Phase 3B Year 1

Annual Report

July 21, 2023

DE-EE0007080
University of Utah

Phase 3B Year 1 Annual Report

Enhanced Geothermal System Testing and Development at the Milford, Utah FORGE Site

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A. OVERVIEW OF PHASE 3B ANNUAL ACTIVITIES

The ultimate objective of Utah FORGE is to demonstrate the viability of Enhanced Geothermal System (EGS) energy development. The project will create a controlled environment where EGS technologies and approaches can be developed and de-risked. The laboratory will function as a dedicated field scale site for technical interaction and public education to support the widespread adoption of EGS as an energy source.

This report presents an overview of the activities conducted during Phase 3B Year 1. Phase 3A Year 1 activities transitioned the Utah FORGE project from site characterization and baseline monitoring to infrastructure development required for full deployment of the Utah FORGE laboratory. By the end of Phase 3A Year 2, the injection well 16A(78)-32 and monitoring wells had been completed (Figure A-1). Phase 3B Year 1 site activities focused on the stimulation of well 16A(78)-32, seismic monitoring and data analysis.

The major accomplishments of the Utah FORGE team during Phase 3B Year 1 include:

1. Three stages near the toe of well 16A(78)-32 were successfully stimulated
2. Seismic monitoring of the stimulation was conducted at reservoir depths using deep geophone strings in wells 56-32, 58-32, and 78B-32.
3. The final three local seismic monitoring stations were installed.
4. The site infrastructure was upgraded to accommodate the needs of the R&D recipients and long-term testing by Utah FORGE.
5. Solicitation 2-2022 was released and reviews by the TARMaC were completed.
6. Repeat groundwater, gravity, GPS, and InSAR surveys were conducted.
7. Petrographic analyses of well cores and cuttings continued. The new data indicate metamorphic rocks are more common than previously recognized. A revised geologic model has been developed.
8. A detailed plan for the production well 16B(78)-32 was prepared and approved by the DOE.
9. Utah FORGE assisted Clemson University, Rice University and UT Texas-Austin in obtaining permits for field activities.
10. Contracts were let for the rig and drilling equipment. The well will be drilled to a MD of 10697 ft and cased to 10,197 ft, leaving 500 ft of openhole.
11. Outreach and Communication activities continued to expand. Information is distributed through a wide variety of electronic media suitable for the general public, students from grade school to graduate levels, scientists and geothermal specialists, regulators, and legislators can be found on the Utah FORGE website, social media platforms, YouTube videos, and scientific forums. Wiki pages have been developed for Utah FORGE data and each of the R&D projects.
12. More than 209 GB of data has been uploaded to the Geothermal Data Repository (GDR). Utah FORGE ranks number 1 in the top 10 downloads from GDR for the year.
13. The stimulations were numerically modelled.
14. Utah FORGE remains most thoroughly documented of any EGS site in the world.

Activity at the Utah FORGE site centered around the stimulation of well 16A(78)-32, the injection well of the injection-production pair. Three stages were stimulated; one stage in the 200 ft of openhole below 10,787 ft and two stages behind casing at 10,560-10,580 ft and 10,120-10,140 ft. These zones were specifically targeted based on the abundance of fractures observed in the FMI logs and the predicted size and shape of the fracture network that will be created during the stimulation of well 16A(78)-32.

A total of 10,054 barrels was pumped at rates of 50 bpm in the openhole section and 35 bpm in the perforated zones. Slickwater was injected into the two lower zones. In contrast, viscosified fluid carrying microproppant was injected into the upper perforated zone. Each stage was tagged with a different organic tracer. Approximately 50% of the injected fluid was recovered.

Seismic monitoring of the three-stage stimulation was conducted utilizing a combination of analogue and digital geophones placed at reservoir depths. A major objective of the monitoring was to determine the vertical extent of the fractured region, information that is required for determining the trajectory of the production well 16B(78)-32. A reference catalogue of 2600 located seismic events with magnitudes of -2.3 to +0.5 was created and submitted to the GDR. A second catalogue of ~23,000 events with magnitudes was subsequently created, but not all of the events could be located. Injection of slickwater into the openhole and lower perforation produced diffuse zones of seismic events. The viscosified fluid yielded a narrow fracture zone approximately parallel to S_{hmax}. All of the fracture zones grew upward. In addition to the deep geophone strings, DAS cables in 78B-32 and on the surface, a BOSS cable (DAS plus three component geophones), and an extensive nodal array were deployed.

Monitoring of the microseismicity surrounding the Utah FORGE site continued. No events have been detected beneath the site since monitoring in the region began in 1981, supporting the conclusion the risk from induced seismicity is low. The installation of broadband instruments in concentric rings at 8 km (5 miles) was completed.

A detailed drilling plan was prepared for completing well 16B(78)-32, which will serve as the production well for reservoir creation, fluid circulation and demonstration of heat extraction. The well will be drilled parallel and 300 ft above well 16A(78)-32. The plan emphasizes techniques that will yield a smooth borehole at high Rates of Penetration (ROP). To achieve this objective, a Rotary Steerable System, in contrast to the bent motors used to drill well 16A(78)-32, will be deployed.

Utah FORGE worked closely with R&D recipients on permitting requirements and the equipment necessary for deploying tools in well 16A(78)-32. Battelle will conduct minifrac tests using straddle packers. UT Austin and Rice University will deploy fiber optic cables and a pressure-temperature tool in the annulus of the 7.5-inch production casing. Rice University will also deploy Stationary Orbital Vibrators (SOV) at up to four sites. Petroquip will deploy a landing nipple for installation of a plug. Permitting activities were completed for Clemson University's borehole strainmeters; two new strainmeters (a total of four) were installed during this project period.

Several improvements were made to the site infrastructure. Additional electric power was brought to the well 16A/B(78)-32 pad for monitoring activities, the R&D Project Office and for the injection/production pumps required for circulation testing. Power was also extended to the well 78B-32 pad for microseismic monitoring. The Project Office will be used as the Command Center during drilling and stimulation activities.

The microseismic data obtained from the 16A(78)-32 stimulation has been used to create a new fracture model based on fitting planar features to the microseismic cloud. A new, simplified Discrete Fracture Network (DFN) model consisting of 15 planes based primarily on the microseismic data was developed. Previous DFN models of the site included hundreds to thousands of discrete fractures and relied on stochastic generation of features. This new DFN model provides an alternative fracture network having fewer discrete features and potentially captures the most significant flow pathways created by the stimulation of 16A(78)-32.

Three stages of stimulation were carried out near the toe of well 16A(78)-32 at Utah FORGE site. Previously, before the actual field stimulations, predictions of stimulation effects were conducted using numerical models. Modeling results were compared to field data in three aspects: 1) injection pressure history, 2) spatial distribution of microseismic events, and 3) b-values of microseismic events.

Models with weak, frictional and permeable DFN yield the best match for all three stages. All three stages appear to include combinations of hydraulic fracturing and stimulation of the DFN. DFN leakoff seems to dominate the response in the openhole and lower perforated stages, consistent with the use of slickwater. Hydraulic fracture propagation dominated in Stage 3, which was pumped with viscosified fluid. For all three stages, the extents of microseismicity events in the models match the field data. The b values of the microseismic events from the models ranging from 2.3 to 2.4 are very close to those obtained from the field.

Solicitation 2-2022 was released. Proposals in five topic areas were solicited: Adaptive induced seismicity monitoring protocols; Alterative stimulation schemes; Field-scale experiments to measure heat-sweep efficiency; High temperature proppants and; Multiset straddle packers for open hole operations. Up to 17 projects will be awarded for a total of $44 M. The proposals were reviewed by the TARMaC.

Technical information on Utah FORGE is being shared with the scientific community through the Utah FORGE website, conferences and publications, field trips, wiki pages and the DOE Geothermal Data Repository (GDR).

InSAR, gravity, water levels and GPS monitoring continued on approximately on a quarterly basis. Although changes in gravity, water level and GPS data were documented, they are interpreted to reflect temporal variations resulting from seasonal changes in precipitation. No deformation was observed in the InSAR data. No changes due to the stimulation were identified.

Public outreach remains a priority of the Utah FORGE program. Information suitable for the general public, students from grade school to graduate levels, scientists, regulators, legislators, and geothermal specialists can be found on the Utah FORGE website, social media platforms, and scientific forums. Wiki pages have been developed for Utah FORGE and each of the R&D projects. The Wiki pages can be accessed through the Utah FORGE website. Scientific data is available through numerous publications and conference proceedings (refer to the Utah FORGE website), and the Geothermal Data Repository (GDR). More than 209 GBytes of data have been uploaded to the GDR since the project was initiated.

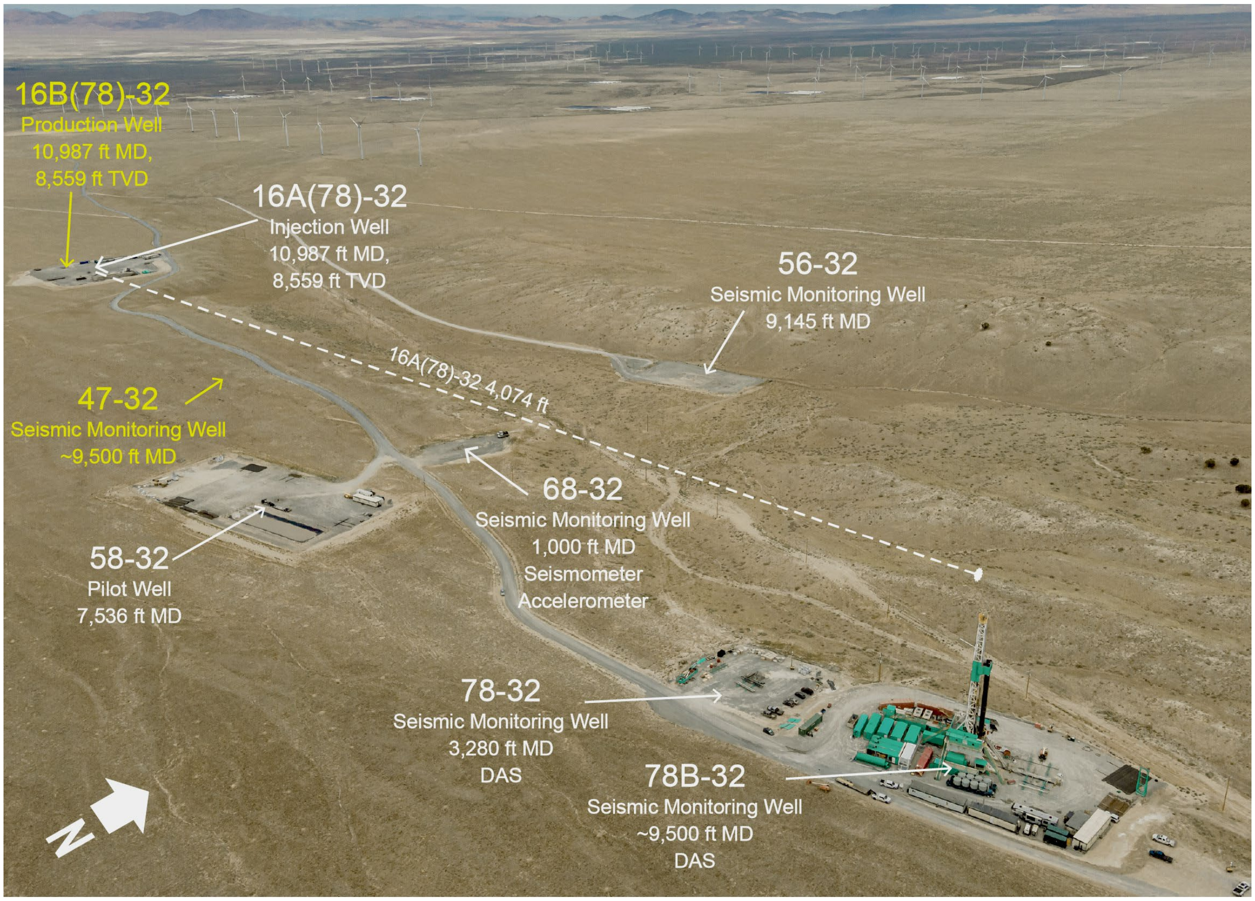


***Figure A-1**. Utah FORGE infrastructure. Wells shown in white have been drilled, those in yellow are planned. The dotted line shows the trajectory of well 16A(78)-32, which will serve as one of the two wells that will be stimulated to create the Utah FORGE EGS reservoir.*

The current Utah FORGE R&D portfolio consists of 17 projects that cover 5 topic areas having a total value of $53.03 million. These projects have been ongoing for 15 to 18 months (Year 1), and have made significant progress and achievements as summarized in figure A-2. Regular monitoring is conducted through quarterly and annual meetings and reports, as well as Go/No Go stage gates.

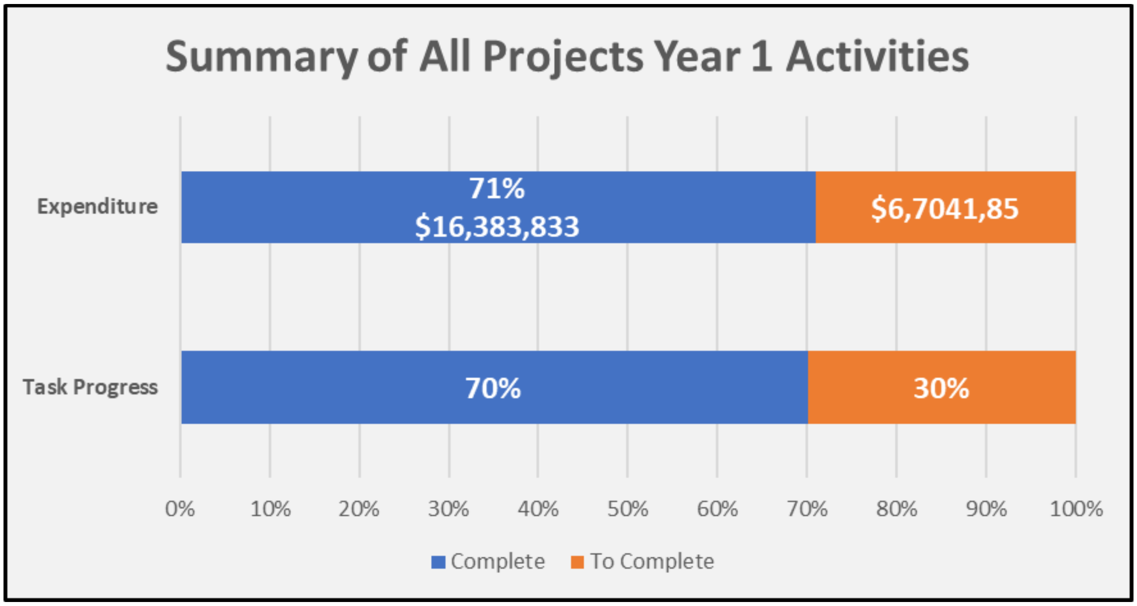


Figure A-2. *Summary of all R&D projects in Year 1 activities.*

B. RESULTS

B.1 SITE INFRASTRUCTURE & OPERATIONS

Infrastructure for the Utah FORGE site has been continuously upgraded to support drilling, stimulation, other site activities, and environmental and seismic monitoring. These cover earthworks, installation of power supply lines, and an upgrade to telecommunications for data transmission.

Earthwork

Earthwork and related activities completed include:

Well 16A/B(78)-32 drill pad

1. Issues related to erosion were remedied on the western edge of the 16A/B drill pad, including installing a gravel berm around the edge to prevent future erosion.
2. A new road bed was constructed on the 16A/B drill pad to accommodate traffic patterns on site during the April 2022 stimulation of 16A(78)-32 (Figure B.1-1).
3. A new sump liner was installed on the 16A/B drill pad prior to the April 2022 stimulation.
4. After the stimulation of 16A(78)-32 a general cleanup was undertaken that involved trash removal from the entire site, weed removal from the well pads and grading of the well pads (as needed).
5. The 16A/B pad was expanded (cleared, graded, and graveled) to the south to accommodate pipe racks, rig traffic and equipment parking (Figure B.1-2).
6. Excess pipe and pond liner were cleared from the northeast corner of the pad for better utilization of the exiting pad and to make room for the mud coolers and fiber optic acquisition trailers.
7. Approximately 20 joints of 7-inch casing were relocated from well pad 58-32 and used to construct pipe storage racks (Figure B.1-2).
8. Twenty truckloads of casing were off-loaded and stacked in the SE corner of the 16A/B drill pad (Figure B.1-2).
9. Geophones and cable removed from well 78B-32.
10. The 16B(78)-32 wellhead was sited and a certified survey was conducted for the state engineer.
11. Multiple efforts to remove wind drifted snow after storms in order to access the site.
12. Replaced damaged signage and added new signage as needed.
13. Installation of the conductor pipe and mouse hole for well 16B(78)-32.
14. Extra gravel laid over a 50 by 50 ft area centered on the 16B(78)-32 well head to provide extra ballast for the drill rig.
15. The 16A/B drill pad was graded and leveled in anticipation of the drilling of 16B(78)-32.
16. The Command Center trailer was installed at its temporary position.
17. A gyro survey was run in 16A(78)-32 to confirm the earlier deviation surveys and to establish the directional drilling program for well 16B(78)-32.

18. All roads within the FORGE site, as well as the access road leading to the site, were graded prior to rig mobilization for the drilling of well 16B(78)-32.

Well 58-32 drill pad

1. Removed and restacked the exiting casing yard to allow for better access, inventory, and safety.
2. Relocated approximately 20 joints of 7-inch casing from the 58-32 pad to construct pipe storage racks on the 16A/B drill pad.
3. Repaired water erosion at the pad entrance

Well 78-32 and 78B-32 drill pads

1. Back filled the west side slope of both pads where water has eroded the existing bank and exposed electrical conduit. Created a gravel berm all along the west slope to prevent future erosion.
2. Repaired water erosion at the pad entrance.

Well 56-32 drill pad

1. Graded and repaired the entire Mag Lee Road that leads to the 56-32 drill pad (on two separate occasions).

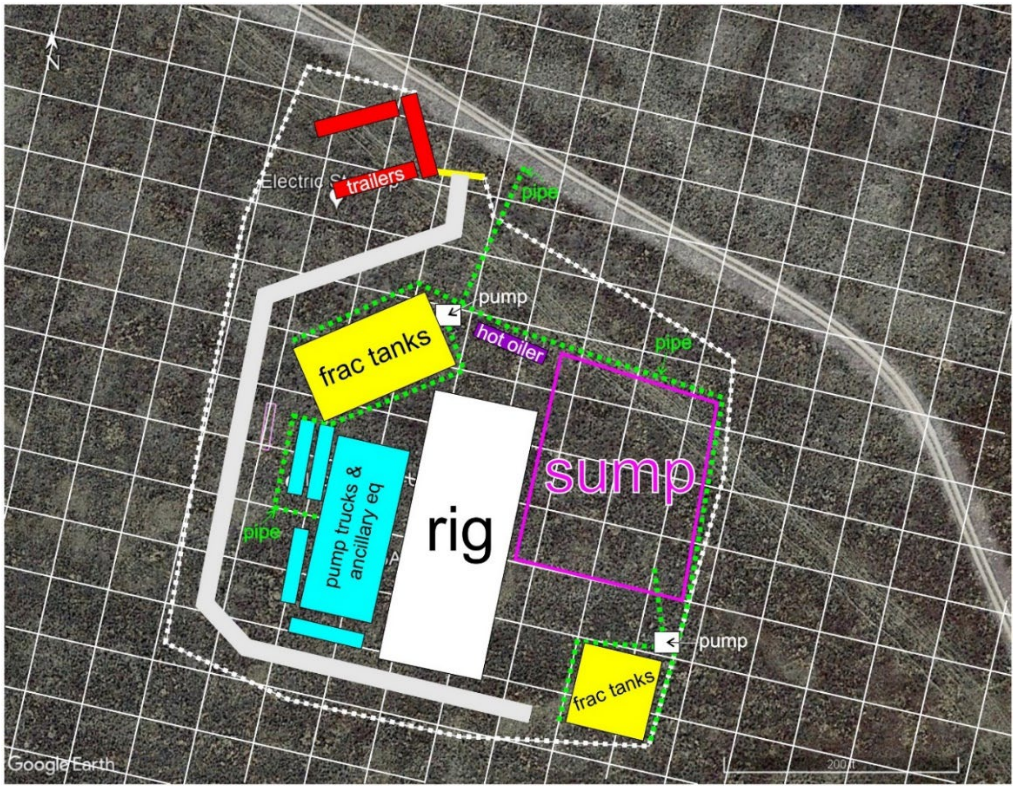


Figure B.1-1. *The thick gray line represents the new road bed that constructed to accommodate traffic patterns during the April 2022 stimulation of 16A(78)-32.*

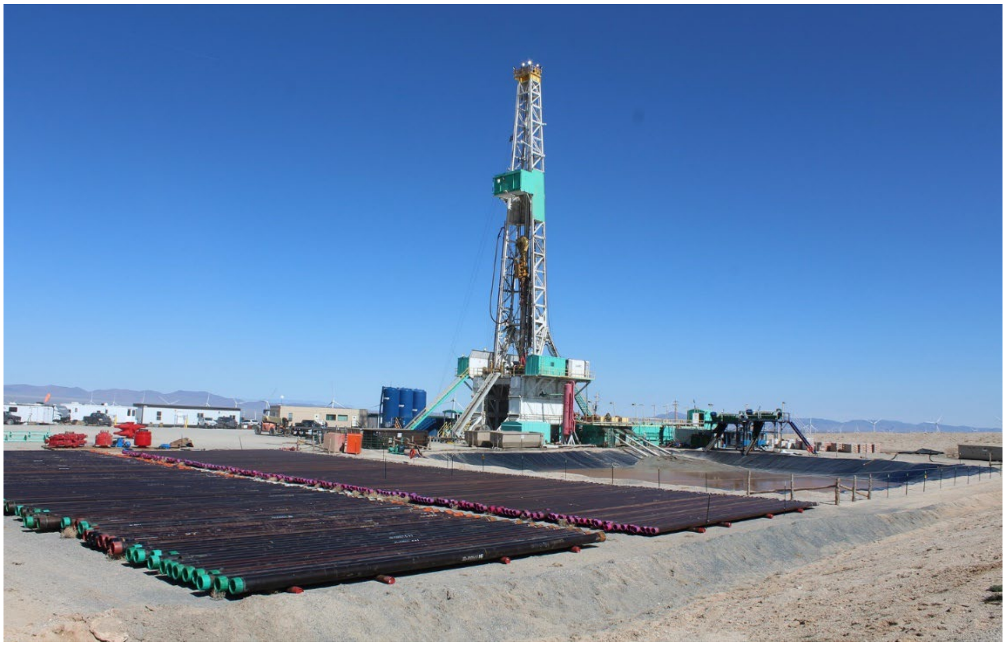


Figure B.1-2. *In the foreground is the newly expanded southern edge of the 16A/B drill pad with casing laid out on pipe racks. In the background Frontier Rig 16 is actively drilling well 16B(78)-32.*

Establish Project Office

1. An invitation for bid was issued for the construction of an office trailer to act as a command center during drilling and stimulation activities, that will also serve as a place to host site visitors.
2. American Portable Building Corp was awarded a contract to build and install a portable office trailer on the 16A/B drill pad
3. Approval for a temporary structure to remain at the site for the duration of the project was granted by Beaver County Building Department.
4. The Command Center trailer was delivered, furnished, and temporarily installed on the 16A/B drill pad (Figure B.1-3). The trailer was placed in this temporary position for optimal observation of site activities by the DSMs and site manager during the drilling of well 16B(78)-32. Upon completion of well 16B(78)-32 the trailer will be moved to the north side of the pad to accommodate upcoming stimulation and circulation activities.

Figure B.1-3*. Internet infrastructure at the Utah FORGE site. Internet services provided by UETN are relayed to the communications mast on the 58-32 pad, then relayed to the communications mast on the 78A-32 pad, and finally broadcast to end user sites across the whole Utah FORGE site.*

Electric Infrastructure

The electric infrastructure has been engineered to provide power for present and future needs, including spur lines to wells 16A(78)-32, 58-32, 78A-32 and 56-32 that can provide 3-phase power for pumps as needed. Power has been trenched to electric distribution points on all drill pads except for 68-32.

Activities completed include:

1. Power was trenched to the 78B-32 wellhead to facilitate fiber optic monitoring activities of the cables in the annuli of wells 78-32 and 78B-32. GES occupied a temporary trailer at the site during the April 2022 stimulation of 16A(78)-32, and the R&D team lead by Rice University will do the same during the upcoming circulation tests between 16A and 16B.
2. Two variable frequency drive (VFD) panels have been installed for the injection and production pumps on the 16A/B drill pad.
3. Power was trenched to the long-term location for the Command Center office trailer. The trailer will be repositioned after the drilling of 16B(78)-32 (see below).

4. Power was trenched to the NW corner of the sump on the 16A/B drill pad where the Rice/Silixa and UT Austin/Shell fiber optic data acquisition trailers will be located.

Internet Connection/Communications

Internet services are provided free of charge by the Utah Education and Telehealth Network (UETN). Internet services are routed to the existing communications mast on the well 58-32 drill pad (Figure B.1-4) with supporting equipment located in the adjacent trailer owned by Idaho National Laboratory. To distribute signal across the entire Utah FORGE site, a directional link has been established between the existing communications mast and a newly erected 30 ft mast on the well 78A-32 drill pad. Supporting equipment is stored in a weathertight panel ~100 ft away. Trenching was required to route power the enclosure and for data cabling that runs from the enclosure to the mast. At the top of the new communications mast are three radial antennas that broadcast the signal in all directions. Endpoints have been set up at the power drops on the well 16A(78)-32, 58-32, 56-32 and 78B-32 drill pads, providing both wireless and hardwired internet access.

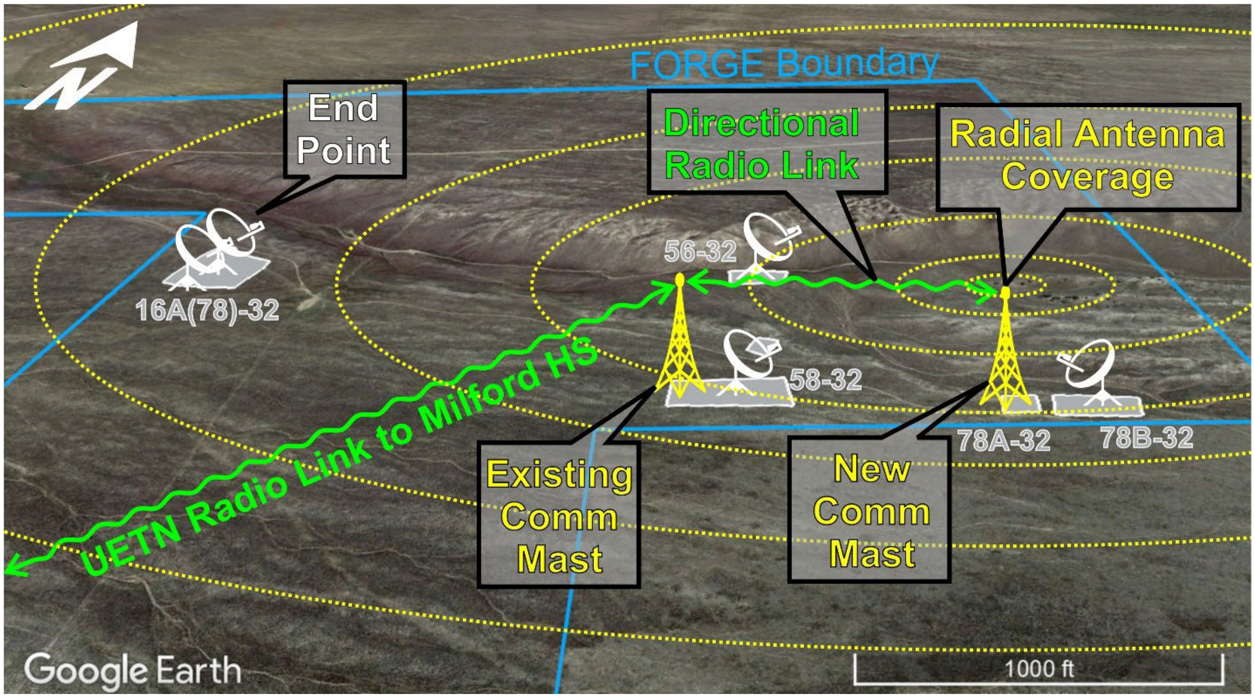


Figure B.1-4. *Internet infrastructure at the Utah FORGE site. Internet services provided by UETN are relayed to the communications mast on the 58-32 pad, then relayed to the communications mast on the 78A-32 pad, and finally broadcast to end user sites across the whole Utah FORGE site.*

Continuous Environmental Monitoring

A summary of the results of environmental monitoring activities, including GPS, InSAR, gravity, and groundwater are covered below.

Across the Utah FORGE site, a distributed network comprising 20 monuments are surveyed on a quarterly basis by the Utah Geological Survey using GPS methods to characterize ground deformation (Figure B.1-5). Between April 1, 2022 and March 31, 2023, four surveys were completed and a time series summary of all the survey results is shown in Figure B.1-6. Over time, the average displacement ranges from -10 to +25 mm. Comparison with rainfall and water level data suggest the possibility of seasonal effects on the pattern of vertical movement. In the period April 1, 2022 to March 31, 2023, the variability in vertical ground movement is between 0 and +10 mm.

Compared to the GPS monitoring, analysis of InSAR images by the University of Wisconsin team shows minimal surface deformation in the area immediately surrounding the FORGE wells. This result is not surprising since the stimulation experiment in April 2022 injected a small volume at a depth on the order of 2000 m. The expected deformation appears to be too small to measure by InSAR. To address the issue of seasonal effects, the time series of displacement derived from InSAR are compared with those estimated from GPS data at nearby stations. To do so, the (scalar) line-of-sight (LOS) displacement from the (vector) GPS displacement is calculated by forming the “dot” product with the unit vector pointing from the GPS station on the ground toward the satellite in orbit. To mitigate regional effects, deformation is calculated by subtracting the displacement at a reference point located near the GPS station GDM-20. The results for a single point located near GPS station GDM-10 are shown in Figure B.1-7. The results for multiple points are shown in Figure B.1-8. In summary, the line-of-sight displacements from GPS and InSAR data do not appear to differ significantly in calendar year 2020. Both data sets show scatter at the level of tens of millimeters. Some differences appear in the second half of 2021 that are most likely due to atmospheric effects in the InSAR data.

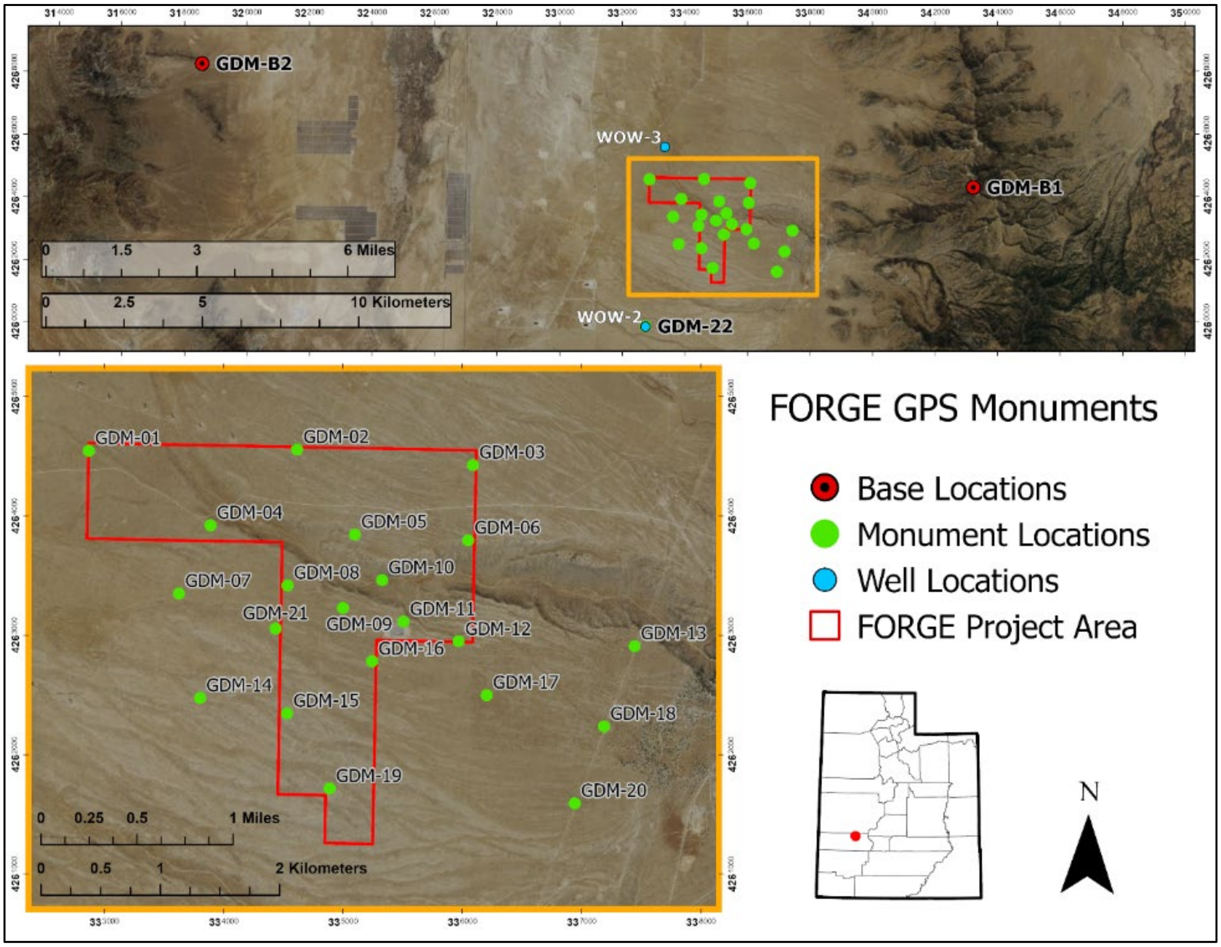


Figure B.1-5. *Location map of the Utah FORGE project area including point locations of the GPS monuments and gravity monitoring stations. WOW 2 and WOW 3 are shallow groundwater wells that are monitored for water levels.*

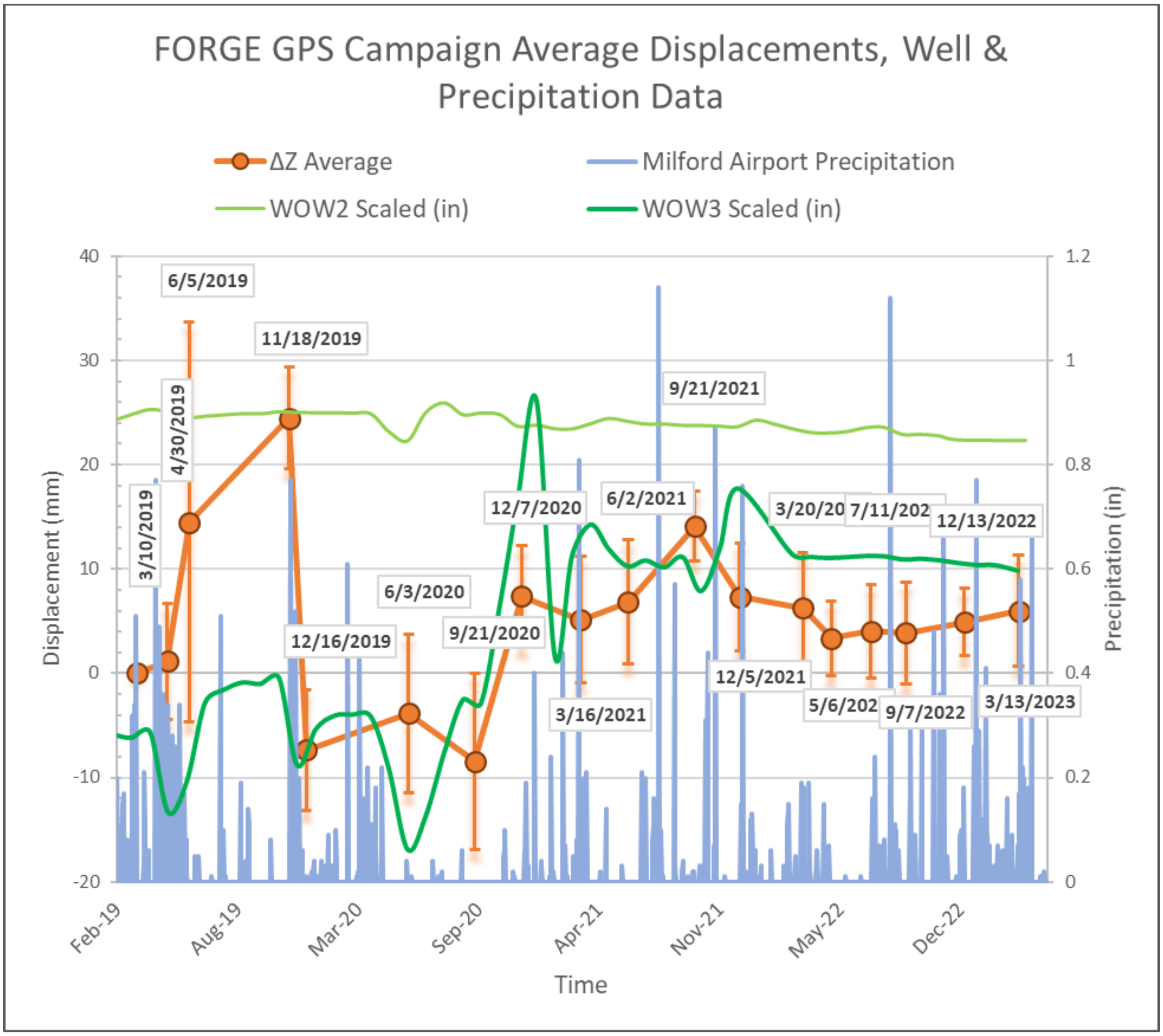


Figure B.1-6. *Time series graph showing average vertical displacements of all monuments compared to precipitation at the Milford Municipal Airport and the groundwater levels of wells WOW2 and WOW3.*

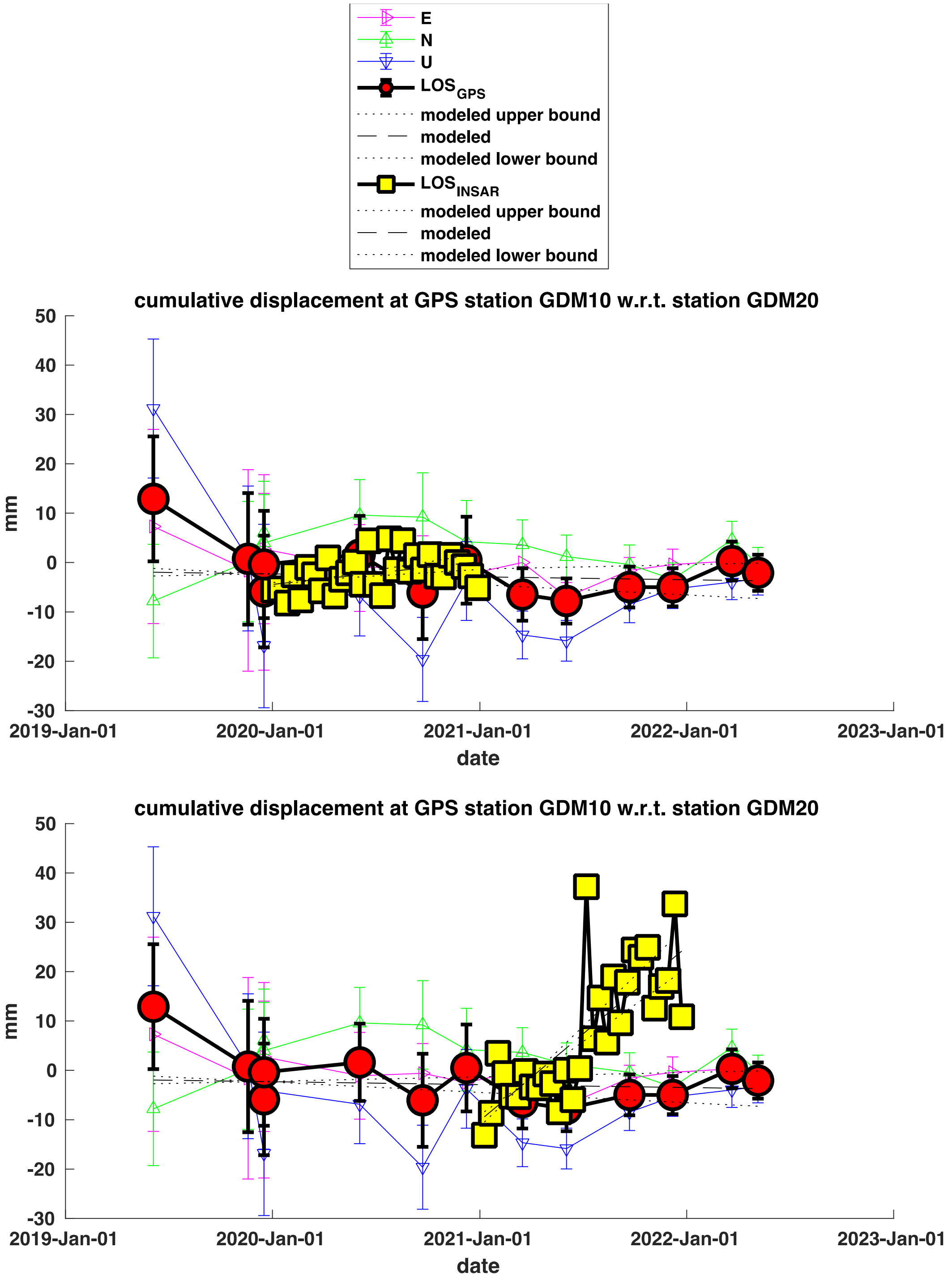


Figure B.1-7. *Line-of-sight (LOS) displacement observed by GPS (red circles) and InSAR (yellow squares) for calendar years 2020 (upper panel) and 2021 (lower panel) at a point located near GPS station GDM-10. Each time series of displacement is calculated with respect to a reference* *point located near GPS station GDM-20.*

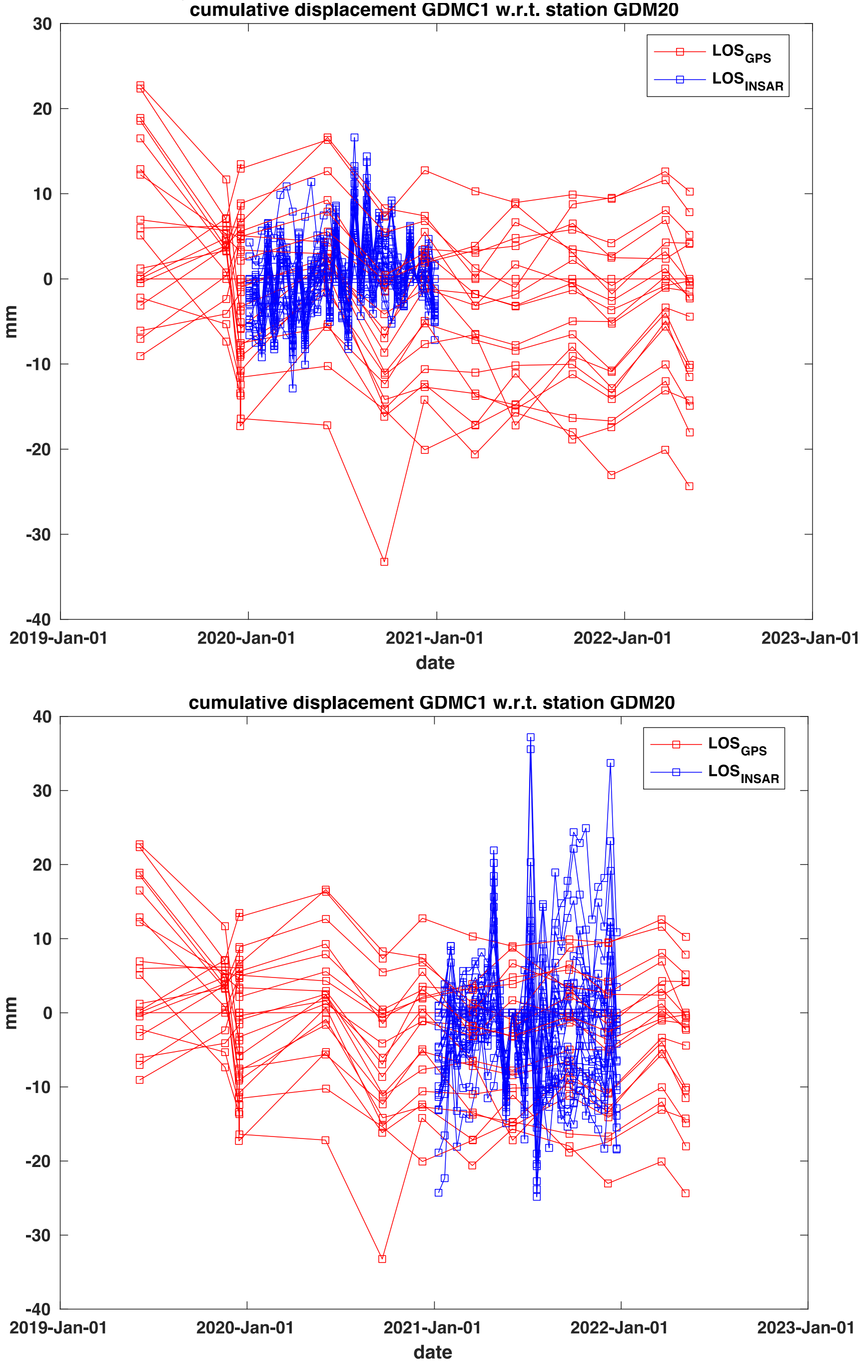


Figure B.1-8. *Line-of-sight (LOS) displacement observed by GPS (red) and InSAR (blue) for calendar years 2020 (upper panel) and 2021 (lower panel)*

Repeat gravity surveys of the GPS monuments by the Utah Geological Survey shows time series variation of -20 to +400 uGal (Figure B.1-9), and this variation seems to correlate with the GPS data. Continued monitoring of the monuments is expected to resolve the source(s) of the time series trends.

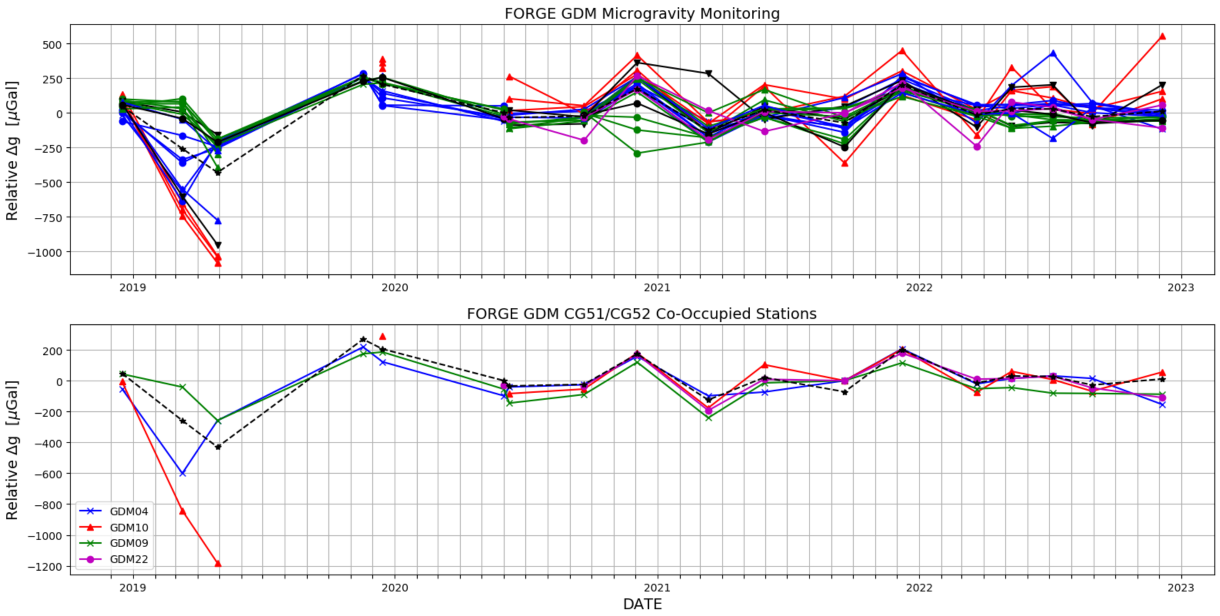


Figure B.1-9. *Plot of gravity station results from December 2018 to December 2022. Top panel shows the observed gravity changes in µGal; bottom panel shows the trends of the local field tie points (GDM10, GDM22) and daily loop base stations (GDM04, GDM09). Dashed lines show the average trend for all stations. Assigned colors based on earlier groupings according to qualitative signal trends.*

Groundwater levels are monitored in two shallow wells, WOW2 and WOW3, and these are the only wells in which access for such measurements are available. WOW2 shows relatively constant water levels with a total change of less than 0.5 feet, whereas WOW3 shows much greater variability of up to 20 feet (Figure B.1-6). This difference is likely due to the confined nature of the aquifer at WOW3 and its proximity to supply wells located west and north of the Utah FORGE site that are subject to intermittent pumping.

Stimulation 2022

A three-stage hydraulic stimulation in the toe section of highly deviated injection well 16A(78)-32 was completed in April 2022. The aims were to establish independent fracture-controlled flow networks and to provide a baseline for evaluating long-term connectivity between the injection and soon to be drilled production wells. In addition, the mechanics of isolating stages and developing fracturing fluid viscosity in a naturally fractured granitic reservoir at 435°F [224°C] were evaluated.

Three stages were pumped. Geophones in three offset wells and shallow distributed acoustic sensors (DAS) and surface monitoring devices tracked the fracture evolution. In the first stage was slickwater was injected into the barefoot section pumped at rates up to 50 bpm (7.95 m^3/min). Bridge plugs were deployed in 7-inch (177.8 mm) casing to isolate the next two stages, which each used a single 20 ft (6.096 m) long perforation cluster, with six shots per ft at 60°

phasing. In the second stage slickwater was injected at pumped rates up to 35 bpm (5.56 m^3/min). In the final stage, a crosslinked carboxymethyl hydroxypropyl guar (CMHPG) polymer fluid with low concentrations of microproppant was pumped at rates up to 35 bpm (5.56 m^3/min). Between each stage, intervals of flowback helped to mitigate the potential for stage interference, facilitate the running of bridge plugs, and reduce the possibility of undesirable microseismicity.

Wellsite Operations

Contingencies were built into the stimulation operations prognosis so that the pumping schedule could be modified in real-time based on the pressure response during the pumping of the treatment and the analysis of microseismicity in offset monitoring wells. The general steps for the stimulation operations are summarized below:

1. Run in the wellbore with a bit, scraper, and drift sub on drill pipe to make sure that wellbore was clean and accessible for the bridge plugs to provide isolation between frac stages. Each joint of drill pipe was strapped while picking up joints to run into the wellbore with the bit, scraper, and drift sub. After reaching near the end of the wellbore in the open-hole section, the drill pipe was tripped back out of the well, and straps were taken for each stand (triples) to compare with the initial pipe straps for verification.
2. Run in the wellbore with a 2 ft (0.61 m) perforating gun and mechanical casing collar locator. After depth correlation, fire the perforating guns in the open-hole section of the wellbore as a check shot for orienting the geophones in the offset microseismic and DAS monitoring wells.
3. Pump a shear stimulation test with water down the 7-inch (177.8 mm) casing at low rates of less than 0.5 bpm (0.0795 m3/min). After shutdown, monitor the shut-in pressure for one hour.
4. Immediately thereafter, pump the first stage hydraulic fracturing treatment down the 7-inch (177.8 mm) casing with slickwater (freshwater plus friction reducer) into the open-hole section of the wellbore. After shutdown, monitor the shut-in pressure for four hours.
5. Open the well to flowback fluid from the first stage fracturing treatment and monitor the flow rate, pressure, and temperature. Collect samples of the flowback fluid to analyze for the presence of tracer.
6. When well conditions allow, run in the wellbore with a 7-inch (177.8 mm) HPHT retrievable bridge plug on drill pipe and set to isolate the stage 1 fracturing treatment.
7. Run in the wellbore with a 20 ft (6.096 m) perforating gun, position the gun at the desired depth, and fire the gun to perforate the 7-inch (177.8 mm) casing.
8. Pump the second stage hydraulic fracturing treatment down the 7-inch (177.8 mm) casing with slickwater (freshwater plus friction reducer) into the perforated section of the wellbore. After shutdown, monitor the shut-in pressure for four hours.

9. Open the well to flowback fluid from the second stage fracturing treatment and monitor the flow rate, pressure, and temperature. Collect samples of the flowback fluid to analyze for the presence of tracer.
10. When well conditions allow, run in the wellbore with a 7-inch (177.8 mm) HPHT retrievable bridge plug on drill pipe and set to isolate the Stage 2 fracturing treatment.
11. Run in the wellbore with a 20 ft (6.096 m) perforating gun, position the gun at the desired depth, and fire the gun to perforate the 7-inch (177.8 mm) casing.
12. Pump the third stage hydraulic fracturing treatment down the 7-inch [177.8 mm] casing with a 45 lb/1,000 gal [5.39 kg/m3] crosslinked polymer (CMHPG) fluid into the perforated section of the wellbore. The crosslinked fluid was displaced (flush stage) into the formation with slickwater. After shutdown, monitor the shut-in pressure for five hours.
13. Open the well to flow back fluid from the third stage fracturing treatment and monitor the flow rate, pressure, and temperature. Collect samples of the flowback fluid to analyze for the presence of tracer.
14. When well conditions allow run in the wellbore with a retrieving tool on drill pipe to latch, unset, and retrieve the upper 7-inch (177.8 mm) HPHT retrievable bridge plug.
15. Run back into the wellbore with a retrieving tool on drill pipe to latch, unset, and retrieve the lower 7-inch (177.8 mm) HPHT retrievable bridge plug.
16. Rig down the equipment and secure the well.

Shear Stimulation Test

A one-hour shear stimulation test was pumped at an average rate of 0.59 bpm (0.094 m^3/min) followed by a shutdown and monitoring of the pressure decline for an hour. A total of 36.1 bbl (5.74 m^3) of water were pumped for this test. Initially, 15.5 bbl (2.46 m^3) of water were pumped to refill the 7-inch (177.8 mm) casing due to displacement by the drill string that was run for the mechanical casing collar locator and check shot perforating trip. After the casing was filled, the surface pressure increased steadily to 3,216 psi (22.17 MPa) at a pump rate of 0.36 bpm (0.057 m^3/min) where it stabilized. There was no indication of a formation breakdown, rather the pressure behavior is more representative of the reopening of an existing fracture(s). The pressure and rate records for this test are shown in Figure B.1-10. Note that a DFIT had been pumped in this zone, immediately after the 7-inch (177.8 mm) casing had been cemented, a year earlier.

During the one-hour shut-in, the surface pressure declined by 665 psi (4.59 MPa). A rudimentary analysis of the calculated bottomhole pressure versus square root of time data for the shut-in period results in an estimated formation closure pressure of 6,350 psi (43.78 MPa) (Figure B.1-11). It is not known where exactly in the open-hole section of the wellbore the hydraulic fracture may have reopened/initiated, but using the mid-point of the open-hole wellbore as a reference, the calculated fracture pressure gradient is 0.746 psi/ft (16.88 kPa/m) which is comparable to the results obtained in the previous DFIT test.

