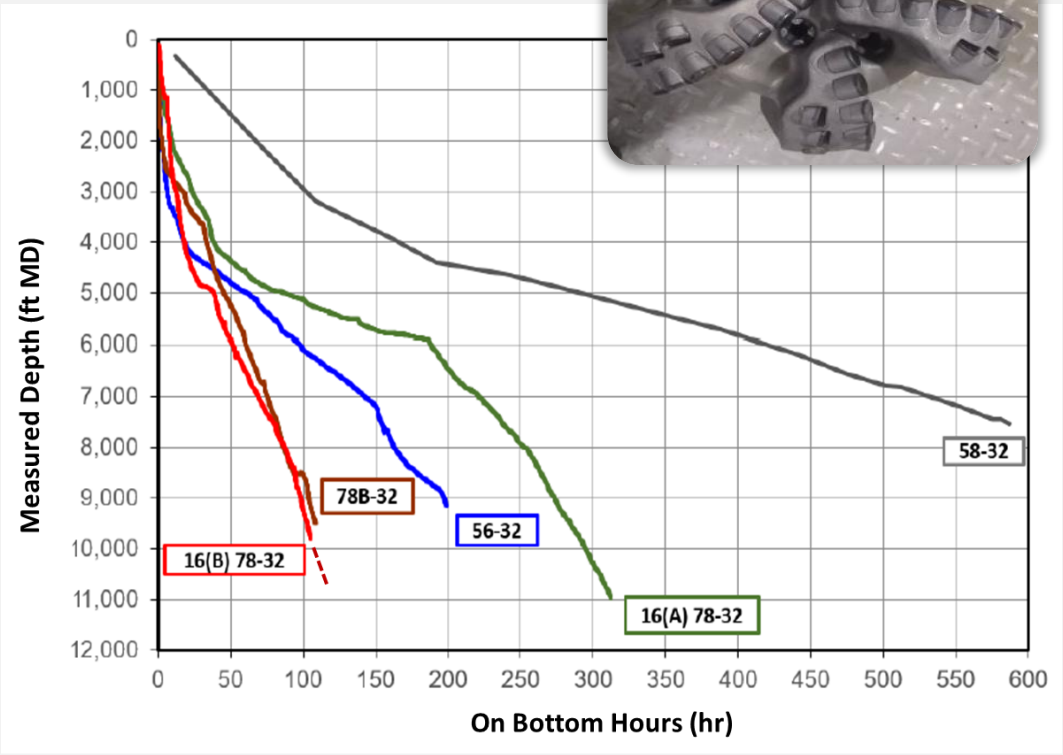
We firmly believe commercial development of EGS resources is possible

- Past projects consisted of a few wells. Failure to demonstrate early economic viability has led to premature abandonment of projects- proof of concept requires multiple wells

Drilling

Drilling costs can account for ~50% of the total project. In the last two years, drilling and equipment costs have increased significantly, some by as much as 100%

- Develop new drilling technologies (tested Particle and Percussion drilling)
- Develop drilling tools that will improve rate of penetration, drill smoother well bores, reduce vibrations (Rotary Steerable Systems)
- Reduce trip time
- Decrease rig footprint
- Optimize MSE in real time (AI)
- Reduce fluid temperatures
- Improve core recovery



On-bottom rotating hours in sequential wells at Utah FORGE (Dupriest and Noynaert (2022) and Olson (2023)

Accelerating Commercial Development

Logging

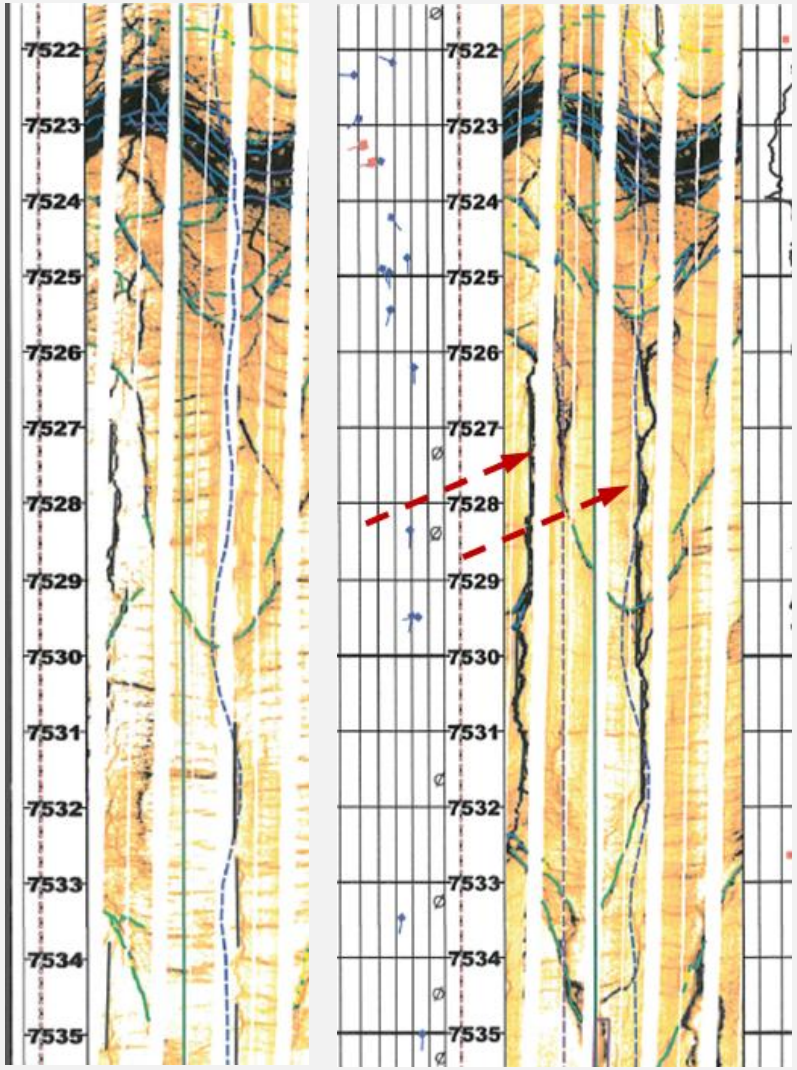
- Build high-temperature tools and batteries
- Deploy tools on wireline
- Build high-temperature conveyance devices for wireline (tractors)
- Tracers (nanotracers, reactive tracers (surface area))
- Log interpretation in granitic rocks (particularly fracture mapping logs)