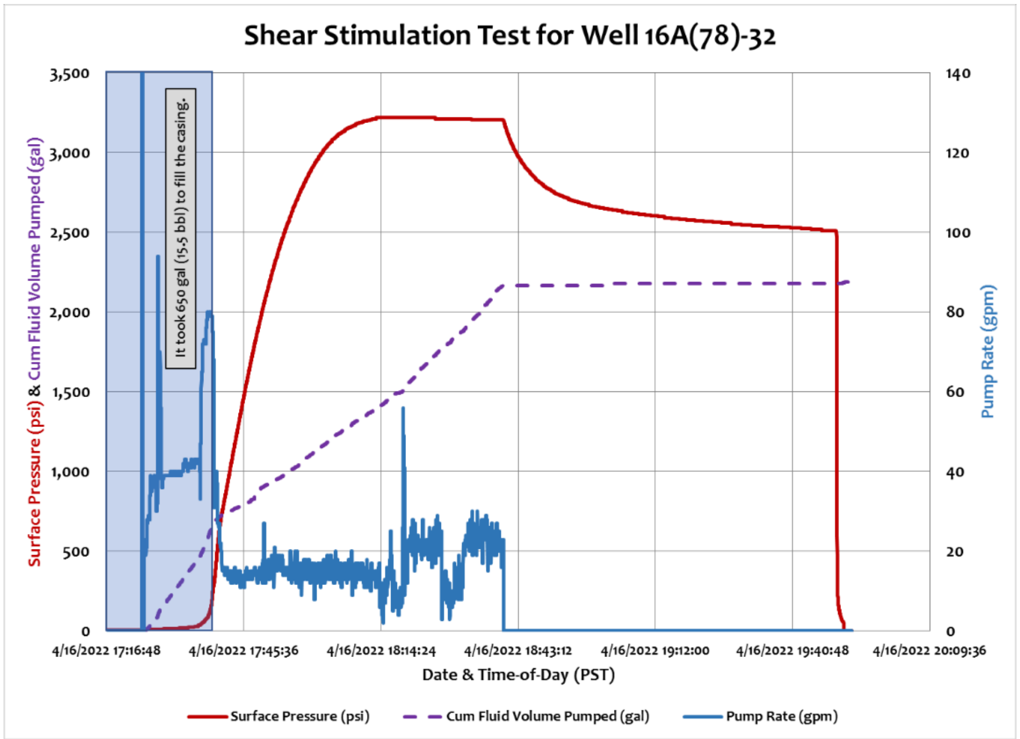


Figure B.1-10. *Pressure record for the shear stimulation test.*

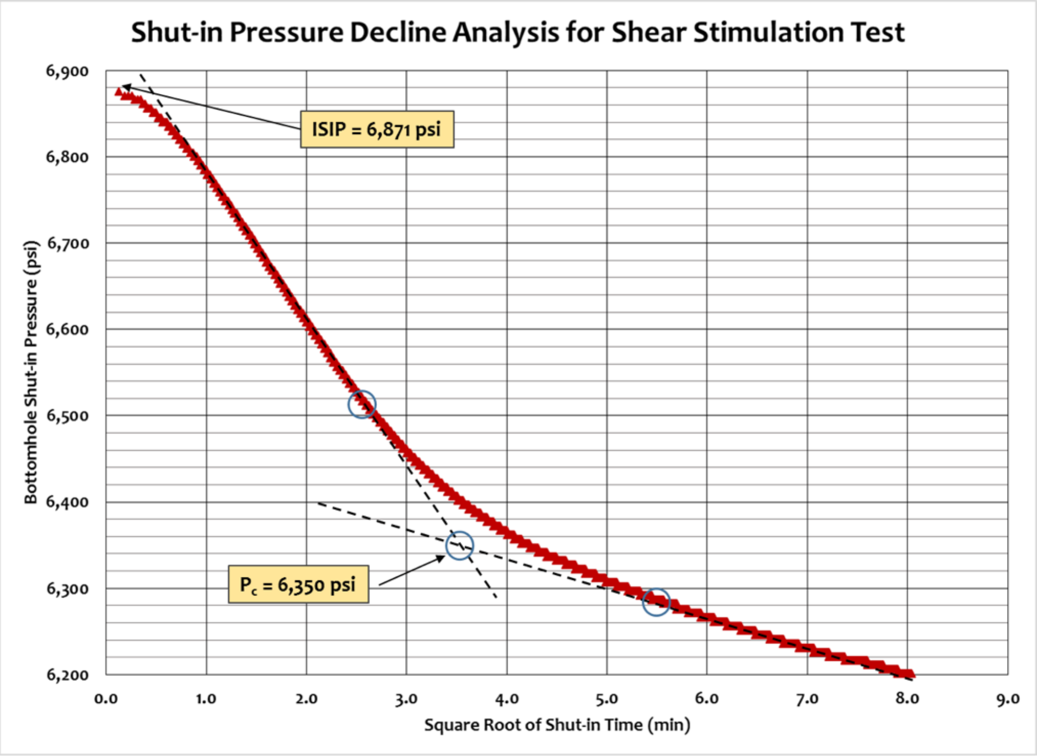


Figure B.1-11. *Analysis of shut-in pressure decline data for the shear stimulation test.*

First Stage Treatment

Following the shut-in period after the shear stimulation test, the first stage slickwater treatment was pumped down the casing, reaching a maximum designed injection rate of 50 bpm (7.95 m^3/min); (Figure B.1-12). This was followed by a step-down in rate to assess the friction pressure. After 4,261 bbl (677.4 m^3) were pumped, the well was shut in for 4 hours before being flowed back.

At a surface pressure of 4,090 psi (28.2 MPa) formation breakdown appears to have occurred during the initial 5 bpm (0.795 m3/min) rate step. Breakdown may not be the preferred term since it would be anticipated that the fluid might preferentially enter where it did during the DFIT and/or shear stimulation test. The jagged nature in the early portions of the pumping could indicate incremental vertical height growth or progressive reopening of new fractures as fluid was forced into the 200 ft (60.96 m) open-hole section. One can notice the flat, rate-independent surface treating pressure after the pump rate became high enough. The constant pressure may indicate some sort of equilibrium between fracture propagation and fluid flow into secondary natural fractures. During the early portions of the first stage, low-magnitude microseismic events were recorded, followed by more significant events (but still small) away from the wellbore before migrating back to the wellbore along an inclined plane representing a possible natural fracture.

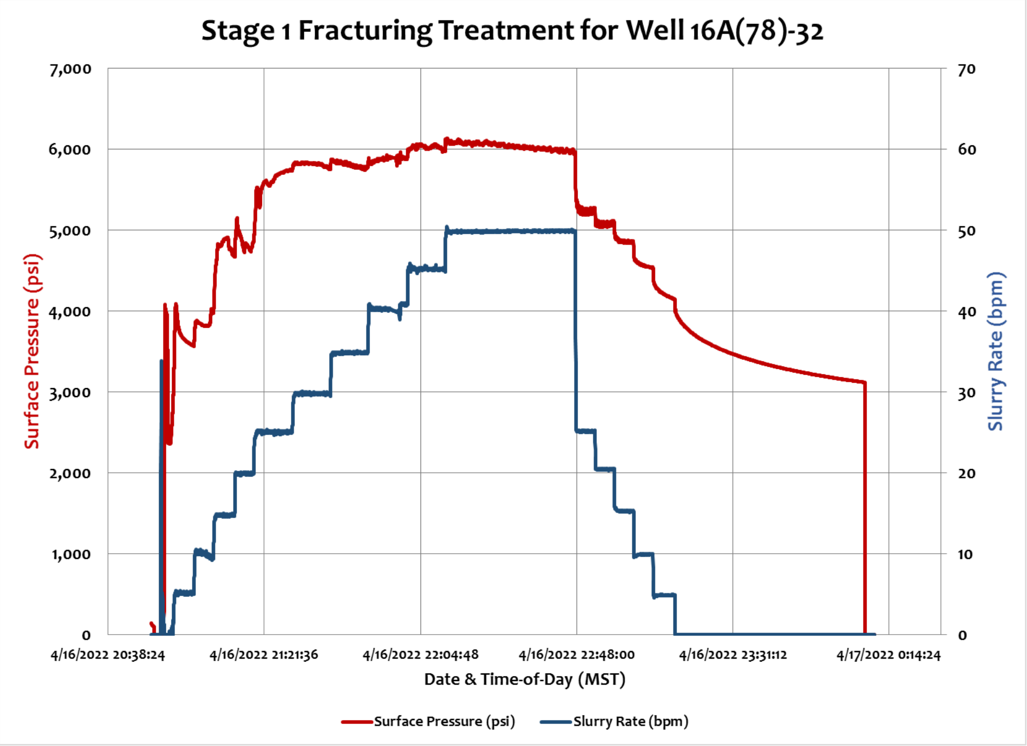


Figure B.1-12. *Treatment record for Stage 1. The blue trace indicates the pumping rate, reaching 50 bpm (7.95 m3/min). The red trace is the surface treating pressure, exceeding 6,000 psi (41.4 MPa). This stage was pumped into the 200 ft (60.96 m) long open-hole section of the wellbore.*

Following the shut-in period after the treatment, the well was flowed back. The flowback was planned and completed to reduce well pressure before running the bridge plug and perforating without surface pressure control equipment. Flowback after each stage also enabled the use of chemical tracers in the different stages to determine if there was any interaction or communication between the stages. The flowback was initiated at a controlled rate of 4 bpm (0.64 m^3/min) and a wellhead pressure of 2,701 psi (18.62 MPa). The well was flowed back for 16.5 hours during which time the wellhead pressure dropped to 0 psi and the flow became intermittent at an average rate of 0.5 bpm (0.0795 m^3/min). A total of 2,055 bbl (326.7 m^3) was recovered during the flowback period. The flowback equipment consisted of a geothermal separator to cool the produced fluid by flashing it to steam. The maximum measured flowback temperature was 224°F (106.7°C).

Isolation and Perforation

The next step in the program was running into the wellbore with an HTHP retrievable bridge plug on drill pipe to isolate the first stimulation stage. Wellbore isolation had historically proven to be difficult for the Utah FORGE project, primarily due to the hot ambient temperature. Several failures to isolate in the past were due to problems with the elastomers and lack of mechanical integrity during the setting and retrieval process. A 7-inch (177.8 mm) HPHT retrievable bridge plug was run and set at a depth of 10,670 ft (3252 m) MD. After positioning the bridge plug at the desired depth, a ball was dropped into the drill pipe. A low-rate pump was used to seat the ball in the hydraulic setting tool. Once the ball was seated, pumping continued until the required pressure was reached to set the bridge plug. After pulling up two stands of drill pipe the bridge plug was pressure tested to ensure isolation integrity before pulling the drill pipe and setting tool out of the wellbore completely.

The 20 ft (6.096 m) perforating gun was then made up on the drill pipe and run into the wellbore. The guns were positioned at the desired depth of 10,560 to 10,580 ft (3218.7 to 3224.8 m) MD and then a ball was dropped into the drill pipe. After allowing the ball some time to fall, a low-rate pump was again used to pump the ball to the seat in the firing head. After the ball was confirmed to be on the seat, the pump rate was increased to ~2 bpm (0.32 m^3/min) until the required pressure was reached and the guns fired. The drill pipe was then pulled out of the wellbore and the perforating guns were recovered and inspected to confirm that all shots had fired.

Second Stage Treatment

The second stage fracturing treatment was pumped with slickwater down the casing following the prescribed fracturing plan. The treatment reached the maximum designed injection rate of 35 bpm (5.56 m^3/min; Figure B.1-13). During the initial 5 bpm (0.795 m^3/min) step, there was an intentional hard shutdown to establish a baseline pressure response with essentially no induced fracture volume created. High-resolution pressure and high-frequency wellhead pressure monitoring could be compared with subsequent shutdowns to better understand hydraulic fracture geometry and near-wellbore effects. A second hard shutdown was performed midway through the maximum pump rate step of 35 bpm (5.56 m^3/min). This was done to measure the shut-in pressure response once a larger hydraulic fracture volume had been created as well as determine the effect of the shutdown on the continuing fracture propagation behavior once the pumping resumed. This shut-in and restart would also be correlated with any potential changes in microseismicity. The maximum pump rate step was again followed by a step-down in rate to generate additional data to determine the pipe and perforation friction pressure behavior. A total of 2,777 bbl (441.5 m^3) was pumped after which the well was shut in for four hours before being flowed back.

Just before the hard shutdown in the initial 5 bpm (0.795 m^3/min) rate stage, a formation breakdown pressure of 6,775 psi (46.7 MPa) was observed. This is significantly higher than the breakdown pressure of 4,090 psi (28.2 MPa) from the first stage. Elevated breakdown pressure considering a surface pressure limitation of 8,000 psi (55.16 MPa) had been a concern because of pressuring out in a perforated zone on a previous well 58-32. The increased breakdown pressure is a result of the difficulty in breaking down the formation through perforations that have a minimal depth of penetration into the high-strength granitic rock. Alternatively, the high breakdown pressure may also have been due to a lack of contact with natural fractures. During the subsequent increased rate steps, there were pressure breaks with decreasing pressure while each rate step was maintained constant. This could be a result of additional fracture height growth with the increased pump rate and possibly the breakdown of additional perforations that were not initially taking fluid.

The hard shutdown midway through the 35 bpm (5.56 m^3/min) rate step was performed mainly to observe any change in fracture propagation behavior and microseismicity once the pump rate was re-established. For background, fracture propagation behavior can change drastically because of shutdowns (planned or unplanned) during the pumping of a fracturing treatment. There are reasons for why this can occur in different types of formations, and the intent here was to observe any changes in the pumping pressure and/or microseismic event behavior that may occur because of the shutdown. In Figure B.1-13, the pressure trend behavior before and after the 5-minute shutdown is unchanged with the same negative slope. This alone likely indicates no change in hydraulic fracture propagation behavior in response to the shutdown. However, there is some indication that microseismic activity was reduced after the shut-in and restart. Some analysts have argued that cyclic injection can reduce microseismicity. After the shut-in/restart, the pump rate was stepped down to gain insight into the friction pressure behavior. After shutdown, pressure was monitored for 4 hours before beginning the flowback.

The stage two flowback was again initiated at a controlled rate of 4 bpm (0.64 m^3/min). The initial wellhead pressure was 2,812 psi (19.39 MPa). The well was flowed back for 13 hours during which time the wellhead pressure dropped to 0 psi and the flow rate was intermittent at an average rate of 0.5 bpm (0.0795 m3/min]. A total of 1,266 bbl (200.6 m^3) was recovered during the flowback period and the maximum measured flowback temperature was 205°F (96.1°C).

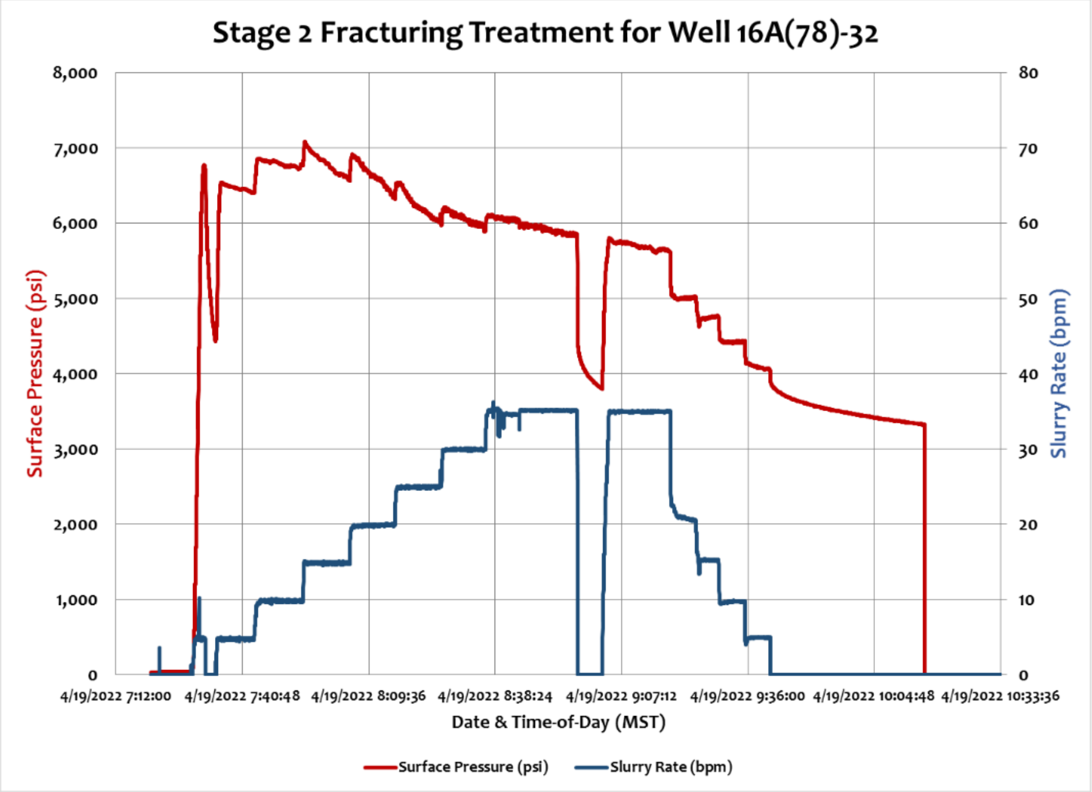


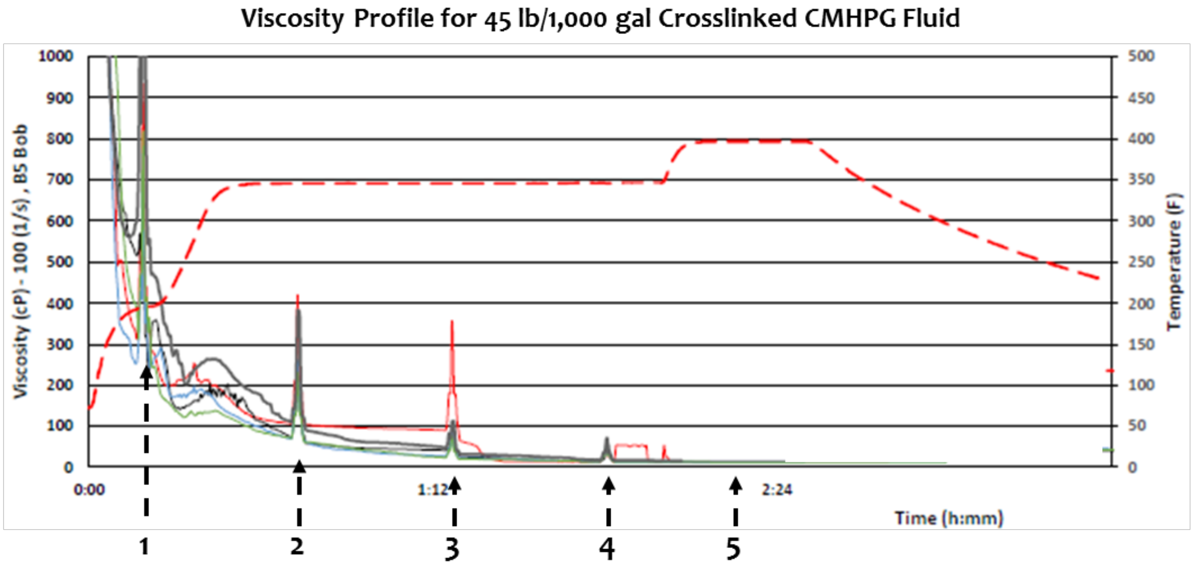
Figure B.1-13. *Treatment record for Stage 2. The blue trace indicates the pumping rate, reaching 35 bpm (5.56 m^3/min). The red trace is the surface treating pressure, exceeding 7,000 psi (48.26 MPa). This stage was pumped into a perforated zone 10,560 – 10,580 ft MD (3218.7 – 3224.8 m) of the wellbore. Note the hard shutdowns where the rate was intentionally rapidly brought to zero in the initial 5 bpm (0.795 m^3/min) stage and partway through the 35 bpm (5.56 m^3/min) step.*

The next operational steps were the same as after the flowback from the first stage treatment. The 7-inch (177.8 mm) HPHT retrievable bridge plug was run on the drill pipe and set at 10,470 ft (3191.3 m) MD to isolate the second stage fracturing treatment. The bridge plug was successfully pressure tested before pulling out of the wellbore completely with the drill pipe and setting tool. The 20 ft (6.096 m) perforating gun was then made up on the drill pipe and run into the wellbore. The guns were positioned and fired to perforate at the desired depth of 10,120 to 10, 140 ft (3084.6 to 3090.7 m) MD. The drill pipe was then pulled out of the wellbore and the perforating guns were recovered and inspected to confirm that all shots had fired.

Third Stage Treatment

The third stage fracturing treatment was designed with the same pump rate schedule as the second stage. The main changes for the third stage were pumping a crosslinked polymer (CMHPG) fluid in place of slickwater and the addition of microproppant early in the pumping schedule.

The crosslinked fluid was selected to determine any changes in hydraulic fracture propagation and final geometry because of the increase in viscosity compared to the slickwater. For simulations performed with hydraulic fracture simulation models, the viscosity of slickwater in the fracture should be considered as water. The addition of polyacrylamide to water provides minimal viscosity in the casing taking into account cool down during the pumping operations but is efficient at reducing the friction pressure. The viscosity of the crosslinked polymer fluid will be significantly higher than the slickwater but would have degraded rapidly upon exposure to the downhole temperature in well 16A(78)-32. Figure B.1-14 shows the viscosity of the crosslinked CMHPG fluid system used for the third stage. The CMHPG polymer loading was 45 lb/1,000 gal (5.39 kg/m^3), and the fluid system contained the necessary crosslinker, buffer, gel stabilizer, and other additives to optimize performance at the formation temperature.



1. As the sample temperature reaches 200°F the viscosity of the fluid is ~350 cP @ 100 sec^{-1}
2. Approximately 15 min after the sample temperature reaches 350°F the viscosity of the fluid is ~95 cP @ 100 sec^{-1}
3. After an additional 30 min of the sample temperature at 350°F the viscosity of the fluid is ~45 cP @ 100 sec^{-1}
4. After an additional 30 min of the sample temperature at 350°F the viscosity of the fluid is <10 cP @ 100 sec^{-1}
5. When the sample temperature is increased to 400°F the viscosity of the fluid is completely degraded to water @ 100 sec^{-1}

Figure B.1-14. *Viscosity profile for several runs of a 45 lb/1,000 gal (5.39 kg/m^3) crosslinked CMHPG fluid system. Notations are the average viscosity at 100 sec^{-1} where shear-rate ramps were taken.*

Microproppant was added to the early steps of the third stage fracturing treatment. The microproppant used for this third stage treatment is manmade with a density of 2.5 g/cm^3 (156.1 lb/ft^3), a particle size distribution of 5 to 200 microns (1.97E-04 to 7.9E-03 inch) and a mean diameter of 25 microns (9.84E-04 inch). The treatment was designed to pump the microproppant at a concentration of 0.5 PPA (0.23 kgPA) starting in the 10 bpm (1.59 m^3/min) step through the 20 bpm [3.18 m3/min] step and increasing to 0.75 PPA (0.34 kgPA) in the 25 and 30 bpm (3.98 and 4.77 m^3/min) steps.

The third stage fracturing treatment was pumped with the crosslinked CMHPG fluid down the casing and followed the prescribed fracturing plan, reaching a maximum designed injection rate of 35 bpm (5.56 m^3/min); (Figure B.1-15). There were no hard shutdowns in the third stage design to avoid additional operational complexity and maintain consistent fluid pumping. When increasing the pump rate to the 10 bpm [1.59 m3/min] an over-pressure sensor was tripped, causing all the high-pressure pumps to come offline but this incident was immediately corrected, and the pump rate was recovered in less than 1 minute. There was some operational difficulty in pumping the microproppant at the designed concentration and schedule. However, no shutdowns occurred and the full amount of microproppant was pumped by extending the 0.75 PPA (0.34 kgPA) concentration into the very beginning of the 35 bpm (5.56 m^3/min) pump rate step.

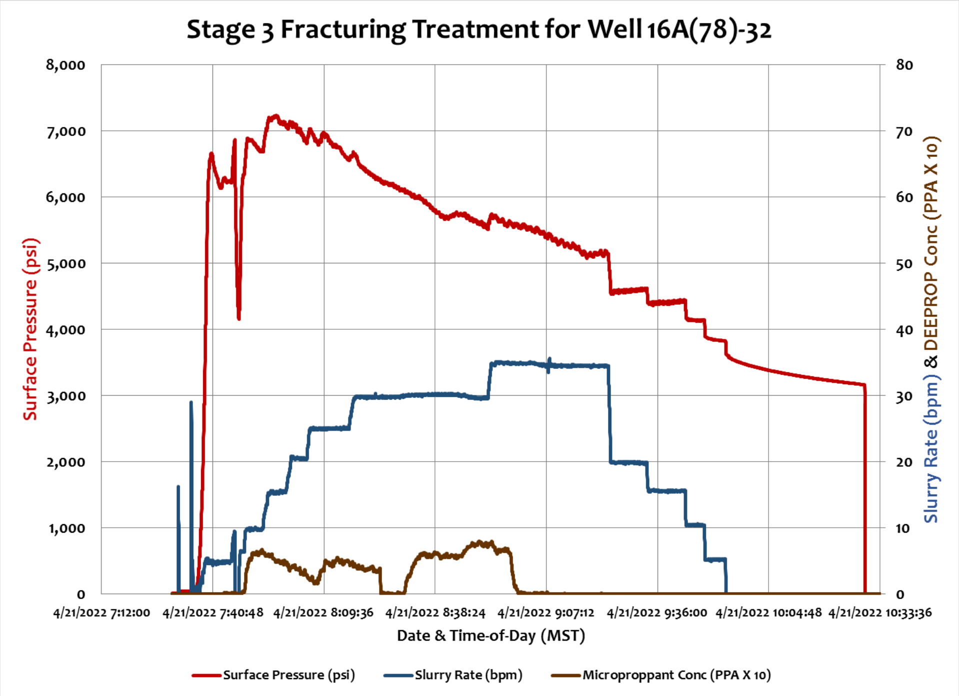


Figure B.1-15. *Treatment record for Stage 3. The blue trace indicates the pumping rate, reaching 35 bpm (5.56 m^3/min). The red trace is the surface treating pressure, exceeding 7,000 psi (48.26 MPa). The brown trace shows the microproppant slurry surface concentration, converted to lb of proppant added to 1 gal of fluid (PPA), based on the slurry rate (Note that the PPA is multiplied by a factor of 10 for scaling purposes). This stage was pumped into a cased and perforated zone 10,120 – 10,140 ft (3084.6 – 3090.7 m) MD of the well.*

During the initial 5 bpm (0.795 m^3/min) step a formation breakdown pressure of 6,659 psi (45.9 MPa) was observed. This is almost the same as the breakdown pressure of 6,775 psi (46.7 MPa) from the second stage. This provides insight and demonstrated consistency for the breakdown of the granitic rock through the perforated casing. During the initial three rate steps, there were similar pressure breaks with decreasing pressure although each rate step was maintained constant. After the pump rate was increased to 20 bpm (3.18 m^3/min), the negative surface pressure trend persisted. This could be an indication that more hydraulic fracture height growth was obtained earlier in the stage than occurred in the second stage. This could have been due to pumping a higher viscosity fluid system. The negative slope of the pressure trend with the increasing rate steps was also substantially higher than what was observed in the second stage.

A more in-depth analysis of the effect of the microproppant was performed by focusing on the pressure response when the different concentrations of microproppant reached the perforations. Each of the concentration changes arrived at the perforations during times when the pumping rate was constant making for a more straightforward interpretation. In all cases when changes in the concentration of microproppant reached the perforations there was no response in the measured pressure. Even after all the microproppant was displaced through the perforations there was no noted variation in the pressure behavior. This means that the microproppant did not seem to have any impact on the hydraulic fracture propagation behavior.

The pump rate was stepped down after the maximum pump rate was reached as in the previous stages. The shutdown pressure was monitored for 5 hours before beginning flowback of the third stage.

The flowback control valve was partially opened and a maximum rate of 3.83 bpm (0.61 m^3/min) was achieved after the valve was fully opened. The initial wellhead pressure at the start of flowback was 2,483 psi (17.1 MPa). The well was flowed back for 15.5 hours during which time the wellhead pressure dropped to 0 psig and the well flowed intermittently at an average rate of 0.5 bpm (0.0795 m3/min). A total of 1,184 bbl (188.2 m^3) was recovered during the flowback period and the maximum measured temperature of the fluid during flowback was 202°F (94.4°C).

Post Stimulation

After flowback, preparations were made to retrieve the bridge plugs from the wellbore. The retrieving tool was made up to the drill pipe, connected to the top drive, and run just below the rig floor (above the BOPs). The rig pumped into the drill pipe at 2 bpm (0.32 m^3/min) to function test the retrieving tool. The test was successful and operations began with running the retrieving tool into the well on the drill pipe. The rig stopped running in the well every ~1,500 ft (457.2 m) to break circulation and provide some cooldown. Upon reaching the depth of the top of the bridge plug the rig sat down weight, latched the bridge plug, and pulled up until the bridge plug was unset. When the plug was unset the well began flowing at ~2 bpm (0.32 m^3/min) up the drill pipe and annulus. Cold water was pumped down the drill pipe at ~0.7 bpm (0.11 m^3/min) so that hot water would not create safety issues at the rig floor when breaking stands as the drill pipe was being pulled from the well. When the bridge plug was at the surface, it was pulled up to just above the BOPs and the blind rams were closed. The top drive was connected to the drill pipe and water was pumped into the drill pipe at 2 bpm (0.32 m^3/min) to hydraulically release the bridge plug from the retrieving tool. This was done successfully, and the bridge plug was pulled up onto the rig floor and laid down on the catwalk. The same procedure was followed to run into the wellbore to unset the second bridge plug and retrieve it to the surface.

After the bridge plugs were retrieved, the well was flowed to get additional fluid samples of commingled fluid from all the fracturing stages that had been pumped. These samples were analyzed for the presence of tracer species to determine the contribution of each stage to the total flowback.

Microseismicity

The most instructive feedback on the hydraulic fracturing came from the recorded microseismicity. Tens of thousands of events were recorded, with magnitudes ranging from -2.3 to 0.5 M. Figure B.1-16 shows reliably detected microseismicity for the open-hole Stage 1 treatment. Only low-magnitude events (~ -2 M) were recorded near the well. These events were identified just below the casing shoe and are not shown in the figure. There is an apparent lack of seismicity in the remaining portion of the open-hole section. It may be that the lack of significant events near the wellbore is the result of potential entry into multiple pre-existing fractures. Equally interesting is to view the chronological growth on an inclined plane, back towards the wellbore. Anticipating that the principal stresses are vertical and horizontal suggests that fluid from the Stage 1 treatment “found” and followed a natural fracture at some distance away from the wellbore.

Figure B.1-17 shows the chronology for each of the three stages; Stage 1 is at the right, and the earliest time is the color at the bottom of each respective bar. Stage 2 appears to have less vertical extent than Stage 3, although the microseismic cloud appears to be near the planned location of the second well (shown as the pink line). The highest quality microseismic data came for Stage 3. A relatively simple vertically growing fracture is indicated, supporting inferences from the treating pressure data. The map view suggests that the Stage 2 fracture may be slightly inclined and shows a possible bifurcation of the Stage 2 fracture. Stage 3 events define a relatively narrow zone that definitively bifurcates away from the well.

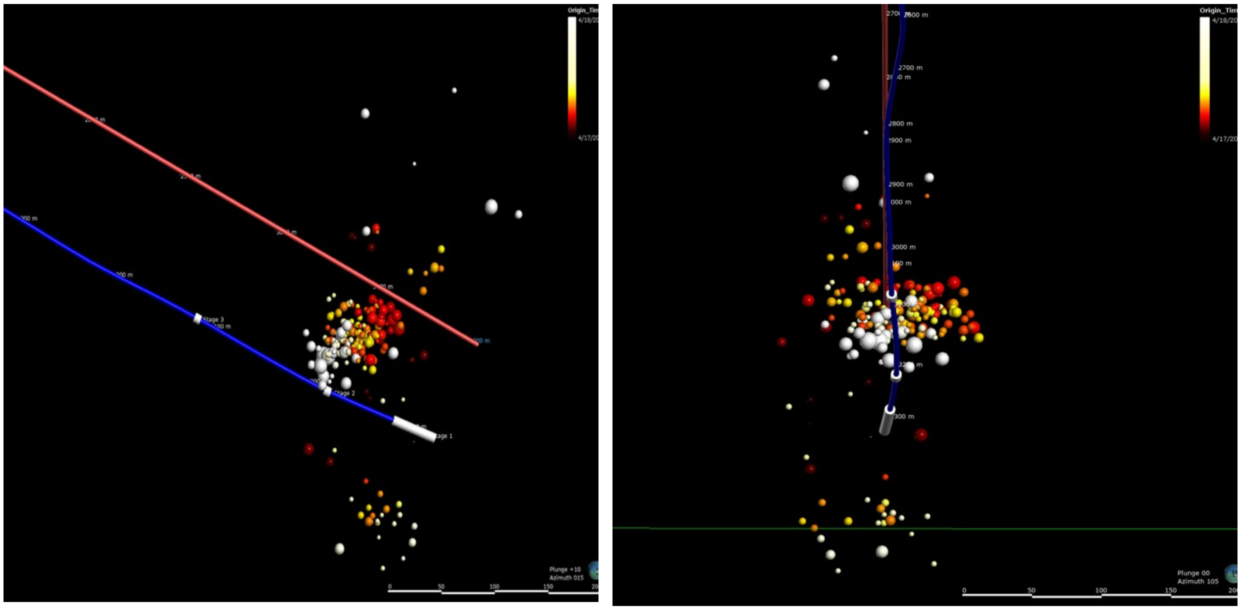


Figure B.1-16. *Detected microseisms from Stage 1. The color bar shows chronology – the earliest occurrence is denoted by colors from the bottom of the color bar. The size of the sphere correlates with magnitude. Left: Stage 1, vertical section, looking north; the blue line represents 16A(78)-32. Right: Stage 1, looking up, azimuth of well is N105E.*

Figure B.1-18 shows the microseismic response associated with the hard shutdown during Stage 2 (Figure B.1-13). While the observation is preliminary, it seems that seismicity rates drop because of the sudden shut-in. When injection resumed at 35 bpm (5.56 m^3/min), the rate of seismicity started increasing but it never reached the earlier rate of approximately 40 to 50 events/minute.

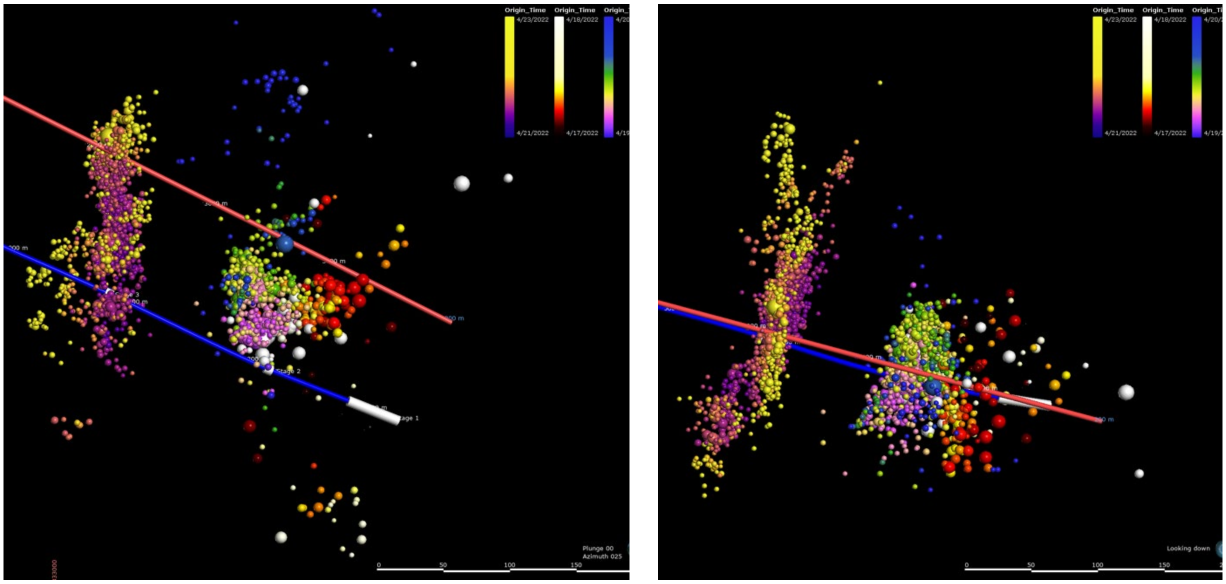


Figure B.1-17. *Detected microseisms from Stages 1 through 3. The color bars show chronology for each stage – the earliest occurrence is denoted by colors from the bottom of the color bar. The size of the sphere correlates with magnitude. Left: Vertical section, showing all three stages looking north with Stage 3 on the far left. Right: Plan view of all three stages, looking to the northeast.*

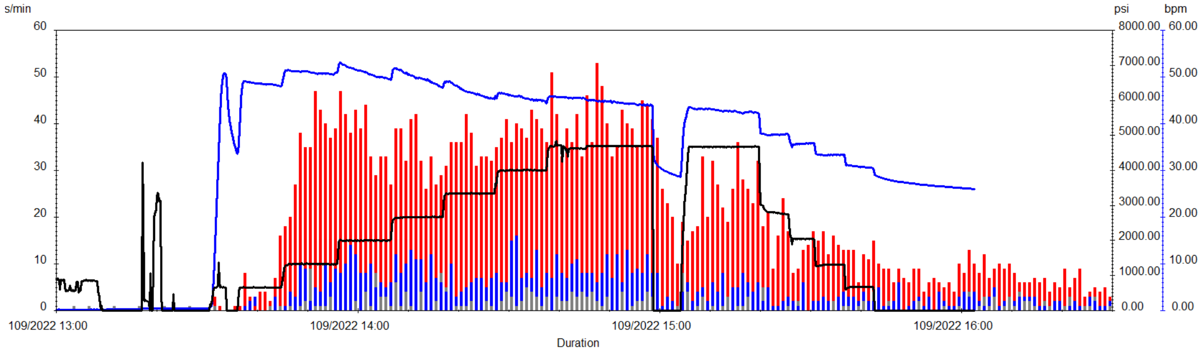


Figure B.1-18. *Recorded microseismic events for Stage 2 where the red bars represent trigger rates, the blue bars show the located event rates, and the grey bars indicate the noise trigger rate. The blue solid line is the surface pressure, and the dark solid line is the pumping rate.*

Geochemistry of Flowback Waters

As described above, two types of fluids were injected, one containing slickwater and a second containing a crosslinked polymer. In addition, a distinct naphthalene sulfonate compound was added to the injected fluids at each stage to act as a non-reactive tracer. Samples of flowback waters were collected and analyzed to monitor tracer concentrations and water chemistry. Of the 10,062 bbl injected, 6,240 bbl, or 62% of the fluid was recovered. That left 3,822 bbl, or 38% in the reservoir at the end of the stimulation activities prior to well shut-in, equivalent to 21,471 ft3 (608 m3). The results of tracer testing (i.e., stage 1 1,6-nds; stage 2 1,3,5-nts; Stage 3 1,3,6-nts) showed there was no interaction or mixing of injected tracers, demonstrating zonal isolation of stimulated fractures and confirming the stability of tracers at reservoir conditions (Figure B.1-19).

Geochemical data for water samples collected in series during each flowback show sharp changes to the composition of the water over short periods of time (Figure B.1-20). The injected water was culinary grade and sourced from the municipal water supply of Milford, Utah, and it was modified in Stages 1 and 2 with friction reducer to create slickwater; in stage 3, a crosslinked polymer system with low concentrations of proppant was mixed into the injectate. Changes in fluid chemistry are observed in water samples, and these become more pronounced with time, presumably due to earlier samples having had limited water-rock interaction compared with fluids sampled later that were displaced further from the wellbore and were in contact with the reservoir rocks for longer periods of time. Although concentrations increase with time for most of the elements analyzed, Mg is an exception. The most pronounced increases are in the concentrations of Cl (51 to 4,643 mg/kg) and corresponding cations Na (50 to 2,319 mg/kg), K (2 to 403 mg/kg), and Ca (24 to 253 mg/kg). SiO_2 concentrations increase sharply from an initial value of ~20 mg/kg and appear to stabilize at different levels in the three flowbacks, with concentrations highest in flowback 1 and lowest in flowback 3. The sharp increase in B for flowback 3 is likely the result of a sodium tetraborate additive in the crosslinked polymer fluid. No contributions to the analyzed elements are expected from the slickwater additives (hydrocarbons and alcohols). Mg shows a sharp decline with time from ~14 to ~2 mg/kg. Geothermal waters are generally depleted in Mg due to the precipitation of Mg-bearing minerals at elevated temperatures in geothermal reservoirs (e.g., Giggenbach, 1988). Within the Utah FORGE EGS reservoir both interlayered chlorite/smectite and ankerite are Mg-bearing phases that have been observed filling fractures.

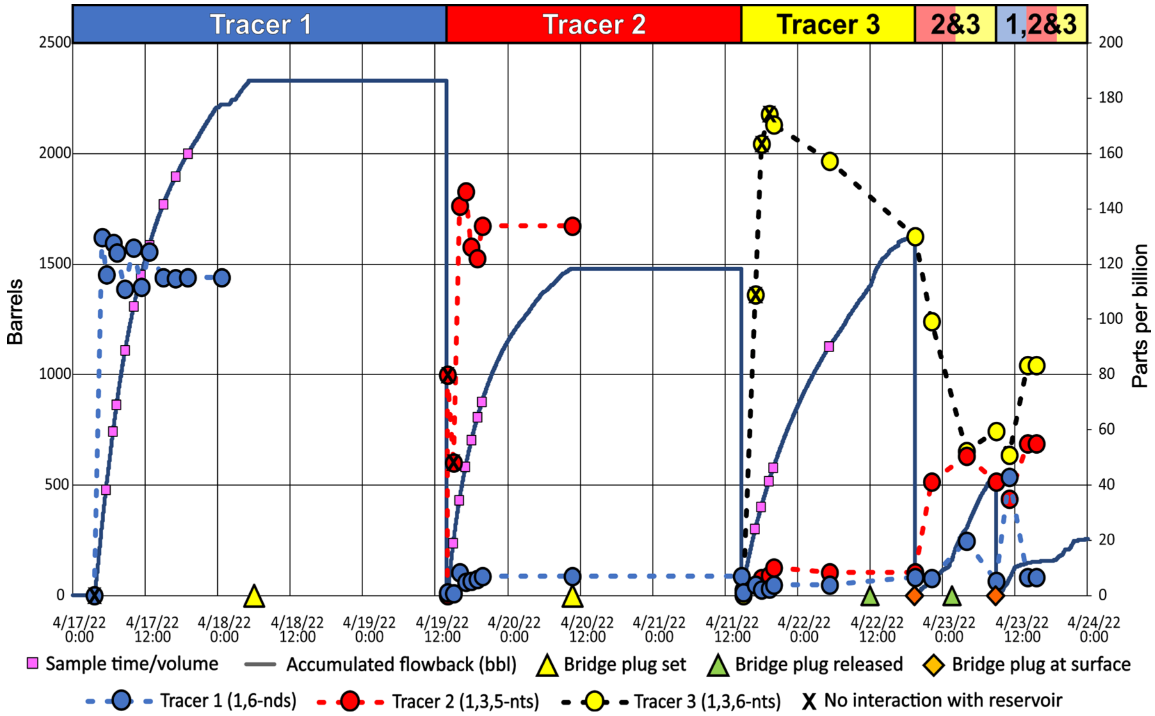


Figure B.1-19. *Summary of tracer concentrations in flowback waters vs time. Also shown are the cumulative flowback volumes with sample times plotted, and time indicators for setting and unsetting the bridge plugs as well as when the bridge plugs were returned to the surface. Tracer concentration values marked with an 'X' denote samples that never left the casing string and often contained water without tracer.*

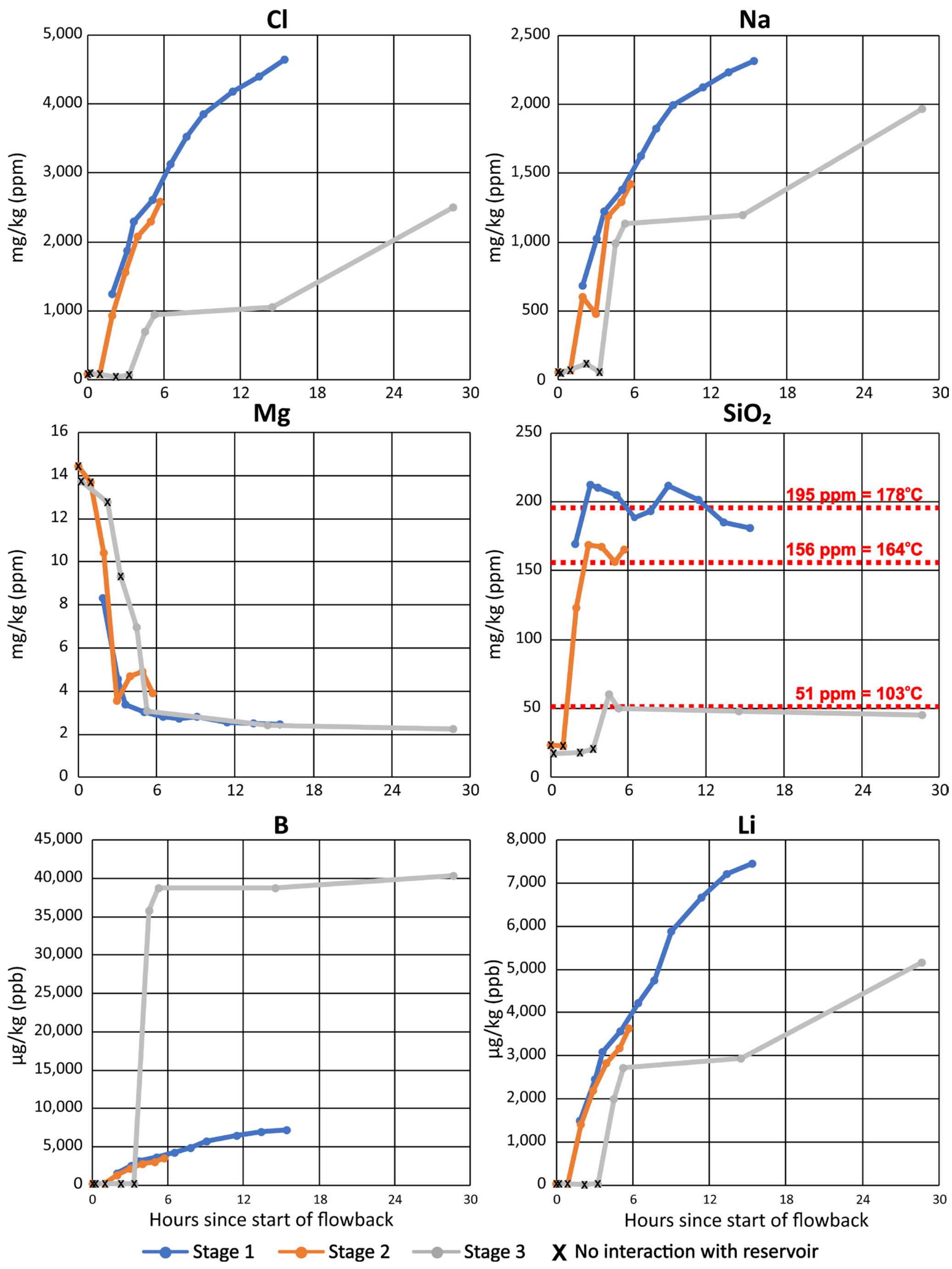
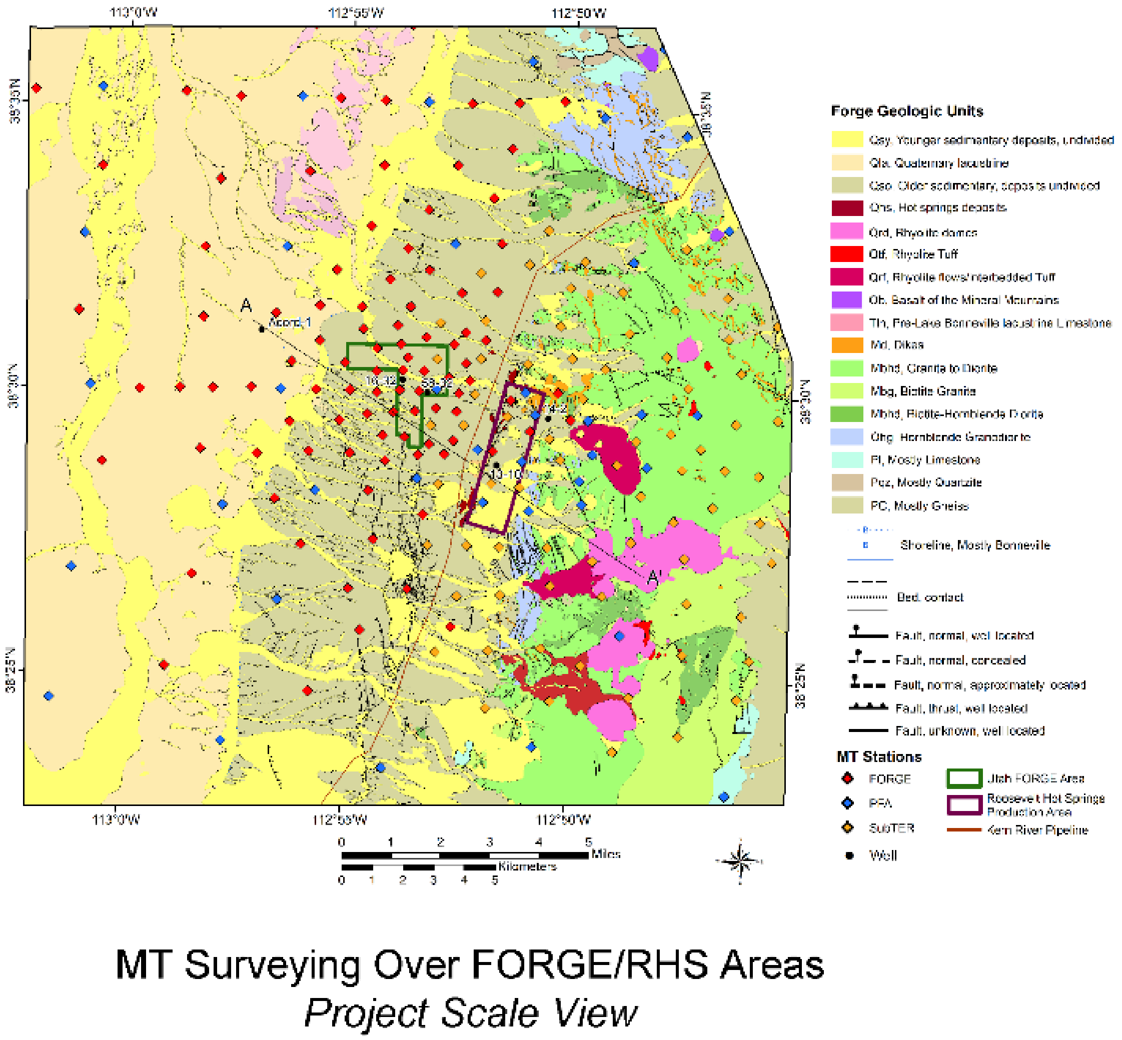


Figure B.1-20. *Select chemistry results for flowback waters plotted vs hours since start of flowback. Samples with an 'X' indicate that that aliquot of fluid did not interact with the reservoir rock. Dashed lines on the* SiO_2 *plot denote average concentrations for fluids that interacted with the reservoir and their corresponding values for the quartz geothermometer (Fournier and Potter, 1982).*

Magneto-Telluric Experiment

In spring 2022, MT data were collected over the Utah FORGE project area aimed at resolving reservoir resistivity changes due to the stimulation experiment at the toe of well 16A(78)-32. These data augment an existing larger dataset previously modeled (Figure B.1-21) (Wannamaker et al., 2021). This work was motivated in part by the results obtained in the Cooper Basin, Australia, hot dry rock project by Peacock et al (2013), where fluid injection resulted in a measurable change in the MT response.



MT Surveying Over FORGE/RHS Areas

Project Scale View

Figure B.1-21. *MT site survey map of the Utah-FORGE project area showing prior station coverage. Red-brown trend running NNE-SSW through the project area is the Kern River pipeline (KRP). Utah FORGE property boundary is shown as a dark green polygon Dark red-brown rectangle shows approximate production area of the Roosevelt Hot Springs (RHS) geothermal system.*

Twenty sites were established to measure electric (E) fields over an area approximately 2 x 3 miles, encompassing the Utah Forge site (Figure B.1-22). A pair of horizontal coils recording magnetic field variations was placed at site #19, used to reference the E fields, and form the tensor MT impedance Z. Additionally, coils were installed at a remote reference ~60 km to the northwest of Utah FORGE for noise cancellation. Data were recorded before (group A), during (group B), just after (group C), and several weeks after (group D) stimulation of well 16A(78)-32 (Figure B.1-23). Soundings showing evidence of heavy noise contamination unable to be removed during processing were discarded, yielding the dataset listed in Table B.1-1.

Table B.1-1. *Available soundings for each site from the 2022 survey.*

	Sounding			
Site	**a**	**b**	**c**	**d**
FTM001	✓	✓	✓	
FTM002	✓		✓	
FTM003	✓	✓		
FTM004	✓	✓	✓	✓
FTM005	✓		✓	
FTM006	✓		✓	
FTM007	✓		✓	
FTM009	✓	✓	✓	
FTM010	✓	✓	✓	
FTM011	✓			
FTM012	✓		✓	✓
FTM013	✓			
FTM014	✓			✓
FTM015	✓			
FTM016	✓			✓
FTM017	✓		✓	✓
FTM018	✓		✓	✓
FTM019	✓	✓	✓	✓
FTM020	✓		✓	✓
FTM021	✓	✓	✓	

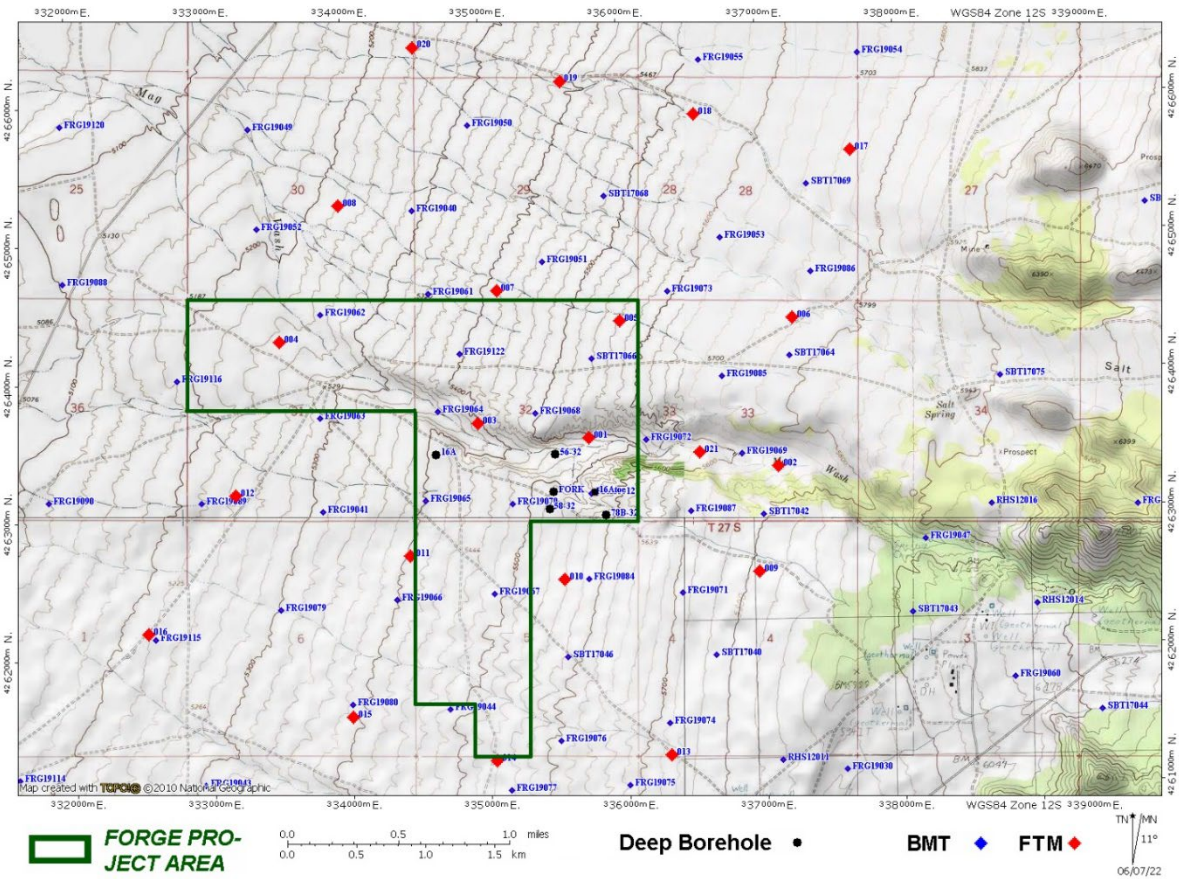


Figure B.1-22. *Layout of MT sites (FTM red diamonds) interspersed among baseline MT sites (BMT blue diamonds) over the Utah FORGE project area (dark green polygonal outline). Site 19 toward the north contained a pair of orthogonal H coils for impedance definition at telluric sites. Several deep well heads are marked, as well as the surface projection of the toe of well 16A(78)-32.*

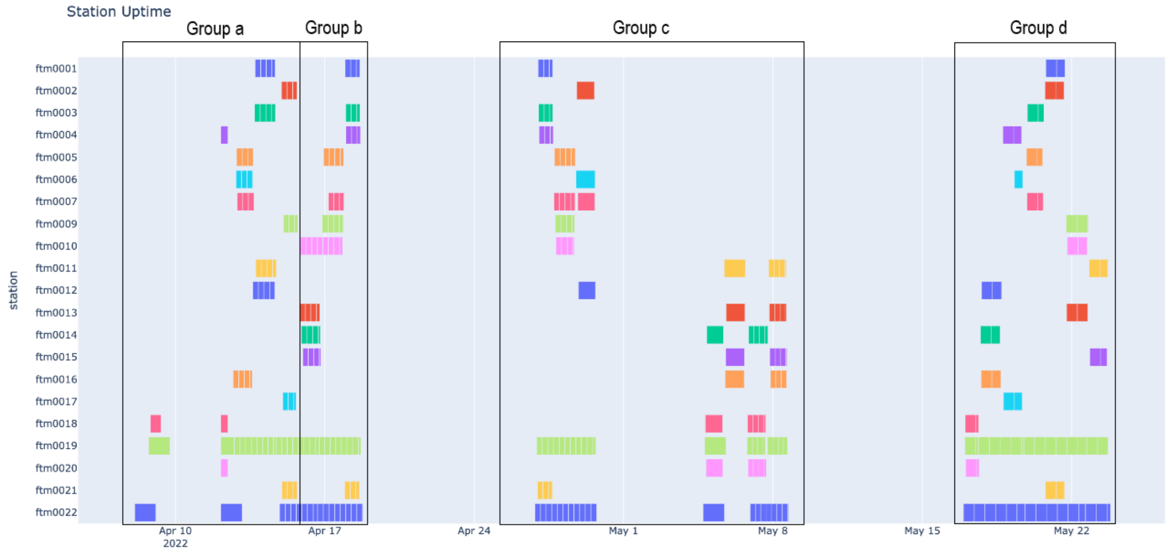


Figure B.1-23. *Plot of overlapping station up times for telluric sites with the base coil and remote reference coil (site 22) recording times.*

Site 1 is located ~ 1 km north of the toe of well 16A, closest to the experiment area. Soundings for site 1 before and after the experiment appear in Figure B.1-24. We do not observe noticeable differences in the measured MT responses beyond the noise floors, attributable to the stimulation experiment at the toe of well 16A(78)-32.

The project area was modeled by 3D inversion of the soundings collected before (inversion #1), and collected after (inversion #2) the stimulation. The 3D model includes a representation of the well casing as highly conductive strings of elements, and a representation of the Kern River Pipeline (KRP). The 3D inversion is done using the 3D finite element algorithm (Kordy et al, 2016). A finite element mesh was constructed, which accommodates the data consisting of 103 (x=grid north) by 129 (y=grid east) by 112 (z=down) cells with 16 layers of air. A surface view of the central part of the finite element mesh is shown in Figure B.1-25. Project area elevations for the finite element mesh nodes are from the Utah FORGE LiDAR project supplemented by the SRTM resource. Outermost surface elevations are fixed to 1500 m. The mesh is deformed vertically to mimic the topography at the air-earth interface. The grid is rotated to orient grid-northing at an azimuth of N020 and deformed in the grid-easting direction such that the finite element cells representing the KRP nearest the Utah FORGE project area are minimally deviated. There is a slight deformation of cells in the vicinity of the drillhole to improve approximation of the drillhole trajectory. Cell widths within the project area vary from 6 to 250 m.

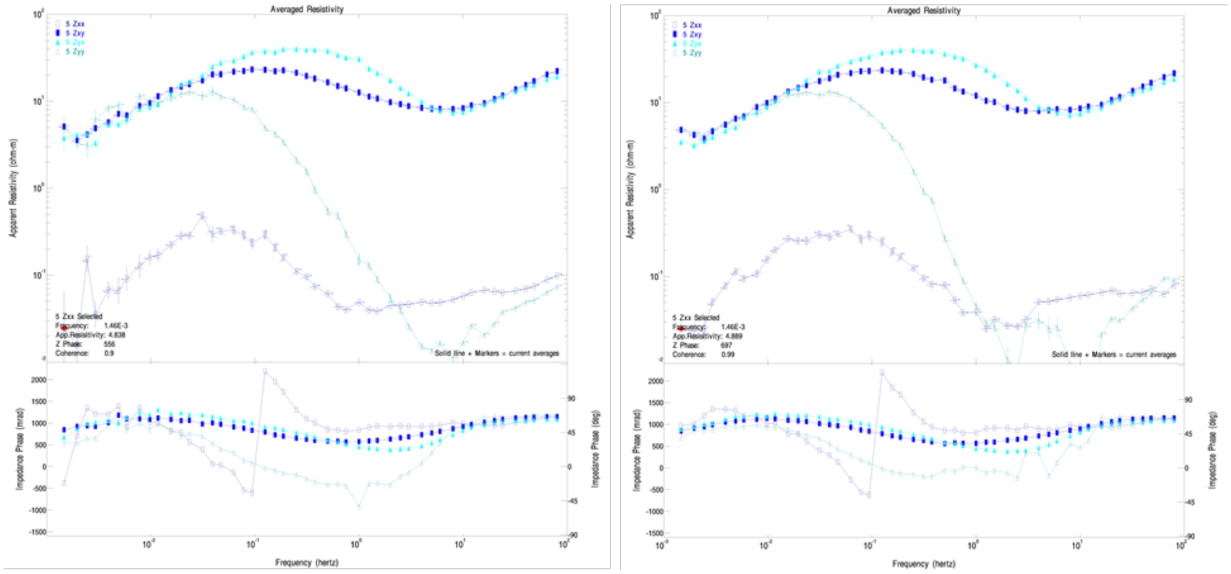


Figure B.1-24. *Site 1 soundings a and c, before and after the injection experiment.*

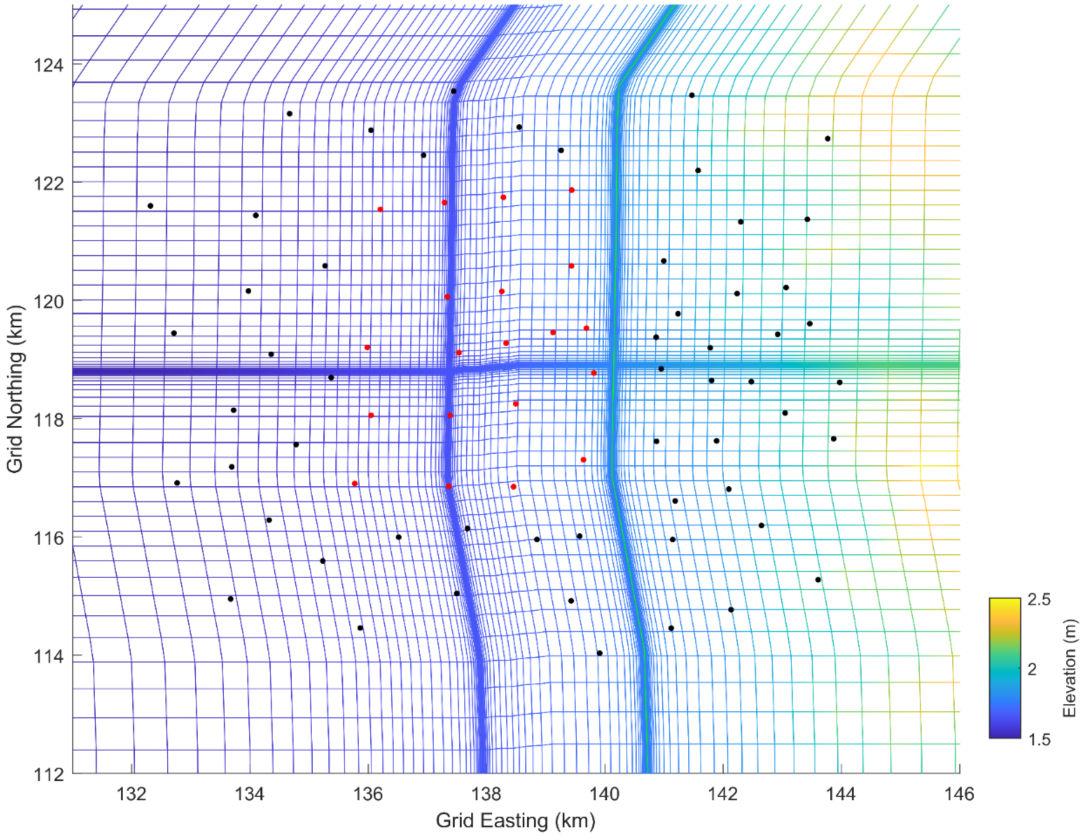


Figure B.1-25. *Surface view of finite element mesh for the 3D inversion. MT stations from 2022 are represented by red dots; prior MT station are represented by black dots. The Kern River Pipeline is shown as the green line running N-S.*

The KRP is represented by a 4x4 string of elements each 12.5 m wide for a total pipeline width of 50 x 50 m, buried in the mesh at a nominal depth of 50 m. Cells representing the pipeline are included as inversion parameters with starting resistivity at 0.0182 ohm-m. The mesh is deformed such that the cells representing the pipeline approximate its path while forming a continuous, edge-to-edge feature without sidestepping. The borehole casing is represented by a 2x2 string of elements each nominally 6 m wide for a total width of 12 x 12 m. Cells representing the casing are included in the inversion with a starting resistivity of 0.018 ohm-m. The mesh is deformed such that the cells representing the casing approximate its path while forming a string of elements.

Air is assigned a fixed resistivity at 1014 Ωm, while the earth starting resistivity is 40 Ωm. Data at 14 frequencies from 75 Hz to 0.0094 Hz are included in the inversion. Error floors are applied to the real and imaginary parts of the complex impedance elements Zij of 5%(|Zxy-Zyx|/2) and to the tipper elements of 0.04 at each frequency.

Inversion #1 was based on the group A dataset, consisting of data at 20 stations. Inversion #2 was based on the group C dataset with additional soundings from Group D for a total of 16 stations. Both datasets were supplemented with surrounding soundings from the larger existing dataset for a total of 76 stations for inversion #1 and 72 stations for inversion #2. The inversion is parallelized to run on a Linux workstation with 36 cores and 1.5 TB RAM and requires approximately 1 week. Test runs were done to test borehole representation and fine tune stabilization.

Results from inversion are shown in Figures B.1-26 through B.1-29. For inversion #1, with data collected before the experiment, a final nRMS misfit in the impedance data of 0.9 is achieved in 12 model updates, from a starting value of 14.8. A west-east vertical cross-section is shown in Figure B.1-26 in the center of the area of interest, showing the representation of the casing and the cross-section of the KRP. A plan view at an approximate depth of 1.1 km is shown in Figure B.1-27. For inversion #2, of data collected after the experiment, we retain the same reference model as for inversion #1, and start the inversion from an approximate model (update 8 from inversion #1). The final nRMS for inversion #2 is 0.94. The west-east vertical cross section is shown in Figure B.1-28 and plan view at approximately 1.1 km depth in Figure B.1-29. Overall, the two results are similar, and accounting for the more restricted data set used in this work, these results appear similar to those from inversions using larger datasets reported previously, including in the Phase 3A Year 2 Annual Report. The most apparent difference in recovered resistivity structure obtained for data recorded before and after the experiment occurs in the center of the survey area. A conductive zone at depths in the range of 0.9 to 1.2 km appears enhanced in the later inversion model. While this coincides with the path of well 16A(78)-32, the lack of data at sites 3, 11 and 15 for inversion #2 makes this inconclusive. The observed differences in recovered models are likely an artefact due to a lack of data and not attributable to the stimulation experiment at the toe of well 16A(78)-32.

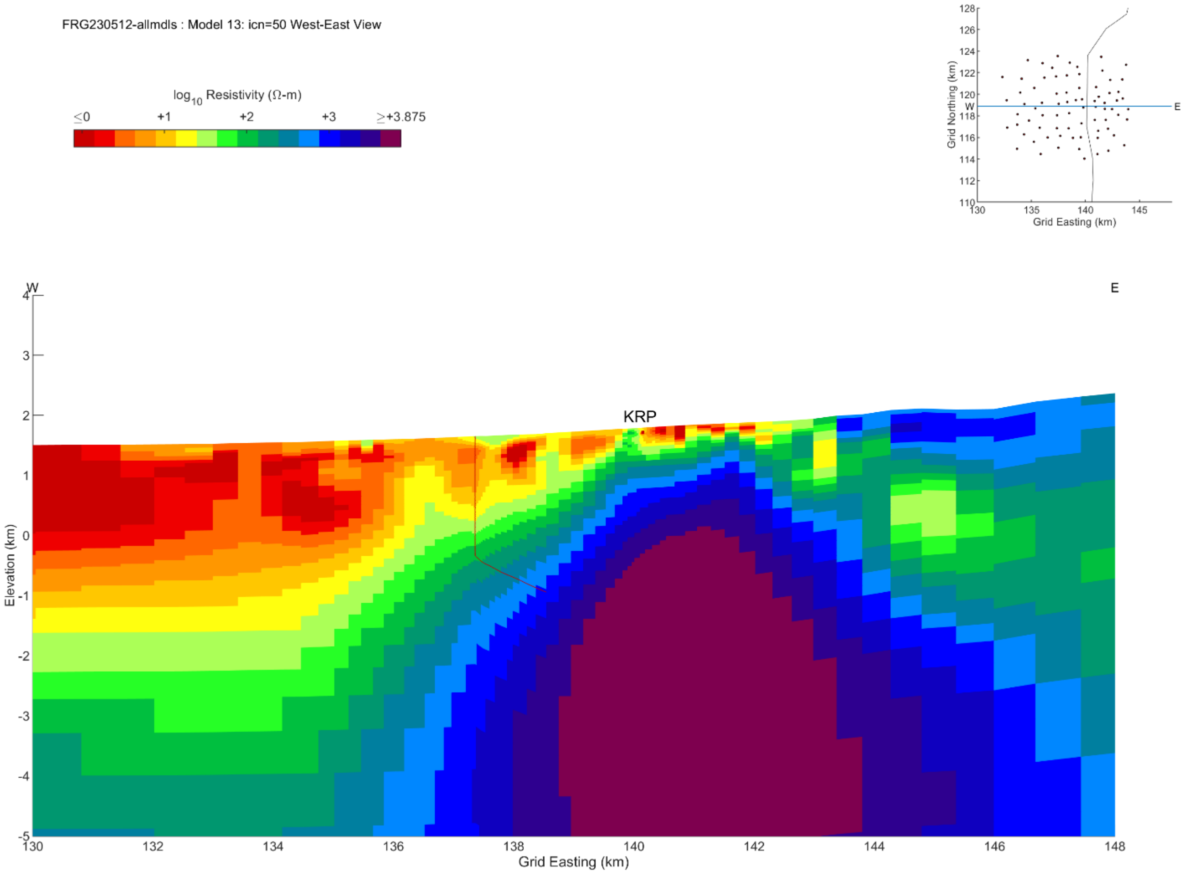


Figure B.1-26. *West-east vertical cross-section of the final resistivity model for inversion #1, including representation of the borehole and Kern River Pipeline cross-section (KRP).*

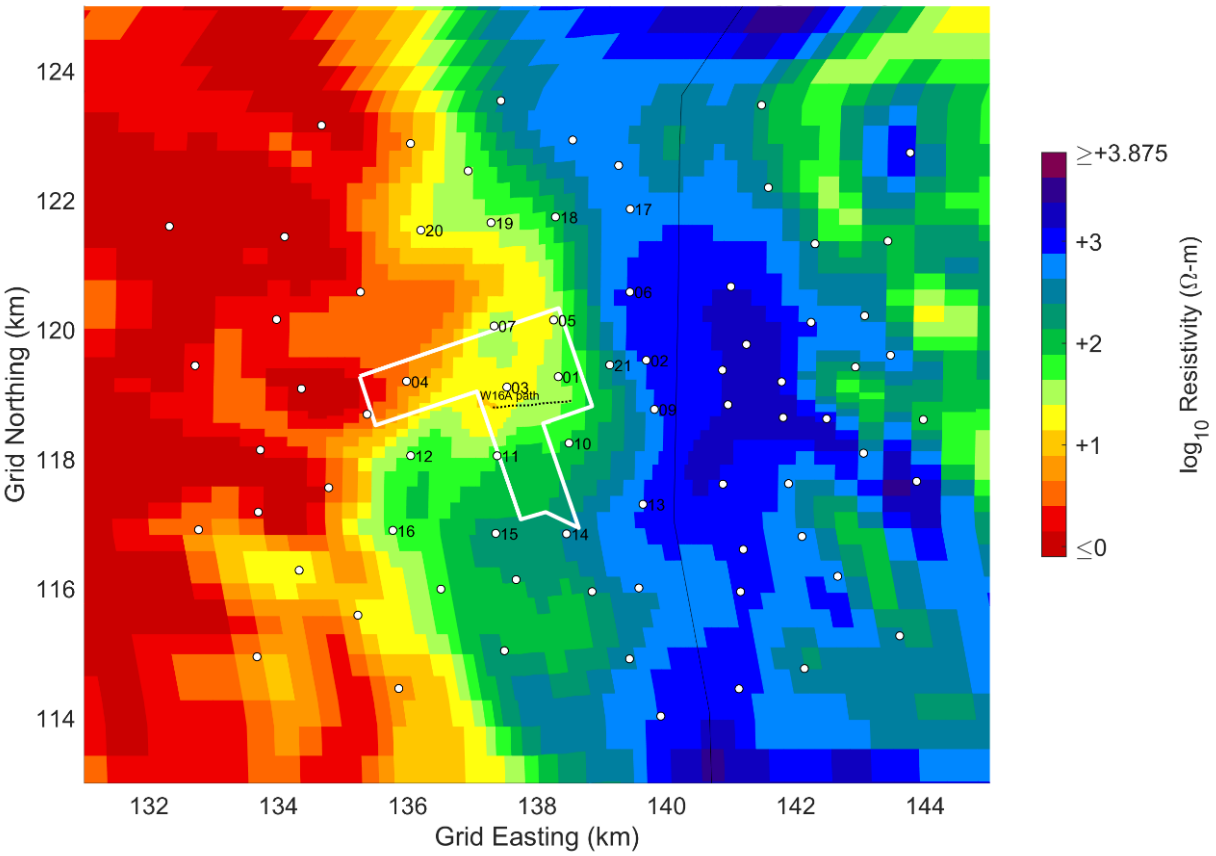


Figure B.1-27. *Plan view of the final resistivity model for inversion #1 at 1.174 km depth. The trajectory of well 16A is shown as the black dotted line inside the Utah FORGE perimeter, shown as a white line; the KRP is the solid black line extending north-south.*

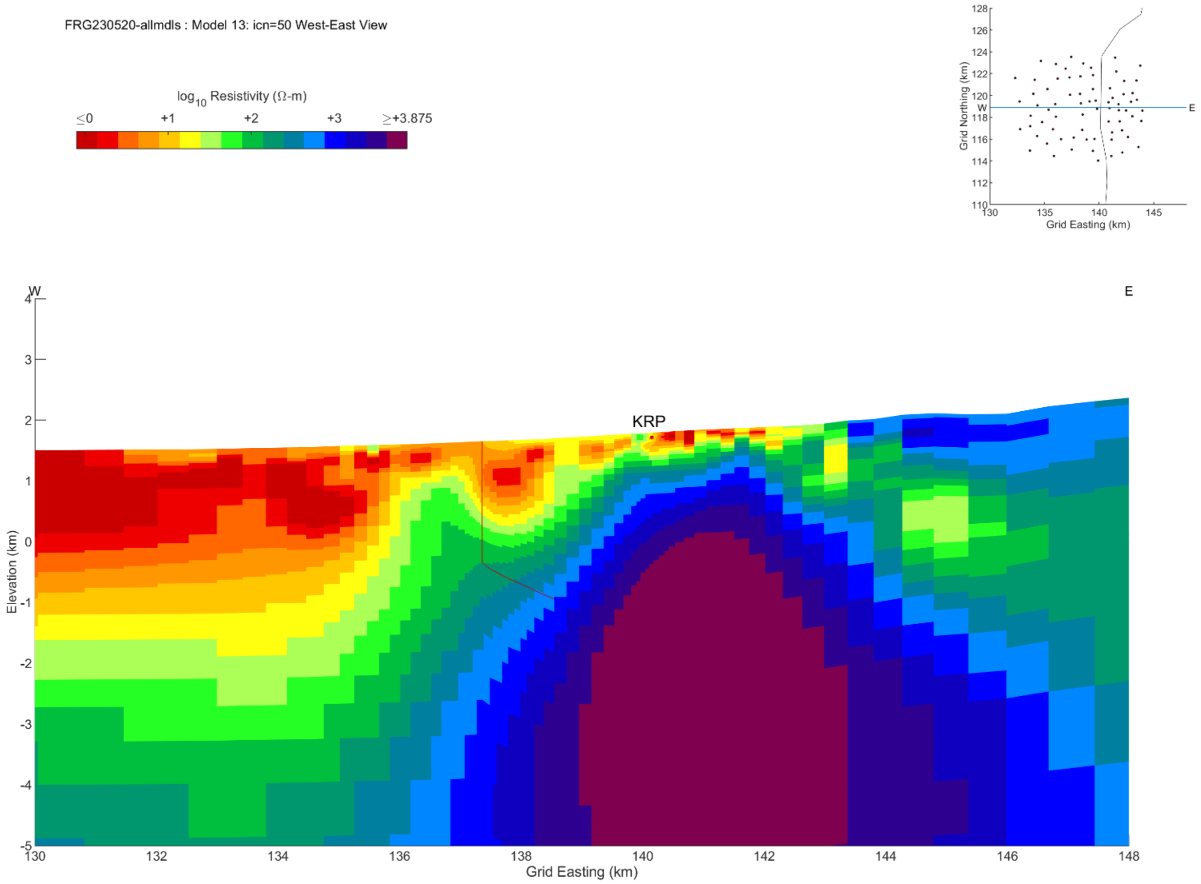


Figure B.1-28. *West-east vertical cross-section of the final resistivity model for inversion #2, which includes data from after the experiment.*

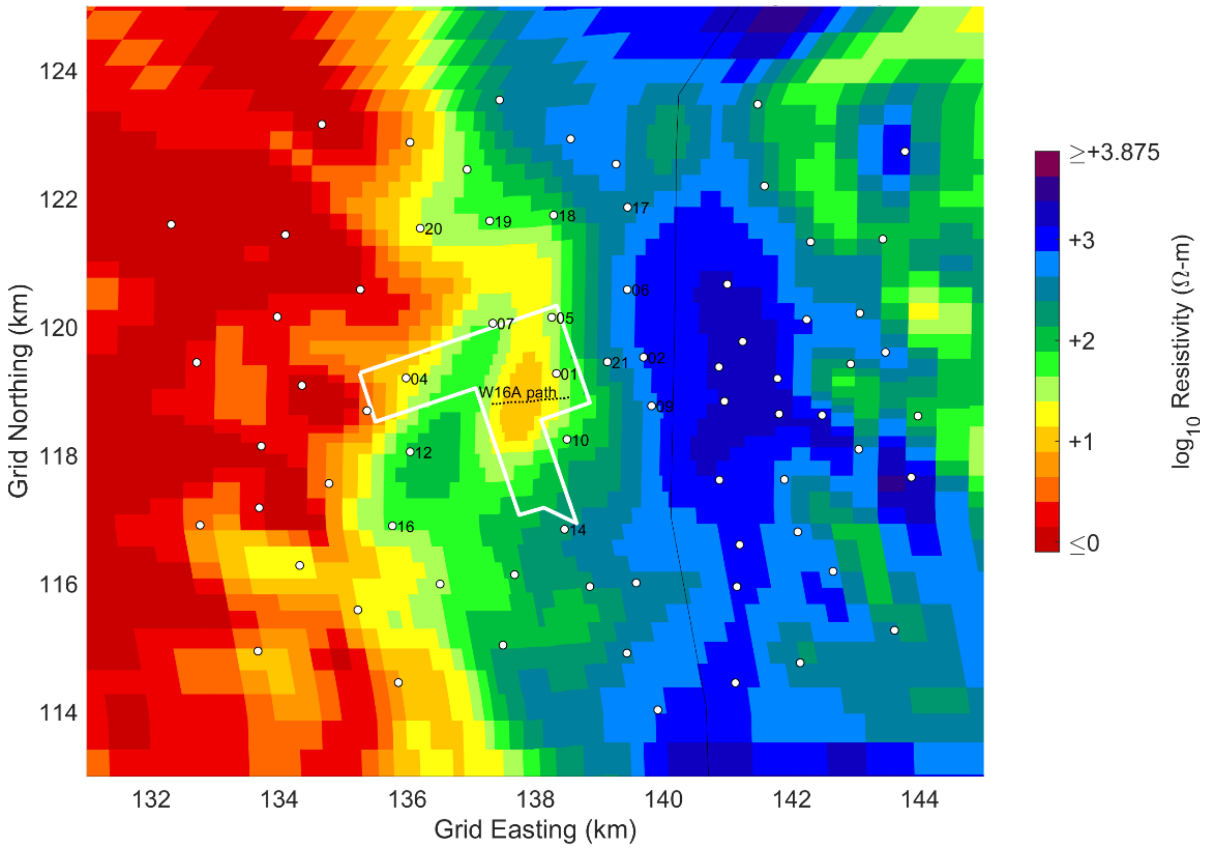


Figure B.1-29. *Plan view of the final resistivity model for inversion #2 at 1.174 km depth. The trajectory of well 16A is shown as the black dotted line inside the Utah FORGE perimeter; the KRP is the solid black line extending north-south.*

B.2 SEISMIC MONITORING

Tasks for seismic monitoring include: (1) Maintenance of Seismic Network and Telecommunications Hub; (2) Monitoring of Local Seismicity for Hazard Assessment; (3) Monitoring of Stimulation and Post-stimulation Seismicity at Reservoir Depths; (4) Convene Post-Stimulation Seismic Forum and Produce Summary Report; (5) Update Induced Seismicity Plan (ISMP); and (6) Collaborate and Coordinate Seismic Experiments. In addition to the tasks explicitly stated in the SOPO, the seismic monitoring group also engages in outreach related talks (Table B.2-1).

Table B.2-1. *Seismic Outreach Talks.*

1. Society of Petroleum Engineers Dinner—Engineered Geothermal Systems Seismic Monitoring: Insights Gained at Utah Forge, February 2023
2. Enhanced Geothermal Systems in the World, Pohang, South Korea Symposium—Invited Speaker, The Utah Frontier Observatory for Research in Geothermal Energy (FORGE): Seismic Monitoring, November 2022.
3. Geothermic DEEP Annual Meeting—Invited Speaker, Seismic Monitoring During the 2022 Utah FORGE Stimulation, September 2022.

Maintenance of the Seismic Network and Telecommunications Hub

Data flow from the local seismic network are monitored using industry standard algorithms, including Nagios. When there is a disruption in data flow, the seismic station is interrogated remotely to diagnose the issue and if possible, apply corrections to restore data. If data cannot be restored an engineer visits the site. There have been several site visits over the last year, and data flow has been restored in a timely manner and when possible data that stored on-site back filled into the system and was added to the data archive.

Local Seismic Monitoring for Hazard Assessment:

Seismic Network Updates

The last of the three local seismic monitoring stations were installed in April 2022. These three stations, FSB 4, FSB 5, and FSB 6, help to form a ring of stations at ~ 8 km from the 58-32 well pad. These stations are located in the valley in ~40m deep boreholes. The instrumentation includes three-component broadband sensors. Table B.2-2 provides details, sensor type, location type, SEED naming, and sample rates for all the stations in the local network.

While the local stations located in shallow boreholes have been operational and the P- and S-arrivals are routinely used in determining event locations, the full use of the horizontal components has yet to be utilized. This is because we have not had the orientations of the sensors. The check shots were too small to record at these stations. As part of his Master’s Thesis, Patrick Bradshaw has used teleseismic surface waves to determine the orientation of these sensors and we will soon be updating the metadata to reflect the results of his analysis. A summary of the orientations is provided in Table B.2-3.

Table B.2-2. *Description of local seismic monitoring stations.*

Type	SEED Name	Depth	Datalogger	Sensor	Sampling Rate
Shallow borehole	**UU. FORK.EH[Z,1,2] UU. FORK.GH[Z,1,2] UU. FORK.EN[Z,1,2] UU. FORK.GN[Z,1,2]**	**~305 m (~1000')**	**Obsidian**	**OMNI-2400 (short-period) Silicon Audio (accelerometer)**	**200 sps 1000 sps 200 sps 1000 sps**
Shallow borehole	**UU.FSB[1,2,3].HH[z,1,2] UU.FSB[1,2,3].EN[z,1,2] UU.FSB[1,2,3].DN[z,1,2]**	**~30 m (~100')**	**Centaur**	**Trillium Cascadia (broadband) Titan (accelerometer)**	**200 sps 200 sps 500 sps**
Shallow borehole	**UU.FSB[4,5,6].HH[z,1,2]**	**~40 m (~140')**	**Centaur**	**Trillium Cascadia (broadband)**	**200 sps**
Rock Site	**UU.FOR[1,5,6,7,8].HH[Z,E,N]**	**Surface**	**Centaur**	**Trillium 120, 120[Q,P]A, or Horizon (broadband)**	**200 sps**
Soil Site	**UU.FOR2.HH[Z,E,N]**	**Surface**	**Centaur**	**Trillium 120PA (broadband)**	**200 sps**
Rock Site	**UU.FORU.HH[Z,E,N]**	**Surface**	**Reftek RT-130**	**Guralp-40T (broadband)**	**200 sps**
Strong-motion	**UU.[FORB, FORW].EN[Z,E,N]**	**In-building, Surface**	**Basalt Obsidian**	**Episensor**	**200 sps**
Strong-motion	**UU.MHS2.EN[Z,E,N]**	**In-building**	**Etna 2**	**Episensor**	**100 sps**

Table B.2-3. *Orientations for the horizontal sensors determined using teleseismic surface waves.*

Station	CC Mean	CC Median	CC σ	Pre-bootstrap Angular Mean	Ang. Mean	Ang. Median	Ang. σ	N ev	Recommend adjust?
FOR1	0.94	0.94	<0.01	0	-4	-4	<1	83	No
FOR2	0.92	0.92	0.01	-1	-2	-2	1	48	No
FOR4	0.92	0.92	0.01	-6	-9	-9	2	14	No
FOR5	0.92	0.92	0.01	-24	-27	-27	1	25	Yes
FOR6	0.92	0.92	0.01	3	0	0	1	12	No
FOR7	0.92	0.92	0.01	2	0	1	1	18	No
FOR8	0.94	0.94	<0.01	-15	-16	-16	1	18	Yes
FORK	0.89	0.89	0.01	-103	-105	-105	1	23	Yes
FORU	0.91	0.91	0.01	1	0	0	1	35	No
FSB1	0.92	0.92	0.01	104	103	103	1	34	Yes
FSB2	0.92	0.92	0.01	-118	-118	-118	1	38	Yes
FSB3	0.92	0.92	<0.01	-23	-24	-24	1	40	Yes
FSB4	0.93	0.93	0.01	142	141	141	2	16	Yes
FSB5	0.93	0.93	0.01	-42	-45	-45	2	16	Yes
FSB6	0.92	0.92	0.01	-40	-42	-42	1	17	Yes

Local Seismic Monitoring

Dedicated seismic monitoring of the Utah FORGE site using both the regional and local Utah FORGE seismic networks has been ongoing since Phase 2A. Earthquake locations, event waveforms, and continuous waveforms are available at http://quake.utah.edu/forge-map. Raw seismic data is available at the EarthScope DMC and seismic events are also available via the USGS Comcat catalog. For this reporting period April 1, 2022 through March 31, 2023, 212 earthquakes (M -0.95 to 2.30) have been located (Figure B.2-1and Figure B.2-2). Primary sources of earthquakes are located under the Mineral Mountains to the east of the Utah FORGE site near the Blundell power plant and further east in a known earthquake swarm region (Mesimeri et al., 2021; Zandt et al., 1982). The seismicity close to the Blundell power plant tends to be shallow and we hypothesize it is a byproduct of production activities. Additionally, there is a cluster located near station FOR6. These events are ongoing throughout the project time period but are small in magnitude and occur at very low rates. The events located near station FOR1 are associated with a swarm (no clear mainshock) that began in 2021. 125 events with magnitudes between 0.53 and 3.53 (note that the M 3.53 occurred south of the normal Utah FORGE reporting region) define this sequence. The events appear to define a structure dipping to the west and the focal mechanisms indicate normal faulting on a mostly north-south plane. A more complete analysis of this swarm was published this year (Whidden et al., 2023a). The few earthquakes inside and just to the east of the Utah FORGE footprint are associated with the April 2022 stimulation. Notably, outside of the 2019 and 2022 stimulation periods, no earthquakes have been recorded within the Utah FORGE footprint.

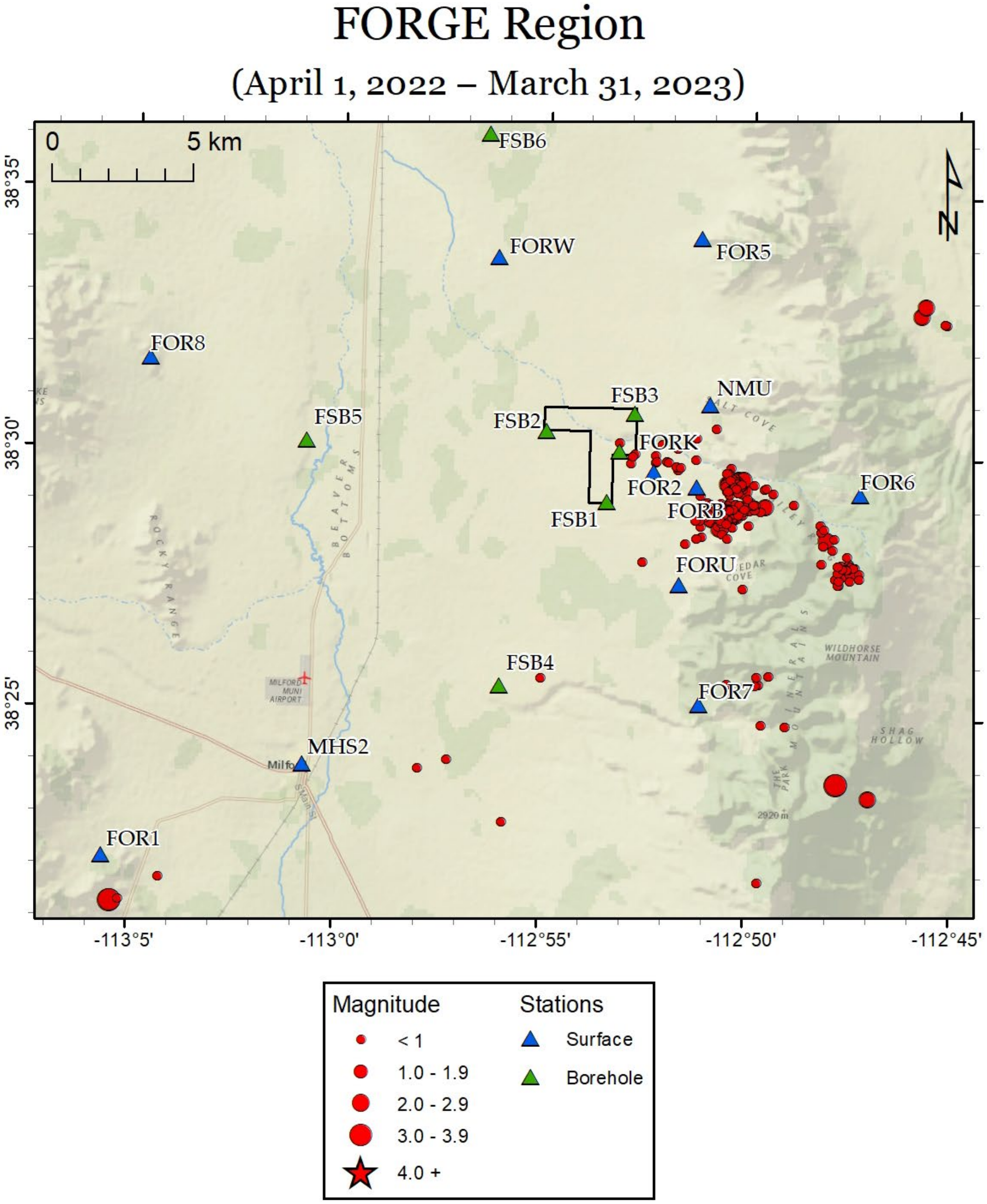


Figure B.2-1. *Seismicity in proximity of the Utah FORGE site for the time period April 1, 2022 through March 31, 2023 recorded as part of the Utah FORGE project.*

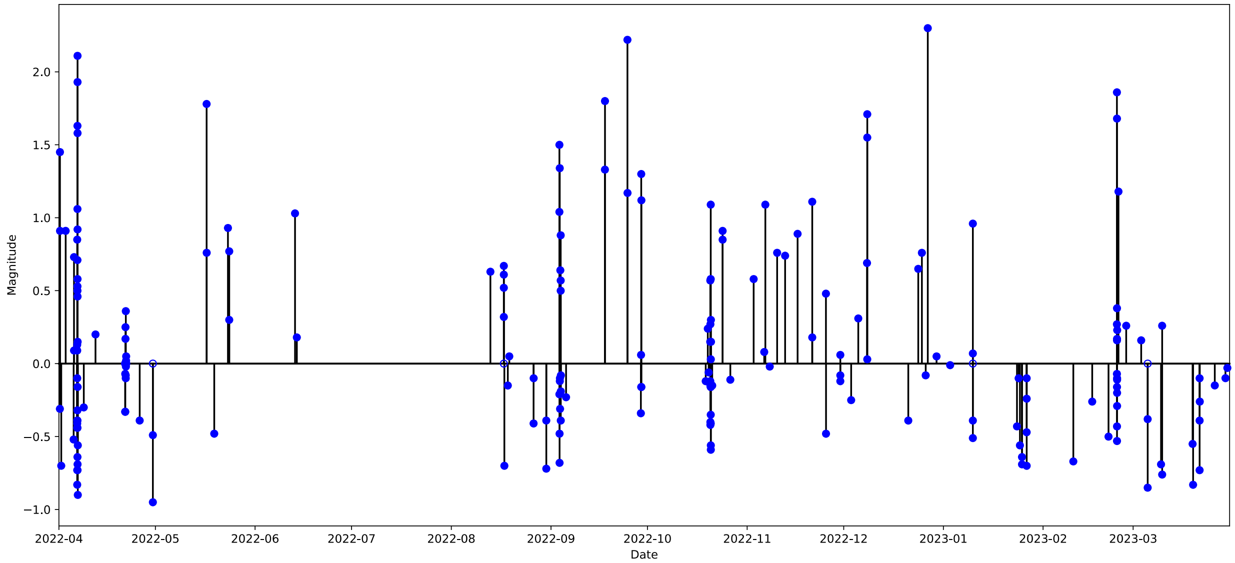


Figure B.2-2. *Magnitude time histories for seismicity located in proximity to the Utah FORGE site (Figure B.2-1) recorded as part of the Utah FORGE project. Open circles indicate events for which a magnitude was not able to be calculated. Time period the same as in Figure B.2-1.*

Seismic Cluster Analysis

Two tectonic seismic source areas were further analyzed during the project period. The first study continued the analysis of the 2021 swarm of earthquakes that located south of Milford Utah, near station FOR1 (Whidden et al., 2022; Whidden et al., 2023a). The 125 catalog events in the swarm were used as templates in a matched-filter analysis, and over 600 earthquakes were detected in addition to the 125 catalog events. The catalog events were relocated using a double difference method and the locations suggest a fault plane dipping to the west. Moment tensors of the largest five swarm events show a consistent near-N striking fault plane (Figure B.2-3). We looked at the potential contribution of fluids but conclude that the swarm was the result of heterogeneous stress conditions in a prefractured region.

In the second study Petersen and Pankow (2023), examine swam zones throughout central Utah. In this analysis, they identify an energetic swarm during 2020 that occurred in the spatially concentrated < 2 km long east-west striking swarm zone documented in Mesimeri et al. (2021). This region is located under the Mineral Mountains east of the Blundell Power Plant.

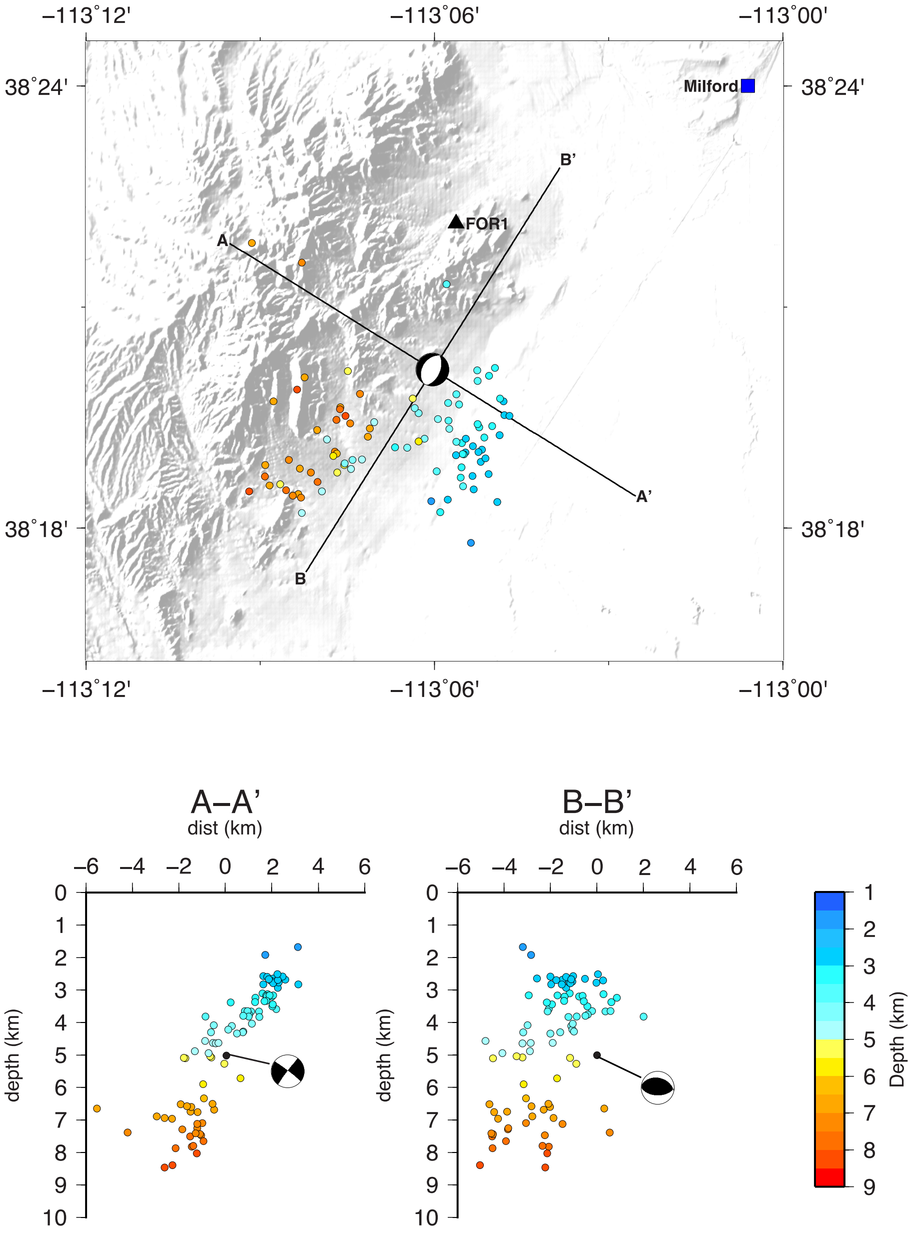


Figure B.2-3. *Taken from Whidden et al. (2023a) (A) Map and (B,C) cross sections of the 2021 Milford swarm, showing HypoDD relocations colored by depth (colored dots) of the 125 events originally located by the UUSS network. Focal mechanism is for the largest swarm event, Mw 3.5 on March 29, 2021. Also shown on the map are the town of Milford (blue square) and station FOR1 (triangle). Cross sections are oriented (B) perpendicular and (C) along-strike of the focal mechanism's west-dipping nodal plane. Seismicity locations are consistent with this west-dipping plane.*

Monitoring of Stimulation and Post-stimulation Seismicity at Reservoir Depths:

The primary activity at Utah FORGE over the last year was the stimulations of 16A(78)-32. The goal of the seismic monitoring for this phase was to enact the Traffic Light System documented in the Utah FORGE ISMP and detect and locate stimulation induced microseismicity with sufficient accuracy to guide the drilling of 16B(78)-32 in to the fracture zone. Monitoring of the stimulation was primarily accomplished using seismic instrumentation of deep boreholes. The use of shallow boreholes and surface geophone arrays was also tested. Several presentations and conference papers, as well as the Utah FORGE Seismic Workshop Report discuss the details of the monitoring and follow-up activities (Dyer et al., 2023; Pankow et al., 2023; Mendoza et al., 2022; Niemz et al., 2023; Rutledge et al., 2022; Wannamaker et al, 2022; Whidden et al., 2023b). Here we provide a summary. There was also some additional work analyzing the data from the 2019 stimulation that is also detailed below.

2022 Stimulation Monitoring

Deep Borehole Monitoring in Collaboration with Geo Energie Suisse (GES)

Based on modeling work that had been performed by Ben Dyer (GES), the plan was to have an 8-level Geochain string at reservoir depth (final depth constrained by the temperature specifications of the tools) in each of the three deep monitoring boreholes, 56-32, 58-32, and 78B-32 (Figure B.2-4). In addition, the DAS cables in 78-32 and 78B-32 would be monitored by Silixa and GES would test a three-level fiber optic string (Avalon BOSS tools) in 78-32. Data from all the Geochain tools would be integrated and processed by GES in near-real-time. The geophone specifications were for temperatures < 210^{o}C and the Camesa wireline cable for temperatures < 246^{o}C. In a second stage of monitoring, 2-level Avalon passive seismic sensors (PSS) would be placed at reservoir depths following the stimulation. These tools had a temperature rating < 260^{o}C. In practice, the Geochains had a temperature limit of ~180^{o}C. This lesson was learned progressively while in the field. The instrumentation not meeting the specifications led to a modified monitoring plan (Figure B.2-5). For all stages there was data from the DAS cables and the BOSS tools. For stage one, there was a single Geochain string in 58-32 (max depth 6700’); stage two, the string in 58-32 and a two-level PSS string in 56-32 (max depth 8315’); and stage three, the string in 58-32, the PSS tools in 56-32, and a Geochain in 78B-32 (max depth 6200’). While the PSS tools were operational in 56-32 for stage two and three, those tools failed within days of the end of the stimulation as did the other PSS strings that had been deployed in 58-32 and 78B-32. In all cases, the temperatures of deployment were well below the temperature specifications for the tools and cable.

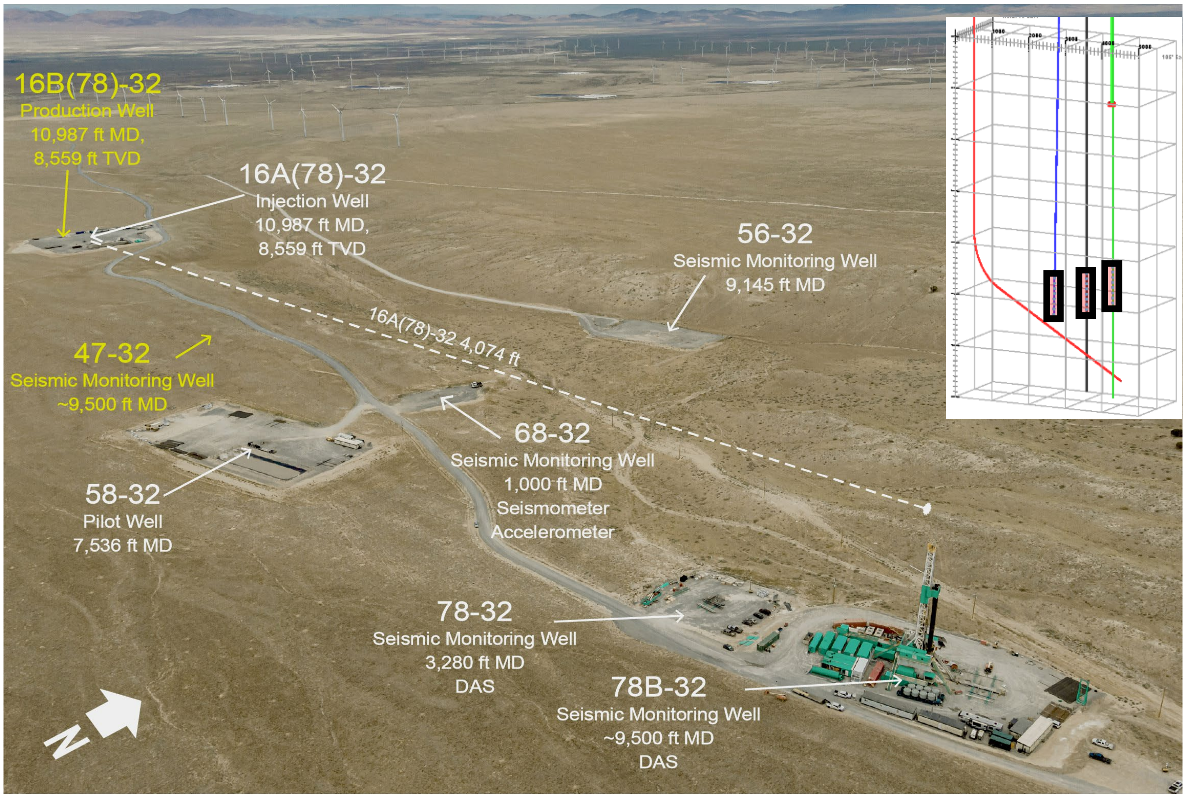


Figure B.2-4. *Plan view of FORGE deep wells. The trajectory of the 16A(78)-32 is shown white dashed line. Wells 58-32, 56-32 and 78B-32 are three existing deep seismic monitor wells at total depths (TDs) of 7536, 9004 and 9500 feet, respectively. Inset, schematic showing planned placement of geophones in the three deep monitoring wells.*

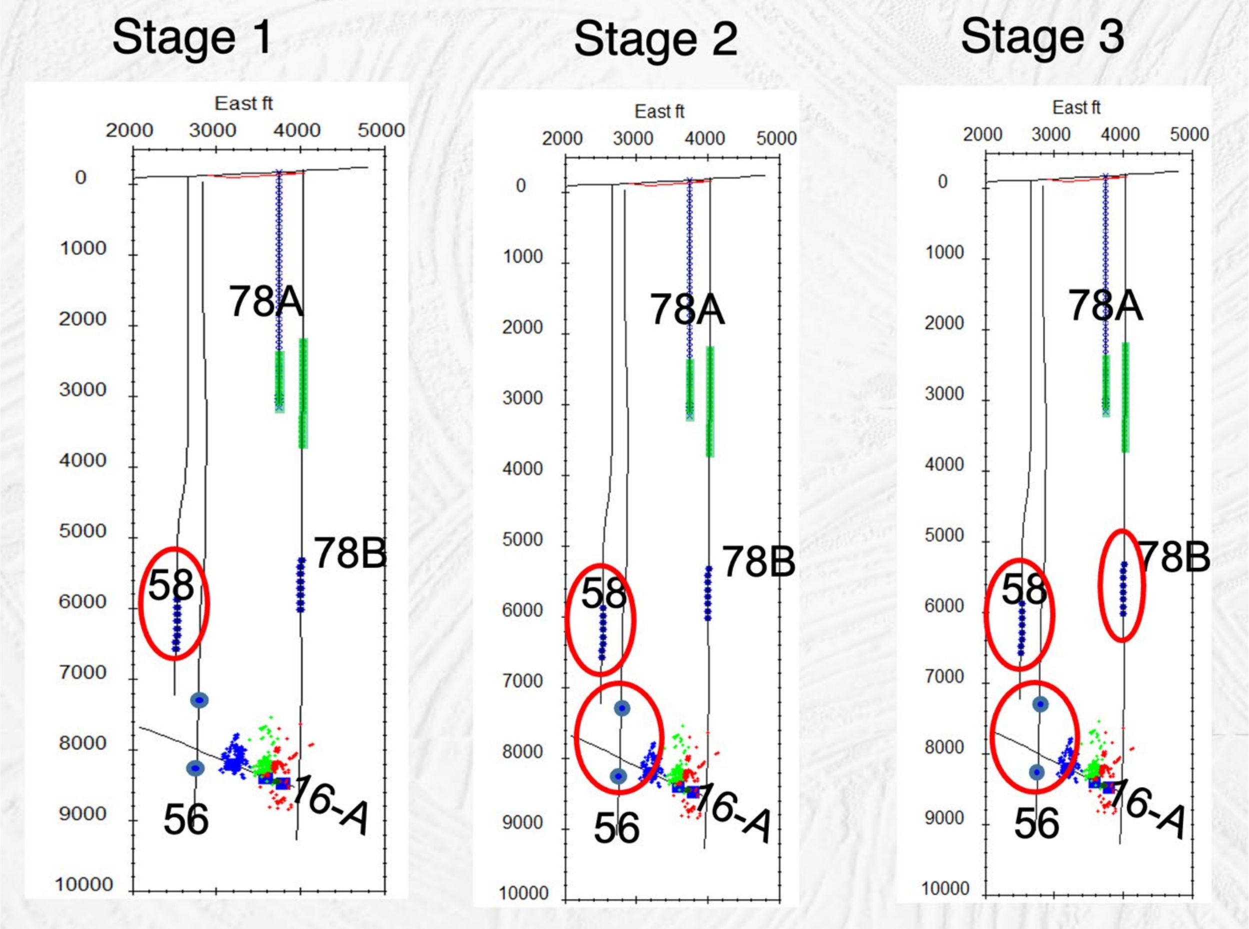


Figure B.2-5. *Deep borehole monitoring for the three stimulation phases. For all stages there was data from the DAS cables and the BOSS tools. For stage one, there was a single Geochain string in 58-32 (max depth 6700'); stage two, the string in 58-32 and a two-level PSS string in 56-32 (max depth 8315'); and stage three, the string in 58-32, the PSS tools in 56-32, and a Geochain in 78B-32 (max depth 6200').*

Over 10,000 micro-events were detected in the field during the stimulation by the revised deep borehole network. A subset of these events was located in near-real-time. This initial processing showed that the seismicity occurring in all stages grew upwards and was elongated in the north-south direction. In the months following the stimulation, the catalog with location and magnitudes was refined and a reference catalog of 211 (stage 1), 957 (stage 2), and 1431 (stage 3) events were released to the Geothermal Data Repository (GDR) (Figure B.2-6). GES then created a second catalog of events of detected events where a magnitude could be determined, but did not require a location. This larger catalog needed more quality control but allows for more robust statistical analysis. This second catalog was also released to the GDR and contains > 3,000 located events with magnitudes stage 1, > 5,000 for stage 2, and > 15,000 for stage 3. Using relative relocation. it was found that the relative error for stage 3 was 8' and for stage 1 23'. Based on this analysis, GES conclude that structural interpretations may reasonably be based on the Stage 3 locations, but stage 1 & 2 distributions should be treated with caution.