Monitoring

- High-temperature geophones
- Ruggedize fiber optic wirelines for recording strain, temperature, seismicity
- Specialized monitoring wells to reservoir depths (slim holes)
- Improved surface seismic monitoring techniques
- Develop alternative geophysical monitoring techniques
- Opportunities for AI

Stimulation and Zonal isolation

- High-temperature packers and plugs that can be set on wireline
- Flow control devices (e.g. sliding sleeves)
- Mitigation of short circuiting
- High temperature, high strength proppants



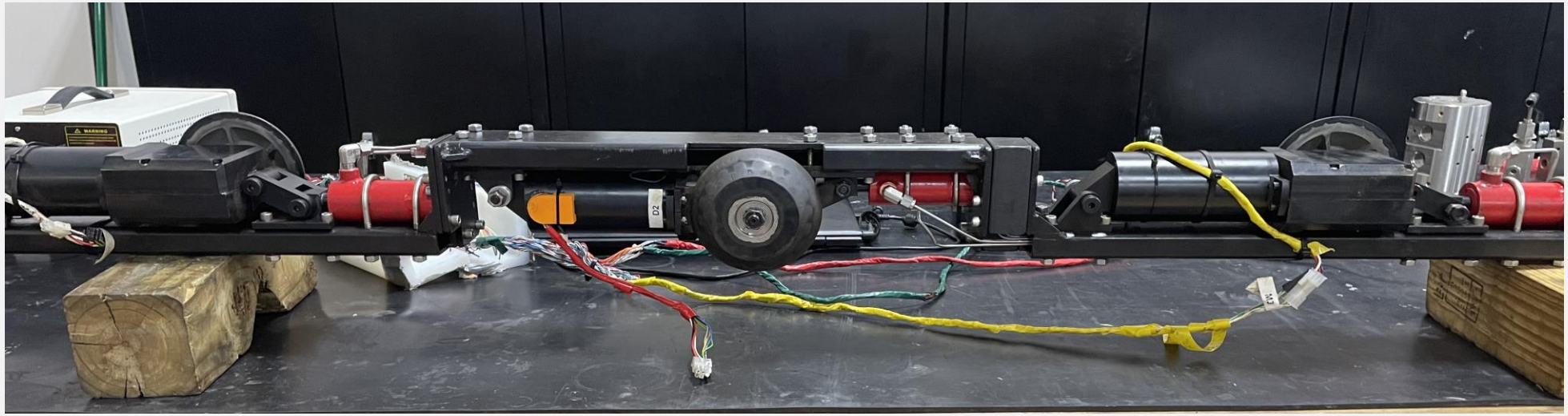
FMI logs before (left) and after stimulation (right). Note aperture increase after stimulation.

Accelerating Commercial Development

Accelerate tool development

- R&D research programs require 4 years to complete. Tools being developed under the current FORGE funded R&D projects may not be available for testing for another 2 years
- Industry has little incentive to develop tools for the geothermal market
  - Fund/cost share with industry directly to provide incentive for tool and technology development
  - Provide site for tool deployment
  - Support “impromptu” or unanticipated testing

Colorado School of Mines Tractor



Summary

- **Essential stepping-stone** to commercial large-scale EGS development and superhot resources
- **Increased drilling rates by >50%** lowering the cost of drilling geothermal wells by 20%
- **Drilled, cased and stimulated first highly deviated well** for geothermal industry
- **Tested new tools and technologies for drilling, flow control, seismic monitoring**
- Demonstrated **connection** between injection/production wells in granite
- Provides critical field data **to the public at no cost**

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