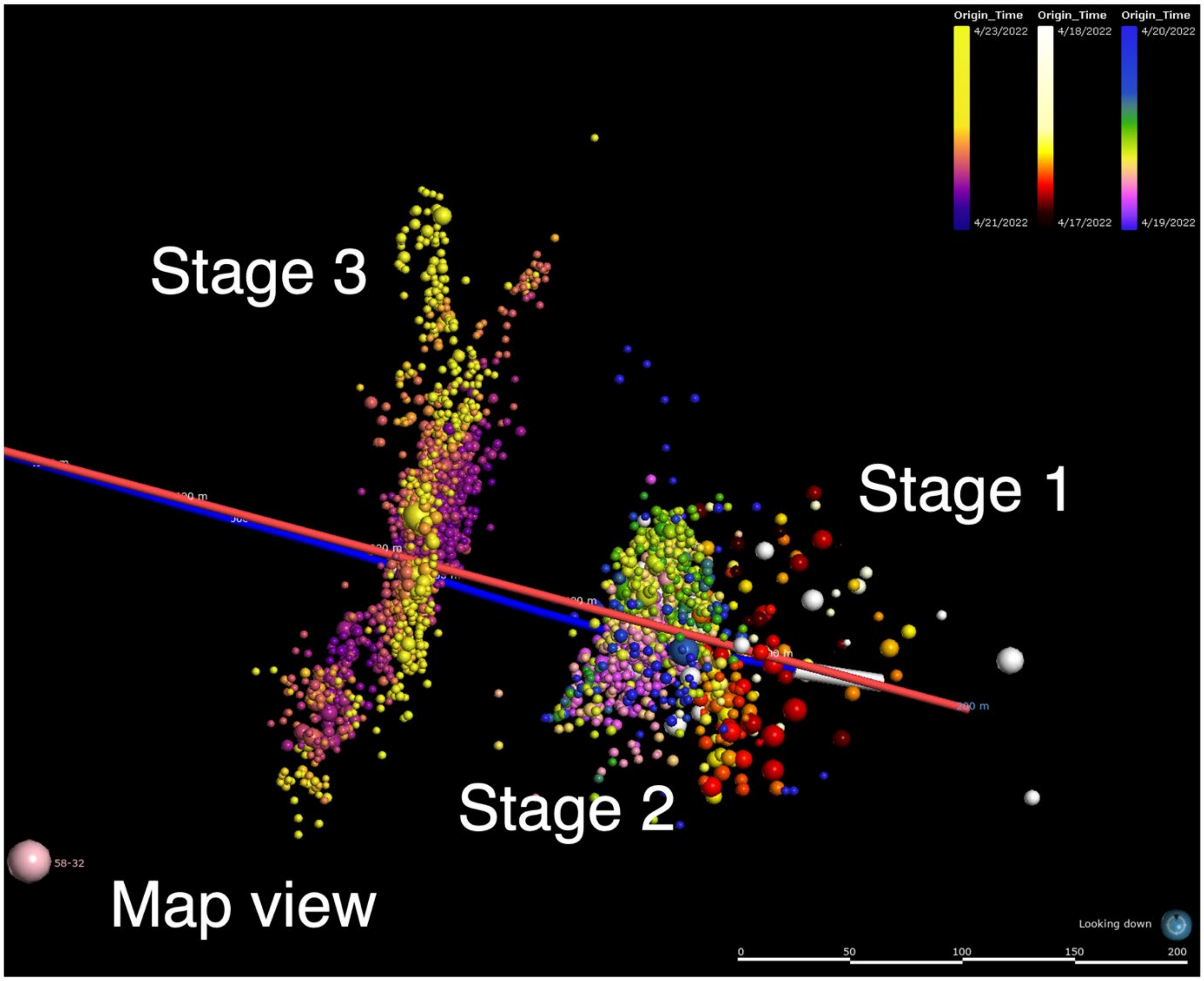


Figure B.2-6. *Map view of microseismicity located by GES. Colors indicate time of occurrence. Blue line is projection of 16A(78)32, white sections, injection zones. Red line potential location of 16B(78)-32.*

Following the stimulation, Permanent Seismic Sensors (PSS) were deployed in wells 58-32, 78B-32 and 56-32 on 7-conductor Camesa wireline cable. The purpose of the PSS system was to provide a long-term (up to one year) downhole microseismic monitoring system for detecting small events (M ≥ -2) that might be associated with continued fluid migration and/or monitoring any post-stimulation flow testing, as well as the drilling of well 16B(78)-32. The PSS tools were specified to operate for up to 500 hours at a maximum temperature of 260°C and the temperature specification of the Camesa wireline was 246°C. All three strings failed within days of deployment for various reasons. Avalon Sciences Ltd (ASL) evaluated the damages to cable, cable heads and sondes upon returning from the field. They applied the following modifications to the tools: (1) All cable heads have been changed to a new type. They use spring energized primary seals, a dual boot system with Krytox grease fill on the primary side primary boot retention discs and dual O-ring K25 feedthroughs; (2) The amplifiers have had the gain setting resistor changed from a thick film resistor (changes value in the presence of hydrogen) to a wire wound part. The switching relays have been removed from the circuit; (3) The sonde nose cones now have spring energized primary seals; (4) The sonde nodes have been bead blasted and coated to help prevent further corrosion; and (5) Inspection of the interconnect cables also indicated cable degradation. The ITCs were also rebuilt with new Rochester Cable.

In September 2022, two of the refurbished dual-level tools were deployed in wells 58 and 78B at different depth levels to test the refurbished tools' performance at various temperatures. Both tools were deployed with the Schlumberger (SLB) 7-46A XXS wireline cable and 1000 ft SLB 7-46A XXS interlinks. The tools in both wells lost most of their six working channels within a few days of deployment. In both wells, only the lower horizontal (Y-component) of the top sondes remained at least intermittently responsive for a period of at least 3 weeks. We pulled both instruments on January 18 and 19, 2023.

ASL conducted a thorough evaluation of the cableheads and sondes at their facility in the UK. Their report includes their evaluation and reporting of the cableheads, the downhole electronics, the geophone sensors and the mechanical integrity of the sondes. The underlying and common problem with all the sondes appears to be that the feed-through connecting pins in every cablehead failed. Once this occurs, electrical contact to the tools is lost. The feed-through pin failures may have also been associated with moisture ingress to the tools leading to the degradation of the sonde's printed circuit boards, geophone elements, etc.

SLB has started to evaluate the XXS wireline cable and the 1000 ft XXS interlinks at their facility in Houston.

Surface Network Reservoir Monitoring

While the deep borehole seismic monitoring provided a state-of-the-art microseismic catalog. Drilling and instrumenting deep boreholes is very costly. As part of the Utah FORGE monitoring efforts, we continue to explore ways to improve seismic event detection using surface and/or shallow borehole networks. For the 2022 stimulation efforts, we had two studies. In the first study, we built on the work in Dzubay et al. (2022) from the 2019 stimulation and used events in the UUSS catalog as templates for a matched-filter analysis at stations FORK, FOR2, FORU, FSB1, and FSB3. In the first pass of the matched filter, the template catalog was increased from the initial 11 events that occurred during stage 3 to 38 templates (7 stage 1, 6 stage 2, and 25 stage 3). Using the revised template catalog, over 1300 detections were found and 735 met the quality control criteria (29 stage 1, 26 stage 2, and 680 stage 3). The magnitude of completeness was Mc -0.7. This compared to the GES catalog of 2409 events with an Mc -1.3 (Figure B.2-7). Using the waveforms from these events, we also performed a clustering analysis. Events from stage 1 and 2 clustered together and events in stage 3 formed 4 separate clusters. Most of the detections are from the single station FORK located at a depth of 1000'. Given the limited number of stations detecting these events, we are not able to get locations. However, this study suggests the potential value of multiple shallow (1000’) boreholes.

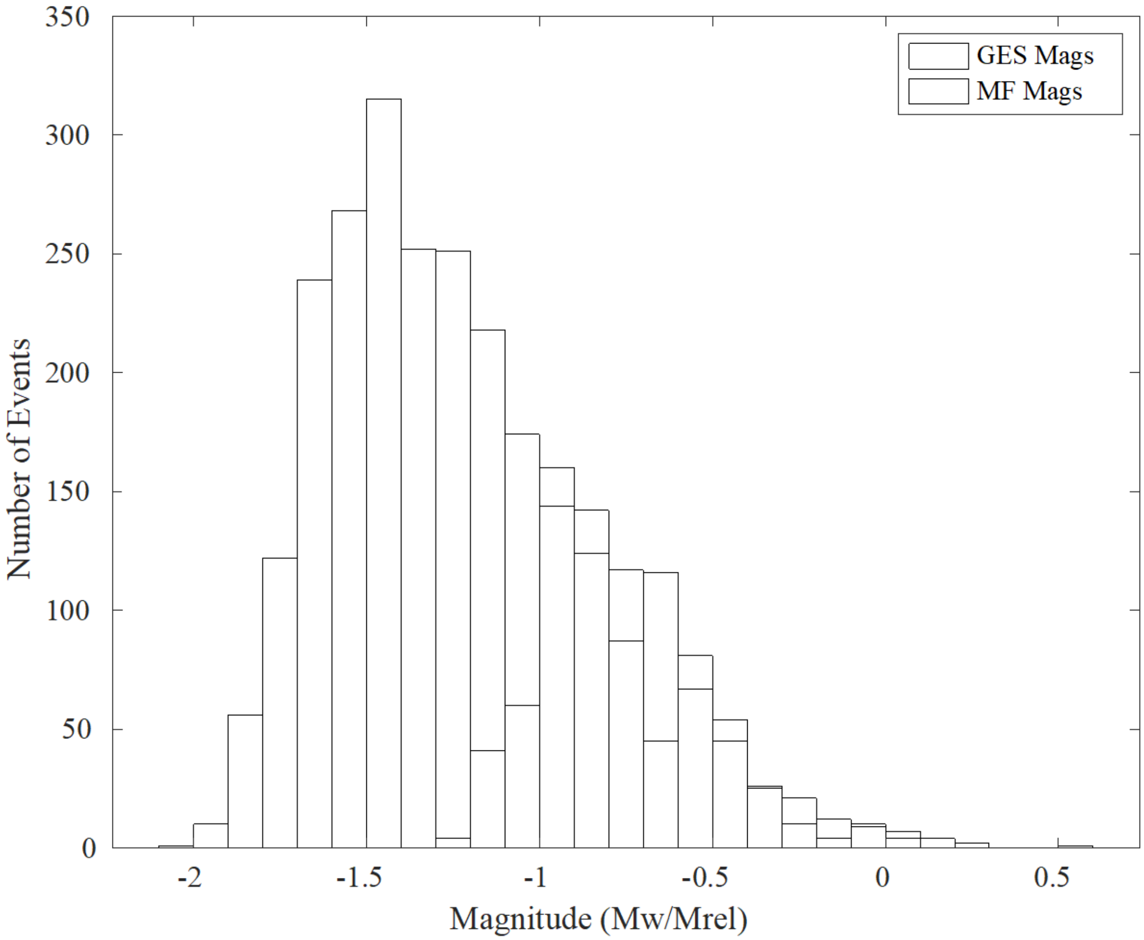


Figure B.2-7. *Comparison between the GES event located catalog (gray) and the catalog generated using matched filters at the local seismic array (orange).*

In the second study, we deployed ~200 geophone Fairfield Nodal geophones. The three-component geophones were deployed in 13 patches of 16 geophones (4 x 4 sensors) with 30 m spacing (Figure B.2-8a) from April 4 – 6 through May 5 – 6. Data from these instruments is not telemetered, and therefore not processed in near-real-time. In initial post-processing, the data from each patch was stacked to form one high signal-to-noise trace per patch. Spectral analysis of the larger events found that the peak signal energy is in the band from 20 to 40 Hz with signal up to 100 Hz. The traces are noisy below ~15 – 20 Hz. In a first pass of processing, a characteristic function and back projection on a spatial-temporal grid was applied to the stacked, filtered traces to determine event detections and preliminary locations. The number of resulting detections is a function of the characteristic function threshold (Whidden et al., 2023a). Figure B.2-9 shows an example of an M -0.4 detection. In comparisons with the GES catalog, it was found that using a characteristic function threshold > 70 reliably detects events with magnitudes M > -0.6.

In continued work, it was found that the nodal patches have heterogeneous noise characteristics, internally and among each other (Figure B.2-8a). Direct stacking of coherent amplitude-normalized waveforms can produce a clear stack with an increased signal-to-noise ratio for single patches, e.g., within patch R10 (Figure 2B.2-8b). However, for most patches, varying internal noise conditions, e.g., due to differences in coupling or small-scale heterogeneities, in combination with a relatively large node spacing of 30m, inhibits direct stacking (Figure B.2-8c). To overcome this limitation, we identify sub-patches of 4 nodes with the highest cumulative power between 20 and 50Hz for the largest events of the borehole-geophone microseismic catalog (Figure B.2-10). Using a local 3D velocity (Zhang and Pankow, 2021) and a full-waveform location algorithm (Grigoli et al., 2014) in preliminary locations, we could successfully locate the largest detected events within the reservoir, relying solely on quality-controlled stacks of surface data. In ongoing work, we are including smaller events by using the machine-learning-based detection-and-location algorithm MALMI (Shi et al., 2022), which refines the aforementioned full-waveform location method.

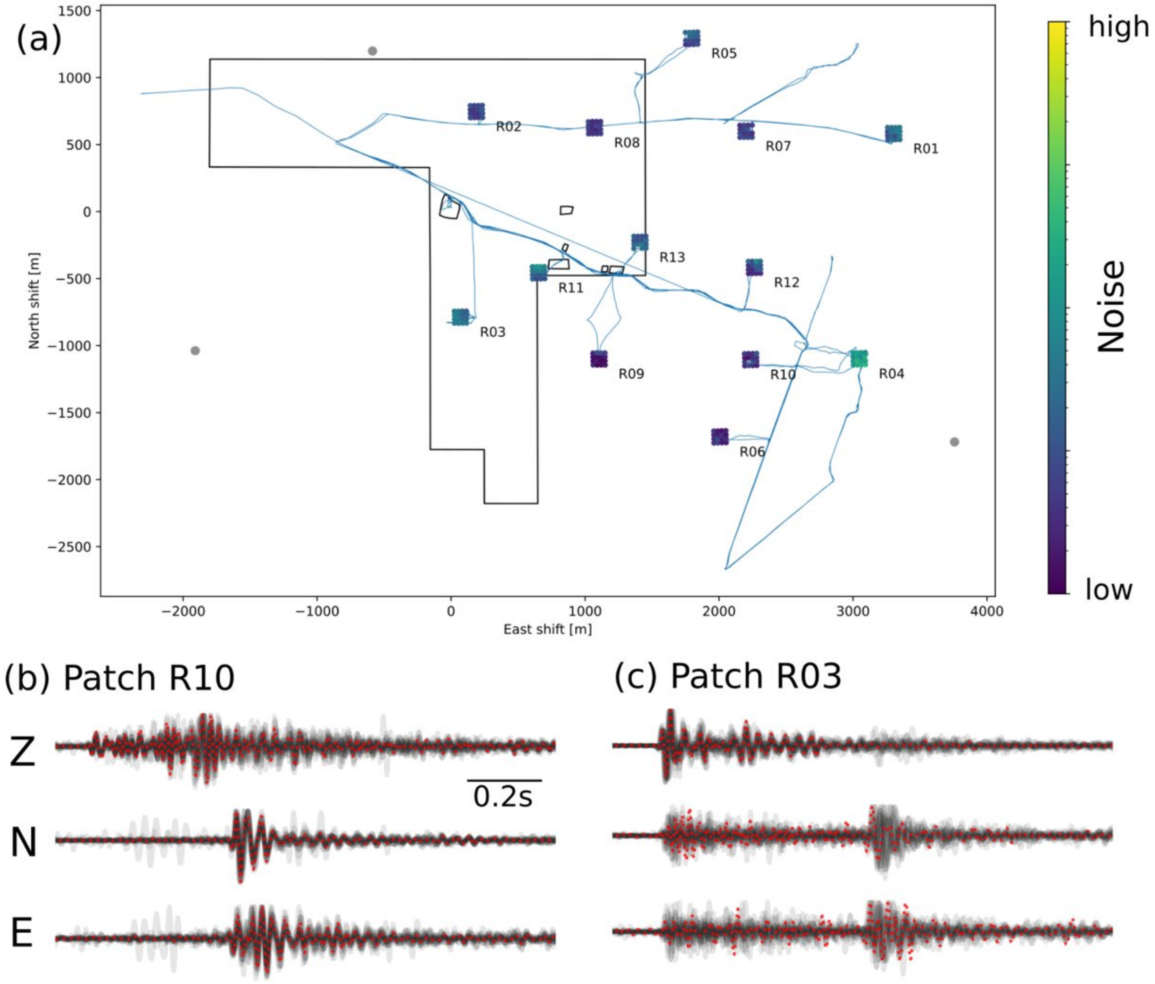


Figure B.2-8. *(a) Map view with node-wise noise levels (time-domain root-mean-square) of the seismic nodes in 13 patches near the Utah FORGE site. Black lines show the Utah Forge footprint and borehole pads; roads and paths are in blue. (b/c) Nodal waveforms plotted above each other for three components (East, North, Vertical) for patches R10 and R03. The red dashed line shows the direct stack of the grey traces.*

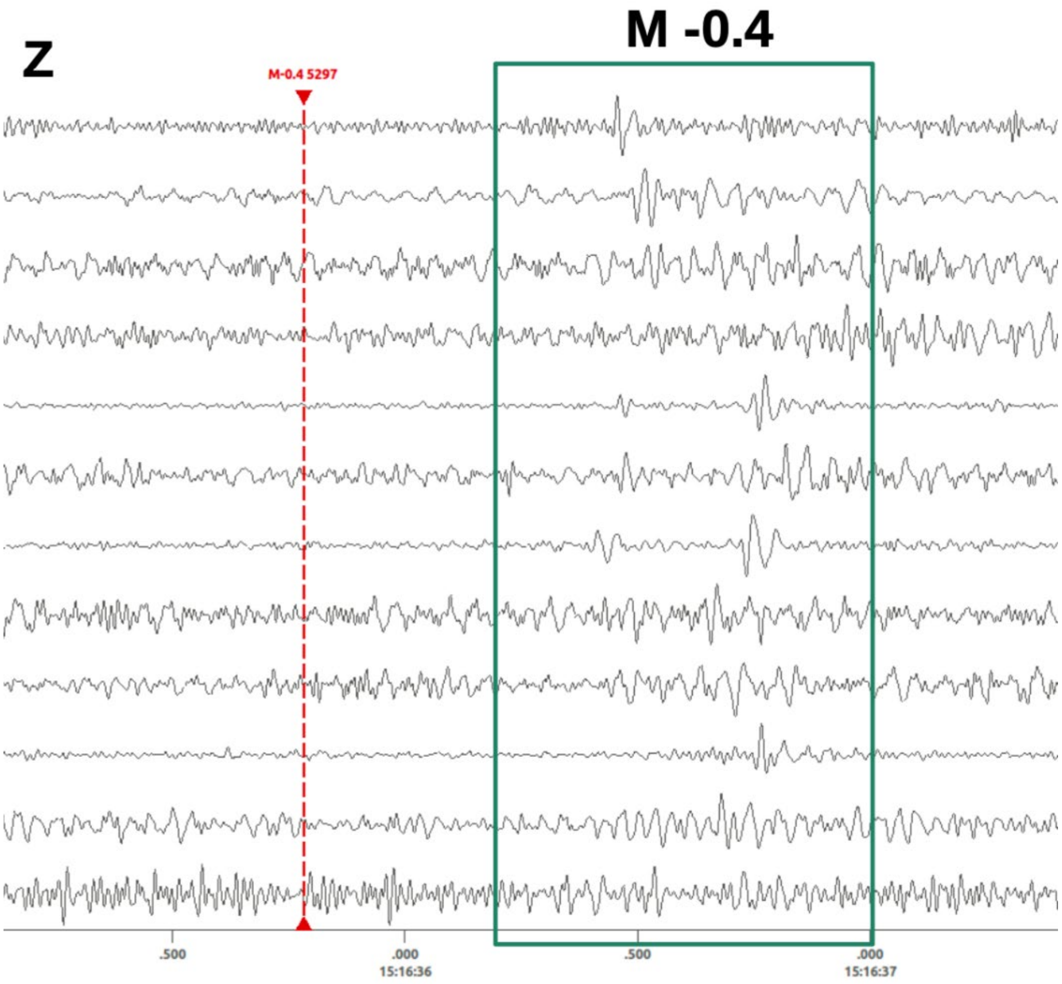


Figure B.2-9. *Example of an M -0.4 microseismic event detected using a characteristic function detector applied to stacked waveforms from the 13 patches. Each waveform is one stacked trace.*

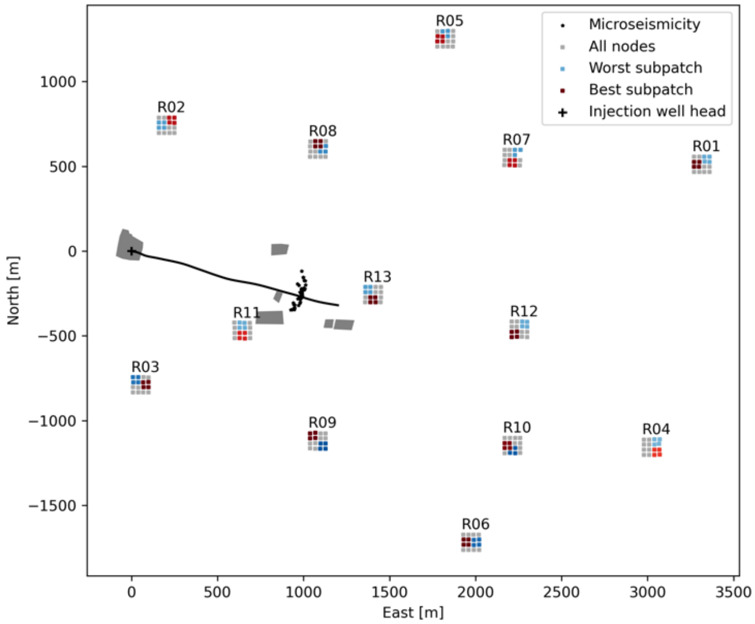


Figure B.2-10. *Map view of the nodal setup with sub-patch classification (best and worst sub-patch). Darker color shades indicate a better signal-to-noise ratio when comparing patches among each other.*

Analysis of 2019 Stimulation:

We utilized an enhanced earthquake catalog for the 2019 stimulation that used matched filters applied to data collected at the ~300 m borehole (Dzubay et al., 2022) to investigate potential for maximum magnitude and relations between injection volume and number of events and magnitude (Bradshaw et al., 2022a; Bradshaw et al., 2022b). We calculate theoretical maximum magnitudes for an induced event using physics-based and statistics-based approaches and compare the theoretical values to the maximum magnitudes found in the enhanced catalog. Importantly, we constrained the seismogenic index to be around -2. While there was a general increase in the number of events with both cumulative injected volume and specific injection periods, there was no clear relation.

Convene Post-Stimulation Seismic Forum and Produce Summary Report

All groups that participated in seismic monitoring during the April 2022 stimulation were invited to a workshop on the University of Utah campus in September 2022. During the workshop, each group presented on their participation during stimulation and their preliminary results. The meeting was structured to cover four key topics: (1) seismic instrumentation; (2) seismic network design; (3) seismic monitoring protocol; and (4) development and implementation of a seismic Traffic Light System. Talks were grouped into four subcategories: (1) Introduction and overview; (2) Borehole geophone monitoring and instrumentation; (3) Surface seismic monitoring; and (4) Downstream monitoring products. The meeting concluded with a discussion on what future geothermal seismic monitoring should look like for both Utah FORGE and Enhanced Geothermal Systems more generally. A workshop report was generated and submitted to the GDR. Outcomes from the workshop were also presented at the 2023 Annual Seismological Society of America Meeting (Pankow et al., 2023). Lessons identified during the workshop are summarized in Table B.2-4.

***Table B.2-4**. Lessons identified at the 2022 Utah FORGE seismic workshop*

Lessons Related to Network Design	Lessons Related to Operations
● Don't do less than was done for 2022 ● Wirelines and cables are not reliable at temperatures >180°C ● DAS is not as sensitive as geophones ● BOSS is not as sensitive as geophones and has troubling resonance	● Data streams ● ATLS groups on-site ● Seismic lead on-site and in frac truck during operations ● Regular seismic themed meetings with all groups involved with seismic monitoring

Update Induced Seismicity Plan (ISMP)

In preparation for updating the Utah FORGE ISMP, two key elements needed to be addressed. The first element was an updated Probabilistic Seismic Hazard Analysis (PSHA). The PSHA was evaluated given newly available information in 2022 by WSP USA Environment and Infrastructure Inc. (formerly Wood Environment & Infrastructure Solutions, Inc.). The recommendation from that analysis was that there were no changes to expected earthquake rates, there may be a slight increase in hazard for T 1.0 s if new seismic sources that are being considered for an update to the U. S. Geological Survey 2023 National Seismic Hazard Map (NSHM) are included, and there may be merit in including 1-D site-specific response analyses depending on the approaches used in the 2023 NSHM. Given that many of the conclusions are dependent on the yet to be adopted 2023 NSHM, it was concluded to not update the model now, but wait and re-evaluate after the release of the 2023 NSHM.

The second element to be addressed was an updated Seismic Monitoring Plan (SMP). While the ISMP contains the framework for seismic monitoring, each stimulation phase requires a reanalysis of the SMP. As for the 2022 stimulation, a separate SMP has been developed for the post 2022 stimulation time-line. This document was reviewed by SAT members David Eaton and Julie Shemeta in March 2023. They requested additional modeling work, which has now been added to the document.

Other sections of the ISMP now updated include an update to the background seismicity analysis and the Outreach and Communications Program.

Collaborate and Coordinate Seismic Experiments

In addition to seismic activities at Utah FORGE run by the operations group, there are research groups involved in seismic monitoring and other groups interested in performing experiments at the Utah FORGE site. For the 2022 stimulation, there was a second nodal experiment, an experiment that deployed surface DAS (Mendoza et al., 2022), and a group testing new sensors. Details of these experiments are in the Utah FORGE Seismic Workshop Report. We worked with all of these groups to help with land ownership/experiment design protocols and to facilitate the sharing of data. We are now starting to work with groups involved in the next stimulation; those with research awards, groups wanting to deploy surface DAS, and other groups hoping to test instrumentation.

Discussion

Continued seismic monitoring of the region reinforced previous reporting—the region immediate to Utah FORGE is characterized by low rates and small magnitude earthquakes primarily located to the east under the Mineral Mountains. Bursts of seismicity tend to occur in swarms that may be related to fluids, heterogeneous stress conditions, and possibly aseismic deformation. Based on the monitoring re-enforcing the previous analyses there are no updates to the seismic potential of the site. It should still be considered a region of low to moderate seismic hazard. An evaluation of the PSHA found that the expected number of earthquakes has not changed with the collection of additional cataloged seismic events. There may be a slight increase in hazard at T 1.0 s periods. However, this depends on the yet to be accepted new USGS NSHM. Given the small possible change to the hazard it was concluded to wait until the 2023 USGS NSHM were released to update the PSHA.

No new seismic velocity model information has been added this year. However, the refined three-dimensional models determined in previous years are being used in the full waveform-based location algorithm being used to locate events detected on the surface geophone arrays.

A key test of the Utah FORGE ISMP was the 2022 stimulation. The maximum magnitudes calculated based on expected volumes were not exceeded. The Traffic Light System did not move out of the green zone. The Communication Plan has been very effective with stakeholder engagement at the local and state levels.

B.3 UTAH FORGE MODELING

Introduction

Modeling team activities in Phase 3B Year 1 included the integration and interpretation of new reservoir data resulting in updates to the site conceptual geologic model, native state model, and fracture model. These updated models were used by the modeling team for reservoir and stimulation modeling designed to support decisions made by the operations team on where to place the production well and provided predictions for the change of the deformation, mechanical stress, pore pressure, and temperature of the site resulting from field operations.

The primary new data set this year that was utilized by the modeling team was collected during the stimulation of well 16A(78)-32 and included the injection pressure history as well as the microearthquake catalogs of the three stimulation stages. This data was used to compare previous modeling predictions of stimulation volumes with measured microseismic clouds and to create a stimulated revision of the Reference Discrete Fracture Network (DFN). The revised DFN was then used to evaluate preferred injection and production well spacing, flow test options, pumping rates and durations, fluid viscosities, and monitoring data collection.

Other data sets utilized by the model team this year were the sonic log data from wells 58-32, 56-32, 16A(78)-32, and 78B-32, updated well temperature data and improved principal stress directions derived from field well tests. The sonic log data was used to add detail to the conceptual geologic model and the temperature and updated stress analysis was used to update the native state model.

The following sections describe the specific modeling team activities. This work has been presented at the 2022 Geothermal Rising Conference and the 2023 Stanford Geothermal Workshop. Summaries of each activity are included below with more detail and references available from the published papers (provided as Attachments to the Annual Report).

Conceptual Geologic Model Update

The modeling team provided suggested refinements to the reservoir geologic model based on performing cluster analysis methods on sonic log data collected from the FORGE wells. This activity is included in Modeling Team SOPO 6.1: Incorporation of new data into the earth model. These refinements may be used for a new Reference Earth Model in the future if greater detail on bedrock lithology contacts is required. The workflow developed for this process is presented in Attachment 1 and provides a new, rapid way for finding significant lithologic boundaries and fractured zones that need to be considered when planning well stimulations. The current geologic model shows uncertainty in the lithology boundaries separating younger, granitic rock from older, metamorphic rock (Figure B.3-1). This model was created using thin-section petrography and X-ray diffraction (XRD) analysis of mud log cuttings. Analysis of available sonic log data was used to supplement this analysis and provide higher spatial resolution for lithology contacts and fracture zones.

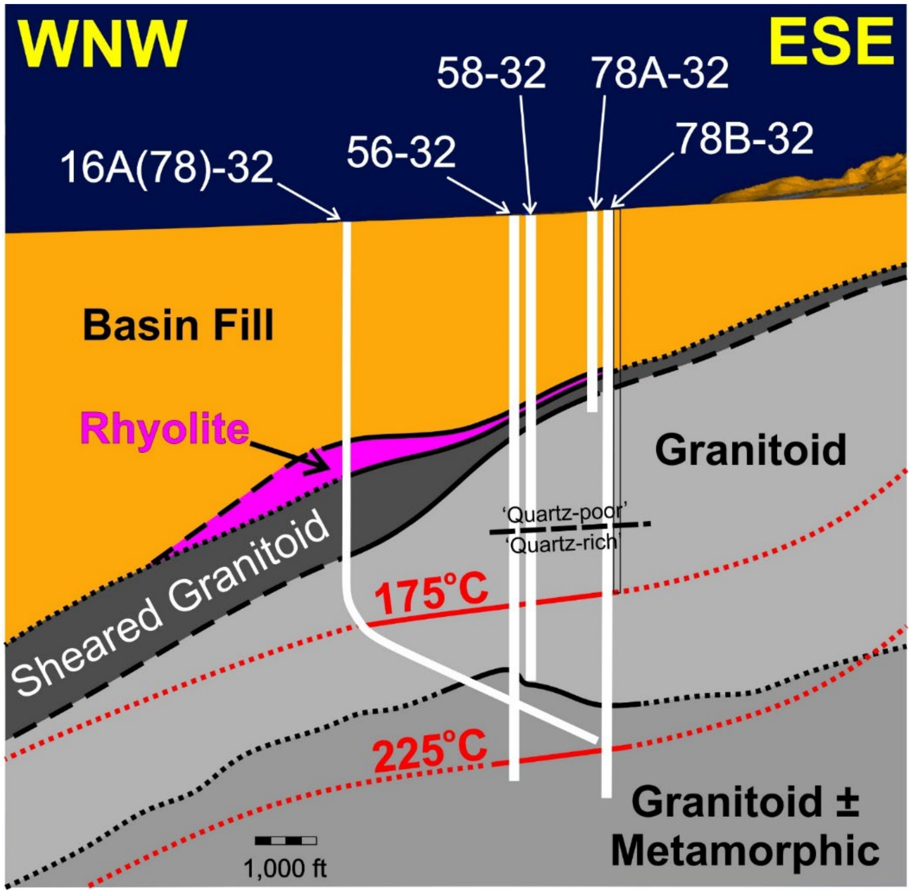


Figure B.3-1. *Schematic view of the geologic model.*

Once the sonic log data has been analyzed using the clustering method, it can be color-coded and plotted by depth to show where different rock types occur and if they are separated by highly fractured zones (Figure B.3-2). Mean property values for each identified rock type can be tabulated and compared with expected lithologies (Table B.3-1). For example, the orange rock type in color-coded sonic logs for well 56-32 shows the highest values for compressional slowness, fast shear slowness, acoustic energy, total porosity, and thermal neutron porosity. This could indicate highly fractured zones or faults possibly with associated alteration. The two orange peaks shown at depths of approximately 6400 ft and 7600 ft could be showing strongly fractured zones which would be very important to build into a future revised geologic model and to also be aware of when planning stimulation activities.

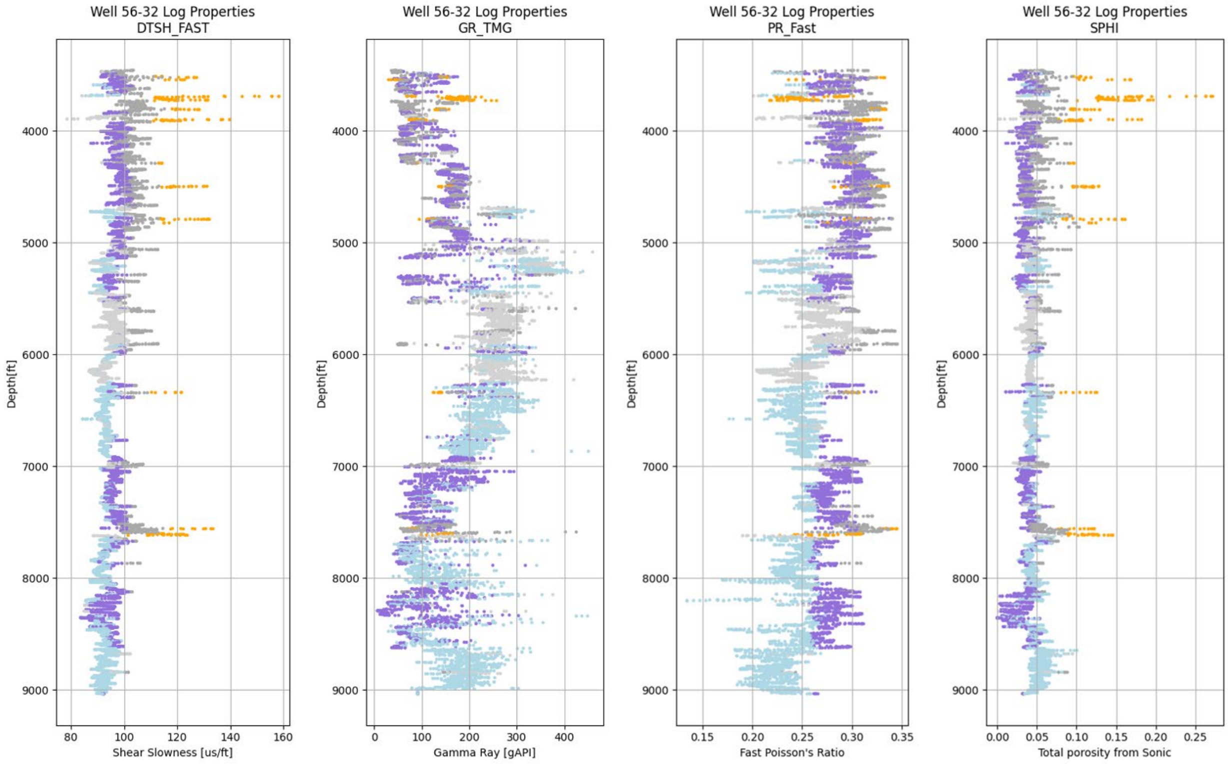


Figure B.3-2. *Selected sonic log properties for well 56-32 are plotted by depth and colored by rock type as determined from cluster analysis.*

Table B.3-1. *Mean property values for five rock type groups in well 56-32. Rock types are identified by the colors used in Figure B.3-2. Property columns are individually colored to show the range of values where red indicates high values and blue indicates low values.*

Color	Depth[ft]	Compressional Slowness (DTCO_MPS_R)	Fast Shear Slowness (DTSH_FAST)	Gamma Ray (GR_TMG)	Acoustic Energy (MAXXENE_OVERALL)	Acoustic Anisotropy (SLOANI [fraction])	Total Porosity (SPHI)	Thermal Neutron Porosity (TNPH)	VpVs (Compressional To Shear) Ratio (VPVS_Fast)
light grey	5862	53.7	94.9	243	0.260	0.052	0.043	0.022	1.77
light blue	7300	54.1	92.6	188	0.080	0.022	0.046	0.032	1.71
dark grey	4852	54.9	103.3	127	0.208	0.015	0.052	0.075	1.88
medium purple	6047	52.7	96.6	131	0.092	0.021	0.036	0.046	1.83
orange	4649	65.7	120.6	138	0.283	0.012	0.128	0.161	1.84

Comparison between these algorithmically derived rock types and XRD/petrography data show that these clustering algorithm categories correspond to units such as weathered granite, quartz-rich plutonic, quartz-poor plutonic, gneiss, carbonates and highly fractured rock as shown in Figure B.3-3 for well 56-32.

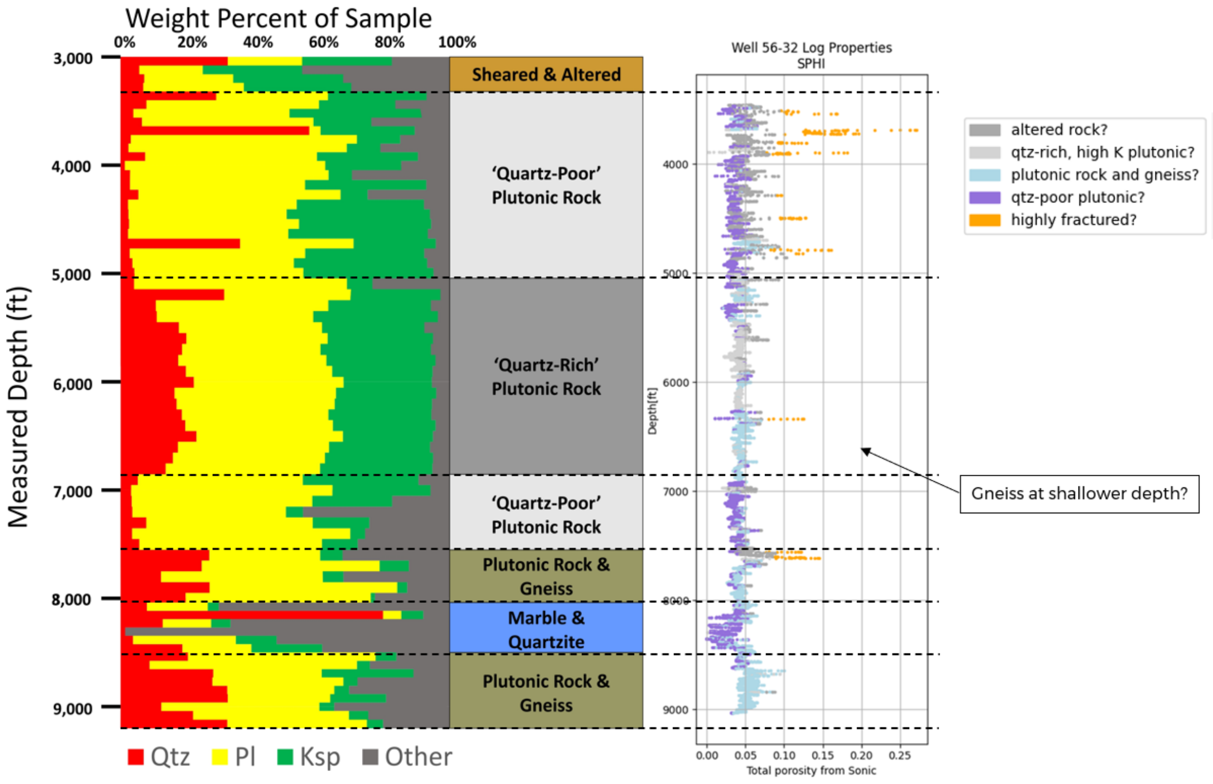


Figure B.3-3. *XRD analysis of mud log chips for well 56-32 showing proportions of quartz, plagioclase, alkali feldspar, and other with suggested lithologic identification (left) and total porosity from sonic values plotted by depth and colored by rock type (right). Dotted lines show lithologic boundaries as identified from the XRD analysis.*

Native State Model Revision

Activities in this section correspond with Task 6.0 in the Modeling Team SOPO. Following the Phase 2 native state mode and based on a large amount of new and updated subsurface data of the site, a revised three-dimensional coupled Thermal-Hydraulic Mechanical (THM) model has been developed as described in Attachment 2. This model initially targets to identify the initial states of the geothermal reservoir and is further calibrated to predict the change of the deformation, mechanical stress, pore pressure, and temperature of the site resulting from the field operations. As a complex coupled three-field approach is adopted, an appropriate setup for boundary conditions for the model is paramount and has been implemented in the updated model. The model is calibrated using large scale parallel computing and field temperature data measured at several deep wells (58-32, 56-32, 78-32, 16A(78)-32) at Utah FORGE site.

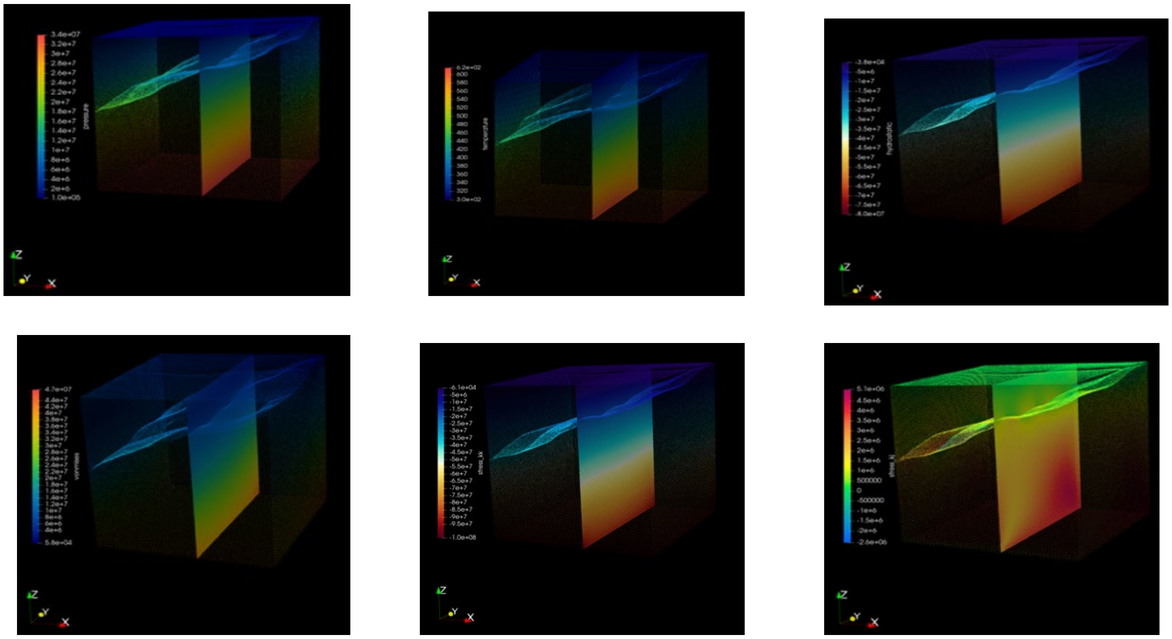


Figure B.3-4. *Contours of calibrated and simulated for pore pressure (the left in the top row), temperatures (the middle in the top row), the mean effective stress (the right in the top row), the von Mises stress (the left in the bottom row), the vertical effective stress (the middle in the bottom row), and the shear stress in ZY-plane (the right in the bottom row).*

Figure B.3-4 from the top to the bottom present contoured results for the pore pressure for the fluid flow field, temperature for the thermal field, the effective mean stress, the von Mises stress, the effective vertical stress, and the shear stress in Y-Z plane for the solid field obtained from the native steady state model. All predicted field variables in the contours exhibit a linear distribution over the vertical direction where the minimum is on the top surface and the maximum is on the bottom surface. However, it also shows that all these pressure, temperature, and stresses exhibit appreciable variations along the horizontal direction. Furthermore, due to the applied shear traction besides the normal pressure traction boundary condition for the solid field, the stress shows a more significant variation across the interface between the sediment and granitoid. The shear stress level is roughly 10% of the vertical normal stress. Calibration is carried on comparisons between the measured variables of the pore pressure, temperature, and field stresses and the corresponding variables predicted from the model. Th pore pressure, and temperature, field stresses were measured from wells 56-32, 58-32, 16A, 78B-32, and 78-32.

Figure B.3-5 presents the calibration using well 56-32 and similar calibration results are also observed from other wells. Generally speaking, they match well except near the ground surface or on the bottom.

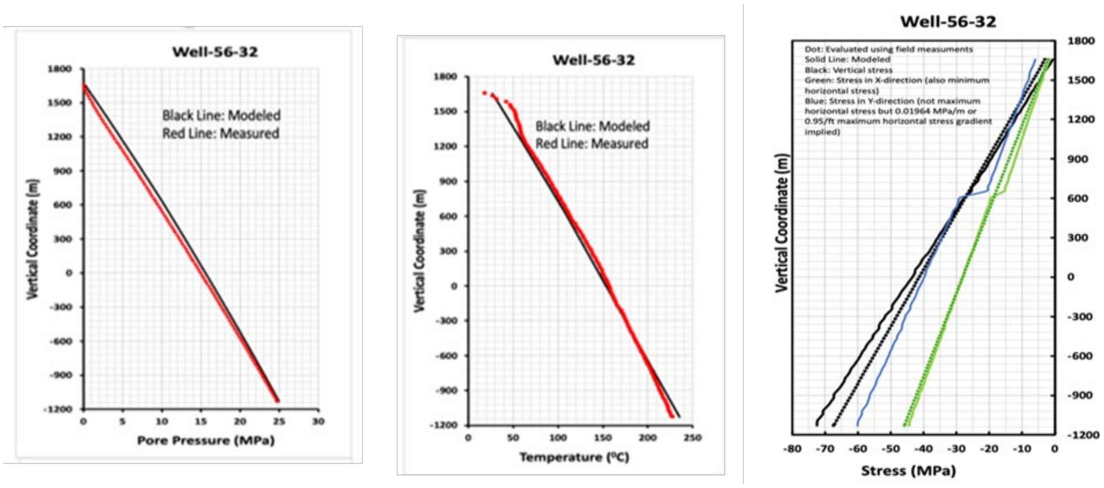
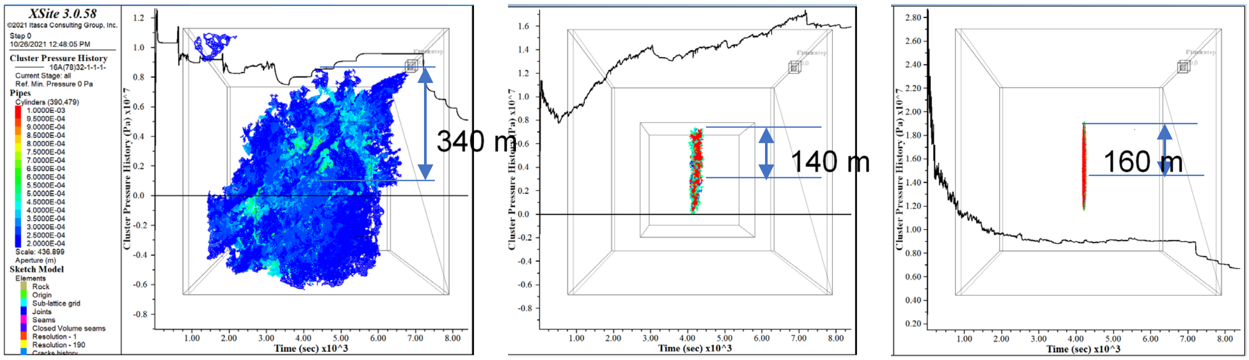


Figure B.3-5. *Model calibration with regard to pore pressure, temperature and vertical stress.*

Numerical Simulations of the Hydraulic Stimulation of Well 16A(78)-32

Activities in this section correspond with Task 2.0 in the Modeling Team SOPO. The planned three stages in well 16A(78)-32 have different pumping schedules (maximum pumping rate of 50 bpm) and working fluids (slickwater or viscosified fluid). In Attachment 3, a numerical study incorporating uncertainties in the in-situ conditions was performed to simulate the planned hydraulic stimulations. These simulations were conducted using a lattice-based code, XSite™. The injection times and rates in the simulations follow the designed pumping schedules. Uncertainties of the DFN model, including different geometrical realizations and strengths, were evaluated. From the simulation results, the heights of open fractures, presumed to reflect the inter-well connectivity, were predicted to be from 20 to 160 m depending on the DFN properties and the treating fluid viscosity (refer to Figure B.3-6). The lateral extent of slipping fractures, which represents the possible interaction between different stages, ranges from 10 to 80 m. The simulated cases with weak and frictional DFNs display a larger area of connected flow paths (see Figure B.3-7). Simulations with strong (high cohesion and tensile strength) DFNs display larger heights of open fractures but smaller lateral extents of the fractures that experience slip.



(a) Permeable, frictional DFN 1 (b) Impermeable, strong DFN 1 (c) No DFN

Figure B.3- 6. *Comparison of simulated fracture apertures (greater than 0.2 mm) for Stage 1 with different DFN properties.*

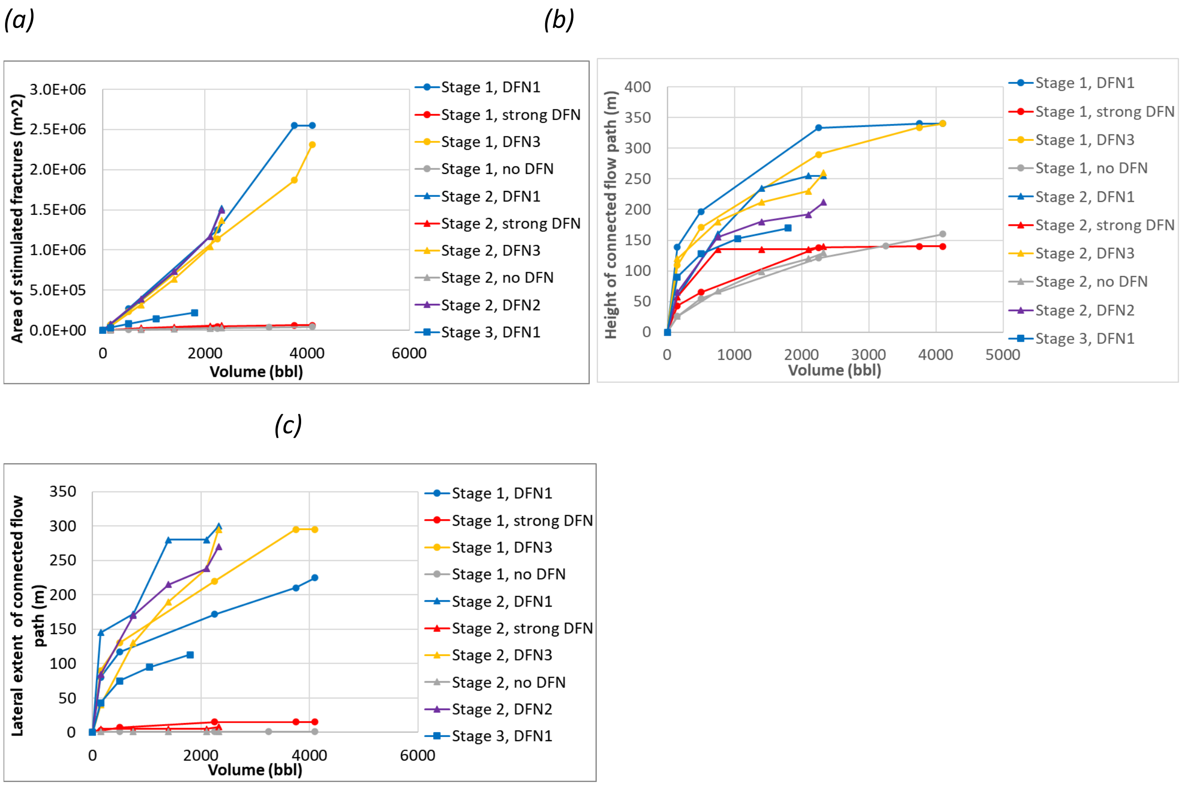
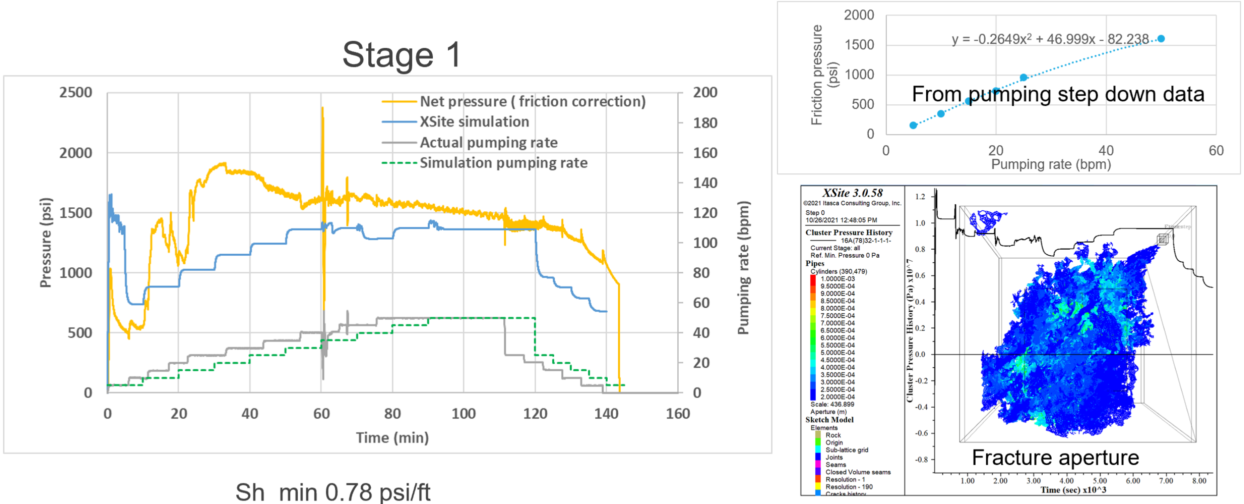


Figure B.3-7. *Connected flow path with fracture aperture greater than 0.2 mm at different pumping volume for all the cases: (a) area, (b) height above injection point, (c) lateral extent.*

As presented in Attachment 4, modeling results were compared to field data of the hydraulic stimulations in well 16A(78)-32 in three aspects: 1) injection pressure history, 2) spatial distribution of microseismic events, and 3) b-values of microseismic events.

After the comparison we find that the models with weak, frictional and permeable DFN yield the best match for all three stages. All three stages appear to include combinations of hydraulic fracturing and stimulation of DFN. DFN leakoff seems to dominate the response in Stages 1 and 2, which is logical considering the use of slick water. Stage 3, which was stimulated with xlink fluid, is dominated by hydraulic fracture propagation. The injection pressure history for Stage 1 matches well with the field data, as shown in Figure B.3-8. Injection pressure histories for Stages 2 and 3 (cased completion with perforations) were not matched well at early period potentially due to complex evolving geometries and processes in the well near field are not included in this model. For all the three stages (refer to Figure B.3-9), the extents of microseismicity events in the models match the field data. The b-values of the microseismic events from the models ranging from 2.3 to 2.4 are very close to those obtained from the field for all three stages.



Sh_min 0.78 psi/ft

Simulation: frictional and weak DFN

Figure B.3-8. *Comparison of the field pressure history with simulation results for Stage 1. Left: pressure history comparison; right top: friction correction for the field pressure; right bottom: simulated fracture hydraulic apertures after pumping. The DFN used in the model is assumed to be frictional, weak and permeable.*

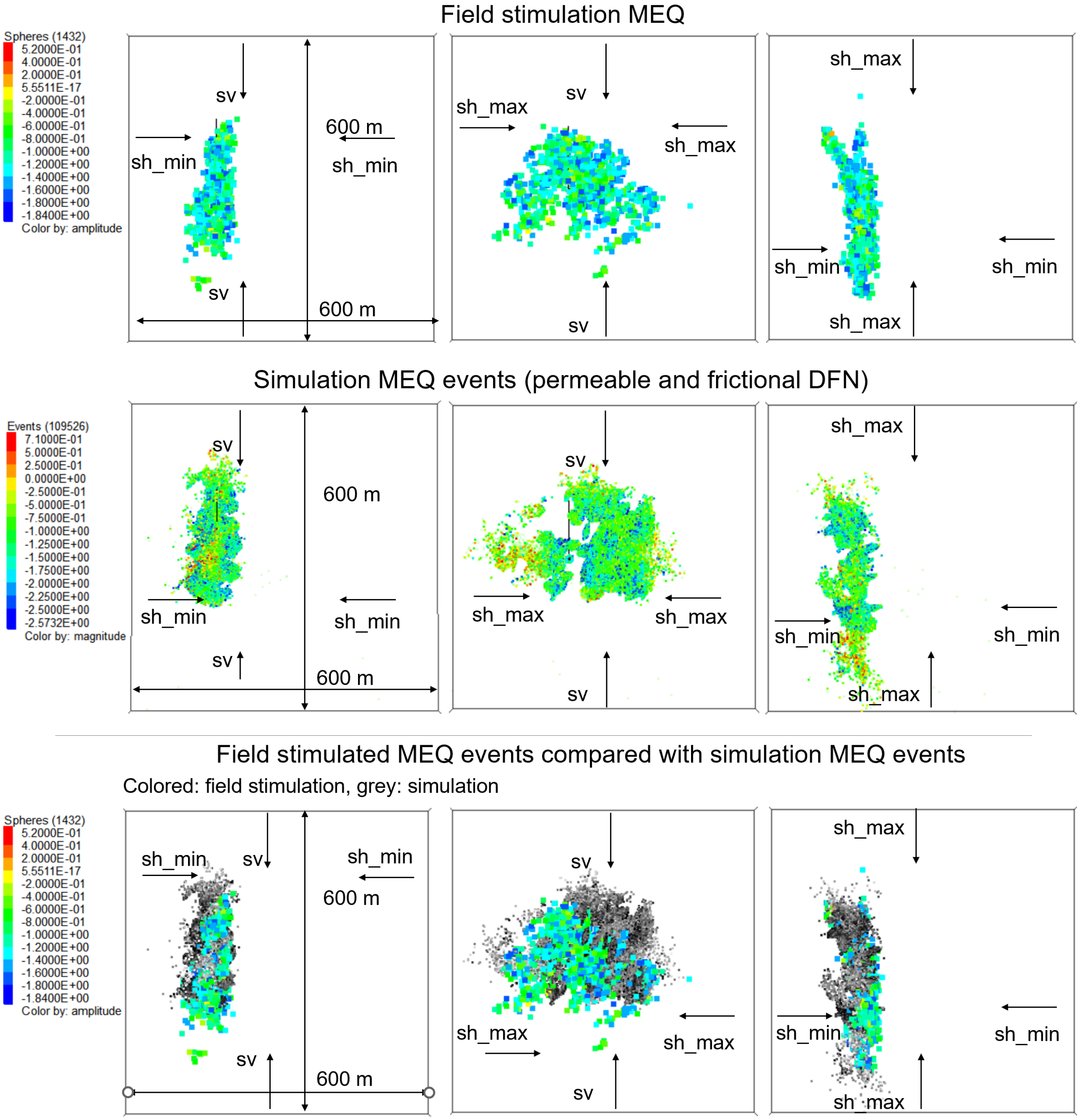


Figure B.3-9. *Comparison of the field detected microseismicity cloud with simulation results for Stage 3. Field detected maximum magnitude is 0.52, and simulation maximum magnitude is 0.71.*

Well 16B(78)-32 Design Assistance

Activities in this section correspond with Task 3.0 in the Modeling Team SOPO and include early work to provide guidance on selecting the location and trajectory of production well 16B(78)-32. It utilizes the Reference DFN from Phase 3A Year 2 as it was done prior to the availability of the stimulated DFN which is described in the following section. Further work to provide design assistance for well 16B(78)-32 was performed after that DFN update and is described in the later section of the Modeling Team update, “Interwell Flow Test Design Assistance”.

Orientation and completion of well pairs subjected to multizonal stimulation plays a critical role in the long-term performance of enhanced geothermal reservoirs. Enhanced geothermal systems often exhibit preferential flow along fractures between injection and production locations. Modeling this preferential flow using DFNs relies on stochastic realizations of the DFN produced from geological sampling. In Attachment 5, we present the development of a stochastic optimization methodology to determine well completion options based on numerical simulations of a DFN using Falcon, a MOOSE based application for modeling porous flow. The proposed stochastic optimization methodology is based on parallel subset simulation implemented in the MOOSE Stochastic Tools Module. Stochastic optimization will provide insight into the regions where placements of the injection and production wells are optimal.

One stochastic realization of the FORGE DFN network is shown in Figure B.3-10 along with the region being simulated in white. These simulations inject tracer at a single injection point in a fully saturated DFN and withdraw fluid at the three production points where the production line intersects the DFN. The network is modeled using a two-component fluid using the Darcy flow equations in the MOOSE porous flow module.

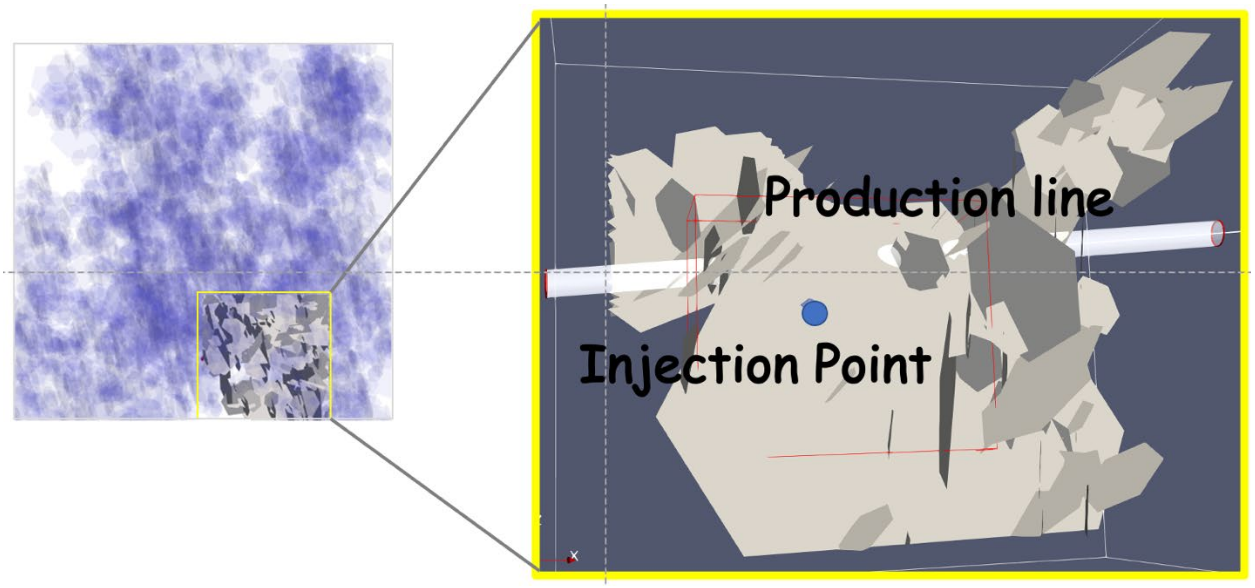


Figure B.3-10. *The entire DFN network is shown in the left figure by the blue cloud. This work focuses on the only a small 150m cubic region of the overall network, indicated by the solid white DFN inside the yellow box. The right figure shows the DFN being simulated along with the single injection point and production line.*

These simulations are being used to determine a meaningful quantity of interest (QOI) for the stochastic optimization simulations. Results from these simulations are shown in Figure B.3-11.

Initially, the production points withdraw the fracture fluid which is gradually replaced by the injected tracer. The mass fraction of injected tracer being withdrawn at each production location is shown in the right plot. These plots suggest the following two QOI's. The first QOI would be to delay the amount of time it takes for the production point to become fully saturated by tracer which would indicate a large fracture network. For the second QOI, we would like to fully saturate the entire DFN at the nearly the same rate which would be indicated by all the tracer output locations withdrawing a similar mass fraction of tracer. For this injection location, we see that the closest production points, 2 and 1, become fully saturated much more quickly than point 0.

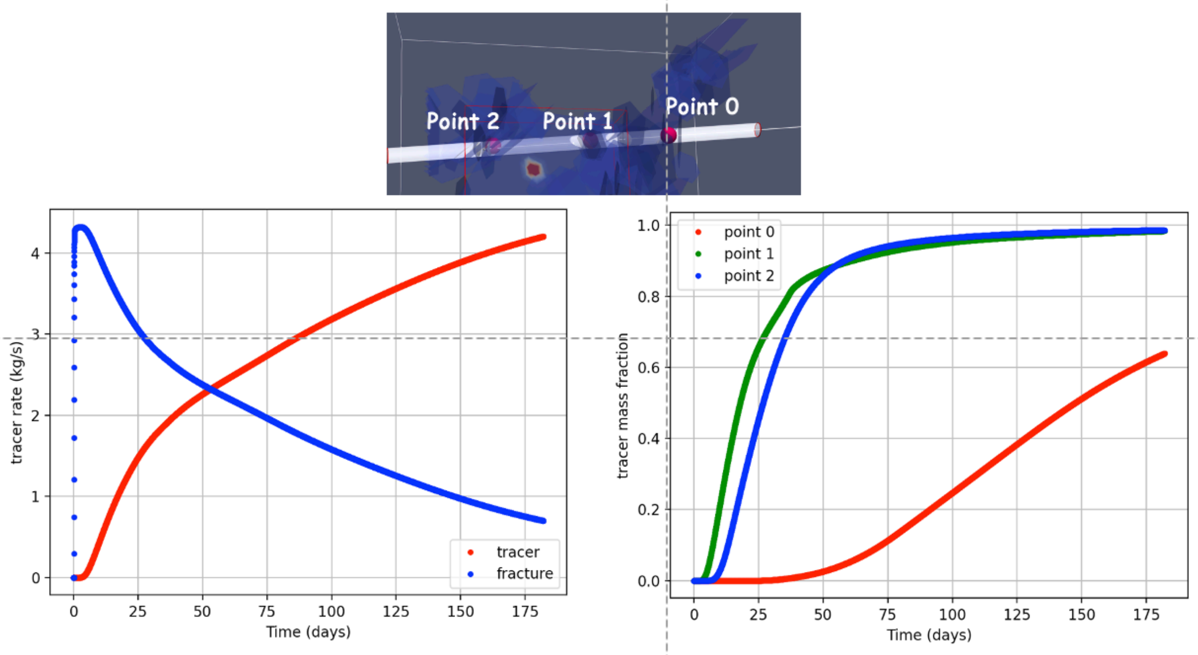


Figure B.3- 11. *In the left plot, the total production rate for each fluid is plotted. In the right, the mass fraction of tracer fluid withdrawn from the three production points is shown.*

In the next set of simulations, the location of the injection point is varied while keeping the three production points fixed. The locations for the injection points being sampled are shown by the green points in Figure B.3-12. The total tracer production is shown in the plot. Each line in the plot is for a different injection point and is colored by the distance of the injection point from the production well line. Injection at points close to the production line are shown in blue and show a sharp initial rise. The injection points further away from the production line are shown in red and initially show a shallower rise than the closer injection points but after about 120 days, they start to saturate the total production output more fully.

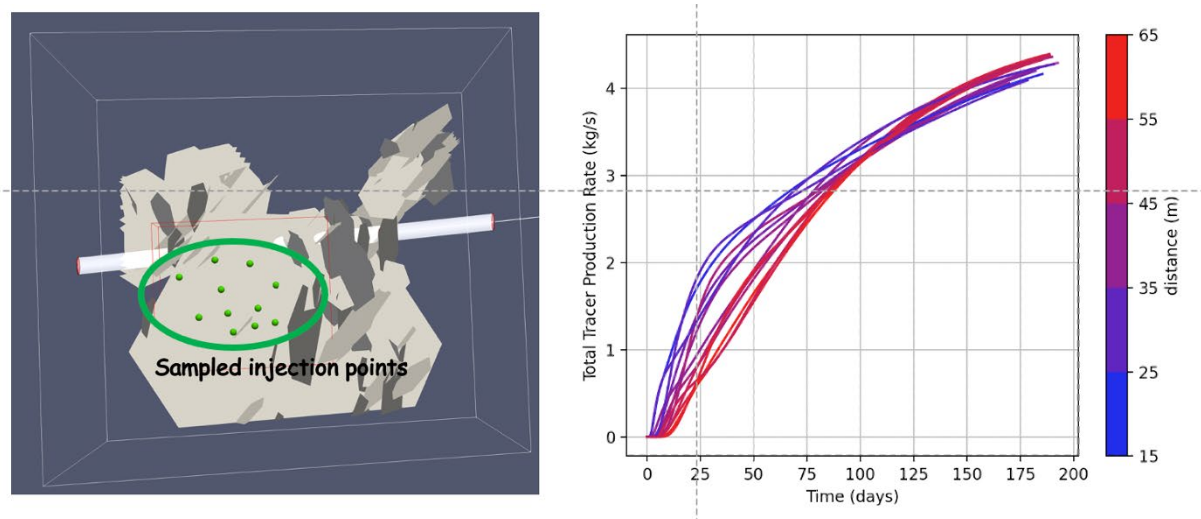


Figure B.3-12. *Location of points being sampled are shown in green in the left plot. The right plot shows the total tracer production rate. Each line is for a different injection point and is colored by the distance of the injection point from the production line.*

In Figure B.3-13, the tracer mass fraction produced at each production point is shown, also colored by the distance of the injection point from the production well. From these plots, we see that point 1 is the closest point to the production line and is the first to become fully saturated by the tracer fluid. Point 0 is the furthest from the production point furthest from the injection points. However, the furthest injection points from the production line shown by the red lines, provide the highest tracer concentration at point 0.

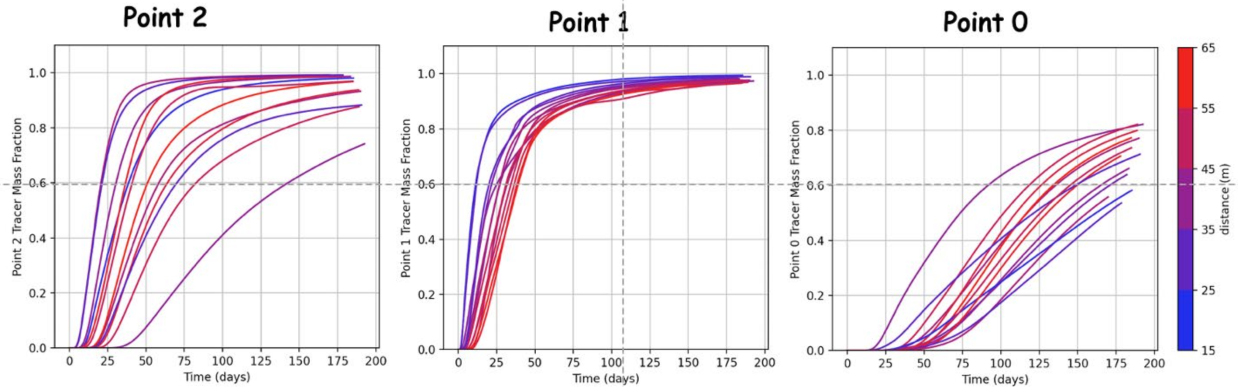


Figure B.3- 13. *Tracer mass fraction being produced at each production point colored by the distance of the injection point from the production line.*

Overall, we see that for the injection/production well pairs studied here that short circuiting of the flow occurs between the injection points and production point 1 on the well line. A larger sampling space of the DFN would lead to a better balance of tracer production at each location. The other component of this work was to apply the parallel subset simulation capability in the MOOSE stochastic tools module to speed-up and provide better sampling of injection/production well pair locations based on the QOI's identified in the above simulations. Some preliminary findings from this are shown in Figure B.3-14 where the y-axis is the QOI given by the minimum total tracer production. This QOI resulted in the separation distance between well production/injection pairs being the deciding factor. Future work will investigate other QOI to produce production/injection pairs that will maximize the extent of the tracer in the DFN and DFN connectivity.

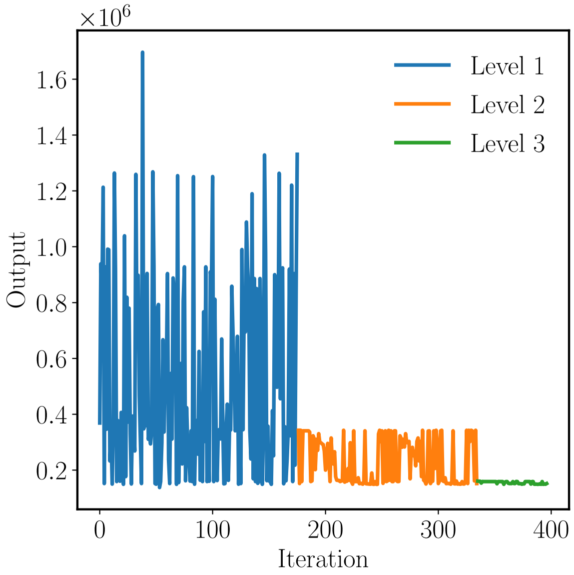


Figure B.3-14. *Integrated tracer output values from the stochastic optimization using the subset simulation algorithm. It is noticed as the optimization level increases from 1 to 3, the total tracer output is minimized. The production coordinates corresponding to the outputs in level 3 of the optimization are the optimized production regions.*

Update Reference DFN

As presented in Attachment 6, a new DFN model was developed for use by the modeling team that incorporates the microseismic data collected during stimulation of well 16A(76)-32. This activity corresponds with Task 7.1 in the Modeling Team SOPO. The new DFN model intends to capture significant flow pathways post-stimulation and was used for modeling of the long-term thermal and mechanical evolution of flow paths between 16A(78)-32 and the planned production well.

The microseismic data utilized for this DFN came from the earthquake (MEQ) catalogues for the three hydraulic stimulation stages of well 16A(78)-32. Potential planar features representing faults or fractures were identified by visual inspection while rotating the MEQ point cloud in 3D. Figure B.3-15 illustrates this process for the Stage 3 data set. Additional planes were added to connect the features identified from the MEQ data as shown in Figure B.3-16 based on previous fracture orientation characterization work. This DFN can be used to for simulations of post-stimulation flow paths between potential well 16A(78)-32 and potential producer wells and is available from the GDR.

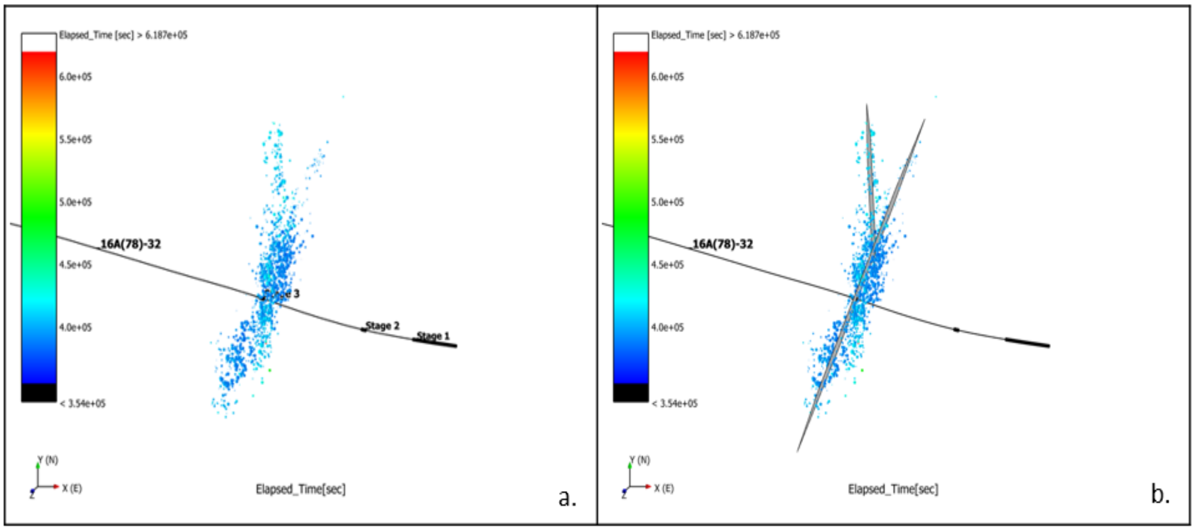


Figure B.3-15. *Top-down view of the preliminary earthquake catalog (MEQ) locations identified for the Stage 3 stimulation of well 16A(78)-32 (a) and the two fracture planes identified for Stage 3 (b). MEQ shown as point data with color corresponding to elapsed time from the first measured event and sizes are scaled by the calculated moment magnitude.*

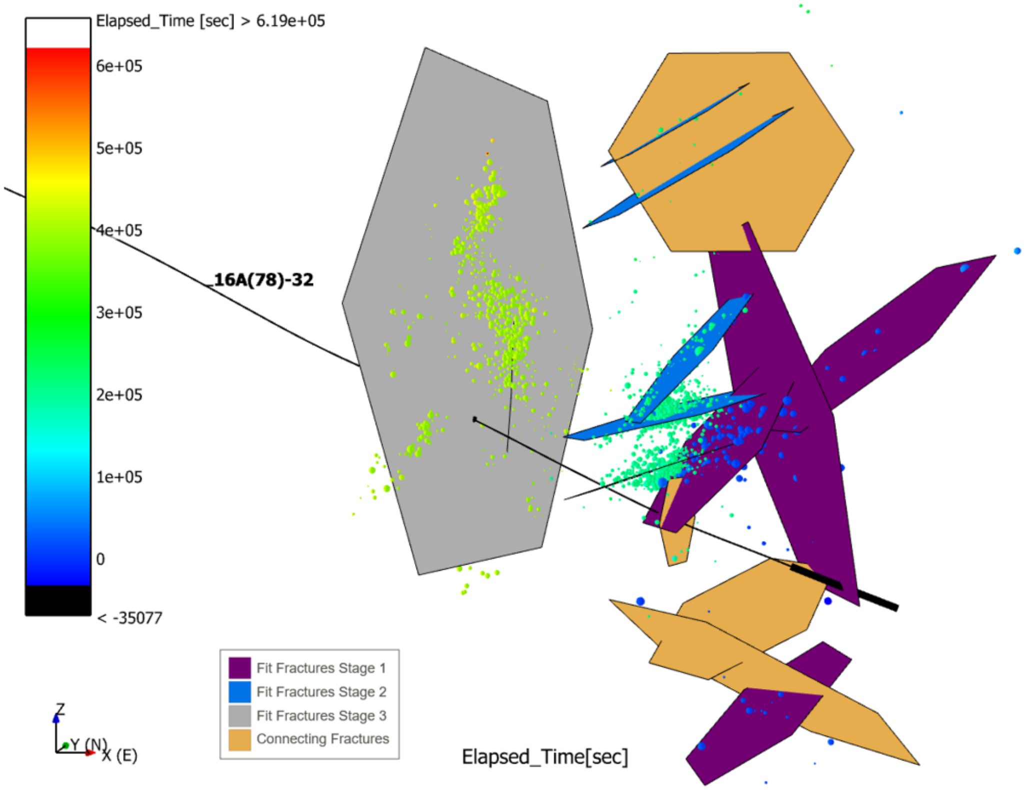


Figure B.3-16. *Side view of the 15 fracture planes included in the updated reference DFN model based on an interpretation of the preliminary MEQ catalog from the stimulation of well 16A(78)-32. MEQ locations are shown as point data with color corresponding to elapsed time from the first measured event and sizes are scaled by the calculated moment magnitude.*

Interwell Flow Test Design Assistance

Activities discussed in this section correspond with Modeling Team Tasks 3.0 and 5.0 in the SOPO. As presented in the published paper (Attachment 7), two different numerical simulators were used to study mid-term flow and transport (6 month) between the injection well 16A(78)-32 and potential production wells at various interwell spacings. Flow paths used the fracture network interpreted to have been created during the April 2022 stimulation activities. This work focused on the breakthrough times for injected tracers and thermal fronts, in an effort to provide input on injection-production well spacing that can ensure reliable and sustainable heat recovery from the geothermal reservoir over the testing timeframe of the FORGE program.

The FALCON simulator used a 3-dimensional Thermal-Hydraulic Mechanical (THM) reservoir model for Zones 1 and 2 that were stimulated in well 16A(78)-32, consisting of a 2.16x10^8 m^3 volume using grid cells that range from 2 to 100 m (Figure B.3-17). The location of the production well was situated directly above the injection well, vertically offset by three distances (75 m, 100 m and 125 m) to examine tracer the thermal breakthrough times. A series of nine modeling cases were developed to examine potential ranges in behavior for flow exiting well 16A(78)-32 and entering the EGS reservoir. With the exception of two cases, all had a total inflow of 10 kg/s, distributed among the accessible inflow zones in well 16B(78)-32.

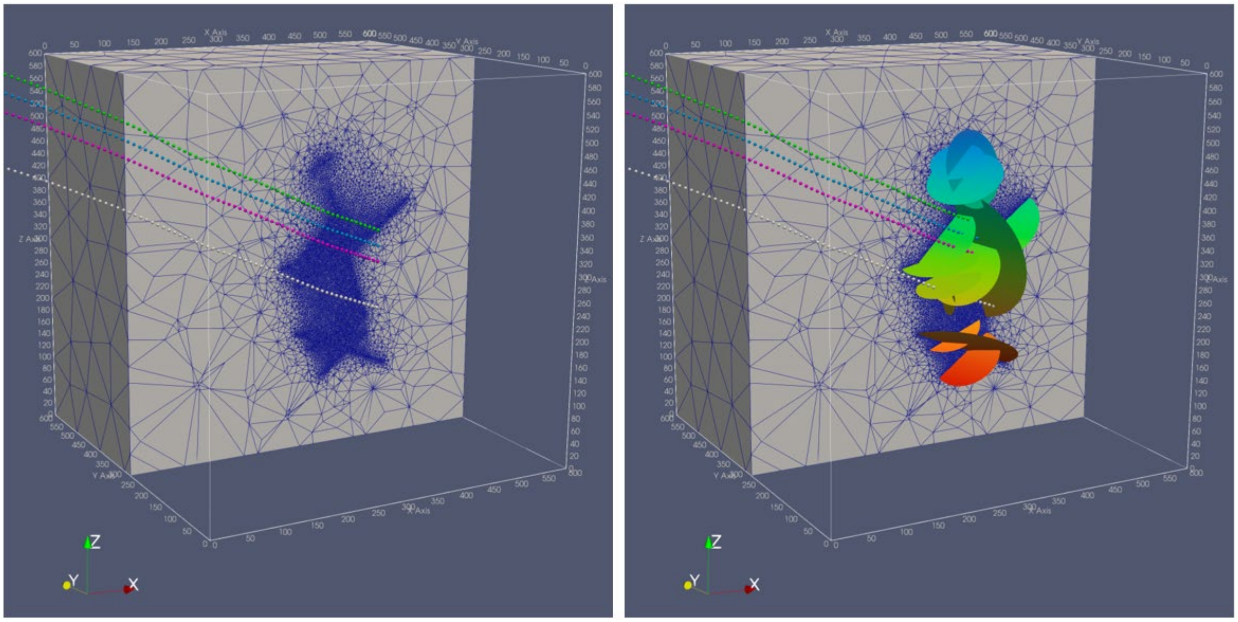


__Figure B.3-17.__ Cut-away of the numerical model domain, approximately along the path of well 16B. Left image shows the mesh density in the matrix needed to capture the thermal interaction with the fractures, right image shows the fracture planes.

Figure B.3-18 presents thermal and injected fluid breakthrough curves for the most likely modeling scenario, Case 1. Case 1 injected 9 kg/s from the open hole section at the well toe and 1 kg/s from Perforation Zone 1 (aka Stimulation Zone 2). Other case results are included in the attached paper. Unsurprisingly, the cases with larger well separation predict a longer amount of time for breakthrough, with injected fluid reaching well 16B(78)-32 in appreciable quantities in as little as 7 days for the closest well separation. Thermal breakthrough takes considerably longer in all cases, owing to the heat exchange between the fractures and the surrounding matrix. For the cases considered, the fastest initial thermal breakthrough occurs after approximately 16-17 days, with the longest being over 50 days.

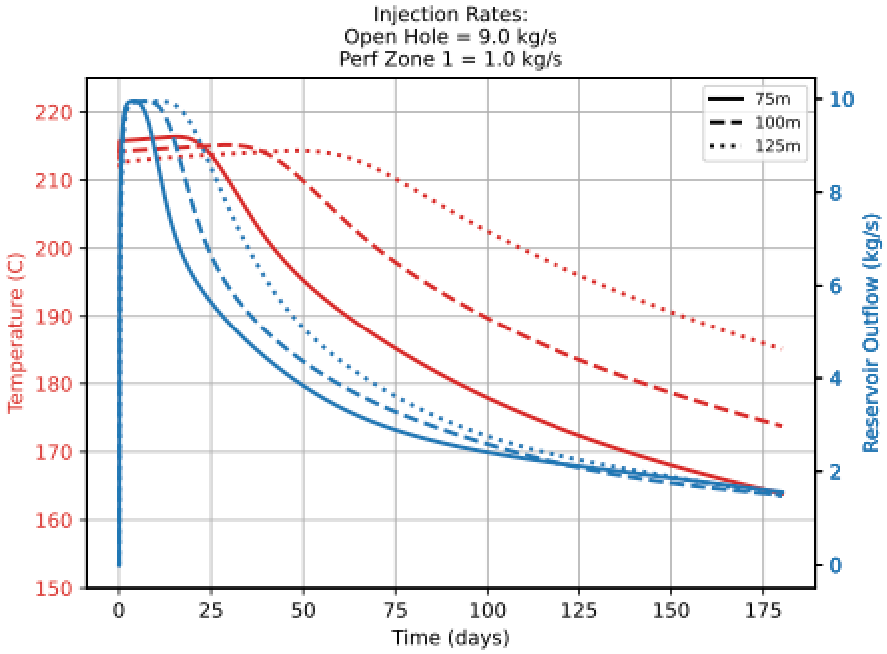


Figure B.3-18. *Numerical model results for Case 1. Red lines represent the simulated thermal breakthrough, while the blue lines represent the mass fraction of in-situ reservoir water produced corresponding to conservative fluid transport. The solid line represents the 75m well separation scenario, the long dash the 100m scenario, and the short dash the 125m separation scenario.*

Figure B-3.19 illustrates an example of the complexity of the heat structures that develop in the reservoir. It presents the temperature distribution in the fracture system after 6 months of injection for Case 1. The multiple flow paths between the injection and production points are clearly illustrated.

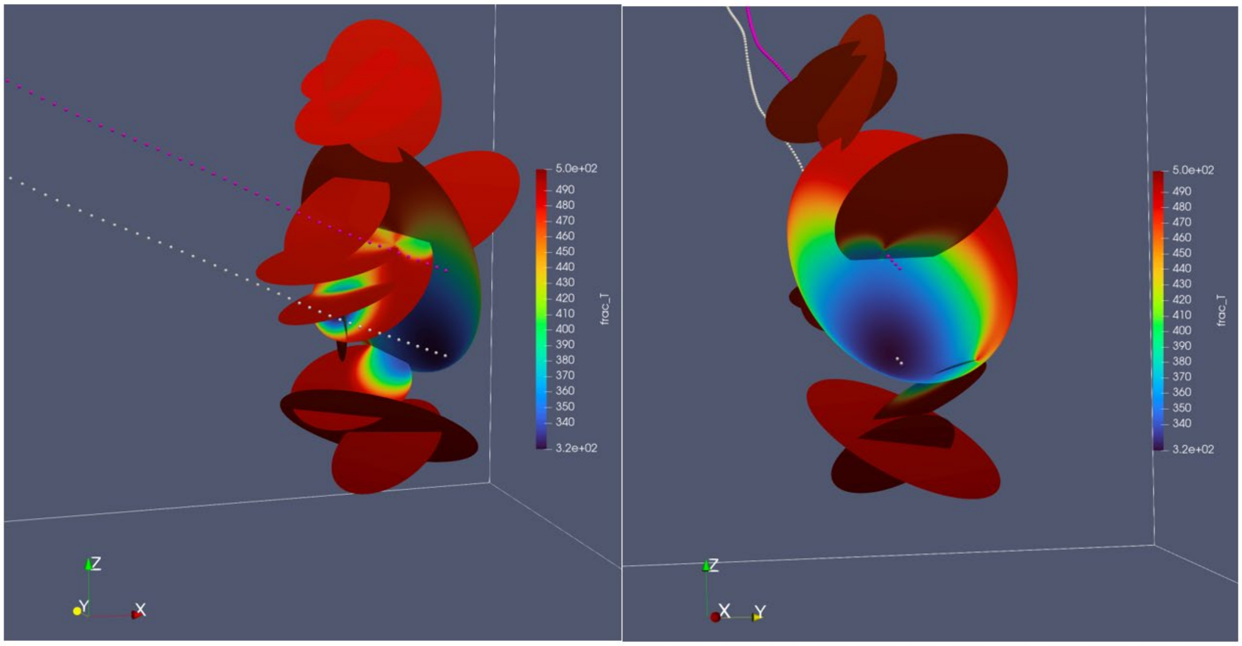
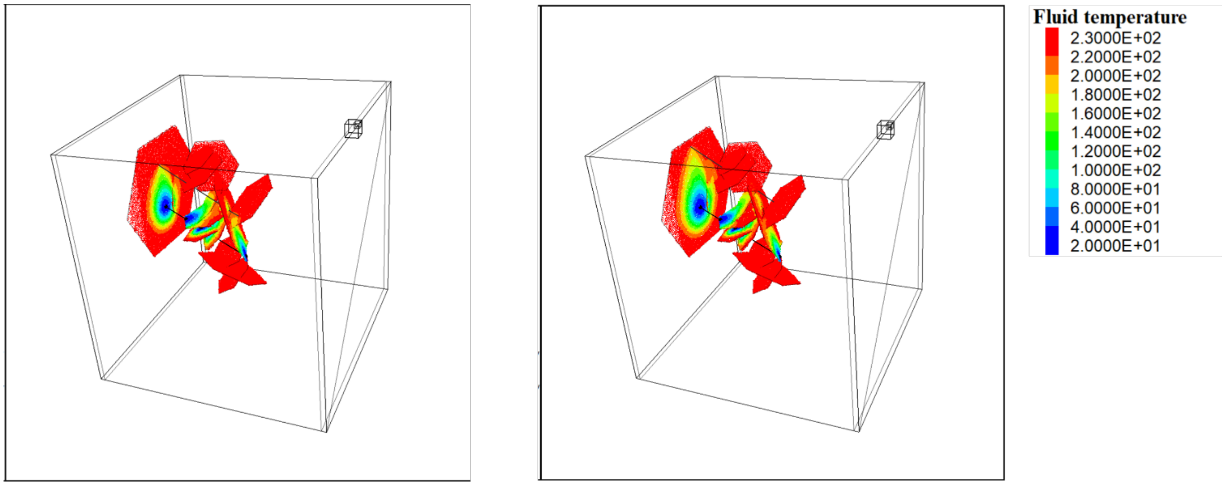


Figure B.3-19. *Three-dimensional view of the temperature distribution in the fracture domain after 6 months of injection. Case 1, 75m separation scenario shown. The temperature distribution in the fracture zone is complex owning to the multiple source and sink locations. Temperature shown in Kelvin.*

An independent modeling of the same problem was carried out using XSite, the numerical model based on the lattice method, with the objective of increasing confidence in the model predictions. Two locations of well 16B(78)-32 were assumed in the analyses, with sub-horizontal section 100 m and 150 m above the sub-horizontal section of well 16A(78)-32. In the XSite model, it is assumed that 10 kg/s is injected in all three stimulated stages of 16A. The perforation pressure drop was not considered in Stages 2 and 3, but the model resolves distribution of injected flow rate between intersected fractures using approximation of flow along the well.

The pressure required to achieve same flow rate is 3.5 MPa greater for larger spacing of the wells. The contours of fluid temperature after 80 days are shown in Figure B.3-20 and histories of produced water temperatures are shown in Figure B.3-21. Only a “skin” of rock cools along the fracture length between wells 16A and 16B. Even though fracture apertures increase slightly around the injection well as a result of this cooling, injection pressures and injectivity remain practically the same. These results indicate that cooling of rock might not be very effective in improving injectivity during water circulation.



a) 100 m well spacing

b) 150 m well spacing

Figure B.3-20. *Fluid temperature (°C) contours after 80 days of circulation.*

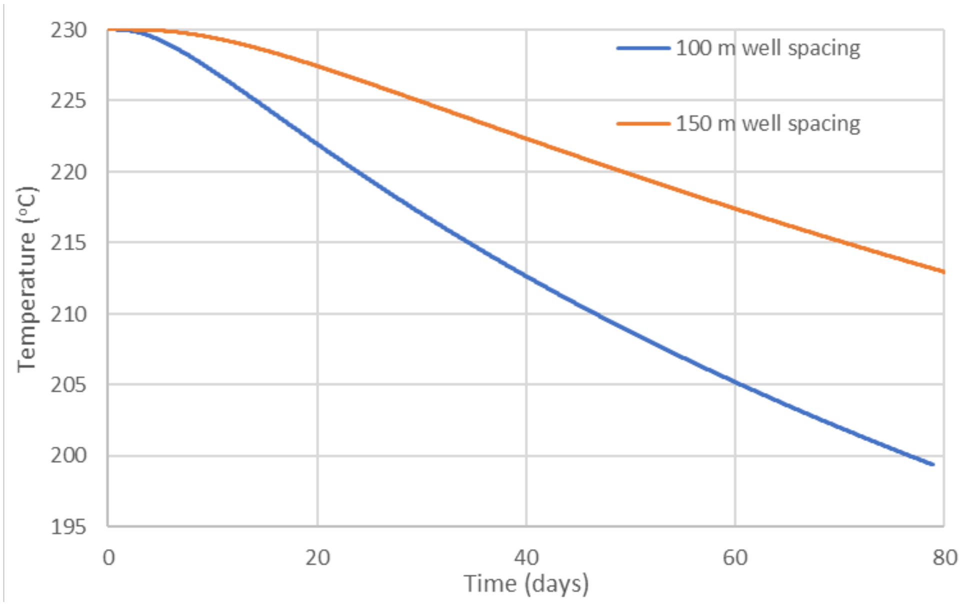


Figure B.3-21. *Temperature histories of produced water.*

Discussion

This section lists some of the most significant findings from the Modeling Team’s activities in Phase 3B Year 1.

The highest priority for the team was to provide guidance to the operational team regarding the design of production well 16B(78)-32. This included:

- Accurate prediction of stimulated volumes including combinations of hydraulic fracturing and stimulation of a weak, frictional, and permeable DFN.
- Predictions of breakthrough times for injected tracers and thermal fronts to provide input on injection-production well spacing that can ensure reliable and sustainable heat recovery from the geothermal reservoir over the testing timeframe.

These modeling efforts support positioning well 16B(78)-32 approximately 100 m above the lateral for well 16A(78)-32 in the FORGE reservoir region.

Additionally, new methodologies were developed to aid future modeling efforts:

- Rapid identification of significant lithologic boundaries and fracture zones from sonic log data which can be used to refine geologic models and choose stimulation target intervals.
- Stochastic optimization to determine well placement and completion options based on numerical simulations of a DFN.

And new reference model updates were developed and made available to other researchers:

- Updated Native State Model
- New Stimulated Reference DFN

B.4 EXTERNAL R&D

External R&D involves two separate sets of activities related to the 2020-1 and 2022-2 Solicitations.

Solicitation 2020-1

The 2020-1 Solicitation comprises a portfolio of 17 projects that covers 5 topic areas having a total value of $53.03 million (Tables B.4-1, B.4-2). The awardees were selected through a competitive process involving responses to the Utah FORGE Solicitation 2020-1, which was published in April 2020. These projects have now been running for 15 to 18 months, with good progress and significant achievements as summarized below.

***Table B.4-1**. Utah FORGE Solicitation 2020-1 R&D Topic Areas.*

Topic 1—Enable strategic permeability enhancement and control, via the development of an integrated zonal isolation and flow control system, operational at temperatures in excess of 225°C, in both cased and open-hole wellbores.
Topic 2—Analyze stresses in the reservoir rocks to design and execute additional in situ stress measurements to support informed and effective stimulations in the Utah FORGE team's field campaign.
Topic 3—Develop a suite of advanced, complementary characterization methods and processing techniques to supplement existing data on the Utah FORGE site and further the community's understanding of the development and evolution of fracture systems.
Topic 4—Develop and test innovative stimulation techniques and methods in available portions of this Utah FORGE well, pair these results with in-depth analysis and recommendations on the orientation and/or completion style of the long reach well (yet to be drilled) to best access the created fracture network
Topic 5—Integrate experiments and/or in situ measurements of rock and reservoir properties in concert with THMC modeling to determine fracture behavior, permeability evolution, and heat transfer over time at Utah FORGE and develop an improved understanding of which properties are most critical for the development of EGS.

***Table B.4-2.** R&D Award Prime Recipients & Project Titles.*

Topic-ID	Title	Recipient	Period	DOE cost	Total Value
1-2551	Development of Multi-Stage Fracturing System and Wellbore Tractor	Colorado School of Mines	10/1/2021-9/30/2024	$4,604,667	$5,342,323

1-2410	Development of a Smart Completion & Stimulation Solution	Welltec	10/1/2021-9/30/2024	$3,887,574	$4,385,707
1-2409	Zonal Isolation Solution for Geothermal Wells	PetroQuip	10/1/2021-9/30/2024	$2,813,596	$3,516,995
2-2439	A Multi-Component Approach to Characterizing In-Situ Stress	Battelle	10/1/2021-9/30/2024	$2,994,436	$2,994,436
2-2446	Closing the loop between in situ stress complexity and near-wellbore fracture complexity	Lawrence Livermore National Lab	1/1/2022-2/28/2025	$1,599,616	$1,599,616
2-2404	Application of Advanced Techniques for Determination of Reservoir-Scale Stress State	Univ. Oklahoma	10/1/2021-9/30/2024	$1,164,581	$1,164,581
3-2418	Wellbore fracture imaging using inflow detection measurements	Stanford Univ.	10/1/2021-9/30/2024	$2,250,623	$2,250,623
3-2535	Joint electromagnetic/seismic/InSAR imaging	Lawrence Berkeley National Lab	12/1/2021-9/30/2024	$2,171,421	$2,258,910
3-2417	Fiber-optic geophysical monitoring of reservoir evolution at Utah FORGE	Rice Univ.	10/1/2021-9/30/2024	$4,411,914	$$4,921,540
3-2514	A Strain Sensing Array to Characterize Deformation at Utah FORGE	Clemson Univ.	10/1/2021-9/30/2024	$3,972,453	$3,972,453
4-2492	Design and implementation of innovative stimulation treatments to maximize energy recovery efficiency	Univ. Texas Austin	10/1/2021-9/30/2024	$3,636,311	$3,673,811
4-2541	Optimization and validation of a plug-and-perf stimulation treatment design at Utah FORGE	Fervo	10/1/2021-9/30/2023	$6,231,329	$7,822,007

5-2419	Seismicity-permeability relationships probed via nonlinear acoustic imaging- of fractures in shear	Penn State Univ.	10/1/2021-9/30/2024	$1,504,415	$1,504,415
5-2615	Experimental determination and modeling-informed analysis of thermo-poromechanical response of fractured rock	Univ. Oklahoma	10/1/2021-9/30/2024	$1,130,229	$1,130,229
5-2565	Evolution of permeability and strength recovery of shear fractures under hydrothermal conditions	US Geological Survey	10/1/2021-9/30/2024	$1,848,564	$1,848,564
5-2428	Coupled investigation of fracture permeability impact on reservoir stress and seismic slip behavior	Lawrence Livermore National Lab	1/1/2022-2/28/2025	$2,350,000	$2,366,291
5-2557	Role of fluid and temperature in fracture mechanics and coupled THMC processes	Purdue Univ.	10/1/2021-9/30/2024	$2,282,941	$2,282,941

Solicitation 2020-1 Project Summaries of Objectives, Activities, and Achievements

1-2551 Colorado School of Mines: Development of Multi-Stage Fracturing System and Wellbore Tractor to Enable Zonal Isolation During Stimulation and EGS Operations in Horizontal Wellbores

Objectives: Develop, test and conduct field trials for 1) sliding casing frac sleeves and 2) a tractor with flow meter survey capability, to control and manage fluid flow in deviated wells for EGS development.

Activities: Tool development, testing & field deployment.

Achievements: Engineering and design for the frac sleeve and the tractor are completed. Manufacturing and testing of components for both devices are advancing.

1-2410 Welltec: Development of a Smart Completion & Stimulation Solution

Objectives: Develop an isolation system comprising an annular barrier and flow valve capable of withstanding geothermal downhole conditions in Utah FORGE wells.

Activities: Lab experiments; data analysis; tool development, testing & field deployment.

Achievements: Engineering and experimentation of components for the high-temperature metal expandable packer (MEP) that performs under differential pressure of up to 6000 psi is advancing and a full-scale testing is ready to commence.

1-2409 PetroQuip: Zonal Isolation Solution for Geothermal Wells

Objectives: Design and build two retrievable tools, a locking bridge plug (LBP) and an open-hole packer (OHP), that perform for extended periods of up to 12 months at EGS geothermal reservoir conditions, and impervious to proppant-bearing stimulation fluids.

Activities: Tool development, testing & field deployment.

Achievements: Engineering and design of the LBP, landing profile (LP), OHP are completed, and testing of the LBP and LP is progressing.

2-2439 Battelle: A Multi-Component Approach to Characterizing In-Situ Stress at the Utah FORGE EGS Site: Laboratory, Modeling and Field Measurement

Objectives: Characterize the stresses in the EGS reservoir based on: 1) the relationship between applied stresses and ultrasonic wave velocities (from Triaxial [polyaxial] stress ultrasonic velocity [TUV] rock physics experiments) and sonic well-log data for the well(s), enabled by machine learning methods; 2) measurement of stresses at multiple depths in Utah FORGE 16B(78)-32 wellbore with a downhole tool; 3) development and application of numerical modeling to estimate far-field (reservoir) stress that is distinct from nearfield stress determined in 1 and 2.

Activities: Lab experiments; data analysis; measurements of stress in up to 10 discrete intervals downhole in well 16B(78)-32 using a subcontracted off the shelf tool. Note, downhole tool deployment requires long open hole interval that may compete with needs to case the deviated leg.

Achievements: Completed laboratory testing of wave speed versus stress characterization on drill core and finalized a field-testing plan for in situ open borehole stress measurement.

2-2446 Lawrence Livermore National Laboratory: Closing the loop between in situ stress complexity and near-wellbore fracture complexity

Objectives: High-fidelity estimations of in-situ reservoir stress based on minifrac and DFIT tests combined with experimental and modeling results. Laboratory experiments will be used to measure rock properties, and both validate and improve numerical model results. The numerical models will simulate fracture initiation and propagation under various conditions.

Activities: Lab experiments; numerical modeling; Utah FORGE data analysis.

Achievements: A novel phase-field to simulate hydraulic fracture nucleation and propagation has been formulated. Simulation of hydraulic fracture propagation mimicking the experimental setup under various stress conditions has been performed. Experimental equipment validated on Cold Spring granite blocks. First two laboratory experiments on Utah FORGE analog samples have been conducted.

2-2404 University of Oklahoma: Application of Advanced Techniques for Determination of Reservoir-Scale Stress State

Objectives: Develop a technology for determination of the in-situ stress state in the reservoir at Utah FORGE via application and integration of alternative wellbore methods and a reservoir-scale methods in conjunction with DFIT and flowback data. Improve estimates of the near-wellbore and the reservoir-scale in-situ stress tensor. The methods include anelastic strain recovery (ASR), fracture mechanics analysis of drilling induced cracks, novel interpretation of induced seismicity focal mechanisms.

Activities: Lab experiments; data analysis; deployment of ASR tool on surface and acquisition of newly recovered drill core to determine transient changes in in-situ stress.

Achievements: The wellbore in-situ stress models for the three deep vertical wells at Utah FORGE site have been established based on the drilling-induced fractures, breakouts, and stress polygon. Obtained fault planes from earthquake clustering for the stage 3 2022 stimulation, and performed full waveform moment tensor inversions for some of the larger micro-seismic events to obtain moment tensor solutions. Procured parts for ASR jacket development

3-2418 Stanford University: Wellbore fracture imaging using inflow detection measurements

Objectives: Make measurements in the Utah FORGE wells, using a refurbished downhole tool with a specific ion probe that detects Cl, for before and after fracturing experiments, detecting flowing fractures and estimating inflow magnitudes in real time.

Activities: Recondition downhole tool; deploy tool in well 16 after stimulation to detect fracture control inflows.

Achievements: New algorithms for flow rate estimation were developed and completed. Calibrations and lab experiments for the downhole tool were completed. Preliminary numerical modeling of results was completed. Fracture inflow behavior within the wellbore-replica flow loop with various flow rates has been captured. A new version of the chloride tool is being built by Sandia to perform at conditions up to 207 MPa and 225°C.

3-2535 Lawrence Berkeley National Laboratory: Joint electromagnetic/seismic/InSAR imaging of spatial-temporal fracture growth and estimation of physical fracture properties during EGS resource development

Objectives: Estimate spatio-temporal fracture growth and fracture properties during the enhanced geothermal system (EGS) experiment at the Utah FORGE site, using electromagnetic, seismic and InSAR data in a novel joint inversion scheme that includes coupled THMC parameter estimation.

Activities: Recondition VEMP downhole tool; obtain/compile before and after geophysical data (EM, induced seismicity, geodetic-strain); joint inversion modeling of geophysical data.

Achievements: The VEMP amplifier was reconditioned and installed within the vacuum dewar. Completed the 3D seismic velocity model describing the resolution of velocity estimates within the future fracture volume. Completed 3D model of the resistivity structure in the vicinity of the EGS reservoir. Completed comparison of the electric and magnetic fields in the model computed with the true source including the 2D cylindrical steel well casing and equivalent dipole sources.

3-2417 Rice University: Fiber-optic geophysical monitoring of reservoir evolution at Utah FORGE

Objectives: Map conductive fractures that contribute to circulation in an EGS reservoir by development and deployment of a state-of-the-art distributed fiber optic monitoring system, utilizing Distributed Acoustic (DAS), Distributed Temperature (DTS), and Distributed Stress (DSS) Sensing.

(DAS/DTS/DSS) combined with periodic hydraulic tests and an array of automated surface seismic sources to constrain multiple phases of fracture evolution induced by stimulation.

Activities: (a) design and install an integrated fiber-optic sensing system for the Utah FORGE site, (b) execute multi-physics field monitoring experiments including the approaches described above (microseismic, time lapse VSP, hydraulic testing), and (c) analyze data and integrate into a THM model.

Achievements: Completed an analysis of the response expected by DAS and DSS during stimulation activities. Completed installation of sub orbital vibrators. Developed a detailed plan for the fiber optic cable package and its deployment in collaboration with the UT Austin project.

3-2514 Clemson University: A Strain Sensing Array to Characterize Deformation at Utah FORGE

Objectives: Demonstrate that strains can be measured and interpreted during EGS reservoir stimulations, using strain meter network deployed in shallow boreholes and one deep well.

Activities: Build and deploy strain meters, monitor stimulations, analyze field data.

Achievements: Completed assembly and installation of four strain meters; field testing indicates that the solid Earth tides can be measured by all strain tensor components with a signal-to-noise ratio > 10. Analysis of data acquired by two instruments operational during the stimulation of well 16A-32 shows that additional refinements are needed to distinguish the strain during the stimulation from background signals. A high temperature strain meter with a configuration that could be deployed outside casing was assembled and was proved capable through lab testing to measure strain while heated to 200°C for 3 days. The analysis of the microseismic data collected during the stage 3 stimulation showed that the size to depth ratio of the main source deformation zone is ~10^{-1}, which represents a likely emerging case in the Utah FORGE conditions.

4-2492 University of Texas-Austin: Design and implementation of innovative stimulation treatments to maximize energy recovery efficiency

Objectives: Use 3-D geomechanical, compositional and coupled reservoir-fracturing simulators to compare three different well completion/stimulation strategies: (i) Plug and perforate (PnP) completion with limited entry uniform or geometric perf design, (ii) Plug and perforate (PnP) with limited entry tapered perf design, and (iii) a single point entry completion with sliding-sleeves. These will be used to: (1) place fractures uniformly in a horizontal well (improve cluster efficiency) to ensure a uniform distribution of flow into the fractures; (2) maximize the surface area of the created fracture network; (3) ensure connectivity of the fractures from the injector to the producer; (4) ensure fracture size is optimized not to exceed well spacing.

Activities: Analyze Utah FORGE field data to design and implement stimulation in well 16B(78)-32, instrument well 16B with fiber optic cable.

Achievements: Developed a detailed plan for the fiber optic cable package and its deployment in collaboration with the Rice project. Simulations were conducted to model fracture propagation in the 16A well using the DFN that was previously generated based on core and log data.

4-2541 Fervo: Optimization and validation of a plug-and-perf stimulation treatment design at Utah FORGE

Objectives: Design and run stimulation at Blue Mountain and use results to advise best stimulation design at Utah FORGE

Activities: Plan and implement EGS reservoir stimulation at Blue Mountain.

Achievements: At the Blue Mountain project, completed DFIT test in monitoring well, completed 16-stage plug-and-perf stimulation treatment in injection well, followed by a 5-day injection test.

5-2419 Penn State University: Seismicity-permeability relationships probed via nonlinear acoustic imaging- of fractures in shear.

Objectives: (1) Explore active and passive acoustic signatures of seismic and aseismic evolution of permeability for fractures in shear, (2) link this to key features of the pre-existing stress state (proximity to failure) as a precursor to, and a key predictor of, moment magnitude of prospective triggered seismicity, and (3) upscale these indexes to reservoir scale as diagnostics and tools to drive successful reservoir stimulation, production, and management. The nonlinear acoustic characterizations of (1) permeability evolution and (2) antecedent stress state for triggered seismicity will be completed in the laboratory and (3) upscaled against field observations using nested micromechanical models.

Activities: Lab experiments; data analysis.

Achievements: Completed friction-permeability velocity stepping experiment with concurrent active acoustics probing; observed stick slip response in apparatus. Defined protocols to link experimentally measured pressures and displacement histories to field anticipated MEQ magnitudes. Incorporated nonlinear contact and permeability/porosity logic in 2D and 3D into particle flow code (PFC).

5-2615 University of Oklahoma: Experimental determination and modeling-informed analysis of thermo-poromechanical response of fractured rock

Objectives: Combine 3D thermo-poromechanical modeling with rock mechanics experimental results to demonstrate the role of thermo-poroelastic effects in reservoir development.

Activities: Lab experiments; data analysis.

Achievements: Completed elastic (static and dynamic) and poroelastic measurements on drill core from Utah FORGE wells. Conducted dynamic tests on these specimens to assess the extent of micro-cracking upon stress release and cooling. Completed poroelastic measurements on fractured rock. Analyzed micro-frac test data and conducted tests for measuring poroelastic properties of rock at high temperatures.

5-2565 US Geological Survey: Evolution of permeability and strength recovery of shear fractures under hydrothermal conditions

Objectives: 1) An enhanced understanding of the mechanisms controlling fracture property evolution and the conditions at which different processes are active, and 2) improved models for predicting fracture evolution at hydrothermal conditions.

Activities: Lab experiments; data analysis.

Achievements: Completed triaxial shear deformation tests on Westerly granite from 22 to 250 °C, including no-flow, cyclic and continuous flow conditions, and completed preliminary analysis of results. Completed two-to-six-month long convergence experiments comprising quartz-on-quartz tests (50 to 100 MPa; 200 - 300 °C) that show reduction in surface roughness (primarily resulting from application of normal stress) as well as evidence for pressure solution and other processes. Developed a python-based simulator of elastic deformation and stress-driven dissolution on a fracture surface that will incorporate strength and flow evolution results.

5-2428 Lawrence Livermore National Laboratory: Coupled investigation of fracture permeability impact on reservoir stress and seismic slip behavior

Objectives: Develop, apply and validate a holistic thermal, hydrologic, mechanical, and chemical (THMC) workflow that includes evaluation of induced seismic slip in EGS reservoirs. Integrate experimental and modelling approaches to reduce parameter uncertainty and better predict and mitigate seismic hazard.

Activities: Lab experiments; data analysis.

Achievements: Conducted 8 double-direct shear experiments on simulated fault gouge. Conducted 4 double-direct shear experiments on granitoid rock surfaces, one at 110°C. Prepared reactive flow and transport model and advanced thermal solver capability in GEOSX to be used in the coupled THMC modeling.

5-2557 Purdue University: Role of fluid and temperature in fracture mechanics and coupled THMC processes for enhanced geothermal systems.

Objectives: Develop and validate a macroscopic model of local deformation/frictional behavior, seismic/aseismic behavior, chemical reactions, and determine the adequacy of classic Coulomb failure vs. rate-and-state friction in response to hydrothermally induced perturbations.

Integrate experimental data and modeling results to: 1) design the reservoir to achieve optimal heat recovery; 2) quantify coupled THMC processes that govern fracture evolution.

Activities: Lab experiments; data analysis.

Achievements: Finite Element Model (FEM) with multiple options for boundary conditions was implemented into MOOSE-FARMS (MOOSE-Fault and Rupture Mechanics Simulations) with adaptive time stepping and variable mesh sizes that were developed to simulate the Utah FORGE reservoir. MOOSE-FARMS was tested in 2D and 3D benchmark problems from the Southern California Earthquake Center (SCEC) code verification exercise for ambient pressure and temperature conditions. Demonstrated simulation of dynamic rupture on pre-existing fault surfaces. Completed 3 direct shear experiments inside a pressure chamber a 10 MPa, consisting of an effective normal stress of 2 MPa and a pore water pressure of 8 MPa. Completed two shear slip experiments under tri-axial conditions to generate experimental data for the rate-and-state friction model. Performed a joint hydro-geophysical-geomechanical inversion of effective permeability and thermal conductivity, using the native state FALCON model.

2020-1 Solicitation R&D Management

All 2020-1 projects are carefully monitored using conventional reporting tools, including quarterly and annual reports, and Go/No Go stage gates. Projects within each Topic are managed by Topic Leads (a team comprising one to two Utah FORGE representatives and two DOE-GTO representatives). The R&D Co-Leads (a team of two from Utah FORGE) oversee the Topic Leads, and they report to the Utah FORGE Principal Investigator and the Utah FORGE Business Manager who have executive decision-making authority on behalf of the University of Utah.

In December 2022, monthly status update meetings were established and held virtually with each project Principal Investigator, as well as the Utah FORGE PI, R&D Lead, and topic leads from Utah FORGE and DOE. These meetings were designed to facilitate progress updates on a regular monthly interval, including updates on task or milestone progress, budget status, and highlights, issues, or achievements leading towards a Go/No-Go decision. Following the March 2022 monthly meetings, the decision was made to shift these meetings from monthly to quarterly, given the forthcoming addition of up to seventeen (17) new R&D projects and the increased time demand required. The quarterly meetings will be more effective in managing the update process, with the option for additional meetings as needed.

Quarterly reviews were completed by specialist Topic Leads assigned by Utah FORGE and DOE, and these were used to judge technical progress based on green, yellow and red health indicators in terms of scope, schedule and budget. The results of these assessments were used as feedback to project Principal Investigators.

As of March 31, 2023, quarterly reports (October 1-December, 31, 2022) reports had been submitted and evaluated. Health Indicators for the R&D projects were finalized in February 2023 after consultation with all the Topic and R&D Leads. All the projects were judged to have a green health indicator in reference to scope, schedule and expenditure, except for five (5) in which a noncompliant report or no report was submitted. Each project Principal Investigator was notified and advised of deficiencies, corrective action was taken, and in all instances a satisfactory report was received.

Utah FORGE has issued contract continuance where applicable. As of March 31, 2023, six (6) projects have been approved to advance to budget year two, whereas nine (9) projects were given six (6) month no cost extensions and one (1) project has been given a three (3) month no cost extension. Utah FORGE continues to actively monitor each of the R&D projects to maintain the current schedule of each project.

Apart from monitoring the progress of the R&D projects' milestone achievements, the R&D Leads also oversaw the committee reviews of Go/No-Go stage gates as they came due. Once a Go/No-Go report was received, a committee review was initiated, which included a presentation of the report by the project Principal Investigator and a review process by the Topic Leads from both Utah FORGE and DOE.

The Go/No-Go stage gates represent the most rigorous of all project management tools, serving as the fundamental basis for the continuation of funding. These stage gates undergo scrutiny from various experts, including the Utah FORGE/DOE Topic Leads, as well as those from the STAT, the Utah FORGE Contracting Officer, and the Utah FORGE Principal Investigator, as deemed necessary. As of March 31, 2023, twelve (12) Go/No-Go Stage Gates were successfully approved (Table B.4-3).

***Table B.4-3** Approved Go/No-Go Stage Gates.*

Project	Go/ No-Go #	Description	Approval Date
4-2541 Fervo	1	Submit the drilling and testing plan for the offset vertical well to Utah FORGE for approval.	1/10/2022
4-2541 Fervo	2	Submit the drilling and testing plan to Utah FORGE for approval.	4/20/2022
1-2409 PetroQuip	1	Evaluating the likelihood that the OHP tool as designed will be functional in Utah FORGE wells.	5/20/2022
4-2492 UT Austin	2	Present the deployment plan and NEPA approval to Utah FORGE for approval, prior to procuring any equipment.	6/10/2022
3-2417 Rice	3	Develop and evaluate a detailed plan for deployment of the fiber-optic cable integral to the FOGMORE experiment.	6/29/2022

2-2439 Battelle	2	Establish the detailed field testing procedures for stress testing and logging within the 16B(78)-32 borehole, complete planning/preparation for field testing.	9/16/2022
1-2551 CSM	2	Analyze and assess existing mud motors, etc. for initial project planning. Test mission critical components of initial prototype.	12/8/2022
3-2417 Rice	1	Pre-modeling Detection Evaluation: decision is contingent on whether modeling studies demonstrate a high likelihood of project success for the fiber deployment and monitoring scheme.	1/24/2023
3-2514 Clemson	1	Approval to commence procurement and fabrication of Phase II strainmeters.	1/24/2023
5-2557 Purdue	1	Initial update of FALCON simulator to simulate dynamic fracture evolution.	1/24/2023
2-2439 Battelle	1	Decision on criterion that p- and s- wave speed correlation with stresses is observed in laboratory data for at least one 78B-32 or legacy FORGE sample.	1/24/2023
3-2535 LBNL	1	Decision to be made on whether the numerical modeling performed during Performance Period 1 suggests that enough signal will be generated in the various geophysical and geodetic data types to warrant the project to move on to the data acquisition and processing.	2/27/2023

The Annual Workshop was held August 15-16, 2022, in a virtual format. All PIs made 20-25-minute-long presentations, and each presentation was followed by a Q&A session lasting another 20-25 minutes. STAT members were in attendance and led the questioning, followed by Topic Leads. An Annual Report accompanied the presentation, and these were used by Topic Leads, R&D leads and 2-3 STAT reviewers to assess annual progress.

For 2023, the Annual Workshop is provisionally scheduled for September 7, in advance of which a short annual report will have been submitted along with a slide deck that is to be presented by each project Principal Investigator. These materials will be peer reviewed by external referees as well as the Topic and R&D Leads to make recommendations to the Utah FORGE Business Manager regarding project continuance, which will be finalized before October 31, 2023. For projects that did not start in October, 2021, separate annual reporting dates may be scheduled.

Solicitation 2022-2

This solicitation was published August 15, 2022, and it covers 5 additional topic areas valued at $44 million and set to be onboarded in 2023. The submission deadline for Concept Papers was

October 10, 2022, and a total of 105 applications were received. The merit review and recommendations of concept paper applications submitted in response to the solicitation was conducted in accordance with the guidelines described in the 2022-2 Evaluation Plan. The process was carried out as planned with the independent reviewers working in concert with the TARMaC (a committee composed of Utah FORGE and DOE representatives) and the STAT resulting in 53% of applications being encouraged to submit full papers across the five topics (Table B.4-4).

On January 10, 2023, the Full Paper submission deadline passed, resulting in 47 full applications being received. These applications were relatively evenly distributed across the various topics and drew participants from a diverse range of institutions and geographical locations, resulting in a cohort of exceptional diversity (refer to Figure B.4-1).

Presently, TARMaC is diligently carrying out the technical review of these applications in accordance with the guidelines described in the 2022-2 Evaluation Plan.

***Table B.4-4** Utah FORGE Solicitation 2022-2 R&D Topic Areas.*

Topic 6—Adaptive Induced Seismicity Monitoring Protocols: Development of practical real-time adaptive seismicity monitoring protocols that can be tested and validated with existing field test data acquired at Utah FORGE and expanded to other locations.
Topic 7—Alternative Stimulation Schemes: Stimulation methods that establish multiple fluid flow paths that permeate the reservoir volume between the injection and the production wells and that avoid short-circuiting of flow via a limited number of these paths.
Topic 8—Field-scale Experiments to Measure Heat-sweep Efficiency: Collection, interpretation, and analysis of data that supports the prediction of reservoir thermal performance without solely relying on the long-term production temperature data.
Topic 9—Stimulation and Configuration of the Well(s) at Utah FORGE High Temperature Proppants: Proppants intended for long-term conductivity support (minimum of 5-year design life) and thermal/pressurization cycles (150 to 250°C and 35 to 70 MPa respectively) in hot aqueous brines (250°C and 10,000 TDS) to demonstrate acceptable long-term fracture conductivity at the flow conditions experienced at the Utah FORGE site.
Topic 10—Multiset Straddle Packers for Open Hole Operations: Capable of operation without being damaged at operational temperatures in the presence of aqueous brines (10,000 TDS) at or greater than 225°C for two weeks, after cycling for 8 times under 5000 psi differential pressures.

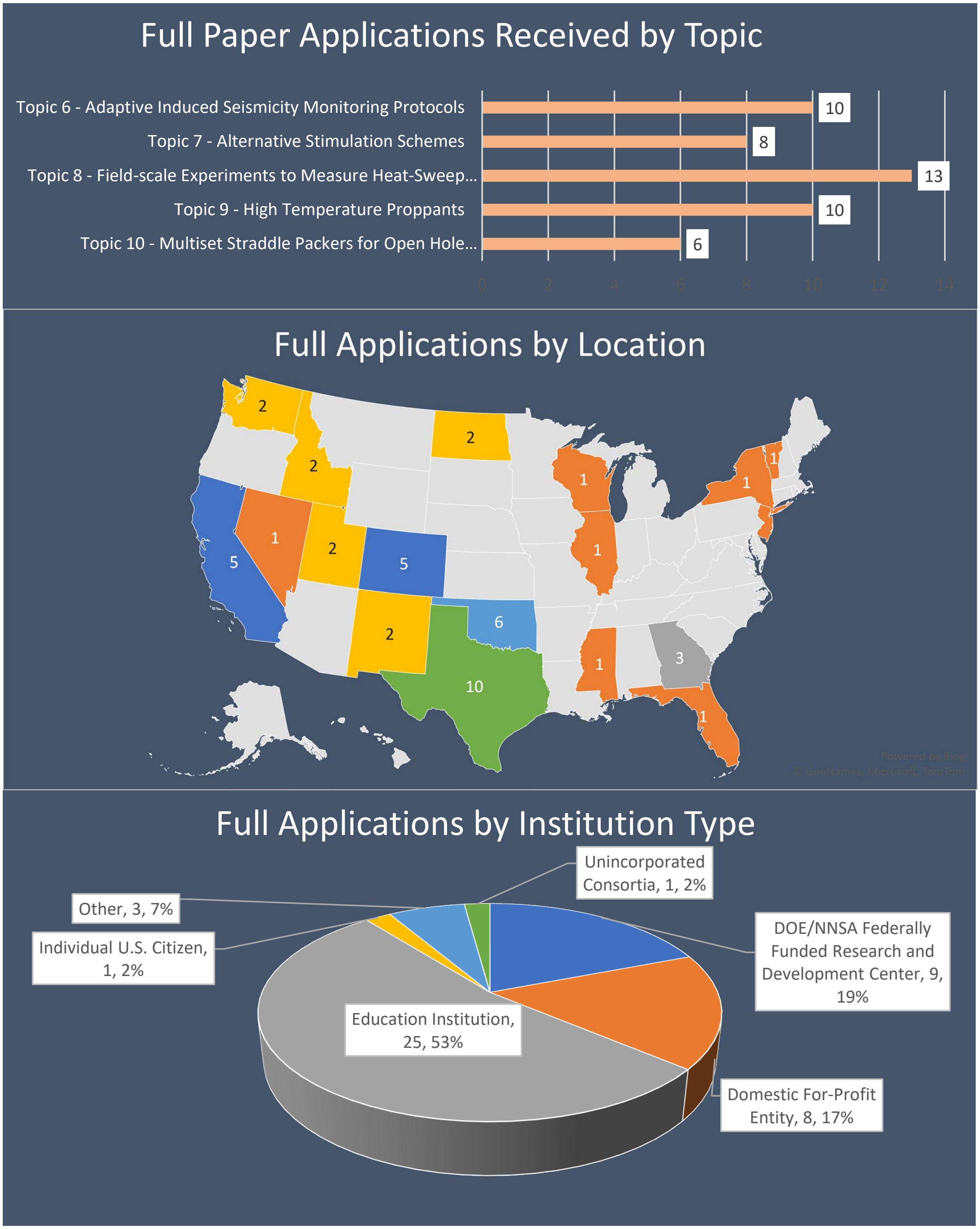


Figure B.4-1. *Solicitation 2022-2 Full Paper Application Statistics.*

B.5 COMMUNICATIONS AND OUTREACH

Outreach and Communication activities were expanded during Phase 3B Years 1. Our efforts realized measurable success during this period, as illustrated in Table B.5-1. To support our efforts, the Outreach and Communication team welcomed the addition of three new interns. These students join us from the College of Humanities, the College of Social and Behavioral Science, and the College of Fine Arts, Department of Art and Art History.

With the easing of the limitations on face-to-face meetings imposed by COVID 19, the outreach program increased its physical presence in the community. Nevertheless, electronic media, including the Utah FORGE website, were extensively used. They continue to serve as the primary means of communication.

Website

We utilized the website to provide updates about the progress of the Utah FORGE project, while offering resources and information to increase overall geothermal and EGS literacy. During the reporting period, we introduced an interactive geothermal-themed crossword puzzle, which is updated monthly. A link to the wiki pages with detailed information about the project and research was also added.

The website continued to gain significant traction year-over-year, with over 67,000 page views during Phase 3B Year 1, an increase of nearly fifty percent over Phase 3A Year 2, which saw just shy of 45,000 page views. Whereas all of the most-visited pages during the previous period experienced year-over-year growth in Phase 3B Year 1, the release of Solicitation 2022-2 resulted in the solicitation page realizing particularly significant growth.

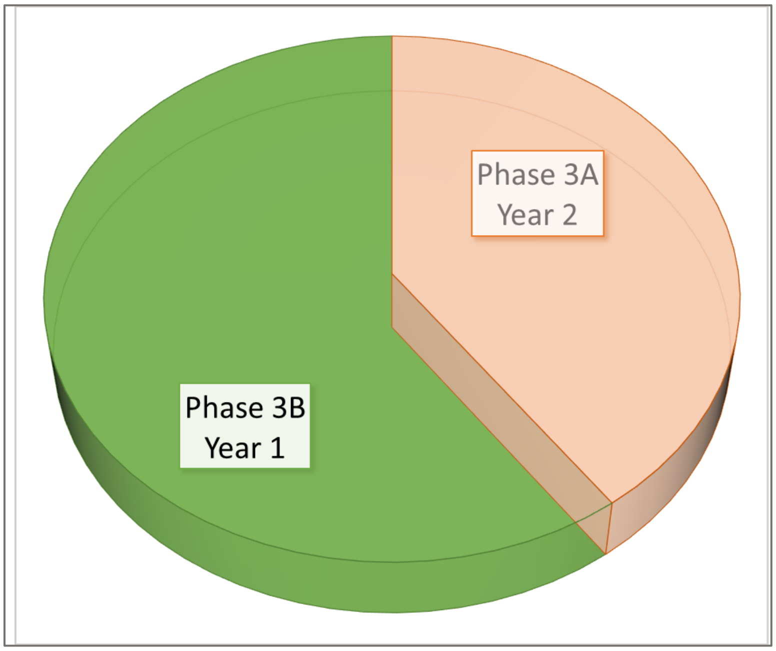


Figure B.5-1. *All page views Phase 3A Year 2 compared to Phase 3B Year 1.*

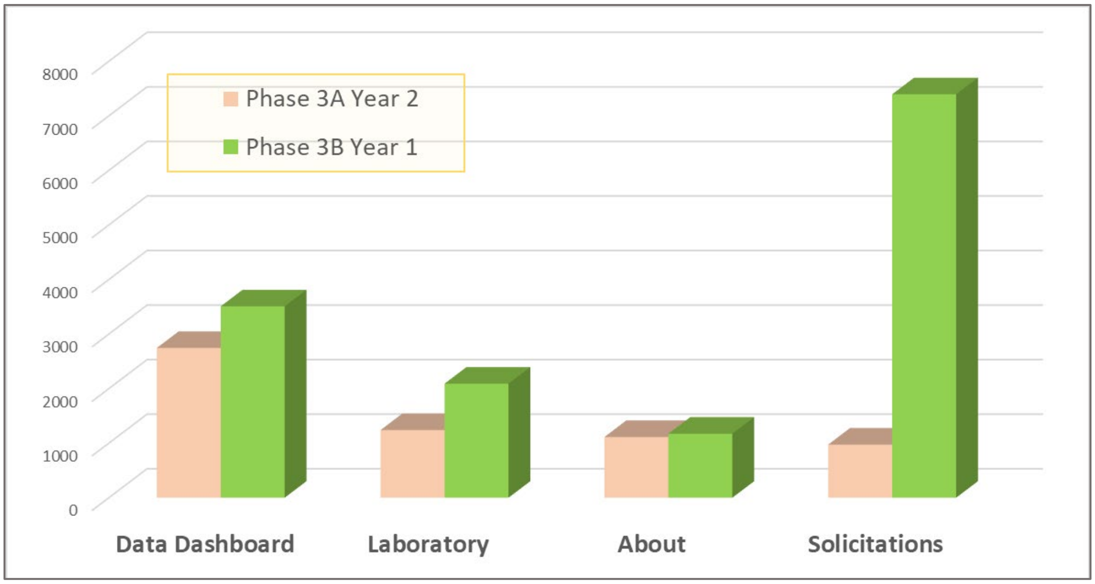


Figure B.5-2. *Top page views Phase 3A Year 2 compared to Phase 3B Year 1.*

Social Media

During the Phase A Year2, there were 422 social media announcements posted on Utah FORGE's social media platforms: Facebook (151), Twitter (169), LinkedIn (80), and YouTube (22) with a total of 1959 followers across all four platforms (234 on Facebook, 452 Twitter, 1072 LinkedIn and 201 on YouTube). A steady rise in both posts and followers occurred in Phase B Year 1. The number of social media posts increased to 453 across the three platforms (Facebook 152, Twitter 189, LinkedIn 98, YouTube 14). The number of followers, however, saw a nearly 75% increase to 3387 (Facebook 281, Twitter 636, LinkedIn 2049, and YouTube 421). Additionally, impressions on LinkedIn nearly doubled from 66292 to 112,377.

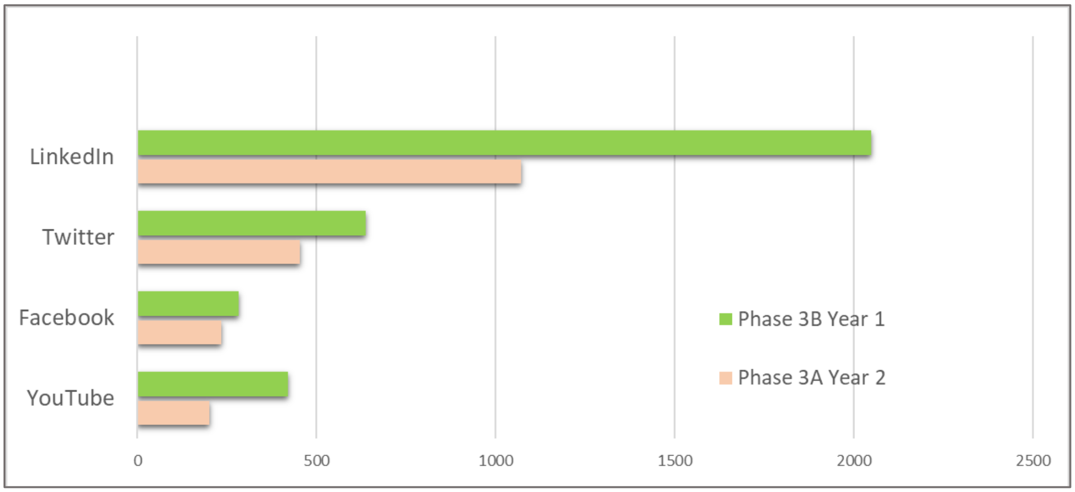


Figure B.5-3. *Growth in Social Media Posts.*

E-Mail Distribution Subscribers

During Phase 3B Year 1, the email subscription list continued to grow, surpassing the complimentary level the service offers. This list is used to email information, announcements, news and other information directly to subscribers. Additionally, for those interested specifically in Modeling and Simulation, a community specific subscription was created. During the reporting period, over 240 individuals subscribed. In total number of subscribers reached 873 from the email distribution list's inception through March 31, 2023, while the number of emails sent saw a modest six percent year-over-year.

Furthermore, according to Campaign Monitor, successful email marketing campaigns result in open rates of 15-25%; Utah FORGE's open rate grew from 46% in Phase 3A Year 2 to over 51% in Phase 3B Year 1, while the click through rate for the period averaged 11% - more than four times higher than the expected average rate.

Media Relations Outreach

Coverage of the Utah FORGE project was highlighted in the general mainstream media and in geothermal and other energy industry outlets. During this time, journalists were proactively pitched news and story ideas, and events such as Secretary Jennifer Granholm's visit to the University of Utah, garnered media coverage. These efforts resulted in an increase in media stories from 32 to 65 plan year over plan year. Media stories were run in general consumer publications such as Utah News and The Deseret News; national- level outlets such as Forbes Magazine, Science and Scientific American; industry publications like Think GeoEnergy, Renewables Now, and Power Magazine. Additionally, stories also appeared in the University of Utah publication @TheU, and in the local Beaver-area newspaper The Beaver County Journal, as well as on n radio and television,

Story topics included the potential offered by geothermal energy and EGS, the second solicitation, the Secretary's visit to the University of Utah, and opinion pieces about climate issues and geothermal energy. Although it is impossible to calculate how many people were reached through media relations efforts, we can quantify that Forbes Magazine has a circulation of over 930,000, Science has a readership of 400,000 weekly, and The Deseret News and The Salt Lake Tribune enjoy a combined circulation of over 150,000 copies.

Scientific Outreach

Research findings were presented at scientific conferences throughout Phase 3B Year 1. Over 50 posters and papers were presented at a variety of conferences, seminars, and webinars. Four manuscripts were also submitted to journals for publication. Among the conferences and meetings at which presentations were made were the Japan Oil, Gas and Metals National Corporation (JOGMEC), the Japan Petroleum Exploration Company (JAPEX), IMAGE 2002, the Geothermal Rising Conference, the DEEP Annual Meeting, the Engineering National Advisory Council, the Society of Petroleum Engineers, the European Geothermal Congress, the ES 2022 Student Conference and Exhibition, the 2022 International Forum on Pohang Earthquake, the Utah Geothermal Working Group, and the Stanford Geothermal Workshop, at which sixteen Utah FORGE presentations were made.

Field Trips

With the lifting of COVID-19 restrictions, field trips to the project site grew during the reporting period. Utah FORGE personnel conducted eight field trips for nearly 100 individuals. Among those attending the field trips were U.S. Senator Mitt Romney, U.S. Rep. John Curtis, Beaver County Commissioners, parliamentarians from Belgium, geoscientists from Hungary, and students participating in the National Science Foundation-funded Research Experience for Undergraduates (REU) / Research Experience in Utah for Sustainable Materials Engineering (ReUSE) at the University of Utah Materials Science and Engineering Department. The students hailed from a variety of colleges including Arizona State University, the University of Minnesota, and the University of Texas, Dallas.

Webinars and Videos

Webinars and videos continued to be an important communication tool for the Utah FORGE Outreach and Communication team. During the reporting period, two webinars were produced, recorded, and promoted, including a webinar intended for grade school students. The webinars have had over 400 combined views. Two videos were also created for a combined viewership of more than 2200.

Please refer to table B.5-1 for a full list of Outreach and Communication products.

Modeling and Simulation Community Updates

A total of eight Modeling and Simulation Community Updates were hosted. They have had over 2,000 combined post-meeting views. A special subscription was created, which now boasts over 250 subscribers.

Tools for Visualizing Data

Tools for visualizing Utah FORGE data have been updated, such as the interactive geologic map and the Utah FORGE map.

Brochures and Printed Materials

The media kit was updated. A new poster highlighting community outreach was also created and placed in a display case in Caboose Park in Milford, Utah. Handouts and other informational materials were updated to reflect the most recent project activities and accomplishments.

Surveys

Collaboration with our colleagues at the University of Utah Department of Communication and the Utah Valley University Department of Communication, a follow-up survey measuring people’s understanding of geothermal energy and Enhanced Geothermal Systems was planned. The survey will be conducted in Phase 3B Year 2 and will be distributed by a third-party surveying company. The survey will seek responses from all fifty states.

Outreach to Elected and Other Officials

Elected officials and regulators were briefed about Utah FORGE through in-person meetings between Dr. Joseph Moore and members of Congress in Washington, D.C. Additionally, meetings with County officials, City officials, and individual Utah state legislators were held. Well over 100 stakeholders have participated in virtual and face-to-face meetings during the reporting period, including U.S. Congressmen Chris Stewart and John Curtis, and Sen. Mitt Romney. Members of the Utah FORGE Outreach and Communications team also met with Utah state Senators Nate Blouin, Kathleen Riebe, and Stephanie Pitcher at Capitol Hill during the 2023 legislative session.

In February, U.S. Secretary of Energy Jennifer Granholm visited the University of Utah to learn about the Utah FORGE project. Along with gaining first-hand knowledge of the project, Granholm toured the Carolyn and Kem Gardner Commons building, which is entirely heated and cooled using geothermal resources. Joining the Secretary were Lt. Governor Deidre Henderson and staff from the Utah Office of Energy Development. GO TO CAP

K-12 Education

During Phase B Year 1, outreach to K-12 teachers and students increased. With the ending of COVID-19 restrictions, in-person classroom activities were resumed in Beaver County. With support from Enel Clean Energy, the Outreach and Communication team conducted two contests. With the first, Utah FORGE team members visited fifth and sixth grade classes at Belknap (Beaver), Milford and Minersville elementary schools. The students learned about geothermal energy and a bit about Utah FORGE’s research. Following the in-class lectures, the students wrote about a geothermal topic and illustrated a poster. Winners were selected and received a prize, and all the posters were displayed in the city library corresponding to the school’s location. Additionally, a short article was published in the local The Beaver County Journal which explained the contest and encouraged the community to visit the libraries to see the posters. A second article was placed in the paper with the photos and names of the winners. One of the local librarians asked if she could continue displaying the posters several months after the contest concluded since community members were still coming in to view them.

The second contest was an expansion of the pilot contest conducted in Milford High School during Phase A Year 2. For this contest, Utah FORGE team members visited middle school science classes to provide an overview of geothermal energy. Students were then encouraged to create a geothermal-themed song parody song and submit it to the contest. The contest was open to middle school students across the state. Information about the contest and its rules, along with geothermal resources, were sent to teachers via the Utah Science Teachers Association monthly newsletter. The submission deadline and award distribution occurred during the current Phase, so an accounting of the submissions and winners is not reflected in this report.

Colleagues at the University of Utah College of Education created a Canvas page. Canvas is a web-based educational tool, which allows educators to present online content to students, and assess student progress. This Canvas site was created specifically to provide geothermal and geoscience resources to teachers. Additionally, these College of Education colleagues provided a professional learning opportunity for teachers to learn about geothermal energy, geoscience in Utah and the Science and Engineering Education (SEEd) Standards. As part of the workshop, Dr. Stuart Simmons presented a geoscience overview. The virtual workshop was held twice, on February 7 and February 21, 2023, with a total of 16 participants. A participant feedback report about the efficacy of the workshop is attached.

A final lesson plan, "Explaining the uneven distribution of the earth's natural resources", was also developed by Tamara Young, a Ph.D. candidate in the College of Education. A total of five standards-based lesson plans have been developed. Although teachers can download the plans from the Utah FORGE website's education section, the five lesson plans were proactively provided to science teacher leads across the state via the Utah Science Teachers Association monthly newsletter.

On September 27 and 28, members of the Utah FORGE Outreach and Communication team, joined by a student intern and Chemical Engineering PhD candidate, hosted a booth during the two-day STEM Fest. The team used a thermal camera and hands-on modules to interact with students and discuss heat transfer, geothermal energy, and Utah FORGE. STEM Fest included two days of school groups and an evening for families. Organizers estimated the event saw over 13,000 participants. This was the first in-person event since the pandemic. Students

Community Relations

A minimum of four times annually, the Outreach and Communication team attends regularly scheduled meetings held by the Beaver County Commission and the Milford City Council. To alert the public to the fact that a Utah FORGE update will be provided during the meetings, advertisements are placed in the local Beaver County Journal, the area's only newspaper. Additionally, individual key stakeholders are personally invited via email. These stakeholders include landholders, regulators, elected officials, and other interested parties. Along with the office holders, any individuals present are encouraged to ask questions of the Utah FORGE team about the project and current activities. On occasion, the local newspaper has reported on the update. At every meeting, the commissioners and councilmen have expressed their continuing support for the project.

For a community outreach video that is currently in production, the team interviewed on camera several members of the community for inclusion. These individuals included elected officials, a librarian, and a teacher each expressing what the project and our engagement has provided the community. The video will be released later this year.

As part of elementary school geothermal poster contest discussed above, Utah FORGE arranged to have all the students' work displayed in the library located in the same town as the individual school. Advertisements in The Beaver County Journal and direct discussions with the teachers encouraged families to visit the libraries to see their student's work.

This is the latest example of our ongoing fostering of relationships with the libraries, which serve as important gathering centers within their communities. The team frequently visited the libraries to continuing fostering the relationship with the librarians, and to check on the computers the project placed in each location, which are set to the University of Utah Seismograph Stations and allow residents to monitor seismicity in real-time.

Additionally, members of the Utah FORGE Outreach and Communication team staffed a booth during the annual Beaver County Fair in Minersville, Utah, providing information, answering questions about geothermal energy in general and the project specifically, listening to concerns and comments, and interacting with the fair attendees. To attract attention and invite people to come to the booth to chat, a thermal camera and a thermoelectric human power module were placed at the table, both of which led to discussions about heat transfer. Additionally, core samples and a 3D printed replica of the drill bit were displayed. Young people were given their own rock kit packet, which included a piece of granite rock, an information sheet, and a magnifying glass. They could also "win" their choice of Utah FORGE branded beach balls or bubbles by answering geothermal questions (with help from the booth's staff.) Over 300 individuals stopped at the booth. During the recent Enhanced Geothermal Shot Summit, Commissioner Tammy Pearson mentioned how excited her grandchildren were to receive the rock kits/magnifying glasses.

Finally, the Utah FORGE team secured inclusion of information about the project in an upcoming exhibit at the Natural History Museum of Utah, which enjoys some 250,000 visitors annually. The exhibit, tentatively titled A Climate of Hope, will focus on steps underway to address climate change. A section of the exhibit to be called Innovators Needed will highlight a specific Utah organization's work. Utah FORGE has been selected to be the first group featured. The exhibit is slated to open in September 2023.

Milestones

Five milestones were achieved during the reporting period; obtain footage for the community video; implement a state-wide song parody contest for middle school students; complete a webinar focused on heat transfer for grade school students; distribute lesson plans to teachers statewide; and produce a video based on stimulation.

Table B.5-1: *Phase 3A and Phase 3B list of communication products with links*

Full Videos	*7*	*1. Forging New Geothermal Technologies Part One;* *2. FORGE: Exploring Utah's Potential for Enhanced Geothermal Systems Part Two;* *3. Unearthing the Utah FORGE Site's Data;* *4. FORGEing into the Future;* *5. Energy Success Stories Discovering;* *6. Drilling into the Geothermal Future;* *7. Utah FORGE Year 2022 Success Story*
Short Videos / Video Clips	*5*	*1. Short Visit to the Utah FORGE Area;* *2. Flyover Infrastructure at the Utah FORGE Site;* *3. Utah FORGE gearing Up to Drill a Seismic Monitoring Well;* *4. Utah FORGE Drill Site Overview – Well 16A(78)-32;* *5. Getting the Frontier Rig Ready for Hydraulic Stimulation*

Modeling and Simulation Forum	23	eling and Simulation Forum Page
Webinars	13	1. Informational Webinar – Utah FORGE Solicitations 2020-1 2. Utah FORGE Geoscientific Overview 3. Geothermal Energy in the 21st Century: Conventional Resources 4. Updated: Geothermal Energy in the 21st Century: Unconventional EGS Resources 5. Status of Utah FORGE Operations and Future Plans 6. Geothermal Energy and the Heath Beneath Our Feet 7. Update to the Utah FORGE Geoscientific Overview 8. Virtual Geological Tour of the Utah FORGE Area 9. Utah FORGE Orientation Webinar for R&D Performers 10. Utah FORGE R&D Orientation Webinar and Q&A Session One 11. Utah FORGE R&D Orientation Webinar and Q&A Session Two 12. Solicitation 2022-2 Webinar 13. Webinar on Heat Transfer
Animations	3	1. Making of an Enhanced Geothermal Reservoir 2. Geothermal Flash Plant 3. Geothermal Binary Cycle Plant
Podcasts	2	1. What is an Enhanced Geothermal System? 2. Interview with Beaver County Commissioner Mark Whitney
Lesson Plans	5	1. Exploring Different Renewable Resources Across the U.S. (Student Handouts) 2. Building a Device that Converts Energy from One Form of Energy to Another to Solve a Problem (Student Handouts) 3. Plan and Conduct an Investigation to Provide Evidence that the Transfer of Thermal Energy When Two Components of Different Temperature are Combined within a Closed System Results in a More Uniform Energy Distribution Among the Components in the System (Second Law of Thermodynamics) (Student Handouts) 4. Design a Method to Change the Rate of Heat Transfer Accommodations (Student Handouts) 5. Explaining the Uneven Distribution of the Earth's Natural Resources (Student Handouts)
Media	127	1. Oct. 20, 2020, The Salt Lake Tribune, Geothermal could help make Utah's 2. climate compact a reality

		2. Oct. 21, 2020, Vox, Geothermal energy is poised for a big breakout 3. Oct. 30, 2020, The Deseret News, Why there's global significance at a geothermal project in Beaver County 4. Oct. 30, 2020, The Deseret News, Why there's global significance at a geothermal project in Beaver County 5. Nov. 2, 2020, Drilling Contractor, Utah FORGE begins drilling of highly deviated geothermal well 6. Nov. 3, 2020, GeoDrilling International, Utah FORGE drills first of two deep wells 7. Nov. 18, 2020, Beaver County Journal, Utah FORGE Drills First of Two Deep Wells 8. Nov. 27, 2020, St. George News, Forging the path for renewable energy in Utah: Drilling begins on geothermal well near Milford 9. Dec. 11, 2020, Forbes Magazine, Does Geothermal Energy Have a Future Under the Biden Administration? 10. Dec. 13, 2020, Think GeoEnergy, As part of wider clean energy efforts, geothermal has important role to play for U.S. 11. Jan. 7, 2021, @TheU, FORGEing a new partnership 12. Jan. 30, 2021, Think GeoEnergy, With first well drilled, what are the next steps for the Utah FORGE project? 13. Feb. 2, 2021, Think GeoEnergy, With first well drilled, what are the next steps for the Utah FORGE project? 14. Feb. 3, 2021, Renewable Energy Magazine, Utah FORGE successfully completes drilling of first deviated deep well 15. Feb. 3, 2021, Beaver County Journal, Utah FORGE Completes First Well 16. Feb. 3, 2021, Journal of Petroleum Technology, Utah FORGE Drills First Deviated Deep Well 17. Feb 8, 2021, GeoDrilling International, Utah FORGE completes drilling of first deviated deep well 18. Feb. 24, 2021, Mirage News, Utah FORGE Chooses 17 project selectees to begin negotiations 19. Feb. 24, 2021 @TheU, Utah FORGE Chooses 17 project selectees to begin negotiations 20. Feb. 24, 2021, Think GeoEnergy, Utah FORGE selects 17 groups for up to $46m in DOE funding. 21. Feb. 24, 2021, Power Magazine, DOE Awards $46 Million for Geothermal Projects

		22. Feb. 24, 2021, Science News Net, Utah FORGE Chooses 17 Selectees to Begin Negotiations 23. Feb. 24, 2021, 15 Minute News, Utah FORGE chooses 17 selectees to begin negotiations 24. Feb. 25, 2021, CleanTechnica, U.S. Department Of Energy Awards $46 Million For Geothermal Initiative Projects With Potential To Power Millions Of U.S. Homes 25. Feb. 25, 2021, Rigzone, DOE Awarding up to $46MM for Geothermal Projects 26. Feb. 26, 2021, Daily Energy Insider, Department of Energy awards $46M to 17 domestic geothermal initiative projects 27. Feb. 26, 2021, Energy Live News, Geothermal energy projects in the US receive $46m boost. 28. March 2, 2021, Think GeoEnergy, Utah FORGE selects 17 groups for up to $46m in DOE funding 29. March 2, 2021, Silixa News, Silixa LLC’s joint proposal for Fiber-Optic Geophysical Monitoring of Reservoir Evolution at the FORGE Milford Site, led by Rice University, selected to enter final negotiations for award by the FORGE Utah team 30. April 2021, AAPG The Explorer, Utah FORGE Applies Unconventional Resource Methods for Geothermal Research 31. April 17, 2021, SLTrib.com, Shanelle Loren: It is time to unleash the potential of geothermal energy 32. April 29, 2021, AAPG The Explorer, Explorer Live 33. May 3, 2021, Power Magazine, Groundswell of Support Heats Geothermal Innovation 34. Summer 2021 U Magazine, Heat Beneath Our Feet 35. June, 5 2021, U Magazine e-newsletter, Heat Beneath Our Feet 36. June 30, 2021, The Beaver County Journal, Utah FORGE Update 37. July, 1, 2021, The Journal of Petroleum Technology, Utah FORGE Spuds New EGS Well 38. July 6, 2021, KUER, Project in Rural Utah Aims to Tap into the ‘Inexhaustible’ Geothermal Energy Below Our Fee 39. July 11, 2021, Associated Press, Project in Rural Utah aims to tap into geothermal energy 40. July 12, 2021, USA Today, News From Around Our 50 States: Utah 41. July 15, 2021, ABC4, Project in Rural Utah aims to tap into geothermal energy

		42. August 18, 2021, Drilling Contractor, Physics-based approach improves drilling of FORGE geothermal well by identifying mitigating limiters *43. August 23, 2021, Think GeoEnergy, Drilling deep at Utah FORGE project requires developing the right tools for the job, such as strong drill bits* *44. September 13, 2021, Survey Notes, Energy News: Geothermal in Utah and he USA: Is a Sleeping Energy Giant Awakening* *45. September 23, 2021, The Salt Lake Tribune Online, Opinion – Joseph Moore: Time for Utah to tap the energy that lies beneath our feet"* *46. September 24, 2021, Public News Service, Geothermal Has a Role in Utah's Clean-Energy Plan* *47. Oct. 18, 2021, Think GeoEnergy – Video, Utah FORGE reports success on drilling of first deep deviated well* *48. Oct. 27, 2021, The Deseret News, Opinion: Utah Lawmakers should focus on boosting clean energy* *49. Nov. 1, 2021, AAPG The Explorer, Casting Sunlight on the Deep Heat Sources with Magnetotelluric Geophysical Imaging* *50. Nov. 19, 2021, Utah Business, Milford, Utah could become the world's next geothermal hub* *51. Nov. 23, 2021, The Beaver County Journal, Commission Conner* *52. Nov. 24, 2021, Ramblers, Did You Know? Some Neat Facts About Ramblers / Green Energy* *53. Dec. 29, 2021, The Beaver County Journal, County Commission Gets Updates on FORGE Project CAFO Map* *54. Dec. 30, 2021, Daily Energy Insider, Energy & Geoscience Institute Partners with NETL in Pursuit of Enhanced Geothermal Systems* *55. Dec. 31, 2021, Opera News, Energy & Geoscience Institute Partners with NETL in Pursuit of Enhanced Geothermal Systems* *56. Jan. 24, 2022, GeoDrilling International, NETL project partner to advance new enhanced geothermal system technologies* *57. Jan. 26, 2022, MarketScreener, Zero-emission energy: Not all wind and solar* *58. Feb. 23, 2022 KSL, University of Utah strikes advanced research agreement with Idaho National Laboratory* *59. Feb. 24, 2022, The University of Utah Engineering News, U of U/ INL Announce Research Partnership* *60. Mar. 21, 2022, The Daily Utah Chronicle, Utah FORGE Continues Groundbreaking Research*

		61. March 25, 2022, PBS Newshour, Is Geothermal Energy a Viable Alternative to Fossil Fuels 62. March 30, 2022, The Beaver County Journal, Commission Corner 63. April 27, 2022, The Beaver County Journal, Congratulations to the Winners! 64. April 27, 2022, The Beaver Journal, What's Happening Around the County 65. April 30, 2022, The Salt Lake Tribune, Vast reaches of Utah's West Desert could be leased for geothermal power 66. May 16, 2022, Utah News, Webinar – Utah FORGE Status and Lookahead, ThinkGeoEnergy 67. May 19, 2022, Forbes, Enhanced Geothermal System Uses Oil and Gas Technology to Mine Low-Carbon Energy (Part 1.) 68. May 19, 2022, Forbes, Enhanced Geothermal System Uses Oil and Gas Technology to Mine Low-Carbon Energy (Part 2.) 69. May 22, 2022, Think GeoEnergy, Interview – Dr. John McLennan, Co-PI Utah FORGE Project Update 70. May 30, 2022, Think GeoEnergy, Geophones and Their Role in EGS Geothermal Projects 71. June 1, 2022, Journal of Petroleum Technology, Drillers vs. Granite: Hard Rock is Losing Its Edge 72. June 7, 2022, Journal of Petroleum Technology, The Fracturing Plan: Hit a Well 300 ft Away – How Hard Could That Be? 73. June 11, 2022, Think GeoEnergy, Registration open for first-ever GEOTHERMAL DATATHON 74. June 20, 2022, Think GeoEnergy, Sandia Lab explores geothermal fracture growth through controlled explosions 75. June 20, 2022, Think GeoEnergy, Canton of Jura signs agreement to start Haute-Sorne geothermal project 76. June 21, 2022, Power, Large-Scale Enhanced Geothermal System Trial Successfully Completed 77. June 22, 2022, Energy Global News, Utah FORGE Achieves Major Milestone in Geothermal System Technologies 78. June 27, 2022, Think GeoEnergy, Webinar Recap – Utah FORGE Status and Look Ahead 79. July 13, 2022, Nature, Feasibility of source-free DAS logging for next-generation borehole imagine 80. July 14, 2022, Science, Catching Fire 81. July 28, 2022, @TheU, Updates from the Utah FORGE projects

		82. August 1, 2022, KSL, Western governors aim to harness geothermal 'heat beneath our feet' *83. August 8, 2022, Seznam Zpravy, He has within his reach an infinite source of energy from the depths of the Earth.* *84. August 15, 2022, Think GeoEnergy, University of Utah and Utah FORGE 2nd solicitation for up to $44million* *85. August 15, 2022, @TheU, University of Utah and Utah FORGE announce second funding solicitation* *86. August 15, 2022, Utah News, University of Utah and Utah Forge second solicit up to $44 million* *87. August 15, 2022, Just the Real News, DOE Announces up to $44M to Advance Enhanced Geothermal Systems* *88. August 16, 2022, Green Car Congress, DOE to award up to $44M to advance enhanced geothermal systems* *89. August 16, 2022, Renewables Now, US DoE lab offers up to USD 44M for enhanced geothermal research* *90. August 17, 2022, EurekAlert!, Forging a path toward safe geothermal energy* *91. August 17, 2022, DailyEnergyInsider, Department of Energy announces up to $44M for enhanced geothermal systems* *92. August 18, 2022, Think GeoEnergy, Pitt research receives funding for stress characterization in geothermal reservoirs* *93. August 24, 2022, National World News, US DOE Announces $44M Funding for EGS Innovation Projects* *94. September 8, 2022, Think GeoEnergy, New US DOE EarthShot initiative aims to reduce EGS cost by 90%* *95. September 10, 2022, Power Magazine, DOE's Latest Energy Earthshot Will Tackle Technical, Economic Challenges for Enhanced Geothermal Systems* *96. September 20, 2022, @TheU Energy research institute celebrates 50th anniversary* *97. September 28, 2022, The Salt Lake Tribune, Is the Future of Energy Sitting Below this Small Utah Town?* *98. October 5, 2022, U News: College of Science, UTAH F.O.R.G.E.* *99. October 6, 2022, Clemson, Murdoch Leading New Project to Improve Enhanced Geothermal Energy* *100. October 10, 2022, Town Lift, Utah Office of Energy Development calls on Utahns to think green for Energy Awareness Month*

		101. November 2, 2022, The Salt Lake Tribune, Opinion, Tom Moyer: Utah's treasurer is trying to hold back the economic tide of sustainability. *102. November 22, 2022, ENERGIES Magazine, On the Cusp* *103. December 1, 2022, Utah Stories, FORGE ENERGY: Feeding Utah's Hungry Power Grid* *104. December 16, 2022, CleanTechnica ¸Witness The Other Side of Geothermal Energy in "The Volcano"* *105. December 23, 2022, Western Governors' Association Roundup, Explore the potential for Enhanced Geothermal Systems in a new WGA Webinar* *106. December 28, 2022, Utah News, UTAH FORGE: New renewable energy project in the middle of nowhere in Utah for the benefit of the entire world.* *107. January 9, 2023, Think GeoEnergy, Utah FORGE publishes video recap of EGS stimulation operations* *108. January 9, 2023, Piensa en Geotermia, Utah FORGE publica video de las operaciones de EGS (Estimulación de Yacimientos Geotérmicos).* *109. January 26, 2023. Sierra Nevada Ally, How One Utah Research Plant Could Unlock Geothermal Energy Across the U.S.* *110. February 3, 2023, Think GeoEnergy, Utah FORGE publishes Wiki dashboard for open-access data* *111. February 8, 2023, The Deseret News, What Utah energy source did U.S. energy secretary call the 'holy grail?'* *112. February 8,, 2023, The Salt Lake Tribune, Energy secretary touts Utah geothermal project, sees green path to U.S. energy independence* *113. February 8, 2023, KSL News, What did Energy Secretary Jennifer Granholm see on her Utah tour?* *114. February 8, 2023, LocalToday, What did Energy Secretary Jennifer Granholm see on her Utah tour?* *115. February 9, 2023, Well Powered, Granholm Touts Geothermal, Announces $74M in Utah* *116. February 9, 2023, MidUtahRadio, U.S. Energy Secretary Granholm Touts Utah Geothermal Project* *117. February 9, 2023, Head Topics, What did Energy Secretary Jennifer Granholm see on her Utah tour?* *118. February 9, 2023, @TheU, U.S. Secretary of Energy visits U, tours geothermal facility*

		119. February 9, 2023, Hunt Daily News, Energy Secretary touts Utah American geothermal project is on the right track to energy independence *120. February 10, 2023, Utah Governor Spencer Cox Newsletter, U.S. energy secretary touts energy advances in Utah* *121. February, 14, 2023, Scientific American, Biden Administration Bets $74 Million on ‘Enhanced’ Geothermal Power* *122. March 1, 2023, Grid, Can geothermal energy finally take a bite out of climate change?* *123. March 1, 2023, Think GeoEnergy, Registration open for SPE Geothermal Datathon 2023* *124. March 7, 2023, MIT Technology Review, This geothermal startup showed its wells can be used like a giant underground battery* *125. March 7, 2023, Jeotermal Haberler, SPE Jeotermal Datathon 2023 için kayıtlar başladı* *126. March 14, 2023, Journal of Petroleum Technology, Geothermal Demands Extreme Tools, but Which Will Really Be Required?* *127. March 16, 2023, Journal of Petroleum Technology, When Fracturing for Geothermal, Is Proppant Really Necessary?*

Table B.5-2: *Phase 3A and Phase 3B List of presentations and lectures.*

Presentations and Lectures			
Oct. 2, 2020	*Graduate Seminar at the University of Pittsburgh*	*Dr. John McLennan and Dr. Pengju Xing*	*Closure stress diagnosis at the FORGE site*
Oct. 21, 2020	*Geothermal Rising Annual Meeting and Expo*	*Dr. Pengju Xing*	*Interpretation of In-Situ Stresses at the Utah FORGE Site using Pressure and Temperature Signatures*
Oct. 21, 2020	*Geothermal Rising Annual Meeting and Expo*	*Dr. Joseph Moore*	*The Utah Frontier Observatory for Research in Geothermal Energy (FORGE): A Laboratory for Characterizing, Creating and Sustaining Enhanced Geothermal Systems*
Oct. 29, 2020	*Utah Seismic Safety Commission meeting*	*Dr. Kristine Pankow*	*Discussion about Monitoring for Potential Induced Seismicity from the Utah Frontier Observatory for*

			Research in Geothermal Energy (FORGE) Project
Nov. 4, 2020	*ARMA-DGS-SEG International Geomechanics Symposium*	*Dr. John McLennan*	*Drilling, Reservoir Characterization, and Fracturing at the Utah FORGE Site*
Nov. 12, 2020	*CouFrac 2020*	*Dr. John McLennan*	*Historical Perspective, Upcoming Activities, Modeling and Simulation at Utah FORGE*
Nov. 25-27, 2020	*NZ Geothermal Workshop*	*Dr. Stuart Simmons*	*Overview of the Geoscientific Understanding of the EGS Utah FORGE Site, Utah, USA*
Jan. 28, 2021	*IRIS webinar on the Best Practices for Seismic Posthole Emplacement*	*Dr. Kristine Pankow*	*A short presentation on the Utah FORGE postholes*
Feb. 3, 2021	*Texas A&M Participants*	*Dr. John McLennan, Duane Winkler and Leroy Swearingen*	*An interactive virtual presentation on FORGE Well 16A(78)-32:EOWR and Lessons Learned*
Feb 16, 2021,	*Stanford Geothermal Workshop*	*Dr. Pengju Xing, et al*	*Numerical Simulation of Injection Tests at Utah FORGE Site*
Mar. 4, 2022	*Utah Science Teachers' Association*	*Tamara Young*	*Presentation on energy transfer*
Mar. 22, 2021	*Geothermal-DHC Webinar*	*Dr. Joseph Moore*	*The Utah Frontier Observatory for Research in Geothermal Energy (FORGE) – an International Laboratory for EGS Research*
Mar. 31, 2021	*Society of Economic Geologists (SEG) McGill Student Chapter Lecture Series*	*Dr. Stuart Simmons*	*Geothermal Resources in the 21st Century*
Apr. 14, 2021	*SPE Hydraulic Fracturing Community's Technical Section*	*Dr. John McLennan*	*Advancements in the Geothermal Industry Attributed to Oilfield Technologies*

Apr. 14, 2021	Duke University's Civil & Environmental Engineering	Dr. Robert Podgorney	The Frontier Observatory for Research in Geothermal Energy, a Field Laboratory for Demonstrating, Testing, and Validating Enhanced Geothermal Systems
Apr. 15, 2021	The Sustainable Energy Class as part of Penn State University's Cameo Lecture Series	Dr. Joseph Moore	EGS and the Utah Frontier Observatory for Geothermal Research (FORGE)
Apr. 21, 2021	Annual Meeting of Seismological Society of America	Dr. Hao Zhang	High-Resolution Bayesian Spatial Auto-Correlation (Spac) Pseudo-3D vs Model of Utah Forge Site with a Dense Geophone Array
Apr. 29, 2021	EGU General Assembly	Dr. Maria Mesimeri	Episodic earthquake swarms in the Mineral Mountains, Utah driven by the Roosevelt hydrothermal system
June 23, 2021	ARMA's 55th US Rock Mechanics/Geomechanics Symposium	Dr. Pengju Xing	Numerical Simulation of Hydraulic Fracturing Simulations of the Enhanced Geothermal System Well at the Utah FORGE Site
June 25, 2021	ARMA's 55th US Rock Mechanics/Geomechanics Symposium	Dr. Aleta Finnela	Estimation of Fracture Size for a Discrete Fracture Network Model of the Utah FORGE Geothermal Reservoir Using Forward Modeling of Fracture-Borehole Intersections.
July 16, 2021	MIT Earth Resource Library's Friday Informal Seminar Hour (FISH)	Dr. Joseph Moore	Utah Frontier Observatory for Research in Geothermal Energy (FORGE)
July 20, 2021	PIVOT 2021	Dr. John McLennan	Forging Ahead: A Deep Dive on the U.S. Department of Energy FORGE Initiative
July 22, 2022	PIVOT 2021	Dr. Kristine Pan	On Solid Ground: Induced Seismicity Forecasting, Prevention and Mitigation
July 27, 2021	The Utah Energy Tour breakout session of the American Legislative	Dr. Ben Barker and	Overview of Utah FORGE

	Exchange Council (ALEC) Annual Conference	Christopher Katis	
Aug. 4, 2021	The American Association of Physics Teachers (AAPT) Summer Meeting	Tamara Young	Energy Transformation with Utah FORGE: Keys to Sustainable Energy Solutions
Sept. 15, 2021	Society of Petroleum Engineers, Salt Lake City Section	Dr. Joseph Moore	Creating Enhanced Geothermal System Reservoirs: The Utah Frontier Observatory for Research in Geothermal Energy
Oct. 5, 2021	Geothermal Rising Conference	Dr. Joseph Moore	Current Activities at the Utah Frontier Observatory for Research in Geothermal Energy (FORGE): A Laboratory for Characterizing, Creating and Sustaining Enhanced Geothermal Systems
Oct. 5, 2021	Geothermal Rising Conference	Dr. Pengju Xing	Numerical Investigation of Stimulation of the Injection Well at Utah FORGE site
Oct. 5, 2021	Geothermal Rising Conference	Dr. Pengju Xing	In-Situ Stresses and Permeability Measurements from Testing in Injection Well 16A(78)-32 at Utah FORGE Site
Oct. 5, 2021	Geothermal Rising Conference	James Rutledge	Seismic Monitoring at the Utah FORGE EGS Site
Oct. 5, 2021	Geothermal Rising Conference	Dr. Aleta Finnila	Revisions to the Discrete Fracture Network Model at Utah FORGE site
Oct. 30, 2021	World Geothermal Congress	Dr. Joseph Moore	The Utah Frontier Observatory for Research in Geothermal Energy (FORGE): A Laboratory for Characterizing, Creating and Sustaining Enhanced Geothermal Systems
Nov. 9, 2021	E3 Student Conference	Dr. Joseph Moore	Geothermal Applications for the FORGE Project
Nov. 15	AIChE Great Salt Lake Local Section Meeting and the University of	Dr. Joseph Moore	Creating Enhanced Geothermal System Reservoirs

	Utah Chemical Engineering Graduate Seminar		
Nov. 17	*Energy & Geoscience Institute Advisory Board*	*Dr. Joseph Moore*	*The Utah Frontier Observatory for Research in Geothermal Energy (FORGE) – a National Laboratory for EGS Research*
Dec. 14, 2021	*American Geophysical Union (AGU) Fall Meeting*	*Dr. Joseph Moore*	*Applications of Geophysics to Enhanced Geothermal System Development: The Utah FORGE Experience*
Jan. 10, 2022	*Utah Geological Association*	*Dr. Joseph Moore*	*An Overview of the Utah FORGE Project*
Jan. 26, 2022	*International Union of Geological Science (IUGS) Energy Transition Series*	*Dr. Joseph Moore*	*An Overview of the Utah FORGE Project*
Feb. 7-9, 2022	*Stanford Geothermal Workshop*	*Alex Dzubay*	*Developing a Comprehensive Seismic Catalog Using a Matched Filter Detector During a 2019 Stimulation at Utah FORGE*
Feb. 7-9, 2022	*Stanford Geothermal Workshop*	*Dr. Sang Lee and Dr. Ahmad Ghassemi*	*Numerical Stimulation of Fluid Circulation in Hydraulically Fractured Utah FORGE Wells*
Feb. 7-9, 2022	*Stanford Geothermal Workshop*	*Dr. Abraham Samuel*	*Improvement in Rate of Penetration in FORGE Drilling Through Real Time MSE Analysis and Improved PDC Technology*
Mar. 20, 2022	*University of Montana Spring Break Trip*	*Dr. Joseph Moore*	*An Overview of the Utah FORGE Project*
Apr. 25, 2022	*Site Tour for Students Working with Dr. Kristine Pankow at UUSS*	*Dr. Joseph Moore*	*An Overview of the Utah FORGE Project*
Apr. 25, 2022	*Site Tour for Staff of EGI*	*Dr. Joseph Moore*	*An Overview of the Utah FORGE Project*
May 27, 2022	*Think GeoEnergy Webinar*	*Dr. John McLennan*	*Utah FORGE Status and Lookahead*

June 2, 2022	*Chevron Representative Visit*	*Dr. Joseph Moore and Dr. John McLennan*	*An Overview of the Utah FORGE Project*
June 6, 2022	*Site Tour for Students in Research Experience for Undergraduates / Research Experience in Utah for Sustainable Materials Enginnering*	*Dr. Joseph Moore*	*An Overview of the Utah FORGE Project*
June 22, 2022	*Japan Oil, Gas and Metals National Corporations*	*Dr. Eiichi Setoyama*	*An Overview of the Utah FORGE Project*
June 23,2022	*Japan Petroleum Exploration Company*	*Dr. Eiichi Setoyama*	*An Overview of the Utah FORGE Project*
Aug. 30 2022	*Geothermal Rising*	*Finnila, Aleta; Jones, Clay*	*Rapid Rock Type Categorization at Utah FORGE from Sonic Logs using K-Means Clustering*
	Geothermal Rising	*Ratnayake, Ruwantha; Ghassemi, Ahmad*	*The Role of Thermo-Poroelastic Effects in Utah FORGE Stimulation Experiments*
	Geothermal Rising	*Zhou, Xuejun; Ghassemi, Ahmad*	*Experimental Determination of Poroelastic Properties of Utah FORGE Rocks*
	Geothermal Rising	*Ye, Zhi; Ghassemi, Ahmad*	*Laboratory Insights into the Potential of Shear Stimulation at Utah FORGE*
	Geothermal Rising	*Xing, Pengju et al.*	*Numerical Simulation of Stimulations at the Utah FORGE Site Using the Designed Pumping Schedules*
	Geothermal Rising	*Wannamaker, Phil et al.*	*Monitoring of Reservoir Scale Microseismicity Using Downhole Geophone Arrays at the Utah FORGE EGS Project During Stimulation of Injector Well 16A(78)-32*

	Geothermal Rising	*Munday, Lynn; Dhulipala, Somayajulu; Podgorney, Robert; Finnila, Aleta*	*Evaluation and Optimization of Well Completion Options for the Utah FORGE Site*
	Geothermal Rising	*Liu, Ruijie et al.*	*Development of a Coupled Multi-Field Utah FORGE _x000d_ Native State Model: Phase 3 Update*
	Geothermal Rising	*Bradshaw, Patrick; Petersen, Gesa; Pankow, Kristine*	*Characterizing the Induced Microseismicity of the 2019 Utah FORGE Well Stimulation*
	Geothermal Rising	*Smith, Christopher et al.*	*Volatiles Analysis of Cuttings from the FORGE 58-32 Well-"Logging" High Temperature Wells, Evaluating Communication Pathways, and Implications for Completions in Enhanced Geothermal System Wells*
	Geothermal Rising	*Lee, Sang H. et al.*	*Numerical Analysis of Fluid Stimulation in Fractured Utah FORGE Wells*
	Geothermal Rising	*Fang, Yuan; Ye, Zhi; Ghassemi, Ahmad*	*Preliminary Wellbore In-situ Stress Models for Utah FORGE*
Sept. 1, 2022	*IMAGE 2022*	*Dr. Joseph Moore*	*Creation and Evolution of Enhanced Geothermal Systems*
Sept. 21, 2022	*Energy & Geoscience Institute Annual Meeting*	*Dr. Joseph Moore*	*An Overview of the Utah Frontier Observatory for Research in Geothermal Energy (FORGE)*
Sept. 22, 2022	*Site Tour for Energy & Geoscience Institute Corporate Associations*	*Dr. Joseph Moore*	*An Overview of the Utah FORGE Project*
Sept. 23. 2022	*DG Short Course IV on the Future of Geothermal*	*Dr. Joseph Moore*	*An Overview of the Utah Frontier Observatory for Research in Geothermal Energy (FORGE)*

	Energy Utilization in Latin America.		
Sept. 26 – 27 2022	*Utah FORGE Post Stimulation Workshop*	*Dr. Joseph Moore*	*Review of Stimulation*
Sept. 28, 2022	*Site Tour for Members of DEEP*	*Dr. Joseph Moore*	*An Overview of the Utah FORGE Project*
Sept. 29, 2022	*DEEP Annual Meeting*	*Dr. Kristine Pankow*	*Seismic Monitoring During the 2022 Utah FORGE Stimulation*
Sept. 29, 2022	*DEEP Annual Meeting*	*Dr. John McLennan*	*Drilling and Stimulation Activities at Utah FORGE*
Sept. 30, 2022	*Engineering National Advisory Council*	*Dr. Joseph Moore*	*An Overview of the Utah Frontier Observatory for Research in Geothermal Energy (FORGE)*
Oct. 6. 2022	*American Association of Professional Landmen*	*Dr. Joseph Moore*	*The Utah Frontier Observatory for Research in Geothermal Energy (FORGE) – A National Laboratory for EGS Research*
Oct. 13, 2022	*Karlsruhe Institute of Technology*	*Dr. Joseph Moore*	*Creating the Utah Frontier Observatory for Research in Geothermal Energy (FORGE)*
Oct. 17, 2022	*SPE*	*Dr. John McLennan*	*Utah FORGE: Engineering an Enhanced Geothermal System*
Oct. 19, 2022	*European Geothermal Congress*	*Dr. Joseph Moore*	*The Utah FORGE Project*
Nov. 2, 2022	*Canadian Pension Plan Investment Board*	*Dr. Joseph Moore*	*An Overview of the Utah Frontier Observatory for Research in Geothermal Energy (FORGE)*
Nov. 2, 2022	*E3 2022 Student Conference and Exhibition*	*Dr. John McLennan*	*Utah FORGE (Frontier Observatory for Research in Geothermal Energy)*
Nov. 4, 2002	*Diplomatic Corps of Kazakhstan*	*Dr. Joseph Moore*	*An Overview of the Utah Frontier Observatory for Research in Geothermal Energy (FORGE)*

Nov. 4, 2022	*ARMA SEG International Geomechanics Symposium*	*Dr. John McLennan*	*Drilling, Reservoir Characterization and Fracturing at the Utah FORGE Site*
Nov. 9, 2022	*Utah Bar Association*	*Dr. Joseph Moore*	*Geothermal Energy: Now and the Future*
Nov. 13, 2022	*2022 International Forum on Pohang Earthquake*	*Dr. Kristine Pankow*	*The Utah Frontier Observatory for Research in Geothermal Energy (FORGE)*
Dec. 9, 2022	*Repsol*	*Dr. Joseph Moore*	*An Overview of the Utah Frontier Observatory for Research in Geothermal Energy (FORGE)*
Dec. 12, 2022	*Western Governors' Association*	*Dr. Joseph Moore*	*An Overview of the Utah Frontier Observatory for Research in Geothermal Energy (FORGE)*
Dec. 19, 2022	*Western Governors' Association - Webinar*	*Dr. Joseph Moore*	*An Overview of the Utah Frontier Observatory for Research in Geothermal Energy (FORGE)*
Jan. 19, 2023	*ConocoPhilips*	*Dr. Joseph Moore*	*An Overview of the Utah Frontier Observatory for Research in Geothermal Energy (FORGE)*
Feb. 1, 2023	*Site Tour European Geologists*	*Dr. Joseph Moore*	*An Overview of the Utah Frontier Observatory for Research in Geothermal Energy (FORGE)*
Feb. 6 - 8, 2023	*Stanford Geothermal Workshop*	*Dr. Joseph Moore*	*Current Activities at the Utah Frontier Observatory for Research in Geothermal Energy (FORGE): A Laboratory for Characterizing, Creating and Sustaining Enhanced Geothermal Systems*
		Dr. Mark McClure	*Calibration Parameters Required to Match the Utah FORGE 16A(78)-32 Stage 3 Stimulation with a Planar Fracturing Model*
		Dr. Robert Podgorney	*Thermal Hydraulics Evaluation of Fluid Flow Distribution in a Multi-Stage Stimulated Enhanced*

			Geothermal System Wellbore at the Utah FORGE Site
		Dr. Pengju Xing	*Comparison of Modeling Results with Data Recorded During Field Stimulations at Utah FORGE Site*
		Dr. Robert Podgorney	*Thermal-Hydraulic-Mechanical (THM) Modeling of Fluid Flow and Heat/Tracer Transport Between Injection and Production Wells at the Utah FORGE Site*
		Dr. Aleta Finnila	*Development of a Discrete Fracture Network Model for Utah FORGE Using Microseismic Data Collected During Stimulation of Well 16A(78)-32*
		Dr. Ahmad Ghassemi	*Modeling and Analysis of Stimulation and Fluid Flow in the Utah FORGE Reservoir*
		Katherine Whidden	*Seismic Monitoring of the 2022 Utah FORGE Stimulation: The View from the Surface*
		Dr. Peter Malin	*Permeability-specific Spatial Correlation Systematics for Utah FORGE EGS Stimulation MEQs*
		Dr. Clay Jones	*Stimulation, Tracers and Geochemistry at Utah FORGE*
		Dr. Ahmad Ghassemi	*Hydraulic Fracturing in Petroleum and Geothermal Reservoirs with Reference to the Utah FORGE Stimulation*
		Dr. Stuart Simmons	*Mantle Helium in Cold Ground Water in the North Milford Valley and the Implications for Geothermal Resources at Roosevelt Hot Springs and the Utah FORGE EGS Field Site*

		Dr. Nori Nakata	*Elastic Characterization at FORGE P-wave Tomography and VSP Subsurface Imaging*
Feb. 23, 2023	*Society of Petroleum Engineers Dinner and Lecture, Salt Lake Section*	*Dr. Kristine Pankow*	*Engineered Geothermal Systems Seismic Monitoring: Insights Gained at Utah FORGE*
Mar. 8, 2023	*Utah Geothermal Working Group*	*Dr. Joseph Moore*	*An Overview of the Utah Frontier Observatory for Research in Geothermal Energy (FORGE)*
Mar. 21, 2023	*SPE Datathon Bootcamp 5*	*Dr. Aleta Finnila*	*The Workflow Used for the Utah FORGE DFN Model*
Mar. 30, 2023	*Utah Municipal Power Agency Member Conference*	*Dr. Joseph Moore*	*An Overview of the Utah Frontier Observatory for Research in Geothermal Energy (FORGE)*

Table B.5-3: *Phase 3A and Phase 3B list of publications.*

Publications List	
1.	*Developing a comprehensive seismic catalog using a matched-filter detector during a 2019 stimulation at Utah FORGE, Alex Dzubay, Maria Mesimeri, Katherine M. Whidden, Daniel Wells, Kris Pankow, Stanford Geothermal Conference. Link*
2.	*Numerical Simulation of Fluid Circulation in Hydraulically Fractured Utah FORGE Wells, Sang H. Lee, Ahmad Ghassemi, Stanford Geothermal Conference. Link*
3.	*In-situ Stresses and Fractures Inferred from Image Logs at Utah FORGE, Pengju Xing, Andy Wray, Edgar Ignacio Velez Artega, Aleta Finnila, Joseph Moore, Clay Jones, Erik Borchardt, John McLennan, Stanford Geothermal Conference. Link*
4.	*Episodic earthquake swarms in the Mineral Mountains, Utah driven by the Roosevelt hydrothermal system, Mesimeri, M., K. L. Pankow, B. Baker, and J. M. Hale (2021b) in J. Geophys. Res.: Solid Earth, 126, e2021JB021659. Link*
5.	*A frequency-domain-based algorithm for detecting microseismicity using dense surface seismic arrays, Mesimeri, M., K. Pankow, and J. Rutledge (2021c) in Bull. Seism. Soc. Am., Link*
6.	*Unusual seismic signals in the Sevier Desert, Utah possibly related to the Black Rock volcanic field, Mesimeri, M., K. L. Pankow, W. D. Barnhart, K. M. Whidden, and J. M. Hale (2021d) in Geophys. Res. Lett, Link*

7.	*Minimum in-situ stress measurement using temperature signatures, Geothermics, 98, Xing, Pengju, Joseph Moore, J. McLennan.*
8.	*In-Situ Stresses and Permeability Measurements from Testings in Injection Well 16A(78)-32 at Utah FORGE Site, Geothermal Rising Conference, Xing, P., D. Winkler, L. Swearingen, J. Moore, J. McLennan.*
9.	*Numerical Investigation of Stimulation from the Injection Well at Utah FORGE Site, Geothermal Rising Conference, Xing, P., B. Damjanac, Z. Radakovic-Guzina, A. Finnila, R. Podgorney, J. Moore, J. McLennan.*
10.	*In-Situ Stress Measurements at the Utah Frontier Observatory for Research in Geothermal Energy (FORGE) Site, Energies.*
11.	*Combining Dense Seismic Arrays and Broadband Data to Image the Subsurface Velocity Structure in Geothermally Active South-Central Utah, Daniel Wells, Fan-Chi Lin, Kristine Pankow, Ben Baker, John Bartley. Link*
12.	*Developing a comprehensive seismic catalog using a matched-filter detector during a 2019 stimulation at Utah FORGE, Alex Dzubay, Maria Mesimeri, Katherine M. Whidden, Daniel Wells, Kristine Pankow, Link*
13.	*Numerical Simulation of Fluid Circulation in Hydraulically Fractured Utah FORGE Wells, Sang H. Lee, Ahmad Ghassemi. Link*
14.	*In-situ Stresses and Fractures Inferred from Image Logs at Utah FORGE, Pengju Xing, Andy Wray, Edgar Ignacio Velez Aretega, Aleta Finnila, Joseph Moore, Clay Jones, Erik Borchardt, John McLennan. Link*

C. LESSONS LEARNED

Reservoir creation and monitoring occupied a significant portion of Utah FORGE's effort during the current reporting period. The preliminary stimulation of well 16A(78)-32 was planned and executed. A microseismic monitoring program was developed and equipment was deployed to record events at reservoir and intermediate depths and at the surface during this stimulation.

In support of Phase 3B, a detailed plan for drilling well 16B(78)-32 was developed and bid packages were prepared based on the results of previous drilling campaigns and the objectives for this well.

Environmental monitoring and Outreach and Communication activities yielded additional lessons that will be applied in future phases of the project. These lessons are described in this section.

Site Infrastructure & Operations

Adaptive management is the key to fulfilling the needs for the site and operations, including last minute requirements.

Stimulation of Well 16A(78)-32

One of the important outcomes of the stimulation efforts at Utah FORGE was to demonstration that cased wells could be perforated and stimulated to create a fracture network required for EGS development. Injection testing on well 58-32 provided preliminary guidance on stimulation criteria. In well 58-32, the deepest perforated zone was selected because of the presence of pre-existing, optimally oriented fractures. The stimulation of this zone demonstrated the application of newly developed protocols for targeting zones for stimulation. The upper-cased zone contained few fractures and the formation could not be broken down. Packers and plugs failed repeatedly.

Based on the insights from well 58-32 injection program, a plan was developed and implemented to stimulate well 16A(78)-32. The aims for this stimulation campaign included developing near-toe fracture morphologies that could be intersected by the new well (16B(78)-32), nominally 300 ft vertically above. Three hydraulic fracturing stages were conducted - near the toe of the well - two behind casing and one in the openhole section of the well. The results indicate:

A. The stimulation treatments suggest relatively straightforward fracture initiation, breakdown, and propagation in high-temperature, low permeability granite and metamorphic rocks through casing at injection flow rates.

B. The tracer data to this point and the data acquired during the treatments suggest no obvious interaction between the fractures generated during the three stages. This is supported by the acquired microseismicity, although there is the possibility that the Stage 1 fracture may have grown back towards the well along a natural fracture.

C. Conventional frac plugs were not available that could withstand the pressures at the temperatures anticipated in the wellbore. Bridge plugs, as opposed to frac plugs, became a viable option, based on validation testing performed (pre-award) by the selected vendor. However, the running tools for the bridge plugs and perforation guns required tubing conveyance because of the high temperatures. Consequently, a drill rig was required to run the tools, adding a significant extra expense to the stimulation. Both perforating runs saw all charges fire. The bridge plugs were set effectively, tested to the required pressures, and held during stimulation. Following shut-in, and flowback, and the bridge plugs were unseated and recovered without incident. In the future drillable plugs that can be set on wireline need to be developed and tested.

D. The bridge plugs functioned successfully because of good engineering practice and design by the vendor, as well as careful and detailed planning.

E. The protocols for selecting zones for stimulation, based on an analysis of the natural fractures, were adopted for the two cased hole zones. While each zone broke down without trouble (one zone with fractures, one “without” fractures) it is envisioned that there are proven methods for facilitating breakdown in troublesome formations.

F. The granitic and metamorphic rocks could be broken down at pressures that are consistent with rudimentary hydraulic fracturing calculations that consider the in-situ stresses inferred for the formation and tensile strengths on the order of those measured on FORGE core in the laboratory.

G. Post facto numerical simulations provided a prediction of the extent of upward fracture growth and the extent of microseismicity. The measured microseismicity provided a platform for inverse analyses to calibrate unknown modeling parameters and allow matching of the microseismic cloud.

H. Viscosified fluids yielded a narrow fracture zone relative to slickwater, which produced broader areas of microseismicity. This is not surprising and is well known in the oil and gas domain where viscosity can inhibit entry into pre-existing natural fractures and restrict pressure dependent leakoff.

I. Chemical analyses of the flowback water indicate sharp increases in total dissolved solutes and changes in isotopic compositions occurred during very brief residence of the fracturing fluids in the reservoir rocks. This result was unexpected and could potentially provide information about the mass, volume, and surface area of reacted or dissolved materials.

Although the 16A(78)-32 stimulation appears to have been highly successful, important questions remain. These include:

A. What role will viscosified fluids, tolerant of temperatures exceeding 400°F (204.4°C), play in controlling fracture growth? This is coupled with the potential need for carrying proppant – more strategically possibly than in oil and gas operations using slickwater.

B. What is the best design for stimulating well 16A(78)-32 (e.g. spacing of stages, number of clusters within each stage, limited entry designs)?

C. What are the most appropriate means of controlling flow into and out of the reservoir once the stimulation has been performed?

D. How will short circuiting be cured or avoided?

E. How should proppant be deployed and in what quantities. The issue of proppant transport is relevant. With surface power generation infrastructure, there could be zero tolerance for future solids, such as proppant, that can be produced back into the injection well during flowback or into the production well during circulation for heat exchange.

F. Finding fracturing fluids tolerant of the reservoir temperatures is essential. The crosslinked CMHPG[1] used in stage three – while appropriate here – may need refining to withstand even hotter regimes where significant proppant concentrations and masses might be required. Although there is also anecdotal information about one-off temperature-tolerant fluids (K. England, personal communication, 2022), these fluids are not always readily available.

G. The production well, 16B(78)-32, is being drilled into the microseismic cloud detected during the three earlier stimulation treatments. The new well is approximately 300 ft above well 16A(78)-32.

H. How can microseismic monitoring be continually refined to provide adequate resolution for tracking the growth of the fracture volume and to indicate the type of fracturing occurring?

I. How will connectivity between wells 16A(78)-32 and 16B(78)-32 be demonstrated? Several methods will be implemented to assess connectivity including:

    i. High-resolution temperature, pressure and spinner surveys in the both wells.

    ii. Monitoring of tracers and (potentially) microproppant injected into well 16A(78)-32 during the stimulation.

    iii. Monitoring of fiber optic cables to be cemented in the annulus behind the production casing in well 16B(78)-32.

Planning for Well 16B(78)-32

The drilling of well 16A(78)-32 represented a major step forward in drilling geothermal wells for both conventional and EGS development. Well 16A(78)-32 was the first highly deviated well

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[1] Carboxymethyl hydroxypropyl guar

specifically drilled for geothermal purposes. New PDC[2] bit designs, the application of MSE[3], and implementation of specific workflows for identifying and overcoming drilling dysfunctionality demonstrated significant improvements over "conventional" drilling practices in hard, hot, low permeability granitic and metamorphic rocks. Continued drill bit improvements by collaborating vendors increased ROPs even further during the subsequent drilling of vertical wells 56-32 and 78B-32.

Detailed analyses of well 16A(78)-32 drilling results and the lessons learned are discussed by Sugiura et al. (2021) and Dupriest and Noynaert (2022). The following lessons were incorporated into the drilling plan for well 16B(78)-32:

A. Drilling with bent motors resulted in significant rugosity (roughness) of the wellbore walls. Drilling with a Rotary Steerable System has the potential to produce a smoother wellbore. Early indications are that this is definitely the case, although additional work on stabilizer placement is required to reduce lateral vibrations.

B. Conduct RPM and WOB[4] step tests during each bit run to optimize drilling parameters.

C. Measure vibrations at the bit and in the BHA[5] to evaluate and mitigate the causes of excessive shock levels. Extensive sensor measurements have been acquired while drilling these wells (in the bit shank, along the centerline of the bit, and in the BHA) – for drilling and for coring observations.

D. Conduct predrilling training and review drilling data daily to identify and mitigate causes of drilling dysfunction.

E. Prepare bid packages for long lead items (e.g., rig, bits, casing, Rotary Steerable Systems) well before the spud date.

Microseismic Monitoring

The most instructive feedback on the hydraulic fracturing came from the recorded microseismicity. Geophone strings in three wells, 56-32, 58-32 and 78-32 were deployed to monitor microseismicity at reservoir depths. Tens of thousands of events – all less than or equal to 0.5M) were recorded. A reference catalog of approximately 2000 located events with magnitudes ranging from -2.3 to +0.5 M was prepared. The in-well microseismicity monitoring was augmented with shallow geophones, and surface and downhole DAS cables. The borehole microseismic results from the April 2020 stimulation provide a unique view of the fractured volume with a resolution unobtainable by other geophysical methods. However, the monitoring was plagued by persistent failures of the geophones. For stage one, only a single 8 level geophone (Geochain) string in well 58-32 (max depth 6700 ft) was operational; for stage two, the string of geophones in well 58-32 and a two-level Passive Seismic Sensor (PSS) string in well 56-32 (max depth 8315') was operational; and for stage three, the string in well 58-32, the PSS

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[2] Polycrystalline diamond compact (PDC)

[3] Mechanical Specific Energy

[4] RPM is revolutions per minute (how fast the bit is turning) and WOB is weight on bit.

[5] BHA is bottomhole assembly.

tools in well 56-32, and a Geochain in well 78B-32 (max depth 6200 ft) were operational. While the PSS tools recorded data in well 56-32 for stages two and three, those tools failed within days after the end of the stimulation as did the other PSS strings that had been deployed in wells 58-32 and 78B-32. In all cases, the temperatures of deployment were well below the temperature specifications for the tools and cable.

Following the stimulation, PSS tools were deployed in wells 58-32, 78B-32 and 56-32 on 7-conductor wireline cable to monitor for post stimulation microseismicity valuation. All three strings failed within days of deployment. The tools were refurbished and two dual-level strings were deployed in wells 58-32 and 78B-32 at different depth levels to test their performance at various temperatures. Again, the tools failed within a few days of deployment.

Analysis of the microseismic monitoring and testing results indicate:

A. Wirelines and geophones are not reliable at temperatures >180°C. To be conservative and optimize successful recording, geophones should be set at a depth with a maximum temperature of 150°C. These shallow depths will reduce the resolution from approximately 40 ft to 90 ft.

B. Deploying temporary surface arrays of seismometers (Nodal arrays) allows for the signals to be stacked. However, for large patches, the noise can vary across the patch and noise may coherently stack, obscuring the microseismic signal. Smaller dimension patches with fewer geophones should be tested.

C. The use of full waveform location algorithms and adaption of machine learning algorithms shows promise for the detection and location of microseismic events using surface microseismic sensors.

D. Using matched-filters, monitoring instruments in well 68-32 (FORK) at 1000 ft [300 m} had a magnitude of completeness down to M -0.6, like what was found in the 2019 stimulation.

E. DAS cables with integrated 3-component geophones currently offer t promise for monitoring microseismicity at reservoir depths and temperatures. These tools require development and testing at reservoir temperatures.

F. With multiple groups involved in microseismic monitoring, it is important to have regular meetings with all participating groups to keep everyone notified of operational activities.

4D Gravity

Changes in microgravity due to elevation changes at the scale resolved by campaign GPS measurements (centimeter scale) are small (10-15 µGal) compared to typical basin-scale mass changes due to hydrological variations (of order 100 µGal). Issues of sensor drift, some of which may be related to transport, require particular care in microgravity surveying

Groundwater Wells

Continuous water level monitoring near the Utah FORGE site shows that water levels are broadly consistent through time and there is no evidence of water level changes resulting from current or previous Utah FORGE project activities. Instead, observed water level fluctuations are likely the result of background climatic and water use signals as well as disturbances related to industrial farming activities. Consequently, continuing water level measurements is recommended.

Communications and Outreach

Ensuring public awareness and increasing geothermal literacy within Beaver County and Utah continues to be an essential part of the Utah FORGE Outreach and Communication Program. During the latest reporting period significant and innovative expansion of Utah FORGE Outreach and Communication activities was realized. Additionally, engagement to new and larger groups of stakeholders was initiated.

These efforts have allowed for several important best practices and lessons to be learned.

A. Younger students are eager to learn about geothermal energy. Although previous engagement with young people focused on middle and high schoolers, younger students proved to be enthusiastic to learn about the topic. A preexisting, albeit rudimentary understanding of plate tectonics aided in their ability to grasp basic geothermal concepts. Fifth and sixth grade teachers inquired if Utah FORGE would be willing to return to their classes during the next academic year.

B. Hands-on, interactive modules are incredibly effective for engagement. Students enjoy these, and the modules serve as physical connection to the concepts being taught. During the reporting period, the Outreach and Communication team purchased “hand boilers” and “energy sticks” which proved wildly popular. The same enthusiasm was shared by the 13,000+ attendees of STEM Fest. The team is currently collaborating with the University of Utah Department of Chemical Engineering to create new modules.

C. Participating in community events creates familiarity. For the second consecutive year, the Outreach and Communication team hosted a booth at the Beaver County Fair. Several attendees mentioned remembering the team from the previous year and wanted to hear an update on activities. Moreover, during the visits to schools, students recognized the team from the Fair, making us a known entity and creating legitimacy and trust. Building from this familiarity, Utah FORGE has been invited to participate in the Fair’s academic session the day prior to opening.

D. Existing communication offerings can be used to generate new forms of engagement. During the reporting period, the Outreach and Communication team launched a new interactive crossword puzzle game. The clues for the crossword came from the previously created Word of the Week. Additionally, these terms will be used for a future product for educators to be launched in the current Phase.

E. Reaching beyond Beaver County yields benefits. Traditionally, Utah FORGE outreach has been limited to Beaver County. Attending Welcome Week at the University of Utah and the Midvale Harvest Days proved to be a cost-effective means to engage with larger audiences with little to no previous familiarity with the project.

Table C-1. *Comments received from elected officials and public*

A sampling of comments made from elected officials and the public during the reporting period	
	“This is really great for the Community,” Commissioner Tammy Pearson.
	“Thank you for the invitation to come visit the site during the stimulation,” (former) Commission Chair Mark Whitney.
	“Yes, that was really cool,” Commissioner Wade Hollingshead.
	“You’ve also stimulated our local economy,” Commissioner Tammy Pearson.
	“It was fascinating; very cool stuff,” Commission Chair Mark Whitney.
	“I have a lot of friends involved in mining and I received a bunch of texts from them asking what Liberty trucks were doing in Beaver County. They saw them from the road!” Commissioner Tammy Pearson.
	“We need to continue having this funded so we can continue moving forward,” Commission Chair Mark Whitney.
	“I think being at the Fair is good because even though we talk about you and all you do, people forget what you’re doing,” Commissioner Tammy Pearson.
	“We always appreciate your updates and we’re happy to help anyway we can,” Commissioner Wade Hollingshead.
	“We really appreciate you keeping the funds in the community,” Commissioner Wade Hollingshead.
The following comments were made by visitors to the Utah FORGE booth at the Beaver County Fair in Aug 2022:	
	Thank you so much for coming.
	Oh yeah. I’ve heard about this before.
	I’ll be watching what you guys are doing!
	This is so exciting.
	This is really exciting stuff. I would love to see this come to fruition.
	I think this is neat. (Made by a child)
	I think this is awesome.
	Wow, this is really interesting.
	This sounds like a really great idea.

	Oh, Utah FORGE. I worked out there! We did the garbage service.
	Remember when Mom worked cleaning those buildings out by the windmills? That was for this group.
	Hey! I remember you from last year. (Made by a child.)
	I remember you guys. You gave me a rock. (Made by a child.)
	The rocks you gave us last year were so fun. (Made by a child.)
	Thanks again for the iPad; I use it more than my phone now. (Made by one of the winners of the song parody contest.)

D. CONCLUSIONS & FORWARD PLAN

Utah FORGE is a unique, publicly funded field-scale laboratory dedicated to derisking the tools and technologies required for commercializing EGS. Good progress has been achieved in addressing the fundamental issue of development of a fracture network that minimizes significant temperature decline, provides economic flow rates, and mitigates detrimental induced seismicity (>M2 events).

In Phase 3B Year 1 of, Utah FORGE activities focused on the stimulation of three stages near the toe of well 16A(78)-32. This is a critical first step in creating the fracture volume that will host the reservoir. Stimulation activities were supported by microseismic monitoring, numerical simulations, high-resolution geophysical surveys and geochemical monitoring. At the same time, engagement with the public, scientists, regulators and elected officials to explain the benefits of geothermal energy and EGS was expanded.

The major accomplishments of the Utah FORGE team are summarized below, with more detail in Table D-2:

1. Successfully completed a critical three stage stimulation program near the toe of well 16A(78)-32 in the open hole and cased sections of the well. Well 16A(78)-33 was drilled approximately parallel to the axis of principal horizontal stress to a depth of 5938 ft before being deviated 65° from vertical. The well has a total measured depth of 10987 ft, a true vertical depth of 8559 ft and a temperature of 428 °F.
2. The stimulation was pumped at commercial rates of 50 bpm in the openhole and 35 bpm in the cased zones.
3. Numerical simulations were conducted to assist in the design of the stimulation. Fracture characteristics and heights at different pumping rates, the extent of microseismicity, tracer and thermal breakthrough, and the optimum locations for stimulating the reservoir were modeled.
4. The stimulation results were compared with the simulation forecasts to produce a refined and simplified Discrete Fracture Network (DFN).
5. Tens of thousands of microseismic events were recorded during the stimulation. A reference catalogue containing locations and magnitudes of approximately 2300 of the most accurately located events ranging from -2.3M to +0.5M was placed in the public domain. The events were recorded on geophone strings at reservoir depth.
6. The microseismic monitoring network was augmented with moderate depth geophones/accelerometers, surface and downhole DAS cables, and an extensive surface nodal array.
7. Completed installation of the 8 km ring of posthole and surface seismometers for microseismic monitoring.

8. A detailed drilling plan was prepared for well 16B(78)-32, which will serve as the production well of the injection/production pair for reservoir creation. The well was designed to pass through the microseismic cloud formed during the stimulation of well 16A(78)-32. The plan incorporates R&D projects by UT Texas and Rice University) (multiple fiber optic cables), Battelle (minifrac tests), and Petroquip (locking bridge plug).

9. Issued Solicitation 2022. R&D proposals addressed five topic areas including: 1) Adaptive induced seismicity monitoring protocols; 2) Alternative stimulation schemes; 3) Field scale experiments to measure heat-sweep efficiency; 4) High temperature proppants; and 5) Multiset straddle packers for open hole operations. The projects will develop and test new technologies, operationally-oriented equipment, and fundamental issues that limit commercialization of EGS development

10. Completed repeat groundwater, gravity, GPS, InSAR surveys and an MT campaign for subsurface characterization of the subsurface.

11. Performed detailed mineralogic and lithologic analyses of the cores and cuttings obtained from the drill holes. Based on these data, the conceptual geologic model (e.g. distribution of rock types, fracture characteristics) was refined.

12. Increased stakeholder interactions with expansion of the Outreach and Communications. Information is available on the Utah FORGE website, social media platforms, YouTube videos, E newsletter, podcasts, and scientific forums. This outreach activities provide information suitable for the general public, students from grade school to graduate levels, scientists, elected officials, regulators, and geothermal specialists.

13. Uploaded more than 209 GB of data to the Geothermal Data Repository (GDR). There were more than 27000 downloads of the data. Forty papers were published and 80 presentations were given at Technical Conferences.

14. Prepared wiki pages of Utah FORGE data by activity and a wiki page for each of the 17 R&D projects funded through Utah FORGE.

15. Utah FORGE is the most thoroughly documented of any EGS site in the world.

Table D-1. *Summary of well data.*

Well	Latitude	Longitude	Ground level (ft)	Kelly Bushing Height (ft)	Measured Depth (ft) from GL	True Vertical Depth (ft)	Max Recorded Temperature (°F)	Core Interval 1 (ft MD)	Core Interval 2 (ft MD)
58-32	38.50051644	-112.8870119	5527.5	21.5	7,536	7,528	386.0	6,800 - 6810.25	7,440 - 7,452.15
68-32	38.50157333	-112.8866409	5530.4	5.7	1,000				
78-32	38.50016375	-112.8832204	5583.7	5.7	3,280		223.8		
16A(78)-32	38.50402147	-112.8963897	5413.5	30.4	10,987	8,559	426.8 [428.7]	5,473 - 5,892	10,955 - 10,987
56-32	38.50402364	-112.8864923	5451.6	30.4	9,145	9,138	435.1		
78B-32	38.50010313	-112.8822486	5595.9	30.4	9,500	9,497	426.8 [463.5]	6,700 -6,740	8,500 -8,540

[] = Extrapolated to TD

Table D-2. *Impacts of Key Accomplishments in Phase 3A, Year 2: A High-Level Overview.*

Key Accomplishments	**Impact**
Stimulation Activities and Infrastructure	
Injected commercial quantities of fluid into each of three stages near the toe of well 16A(78)-32.	Represents critical first test in the creation of a commercial scale reservoir.
Tested bridge plugs and perforating guns at temperatures exceeding 200°C.	Demonstrated application of essential technologies for reservoir creation in high-temperature rocks.
Prepared drill plan for the production well 16B(78)-32. Plan incorporates learning from previous wells.	Test technologies with potential to better control wellbore trajectory, decrease wellbore rugosity, improve ROP, and decrease drilling costs.
Completed and awarded bids for long lead items.	Mitigates supply chain issues and costly delays.
Completed electric distribution lines.	Allows connecting electric power to the drill pads and facilities for Phase 3 operations and R&D activities.
Microseismic Monitoring and Modeling Evaluations	
Continued microseismic monitoring.	Demonstrates continued low natural seismicity at the Utah FORGE site and low risk of seismic hazards.
Conducted microseismic monitoring at reservoir depths.	Allows detection of low magnitude (~-2) induced seismic events, facilitates events location, growth of fracture volume, and mitigates hazards. This information is essential for managing stimulations and fluid circulation.
Tested downhole and surface DAS, nodal arrays, and moderate to shallow depth seismometers.	Documents applications and limitations of microseismic monitoring tools for managing stimulations and long-term fluid circulation.
Installation of the 8 km(5 mile) microseismic monitoring ring completed.	Provides monitoring capability to detect fractures resulting from Utah FORGE operations at distance from the wells during drilling, stimulation and circulation testing These are shallow deployments for permanent monitoring that are part of the overall seismic monitoring network.

Numerically modelled magnitude and location of microseismic events at different.	Establishes ability to locate and resolve microseismic events.
Reservoir Characterization	
Continued analysis of Formation Microimager and Ultrasonic Borehole logs.	Allows refinement of the Discrete Fracture Network (DFN).
Repeated gravity, GPS, water level, and InSAR surveys. Conducted MT campaign during the 16A(78)-32 stimulation.	Provides essential information for monitoring, managing and predicting reservoir behavior. The geoscientific investigations have confirmed the conceptual geologic model that informs the earth model. This model is essential for planning drilling and stimulation programs.
Continued detailed petrographic and lithologic analyses of cuttings and core.	Provides basis refinement of earth and reference numerical models.
Numerical Simulations	
Refined DFN.	Provides basis for numerical modeling and prediction of fracture behavior including ability to initiate, extend, dilate and/or reactivate fractures behind casing. Allows history matching of previous injection data.
Refined reference numerical reservoir model.	Informs drilling and stimulation programs 3, indicating anticipated temperature, pressure and stress values, according to acquired logging and other geophysical information.
Refined dynamic reservoir modeling.	Allows improved probability for predicting the geometry of the of the interconnected fracture network formed during reservoir evolution.
Management and Outreach Activities	
Released Solicitation 2022-2 and reviewed concept papers and full proposals.	Addresses R&D needs defined by the STAT.
Outreach and Communications activities.	Engages stakeholders including general public, students, the scientific community, legislators, regulators, educators, and local stakeholders.

PHASE 3B YEAR 1 PLANNED ACHIEVEMENTS

Year 1 of Phase 3B will focus on reservoir creation and circulation of fluids between the production and injection wells. The major achievements planned for Phase 3B, Year 1 include:

1. Drill, and complete, well 16B(78)-32. Well 16B(78)-32 will be geosteered into the microseismic cloud created by the stimulation at the toe of well 16A(78)-32.
2. Perform a short circulation test after drilling to ascertain connectivity between wells 16A(78)-32 and 16B(78)-32
3. Drill water supply well and complete infrastructure for long-term flow testing.
4. Stimulate well 16A(78)-32 and perforate well 16B(78)-32. If necessary, also stimulate well 16B(78)-32.
5. Initiate long term flow testing and monitoring.
6. Complete negotiations and award Solicitation 2022-2 R&D projects. Provide necessary technical and financial management support of all R&D projects.
7. Develop and implement a long-term microseismic and high-resolution geophysical monitoring program to track the evolution of the reservoir over time.
8. Drill Well of Opportunity -2 (well 47-2) for tool testing and microseismic monitoring.
9. Continue to advance drilling improvements through testing and derisking drilling technologies, refinement of bit designs, and application MSE.
10. Prepare wiki pages for new R&D projects and continue to support dissemination of results from existing projects.
11. Encourage industry to develop new drilling tools and technologies for testing at Utah FORGE.
12. Expand the Outreach and Communication program by fostering a greater understanding of geothermal energy and EGS across a broad range of audiences, including the general public, the scientific community, students, legislators, regulators, educators, and local stakeholders. Continue engaging these audiences through our website, social media platforms, emails, community relations, scientific conferences, videos, webinars, and presentations. Collaborate with colleagues at the University of Utah College of Education to provide resources about geothermal energy to teachers, and with the University of Utah Department of Communication to gain insight on geothermal and EGS literacy among the general public. Redesign the website to expand Utah FORGE’s following.
13. Complete development of a Virtual Visitor center and finalize Utah FORGE's inclusion in an exhibit in the Natural History Museum of Utah.

VISION

Meeting the US DOE's goal of 90,000 MWe by 2050 and reducing the cost of electricity from EGS to $45 per MW-hour requires multiple, large-scale development. No other approach, including the development of conventional geothermal resources, offers the potential to reach this goal. Since the late 1970s, there have been more than a dozen attempts worldwide to create EGS reservoirs by hydraulically fracturing hot rocks. While there have been important learnings, no commercial scale reservoir has been created.

Utah FORGE is on the verge of demonstrating the necessary technology for the first time. No similar field laboratory exists elsewhere in the world.

The primary objectives of Utah FORGE are to: 1) create a fractured volume with sufficient permeability to extract heat from hot rock for long periods of time; 2) achieve economic flow rates (>40 l/s) without significant reservoir cooling; 3) mitigate detrimental induced seismicity; 4) develop a roadmap for commercialization of EGS.

Meeting the objectives of Utah FORGE, the DOE and achieving commercialization of EGS will require: 1) developing new completion methodologies; 2) developing, testing and derisking tools and technologies suitable for high temperature reservoirs (e.g., flow control devices, logging tools, geophones) ; and 3) managing the stress field to control permeability and induced seismicity. Utah FORGE is actively engaged with the R&D and commercial tool communities to meet these objectives through its external, competitively awarded R&D program and operational activities

The Gantt Chart in Figure D-1 illustrates the succession of field operations that will be undertaken at the Utah FORGE site beginning in Phase 3B-Year 1 and extending through September 2024. Well 16B-(78)-32 will be drilled and connected to well 16A(78)-32. Well 16B(78)-32 will provide the first opportunity to demonstrate the application of tools and techniques developed under Solicitation 2021-1. Prior to casing well 16B(78)-32, analyses for injected tracers and proppant and pressure-temperature-spinner surveys will provide evidence of connection between the two wells. Fiber optic cables deployed by UT Austin and the University of Texas at Rice in well 16B(78)-32will allow us to locate zones of permeability after the well is cased. The stimulation program for connecting well 16A(78)-32 and 16B(78)-32 will incorporate field and modeling results from Fervo and UT Austin.

Once connectivity is demonstrated, the size of the stimulated rock volume and the circulation times will be increased. In Phase 4, at least one additional deviated well, 16C(78)-32, will be drilled based on detailed analysis of all data acquired, including that resulting from the stimulation, flow testing, and seismic monitoring of wells 16A(78)-32 and 16B(78)-32.

Although the 2019 DOE road mapping report, GeoVision, did not identify drilling tools and technologies as a funding priority for EGS development, Utah FORGE drilling and stimulation results demonstrate that improvements are necessary. Improvements in five areas are particularly relevant: 1) reducing vibrations at the bit through improvements in bottom hole assembly designs and vibration measurement; 2) high temperature Rotary Steerable Systems

(RSS) and fixed angle mud motors for controlling well deviations; 3) bit designs that support longer performance and faster drilling while preserving well bore smoothness; and 4) improved recovery of material from cored intervals.

A new generation of tools essential for managing fluid flow and reservoir stimulation in are under development by Welltec and Petroquip (packers/bridge plugs), and the Colorado School of Mines (sliding sleeves/tractors). Funding for multiset straddle packers and high temperature proppants will be provided under Solicitation 2022-2. Although these tools may not be available prior to drilling and completion of well 16B(78)-32, they are expected to be available for use in well 16C(78)-32.

Six wells will be available throughout the project life for testing tools, geophones, and new technologies under reservoir conditions These include: wells 56-32, (cased to TD of 9200 ft), 58-32 (uncased from 7500-TD at 7536 ft), 78B-32 (uncased from 8500-9500 ft), and future Well of Opportunity – 2. Wells 16A/B/C(78)-32 will provide opportunities for post stimulation reservoir characterization; seismic monitoring; core collection; in-situ stress and other measurements; chemical monitoring techniques; and tool testing (e.g., flow control tools, and drilling tools such as bits and motors).

Our vision for Utah FORGE will continue to include Outreach and Communication activities to help increase overall geothermal literacy. The Virtual Visitor Center and Natural History Museum of Utah exhibit will provide access to information about the project, geothermal energy and EGS to unlimited audiences. Our outreach efforts will strive to include greater populations outside of Beaver County, including those in remote areas, communities of color, the Native Tribes, the LGBTQ+ community, those for whom English is not a first language, and girls and women in STEM programs.

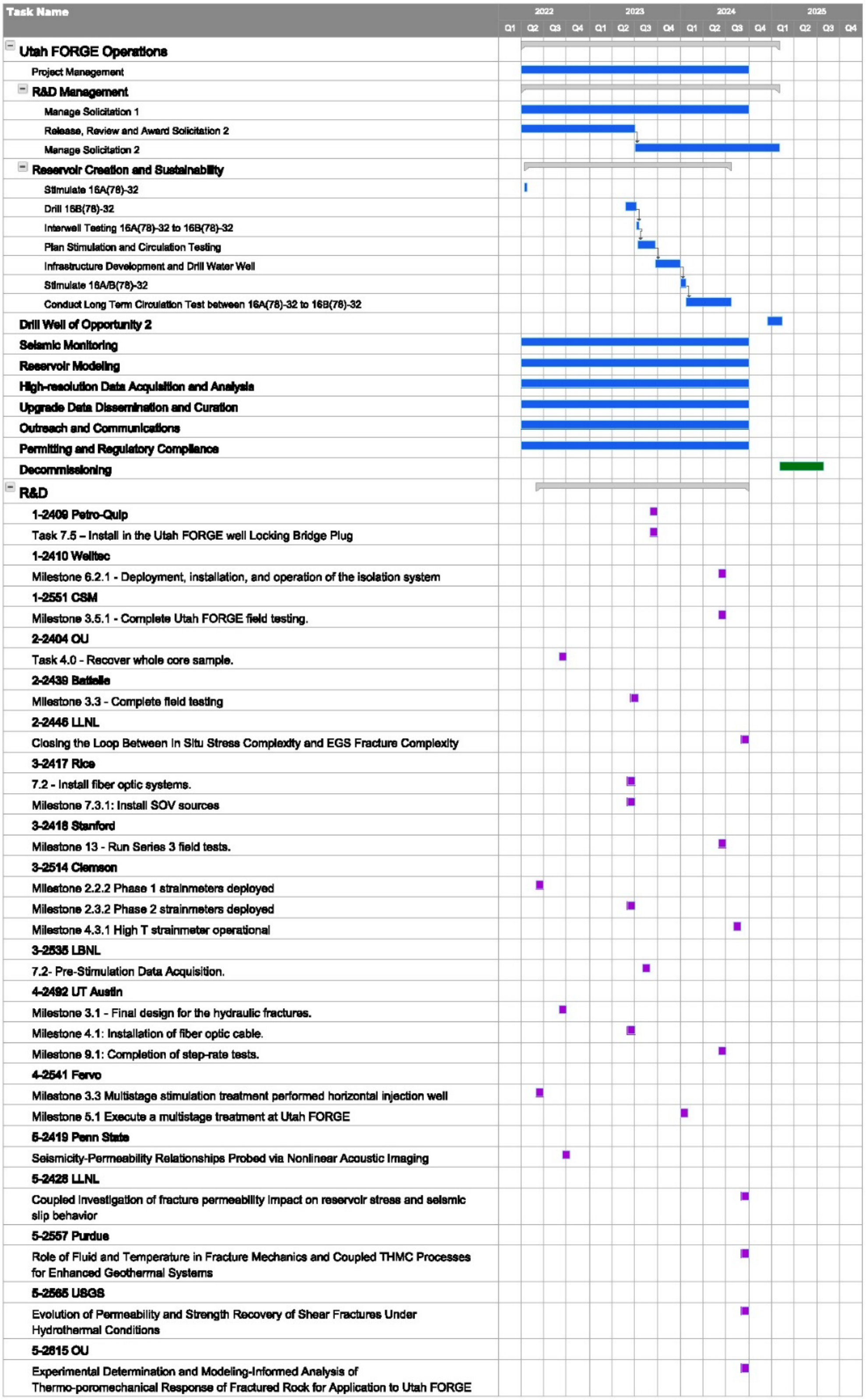

Figure D-1. *Gantt chart of Utah FORGE Operations integrated with R&D activities.*

REFERENCES

Bradshaw, P., B. Dyer, F. Bethmann, A. Dzubay, G. Petersen, P. Meier, and **K.** Pankow (2022a). Using the 2009 Basel enhanced geothermal systems project as a proxy for predicting reservoir development at Utah Forge, 2022 Annual Seismological Society of America Meeting, Bellevue, WA, April 10-23.

Bradshaw, P., G. Petersen, and K. Pankow (2022b). Characterizing the induced microseismicity of the 2019 Utah FORGE well stimulation, *GRC transactions, **46**,* Reno, Nevada.

Dupriest, F. and Noynaert, S., 2022, Drilling practices and workflows for geothermal operations. IADC/SPE International Drilling Conference and Exhibition, 8-10 March, 2022, SPE-208798-MS, 42 p.

Dyer, B., F. Bethmann, D. Karvounis, P. Meier, K. Pankow, P. Wannamaker, J. Moore, J. Rutledge, and A. Ammon (2023). Innovative microseismic monitoring tools and configurations for geothermal applications, World Geothermal Congress 2023, Beijing, China, April 17 – 21, 2023.

Dzubay, A., M. Mesimeri, K. M. Whidden, D. Wells, and K. Pankow (2022). Developing a comprehensive seismic catalog using a matched-filter detector during a 2019 stimulation at Utah FORGE: *Proceedings, 47th Workshop on Geothermal Reservoir Engineering*, Stanford University, CA February 7- 9, 8 p.

Fournier R. O., and Potter, R. W. (1982). A revised and expanded silica (quartz) geothermometer Geothermal Resources Council Bulletin. 11, 3-12.

Grigoli, F., Cesca, S., Amoroso, O., Emolo, A., Zollo, A., & Dahm, T. (2014). Automated seismic event location by waveform coherence analysis. *Geophysical Journal International*, *196*(3), 1742-1753.

Kordy, M. A., P. E. Wannamaker, V. Maris, E. Cherkaev, and G. J. Hill (2016). Three-dimensional magnetotelluric inversion using deformed hexahedral edge finite elements and direct solvers parallelized on SMP computers, Parts I & II: direct data-space inverse solution: Geophysical Journal International, 204, 74-110.

Mendoza, M., A. Sheehan, G. Jin, A. Titov, K. L. Pankow, and H. Dingo (2022). On the utility of a surface DAS array to monitor induce micros-seismicity and operation activities at the Utah FORGE EGS facility, 2022 AGU Meeting, Chicago, IL, December 12- 16.

Mesimeri, M., K. L. Pankow, B. Baker, and J. M. Hale (2021). Episodic earthquake swarms in the Mineral Mountains, Utah driven by the Roosevelt hydrothermal system, *J. Geophys. Res.: Solid Earth*, 126, e2021JB021659. https://doi.org/10.1029/2021JB021659.

Niemz, P., G. Petersen, K. M. Whidden, and K. L. Pankow (2023). Exploring the potential of surface monitoring networks for induced seismicity in the Utah FORGE geothermal project (abstract), 28th Assembly, IUGG Meeting, Berlin, Germany, July 11 – 20, 2023.

Pankow, K., J. Rutledge, B. Dyer, P. Bradshaw, A. Dzubay, J. M. Hale, G. Petersen, J. Rusho, P. Wannamaker, K. Whidden, J. Moore (2022). Local seismic monitoring of a stimulation at the Utah Frontier Observatory for Research in Geothermal Energy site, 2022 Annual Seismological Society of America Meeting, Bellevue, WA, April 10-23.

Pankow, K. L., B. Dyer, J. Rutledge, *and 11 others* (2023). Towards Best Practices for EGS Seismic Monitoring: Insights gained at Utah FORGE, 2023 Annual Seismological Society of America Meeting, San Juan, Puerto Rico, April 17-20.

Peacock, J. R., S. Thiel, G. S. Heinson, and P. Reid (2013). Time-lapse magnetotelluric monitoring of an enhanced geothermal system: Geophysics, 78, , B121–B130, 10.1190/GEO2012-0275.1, 2013.

Petersen, G. M. and K. L. Pankow (2023). Four decades of seismic swarm activity in the Basin and Range - Colorado Plateau Transition Zone in Central Utah (US), *Geochemistry, Geophysics, Geosystems, in revision..*

Rutledge, J., B. Dyer, P. Wannamaker, K. Pankow, F. Bethmann, P. Meier, and J. Moore (2022). Downhole microseismic monitoring of injection stimulations at the Utah FORGE EGS site, *56th U.S. Rock Mechanics/Geomechanics Symposium,* Santa Fe, New Mexico.

Shi, P., Grigoli, F., Lanza, F., Beroza, G. C., Scarabello, L., & Wiemer, S. (2022). MALMI: An automated earthquake detection and location workflow based on machine learning and waveform migration. *Seismological Society of America*, *93*(5), 2467-2483.

Sugiura, J., Lopez, R., Borjas, F., Jones, S., McLennan, J., Winkler, D., Stevenson, M., and Self, J., (2021), Oil and gas optimization technologies applied successfully to unconventional geothermal well drilling. Society of Petroleum Engineers 2021 Annual Technical Conference, 21-23 September, SPE-205965-MS, 33 p.

Wannamaker, P., V. Maris, K. Mendoza and J. Moore, (2021). Deep heat and fluid sources for the Roosevelt Hot Springs hydrothermal system and potential heat for the Utah FORGE EGS from 3D FORGE and SubTER magnetotelluric coverage: Geothermal Resources Council Transactions, 45, 17 pp.

Wannamaker, P., B. Dyer, J. Rutledge**,** K. Pankow, D. Karvounis, F. Bethmann, P. Meier, J. McClennan, and J. Moore (2022). Monitoring of reservoir scale seismicity using downhole geophone arrays at the Utah FORGE EGS project during stimulation of injector well 16A(78)-32, *GRC transactions,* ***46****,* Reno, Nevada.

Whidden, K., M. Mesimeri, and K. Pankow (2022). The 2021 Milford, UT earthquake sequence, 2022 Annual Seismological Society of America Meeting, Bellevue, WA, April 10-23, 2022.

Whidden, K., G. Petersen, M. Mesimeri, and K. Pankow (2023a). Analysis of the 2021 Milford, Utah earthquake swarm: Enhanced earthquake catalog and migration patterns, Frontiers in Earth Science (Solid Earth Geophysics), vol. 11, doi:10.3389/feart.2023.1057982.

Whidden, K., G. Petersen, P. Bradshaw, A. Dzubay, and K. Pankow (2023b). Seismic monitoring of the 2022 Utah FORGE stimulation—the view from the surface, 2023 Stanford Geothermal Workshop, Palo Alto, California.

Zandt, G., McPherson, L., Schaff, S., & Olsen, S. (1982). Seismic baseline and induction studies: Roosevelt Hot Springs, Utah and Raft River, Idaho. Topical report No. DOE/ID/01821-T1. University of Utah Research Inst., Earth Science Lab, Salt Lake City (USA) 63 pp.

Zhang, H. and K. L. Pankow (2021). High-resolution Bayesian spatial auto-correlation (SPAC) pseudo-3D Vs model of Utah FORGE site with a dense geophone array, *Geophys. Res. Int*, https://doi.org/10.1093/gji/ggab049

APPENDICES

Appendix A1: Infrastructure Assessment

Phase 3B Annual Report

Enhanced Geothermal System Testing and Development at the Milford, Utah FORGE Site

Utah FORGE
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Prepared for the U.S. Department of Energy

Office of Energy Efficiency and Renewable Energy

Contract DE-EE0007080

June 15, 2023

A1. FORGE INFRASTRUCTURE ASSESSMENT

This section considers the infrastructure and budgets required to support Utah FORGE operations and complimentary R&D activities in Phase 3B. Anticipated expenditures for infrastructure development in Phase 3B are included in the following sections.

Well 16B(78)-32

Well 16B(78)-32 will serve as the production well for the Utah FORGE field laboratory. It will be drilled approximately parallel and above well 16A(78)-32 on the same pad. The design and trajectory of the well reflects the results of the stimulation of well 16A(78)-32, R&D and operational requirements (e.g., deployment of optic fibers, minifrac tests, core, open hole measurements, logging). The estimated budget for drilling and testing well 16B(78)-32 is $21,000,000.

Well of Opportunity-2 (WOO-2)

Well of Opportunity - 2 (WOO-2) is anticipated to be drilled in late 2024. The purpose of this well is to provide opportunities for testing EGS technologies by Utah FORGE and the R&D community and for seismic monitoring. Meetings will be convened with the STAT, DOE and Utah FORGE to discuss well design requirements and review possible well locations. Construction of a drill pad , biological surveys, and connection to the electrical power line will be required.

A budget of $6,200,000 is available for drilling and decommissioning WOO–2 and decommissioning WOO-1.

Seismic Monitoring Network

Real time monitoring of low magnitude induced and natural seismicity is an essential component of the Utah FORGE program. Microseismic data is necessary for monitoring the creation and evolution of the reservoir’s fracture network and for hazard mitigation. Figure A1-1 illustrates the permanent microseismic monitoring network at the Utah FORGE site. The network is monitored continuously. During the stimulation of wells 16A(78)-32 and 16B(78)-32, temporary multilevel geophone strings will be installed in wells 58-32 and 78B-32. At the same time a BOSS cable (combination of DAS and 3-component geophones from Avalon Scientific Ltd) will be deployed in well 56-32. The monitoring program during long-term circulation has not yet been defined. GeoEnergie Suisse has agreed to provide the BOSS cable and one of the geophone strings for microseismic monitoring during the stimulations. The estimated cost for the remaining geophone string is $500,000.

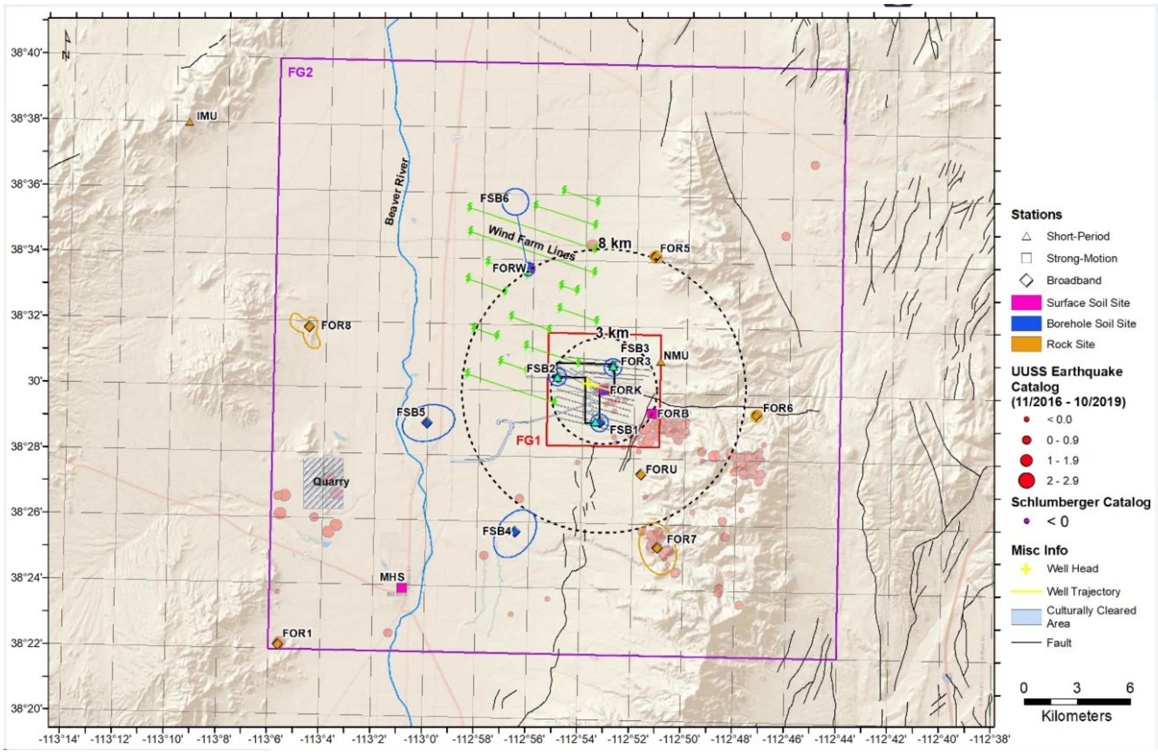


***Figure A1-1**. Permanent seismic network at Utah FORGE. Symbols: triangle = short period instrument; square = strong motion sensor; diamond = broadband instrument. Locations of proposed shallow boreholes are shown in blue and rock stations in gold.*

Electrical Requirements

Electric power is available at all of the pads (Fig. A1-2). The electric lines have been engineered to provide power for present and future needs of Utah FORGE and the R&D community. Power is being provided for the following:

a. Housing and trailers, including the R&D project office (currently being used as the Command Center during the drilling of 16B(78)-32
b. Production and injection well pumps for circulating water between wells 16A(78)-32 and 16B(78)-32
c. Pump for the water supply well and a transfer pump
d. Microseismic monitoring
e. R&D activities occurring on the pads
f. Communications

Additional spur lines may be required in the future for Well of Opportunity -2 (WOO-2) and any additional monitoring wells that are drilled. The cost of electrical infrastructure/use during Phase 3B. $100,000 has been budgeted.

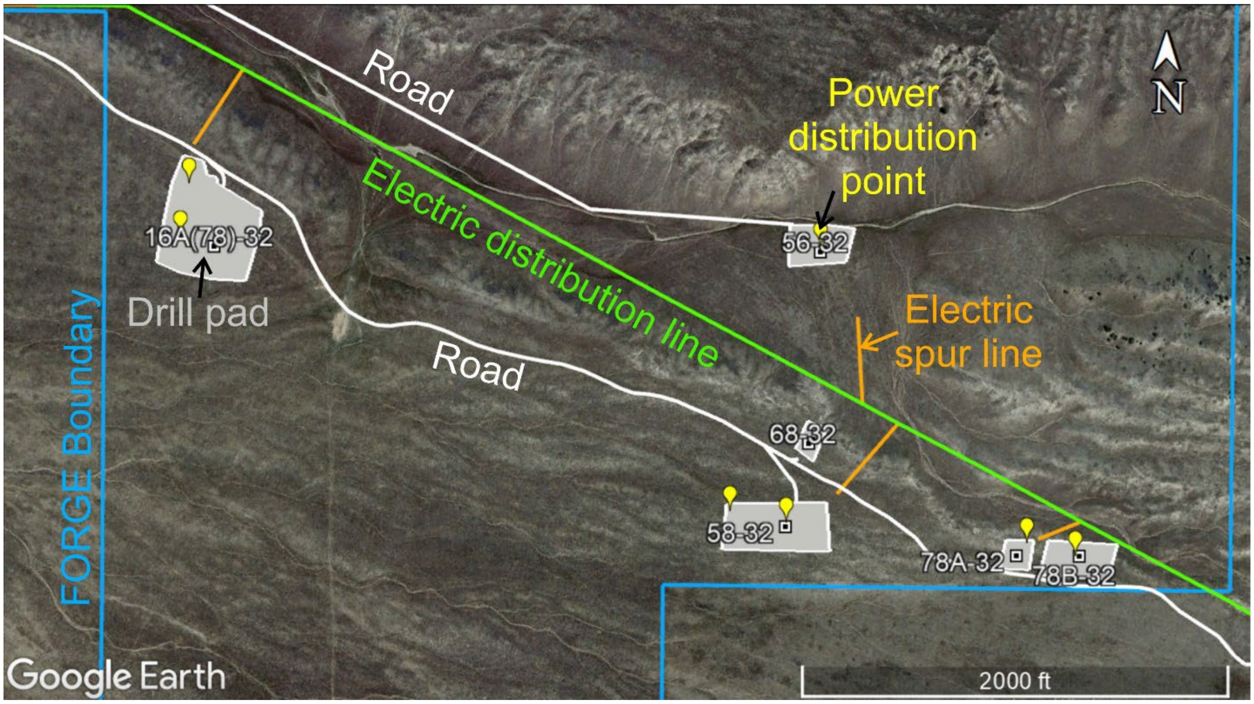


Figure A1-2. *Electric infrastructure map for Utah FORGE. The main, overhead electric distribution line in shown in green. Electric spur lines to various points within the Utah FORGE footprint (blue) are shown in orange. Power distribution points on the drill pads (gray) are shown in yellow.*

Road Maintenance and Construction

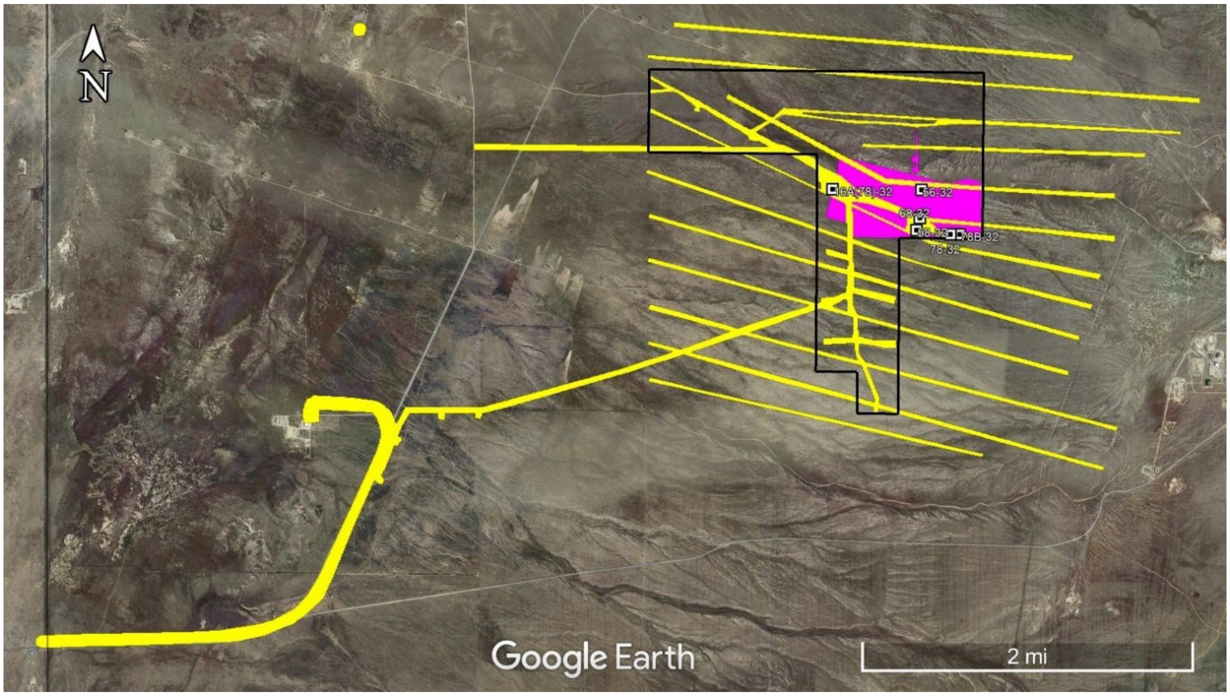
All of the well pads drill pads are accessible by roads. During Phase 3B, Utah FORGE will continue to provide routine maintenance of the roads and pads. The majority of the work will consist of road grading and snow clearing estimated at $25,000.

Cultural and Biological Surveys

The existing culturally cleared (Fig A1-3) areas provide flexibility for the operational and R&D activities that will be conducted during Phase 3B. The locations of future drilling and well stimulation activities including those required for current and future R&D projects will occur on culturally cleared land.

Biological surveys will be required for future Clemson University's additional strainmeter boreholes and for Rice University's Surface Orbital Vibrators (SOV) Utah FORGE will assist the

R&D performers in obtaining the necessary clearances but costs for the surveys will be borne by the R&D projects. We estimate biological clearances will cost $25,000.



FigureA1-3. *Areas that have been culturally cleared within the Utah FORGE footprint during the reporting period are shown in magenta. Previously cleared land is shown in yellow.*

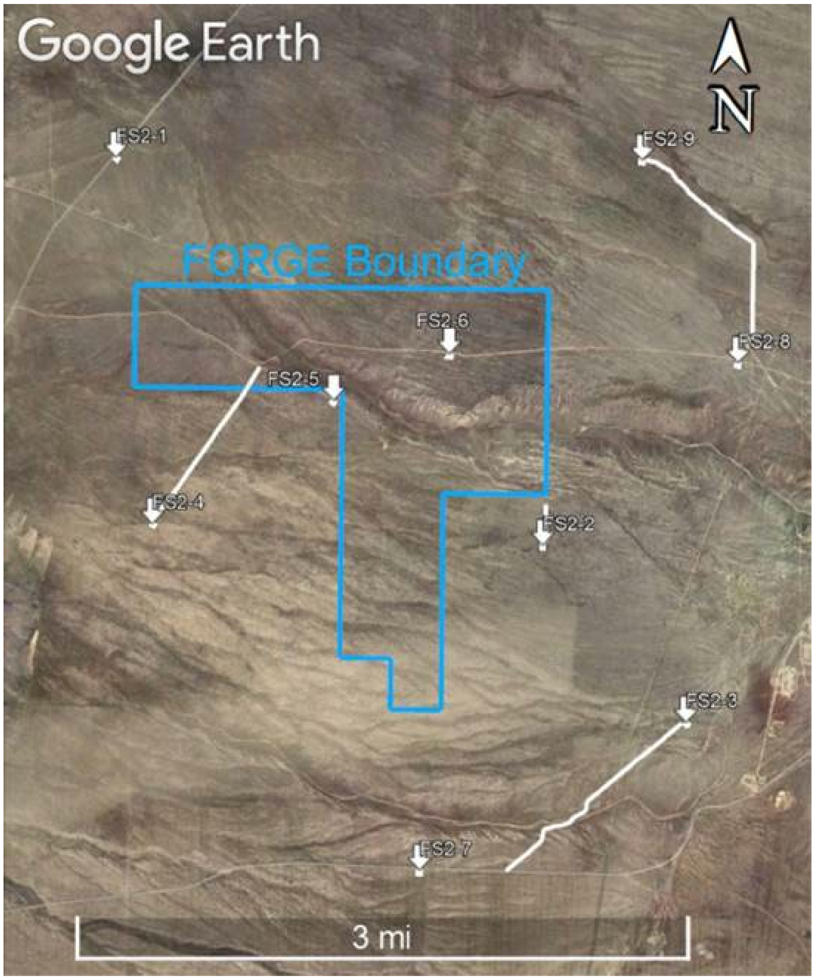


Figure A1-4. *Clemson University strainmeter sites. The drill sites are shown as small white squares at the arrow tips; two track access roads to the drill pads are shown as white lines. The pad locations and roads have been culturally cleared. Biological clearances by Clemson University are pending.*

Future Water and Circulation Requirements

At least one water well will be required for future drilling, stimulation and circulation testing. Water rights for 250 acre-ft per year (81 million gallons/year) of non-consumptive use (Water Right 71-5429) and 50 acre-ft per year (16 million gallons/year) for consumptive use (Water Right 71-5430) have been acquired by the project. An additional 200 acre-ft of water has been offered by Smithfield Foods under a lease arrangement. Water can also be purchased from Milford. Water from Milford will be used for drilling 16B(78)-32 and the short-term circulation tests that will be conducted immediately after the well is drilled.

Testing of well 78-32 indicated that the aquifer could produce 200 gpm, a volume considered sufficient for circulation testing. Several options for supplying water to the 16A/B(78)-32 pad are being considered including temporary storage on the well 58-32 pads and direct injection into well 16A(78)-32. The cost of drilling the water well and associated infrastructure required for circulation testing (injection, production and transfer pumps, piping, storage) is estimated to be $1,000,000.

All electric drops have been oversized to accommodate both a 105 hp water well pump and a 75 hp booster pump, giving flexibility in the placement of a future groundwater well.

Communication System

A microwave radio link to bring high-speed internet to the Utah FORGE site has been installed by Utah Education and Telehealth Network (UETN). Internet connections were adequate for the well 16A(78)-32 stimulation but upgrading the antennas and radios could improve the communication system. We are currently exploring these options. We expect the cost to upgrade the communication system will be approximately $25,000.

R&D Support

Several of the R&D projects will require significant support for testing tools and stimulation technologies. On-site facilities during these periods could include drill rigs, cranes/boom trucks, storage facilities, a Project Office and oversight by the Site Safety Manager and the Drill Site Manager. Additional personnel may be required, depending on the activities to ensure they are conducted in a safe manner, will not cause damage to the infrastructure and wells, and are in accordance with permitted activities. Every attempt will be made to schedule R&D activities at times when costs can be minimized. However, we will work closely with the R&D teams to ensure their projects are completed in a timely manner. The bulk of cost for R&D field activities will be borne by the projects. DOE has agreed to provide additional funds for R&D equipment and deployment costs.

Decommissioning

Under the current SOPO, the site must be decommissioned, or transferred to a third party, at the conclusion of Phase 3B. The current project end date is July, 26, 2025. Decommissioning requires returning all pads to grade level, plugging and abandoning the wells, and reseeding. All equipment and site facilities must be removed, unless transferred to the land owner, Utah School and Institutional Trust Lands Administration (SITLA). We currently have budgeted/encumbered $3,400,000 for restoration and abandonment through Phase 3B.

Appendix A2: Update on Site Data Uploaded to the GDR Data Archive

Phase 3B Year 1 Annual Report

Enhanced Geothermal System Testing and Development at the Milford, Utah FORGE Site

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Salt Lake City, UT, 84105

Prepared for the U.S. Department of Energy

Office of Energy Efficiency and Renewable Energy

Contract DE-EE0007080

June 15, 2023

A2. DATA SHARING

Work during Phase 3 has produced a tremendous amount of data as well as reports. All of data and reports as of March 31, 2023 has been uploaded to the Geothermal Data Repository and the Utah FORGE wiki site and are available for downloading. These data include the following:

(1) High-Resolution DAS microseismic data from Well 78-32 (two separate submissions 11/13/2019 & 04/01/2020):
https://gdr.openei.org/submissions/1185 and https://gdr.openei.org/submissions/1207
127,676 files

(2) Utah FORGE: Phase 2C topical report (added 12/09/2019):
https://gdr.openei.org/submissions/1187
34 files

(3) Data for 3-D model development - lithology, temperature, pressure, and stress (added 03/13/2020):
https://gdr.openei.org/submissions/1205
12 files

(4) Utah FORGE well 16A(78)-32 planned trajectory coordinates and depths (added 03/24/2020):
https://gdr.openei.org/submissions/1208
1 file

(5) 2019 ARMA Slide presentation (added 03/24/2020):
https://gdr.openei.org/submissions/1209
1 file

(6) 58-32 Injection and packer performance, April 2019 (added 03/25/2020):
https://gdr.openei.org/submissions/1210
1 File
(7) Utah FORGE seismic activity: April 2019 (added 04/24/2020):
https://gdr.openei.org/submissions/1215
1 file

(8) Report: numerical modeling of microearthquake monitoringat the Utah FORGE Site, LANL (added 06/08/2020):
https://gdr.openei.org/submissions/1187
1 file

(9) Utah FORGE Well 16(78)-32 planned trajectory (added 04/29/2020):
https://gdr.openei.org/submissions/1216
1 file

(10) Discrete fracture network (DFN) data (added 06/24/2020):
https://gdr.openei.org/submissions/1222
154 files

(11) InSAR Study results: report and data (added 09/29/2020):
https://gdr.openei.org/submissions/1251
279 files

(12) Ground water monitoring data from wells WOW-2 and WOW-3 (added 09/30/2020):
https://gdr.openei.org/submissions/1252
1 file

(13) Microgravity data through time (added 10/7/2020):
https://gdr.openei.org/submissions/1256
1 file.

(14) Magnetotelluric (MT) data (added 10/7/2020), 3 files. Updated model 17 MT model cell center data (added 12/6/2021), 3 files. MT model 17 cell corner data (added on 02/21/2022), 2 files:
https://gdr.openei.org/submissions/1255
7 files total.

(15) Utah FORGE updated Phase 2C well location coordinates (added 12/7/2020):
GDR: Utah FORGE Updated Phase 2C Well Location Coordinates (openei.org)
9 files.

(16) Utah FORGE seismograph stations link (added 1/26/2021):
GDR: Utah FORGE Seismograph Station Information and Data (openei.org)
1 link

(17) Well 16A(78)-32 Drilling Data: daily reports, drilling data @ 10 second intervals, drilling data @ 1 second intervals, standard survey report, summary of daily operations, survey data, and rig photos (added 3/1/2021 by NREL):
https://gdr.openei.org/submissions/1283
116 Files

(18) Well 16A(78)-32 Logs: mud logs, Sanvean Technologies logs, and Schlumberger logs These

include (1) through bit FMI, (2) through bit sonic, (3) time lapse casing integrity, (4) CBL and gamma, (5) mud temperature and gamma, (6) array induction and gamma, (7) array induction, spectral density, dual spaced neutron/gamma ray, (8) spectral GR and temperature, (9) HID, (10) temperature, (11) ultrasonic imager/casing integrity/gamma ray-CCL, and (12) ultrasonic borehole imager logs. (added 3/10/2021):
GDR: Utah FORGE Well 16A(78)-32 Logs (openei.org)
122 files.

(19) Well 56-32 Drilling Data, bit data, BHA data, mud motor data, well logs, Pason data, daily reports, days vs depth, and daily mud logs. Schlumberger Logs: FMI, shear anisotropy analysis, memory, sonic, array induction/spectral density/dual spaced neutron/gamma ray/caliper, spectral GR/temperature, Gardner density correlation, caliper, and well survey data (added 4/7/2021):
GDR: Utah FORGE Well 56-32 Drilling Data and Logs (openei.org)
180 files

(20) 1-D seismic velocity models: Kristine Pankow, University of Utah Seismic Stations (added 3/18/2021):
GDR: Utah FORGE Seismic Velocity Models, February 2021 (openei.org)
64 files

(21) Summary of drilling activities for well 16A(78)-32 (added 3/21/2021): GDR: Utah FORGE Well 16A(78)-32: Summary of Drilling Activities (openei.org)
1 file

(22) Text file containing the results of a final Schlumberger FMI log run from 7390' to 7527' in well 58-32, originally known at well MU-ESW1. (added 4/4/2021):
https://gdr.openei.org/submissions/1299
1 file

(23) Simplified DFN files and short report for well 16A(78)-32 (added 6/2/2021):
GDR: Utah FORGE Well 16A(78)-32 Simplified Discrete Fracture Network Data (openei.org)
25 files

(24) Utah Geological Survey interactive geoscience map. (added 6/10/2021):
GDR: Utah FORGE UGS Interactive Geoscience Map (openei.org)
1 link

(25) Induced seismicity mitigation plan revision and addendum. (added 6/29/2021):
GDR: Utah FORGE Induced Seismicity Mitigation Plan (openei.org)
2 files

(26) Utah FORGE Seismic stations and wells GPS survey data (UGS), 2021 (added 7/7/2021):
GDR: Utah FORGE Seismic Stations and Wells GPS Survey Data, 2021 (openei.org)
1 file

(27) Well 58-32 Schlumberger sonic waveform data (added 7/7/2021):
GDR: Utah FORGE: Logs and Data from Deep Well 58-32 (MU-ESW1) (openei.org)
4 files

(28) 2020-2021 Geothermal energy/EGS knowledge survey and results (added 7/20/2021):
GDR: Utah FORGE 2020 Geothermal Energy/EGS Survey and Results (openei.org)
2 files

(29) XRD data from well 16A(78)-32 (added 7/29/2021):
GDR: Utah FORGE Well 16A(78)-32 X-ray Diffraction Data (openei.org)
3 files

(30) Updated well temperature and pressure logs for wells 58-32, 56-32, and 78-32 (added 8/6/2021):
GDR | Successfully Submitted Utah FORGE Wells Updated Temperature/Pressure Logs (6/2021) (openei.org)
8 files

(31) Updated Utah FORGE composite raw gravity dataset covering the period from December2018 to June 2021 (added 8/9/2021):
GDR | Successfully Submitted Utah FORGE Composite Raw Gravity Data 2021 (openei.org)
3 files

(32) Well 16A(78)-32 core photos (added 8/11/2021):
GDR: Utah FORGE Well 16A(78)-32 Core Photos (openei.org)
30 files

(33) Schlumberger Logs for well 78B-32 from the following tools:

1. QAIT - Slim Hostile Array Induction Tools
2. QSLT - Slim Xtreme Sonic Logging Tool
3. QCNT - Slim Hot Compensated Neutron Tool
4. QTGC - SlimXtreme Telemetry and Gamma Ray
5. HLDS - Hostile Litho-Density Sonde Tool
6. QCNT - Slim Hot Compensated Neutron Tool

7. QAIT - Slim Hostile Array Induction Tool
8. USIT - Ultrasonic Imager Tool
9. PPC - Powered Positioning Caliper Tool
10. GPIT - General Purpose Inclinometry Tool
11. FMI - Fullbore Formation Microimager
12. UBI - Ultrasonic Borehole mager(added (8/23/2021):

GDR: Utah FORGE Well 78B-32 Daily Drilling Reports and Logs (openei.org)
68 files

(34) Schlumberger concrete bond log (CBL) for 16A(78)-32, which also included gamma andmud temperature logs (added 9/7/2021):
GDR: Utah FORGE: Well 16A(78)-32 Logs (openei.org)
4 files

(35) Schlumberger concrete bond log (CBL) for 56-32, which also included gamma and mud temperature logs (added 9/7/2021):
GDR: Utah FORGE: Well 56-32 Drilling Data and Logs (openei.org)
2 files

(36) Utah FORGE groundwater data from well WOW2 and WOW3 updated by the Utah Geological Survey on 10/5/2021 (added 10/12/2021):
GDR: Utah FORGE Groundwater Levels: Updated 2021 (openei.org)
2 files

(37) Utah FORGE microgravity data composite updated on October 1, 2021 by the Utah Geological Survey (added 10/14/2021):
GDR: Utah FORGE Microgravity Composite Data: Updated 10/2021. (openei.org)
3 files

(38) North Milford Valley Groundwater Geochemistry (added 10/18/2021):
GDR: Utah FORGE: North Milford Groundwater Geochemistry 2021 (openei.org)
10 files

(39) Well 78B-32 core photos, but wet and dry (added 10/22/2021):
GDR: Utah FORGE Well 78B-32 Core Photos: Wet and Dry in Boxes (openei.org)
42 files

(40) Well 78B-32 Schlumberger 7-inch casing cement bond log data (added 10/29/2021):
GDR: Utah FORGE Well 78B-32 Daily Drilling Reports and Logs (openei.org)
5 files

(41) Well 78B-32 1 and 10 second Pason drilling data (added 12/6/2021):
GDR: Utah FORGE Well 78B-32 Daily Drilling Reports and Logs (openei.org)
3 files

(42) Well 56-32 1 and 10 second Pason drilling data (added 12/6/2021):
GDR: Utah FORGE: Well 56-32 Drilling Data and Logs (openei.org)
2 files.

(43) Well 78B-32 directional survey (added 12/14/2021):
GDR: Utah FORGE Well 78B-32 Daily Drilling Reports and Logs (openei.org)
2 files

(44) Updated GPS survey coordinates for wells, well pads, and seismic stations completed in December, 2021 by the Utah Geological Survey (added 12/6/2021):
GDR: Utah FORGE Updated Well, Well Pad, and Seismic Station GPS Coordinates December, 2021 (openei.org)
1 file

(45) 1-D seismic velocity models coordinate data (latitude and longitude): Kristine Pankow, University of Utah Seismic Stations (added 12/17/2021):
GDR: Utah FORGE Seismic Velocity Models, February 2021 (openei.org)
1 file

(46) Sanvean Technology data for Well 78B-32. This included information such as Gyro performance, shock, vibration, and temperature (added 12/20/2021):
GDR: Utah FORGE Well 78B-32 Daily Drilling Reports and Logs (openei.org)
14 Files

(47) The Geothermal Resources Group "End of Well Report" for well 78B-32 (added 12/20/2021):
GDR: Utah FORGE Well 78B-32 Daily Drilling Reports and Logs (openei.org)
1 File

(48) X-ray diffraction results for 69 samples taken from well 56-32 from depths between 3050 and 9130 feet (added 12/21/2021):
GDR: Utah FORGE: Well 56-32 Drilling Data and Logs (openei.org)
1 file

(49) Final mud log from well 16A(78)-32 from Horizon Well Logging, Inc. (added 12/23/2021):
GDR: Utah FORGE: Well 16A(78)-32 Drilling Data (openei.org)

1 file

(50) Well 16A(78)-32 DFN Permeability Tensor Supplement -- Golder Associates Inc. (added 01/05/2022):
GDR: Utah FORGE Well 16A(78)-32 Simplified Discrete Fracture Network Data (openei.org)
7 files

(51) Well 58-32 one-foot interval drilling data (01/13.2022):
GDR: Utah FORGE: Logs and Data from Deep Well 58-32 (MU-ESW1) (openei.org)
1 file

(52) Reinterpreted FMI data from well 56-32 (added on 02/21/2022):
GDR: Utah FORGE: Well 56-32 Drilling Data and Logs (openei.org)
5 files

(53) Schlumberger processed anisotropy log data for well 16A(78)-32 (added 3/7/2022):
GDR: Utah FORGE: Well 16A(78)-32 Logs (openei.org)
6 files

(54) Woolsey Land Surveying, as located, Longitude and Latitude coordinates for shallowseismic well locations including FSB4, FSB5, and FSB6 (added 3/8/2022):
GDR: Utah FORGE FSB4, FSB5, & FSB6 Shallow Seismic Well Locations (openei.org)
1 file

(55) Utah FORGE water table levels for wells WOW2 and WOW3 updated on 3/16/2022 by the Utah Geological Survey (added 3/16/2022):
GDR: Utah FORGE Groundwater Levels: Updated March 2022 (openei.org)
1 file

(56) Utah FORGE well 16A(78)-32 stimulation data April, 2022. These included daily reports, low rate pumping data, 1 second Pason data, shear data, Stage 1,2, and 3 data, and the EOJ report (added 5/18/2022):
GDR: Utah FORGE Well 16A(78)-32 Stimulation Data (April, 2022) (openei.org)
48 Files

(57) Seismic data related to the 2019 well 58-32 stimulation (added 6/13/2022):
GDR: Utah FORGE Seismicity Associated with the 2019 Well 58-32 Stimulation (openei.org)
2 files

(58) DAS seismic data collected from wells 78-32 and 78B-32 during the 16A(78)-32 2022 stimulation (added 7/12/2022):
GDR: Utah FORGE DAS Seismic Data (2022) (openei.org)
319 SEGY files

(59) Purdue University: Results of B-Value Tests for Rock Saturation (added 7/19/2022):
GDR: Purdue University: Results of B-Value Tests for Rock Saturation (openei:org)
2 files

(60) Native state model updated for 2022 covering the entire well field (added 7/29/2022):
GDR: Utah FORGE Phase 3 Native State Model: 2022 Update (openei:org)
11 files

(61) Seismic Data from the Well 16A(78)-32 Stimulation April, 2022 (added 7/30/2022):
GDR: Seismic Data from the Well 16A(78)-32 Stimulation April, 2022 (openei:org)
3 files

(62) Utah FORGE Phase 3A, Year 2, Annual Report (added 8/2/2022):
GDR: Utah FORGE Phase 3A, Year 2, Annual Report (openei:org)
1 file

(63) Utah FORGE well 56-32 sludge X-ray fluorescence results (added 8/2/2022):
GDR: Utah FORGE Well 56-32 Sludge XRF (openei:org)
1 file

(64) Penn State University: Utah FORGE Friction-Permeability-Seismicity Laboratory Experiments with Non-Linear Acoustics (added 8/3/2022):
GDR: Utah FORGE Friction-Permeability-Seismicity Laboratory Experiments with Non-Linear Acoustics (openei:org)
2 files

(65) USGS: Utah FORGE Hydrothermal Friction-Hydraulic Transmissivity Laboratory Experiments (added 8/3/2022):
GDR: Utah FORGE Hydrothermal Friction-Hydraulic Transmissivity Laboratory Experiments (openei:org)
15 files

(66) Colorado School of Mines: Utah FORGE Well 16A(78)-32 Stage 1 - Pressure Falloff Analysis Report (added 8/4/2022):
GDR: Utah FORGE Well 16A(78)-32 Stage 1 - Pressure Falloff Analysis (openei:org)
1 file

(67) This is a link to downhole geophone data collected by Schlumberger: These data were collected in the Utah FORGE deep seismic monitoring wells 58-32 and 56-32 (added 8/26/2022):
[GDR: Utah FORGE Downhole Geophone Seismic Data (2022) (openei:org)]
1 link

(68) Clemson R&D: Utah FORGE Phase 1a tensor strainmeter data for the April, 2022 stimulation of well 16A(78)-32 (added 9/15/2022):
[GDR: Utah FORGE Phase 1a Tensor Strainmeter Data for the April, 2022 Stimulation of Well 16A(78)-32 (openei:org)]
7 Files

(69) Lawrence Berkeley National Laboratory R&D: This report describes the current status of the Vertical Electromagnetic Profiling, or VEMP tool, that is on loan to LBNL from GERD. The report describes the initial inspection of the tool by LBNL scientists and engineers, and presents a path forward for it to be used at Utah FORGE (added 9/16/2022):
[GDR: LBNL FORGE Project Report for Milestone 2:1 Status Report on The VEMP tool (openei:org)]
1 file

(70) Utah FORGE deep wells temperature surveys. This spreadsheet contains temperature survey results for Utah FORGE wells 58-32, 78-32, 56-32, 16A(78)-32 and 78B-32: It also contains charts and comparisons (added 9/17/2022):
[GDR: Utah FORGE Deep Wells Temperature Surveys (openei:org)]
1 file

(71) Utah FORGE Well 16A(78)-32 stimulation tracer test results. This archive contains data from the tracer test performed during the Utah FORGE well 16A(78)-32 stimulation (added 9/17/2022):
[GDR: Utah FORGE Well 16A(78)-32 Stimulation Tracer Test Results (openei:org)]
4 files

(72) Utah FORGE well 16A(78)-32 stimulation microseismic detection and location report from Silixa LLC (added 9/26/2022):
[GDR: Utah FORGE Well 16A(78)-32 2022 Stimulation Silixa Microseismic Report (openei:org)]
2 files

(73) Utah FORGE Well 16A(78)-32 stimulation DFN fracture plane evaluation data related to the April, 2022 well 16(A)78-32 well stimulation (added 10/28/2022):
[GDR: Utah FORGE Well 16A(78)-32 Stimulation DFN Fracture Plane Evaluation (openei:org)]

8 files

(74) Report by the Colorado School of Mines R&D: Development of Multi-Stage Fracturing System and Wellbore Tractor to Enable Zonal Isolation During Stimulation and EGS Operations in Horizontal Wellbores (added 10/31/2022):
GDR: Utah FORGE: Development of Multi-Stage Fracturing System and Wellbore Tractor to Enable Zonal Isolation During Stimulation and EGS Operations in Horizontal Wellbores (openei:org)
1 file

(75) Lawrence Berkeley National Laboratory R&D: Utah FORGE Project 3-2535 Powerpoint Report for Milestone 4:1: resistivity models that will be employed in the survey design phase of our project (added 11/04/2022):
GDR: Utah FORGE Project 3-2535 Powerpoint Report for Milestone 4:1 (openei:org)
1 file

(76) Utah FORGE seismic event catalogs related to the April, 2022 well 16A(78)-32 stimulation (added 11/10/2022):
GDR: Utah FORGE Seismic Events Related to the April, 2022 Well 16A(78)-32 Stimulation (openei:org)
3 files

(77) Metarock Laboratories report on the thermal properties of well 58-32 granite core (added 11/15/2022):
GDR: Utah FORGE Well 58-32 Granite Core Thermal Properties Test Results Report (Oct: 2021) (openei:org)
1 file

(78) Lawrence Berkeley National Laboratory R&D: tests and workflow report for their proposed EM borehole surveys (added 11/15/2022):
GDR: Utah FORGE Project 3-2535 Report for Milestone 4:2 (openei:org)
1 file

(79) Lawrence Berkeley National Laboratory R&D: A report that outlines the creation three 3D resistivity models that will be used to determine the sensitivity of EM measurements to the hypothetical stimulated reservoir at FORGE as well as for EM survey design (added 12/1/2022):
GDR: LBNL FORGE Project 3-2535 Report for Milestone 4:1 (openei:org)
1 File

(80) Deep wells water and gas sampling with analyses results by ThermoChem: These samples were from wells 16A(78)-32, 58-32, 56-32 and 78B-32 (added 12/7/2022):

[GDR: Utah FORGE Deep Wells Water and Gas Sampling with Analyses by ThermoChem (October, 2022) (openei:org)]()
7 files

(81) Colorado School of Mines R&D: “Utah FORGE GeoThermOPTIMAL” video by Dr: William Fleckenstein (added 12/12/2022):
[GDR: Utah FORGE GeoThermOPTIMAL Video (openei:org)]()
1 file

(82) Battelle Memorial Institute R&D: Report “A Multi-Component Approach to Characterizing In-Situ Stress:” (added 12/14/2022):
[GDR: Utah FORGE Project 2439: A Multi-Component Approach to Characterizing In-Situ Stress (openei:org)]()
1 file

(83) This is a link that leads to a University of Utah Seismograph Stations webpage with spreadsheets containing seismic borehole sensor locations and well trajectories for wells 56-32, 58-32, 78-32, 78B-32 (added 12/24/2022):
[GDR: Utah FORGE Borehole Sensors and Well Trajectories (openei:org)]()
2 links

(84) Perdue R&D: Results of Direct Shear Tests on Saturated Joints in Sierra White Granite (added 12/29/2022):
[GDR: Utah FORGE: Results of Direct Shear Tests on Saturated Joints in Sierra White Granite (openei:org)]()
2 files

(85) This is a report on the Utah FORGE 2022 Seismic Workshop (added 1/4/2023):
https://gdr:openei:org/submissions/1460
1 file

(86) Borehole Passive Seismic Sensors (PSS) Tools Status Report by Instrumental Software Technologies, Inc. (added 1/28/2003):
[GDR: Utah FORGE: Borehole Passive Seismic Sensors (PSS) Tools Status Report (openei:org)]()
1 file

(87) Lawrence Berkeley National Laboratory R&D: report on development of an elastic compressional velocity model for the FORGE site and on the estimation of ground deformation associated with various stimulation scenarios (added 2/1/2023):
[GDR: Utah FORGE Project 3-2535 Task 5:1 Milestone Report (openei:org)]()
1 file

(88) Lawrence Berkeley National Laboratory R&D: This is a milestone report describing the 3D modeling studies of energized steel-casing source electromagnetic method for detecting stimulated zone at the Utah FORGE Site (added 2/6/2023):
GDR: Utah FORGE Numerical modeling Studies for EM Data Acquisition Survey Design (openei:org)
1 file

(89) University of Texas at Austin R&D: This is a set of two reports and a slide presentation discussion on their work on discrete fracture networks and fracture propagation modelling (added 2/10/2023):
GDR: Utah FORGE: Discrete Fracture Network and Fracture Propagation Modelling (openei:org)
3 files

(90) Lawrence Berkeley National Laboratory R&D: Preliminary report on development of a reservoir seismic velocity model (added 2/10/2023):
GDR: Utah FORGE LBNL 3-2535 Preliminary Report on Development of a Reservoir Seismic Velocity Model (openei:org)
1 file

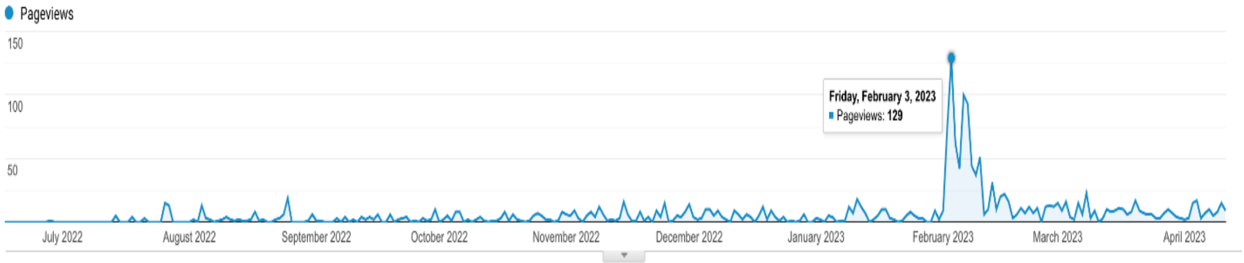
(91) Well 78B-32 core sample petrography report and data (added 2/21/2023):
GDR: Utah FORGE: Well 78B-32 Core Sample Petrography (openei:org)
41 files

(92) A YouTube video containing the specifics of well planning for Utah FORGE 16B(78)-32 (added 3/9/2023):
GDR | Submission Status for Utah FORGE: Video of Utah FORGE Drilling Planning for Production Well 16B(78)-32 (openei:org)
1 link

(93) Fervo Energy R&D: Optimization of a plug-and-perf stimulation slide presentation (2/22/2023):
GDR: Utah FORGE: Optimization of a Plug-and-Perf Stimulation (Fervo Energy) (openei:org)
1 file

(94) The Pennsylvania State University R&D: Friction experiment data and report (added 3/23/2023):
GDR: Utah FORGE Friction Experiments (openei:org)
6 files

Phase 3 work has produced a total of 129,426 files and 8 external data links. Additionally, there have been numerous hits on the wiki site since its inception (Figure A2-1).



FigureA2-1. *Utah FORGE wiki site hits.*

Appendix A3: Updated Permitting Inventory

Phase 3B Year 1 Annual Report

Enhanced Geothermal System Testing and Development at the Milford, Utah FORGE Site

Utah FORGE
University of Utah
423 Wakara Way, Ste 300
Salt Lake City, UT, 84108

Prepared for the U.S. Department of Energy

Office of Energy Efficiency and Renewable Energy

Contract DE-EE0007080

June 15, 2023

A3. UPDATED PERMITTING INVENTORY

Permitting activities in this period were undertaken for both the needs of R&D recipients and for Utah FORGE site management purposes.

R&D Performers

Clemson – Strainmeters

- Utah FORGE worked closely with Clemson to select appropriate sites for the installation of the strainmeters to optimize data acquisition, minimize land disturbances, and reduce construction/reclamation costs, while dealing with constraints such as land ownership, topography and infrastructure (Figure A3-1).
- Preliminary proposals were submitted to Rocky Mountain Power (RMP), Smithfield Foods, BLM and SITLA. Approvals to install strainmeters were granted by Smithfield Foods, BLM and SITLA.
- A SF-299 was prepared by Utah FORGE and submitted to the BLM on behalf of Clemson.
- Utah FORGE contracted for cultural surveys to be conducted by SWCA on the ground where ~50 x 50 ft drill pads were be constructed and over existing two-track access roads.
- The Utah State Historic Preservation Office ruled that there would be no adverse effects of the construction of the strainmeters to cultural resources.
- Clemson contracted for biological surveys to be conducted by Salter Wetland Associates, LLC.
- Upon completion of the cultural and biological surveys, a right-of-way was issued by the local BLM office in Cedar City, UT.
- A Categorical Exclusion was issued for the installation of the strainmeters by the local BLM office in Cedar City, UT.
- To date Clemson has installed four of thirteen strainmeters located on Smithfield and SITLA land as part of their phase 1A and 1B efforts.

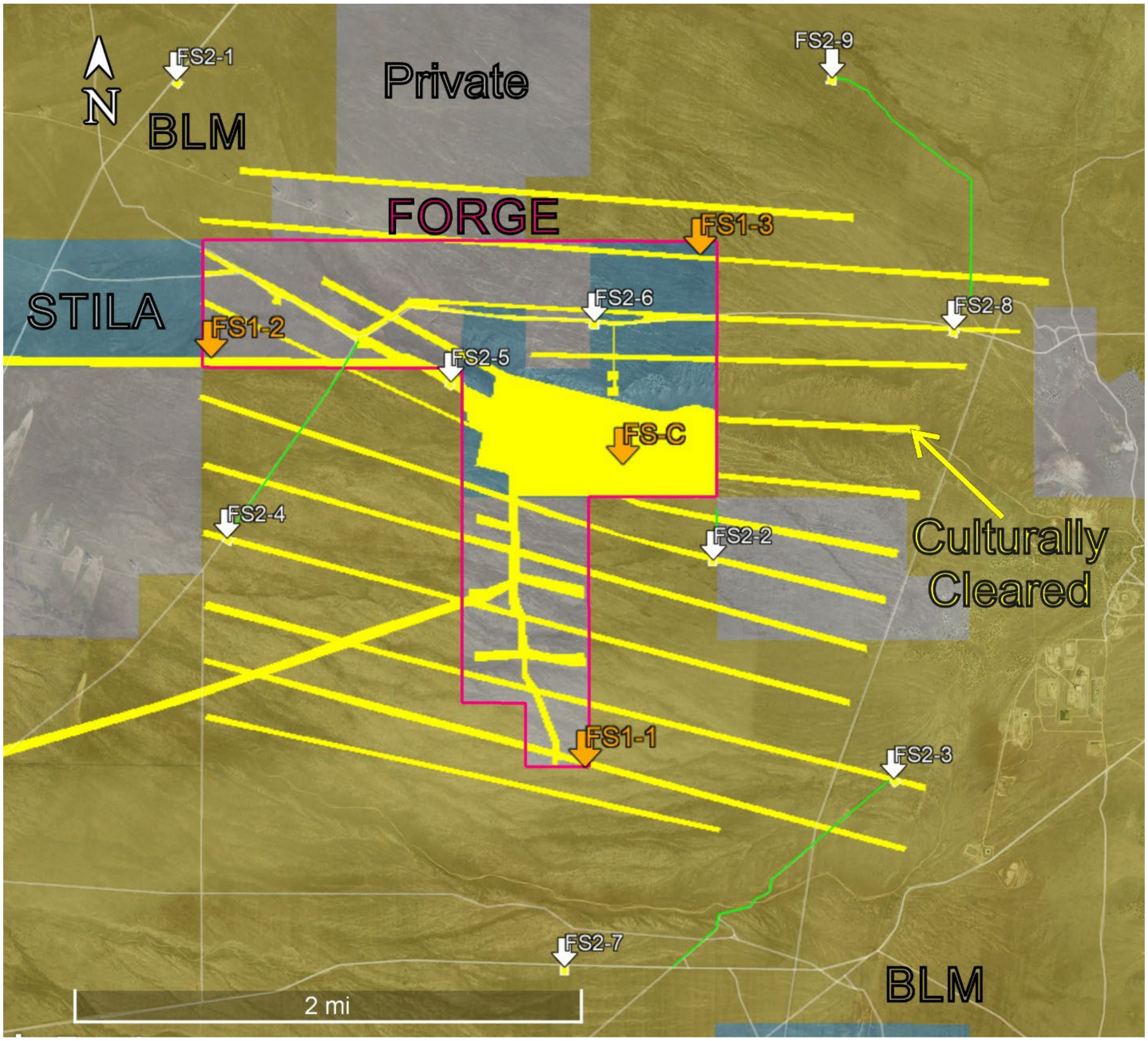


Figure A3-1. *Map showing land ownership (BLM, SITLA and private parcels); the Utah FORGE footprint (pink outline); culturally cleared ground (yellow); the locations of strainmeters installed by Clemson as part of phases 1A and 1B (orange); permitted strainmeter locations as part of phase 2 (white); and access roads that have been surveyed for cultural artifacts (green lines).*

***Rice -** Stationary orbital vibrators (SOVs) and fiber deployment in the annulus of 16B(78)-32*.

- Utah FORGE worked closely with Clemson to select appropriate sites for the installation of the SOVs to optimize data acquisition, minimize land disturbances, and reduce construction/reclamation costs, while dealing with constraints such as land ownership, topography and infrastructure (Figure A3-2).
- Proposals to install SOVs were submitted to SITLA, Rocky Mountain Power (RMP), Kern River Gas Transmission, and Smithfield Foods/Fervo Energy). A follow-up, in

person meeting between representatives of Utah FORGE, UGS and SITLA was held in Salt Lake City to discuss the SOVs in which approval was granted for SOV installation on their property. Approval was not granted by RMP. A MOU is currently being negotiated between Fervo Energy and Rice for installation on Smithfield property.

- Sites were selected that had already been culturally cleared by Utah FORGE for the 3D seismic survey, or other site activities (Figure A3-2).
- Utah FORGE provided guidance and resources to initiate the biological surveys by putting the FORMORE team in contact with local environmental consulting firms and the managing BLM office in Cedar City, UT.
- Utah FORGE is working with the FOGMORE team to complete their NEPA EQ for site activities (installing SOVs and fiber in the annulus of 16B(78)-32) and will review their application before relaying the document to NETL for approval.

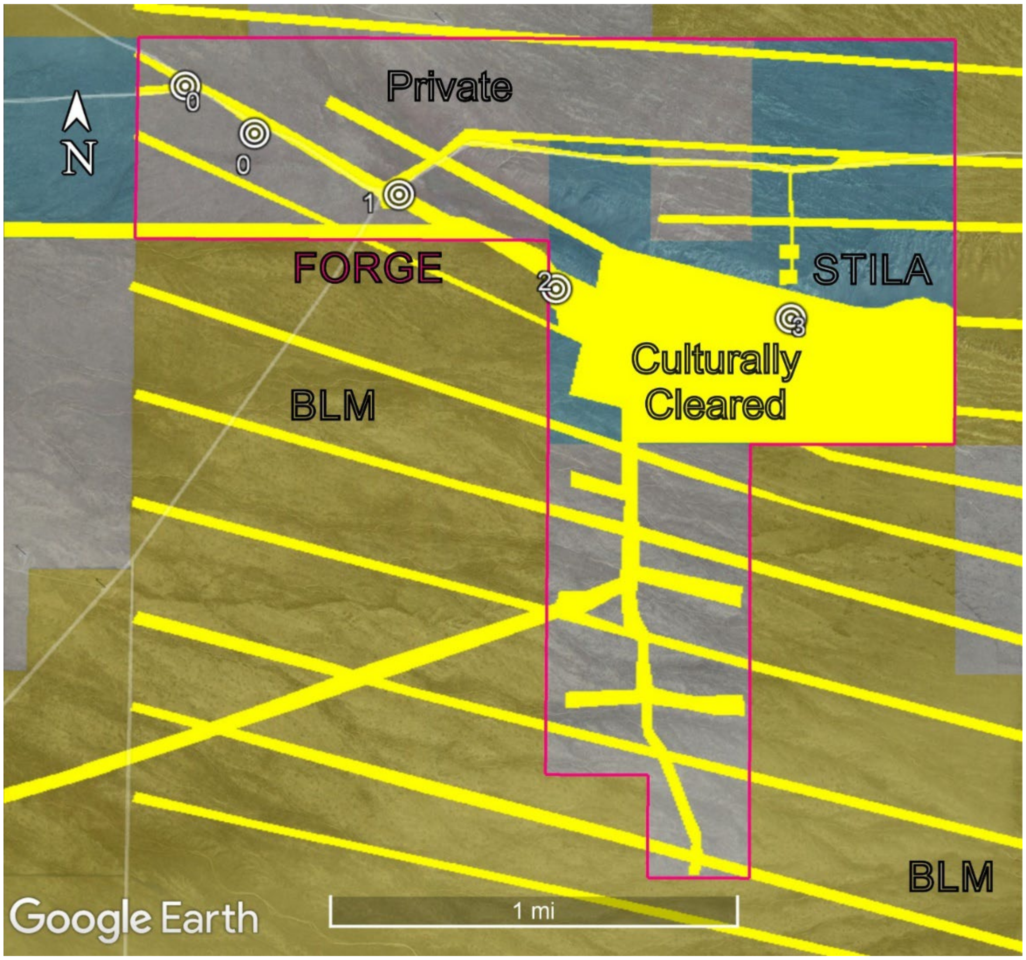


Figure A3-2. *Map showing land ownership (BLM, SITLA and private parcels); the Utah FORGE footprint (pink outline); culturally cleared ground (yellow); the proposed locations of the SOVs (including alternates, in white).*

UT Austin – Utah FORGE is working with UT-Austin to complete their NEPA EQ for site activities (installing fiber in the annulus of 16B(78)-32) and will review their application before relaying the document to NETL for approval.

New Solicitations – NEPA EQs were required to be submitted by applicants in the latest round of solicitations. These have been reviewed by the Utah FORGE team.

Utah FORGE

Seismic network

- Five additional seismometers were installed to complete an outer ring that encircles the FORGE site to the north, west and south (Figure A3-3). Surface stations were anchored to rock on BLM land. Seismometers in shallow (<200 ft) wells are on SITLA property.
- An application for transportation and utility systems and facilities on Federal Lands was submitted to, and approved by the BLM for the stations anchored to rock (FOR7 and FOR8).
- A special use lease agreement (SULA) was signed with SITLA for sites FSB4, FSB5 and FSB6 with approval from Dominion Energy/Escalante II who holds a co-lease on the same parcel as FSB5 that is occupied by their solar array.
- Cultural surveys were conducted by environmental consulting firm SWCA prior to the construction of the ~50 x 50 ft drill pads at sites FSB4, FSB5 and FSB6.
- The Utah State Historic Preservation Office (SHPO) ruled that there would be no adverse effects of the construction of the seismic boreholes to cultural resources.

Approval for the installation of the Command Center (a mobile office trailer) on the 16A/B drill pad was granted by the Beaver County Building/Zoning Commission under the terms of the CUP permit granted in 2020, with the understanding that the command center office trailer will remain on site for the duration of the project.

A Conditional Use Permit (CUP) was filed for the construction of well 16B(78)-32 with the Beaver County Building/Zoning Commission.

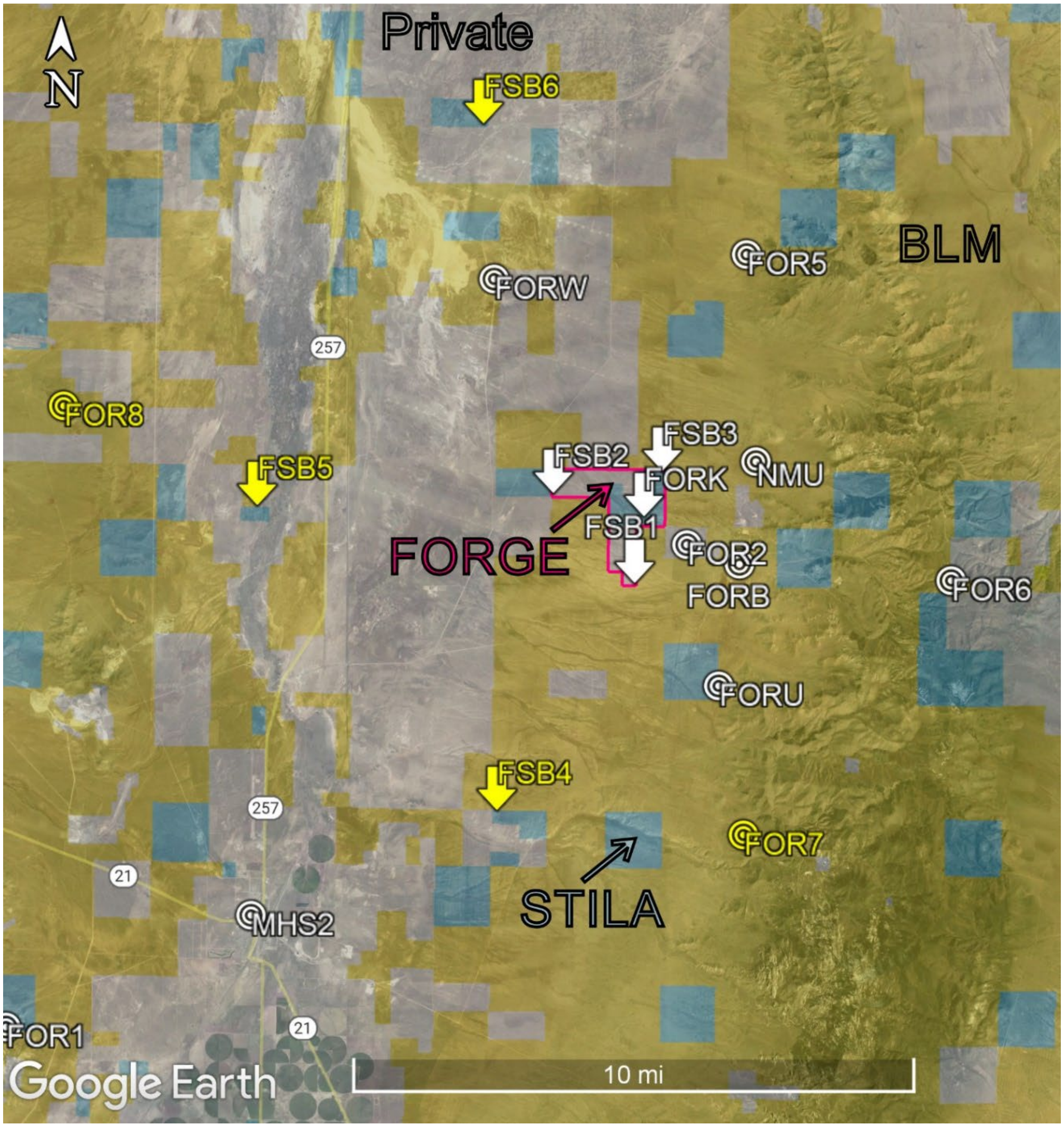


Figure A3-3*: Map showing land ownership (BLM, SITLA and private parcels), the Utah FORGE footprint (pink outline) and the locations of seismometers in and around the Utah FORGE site. Arrows represent seismometers in shallow wells, concentric circles represent surface stations. Seismometers installed in this reporting period are yellow, preexisting stations are white.*